Electrostatic charging of the lunar surface

James R. Phillips III, Charles R. Buhler, Michael R. Johansen, Carlos I. Calle
NASA Kennedy Space Center (KSC) Electrostatics and Surface Physics Laboratory (ESPL)

Adrienne R. Dove
University of Central Florida (UCF) Center for Microgravity Research (CMR)

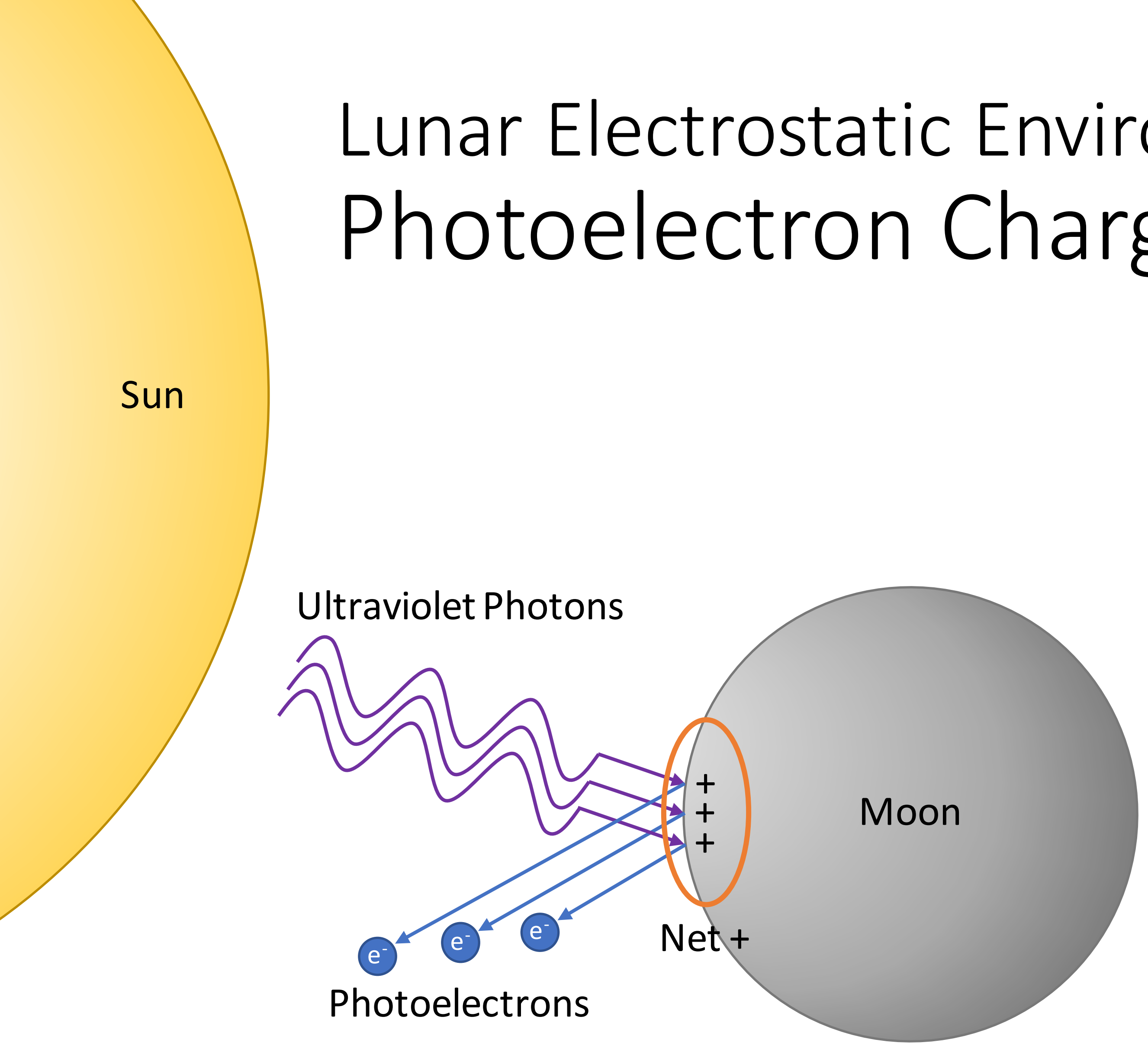
Introduction

- The lunar surface interacts directly with solar wind, cosmic rays, and solar ultraviolet radiation.
- Knowledge of the complex electrical environment that this interaction produces is essential from a scientific perspective as well as for hazard mitigation for lunar human missions.
- A full understanding of the lunar electrical environment requires measurements *in situ*, so we have developed a sensor suite.

Lunar Electrostatic Environment:
Overview of Charging

- Conservation of electric charge: in equilibrium, lunar surface will develop charge such that sum of current fluxes is zero [1][2][3]
- Measurements from electron reflectometer instrument on NASA Lunar Prospector mission [2] showed majority of lunar surface electrostatic charging is provided by just four currents [4]:
  - Photoelectrons – ejected from surface by incident high energy photons
  - Solar wind electrons – collect on surface from solar wind plasma
  - Solar wind ions – collect on surface from solar wind plasma
  - Secondary electrons – ejected from surface by incident primary electrons

