Lunar Surface Innovation

CONSORTIUM

Extreme Environments Focus Group October Meeting

October 12, 2021

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APL
JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

Today's Agenda

- LSIC Updates (Porter)
- Karen's Korner (Stockstill-Cahill)
- EE Fall/ Winter Meeting Path Forward (Porter)
- Featured Presentations (Erin Hayward)
  - Space Environmental Effects Testing Capabilities at MSFC
- Open floor

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LSIC Updates

Lunar Community Meetings

- NASA SBIR / STTR Interactive Learning & Networking Session: Infusion & Commercialization, Part II
  - Meeting consist of a short presentation, a Q&A session with NASA experts, and open networking time to speak directly with our program representatives and other small businesses and research institutions
  - November 3rd from 12:00pm – 2:30pm ET
  - https://sbir.nasa.gov/events
- Next Dust Mitigation Focus Group meeting
  - Thursday, October 21st at 12 PM EDT
  - Dr. Kristen John (NASA JSC) will speak about ***new*** NASA Standards Document (NASA-STD-1008): "CLASSIFICATIONS AND REQUIREMENTS FOR TESTING SYSTEMS AND HARDWARE TO BE EXPOSED TO DUST IN PLANETARY ENVIRONMENTS"
  - https://standards.nasa.gov/standard/nasa/nasa-std-1008
  - Fill out the LSIC Survey and indicate interest in Dust Mitigation to receive event invitations: https://lsic.jhuapl.edu/News-and-Events/survey.php

Funding Opportunities

- Sources Sought Notice (SSN) From NASA GSFC
  - https://sam.gov/opp/84c5924758d64c99bc42f70038a2531c/view
  - Deadline: October 15th, 2021
- Over the Dusty Moon Challenge (Colorado School of Mines & Lockheed Martin)
  - https://www.overthedustymoon.com/
  - Webinar Nov 29, 2021 & Deadline for entries: Dec 20, 2021
- 2022 Breakthrough, Innovative and Game-Changing (BIG) Idea Challenge: Extreme Terrain Mobility Challenge
  - http://bigidea.nianet.org/competition-basics/
  - Proposal and Video deadline: January 18, 2022
- Please visit LSIC website for full list
  - http://lsic.jhuapl.edu/Resources/Funding-Opportunities.php

LSIC Updates

LSIC Facilities Directory

- NASA and the LSIC have teamed up to create the LSIC Facilities Directory (https://lsic-wiki.jhuapl.edu/x/HINf)
  - LSIC Resources webpage under the LSIC wiki Tools and Resources section
- Purpose is to inform the community of facilities that might be utilized for advancement of their future lunar surface technologies that are currently under development
- Facilities include NASA, commercial, non-profit, or academic institutions
- Searchable interface with details on each facility, its location, availability, scheduling, pricing, and POC
- Annual POC updates will be performed by LSIC
- POCs will be able to make edits and additions to their content within this interface at their discretion
- Institutions who would like to have their facility listed in the directory need to be a member and fill out a questionnaire (https://forms.gle/MronYz72WeWbAqdx6)

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LSIC Updates

NASA Leadership Positions Agency for Future

- Separating Human Exploration and Operations Mission Directorate into the new Exploration Systems Development Mission Directorate (ESDMD) and Space Operations Mission Directorate
- NASA making change because of increasing space operations in low Earth orbit and development programs for deep space exploration, including Artemis missions
- https://www.nasa.gov/press-release/nasa-leadership-positions-agency-for-future

NASA Selects Five U.S. Companies to Mature Artemis Lander Concepts

- NASA selected five companies to help enable a steady pace of crewed trips to the lunar surface for Artemis
- These companies will make advancements toward sustainable human landing system concepts, conduct risk-reduction activities, and provide feedback on NASA's requirements to cultivate industry capabilities
- Work will be conducted over the next 15 months
- https://www.nasa.gov/press-release/nasa-selects-five-us-companies-to-mature-artemis-lander-concepts

LSIC Updates

LSIC Fall Meeting (http://lsic.jhuapl.edu/News-and-Events/Agenda/index.php?id=148)

- Day 1
  - Keynote address
  - Brief status update on NASA's LSII and the LSIC Focus Group work
  - Community discussions
    - Bowie State's partnerships with NASA
    - Pathways for early career and students to develop networks in the lunar community
    - Panel discussing government resources for small business programs
    - Panel of technology investors
    - Technical presentations and posters
- Day 2
  - Overview of NASA's investments relative to robotics and autonomy along with overarching plans
  - Technical panels about specific projects
  - Breakout sessions will focus on examining several scenarios to understand:
    - What elements require autonomous operation?
    - What technology gaps exist?
    - Where each of our different FGs need to be engaged?

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Karen's Korner

lsic-wiki.jhuapl.edu/display/EE/Radiation+Environment

Radiation Environment - Extreme Environments - LSIC

LSIC Spaces People Create ··· Search

Extreme Environments

Pages
Blog

SPACE SHORTCUTS
Meeting notes
File lists

PAGE TREE
- Specific Lunar Surface Environments and Technical Ch:
- APL Internal Page
- EE Monthly Meeting
- Extreme Environments Subgroups
  - Radiation Environment
    - Lunar Radiation Environment Guidance
    - Lunar Radiation Environment Resources
    - RadEnv lunar surface environments ranking
    - Radiation Environment Conversations
    - Recordings of subgroup meetings
  - Regolith / Surface Interface
  - Space Weather / Plasma Environment
  - Thermal and Illumination Environment
  - Vacuum / Exosphere Environment

Space tools

Pages / Extreme Environments Home / Extreme Environments Subgroups

Edit Save for later Watching Share

Radiation Environment

Created by Benjamin Greenhagen, last modified by Lawrence Heilbronn on Sep 20, 2021

Subgroup Lead: Lawrence Heilbronn

Subgroup Lead Email: lheilbro@utk.edu

Monthly Meetings: 4th Wednesday of every month, 2 p.m. (Eastern time zone)
https://tennessee.zoom.us/j/97211725903 (updated zoom link 9/20/2021)
Or Telephone: +1 301 715 8592 (US Toll) - Meeting ID: 972 1172 5903

Upcoming meeting agenda will be posted below a few days before the meeting

The radiation environment on the surface of the Moon is considered here to be the ionizing radiation that can cause harmful biological and electronic effects. The plasma environment consisting of solar wind is considered in another subgroup. The ionizing radiation environment is made up of three sources - (1) Galactic Cosmic Rays (GCR), a continuous flux of high energy particles made up of electrons, protons, and heavier ions made up of nuclei of all naturally occurring elements; (2) Solar Energetic Particles (SEP) consisting primarily of protons with some heavier nuclei that are emitted sporadically from the sun in events such as coronal mass ejections; and (3) albedo secondary radiation that is produced by GCR and SEP interaction in lunar soil, creating a flux of charged light ions and neutrons. Recent calculations and measurements show that the dose from GCR to crew members during relatively short stays on the Moon will be below current limits for health effects; however, a large SEP event could have immediate detrimental effects on both crew and electronics if not properly shielded. Realtime monitoring of the radiation environment and crew doses is required to maintain the safety and health during operations on the Moon. Space weather (see "Space Weather and Plasma" subgroup) affects the intensity of GCR and the probability of a SEP event. Fission power sources on the Moon will create a man-made radiation field that will consist of low-energy neutrons (below 20 MeV) and gamma rays. If utilized, these power sources will add to the overall radiation encountered on the Moon and will require shielding that is consistent with their operation.

Task 1 Kickoff Quad Chart

Subgroup Roster

Lead: @Lawrence Heilbronn

Supporters:

Hugh Barnaby
John Schaf
@Kevin Somervill

Upcoming Meeting Agenda

Our next monthly subgroup meeting is this Wednesday, September 22, at 2:05 p.m. EDT. Zoom link is in the general announcement at the top of the page. Our agenda for the meeting:

1. Welcome new members
2. Announcements from Jamie and Karen
3. Featured subgroup member presentation - Jamie Porter
4. OLTARIS tutorial
5. If time allows - Updates on Confluence LSIC RE Resources and Guidance pages, and,
6. Discussion of upcoming task on technology gaps

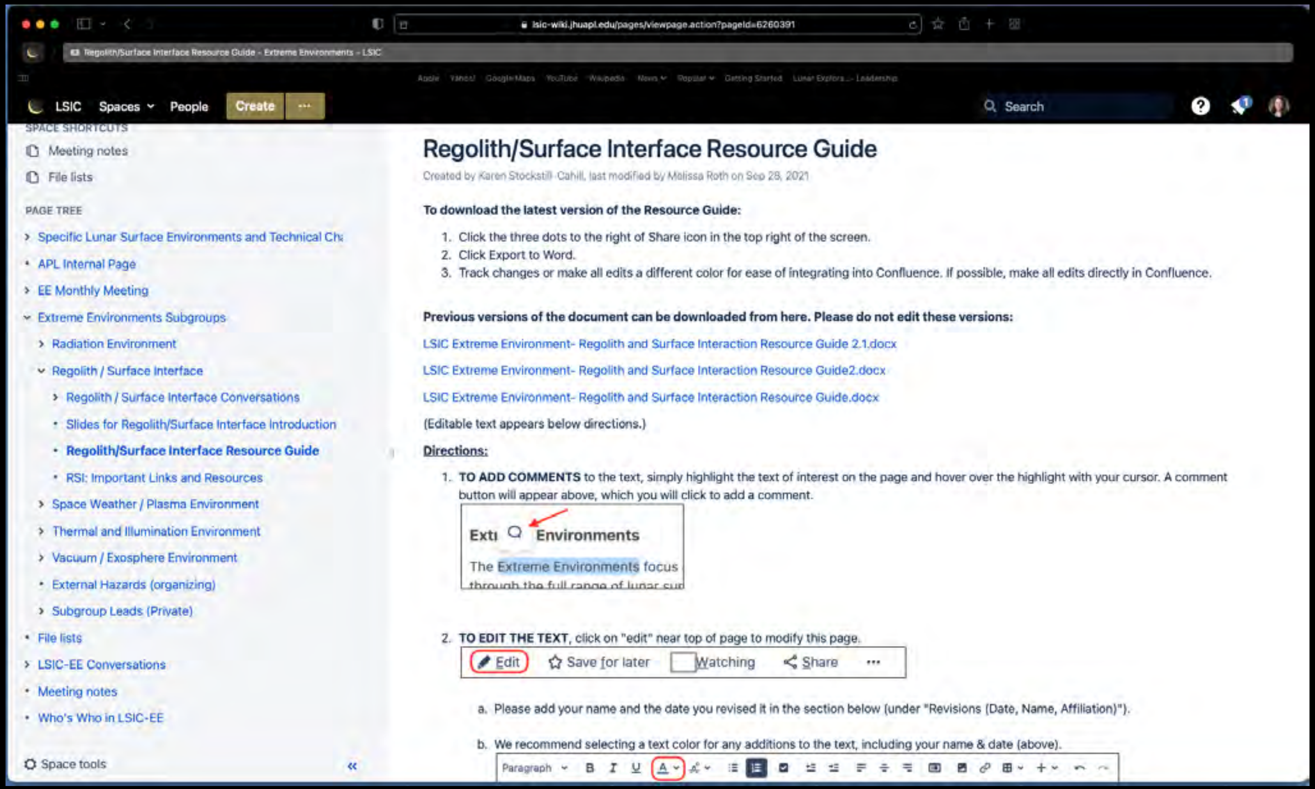
Looking forward to hearing from Jamie on her research related to ionizing space radiation. I'll be looking for a volunteer to present at our October meeting, please consider sharing your exciting work with the group!

