Lunar Surface Innovation
CONSORTIUM

NASA
Administered by the
Johns Hopkins
APPLIED PHYSICS LABORATORY

Extreme Environments - Electrostatics

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Designing for the Extremes Workshop August 5, 2022

Electrostatics and Surface Physics Lab


9:30 A.M., the giant Thor-Delta's third-stage motor was ready for final checkout. Suddenly, Spin Test Lab technicians heard a loud crack. As they stared in horror, the five-foot package of hell sizzled into premature life, kicked out with a 3000-pound thrust and tore loose—turning the sealed room into a missileman's nightmare.

11 MEN BURNING ALIVE"

TRAVIS

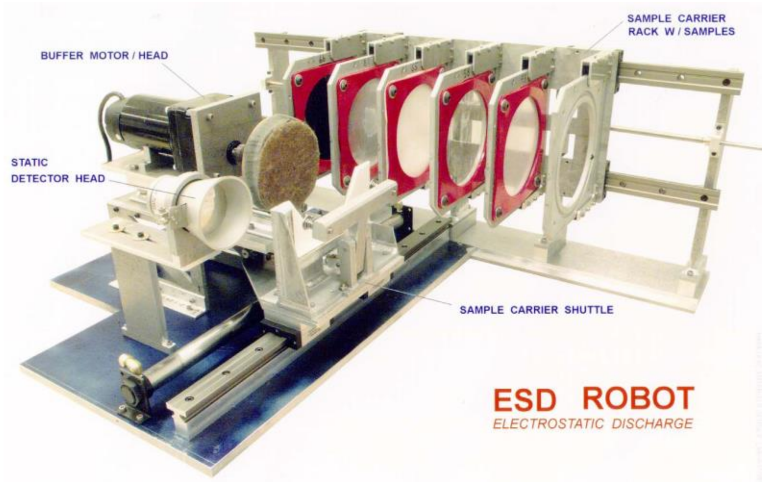
WORLD'S WORST SPACE AGE DISASTER

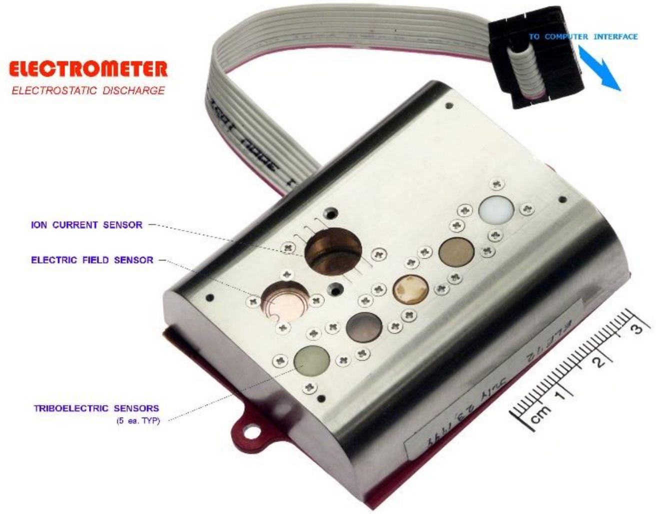
STORY STARTS ON NEXT PAGE▶

Spectacular as on-pad misfires have been, none compare with holocaust that exploded inside the Cape's Spin Facility Building.

April 14, 1964

KSC has been performing electrostatic measurements on spaceport materials since the 1960's.





The Electrostatics and Surface Physics Laboratory (ESPL) at KSC was formed in 1998 by Dr. Carlos Calle with its mission to provide guidance in electrostatic phenomenon for various programs inside and outside of the agency.

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The Laboratory

- Founded in 1998
- Mission: investigate electrostatics and surface physics problems with application to space flight and planetary exploration
- Perform electrostatic analysis and material characterization to assist in detection, mitigation and prevention of electrostatic charge generation on space flight hardware and ground support equipment
- Develop technologies for NASA's planetary exploration missions
  - Dust mitigation technologies
  - Instrumentation for planetary science



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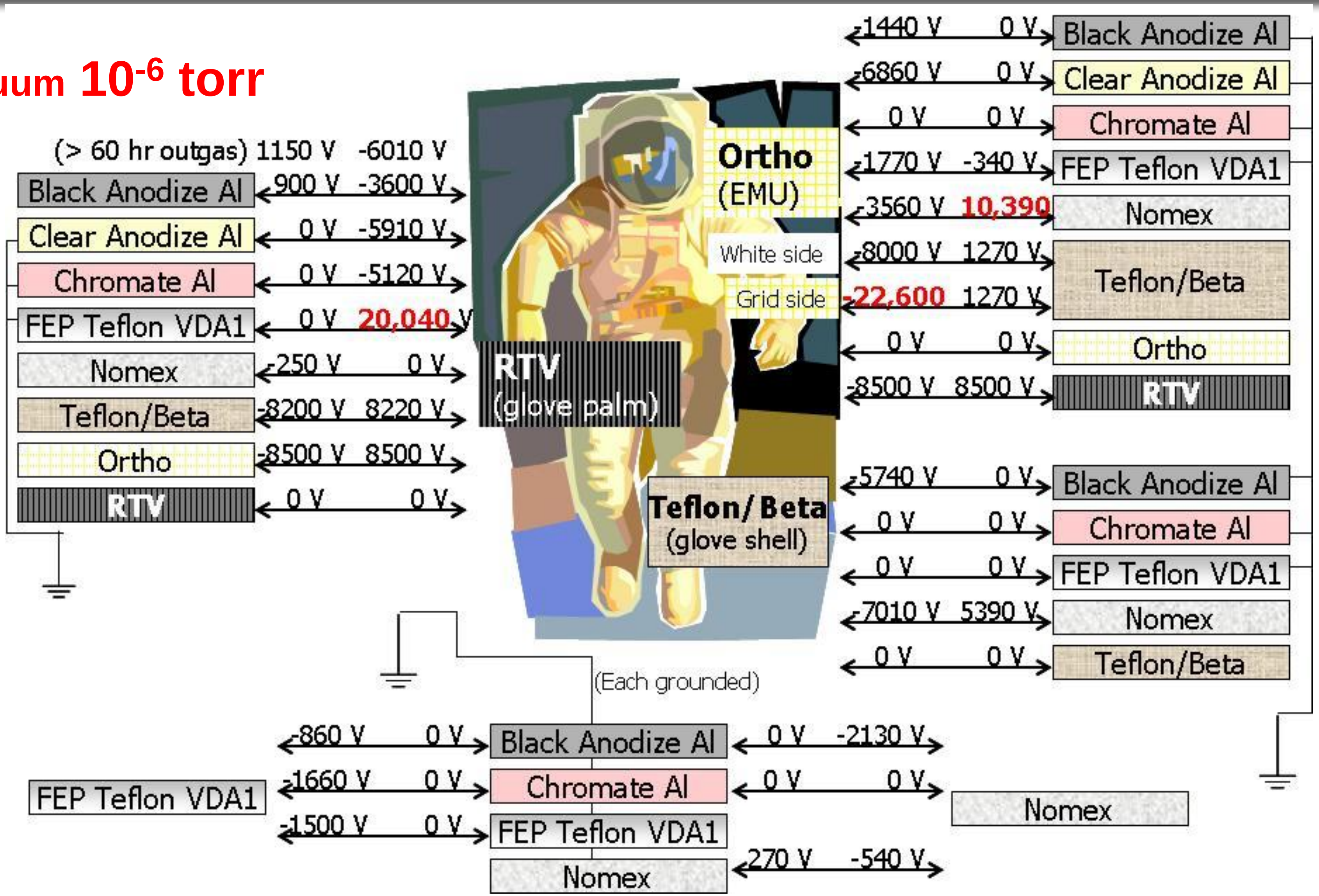
Spacesuit Charging for Hubble Mission IV

Exploration Research and Technology Programs

High vacuum 10^{-6} torr



Note: When approached with a ground probe, there were <u>no</u> brush discharges from surfaces in high vacuum!

