Geoscience / Space Environment

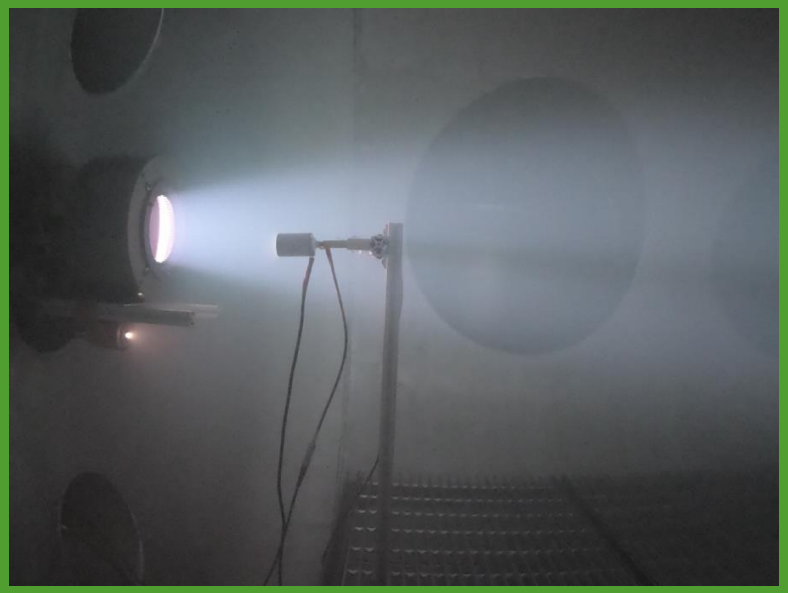


Image credit: NASA

Daoru (Frank) Han, Missouri S&T, handao@mst.edu

Assistant Professor of Aerospace Engineering

Director, Gas and Plasma Dynamics Lab

DL-GPU 2023

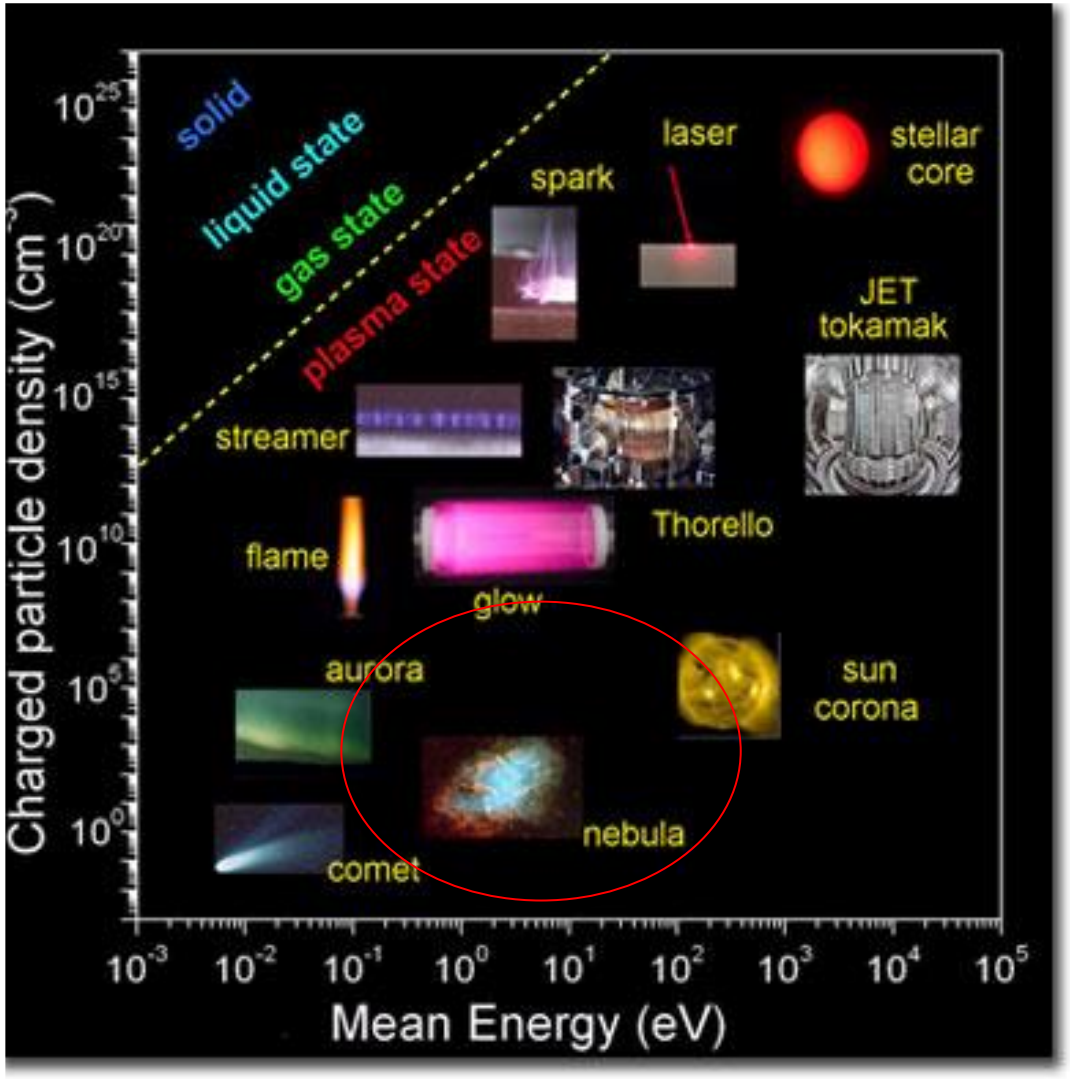
MISSOURI S&T

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!

