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The Dust Problem

Mitigation Methods for Flexible Solar Arrays under Lunar Conditions

R. Campos, H. Yates, B. Tranter.

In collaboration with M.Bush and T. Peshek from NASA Glenn Research Center

Prepared by: Roselin Campos
Maxar Space LLC
3825 Fabian Way
Palo Alto, CA 94303-4604
USA

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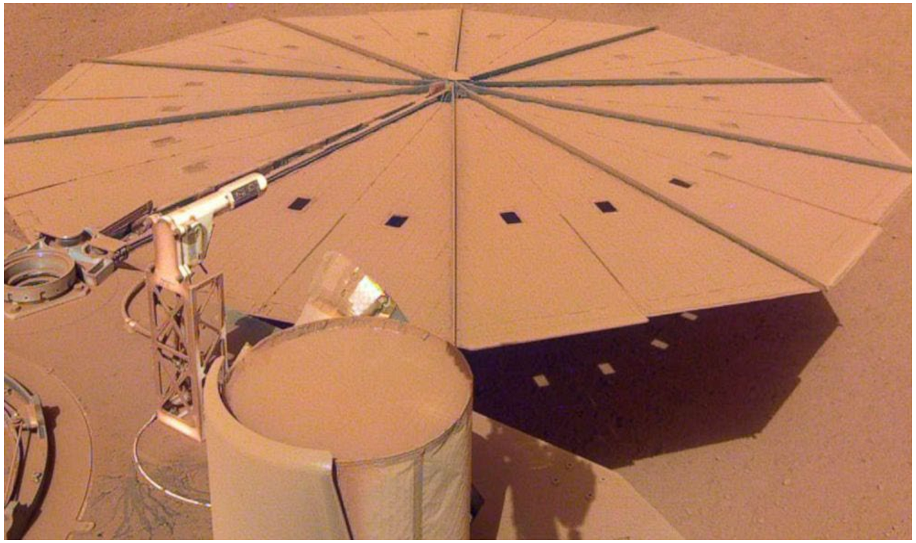
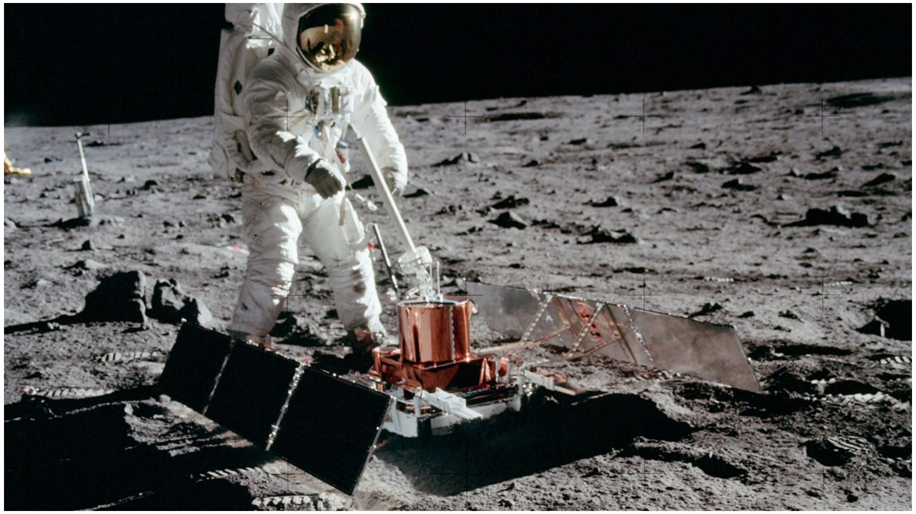
A Problematic History with Dust

- Dust has always caused concern for solar array capability



NASA/JPL-Caltech. (2022, May 18). *Mars Lander losing power because of dust on solar panels (Kekatos, Mary Ed.)* https://abcnews.go.com/Technology/mars-lander-losing-power-dust-solar-panels/story?id=84805112



National Aeronautics and Space Administration. (2017, September 22). *Apollo 11 Seismic Experiment* https://moon.nasa.gov/resources/13/apollo-11-seismic-experiment/

- What causes dust?
- How do we deal with this?

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Why is dust an issue?