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Problem: Dust and Electrostatics on the Moon

- The particles are good dielectrics (permittivities between 2-3) and resistivities (ρ above 10^{13} Ωm) and are most likely charged (positive and/or negative) or net zero total charge (bipolar).
- The surface of the moon is also a dielectric (no electrical ground)
- Very, very dry – no moisture to allow charge decay ($\tau = RC = \rho\varepsilon\varepsilon_o$)
- The allowed electric field is much higher than the Earth and Mars
    - E_Moon >> E_Earth >> E_Mars
    - 10^8 V/m >> 10^6 V/m >> 10^4 V/m
    - Field Emission >> Air Breakdown >> CO_2 at Paschen minimum
    - **Thus stored energy and particle charging can be a lot higher on the moon than on Earth**

- Polarization effects are important.
- There is a neutralization current of about ~ 1 μA/m^2
- No benefit of this current in the Permanently Shadowed Regions
- Apparently, the current does not prevent dust accumulation from the Apollo missions.
- Is Discharging an issue? Propagating Brush Discharges, Brush and Cone Discharges, Sparking, etc..
- Dust has initial charges due to photoemission, SEE, etc…
- Dust adhesion and removal leads to high electric fields and vice versa.
- Dust accumulation inside mechanisms limited Apollo to only 3 EVAs/mission.

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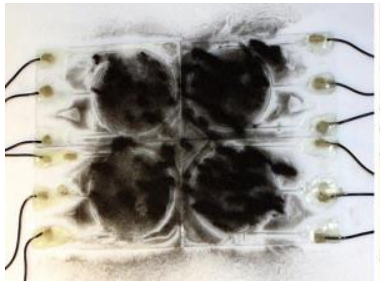
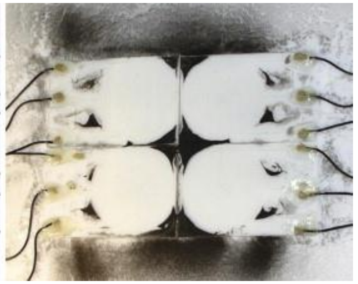
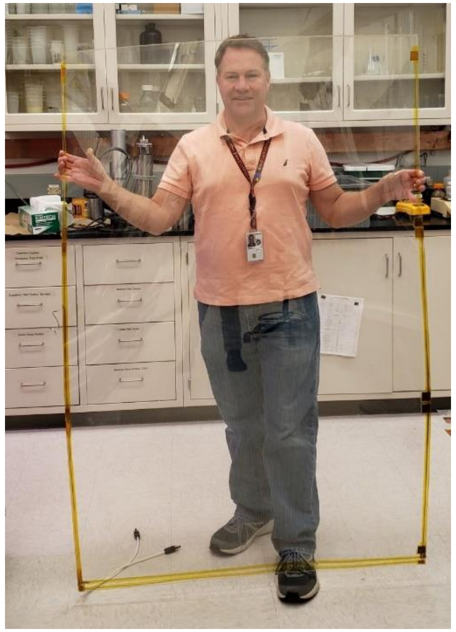
Electrodynamic Dust Shield

The Electrodynamic Dust Shield or EDS is a method of using travelling electric fields to lift and remove particles from surfaces without the use of moving parts.

- Well-developed Technology
- Flying as a payload for the MISSE-11 and 15 carrier on the ISS
- Very versatile technology
- Can be made transparent, flexible, applied to metals
- Works well in conjunction with passive dust mitigation methods/coatings
- Multiple phases available [2-phase, 3-phase, 3D versions (single phase)]
- Uses include:
    - Camera Lenses
    - Solar panels, solar cells
    - Thermal radiators, thermal painted surfaces
    - Viewports, visors, helmets
    - Flexible surfaces such as Doormats
    - Clothing/spacesuits
    - Doors, seals hatches
    - Gasket EDS







2 Phase Glass EDS
Vacuum 1E-6
10 μm – 50 μm JSC-1A
Video sped up 15x

Polarization Steps needed
In high vacuum

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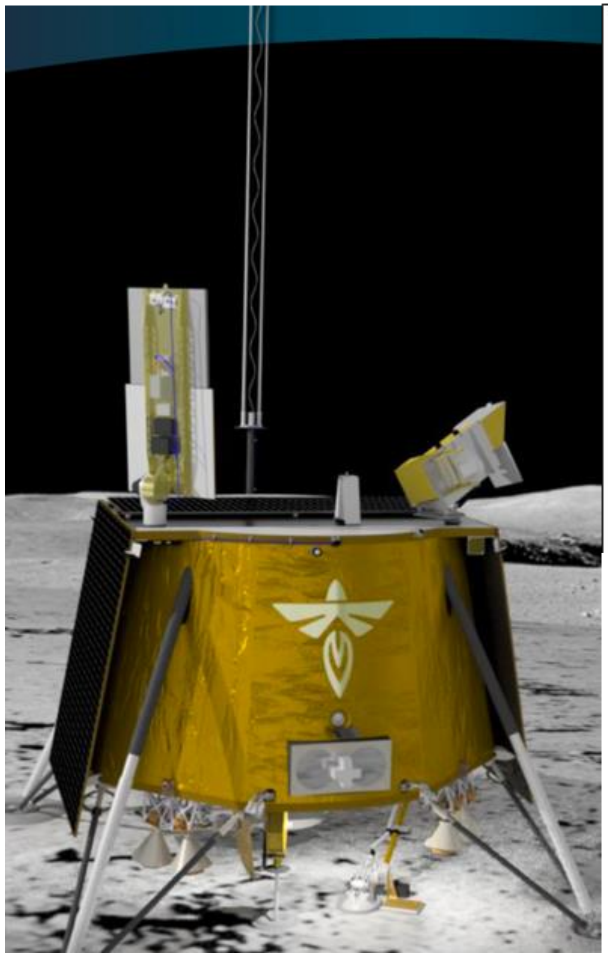
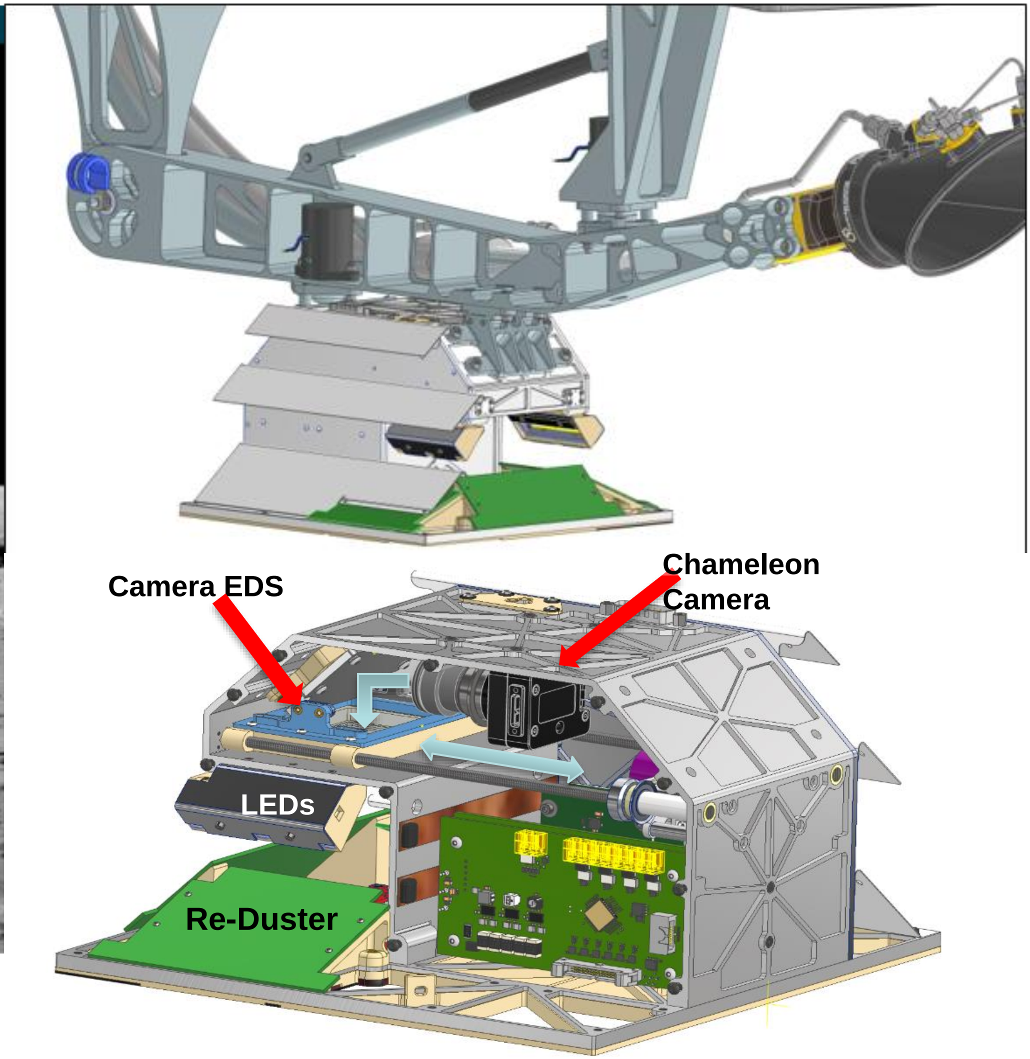
EDS to the Moon

