SEISMIC SHAKING EXPERIMENTS IN MILLIGRAVITY ENVIRONMENTS. N. R. Izenberg, [1]Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, MD, 20723, USA (noam.izenberg@jhuapl.edu).

Introduction: Understanding the surface features, processes, of low gravity bodies in our solar system are critical to their evolution. Craters on the rocky and icy planets and moons, and on small bodies are fundamental tools in determining relative age, and provide geological windows into the subsurface. The cratering process itself is extensively studied, but the effects of moderate to small-scale impact events on low gravity bodies is not well researched. Seismic shaking and reverberation from small impacts causes significant local mobilization of surface materials, and affects the apparent age of a small body. In milligravity environments the impact process (or any other induced seismic signal) also may transport quantities of surface materials for some distance over some time, which may have effects on potential future robotic and human exploration of small bodies.

Planetary and Spacecraft observations. Recent spacecraft observations [1-4] indicate that seismic shaking due to impact cratering may play a key role in the surface evolution of asteroids. Indeed, such a process could be one of the reasons for the decrease in the spatial density of small craters on asteroid 433 Eros (200m diameter and below) relative to an empirically saturated surface, with an increase in boulder spatial frequency [5-7] (Fig. 1). Seismic shaking may also best explain the removal of craters up to 500 m in diameter in the vicinity of the large (7.5 km) crater Shoemaker on Eros [2], and the observations of surface flow and imbrications seen on Itokawa [4].

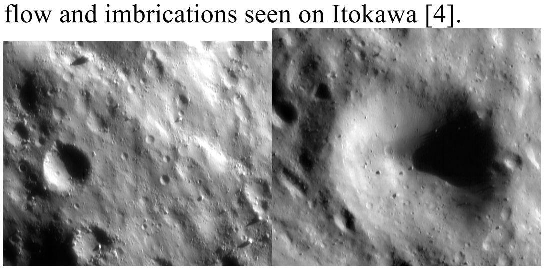

Fig. 1. Left: Degraded, bouldered terrain on Eros; Right: Eros crater with smoothed rim, and evidence of slope failure.

The lunar record [8, 9] suggests that seismic shaking is potentially very important on small bodies. Substantial seismic signals [2, 10-13] could not only destroy small craters, but also significantly modify the appearance of the entire surface. However, while spacecraft observations show the record of events from ancient to modern, no spacecraft observer has had the capability or opportunity to an impact event and its downrange seismic effects in real time.

Numerical and Simulation. Simple modeling [7] to rigorous numerical simulations [12,13] show that seismic signals from craters as small as 300m in diameter may be able to modify surface regolith to significant distances from their rim (Fig. 2). Global ringing effects can destabilize regolith on all slopes, while lower energy impacts and/or impacts into more fractured bodies (i.e. "rubble pile" asteroids with greater interior attenuation) result in more localized seismic effects. As well, smaller individual effects may aggregate over time into significant surface modification. Theoretical modeling also indicates that seismic shaking might: contribute to the development of "ponds" on 433 Eros [14]; affect the placement and evolution of boulders on Eros' surface; and affect the evolution of regolith on other small bodies (e.g. 25143 Itokawa, Phobos, Deimos) and to some extent bodies resolved to lower resolution (e.g. 243 Ida and 951 Gaspra [15, 16]).

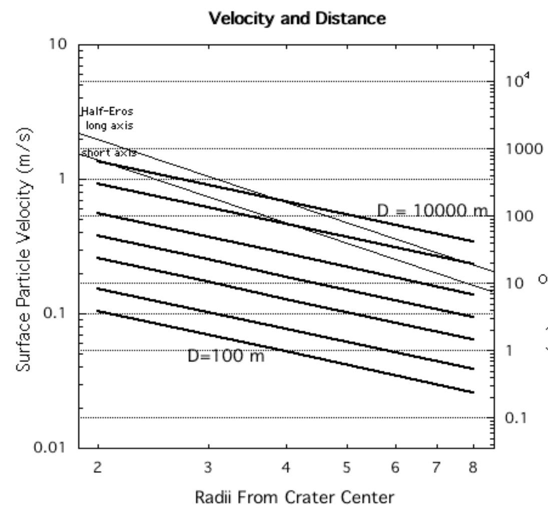

Fig. 2 Simple models derived from [9] showing the initial velocity of and maximum flat-surface distance traveled by a regolith particle mobilized by an impact a given distance away on asteroid 433 Eros. Depending on attenuation effects, even small craters can mobilize surfaces multiple crater radii away.

Early laboratory shaking experiments [7, 17-19] have demonstrated that small seismic jolts, both individually and in aggregate, can induce slumping of crater walls, migration of boulders, smoothing of regolith topography (Fig. 3). Single large jolts may induce larger scale changes more quickly, and result in significant horizontal transport of regolith in ballistic trajectories if the mobilizing acceleration is at an angle to local gravity.

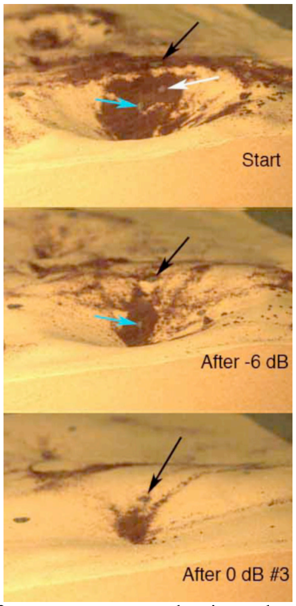

Fig. 3. Vertical laboratory seismic shaking sequence showing slope failures in model asteroid regolith, terrain smoothing, and "boulder" movement.

