The Need for Conductive Space Suits: A Summary of DREAM2 findings

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What is a Space Suit?

- Multi-tasking outfit
- Life support
- Interface with environment
  - Pressure Vessel –yes!
  - Thermal regulation – yes!
  - Micro-meteoroid protection - yes!(?)
  - Protection from radiation? [Hu et al., 2008]
  - Reduce Dust Adhesion? [Christoffersen et al, 2009]
  - Plasma/Electrostatic equilibrium? [Jackson et al., 2011]

Can we improve these other aspects?

Suit Immersed in a Plasma (Conducting) Medium

I_p I_e I_i I_s

<-- ϕ
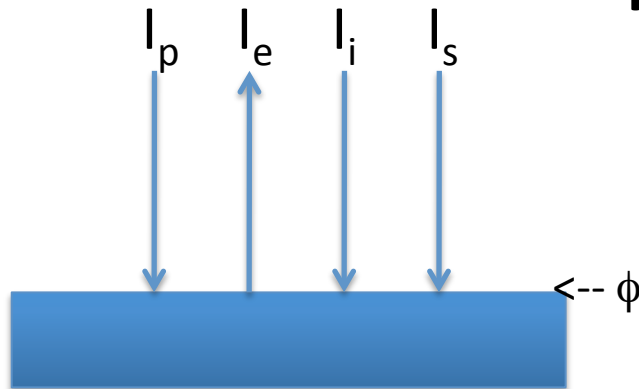
Steady-state current balance is:

$dQ/dt = I_{photoelec} + I_{elec} + I_{ion} + I_{secondary\ elec} = 0$

$Q = Q_o$ constant, $dQ/dt = 0$

However, if have a dynamic source

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

$Q = Q(t)$, dQ/dt = nonzero value

- Photo-electron currents, I_p
- Thermal flux of solar wind electrons, I_e
- Flow of solar wind ions, I_i
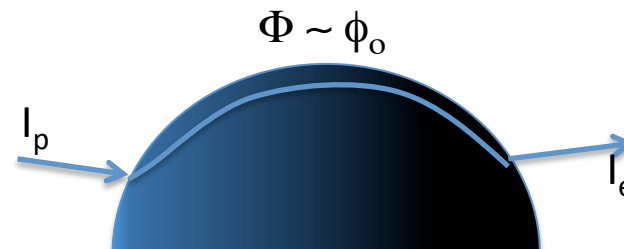- Secondary electrons, I_s
- Source, S(t)

Where to apply these charging equations (locally or globally)?

- Insulating dielectric: Apply equations locally
- Conducting body: Apply equations globally

Non-Conductive (differential potentials)

$\Phi = +\phi$ $\Phi = -\phi$

I_p

+   -

+   -

I_e
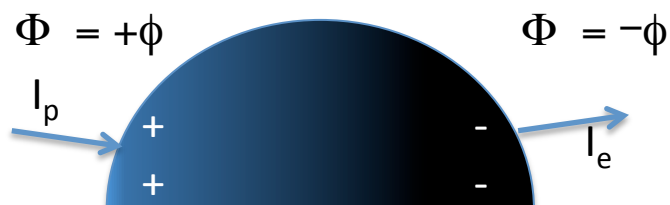
Conductive (iso-potential)

$\Phi \sim \phi_o$

I_p

I_e

Different regions ARE NOT electrically connected

Differential charging across body

Different regions ARE electrically connected

Uniform Charging across body

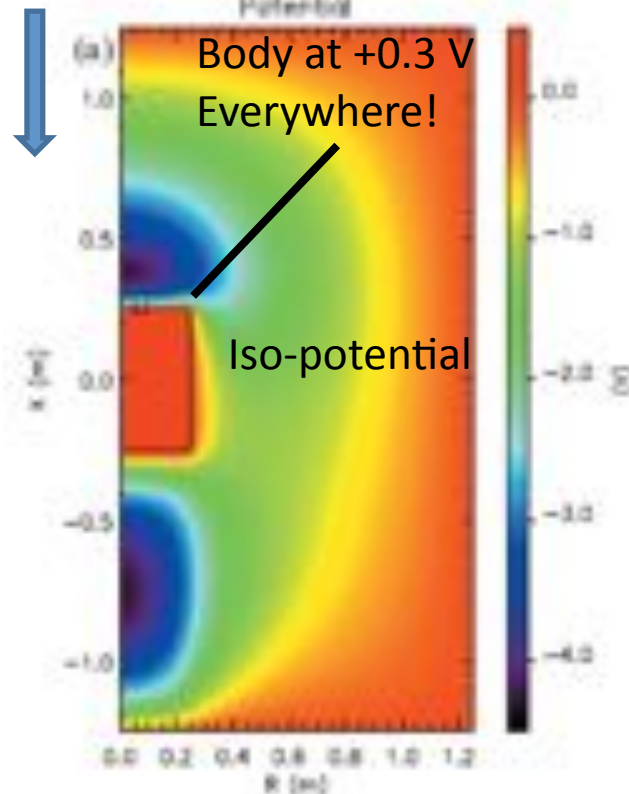# Analog: Spacecraft Differential Charging Issues

