Lunar Dust Mitigation Technology using E-beam: Cleaning EVA suits

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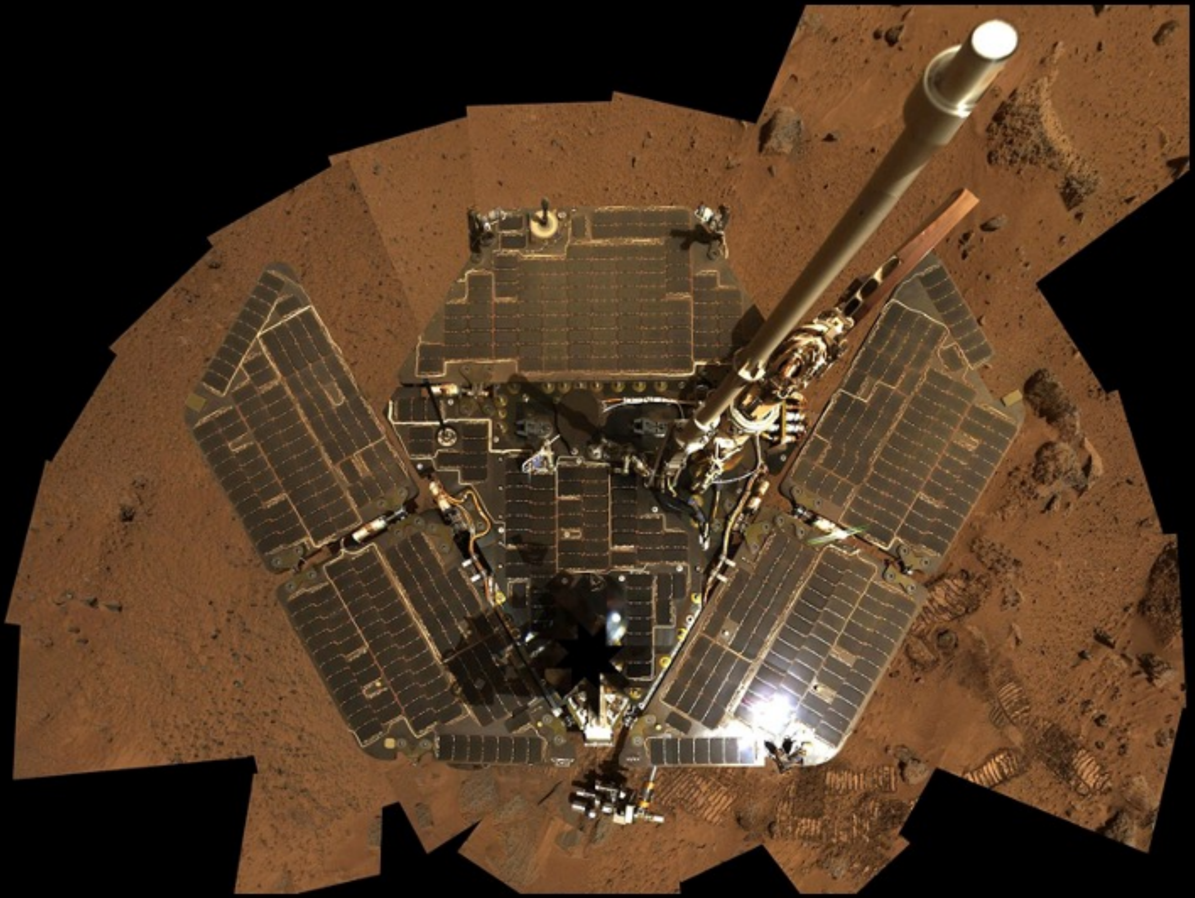
LSIC DUST MITIGATION FOCUS GROUP MEETING
MARCH 17, 2022

Figure 5.7.1: Apollo image AS17-134-20472. Apollo 17 astronaut Jack Schmitt at the lunar roving vehicle after his third EVA. Astronaut Schmitt's spacesuit became particularly dirty as he was eager to get near the surface to get close-up views of the samples he collected (Schmitt, personal communication, and https://apolloinrealtime.org/17/?t=144:51:01)

”Harrison “Jack” Schmitt said that on Apollo 17 he had to keep brushing the dust off his visor… By the end of the third moonwalk, his glove had so badly scratched the visor that it was difficult to see."



Mars Exploration Rover: Opportunity
(image credit: NASA/JPL)

Current Dust Mitigation Technologies

Reviewed by Afshar-Mohajer et al., 2015

Fluidal Methods

Gases or foams/liquids (e.g., *Peterson and Bowers, 1990; Wood ,1991*)

Mechanical Methods

Mechanical brush or vibrational surface (e.g., *Tatom et al., 1967; Gaier et al., 2011a,b; Gaier et al., 2012*)

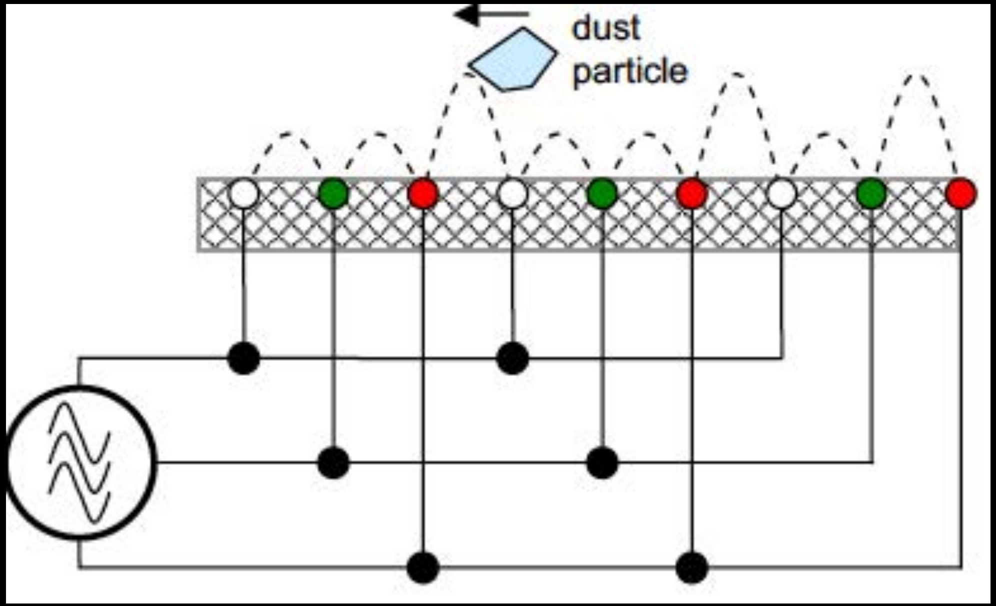
Electrodynamic Dust Shield (EDS)

Dust (charged) is released by an oscillating high-voltage on electrodes embedded beneath the surface of equipment (e.g., *Sims et al., 2003; Calle et al., 2006, 2009, 2011; Manyapu et al., 2017; Kawamoto and Hashime, 2018*)

Passive Methods

Surface modification to reduce the dust-surface adhesion (e.g., *Gaier et al., 2011a,b; Dove et al., 2011*)

Electrodynamic Dust Shield (EDS)



Calle et al., 2011

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Dust mitigation technology for lunar exploration utilizing an electron beam

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Improvement of the electron beam (e-beam) lunar dust mitigation technology with varying the beam incident angle

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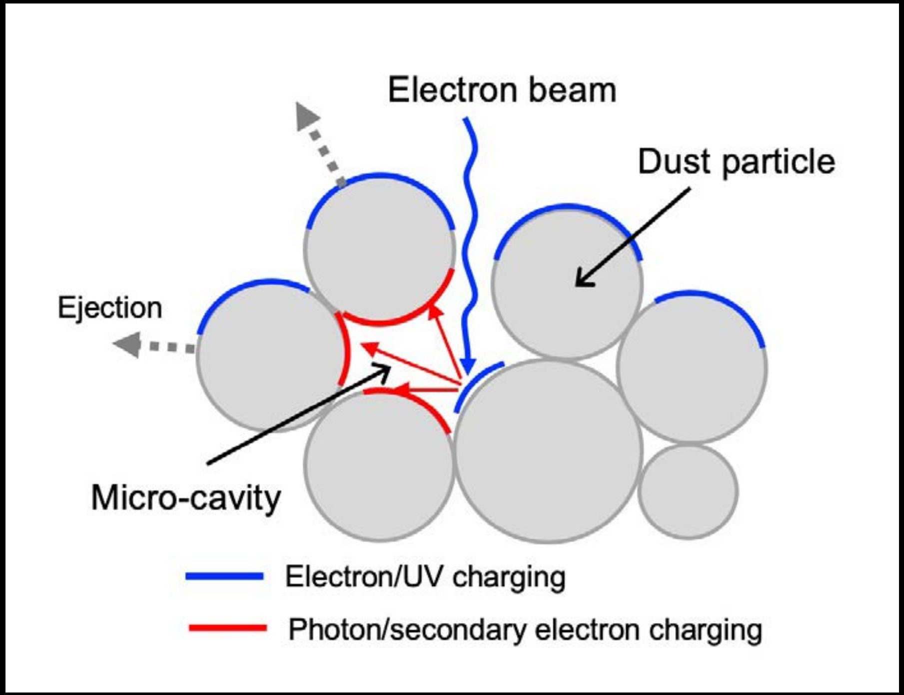
New Dust Mitigation Method Utilizing an Electron Beam

