Kennedy Space Center

Space Environmental Testing of the Electrodynamic Dust Shield Technology

Carlos I. Calle, Ph.D.

P.J. Mackey, M.D. Hogue, Ph.D., M.R. Johansen

Electrostatics and Surface Physics Laboratory

NASA Kennedy Space Center

H. Yim, P.B. Delaune

NASA Johnson Space Center

J.S. Clements

Department of Physics and Astronomy

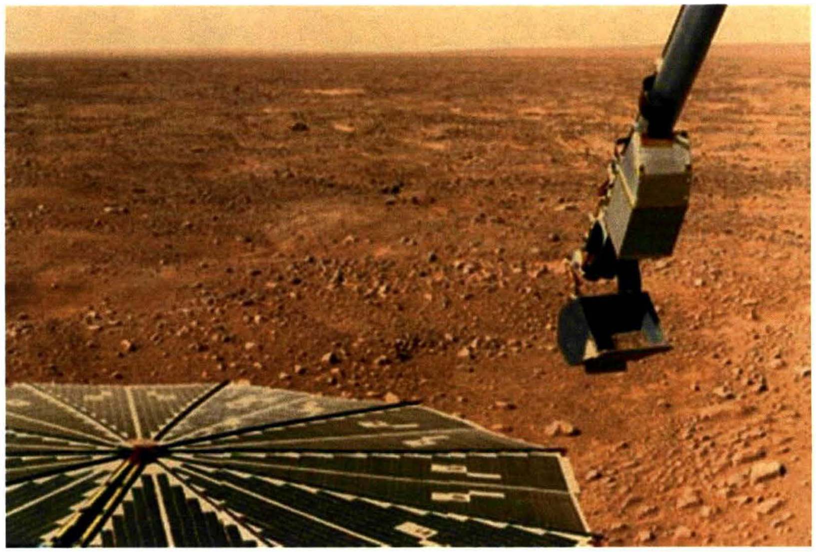
Appalachian State University

Annual Meeting of the Electrostatics Society of America, Cocoa Beach, FL, June 11-13, 2013

Kennedy Space Center

Martian Dust Environment

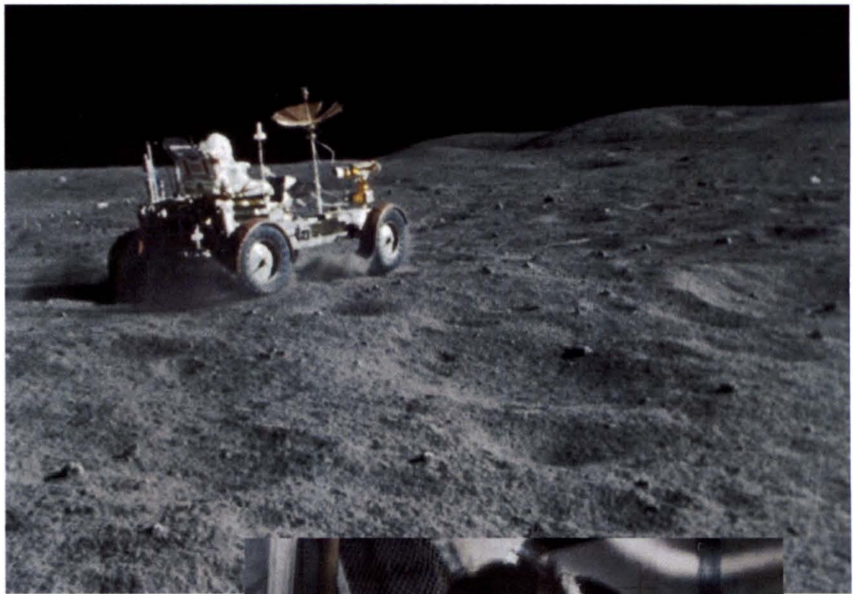
- Estimates from optical data: Average dust particle in the Martian atmosphere: 3 μm in diameter
- Average particle size changes with dust storm activity:
  - 2001: Derived particle data ranged from 2 to 5 μm
- Data from MI on Spirit & Opportunity (Landis et al 2006)
  - Suspended atmospheric dust: 2-4 μm
  - Settled dust uploaded by wind, diameter: ≤ 10 μm
  - Saltating particles: ≤ 80 μm
- Particle in soil (MI on Spirit on Scamander crater) ~ 220 μm



Kennedy Space Center

Lunar Environment

- Top layer of the lunar regolith is comprised of dust
- Lunar dust is an abrasive powder that clings to space suits, robots, and virtually all machinery
- Apollo 12, November 1969:
  - A total of 3 hours, 31 minutes were spent on the lunar surface before the LM ascent engine fired for liftoff
  - Lunar dust tracked into the LM became a problem
  - Since the dust became weightless after liftoff from the Moon, the astronauts had trouble breathing without their helmets.



Expected Electrical Environment

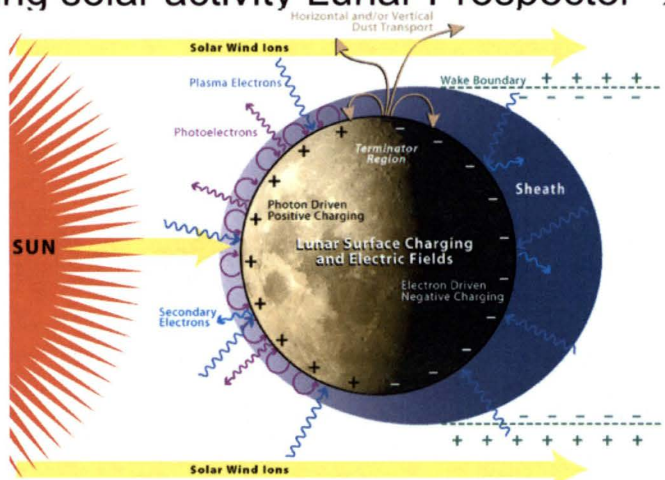
Kennedy Space Center

MARS

- Tribocharging of particles expected to generate E-fields up to Paschen breakdown ~ 20 kV/m
- Terrestrial dust devils ~ >120 kV/m (Jackson & Ferrell, 2006)
- 1973: Eden and Vonnegut performed lab experiments with sand in Martian-like atmosphere:
  - Dust particle $q \sim 10^4$ e^-
  - Observed glow and filamentary discharges
- Recently, we observed glow discharges with Mars simulant
  - Showed alteration of known organics added to Mars simulant under simulated conditions
- 2001-2006: Fabian et al and Kraus et al: charging due to dust vertical motion; electrical discharges in atmosphere
- In dusty, turbulent Martian environment:
  - $E \sim 5$ kV/m

MOON

- Charged body in a plasma
  - Ions and electrons from solar wind, cosmic rays
- Sunlit side: photoelectric charging by solar UV → 5 to 10 V
- Night side: plasma electrons → -50 to -100 V
- Regions of non-uniform charge
  - Dayside ~ m
  - Nigthside ~ km
- Crossing Earth's plasma → kV
- During solar activity Lunar Prospector → 5 kV



