# Strategies Toward Lunar Dust Adhesion Mitigation

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*Specific vendor and manufacturer names are explicitly mentioned only to accurately describe the hardware used in this study. The use of vendor and manufacturer names does not imply an endorsement by the U.S. Government nor does it imply that the specified equipment is the best available.*

# Outline

- Why lunar dust?
- Lunar dust adhesion mitigation
- Evaluation of mitigation efficacy
- Conclusions and outlook
- Acknowledgements

Image credit: NASA

# The Lunar Environment

**Low Gravity**
1/6$^{th}$ of Earth's gravity

**Lack of Atmosphere**
$10^{-12}$ Torr

**Elevated Radiation Exposure**
~200x more than Earth
~2.6x higher than that of International Space Station (ISS)

**Extreme Temperature Variation**
127°C to
-173°C

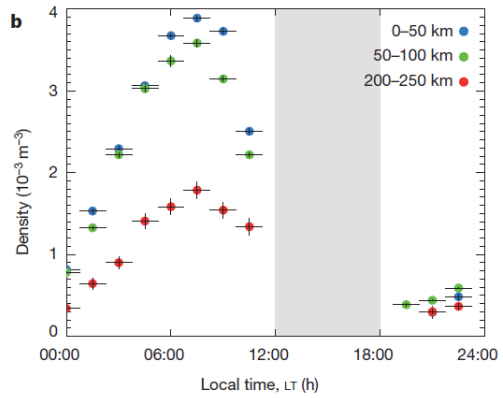
**Lunar Regolith**
Particle size by weight,
50% < 50 µm
20% < 20 µm
1% < 1 µm

Image credit: NASA

# What, Where, and Why of Lunar Dust

## Particle Counts

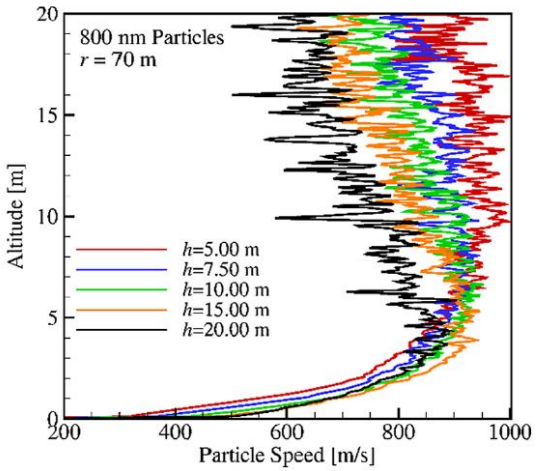
Lunar Dust Experiment (LDEX) Results



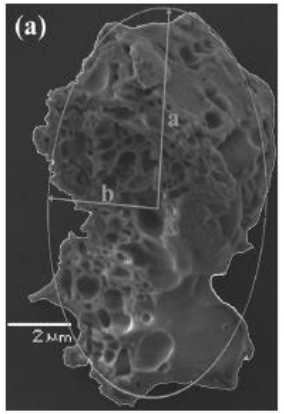

Particle counts as high as 4 x $10^{-3}$ m$^{-3}$ up to 50 km off the lunar surface. Increased particle counts at terminator.

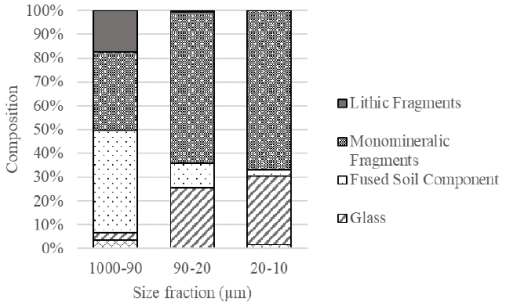
Single engine plume impingement can generate particle velocities > 1000 m/s.

## Particle Velocity



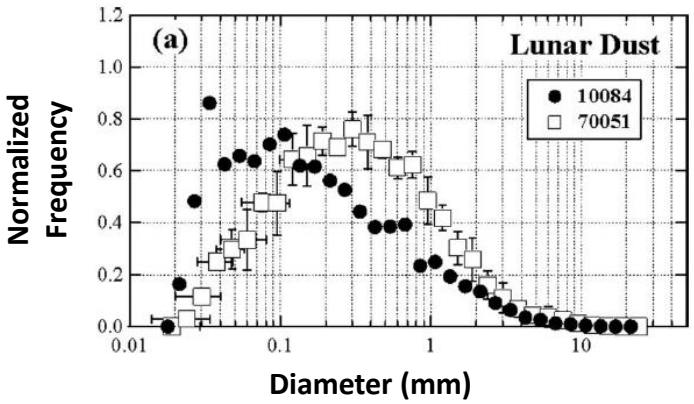

## Particle Morphology



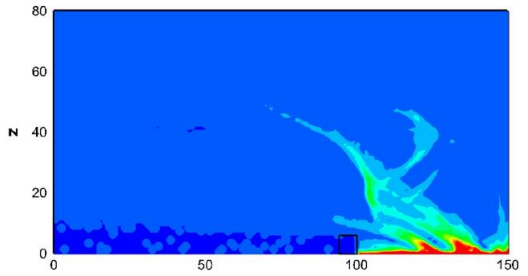

Smooth, glassy spheres <-> High angularity agglutinates

## Particle Size



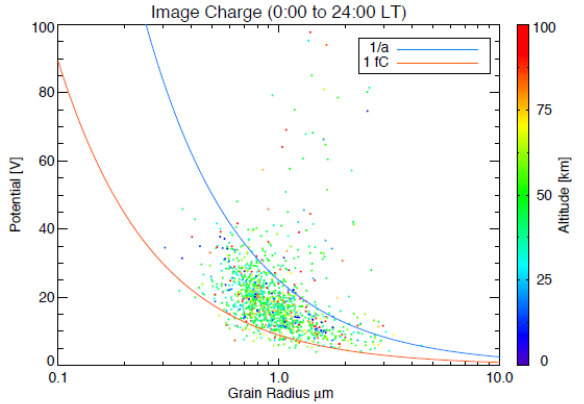

Lunar dust particles range from nm to up to 50 µm in diameter.

Simulated Lofted 10 µm Dust




## Electrostatic Environment

LDEX Results




*Wohl, Christopher J.; et al., "Lunar Dust Considerations for Vertical Solar Arrays, Volume 1: Lunar Environment and Dust Interactions," NASA Technical Memorandum, 2024, TM-20240003496.*

# Natural vs. Anthropomorphic Lunar Dust Exposure

**Dust Accumulation from Natural Phenomena**

100 μg/cm$^2$ annually[1]

**Dust Accumulation from Human Activity**

<u>Lunar landing:</u>

Apollo 14, 848 μg/cm$^2$

<u>Lunar rover:</u>

Dust traveling ~ 20 m away from rover

<u>ISRU and construction:</u>

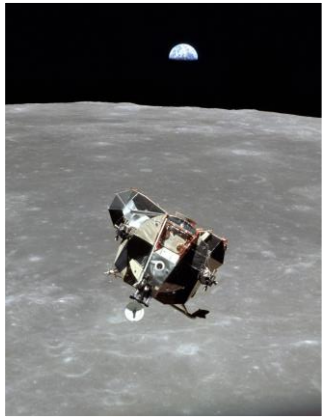
Unknown, likely highly variable

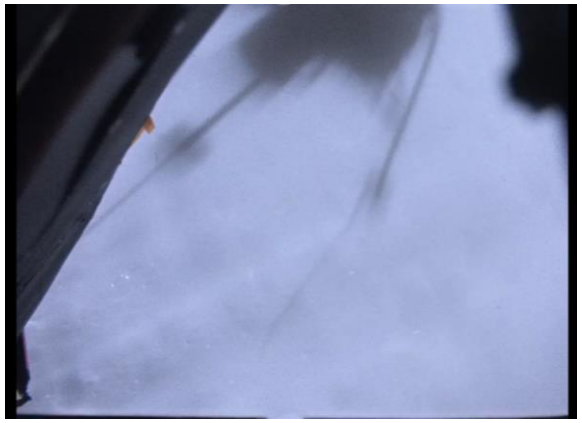
*Image generated using Gemini AI*

*1. Katzan, Cynthia M.; Brinker, David J.; and Kress, Robert: The Effects of Lunar Dust Accumulation on the Performance of Photovoltaic Arrays. Space Photovoltaic Research and Technology Conference, Cleveland, OH, 1991.*

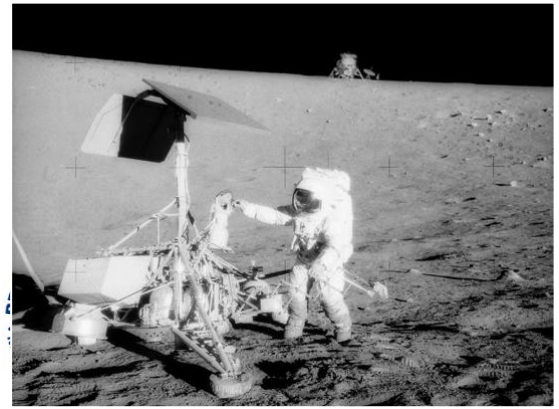
# Lessons from the Apollo Missions

**Land:** Plume surface interactions (PSI)



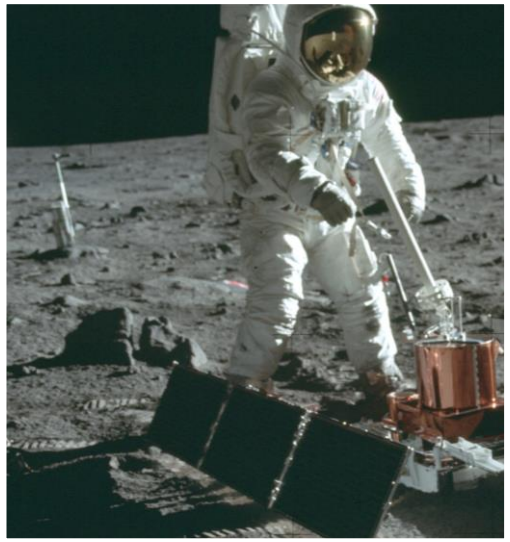


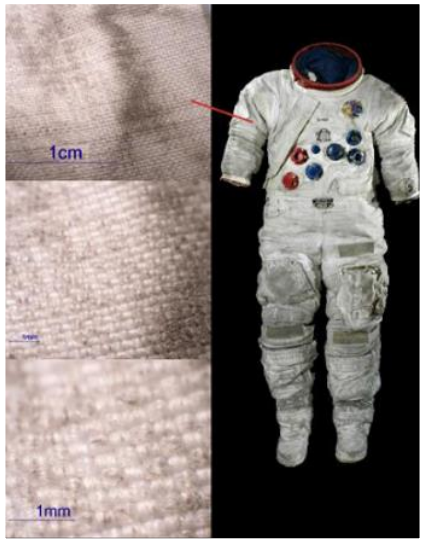
Regolith ejecta from Apollo 12 landing resulted in ***scouring, pitting*** *and* ***cracking*** of nearby Surveyor III's aluminum spacecraft structure



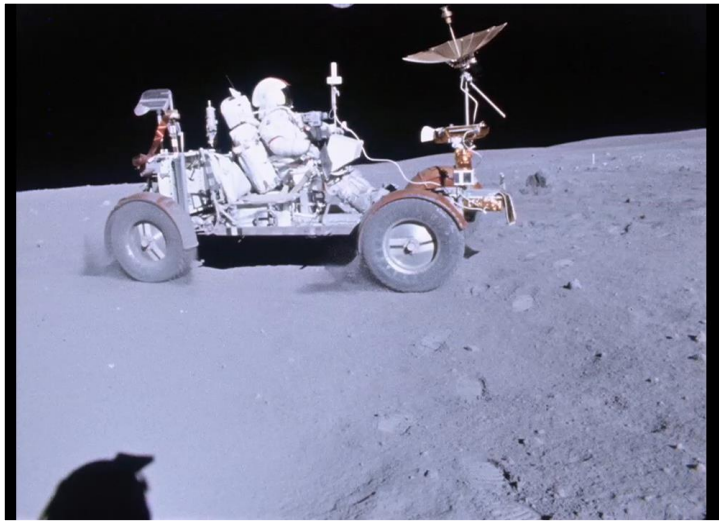
Apollo 12 extravehicular activity (EVA) showing Apollo 12 Lunar Module and Surveyor 3 spacecraft

**Explore:** Human-generated surface transported dust






"Dust is probably one of our greatest inhibitors to a nominal operation on the Moon."
Apollo 17 Commander Gene Cernan



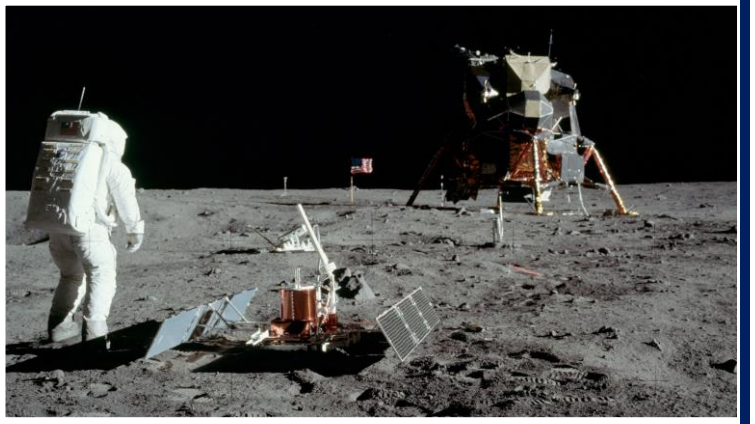
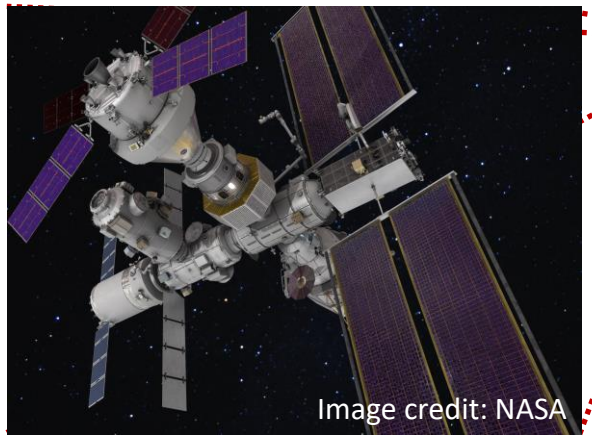
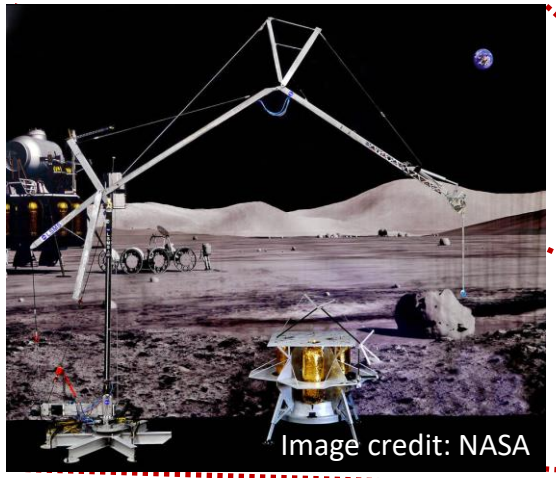


Image credit: NASA

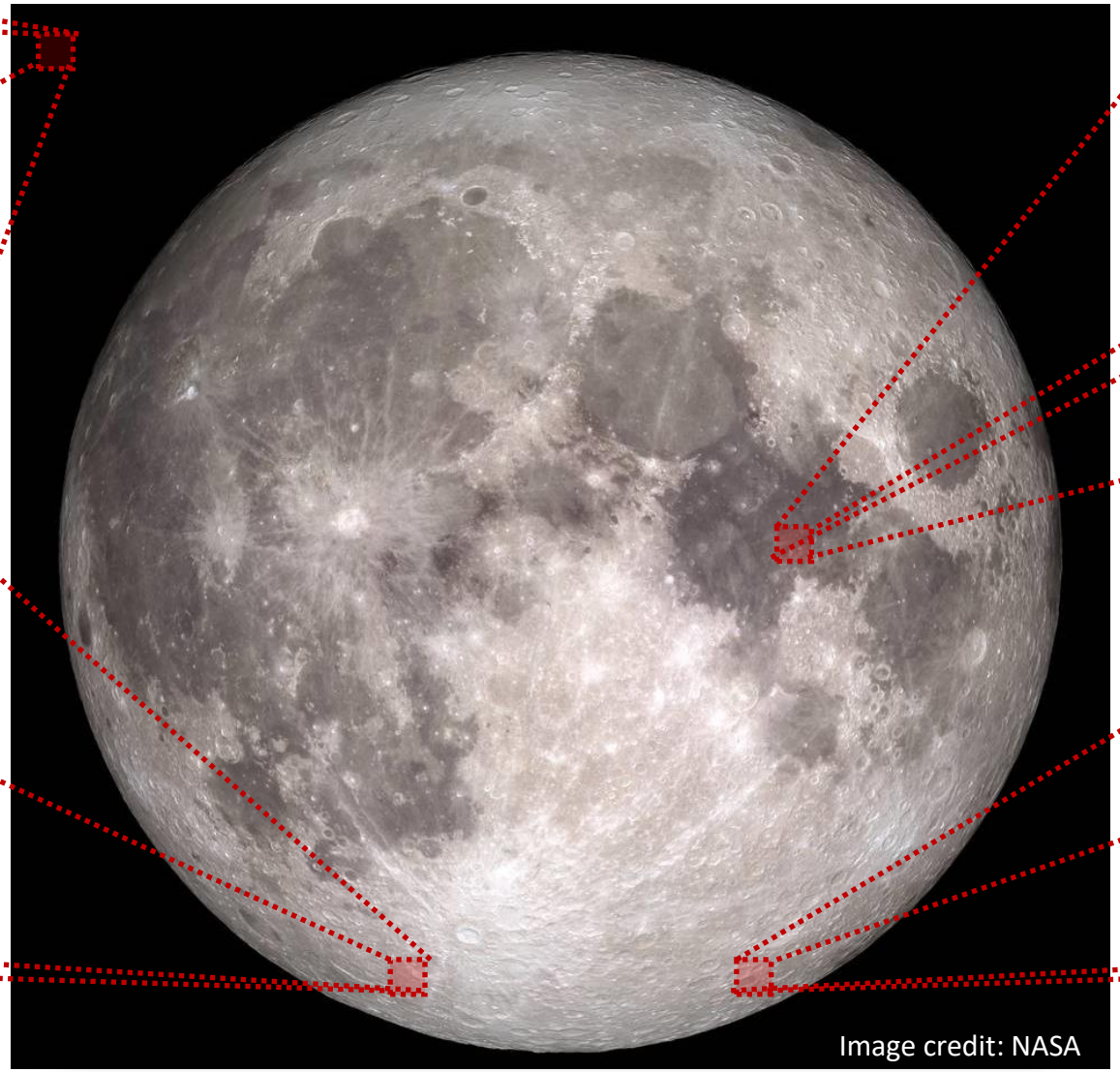
# How do we Consider the Influence Lunar Dust Has?




**Gateway**

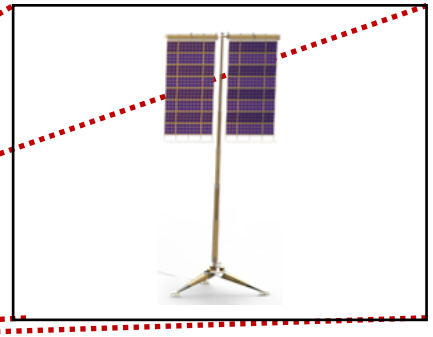



**Infrastructure**




**Lunar Lander**

*Image generated using Gemini AI*



**Vertical Solar Array Technology (VSAT)**

Image credit: NASA

# How do we Approach Lunar Dust Adhesion Mitigation?

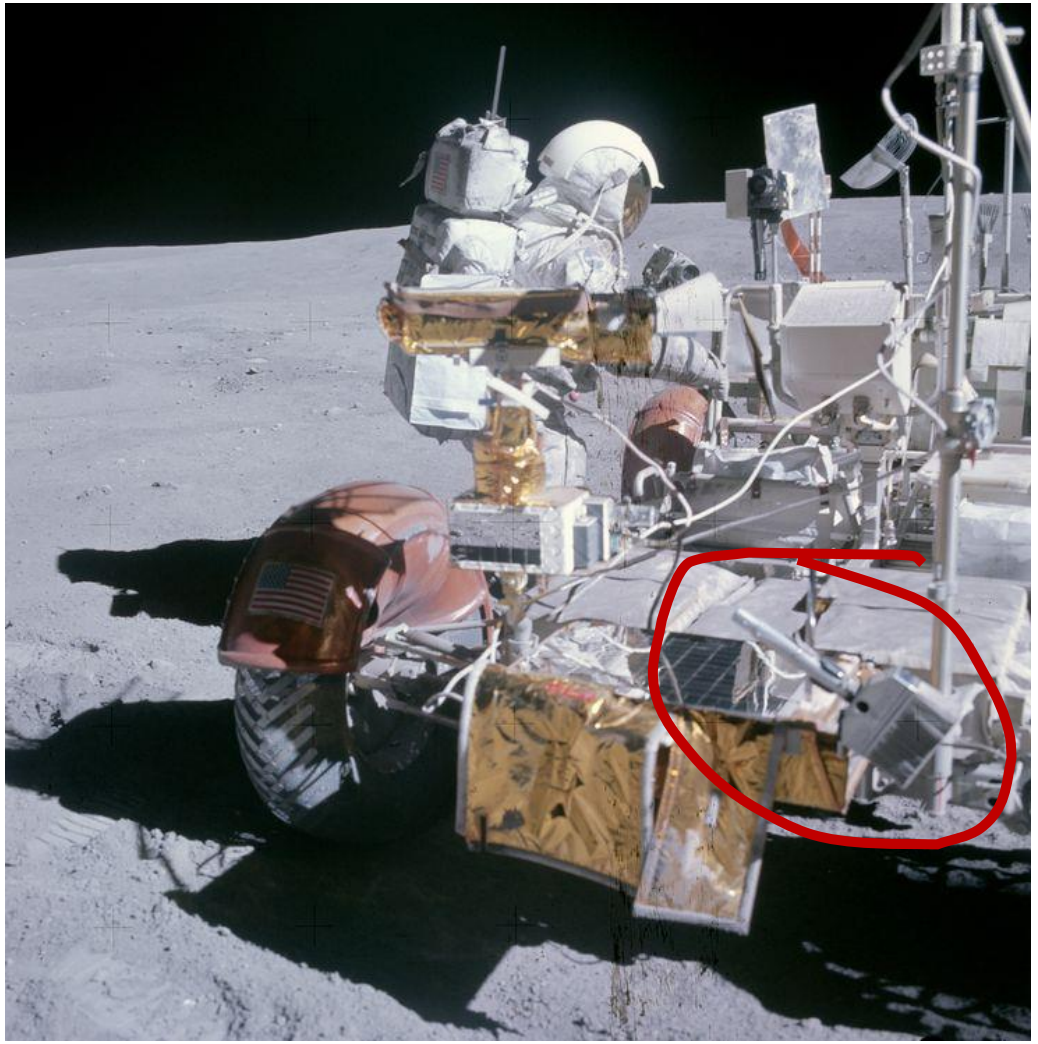
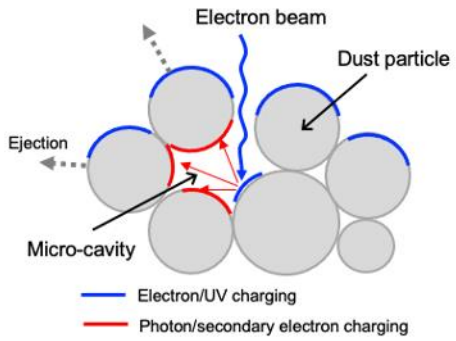
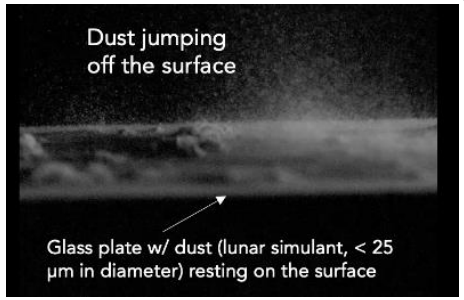