In terrestrial magnetosphere: charging anomalies typically on nightside (eclipse) when in larger geomagnetic tail current flows [Garrett, 1985]

- Applications Technology Spacecraft (ATS) 5 and 6 (late 60's-70s) reported large negative ~ 10kV potentials in eclipse and in the hot terrestrial plasma sheet

- in 1979, Spacecraft Charging AT High Altitudes (SCATHA) studied the effect – patch plate with different dielectric that could develop differential potentials of 1-3 kV.

Given these early studies, its now common practice to require spacecraft skin conductivity requirements

Analog: Outer skin of Spacecraft

Sun, Plasma Flow
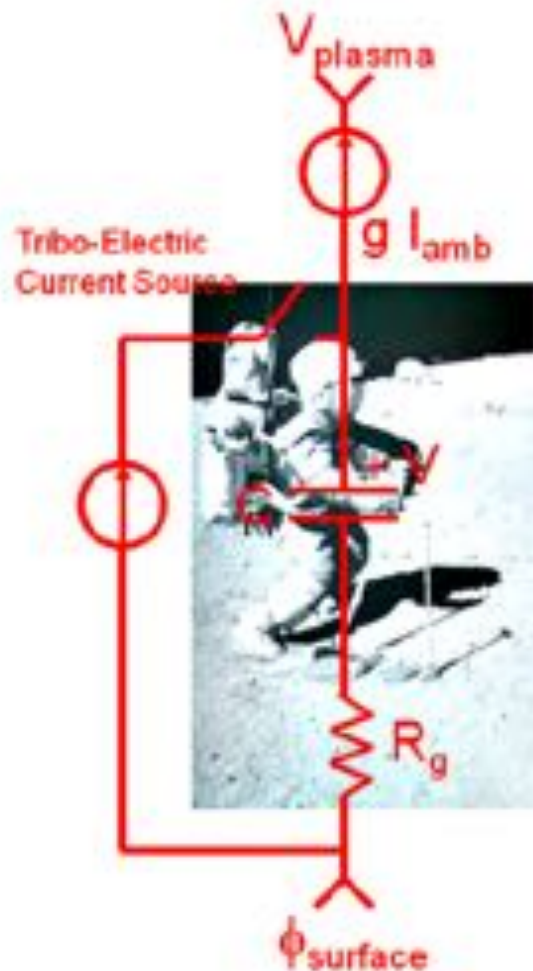
Body at +0.3 V Everywhere!

Iso-potential

Solar Probe Plus Charging, Ergun et al., 2010

- For spacecraft immersed in space plasmas, usually have well-stated skin conductivity requirements

- Highly conductive skin everywhere

- Eliminates differential charging

Why don't we have strict conductivity requirements for space suits – that are also exposed to the space plasma environment?

