SPARTA: A Toolkit for Subsurface Exploration of Planetary Regolith. R. C. Anderson[1], K. Chin[1]. J. Dohm[2], L. Sollitt[3], K. Zacny[4], D. Buczkowski[5], and D. Wyrick[6], (Robert.c.anderson@jpl.nasa.gov), [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, 4800 Oak Grove Boulevard, Pasadena, CA 91109. [2]Exploration Institute. Cheyenne, WY 82001; [3]Planetary Science Institute, Tuscon AZ 85719 ; [4]Honeybee Robotics, Altadena CA 91001; [5]Johns Hopkins Applied Physics Laboratory, Laurel, MD 20723; [6]Southwest Research Institute, San Antonio, TX 78238; (Robert.c.anderson@jpl.nasa.gov).

Introduction: Detailed characterization of the 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. Understanding the geomechanical properties of planetary regolith, as well as determining the presence and the chemical potentials of water and ice, are both central to NASA's exploration strategy for future manned long-term exploration of the Moon and Mars. SPARTA (Regolith Properties Assessment, Resistance, Thermal, Analysis) is a highly versatile, miniature toolkit that provides NASA with a new capability for in situ measurements of mechanical, thermal, electrical, and chemical properties of dry or icy regolith and permafrost during surface-landed missions. SPARTA is designed for planetary bodies such as the Moon, Mars, Mercury, Venus, asteroids, and comets with or without atmospheres, that may/may not contain water/ice.

Background: Major advances in robotics have enabled in situ surface exploration on a variety of planetary bodies within our solar system. Recent science payloads on these rovers have focused primarily on instruments designed to identify the mineralogy and elemental chemistry of rocks and regolith. 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. 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 [1]. However, instruments specifically designed to measure these properties have been grossly underrepresented on planetary missions since the conclusion of Apollo; they have been largely absent from our explorations of other worlds beyond the Moon.

Knowledge of planetary regolith geotechnical properties is of practical importance to trafficability [2], construction, and excavation/mining operations [3]. For trafficability, near-surface strength measurements will help with rover wheel design; not only to prevent dangerous conditions, such as the rover becoming stuck or slipping but also to make traverses more energy-efficient [4]. For construction, the strength of the layers below the surface will drive the placement, size, and depth of the foundations. For mining and excavation purposes, knowledge of the strength of the regolith will help establish preferred excavation protocols, determine the size of the excavators' scoops or blades, and estimate energy requirements [5]. Alternatively, excavation sites with less dense regolith, and therefore are easier to excavate, could be identified. Geotechnical tools could be used to assess the quality of blast protection berms, launch pads, radiation shielding on top of human habitats, trafficability of regolith from one outpost to the next, and ease of excavation.

Current SPARTA Design: SPARTA provides NASA with a highly versatile, miniature in situ penetrating device/instrument package capable of measuring the physical properties of regolith (soil-like material, dry and ice-rich) for future surface landed missions. The SPARTA instrument includes four terrestrial regolith measurements in one small package, each component of which is based on a classical terrestrial geochemical, geotechnical instrument (Fig. 1). It consists of a percussively driven cone-penetrometer capable of measuring penetration resistance. Once deployed to the subsurface, the cone is configured with vanes and a torsional degree of freedom (DOF) to accommodate a vane-shear resistance measurement. Also contained within the end effector are platinum resistance thermometers (PRT) that serve as a resistive heating element and a high-precision temperature sensor that provides single needle heat-pulse thermal conductivity measurements (TCP). The end effector consists of a cone penetrator (CPT) that also houses a dielectric spectrometry probe (DSP) that can detect and characterize water/ice and chemical composition based on the electrical properties in the surface and/or subsurface [6]. Lastly, while not part of the end effector, an atmospheric relative humidity sensor (RS) is incorporated into SPARTA for planetary bodies that contain an atmosphere. Measuring relative humidity is essential for calibrating the dielectric spectrometer.

