



# Mitigating Electrostatics on the Moon!

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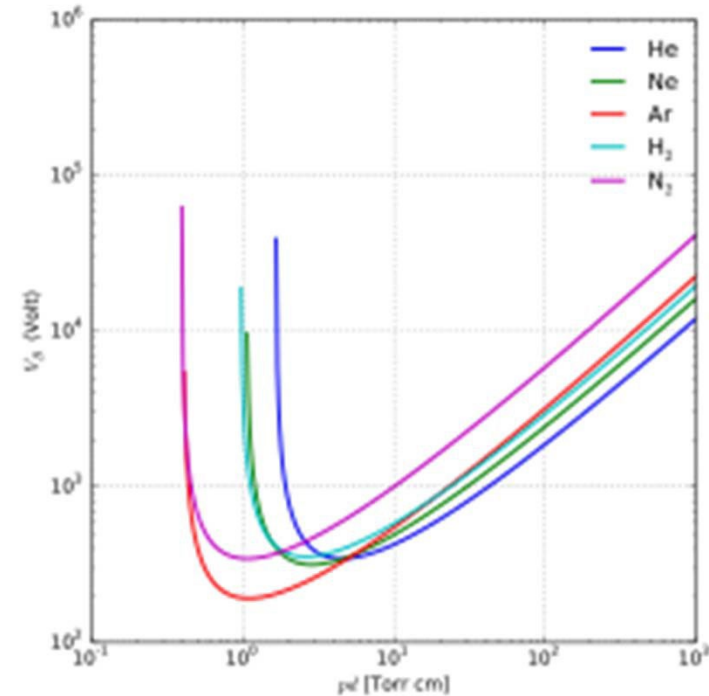


# What do we know about the Natural electrostatics environment on the moon?



- The particles are good dielectrics (permittivities between 2-3) and resistivities ( $\rho$  above  $10^{13} \Omega\text{m}$ ) and are most likely charged (positive and/or negative) or net zero total charge (bipolar). *No such thing as **uncharged** particles.*
- The surface of the moon is also a dielectric (no electrical ground)
- Very, very dry – no moisture to allow for charge decay ( $\tau = RC = \rho\epsilon\epsilon_0$ ).
- The allowed electric field is much higher than the Earth and Mars. Charge levels on particles can reach the maximum electric field of the environment.

**E\_Moon**      >>    **E\_Earth**      >>    **E\_Mars**  
 $10^8 \text{ V/m}$     >>     $10^6 \text{ V/m}$       >>     $10^4 \text{ V/m}$   
 Field Emission >> Air Breakdown >> CO2 at Paschen minimum



- *Natural Environmental Charging could result in surface potentials as high as **-4 kV** in shadowed and ambipolar regions (H. Hodes, 2021).*
- Artemis Missions are planned for the South Pole!



# Surface Plasma estimations



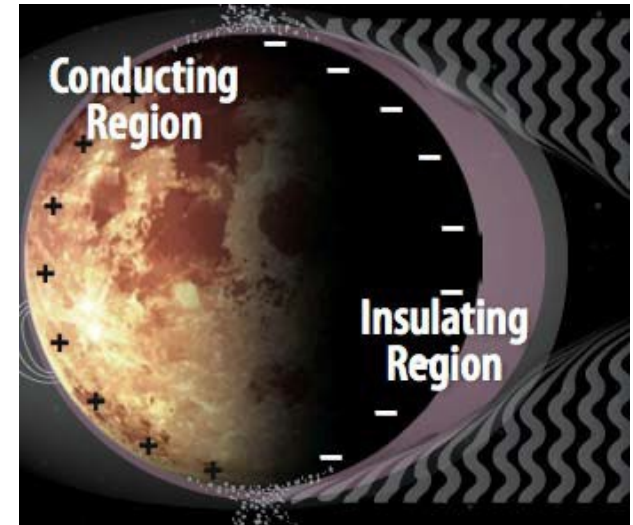
Table 1  
Electron, ion and secondary electron currents for various lunar regions at the Moon

Current	Day	Term	Night	Crater
$J_{e-env}$ (A/m <sup>2</sup> )	$1 \times 10^{-6}$	$3.52 \times 10^{-8}$	$4 \times 10^{-10}$	$5.1 \times 10^{-10}$
$J_{i-env}$ (A/m <sup>2</sup> )	$3.2 \times 10^{-7}$	$3.52 \times 10^{-8}$	$4 \times 10^{-10}$	$1.6 \times 10^{-11}$
$J_{s-env}$ (A/m <sup>2</sup> )	0	0	$4 \times 10^{-11}$	$5.1 \times 10^{-10}$
$J_{p-env}$ (A/m <sup>2</sup> )	$4 \times 10^{-6}$	0	0	0

~5  $\mu$ A/m<sup>2</sup>

~0.8 nA/m<sup>2</sup>

Jackson et al., 2015



## Best Practices for ESD Avoidance:

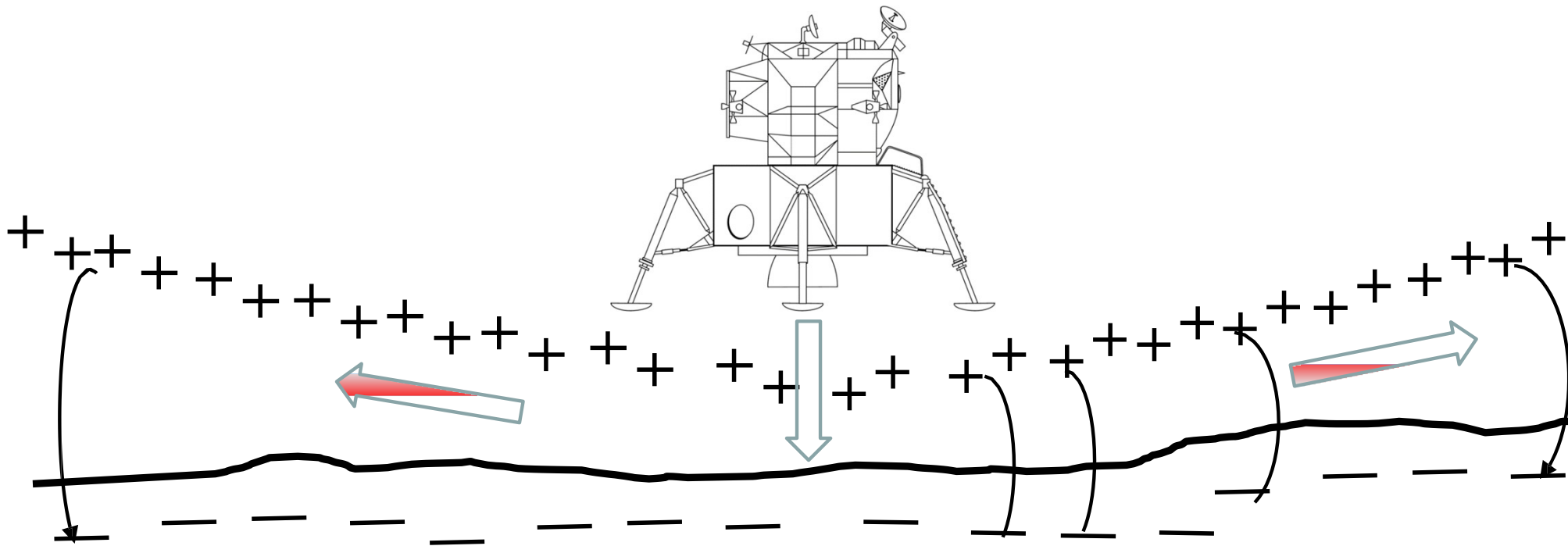
- 1) Have part of human system in sunlight
- 2) Have human system in high plasma density flow
- 3) Stay away from shadowed regions (like the South Pole!)