Surface Astronaut Charging Equivalent Circuit

Tribo-Electric Current Source

V_{plasma}

$g\,I_{amb}$

R_g

$\phi_{surface}$

Farrell et al, 2008
Jackson et al., 2011

- 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

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

- Actually grounded to the local plasma, and not to 'surface' ground

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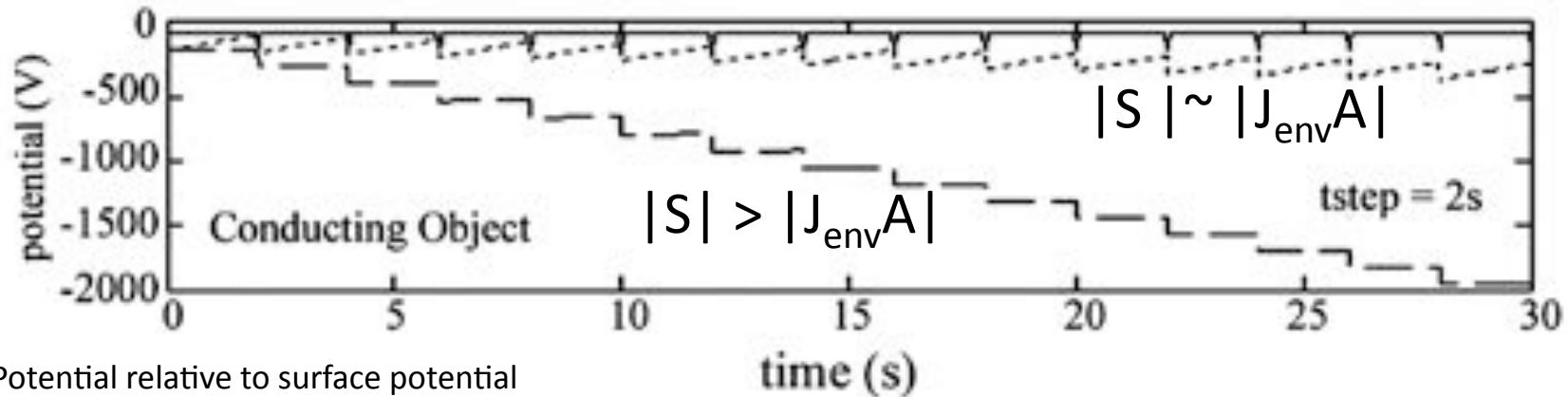$$S(t) + I_{grnd} + I_{photoelec} + I_{elec} + I_{ion} + I_{secondary\ elec} = dQ/dt$$

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Suit Charging at Various Locations on the Lunar Surface

$$C\frac{d\phi_{obj}}{dt} = J_{e-env}A(1 - \delta_{eff}^{obj})\exp\left(\frac{e\phi_{obj}}{kT_e}\right) - J_{i-env}\frac{A}{2} - C\frac{\phi_{obj}}{\tau_R} + S$$

