On the existence of near-Earth-object meteoroid complexes producing meteorites

J. Trigo-Rodriguez[1], J. Madiedo[2,3], and I. Williams[4]

[1]Institute of Space Sciences (CSIC-IEEC), Barcelona, Spain
[2]Facultad de Ciencias Experimentales, Universidad de Huelva, Spain
[3]Departamento de Física Atómica, Molecular y Nuclear, Facultad de Física, Universidad de Sevilla, Spain
[4]School of Physics and Astronomy, UK

It is generally thought that meteorites are formed as a result of collisions within the main belt of asteroids [1]. They are delivered onto Earth-crossing orbits because of the effects of orbital resonances, primarily with Jupiter. About 15 meteorites are known where their passage through the atmosphere was observed and recorded, allowing the parameters of the pre-encounter orbit to be derived [2]. The cosmic-ray-exposure ages (CREAs) are suggesting that most meteorites have been exposed to cosmic rays for tens of millions of years (Myrs) [3], re-enforcing the belief that the process of modifying the orbit from being near-circular in the main belt to highly elliptical as an Earth-crossing orbit was a gradual process like the effects of resonance. However, there is growing evidence that some meteorite could originate directly from the near-Earth-object (NEO) population. A good example of this is the recent discovery of rare primitive groups in the Antarctic, an example being Elephant Moraine (EET) 96026: a C4/5 carbonaceous chondrite with a measured cosmic ray exposure age of only 0.28 Ma [4].

Here, we focus on recent dynamic links that have been established between meteorite-dropping bolides and NEOs that support the idea of short-life meteoroid streams that can generate meteoroids on Earth. The fact that such streams can exist allows rocky material from potentially-hazardous asteroids (PHA) to be sampled and investigated in the laboratory. The existence of meteoroid streams capable of producing meteorites has been proposed following the determination of accurate meteoroid orbits of fireballs obtained by the Canadian Meteorite Observation and Recovery Project (MORP) [5]. Some asteroids in the Earth's vicinity are undergoing both dynamical and collisional evolution on very short timescales [6]. Many of these objects are crumbly bodies that originated from the collisions between main-belt asteroids during their life-time. An obvious method of forming these complexes is fracturing. Many asteroids are known to be rubble piles and such structures can be unstable during a close approach to a planet due to tidal forces. The irregular shape of many fast-rotators can allow the YORP effect to increase the spin rate, also leading to fracturing [7]. The escape speed from a fragmenting asteroid is considerably smaller than the orbital velocity so a large amount of the initial mass can be ejected. The fragmentation process is likely to produce many metre-sized rocks as well as few tens of meters fragmental asteroids that could form a complex of fragments, all moving on nearly identical orbits. The lifetime of such orbital complexes is quite short (few tens of thousand of years) as consequence of planetary perturbations[8], except perhaps for those cases exhibiting orbits with high inclination, where lifetimes can be considerably higher [9].

Catastrophic disruptions in the main asteroid belt have been extensively studied, but little is known about the relevance of the process in the NEO population. The Spanish Fireball Network (SPMN) regularly monitors the skies and is obtaining evidence that NEO complexes can be a source of meteorites. By performing backward integrations of meteoroid orbits and NEO candidates, previously identified by using our ORAS software to compute several orbital similarity criteria, we have identified several complexes associated with NEOs of chondritic nature [10–12] and even one, 2012 XJ_{112} of likely achondritic nature [13]. Another recent example was probably the Feb 15th, 2013 Chelyabinsk superbolide. The meteorites recovered were shocked to a very high level [14,15], and the $\sim$19-meter-diameter Chelyabinsk NEA was probably a monolithic single stone produced from its presumable progenitor, the 2.2 km in diameter asteroid (86039) [16]. This association should, however, be tested by performing backward integrations of both orbits.

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