- Apollo-era lunar surface experiments lost ~16% of solar array power
  - lunar dust caused surface obscuration
  - Source: vehicle-generated clouds
  - During lunar nights, charge on dust dissipates and surfaces clear to ~1%
- For longer lunar missions: active dust mitigation is a **MUST**
- Maxar is working on dust mitigation methods along several fronts
  - ACO with NASA GRC (discussed today)
  - PPE and Gateway (dust contamination from visiting landers)
- Dust mitigation efforts from other US and international institutions

Lunar dust risk is a high-visibility issue with many unknowns

Lunar Regolith is a new “Monster Under the Bed”

- Lunar soils are unique
  - Not sorted (size, shape or chemistry), sharp edges, agglutinates, rims, everything is coated, small grains stick to larger grains
- Lunar soils mature over time
  - Become finer grained, more agglutinates, more nanophase iron, ion implantation, finest fraction is mostly plagioclase and nanophase iron-bearing glass
- Lunar soils differ from location to location
  - Lighter impact craters are newer
- JSC-1A was chosen as a simulant for testing purposes

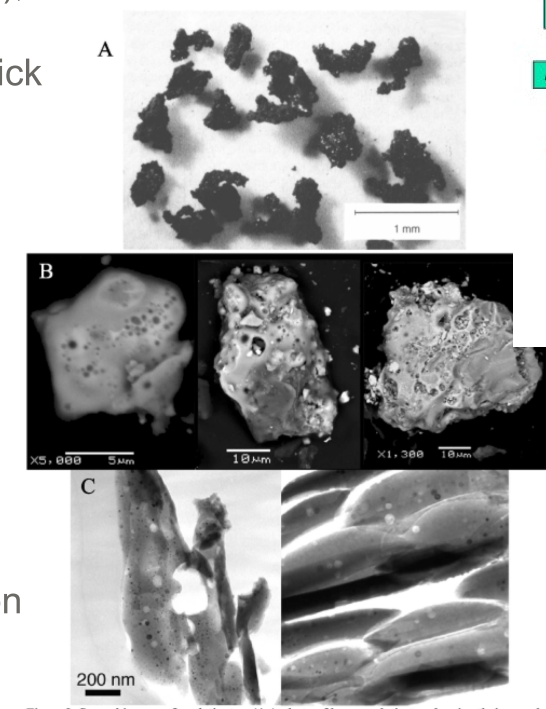
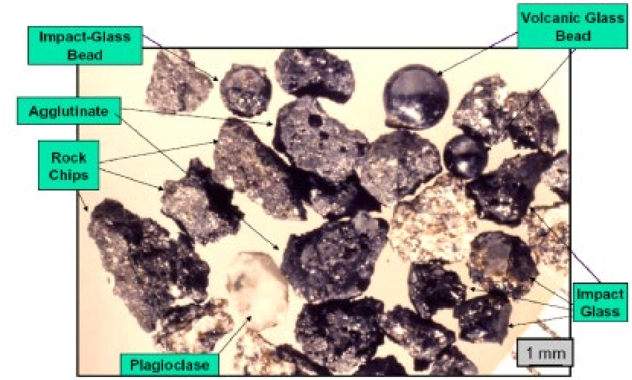


Figure 3. Several images of agglutinates. A) A photo of large agglutinates showing their complex shape (McKay et al., 1991). B) Scanning electron microscope (SEM) backscatter images of agglutinates showing their vesicular nature. C) Transmission electron microscope (TEM) images of cross sections through agglutinates showing vesicles (white spots) and nanophase iron (black spots).