$$S = \phi_o C\delta(t - n\Delta t) \quad n = 1, 2, 3, \ldots$$

Jackson et al., 2011

Potential relative to surface potential

$|S| \sim |J_{env}A|$

$|S| > |J_{env}A|$

tstep = 2s
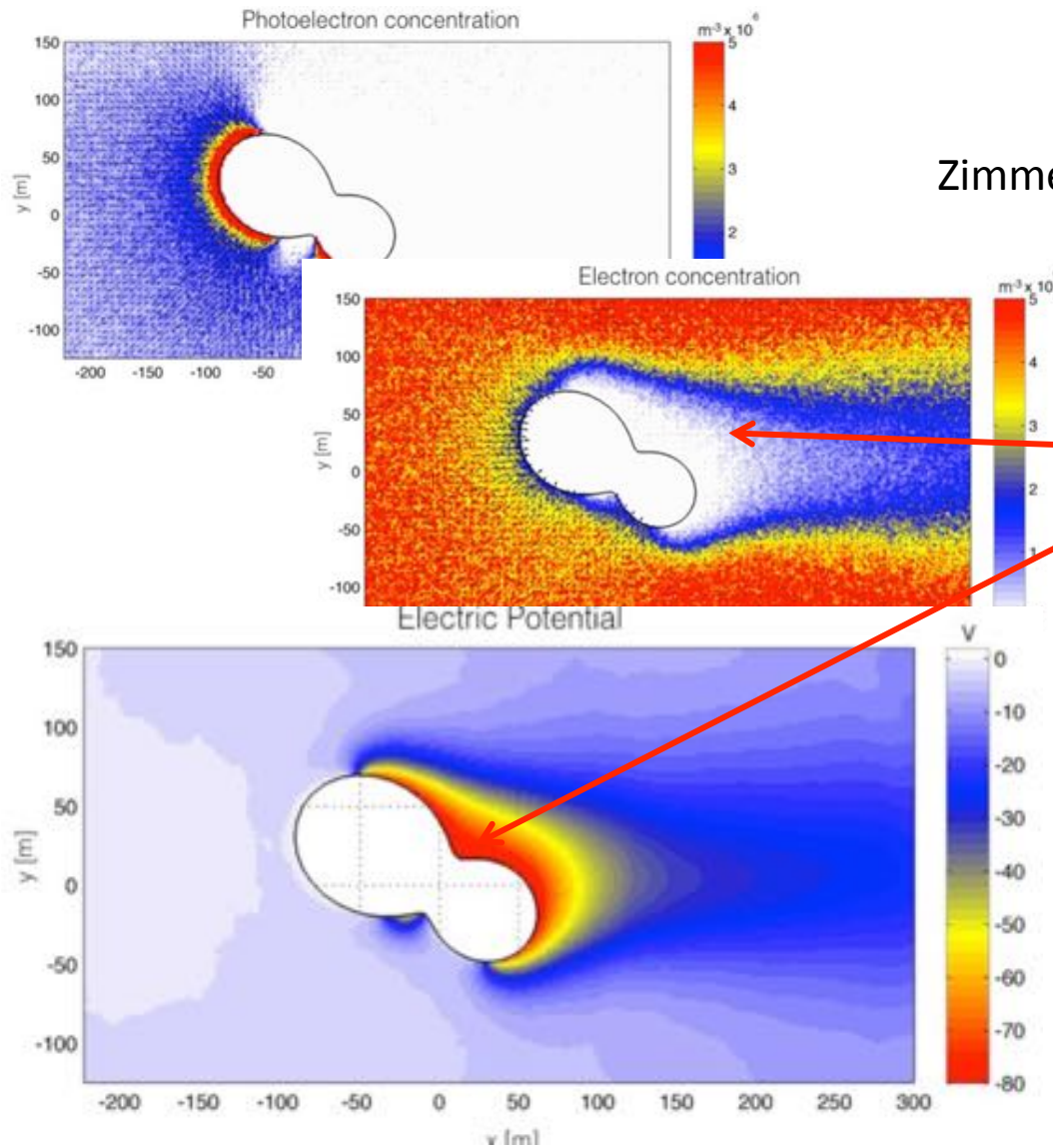
Solid Line – Solar wind exposure (e.g., at terminator)
Dotted Line - ~ 1% of solar wind plasma (e.g., wake behind terminator)
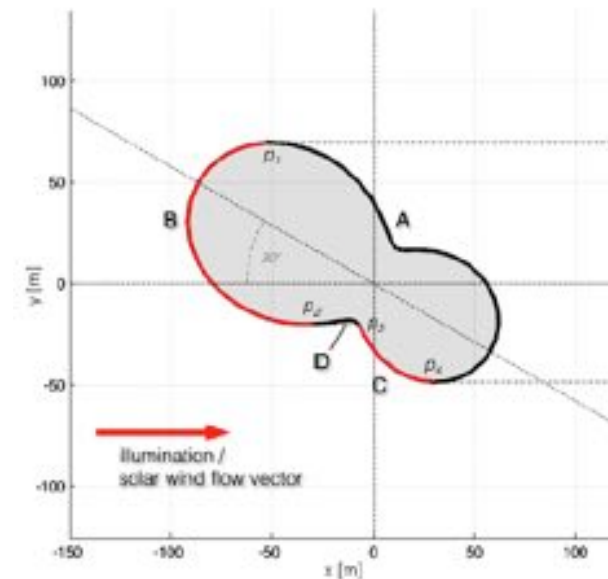Dashed Line -~ 0.01% of solar wind plasma (e.g., anti-solar point, polar crater)

For surface roving, want to stay in plasma flow,
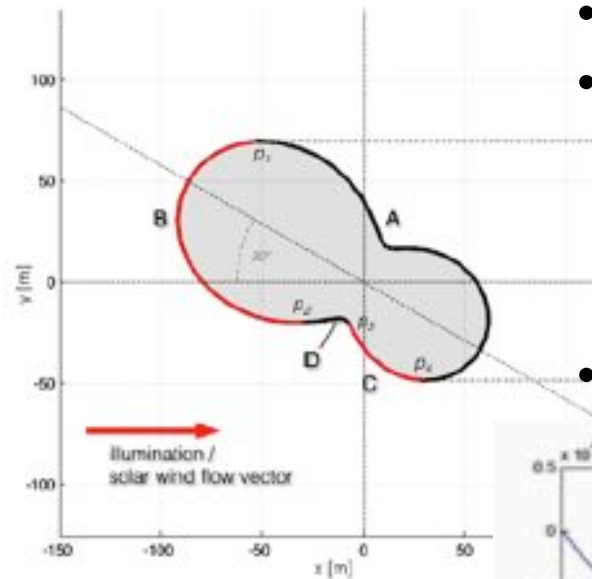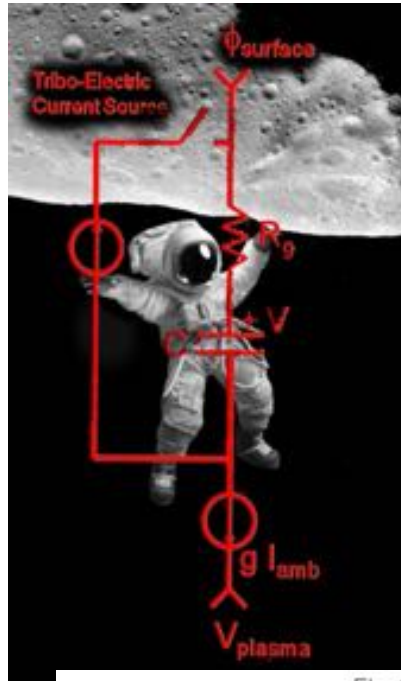stay connected to the electrical ground!