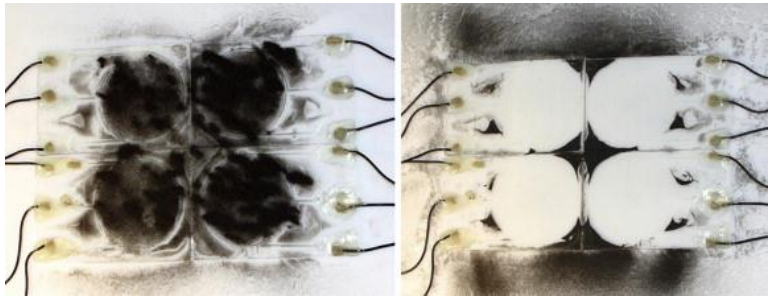
Image credit: NASA

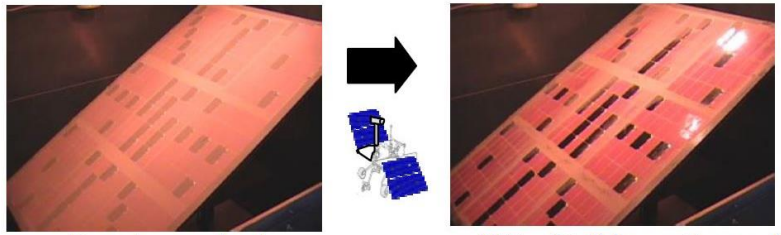
# Lunar Dust Adhesion Mitigation Strategies

## Active Mitigation Strategies






## Passive Mitigation Strategies

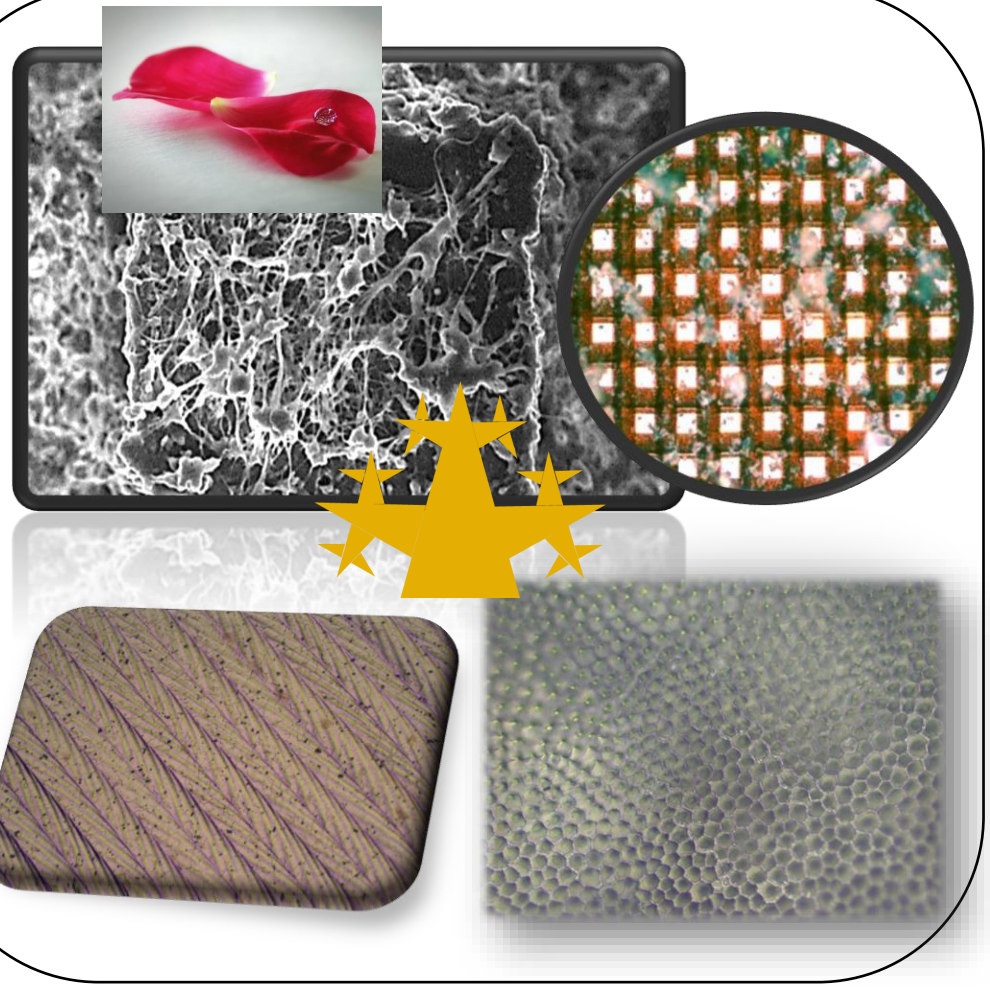


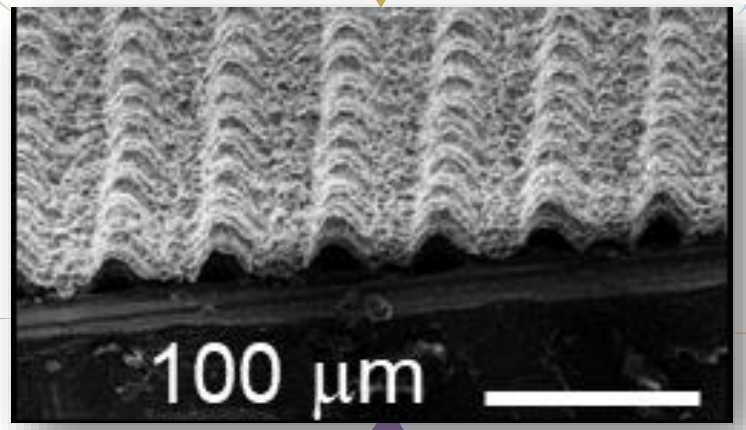
Image credit: NASA

Surface Chemistry

Surface Topography

Surface Conductivity

Surface Mechanical Properties



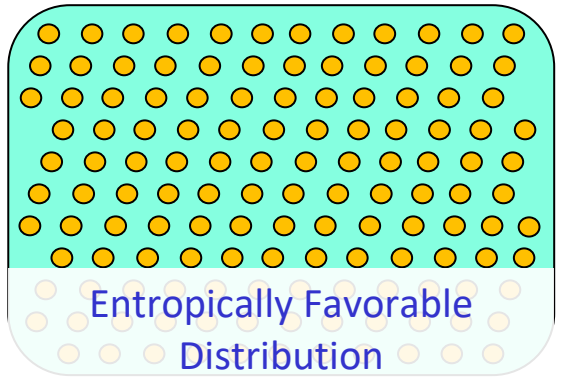

Responsive Surfaces

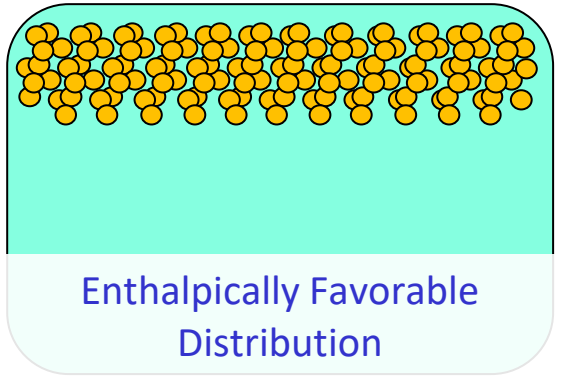
Surface Hardness

Image credit: NASA

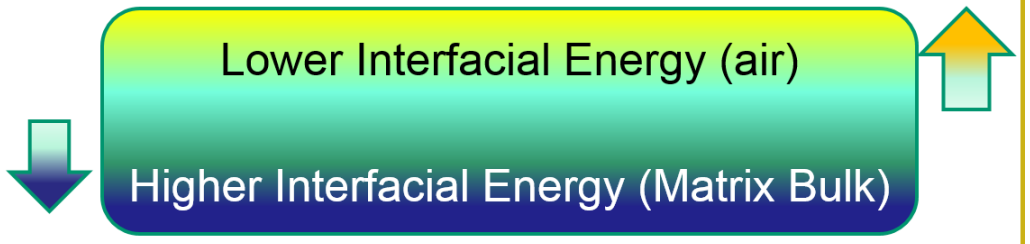
# Surface Chemical Modifications

## Surface Migration Agents (SMA)

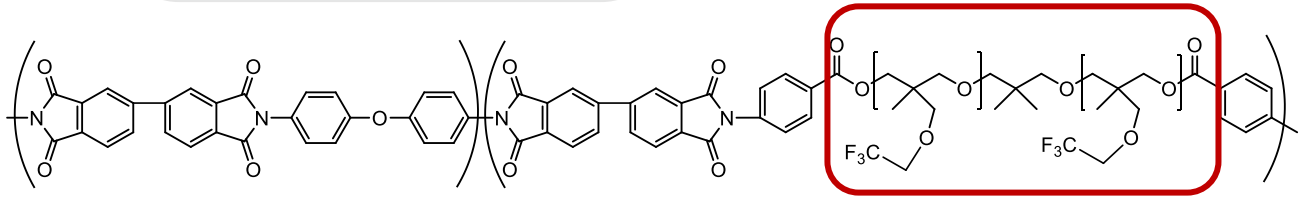


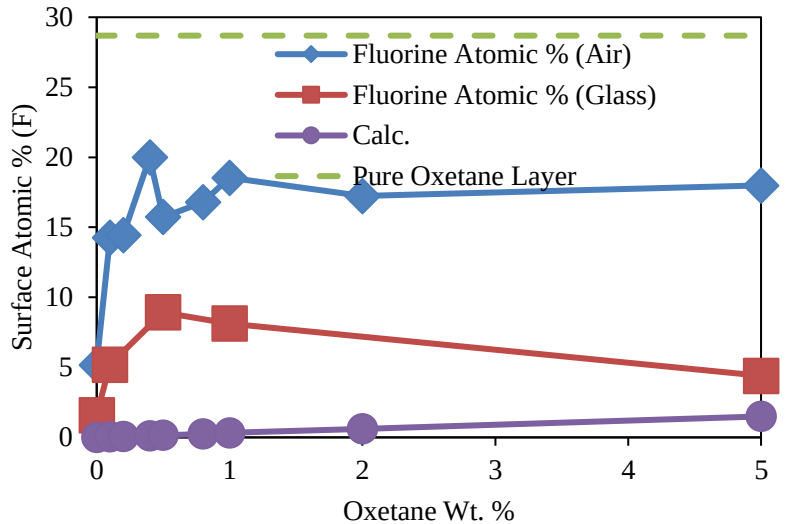




**Thermodynamic Response of SMA**




Arrows indicate enthalpy-driven migration of **LOW** and **HIGH** surface energy components

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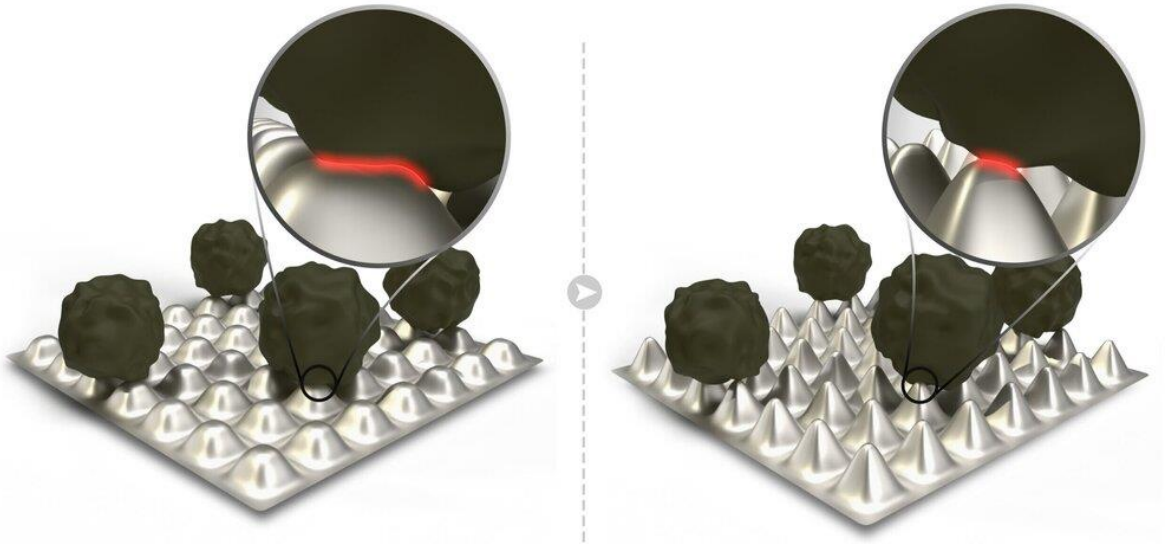
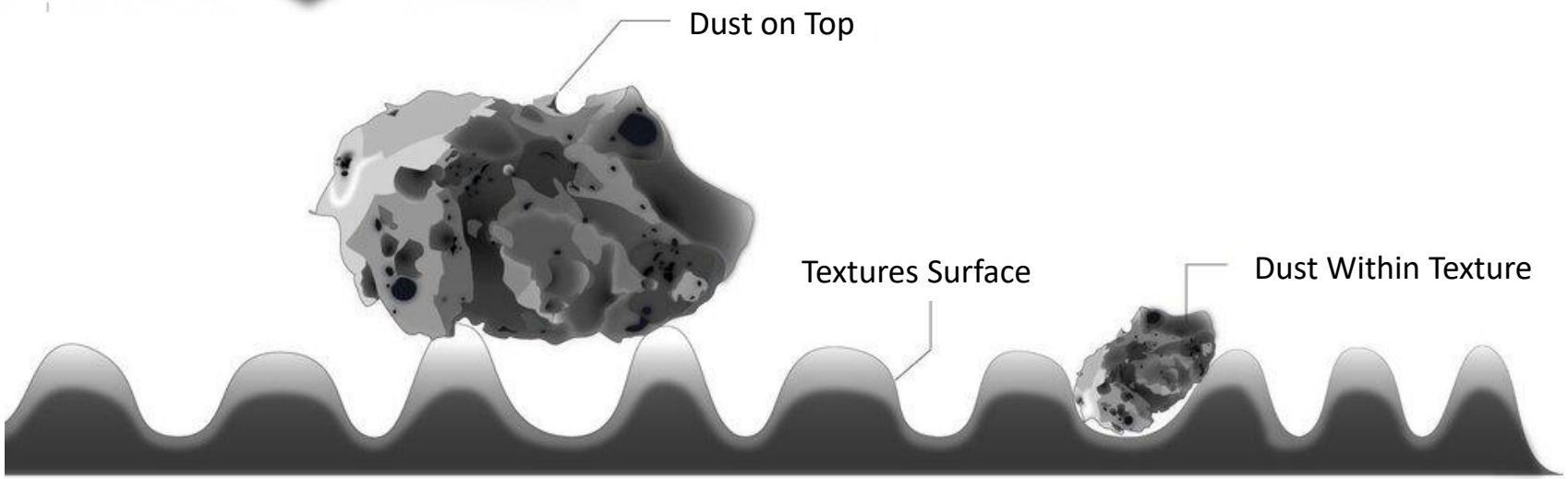
*Wohl, Christopher J.; et al., "Lunar Dust Simulant Particle Adhesion on Copolyimide Alkyl Ethers" in The Impact of Lunar Dust on Human Exploration, ed. Joel S. Levine, Cambridge Scholars Publishing, February, 2021.*

# Surface Topographical Modification






Smart Material Solutions

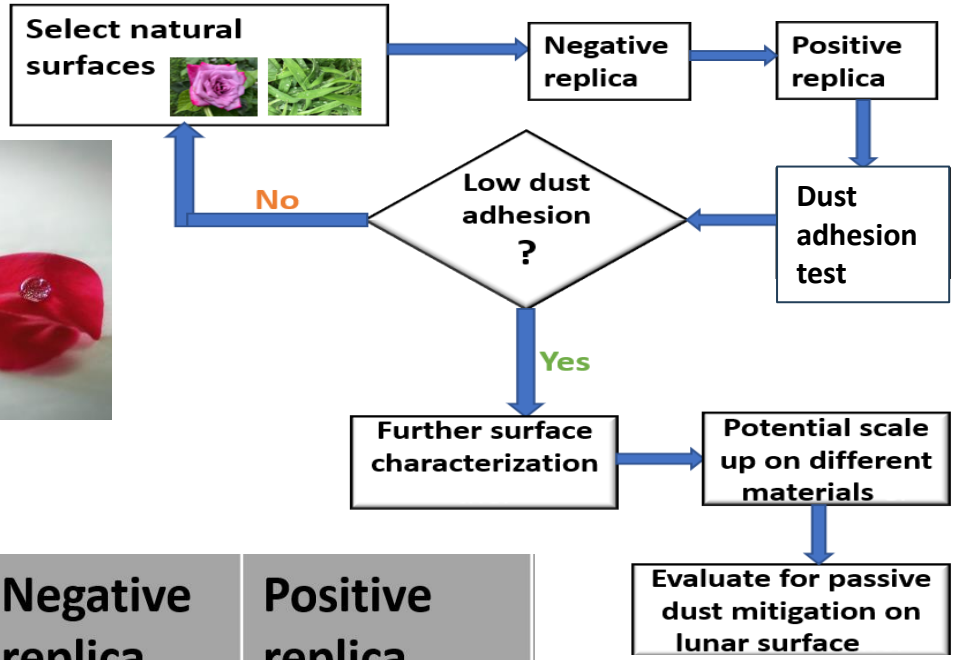
UT Austin

*POC: Stephen Furst, Smart Material Solutions, furst@smartmaterialsolution.com; Chih-Hao Chang, University of Texas-Austin, chichang@utexas.edu*

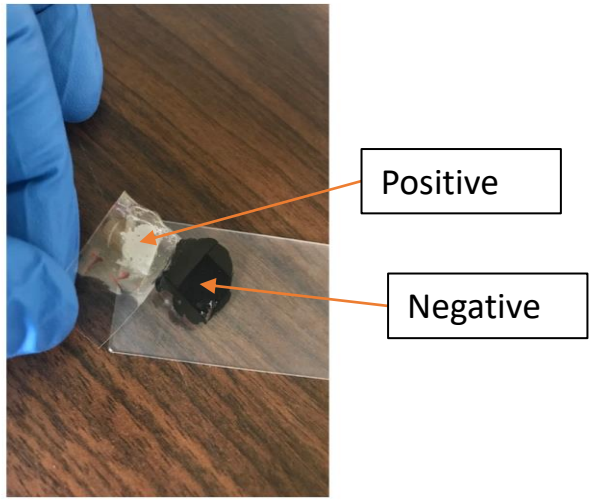
# Surface Topographical Modification
## Biomimetic Surfaces

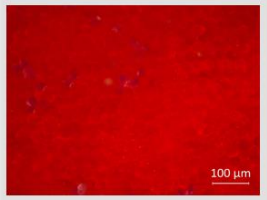
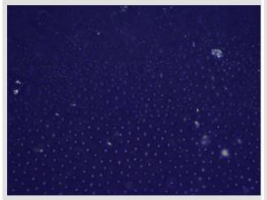
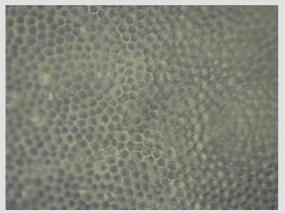
### Natural adhesion mitigating surfaces




### Replication example: rose petal




| Sample name | Original surface | Negative replica | Positive replica (ctrl) |
|---|---|---|---|
| Rose petal |  |  |  |



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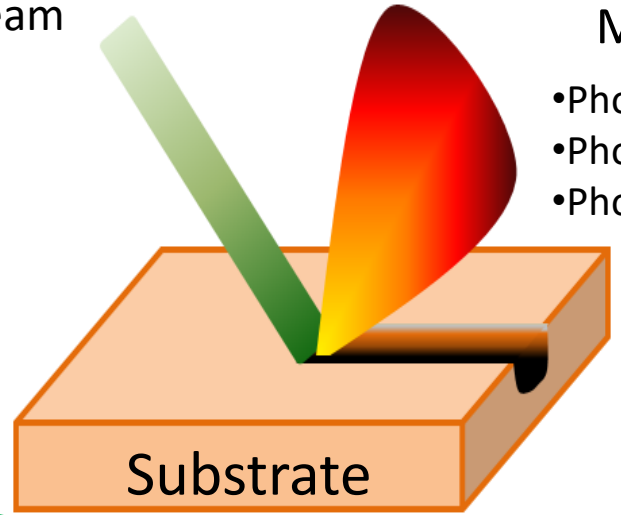
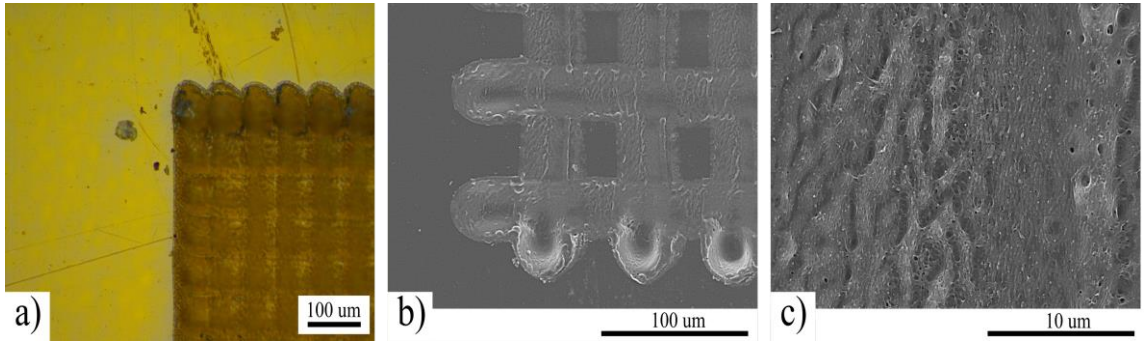
*Das, Lopamudra; et al., "Extending Lunar Presence: Dust Adhesion Mitigation Materials and Surfaces to be Evaluated on the Lunar Surface," Acta Astronautica, 2024, 219, 532-541.*