MISSOURI S&T

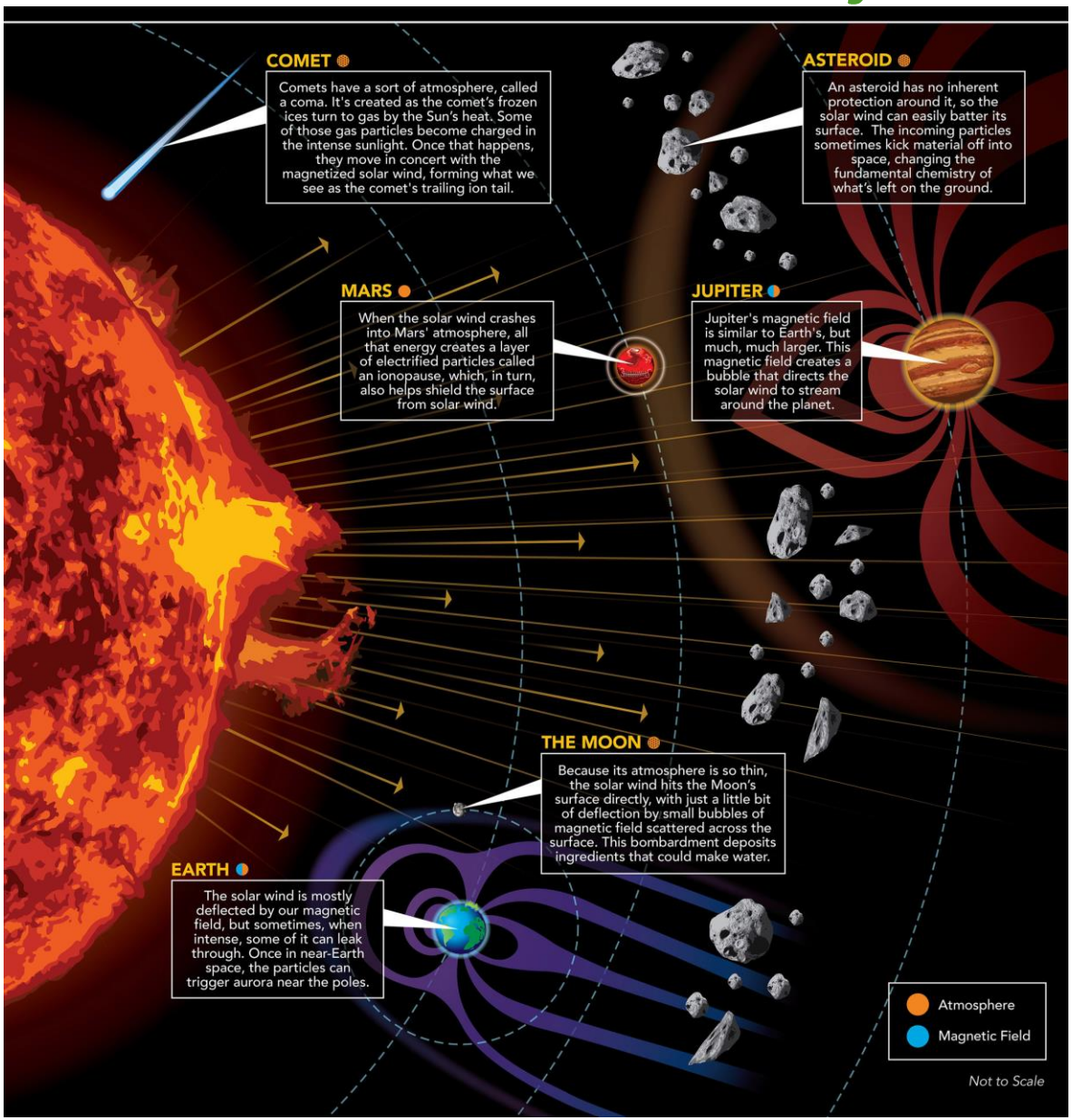
Plasma as the fourth state of matter…



- 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

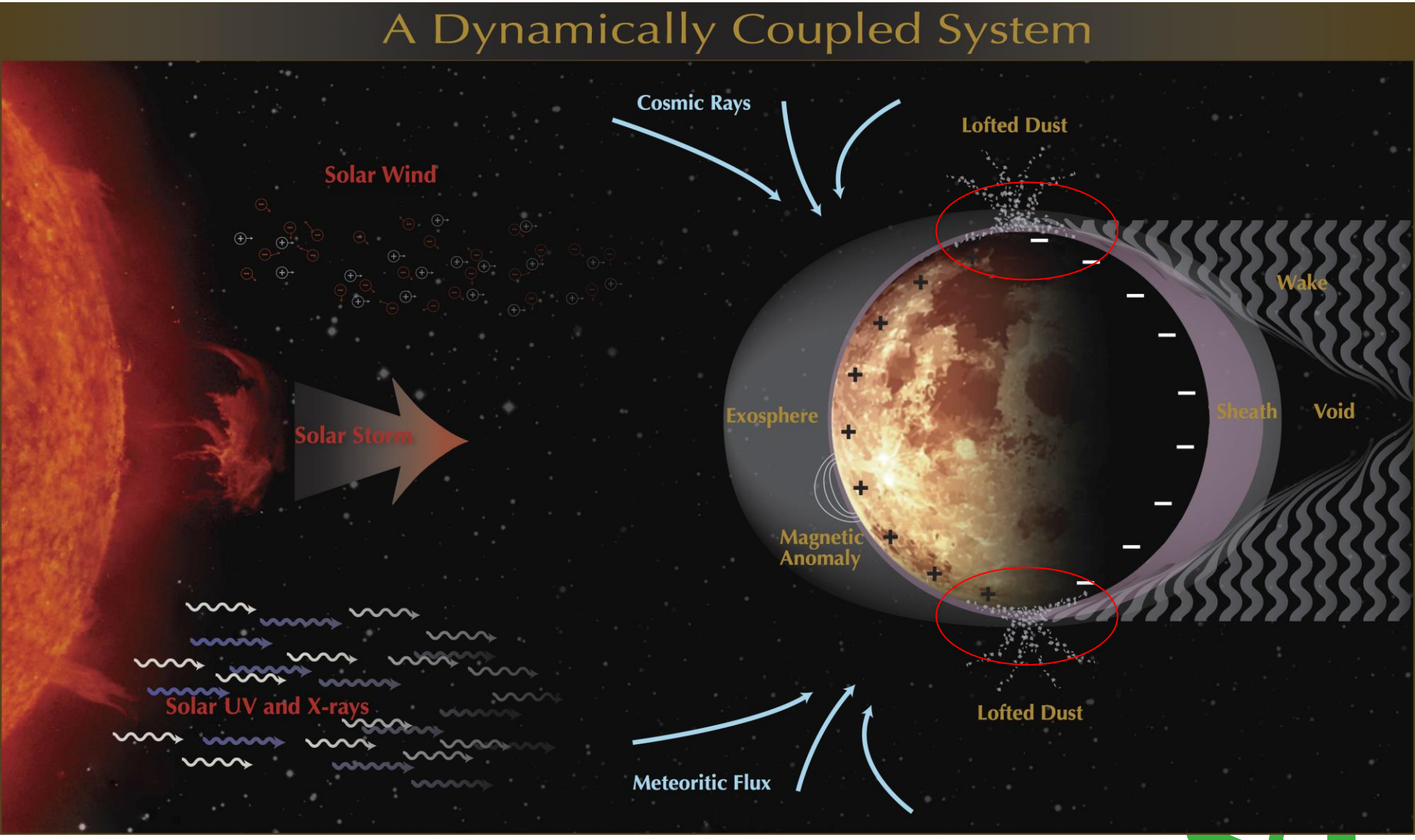
http://www.plasmaprometeo.unimib.it/wp-content/uploads/2013/03/plasma.jpg, accessed 9/2/2020

The space environment in our solar system



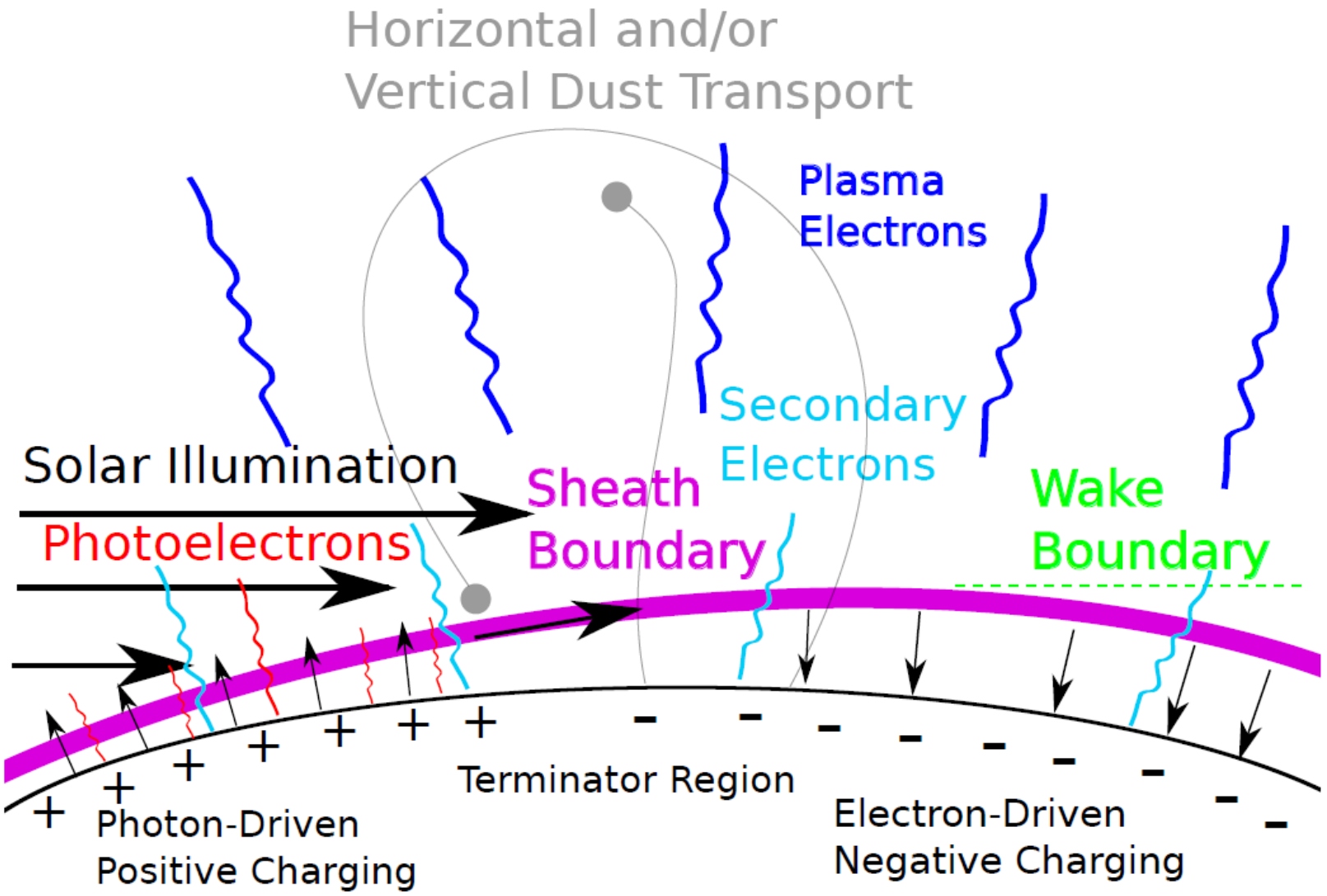
https://www.jpl.nasa.gov/infographics/infographic.view.php?id=12279, accessed 9/2/2020

There are rich processes on the Moon



https://ssed.gsfc.nasa.gov/dream/DREAM/faq.html, accessed 9/2/2020

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

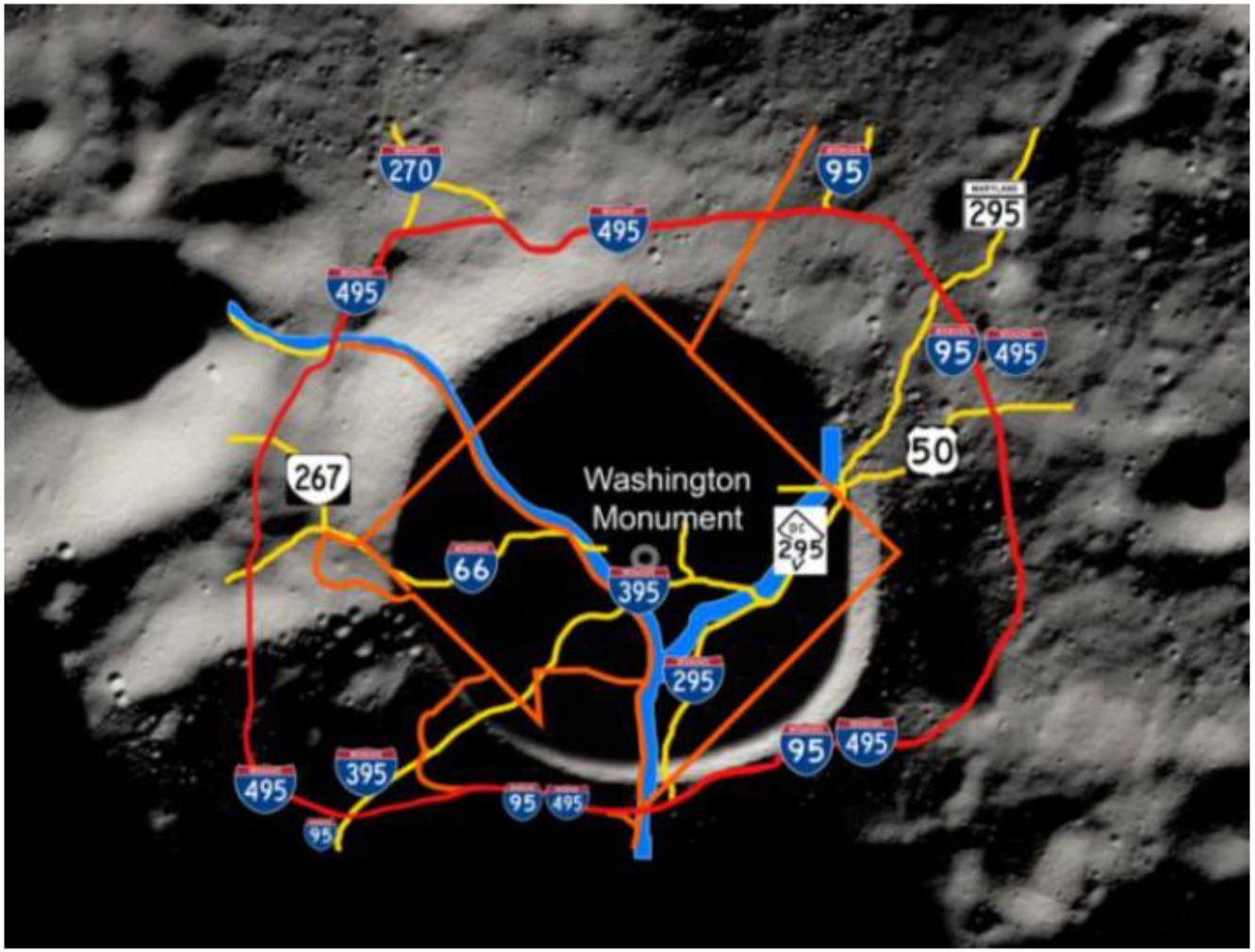


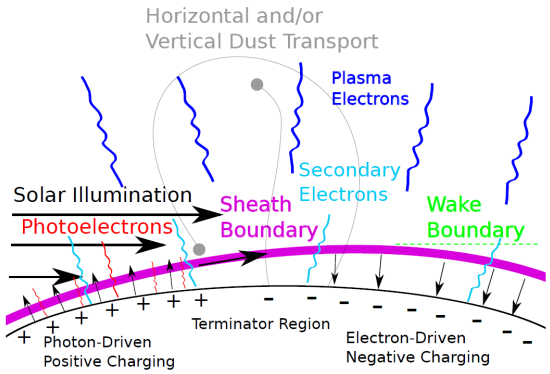
Figure 7: The lunar South Pole's Shackleton Crater, as captured by the Lunar Reconnaissance Orbiter, with the Capital Beltway overlaid for scale.