It is developed based on previous studies for a natural process of electrostatic dust lofting that may occur on the surfaces of airless bodies (e.g., the Moon and asteroids)

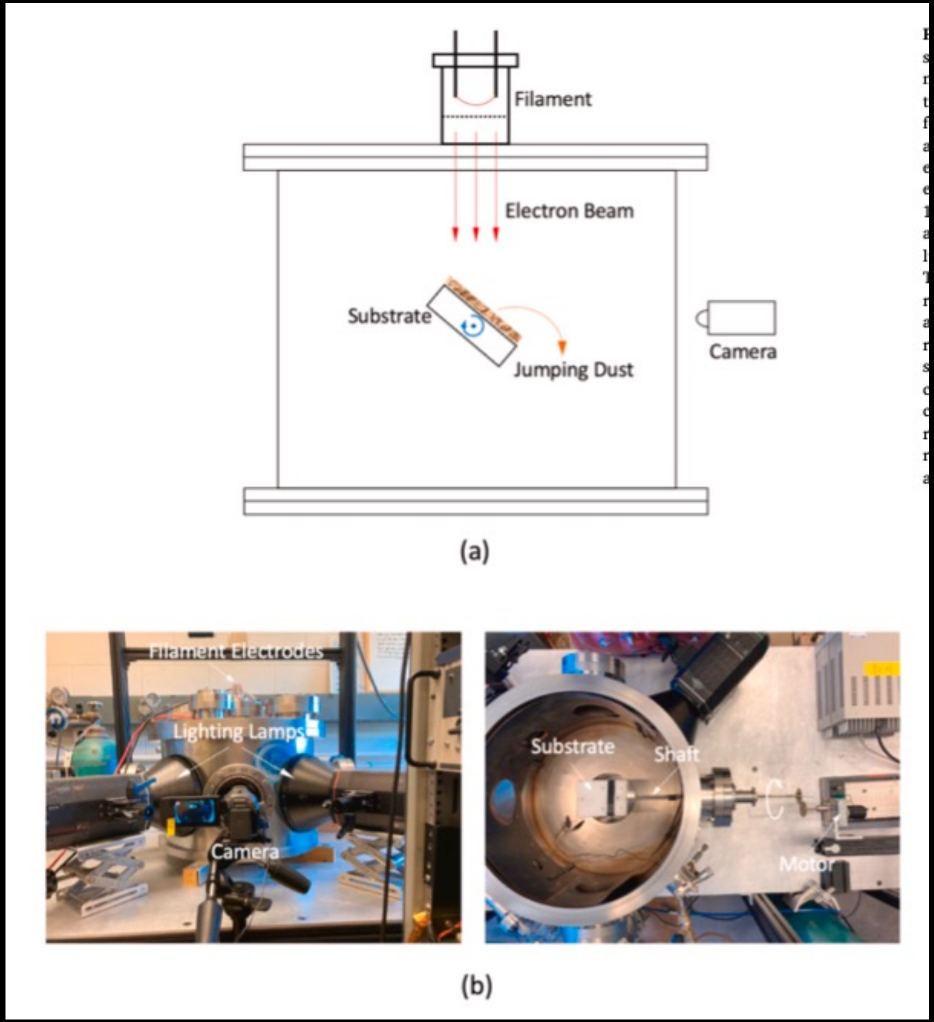
Dust Charging and Releasing Mechanisms



Wang et al., 2016

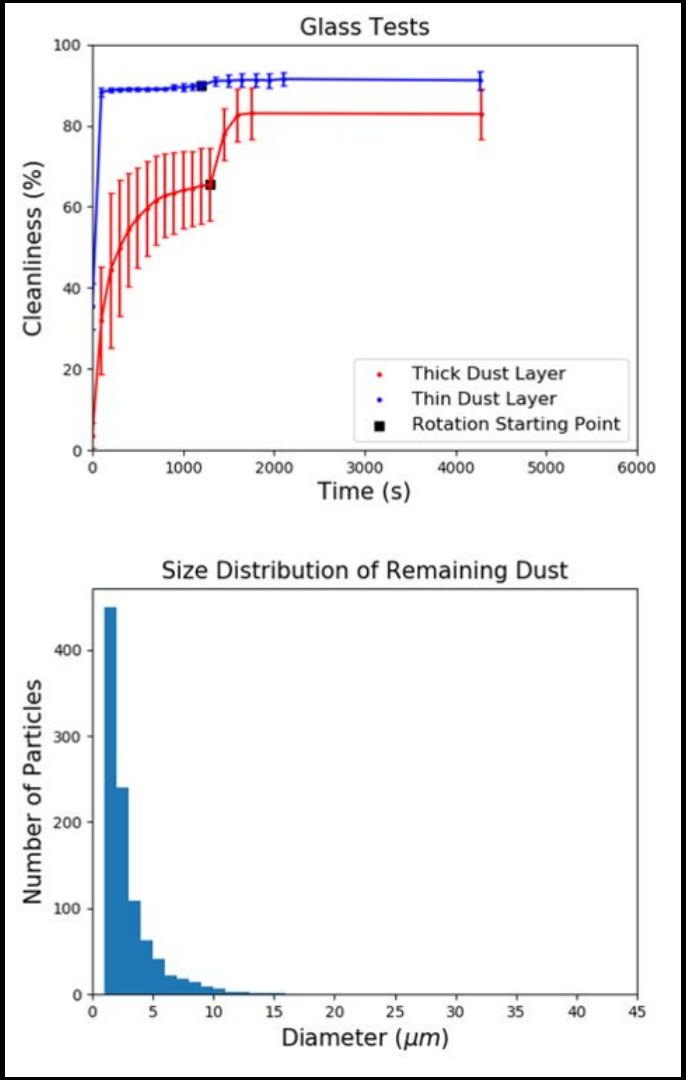
- A new Patched Charge Model was developed to explain dust charging and releasing due to electrostatic forces.
- Secondary electrons or photoelectrons are absorbed inside a microcavity and collected by the surrounding particles, resulting in substantial negative charge buildup on their surfaces.
- The repulsive force between the negatively charged particles ejects them off the surface.

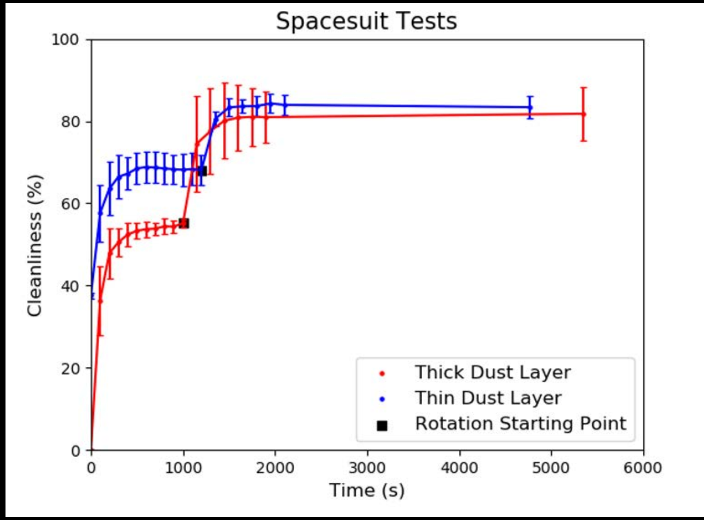
Experimental Setup

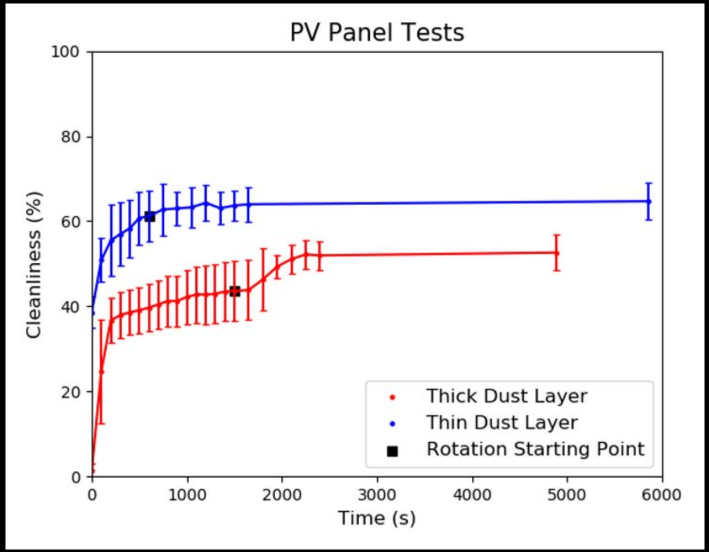


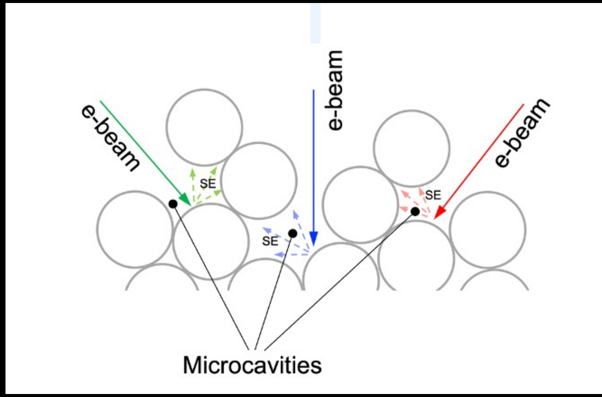
- Electron Beam
  - 80 – 230 eV
  - 0.3 – 6.1 μA/cm^2
- Dust
  - Lunar simulant JSC-1A (< 25 μm in diameter)
- Substrate
  - Glass, spacesuit sample, solar panel

