Asteroids: New Observations, New Models
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Lessons from the Chelyabinsk event

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Abstract. Recent investigations on small asteroids, initiated by the Chelyabinsk event, are reviewed. New estimates of the terrestrial impact rate, importance of Sun-grazing conditions in the evolution of near-Earth objects, and problems associated with dangerous objects approaching the Earth from the Sun direction are discussed.

Keywords. celestial mechanics, meteors, meteoroids, minor planets, asteroids

1. Introduction

After the Chelyabinsk event, it is evident that not only large asteroids but also ~ 10 m size bodies pose a substantial hazard to the Earth civilization. Although the number of near-Earth objects has been growing rapidly in this century due to dedicated surveys, there are large uncertainties in the population count, physical properties and dynamical features of small asteroids. Some new results in addressing these issues, initiated by the Chelyabinsk event, are reviewed here.

2. Distribution of near-Earth objects

After the Chelyabinsk event, Brown *et al.* (2013) confirmed earlier infrasonic influx estimates (Silber *et al.* 2009) that the bolide impactor flux at the Earth is an order of magnitude higher than estimates based on telescopic surveys. This prompted Harris & D'Abramo (2015) to consider again the size distribution of near-Earth objects. The new estimated frequences of the impacts are substantially higher than earlier results. Nevertheless, there are still differences between the data obtained from the bolide statistics and the near-Earth asteroid surveys. While Harris & D'Abramo (2015) predict that the Tunguska-sized body impact and the Chelyabinsk-sized body impact should occur about once in 500 years and 50 years, correspondingly, Brown *et al.* (2013) give 80-210 years and 20 years for these events.

There are problems not only on numbers of small asteroids, but also about distributions of their sizes and dynamical characteristics. In particular, the dip in the size distribution curve around 100 m is a long-standing problem. Harris & D'Abramo (2015) suggest that this may correspond to a transition from weak, rubble-pile bodies to stronger, monolithic small asteroids. One more feature is associated with an unusual dependence of mean velocities with respect to the Earth on absolute magnitudes of small objects approaching the Earth (Emel'yanenko & Naroenkov 2015).

3. Origin of small asteroids near the Sun

The classical interpretation for the origin of small near-Earth objects is a catastrophic disruption event through a major collision within the main belt. But very short cosmic ray exposure (CRE) ages for some meteorites are inconsistent with their origin from catastrophic disruption within the main belt (Connolly *et al.* 2015). The Chelyabinsk meteorite has added one more example to the set of short CRE ages. The estimates of its CRE age range from 1.2 Myr (Popova *et al.* 2013, Povinec *et al.* 2015) to 1.6 Myr (Nishiizumi *et al.* 2013). This implies the origin of Chelyabinsk as a free-floating body in the near-Earth region.

A sudy of the dynamical evolution of the Chelyabinsk object has shown that there exists a large probability that the Chelyabinsk object was near the Sun in the past (Emel'yanenko *et al.* 2014). The most probable time of the encounter with the Sun lies in the interval from 0.8 Myr to 2 Myr. This is consistent with the estimates of the Chelyabinsk CRE age. It is natural to assume that tidal and thermal effects could lead to disruption of a larger parent body near the Sun.

It is well known from dynamical studies that near-Earth objects evolve frequently to orbits with small perihelion distances (Farinella *et al.* 1994, Gladman *et al.* 2000, Foschini *et al.* 2000, Marchi *et al.* 2009). It is estimated that up to 70 percent of near-Earth objects collide with the Sun during their orbital evolution (Marchi *et al.* 2009). Thus, disruption of bodies due to the strong solar tide, thermal stresses and interaction with the solar atmosphere at Sun-grazing conditions may play a key role in the origin and modification of small near-Earth objects. Now theoretical and experimental works on the physical changes of asteroids near the Sun are clearly insufficient.

4. Day-time impactors

It is known that the Chelyabinsk object came from the sunward direction. The number of observed daytime bolides is almost equal to the number of observed nighttime bolides (http://neo.jpl.nasa.gov/jpl/bolide-events-1994-2013). Thus, discovery of dangerous objects approaching the Earth from the Sun direction is a very serious task in the asteroid hazard problem. A dedicated space system is the only way for us to be warned about threatening bodies that come to the Earth from the day sky. In this coonnection, a special project of space telescopes located near the L_1 point is developed in Russia (Shustov *et al.* 2015).

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