Energy-Varied Electron Beam Dust Mitigation (EBDM) Source for Lunar Exploration

A. Cabra[1,2,3], X. Wang[1,2,3], B. Farr[3], D. Hansen[3], and M. Horanyi[1,2,3]

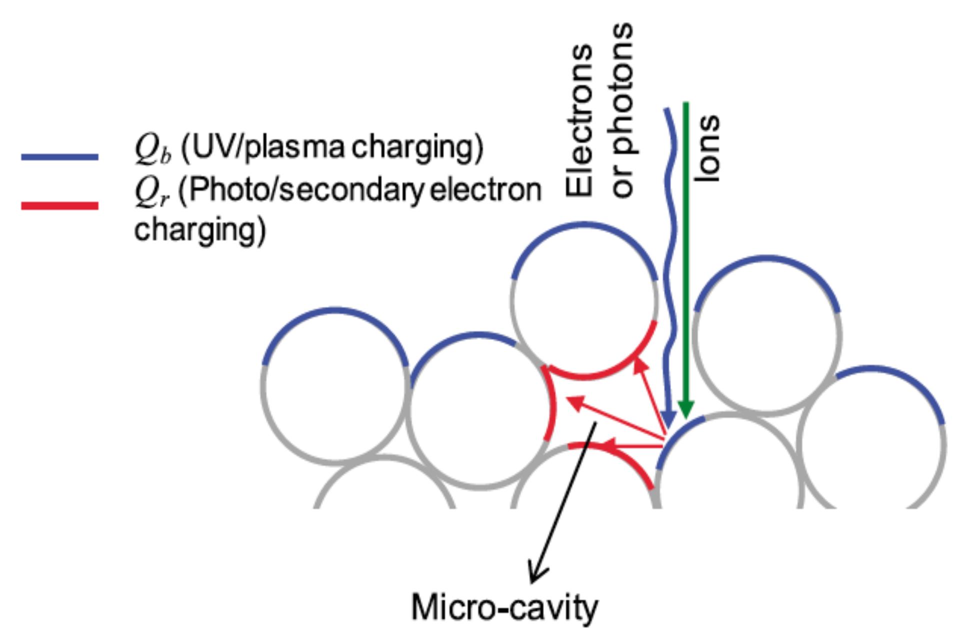
[1] NASA SSERVI's Institute for Modeling Plasma, Atmospheres, and Cosmic Dust (IMPACT), University of Colorado, Boulder, CO 80303;
[2] Laboratory for Atmospheric and Space Physics (LASP), University of Colorado, Boulder, CO 80303
[3] Space Dust Research & Technologies LLC (SDRT) Louisville, CO 80027

Motivation

- In-Situ Resource Utilization (ISRU) is essential for sustainable lunar exploration, but electrostatically charged lunar dust strongly adheres to surfaces such as solar panels, optics, excavation systems, and astronaut suits
- Dust adhesion can lead to material degradation, human health hazards, and reduced system performance, creating a need for effective dust mitigation technologies
- Electron-Beam Dust Mitigation (EBDM) is an active dust removal technology that mobilizes dust through electrostatic charging repulsion [1]
- Previous EBDM studies focused on fixed electron beam conditions
- This work experimentally investigates variable electron beam energy to modulate dust charging conditions and enhance electrostatic dust removal efficiency