NASA's Plan for Sustained Lunar Exploration and Development, NASA, 2020

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

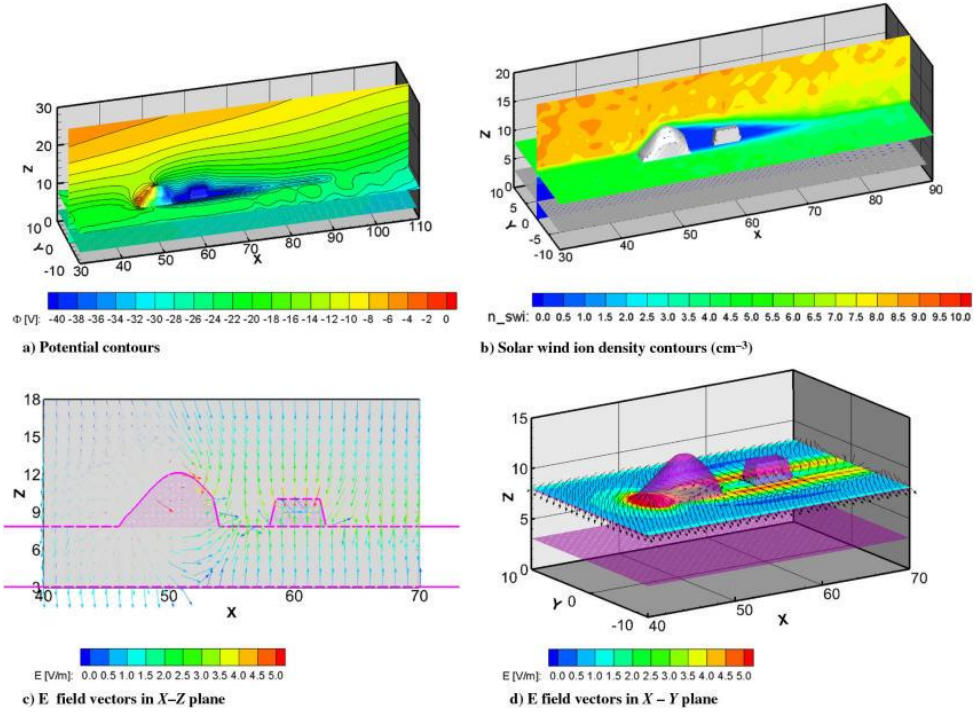
Apollo Astronaut Eugene Cernan Covered in Moon Dust



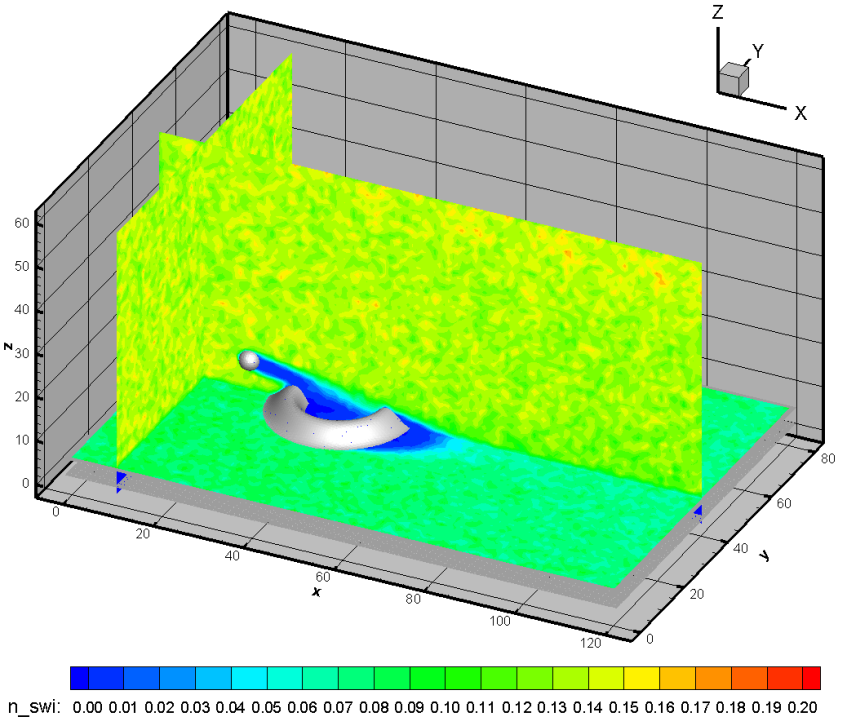
MISSOURI S&T

https://www.space.com/moon-dust-problem-lunar-exploration.html, accessed 9/2/2020

High-fidelity plasma simulation codes to study lunar surface charging



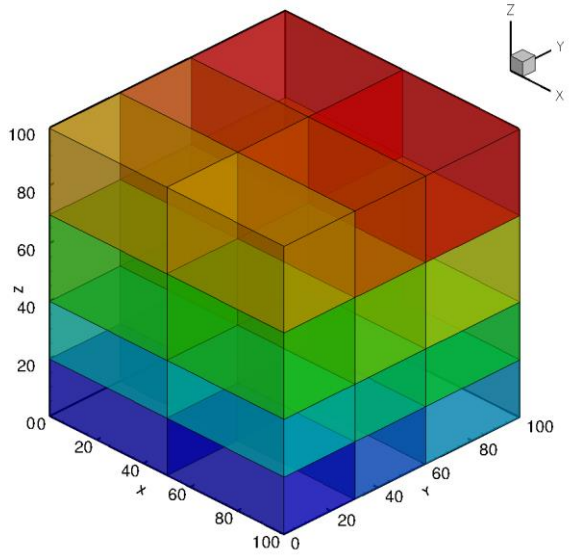
Han et al., Journal of Spacecraft and Rockets, 2018

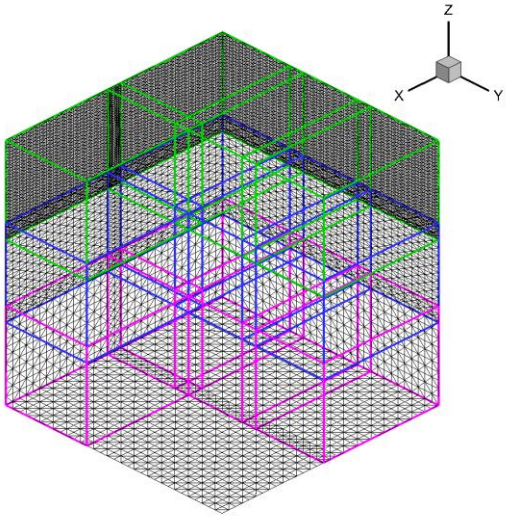


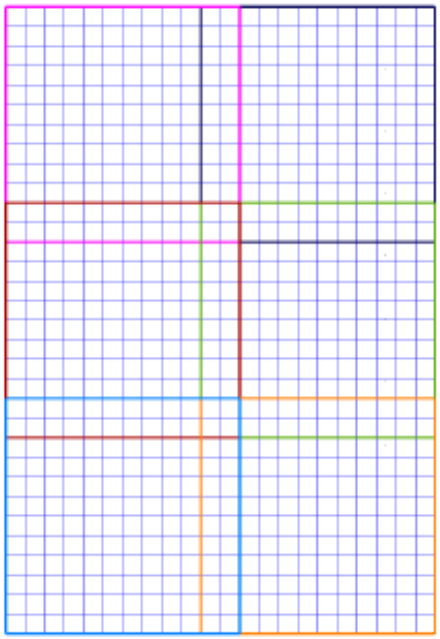
Lund et al., AIAA 2020-1549

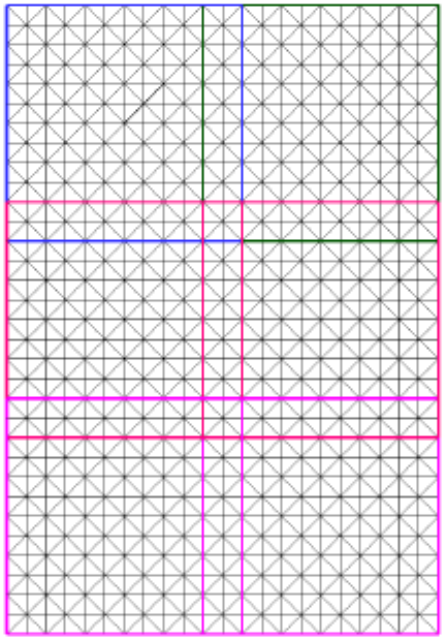
MISSOURI S&T

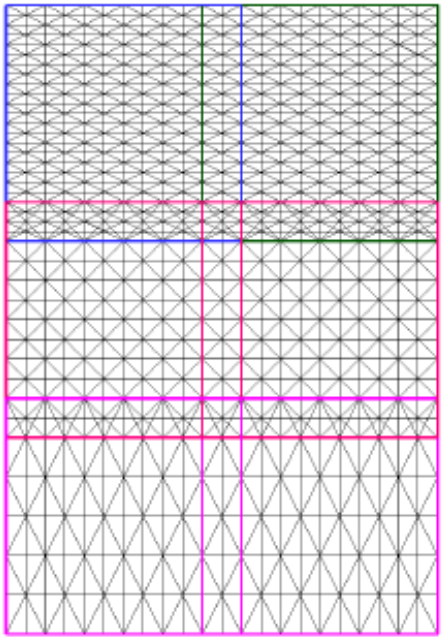
State of the art code: Parallel IFE-PIC (PIFE-PIC)