The OLTARIS tutorial will focus on how the code handles the lunar radiation environment. If you're thinking of habitat design or are wondering what level of radiation to expect for your particular application, the online tool OLTARIS is a great utility that will calculate dose, dose equivalent, effective doses, and particle fluences on the surface of the Moon. You don't need to be an expert in radiation transport to use it.

See you this Wednesday,

Lawrence

Karen’s Korner



Revisions to current versions (Date, Name, Affiliation)

- 2021-02-18 Karen R. Stockstill-Cahill, JHU-APL
- 2021-06-27 Melissa Roth, Off Planet Research
- 2021-06-29 Melissa Roth based on June RSI Subgroup Meeting Comments and Discussion
- 2021-08-24 Walter C. Houston, Workforce 2.0 and Melissa Roth, Off Planet Research (intermediate version)
- 2021-08-24 Melissa Roth and others based on August RSI Subgroup Meeting Comments and Discussion
- 2021-08-25 Karen R. Stockstill-Cahill, JHU-APL
- 2021-09-28 Melissa Roth and others based on September RSI Subgroup Meeting Comments and Discussion

Contact the subgroup lead, Melissa Roth, with comments or questions. The latest revision of this document is available on the LSIC Confluence page.

TABLE OF CONTENTS (Click on Section Titles to jump to that Section)

EE Fall/ Winter Meeting Path Forward

* Joint TBD workshop with EA in late winter/early spring

Featured Presentation

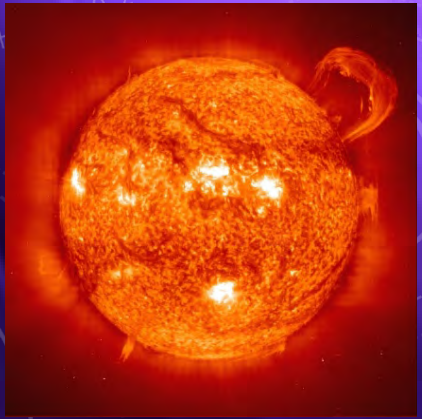
- DSNE and the lunar plasma environment
  - Erin Hayward, ***Space Environmental Effects Testing Capabilities at MSFC***

SPACE ENVIRONMENTAL EFFECTS TESTING CAPABILITIES AT MSFC

EM41: NONMETALLIC MATERIALS & SPACE ENVIRONMENTAL EFFECTS BRANCH

ERIN HAYWARD

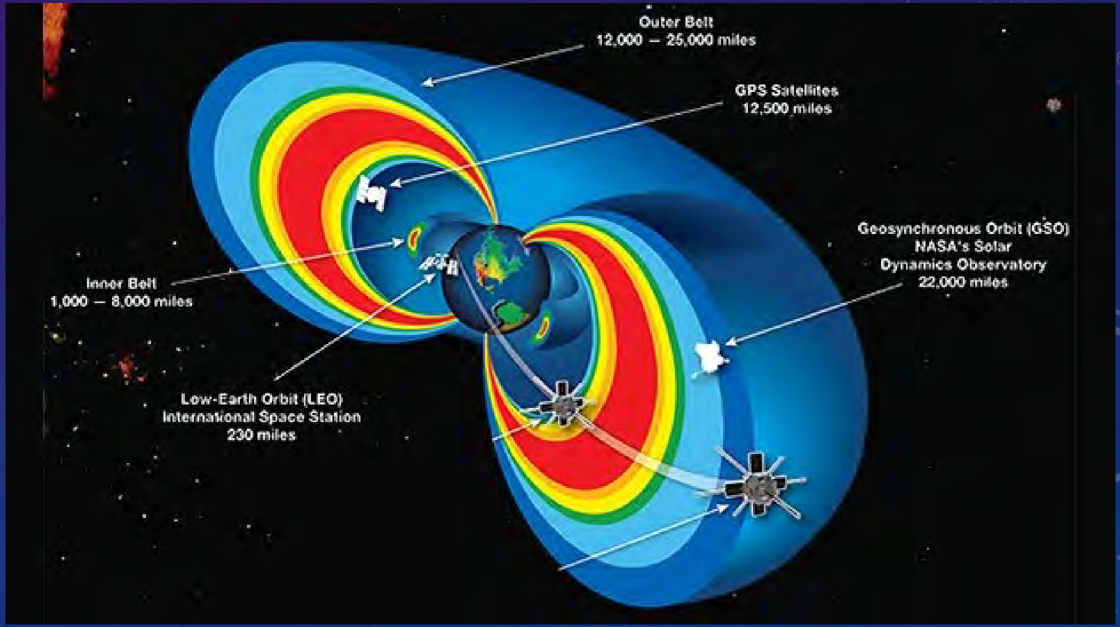
ERIN.G.HAYWARD@NASA.GOV



Presented to LSIC Extreme Environments
October 2021

SPACE ENVIRONMENTAL EFFECTS (SEE)

- The space environment is not just vacuum but includes a host of challenging conditions that affect spacecraft materials and systems.
- The space environment varies by location, for example, one material suitable for Low Earth Orbit (LEO) might not survive in lunar and vice versa.
- Testing will differ whether the spacecraft is in LEO, geosynchronous, lunar, Mercury, Mars, Jupiter, etc. and how much solar activity is predicted for the mission.



SEE Team's test systems can be used to support projects and materials for any space environment from near earth to lunar to deep space.

SPACE ENVIRONMENTAL EFFECTS (SEE)

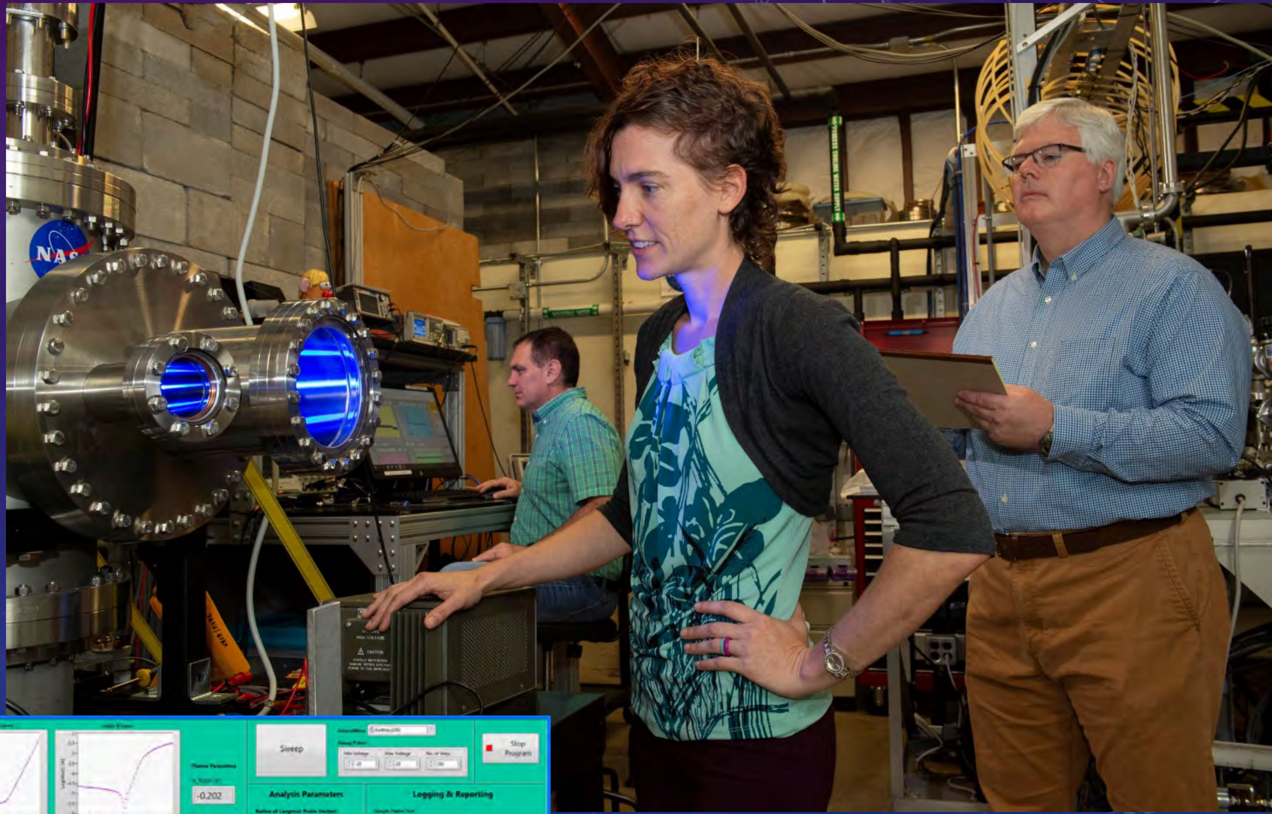
MSFC has world class SEE expertise and test facilities to recreate the space environment in the lab.