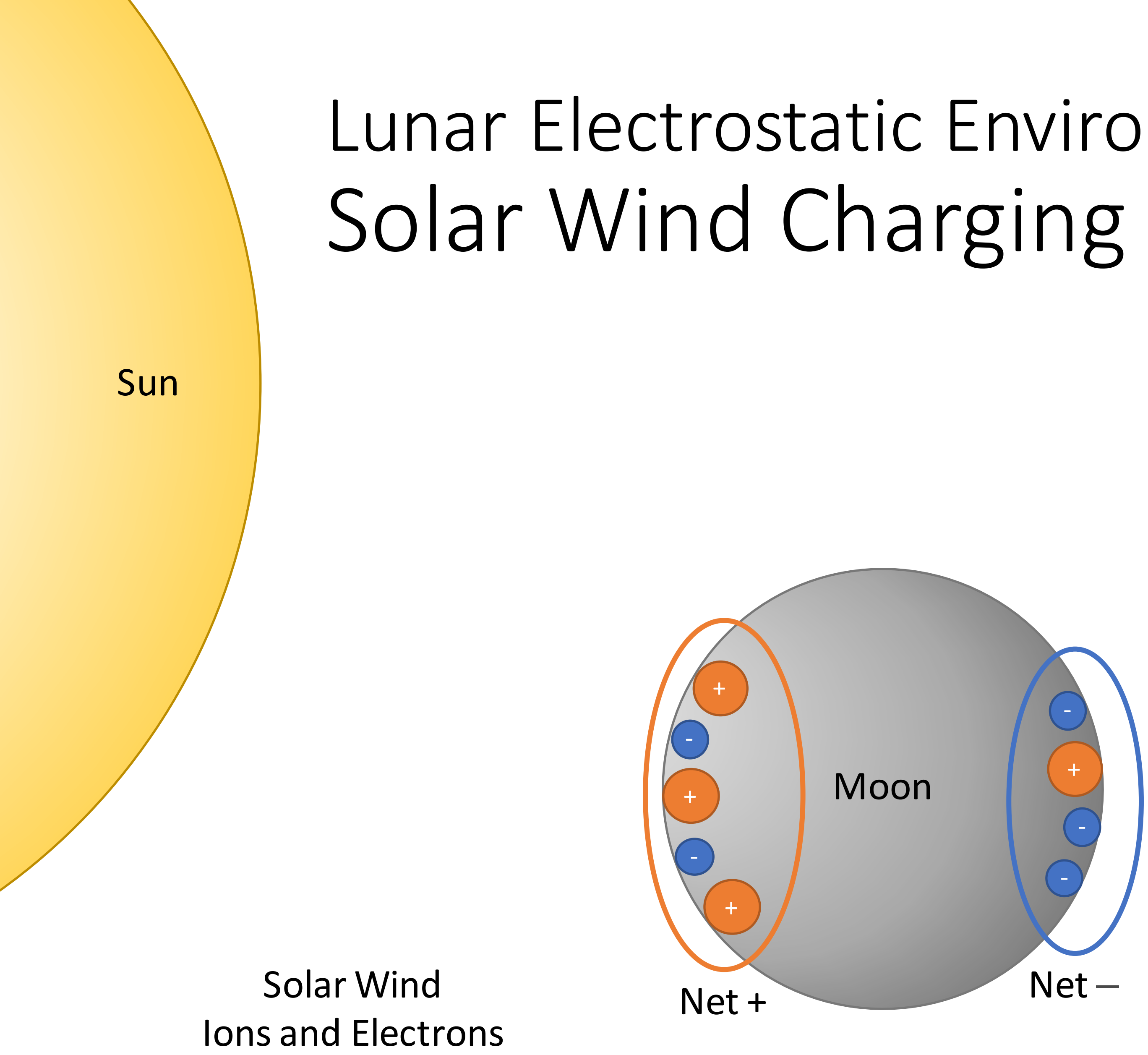
Lunar Electrostatic Environment:
Photoelectron Charging



- High energy photons are emitted from Sun
- Photoelectric effect releases electrons from lunar surface
- Lunar surface is net positively charged

*not to scale

Lunar Electrostatic Environment:
Solar Wind Charging



- Solar wind consists of charged particles from Sun
- Some will collect on sunlit lunar surface
- Many will carry on undisturbed by Moon
- Few will occupy lunar wake and collect on nightside
- Sunlit region is more positively and nightside is more negatively charged

*not to scale

Lunar Electrostatic Environment:
Combined Effects of Charging

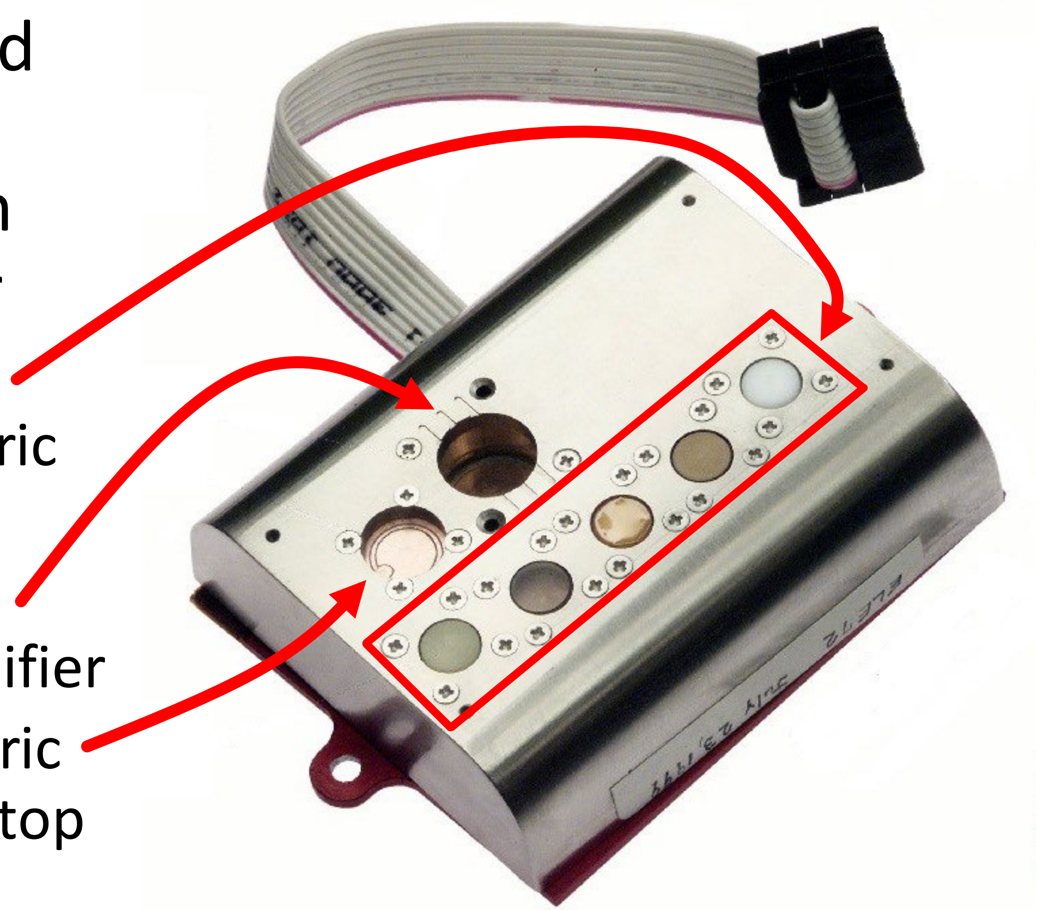
- Magnitude/sign of charge differs for sunlit and nightside of Moon. [5]
- On sunlit side, surface charges positively due to high energy solar photons.
  - Photoelectrons form a sheath about 1 m above the lunar surface. [6]
  - A small positive potential of 5 V to 10 V balances the incoming currents. [7]
- On nightside, surface charges negatively due to solar wind electrons.
  - In solar wind wake, density of charged particles from solar wind is reduced.
  - Electrons are more mobile than ions and become prevailing current.
  - A larger negative potential of –50 V to –200 V balances these currents. [8]
  - This plasma forms a sheath that reaches about 1 km from the surface. [10][11]
- Similar phenomenon at smaller scale occurs in shadows around craters.

