Integrative Regolith Characterization for Space Resources, Surface Infrastructure, and Planetary Exploration

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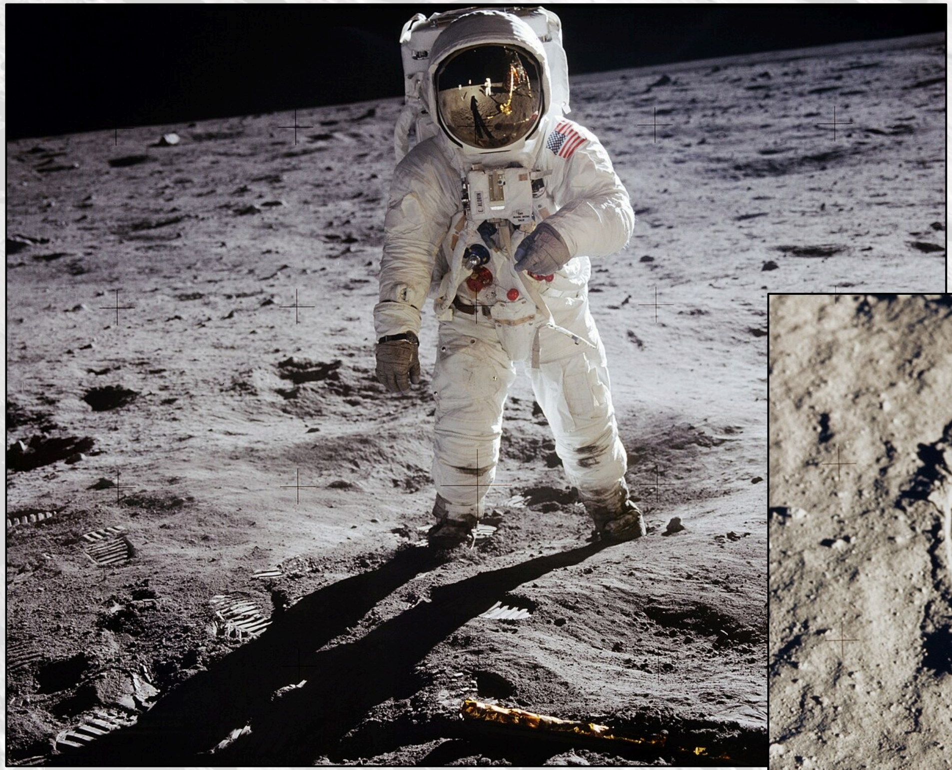
Space Resources Roundtable XXVI
Golden, CO, USA
June 4, 2026

Space Construction III

Image credit: LPI

Introduction and Background

- **NASA priorities call for safe and sustainable human and robotic exploration of the Moon, Mars, and beyond**
  - **Science priorities tell us why we explore; Exploration architectures tell us how we explore; Technology development bridges these**



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Introduction and Background

- **Exploration is science, science is exploration**
  - **Exploration activities, ISRU, and infrastructure development depend on regolith mechanical behavior which is determined by local geology and geologic history**
  - **Surface operations may serve as opportunistic scientific measurements**
- **Sustained lunar presence will not be enabled by science or engineering alone, but by deliberate integration at their natural intersection – regolith**