- Capabilities include **individual** and **combined** effects utilizing **multiple unique test systems** for the most complete SEE test capability available in the world.

- MSFC's ability to test all effects in one location is critical for minimizing the handling of sensitive material coupons after environmental aging.

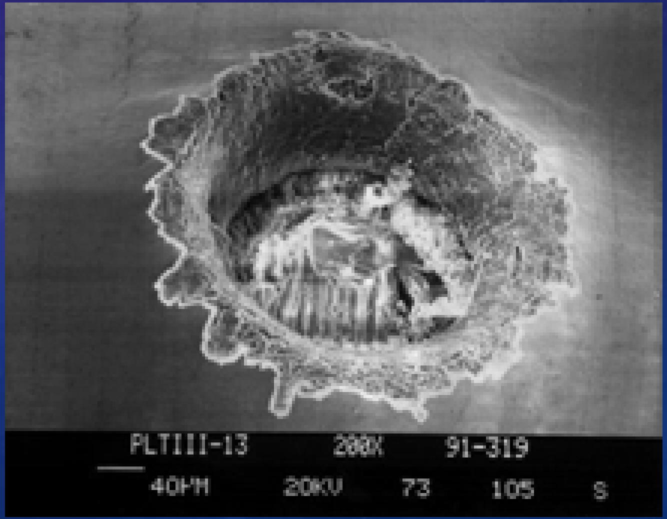
- Test systems can be rapidly adapted and reconfigured to customize tests to meet customers needs.

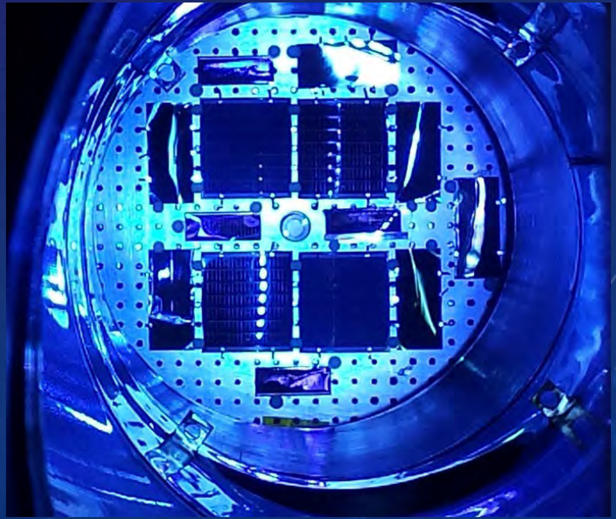
- The SEE Team provides space-flight technology development programs the ability to elevate their hardware to **TRL-6** "Qualification in a Relevant Environment".



SEE TEAM CAPABILITIES

- **Ultraviolet Radiation (UV & VUV)**
- **Ionizing Radiation – Charged Particle (p+, e-), X-ray**
    - Total Ionizing Dose (TID)
- **Space Plasma Interactions and Spacecraft Charging**
    - Internal charging/iESD, surface charging
- **Thermal Extremes (hot to LN2 cryo)**
- **Atomic Oxygen (AO)**
- **High Velocity and Hypervelocity Impact**
- **Planetary and Extraterrestrial Environments**
- **Planetary Protection**
- **Analytical Capabilities**
- **High Temperature Emissivity Measurement System (HiTEMS)**
- **Materials Flight Experiments**



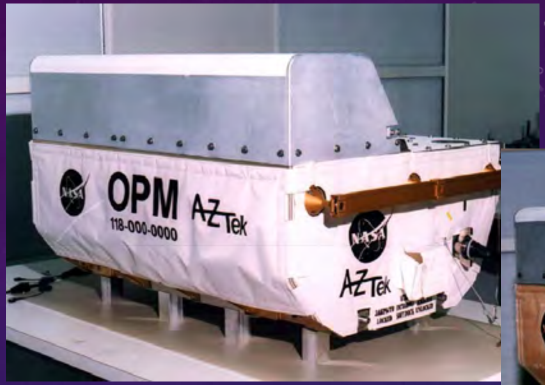


ULTRAVIOLET (UV) RADIATION

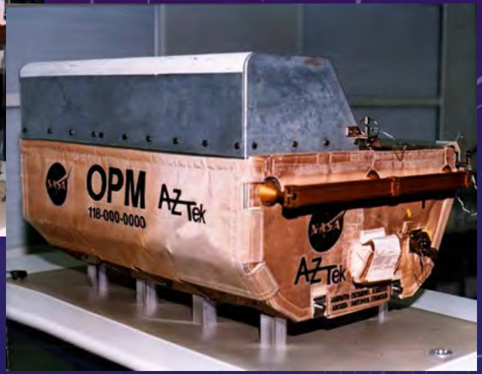
UV can change tensile properties of polymers and thermal properties of polymers, coatings, and optics. Increased effect in the presence of contamination/outgassing.

Two UV regions:

- Near ultraviolet radiation (NUV)- wavelength range 200 nm to 400 nm
- Vacuum ultraviolet radiation (VUV)- wavelength range 115 nm to 200 nm
- VUV is absorbed by atmosphere and only found in space

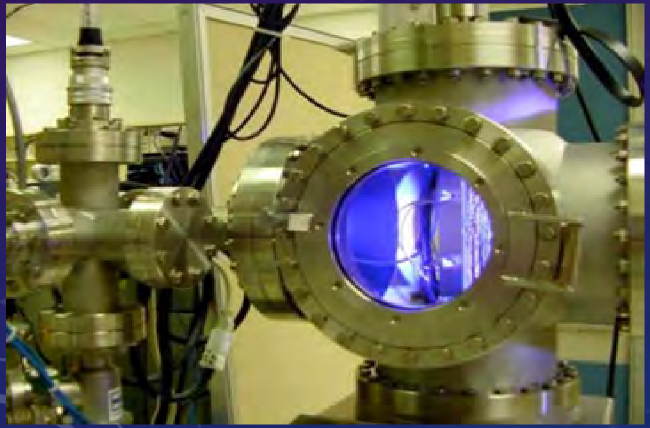


Before space exposure

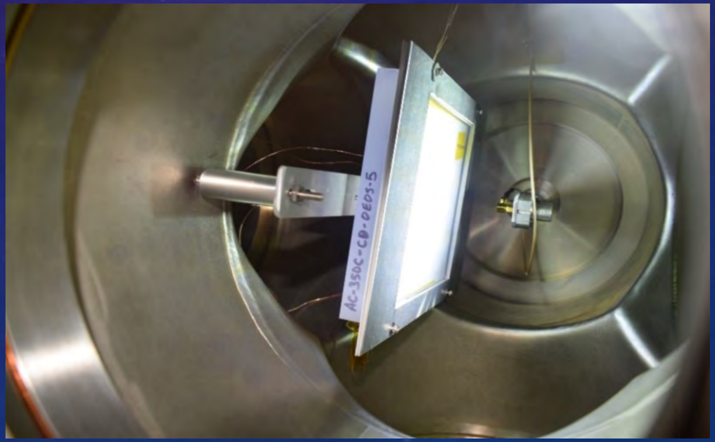


After space exposure

MSFC has many test systems sources for exposing materials to NUV radiation, VUV radiation and combined NUV and VUV radiation. These tests range from a month (24/7) to over a year.



