


Regolith Characterization in Small-Scale Laboratory Experiments

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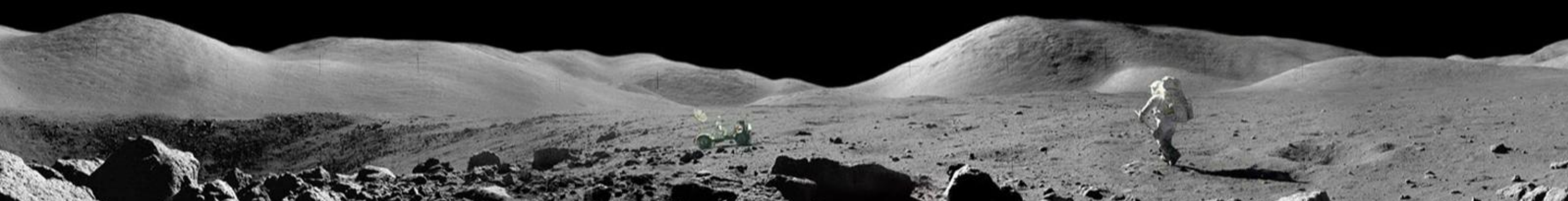
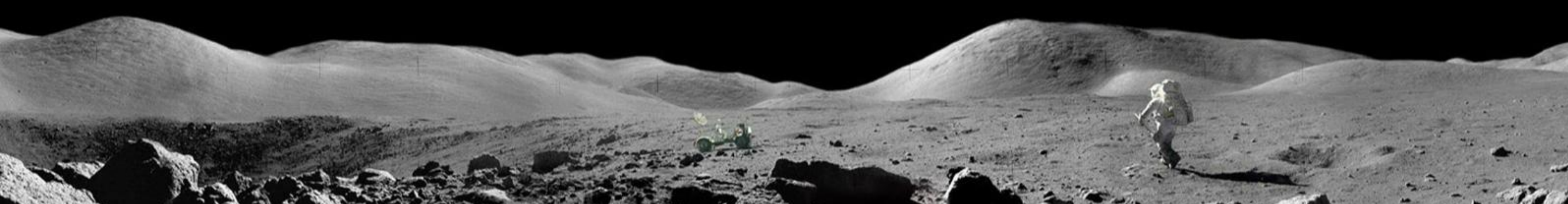
All: SSERVI Institute for Modeling Plasma, Atmospheres, and Cosmic Dust (IMPACT)