Schematics from T.J. Stubbs, "Characterizing the near lunar plasma environment," White Paper, *Workshop on Science Associated with the Lunar Exploration Architecture*, LPI, 2007

Kennedy Space Center

Dust Removal for Exploration

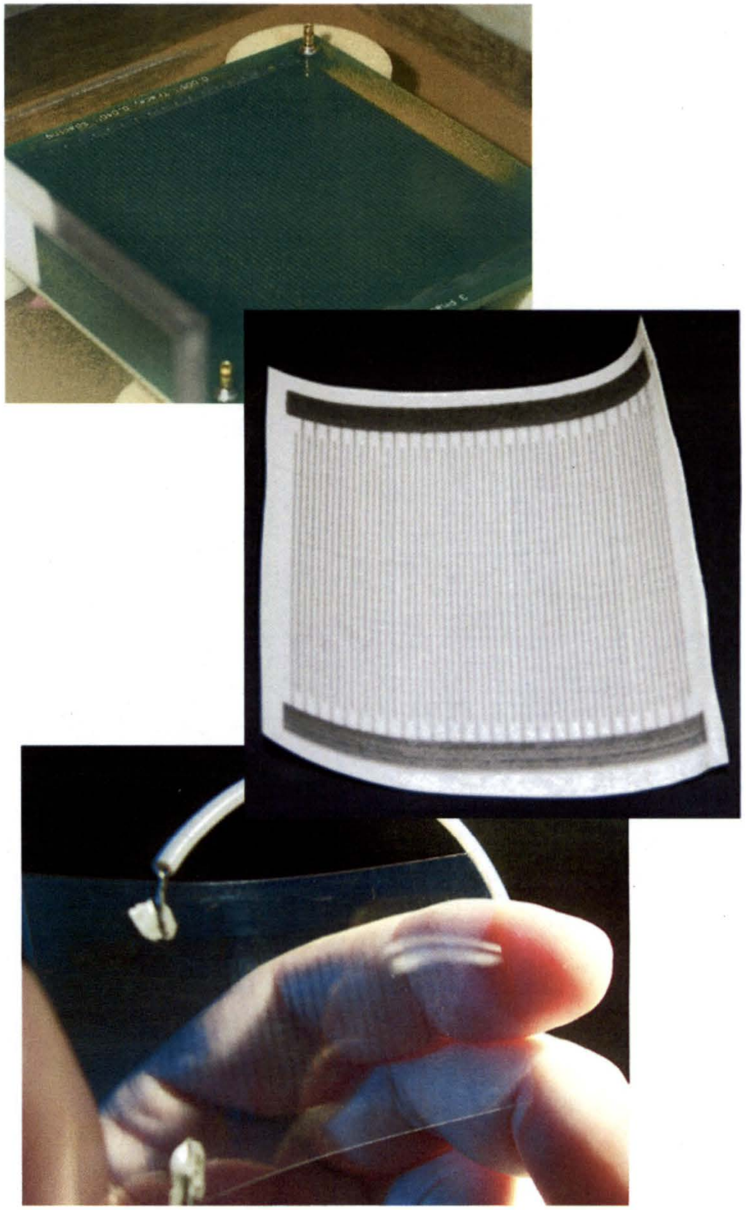
- NASA KSC's *Electrodynamic Dust Shield* (EDS) Technology removes dust from surfaces and prevents dust accumulation
- Electrodynamic Dust Shield is based on the Electric Curtain concept developed at NASA in 1967*
- Masuda at U. Tokyo built first prototypes (1970s)
- NASA KSC and University of Arkansas developed EDS for Solar Panels on Mars
(Science Mission Directorate NRA – 2003-2006)
- NASA KSC further developed technology for lunar applications (ESMD Dust Project – 2007-2010)

* Tatom, F.B., V. Srepel, R.D. Johnson, N.A. Contaxes, J.G. Adams, H. Seaman, and B.L. Cline, "Lunar Dust Degradation Effects and Removal/Prevention Concepts", *NASA Technical Report No. TR-792-7-207A*, p. 3-1 (1967)

Kennedy Space Center

Electrodynamic Dust Shield

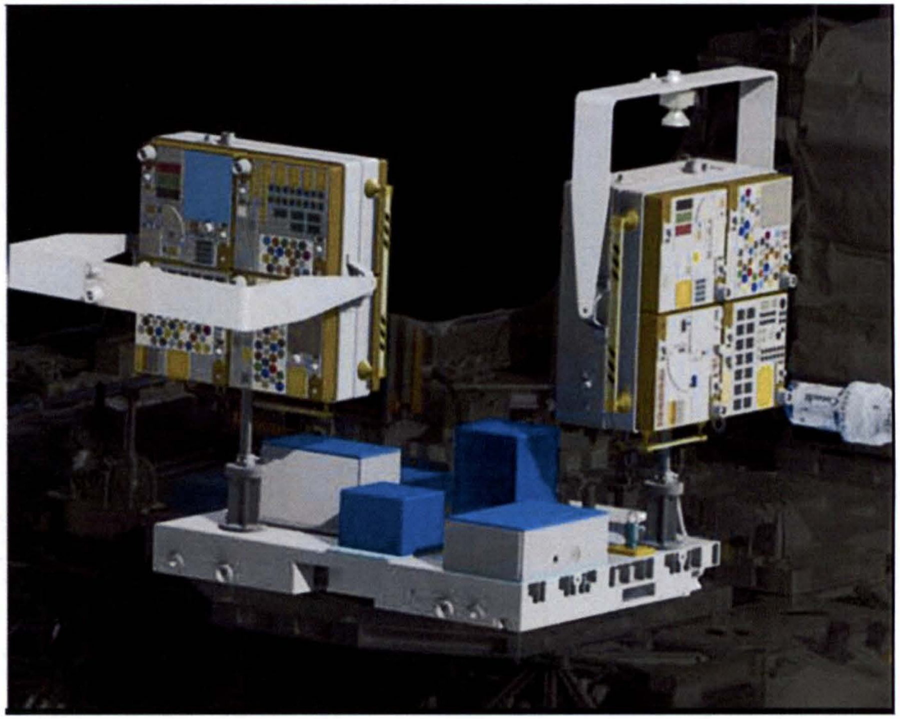
- With the EDS, Particles are removed by applying a multi-phase traveling electric field to electrodes that are embedded in the surface
- Electrodes:
  - Thin wires on opaque surfaces
  - CNT electrodes on fabric
  - Transparent, flexible electrodes on transparent surfaces for optical devices, windows, visors
- Applications developed:
  - Solar panels
  - Optical systems
  - Thermal radiators
  - Flexible films
  - Fabrics



