ASTEROID ANALOGS TO ORDINARY CHONDRITE METEORITES: EARTH ENCOUNTERS AS THE KEY TO RESOLVING THE PARADOX

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Introduction: For more than two decades, the link between the most common meteorites (ordinary chondrites) and the most common asteroids (S-types) has been problematic. The 'ordinary chondrite problem' [1] can be stated as "Why is it difficult to find abundant spectral matches between telescopically measured asteroids and laboratory measured ordinary chondrite meteorites?"

The process of "space weathering" [2] is most often offered to explain the mismatch, supported by *in situ* spacecraft confirmation that S-type asteroids have ordinary chondrite-like elemental abundances [3]. Also alleviating the 'problem' is the finding that among near-Earth asteroids, roughly 25% do have telescopic spectra that directly match fresh ordinary chondrite meteorites measured in the laboratory [4]. These "Q-type" [5] asteroids are interpreted to have fresh surfaces too young to have experienced significant space weathering. Yet a mystery remains: "Why are Q-types effectively found only among near-Earth asteroids, and in corollary, why are Q-types (specifically, fresh ordinary chondrite surfaces) rare or effectively absent in the main-belt?"

New Findings: As we report in *Nature* [6], we analyzed the spectral and orbital properties of nearly 100 near-Earth asteroids in the S- and Q-type taxonomic classes. For the orbital analysis, we integrated to find the closest Earth encounter for each asteroid within the past 10^6 years by calculating the Minimum Orbit Intersection Distance (MOID). We find a strong correlation between the freshest near-Earth asteroid surfaces, the Q-types, among those asteroids whose integrated orbits reveal MOID values allowing recent Earth encounters at distances substantially closer than the Moon. All objects in our sample for which orbital integrations rule out recent close Earth approaches have "old" space weathered S-type asteroid surfaces. Taken together, our findings substantiate the proposition [7] that planetary encounters can freshen asteroid surfaces. Thus our results place the "ordinary chondrite problem" into a new context between two rapidly competing timescales: Space weathering (now recognized as being effective within ~10^6 years [8]) and planetary encounters. Consequently, nearly all main-belt and non-encountering near-Earth asteroids *should* appear space weathered. And they do. Asteroid encounters within about 16 Earth-radii appear to induce sufficient tidal stress and seismic shaking to expose fresh regolith from below. Thus we find Earth encounters to be the cause of fresh "ordinary chondrite-like" (Q-type) asteroid surfaces being seen so predominantly among near-Earth asteroids.

References: [1] Wetherill G., Chapman C. 1988. In *Meteorites and the Early Solar System* (J. Kerridge, M. Matthews, eds.), pp. 35-67. [2] Clark, B., et al. p 2002. In *Asteroids III* (W. Bottke, et al., eds.), pp. 585-589. [3] Trombka, J. I., et al. 2000. *Science* **289**, 2101-2105. [4] Binzel, R. P., et al. 2004. *Icarus* **170**, 259-294. [5] McFadden, L. A., et al. 1985. *Science* **229**, 160-163. [6] Binzel, R. P., et al. 2010. *Nature* **463**, 331-334. [7] Nesvorný, D., et al. 2005. I*carus* **173**, 132-152. [8] Vernazza, P., et al. 2009. *Nature* **458**, 993-995.