Lunar Electrostatic Environment: Triboelectric Charging

- Triboelectric charging develops when two surfaces make contact and separate from each other, exchanging charge.
- Rover wheels or soles of astronaut boots will be triboelectrically charged as they move along the lunar surface.
- The time it would take for this electrostatic charge to dissipate depends on the surrounding plasma environment. [15][16]
- A rover is also exposed to all the current fluxes reaching the surface of the Moon, developing a charge that balances out the net sum of the fluxes.
- In the conductive photoelectron-dominated plasma region of the sunlit surface of the Moon, the triboelectric-generated charge that would develop on a rolling rover wheel should dissipate quickly. [17]

Mars Environmental Compatibility Assessment (MECA) Electrometer

- Suite of triboelectric, ion current, and electric field sensors developed by JPL/KSC for mounting on robotic arm scoop of Mars 2001 Surveyor Lander
  - Triboelectric sensors use five different insulator materials spanning triboelectric series to contact the surface
  - Ion current sensor is a metal electrode connected to a current to voltage amplifier
  - Electric field sensor is a bare triboelectric sensor with no insulator installed over top



Flight Instrument Characteristics

- MECA electrometer includes temperature sensor, ion current sensor, electric field sensor, and five triboelectric sensors inside titanium case
  - Total mass of 160 g with volume of 80 cm^3
  - Triboelectric/electric field sensors
    - Full-scale potential detection capability of 7.3 kV with resolution of 3.5 V
    - Full-scale charge detection capability of 1.8 nC with resolution of 0.9 pC
  - Ion current sensor
    - Full-scale ion current capability is 120 pA with resolution is 60 fA
- While this setup was originally planned for deployment on Mars, application to lunar surface will be possible with minor modifications

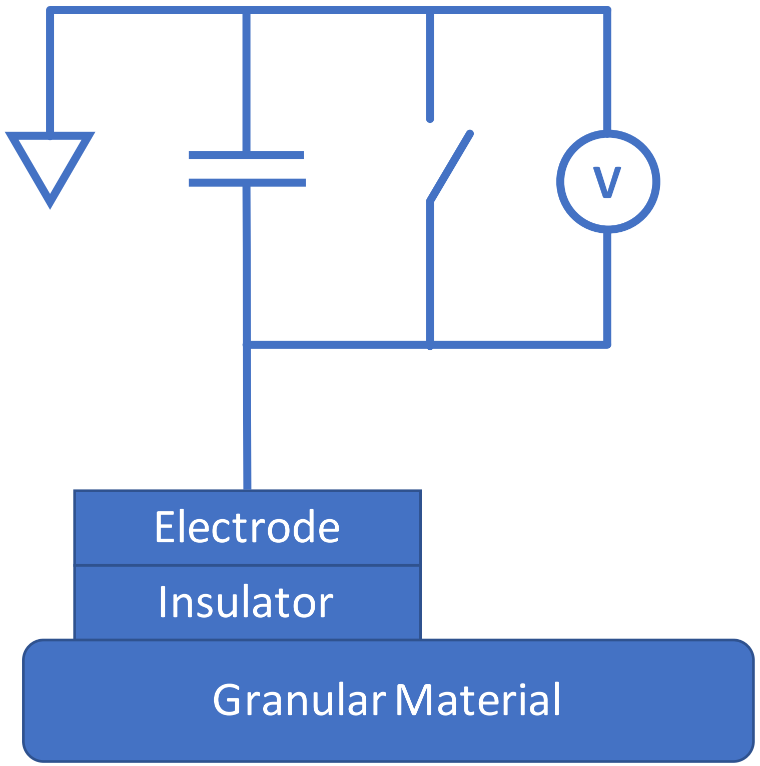
Mars Environmental Compatibility Assessment (MECA) Electrometer

- Polymers for triboelectric sensors were selected from commonly used space flight insulating materials
- Triboelectric series outlines tendency of a material to gain or lose charge when in contact with another material
- Relative position of two materials in series determines which will be positively charged and which will be negatively charged [19]

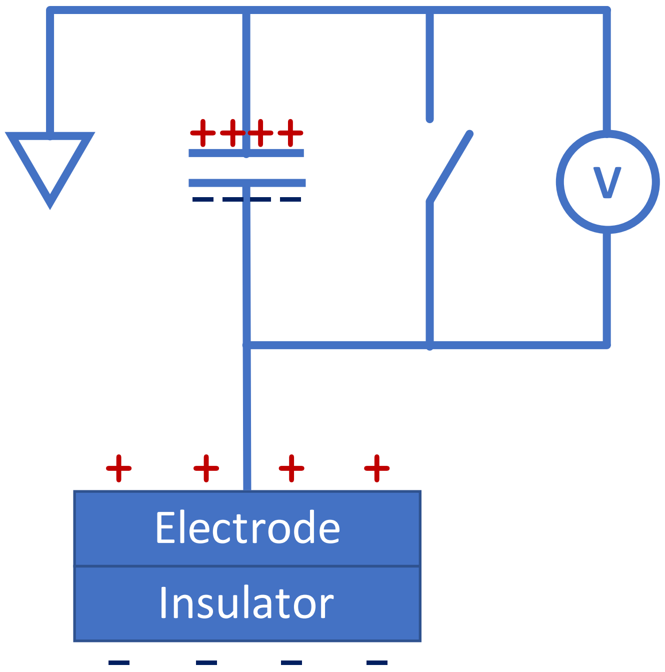
ID	Material Name		Relative Permittivity	Resistivity (ohm-cm)
	Trade	Chemical		
1	Garolite™	Fiberglass/Epoxy Composite	4.7	7.8×10^{15}
2	Lexan™	Polycarbonate	2.96	2×10^{16}
3	Teflon™	Polytetrafluoro-ethylene (PTFE)	2.1	1×10^{18}
4	Rulon-J™	----------------------	2.4	8.2×10^{18}
5	Lucite™	Polymethylmeth-acrylate (PMMA)	2.63	$>5\times10^{16}$

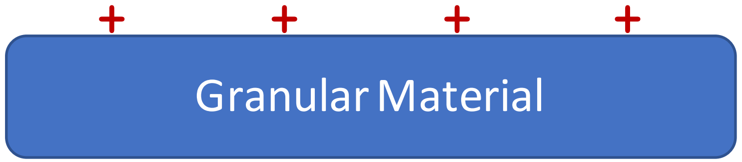
Polymers used for MECA electrometer sensors to span triboelectric series [18]

