FY23 Innovative Spontaneous Concepts Research and Technology Development (ISC)

Geotechnical Assessment of Soil Analogs under Extreme Environments using the SPARTA Instruments

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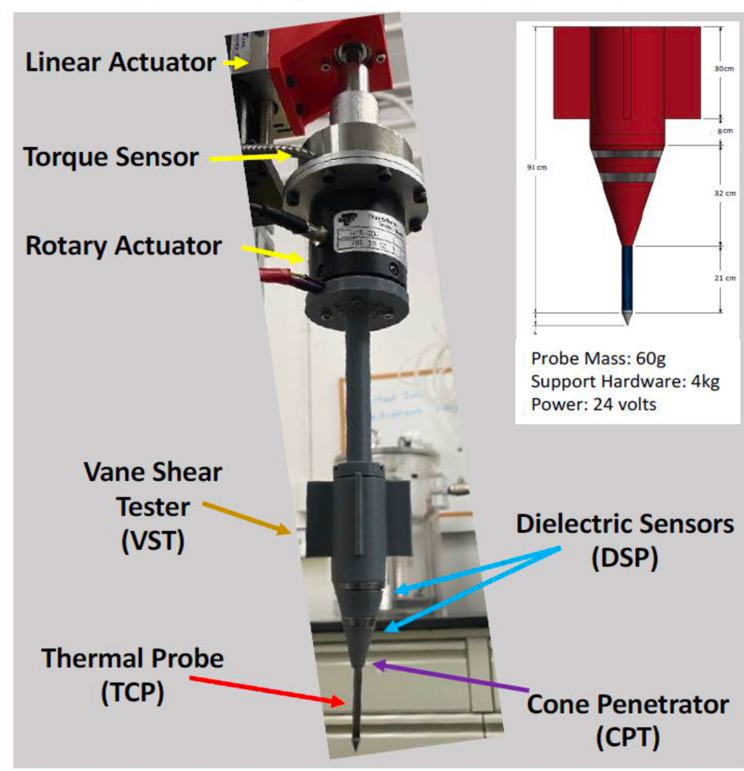
Objectives: To progress the development of the SPARTA toolkit by testing newly acquired terrestrial samples for characterizing each component listed above under Martian environmental conditions (i.e., pressure, temperature) and varying amounts of water/ice. A prototype benchtop of SPARTA was developed under a NASA PICASSO program (funded in 2020), currently located in Geotechnical Regolith Active-Passive Test (GRAPT) lab. To achieve TRL 4, functional testing and soil analog evaluation using this SPARTA prototype is still incomplete especially under realistic environmental conditions. This work fulfilled a critical requirement on the SPARTA for geotechnical application by leveraging both soil analogs available and existing geochemical testbed systems (i.e., thermal vacuum (TVAC)).

SPARTA
Science Components & Relevance



SPARTA is a unique, all-in-one science toolkit with the ability to **simultaneously measure *in situ* electrical, mechanical (shear and penetration), and thermal properties of lunar regolith**. SPARTA is a versatile system that is able to be deployed on **autonomous rovers and landers or used by personnel** during exploration and resource prospecting efforts

Electrical Properties

- SPARTA Dielectric Spectroscopy Probe (DSP)
  - **Measures:** Volatile content
  - **Scientific Relevance:** Spatial extent and mode of water (e.g., adsorbed, bound/film, capillary, or pore water), regolith permeability
  - **Engineering Relevance**: ISRU/human exploration

Mechanical Properties

- SPARTA Vane Shear Tester (VST) and Cone Penetration Tester (CPT)
  - **Measures:** Shear strength (Mohr-Coulomb cohesion and angle of friction), bearing capacity, compaction, relative density.
  - **Scientific Relevance:** Site characterization, volatile transport, stratigraphy
  - **Engineering Relevance**: Infrastructure development, vehicle/rover design, trafficability, drilling, excavation.