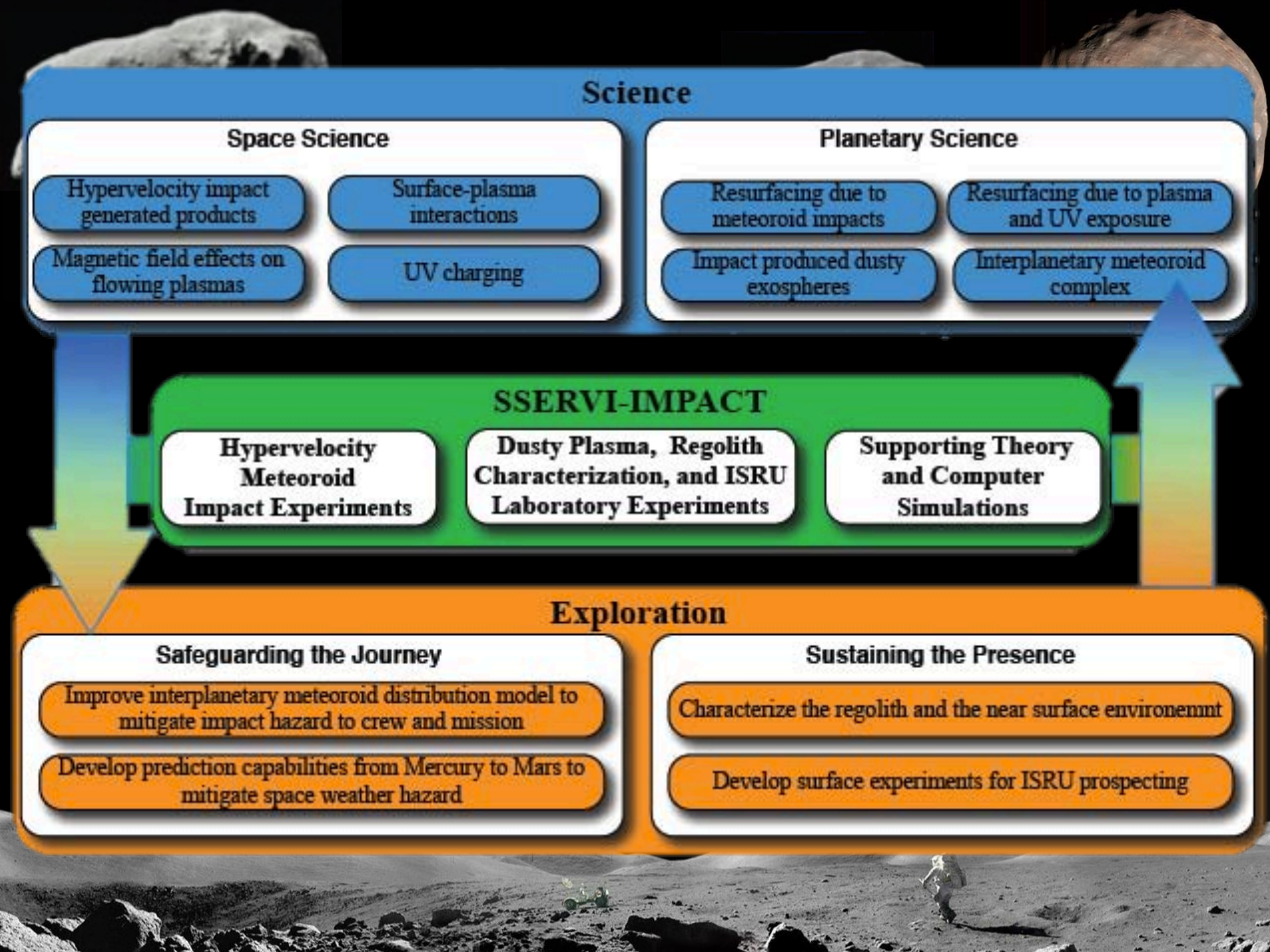





SSERVI-IMPACT

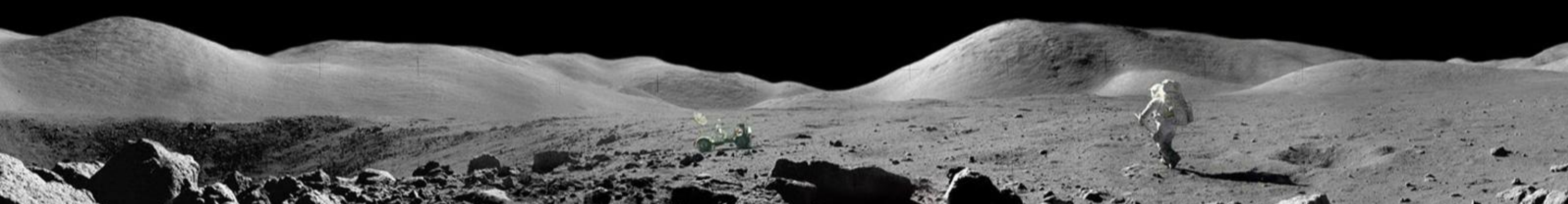
- Studying the effects of hypervelocity meteoroid impacts and dusty plasmas caused by naturally occurring processes and by human/robotic activities near or on the surface of airless planetary objects: the Moon, NEAs, and the moons Phobos and Deimos.
- Successor to the NLSI Colorado Center for Lunar Dust and Atmospheric Studies