Triboelectric Sensor Detail



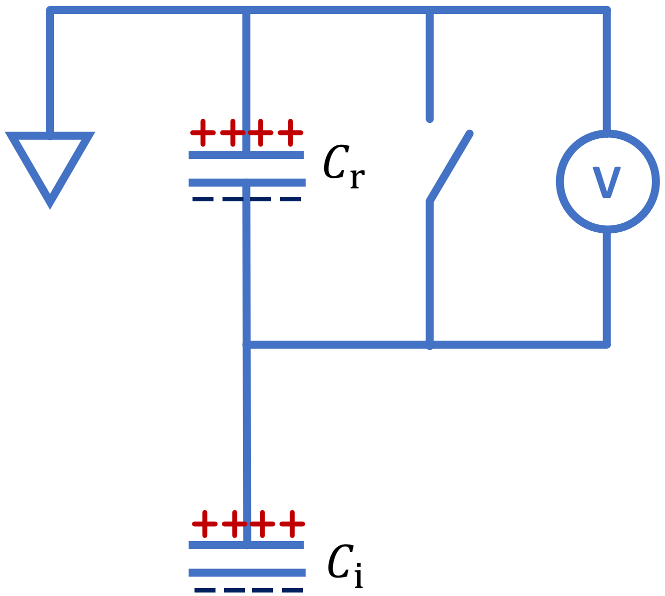
Triboelectric Sensor Detail





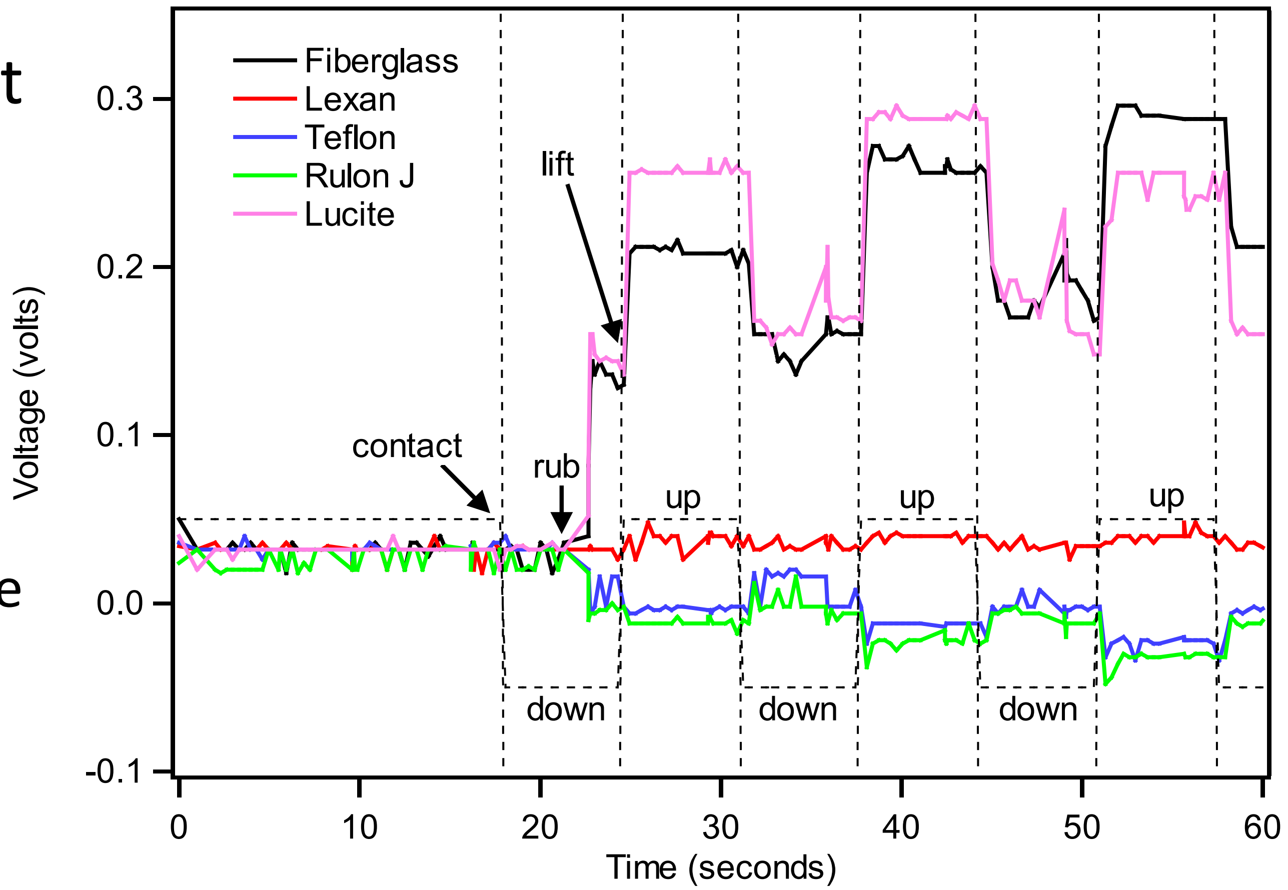
Triboelectric Sensor Detail

- Charge, Q, deposited on an insulator surface induces an equal charge, Q, on a series reservoir capacitor, C_r
- $Q = C_\mathrm{r} V_\mathrm{r} = C_\mathrm{i} V_\mathrm{i} \;\rightarrow\; V_\mathrm{r} = V_\mathrm{i} \dfrac{C_\mathrm{i}}{C_\mathrm{r}} = \dfrac{Q}{C_\mathrm{r}}$
- Circular insulator of radius, r, and thickness, t, has capacitance given by $C_\mathrm{i} = \varepsilon_\mathrm{r} \varepsilon_0 \dfrac{\pi r^2}{t}$
- C_i is determined by permittivity of insulator
- C_r is low leakage capacitor installed on board
- V_r is measured via electrometer amplifier and is directly proportional to accumulated charge, Q