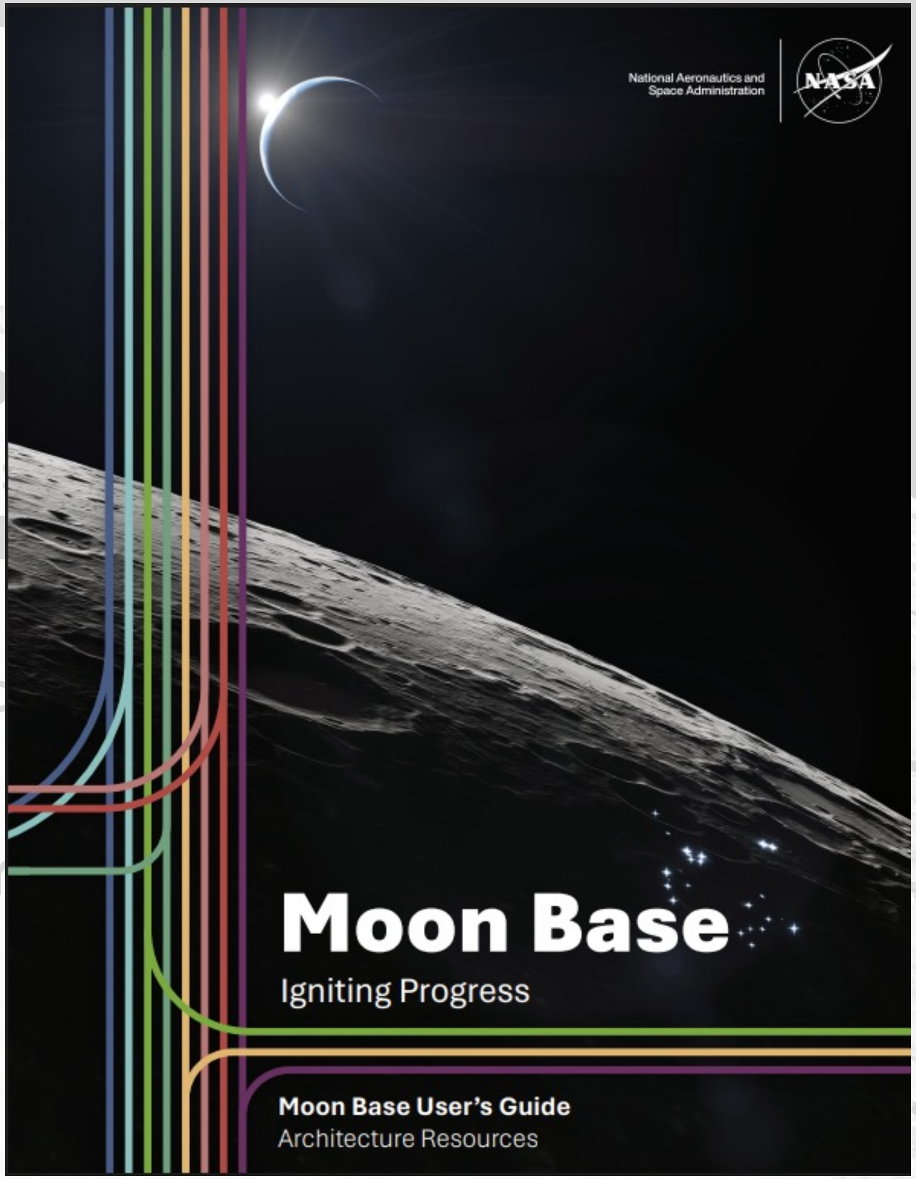
Image credit: LPI

Introduction and Background

Cool… But what does this all mean, how does this all come to fruition? It all seems kind of ethereal… Or, well, seemed ethereal until…

Image credit: LPI

Introduction and Background



March 24, 2026 – NASA unveils plans to build a Moon Base

https://www.nasa.gov/ignition/

Image credit: LPI

Do You Wanna Build A… Moon Base?

- **If your answer is "yes", you need (amongst many other things):**
  - **Science: Geology, environment**
  - **Technology: Regolith operations**
  - **Exploration: Be agile, be resourceful, and be prepared to be surprised**
- **We must have a solid, quantitative understanding of regolith**
  - **Dedicated *in situ* regolith characterization instruments**
  - **Predictive, multiphysics-based computational regolith mechanics modeling methods**

Image credit: LPI

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Soil Properties Assessment, Resistance, and Thermal Analysis (SPARTA)