Kennedy Space Center

ISS Experiment

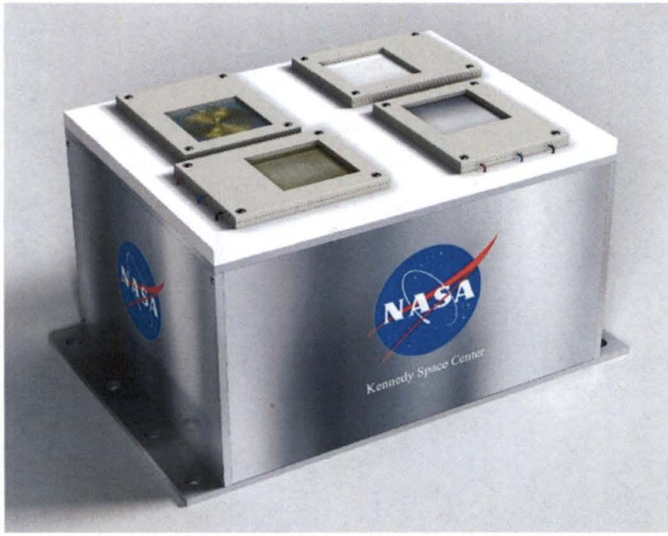
- The EDS has been extensively tested
  - In the laboratory under simulated lunar and Martian conditions:
  - On a reduced gravity flight at lunar and Martian gravity
- A flight experiment is being developed to fly on ISS as part of the Materials International Space Station X (MISSE-X) experiment
  - MISSE-X is an external platform for space environmental effects
  - Will expose experiments to the ram, wake, zenith, and nadir directions
  - Our payload will face the wake direction, to expose the EDS panels to the space environment most closely resembling the lunar environment

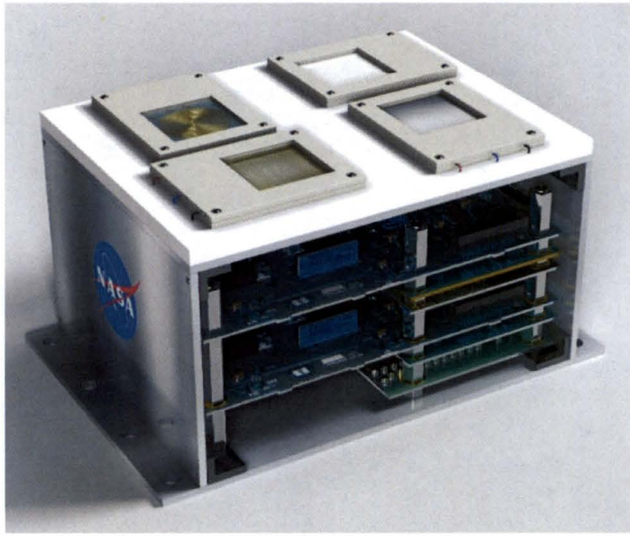


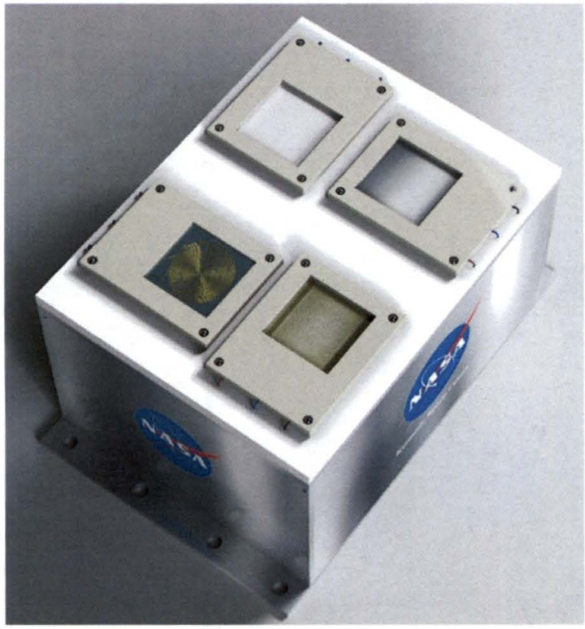
- The EDS experiment will contain four panels and an electronics control box:
  - Transparent EDS for optical systems and solar panels
  - Two EDS panels for thermal radiators
  - An EDS on fabric for spacesuit dust protection