Jackson T L, Farrell W M and Zimmerman M I 2015 Rover wheel charging on the lunar surface Adv. Space Res. 55 1710-20

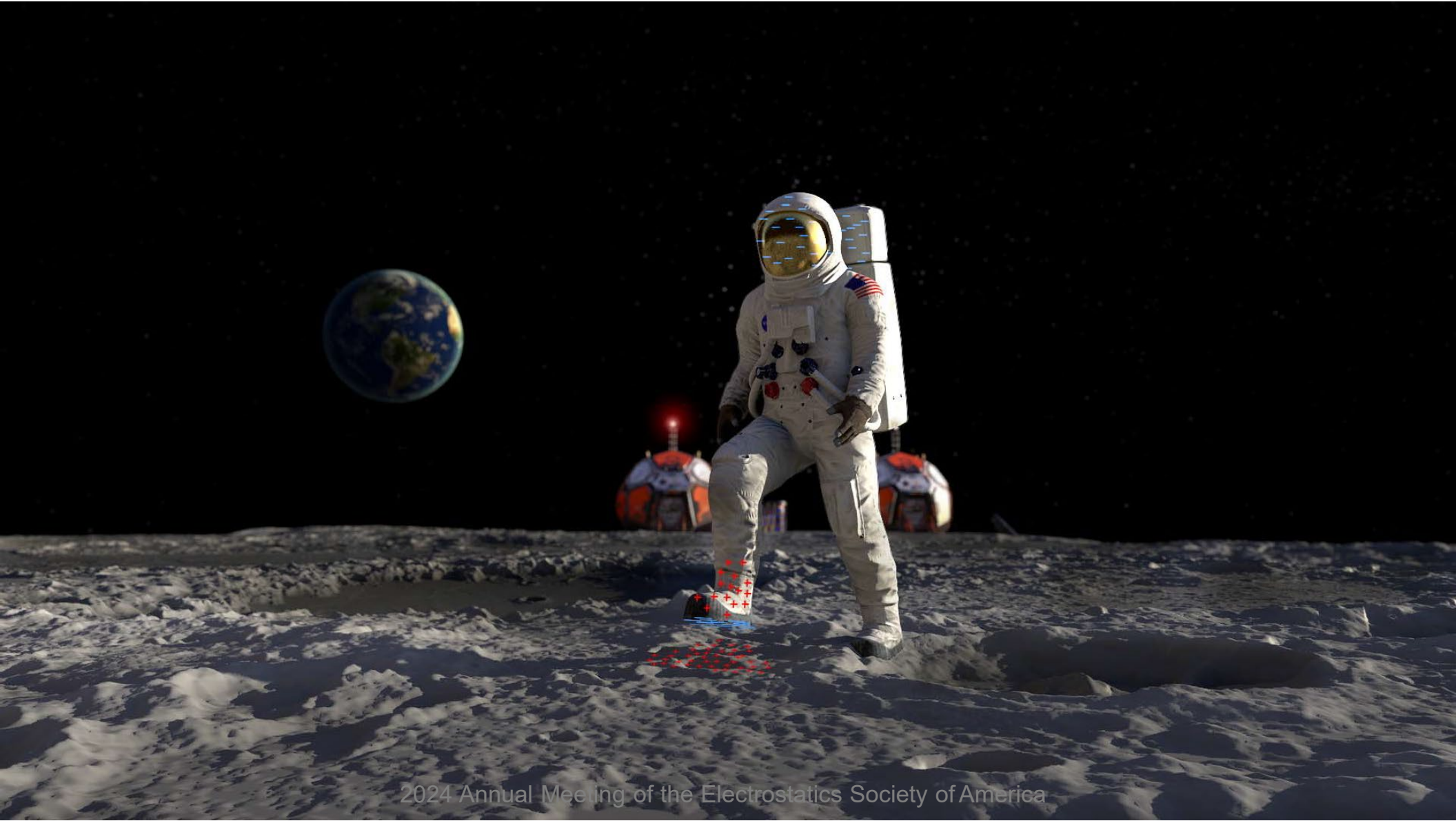
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# What about the Induced Environment?