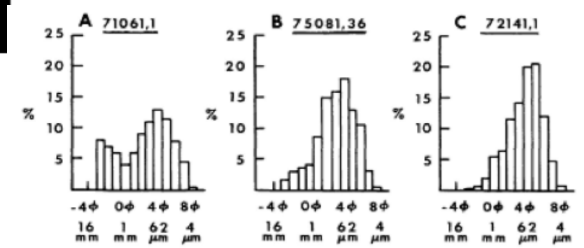


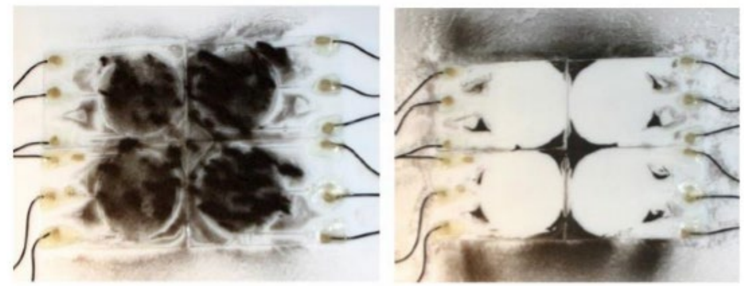
Figure 7. Grain size histograms of an immature soil (A), a submature soil (B), and a mature soil (C) (McKay et al, 1974).

“Within 2-3 days the dust had rendered all mechanisms inoperable”
Anecdote from Apollo Program

Some Dust Mitigation Techniques

- **Electrodynamic Dust Shield (EDS)**
  - AC current through thin conductive coating applied to cell coverglass
  - Fields from the AC currents are intended to reduce & remove collected dust

EDS



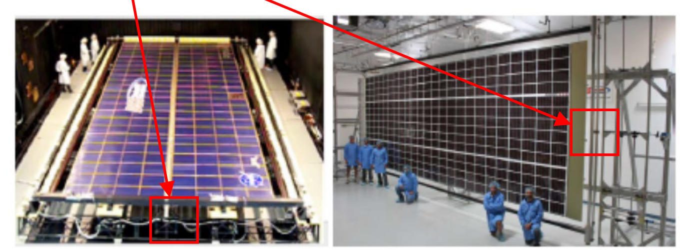
- **Piezoelectric Dust Mitigation**
  - Uses piezoelectric effects to gently vibrate arrays to mechanically dislodge dust collected the assembly

Piezoelectric

- **Dynamic Dust Mitigation**
  - Applied to RedWire ROSA wing level
  - Linear actuator pulses the base of the array, exciting the tensioned array blanket, thereby loosening collected dust
  - Similar method used on ISS ROSA demonstrator to determine ROSA dynamic characteristics, repurposed as a dust mitigation method

Linear actuator placement

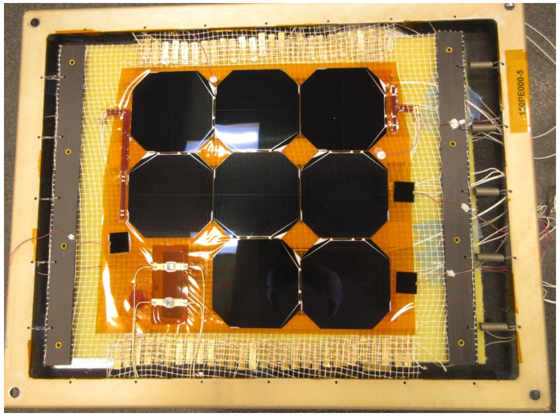
Dynamic



Space Power Technologies for Future Planetary Science Missions (2017, December 21). Retrieved April 3, 2023, from https://solarsystem.nasa.gov/resources/548/solar-power-technologies-for-future-planetary-science-missions/

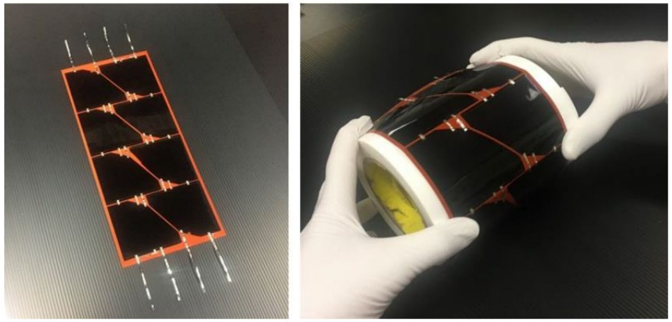
Test Coupon Descriptions

- Coupon 1 - **ROSA**
  - Maxar development coupon
  - 4 piezoelectric devices bonded onto back side of coupon