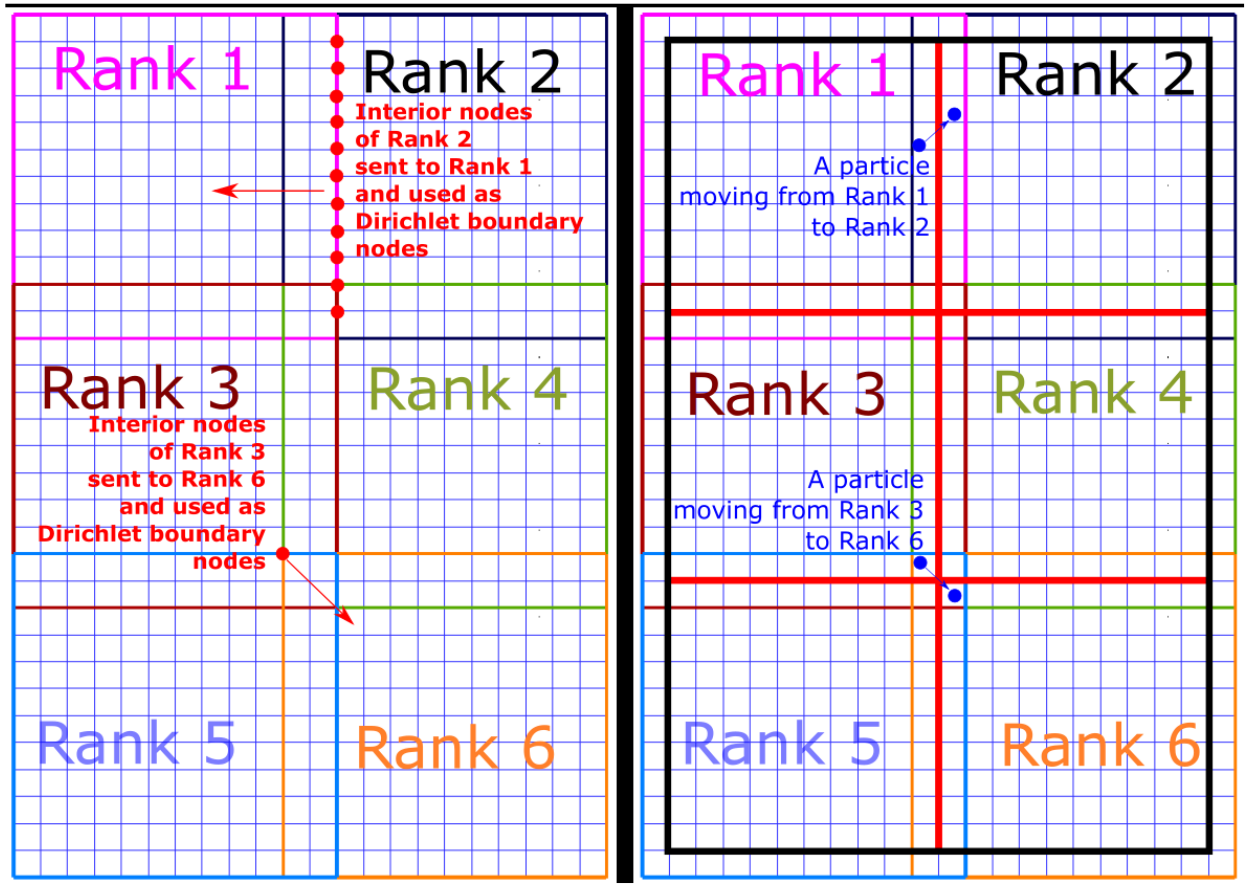






Han et al., SISC, 2021

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

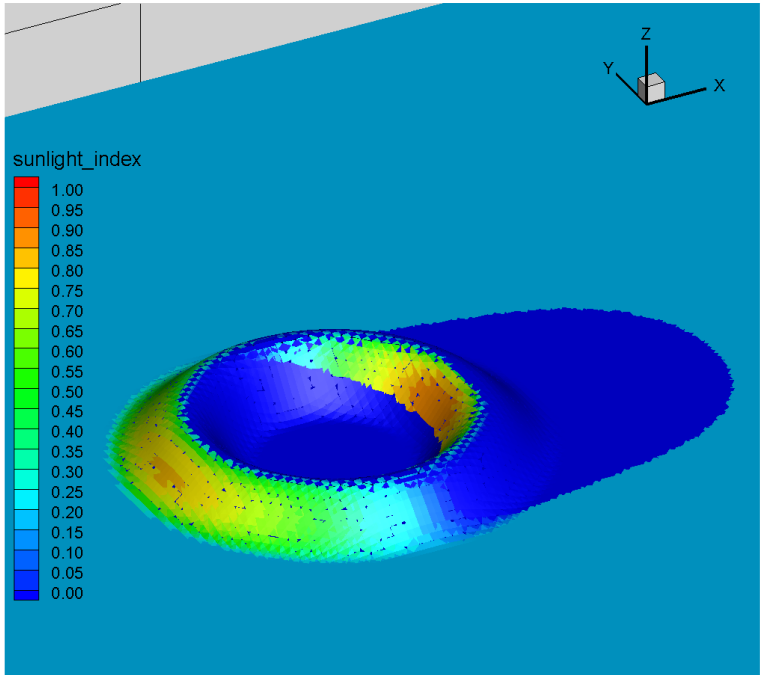


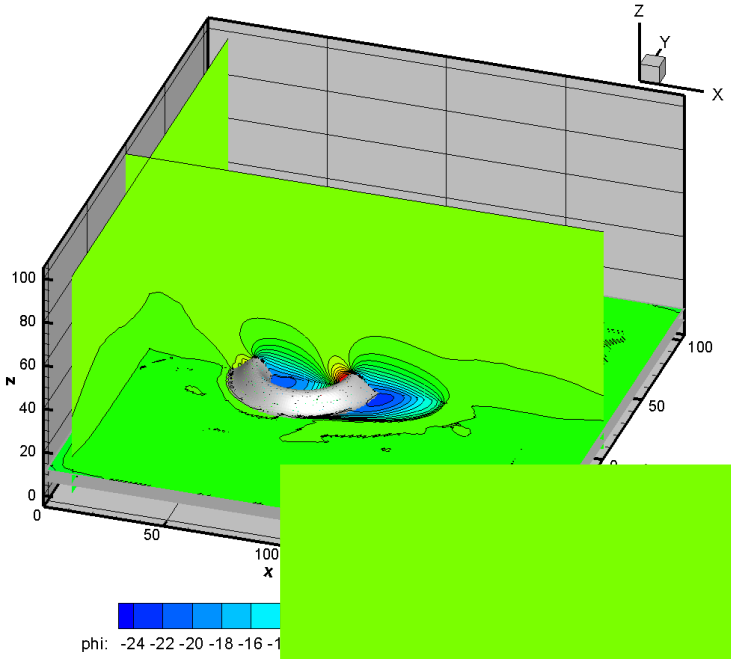
# of sub-domains	Efficiency E_{II}
1 (serial)	100.00%
64	109.02%
80	111.99%
100	106.57%
125	100.79%
150	94.99%
180	91.12%
216	89.62%
252	83.10%
294	68.35%
343	66.47%

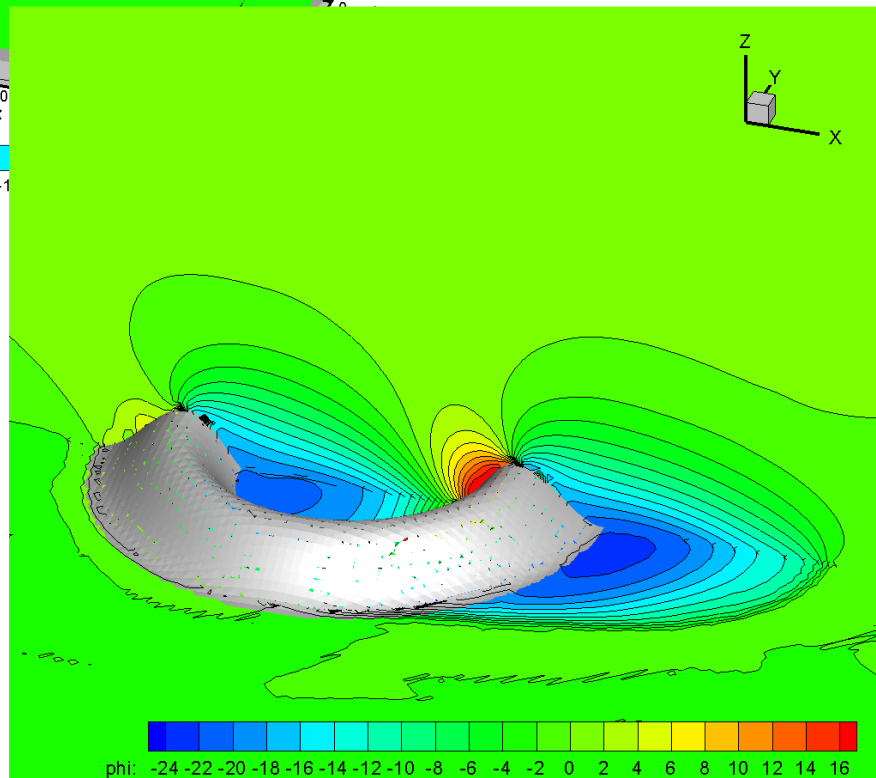
Strong scaling: Han et al., SISC, 2021
Weak scaling: Lund et al., JCPM, 2022

MISSOURI S&T

Routine HPC: 2M mesh cells, 1B particles



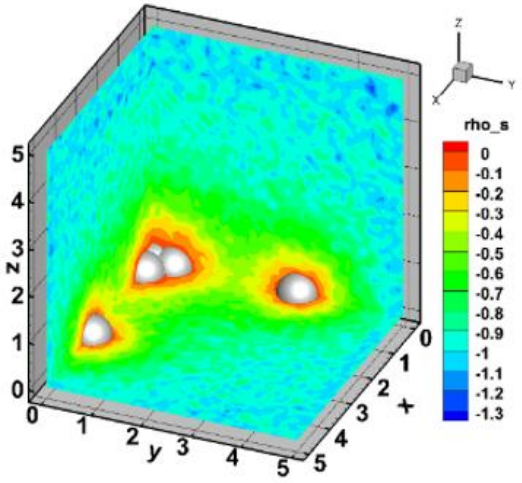




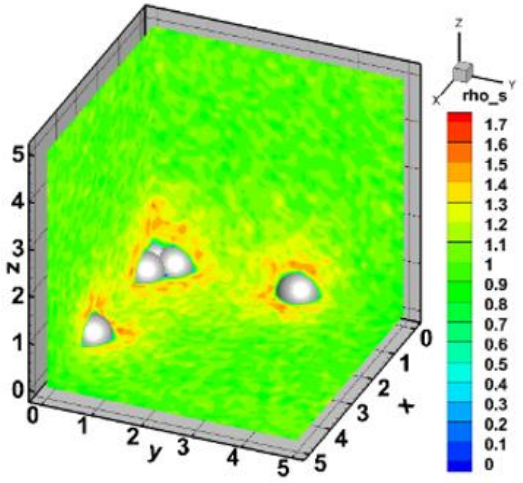
Very detailed surface differential charging at crater scale