# Surface Topographical Modification
## Laser Ablation

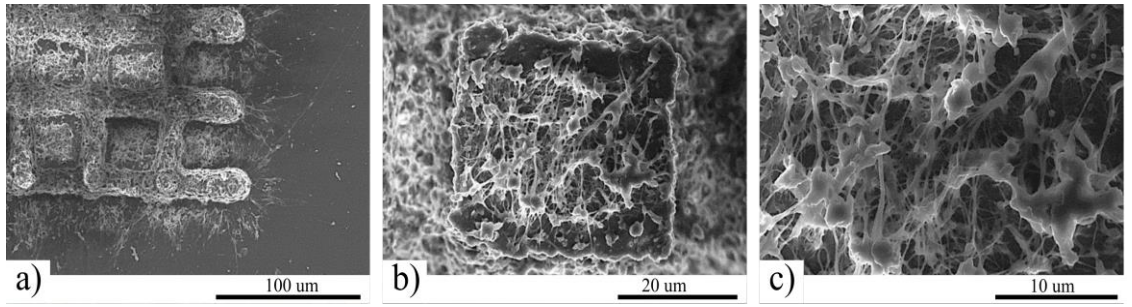
### Laser Ablation Patterning



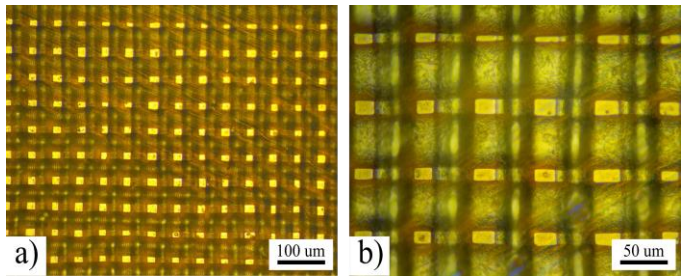

Polyimide




Fluorinated Ethylene Propylene (FEP)




Epoxy

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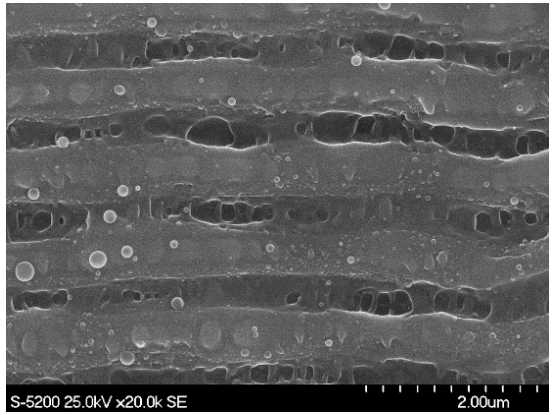
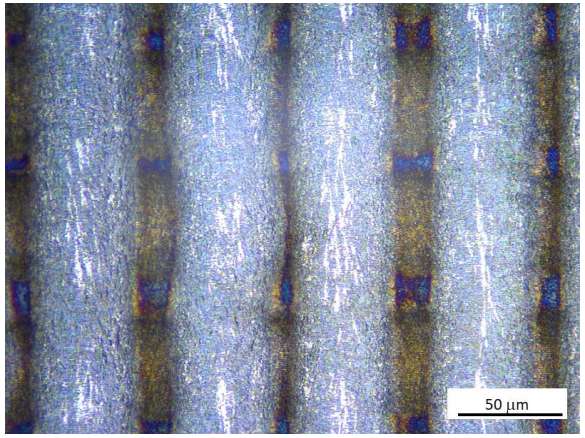
# Surface Topographical Modification

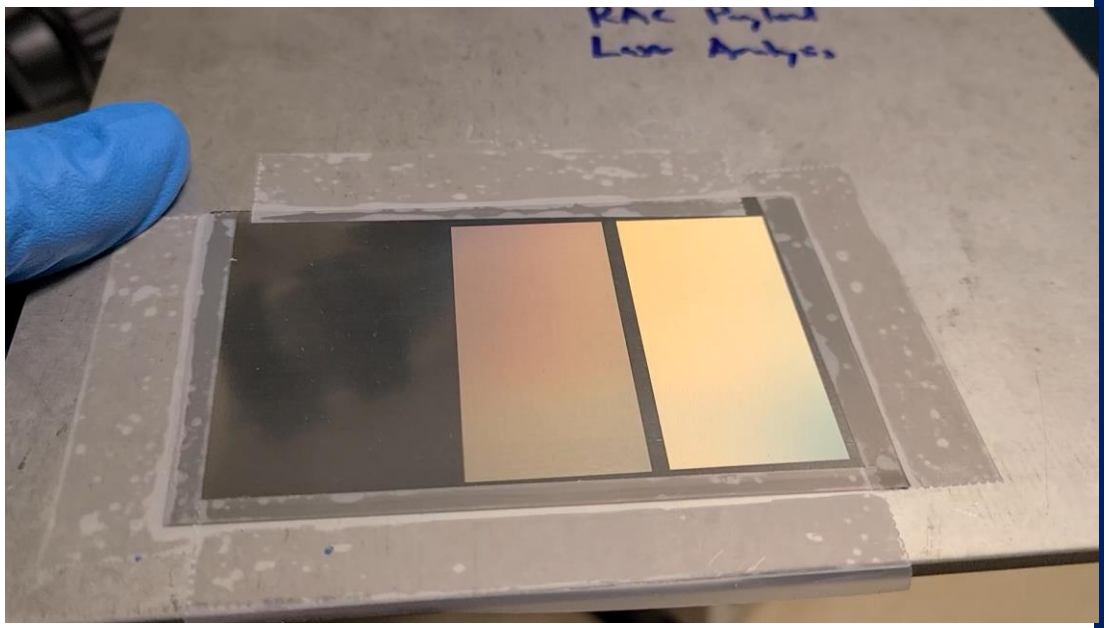
## Laser Ablation




Nanometer-scaled Laser-Induced Period Surface Structure (LIPSS)




Micrometer-scaled Direct-write Laser Patterning



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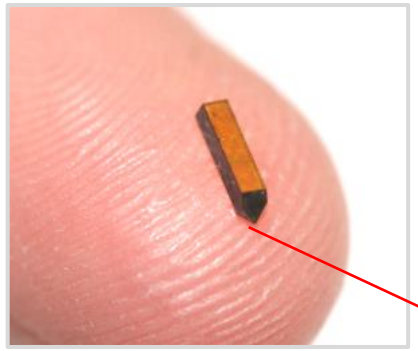
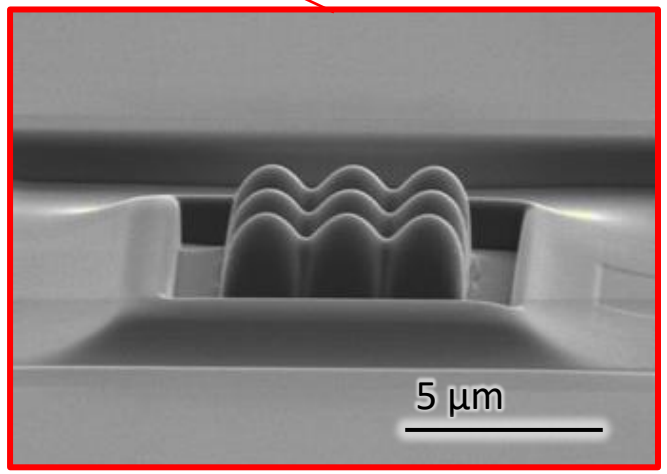
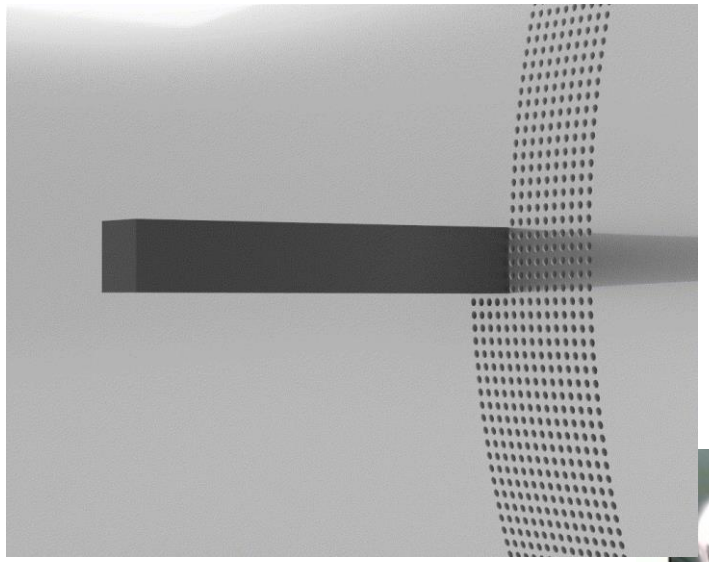
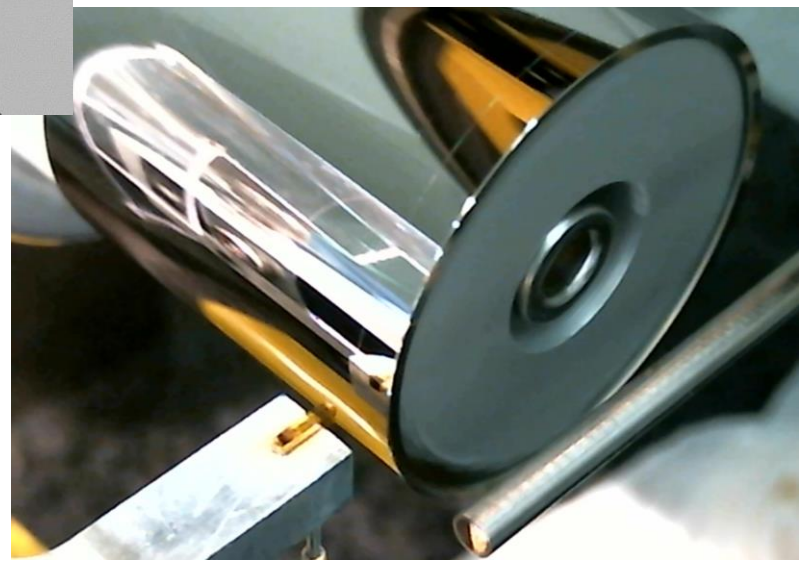
# Surface Topographical Modification

## Nanocoining







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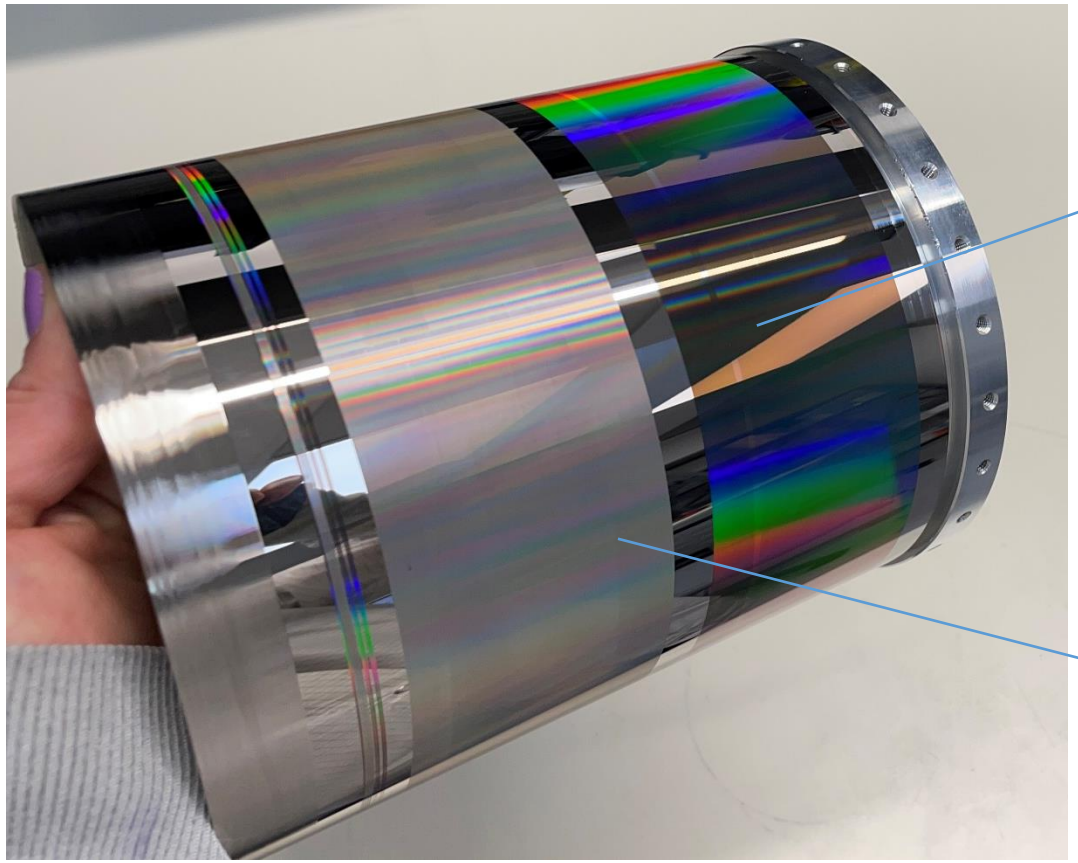
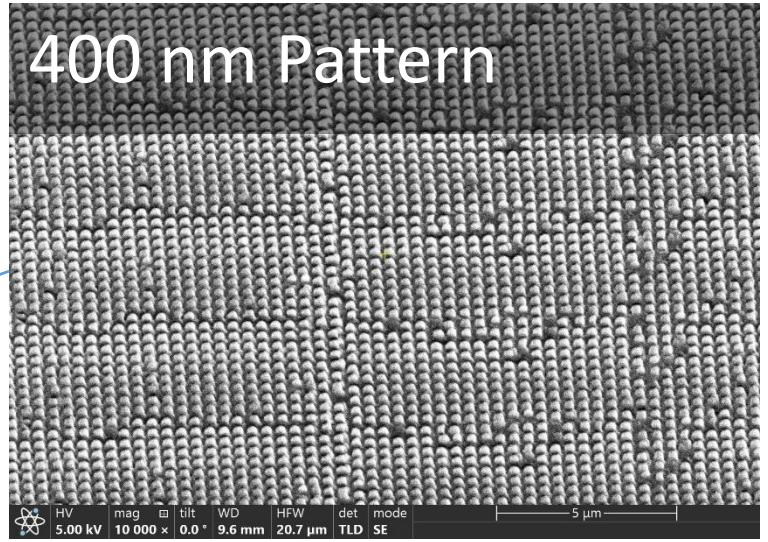
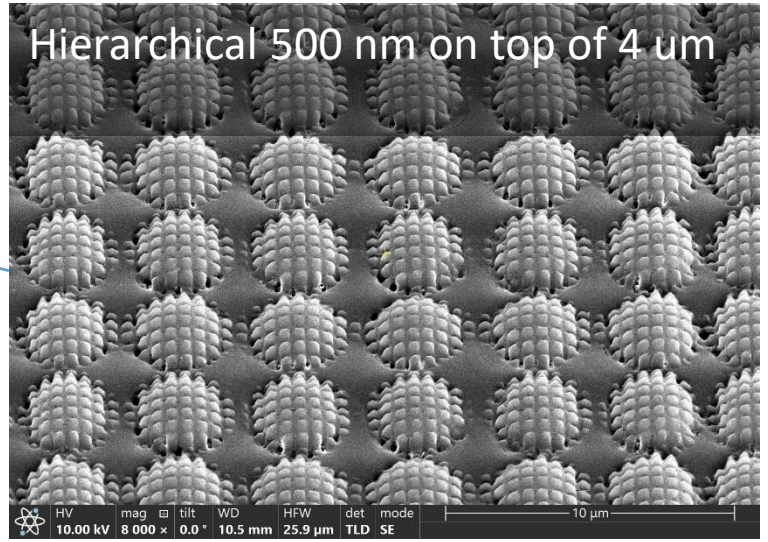
*POC: Stephen Furst, Smart Material Solutions, furst@smartmaterialsolution.com; Chih-Hao Chang, University of Texas-Austin, chichang@utexas.edu*

# Surface Topographical Modification

## Nanocoining






Smart Material Solutions

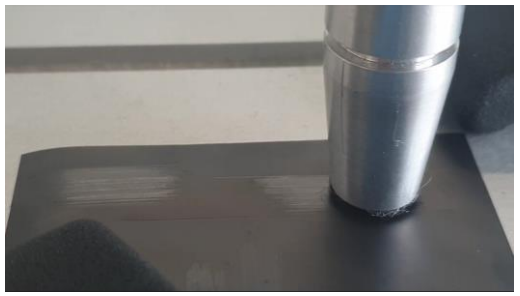
*POC: Stephen Furst, Smart Material Solutions, furst@smartmaterialsolution.com; Chih-Hao Chang, University of Texas-Austin, chichang@utexas.edu*

# Surface Conductivity Modifications

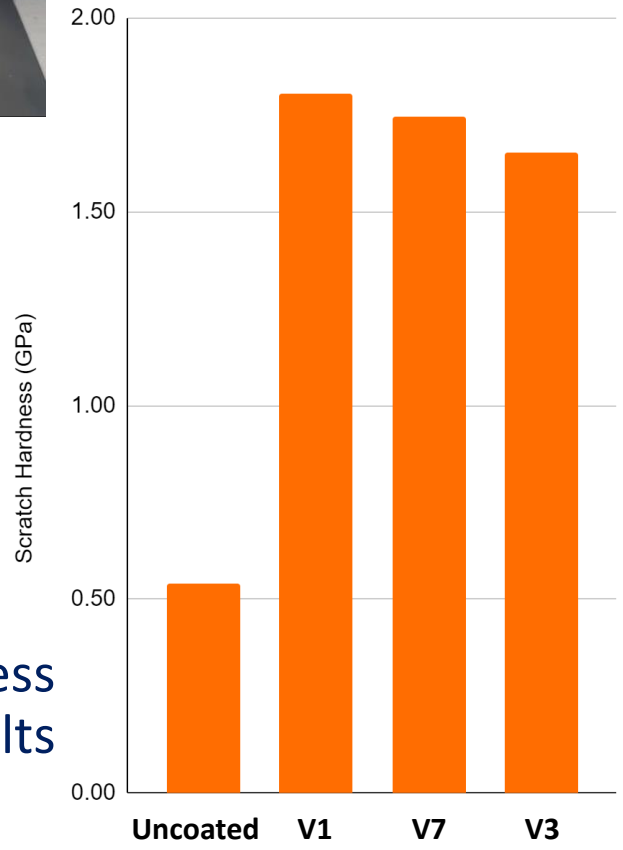
(a).

| Graphene ink coated Kapton sheets | Surface Resistivity (Ohms/sq) |
|---|---|
| V1 | 0 |
| V2 | $10^3$ |
| V3 | $10^4$ |
| V4 | $10^6$ |
| V5 | $10^8$ |
| V6 | $10^{10}$ |
| V7 | $10^{11}$ |

(b).



Abrasion testing with steel wire mesh




Scratch hardness results

Decreasing sheet resistance

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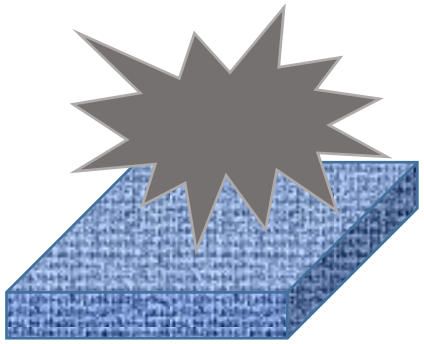
*Gordon, Keith L.; et al., "Spray-deposition of Graphene/Polymer Thin Coatings on Polyimide Sheets for Lunar Dust Adhesion Mitigation," Acta Astronautica, 2024, 219, 449-458.*

# Evaluation of Mitigation Efficacy

## Generation of a Contaminated Surface

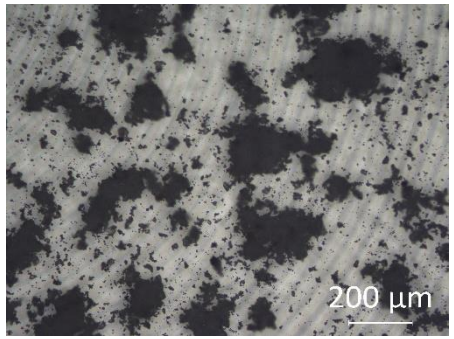
### Ideal Case: Isolated Particle



☑ Adhesion forces
- Van der Waals
- Electrostatic
- Magnetic
- Chemical
- Mechanical

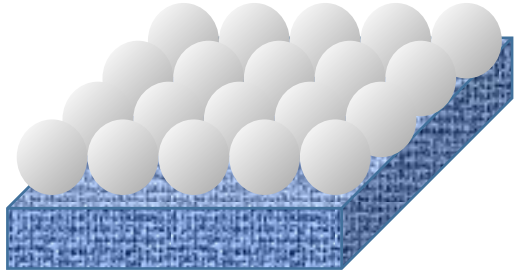
☒ Contributing forces
- Gravitation (Earth)
- Capillary (ambient atmosphere)

### Actual Case: Aggregated Particles




☒ Contributing forces
- Cohesion force
- Mechanical interlocking
- Deformation

### Hypothetical Case: Particle Monolayer



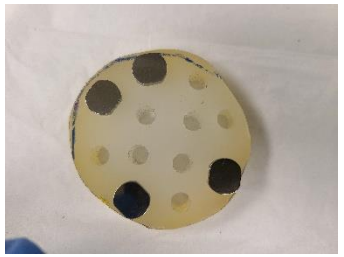
☒ Contributing forces
- Cohesion force
- Mechanical interlocking