Triboelectric Sensor Data

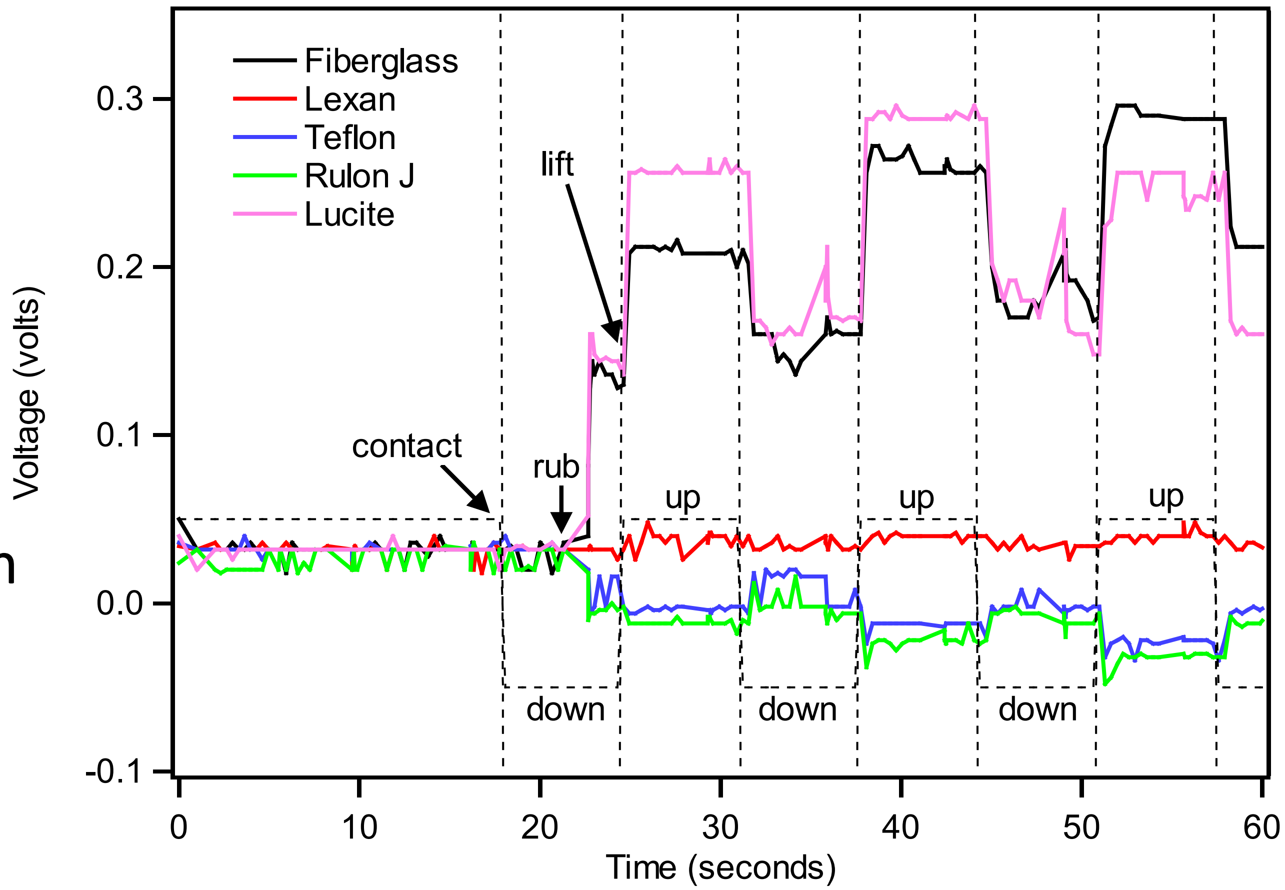
- Experiment with MECA electrometer rubbing against JSC Mars-1 simulant [20]
  - Rubbing begins around 20s and tribocharging occurs
  - Sensor lifts at 21s causing charge separation and larger detected potential difference
  - Sensor returns to surface at 31s where equal and opposite charges from initial tribo-charging mask signal
  - Lifting and lowering repeats twice more to show stability



Test performed under Martian atm. pressure at room temp.

Triboelectric Sensor Data

- Each polymer acquires different triboelectric charge against sample
  - Lucite™ and Garolite™ charge positively while Rulon-J™ and Teflon™ charge negatively
  - Places this sample between Garolite™ and Rulon-J™ on the triboelectric series



Test performed under Martian atm. pressure at room temp.

Triboelectric Sensor Interpretation

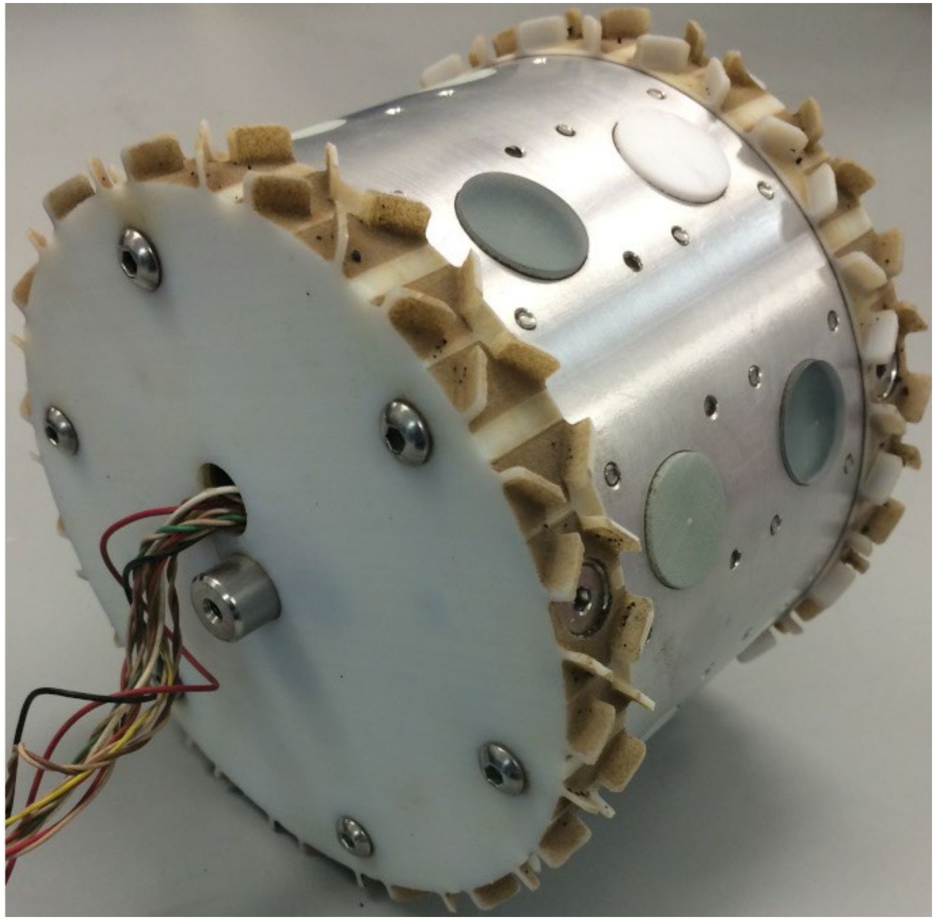
- These electrostatic responses can be arranged in a triboelectric series table according to the amount of charge transferred. [21]
- Measurements obtained by the instrument will place the lunar regolith in these tables.
- Since other widely used polymer materials are classified in these tables, the magnitude and sign of the charge that they may acquire if they were to be placed in contact with the regolith can be predicted.
- This information will allow mission designers to predict if the proposed material will accumulate dust.