Kennedy Space Center

Payload Concept

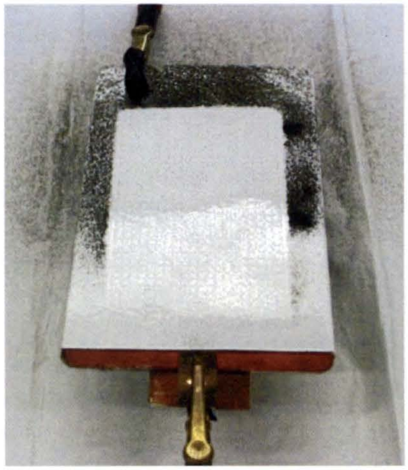


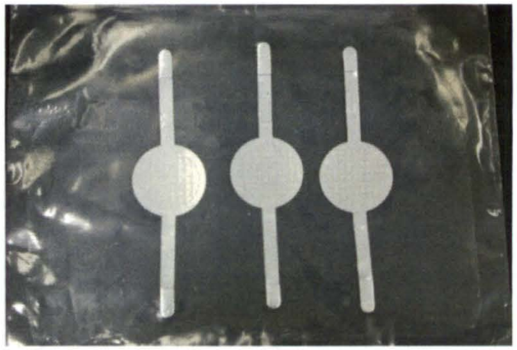




The EDS experiment will contain four panels and an electronics control box

Transparent EDS for optical systems and solar panels



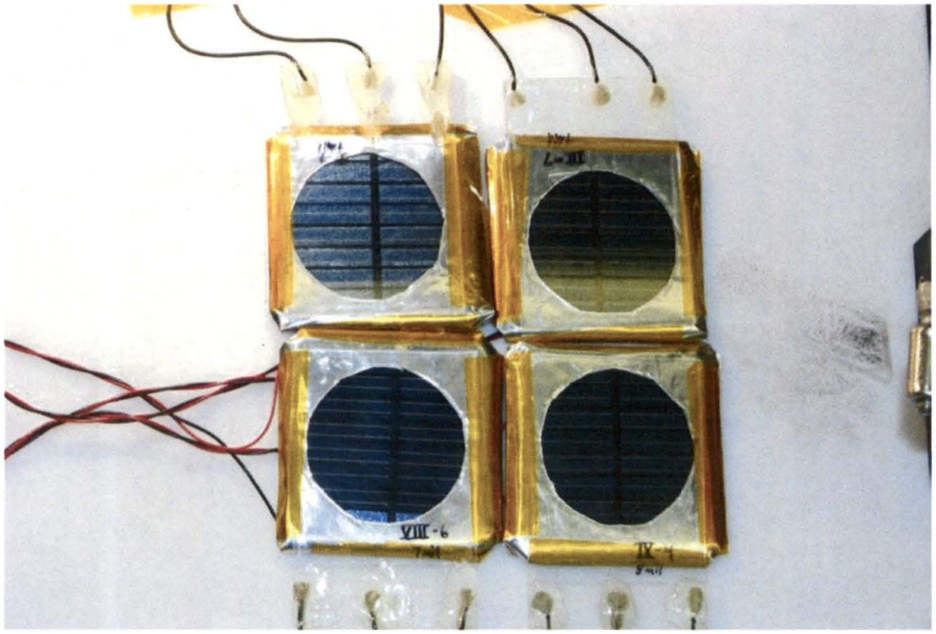


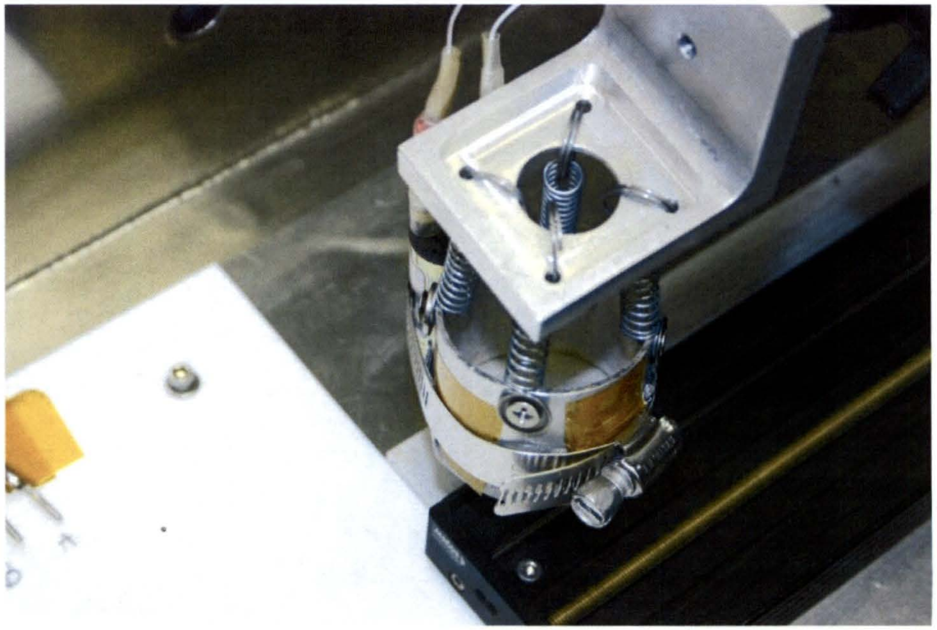
Two EDS panels for thermal radiators

An EDS on fabric for spacesuit dust protection

Laboratory Tests: High Vacuum Dust Shield for Solar Panels

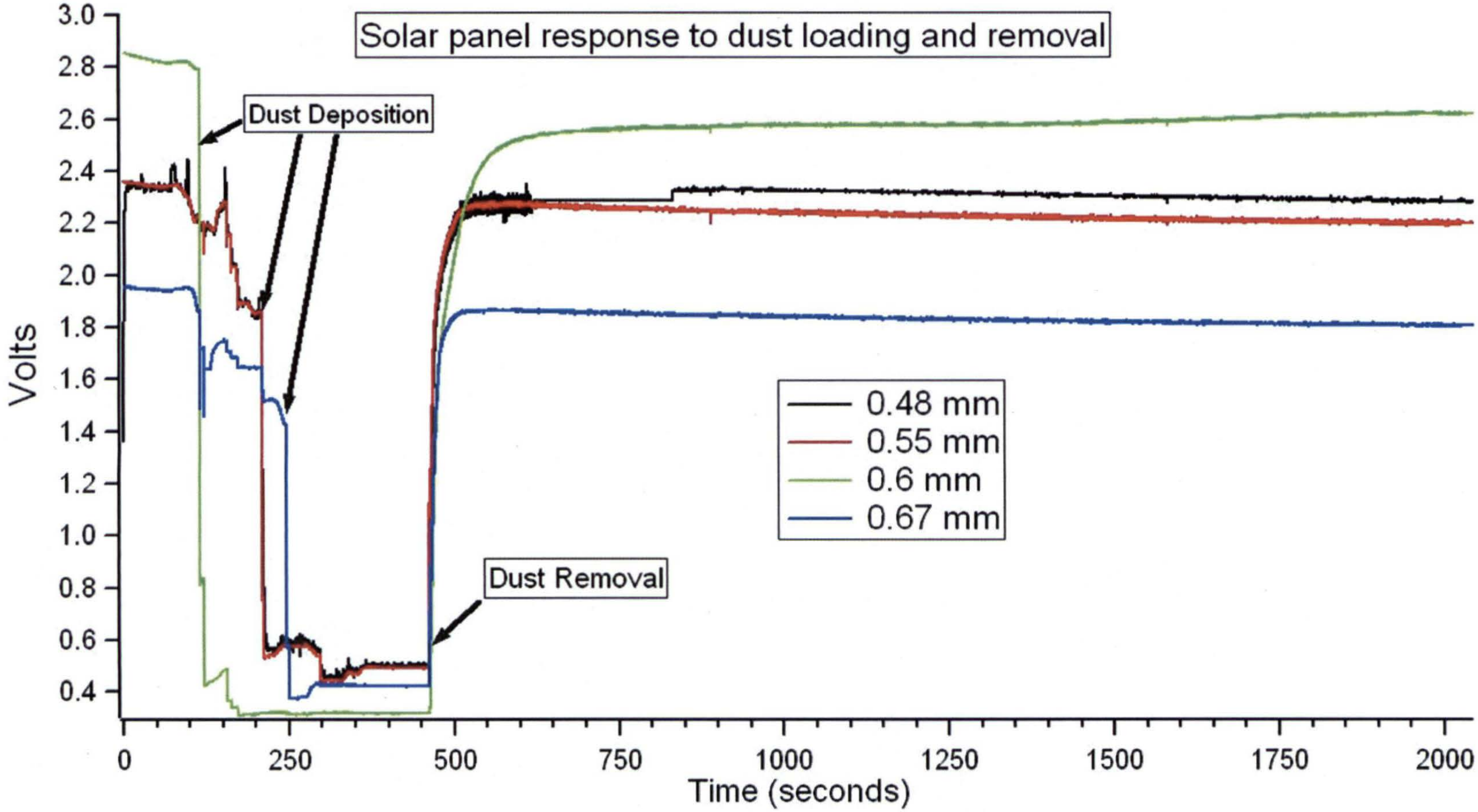
Kennedy Space Center





(Left) Solar panel-backed transparent Dust Shields used for testing at high vacuum conditions. (Right) Feeder cup used to deliver dust to the Dust Shields