Image credit: NASA

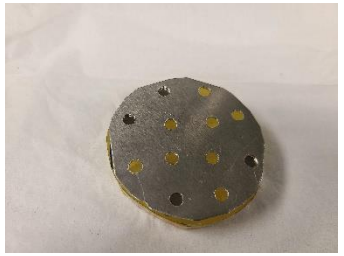
# Evaluation of Mitigation Efficacy

## Generation of a Contaminated Surface

### Step 1. Prepare Samples

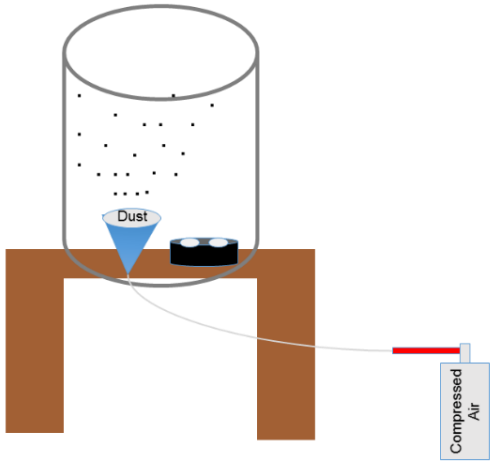


Sonic wand samples on sample holder



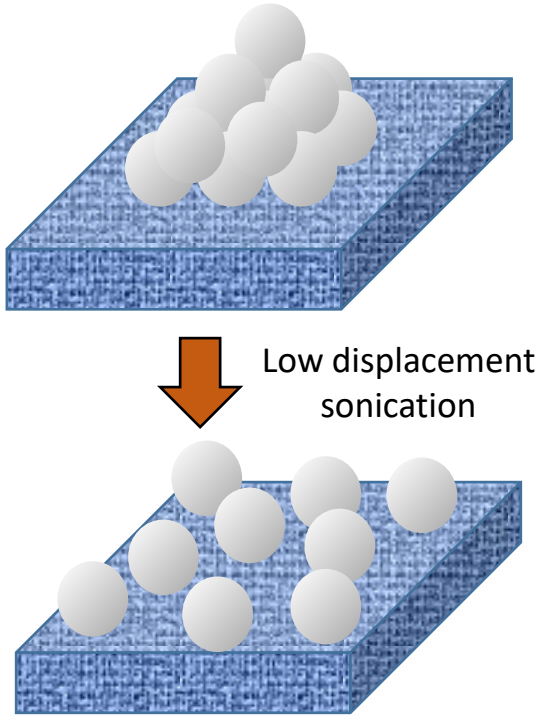
Sample deposition screen

### Step 2. Deposit Simulant




Aerosolization technique selected

### Step 3. Resolve Cohesion

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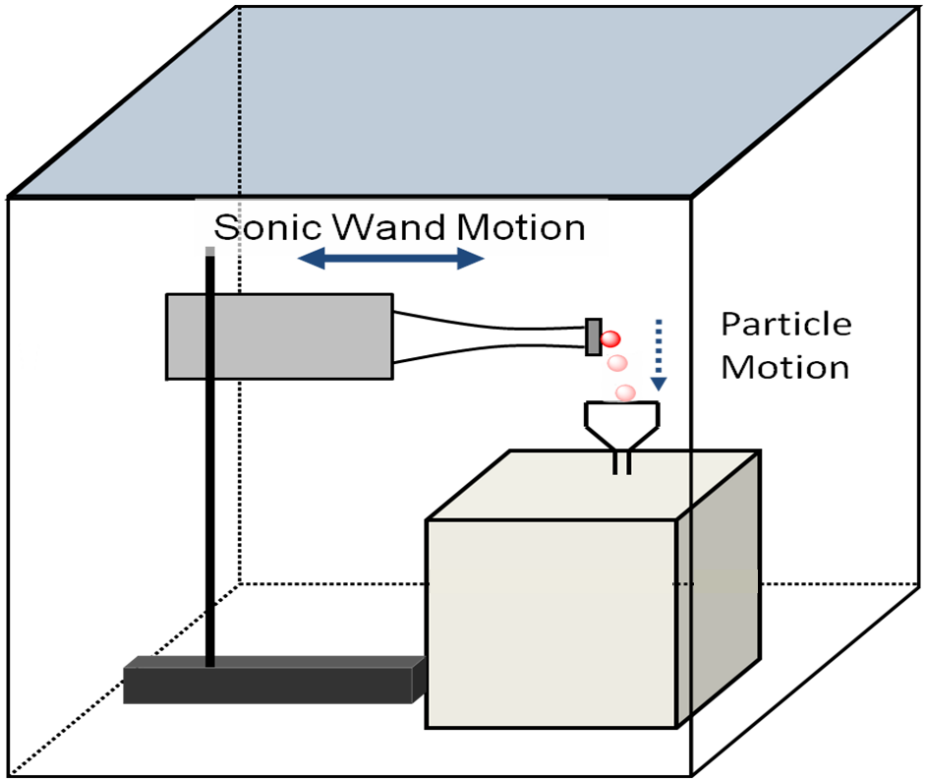
*Wohl, C.; Atkins, B.; Connell, J. "Evaluation of Particle Adhesion Properties of Materials Using a Sonication Device: Identifying Materials for Lunar Dust Adhesion Mitigation" NASA Technical Memorandum, 2011, TM-2011-217048.*

Image credit: NASA

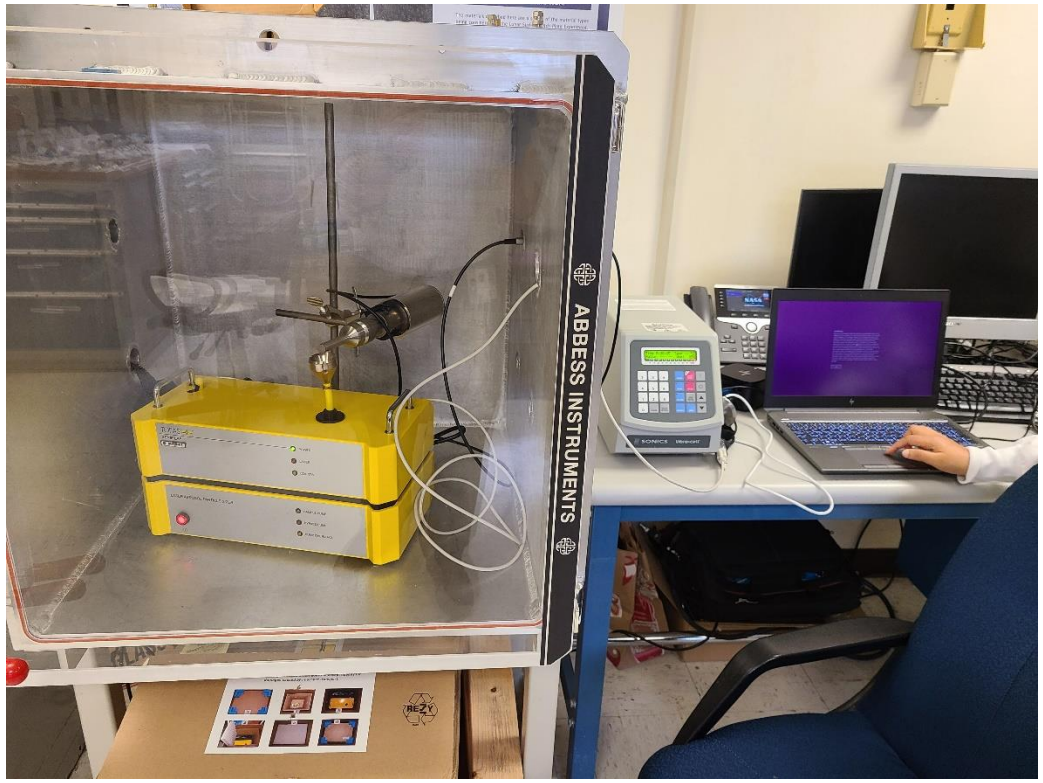
# Evaluation of Mitigation Efficacy

## Sonication Instrument

### Schematic




### Actual Instrument



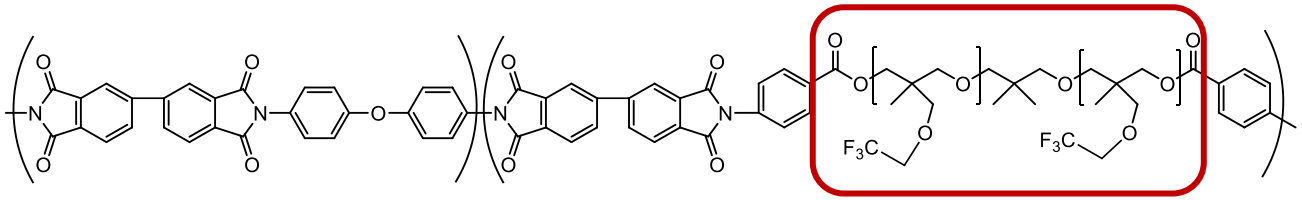

LaRC

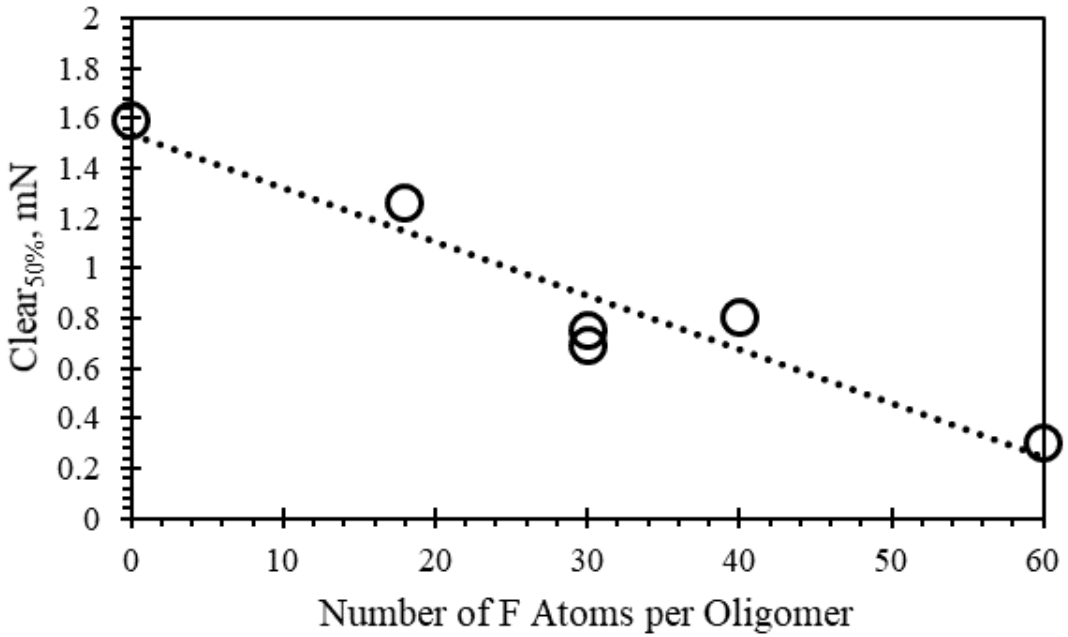
*Wohl, C.; Atkins, B.; Connell, J. "Evaluation of Particle Adhesion Properties of Materials Using a Sonication Device: Identifying Materials for Lunar Dust Adhesion Mitigation" NASA Technical Memorandum, 2011, TM-2011-217048.*

Image credit: NASA

# Evaluation of Mitigation Efficacy

## Sonication Instrument-Surface Chemistry



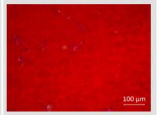
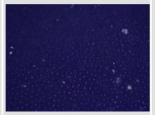
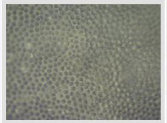
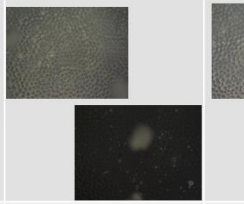
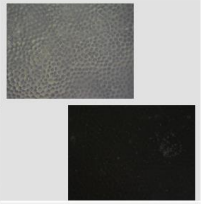
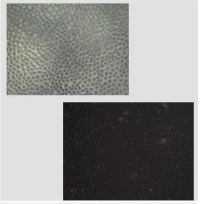
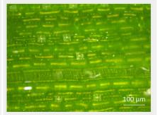
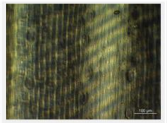
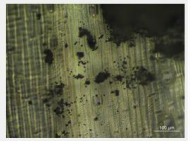
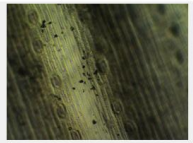
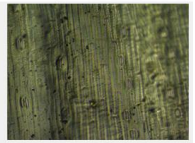
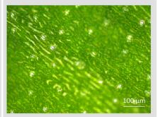
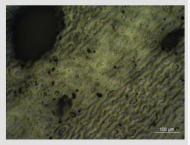
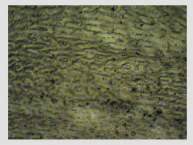
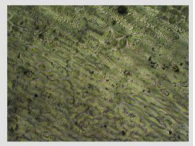


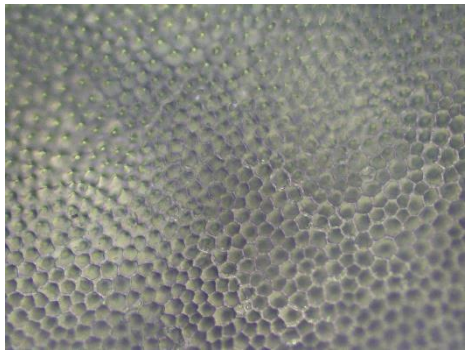

LaRC

*Wohl, Christopher J.; et al., "Lunar Dust Simulant Particle Adhesion on Copolyimide Alkyl Ethers" in The Impact of Lunar Dust on Human Exploration, ed. Joel S. Levine, Cambridge Scholars Publishing, February, 2021.*

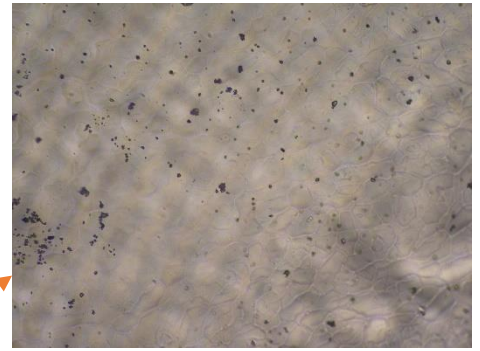
# Evaluation of Mitigation Efficacy

## Sonication Instrument-Biomimetic Surfaces

| Sample no. | Sample name | Original surface | Negative replica | Positive replica (ctrl) | Dust | First run | Full run |
|---|---|---|---|---|---|---|---|
| 1) | Rose petal |  |  |  |  |  |  |
| 2) | Grass leaf |  |  |  |  |  |  |
| 3) | Water clover |  |  |  |  |  |  |

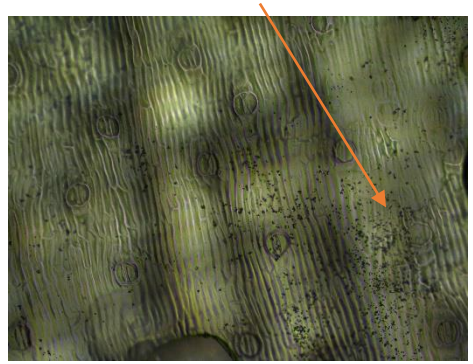


Rose Petal



Cabbage

Clusters of dust particles remain adhered



Banana Leaf

**Certain surface topographies exhibited better lunar simulant adhesion mitigation**

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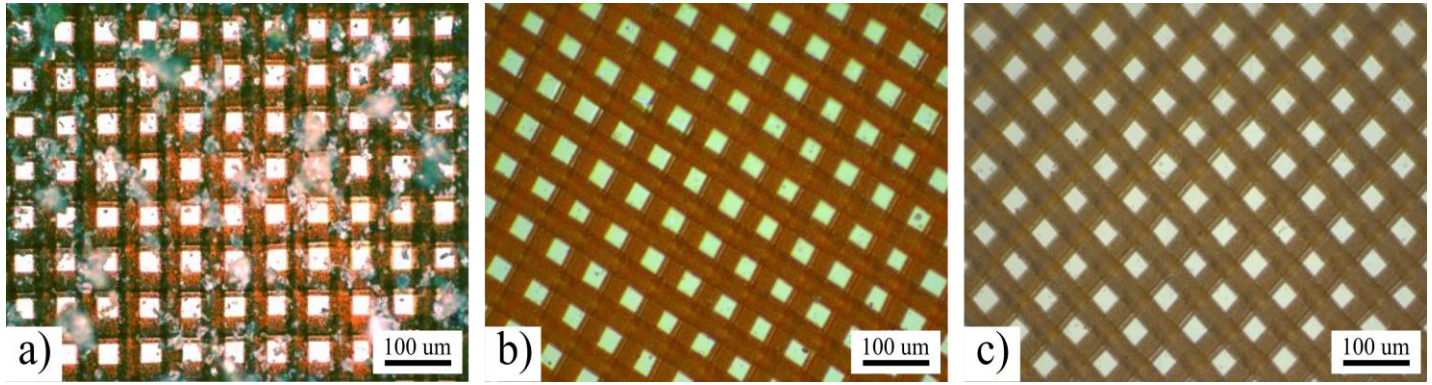
Image credit: NASA

# Evaluation of Mitigation Efficacy

## Sonication Instrument-Laser Patterning

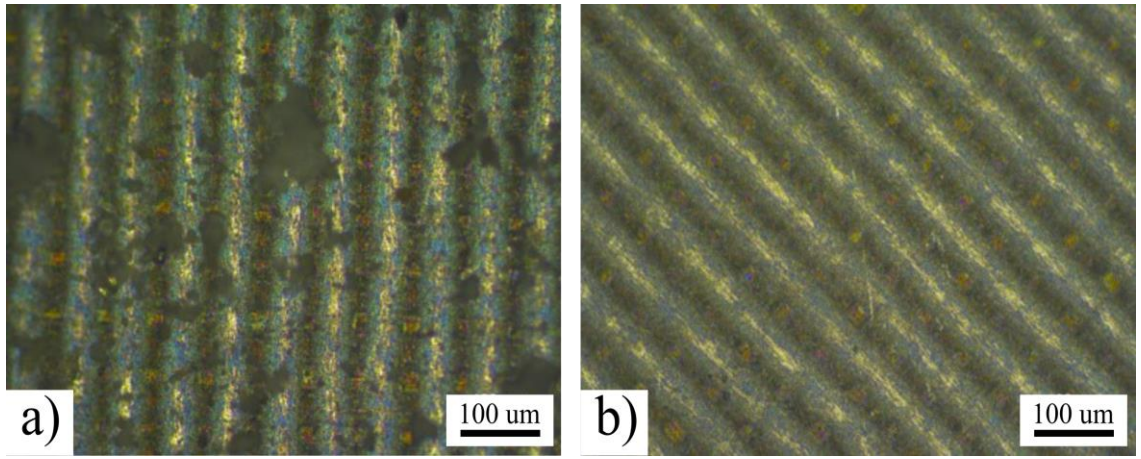



**Polymeric Surface**

–Left to Right: Contaminated Surface, Cohesion Removal, Full Test

**Titanium Surface**

–Left to Right: Contaminated Surface, Cohesion Removal

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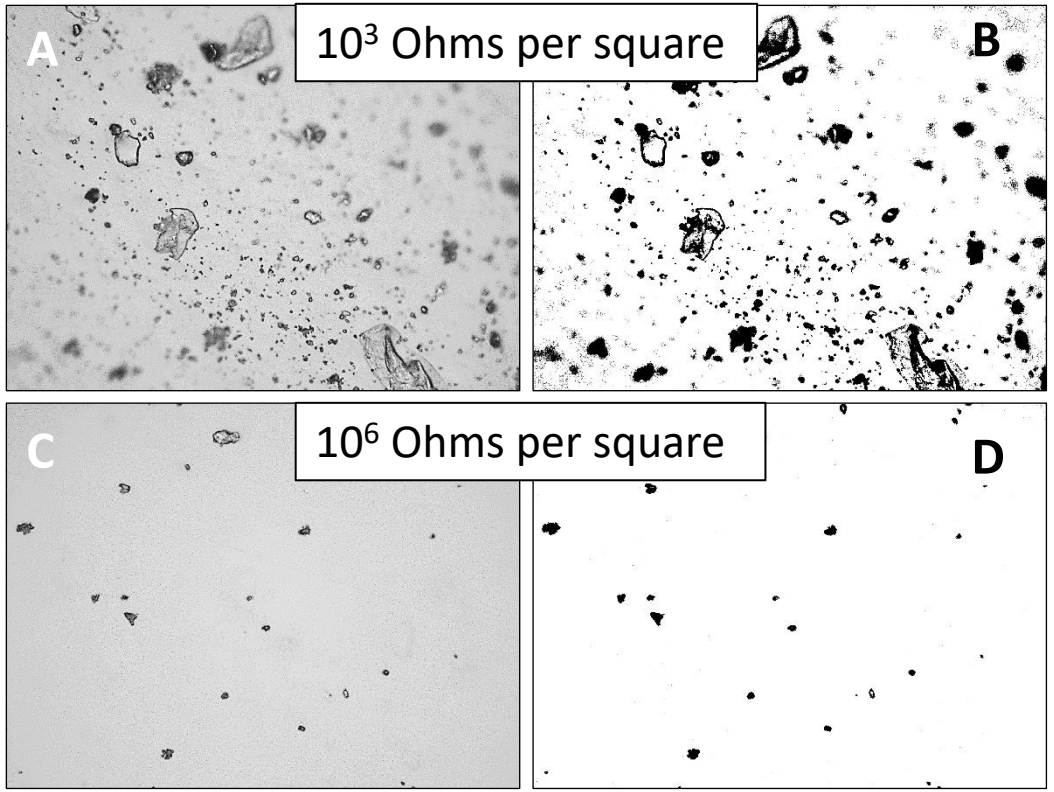
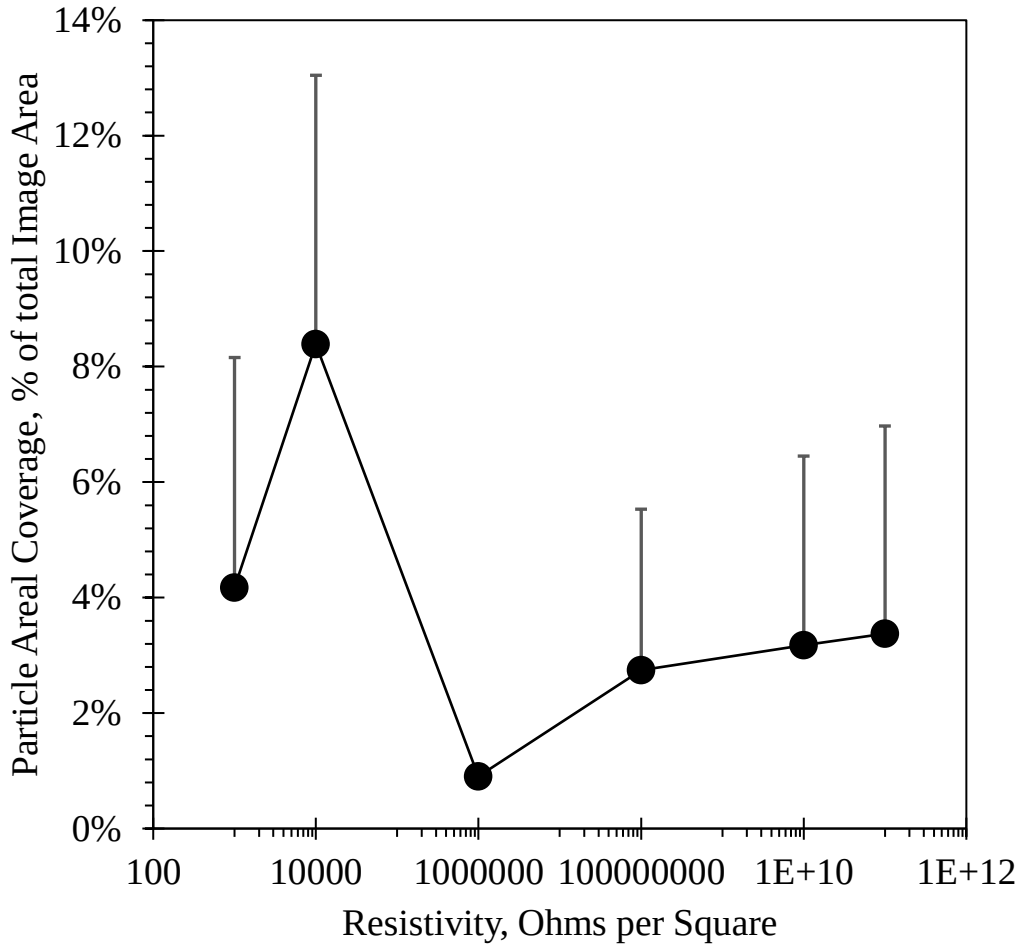
*Das, Lopamudra; et al., "Extending Lunar Presence: Dust Adhesion Mitigation Materials and Surfaces to be Evaluated on the Lunar Surface," Acta Astronautica, 2024, 219, 532-541.*