Triboelectric Sensor Further Applications

- Several configurations of the triboelectric sensors included in original MECA electrometer have been examined for different applications:
  - Wheel Electrostatic Spectrometer (WES) [20][22]
  - Electrostatic Regolith Interaction Experiment (ERIE)

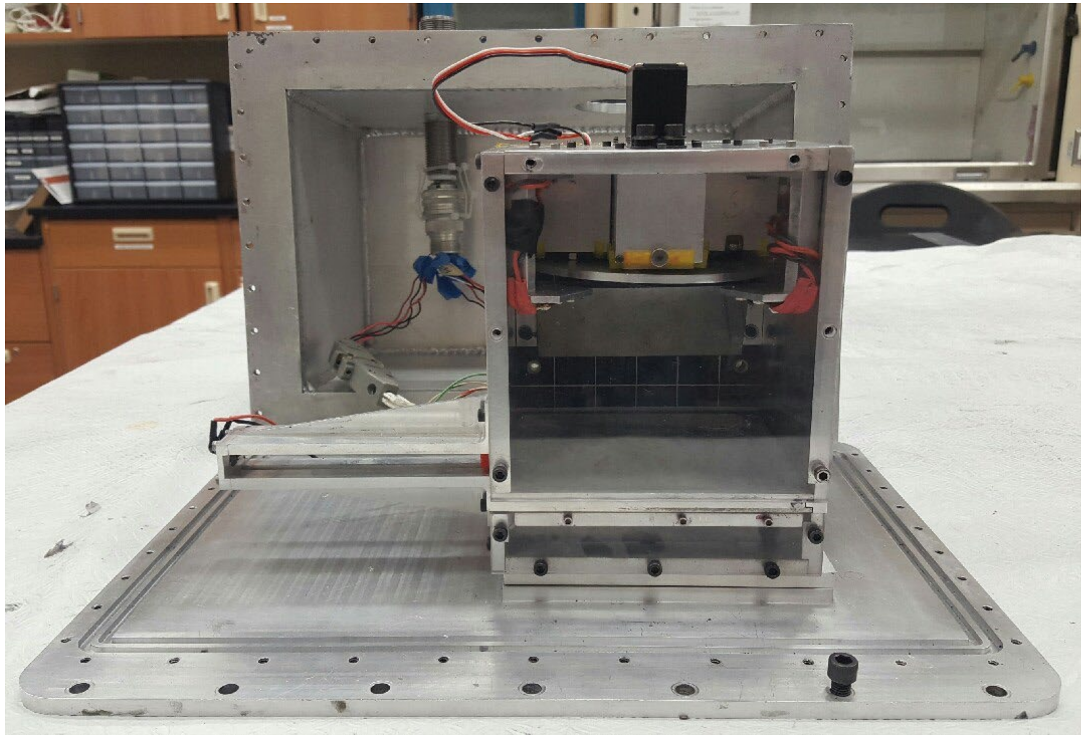
Wheel Electrostatic Spectrometer (WES)

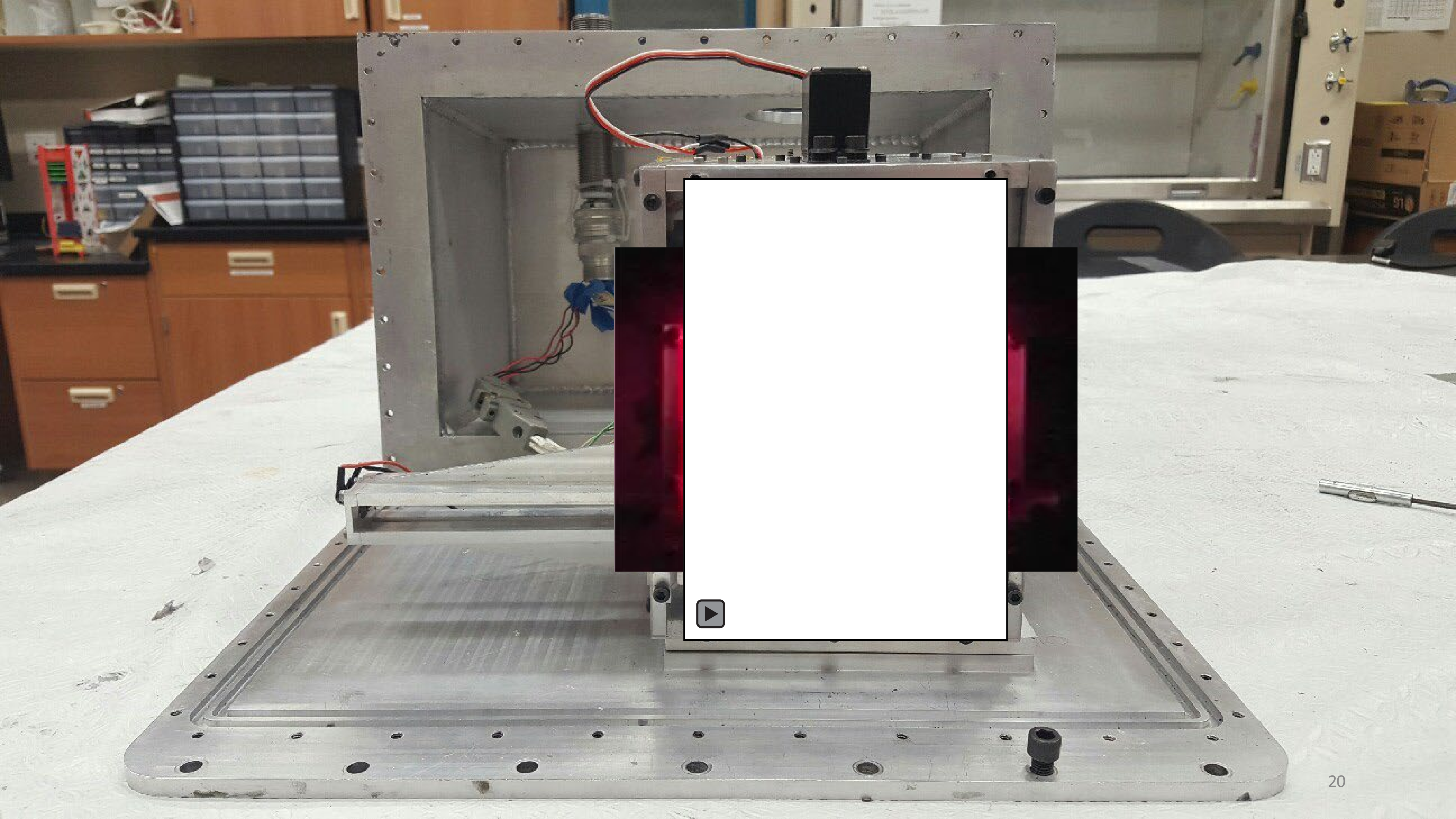
- Updated triboelectric sensors from MECA electrometer installed along perimeter of rover wheel proposed to characterize triboelectric properties of Martian regolith through contact with surface as wheel rotates [20][22]



COLLisions Into Dust Experiment (COLLIDE)