Thermal Properties

- SPARTA Thermal Conductivity Probe (TCP)
  - **Measures:** Temperature, thermal conductivity, thermal diffusivity, thermal history.
  - **Scientific Relevance:** Transient thermal gradients, thermal transfer rates, volatile content, compaction, density
  - **Engineering Relevance**: ISRU (volatile extraction, molten regolith electrolysis, additive manufacturing, glass-ceramic production)

Background: 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 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 the amount of water/ice, strength, and deformation behavior of in situ planetary regolith. Understanding the environmental and geomechanical properties of in situ planetary regolith is critical for such determinations. SPARTA (Soil Properties Assessment Resistance and Thermal Analysis) is a toolkit designed to analyze the in situ geomechanical properties and the ice content of planetary regolith, including the relative density and thermal gradient at specified increments with depth. The miniaturized SPARTA toolkit encompasses four terrestrial regolith components, each at or above a NASA Technical Readiness Level (TRL) of 4. The toolkit consists of a Thermal Conductivity Probe (TCP), a Vane Shear Tester (VST), a Cone Penetration Tester (CPT), and a Dielectric Spectroscopy Probe (DSP) designed for a variety of planetary surfaces; for bodies as diverse as Trojan asteroids, Mars, Titan, Moon, and Ocean World bodies.

Approach and Results: The project developed the capability to perform TVAC testing on controlled environments my means of developing new HW and SW capabilities, and performed lab experiments on soil analogs. The testbed specifications included portability to be housed in the thermal environmental chamber with electrical feed-throughs and user control interfaces. SW specifications include automation of experimental execution and data collection at highest data return throughput.

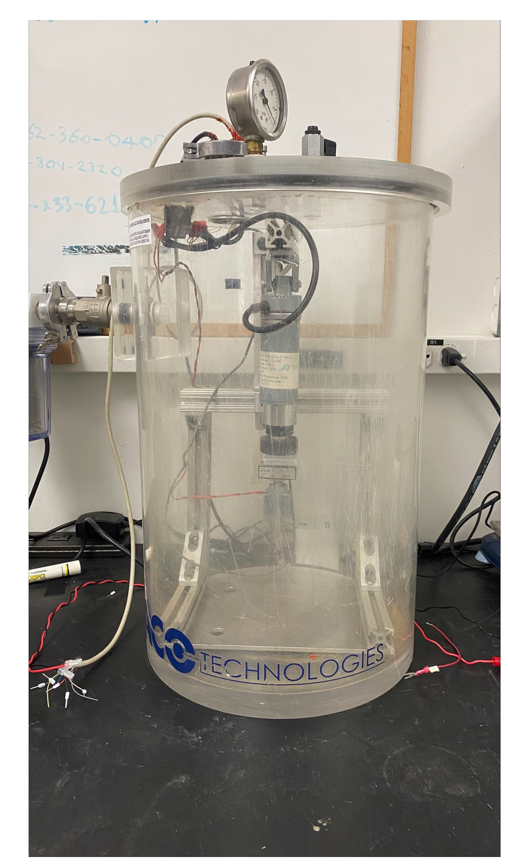


Fig. 1 Vaccum chamber for environmental testing.

Experimentations: Ten terrestrial analog soil samples were collected from multiple regions in the western US. For this proposal, we characterized each sample to define a set of requirements for SPARTA that will be used for a proposed PRISM proposal and setting a baseline for a scheduled Blue Origin suborbital Flight (8/2023). Our approach for each sample was 1) sieved and sort by grain size (e.g., <150 microns, 150 micron to 1 mm, and 1-2 cm) and dry. These categories were chosen based on Mars observations; 2) characterize under terrestrial and Mars environmental conditions (pressure, temperature, etc.) each soil categories with varying the amount of water (1%, 5%, and >5%) and ice. A total of 90 samples were characterize from this proposal. All activities (e.g., sieving, drying oven, and Mars vacuum testing chamber) will take place in the newly developed GRAPT lab located in bldg. 67-121. For testing under Martian temperature, the plan was for the vacuum chamber to be transported to in-situ Geochemical Electrochemistry Sensor (i-GES) lab and incorporated into an environmental chamber (+/- 40^{o}C). However, the slated thermal environmental chamber to be used for the project had malfunctioned, and failed to operate below sub-zero temperatures. This curtails our test our target experimental matrix (e.g., Martian temperature) until the chamber is replaced. We are in the process of procuring a new environmental chamber to completed this project as outlined.