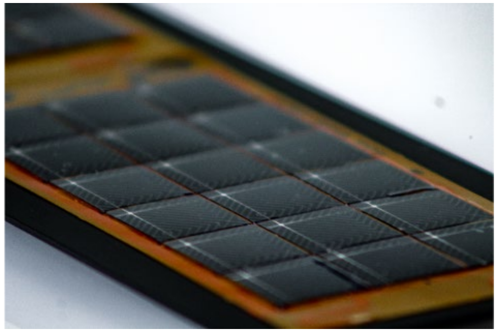
Courtesy of Maxar Technologies/RedWire

- Coupon 2- **MicroLink IMM flex array**
  - Cell module bonded onto black Kapton-coated glass fiber composite
  - 4 piezoelectric devices bonded onto back side



Courtesy of MicroLink Devices, Inc.

- Coupon 3 – **mPower Silicon flex array**
  - Cell module bonded onto black Kapton-coated glass fiber composite
  - 4 piezoelectric devices bonded onto back side



Courtesy of mPower Technology

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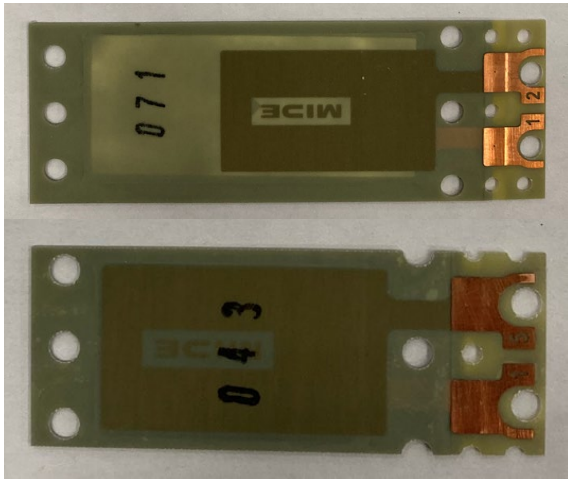
Mechanical Movement

- Lunar Dust Testing