Typical MSFC UV Test Facility



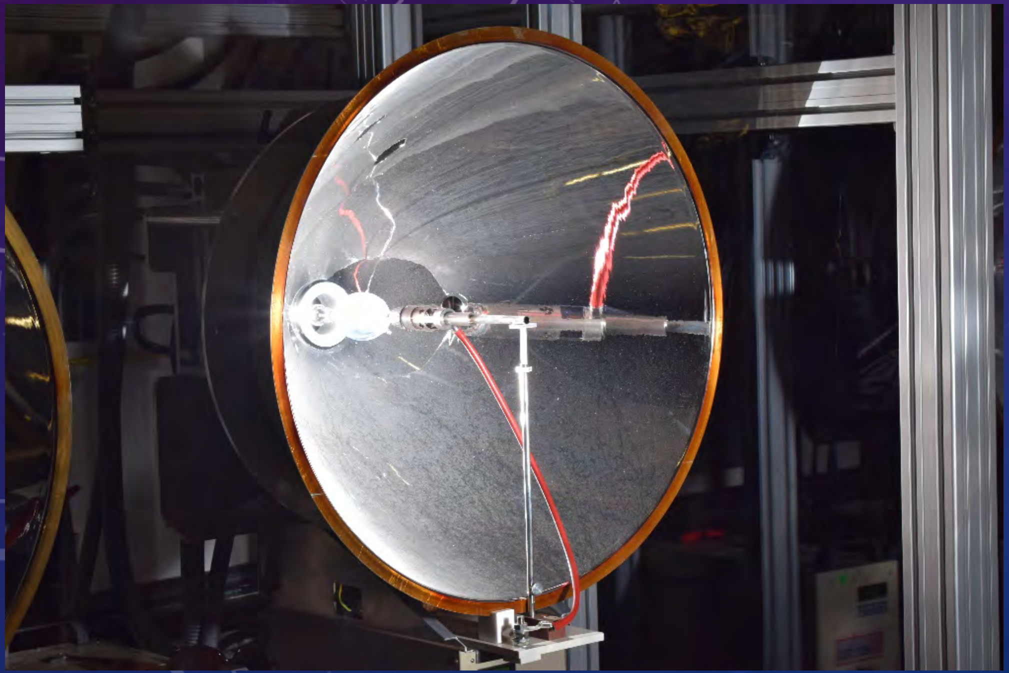
Spacecraft Window Material Under Test

Polymeric Material Under Test

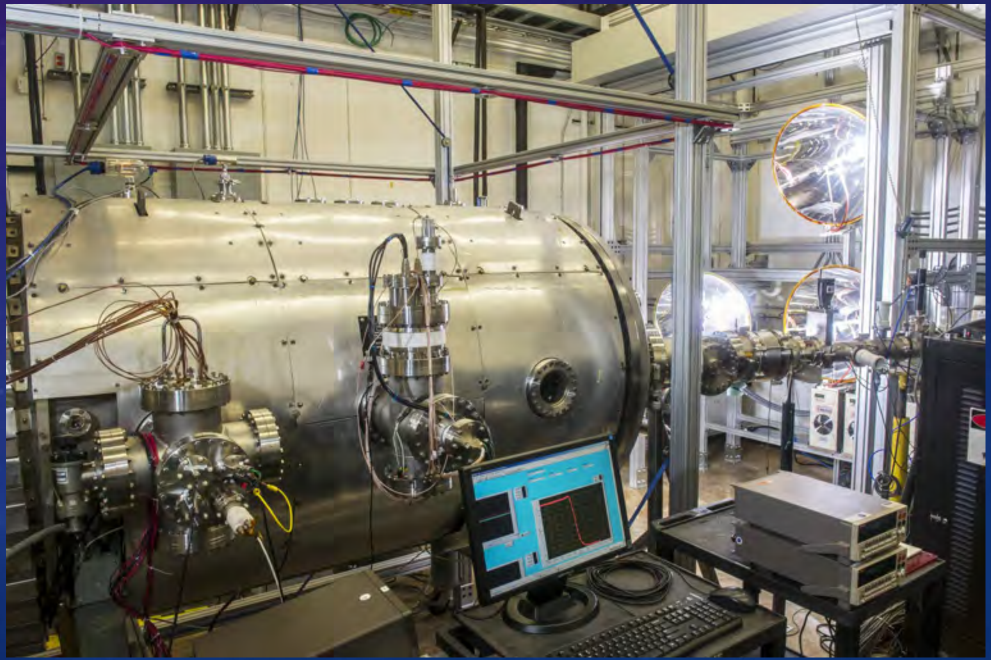
SOLAR PHOTON RADIATION INCLUDING UV

High Intensity Solar Environment Testbed (HISET)

- Able to produce intensity from 1 equivalent sun over a 2-foot beam spot to 600 equivalent suns over a 4-inch beam spot
  - 1 equivalent Sun is the illumination in earth orbit, compared to about 2 equivalent Suns at Venus and about 0.4 equivalent Suns at Mars
- Able to simulate the effects of spacecraft flying towards the sun



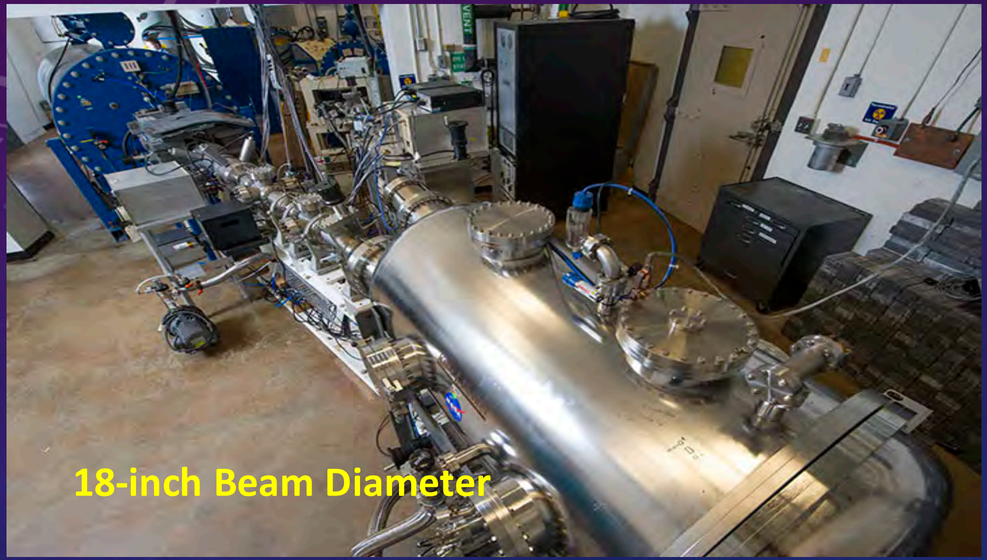
Single 6.7 kW Xenon Lamp



HISET has Three 6.7 kW Xenon Lamps

IONIZING RADIATION: HIGH-ENERGY ELECTRONS AND PROTONS

- Charged particle radiation occurs naturally in space – GCR, SPE, SW
- While we typically think of radiation being harmful to humans or causing single event effects in electronics, radiation can also damage materials.
- Exposure to radiation can embrittle polymers through cross-linking or chain-scission. It also degrades solar array performance.



Top View of Target Chamber

Side View of Pelletron beam line

- Two Pelletron particle accelerators
  - <= 2.5 MeV electrons (spot/beam)
  - <= 700 keV protons (square/raster)
- Both beam lines converge in single chamber
- Single energy at a time, but can vary to do different profiles
- Cryogenic capability
- Test Types: total ionizing dose (TID), iESD

IONIZING RADIATION: X-RAY AND SOLAR WIND

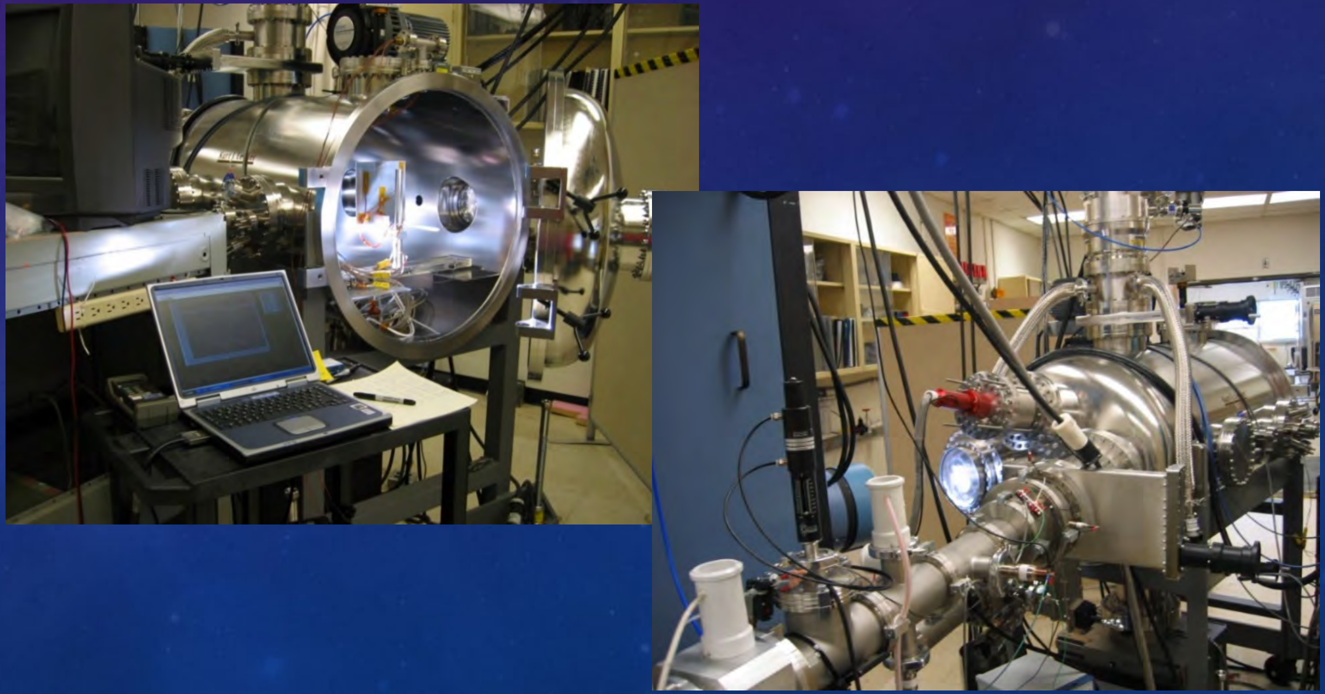
X-Ray Source

- The MSFC x-ray system for radiation effects provides materials with mission predicted total ionizing dose (TID)
- Spot size varies as inverse of dose rate (<= Mrad/hr)
- More penetrating than particles; no charging

320 kV X-Ray Source

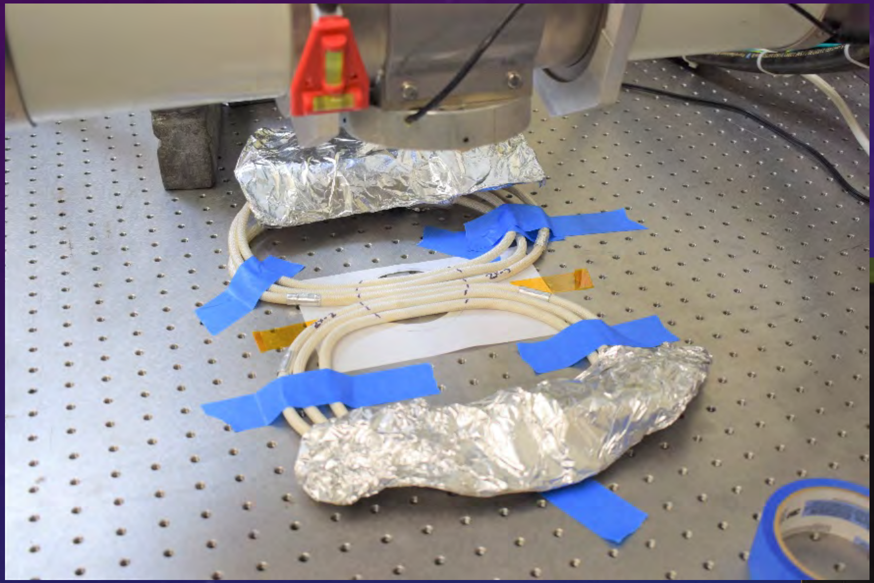
Solar Wind Chambers

- Low Energy Electrons (1 keV – 100 keV)
- Low Energy Protons (1 keV – 30 keV)
- Ultraviolet Radiation (VUV & NUV)
- 12-inch Diameter Exposure Area

