

Geoscience / Space Environment

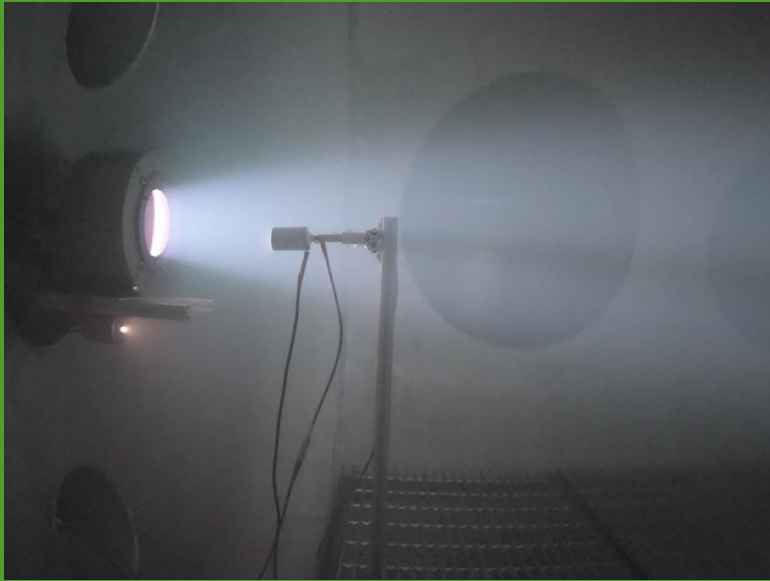


Image credit: NASA

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Associate Professor of Aerospace Engineering
Director, Gas and Plasma Dynamics Lab

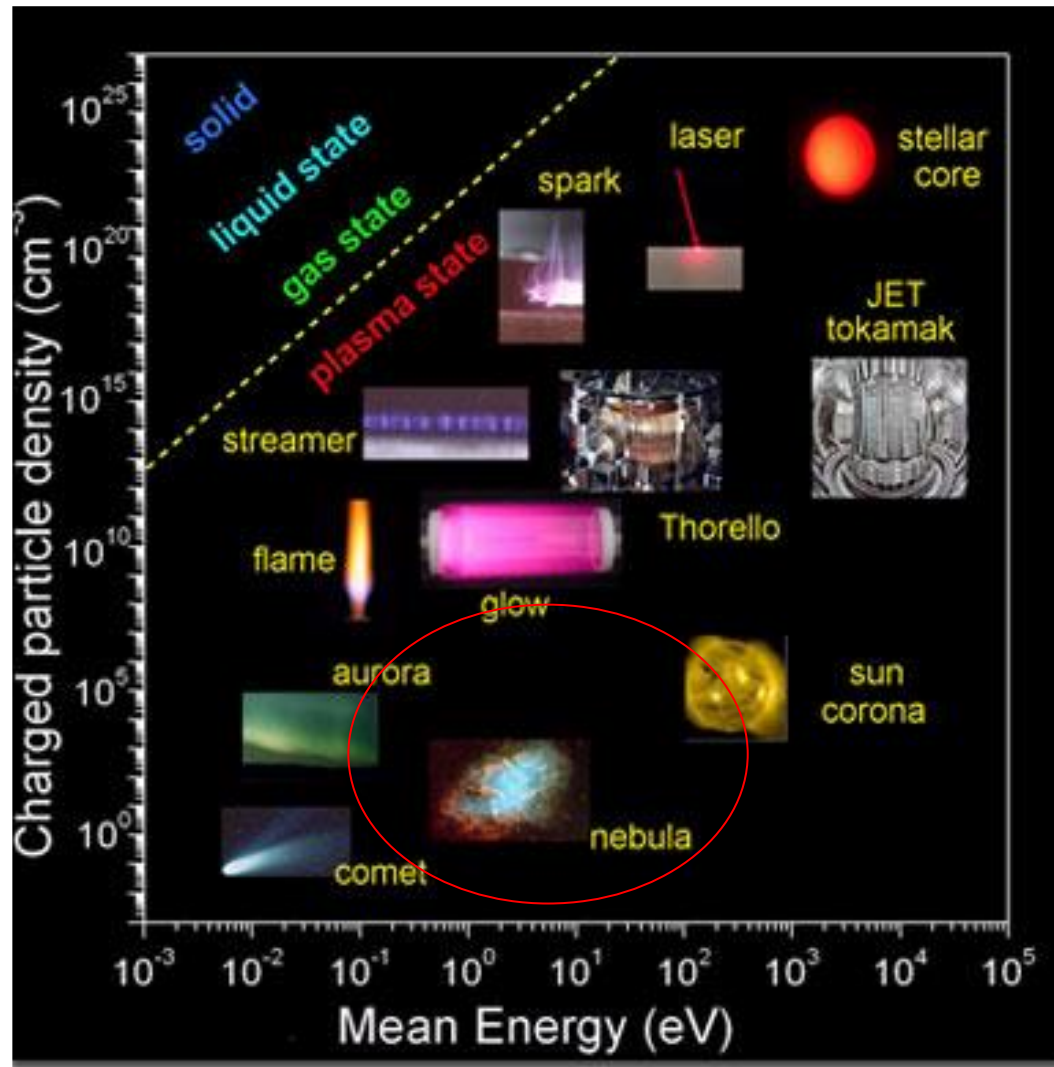
DL-GPU 2024

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Outline

- > Plasma and Space Environment
- > Lunar Exploration (in the Age of Artemis)
 - Dielectric charging and dust transport
 - In-Situ Resource Utilization (ISRU)
 - High-fidelity modeling and simulation
 - > Dusty Plasma
 - > Electrostatic Sieve Modeling
 - Ground vacuum-plasma chamber testing
- > Other on-going projects
 - Space/plasma propulsion
- > Openings!

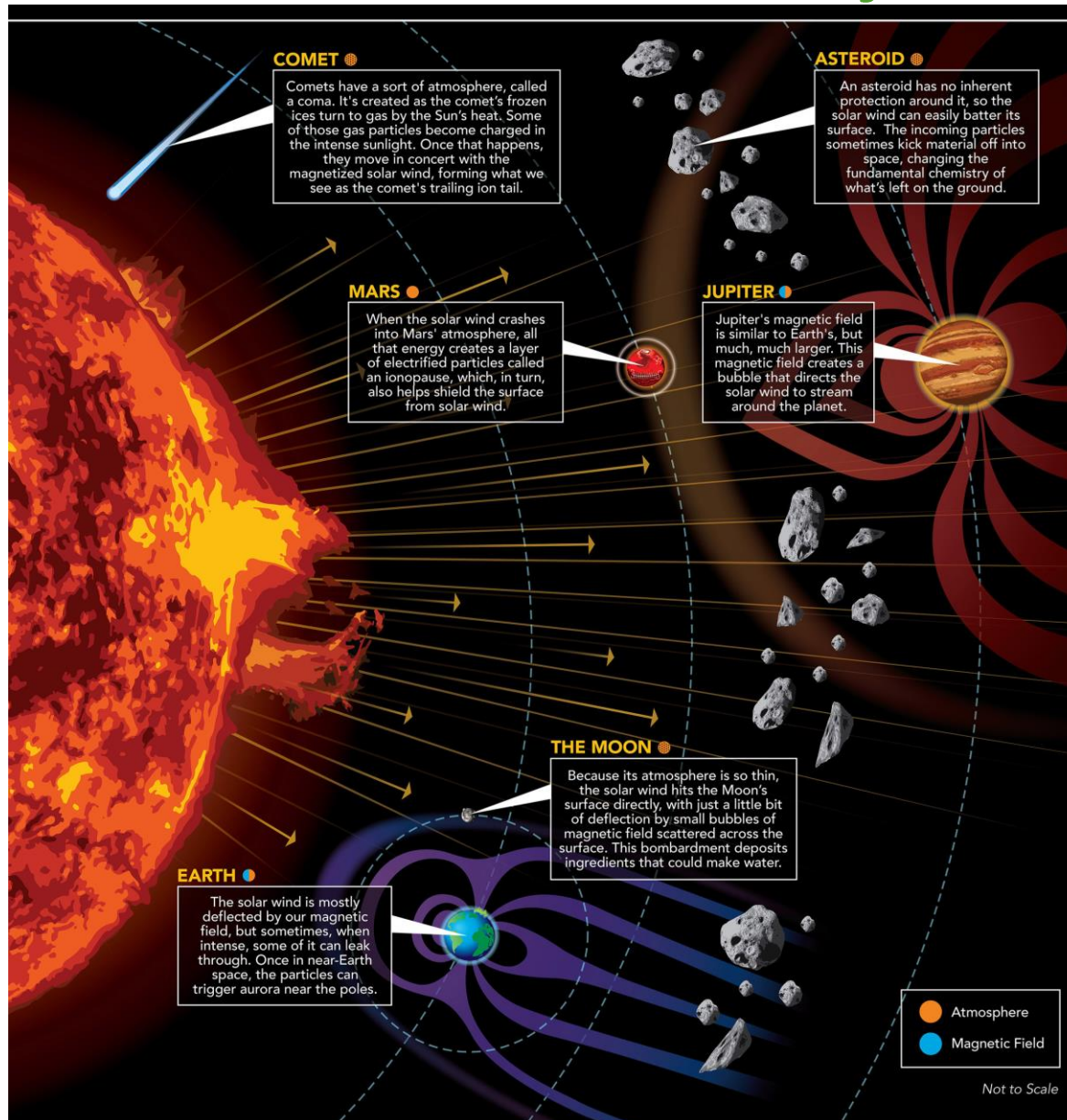
Plasma as the fourth state of matter...