Improvement of cleaning with varying the beam incident angle









$$C = (L_s - L_d)/(L_c - L_d)$$

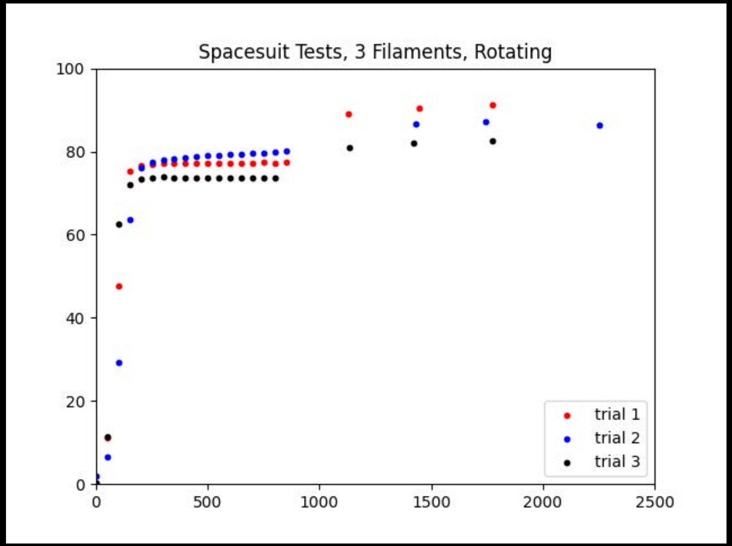
L_s is the average pixel brightness of the sample surface

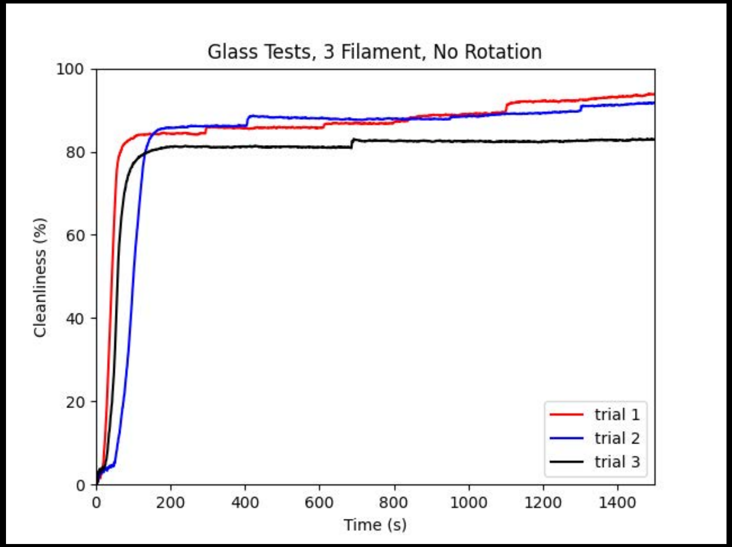
L_c is the average pixel brightness of the clean surface (no dust)

L_d is the average pixel brightness of the surface fully covered by dust

B. Farr et al. Acta Astronautica, 188, 362 (2021)

Three beam source results





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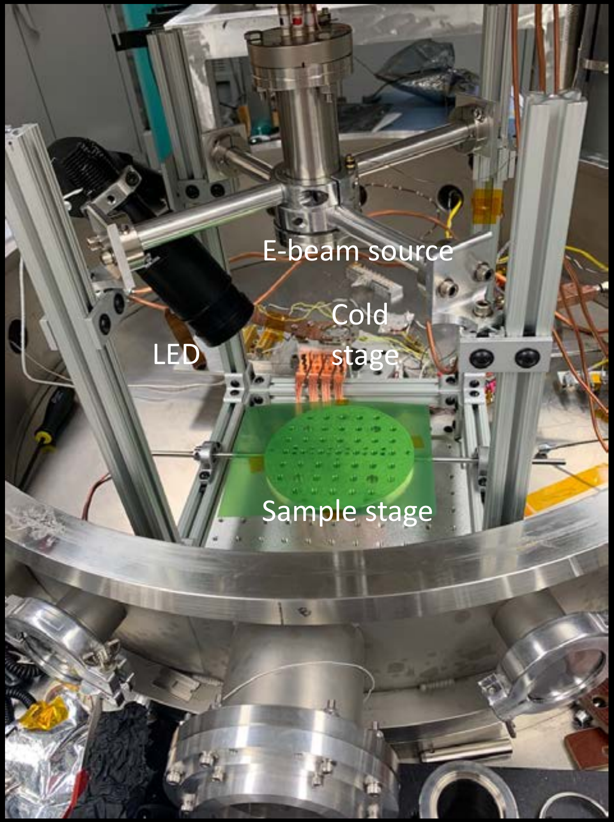
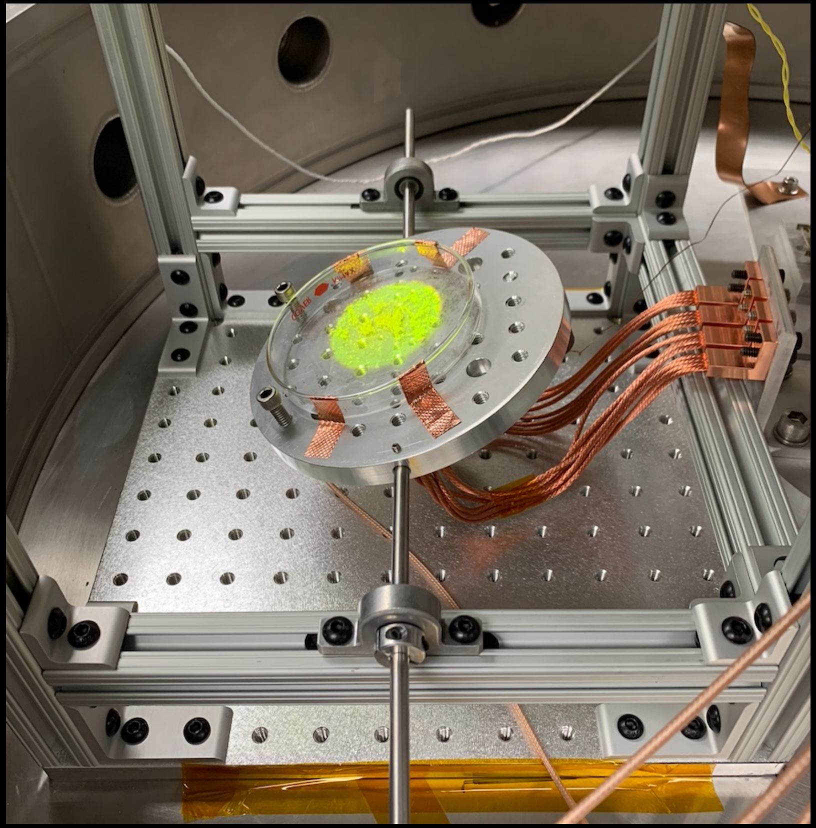
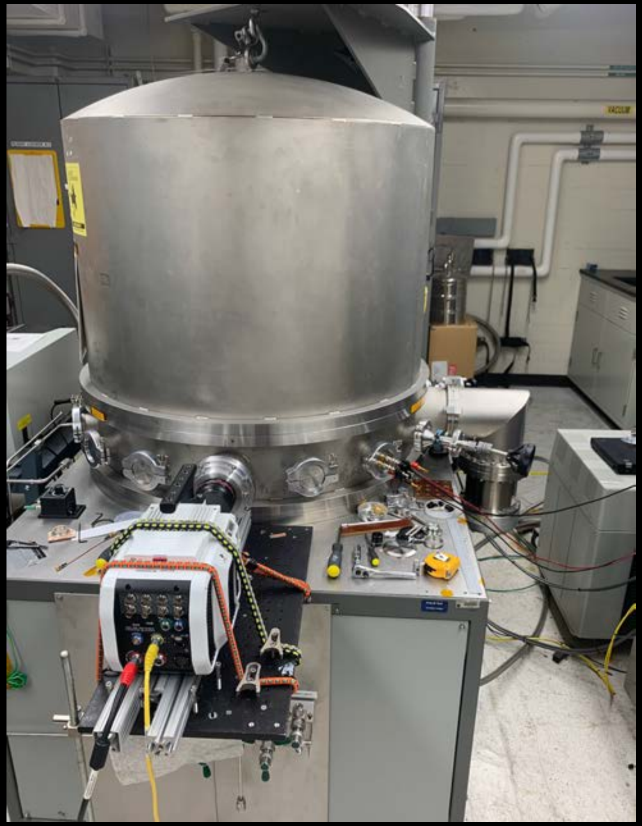
Low temperature test setup