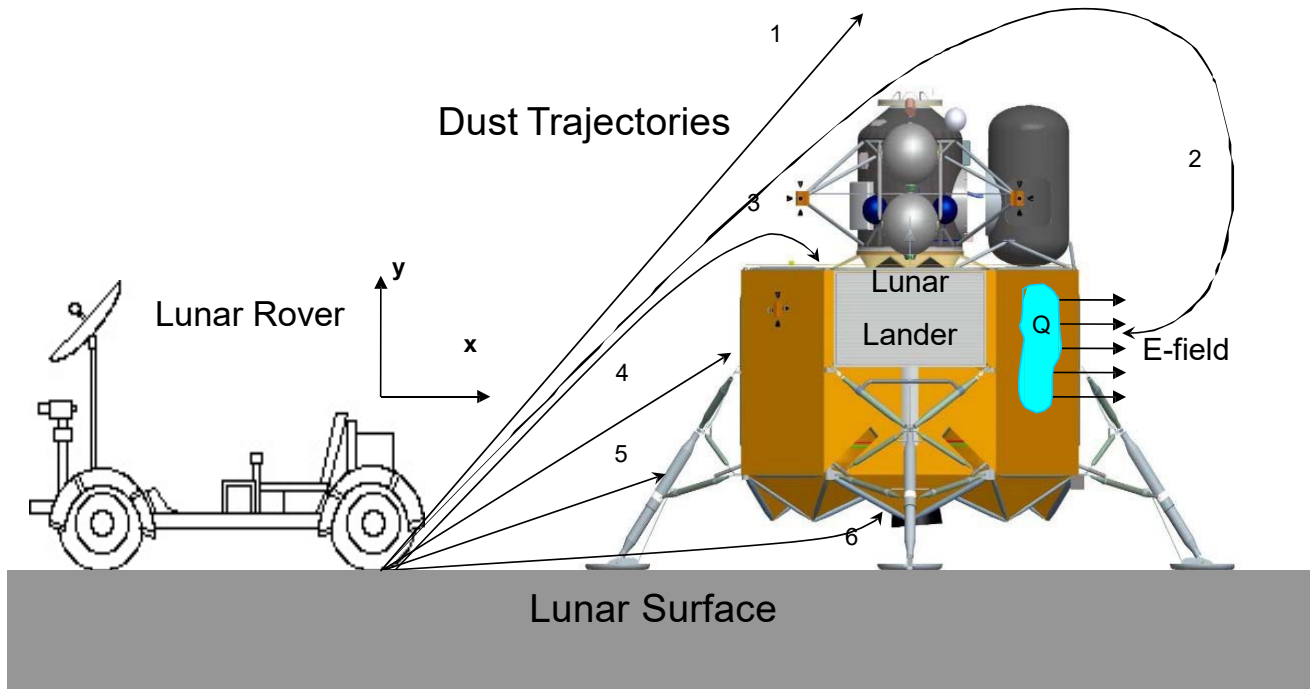




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# Other Induced Electrostatics



What if an astronaut touches this?

Capacitance  $\sim 100 \cdot D$  in pF  
(where D is in meters)

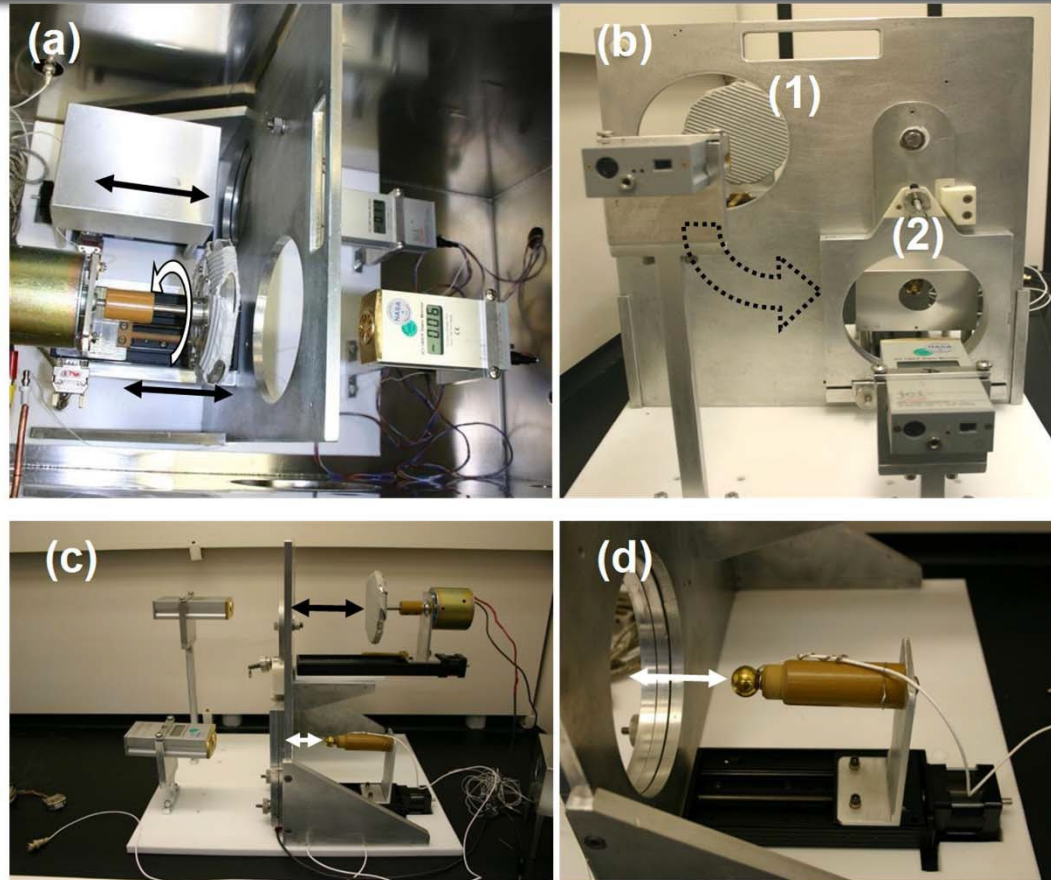
Starship is about 120 meters tall thus  $C \sim 20$  nF

We have the capacitance but what about the voltages?