Science
Space Science
Hypervelocity impact generated products
Surface-plasma interactions
Magnetic field effects on flowing plasmas
UV charging
Planetary Science
Resurfacing due to meteoroid impacts
Resurfacing due to plasma and UV exposure
Impact produced dusty exospheres
Interplanetary meteoroid complex
SSERVI-IMPACT
Hypervelocity Meteoroid Impact Experiments
Dusty Plasma, Regolith Characterization, and ISRU Laboratory Experiments
Supporting Theory and Computer Simulations
Exploration
Safeguarding the Journey
Improve interplanetary meteoroid distribution model to mitigate impact hazard to crew and mission
Develop prediction capabilities from Mercury to Mars to mitigate space weather hazard
Sustaining the Presence
Characterize the regolith and the near surface environennt
Develop surface experiments for ISRU prospecting

IMPACT Experiments and Modeling

- **Dust Accelerator Experiments** – Ejecta Experiments, Cratering Studies, Ion composition Experiments, Neutral Gas Experiments, Gas Target Experiments
- **Dusty Plasma, Regolith, and ISRU Laboratory Experiments** – Dusty Surface in the solar wind, Regolith charging via Solar wind and UV, Dust launch experiment, Regolith characterization, ISRU experiments
- **Theory and modeling** – Molecular-dynamics models of cratering, plasma simulation, dust ejecta clouds, space environment modeling






ISRU in IMPACT

- How do the mechanical properties of the surface of NEAs, Phobos and Deimos depend on the size of these objects?
- What are the characteristics of the near-surface dust environment of small bodies?
- Can the geotechnical properties and ISRU potential be predicted prior to landing by observation of the dust and surface-bound exospheres?
- What are the methods and associated risks for resource extraction from dry and icy regolith, in plasma and UV environments?

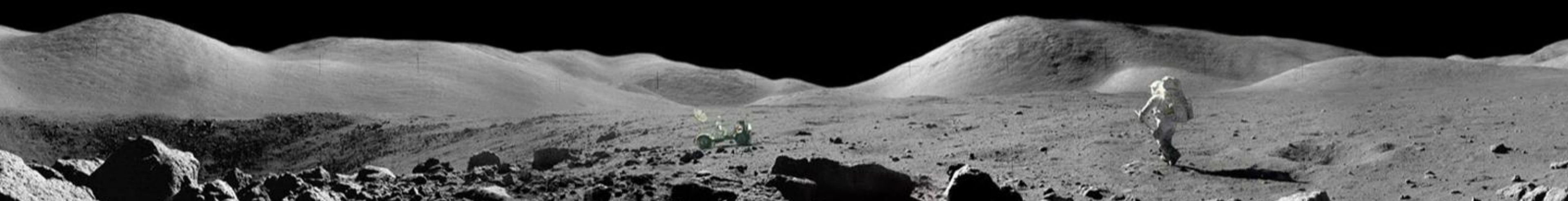
ISRU Experiments consist of three inter-related activities

- Regolith Reference Surface Development
  - Simplified regolith simulants
  - High fidelity regolith simulants
- ISRU Experimental Probe (IEP)
  - Fundamental physical-science experiments
  - Generic hardware. Simple mechanical interaction
- Discrete Element Modeling
  - Modeling of IEP with regolith reference surfaces

Regolith Reference Surface Development

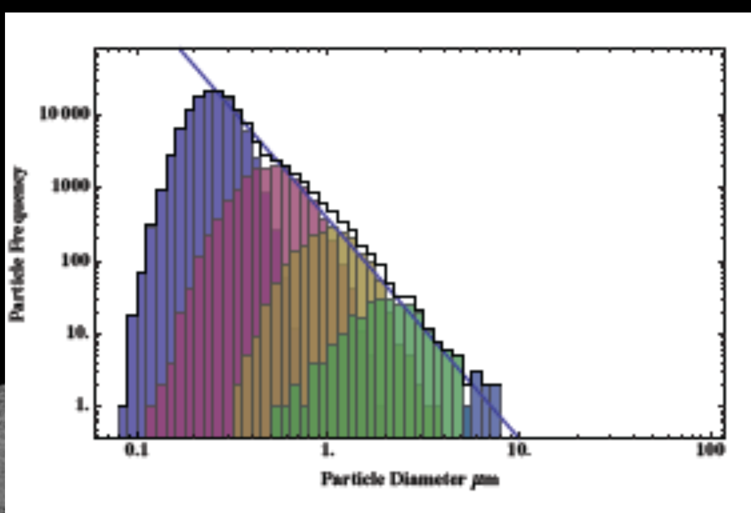
Geologically derived regolith simulants are complex