Han et al., SISC, 2021

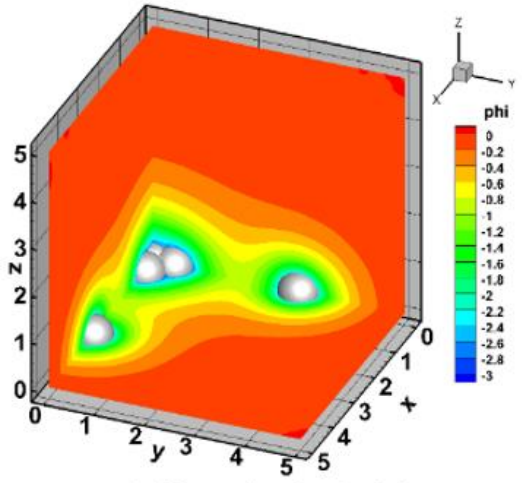
Ongoing: Grain scale charging, non-spherical shapes



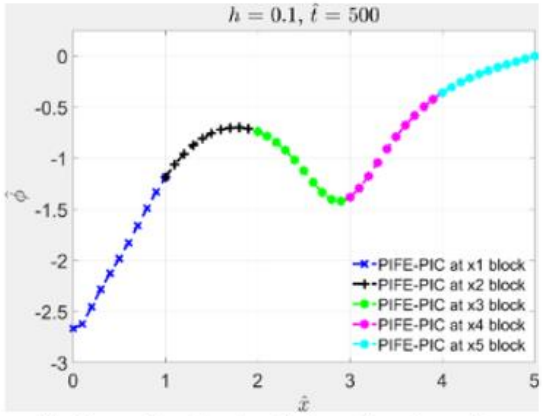
(a) Normalized electron density



(b) Normalized ion density



(c) Normalized potential



(d) Normalized potential profile along the x-direction

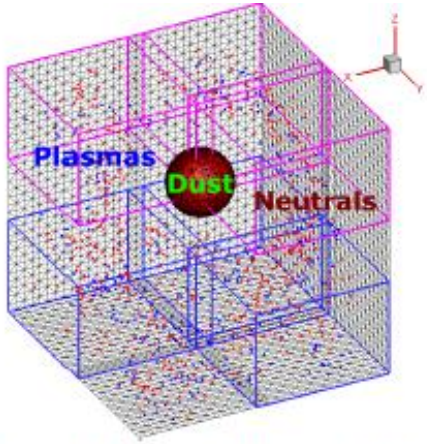
Looking into net charge on each grain

(for dust transport models)

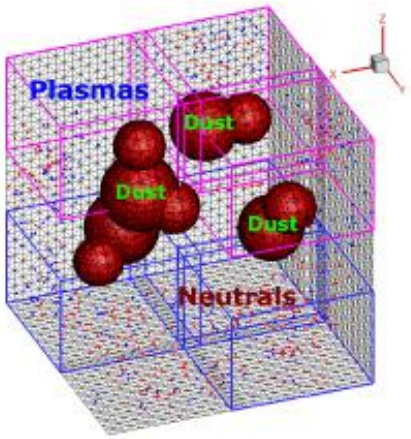
MISSOURI S&T

Presented at SIAM-CSS-2022, AGU 2022, and AIAA SciTech 2023 (AIAA 2023-2616)

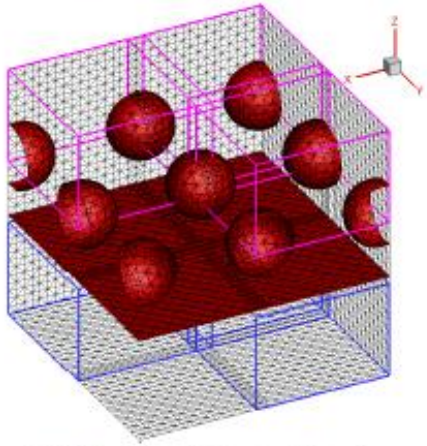
Dusty plasma – rich physics unresolved



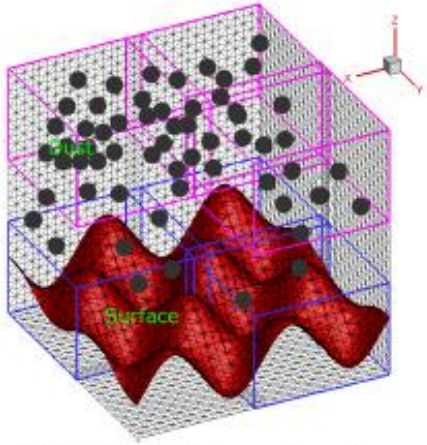
(a) Single-dust charging and forces/moments



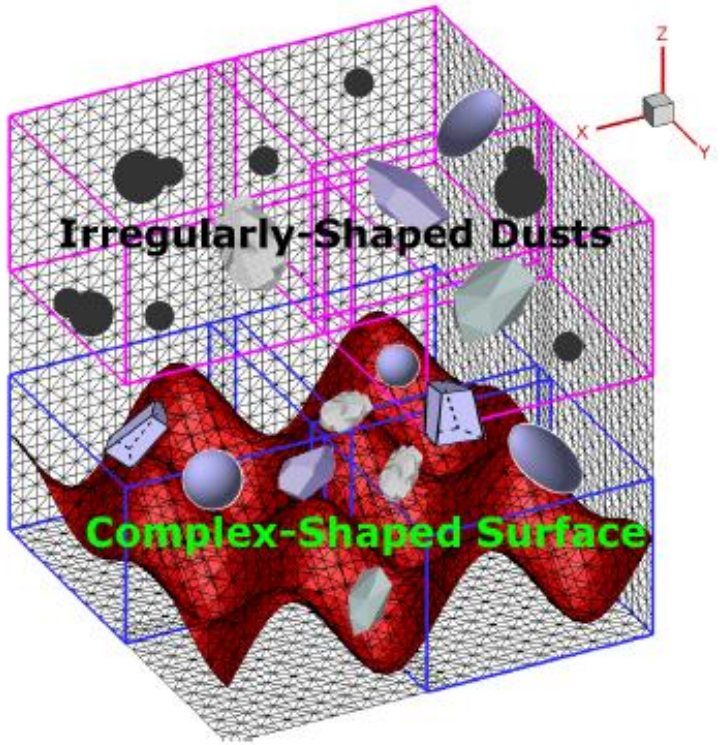
(b) Multi-dust interaction



(c) Multi-dust packed near a flat surface

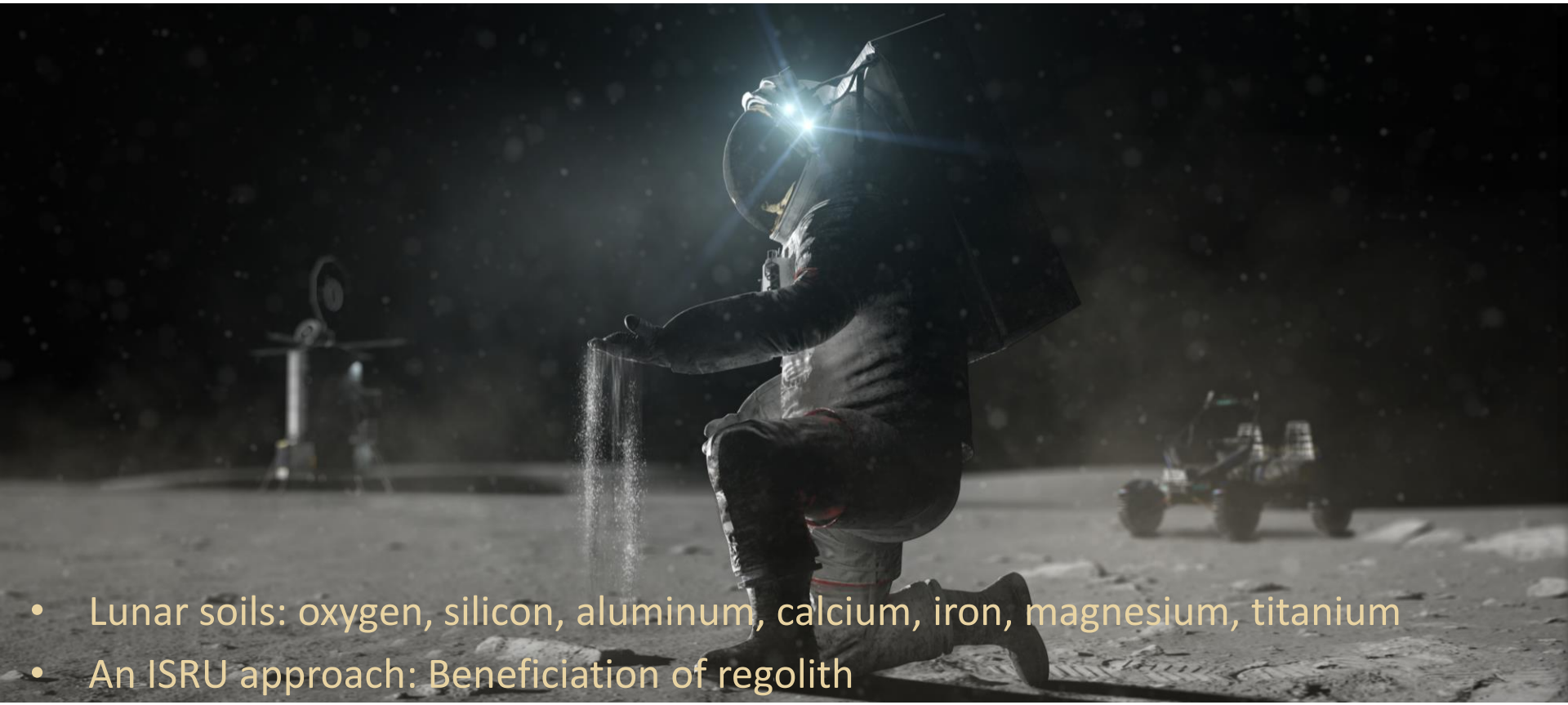


(d) Dust transport near complex surfaces



MISSOURI S&T

Dust… dust… (RESOURCE!)

