THE HITCHHIKERS GUIDE TO THE MOON: DELIVERING INSTRUMENT SUITES WITH LUNAR PENETRATORS T. Marshall Eubanks[1], W. Paul Blase[1], [1]Space Initiatives Inc , Newport, Virginia 24128 USA; tme@space-initiatives.com;

Introduction: Poorly understood features on the Moon include the lunar caves, tectonically active areas, permanently shadowed regions, and areas with transient phenomena. Studying as many of these areas as possible with seismometers and other instrumentation is important to understanding the Moon's inner structure and surface stability, which in turn will be critical to the safety of any manned habitats and other facilities that we may place there. However, sending landers to every interesting location will be prohibitively expensive.

Ballistic penetrators, dropped from a carrier spacecraft in small swarms across a target of interest offer an economical way to study and instrument a large number of sites. The penetrators may be carried onboard landers and dropped during their descent trajectory or may be deployed from dedicated self-propelled "Mooncranes" carried as secondary payloads onboard other lunar missions. At Space Initiatives Inc we have been developing this technology for several years [1, 2], focusing on the "Mote" lunar penetrator, designed to economically carry instruments to the lunar surface (and other locations).

Figure 1 shows a cross section of the Mote Ballistic Penetrator. Motes are 360 mm long by 50 mm diameter and feature a hardened steel nosecone with a composite body; an electronics package with power management, data acquisition and storage, flight instrumentation including accelerometers and gyroscopes, and mesh-network RF transceivers; a precise clock source; and on-board power sufficient for operation through one lunar day (more if photovoltaics are carried on the antenna mast). It can carry a variety of miniature instrumentation, including geophones and regolith-analysis equipment.

The Motes are designed to withstand an impact of up to 300 m/s. While the penetrator body with its instruments burrows through the regolith, coming to a rest up up to one meter below the surface, the tail section will remain near the surface after impact and deploys an antenna mast. Figure 3 shows the Mote in the surface, with the antenna mast deployed.

The Mote Instrument Suite: The penetrators can be deployed from a lander or Mooncrane, imaging the terrain as they fall, and gathering geotechnic data during impact. After impact they will an RF mesh network with established communications protocols, and use this both to communicate within the mesh network, and also to send data back to a lander or other base station.. Each penetrator will carry a geophone, magnetometer, thermometer, 2-D tilt-meter, mass-spectrometer, low-

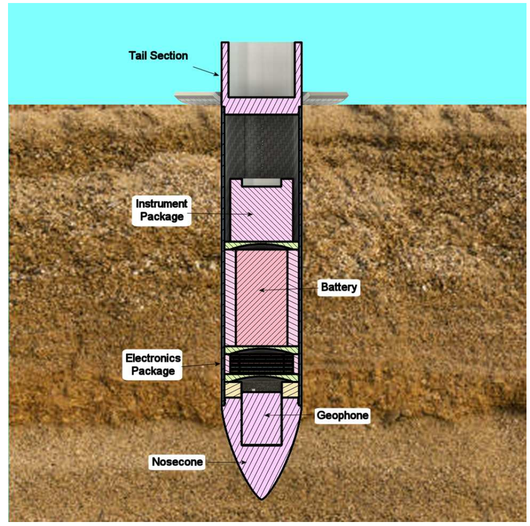

Figure 1: A Mote penetrator after deployment into the lunar regolith (shown in this artist's conception with a very shallow regolith penetration). The electronics and most of the scientific payload would be carried in the penetrator itself and would be automatically embedded below the lunar surface. Cameras, other instruments, and communication antennas are carried in the tail section left on the surface.

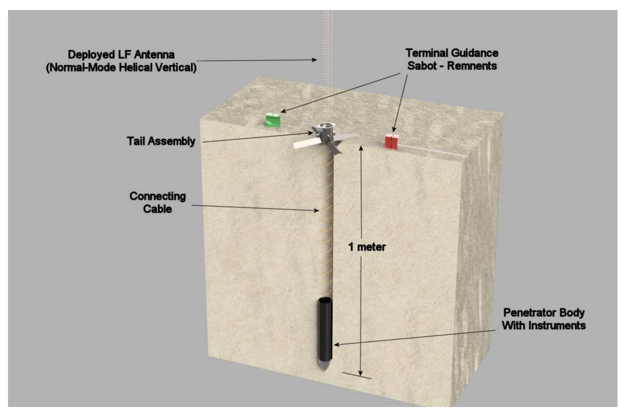

Figure 2: A Mote penetrator after deployment with a typical 1 meter penetration into the lunar regolith. The Mote electronics will be below the insulating surface layer of the regolith, and should remain at a constant temperature (about 250 K near the equator) throughout the entire lunar day.

frequency (1 MHz) RF unit implementing a bi-static surface-penetrating radar system, and an electrode for measuring the local electrostatic fields. Each penetrator could carry a regolith sampling system and a test cell to measure the sample's electrical impedance response over a wide frequency range, to characterize the regolith properties and detect volatiles [3].