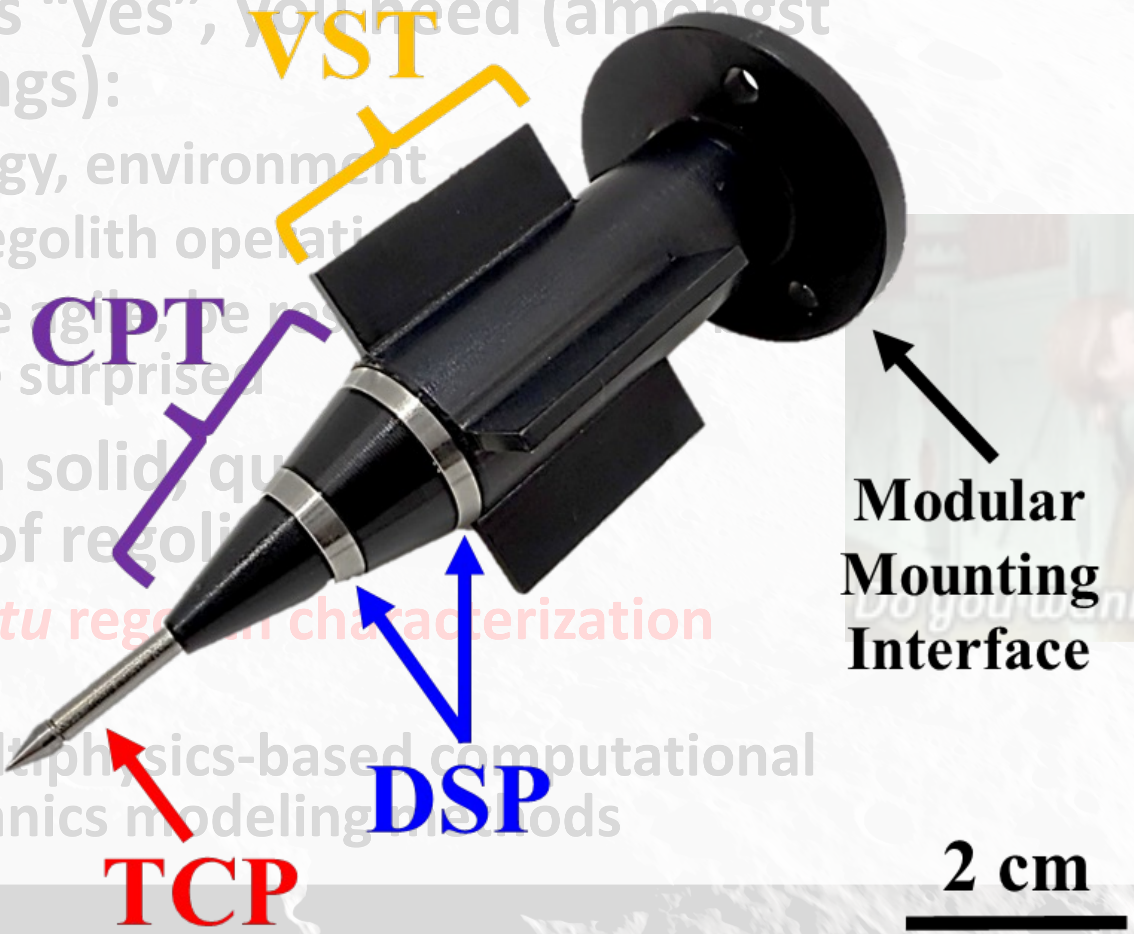
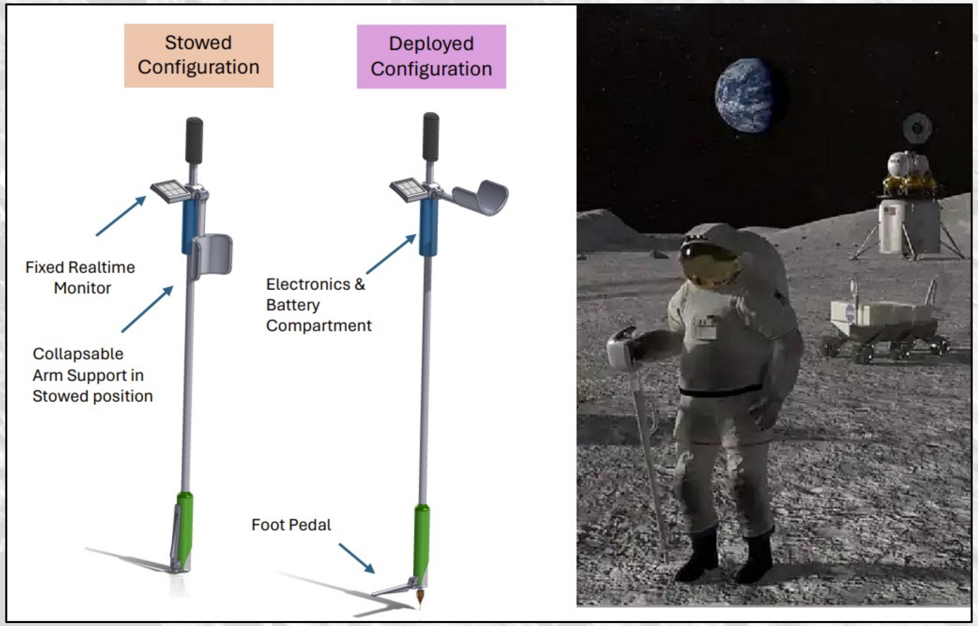