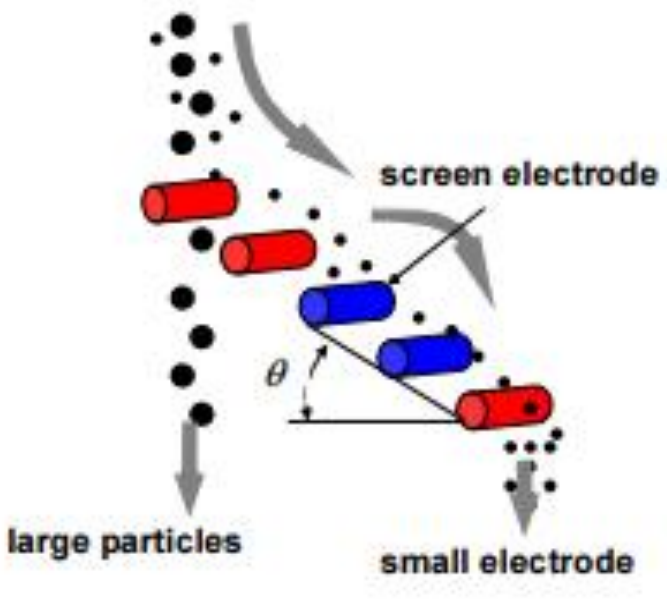


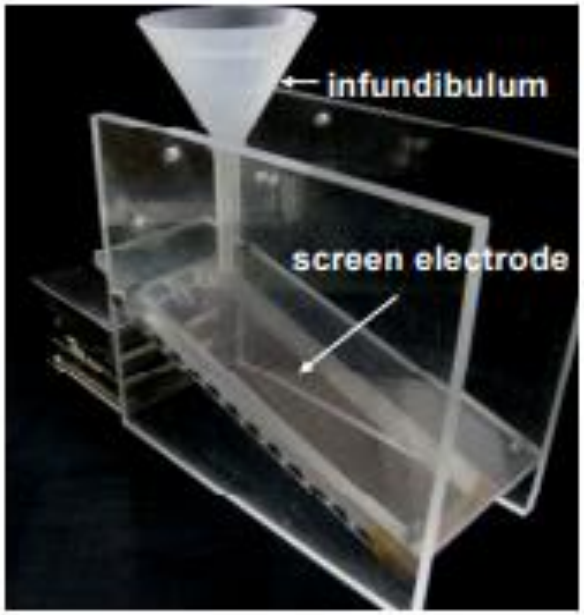
- Lunar soils: oxygen, silicon, aluminum, calcium, iron, magnesium, titanium
- An ISRU approach: Beneficiation of regolith
  - Separation of particles by size
  - Traditional methods: mechanical sieve – not suitable for use on the Moon – SWaP constraints
  - Electrostatic / Electrodynamic methods: lower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

MISSOURI S&T

https://www.nasa.gov/sites/default/files/thumbnails/image/sandyastrov2_16x9_0.jpg, accessed 10/7/2022

Concept of Electrostatic Sieve



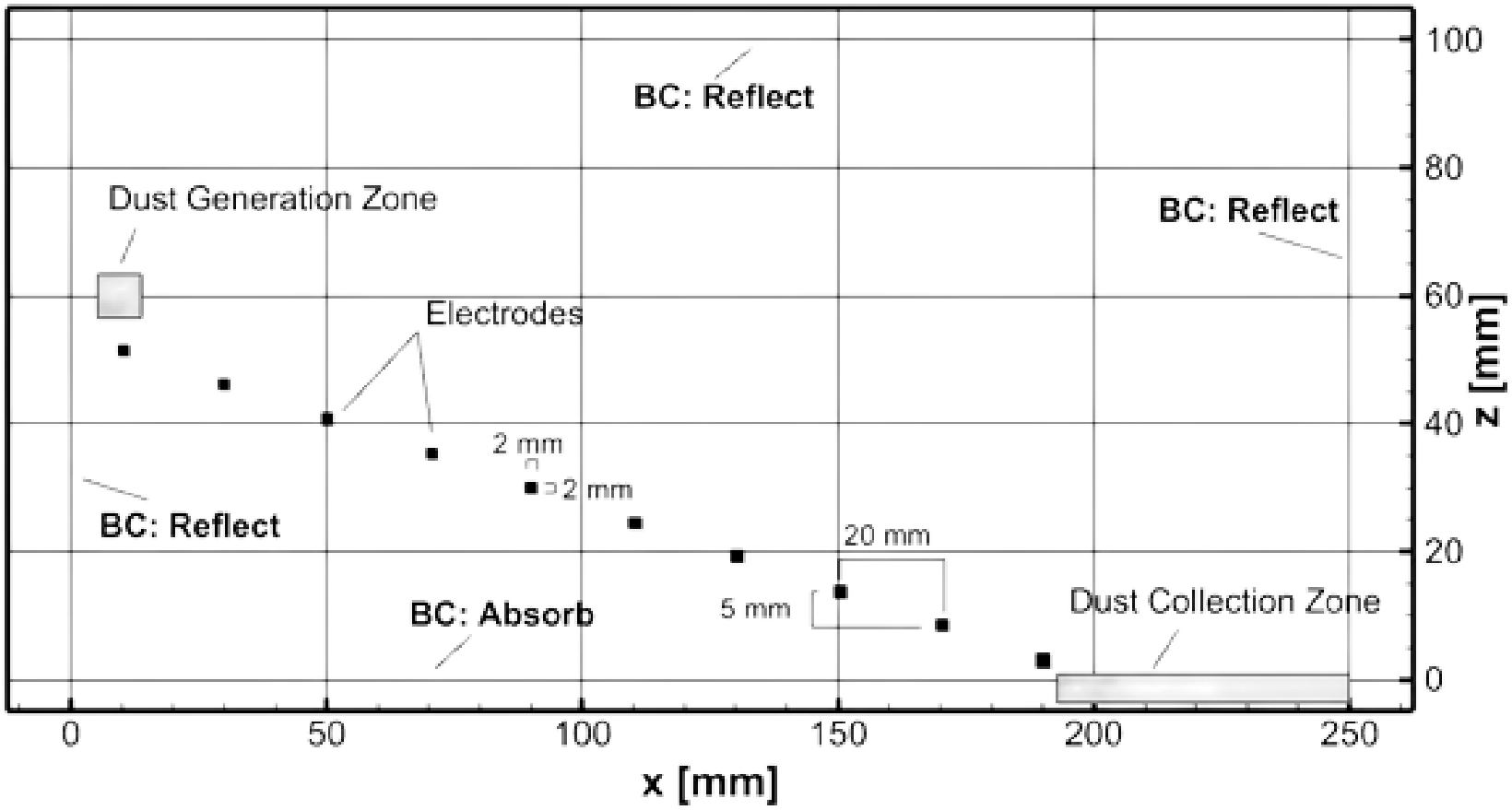


- Four-phase rectangular traveling wave and parallel electrodes to generate an electric field and separate dust
- Develop modeling capabilities for these concepts
- Use as an effective design and analysis tool