# Evaluation of Mitigation Efficacy

## Sonication Instrument-Surface Conductivity




(A and C) Optical micrographs of simulant particles present on the transfer tape and (B and D) binary image for determination of simulant areal coverage

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*Gordon, Keith L.; et al., "Spray-deposition of Graphene/Polymer Thin Coatings on Polyimide Sheets for Lunar Dust Adhesion Mitigation," Acta Astronautica, 2024, 219, 449-458.*

# Evaluation of Mitigation Efficacy

## Centrifuge Instrument


- Take mass of clean sample
- Deposit simulant and take mass
  - Aerosolize 500 mg of dust in chamber and allow it to fall onto sample
- Run the sample at a given speed (500-4000 RPM) in centrifuge and take mass
  - Custom 3D printed sample holder

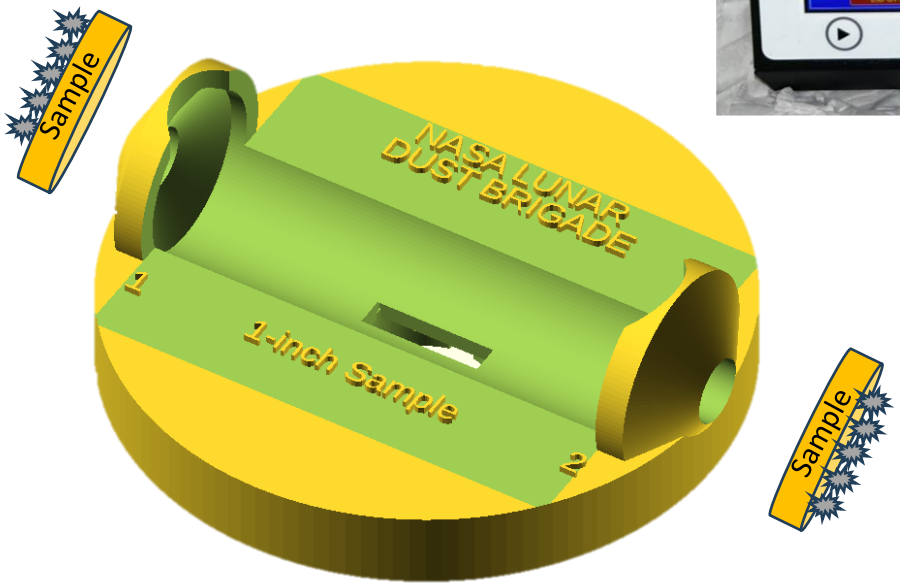


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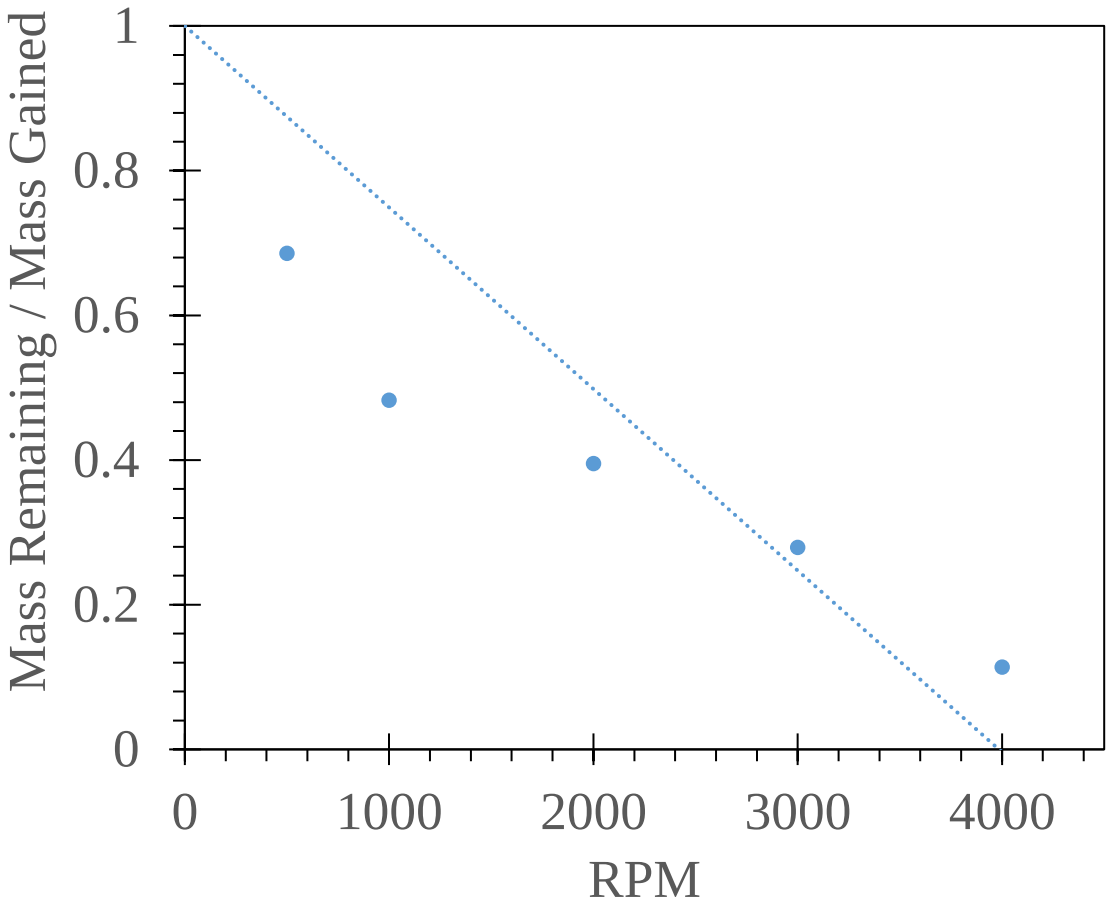
Image credit: NASA

# Evaluation of Mitigation Efficacy

## Centrifuge Instrument-Calculating Clearance Velocity




Hoekstra-Voigt Coefficient

Mass Remaining

$$\frac{m_1}{m_0} = -\mu\omega + 1$$

Mass Gained

Angular Velocity

Zero Mass Remaining at rotations per minute (RPM) of…

$$m_1 = 0$$

$$0 = -\mu\omega + 1$$

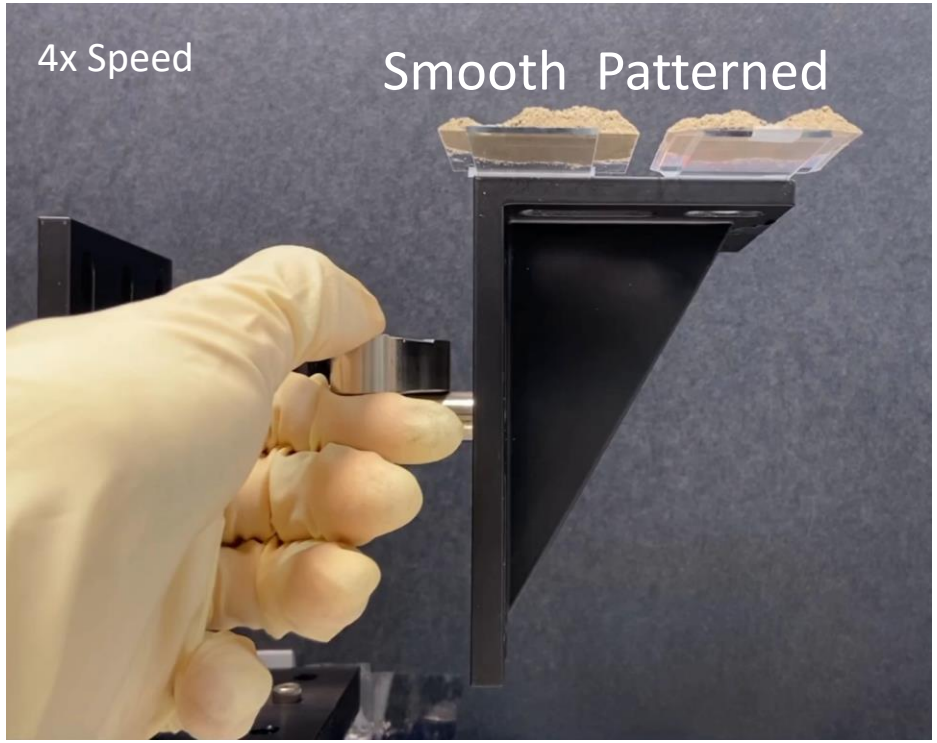
$$-1 = -\mu\omega$$

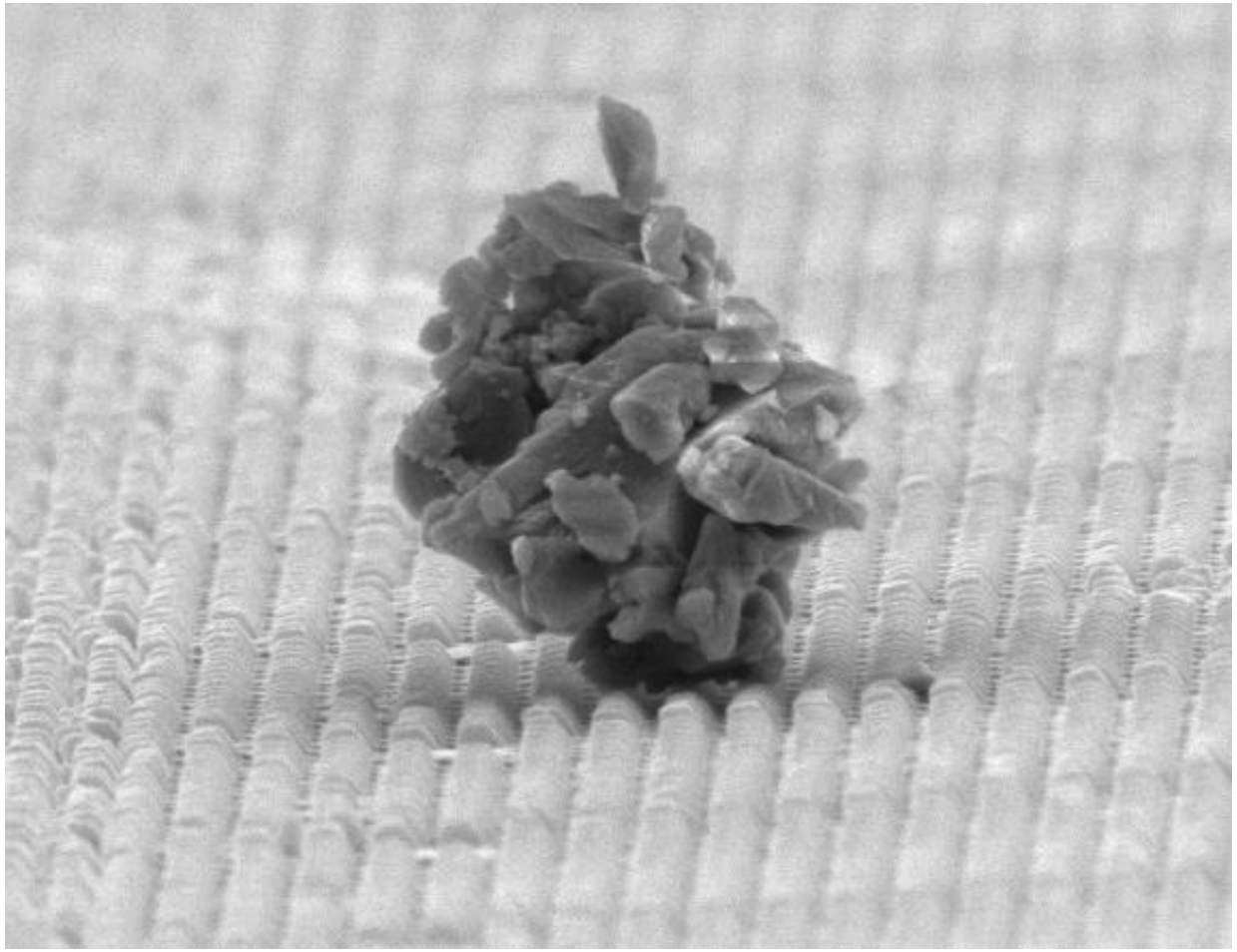
$$\frac{1}{\mu} = \omega$$

Image credit: NASA

# Evaluation of Mitigation Efficacy

## Tilt Testing



Smart Material Solutions

UT Austin

*ACS Appl. Mater. and Interfaces. Samuel Lee et. al. 10.1021/acsami.2c19211*

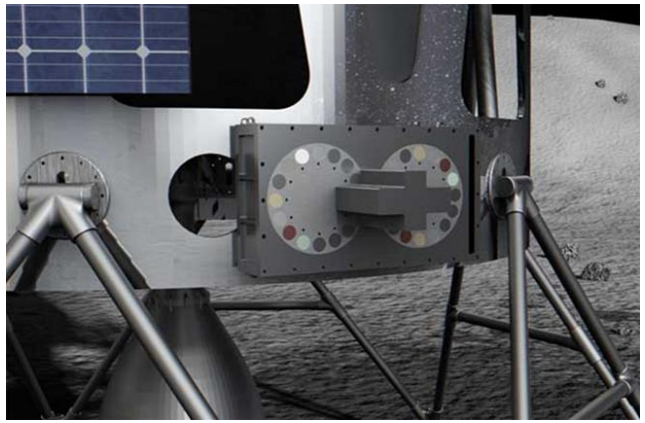
# Evaluation off Planet

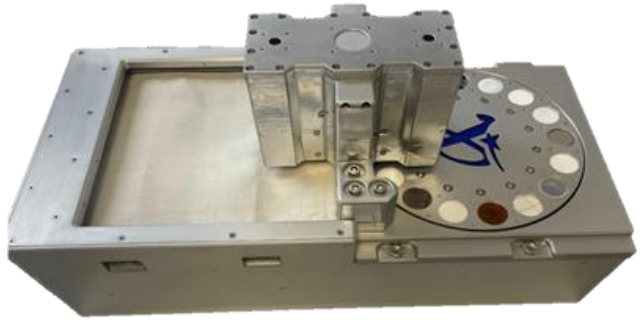
## Materials International Space Station Experiment (MISSE) Samples

| | | |
|---|---|---|
| Copper Zirconium | Bulk Metallic Glass | Considered for RAC Payload |
| Boron Carbide (B4C) | Ceramic | Considered for RAC Payload |
| Chrome Carbide | Ceramic | LO-DuSST, high wear surface |
| Chromium Oxide | Ceramic | LO-DuSST, high wear surface |
| Laser Patterned Kapton | Polymer | On RAC Payload |
| Laser Patterned FEP | Polymer | On RAC Payload |
| Laser Patterned Low Creep/Relaxation Polymer | Polymer | Considered for RAC Payload |
| Laser Patterned Low Creep/Relaxation Composite | Polymer | On RAC Payload (Secondary) |

Launched on July 15, 2022 (SpaceX CRS-25)
Returned to Earth on April 15, 2023 (CRS-27)

## Regolith Adhesion Characterization (RAC) Payload

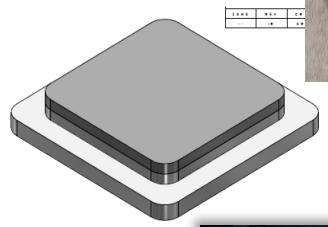


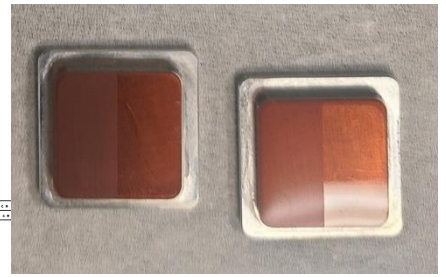


Images credit: Aegis Aerospace

## Honeybee Robotics PlanetVac

Coupon Schematic





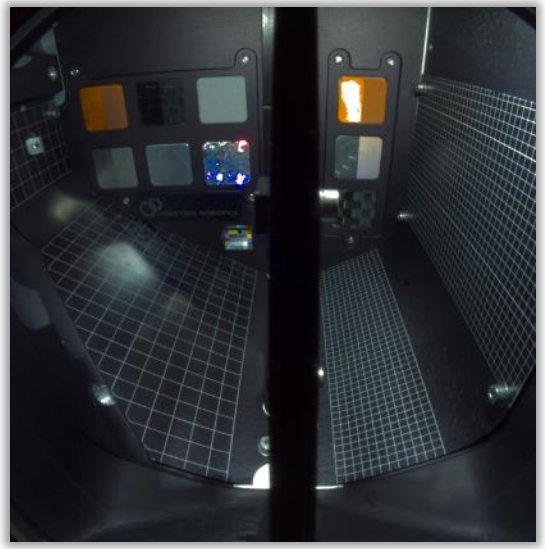


Image credit: NASA

Both payloads launched on SpaceX Falcon 9 - Firefly Blue Ghost lander, on January 15, 2025.
**Landing on the Moon on March 2, 2025!**

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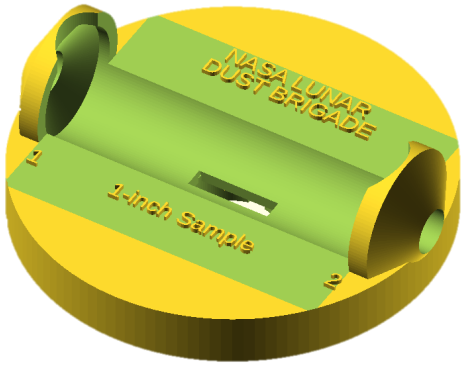
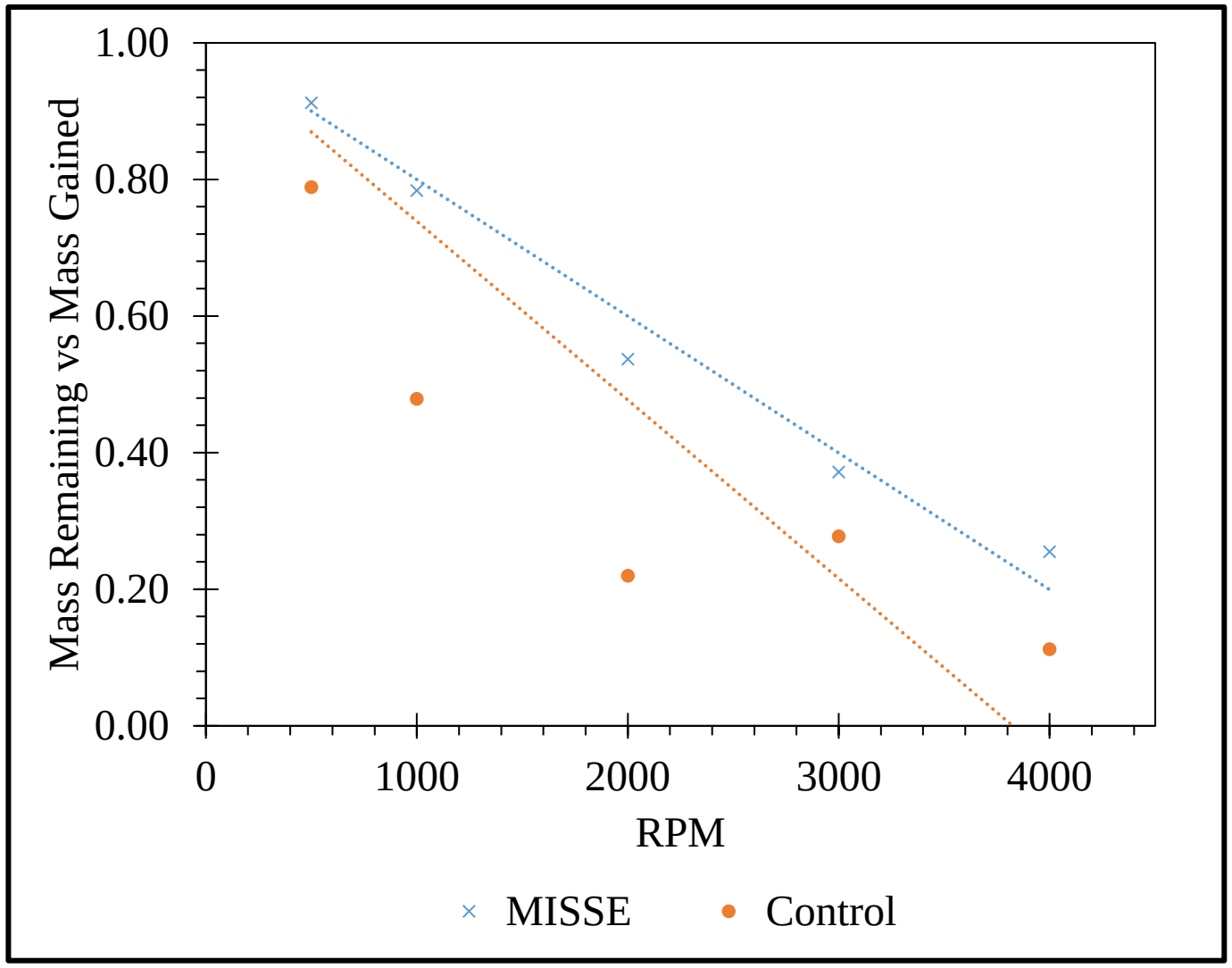
# Results: MISSE-16




Zero Mass Remaining:
3825.26 RPM

Zero Mass Remaining:
4996.25 RPM

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# Conclusions

- Shortfalls Assessment … why does this work need to continue
- There is great work going on across the agency and supported by the agency to make significant inroads to mitigate mission impact as a result of lunar dust contamination
- An array of materials solutions will be required to address the breadth of the need for lunar dust adhesion mitigation
- Evaluation of candidate surfaces is complex and will not be able to completely represent the lunar surface unless it is conducted on the lunar surface


# Acknowledgements

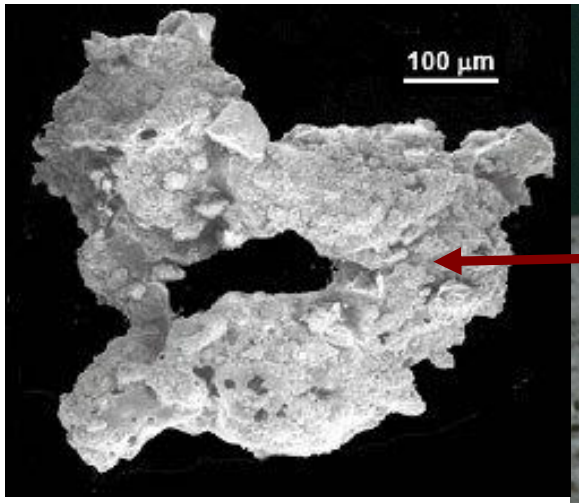

- **NASA Langley Research Center**
  - Valerie Wiesner, Lopamudra Das, Keith Gordon, Glen King, Jonathan Hernandez, Jackson Hoekstra, Eric Voigt, John Hopkins, Michael Oliver, Wade Hall, John Lowe, John W. Connell (retired)
- **NASA Glenn Research Center**
  - Sharon Miller, Meghan Bush
- **NASA Johnson Space Center**
  - Josh Litofsky
- **NASA Marshall Space Flight Center**
  - Miria Finckenor
- **NASA Game Changing Development (GCD) and NASA Lunar Surface Innovation Initiative (LSII)**
  - Niki WerkHeiser, Michael Johansen, Erica Montbach, Jennifer Fothergill, Kristen John, Cameron Hartman
- **Smart Material Solutions/ UT Austin**
  - Dr. Stephen Furst, Dr. Nicky Cates, Robin McDonald, Sidney Cox, Lauren Micklow, Andrew Tunell, and Chih-Hao Chang

