GEOMECHANICAL CHARACTERIZATION OF PLANETARY REGOLITH USING THE SPARTA TOOLKIT. D.Y. Wyrick[1], R.C. Anderson[2], D. Buczkowski[4], K Chin[2], A. Colaprete[3], J.M. Dohm[5], R. Elphic[3], E. Fritzler[3], I. King[6], D. Lim[3], J. Long-Fox[7], Z. Mirmalek[3], L. Sollitt[3], A. Yingst[8], K. Zacny[6], [1]Southwest Research Institute, [2]NASA/Jet Propulsion Laboratory/California Institute of Technology, [3]NASA/Ames Research Center, Moffett Field, CA, [4]JHU/Applied Physics Laboratory, [5]Exploration Institute, [6]Honeybee Robotics, [7]University of Central Florida, [8]Planetary Science Institute; danielle.wyrick@swri.org.

Introduction: Regolith materials on planetary bodies display a wide range of geomechanical characteristics, which in turn influence the geotechnical behavior and volatile storage capabilities. In order to better understand regolith properties, we have developed the Soil Properties Assessment, Resistance, Thermal Analysis (SPARTA) toolkit [1] for use on multiple deployment platforms to various planetary bodies, with or without atmospheres. The SPARTA toolkit is a miniature suite of instruments capable of measuring the mechanical, thermal, electrical and chemical properties of dry and/or icy regolith (Fig.1). Once deployed into the subsurface, SPARTA will measure, collectively, the in situ electrical, mechanical, and thermal properties of the regolith in real-time, providing a comprehensive look at a planetary regolith's basic properties such as porosity, bulk density, material strength, thermal conductivity, and water content.

SPARTA is proposed as part of a payload onboard a low-cost lunar PRISM rover mission concept, Silfela [2]. The primary science objective of the Silfela mission is to explore the surface and near-surface (depths to ~10 cms) environmental conditions at Aristarchus plateau, with particular foci on the geomechanical properties and water content of multiple geological units.

Background: Detailed characterization of planetary regolith geomechanical properties and ice content is critical to many applied areas in planetary science, astrobiology, space engineering, and to the operational success of all future landed and/or roving science missions involving surface or near-surface contact. Planetary missions have failed or have had difficulties because planners did not understand basic surface properties such as regolith shear strength (Apollo 15 drill, Philae harpoon; [3]), triboelectric charging (Phoenix sample handling system, Curiosity sample handling system; [4]), or regolith bulk strength in a reduced gravity environment (InSight's Mole Drill; [5]). The validation of future rover concepts and operations will rely on a comprehensive determination of the strength and deformation behavior of granular materials. None of the previous landers sent to other planetary surfaces has directly measured the geomechanical properties of the subsurface (e.g., shear and compressive strength, amount of compaction of regolith, etc.) primarily due to lack of suitable hardware. SPARTA seeks to directly measure local in situ regolith properties to answer scientific questions that can only be answered through direct localized measurements.

SPARTA design: SPARTA consists of five components [1]: a Thermal Conductivity Probe (TCP), a Vane Shear Tester (VST), a Cone Penetration Tester (CPT), a Dielectric Spectroscopy Probe (DSP), and an imager, which in turn measure the in situ thermal, mechanical and electrical properties of a planetary regolith. The TCP will measure temperature, thermal conductivity and thermal diffusivity, providing constraints on thermal gradients, thermal transfer raters, density, and thermal history. The VST and CPT measure shear strength (Mohr-Coulomb cohesion and angle of friction), bearing capacity, compaction and relative density, proving critical data on the stratigraphy, volatile transport and site characterization. The DSP measure volatile content, allowing the characterization of both the spatial extent and mode of water present (e.g., adsorbed, bound/film, capillary or pore water) as well as regolith permeability. The imager is a high flight-heritage commercial instrument consisting of a 5-megapixel color CMOS camera and DVR with a configuration yielding ~500µm/pxl at 1m distance [6]. Together, the SPARTA toolkit allows for multiple site measurements to be performed in order to characterize the regolith geomechanical properties.