Image credit: LPI

Soil Properties Assessment, Resistance, and Thermal Analysis (SPARTA)

- **Simultaneous *in situ* shallow subsurface (≤ 15 cm) measurements at unprecedented spatial resolution on any rocky body (Moon, Mars…)**
- **Deployment mechanism can vary (astronaut, rover/lander)**

Credit: Honeybee Robotics



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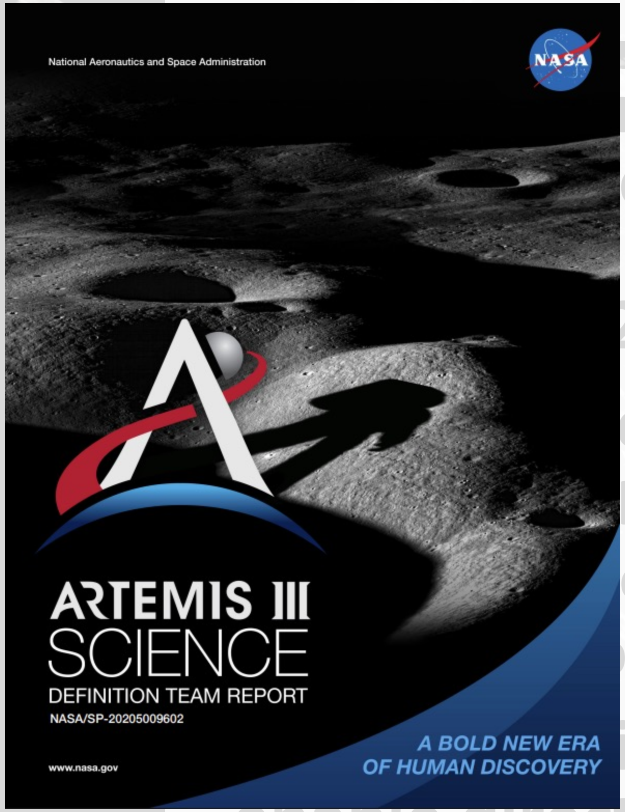
Surface and Subsurface Characterizations for Science