- 99% of the matter in the known universe
- A **quasi-neutral** gas of charged (and neutral) particles exhibiting **collective** behavior
- **Spatial**: shielding distance (Debye length λ_D) \ll characteristic length of interest L
- **Temporal**: Oscillation frequency vs. collision frequency (with neutral particles): plasma or gas behavior



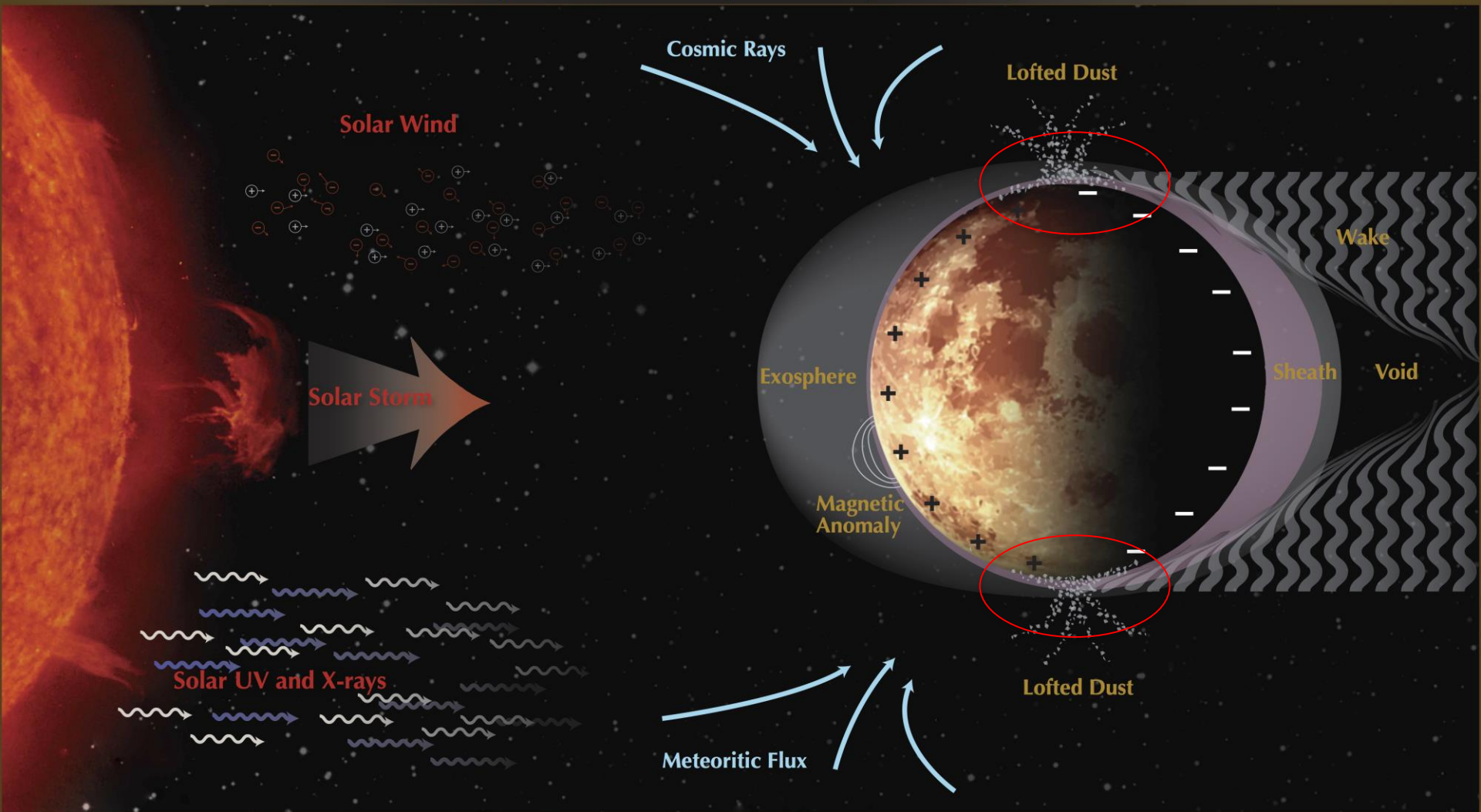
The space environment in our solar system



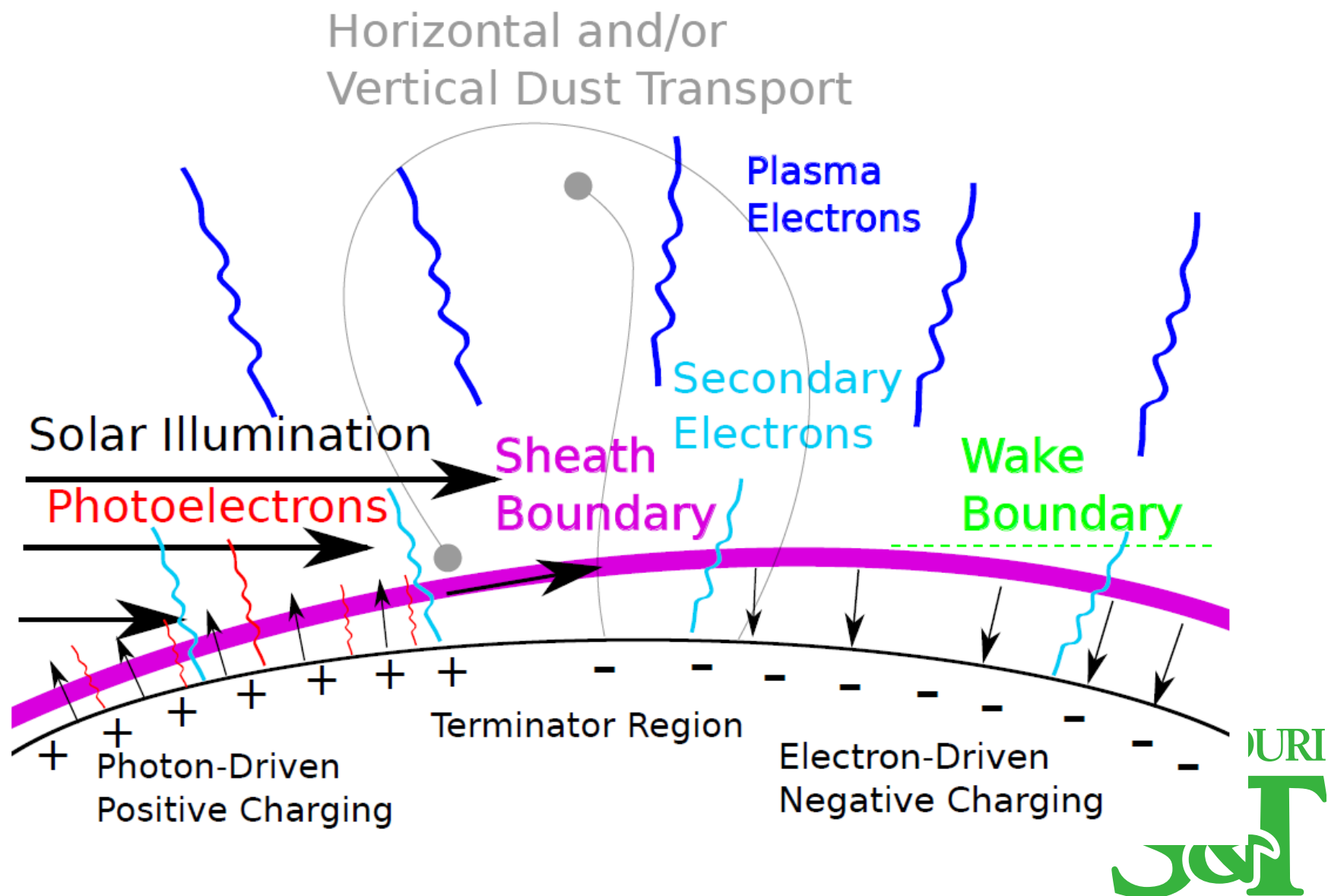
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There are rich processes on the Moon

A Dynamically Coupled System



Lunar polar regions are of particular interest



At local scales, surface terrain is complex



https://www.nasa.gov/multimedia/imagegallery/image_feature_25.html, accessed 9/2/2020

NASA's vision for Artemis Base Camp

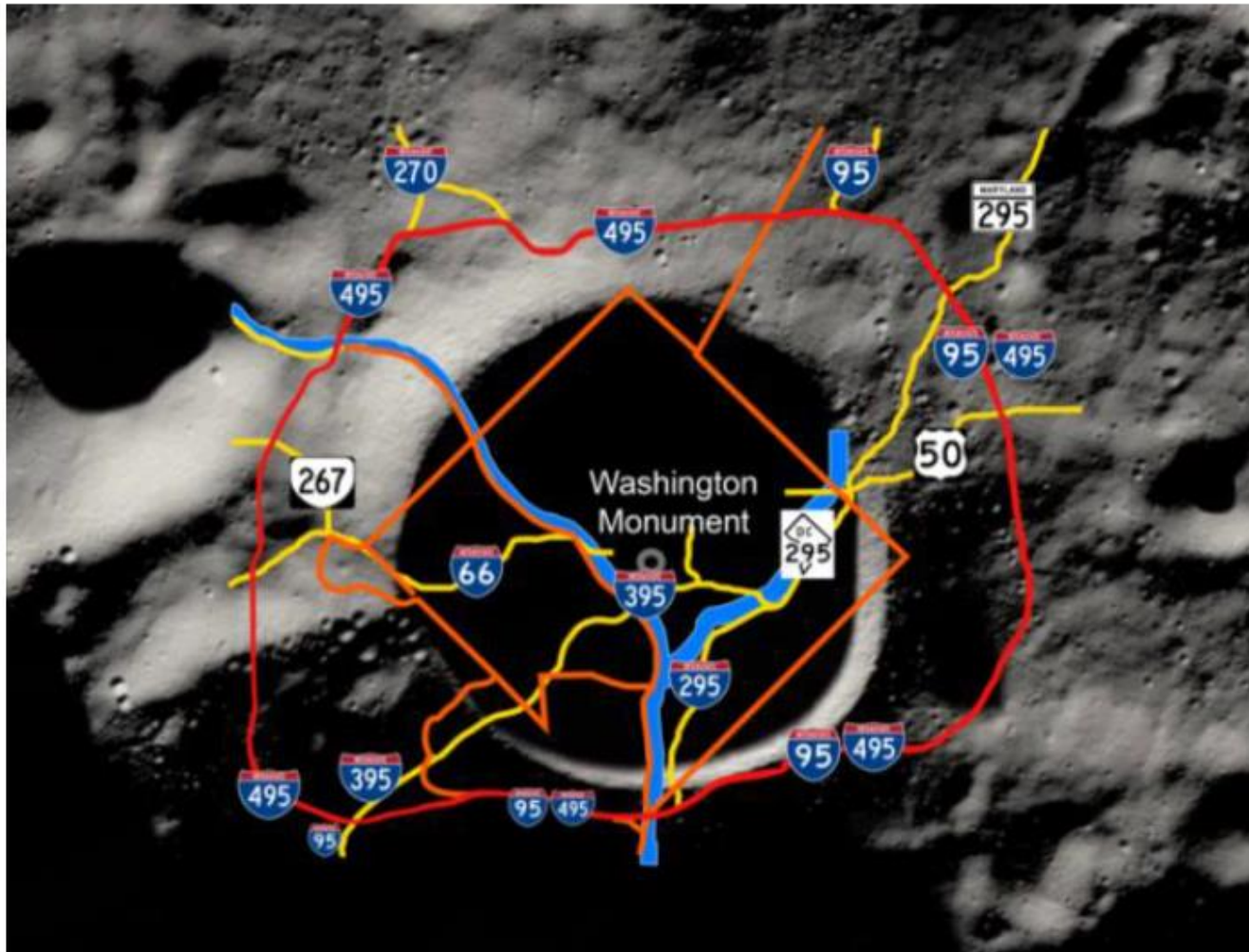
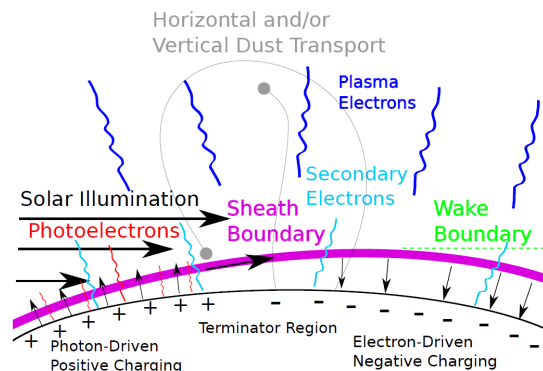


Figure 7: The lunar South Pole's Shackleton Crater, as captured by the Lunar Reconnaissance Orbiter, with the Capital Beltway overlaid for scale.