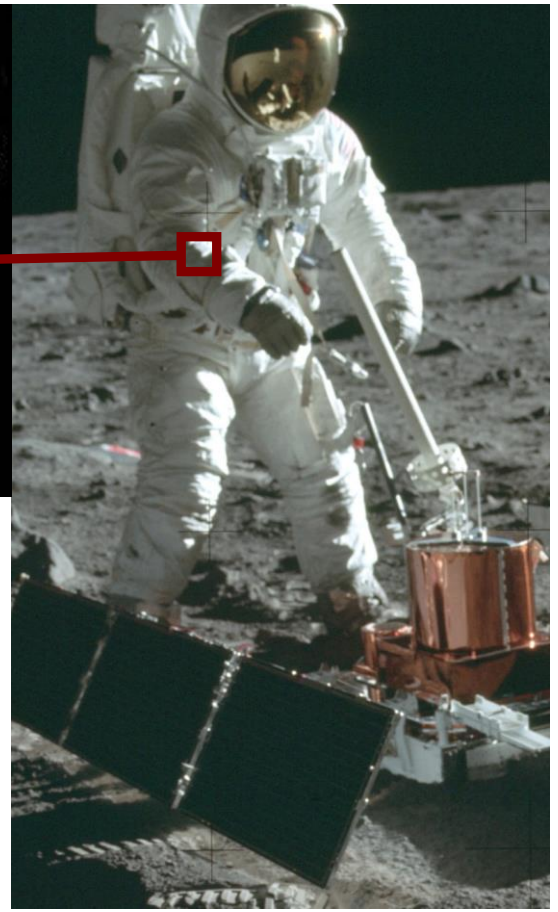
# Back Up

# Lunar Dust Composition and Characteristics

**Composition (by wt.):** 50% $SiO_2$, 15% $Al_2O_3$, 10% CaO, 10% MgO, 5% $TiO_2$ and 5-15% Fe

- Composition varies depending on location [1]
  - Lesser amounts of sodium, potassium, chromium and zirconium
  - Trace amounts of virtually all elements from parts per billion (ppb) to parts per million (ppm) level
  - Mixture of crystalline and amorphous material
- Particle properties [2]
  - Particle size varies from nm to mm; range of primary concern 1 to 100 µm-sized particles
  - Nominal density ~1.5 g/cm$^3$
  - Irregular, jagged morphology
  - Electrically charged



Preventing dust adhesion and wear to spacesuits and equipment is a critical component of safety and success of future lunar surface exploration missions

*Image Credits Left:* NASA **Right:** NASA AS11-40-5951

[1] D.J. Loftus, et al., "The Chemical Reactivity of Lunar Dust Relevant to Human Exploration of the Moon," *Planetary Science Division Decadal Survey white paper* (2020).
[2] C. Meyer, NASA Lunar Petrographic Thin Section Set (2003).

# Lunar Surface Electrostatic Environment

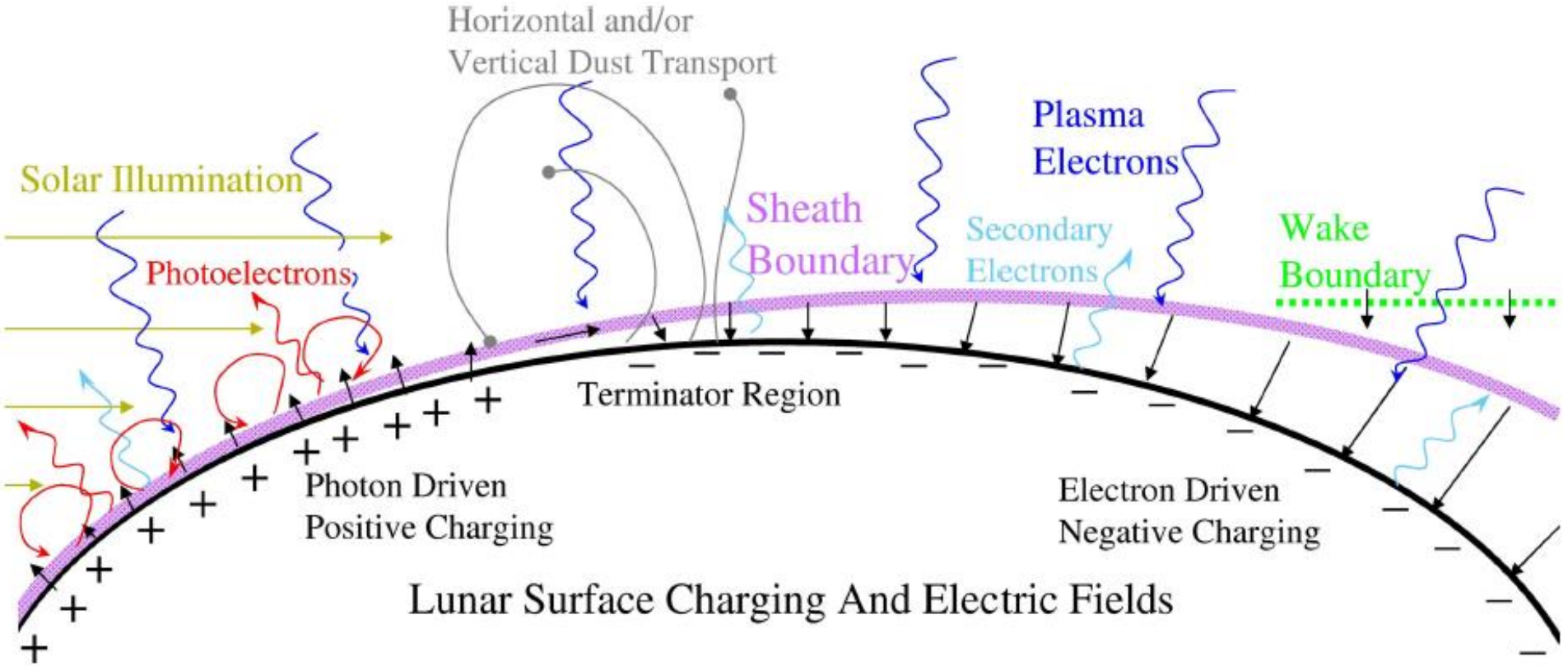
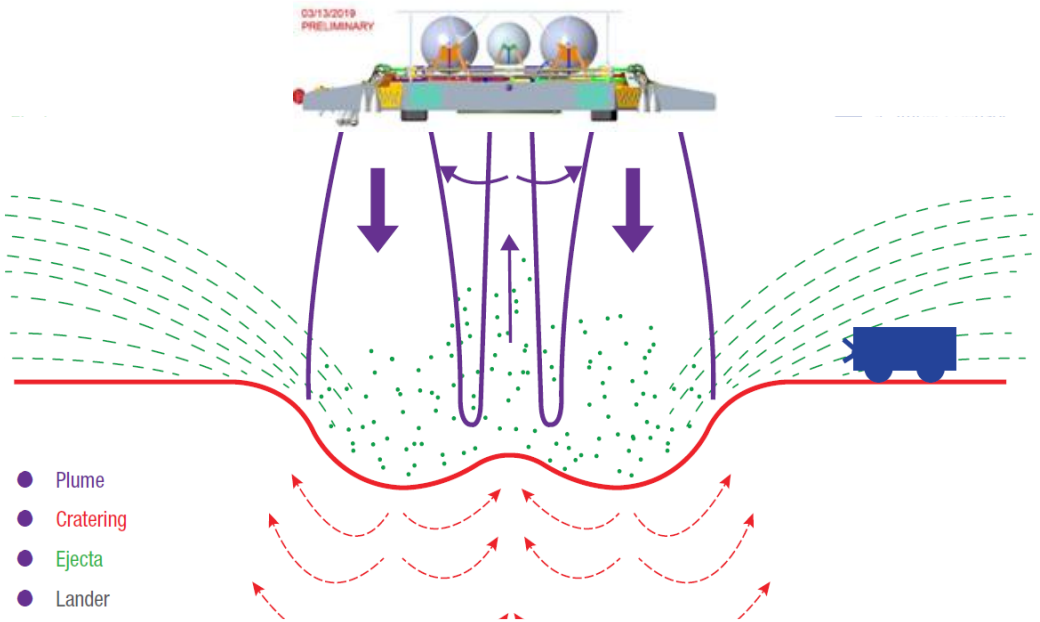



*Image Credits: Stubbs, T. J.; Halekas, J. S.; Farrell, W. M.; Vondrak, R. R. Lunar Surface Charging: A Global Perspective using Lunar Prospector Data. Workshop of Dust In Planetary Systems, Lunar and Planetary Institute, Kauai, Hawaii, United States of America, September 26-30, 2005. (used with author permission)*

# What Else Can Stir up Dust?




Within 50 m of landing site, particle velocity estimates range from 300 m/s – 2000 m/s

Image credit: Michelle Munk, NASA LaRC

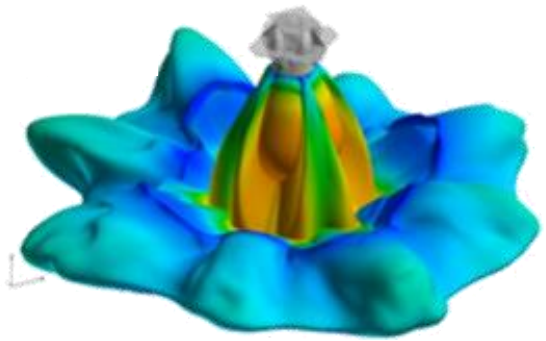
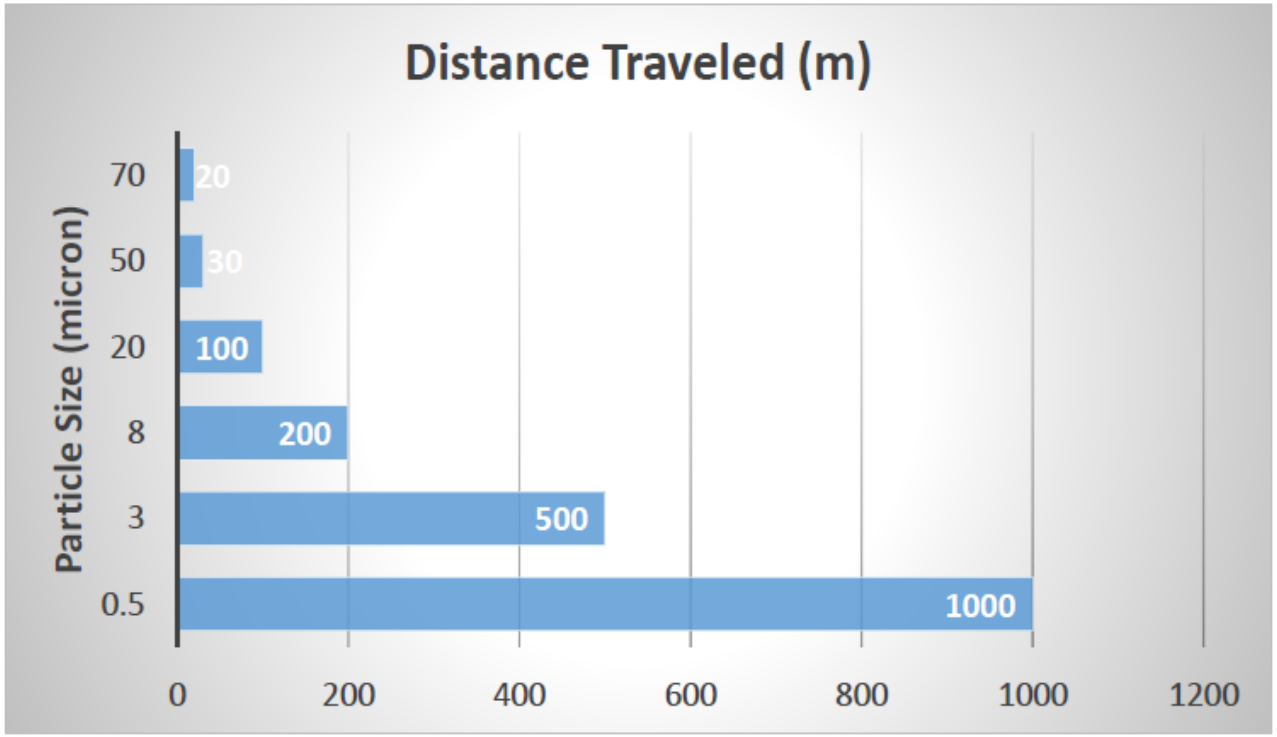
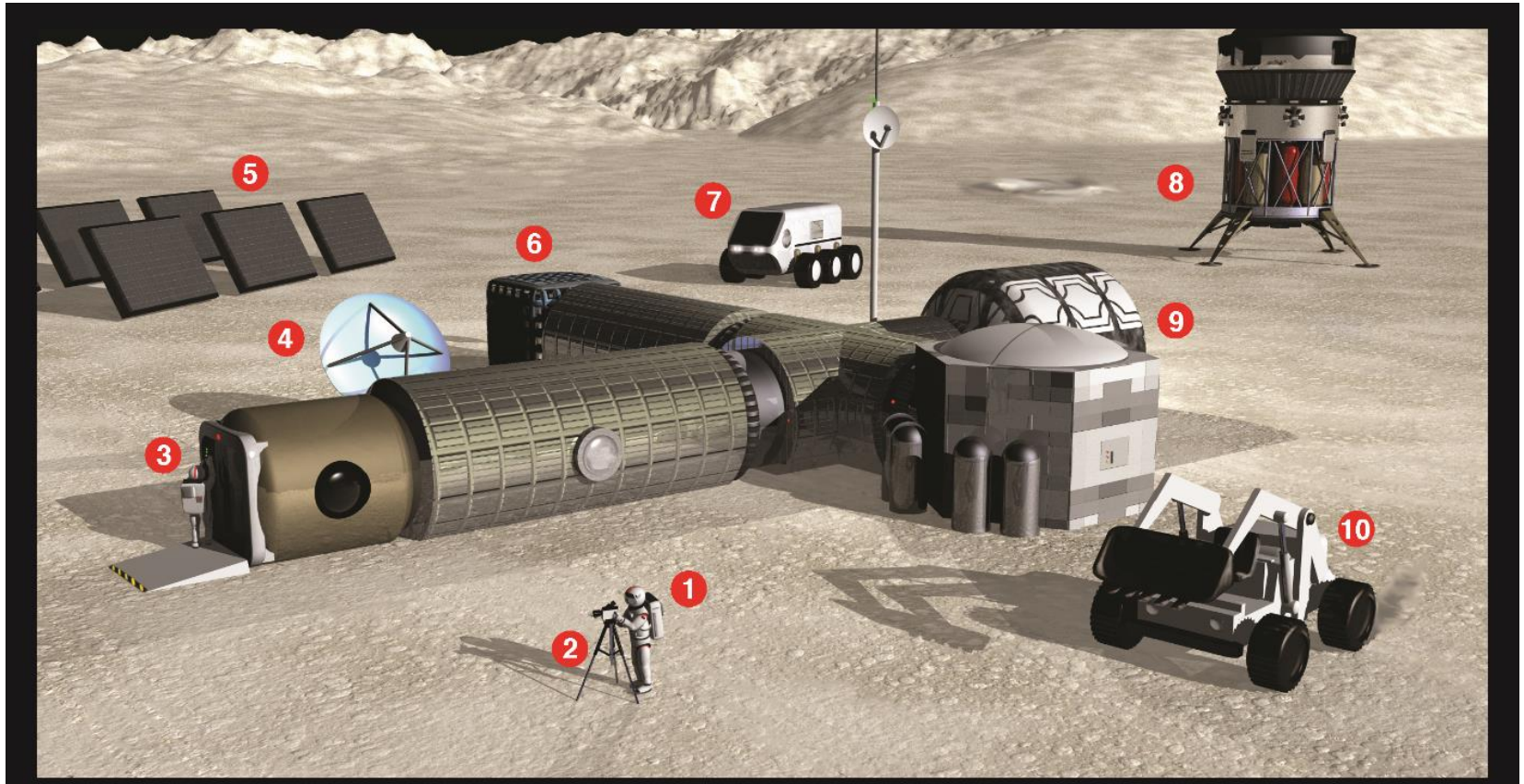


*Image Credit*: NASA MSFC/Peter Liever



# Where will Lunar Dust Pose a Challenge?



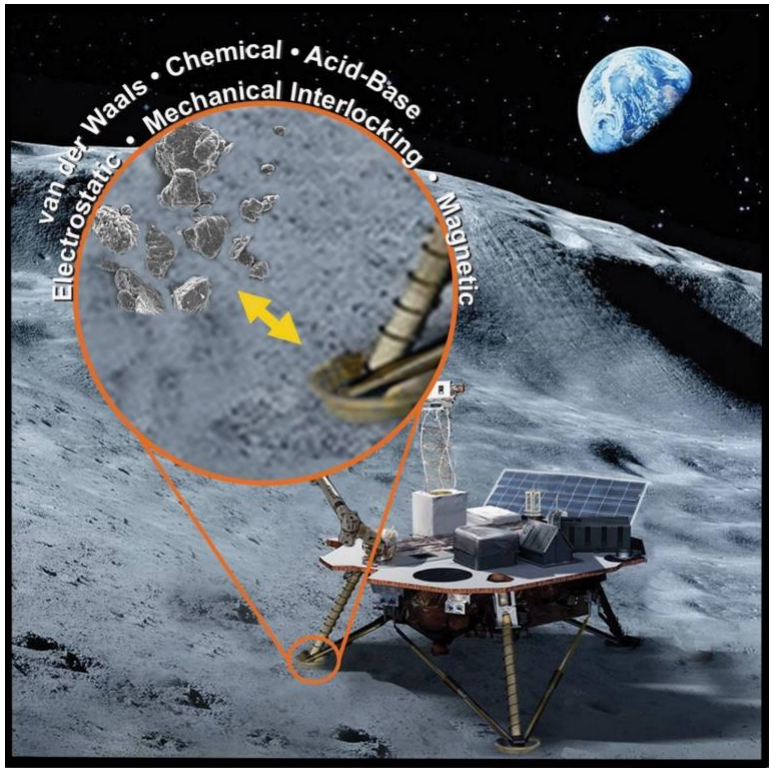

## Lunar Dust Adhesion Mitigation Opportunities and Needs

1. **Environment suits** Visors, joints, controls
2. **Sensing / optical equipment** Lenses, sensors, connectors
3. **Airlocks** Door seals, interior surfaces, controls
4. **Communications equipment** Dish surfaces, sensors
5. **Solar arrays** Panel surfaces
6. **Power distribution equipment** Connectors, radiators
7. **Lunar rovers** Gears, bearings, shafts, screens, radiators, instrumentation
8. **Lander / Landing site** Hatches, instrumentation, fueling equipment
9. **Habitat** Joints / seals / interlocks
10. **Excavating equipment** Bearings, controls, gears

Image credit: NASA

# Material Design and Selection for Lunar Applications

Dust Mitigation-
Must Remove




Dust Management-
Must Tolerate

❖Goal: Engage aspects of lunar dust from mitigation to management

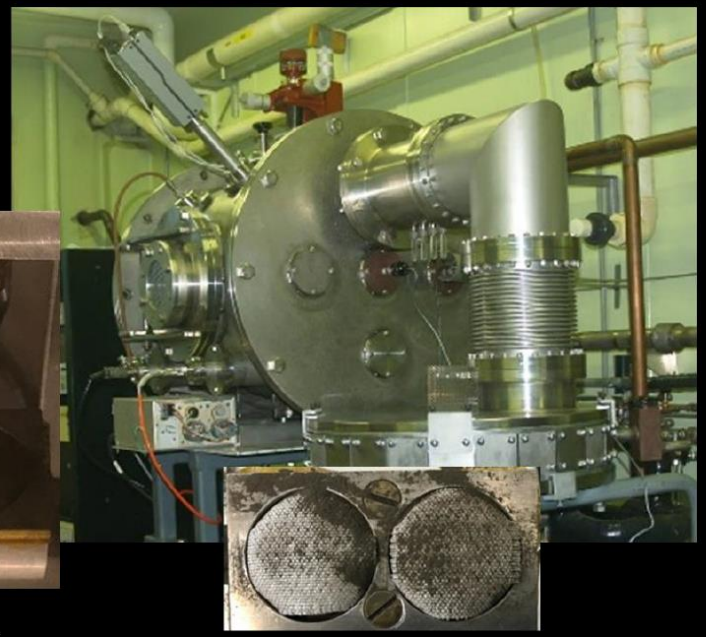
Image credit: NASA

# Surface Chemical Modifications
## Work Function Matched Surfaces

Ground Testing:

- Simulant (JSC-1AF, LHT-1…) sifted onto surfaces in vacuum (<1e-6 Torr) after bakeout at 200 °C for several hours
- Non-adhering simulant removed by nitrogen jet

Lunar Dust Adhesion Belljar



Sample pair under nitrogen jets after dusting, prior to nitrogen jet

Sample pair after exposure to nitrogen jet

*Simulants: JSC-1AF, fine portion of JSC simulant; LHT-1, lunar highland terrain simulant