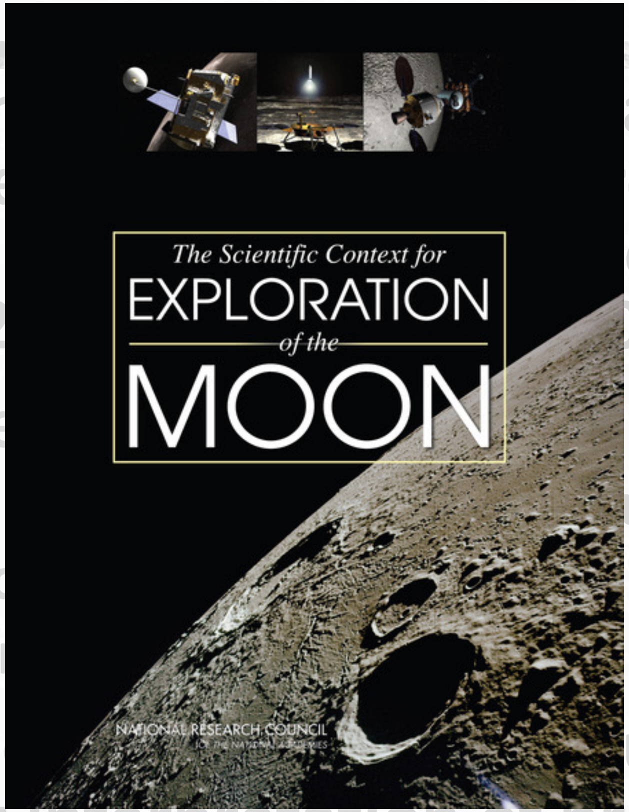
- **Understanding origin, evolution, and current state of planetary surfaces requires regolith and near-surface property measurements [National Academies, 2007; 2023; NASA, 2020; 2022]**
- **Key properties**
  - **Mechanical stratigraphy and structure (VST, CPT)**
  - **Thermal properties (TCP)**
  - **Dielectric properties (DSP)**
- **High-resolution, co-located measurements enable direct interpretation of processes and history**

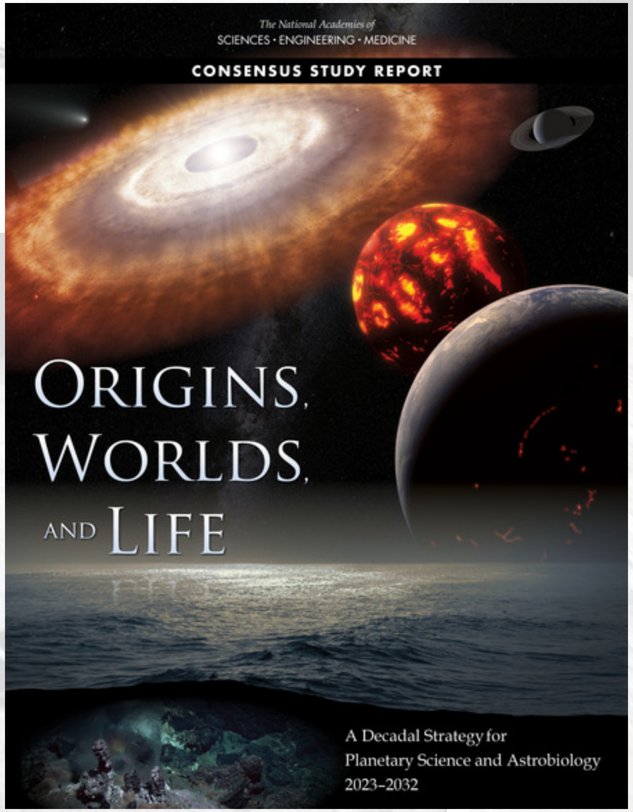
Credit: NASA

Image credit: LPI

Surface and Subsurface Characterizations for Science







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Credit: NASA

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Credit: NASA

Image credit: LPI

Surface and Subsurface Characterizations for Exploration

- **High-resolution, quantitative regolith characterization is critical for mobility, excavation, infrastructure, and ISRU [Sanders et al., 2022; Hilburger, 2023; Neal et al., 2024; NASA 2025]**
- **Measurements inform:**
  - **Trafficability and bearing capacity (VST, CPT)**
  - **Site selection (VST, CPT, TCP, DSP)**
  - **Site preparation (CPT, VST)**
  - **Thermal management (TCP)**
  - **Resource potential (DSP, TCP)**

Credit: NASA

Image credit: LPI

Surface and Subsurface Characterizations for

Acta Astronautica 214 (2024) 737–747

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

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The Moon needs an international lunar resource prospecting campaign

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ARTICLE INFO

Keywords:
Moon
Lunar resources
Prospecting
Evaluation
Reserve potential
International campaign
Space law
Outer Space Treaty