Dust... dust... (PROBLEM)

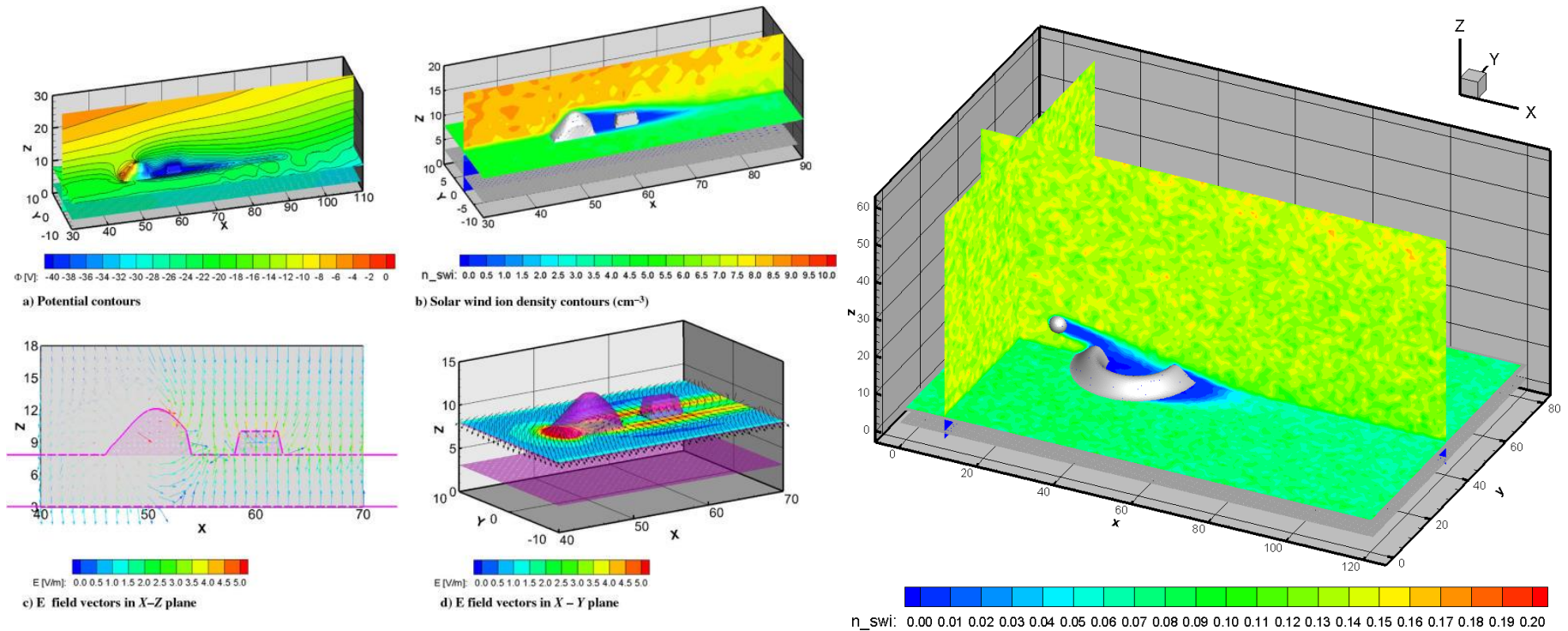
- Charged particles attach to instruments and spacesuits which could generate arcing
 - Risk of instrument failure
 - Threat to astronaut's health
- Critical to resolve surface charging



Apollo Astronaut Eugene Cernan Covered in Moon Dust

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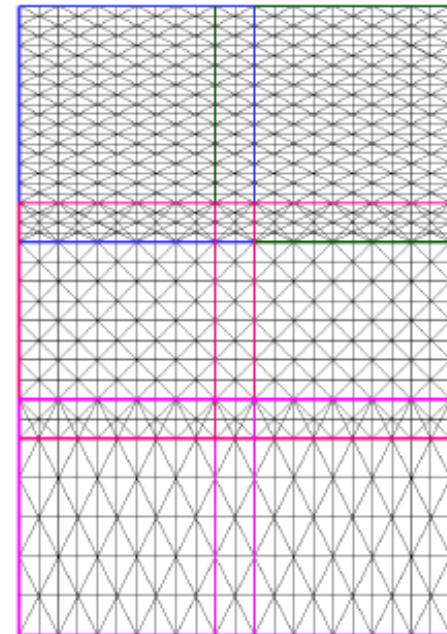
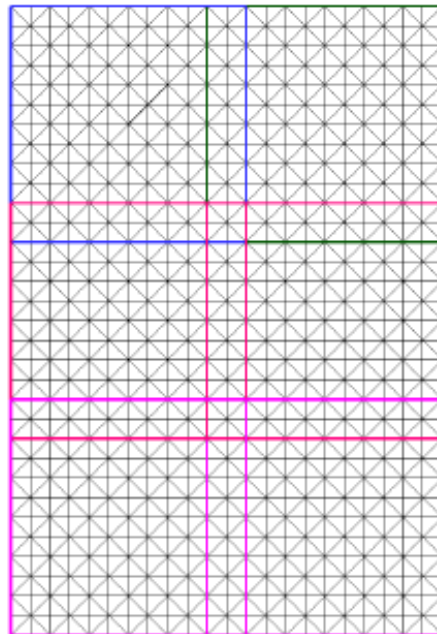
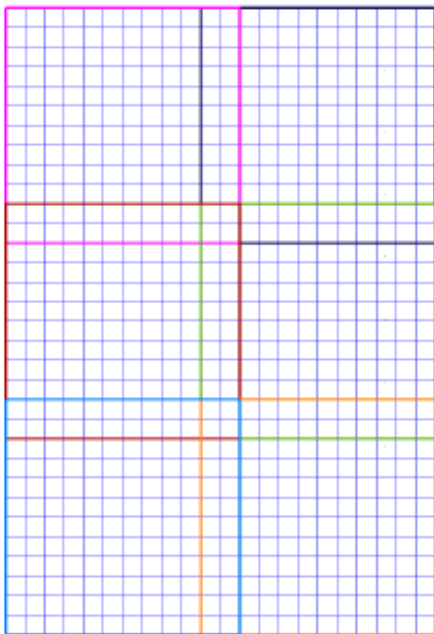
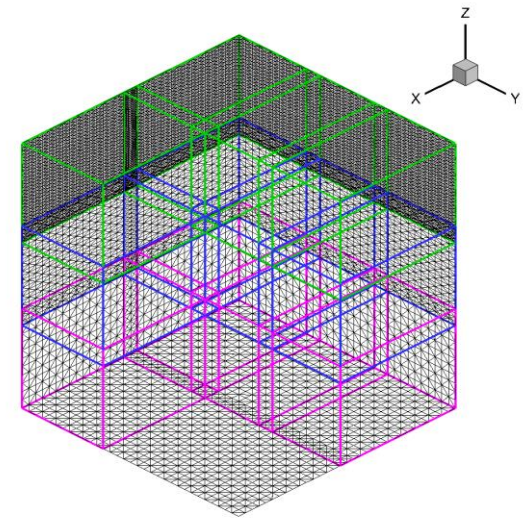
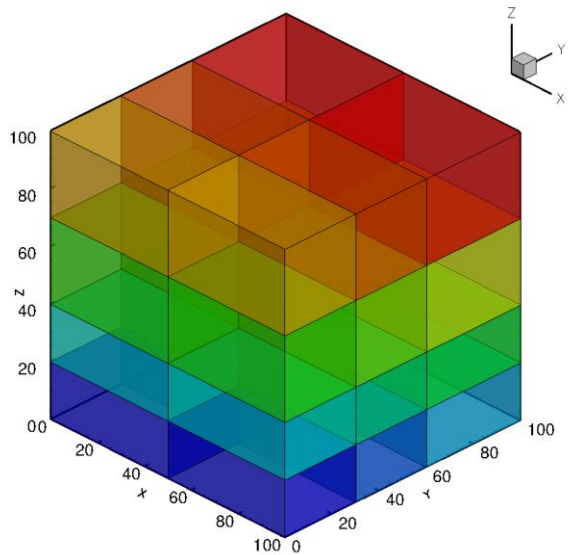
High-fidelity plasma simulation codes to study lunar surface charging