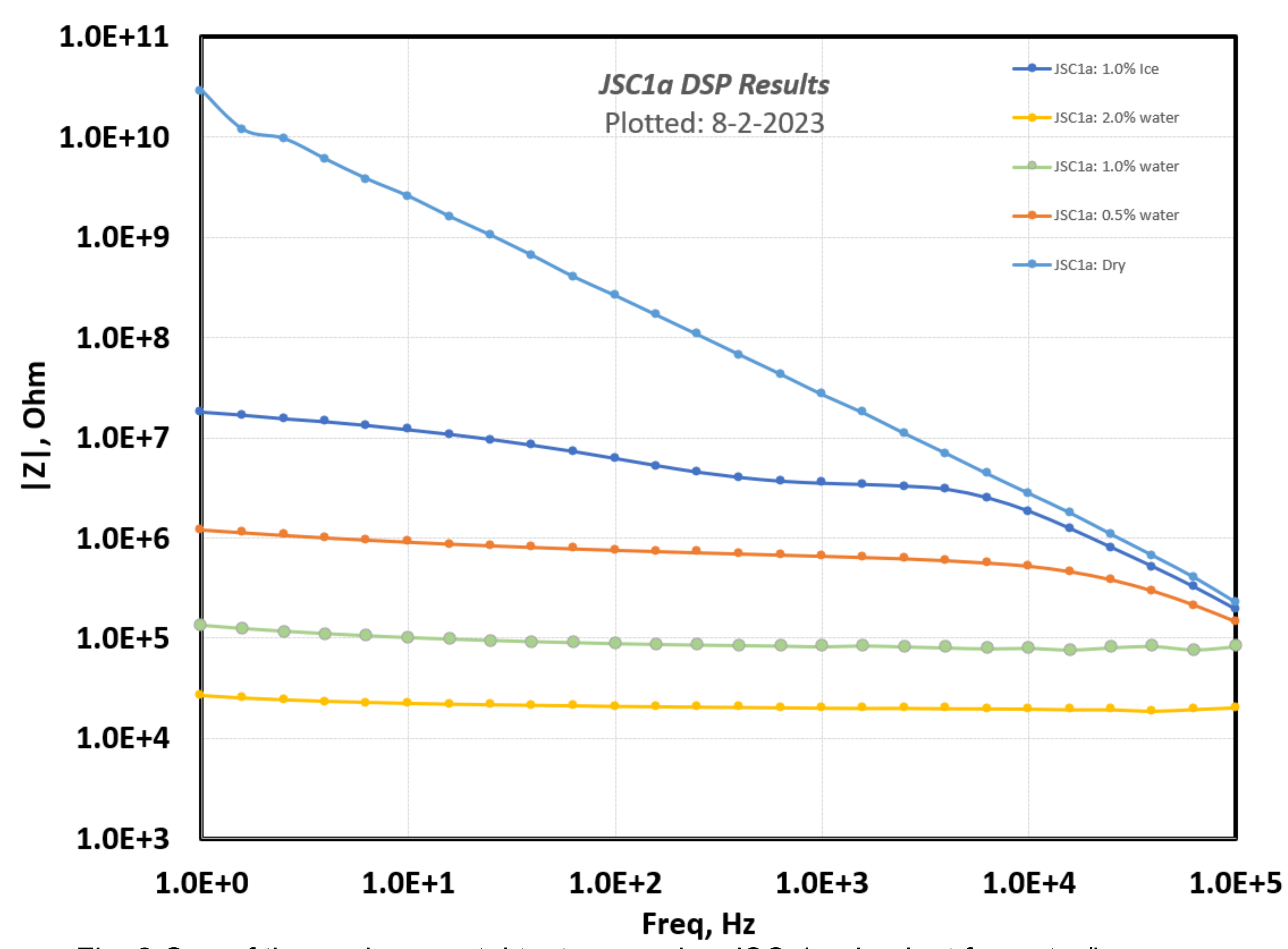


Fig. 2 One of the environmental test runs using JSC-1a simulant for water/ice detection. Four runs were completed under Martian pressures. The "flatness" of the lines indicates the presence of water. From the graph, water was detected down to 0.5% (orange line). In addition, 1% ice was detected (dark blue line). The dip in the line around 1000 Hz is an indication of the presence of ice.

Results: As shown Figure 1, a portable version of SPARTA benchtop was integrated in a TVAC system. Control SW was developed to perform automated experimental runs and data collect in Python script language with IVI protocols for instrumentation. Figure 2 is one of the test runs for JSC-1a (lunar simulant). Note: water was detected down to 0.5% mass, and ice was detected down to 1% mass.

Significance/Benefits to JPL and NASA:
To achieve TRL 4, functional testing and soil analog evaluation using this SPARTA prototype is still incomplete especially under realistic environmental conditions. This proposed work will fulfill a critical requirement on the SPARTA for geotechnical application by leveraging both soil analogs available and existing geochemical testbed systems (i.e., thermal vacuum (TVAC)).

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