- NASA's Commercial Lunar Payload System of CLPS will fly an EDS Payload as a technology demonstration to show the removal of dust from a glass panel as well as thermal radiator surface (Thermal Bright® by NeXolve™).
- The EDS Payload will fly on Firefly Aerospace's *Blue Ghost* Lander on July 27, 2023 to Mare Crisium.
- The EDS hardware being developed for this payload is based on EDS payloads flown on the International Space Station (MISSE 11 and 15).
- The EDS payload consisting of the camera and EDS panels for the lens, the thermal radiator, and the glass EDS will be deposited on the ground by a deployable structure on the lander shortly after landing.
- Mission operations will start shortly after deployment and will take precedence over those of the other payloads.
- The camera will record dust deposition and removal on the Thermal Radiator EDS and the Glass EDS.
- Data handling will be done with a Data Storage Unit (DSU) which is being developed by NASA Langley Research Center. The DSU has flight heritage at JPL.





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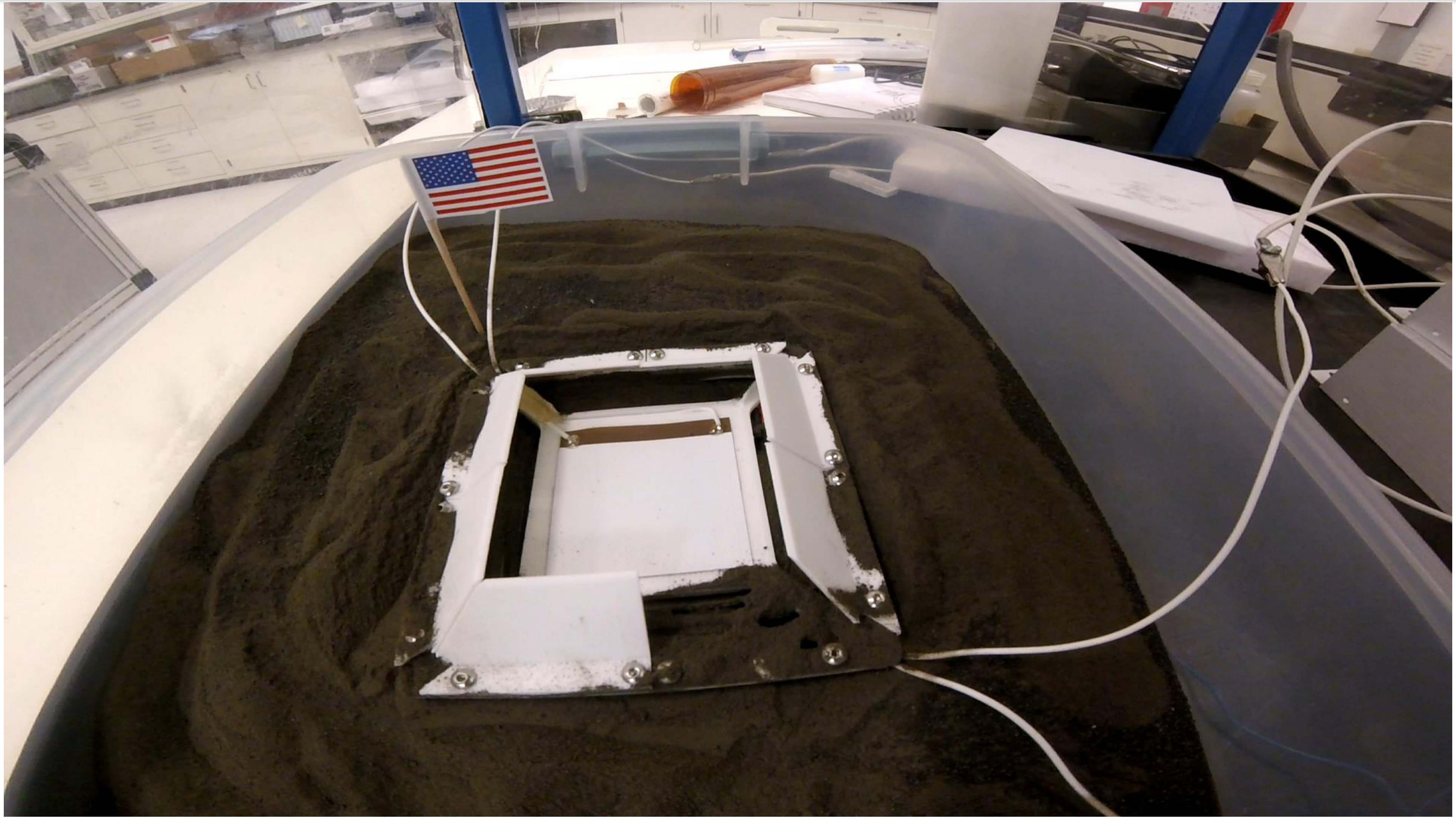
The Re-Duster!