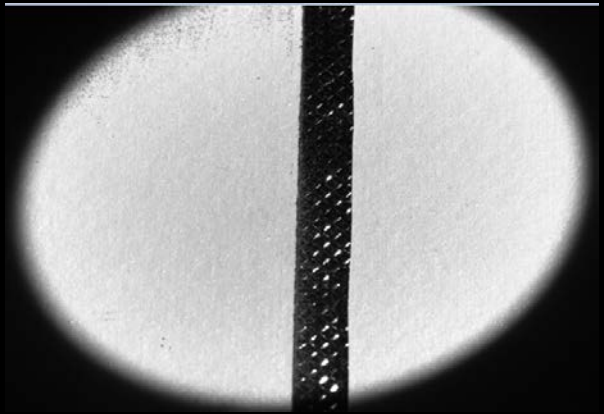


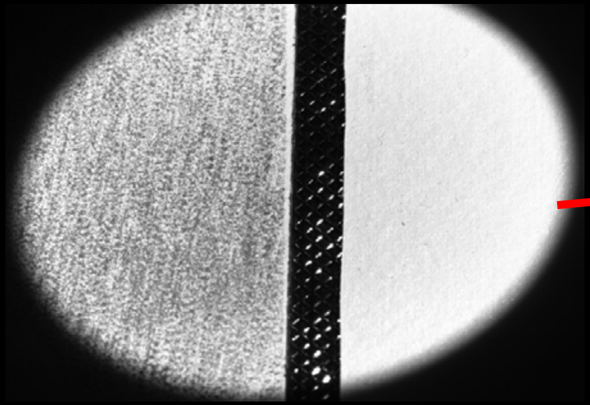




The testbed setup is completed to test the e-beam technology with LHS-1 simulant on various substrates at temperature below -100degC.

Room-T vs Low-T (dust on glass)





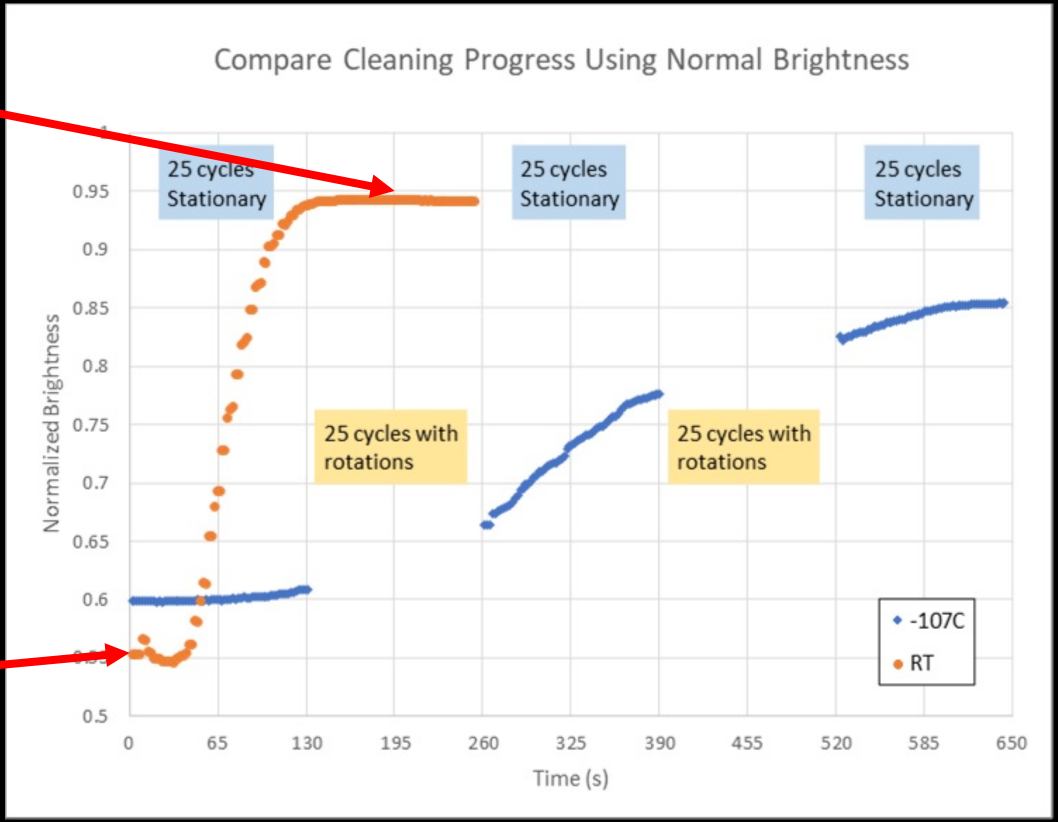
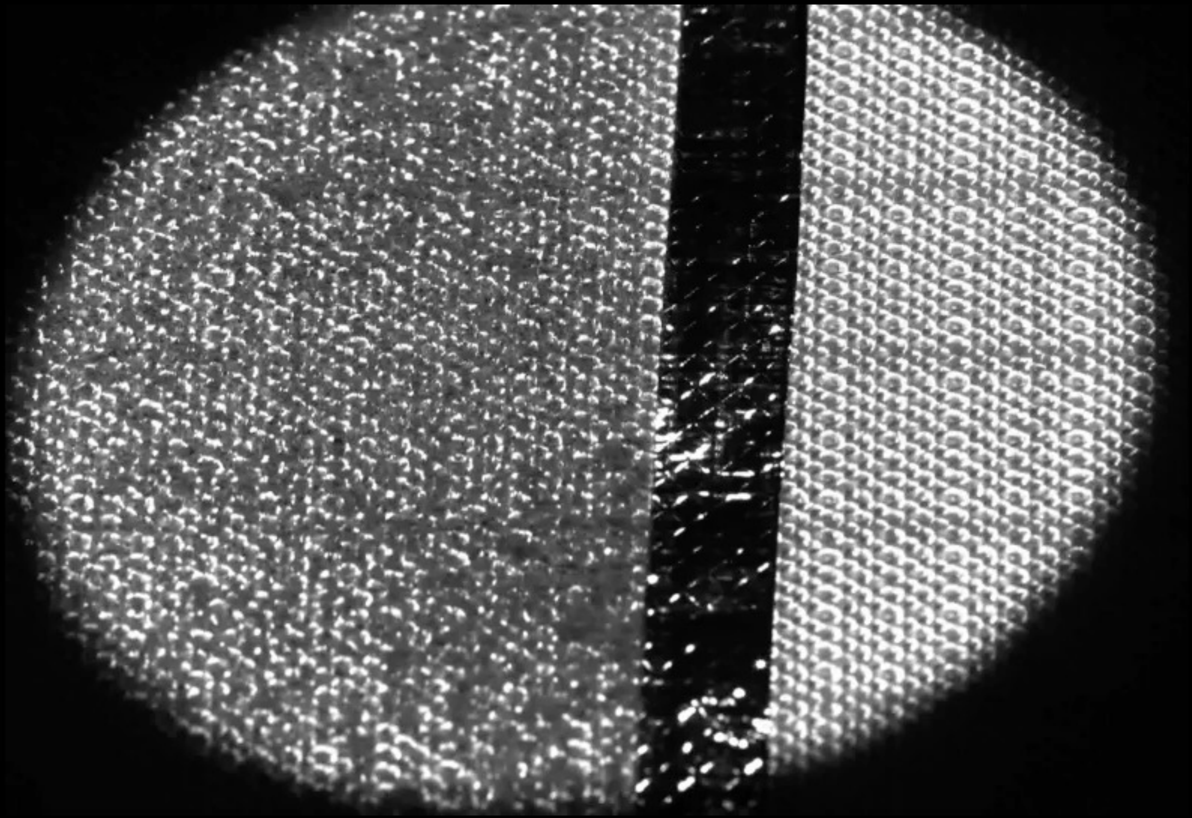
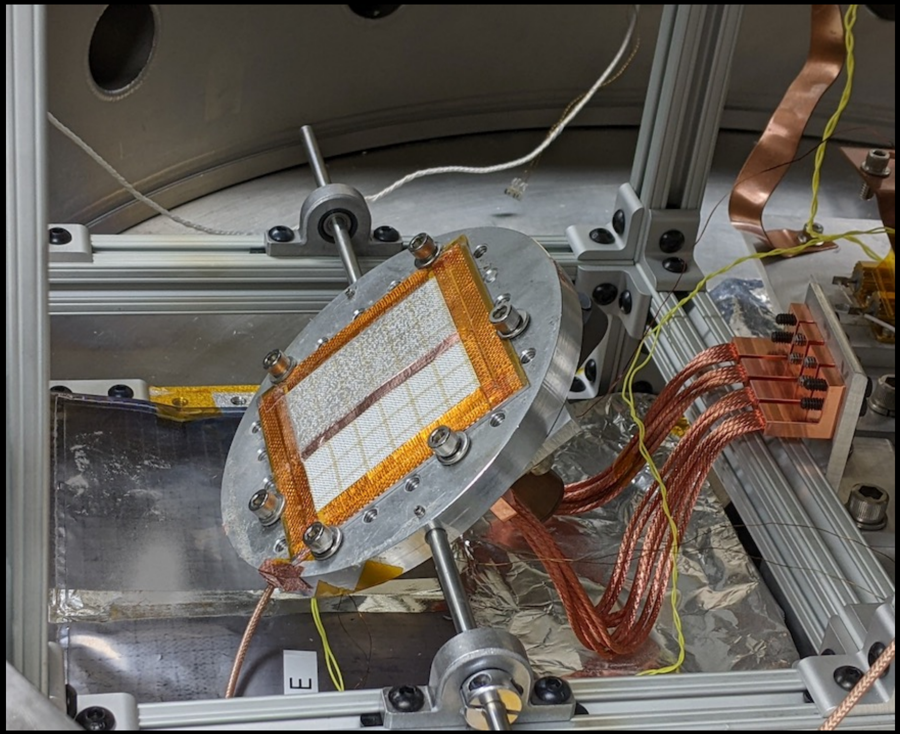