  - Main source of movement: piezoelectric motor
    - Electrical power into a bending movement
  - Motors actuated through the full range of operational frequency to ensure both resonant frequencies are hit (1Hz – 500Hz)
    - Coupons undergo test with dust simulant exposure at different angles and frequency input modes



- To establish coupon functional baseline, coupon undergoes the following:
  - Visual Inspections
  - Electrical baseline : LAPSS test, Electroluminescence, Infrared Inspection
  - Piezoelectric motor checkout

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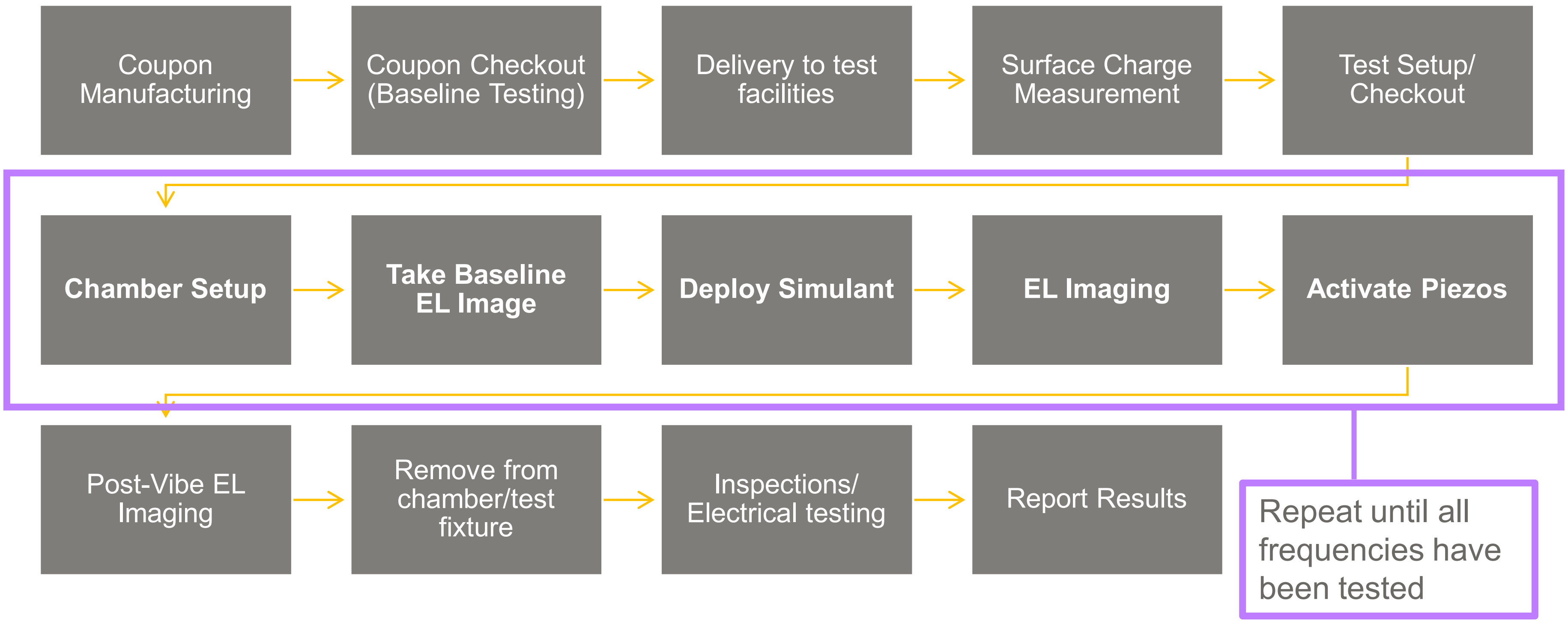
Demo of Piezoelectric Motors

