TIDALLY-INDUCED TUMBLING AS A MECHANISM FOR NEA SURFACE REFRESHING.

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Introduction: Spacecraft exploration of near-Earth Asteroids (NEAs) have shown that these objects are covered by a weakly-cohesive regolith layer dominated by boulders [1-3]. Telescope observations have suggested that close tidal encounters with the inner-planets can mobilize this regolith layer, refreshing the surface and removing evidence of space weathering [4,5]. This mechanism may explain the relationship between stony S-type and Q-type asteroids: Q-types, which have reflectance spectra similar to Ordinary Chondrites, are S-type asteroids that have experienced a recent resurfacing event.

While other physical mechanisms have been shown to be plausible sources for NEA surface refreshing (e.g., YORP spin-up and thermal fatigue [6-8]), dynamical calculations indicate that NEA Q-types preferentially experience distant tidal encounters (up to 15 planetary radii [4]) compared to S-types. However, direct numerical simulations of the tidal encounters of NEAs with terrestrial planets have shown that only close encounter (<3 planetary radii) at moderate encounter speeds lead to global-scale NEA disruption and/or mass shedding [9]. Therefore, a physical mechanism for a tidal-based refreshing of NEAs that is compatible with observations has remained elusive.

Approach: Here, we approach this long-standing problem by considering new insights into the surface mobility of small bodies due to time-varying tidal forces, excited spin states, and spacecraft observations of NEA surfaces. Specifically, recent work on granular flow on Phobos has shown that tidal forces from Mars can cause a time-variable tilting of slopes that induces a creep motion on the surface [10]. A similar time-variable surface tilting has also been found to occur for NEAs that experience non-principal axis rotation [11], which may be induced by external forces such as tides. Furthermore, spacecraft observations of km-scale rubble-pile asteroids revealed that their surfaces are weak and dominated by large boulders, which can control regolith mobilization [12,13].

We study the outcomes of distant tidal encounters (> 3 planetary radii) of NEAs in the context of these new geophysical insights by using the following multi-scale modeling approach: 1) N-body simulations of tidal encounters to compute excitations in the spin-state of NEAs with variable surface and interior strengths (1-1000 km scales), 2) Polyhedron gravity computations to compute resulting changes in the surface slopes of the NEA post-encounter (1m – 1km scales), and 3) Discrete element simulations of granular-flow in boulder-dominated asteroid regolith (1 mm – 1 m scales). At this workshop we will present proof-of-concept results that this mechanism may shed new light on tidal encounters.

Relevance to the 2029 Apophis Close Encounter: The S-type asteroid (99942) Apophis' encounter with Earth (~ 5 planetary radii) in 2029 may demonstrate the effectiveness of tidal encounters at refreshing the surfaces of NEAs. While the community has provided varying, sometimes conflicting, predictions for the scale and magnitude of surface alterations on Apophis due to the encounter ([14], and references therein), various studies have all agreed that the spin state will change [14-16]. If the encounter induces stronger tumbling or wobbling, then Apophis may experience continued surface alterations as its excited spin state dampens. Thus, we hypothesize that the total effect of surface refreshing may not be immediate, but through the gradual mobilization of the surface through the tumbling or wobbling of the asteroid.

Outlook: While we will only present a proof-of-concept model for this mechanism, we intend to run a suite of simulations whose results will be integrated into a population model that considers typical encounter distances, speeds, and asteroid orientations to test if tidal encounters could be responsible for surface refreshing of NEAs. This work would provide a theoretical underpinning for understanding the influence of tidal encounters on NEA surface evolution.

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