Figure Caption

- The room-T test (orange) was done without sample rotations
- The low-T test (Blue) was done with sample rotations.
- The low-T, no-rotation test (not shown) requires much longer removal time, > 30 minutes.

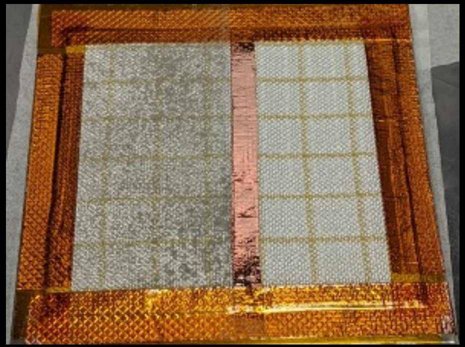
Room-T (dust on Ortho Fabric spacesuit)

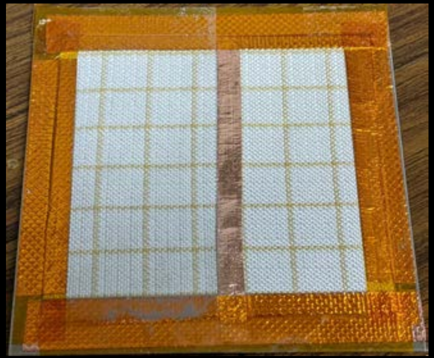




Speed: x40 real time

Thanks to Christopher Wohl (LHS-1 Milled simulant: mean size ~ 10micron) and Everlyne Orndoff (Ortho Fabric)

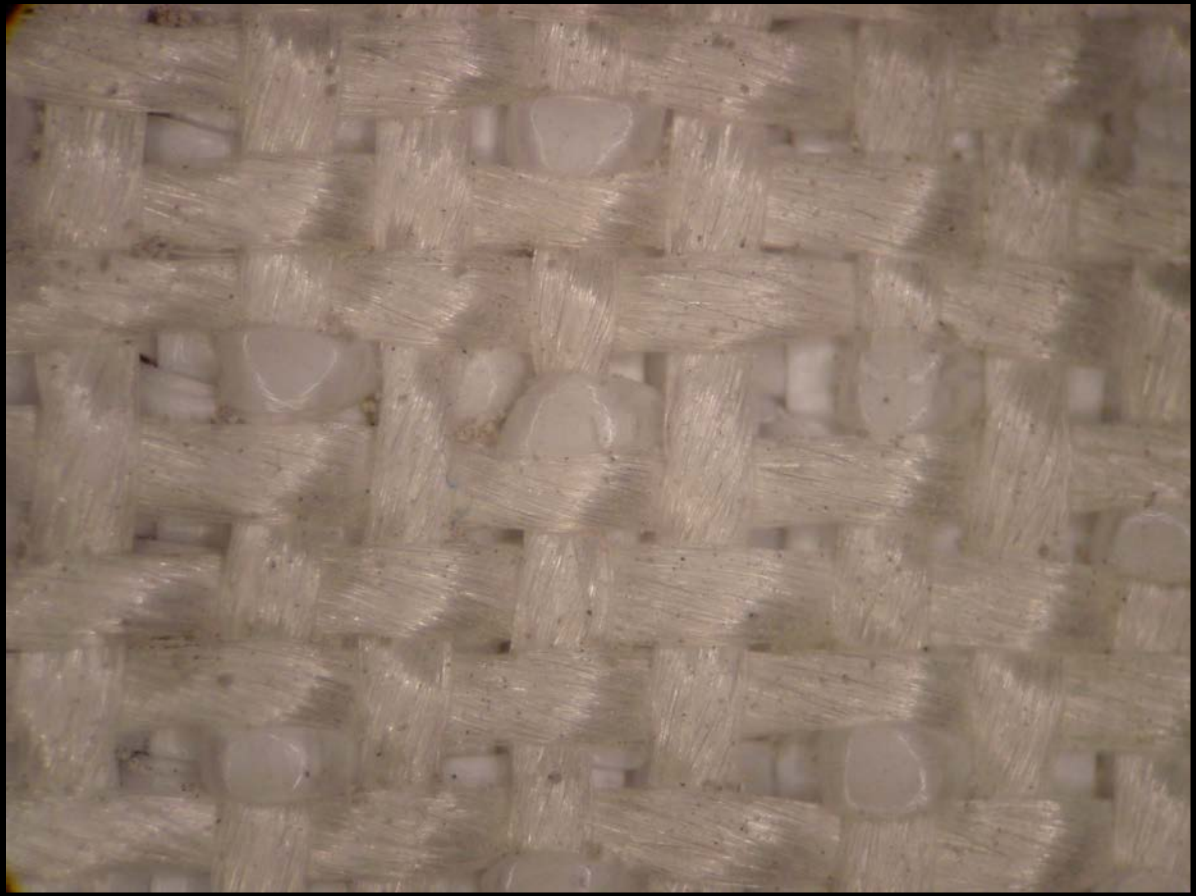




Room-T (dust on Ortho Fabric spacesuit)