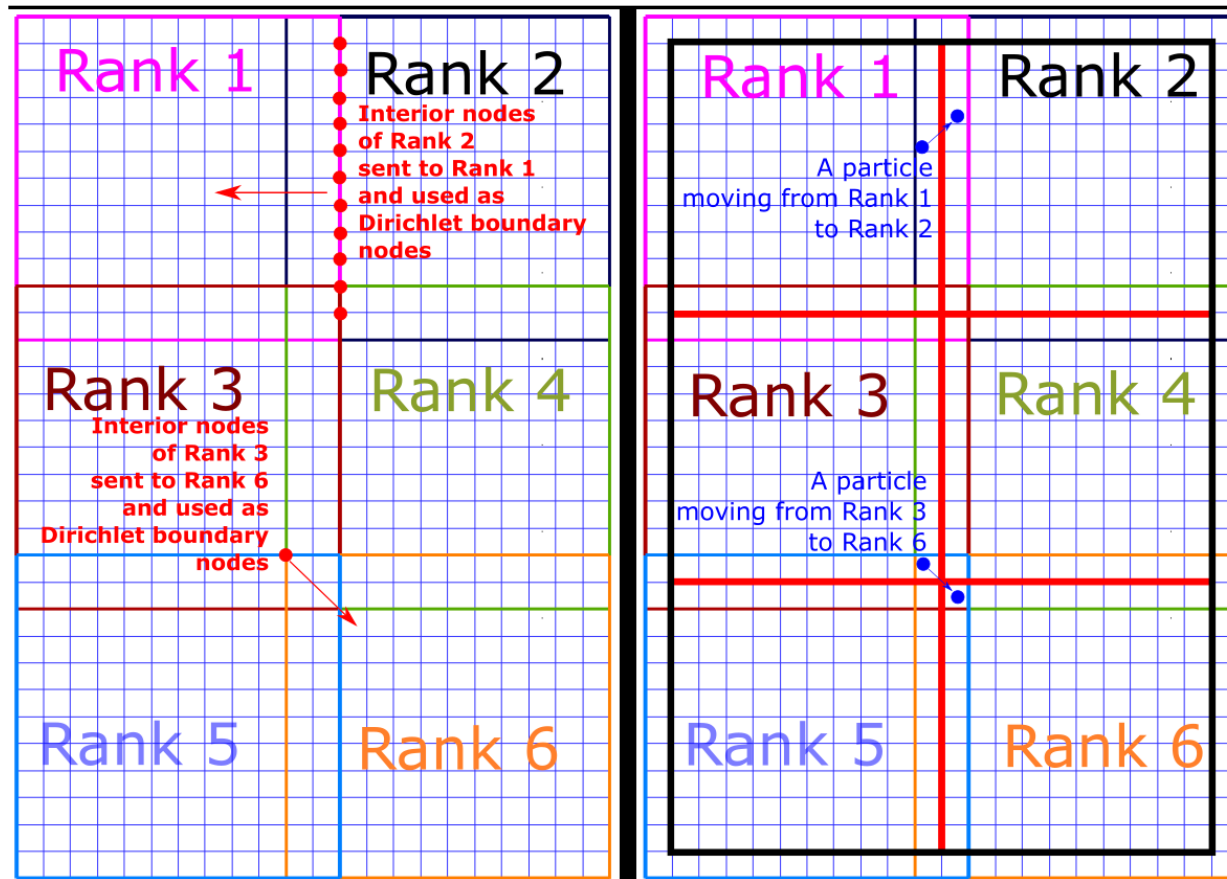
Han et al., Journal of Spacecraft and Rockets, 2018

Lund et al., AIAA 2020-1549

State of the art code: Parallel IFE-PIC (PIFE-PIC)



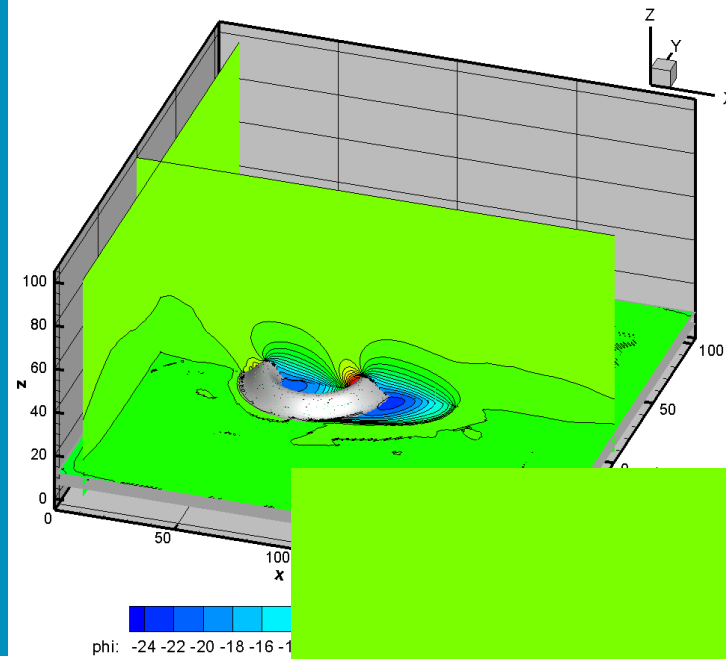
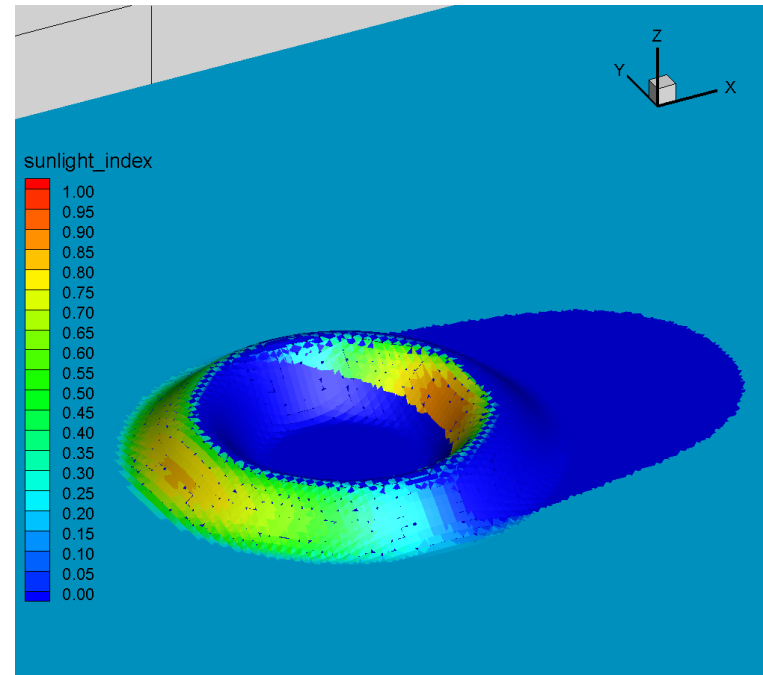
State of the art code: Parallel IFE-PIC (PIFE-PIC)



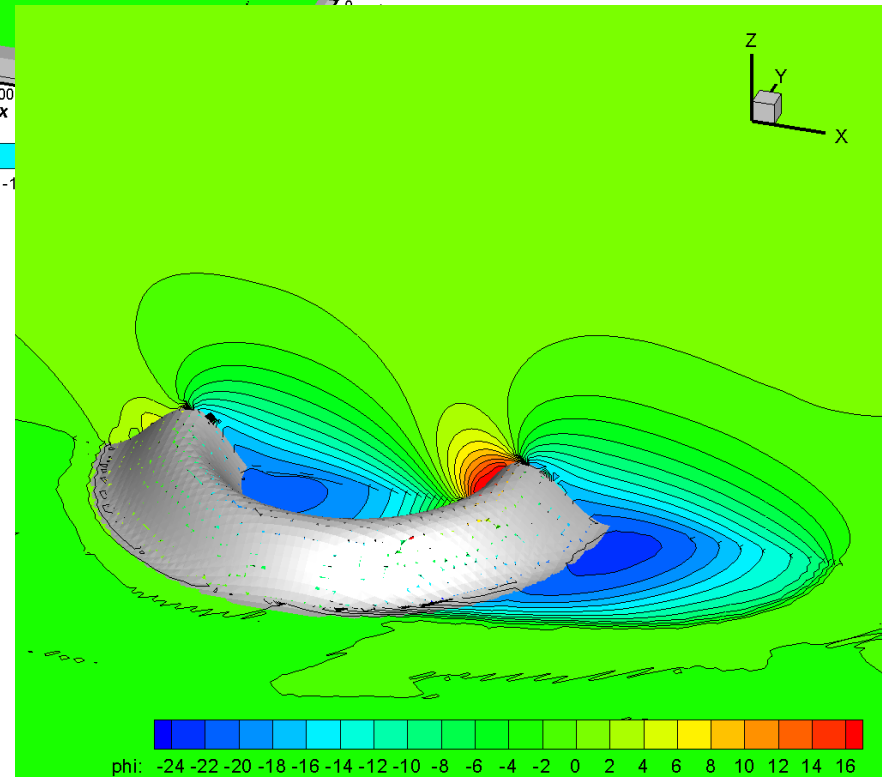
# of sub-domains	Efficiency E_{II}
1 (serial)	100.00%
64	109.02%
80	111.99%
100	106.57%
125	100.79%
150	94.99%
180	91.12%
216	89.62%
252	83.10%
294	68.35%
343	66.47%

Strong scaling: Han et al., SISC, 2021
Weak scaling: Lund et al., JCPM, 2022

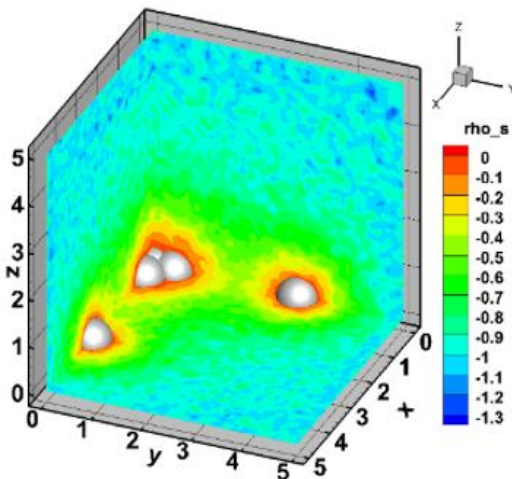
Routine HPC: 2M mesh cells, 1B particles



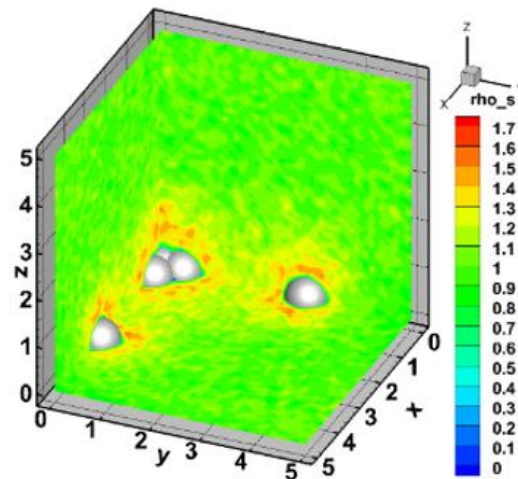
Very detailed surface differential charging at crater scale