SPARTA is currently designed to characterize the subsurface for water/ice content (detection to 0.5%), relative permittivity, soil relaxation time, thermal conductivity/resistivity, and shear strength and penetration resistance. SPARTA will be adapted and integrated into future lander roving missions. Miniaturization allows SPARTA to be placed on a robotic arm, while subsets of components might also be placed on a sample gathering apparatus and/or lander footpads. The simplicity of the instrument, its miniature size, and minimal sample and power handling requirements are synergistic with the existing spacecraft hardware. This benefit enables use without taxing strict power, payload, communications, and operational constraints of future subsurface lunar explorer missions, making it ideal for in situ surveys of planetary subsurface.

Conclusion: 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 will require analysis toolkits exemplified by SPARTA. The utility of SPARTA includes determining the content and structure of the regolith and water/ice, and roving vehicle trafficability, and ISRU (e.g., bearing strength for the construction of off-Earth bases). Application and adaptation of SPARTA will continue through laboratory, field, and environmental (e.g., Zero Gravity) testing regimes. SPARTA is currently designed to analyze the water content, geo-mechanical properties, and thermal gradient of the regolith down to a depth of about one meter.

References

[1] Poulson, D. (2005) *Nature,* 433(433), 204–205. [2] Chhaniyara, S., et al. (2012) *J. of Terramechanics*, 49, 115-128. [3] Zacny, K., et al. (2010) *ASCE Earth and Space 2010*, 15-17 March 2010, Honolulu HI. [4] Iagnemma, K., & S. Dubowsky (2003) *Springer Berlin Heidelberg New York*,. [5] Crawford, I. (2015) Lunar Resources: A Review. Progress in Physical Geography, 39(2), 137–167. [6] Seshadri. S., (2008) *Astrobiology***,** 8(4). 781,.

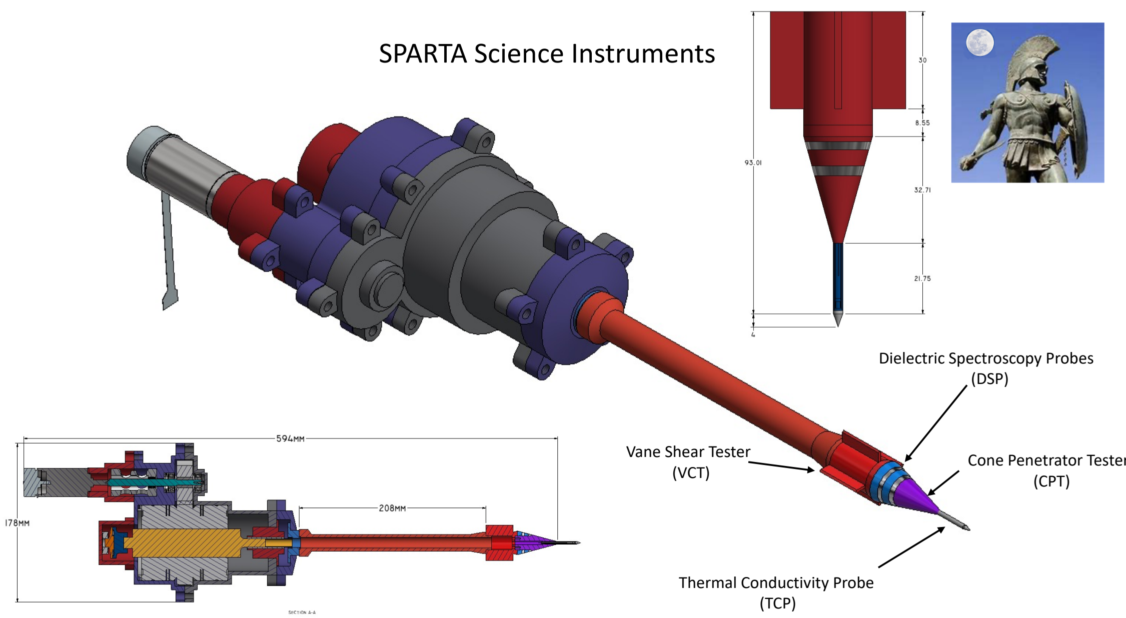

Fig. 1. Present design for SPARTA showing dimensions.