# Suit Tribocharging Tests for Hubble Servicing Mission



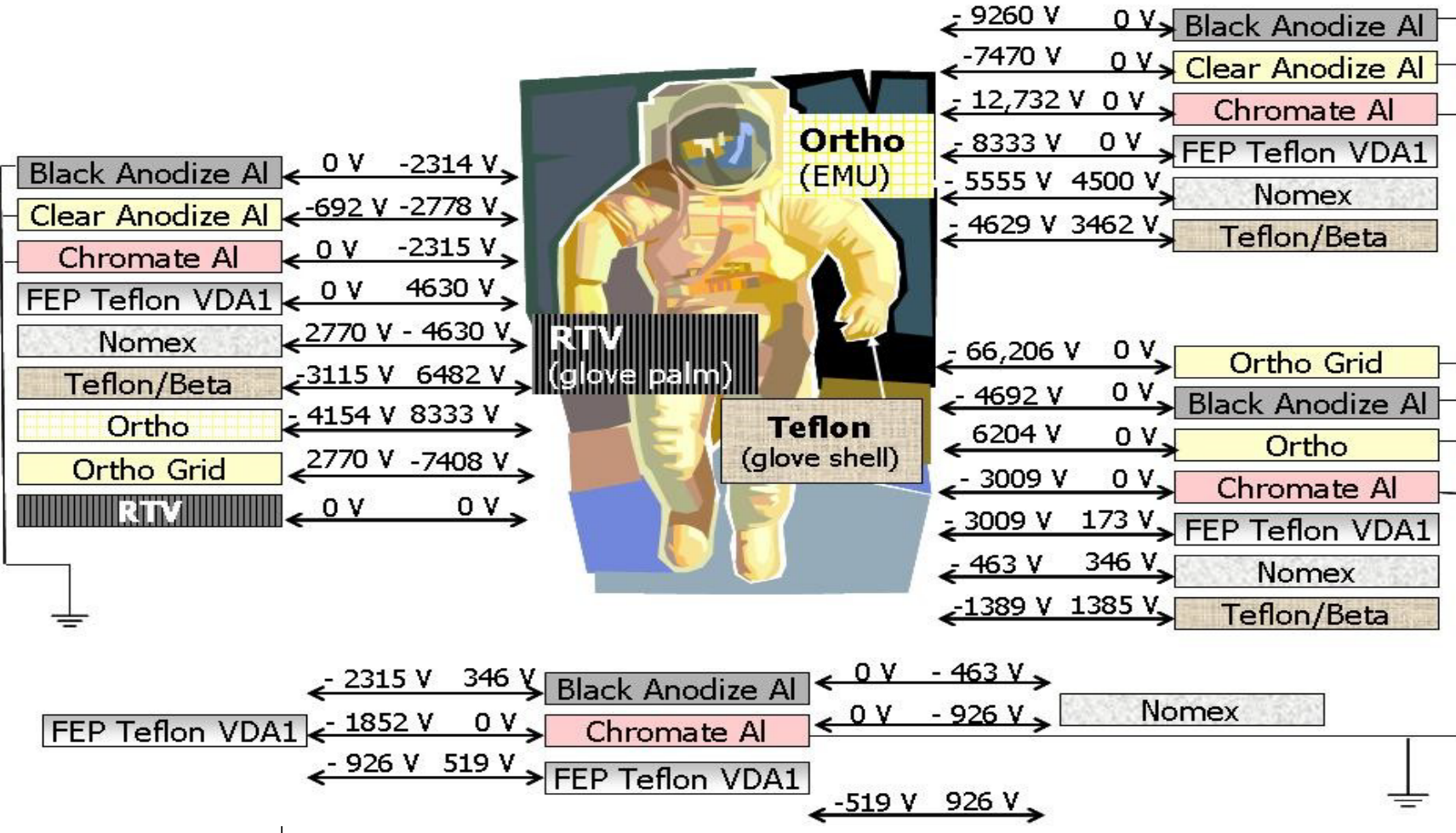
Buhler C R, Clements J S and Calle C I 2012 Electrostatics studies for the 2008 Hubble Repair Mission Proc. 2012 Joint Electrostatics Conf. (Cambridge, ON)

(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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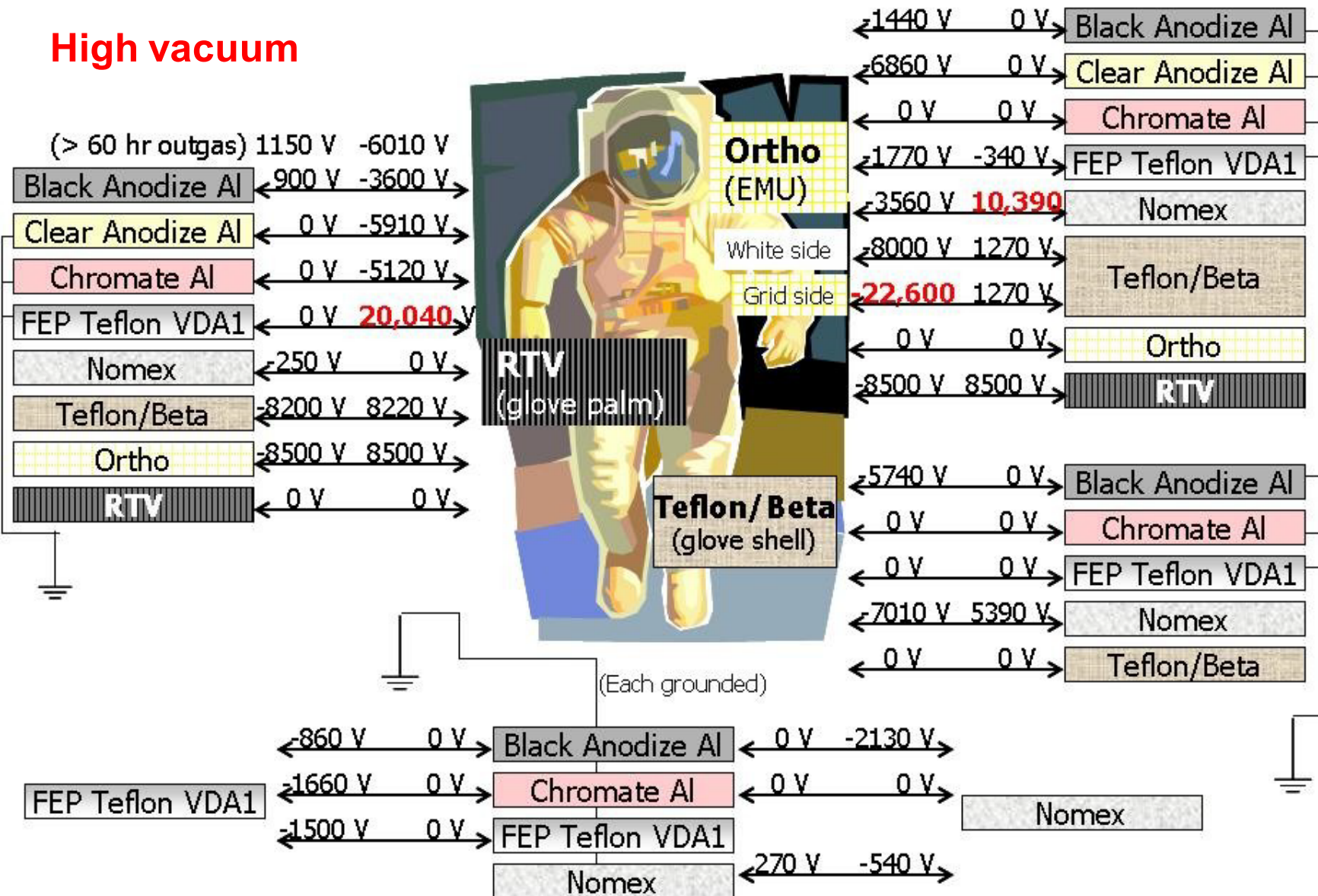


# 0% RH in air



There were brush discharges almost every time.

# High vacuum



There were NO brush discharges every time.