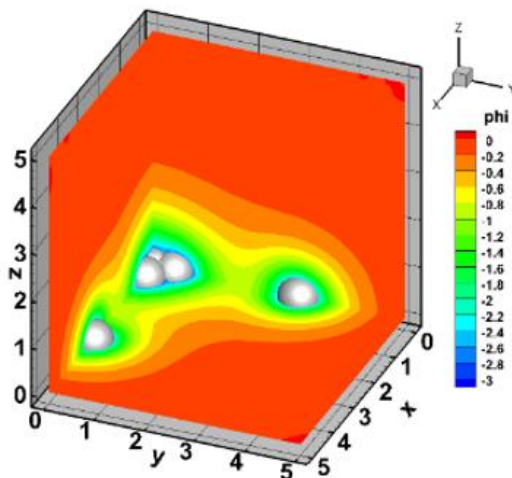
Ongoing: Grain scale charging, non-spherical shapes



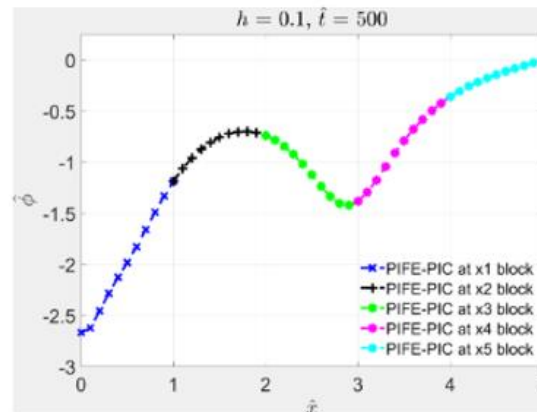
(a) Normalized electron density



(b) Normalized ion density



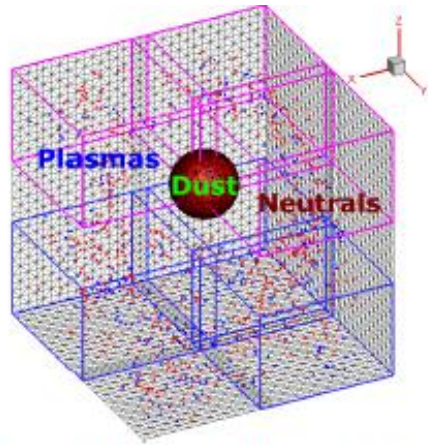
(c) Normalized potential



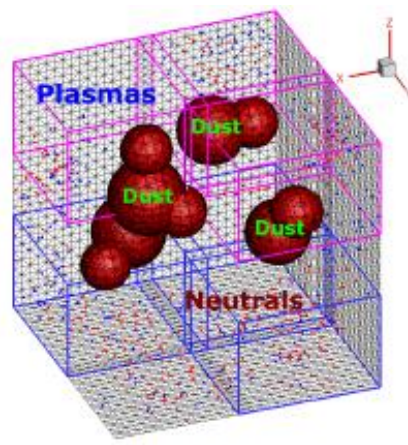
(d) Normalized potential profile along the x-direction

Looking into net charge
on each grain
(for dust transport
models)

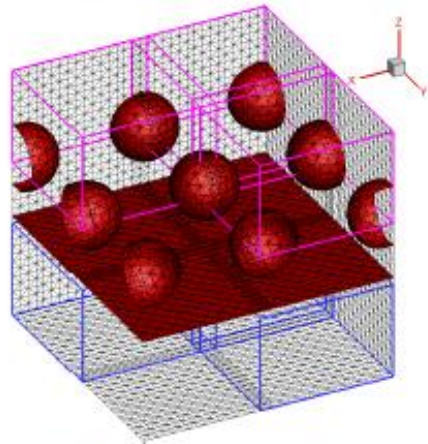
Dusty plasma – rich physics unresolved



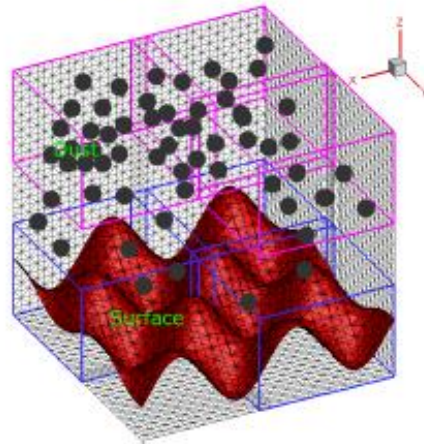
(a) Single-dust charging and forces/moments



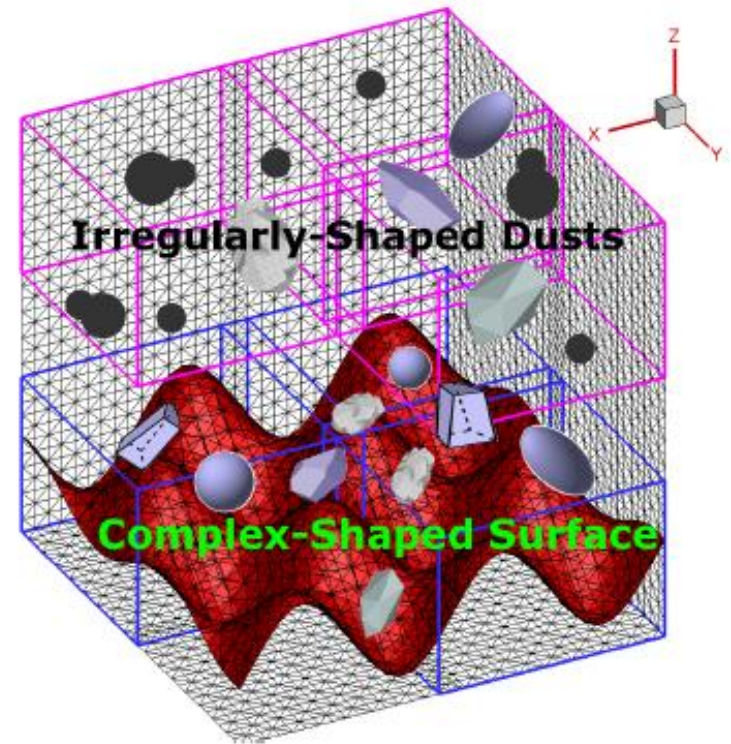
(b) Multi-dust interaction



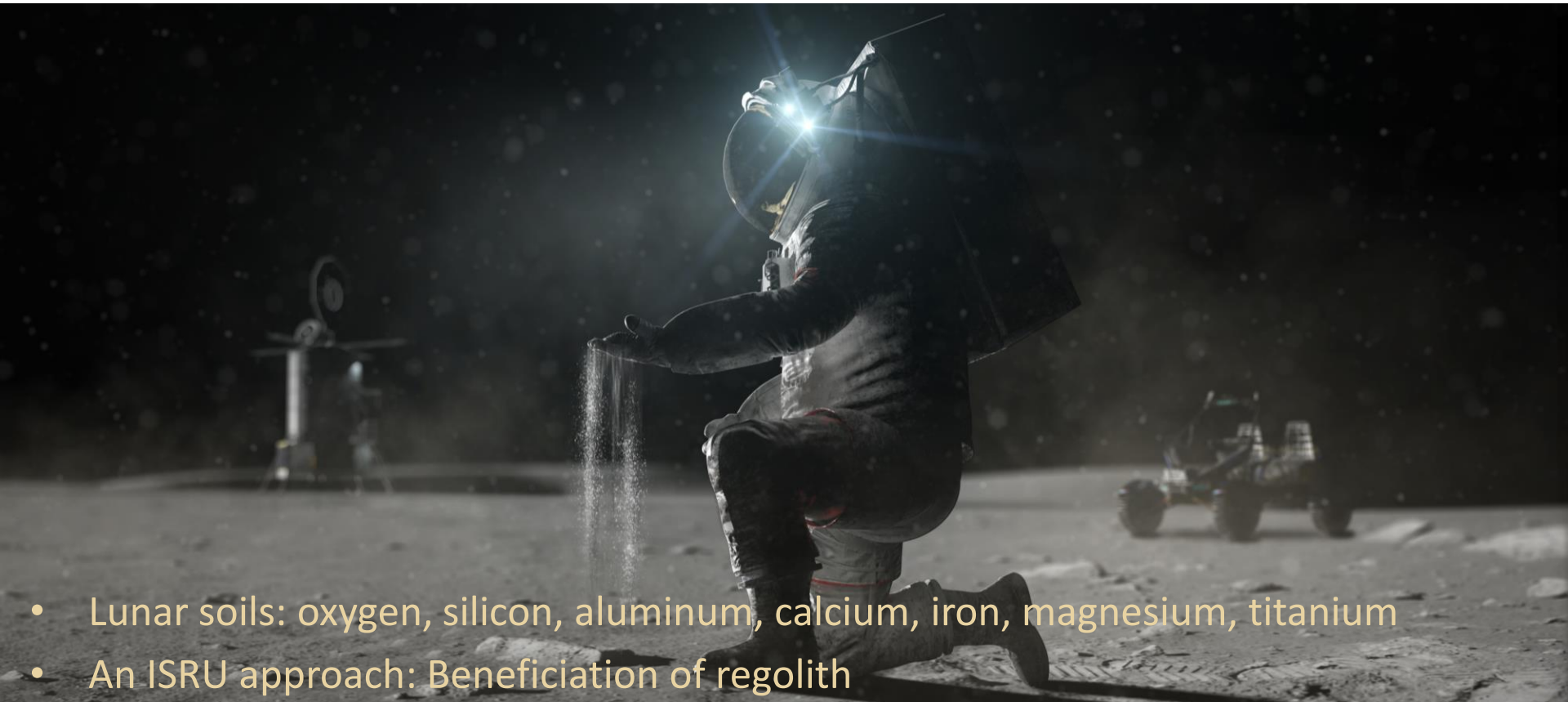
(c) Multi-dust packed near a flat surface