Courtesy of Maxar Technologies

Test Plan

- Baseline testing of coupons
- Baseline testing of piezos/linear actuators

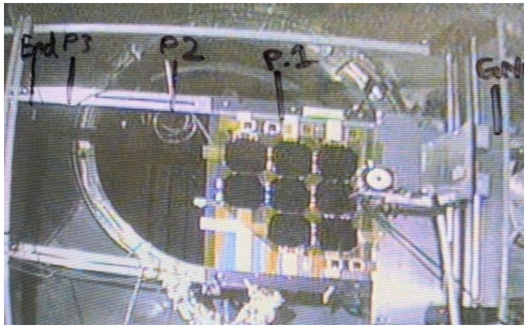


Formal Test Flow – MAXAR/NASA ACO TRL Goal: 4

NASA GRC
Testing Chambers & Dust Deposition System

Dust Deposition Chamber

VF-20 Charging Chamber



Maxar test coupon in VF-20

Dust Deposition System

Images courtesy of NASA GRC

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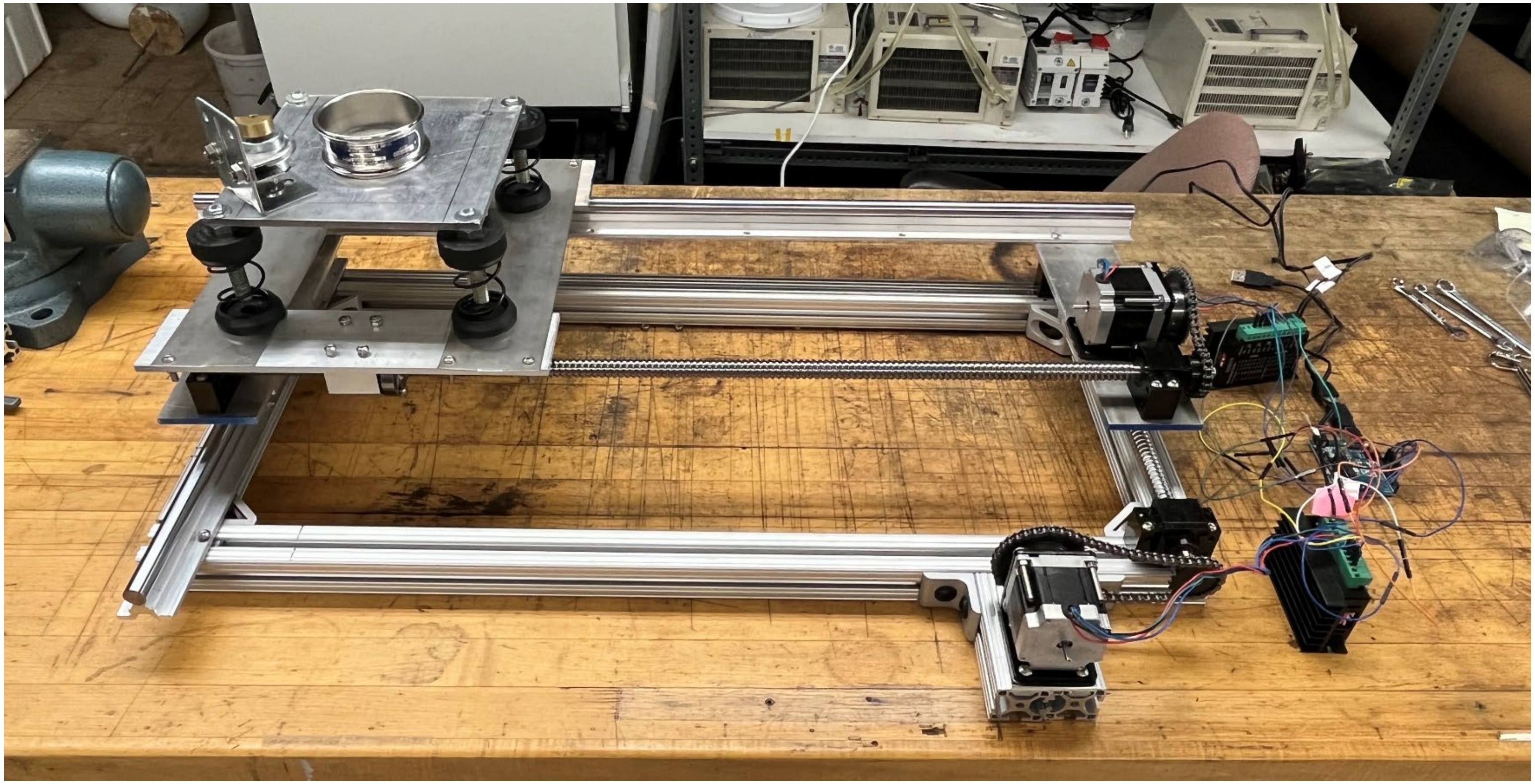
Dust Deposition System

- Vibration motor mechanically excites lunar simulant loaded into a sieve, depositing dust
- XY stage rasters the vibration plate over the solar array test coupon to allow for full coverage