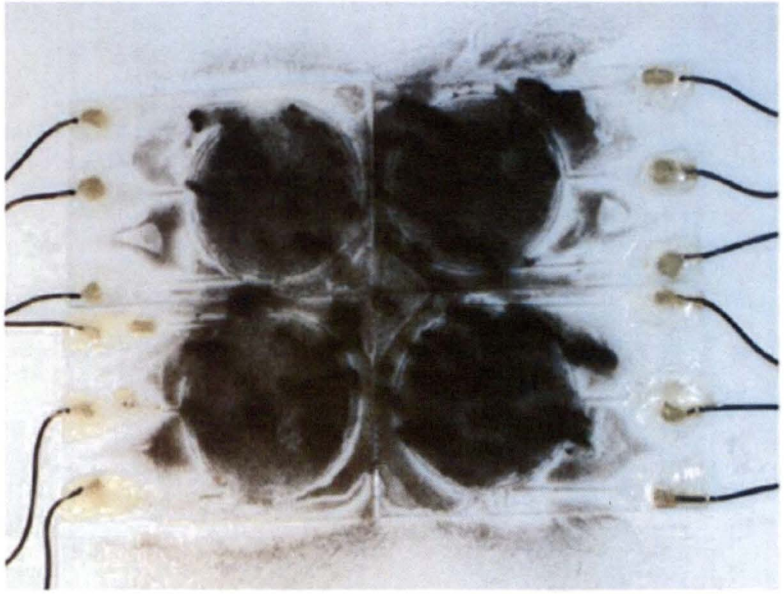
Solar Panel Response



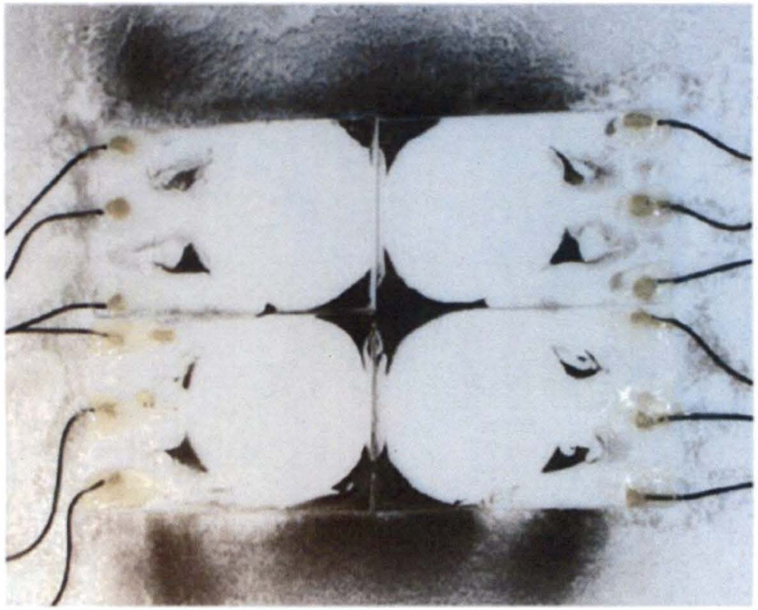
Solar panel response to 20 mg, 50-75 μm JSC-1A dust deposition and removal under high vacuum conditions. Removal was accomplished using Dust Shields of four different spacings.

EDS for Optical Systems High Vacuum Testing

Kennedy Space Center



(a)

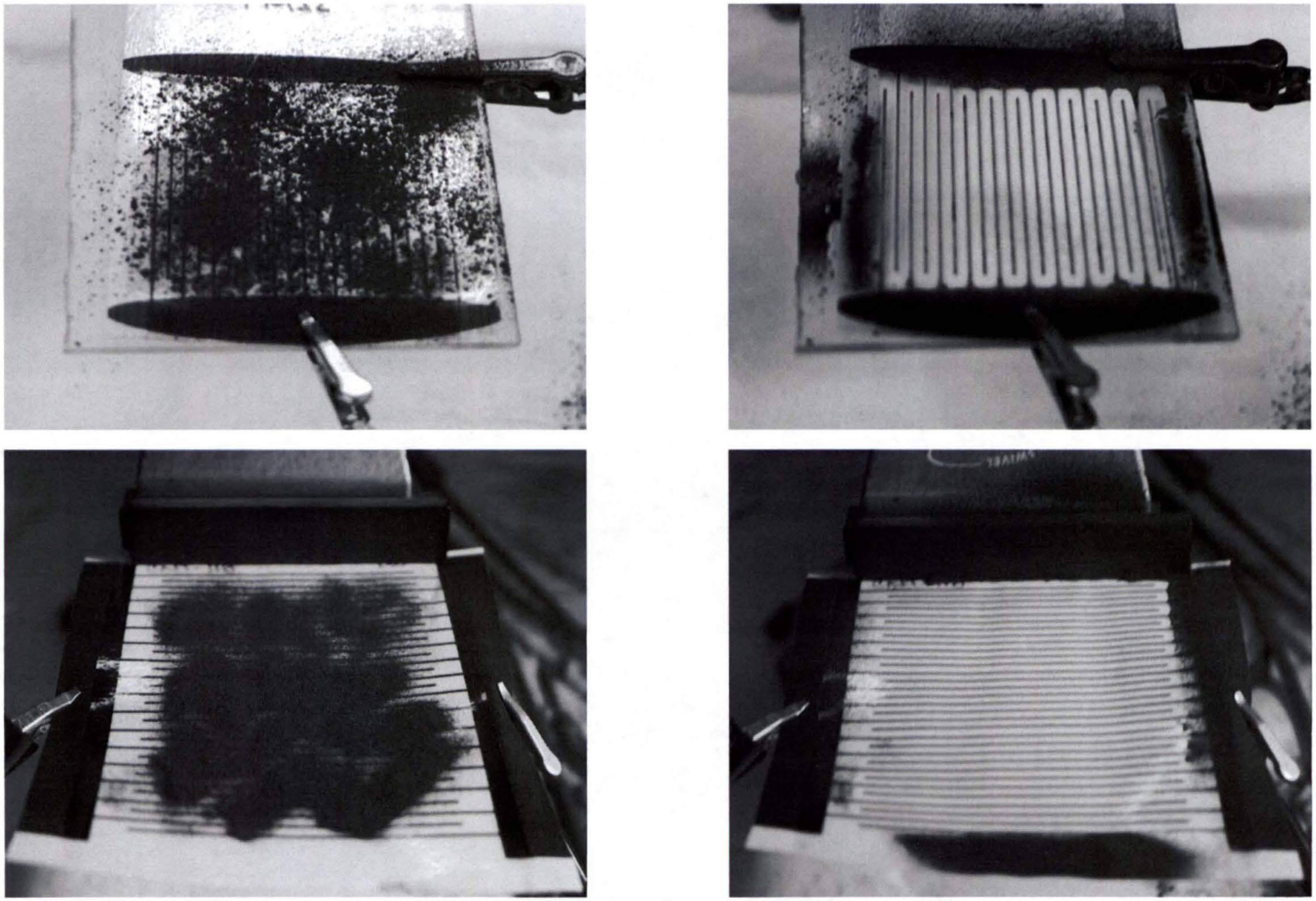


(b)

Transparent EDS coating on glass (a) before and (b) after dust removal at vacuum. Dust removal efficiencies are greater than 99%.