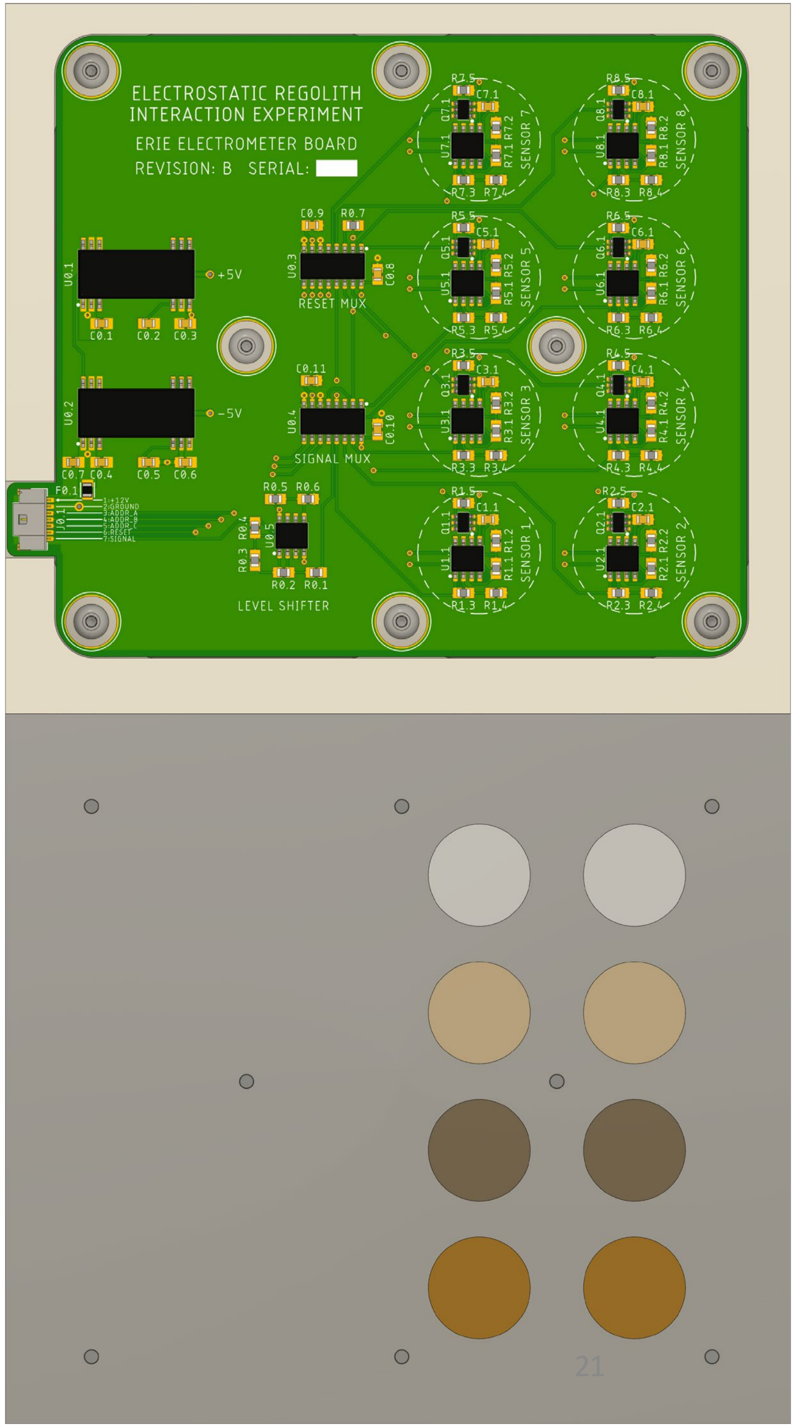
- Microgravity experiment to study cratering events in granular beds flown on Space Shuttle, parabolic aircraft, and suborbital flights
- Retains granular material under vacuum in tray behind metal door, which then opens and releases particles into larger open volume when microgravity is achieved
- Electrostatic repulsion between grains in bed was observed prior to collision with impactor



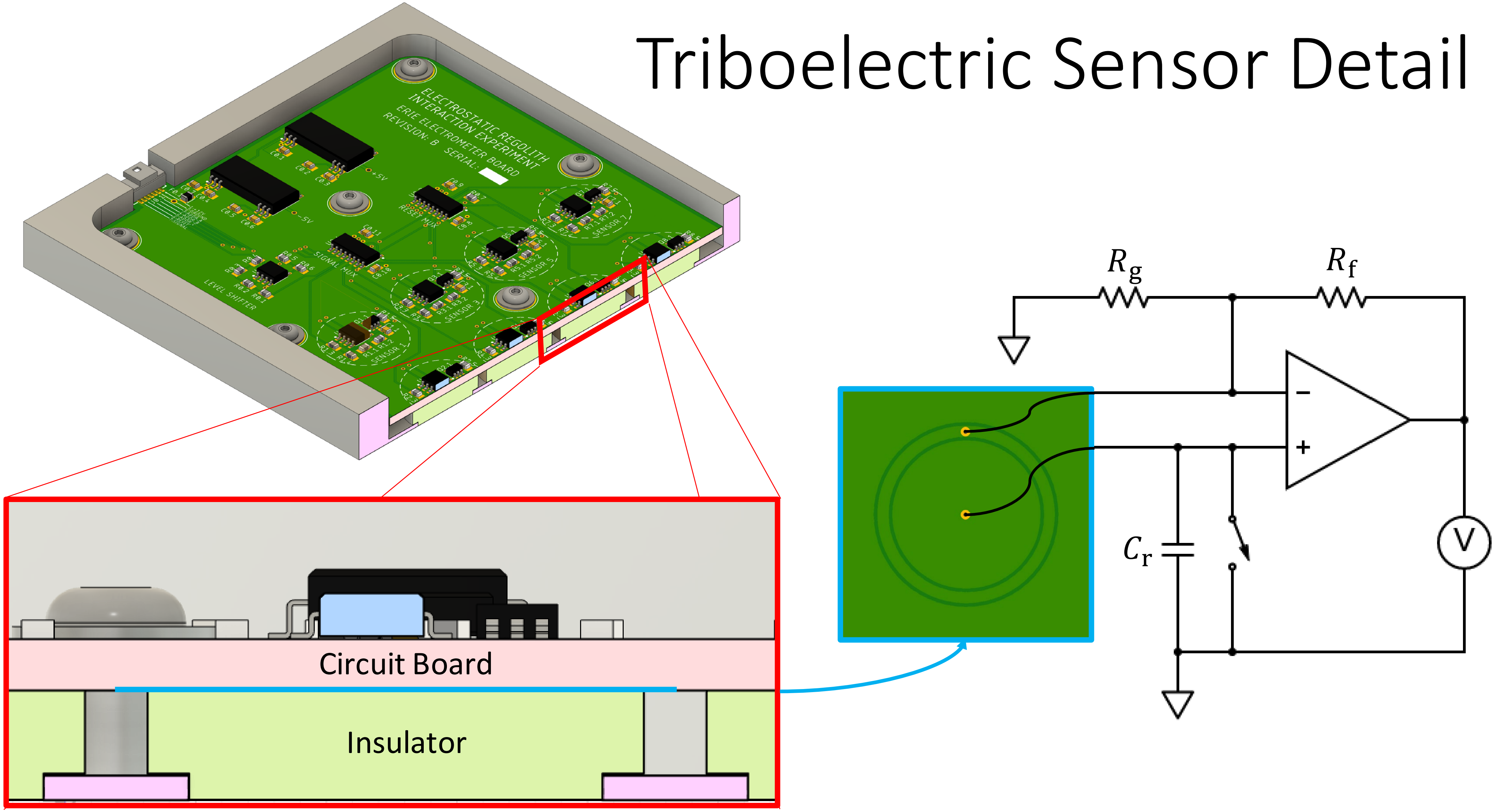


Electrostatic Regolith Interaction Experiment (ERIE) Electrometer

- Improved triboelectric sensors from WES installed inside COLLIDE dust retaining door
- Measures charge transferred between granular material and insulators protruding through door
- Insulator disks span triboelectric series so each will accumulate charge consistent with relative position to grains within series as door slides open
  - Sensors 1/2 (−−) Teflon™ Polytetrafluoroethylene (PTFE)
  - Sensors 3/4 (+) Garolite™ Fiberglass/Epoxy Composite
  - Sensors 5/6 (++) Lucite™ Polymethylmethacrylate (PMMA)
  - Sensors 7/8 (−) Lexan™ Polycarbonate