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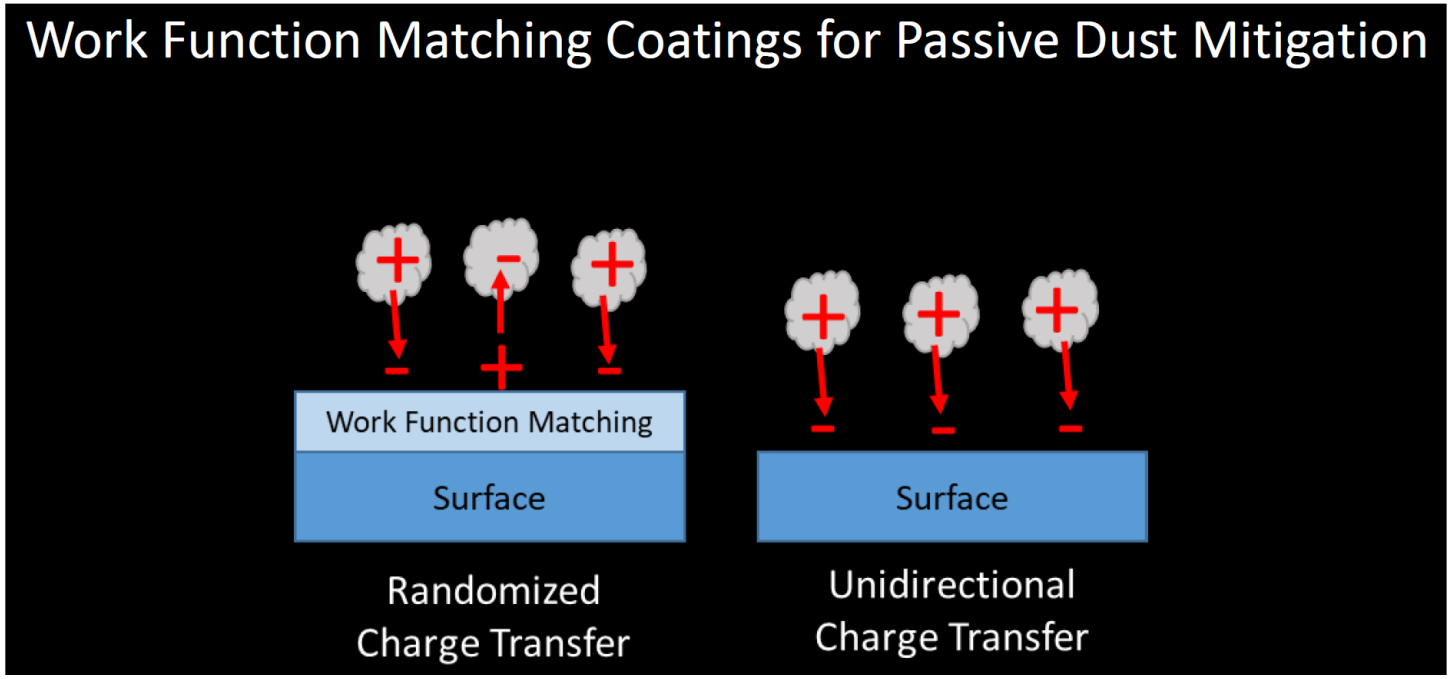
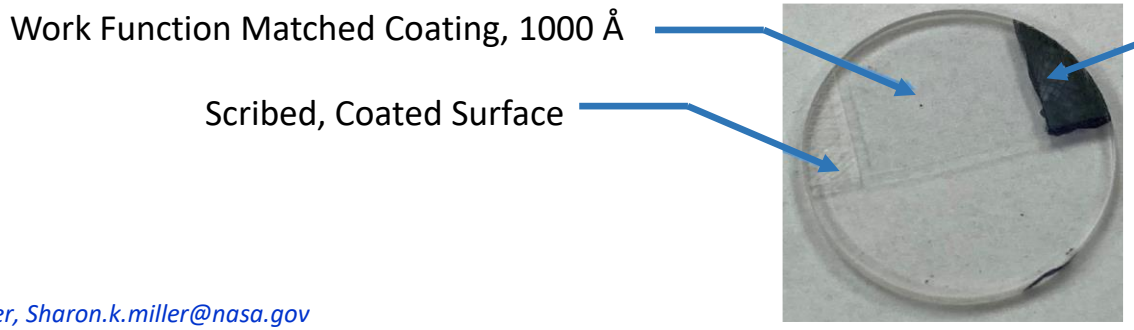
*POC: Sharon Miller, NASA Glenn Research Center, Sharon.k.miller@nasa.gov*

# Surface Chemical Modifications
## Work Function Matched Surfaces




Coating Generation Facility

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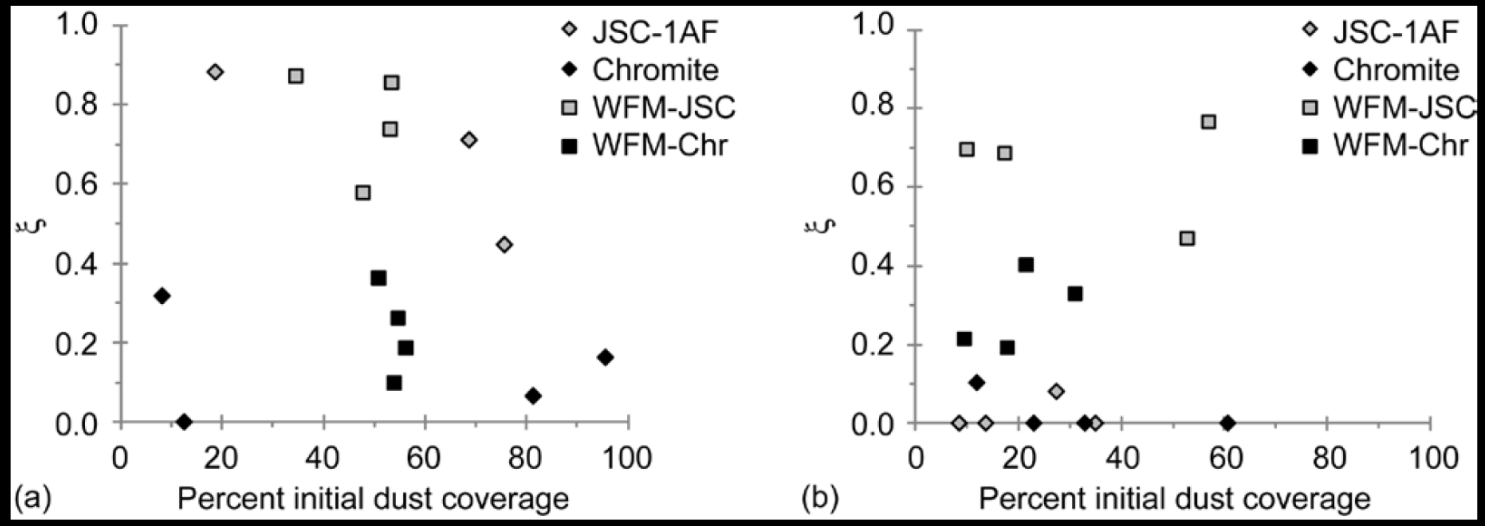
*POC: Sharon Miller, NASA Glenn Research Center, Sharon.k.miller@nasa.gov*

Image credit: NASA

# Surface Chemical Modifications
## Work Function Matched Surfaces

### Effectiveness of Work Function Matching Coatings in Removal of Lunar Simulant Using a Regulated Puff of Nitrogen Gas




Dust removal efficiency, ξ, calculated for pristine and workfunction matching coated (a) AZ93 and (b) AxFEP using JSC1-AF and Chromite simulants for dusting. (From Gaier, J.R., Waters, D.L., Misconin, R.M., Banks, B.A and Crowder, M. "Evaluation of Surface Modification as a Lunar Dust Mitigation Strategy for Thermal Control Surfaces" NASA/TM—2011-217230.)

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*POC: Sharon Miller, NASA Glenn Research Center, Sharon.k.miller@nasa.gov*

# Evaluation of Mitigation Efficacy

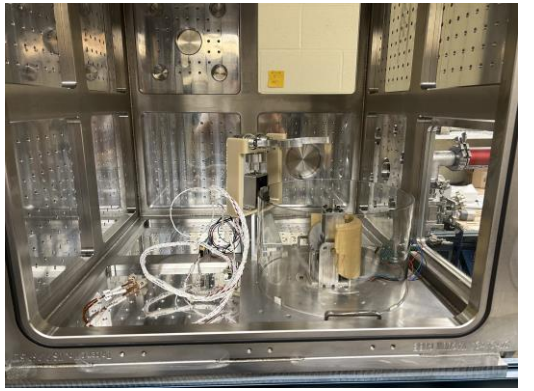
## Dust Ejection by Excessive Rotation (DEER)

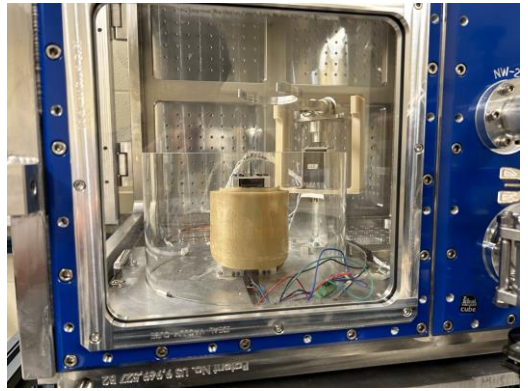
Purpose

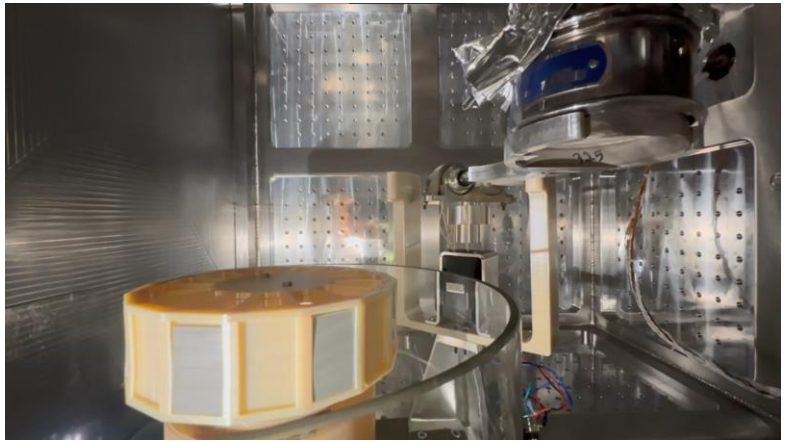
- To determine the adhesive forces of lunar simulant on a variety of materials. These forces are determined by centripetal force calculations after ejection or adhesion on a rapidly spinning sample holder.
  - Tests performed in a vacuum chamber ($10^{-6}$ Torr) with and without UV light exposure.

Objectives

- (Primary) determine the adhesive forces of lunar simulant on a variety of materials
- (Secondary) establish a facility to continue this testing, as needed, for Providers and stakeholders







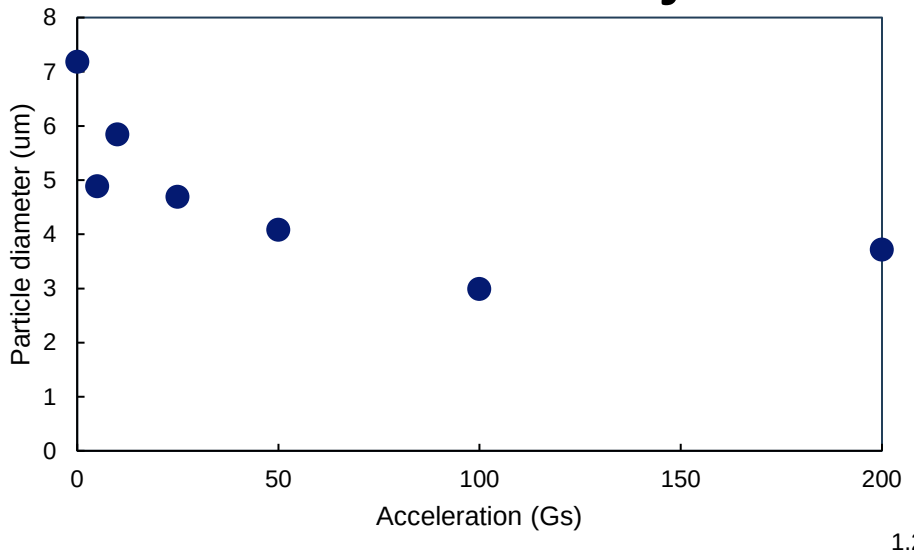
JSC

*POC: Josh Litofsky, NASA Johnson Space Center, Joshua.h.Litofsky@nasa.gov*

Image credit: NASA

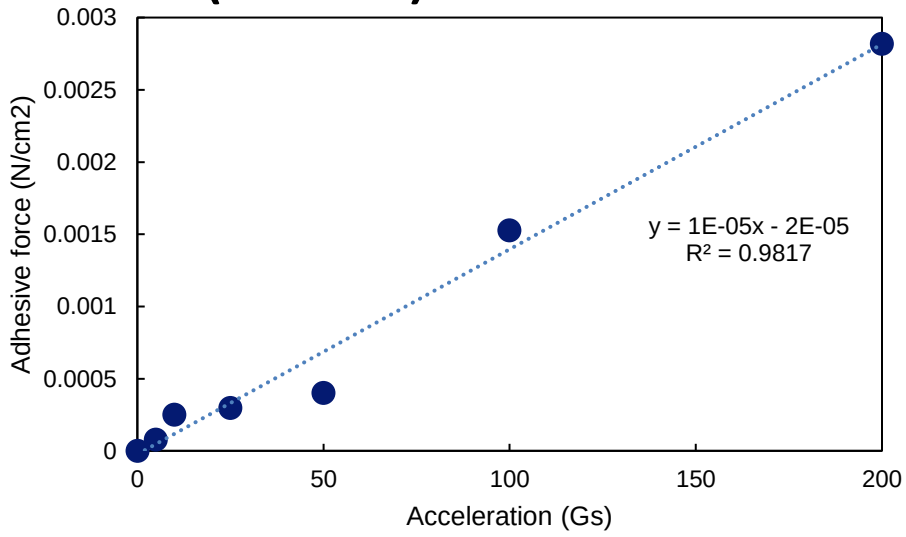
# Evaluation of Mitigation Efficacy

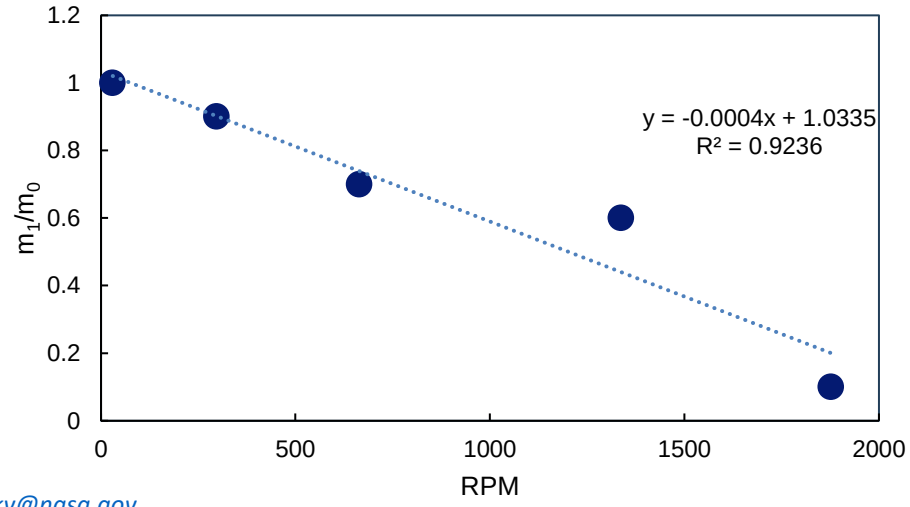
## Dust Ejection by Excessive Rotation (DEER)




Average particle diameter decreased with increasing centripetal force

Adhesion force increased linearly with centripetal force




Remaining simulant mass decreased linearly with increasing centripetal force

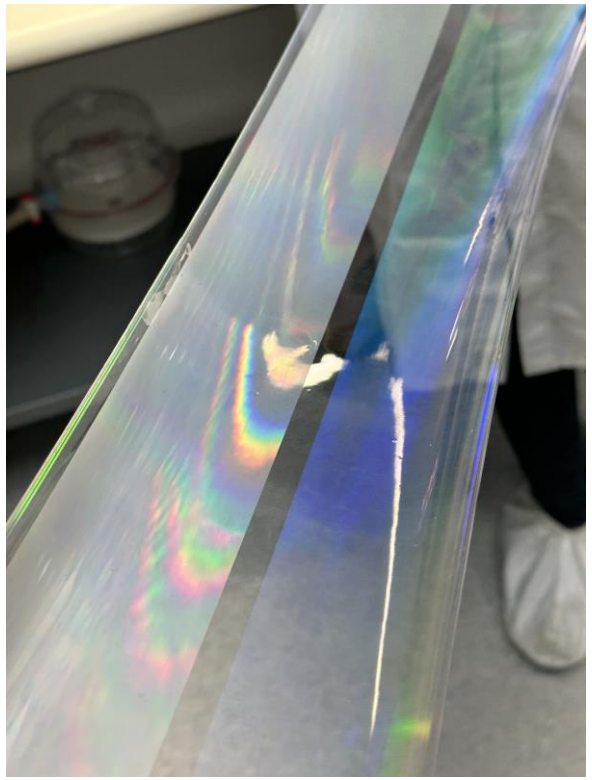
JSC

*POC: Josh Litofsky, NASA Johnson Space Center, Joshua.h.Litofsky@nasa.gov*

# Surface Topographical Modification
## Nanocoining

More than 150 ft. of imprinted polycarbonate

MicroContinuum



Smart Material Solutions

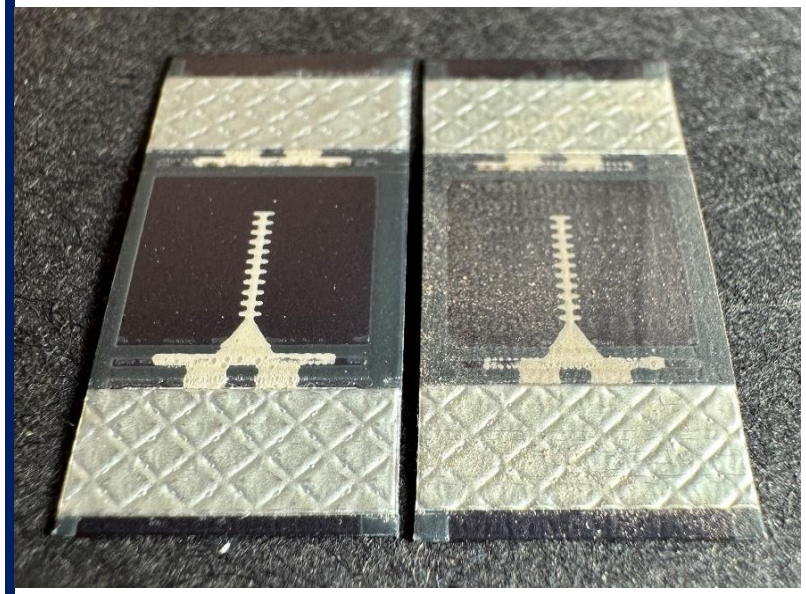
*POC: Stephen Furst, Smart Material Solutions, furst@smartmaterialsolution.com; Chih-Hao Chang, University of Texas-Austin, chichang@utexas.edu*

# Evaluation of Mitigation Efficacy

## Tilt Testing- Solar Cells with Nanocoin Topography

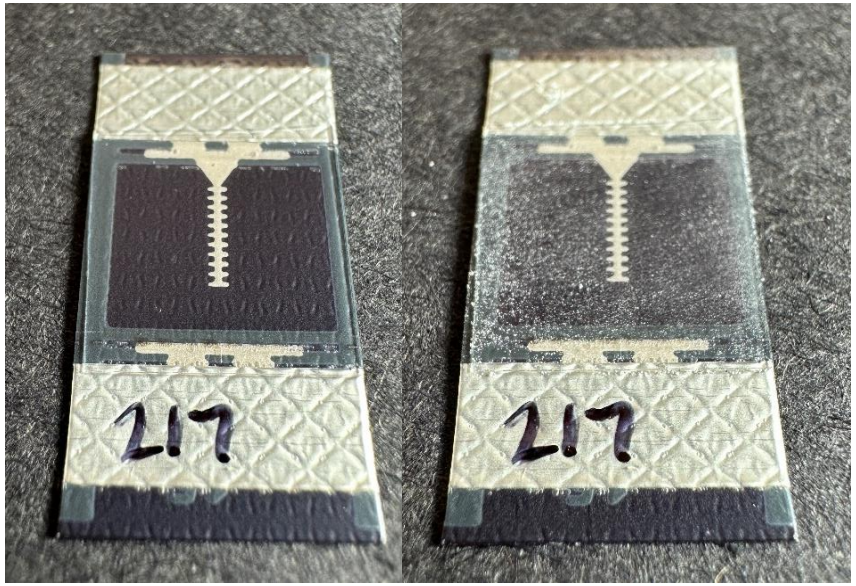
### No Coating

Before dusting After dusting



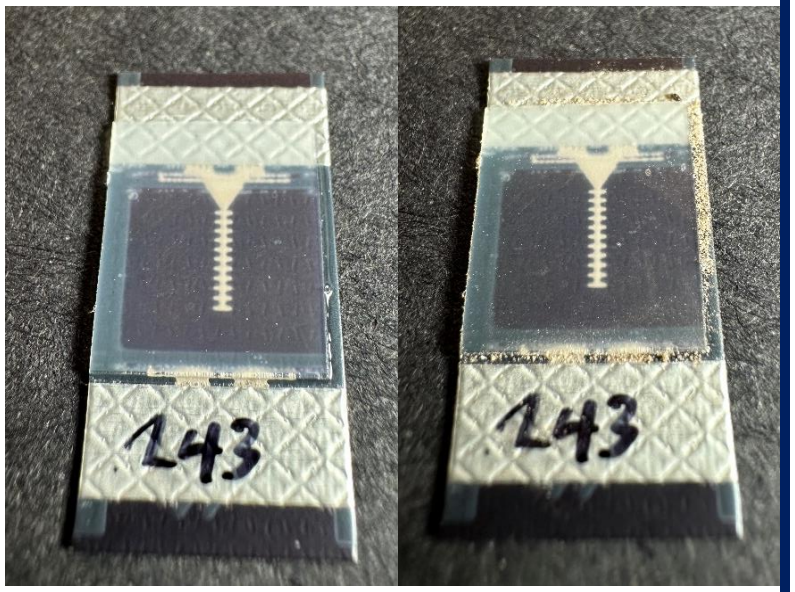
### Smooth Coating

Before dusting After dusting




### Hierarchical Coating

Before dusting After dusting




Smart Material Solutions

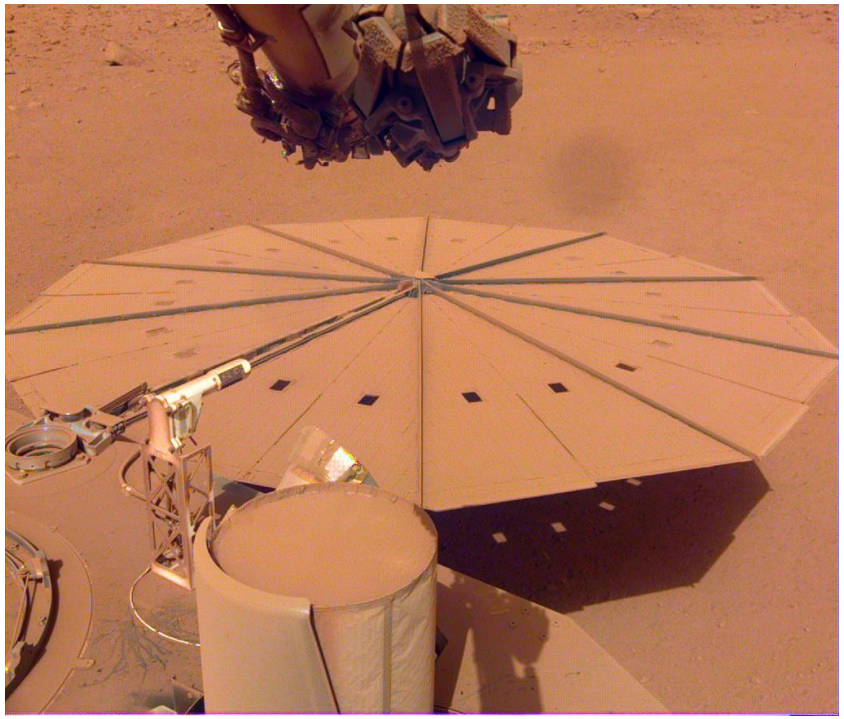
UT Austin

*POC: Stephen Furst, Smart Material Solutions, furst@smartmaterialsolutions.com; Chih-Hao Chang, University of Texas-Austin, chichang@utexas.edu*

