

Ground-Based Near-Earth Object Studies in the post-Russian (Chelyabinsk) Meteor Airburst World

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ABSTRACT

Public awareness of the danger of potentially hazardous asteroids has been heightened by the airburst of a meteor over Chelyabinsk, Russia, on February 15, 2013, which caused millions of dollars in damage from a shock wave that impacted structures and injured ~1500 people. Later that same day, a larger asteroid, 2012 DA14, made a close approach to the Earth, but harmlessly skimmed past. Further, other very close-approaching Near-Earth objects (NEOs) have recently posed threats to man-made space assets by passing through or very near the geosynchronous satellite zone. These events have led to increased awareness and concern, and have subsequently served as a catalyst for deeper exploration of what is being done to mitigate such hazards, and whether more effort needs to be placed in this area of study.

An NEO is designated as “potentially hazardous” when its orbit comes to within 0.05 AU of the Earth's orbit. Ground-based physical characterization studies of Near-Earth Objects (NEOs) that are cataloged as potentially hazardous objects (PHOs) are very beneficial to any mitigation plan that might be devised if the risk of impact is high. After a well-defined orbit has been determined for a PHO, other physical parameters such as size, rotation rate, and composition are important. For the smallest PHOs being discovered, observational efforts must commence at or near the time of discovery to ensure favorable parameters for data collection. Otherwise, subsequent optimal apparitions for observing an asteroid or comet may be decades away.

1. INTRODUCTION

Researchers at the Magdalena Ridge Observatory (MRO) 2.4-meter telescope facility are well positioned to acquire real-time physical information on PHOs since their ongoing NEO follow-up and characterization program collects data monthly throughout the year on the smallest, close-approaching NEOs being discovered. Over the past 5 years that this program has been in operation, spin rates for over 50 Near-Earth asteroids have been obtained, several of which are the fastest rotators in the Solar System [1]. The rotation rate of an object can imply important information about its internal composition and degree of fracture, and thereby its collisional history. In particular, objects with sub-hour rotation periods are likely to have a non-negligible tensile strength. Knowing the material strength of a PHO has a direct bearing on any threat reduction plan.

To address the renewed focus on asteroid threats, we present new data obtained via photometric and spectroscopic techniques on the physical properties of several Earth-approaching asteroids that are potentially hazardous. We will discuss strategies to further reduce the threat of objects that may hit the Earth or airburst in the upper atmosphere, and the role ground-based telescopic monitoring plays in that endeavor.

2. DANGERS FROM EARTH-APPROACHING ASTEROIDS

On 15 February 2013, a small (about 20 meters in diameter) asteroid entered Earth's atmosphere over Chelyabinsk, Russia with an estimated speed of 18.6 km/s (over 41,000 mph). The object exploded in an airburst (see Fig. 1) and created a bright flash (it cast shadows and was brighter than the Sun). Many small

meteorite fragments were expelled in a powerful shockwave over the city. Eyewitnesses also felt intense heat from the fireball. The object was undetected before its atmospheric entry (it approached from the direction of the Sun so was obscured by its light), and about 1,500 people were injured seriously enough to require medical treatment.

A close-approaching asteroid (one that will not hit the ground) is threatening only if its orbit brings it near enough to the Earth to potentially damage or destroy man-made satellites in the geosynchronous zone, or if it airbursts in the upper atmosphere as the Chelyabinsk meteor did. It is generally believed that Earth's atmosphere filters out objects approximately larger than 25 meters in diameter. However, new studies [2] simulating airbursts have indicated that even at that size or smaller, stress waves and temperatures at ground level can be highly damaging. As a case in point, the Chelyabinsk meteor was only about 20 meters in diameter, but had a total kinetic energy equivalent to ~440 kilotons of TNT which is 20–30 times more energy than was released from the atomic bomb detonated at Hiroshima. More intense airbursts (e.g., Tunguska, in 1908) have scorched, vaporized, and blown down trees, as well as melted surface rocks in unpopulated areas.



Fig. 1. Image of the Chelyabinsk meteor (left) captured by eyewitnesses as it exploded in the atmosphere. On the right, a map showing the location of the airburst event in the city of Chelyabinsk, Russia.

About 12 hours after the Chelyabinsk meteor encountered Earth's atmosphere, another, unrelated asteroid, 2012 DA₁₄, made a close approach to the Earth. 2012 DA₁₄ came extremely close, passing closer than the geosynchronous satellites. At 45 meters in diameter, it was the largest asteroid to date that has come that close to the Earth. Researchers at the MRO 2.4-meter facility acquired physical data on 2012 DA₁₄, and Figure 2 shows the time variability in its brightness (lightcurve) that was used to determine its rotation rate. This object's magnitude was $V \sim 16$ at the time the observations were collected. However, its lightcurve behavior was not consistently repeatable such that it appears to be tumbling with a rotation rate longer than 9 hours.