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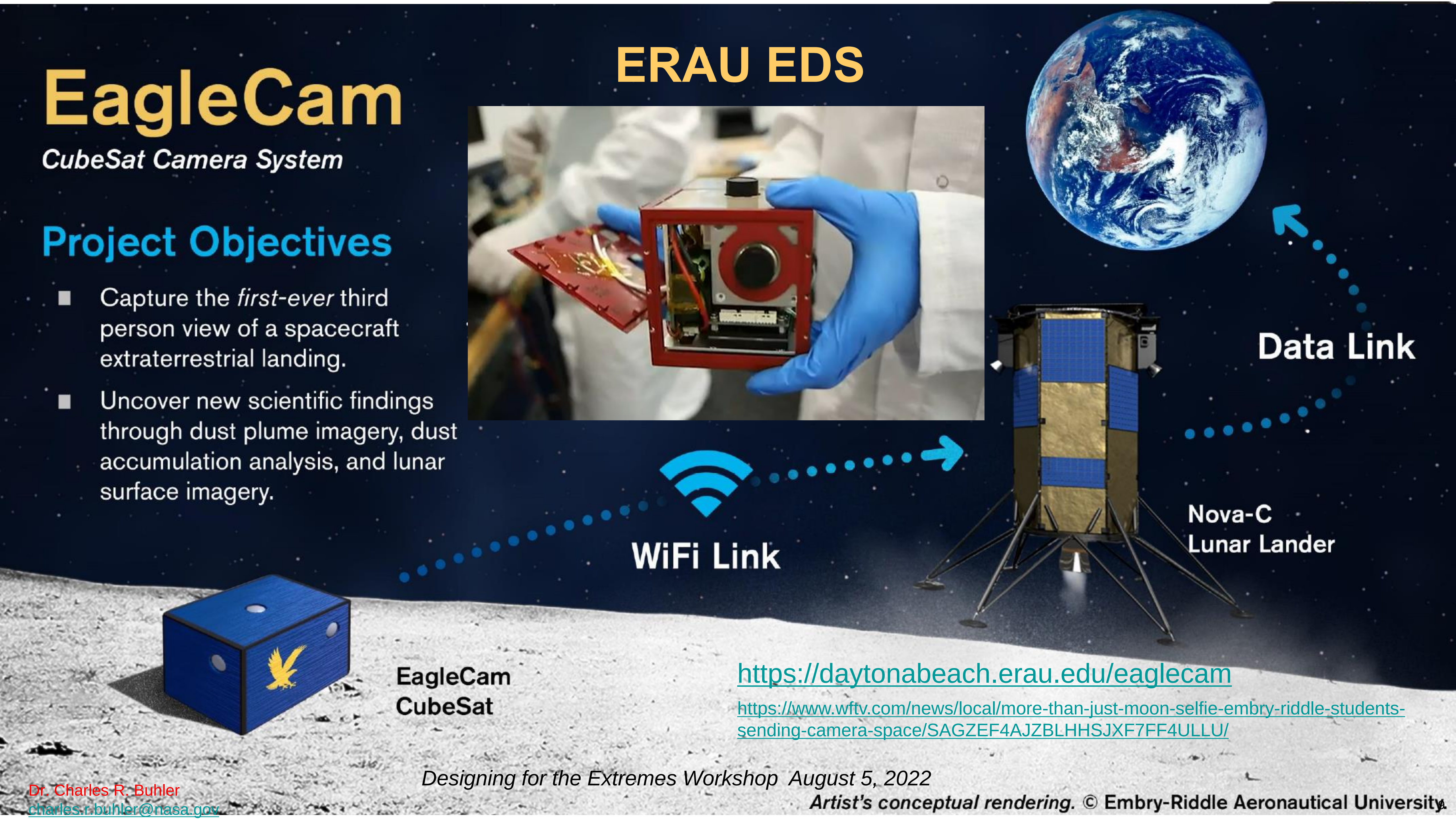
ERAU EDS



https://daytonabeach.erau.edu/eaglecam

https://www.wftv.com/news/local/more-than-just-moon-selfie-embry-riddle-students-sending-camera-space/SAGZEF4AJZBLHHSJXF7FF4ULLU/

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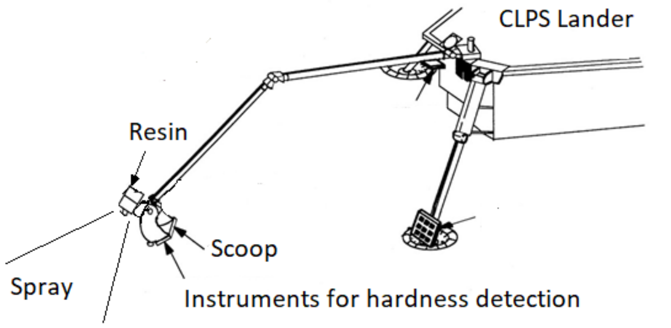
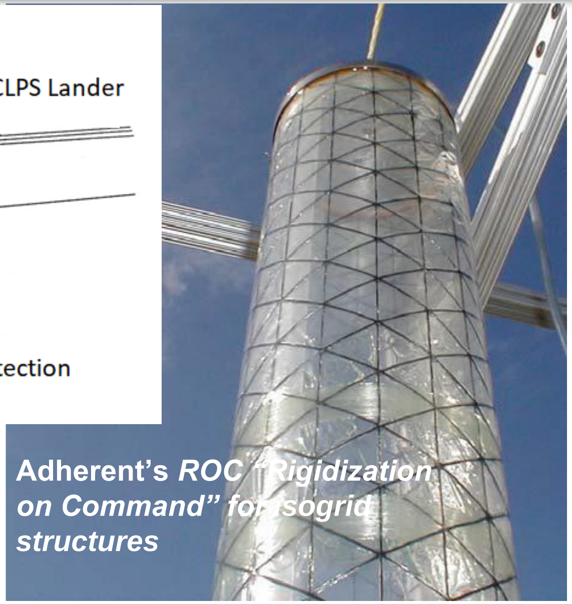
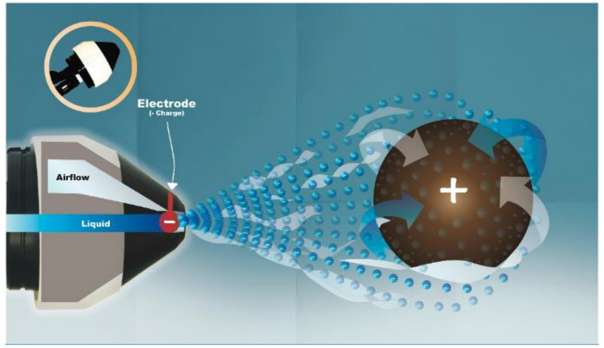
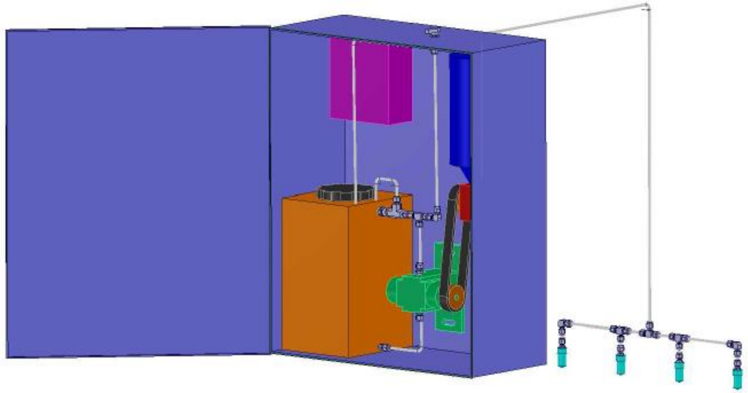
Surface Stabilization Technologies