ABSTRACT

The Moon is a highly valued destination for human space exploration because it is close and it contains a wide array of lunar and Solar System science targets, which include resources that could be used to sustain humans on the lunar surface. These resources have the potential to enable sustainable human space exploration, develop a vibrant cislunar economy, and directly benefit society here on Earth. However, recent rhetoric about the importance and value of these resources has used the term as if we know they are reserves. An immediate and vital next step has not yet been realized to define the reserve potential of such resources, and that is designing and implementing a coordinated international lunar resource evaluation (prospecting) campaign. This paper outlines the issues that need to be addressed by such a campaign, including why it needs to be international in nature and how the coordination can be started and evolved, as well as exploring the benefits that would come from prospecting on the Moon.

Credit: NASA

Image credit: LPI

Surface and Subsurface Characterizations for Exploration

- **High-resolution, quantitative regolith characterization is critical for mobility, excavation, infrastructure, and ISRU [Sanders et al., 2022; Hilburger, 2023; Neal et al., 2024; NASA 2025]**
- **Measurements inform:**
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Credit: NASA

Image credit: LPI

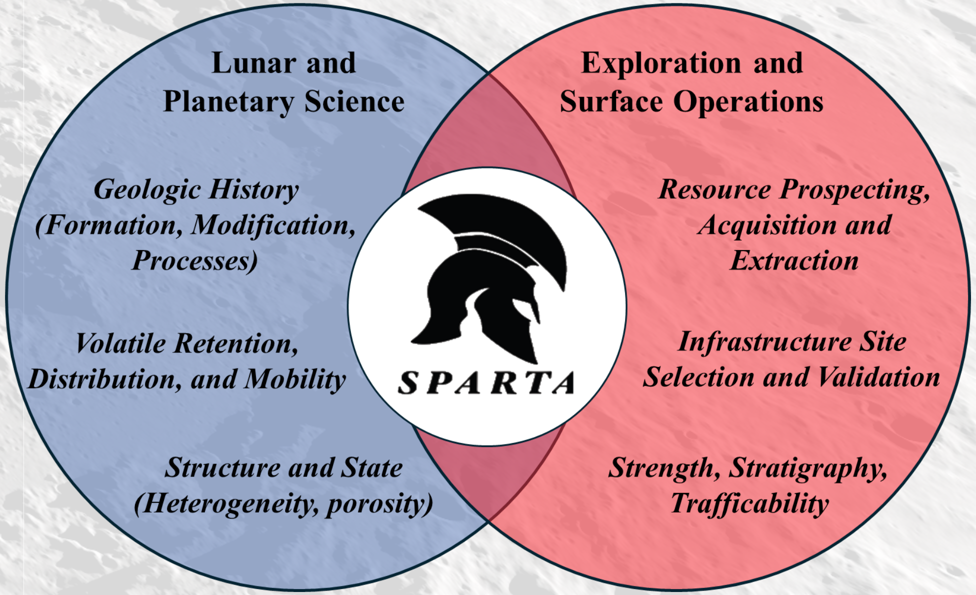
Safety and stability of the Moon Base and all other infrastructure and exploration activities fundamentally rely on high spatial resolution, low uncertainty measurement of lunar regolith geotechnical properties!

We must fly proper instrumentation to do so… Dedicated, standardized geotechnical instrument suite?

Image credit: LPI

Discussion and Conclusions

- **Safety and stability of the Moon Base and all other infrastructure and exploration activities fundamentally rely on high spatial resolution, low uncertainty measurement of lunar regolith geotechnical properties**
- **Must prioritize developing and flying proper instrumentation to reduce risk and enable reaching NASA's Ignition goals**
  - **Dedicated, standardized geotechnical instrument suite**



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Acknowledgements

This work was directly supported by the NASA Solar System Exploration Research Virtual Institute Cooperative Agreement Numbers #80NSSC23M0161 and #80NSSC19M0214, and by NASA Space Technology Mission Directorate Cooperative Agreement Number #80NSSC23K1173

Image credit: LPI

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