Astronauts at an Asteroid
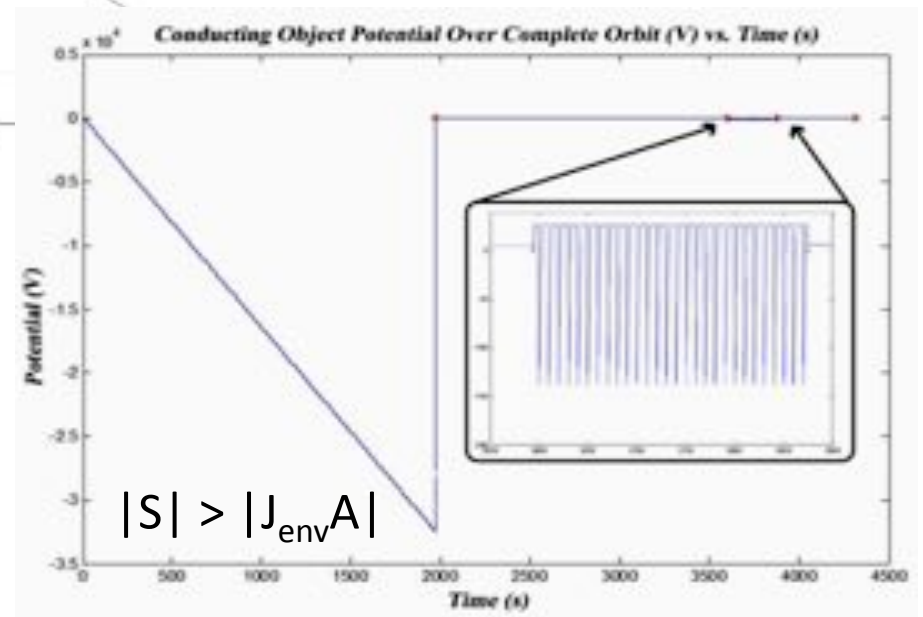

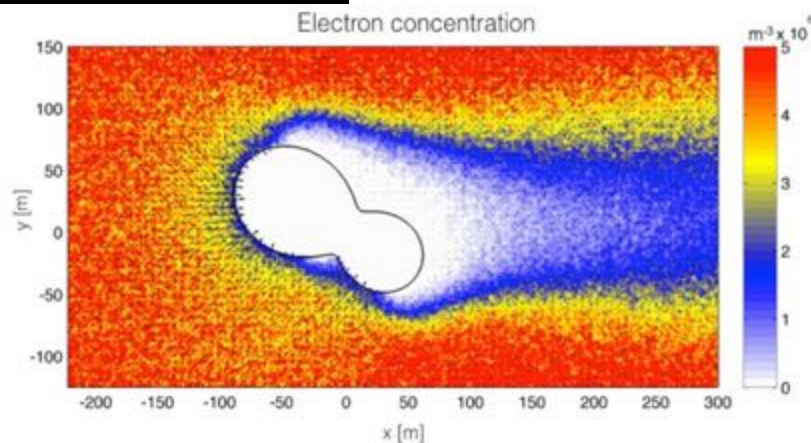Zimmerman et al., 2014

Plasma Wake
and differential potentials

Equivalent Circuit: Astronaut at an Asteroid

- **Jackson et al., 2014, LPSC**
- Now take Zimmerman asteroid model & consider astronaut traversing over the surface by pushing along with hands
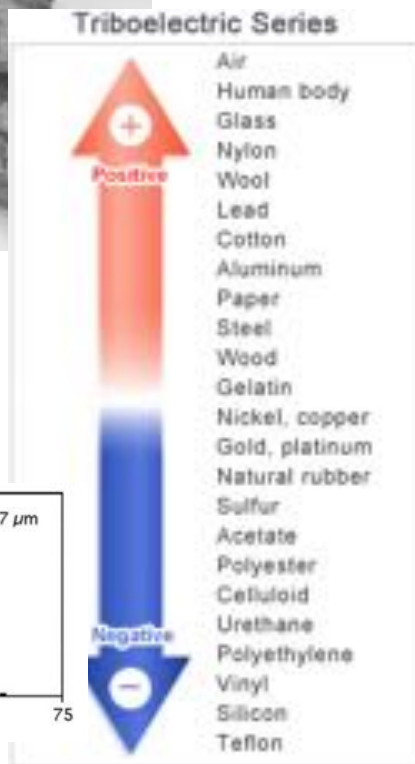- Glove charging