- One exciting technology we are developing is a method to apply a Surface Stabilization resin developed under a Phase II SBIR by Adherent Technologies using Electrospray Technology
- KSC has licensed the development for a small-scale Electrospray used for applying disinfectants for the food process industry.
- Electrospraying a single-part acrylic-epoxy resin that cures in the presence of UV irradiation could help reduce/eliminate dust at a particular landing site.
- The resin is used by the military for helicopter landing pads in deserts as well as a liner for toxic waste dumps to prevent leakage into the ground water systems.
- Electrospray allows for precise control of the resin and only about 2 cubic feet of it is needed to cover 1000 square meters for a landing/launch platform on the lunar surface. It can withstand the loads of the lander as well as astronaut loads with only 2 mils thickness.
- Could eliminate dust lofting during Plume-Surface-Interactions (PSI).




Adherent's ROC "Rigidization on Command" for Isogrid structures





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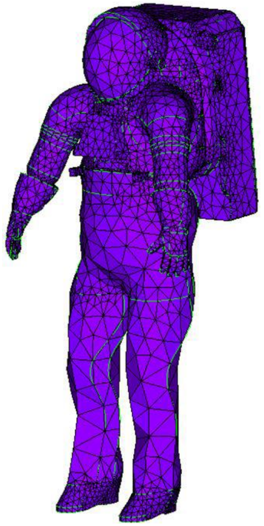
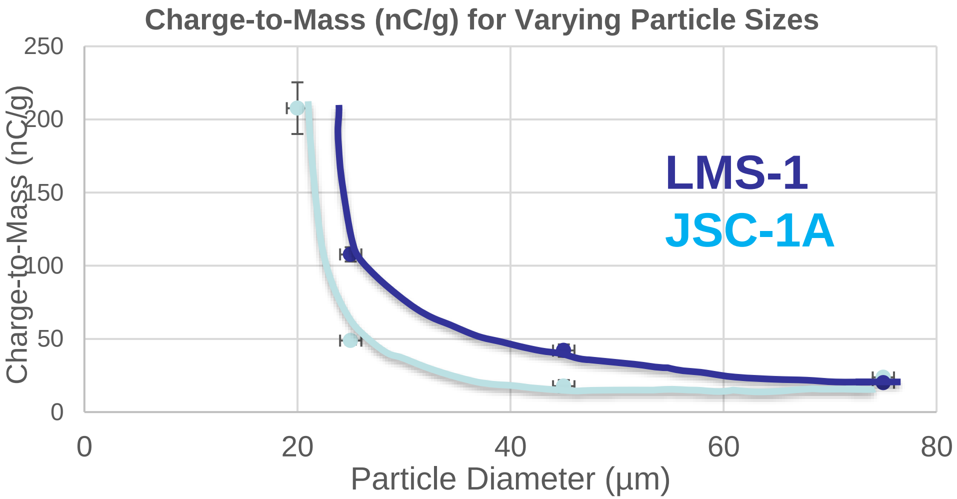
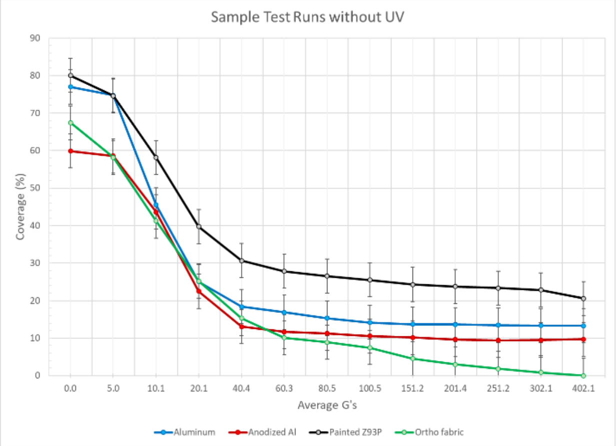
Several Other Research Topics

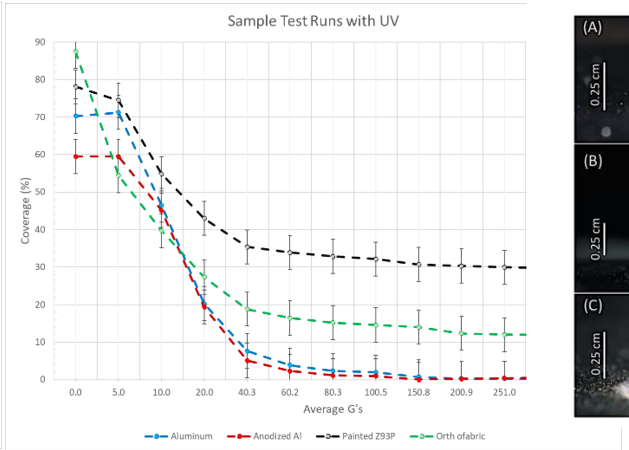
- Applying Dust to Test Articles in accordance to the new NASA STD-1008 (Dust Standards) (see graph).
- Working on the Extreme Environments Handbook led by Erin Haywood (MSFC).
- Recent paper on dust adhesion (Barker et al. 2022). Showing effects of UV.
- Microgravity experiments for charged particle physics.
- Regolith Conveyor technologies based on EDS technology.
- Development of Astronaut Tools for dust removal and electric field mitigation (UV, e-beam, ion beams)
- Quantifying charge levels during astronaut xEVA ops.
- Spacecraft charging analysis and measurement (members of E3 community).
- Modelling and simulations for dust interactions with Gateway.
- Working directly with HLS providers through Appendix N and soon P.

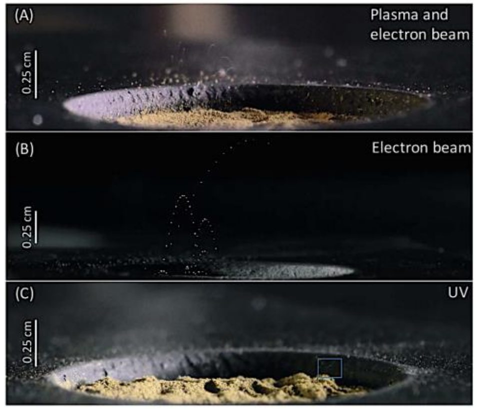


xEMU

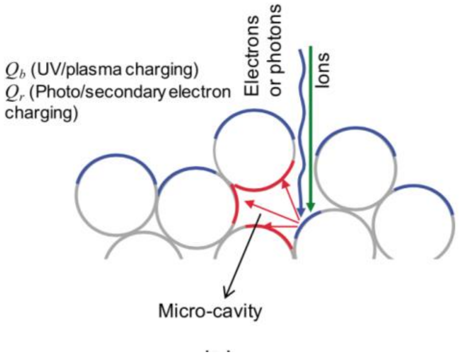








Wang, et al. 2016



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Thank you!