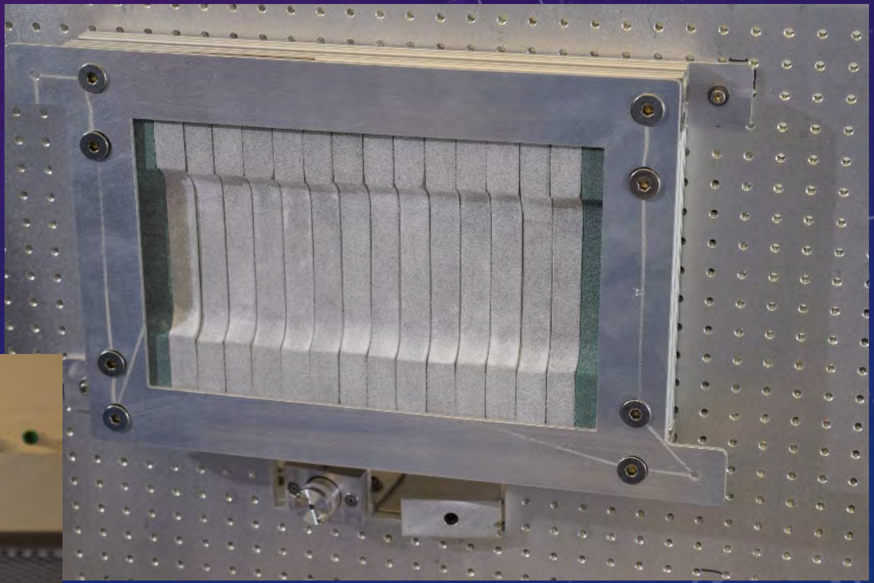


IRRADIATION OF EXPLOSIVE MATERIALS

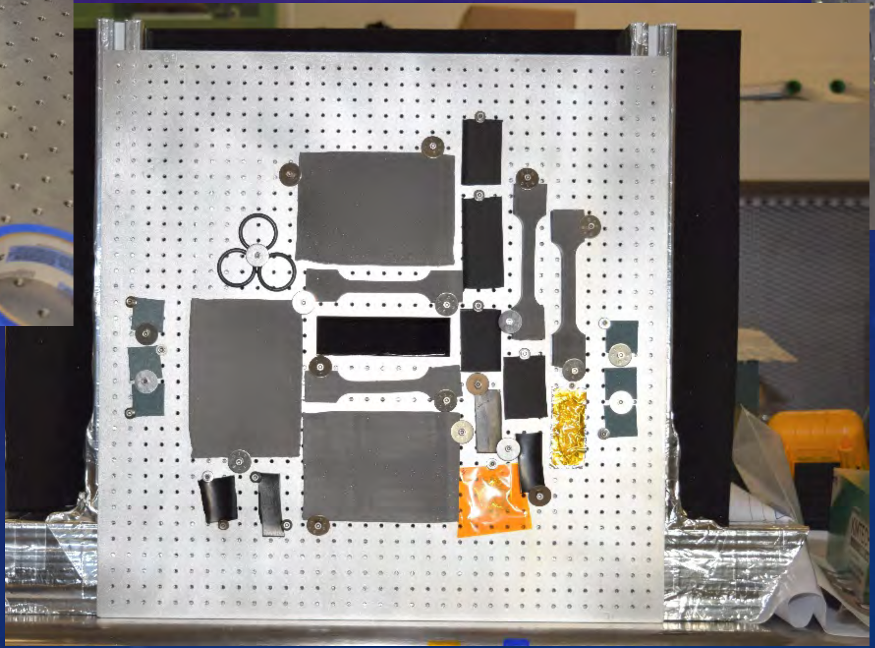
MSFC has the capability to irradiate all the materials and components used to produce a Solid Rocket Motor (SRM) including live propellant, insulation, and initiator train materials and components.



Confined Detonating Fuse Assemblies (CDFA) for SRM Initiation



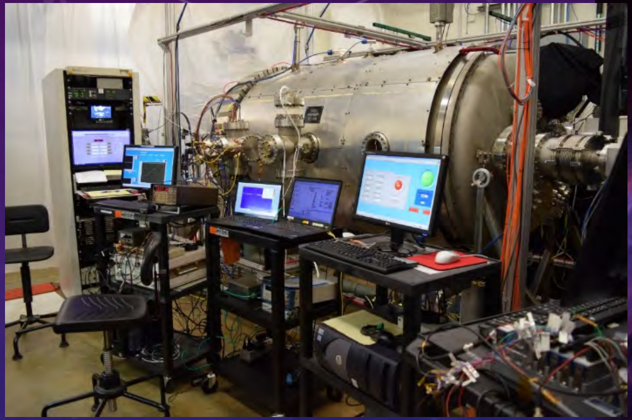
Solid Rocket Motor (SRM) Live Propellant



Insulation and O-rings

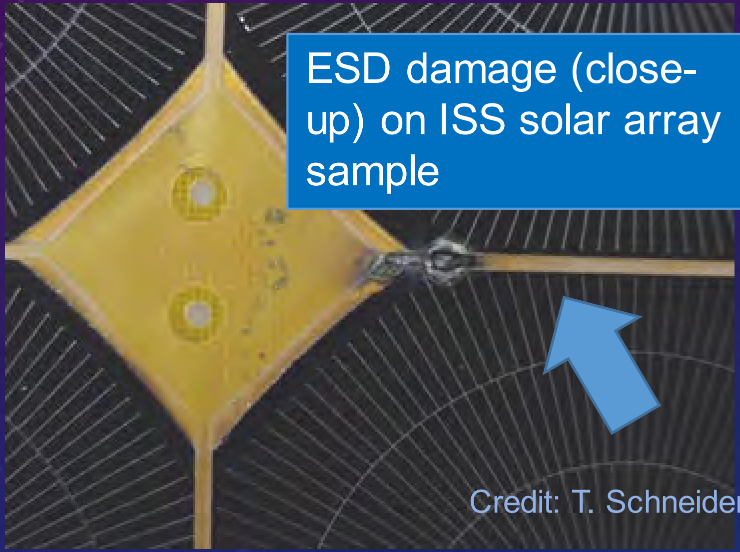
PLASMA ENVIRONMENTS & SPACECRAFT CHARGING

- Plasma is a rarefied gas composed of charged particles
  - Ions or protons (+)
  - Electrons (-)
  - May be out of balance, resulting in different interactions with spacecraft
- The Sun is composed of plasma and is a source of plasma in our solar system
  - Solar Wind Plasma
    - Sun streams charged particles (radially) in all directions
    - Protons (+) and electrons (-)
    - Streaming Speed of 300 km/s (670,000 mph)
  - Lunar surface has complicated plasma environment, depending on relative positions of Sun, Earth, & Moon
- Can result in surface charging or deep charge deposition (depending on energy), or even charge removal



DAMAGE DUE TO ELECTRO-STATIC DISCHARGE (ESD)

- ElectroStatic Discharges (ESD) can occur when charge build-up and potential differences occur within or across a system
    - Different & non-conductive materials
    - Varying illumination conditions
    - Tribocharging – lunar rovers
- A poor design can lead to an ESD event that can permanently damage the system, via property changes or complete loss of function

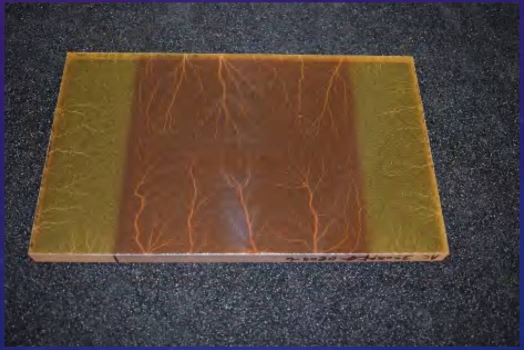


ESD damage (close-up) on ISS solar array sample

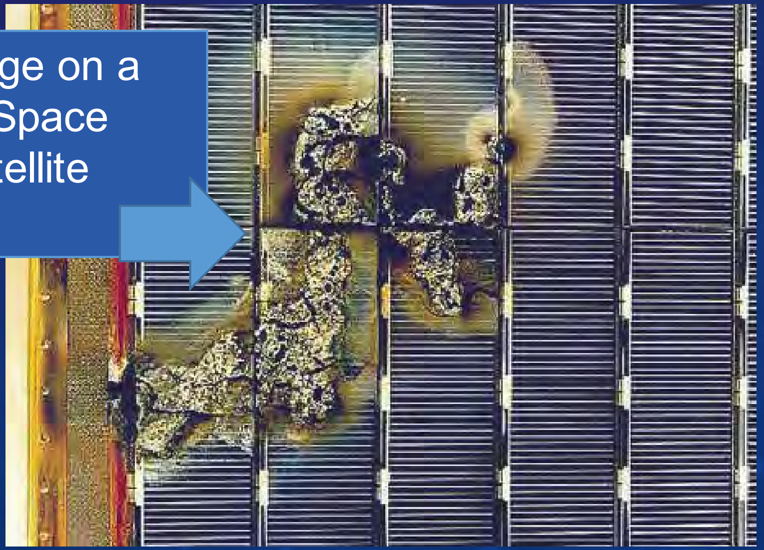
Credit: T. Schneider

Clear Window Sample (on a black mat) Before Radiation Exposure

Internal ESD!