Images courtesy of NASA GRC

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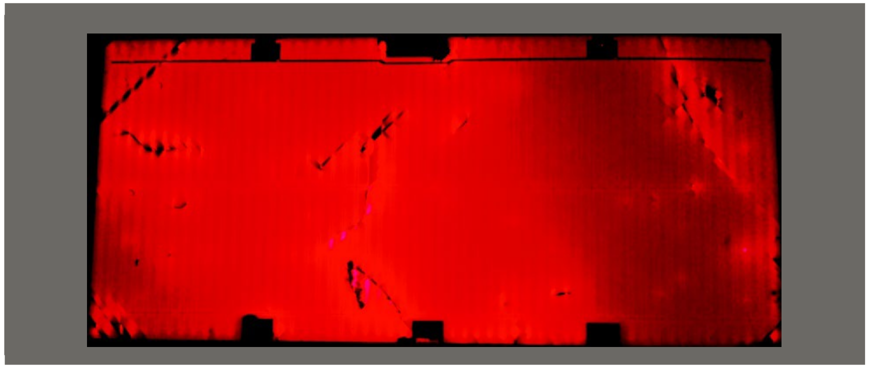
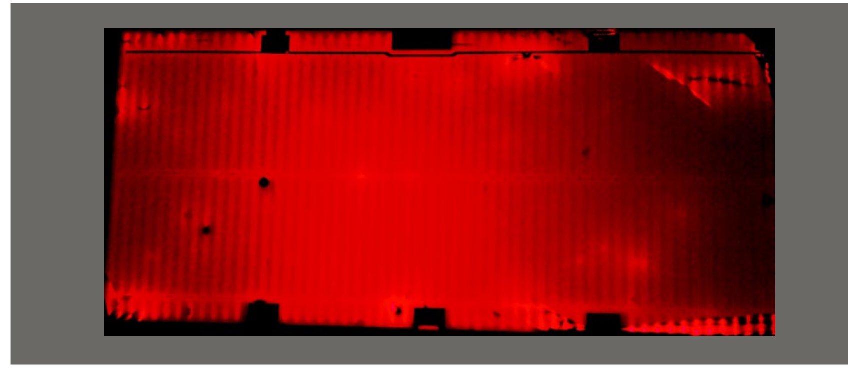
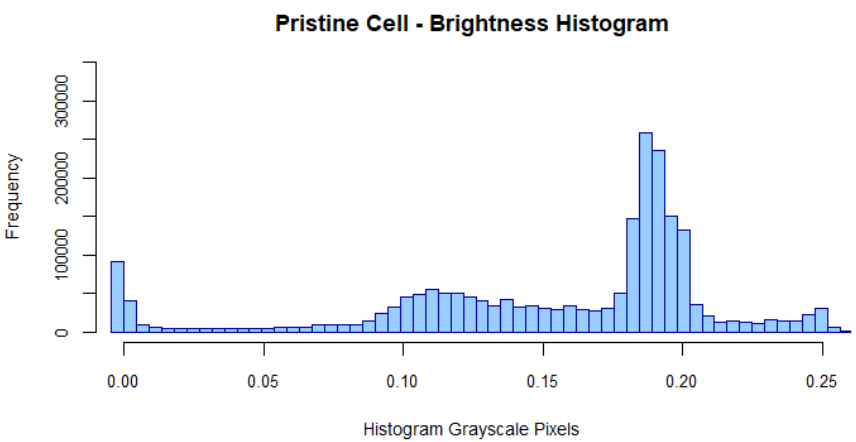
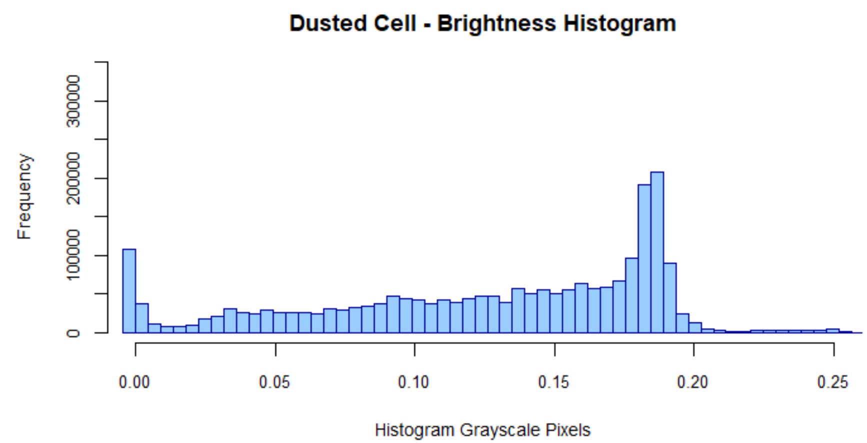
Electroluminescence Imaging

- NASA GRC developed a quantitative method for evaluating solar cells when in a “dusted” stated









M. Bush, T. Peshek and E. Montbach, "Evaluating Electroluminescence Imaging and Image Processing as a Quantitative Solar Cell Characterization Method," 2022 IEEE 49th Photovoltaics Specialists Conference (PVSC), Philadelphia, PA, USA, 2022, pp. 232-232, doi: 10.1109/PVSC48317.2022.9938480.

Looking Ahead – Potential Forward Work

- **Not recreating environment on the moon**
  - Types of regolith
  - Effects of temperature
  - Charging dust

- **Implementation at the wing level**
  - Required power source
  - Piezo placement
  - Scaled up resonance characteristics
- **Return to Basics**
  - Individual compound effects on solar arrays
  - Effects of lunar dust compounds on solar cells