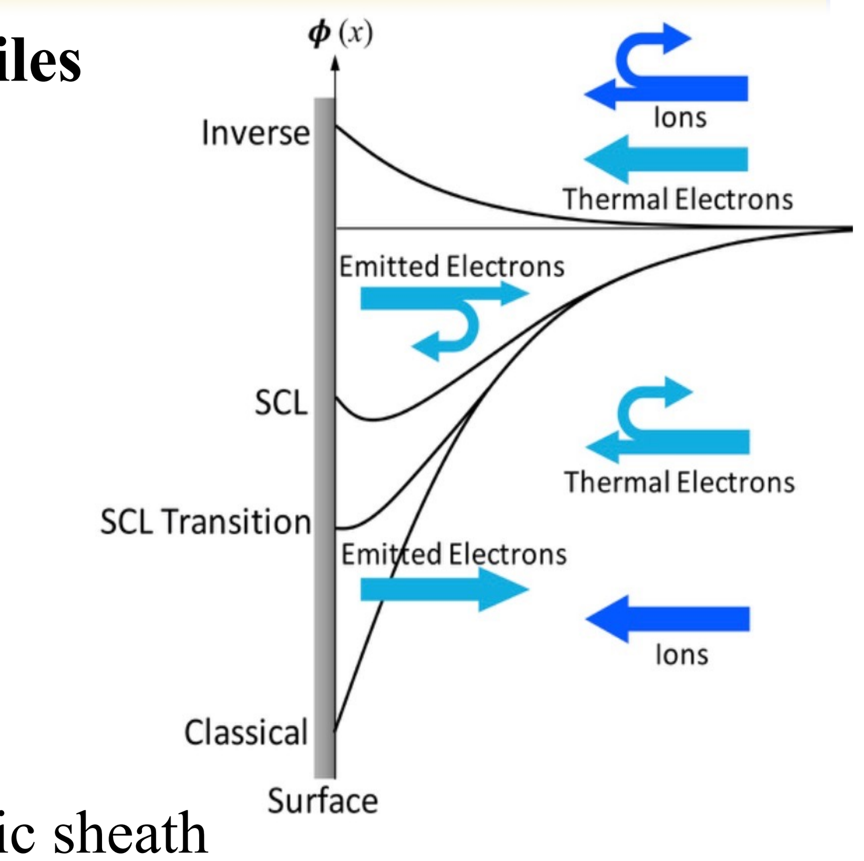
EBDM Charging Theory

Patched Charge Model (PCM)



- Emission and re-absorption of photo- or secondary electrons within microcavities result in negative surface charging [2]
- Resulting coulomb repulsive forces between negatively charged particles overcome adhesion and cause lofting [2]