MISSOURI S&T

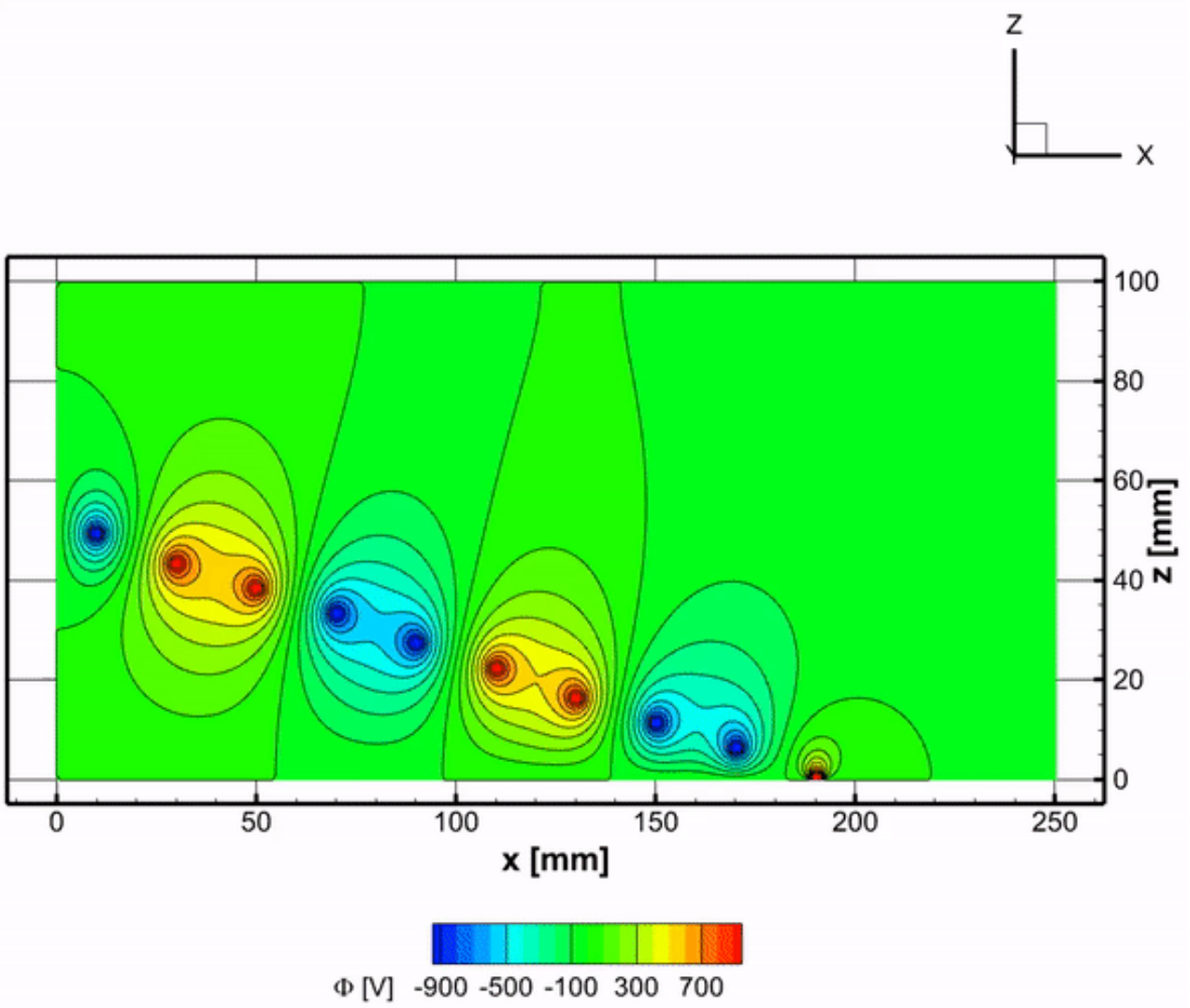
Kawamoto and Adachi, AIAA 2014-0341

Modeling operation of an electrostatic sieve



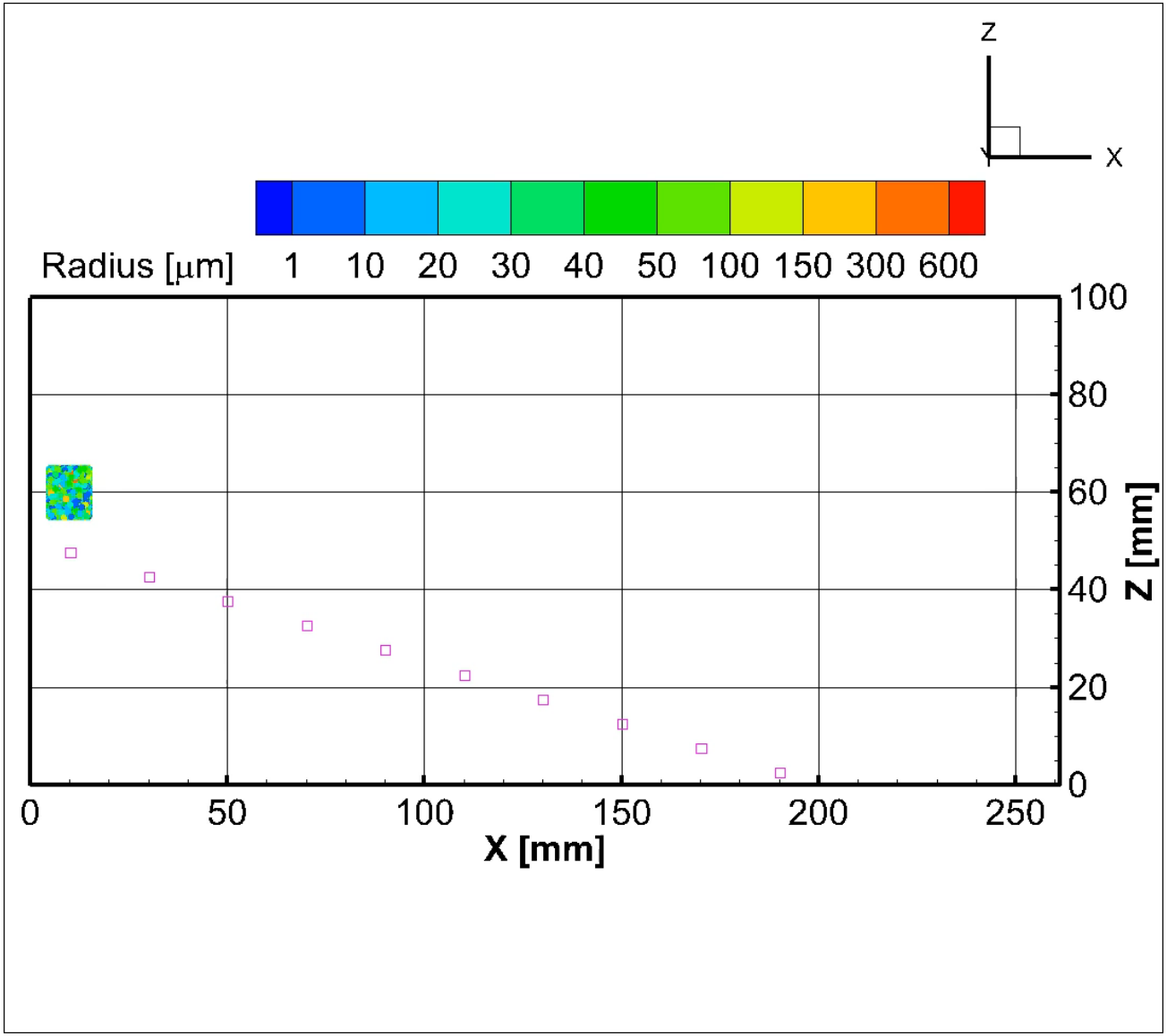
Berkhoff et al., SIAM-CSS-2022

Modeling operation of an electrostatic sieve



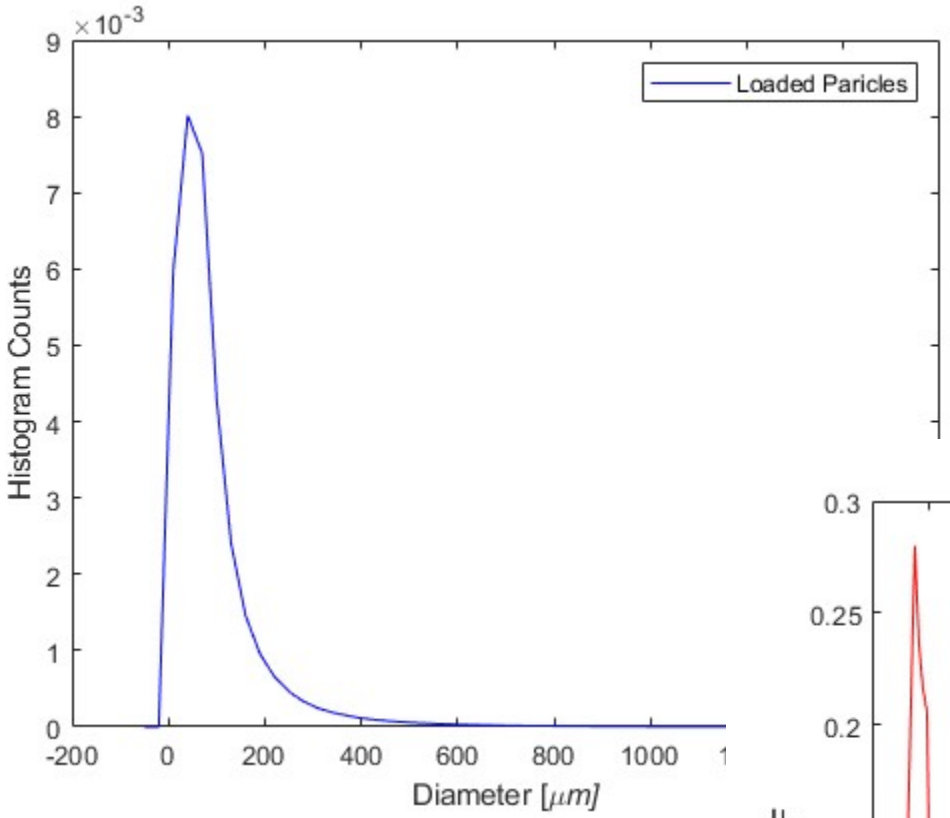
Berkhoff et al., SIAM-CSS-2022

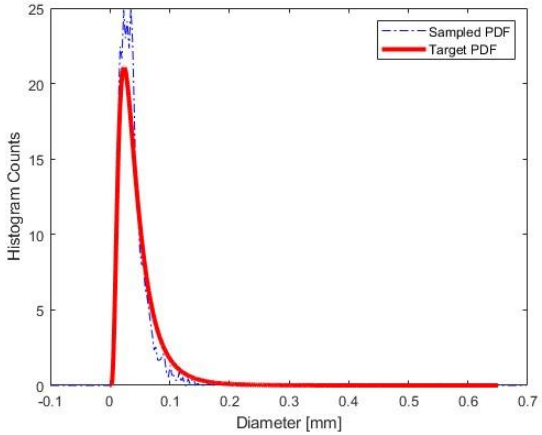
Modeling operation of an electrostatic sieve