$|S| > |J_{env}A|$

Apollo 12 AL7 Suit

Alan Bean's suit
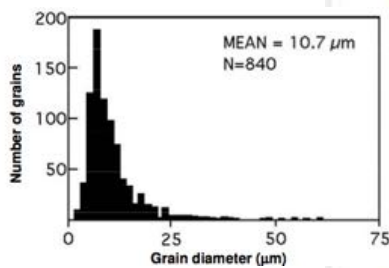
- **Christoffersen, Lindsay, et al., 2009**
- Multi-layer w/ outer skin T-164 woven teflon
- Insulating fibers mechanically trapped dust
- Generally more favorable to attach plagioclase feldspar dust, up to 10^5 grains/cm^2, <10 microns>
- Teflon is an insulator and a strong tribo-electric generator when rubbing (with just about anything)
- We wrapped the astronauts in woven dielectric material ideally suited for dust collecting
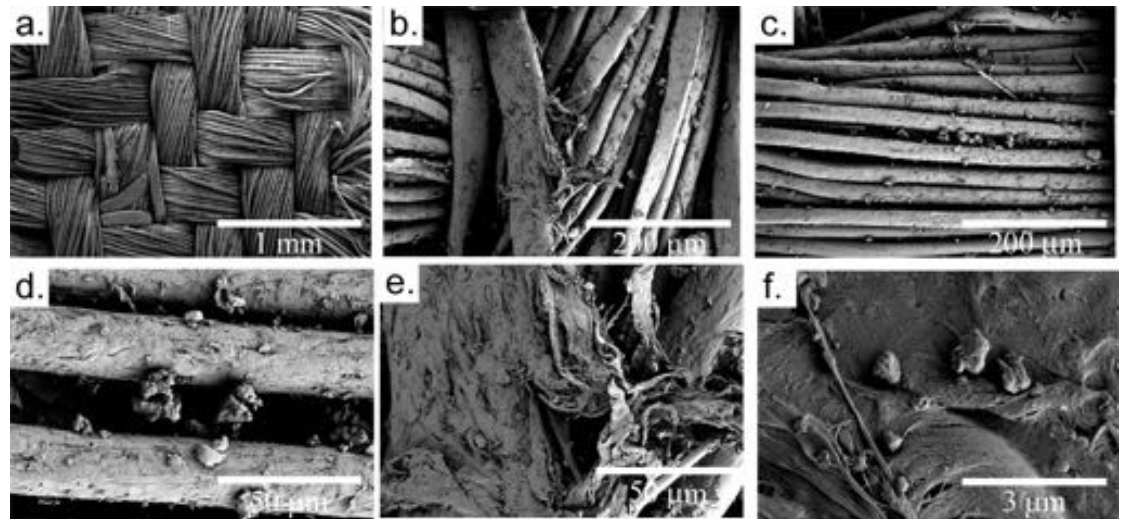
Teflon Tribocharging of Granular Material

TABLE II   The average triboelectric charge-to-mass ratio (nC/g) for different particle size fractions (μm), using cyclone tribocharger

Tribocharger/ Temperature		Feldspar			Quartz			Wollastonite		
		-600 +300	-300 +150	-150 +75	-600 +300	-300 +150	-150 +75	-600 +300	-300 +150	-150 +75
Brass	room*	-2.31	-8.72	-25.2	-5.69	-18.1	-69.1	-6.54	-14.3	-47.2
	50°C	-4.49	-12.0	-27.3	-8.98	-28.7	-38.0	-12.0	-19.3	-89.2
Steel	room*	-2.61	-4.52	-12.1	-4.99	-12.7	-7.68	-3.75	-6.94	-10.9
	50°C	-3.96	-6.37	-17.7	-5.95	-13.2	-26.2	-4.03	-7.43	-16.4
Teflon	room*	25.0	69.3	209	8.91	26.3	44.1	48.5	198	399
	50°C	28.7	86.9	160	-16.7	-28.3	-82.4	70.9	173	344
Perspex	room*	-15.4	-43.2	-683	-12.6	-35.4	-83.1	-4.92	-11.5	-272
	50°C	-22.4	-76.4	-173	-51.1	-84.6	-584	-9.50	-39.2	-48.5

* Room temperature.