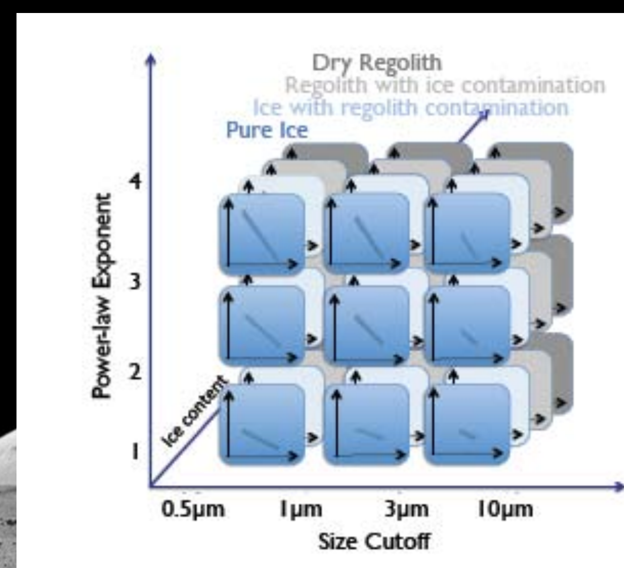
- Large number of parameters describe geologically derived simulants
- Isolate the effect of individual regolith characteristics
- IMPACT will develop a family of simplified well-characterized regolith reference surfaces composed of glass spheres of defined size distributions and ice content, thus reducing the number of parameters.



Regolith Reference Surfaces

- Glass spheres of narrow size distribution are mixed to form a range of mixtures
- Experimentally search for 2-parameter size distribution and ice content that demonstrate differences in properties.
- Compare to high-fidelity simulants with complex mineralogy and morphology to be developed by Zybek Advanced Products.





Credit: A. Collette, M. Horanyi, et al.




Regolith Simulations

- Soft-Sphere Discrete Element Model applied to granular material with cohesion and rolling-resistance.
- Able to track forces and motion of grains

Credit: D. Scheeres and P. Sanchez

ISRU experiments in IMPACT

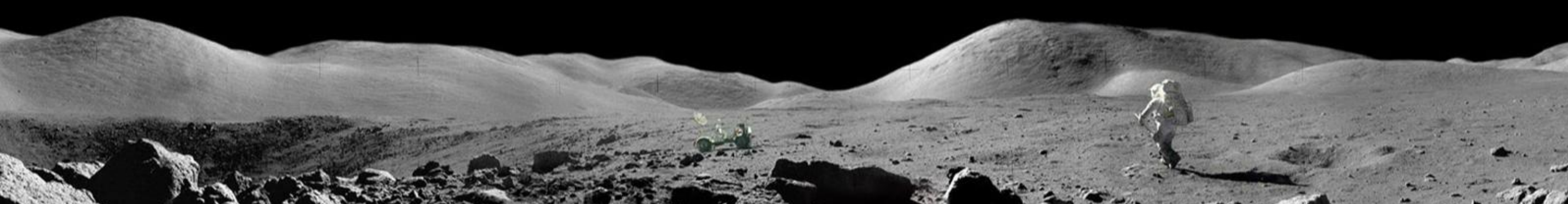
- Geotechnical Properties
  - "…those properties of a planetary surface needed to evaluate engineering problems, including the mechanical properties of soil and rock…" – Lunar Source Book
- ISRU Properties
  - Historically geotechnical properties are defined for geotechnical engineering needs that are related to construction, mining, and trafficability.
  - ISRU technology development requires geotechnical properties, *but* ISRU engineering needs are not fully addressed by geotechnical properties alone.



