HILL SLOPE FAILURE AS A MECHANISM TO RESURFACE ASTEROIDS DURING PLANETARY FLYBYS. J. T. Keane[1] and I. Matsuyama[1]; [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, USA (jkeane@lpl.arizona.edu).

Introduction: Laboratory measurements of the reflectance spectra of the most common types of meteorites (the ordinary chondrites) do not match the reflectance spectra of the most common type of main belt asteroids (the S-types), from which they are presumably derived. This difference is thought to be the result of the processes associated with space weathering, which rapidly darken and redden asteroid surfaces on million-year timescales [1, 2]. While nearly all main belt asteroids appear weathered, many near-Earth asteroids – the Q-types – appear unweathered compared to S-types, and are much closer spectral matches to the ordinary chondrites (Fig. 1). Q-types are thought to represent former main belt S-types, that have migrated into the inner solar system, and have been recently resurfaced, thus erasing any previous signatures of space weathering. While the exact resurfacing mechanism is unknown, there is growing evidence that the resurfacing events are linked to close planetary flybys [3, 4, 5, 6]. To explain the current population of Q-type asteroids, this unknown resurfacing mechanism must operate at large flyby distances: 5-20 planetary radii – which is well beyond typical tidal disruption distances of 2-5 planetary radii [7, 8, 9]. In this paper, we propose that the weaker tidal perturbations during these larger planetary flybys are still significant enough to trigger debris flows on the surface of the asteroid. While not as dramatic as global disruption, this process may still be able to resurface the uppermost layers of the asteroid and change its spectral characteristics. By understanding this process, we will be able to better constrain the nature and timescale of space weathering on near-Earth asteroids.

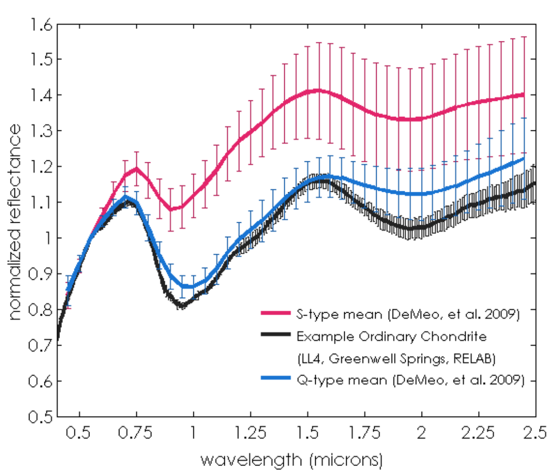

Fig. 1: Mean reflectance spectra for S-type and Q-type asteroids, and an example spectra of an ordinary chondrite.

Asteroid Resurfacing Model: Hill slope stability can be thought of as an application of the classic physics problem of a block sliding on an inclined plane [e.g. 10]. If the down-slope shear force on a test block exceeds some critical, resisting frictional force (which is dependent on the angle of repose for granular material) then the block will slide and a debris flow will be initiated.

We have adapted this simple model of hill slope stability to asteroids undergoing close planetary flybys. Unlike the typical terrestrial application, the total force acting on some test block of regolith on the surface of an asteroid is non-trivial: it is a combination of gravitational force from the asteroid, centrifugal force due to the asteroid's spin, and the tidal force from the the close approach with the planet (Fig. 2). All of these forces vary across the surface of an asteroid, and are strongly depedent on the asteroid's shape, mass distribution, and spin state. Furthermore, the tidal force is time varying and dependent on the flyby geometry.

To model all of these forces during an individual flyby, we generate a synthetic asteroid shape model, with a prescribed density and spin state. On top of the base asteroid shape model, we superimpose randomized hill slopes to each surface element, in order to replicate the typical surface hill slope distribution of asteroids [11]. We then numerically integrate all of the forces acting on each surface element as a function of time, during an individual planetary flyby of arbitrary geometry. For each surface element, we track whether regolith becomes unstable to hill slope failure, or if the regolith becomes gravitationally unbound.