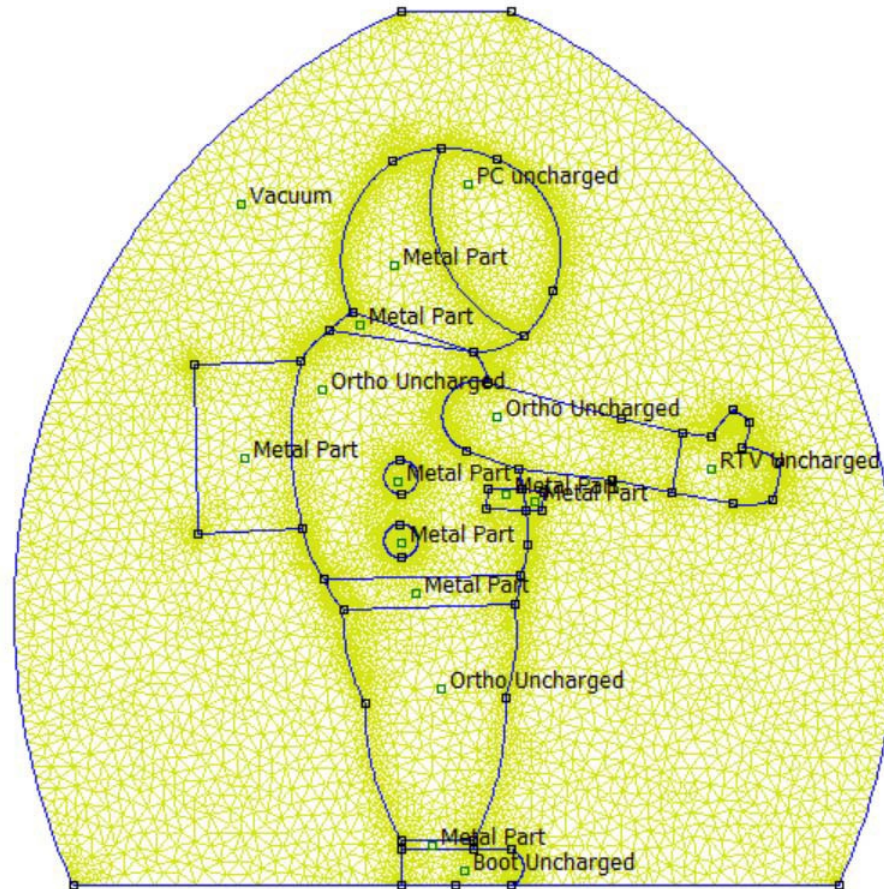


# FEMM Modelling



Modelling is useful for exploring potential hazards

- O2 leak locations
- Dust deposition

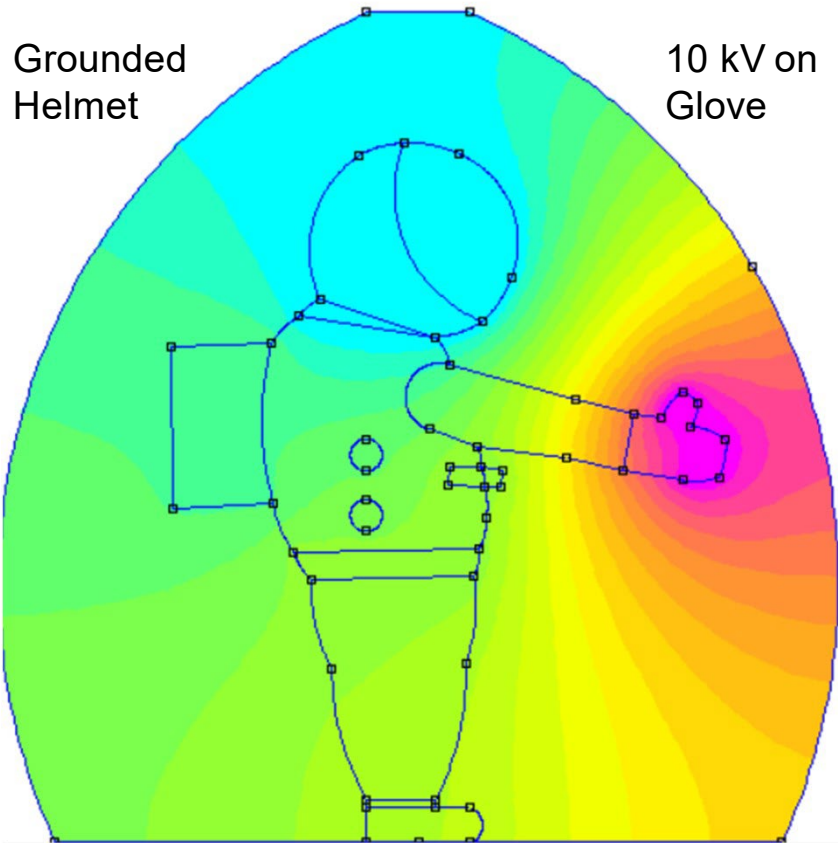


Many models can be used

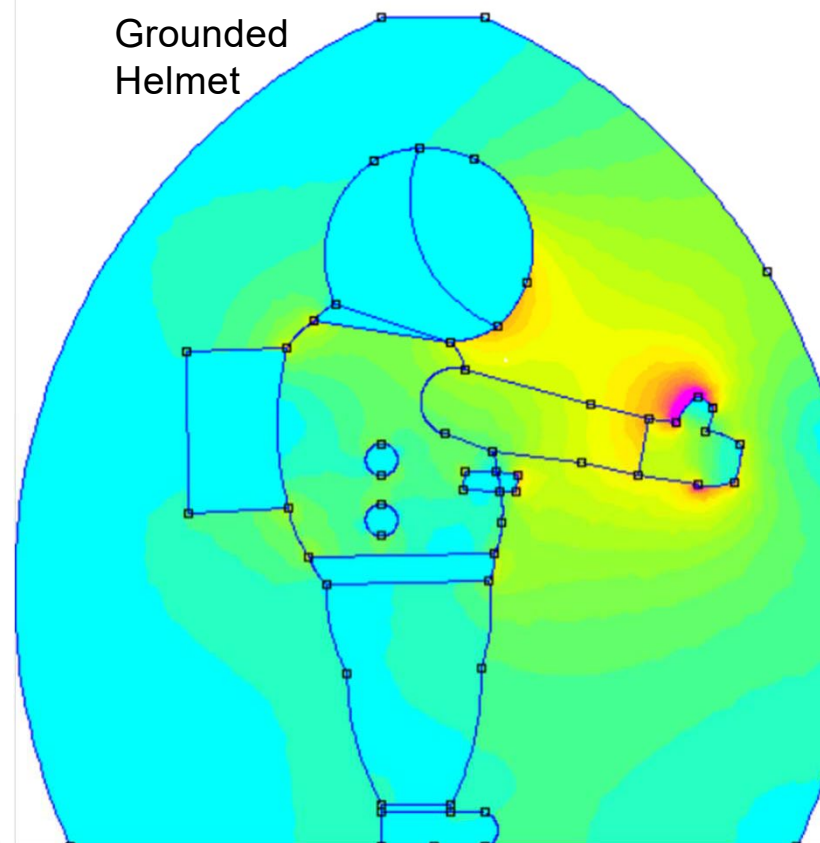
- FEMM
- COMSOL
- EMA-3D



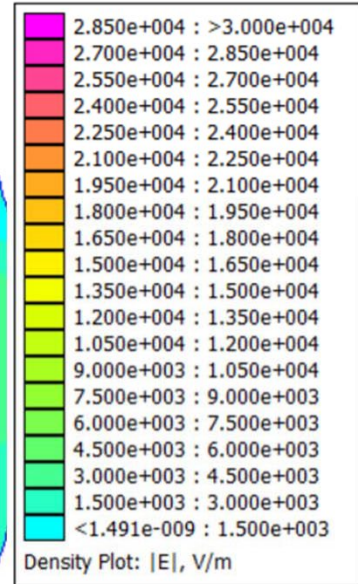
# FEMM Modelling potentials and fields



Electrostatic Potentials



Electric Fields





## Lunar Electrostatics and Dust Removal (LEDM) Tool



- **Test Charge neutralization and Dust Removal Efficiency**

- Performed simultaneous tests on dust removal and charge removal
- Aim is to get to below +/- 100 volts surface potential ANSI/ESD STM 3.1.
- GN2 blast of 1 second duration

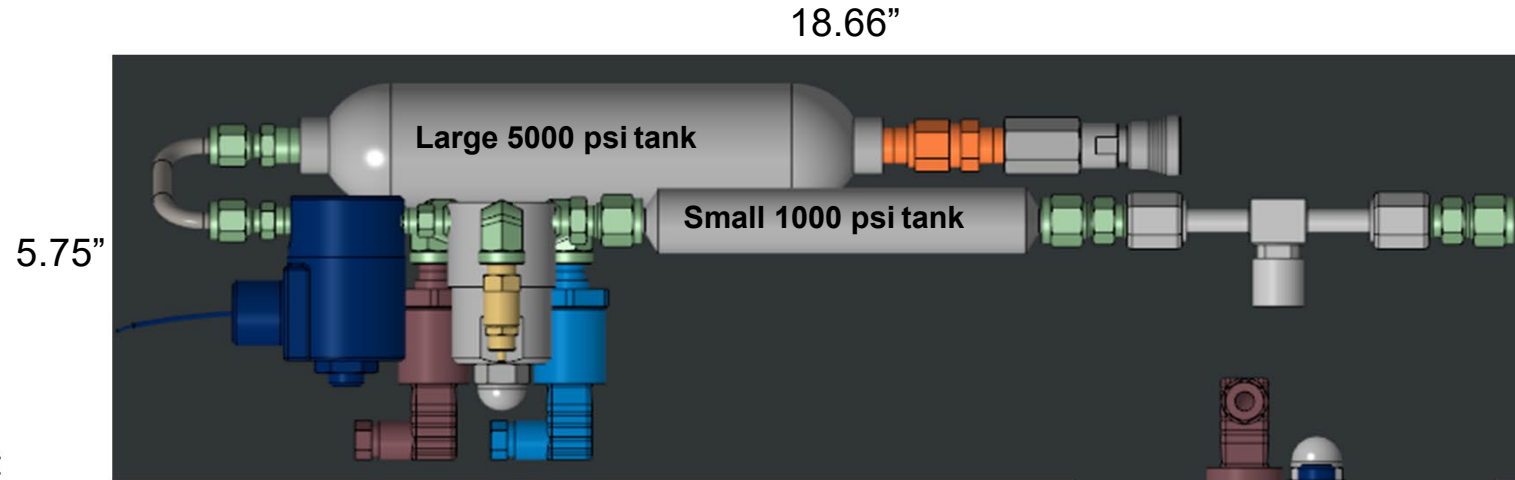