Clear Window Sample (on a black mat) After Radiation Exposure



ESD damage on a European Space Agency satellite solar array

Credit: ESA

MSFC frequently tests systems, materials, & coatings for arcing & ESD generation

PLASMA INSTRUMENTS: ON-ORBIT AND IN THE LAB

Floating Potential Measurement Unit (FPMU) on ISS

- Measures the Low Earth Orbit Plasma Environment
- Directly Measure Spacecraft Charging Voltage
- Qualified by the MSFC SEE Team
- Deployment, Check-out, and Initial Operation by the MSFC SEE Team

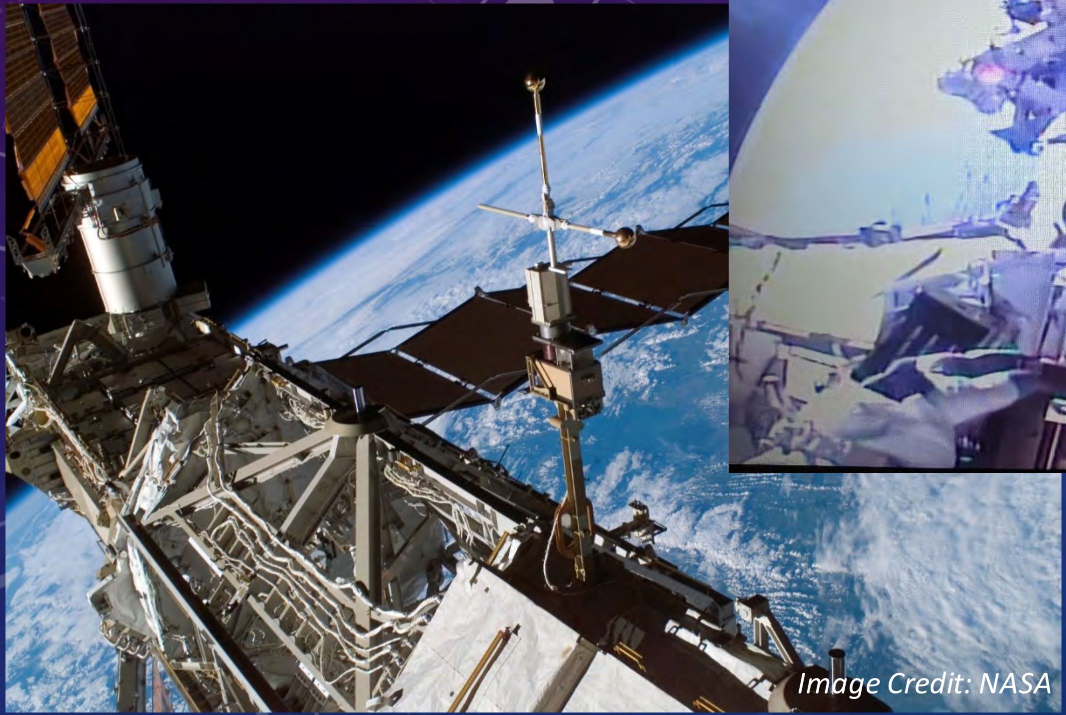
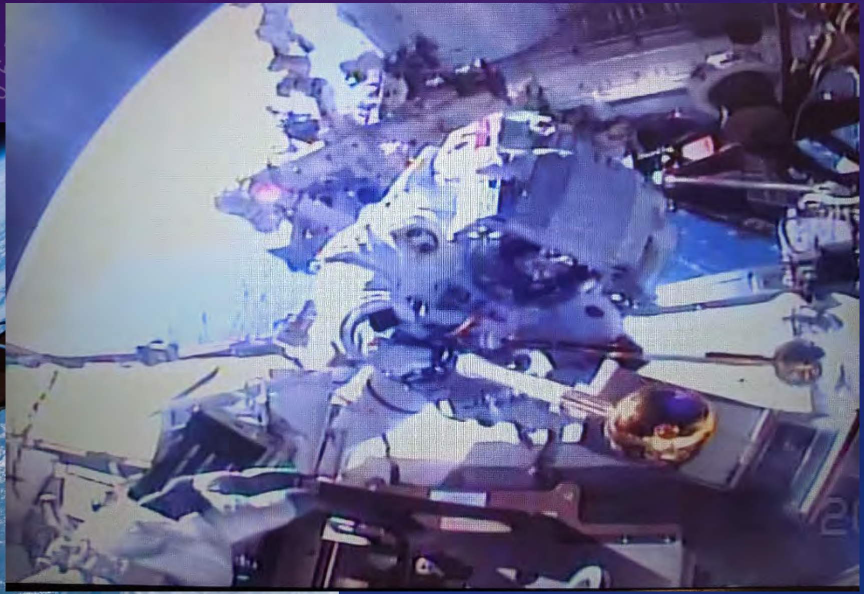
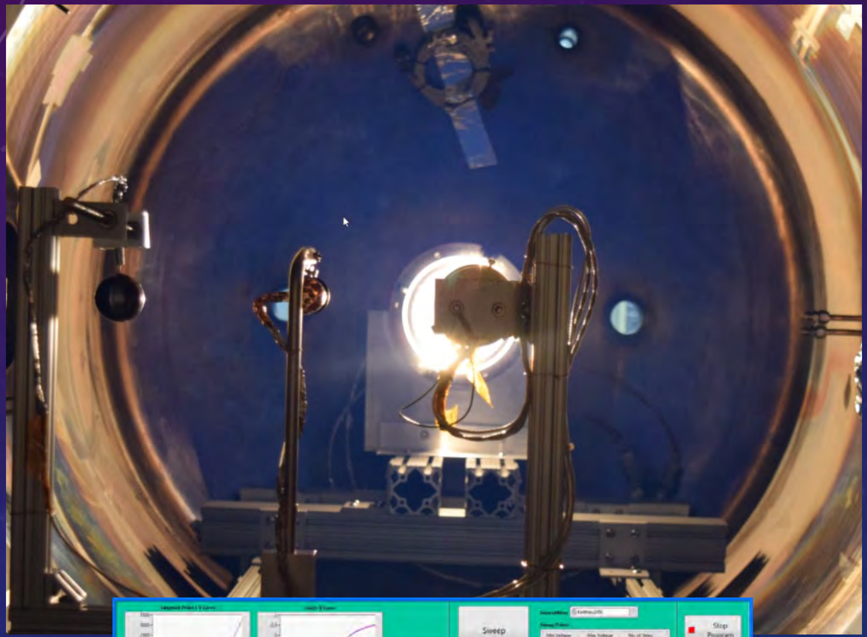
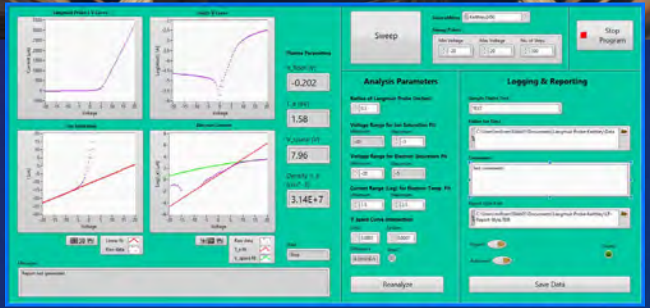


Image Credit: NASA



Aki Hoshide & Thomas Pesquet replacing the FPMU with an on-orbit spare (2021)



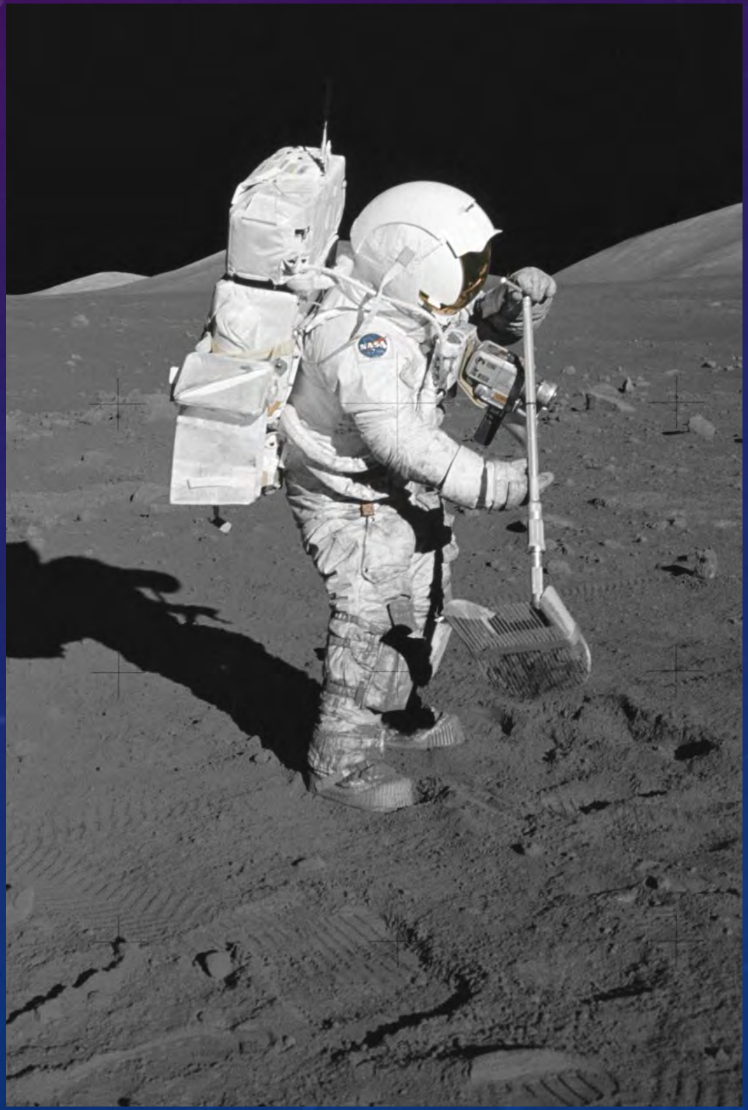


The SEE Team also utilizes specialized plasma diagnostic instruments in their labs

Lunar Environment Test System (LETS)

- Fully functional test system for studying the effects of the lunar surface environment on materials and systems as well as enabling the study of the effect of lunar dust charging on materials and mechanisms.