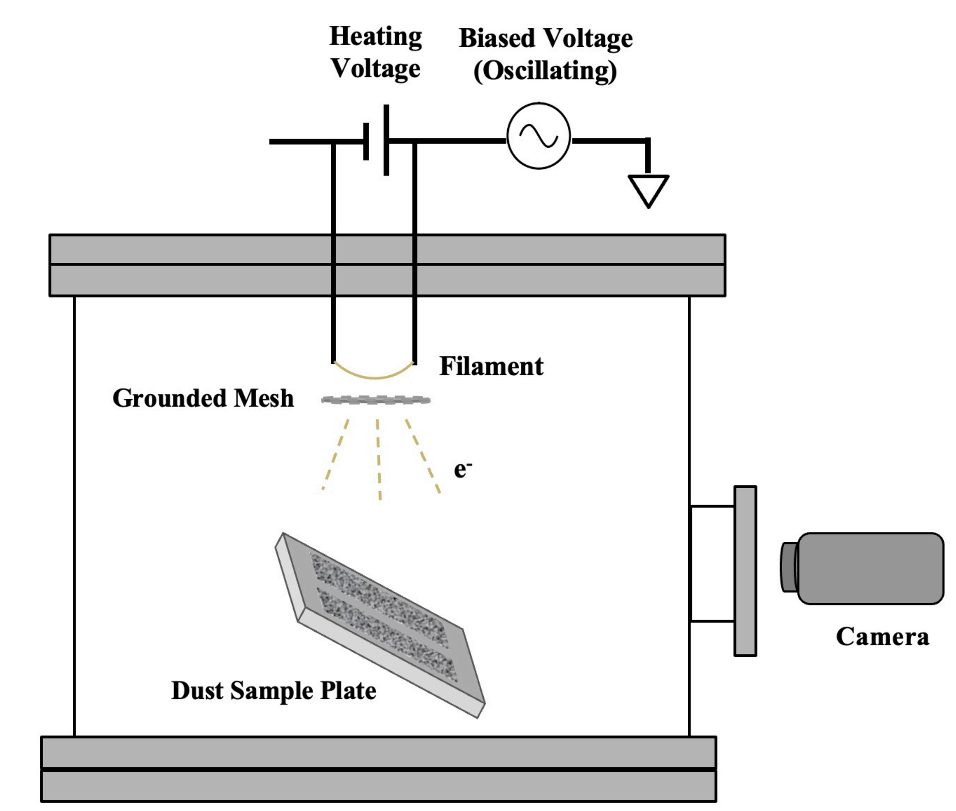
Varying Sheath Profiles



- Dust lofting rate depends on secondary electron emission (SEE) and surface plasma sheath structure [3]
- Low beam energies:
  - < 90 eV
  - SEY <1
  - Classical monotonic sheath
  - Surface potential ~ follows beam energy
- High beam energies:
  - > 90 eV
  - SEY > 1
  - Non-monotonic to inverse sheath
- Transitions between these sheath regimes crosses over a maximum effective SEE, enhancing electrostatic charging and dust removal efficiency.

Experimental Setup

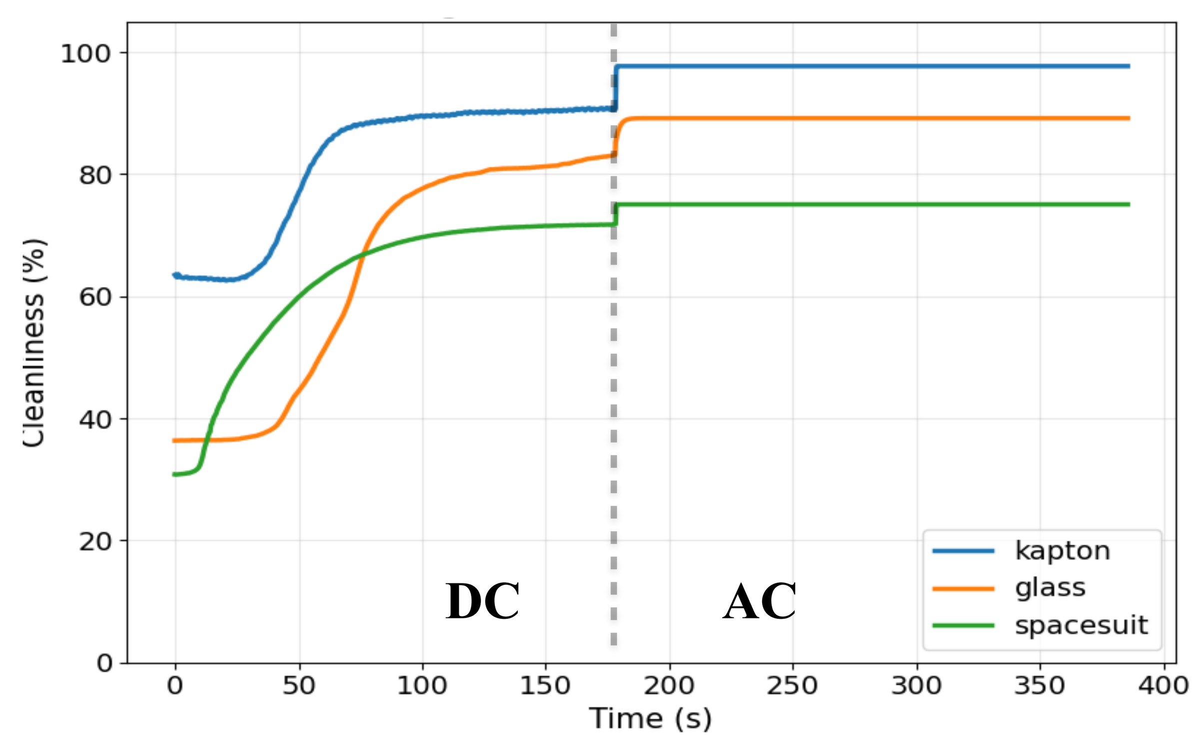
- Tested in a vacuum chamber at 1×10^{-5} Torr
- 2 modes:
  - Fixed beam energy (DC mode): 200 eV | 75 mA
  - Varying beam energy (AC mode): 40-200 eV | 1 Hz triangle wave
- Dust simulants: JSC 1A, Lunar Highland
- Dust size: < 25 µm
- Samples: Kapton, Glass, Spacesuit, Thermal Radiator