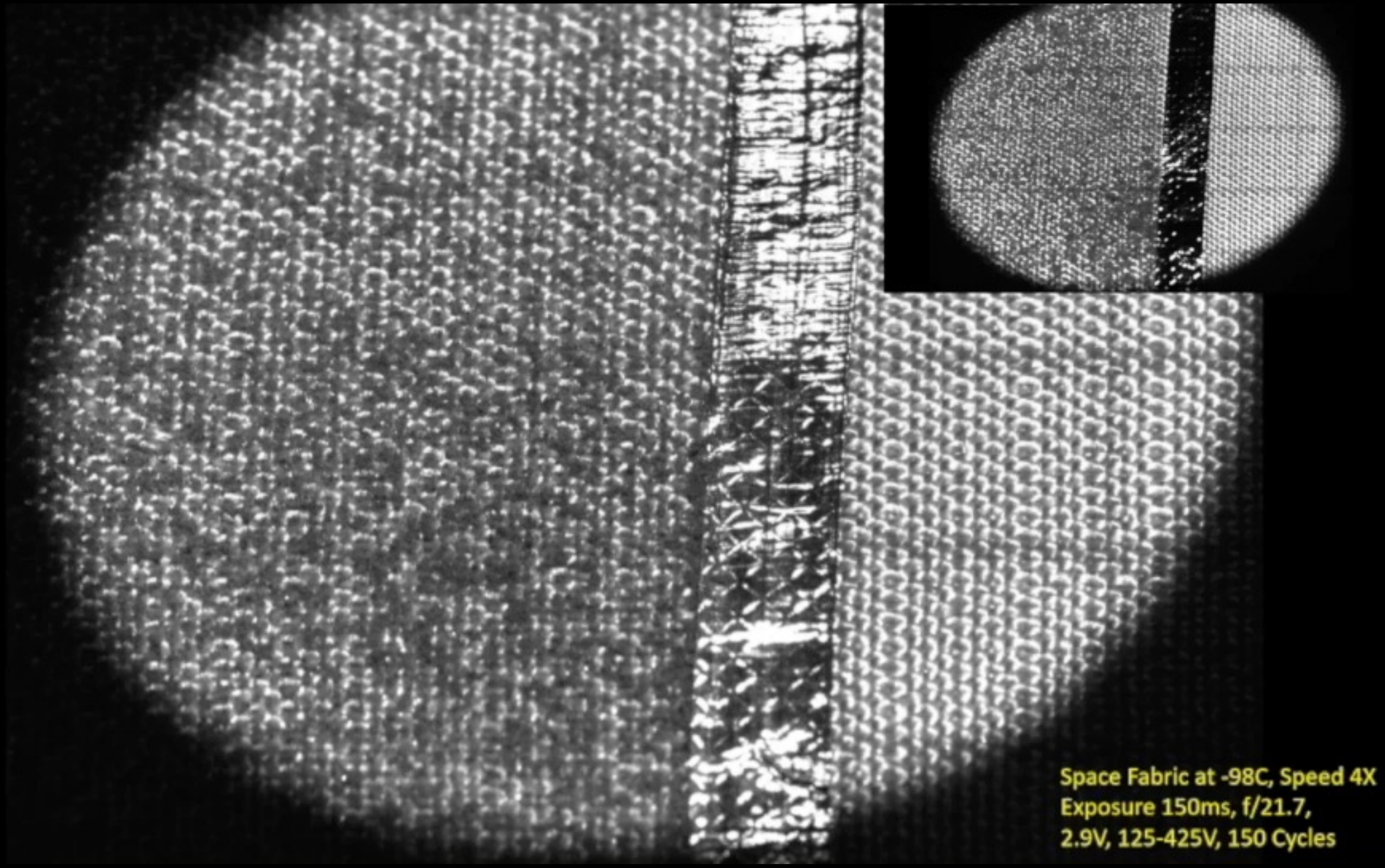
Before

after



Magnification: x25

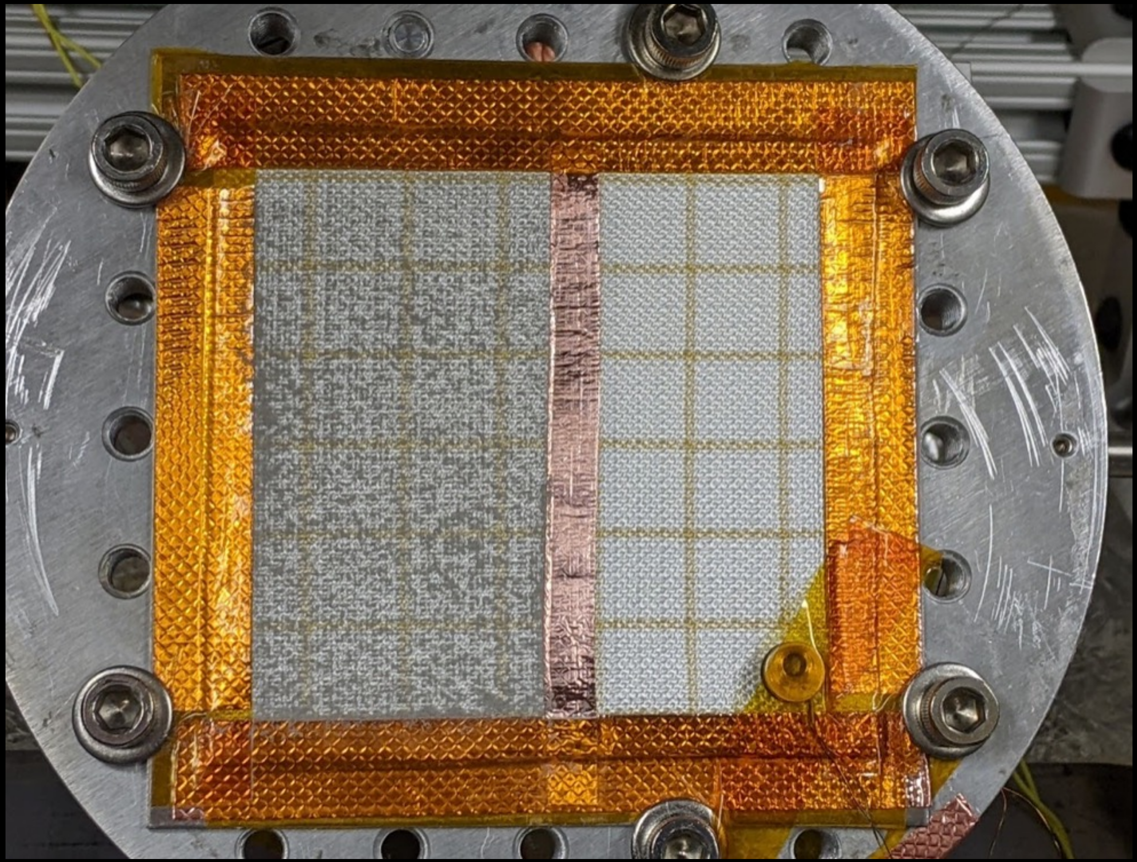
Low-T (dust on Ortho Fabric spacesuit): -98degC



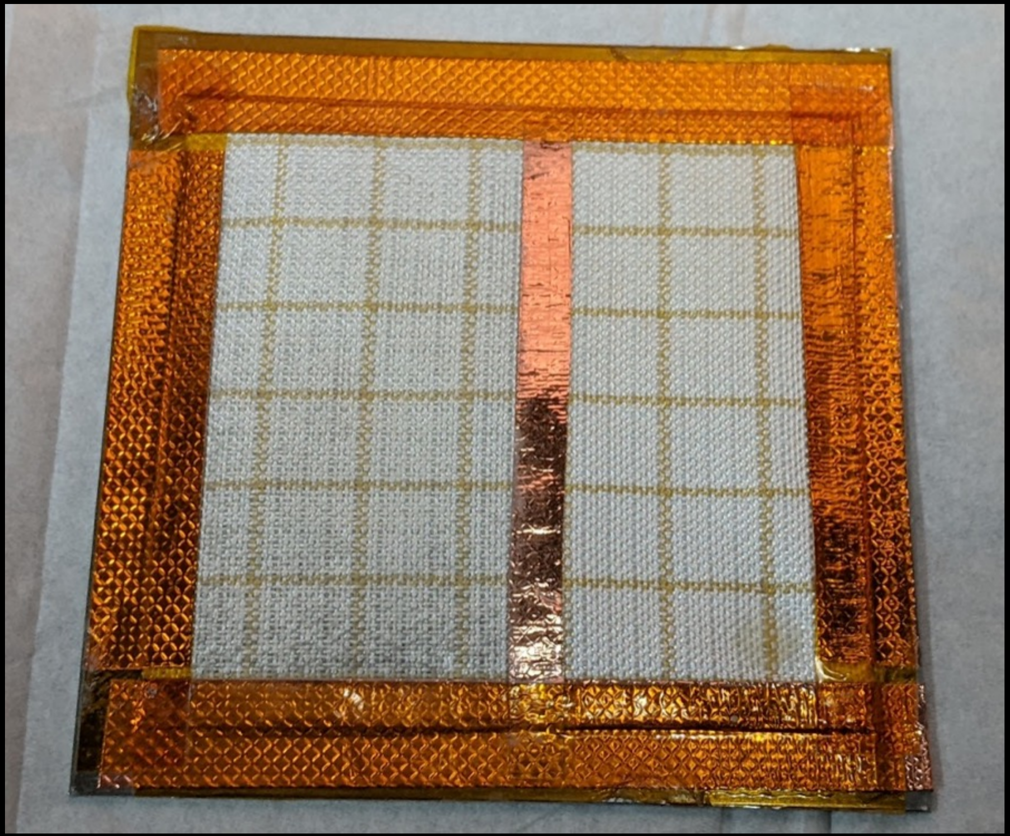
Speed: x40 real time
Inset clip is from the room-T run previously shown.
Same e-beam parameters are used.

Low-T (dust on Ortho Fabric spacesuit): -98degC

Before



after



Future Work

- Improving efficiency of dust cleaning
  - e-beam profile
  - Energy
  - Flux
- Path toward a flight tech-demo mission
  - Design/Fab/Test of a TRL-5 level prototype e-beam gun, electronics.

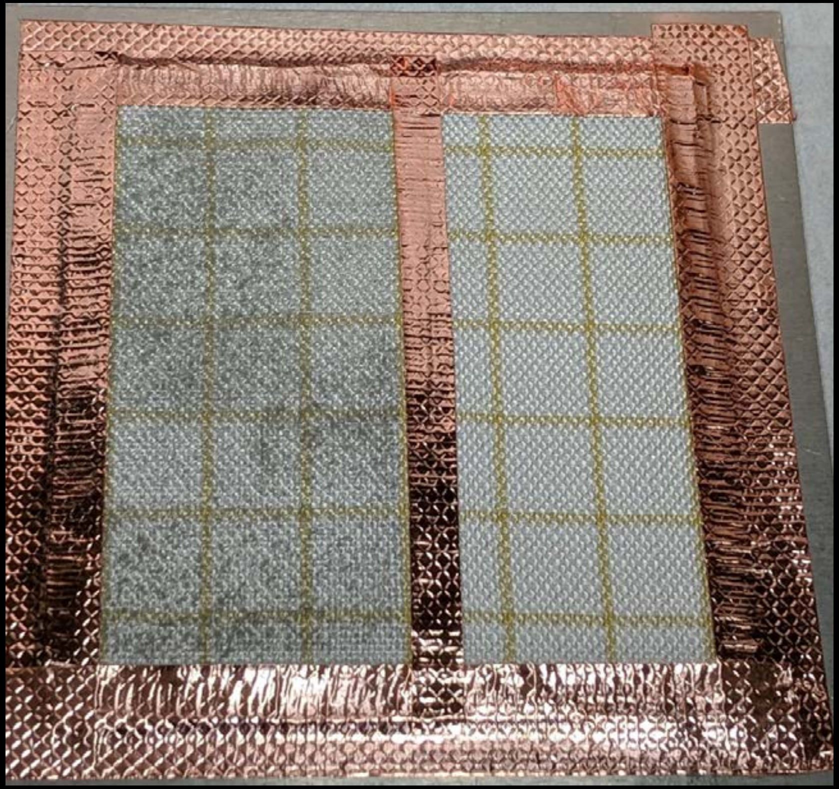
Thank You

This work is supported by **NASA/BPS** and **NASA/STMD**/Game Changing Development/**Lo-DuSST** project, and by the **NASA/SSERVI**′s Institute for Modeling Plasma, Atmospheres and Cosmic Dust (IMPACT).

