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○ **NEO Characterization**

Sensitivity of surface modification to seismic waves in rubble-pile asteroids

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There are two primary mechanisms of seismic wave generation in rubble-pile asteroids. Seismic waves are generated by natural, random impacts ([1]) and in binary systems they are also generated by tides ([2]). In-situ measurements of such waves (planned in upcoming missions [3], [4]) can provide valuable insights as to the internal structure of rubble-piles. At larger input energies (hypervelocity deflection), impact could lead to a reshaping of the entire surface ([5]). Some works propose that an impact induced-seismic pulse ([6]) would eject regolith across the entire surface of a rubble-pile, while others suggest a modest lofting of the surface-most material, proximally confined to the impact site ([7]). An improved understanding of seismic expression at the surface of rubble-piles is important for both revealing the details of their internal structure as well as the effectiveness of deflection techniques. In this work, we consider the ejection sensitivity of surface material to an impact-generated seismic pulse. One recent work modeling near-surface seismic waves on the Moon ([8]) suggested that an impact-generated pulse modifies surface material to a greater extent than previously known. We adapt and modify (see Eqn. 1) their proposed method for determining the depth extent of modification resulting from laterally propagating near surface waves in order to assesses the likeliness of a rubble-pile's surface material to be ejected from the system.

$$F_v = \mu sin(\theta) C \left(\frac{125}{36} m_{eq}^3 v_0^6 E_{eq}^2 R_{eq}\right)^{1/5} - \left(\phi \pi R^2 z + \frac{4}{3}\pi R^3\right)\rho_1 g \qquad (1)$$

Equation 1 evaluates the vertical force (F_v) felt by surface material at some depth (z), depending on the wavefront velocity (v_0) at that depth, resultant gravity (g) loading from surface particles of radius R and density ρ, as well as the equivalent material parameters (R_{eq}, E_{eq}, m_{eq}) between particles in contact at that depth (E, elastic modulus; m, mass) and the friction μ between them. Some limitations of the methods in [8] were that the numerically derived scaling parameter C was not determined for small-body levels of gravity in [8], nor was the wavefront angle θ (representing the curvature of transverse near-surface waves) accounted for. Furthermore, [8] considered idealized monodisperse spherical particles. Given the form of Eqn. 1, gravity is dominant (compared to material properties) in determining when particles have sufficient velocity to loft, suggesting that seismic waves in lower gravity environments (i.e., rubble-piles) have an enhanced ability to eject surface material. We address the limitations of [8] using GRAINS ([9], [10]), a soft body particle based simulation tool that can model aspherical particles. We generate wavefronts of varying v_0 in long granular assemblies under vacuum and exposed to Dimorphos surface gravity (following the procedures in [8]). The objective of these piston-impact simulations (conducted for varying impact velocities, material parameters and size distributions) is to evaluate

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the hypothesis that near surface particle ejection as a result of seismic waves is greater in magnitude in low gravity environments. Understanding the effectiveness of wave-based particle ejection may help to constrain the contribution of distal-to-impact seismic waves in the momentum transfer of a kinetic deflection event.

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