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Exploration Research and Technology Programs

Backup

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Adhesion Forces

Force	Equation	Magnitude (N) (for a 10 μm particle)	Mitigation Strategy
Gravity	$F = \frac{4}{3}\pi\rho a^3 g$	10^{-10}	Steep angle of incidence Vibrations
Van der Waals	$F = aA/6z^2$	$10^{-5} – 10^{-6}$	Keep surfaces rough Disallow contact
Capillary	$F = 2\pi\gamma d$	$10^{-5} – 10^{-6}$	Keep RH < 65% Nonexistent outside habitat
Chemical	$F = \frac{\partial W}{\partial x} = -\frac{\partial}{\partial x}(f n\Delta H)$	$>10^{-5}$	Possibly significant within habitat Unknown outside habitat
Mechanical	$F \sim d$		Vibrations Disallow particle interlocking
Electrostatic Image (point charge)	$F = q^2/16\pi\varepsilon_0(a+z)^2$	10^{-7}	Make surface more conductive to remove *q* Inside habitat increase RH Match dielectric constant of surface and particle Disallow contact
Electrostatic Image (solid sphere)	$F = \frac{q^2}{\left[16\pi\varepsilon_0 az\left(\psi + \frac{1}{2}\ln 2a/z\right)^2\right]}$	$10^{-5} – 10^{-6}$	Make surface more conductive to remove *q* Inside habitat increase RH Match dielectric constant of surface and particle Disallow contact
Electrostatic Charge Exchange	$F = \pi\varepsilon_0 a\varphi^2/z$	10^{-7}	Minimize work function difference between particle and substrate Disallow contact
Electrostatic Layers	$F = qE_{bk}$	10^{-7}	Minimize dust layer thickness Minimize surface charging Disallow contact

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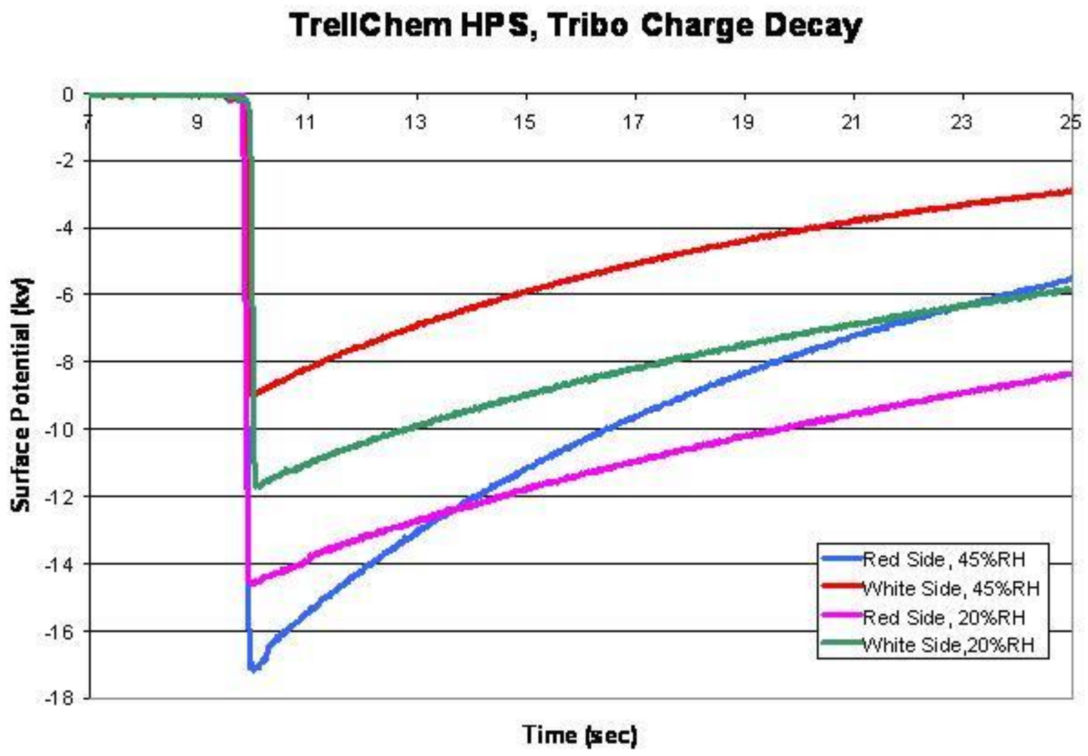
Spacecraft Charging Materials Database

Exploration Research and Technology Programs

The aim of this work is to add the triboeletric data taken at KSC since the 1980's and include it within the SCMD.

We would also like to include this data into the MAPTIS database.

Parameter	Value
[1] Pass/Fail at 30% RH	
[2] Testing Temperature at 30% RH [° F]	
[3] V_{peak} at 30% RH [V]	
[4] $V_{t=5}$ at 30% RH [V]	
[5] Pass/Fail at 45% RH	
[6] Testing Temperature at 45% RH [° F]	
[7] V_{peak} at 45% RH [V]	
[8] $V_{t=5}$ at 45% RH [V]	



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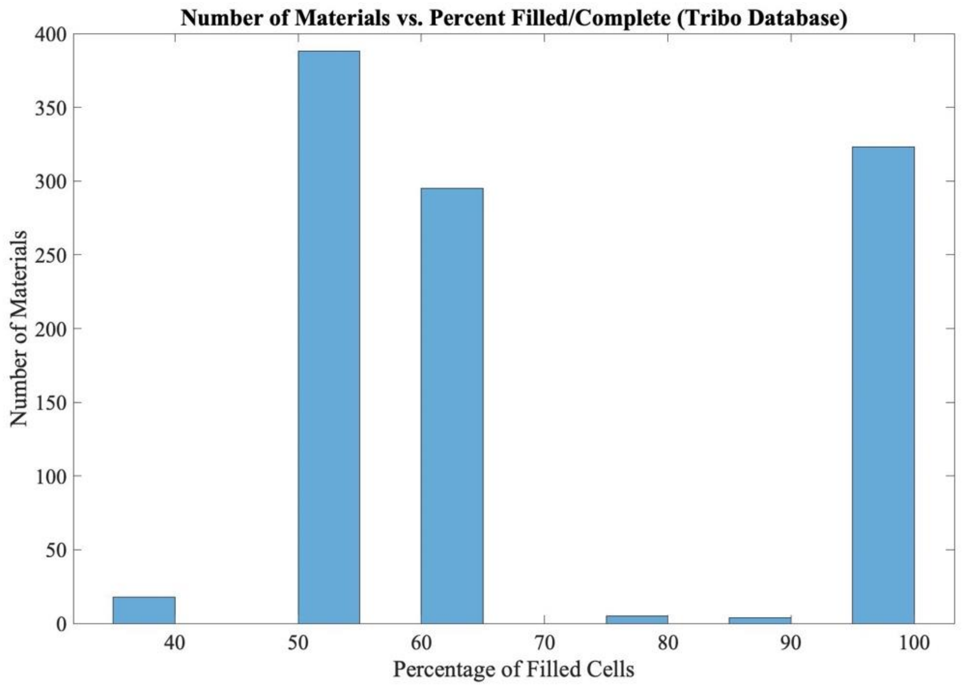
Spacecraft Charging Material Database Expansion

- 982 unique test reports available
- Triboelectric Charging data in both 30% and 45% RH environments available for around **1100** different materials
- Materials mentioned in KTI-5212, data has not been made available until now
- An initial database made in Microsoft Database included 70 columns of information for **1873** different materials (physical descriptions, manufacturers, flammability, etc).
- Narrowed the criteria to 8 columns for SCMD (shown above)



Data is not complete from the previous database and requires additional testing.