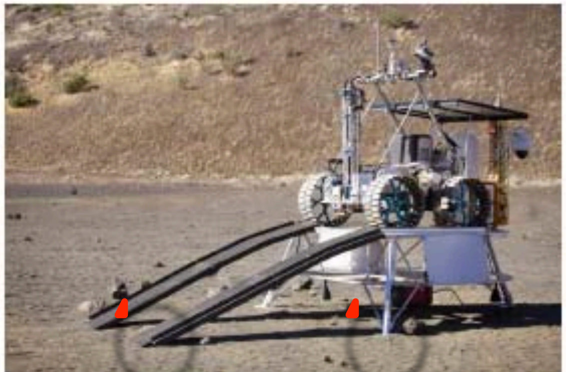

Examples of “ISRU Properties”

- Volatile content
- Sublimation and other phase changes
- Tribocharging
- Processing related properties

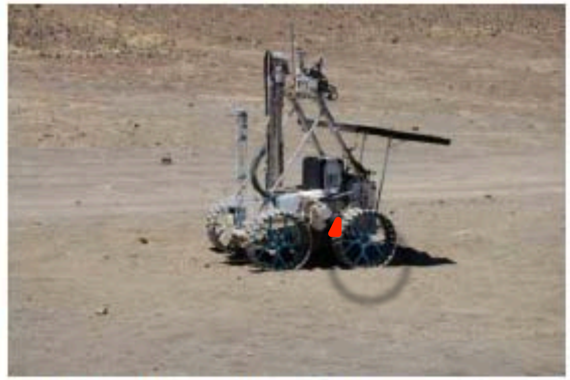
- More properties will be needed as ISRU develops.



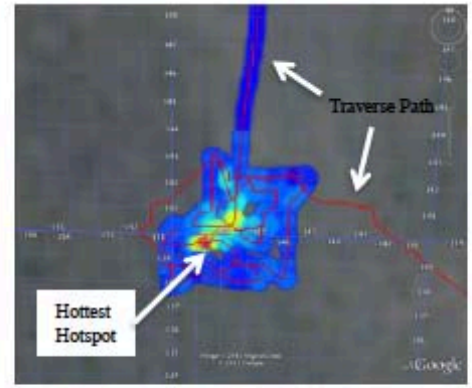
Example of regolith-hardware interaction



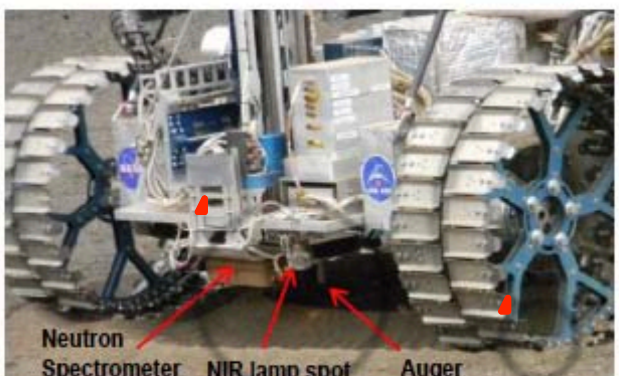
Rover Egress from Lander



Rover Searching Exploration Site



Data from Neutron Spectrometer and Rover Navigation displayed on xGDS showing 'hot spot' found by RESOLVE



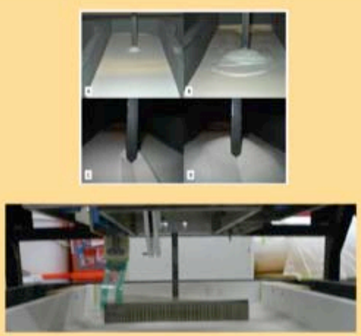
Auger and Examine Cutting Pile for Ice with Near Infrared Spectrometer