- Large quantity of regolith simulant
- Vacuum UV radiation
- Electrons
- Protons
- Samples can be heated and/or cooled
- Particle Image Velocimeter (PIV) to measure dust particle movement



FUTURE REGOLITH TEST CHAMBERS…

PLANET:
Planetary, Lunar, & Asteroid Natural Environments Test Bed

- Will be Agency's only complete space environment testbed with m^3 exposure envelope
  - 2m diameter x 3m length
- Vacuum, UV, charged particle, regolith bed, planetary atmosphere, shroud (LN2, He)
- Currently looking for funding!

Ongoing at MSFC: V20 Conversion from a clean chamber to a dirty thermal vac chamber.
Will NOT have other space environmental effects, but has a large volume (20' diameter).
Within the ET20 group.

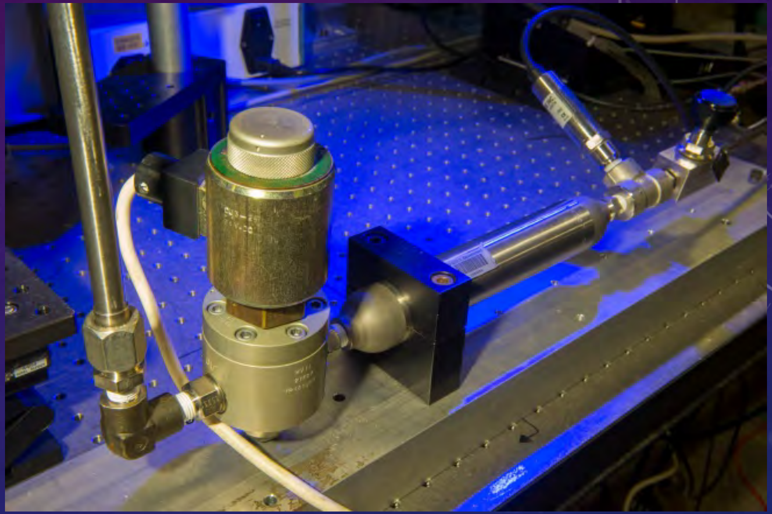
EM41 IMPACT TEST CAPABILITIES

Hypervelocity Impact Range Micro-Light Gas Gun (MLGG)

- Velocity Range: 0.3 – 7.5 km/s
- Bore size .22 caliber (0.223 in.) diameter
- Target chamber approx. 1 ft. wide x 2ft. long
- Projectile Types include but are not limited to: Al, glass, polymers, ceramics

Hypervelocity impact testing is often performed in combination with other SEE exposures to evaluate combined effects.

Microballistic Gas Gun/ Sand Gun

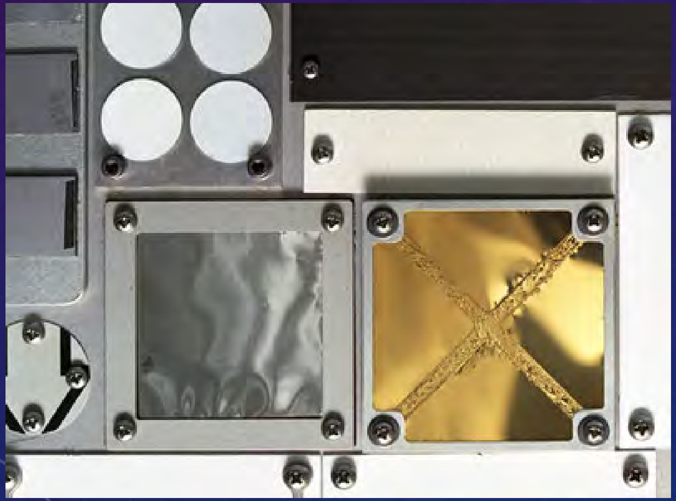


- Velocity: Up to 3,000 ft/s (Mach 2.76)
- Projectile Diameter: 2-4 mm
- Target Size: 51 x 51 mm (2x2 in.) up to full-scale hardware
- Research focused
- High Speed Digital Video
- Working on conversion to shoot regolith simulant

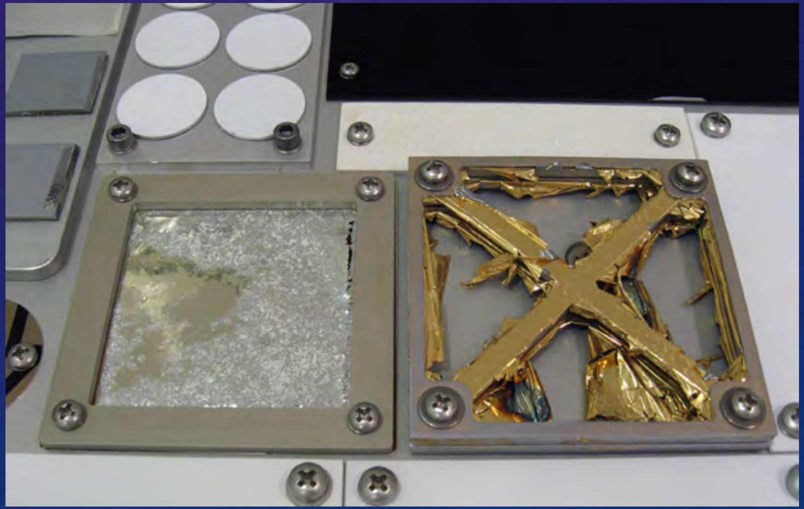
Upcoming new capability: low speed regolith blaster for erosion and wear studies

MATERIAL FLIGHT EXPERIMENTS

- Lessons learned from past experiments
  - Shuttle experiments, Long Duration Exposure Facility, *Mir* space station solar array
- Experiments on International Space Station and X-37
  - Materials on International Space Station Experiment (MISSE)
  - Materials Exposure and Technology Innovation in Space (METIS)
- Future experiments on Gateway, Lunar surface, Mars?



Polymer films before space exposure

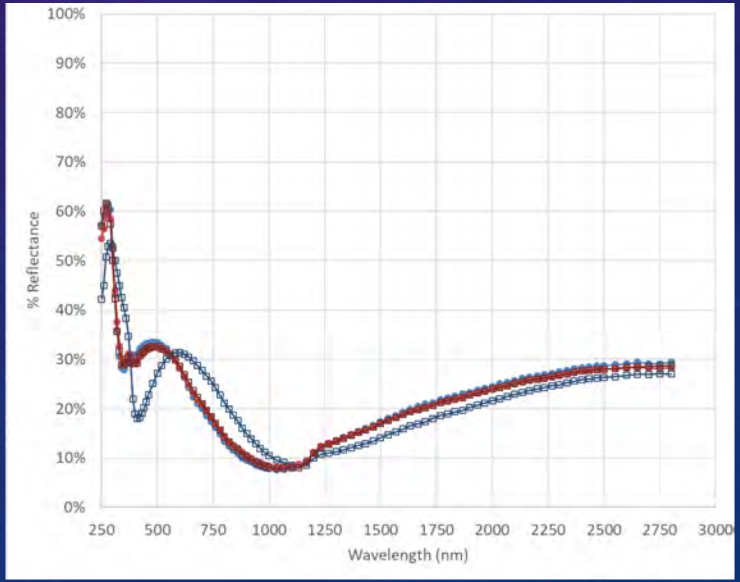


Polymer films after space exposure

MISSE-3 on orbit

ANALYTICAL CAPABILITIES

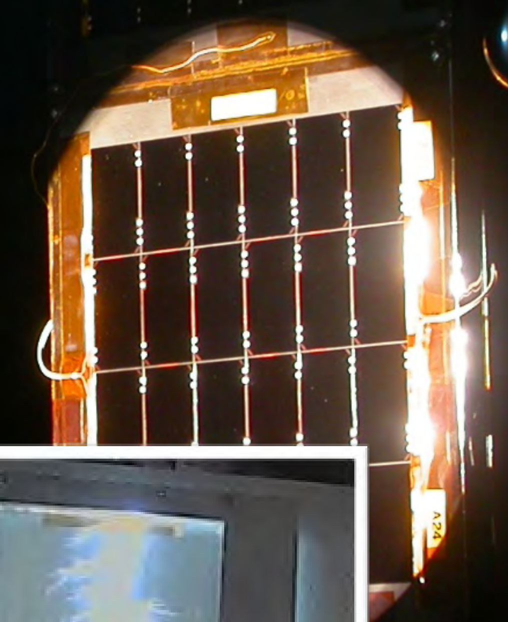
- Solar Absorptance Measurements (LPSR)
- Transmission Measurements (Lambda 1050)
- Vacuum Ultraviolet Radiation (VUV) Reflectance and Transmission
- Infrared Reflectance Measurements (LPIR)
- Infrared Emittance Measurements (TEMP 2000)
- Surface Resistivity for Conductive Coatings
- Surface Roughness
- Thin Films Tensile Testing



SEE for Exploration

MSFC Space Environmental Effects Team has unique capabilities to simulate a dramatic range of environments, from Heliophysics Missions to Deep Space Missions, and everything in between!