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Electrostatics and Surface Physics Lab

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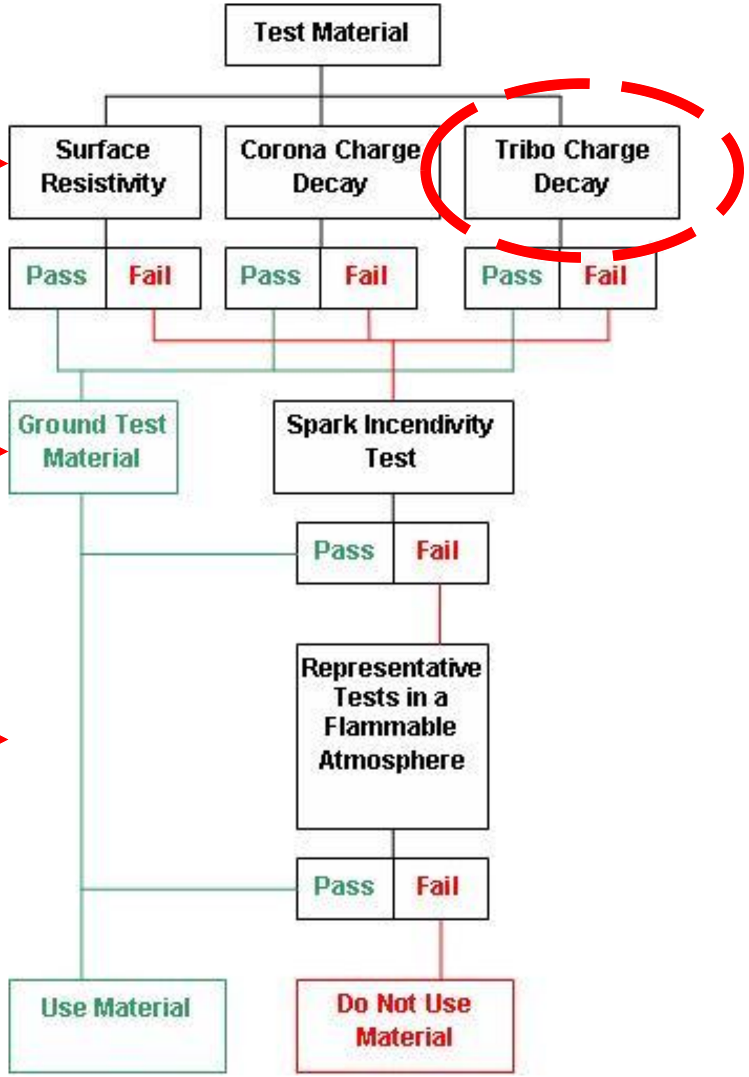
Classification: Can the material dissipate charge?

Possible: Can the material hold enough charge to cause an incendive sparks under extreme charging?

Likelihood: Can the process generate enough charge on the material?



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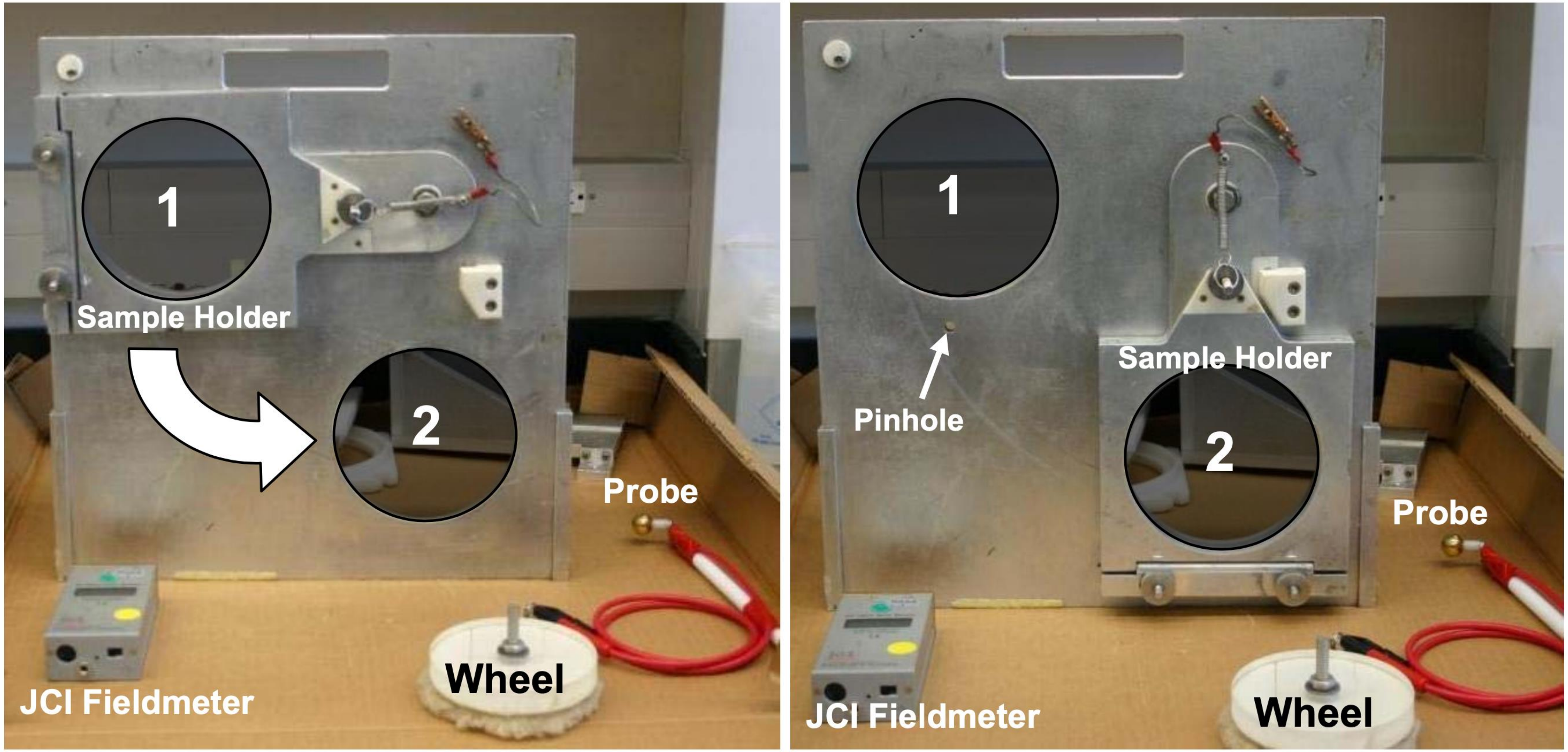
Testing device for Triboelectric Charging at 0% RH and high vacuum conditions



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Spacecraft Charging Materials Database