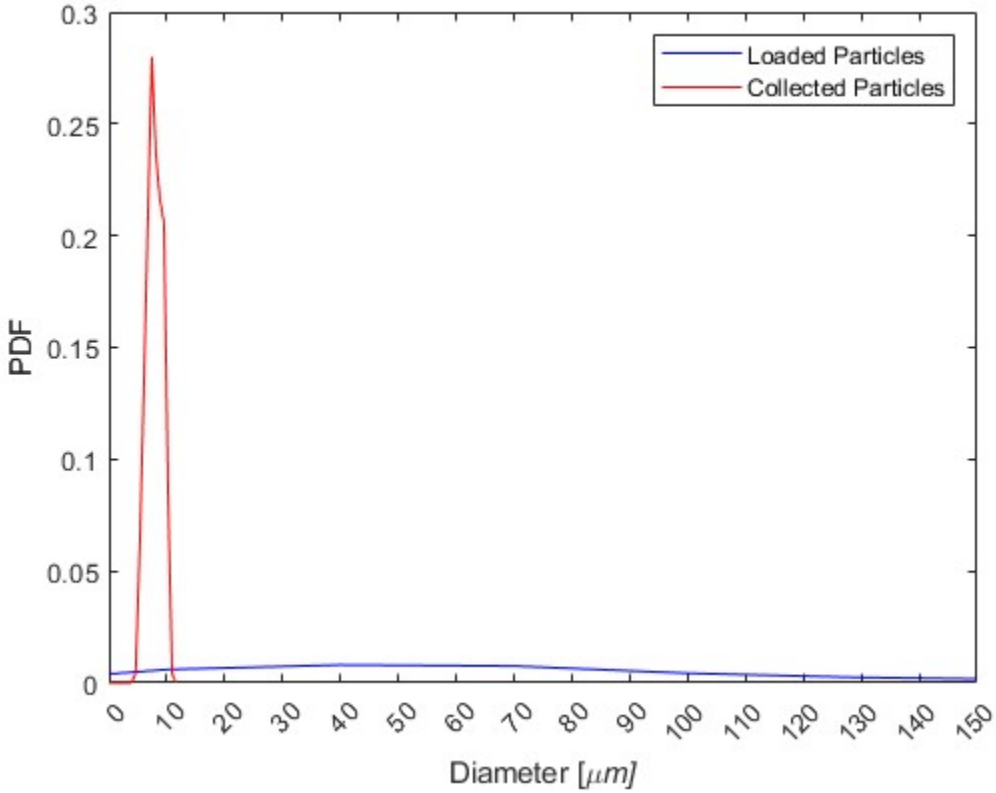


Berkhoff et al., SIAM-CSS-2022

Modeling operation of an electrostatic sieve

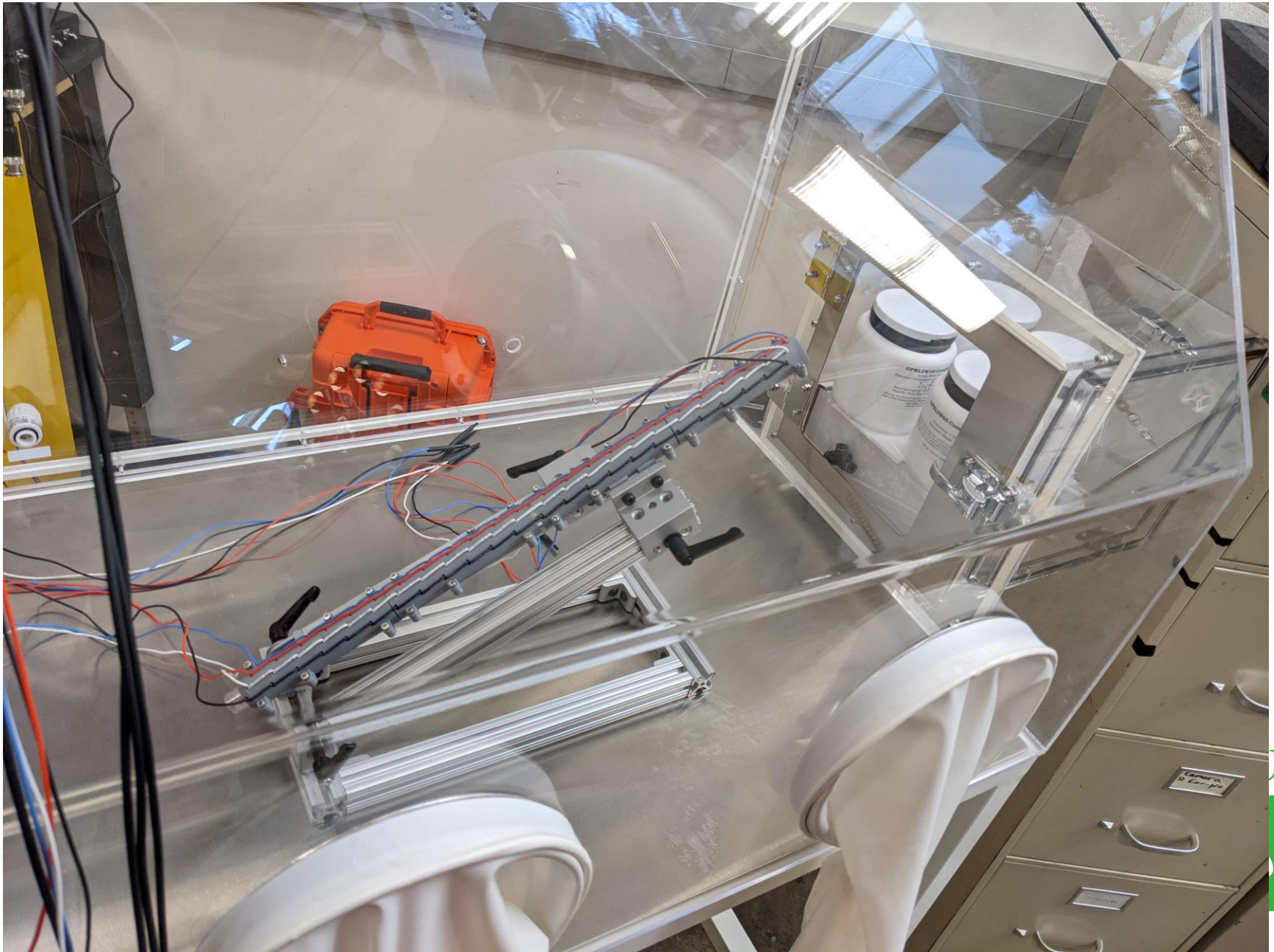






Berkhoff et al., SIAM-CSS-2022

Ongoing: Ground testing in atmospheric conditions

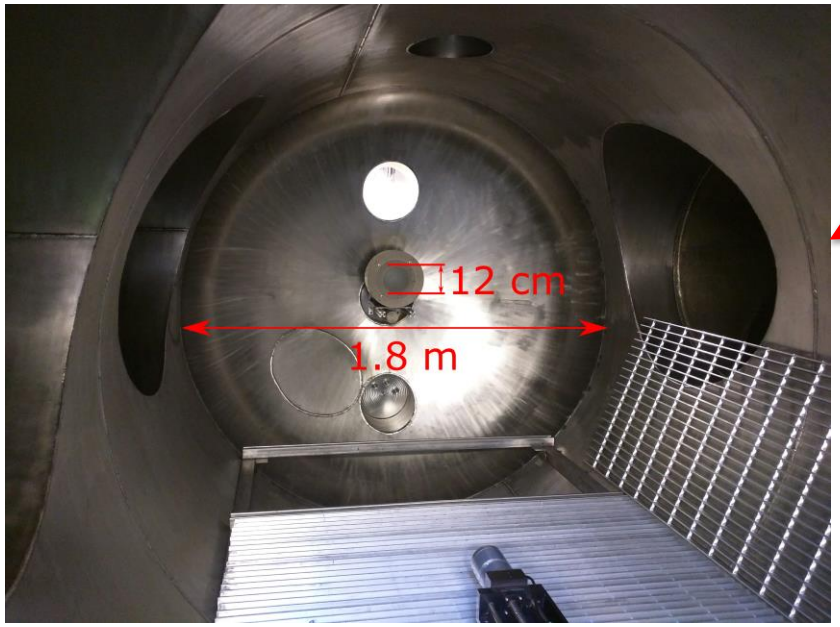


Outline

- 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!

MISSOURI S&T

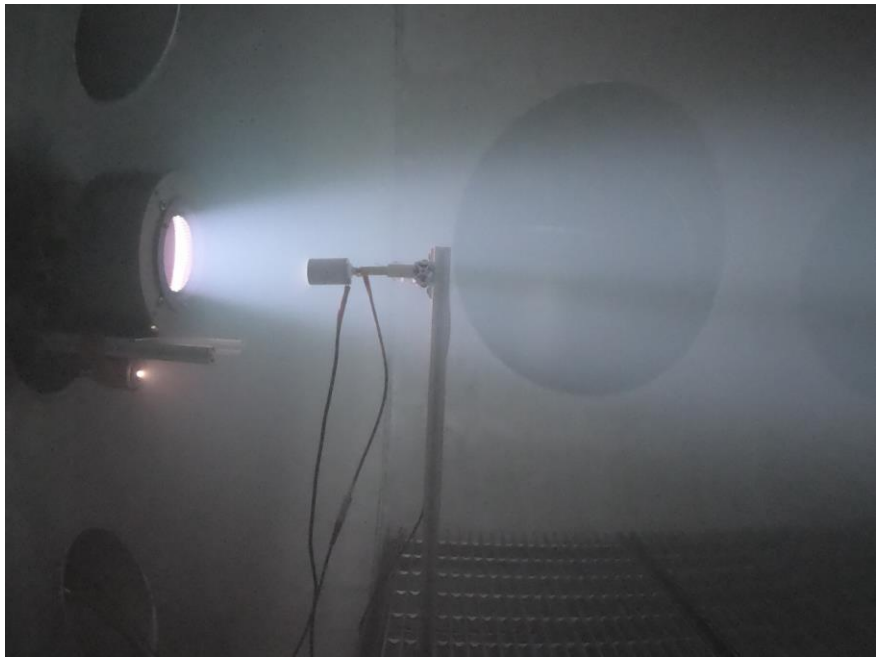
We also simulate the vacuum/plasma environments in a large chamber

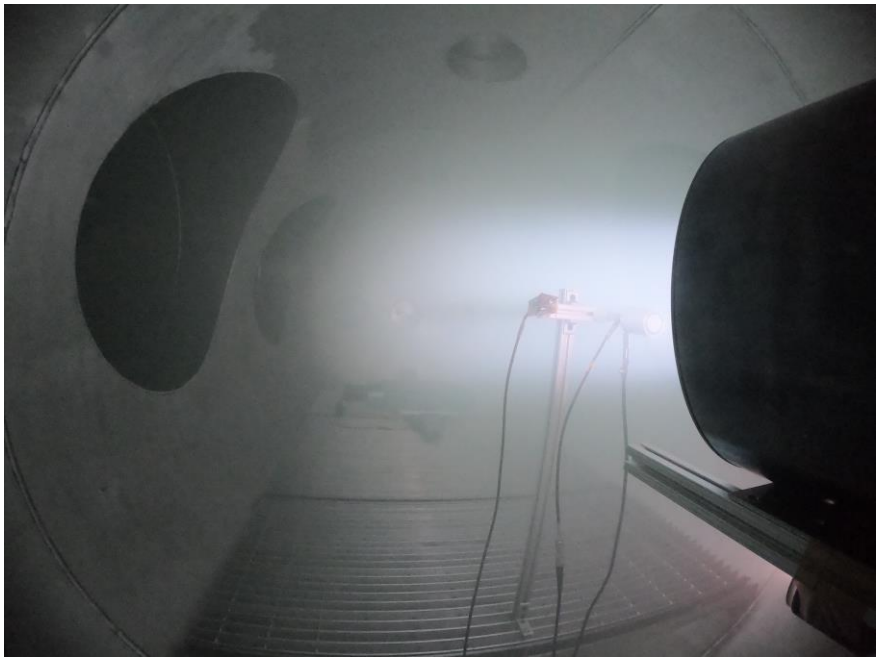


MISSOURI S&T

The Space Environment Ground Simulator (Video Tour)

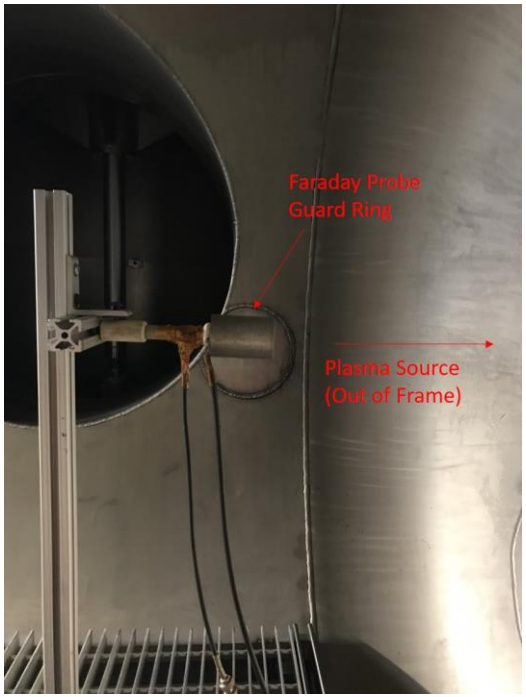
Plasma beams in chamber

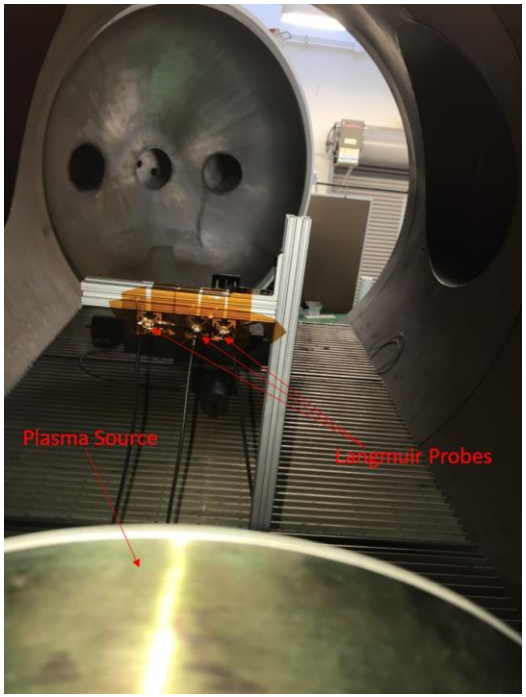




MISSOURI S&T

Diagnostics, and more ongoing





Helpers needed!

MISSOURI S&T

Geoscience / Space Environment

THANK YOU!

Daoru (Frank) Han, Missouri S&T, handao@mst.edu
Assistant Professor of Aerospace Engineering
Director, Gas and Plasma Dynamics Lab

DL – GPU 2023