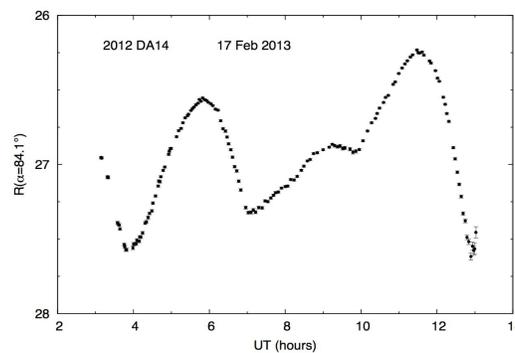


Fig. 2. Lightcurve data obtained for asteroid 2012 DA₁₄. This object has an absolute magnitude $H \sim 24.5$, with a diameter of ~35 meters. The rotation rate is greater than 9 hours, and data taken on subsequent nights revealed the asteroid to be in a tumbling state.

In general, when an asteroid makes a close flyby, it is a unique opportunity to study it in unprecedented detail and obtain scientific and practical data. In this way, essential tools can be assembled in case the need arises to deflect the object or otherwise mitigate it. Close approaches can reveal many physical details via ground-based observing efforts (using both visible and radar-based systems) that would otherwise require expensive and technically challenging methods to acquire. Data collected at the 2.4-meter telescope facility during these near misses contributes to the growing database that helps to establish strategies in asteroid risk remediation.

There have been many more very close Earth-approaching asteroids detected and tracked over the last few years. Table 1 lists some recent objects, several which have passed closer to the Earth than the geosynchronous satellite zone. Studying such bodies can have implications for the health and safety of man-made objects in orbit around the Earth. Further, many of these asteroids have orbits similar to Earth's, so it is likely that they will be passing close by on a regular basis. Since asteroid orbits can change over time, future passes may be more threatening if the alteration produces a probable Earth-impacting scenario. In the absence of active defense, even being able to give some warning of the time and place of an impact would allow evacuation of the area near ground zero where damage would be the greatest.

Near-Earth Asteroid	Date of Closest Approach	Distance from Earth (km)
*2010 JL ₈₈	05/17/10	384,616
2011 CQ ₁	02/04/11	11,900
*2011 MD	06/27/11	18,700
*2005 YU ₅₅	11/08/11	325,000
*2012 BX ₃₄	01/27/12	59,044
*2012 DW ₆₀	03/12/12	957,726
*2012 HM	04/28/12	556,355
2012 KP ₂₄	05/28/12	57,300
2012 KT ₄₂	05/29/12	20,800
*2012 TC ₄	10/12/12	95,114
*2012 DA ₁₄	02/15/13	27,700

Table 1. Shown is a sample list of recent close-approaching asteroids. Objects highlighted (grey shading) passed closer than the geosynchronous satellite zone which is located about 35,900 km above the Earth. Objects preceded by (*) were observed with the MRO 2.4-meter telescope as part of their ongoing survey to establish robust physical descriptions of potentially hazardous objects.

3. ASTEROID MONITORING AND MITIGATION

So how do we deal with close-approaching asteroids? Ground-based monitoring efforts (called NASA's Spaceguard program) to find and characterize objects in the near-Earth zone require moderate to large-sized telescopes. At present, the vast majority of near-Earth object discoveries are being accomplished by the Catalina Sky Survey near Tucson, AZ, the Pan-STARRS1 survey on Maui, HI. The primary objective is to discover and define the orbits of objects coming close to the Earth. Follow-up of these objects to derive more precise orbits and physical properties is accomplished by ancillary telescopes like the MRO 2.4-meter facility. Impediments to the discovery and follow-up process include the existence of blind spots (when an object is near the Sun), bright moonlight, or bad weather. Objects in blind spots will likely be picked up later, typically within a few years, when they are in a more favorable geometry with respect to the Earth.

Researchers at the 2.4-meter facility have capitalized on opportunities to observe close-approaching, newly discovered NEAs to derive better orbits, calculate spin rates, and to determine composition. Figures 3 and 4 display a sample of the results of physical characterization studies of several Earth-approaching asteroids from Table 1. Both photometric (for spin rate) and spectroscopic data (for composition) are shown.

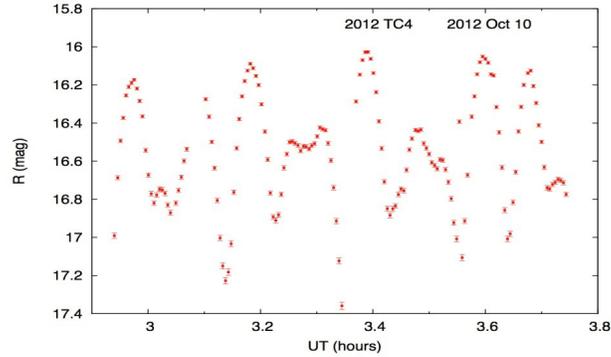


Fig. 3. Asteroid 2012 TC4 (diameter ~ 22 meters) had a magnitude $V \sim 17.4$ at the time the observations were collected with the MRO 2.4-meter telescope. Exposure times of 10 seconds gave good time resolution and allowed the exclusion of a ~ 12 minute period estimate in favor of concluding that the object is tumbling, perhaps a common state for close-approachers.