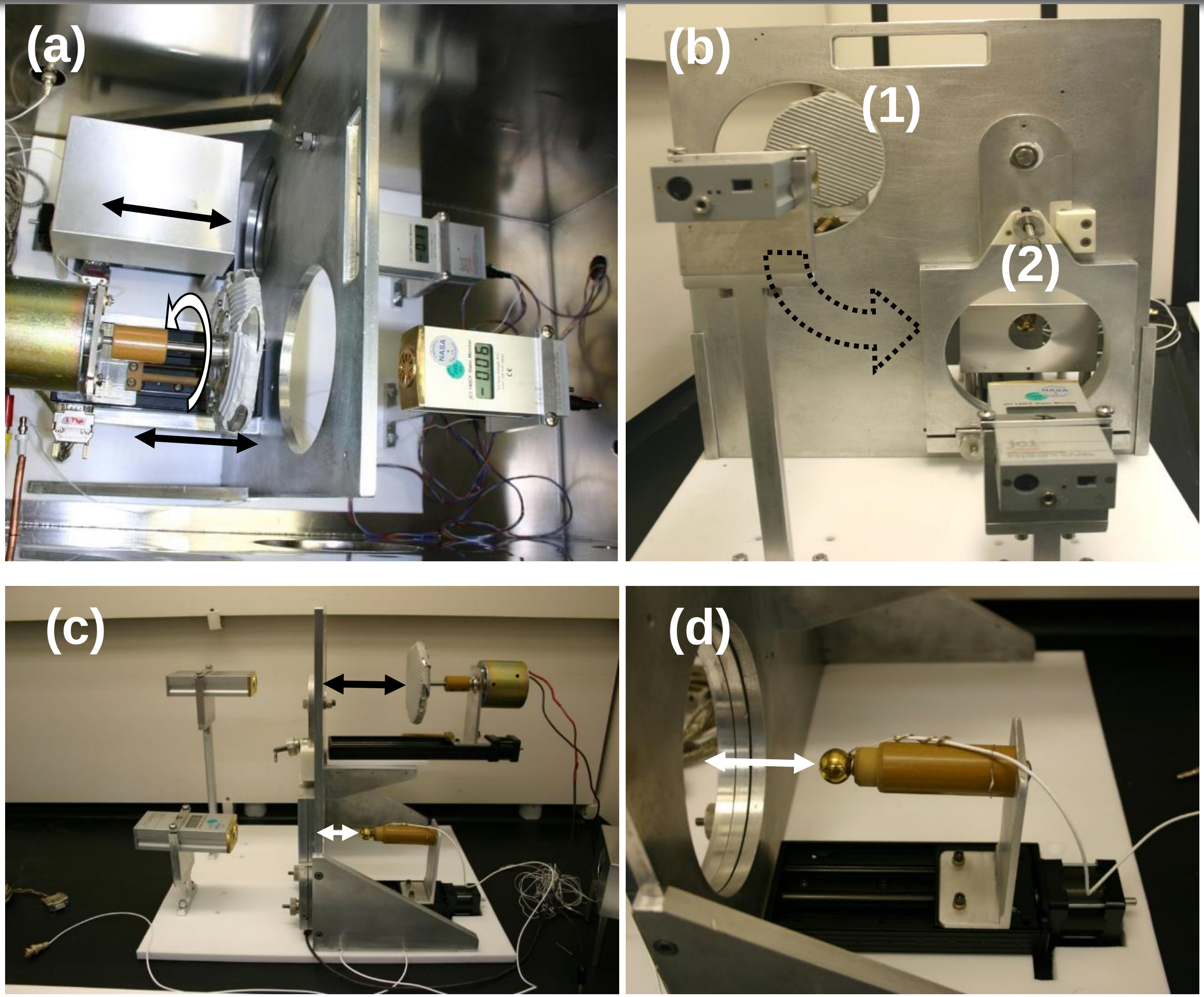

Figure 1. (a) The top view of the Tribot within the vacuum chamber. (b) The front view. (c) The side view. (d) The discharge electrode that extracts charge from the surface (brush discharges).

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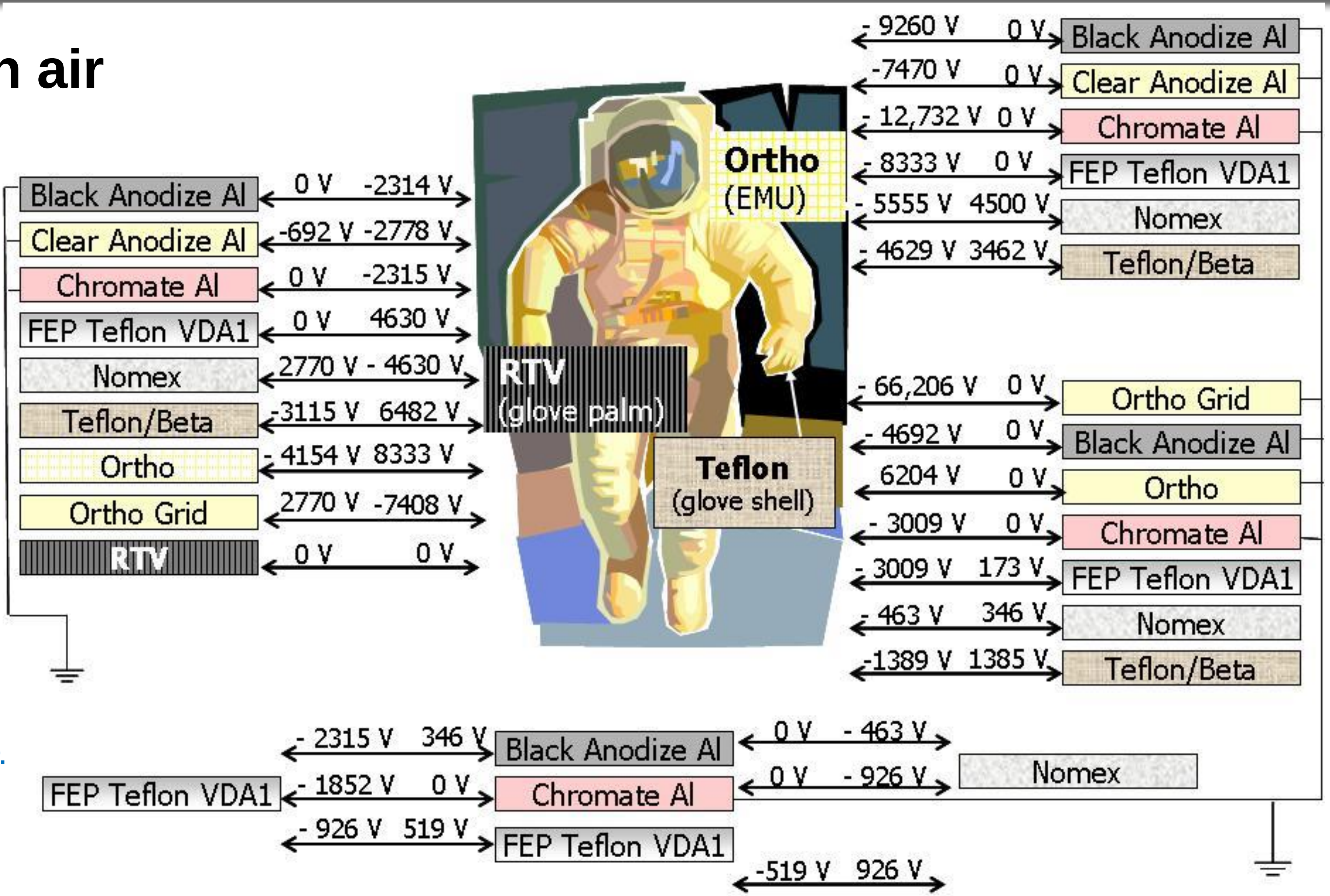
Spacecraft Charging Materials Database

0% RH in air



Note: There were several brush discharges in dry air.

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