(d) Dust transport near complex surfaces



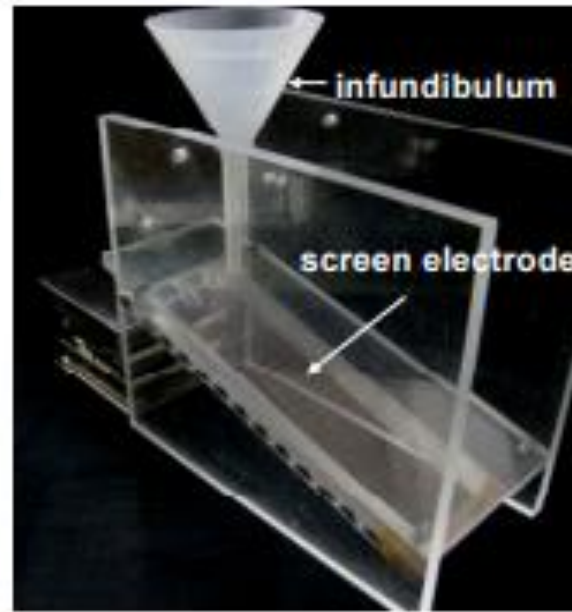
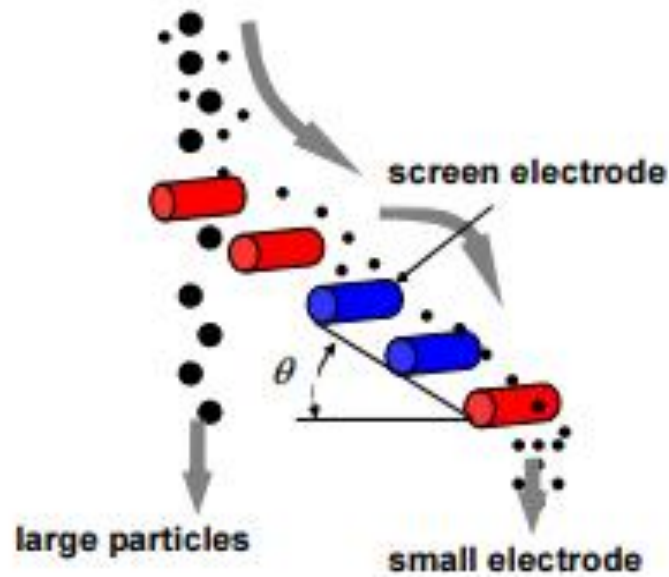
Dust... dust... (RESOURCE!)



- Lunar soils: oxygen, silicon, aluminum, calcium, iron, magnesium, titanium
- An ISRU approach: Beneficiation of regolith
 - Separation of particles by size
 - Traditional methods: mechanical sieve – not suitable for use on the Moon – SWaP constraints
 - Electrostatic / Electrodynamic methods: lower power and more compact

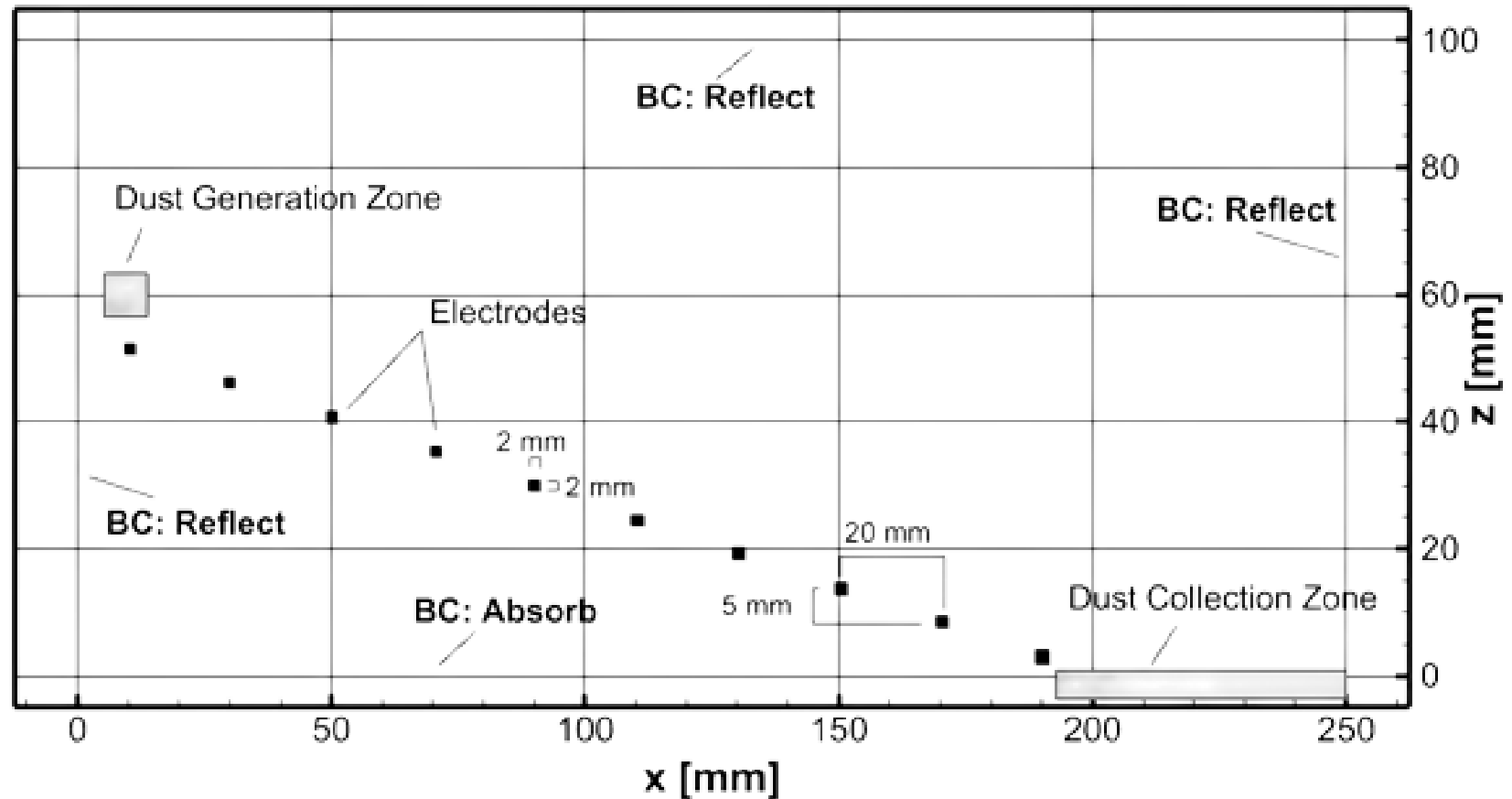
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Concept of Electrostatic Sieve

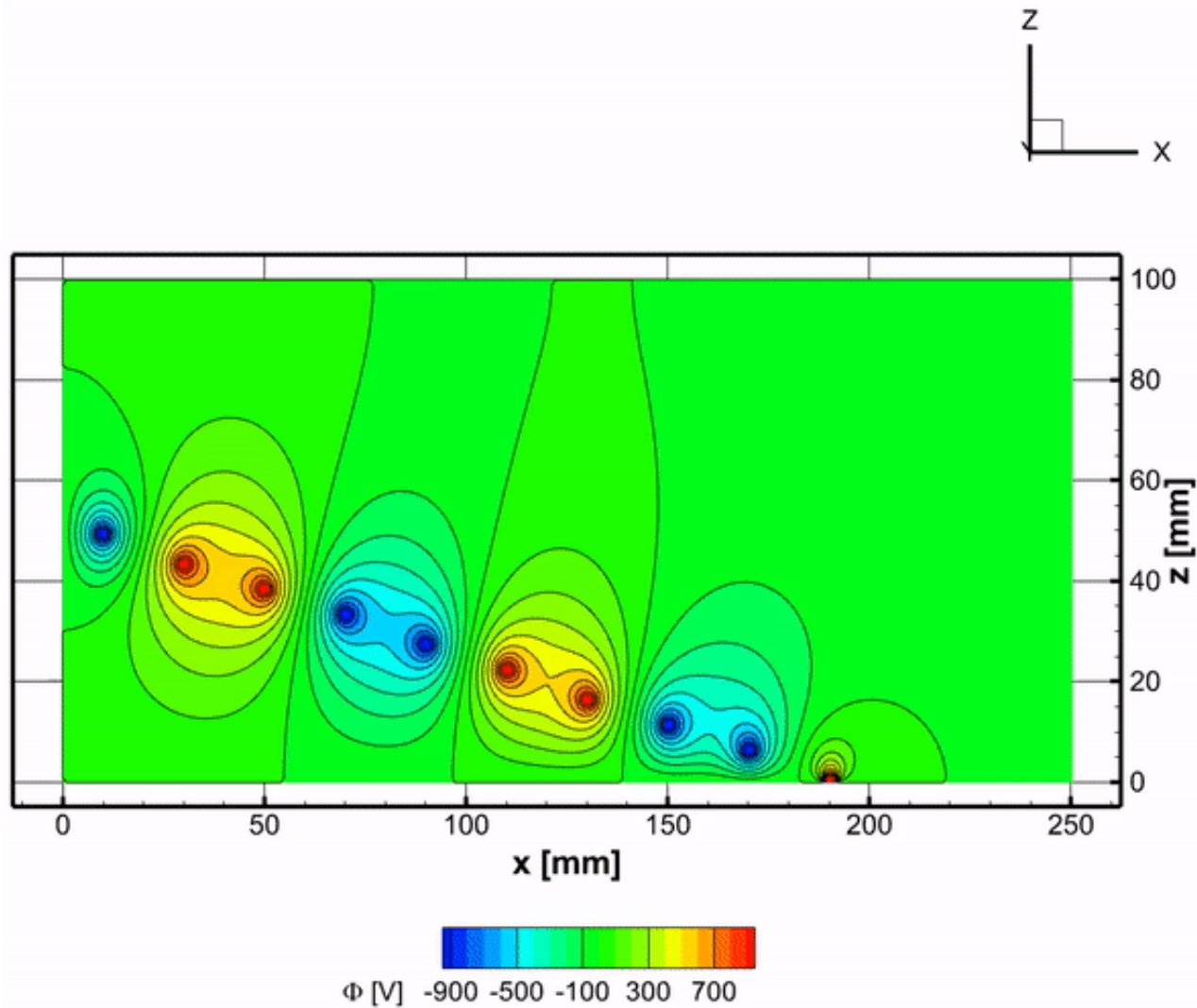


- Four-phase rectangular traveling wave and parallel electrodes to generate an electric field and separate dust
- Develop modeling capabilities for these concepts
- Use as an effective design and analysis tool