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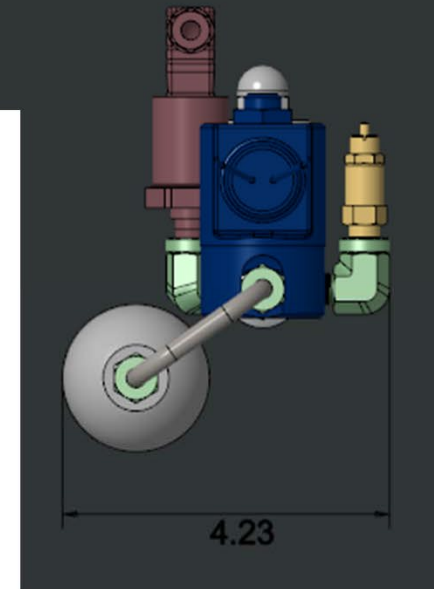


# DEMO 1 Gas Delivery System

- Engineering Team produced the 1<sup>st</sup> standalone prototype
- Uses a standalone gas delivery system instead of shop air and gas cylinders housed outside of the vacuum chamber
- Fully functional electronics package
- Pressure subsystem has been successfully tested over the past few months.



Small tank 30-40 psi



$P_0 := \begin{bmatrix} 129.7 \\ 1514.7 \\ 3014.7 \end{bmatrix} \text{ psia}$	Supply bottle pressure (115psig, 1500 psig, 3000 psig)
$pulses := \text{floor} \left( \frac{P_0 - P_1}{dP} \right) = \begin{bmatrix} 4 \\ 88 \\ 178 \end{bmatrix}$	Total number of pulses available