Drilling, Sample Collection, Sample Transfer, & Processing to Measure Water and Other Volatiles

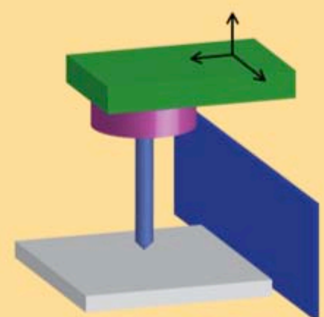
Credit: G. Sanders, et al., LEAG presentation 10/24/12

Experimental Scales

System Level Technology Development

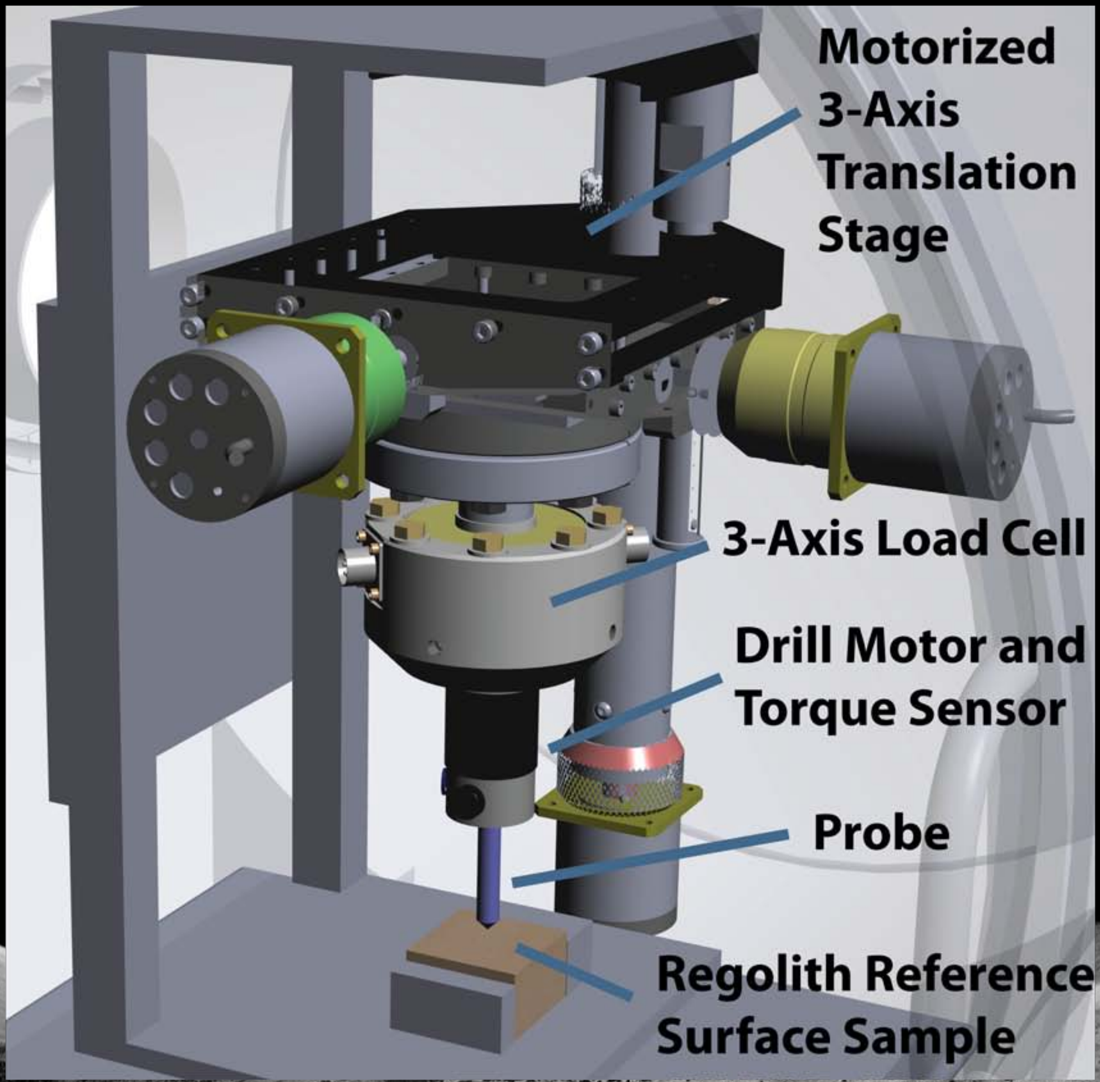


Lab Scale Low TRL Experiments

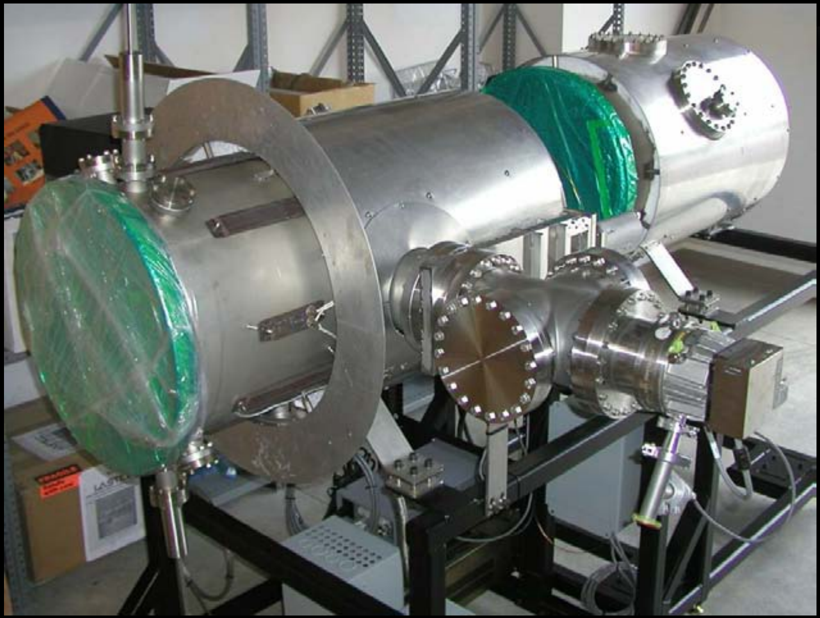


Fundamental Physical Sciences Experiments

ISRU Experimental Probe in IMPACT

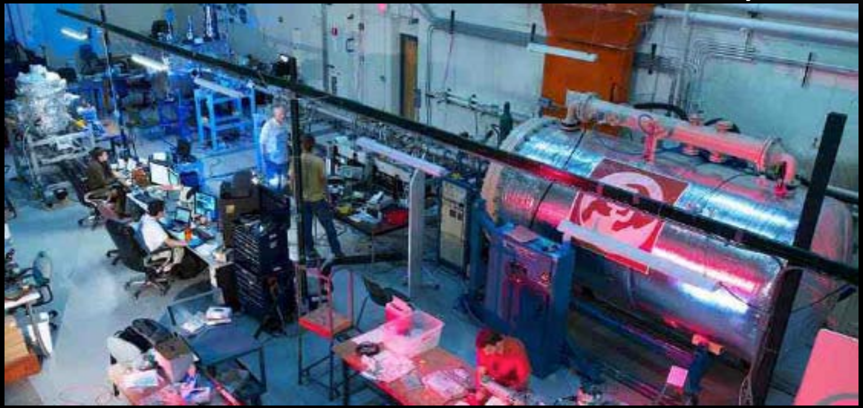


CSM Vacuum Facilities



CU Facilities

DAL – Dust Accelerator Laboratory



LEIL – Lunar Environment Impact Laboratory

DPL – Dusty Plasma Laboratory

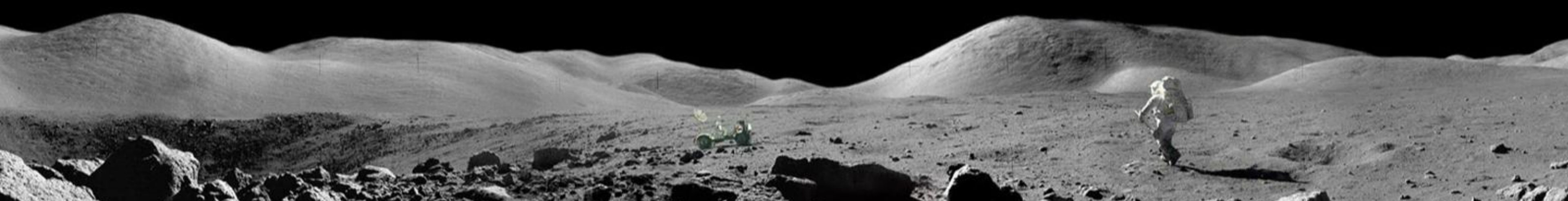
Experiments

- Geotechnical
  - Probe: Conical Tip Penetrometer
- Charging and Plasma
  - Probe: Wedge and Penetrometer
- Anchoring
  - Probe: Penetrometer and Drill
- Sublimation
  - Probe: Penetrometer, Wedge, and Drill