Kennedy Space Center

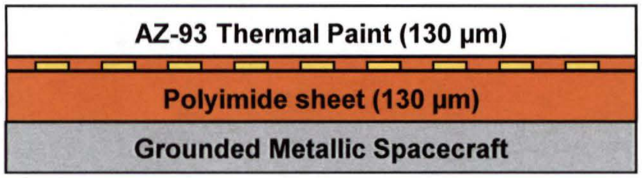
Flexible Dust Shield on Fabric



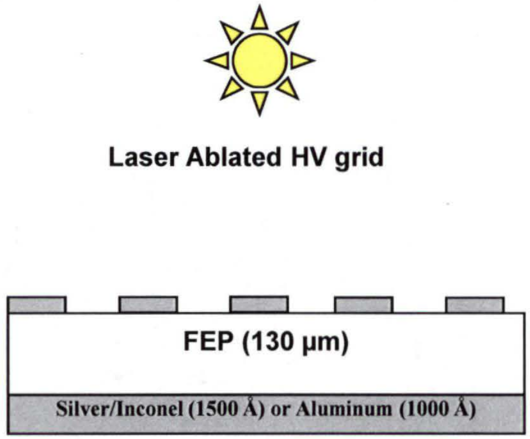
- Before and after photographs of a dust shield on fabric with JSC-1A, 50-75 μm lunar simulant in air

Kennedy Space Center

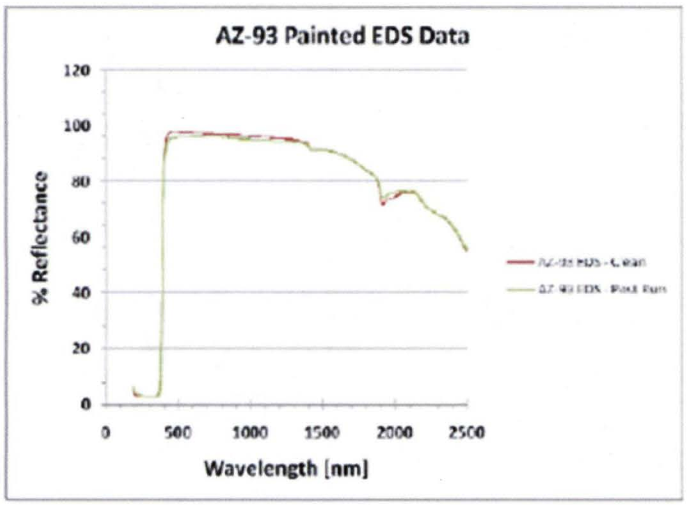
EDS for Thermal Radiators



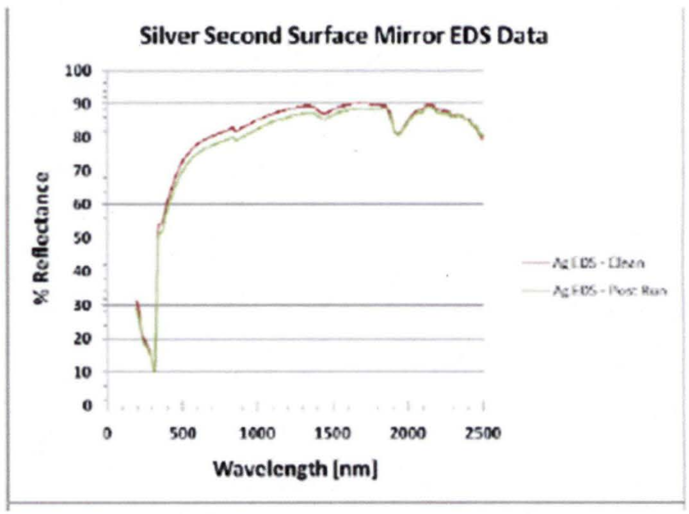
Schematic diagram of the multi-layer EDS coating for painted metallic radiators



Schematic diagram of the EDS for flexible Thermal Radiators (second surface mirrors)



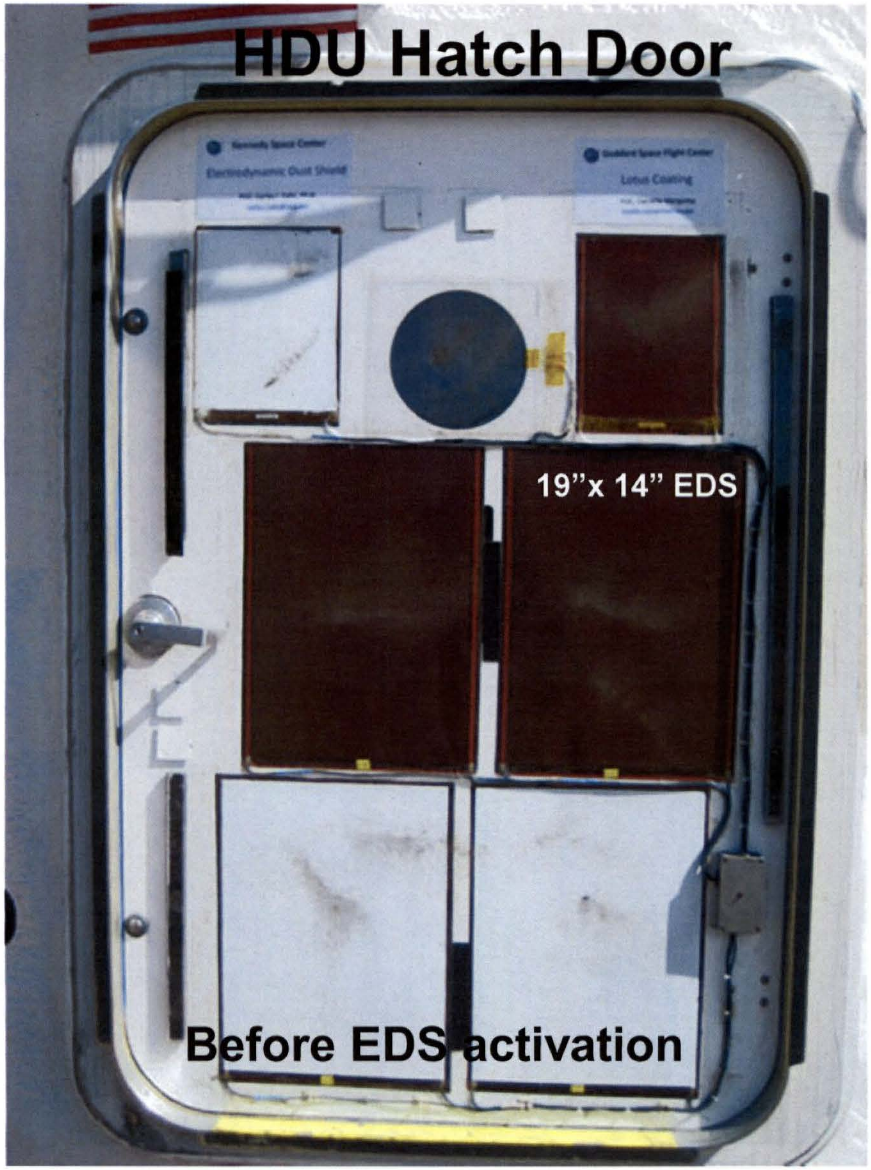
Reflectance spectra from 190 nm to 2500 nm for painted thermal radiator surfaces clean(red line) and after dust removal (green line)