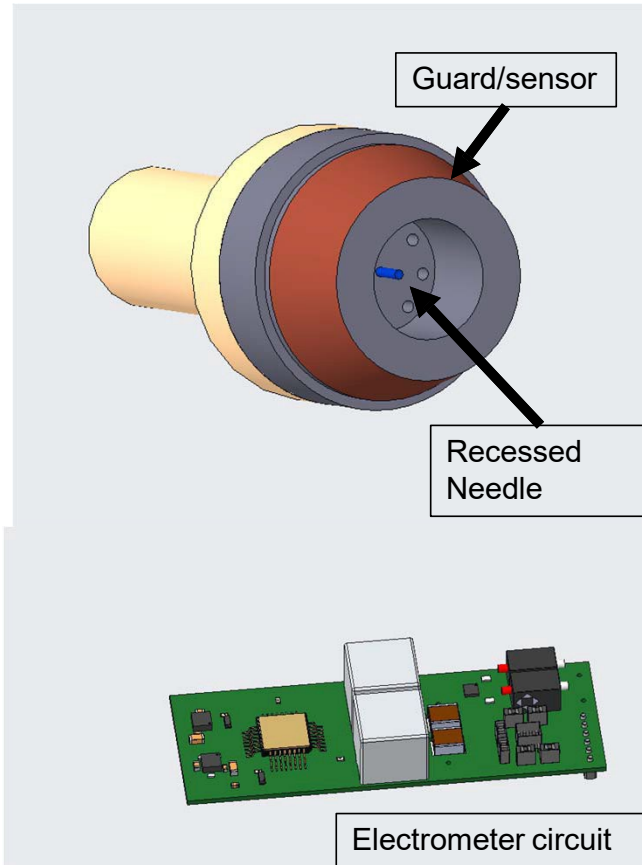
**178 total shots available at 3000 psi**



# Nozzle design that neutralizes charged surfaces in vacuum



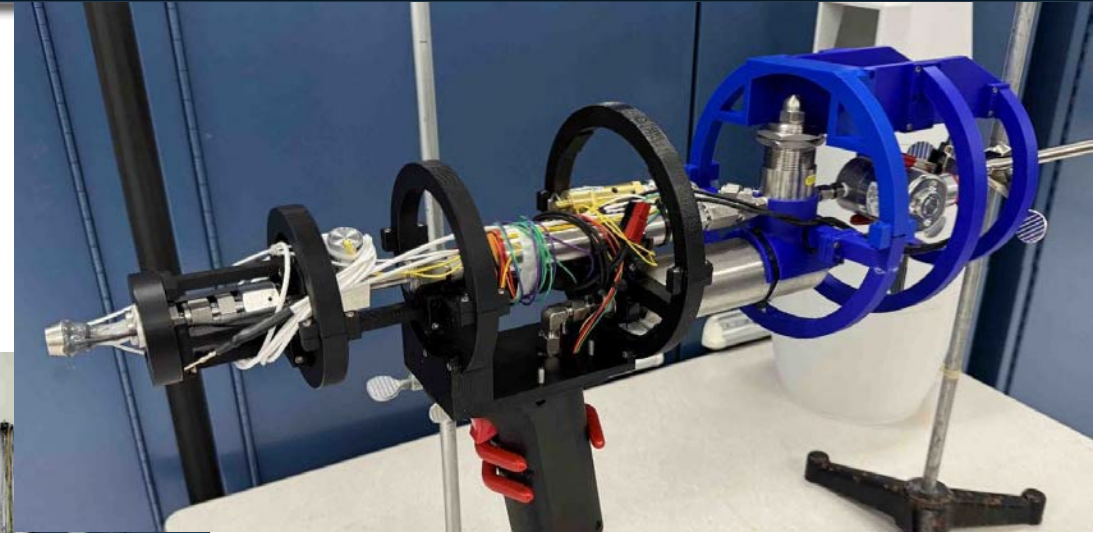
- Electrical team finished breadboarding.
- Able to supply current/voltage waveforms to tungsten needle when switched on (trigger depressed).
- During non-high voltage operations, the guard is used as an electrometer sensor using MECA technology to measure ambient electric fields.
- The value of the electric fields is used to dictate the waveform characteristics of the pulse optimized for both high and low, and positive and negative static field elimination in-situ to minimize unbalanced charging.
- Software package under development.



- Voltage ranges are  $\pm 3$  kVpp that has a variable offset and duty cycle dependent on the external field
- 10 mA max current used in blast



# DEMO I Prototype



- First successful prototype of a fully encased design.
- However, it was too large for a hand-held device.

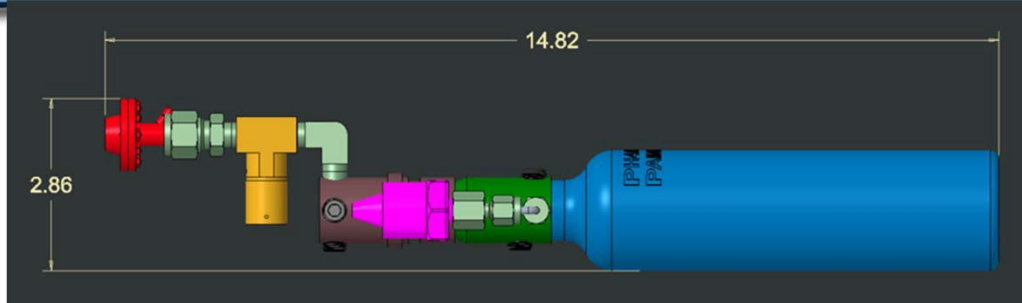
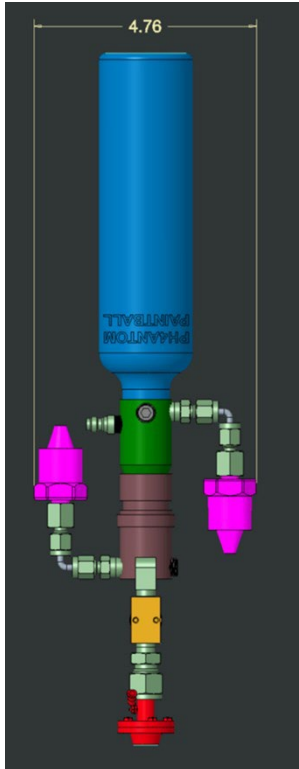


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# DEMO II



- Second design is much more promising.
- Several non-essential parts were removed.
- Waiting on the two-stage regulator and other small parts.
- Contains the first machined nozzle prototype.
- Should be ready for EMI testing at the end of the summer