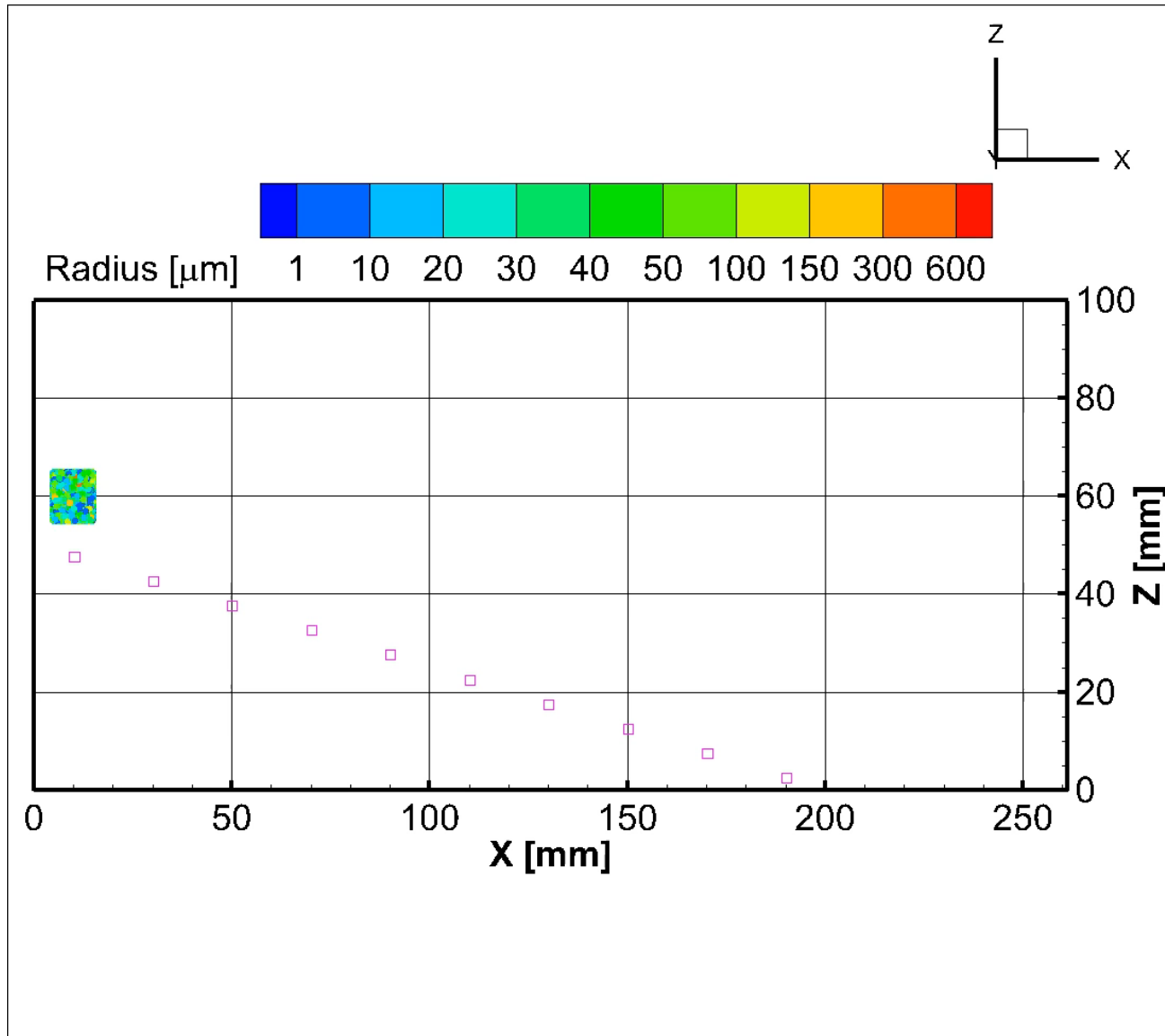
Modeling operation of an electrostatic sieve



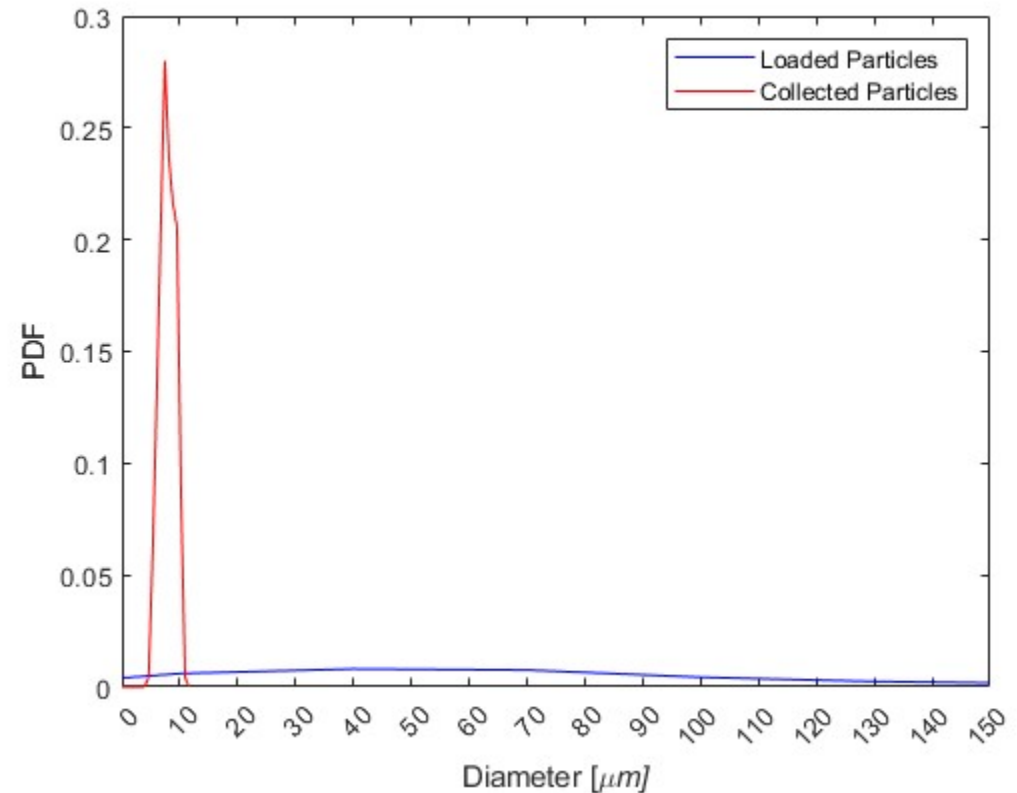
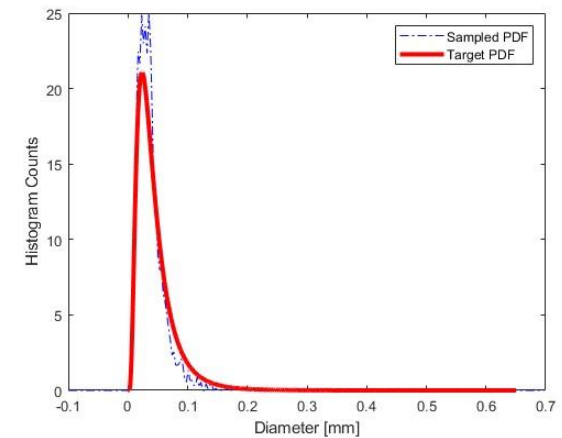
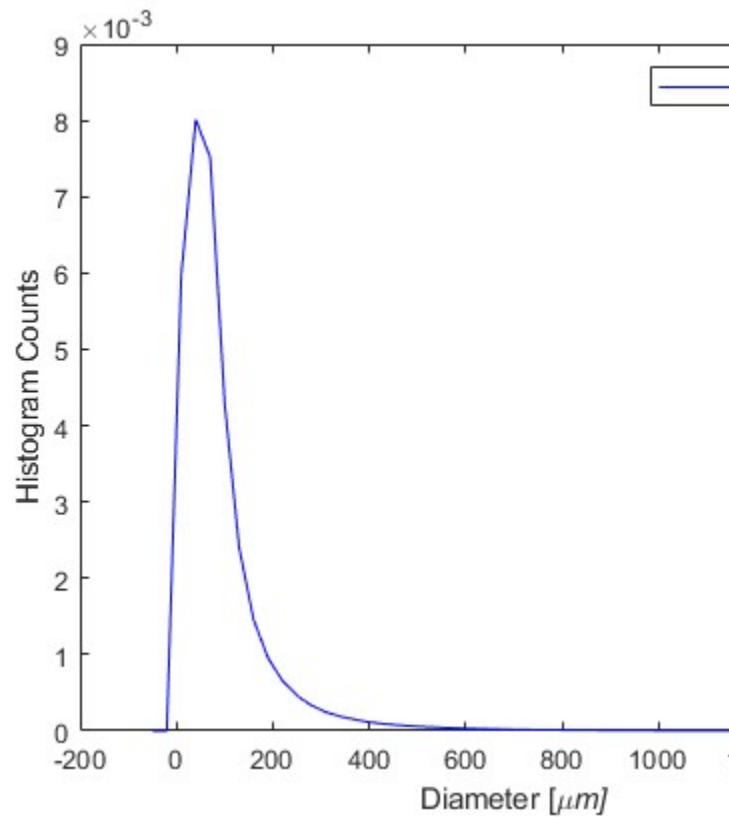
Modeling operation of an electrostatic sieve