Manouchehri et al., 2001

Z-2 Suits: Surface Specific EVA Garment

- **Ross et al., 2014**
- Still in development at JSC via AES funding
- Now integrating environmental considerations like impact protect
- S-glass fiberglass layer sandwiched with IM10 composite fiber layer
- DREAM2 team recommendation: that outer skin have spacecraft-like plasma conductivity requirements.
- Initiated discussion with JSC group

Suit Optimization for the Surface-Plasma Environment

Triboelectric Series

- **Reduce Tribocharging, S:** Make the areas that contact regolith surface (Boots, gloves) of material close to the triboelectric potential or work function of the asteroids regolith
  - Likely specific to the body itself, and composition of regolith at body

- **Increase Dissipation Area, A:** improve electrical connection to plasma medium by having a large conductive return current collecting area...connect all points on the suit electrically (i.e., make conductive)

- **Stay in dense plasmas, J_{env}**

$$dQ/dt = S_{tribo} - J_{env}A$$

$$J_{env}A \gg S_{tribo}$$

Optimizations: Where to step along the Surface-Plasma Interface?

Table 1

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

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

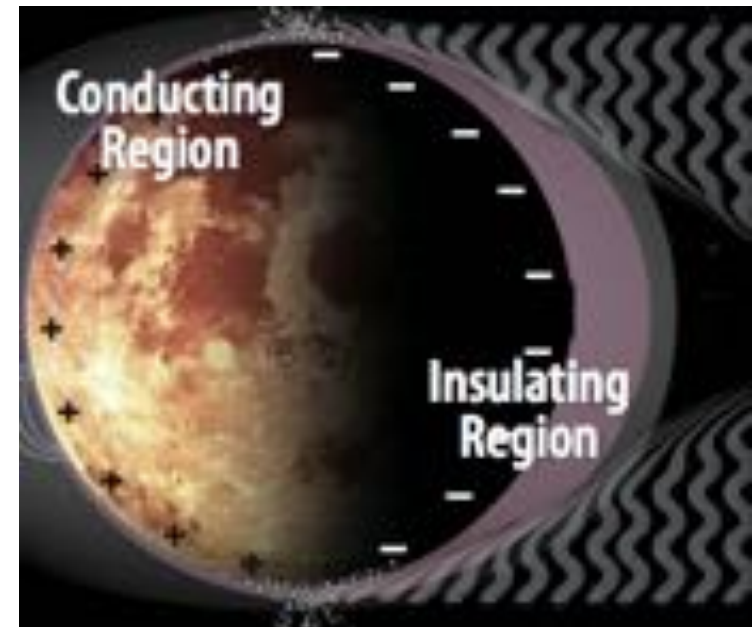~5 µA/m^2 ~0.8 nA/m^2

$$\tau^+ \sim (kT_e/e)(C/|J_{amb}^-|A)$$

$$\tau^- \sim (kT_i/e)(C/|J_{amb}^+|A)$$

'Best Practices' for ESD Avoidance:
1) Have part of human system in sunlight
2) Have human system in high plasma density flow
3) Shy away from shadowed regions