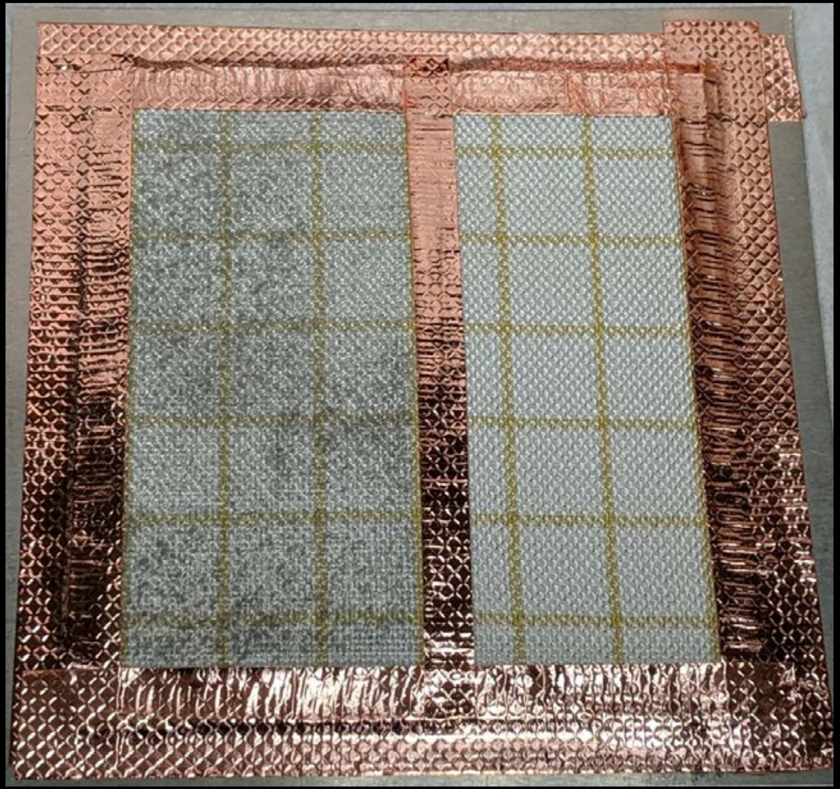
Adhesion/cohesion test on Ortho Fabric: “quick & dirty”

Detachment not noticeable during upside down motion and at vertical position

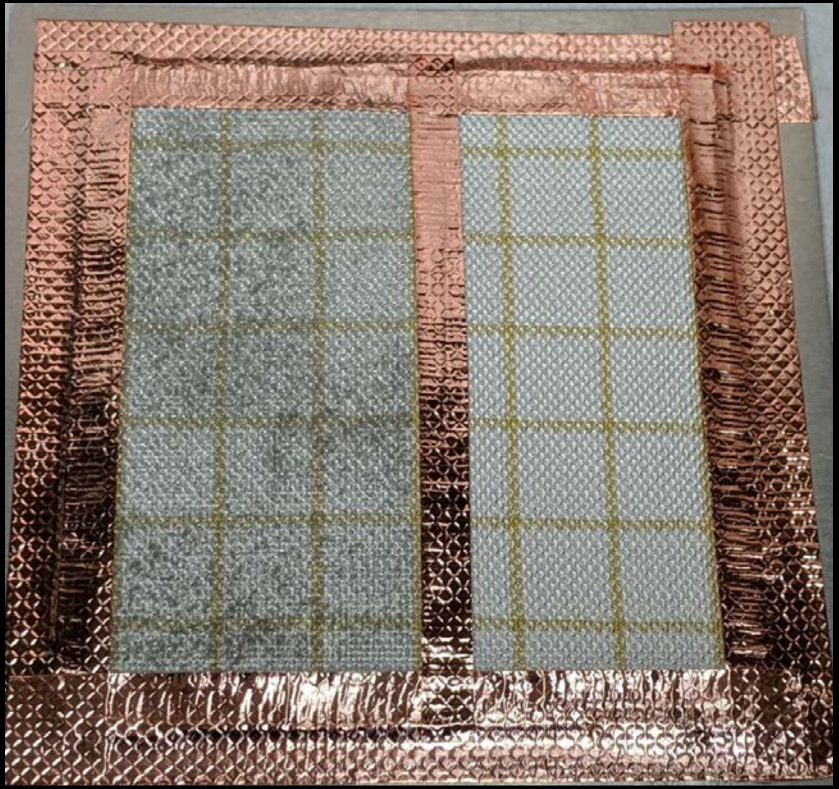
Original



After being turned facing down



After being turned vertically



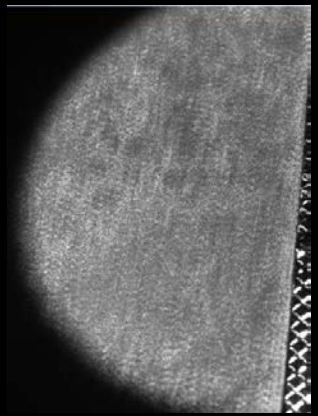
Adhesion/cohesion test on glass: “quick & dirty”

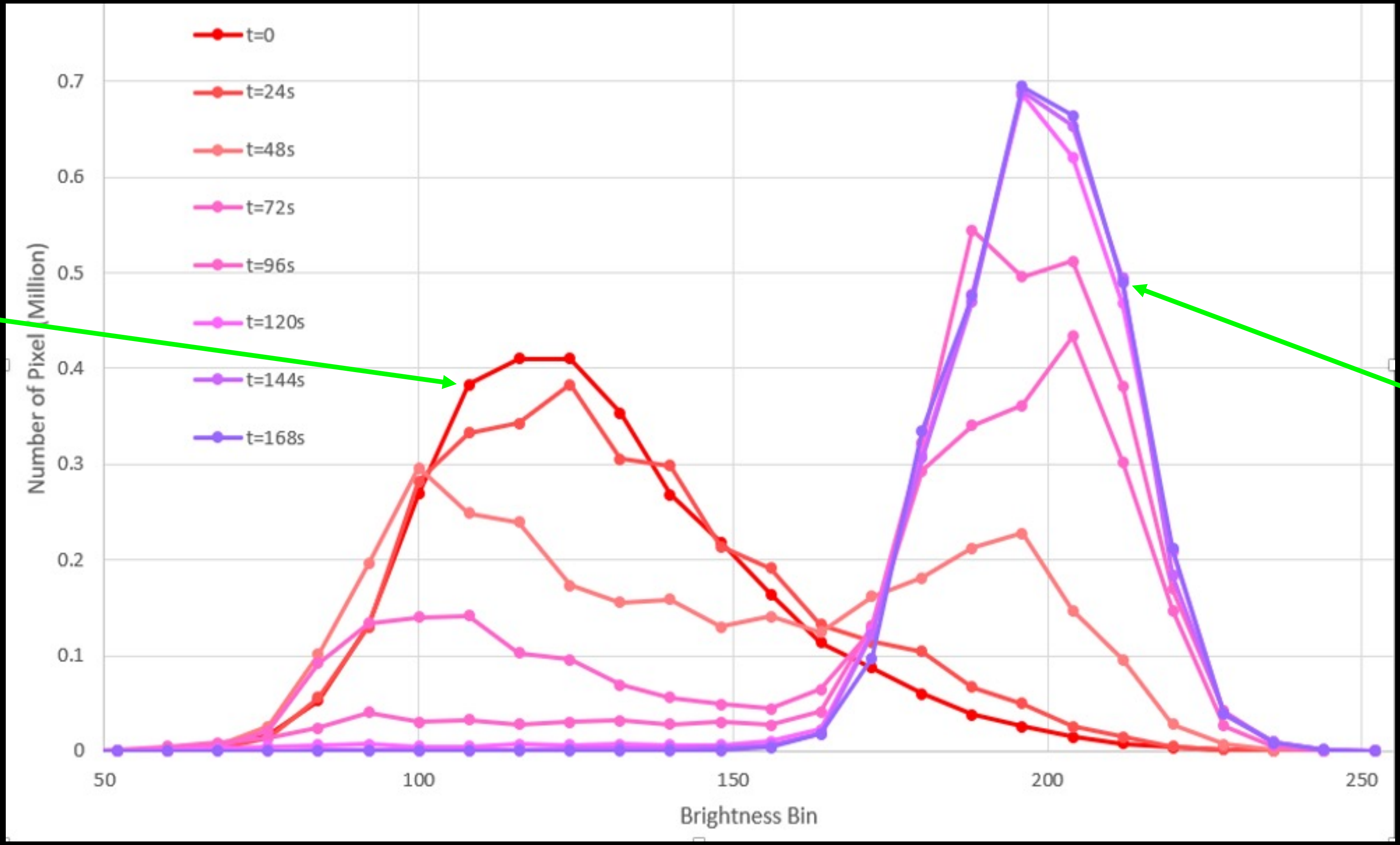
No detachment during upside down motion
some portion slid down at vertical position

