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THE PHYSICAL NATURE OF SMALL EARTH-APPROACHING ASTEROIDS

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ABSTRACT

Various influences, such as lunar craters, museum displays of large, single meteorites, and certain terrestrial impact craters, such as Meteor Crater in Arizona, may have given rise to early conception of 1 m-, 10 m-, and 100 m-scale meteoroids in space as single bodies of coherent rock or metal. Studies of impacts, cratering, and fragmentation in the 1970s suggested a more complex picture, including polymict breccias [1], rubble pile structure [2], and formation of contact binaries and asteroid satellites as a result of collisional evolution and fragmentation [3].

Here we describe three lines of work that support these concepts, and suggest that even small, boulder-sized asteroids cannot be assumed to be strong, coherent rocks. These results have implications for asteroid sampling expedition (human or robotic), asteroid mining, and defense strategies against modest-sized near-Earth objects (NEOs).

First are direct observations of asteroids' fragments and their behavior. In 2011, Popova et al. [4] examined the 13 then-known cases where terrestrial fireball breakup had been well observed, and "ground truth" fragments had also been collected. In all cases, they found initial breakup at very high altitudes, corresponding to a bulk strength much weaker than the strength of the intact fragments on the ground. They suggested that even small asteroidal fragments are laced with fractures, or are even full-fledged rubble piles.

The 2008 Almahata Sitta meteorite gave a particularly provocative example. It broke up at high altitude and showered a Sudanese desert area with fragments of asteroid 2008 TC3 (diameter 4.1 ± 0.3 m). About 90% of the mass was lost in the form of dust during entry, and the remaining fragments were a mixture of ureilites, enstatite chondrites and other ordinary chondrites [5]. These observations suggest that the object was a very weakly

bonded mass of regolith-like material, containing impacting asteroidal fragments of multiple types. In another example, the 200 m× 500 m asteroid 25143 Itokawa appears to be more like a rubble pile than coherent rock fragment, with large rocky masses projecting from finer material [6].

Such data suggest that many asteroidal objects in diameter range ~4 m to ~500 m are masses of loosely consolidated regolith, some capturing multiple, intact meteorite impactors of different types, at relatively slow velocity.

A second line of investigation about small asteroid fragments involves small, “primary crater clusters” on Mars. In 2003, Popova et al. [7] estimated that meteoroids of common strengths would fragment at heights around 10-20 km above the mean surface of Mars, producing clusters of ~5 m to 20 m craters ~100 m to ~300 m wide. They confirmed the existence of such clusters. In our current work, Popova used the 2011 data to estimate that weak meteoroids would fragment at elevations all the way from 45 km above the mean Martian surface down to the mean elevation level, or lower. Both sets of calculations suggest at least some meteoroid breakups on Mars between the highest (+24 km) and lowest (-8 km) surface elevations. By measuring frequencies of such clusters at different elevations, we have proposed a project to obtain the direct statistics on strength distributions of interplanetary meteoroids from a large sample of breakup events. Our preliminary data support the above concepts [8]. Such data, positive or negative, will constrain knowledge of strength distributions among asteroid fragments.

A third line of investigation of small NEOs' properties involves theoretical estimates of collision lifetimes, and suggests shorter lifetimes against collisional brecciation for smaller objects than for larger objects.

Mechanical properties of NEOs will be important in future human interactions with such bodies, including experiments aimed at resource extraction or hazard mitigation. A legal cloud hangs over human visitation and use, however. The language in the 1967 “Treaty Governing the Activities of States in the...Use of Outer Space, including the Moon and Other Celestial Bodies,” signed by the USA and most other nations with space-faring capability, states that space and its celestial bodies “shall be province of all mankind...not subject to national appropriation.” The so-called Moon Agreement, “Governing the Activities...on the Moon and Other Celestial Bodies,” finalized in 1979, expanded such language, referring to the “common heritage of mankind.” It prohibited the appropriation of such bodies by governmental entities or private persons, proposing rather “an equitable sharing...in the benefits derived from those resources” [9, p. 121]. It was not ratified by the USA and other space-faring nations, however, but only by about a dozen of smaller countries. Legal theorists are picking apart the language of such agreements. One argument, in the case of asteroids and their resources, is that not all of them are, legally speaking, celestial bodies. (This argument is developed on the grounds that they are “moveable” [9].) Another allegation is that while national appropriation is excluded, this does not exclude private ownership. It is unclear, therefore, whether our human interaction with such objects may be exploited mainly for the benefit or financial profit of a few, already wealthy nations and organizations (probably aggravating human tensions), or whether a new geoeconomic framework can be found to motivate a wider distribution of the benefits.

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