Conclusions & Recommendations

- Space suits should be conductive: Avoid differential charging, maximize return current collection area, A
- For roving human system: No longer expect current balance due to tribo-electric source term, S
- **Key Takeaway:** Want to maintain $J_{env}A \gg S_{tribo}$
  - Boot and glove material could having a contact potential close to that of the regolith... tailored to the environment
  - Keep J_{env} large: Stay in sunlight, avoid shadowed regions
- Possibly include portable plasma discharge device? Electron emitter.
- Next step: Consider a tethered astronaut at an asteroid, consider the effect of outgassing and near-suit exo-ions (which might act to remediate charge buildup), more detailed roving astronaut model
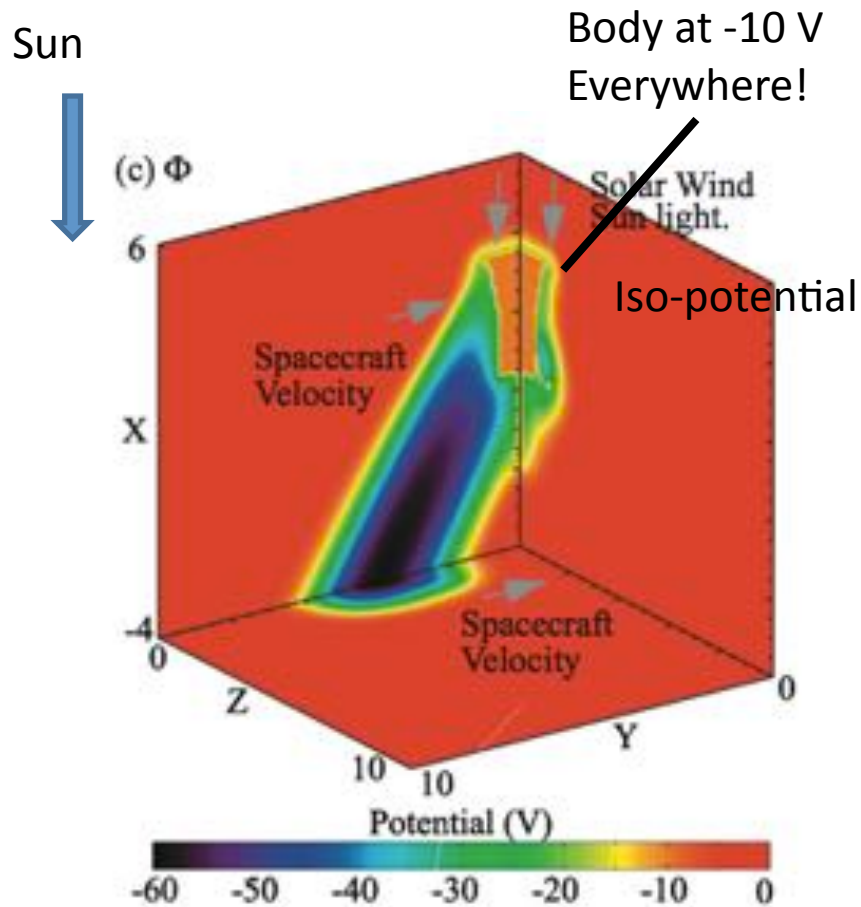
Backup

Nice example of conducting applications: Shuttle's SpaceLab-2 (1985)
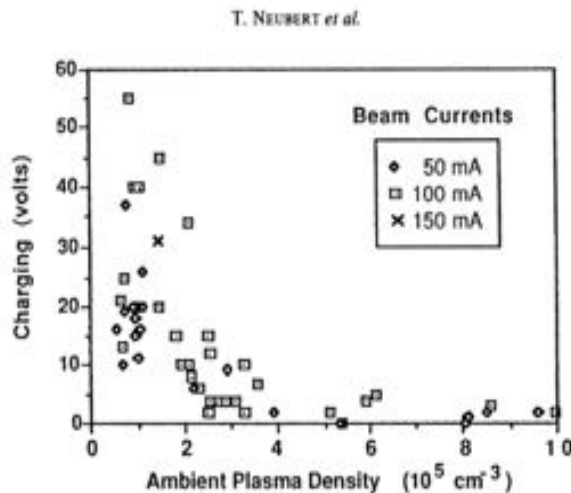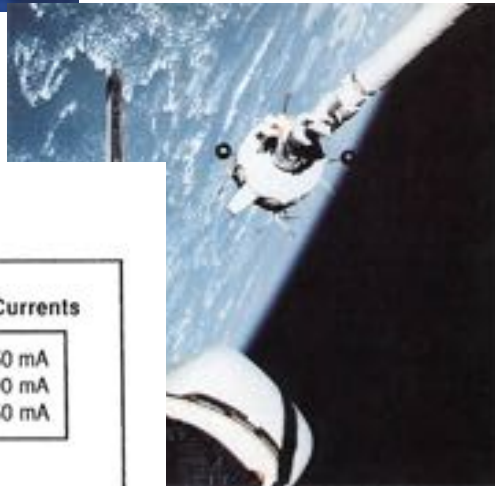
- Emitted 1 kA, 50 mA electron beam from bay
- Early debate was if the electron beam escaped the near shuttle region
- If electrons trapped $V_{shuttle}$ ~ +1000V
- However, Vehicle charging found < + 60 V potentials [Neubert et al. 1988]
- Why so low? Shuttle engine faring are 30 m^2, electrically connected to shuttle bay, and draw in ionosphere current from rear to compensate for beam

T. NEUBERT et al.

Beam Currents
- ◆ 50 mA
- □ 100 mA
- × 150 mA

Charging (volts)

Ambient Plasma Density (10^5 cm^{-3})

Analog: Outer skin of Spacecraft

Sun

Body at -10 V Everywhere!

Iso-potential

Solar Probe Plus Charging, Ergun et al., 2010

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