Triboelectric Sensor Detail



Conclusions

- Vehicles moving over lunar regolith during exploration activities will develop electrostatic charges due to interaction with lunar soil and with lunar plasma environment.
- This plasma environment will also determine how charge developed on rover wheels will dissipate.
- Laboratory vacuum tests indicate that charge that will be developed on many polymer materials placed on lunar surface can be predicted.
- The instrument will provide direct measurements of the ion flux and electric field strength in vicinity of triboelectric sensors, providing information on electrostatic environment that will affect dissipation of charge from these polymers.

References

[1] Manka, R.H., "Plasma and Potential at the Lunar Surface,", *Photon and Particle Interactions with Surfaces in Space*, Grard Springer, NY, 1973, pp. 347–361.
[2] Halekas, J.S., Bale, S.D., Mitchell, D.L., and Lin, R.P., "Electrons and Magnetic Fields in the Lunar Plasma Wake," *J. Geophys. Res.*, Vol. 110, 2005, A07222.
[3] Farrell, W.M., Stubbs, T.J., Vondrak, R.R., Delory, G.T., and Halekas, J.S., "Complex Electric Fields Near the Lunar Terminator: The Near-Surface Wake and Accelerated Dust," *Geophys Res. Lett.*, Vol. 34, 2007, L14201.
[4] Stubbs, T.J., Halekas, J.S., Farrell, W.M., and Vondrak, R.D, "Lunar Surface Charging: A Global Perspective using Lunar Prospector Data," *Workshop on Dust in Planetary Systems Lunar and Planetary Institute*, 2005, p. 4070.
[5] Calle, C.I., *Electrostatic Phenomena on Planetary Surfaces*, IOP Concise Physics series, Morgan and Claypool Publishers, San Rafael, CA, 2017.
[6] Singer S.F. and Walker, E.H., "Photoelectric Screening of Bodies in Interplanetary Space," *Icarus*, Vol. 1, 1962, pp. 7–12.
[7] Halekas, J.S., Poppe, A., Delory, G.T., Farrell, W.M., and Horanyi, M., "Solar Wind Electron Interaction With the Dayside Lunar Surface and Crustal Magnetic Fields: Evidence for Precursor Effects," *Earth, Planets and Space*, Vol. 64, 2012, pp. 73–82.
[8] Halekas, J.S., Mitchell, R.P., Lin, L.L., Hood, M., Acuña, H., and Binder, A., "Evidence for Negative Charging of the Lunar Surface in Shadow," *Geophys Res. Lett.*, Vol. 29, 2002, p. 1436.
[9] Halekas, J.S., Delory, G.T., Stubbs, J.K., and Farrell, W.M., "Lunar surface charging during solar energetic particle events," *J. Geophys. Res.*, Vol. 114, 2009, A05110.
[10] Delory, G.T., "Electrical phenomena on the moon and Mars," *ESA Annual Meeting on Electrostatics*, Charlotte, NC, 2010, paper A1.
[11] Freeman J.W. and Ibrahim M, "Lunar Electric Fields Surface Potential and Associated Plasma Sheaths," *The Moon*, Vol. 14, 1975, 103–114.
[12] Farrell W.M. *et al.*, "Concerning the Dissipation of Electrically Charged Objects in the Shadowed Lunar Polar Regions," *Geophys Res. Lett.*, Vol. 35, 2008, L19104.
[13] Winslow, R.M. *et al*, "Lunar Surface Charging and Possible Dielectric Breakdown in the Regolith During Two Strong SEP Events," *46th Lunar and Planetary Science Conference*, 2015, p. 1261.
[14] Jordan, A.P., Stubbs, T.J., Wilson, J.K., Schwadron, N.A., and Spence, H.E., "Dielectric breakdown weathering of the Moon's polar regolith," *J. Geophys. Res.* Vol. 120, 2015, pp. 210–225.
[15] Jackson, T.L., Farrell, W.M., and M.I. Zimmerman, "Rover Wheel Charging on the Lunar Surface," *Advances in Space Research*, Vol. 55, 2015, pp. 1710–1720.
[16] Rhodes, D.J., Farrell, W.M., and McLain, J.L., "Tribocharging and electrical grounding of a drill in shadowed regions of the Moon," *Advances in Space Research*, Vol. 66, 2020, pp. 753–759.
[17] Farrell, W.M. *et al.*, "Anticipated Electrical Environment Within Permanently Shadowed Lunar Craters," *J. Geophys. Res.*, Vol. 115, 2010, E03004.
[18] Buehler, M.G., Cheng, L-J., Orient, O., Gompf, R.H., Calle, C.I., Bayliss, J., and Rauwerdink, J., "From Order to Flight in Eighteen Months: The MECA/Electrometer Case Study," *IEEE Aerospace Conference*, Big Sky, Montana, 2000.
[19] Cross, J., *Electrostatics*, IOP Publishing, Bristol, UK, 1987.
[20] Johansen, M.R., Mackey, P.J., Holbert, E., Clements, J.S., and Calle, C.I., "Characterizing the Performance of the Wheel Electrostatic Spectrometer," *Proc. ESA Annual Meeting on Electrostatics*, Cocoa Beach, FL, 2013.
[21] Calle, C.I., "Sensors to characterize the properties of the Martian regolith," Concepts and Approaches for Mars Exploration, Houston, TX, 2012.
[22] Johansen, M.R., Phillips, J.R. III, Kelley, J.D., Mackey P.J., Holbert, E., Clements, J.S., and Calle, C.I., "A Feasibility Study of the Wheel Electrostatic Spectrometer," *Proc. ESA Annual Meeting on Electrostatics*, Cocoa Beach, FL, 2014.
[23] Colwell, J.E., "Low velocity impacts into dust: results from the COLLIDE-2 microgravity experiment," *Icarus*, Vol. 164, 2003, pp. 188–196.

Questions?

James R. Phillips III

NASA Kennedy Space Center

Electrostatics and Surface Physics Laboratory

james.r.phillips.iii@nasa.gov