Testing and Results

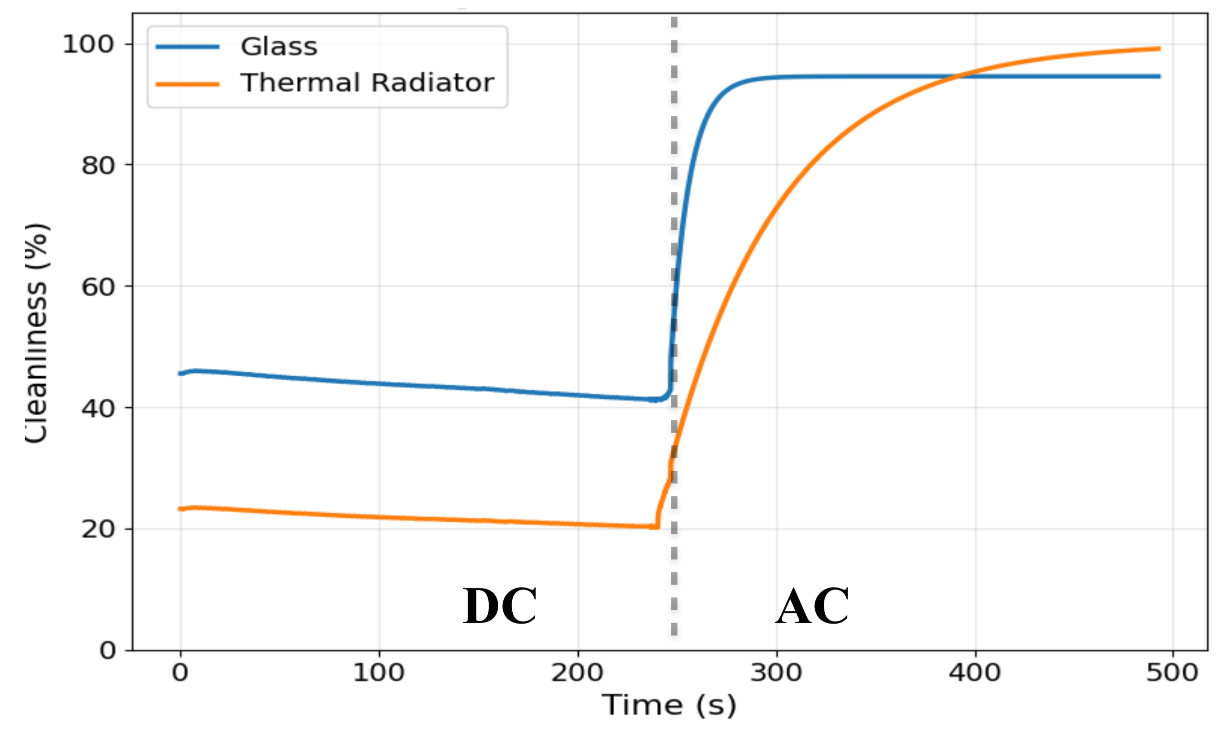
JSC-1A: Before and After

JSC-1A: DC then AC



AC mode increased efficacy by 5-10%

Lunar Highland: DC then AC



Highland is more adhesive and AC mode is more effective than DC mode

Conclusion and Discussion

- Energy-varied EBDM passes through transitions between sheath regimes, resulting in maximum effective SEE and dust removal rate
- This improved dust removal efficacy compared to fixed-energy EBDM by 5-10% for JSC-1A, and 50-75% for Highland
- Results demonstrate that EBDM with DC and AC modes provides a high efficient, non-contact dust mitigation approach for lunar exploration

References

[1] Farr et al. (2020), Acta Astronautica, 177, 405-409; [2] Wang et al. (2016), GRL, 43, 6103-6110. [3] Cabra et al. (2026), GRL, Under Review [4] Wang et al., Issued Patent, Application No.17/881,880, 2022. [5] Pending patent for oscillating bean energy