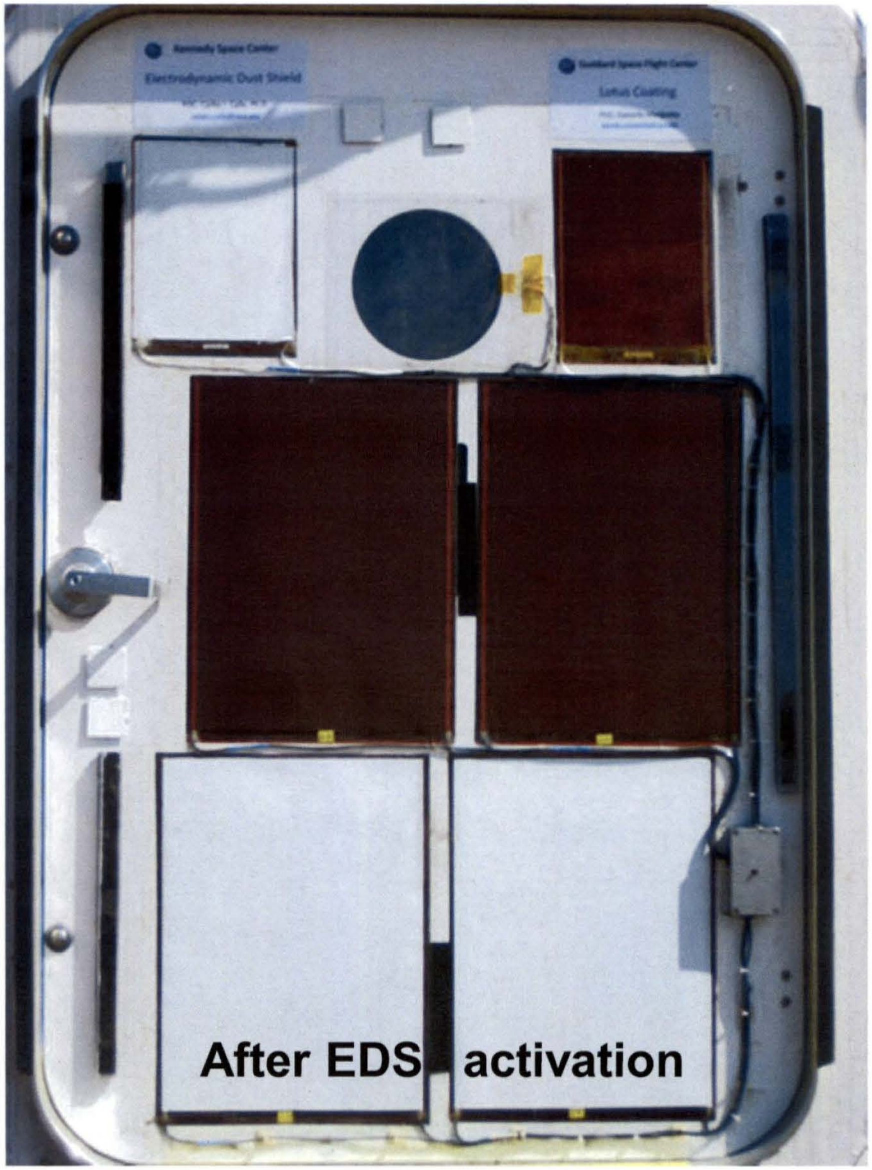


Reflectance spectra from 190 nm to 2500 nm for flexible radiator surfaces clean (red line) and after dust removal (green line)