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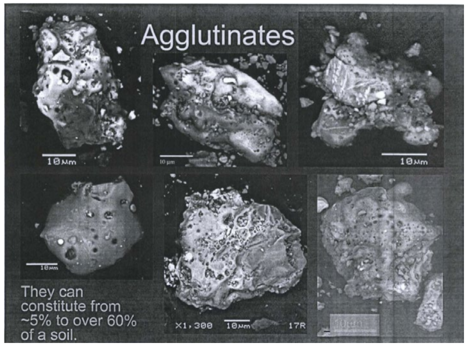
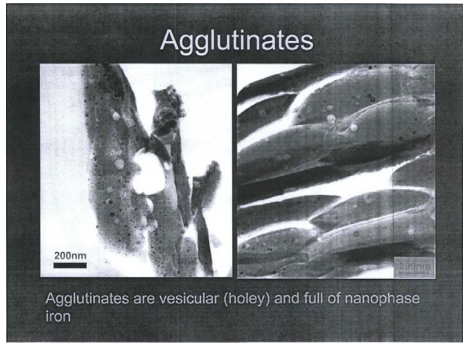
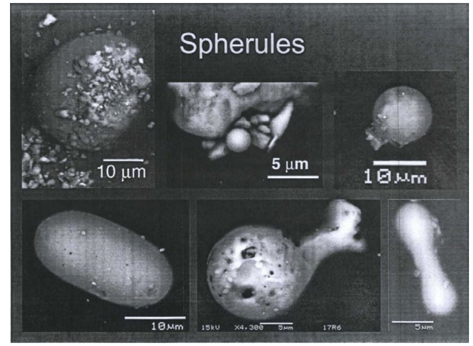
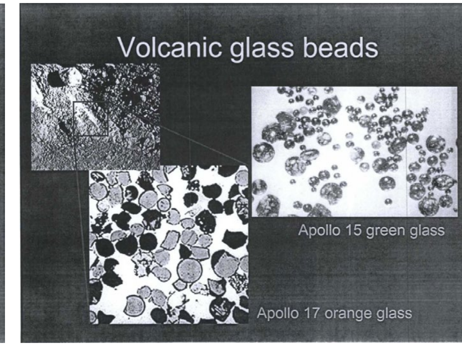
Q & A

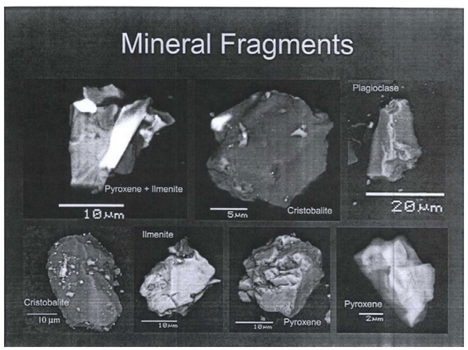
Wide Variation in Lunar Regolith Dust Particles

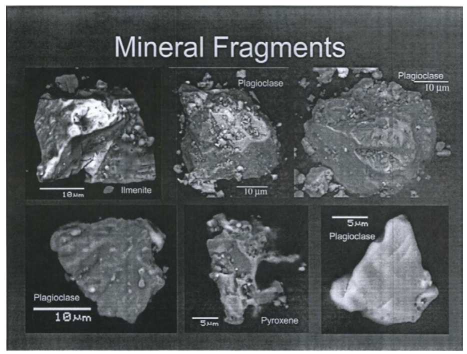


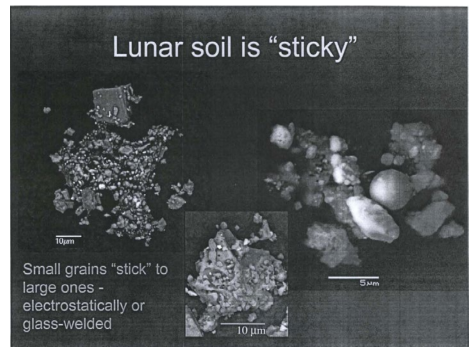


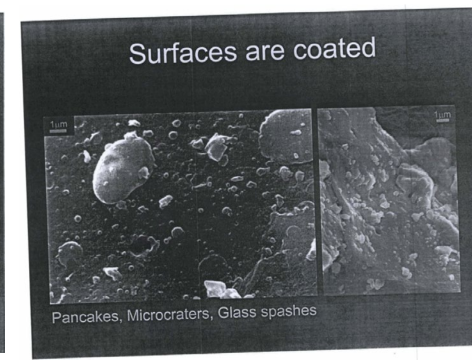












Ascent / descent thrusters kick up clouds, the composition of which varies by altitude

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