Experimental Objective	Measurement		Experimental Requirement		Experimental Product	Relevance to System Level development
	Probe configuration	Physical parameter	Control	Measurement		
Measure geotechnical properties	Penetrometer	Shear strength, cohesion, compressibility, friction angle	Force normal to surface	Penetration rate into sample (z axis)	Force versus probe penetration	Trafficability, surface stability, slope stability
Measure electrical effects	Wedge Penetrometer	Dust charging, dust collection, video observation of dust migration	Force lateral to wedge lateral translation	X, Y, and Z axis translation. Video.	Force versus probe position, accumulated charge, dust movement videos	Tribocharging potential
Anchoring properties	Penetrometer Drill	Shear strength, cohesion, compressibility, friction angle of compacted anchor hole.	Force normal to surface on extraction	Z axis translation	Extraction force per unit probe surface area	Anchorability of surfaces
Measure sublimation rate	Penetrometer Wedge Drill	Mass of gas generated. Observe dust migration	Normal force. Drill speed	Chamber pressure rise. Video.	Sublimation rate versus applied load	Sublimation potential of surfaces

Plan

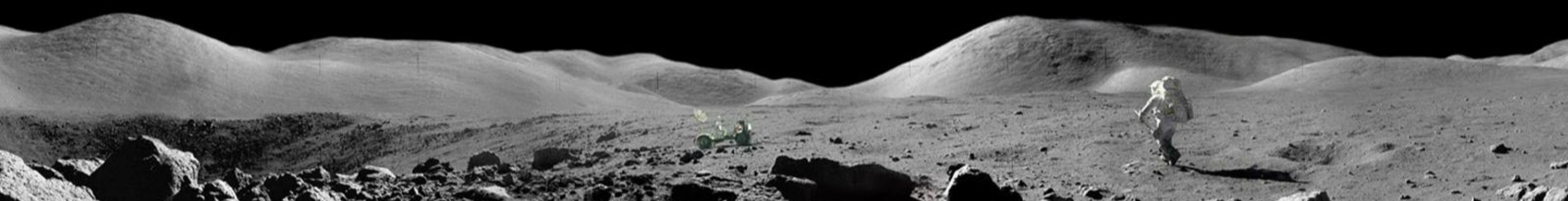
- Year 1: Design and build the apparatus
- Year 2: Initial experiments and integration with CU experiments
- Year 3 to 5: Detailed experiments






Seeking further input

- Work with fellow SSERVIs
- ISRU Industrial Partner Group
    - Rapidly communicate results
    - Recommend experimental parameters
  - Ball Aerospace
  - Lockheed Martin
  - Honeybee Robotics
  - Nscience






Conclusions

- IMPACT ISRU activities aim to produce a series of small scale fundamental physical-science experiments to reveal the behavior of ISRU systems on the Moon, NEAs, and the moons Phobos and Deimos.