- high vacuum
- UV/VUV radiation
- temperature extremes
- solar wind plasma
- particle & x-ray radiation
- atomic oxygen
- planetary surface and regolith effects
- impact testing



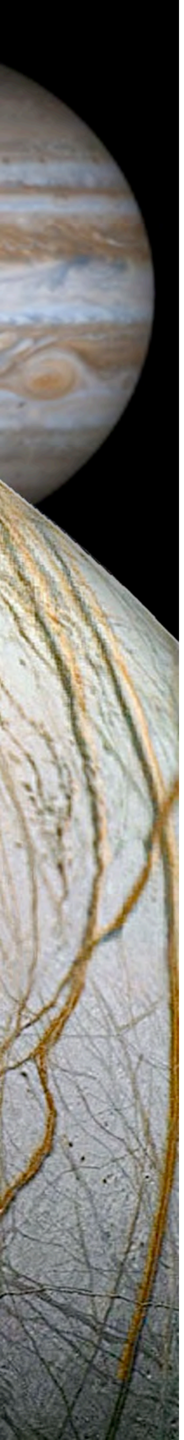
Some of the projects we have worked on…

- Europa Clipper
- Europa Lander
- ISS – Payloads & Safety Assessments
- ROSA (Roll Out Solar Array)
- Parker Solar Probe
- IXPE
- Gateway PPE
- Lunar GATR
- KNaCK
- MISSE
- E-Sail

SEE testing can raise hardware and components to TRL-6: “Qualification in a Relevant Environment”

BACKUP

MSFC Space Environmental Effects Team has unique capabilities to simulate a dramatic range of environments, from Heliophysics Missions to Deep Space Missions, and everything in between!

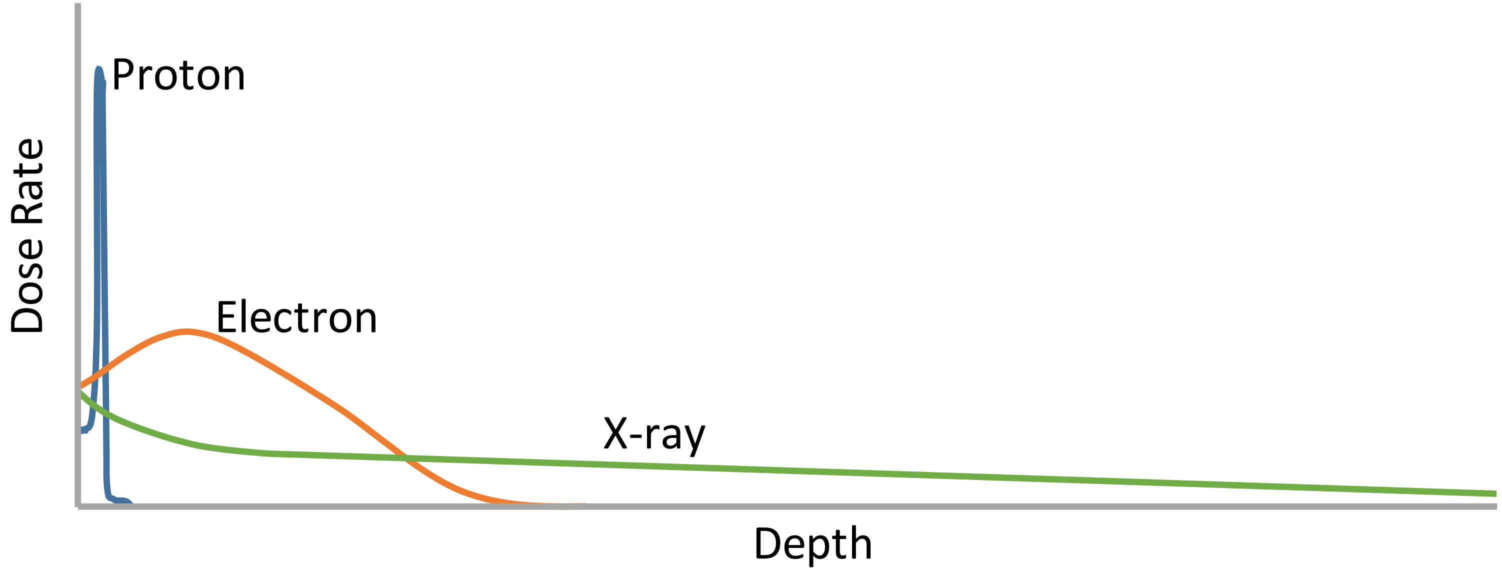


Comparison Of Capability

- Complimentary facilities…

	X-ray Irradiation	Pelletron Electron	Pelletron Proton
Max dose rate	~10^6 rad/hr	~10^7-10^8 rad/hr	~10^8 rad/hr
Spot width (and Area)	4” Circle (12 in^2)*	16-24” Circle (200 in^2)	16” Square (256 in^2)
Penetration	cm scale	mm scale	µm scale
Charging	None	Deep, Negative chg	Shallow, Positive chg

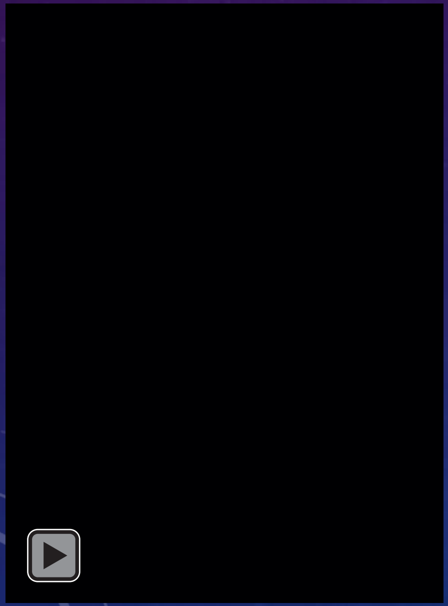
*Larger spot areas are easily achievable on X-ray, but dose rate reduces proportionally



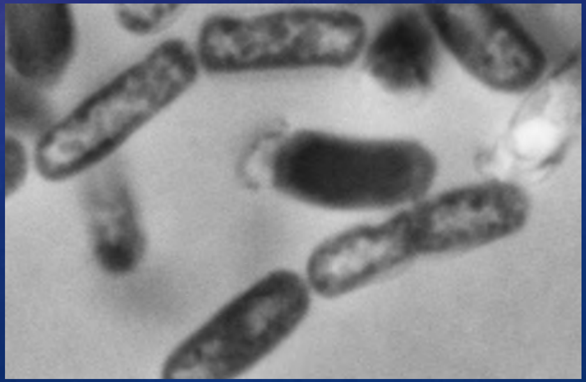
PLANETARY PROTECTION

Tardigrade

- Current NASA projects include landers to touchdown on the surface of potentially life-supporting planets and moons.
- Planetary protection is the required prevention of accidental transportation of Earth's microbes to these environments.
- In addition to traditional interplanetary spacecraft decontamination operations, EM41 is investigating new techniques for biological burden reduction.
- Studies are focusing on solid rocket propulsion systems and the innate antimicrobial capacity of both the chemical agents within the motor and of the assembly and operational environments.



Video of Tardigrade through a microscope lens



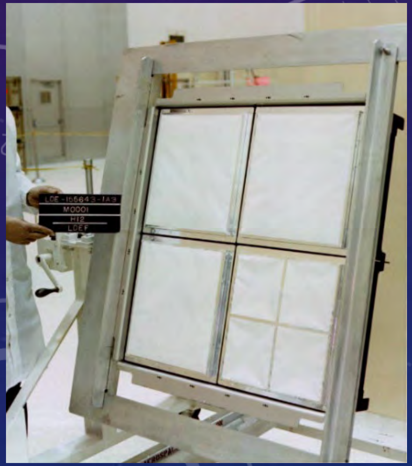
Bacilli on Propellant Sample

ATOMIC OXYGEN (AO)

- WE BREATHE O_2 MOLECULAR OXYGEN. IN THE IONOSPHERE, UV BREAKS O_2 INTO OXYGEN ATOMS (O). THIS REACTS WITH MANY MATERIALS AND CAN BE EXTREMELY DESTRUCTIVE.
- AO IS FOUND IN LOW EARTH ORBIT (LEO) AND LOW MARTIAN ORBIT.

MSFC's **Atomic Oxygen Beam Facility (AOBF)** provides an accurate simulation of AO in LEO

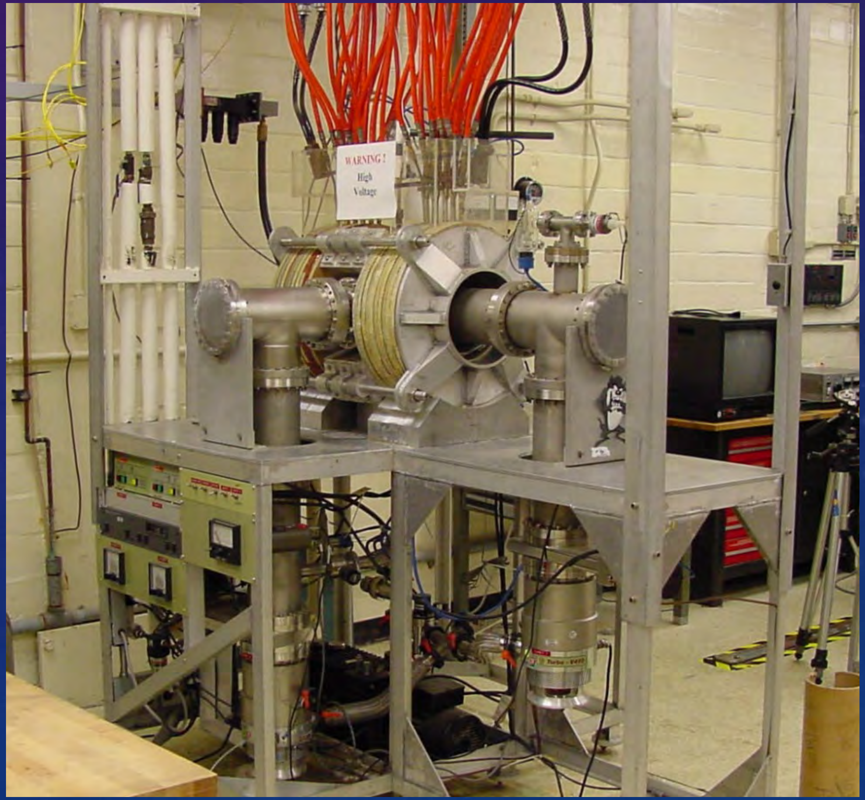
- 5 eV atomic oxygen source
- Used to determine the erosion rate of materials and the effect on thermal properties



Before Space Exposure

After Space Exposure

Heatshield Material



AOBF

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