Scaling up the EDS: HDU Field Tests

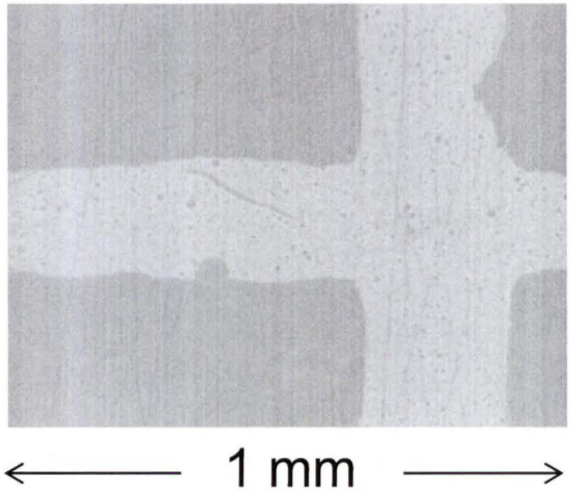
Kennedy Space Center



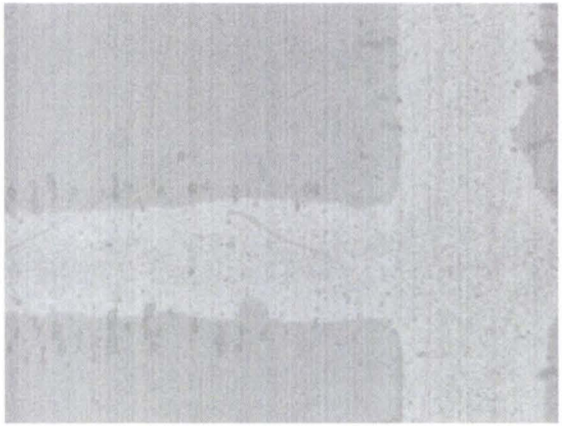


Dust Removal Quantification

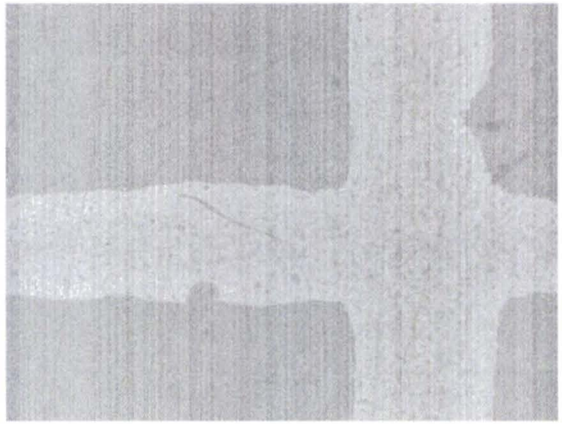
Kennedy Space Center



Before dust deposition



After stage 1 of dust removal



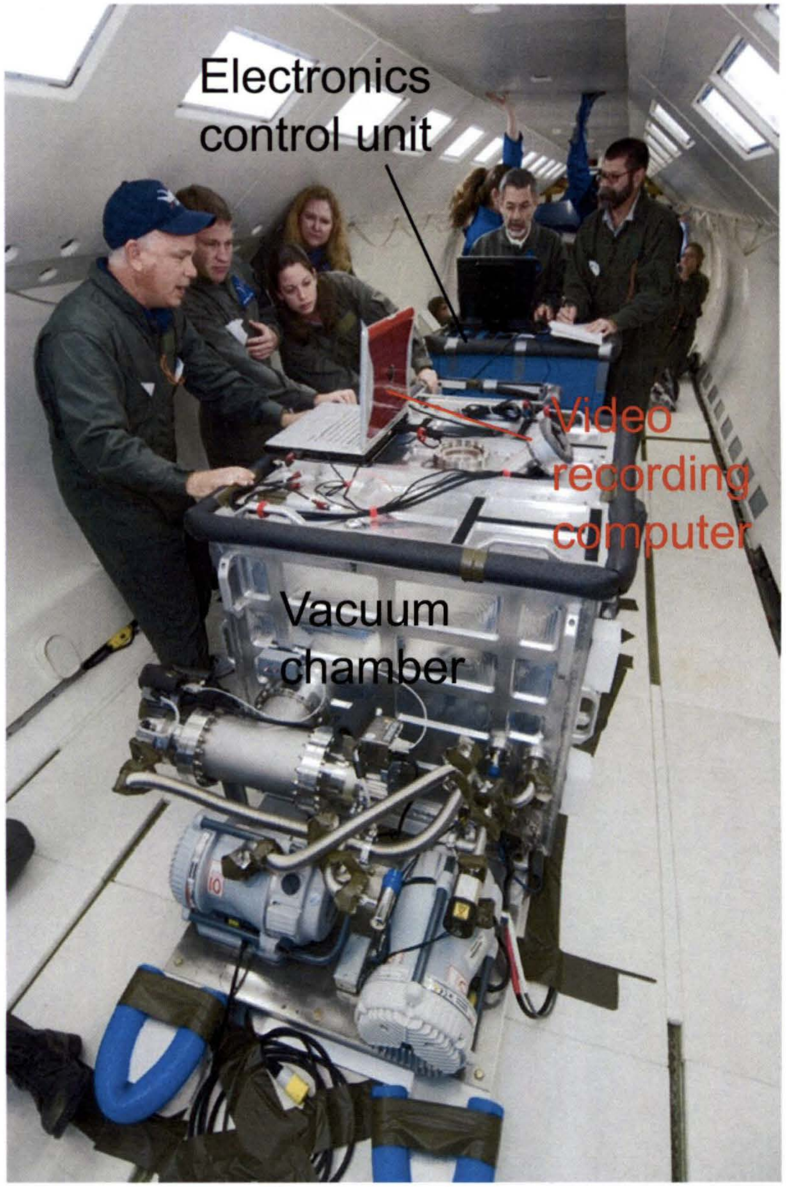
After dust removal

Vacuum Testing – Under 10 µm fraction.
After dust deposition, area is completely covered with several layers of dust (image not shown—it would be a black rectangle)

Kennedy Space Center

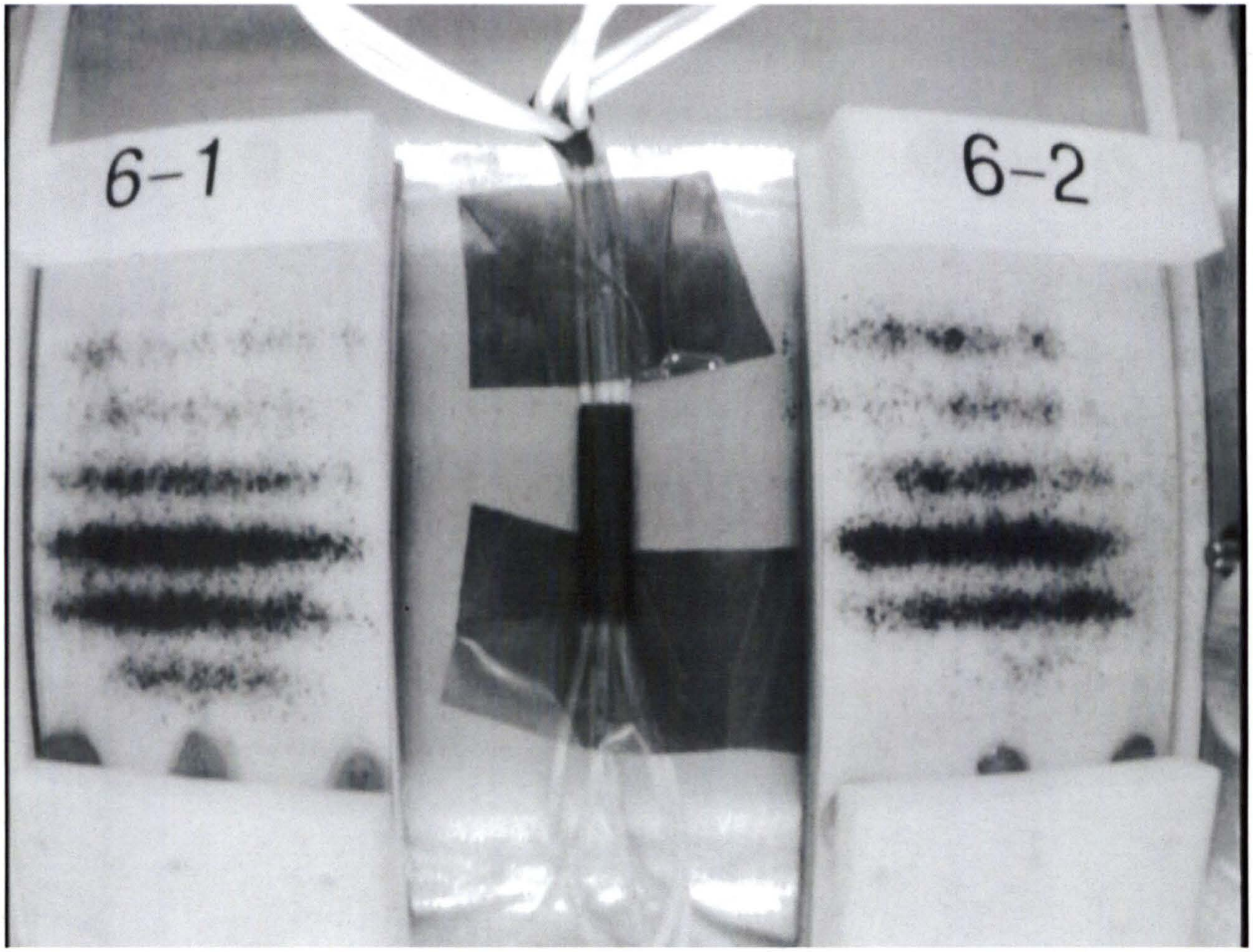
Reduced Gravity Flight Experiments

- Experiments were performed under lunar and Martian gravity
- Four dust containment boxes with metal filters were used for each RGF



Kennedy Space Center

Video Clip: 10μm Simulant



Real time video clip showing dust delivery to the shields in vacuum chamber followed by polarization phase and dust shield activation

Kennedy Space Center

Conclusions

- NASA's exploration missions to Mars and the moon may be jeopardized by dust that will adhere to surfaces of
  - Optical systems, viewports and solar panels
  - Thermal radiators
  - Instrumentation
  - Spacesuits
- We have developed an active dust mitigation technology, the *Electrodynamic Dust Shield*, a multilayer coating that can remove dust and also prevents its accumulation
- Extensive testing in simulated laboratory environments and on a reduced gravity flight shows that high dust removal performance can be achieved
- Long duration exposure to the space environment as part of the MISSE-X payload will validate the technology for lunar missions