Regolith characterization: The shear strength of a soil is indicative of its resistance to erosion. Specifically, it is defined as the resistance to deformation by the action of tangential (shear) stress [8,9]. Soil shear strength is made up of cohesion between particles and the resistance of particles sliding over each other due to friction or interlocking. 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 a soil [9].

Shear strength measurements for planetary surfaces contribute to 1) the design of landing and mobility systems (since the evaluation of the bearing capacity of the regolith being dependent on the shear strength); 2) the analysis of the stability of natural or artificial slope(s); and 3) an understanding on how gardening and meteoritic impact affect the regolith on small bodies.

Vane shear testing is one of the most common terrestrial soil tests used to measure the undisturbed shear strength directly in the soil. A vane of crossed steel plates is pressed down in the soil, and then the torque is measured when the vane is rotated. To date, no such instrument has ever flown on a planetary mission. [10] evaluated a pocket vane shear tester in lunar soil simulant and concluded that the vane shear tester was simpler to use than other instruments and could be easily adapted for use by a robotic lunar lander.

Cone penetration testing is another common terrestrial soil method used to determine several geotechnical engineering properties of soils, including: 1) soil penetration resistance (mainly depends on soil type, bulk density, and soil water content); 2) compaction, as it relates to the changes in soil porosity and pore-size distribution; and 3) soil moisture content, which affects cohesion, angle of internal friction, compressibility, and adhesion. CPT can also be used to pinpoint changes in the lithology and stratigraphy <1cm, as well as identify the areas to be sampled. CPT tests allow for a continuous record of the ground resistance profile with depth, and can be used to estimate both soil friction angle and shear modulus.

CPT has been used successfully on the moon by Apollo astronauts and the Lunokhod rover. A self-recording penetrometer was used on Apollo 15 and 16 to measure the geomechanical properties of the lunar soil to obtain data on the characteristics and mechanical behavior of lunar soil at the surface and subsurface, and the variation of its properties in lateral and vertical directions, on slopes and between different localities of the Moon [11]. The SPARTA Cone Penetrator test method is similar to the Apollo and Lunokhod design and consists of deploying a cone of known tip-angle and cross-sectional area into the subsurface.

Conclusion: In-depth characterization of the subsurface properties of in situ planetary regolith (e.g., environmental and geomechanical properties) is essential to many areas in planetary science, astrobiology, space engineering, and the operational success of all future landing/roving missions involving surface or near-surface contact. Determining the presence of water/ice as well as the validating of future rover concepts and operations will rely on a comprehensive examination of in situ planetary regolith. For engineering, designers of landing systems, such as pads, airbags, and braking rockets, require an understanding of how their hardware will interact with the regolith. Moreover, estimating how rover mobility is affected by traversing on loose, granular regolith remains challenging. Although it is relatively straightforward to calculate the forces imparted on the terrain by rover hardware, characterization of the terrain response and its effect on trafficability has proven to be more difficult. Understanding the environmental properties (e.g., water/ice content) of in situ planetary regolith is critical for science and ISRU evaluations.

SPARTA is designed to analyze the in situ geomechanical properties and ice content of planetary regolith, including the relative density and thermal gradient at specified increments with depth. The miniaturized SPARTA toolkit is designed for a variety of planetary surfaces of regolith-containing bodies, such as Trojan asteroids, Mars, Titan, and the Moon [12].

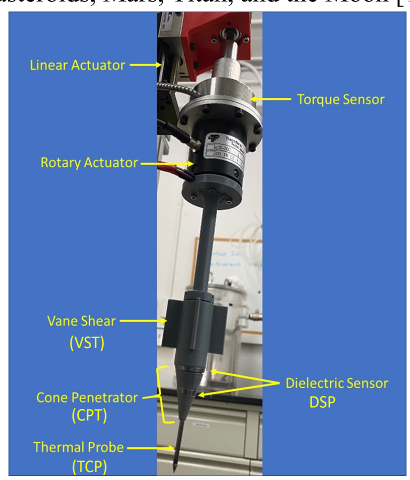

Fig 1. The Soil Properties Assessment, Resistance, and Thermal Analysis (SPARTA) toolkit design. The size is 16 cm from the top to the tip, with a chassis diameter of 10 cm at its widest point.

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