Current laboratory simulations of asteroid regolith processes must compensate for the fact that Earth gravity is orders of magnitude higher than surface gravity on small bodies. Earlier work [7,17,18 attempts this by recording shaking experiments with a high-speed video camera, slowing high frame rate to scale time down to simulate lower accelerations. This approach has achieved some success in simulating low gravity effects, but the validity of the scaling of time for gravitational acceleration is unverified. The limits of frame rate in available cameras can approach scaling to around 0.0100 to 0.0025 g at best (1000-4000 frames per second scaled to playback of 10 fps), when surface gravity of bodies the size of 433 Eros is on the order of 0.01g or smaller. Finally, current laboratory simulations must be carried out in air, where air resistance and displacement may affect particle motion of small grains of regolith simulant.

Suborbital Experiments (VASE) The scientific goals of a suborbital Variable Angle Seismic Experiment (VASE) would be to determine the behavior of a simulated asteroid surface subjected to a seismic impulse in both simulated and actual microgravity conditions, and in both air and vacuum. A direct comparison between near-identical experiments in simulated microgravity (1-g observations with high speed camera observations) and actual microgravity (in suborbital flight) will provide crucial ties between laboratory simulations and space environments. On-ground observations in air and vacuum will determine the fidelity of pressurized and vacuum simulations microgravity experiments.

The VASE is a self-contained experiment box, designed to be "reloadable" and reusable in both ground experiments and sub-orbital flight. The approximately 2-foot transparent (Lucite) cube is mounted on a metal plate, attached to a shake-table on ground, or a "seat"-mount in a flight vehicle. The cube is half-filled with an asteroid regolith simulant (Fig 3). This simulant can be a variety of materials from simple beach or playground sand, to pebbles, to a more complicated and accurate lunar or other simulated soil, to a mixture of multiple grain sizes and shapes. A starting "terrain", initially either a crater-shape or a hill-shape is formed into the surface by a mold-like cover that is manually raised when the experiment is ready to be executed. The mold/cover will be designed to lock in the closed position pre-flight, to be unlatched and opened by the operator in flight. The cover edges and box penetrations for the opening mechanism will be sealed by gaskets to permit movement of the mechanism, yet prevent escape of regolith simulant to the outside environment. An alternative design for a low vacuum experiment box is in preparation. The hand-lifted molt cover will likely need to be replaced with an automated door-type operation as in the COLLIDE experiments [20, 21].

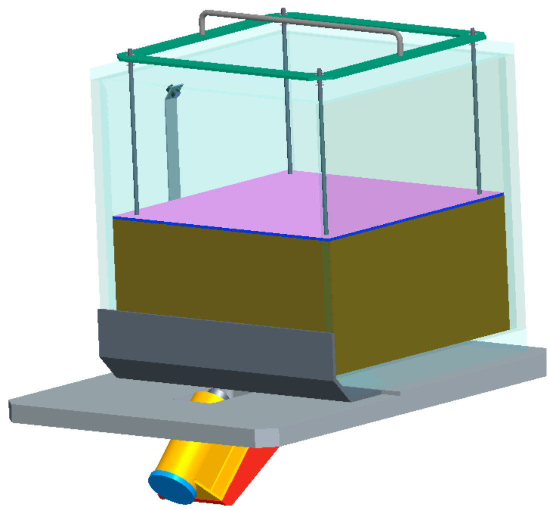

Fig 3. VASE prototype nonvacuum design with in "closed" state with thumper facing the kick plate in the 45° configuration. Camera is mounted to the left wall of the transparent cube. Not shown are lighting brackets, and mounted accelerometers.

References: [1] Robinson M.S. et al. (2002) *Met. Planet. Sci.* 37, 1651-1684. [2] Thomas P.C. & Robinson M.S. (2005) *Nature* 436, 366-369. [3] Fujiwara A. et al., (2006) *Science* 312, 1330-1334. [4] Miyamoto H. et al. (2006) *LPS XXXVII*, #1686. [5] Bottke W.F. (2002) *Asteroids III, U of A, Tucson.* [6] Chapman C.R. et al. (2002) *Icarus*, 155, 104-118. Izenberg N.R. et al. (2001) *Spring AGU* #P22B-01. [8] Houston W.N. et al. (1973) *LPS IV* 2425–2435. [9] Schultz P.H. & Gault D.E, (1975) *Moon* 12, 159-177. [10] Horz F. & Schall R.B. (1981) *Icarus* 46, 337-353. [11] Greenberg R. *e*t al. (1996) *Icarus* 120, 106-118. [12] Richardson J.E. et al. (2004) *Science* 306, 1526-1529. [13] Richardson J.E. et al. (2005) *Icarus* 179, 325-349. [14 Cheng A.F. et al. (2002) *Met. Planet. Sci.* 37, 1095-1105. [15] Sullivan R. et al. (1996) Icarus 120, 119-139. [16] Carr M.H. et al, (1994) *Icarus* 107, p. 61-71. [17] Izenberg N.R. & Barnouin-Jha O.S. (2006) *LPS XXXVII* #2017. [18] Malanosky S.A. et al. (2007) *LPS XXXVIII* #1947. [19] Busuttil C. et al. (2008) *LPS LIX* #1648. [20] Colwell J.E. & Taylor M. (1999) *Icarus* 148, 241-248. [21] Colwell J.E. (2003) *Icarus* 164, 188-196.