Operating on Different Planetary Surfaces: Why is it Crucial to Understand the Geomechanical Properties of Planetary Regolith. R. C. Anderson¹, D. Buczkowski², K Chin¹, J. Long-Fox³, L. Sollitt⁴, and D. Y. Wyrick⁵, ¹NASA/Jet Propulsion Laboratory/California Institute of Technology, ²JHU/Applied Physics Laboratory, ³University of Central Florida, ⁴NASA/Ames Research Center, ⁵Southwest Research Institute, Robert.c.anderson@jpl.nasa.gov

Introduction: Planetary bodies found throughout the solar system are covered with a thin layer of ‘regolith’ that reflects the formative surface processes and environmental conditions that influenced its evolution [e.g.1]. Detailed characterization of the surface and subsurface properties of in situ planetary regolith is critical to many applied areas in planetary science, astrobiology, space engineering, and to the operational success of all future science missions involving surface or near-surface contact. Robotic and human missions have been employed in a variety of planetary environments (e.g., temperature, pressure, etc.) and surface conditions (e.g., Mercury, Venus, Mars, Moon, planetary satellites, and asteroids) [2, 3]. The success of future planetary missions will pave the way for astronauts to land, set foot, and operate on and within these hostile planetary environments. Characterizing the geomechanical properties of the regolith, and spatial distribution, as well as determining the presence and the chemical potentials of liquid water and water-ice, is a crucial first step toward understanding the geologic history as well as the active processes that are operating. Placing humans in these extreme environments will depend on a thorough understanding of the geomechanical and environmental properties of planetary regolith (Figure 1).

Major advances in robotics have enabled in situ surface exploration on various planetary bodies within our solar system. Recent science payloads on landers and rovers on these explorations have focused primarily on instruments designed to identify rock and regolith mineralogy and bulk chemistry. Although important, these measurements are insufficient to understand the origin and formational history of a planetary surface, especially if the goals are to look for evidence of life and to understand surface processes such as atmosphere-regolith energy and mass exchanges. Instruments specifically designed to measure geomechanical properties have been grossly underrepresented since the conclusion of the Lunokhod and Apollo lunar missions and they have been largely absent from our explorations of other worlds beyond the Moon.

Figure 1. Examples of planetary regolith on Mars (A, E), the Moon (B), Titan (C), and Venus (D).

Planetary Regolith: The development of a planetary surface directly reflects the processes associated with the dynamic environment in which it has formed. In-depth studies of terrestrial regolith have demonstrated a close connection between the depositional environment (e.g., climate, temperature, etc.) and the physical and chemical properties of the sediment/regolith deposited on the surface [4]. In addition,
examining the regolith is crucial for determining whether life is/was present. Analysis requires a comprehensive environmental characterization beyond simply looking for an organic molecule. Research has shown that terrestrial life colonizes almost every possible habitat. Characterizing possible habitats on other worlds is important to (1) identify target environments to search for biosignatures; and (2) to constrain what types of life could be compatible with a surface environment, with implications for optimizing instrument design for detection. Rigorous quantification of the geotechnical properties of regolith can answer several scientific questions and these properties can be characterized by three main types of critical measurements: thermal, mechanical, and electrical properties. These measurements, including rover trafficability and base construction, are critical for lunar exploration and habitation.

**Thermal Properties:** The thermal properties of planetary surface and subsurface layers strongly influence the way a body interacts with its environment, specifically how it responds to solar irradiation and how it interacts with any potentially existing atmosphere. If the depth-dependent thermal gradient can be measured *in situ*, this gives important information about the heat flux from the interior and thus provides information about the thermal evolution of the body. Properties that need to be assessed include temperature and thermal history of the regolith, thermal conductivity (its ability to conduct heat), thermal diffusivity (ratio of density to specific heat), thermal resistivity (measurement of the resistance of heat flow), and specific heat of the regolith.

**Mechanical Properties:** Properties that need to be evaluated include soil shear strength (cohesion and angle of internal friction) compaction, relative density, and particle size range and distribution. Shear strength defines the magnitude of the shear stress that a soil can sustain and is defined as the resistance to deformation by the action of tangential (shear) stress. For terrestrial soil investigations, shear strength tests are performed to determine load-bearing capability and internal shear under various loadings. These measurements are used in civil engineering practice to determine the stability of slopes or cuts, to find the bearing capacity of soil to optimize foundation design, and to calculate the pressure exerted by soil [5].

**Electrical Properties:** Soil electrical property measurements are influenced by temperature, mineral type, grain size, porosity, and soil conductivity. Determining the electrical properties (e.g., conductivity, dielectric constant, etc.) of planetary surface materials is very important in providing a quick characterization of surface deposits, especially for materials that contain water and other volatiles on the Moon and Mars [6].

**Conclusions:** Subsurface exploration beyond Earth has been severely limited and only performed locally on the Moon and Mars. Exploring subsurface environmental conditions of planets and planetary bodies such as moons, asteroids, and comets is important in determining the content and structure of the regolith and water/ice, roving vehicle trafficability, and ISRU (e.g., bearing strength for the construction of off-Earth bases). In this presentation, we will illustrate the critical need for new subsurface exploration tools that can quickly and accurately evaluate the geomechanical properties of different planetary regolith.