Six penetrators will be aimed outside of the pit and will serve as control references for data from the pit and as communications relays for penetrators inside the pit, while four penetrators will be aimed for the floor of the pit itself. With multiple penetrators, the system can measure tilt and distance changes over the entire area of the pit and thus provide a measure of any variation in the lunar soil, dust, and volatiles over time. The magnitude of these tides in any particular location is determined in large part by the subsurface rock and any features in it (i.e. voids), so measuring them will give considerable insight into the underlying structure of the pit area. The geophones can be used as both seismic sources and receivers, allowing for active seismology of any structure under the pit floor.

Deployment in a Tectonicially Active Region in Philolaus Crater: In an extensive search of Northern lunar latitudes we found several regions with evidence of recent tectonics, including an apparently active region in the Western region of Philolaus crate with many signs of recent activity, including a apparently intrusive region we called the Stegosaurus Dome (Figure 3) at 31° 2' 13.45" W 72° 30' 32.44" N. Figure 5 shows how a string of Motes (4 in this case) can be deployed over an tectonically active region, providing information about the surface and subsurface activity at the site. Active tectonic features such as this are high priority targets for future missions focused on lunar surface geodesy.

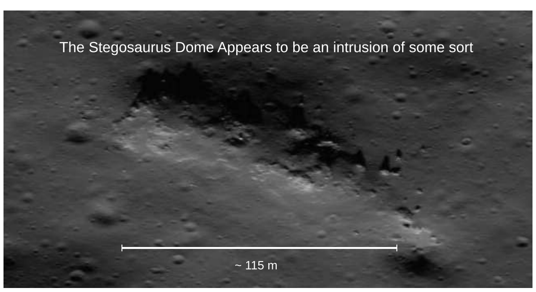

Figure 3: A portion of LROC NAC images from the NASA Quicklook service, showing the Stegosaurus Dome, so-called because of the plate-like boulders apparently being shaken or forced from it.

References: [1] C. J. Ahrens, et al. (2021) *The Planetary Science Journal* 2(1):38 doi. [2] T. M. Eubanks, et al. (2021) in *2021 Annual Meeting of the Lunar Exploration Analysis Group* vol. 2635 of *LPI Contributions* 5036. [3] R. A. Gerhardt (2022) *IEEE Instrumentation & Measurement Magazine* 25(4):14 doi.

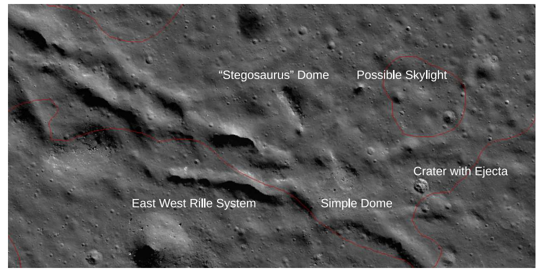

Figure 4: The area around the Stegosaurus Dome, which shows a number of interesting geological features, and numerous fresh boulder fields, in a small area of the Philolaus Crater floor.

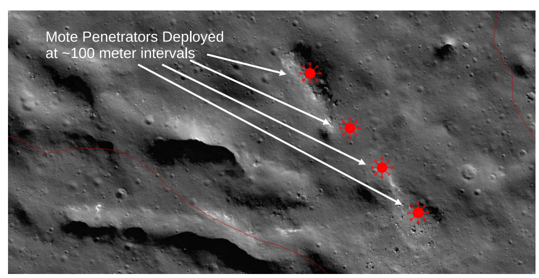

Figure 5: A string of 4 Motes deployed on the Stegosaurus dome, the crater floor, and another nearby dome, also with a boulder field on its crest. With geophones, and the use of Motes as seismic sources in sequence, it should be possible to determine if these domes are still tectonically active, and also possibly the subsurface manifestation of this activity.