# Any Questions?



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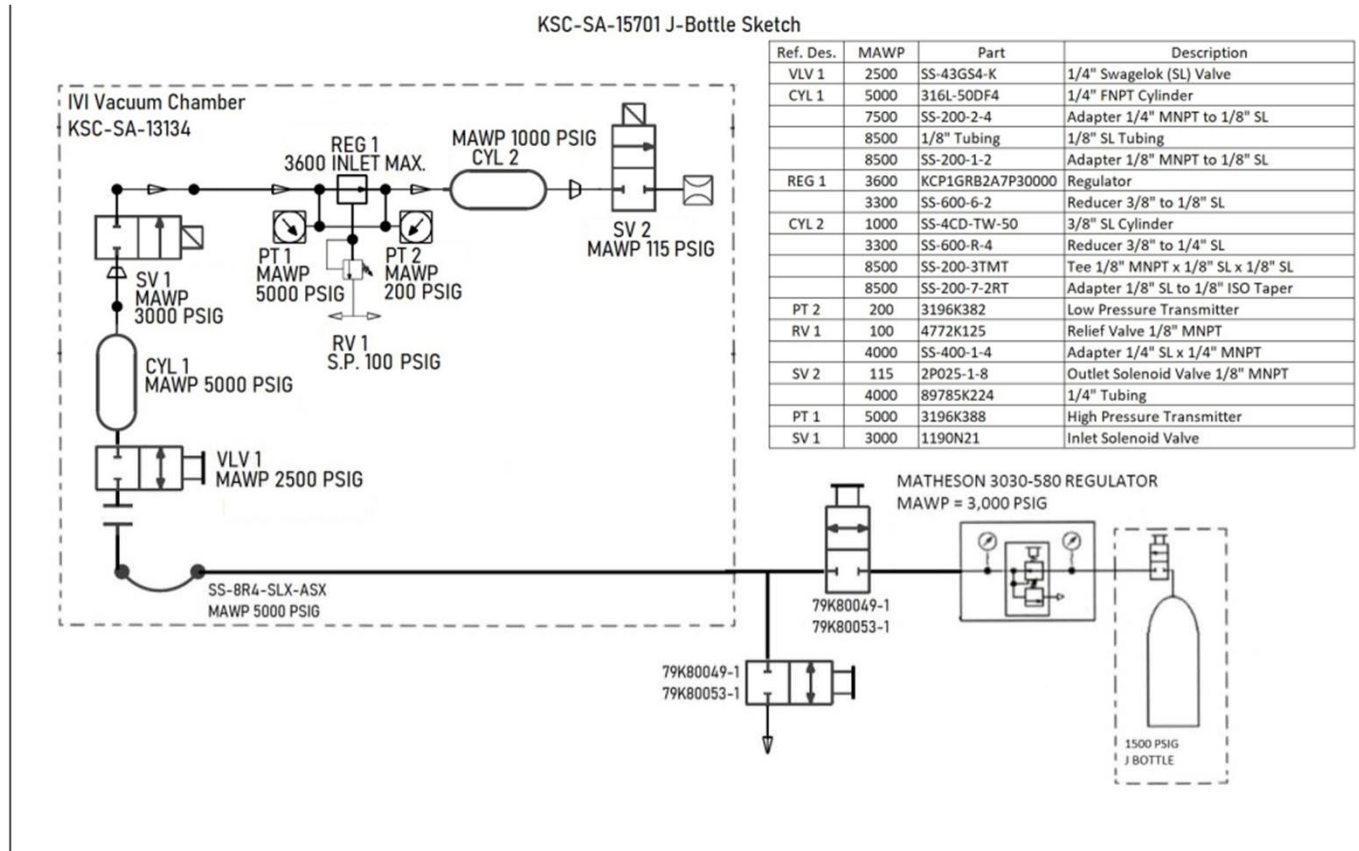
# Backup



# Current SOA Gas Delivery System



- We have determined the gas/pressure subsystem for the 1<sup>st</sup> prototype
- We are working the safety aspects and final procurements.
- Working on PVS (Pressure Vessel System) approval for standalone unit.

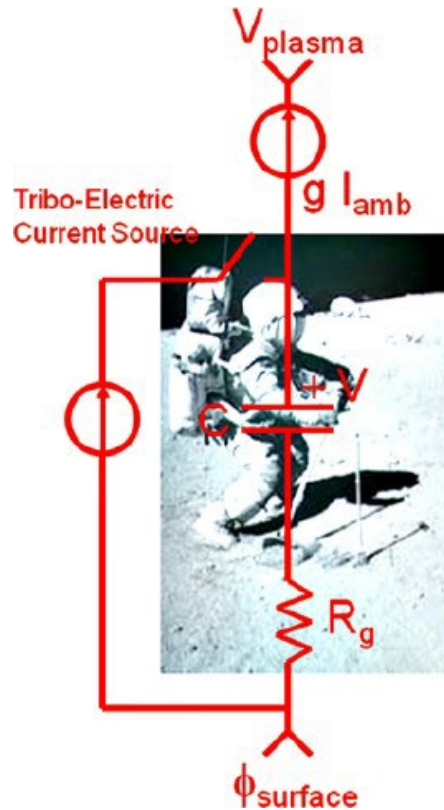




		Source of External Electric Field	Large (> 1 Joule) Discharge	Source of Polarization	Source of EMI / Brush Discharges	Susceptible to Dust Adhesion	Tribocharges against Lunar Regolith?	Incendivity Hazard in presence of O2 w/GND Probe
Charged Insulator		YES	No	YES	YES	Yes (Strongly)	YES	in air YES, in vacuum NO
Grounded Metal		No	No	No	No	Yes (weakly)	YES	NO
Charged Floating Metal		YES	YES	YES	YES	Yes (Strongly)	YES	trapped gases YES, in vacuum NO
Charged Insulator (or metal) with grounded metal backing		Yes Internal No External	Yes Highest PBD No Otherwise	Yes for contact No far away	Yes (few)	Yes (weakly)	YES	Internal YES (low chance) External YES with gases in vacuum NO
Uncharged insulator or floating metal behind charged insulator (or metal)		YES	NO	YES	YES	Yes (Strongly)	YES	trapped gases YES, in vacuum NO
Charged metal (or insulator) with an uncharged insulator in between a grounded metal		Yes Internal No External	Yes Highest PBD No Otherwise	Yes for contact No far away	YES (many)	Yes (weakly)	YES	Internal YES (High chance) External YES with gases in vacuum NO



# Charging Equivalent Circuit



On surface, now add dynamic terms to current balance:

- Moving over surface creates a tribo-electric source of charge,  $S(t)$
- Surface 'ground', but the Moon is a very poor conductor (in shadowed regions can be as low as  $10^{-17}$  S/m) [Carrier et al., 1991]
- On dayside, photoelectrons and solar wind ions provide a good ground. The medium is conductive.
- **Problem areas:** Nightside and shadow – no photoelectron currents, and have reduced plasma currents

$$S(t) + I_{\text{ground}} + I_{\text{photoelec}} + I_{\text{elec}} + I_{\text{ion}} + I_{\text{secondary elec}} = dQ/dt$$

- *Ground to the local plasma, and not to 'surface'ground*

Farrell et al, 2008

Jackson et al., 2011

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