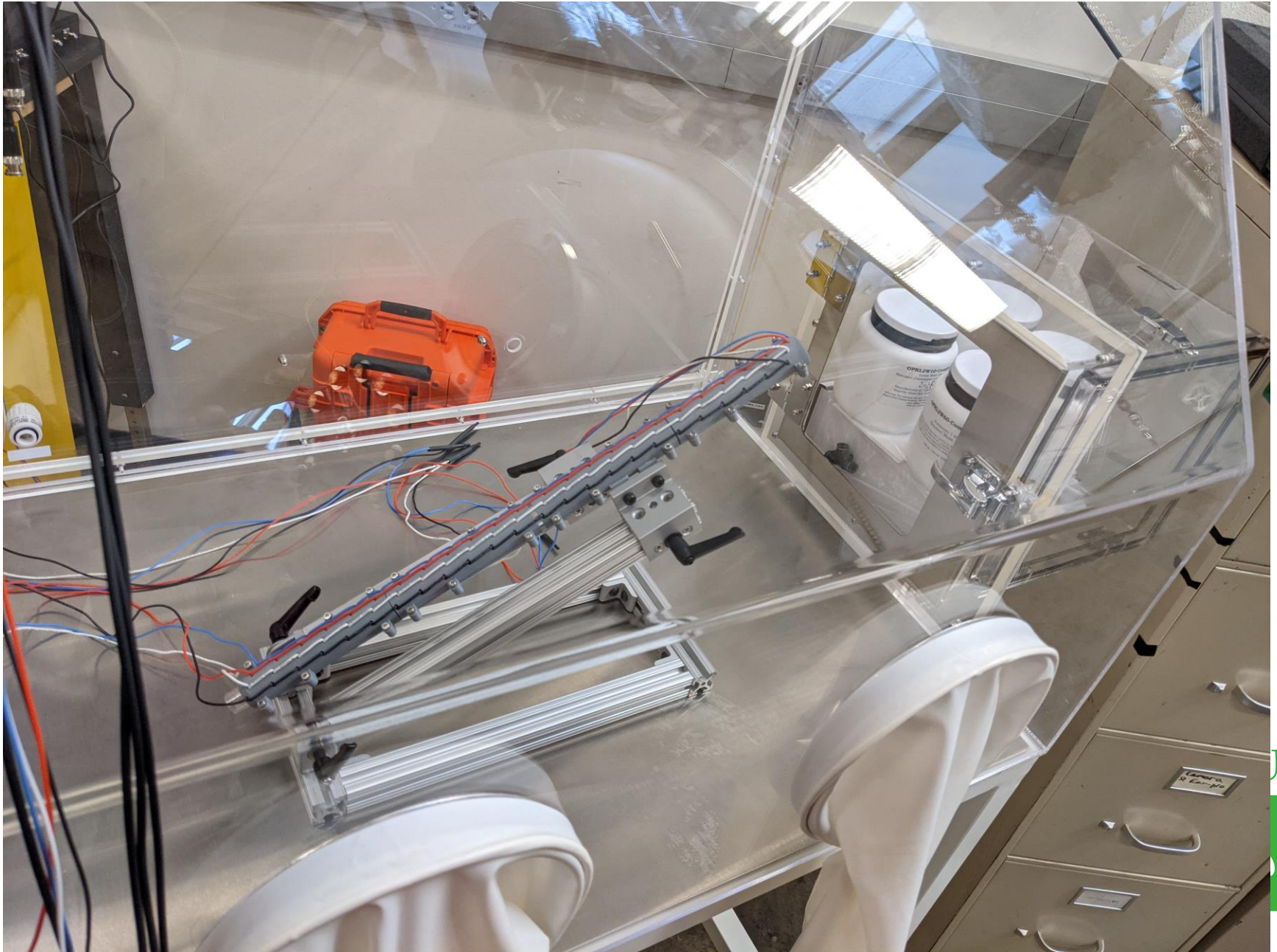
Modeling operation of an electrostatic sieve



Modeling operation of an electrostatic sieve



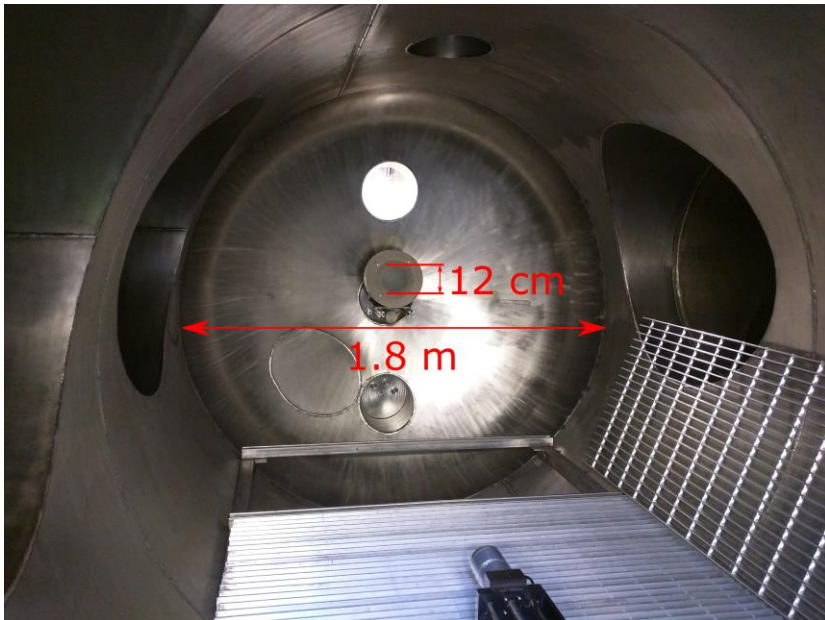
Ongoing: Ground testing in atmospheric conditions



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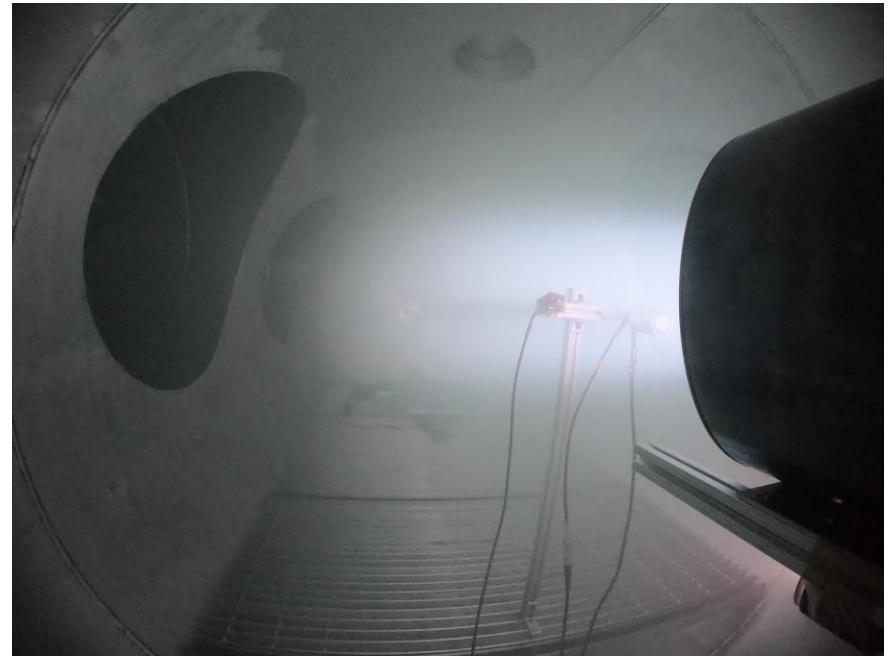
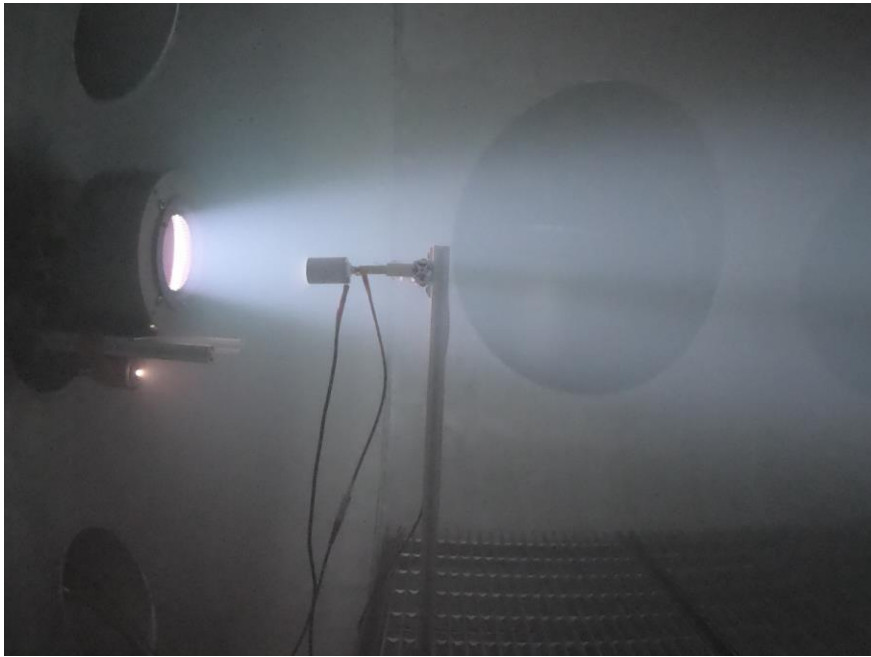
We also simulate the vacuum/plasma environments in a large chamber



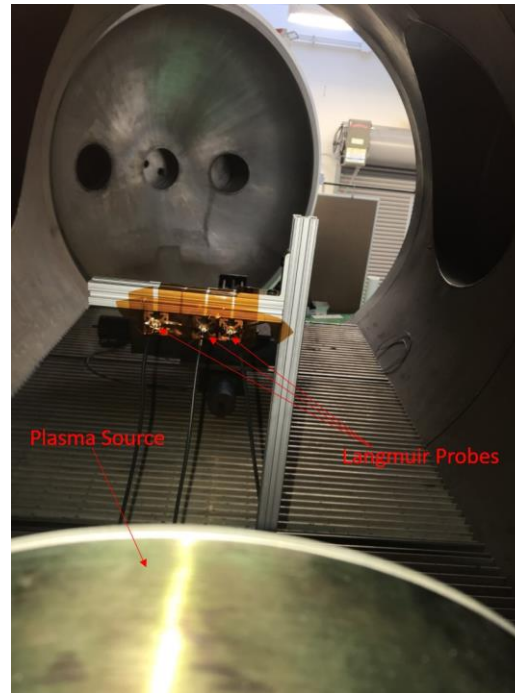
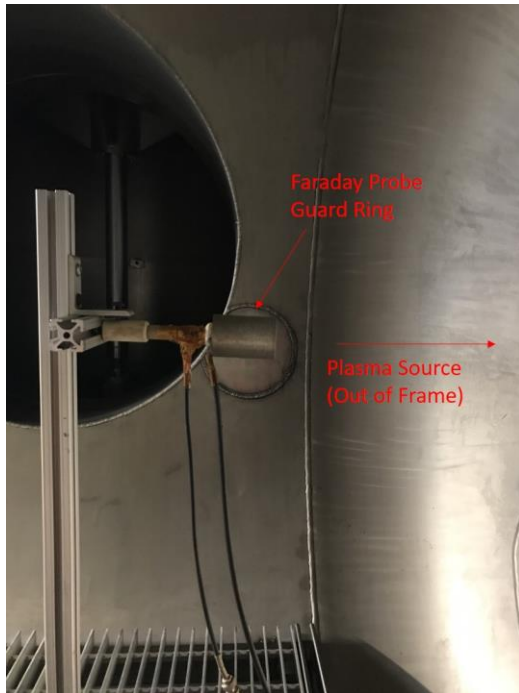
The Space Environment Ground Simulator (Video Tour)



Plasma beams in chamber



Diagnostics, and more ongoing



Helpers needed!

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THANK YOU!

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Director, Gas and Plasma Dynamics Lab