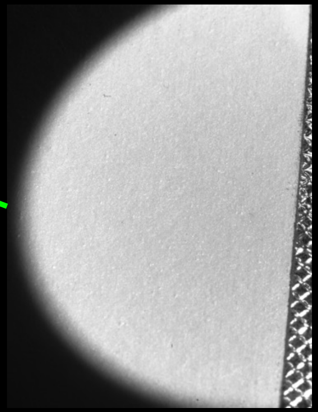
Original

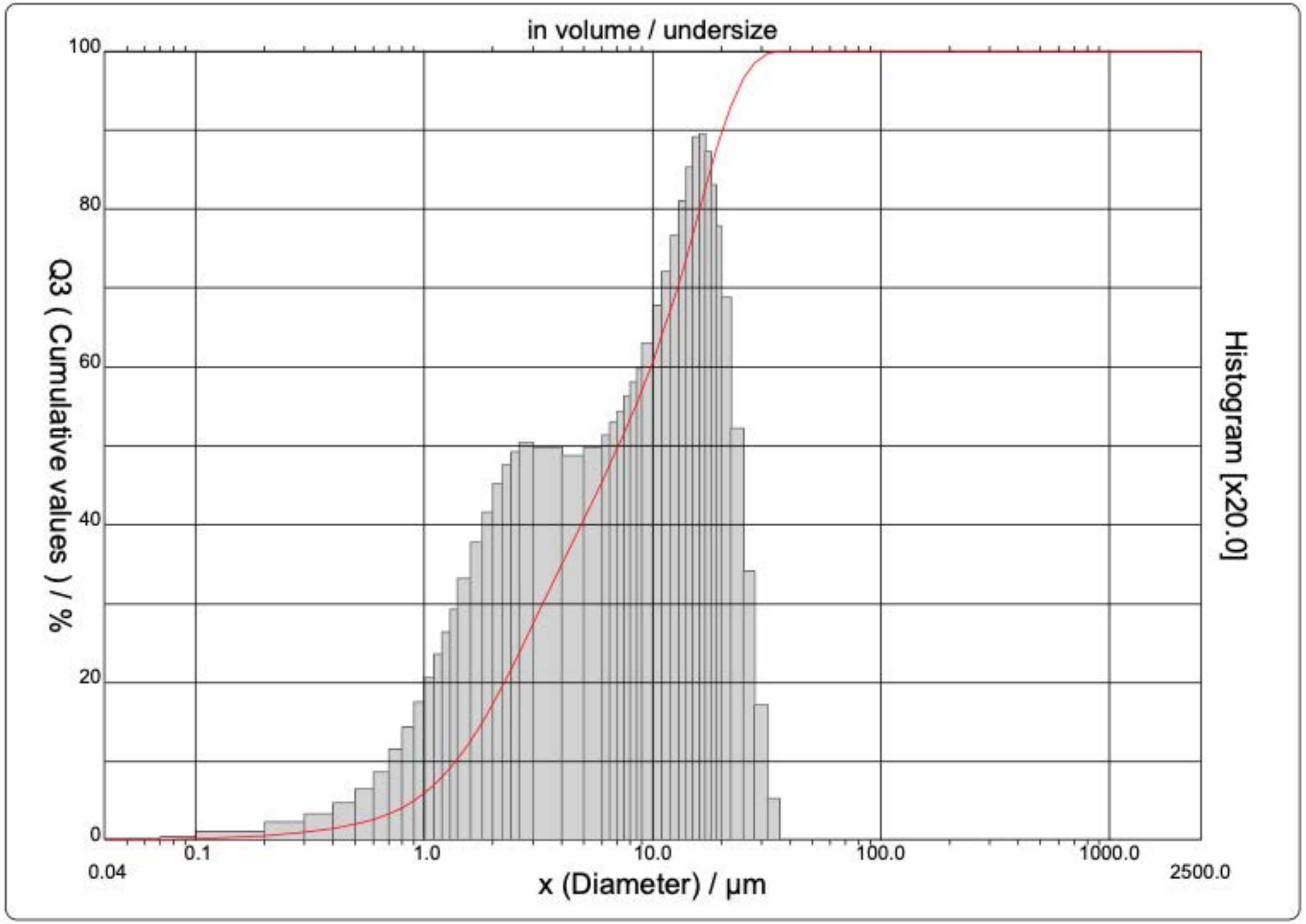
After being turned vertically

Histogram Analysis








in volume / undersize
100
80
60
40
20
0
Q3 (Cumulative values) / %
Histogram [x20.0]
0.04
0.1
1.0
10.0
100.0
1000.0
2500.0
x (Diameter) / µm

Room-T (dust on solar cell: preliminary)

same e-beam parameters as glass substrate for comparison, a portion of dust is compressed down.

Speed: x40 real time

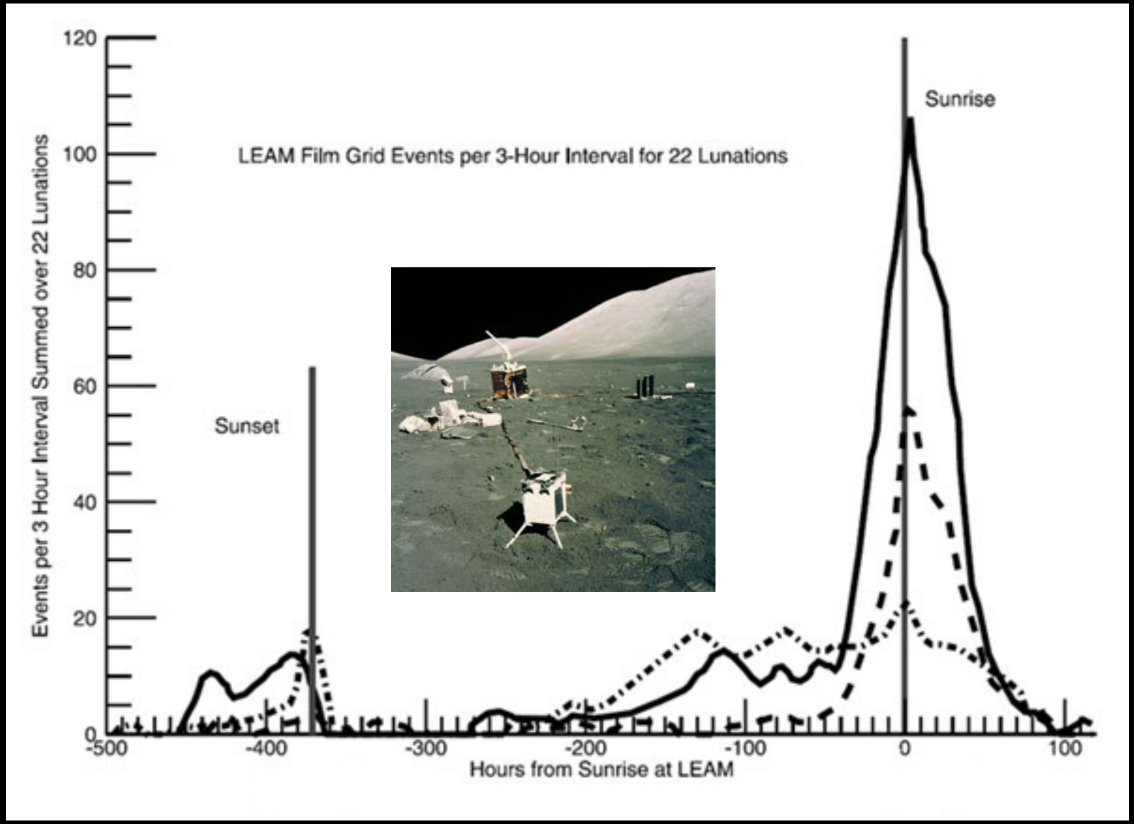
A part of work was done in collaboration with Joel Schwartz at JPL

Lunar Dust Hazards due to Natural Processes
(Electrostatic dust lofting/transport)

Lunar Horizon Glow

Rennilson & Criswell, 1974

Low-speed Dust Detection
by the Lunar Ejecta and Meteorites (LEAM) experiment



Berg et al., 1976

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