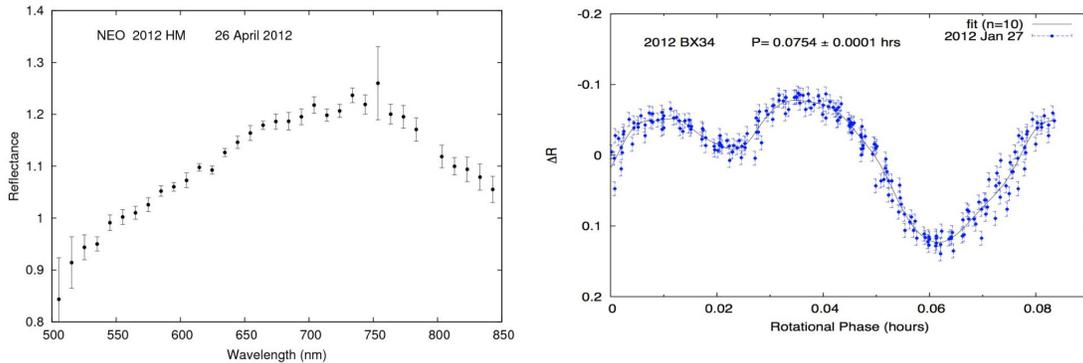


Fig. 4. Spectra of asteroid 2012 HM (left) indicating that it is likely an S-type asteroid: characteristic steep slope shortward of $0.7 \mu\text{m}$, and a small dip at $0.63 \mu\text{m}$. On the right is lightcurve data obtained for asteroid 2012 BX34. This object has a diameter of ~ 12 meters, and the derived rotation rate is 4.52 minutes.

4. FUTURE DIRECTIONS IN HAZARDOUS ASTEROID MONITORING

NASA is currently investigating how best respond to asteroid threats. Mitigation methods may include reducing an asteroid's spin, or diverting it from an Earth-crossing path. Ground-based characterization efforts such as those described above help provide vital physical parameters and are an important component of dealing with potentially hazardous objects. As discussed, researchers at the Magdalena Ridge Observatory's 2.4-meter telescope are investigating various methods to enhance and improve existing capabilities for characterizing asteroids making close flybys in the near-Earth zone.

Since there are a wide range of possible sizes, trajectories, and warning times for Earth-threatening asteroids, there exists a correspondingly wide range in the levels of difficulty associated with mounting a sufficient response. With a few decades of warning time, dangerous asteroids larger than a few hundred meters in diameter could possibly be deflected into alternate orbits. Such a mission would be technically challenging but potentially feasible, so efforts are underway now to explore the development of such capabilities.

NASA's *Asteroid Redirect Mission* (ARM) included in President Obama's fiscal year 2014 budget request would investigate how to best identify, capture, and relocate a small (less than 10 meters in diameter) near-Earth asteroid for closer study as a response to protecting the planet from catastrophic asteroid impacts or airbursts. For the mission to be successful, mechanisms need to be developed to decrease an asteroid's spin, and to push it away from an Earth-crossing trajectory. This approach leverages NASA's construction of the Space Launch System rocket, the Orion spacecraft, and state-of-the-art technology development. If funded, ARM would also require an augmentation and increased deployment of ground- and space-based capabilities for detecting near-Earth asteroids that are in retrievable orbits. Asteroid orbits, shapes, rotation states, and composition would have to be determined as accurately as possible.

In addition to a space-based mission approach, NASA has funded a new ground based observing facility expected to be operational by 2015. The project is called the Asteroid Terrestrial-impact Last Alert System (ATLAS) project and is currently under development. ATLAS would use two telescopes to simultaneously scan the entire night sky visible from their locations twice a night. This would result in a comprehensive early warning system against incoming asteroids. Experts estimate that such a system could provide many hours or even days notice of an impending Earth impact.

Efforts such as these are necessary stepping stones to better protect the Earth from asteroid collisions. Since even very small bodies can do extensive damage by airbursting in the upper atmosphere, enhanced public awareness has dictated a more serious focus on risk reduction. It is likely that a combination of ground- and space-based systems will be called upon to provide the necessary capabilities.

5. ACKNOWLEDGEMENTS

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7. REFERENCES

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2. Boslough, M., and D. Crawford (2008). "Low-altitude airbursts and the impact threat", *International Journal of Impact Engineering*.