

GOOD VIBRATIONS: RECENT NEAR-EARTH ENCOUNTERS AS THE MISSING PIECE OF THE S-ASTEROID AND ORDINARY CHONDRITE METEORITE PUZZLE. R. P. Binzel¹, A. Morbidelli², S. Merouane³, F. E. DeMeo³, M. Birlan⁴, P. Vernazza⁵, C. A. Thomas⁶, A. S. Rivkin⁷, S. J. Bus⁸, A. T. Tokunaga⁸,

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Introduction: For more than two decades, the link between asteroids and the most commonly falling meteorites (80% are stony ordinary chondrites) has been problematic. This ‘ordinary chondrite problem’ [1] is often stated as “Why is it difficult to find abundant spectral matches between asteroids measured telescopically and fresh ordinary chondrite meteorite samples measured in the laboratory?”

Resolution of the ordinary chondrite problem. Resolution of this problem has come in steps:

- Recognition that among the most common inner main-belt and near-Earth asteroids, so-called S-types, ordinary chondrite mineralogies are plausible [2] even though S-type asteroids display redder spectral slopes and diminished mineral absorption bands in comparison with their ordinary chondrite meteorite analogs;
- Recognition that the asteroid-meteorite spectral mismatch is caused by surface exposure to the space environment. This space weathering process [3] produces the reddened slopes and diminished mineral absorption bands characteristic of S-type asteroids;
- *In situ* spacecraft confirmation that S-type asteroid surfaces have ordinary chondrite like elemental abundances [4]. Although the S-type asteroids can now be recognized as a suitably abundant source for the flux of ordinary chondrite meteorites [5,6] with space weathering at fault for the spectral mismatch, one curious piece of the puzzle remains to be explained...

Where Do the Q-type Asteroids Come From?

There is one taxonomic class of asteroids, the so-called Q-types [7], which have telescopic spectra that do directly match fresh ordinary chondrite meteorites measured in the laboratory. Thus Q-types are interpreted to be asteroids with fresh surfaces having ages that are too young to have experienced significant space weathering; the underlying assumption being that as space weathering occurs, the Q-type surface spectrum evolves toward the redder spectral slopes and diminished mineral absorption characteristic of the S-types. Thus even though Q-type asteroids are understood in the context of ordinary chondrite meteorites and space weathering, they nevertheless pose their own mysteries. Here we pose the ‘Q-type problem’ as:

“Why are Q-types effectively found only among near-Earth asteroids, and in corollary, why are Q-types rare or effectively absent in the main-belt?” Two answers have been proposed: (i) Near-Earth asteroids are observable at much smaller sizes than main-belt asteroids, hence they can have younger and fresher surfaces since smaller objects, on average, have shorter collision lifetimes [8]; (ii) Near-Earth Q-type asteroids are fresh because they reside in planet crossing orbits. Actual planetary encounters may tidally deform and reshape these asteroids, creating fresh surfaces [9]. A general correlation with decreasing perihelion distance is found for near-Earth asteroids having less reddened slopes, interpreted as showing that the greater likelihood of planetary encounter the greater likelihood of evidence of the surface appearing more fresh [10].

Space Weathering Rate. Key to understanding the relative roles of collisions or planetary encounters for creating fresh Q-type asteroids is the timescale for space weathering. Most critical to constraining this timescale has been the discovery of young asteroid families in the main belt, i.e. groups of asteroids dynamically linked to a common formation age of less than one million years [11]. Telescopic spectral measurements of these young asteroids show them to be already space weathered, and when combined with the spectral measurements of older asteroid families, analyses for the rate of space weathering can be performed [12, 13]. Correcting for the dependence of spectral slope change versus olivine abundance yields a strong correlation for the weathering amount versus time: the space weathering rate is sufficiently rapid for the Q-type to S-type surface transition to occur within a timescale of less than one million years [13].

Rapid Space Weathering and the Q-type problem. For a short space weathering timescale of $< 10^6$ yr [13], collisions do not occur frequently enough [8] to maintain the apparently fresh surfaces of Q-types. Hence if rapid space weathering [13] is correct, then tidal shaking by planetary encounters [9] on timescales $< 10^6$ yr should be the dominant process for creating fresh asteroid surfaces more frequently than the space weathering process can completely alter them.

Good Vibrations Results: In this talk we will report [14] on the orbital properties of nearly 100 near-Earth asteroids for which we have visible and near-infrared spectral measurements placing them in the S- and Q-type taxonomic classes [15]. Most specifically, we explore the Minimum Orbit Intersection Distance (MOID) of our near-Earth asteroid sample to determine which asteroids show the greatest likelihood of encountering the Earth in a time shorter than the 10^6 year timescale of rapid space weathering [13]. 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 lunar distance. All objects in our sample for which orbital integrations rule out close Earth approaches within the past few $\times 10^5$ years, have “old” space weathered S-type asteroid surfaces. Taken together, our findings therefore substantiate the proposition [9] that planetary encounters (and altogether for our sample, Earth encounters) dominate over collisions [8] for freshening near-Earth asteroid surfaces. (Venus and Mars may also be effective, but our sample is biased toward Earth-crossers because asteroid discovery surveys are Earth-based.) We will present a method to estimate the encounter distance that is “close enough” to the Earth to tidally induce the seismic vibrations sufficient to refresh the surface. Interestingly, there may be opening an entirely new area of investigation to find the lowest seismic vibration limit (in terms of both encounter and physical parameters) for inducing the redistribution of fresh surface material.

The “Ordinary Chondrite Problem” in a new light. One consequence of our results is to place the entire “ordinary chondrite problem” into a new context of rapidly competing timescales: rapid space weathering now recognized as occurring in $\sim 10^6$ years means that practically all main-belt and non-encountering near-Earth asteroids *should* appear space weathered – and they do. (Collisions and/or YORP spin-up remain viable freshening processes; they simply occur less frequently at the asteroid sizes currently observable.) The Earth itself (i.e. the tidal stresses inducing good vibrations and seismic excitations) is the cause of fresh “ordinary chondrite-like” Q-type asteroid surfaces being seen so predominantly among near-Earth asteroids.

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