Results: We have performed a preliminary parameter-space survey of hill slope stability for elliptical asteroids undergoing close approaches with varying perigee distance, flyby velocity, and asteroid rotational period. Fig. 3a displays the fractional surface area that becomes unstable to either hill slope failure, or becomes gravitationally unbound, as a function of flyby distance and hyperbolic excess. We find that for this particular asteroid shape/spin model (based on 433 Eros [12]), a few percent of the asteroid's surface can become unstable to hill slope failure out to ~10 planetary radii. While these small surface areas may seem trivial, it is important to realize that we are modeling the region that becomes initially unstable. Like any terrestrial debris flow, the region covered by the result-

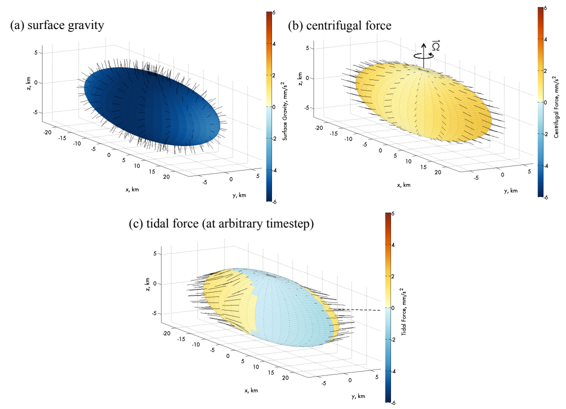

Fig. 2: Example maps of the (a) surface gravity, (b) centrifugal force, and (c) tidal force (for arbitrary timestep) in our asteroid hill slope stability model. For each surface element, at every timestep, the forces are projected into the normal and down-slope direction, and the stability of the hill slope is evaluated.

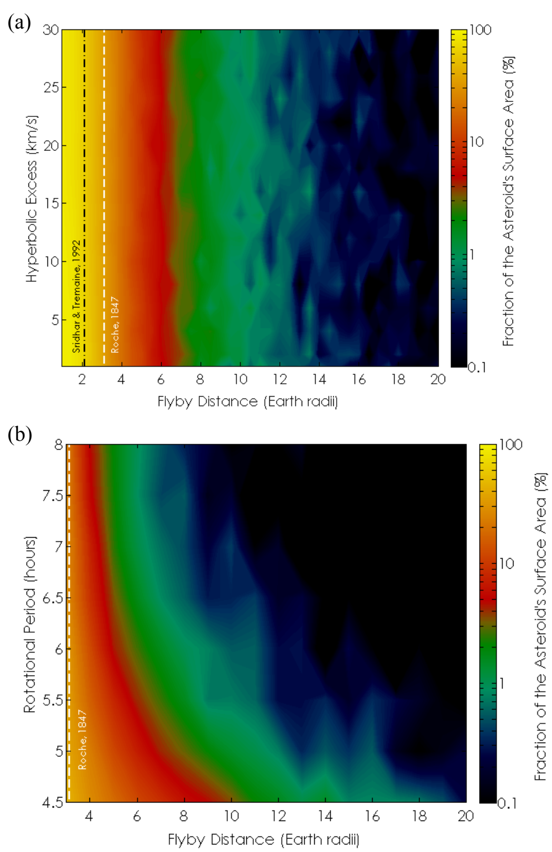

Fig. 3: Preliminary parameter space survey of the hill slope stability as a function of (a) flyby distance and hyperbolic excess, and (b) flyby distance and asteroid rotational period. Color indicates the fraction of the surface area that becomes unstable to hill slope failure. Note that failure can occur at much larger distances than predicted by classical tidal disruption models [7, 8, 9].

ing debris flow is significantly larger than the region that becomes initially unstable. We are currently developing a geodynamic model for these asteroidal debris flows, to more accurately determine the surface area that becomes resurfaced.

Fig. 3b displays the fractional surface area that becomes unstable as a function of flyby distance and the asteroid's spin period. We find that faster rotating asteroids can experience debris flows at larger distances. This is easily understood as the result of larger centrifugal forces for larger spin periods, which weakens the effective gravity on the surface, and decreases the threshold frictional force for hill slope failure. The current implementation of our model keeps the asteroid in a principal axis spin state, with fixed spin period. However, it is thought that close planetary flybys may change the spin state of asteroids [13]. We will investigate this effect in a future work.

Conclusions: We have demonstrated an original geodynamic model of tidally-induced hill slope failure on asteroids undergoing planetary flybys. We have shown that asteroids may be resurfaced at larger flyby distances than previously thought. Future work will explore the full possible parameter space associated with asteroid shapes, spin-states, and flyby geometries, in order to constrain the efficiency of this process at resurfacing asteroids. Understanding this efficiency will provide important insight into the processes of space weathering and their corresponding (and still uncertain) timescales. Finally, we predict that asteroids undergoing close flybys with the Earth (within ~10 Earth radii) may show *observable* changes during flybys, including spectral or photometric changes, and possibly rearrangement of surface features that might be resolvable with radar observations. These hypotheses may be directly testable in the coming decade, with observations of asteroids similar to 2012 DA14.

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