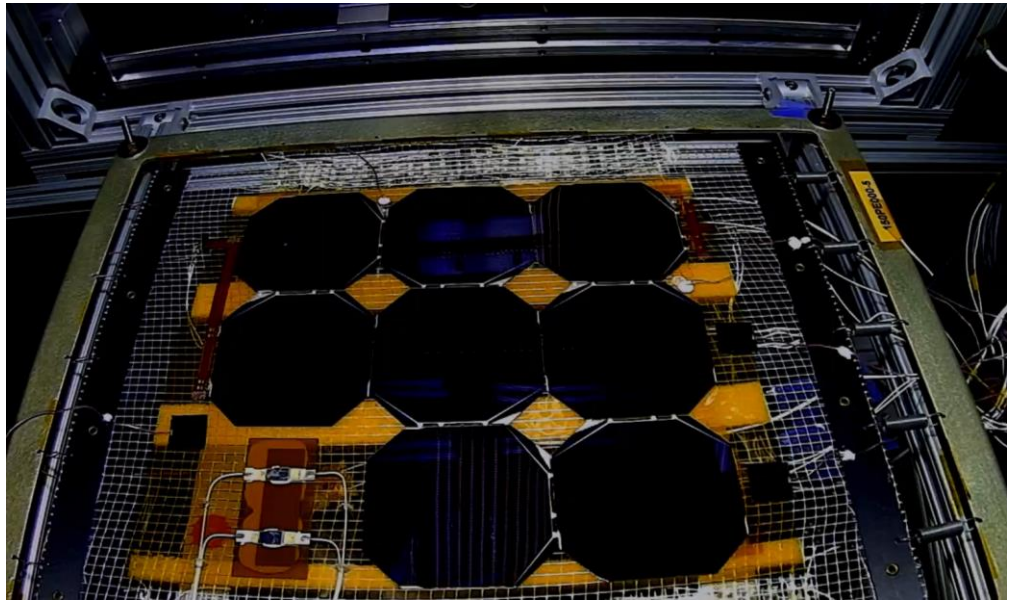
# Evaluation of Mitigation Efficacy

## Solar Cell Testing- Evaluation of Vibromechanical Dust Removal

### Mars Insight Lander



forward bias solar cell → solar cell emits light



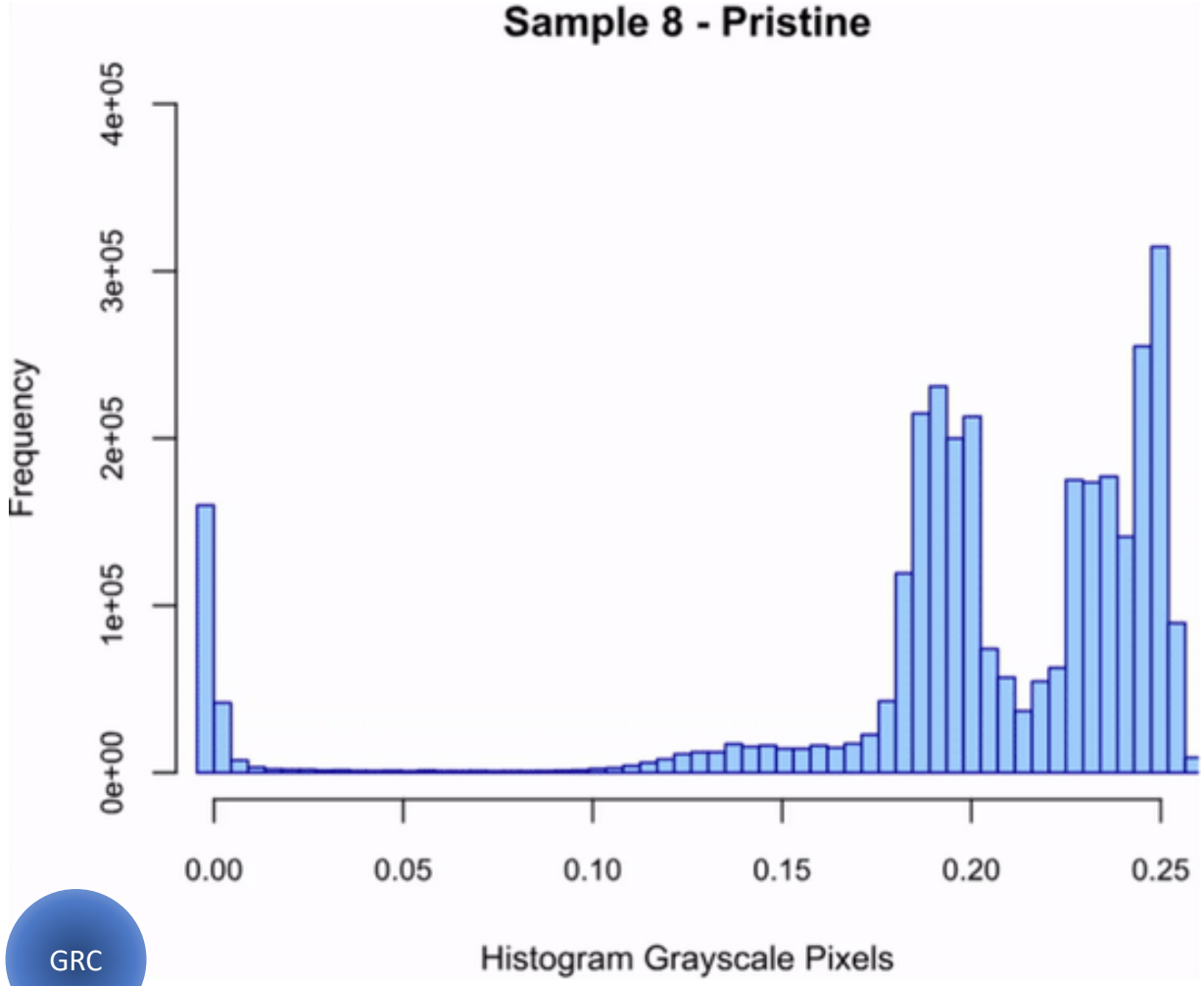
GRC

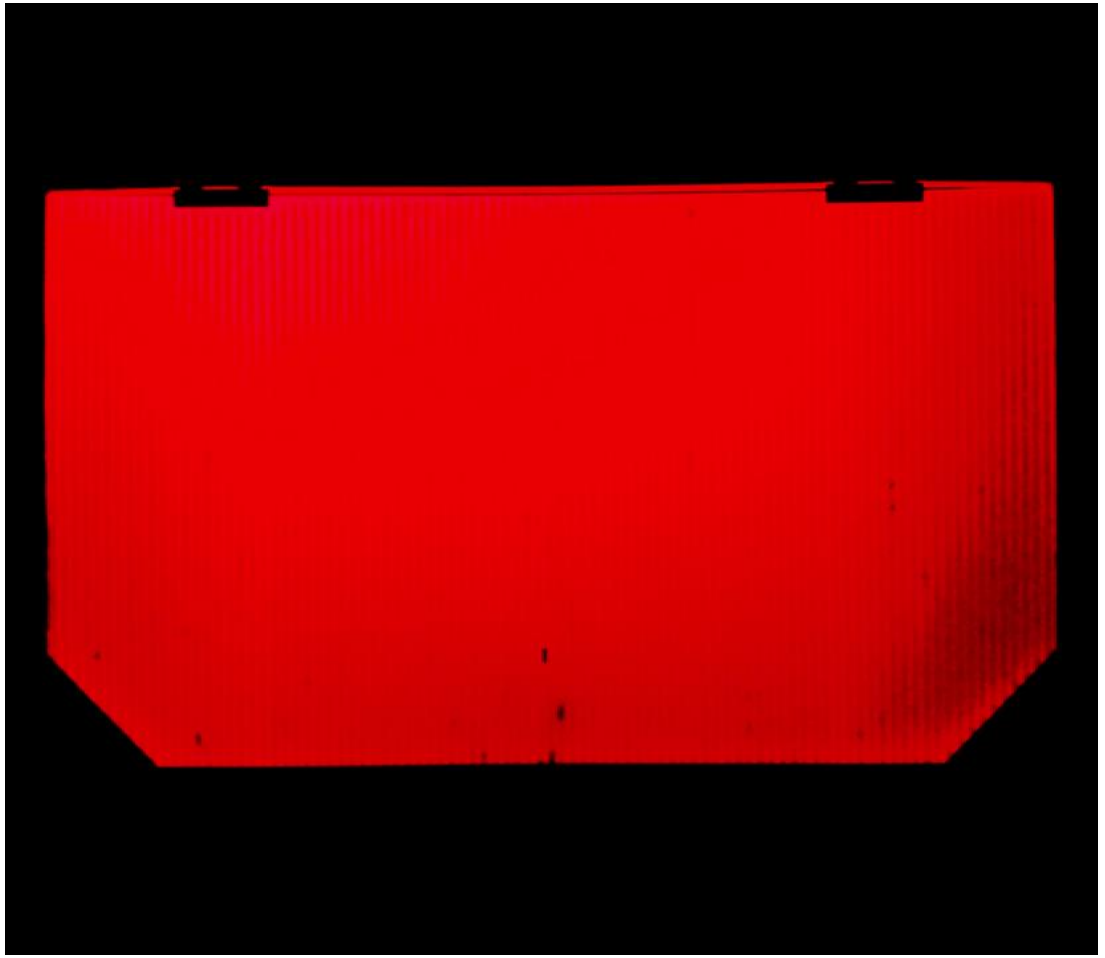
*POC: Meghan Bush, NASA Glenn Research Center, Meghan.bush@nasa.gov , DMFlex ACO – 20 – 20 ACO Final – 0020*

Image credit: NASA

# Evaluation of Mitigation Efficacy

## Solar Cell Testing- Evaluation of Vibromechanical Dust Removal



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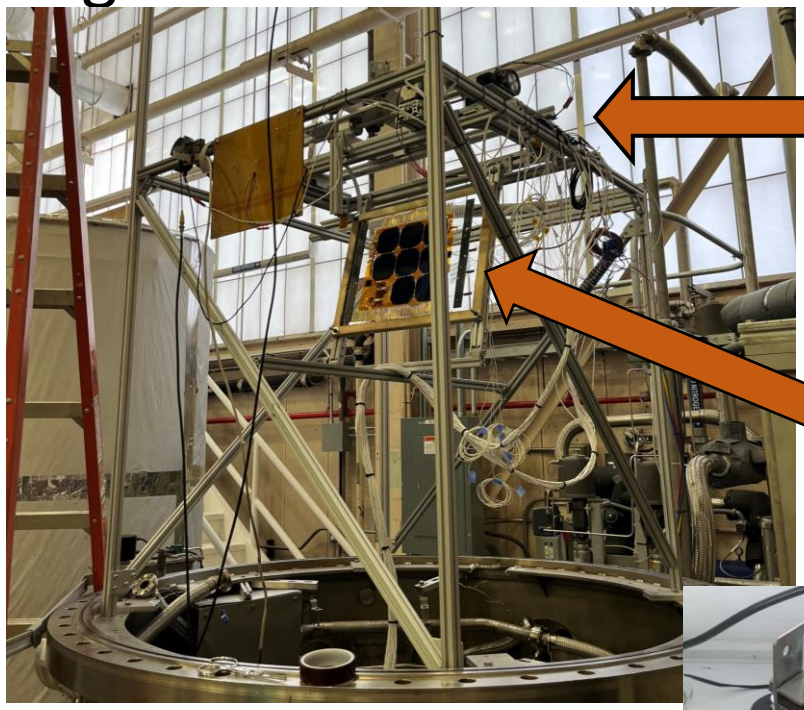
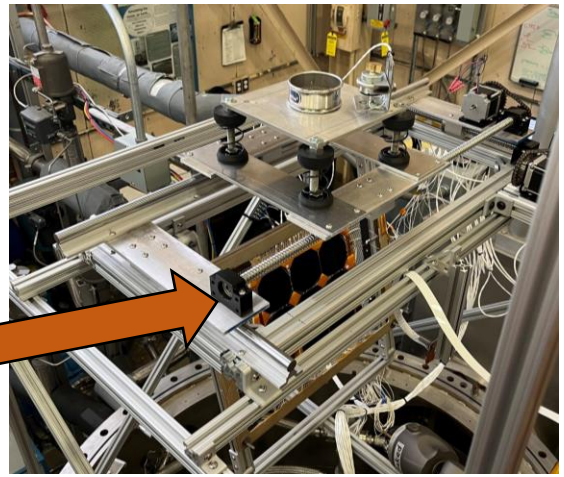
# Evaluation of Mitigation Efficacy

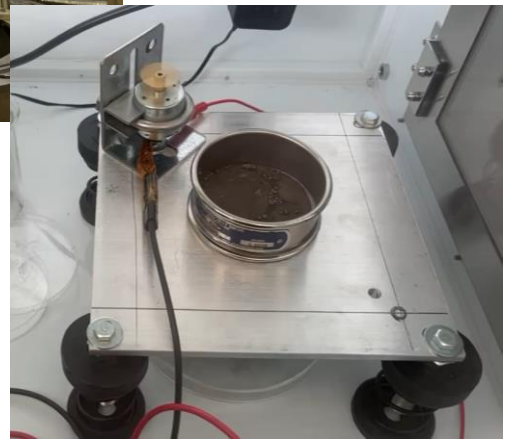
## Solar Cell Testing- Evaluation of Vibromechanical Dust Removal

*Dust Deposition System*

*Test coupon*





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# Evaluation of Mitigation Efficacy

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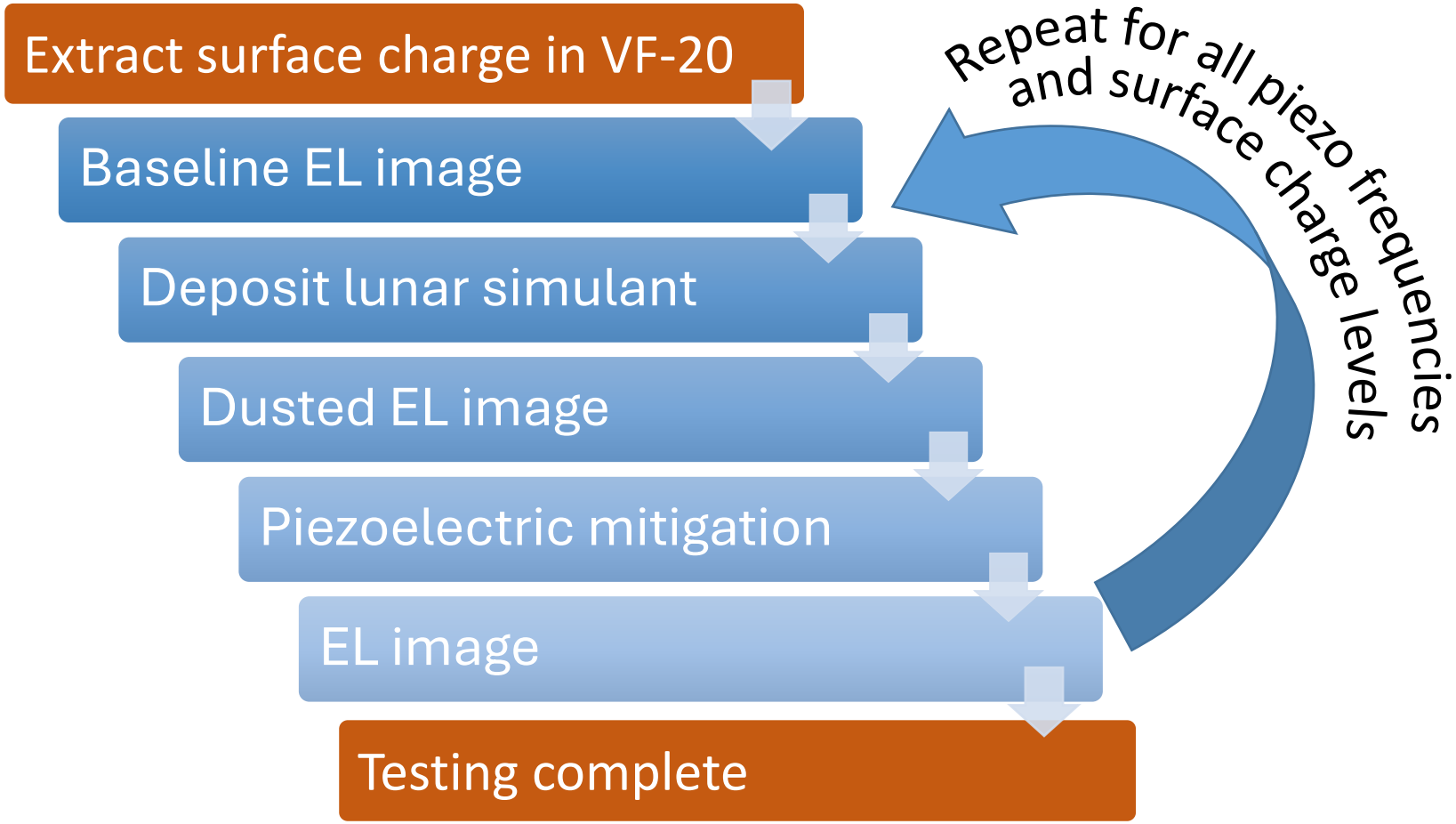


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# Evaluation of Mitigation Efficacy

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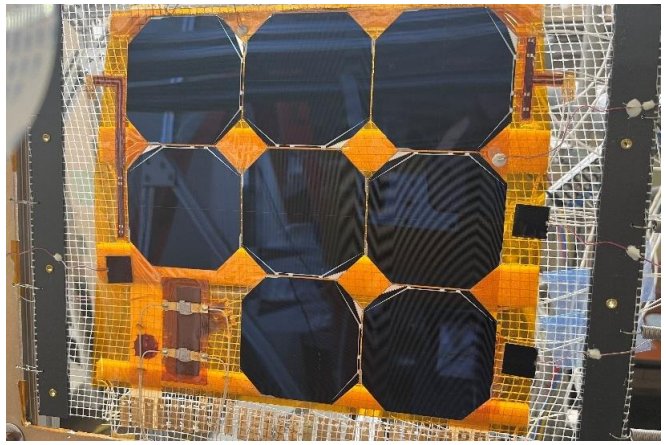

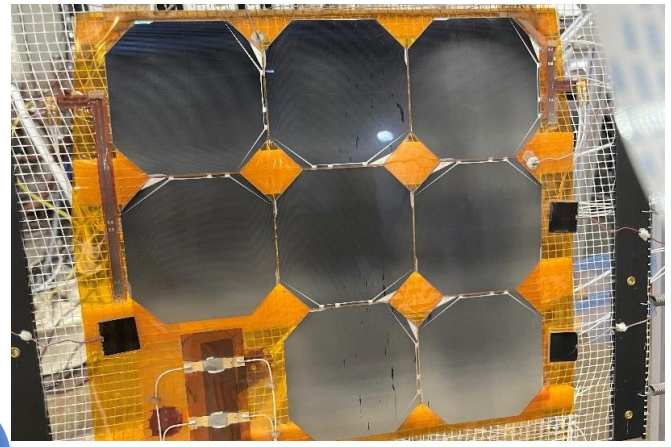

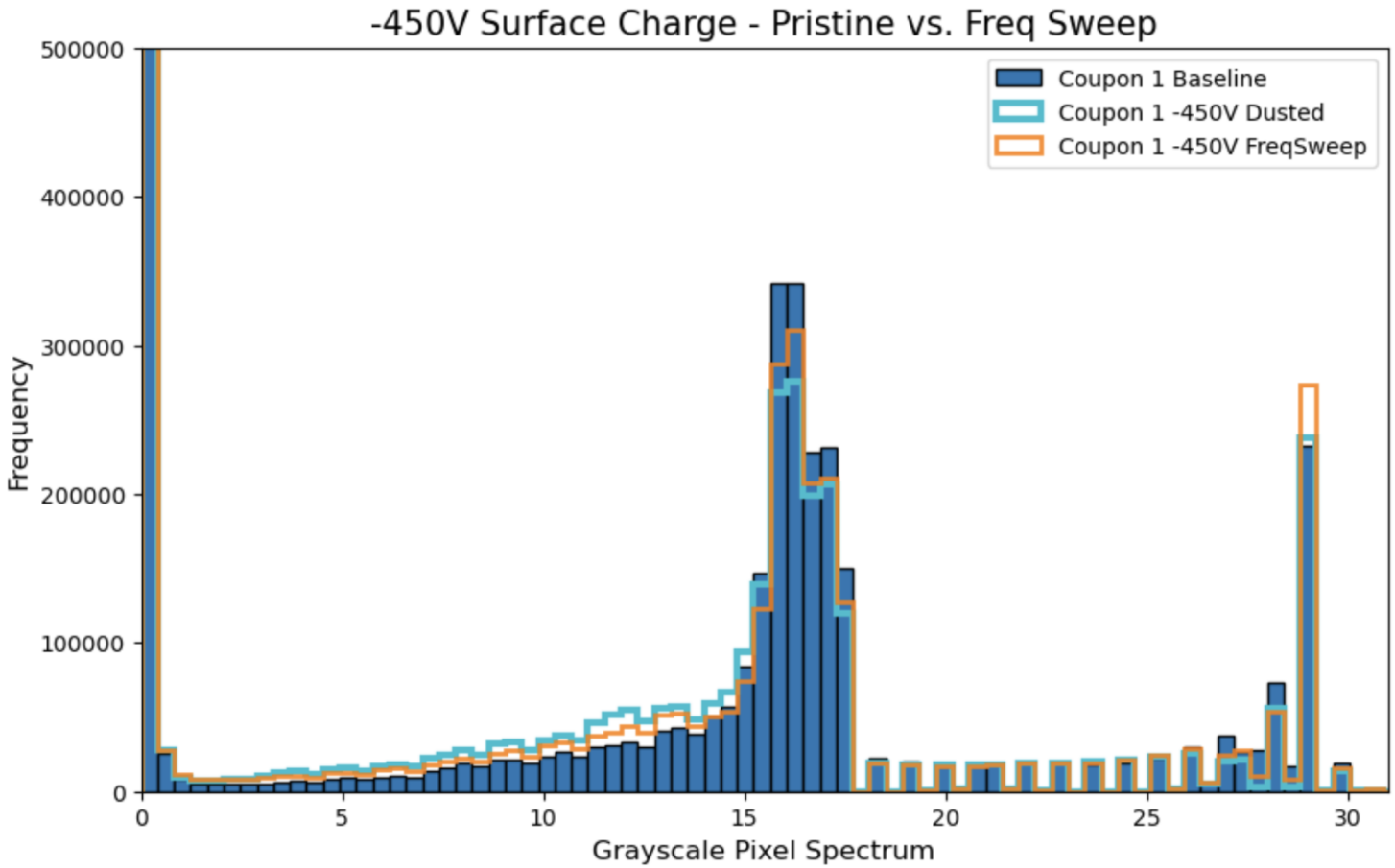


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