# Thermal Materials and Coatings for Near Rectilinear Halo Orbit (NRHO)

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# About Us

- **Early career engineers at Johnson Space Center (JSC) in the Thermal Design Branch**
- **Working on the Gateway program**

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# Agenda

- Background
- Introduction
- NRHO Environment
  - Natural Environment
  - Induced Environment
- Material Options
- Estimating EOL properties
- Conclusions and Future Work
- Resources

# Background

- **Purpose**
  - **Gateway:** “The Gateway will be an outpost orbiting the Moon that provides vital support for a sustainable, long-term human return to the lunar surface, as well as a staging point for deep space exploration. It is a critical component of NASA’s Artemis program.” – nasa.gov
  - Future spacecraft visiting Gateway or NRHO must withstand the space environment
  - Proper selection and placement of thermal control coatings is essential to continued operation for the mission lifetime in NRHO

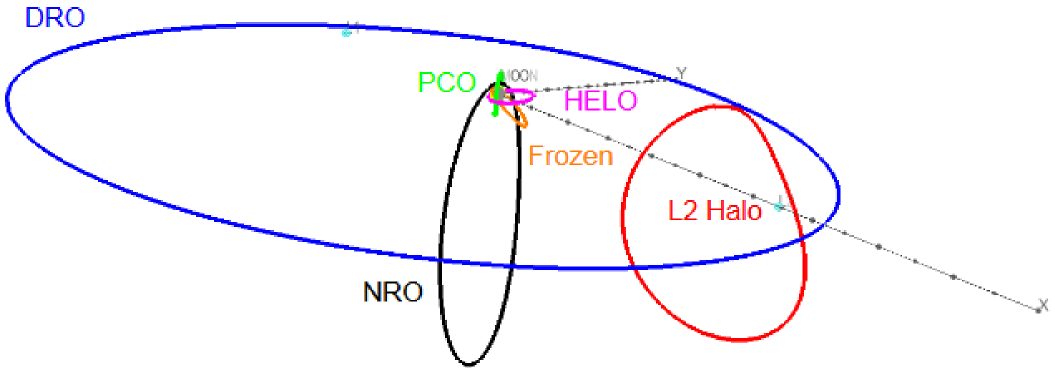
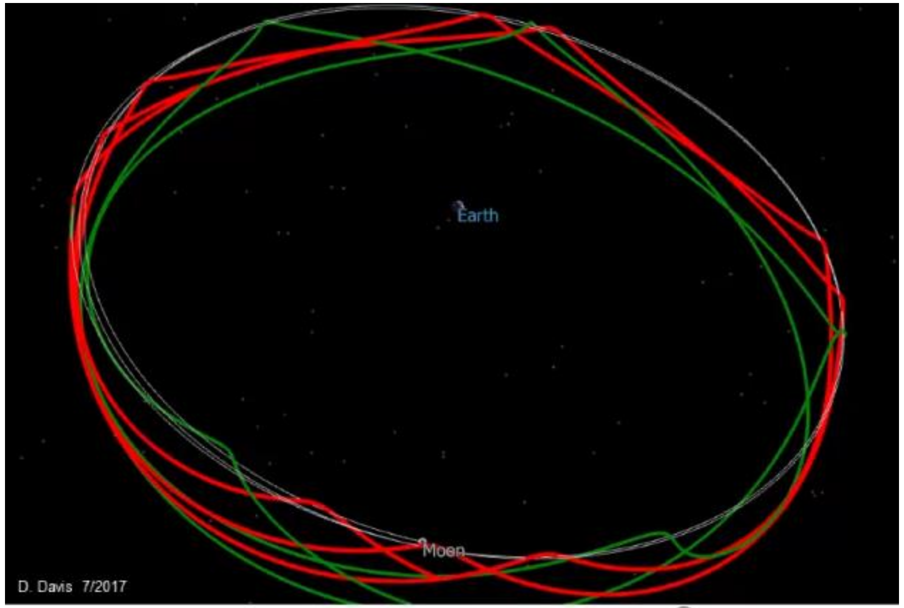



Figure 1. Potential Staging Orbits

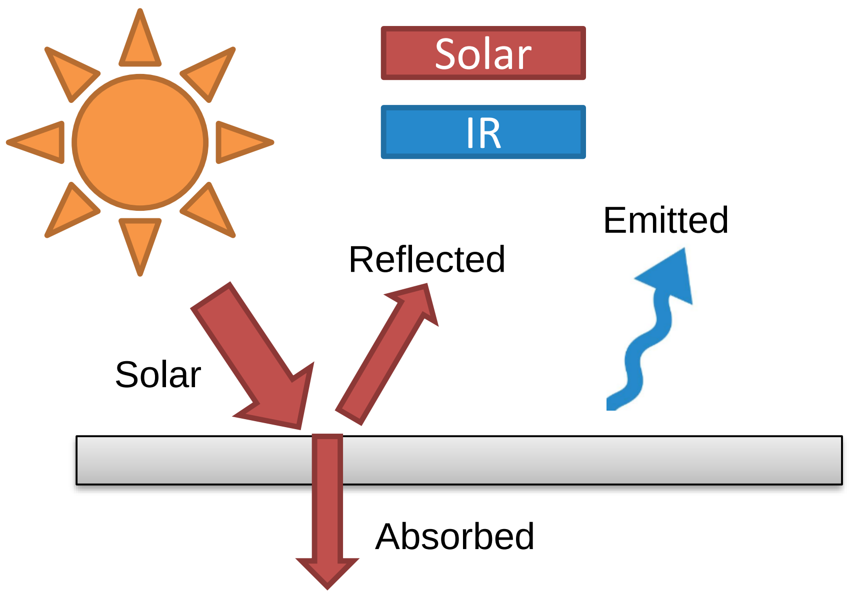
Moon centered inertial frame




Earth centered inertial frame (NASA)

# Background

- **Optical Properties**
  - **IR Emissivity (ε)** - effectiveness in emitting energy as thermal radiation
  - **Solar Absorptivity (α)-** effectiveness in absorbing radiant solar energy
- **Why are optics important?**
  - Spacecraft thermal control depends on optics of the materials surface
    - High emissivity and low absorptivity make the best radiators
    - High solar absorptivity maximizes the heat load your surface will receive from the sun
    - High IR emissivity maximizes how much energy you can output from your surface
    - a/e ratio helps determine how hot a surface will get in sunlight



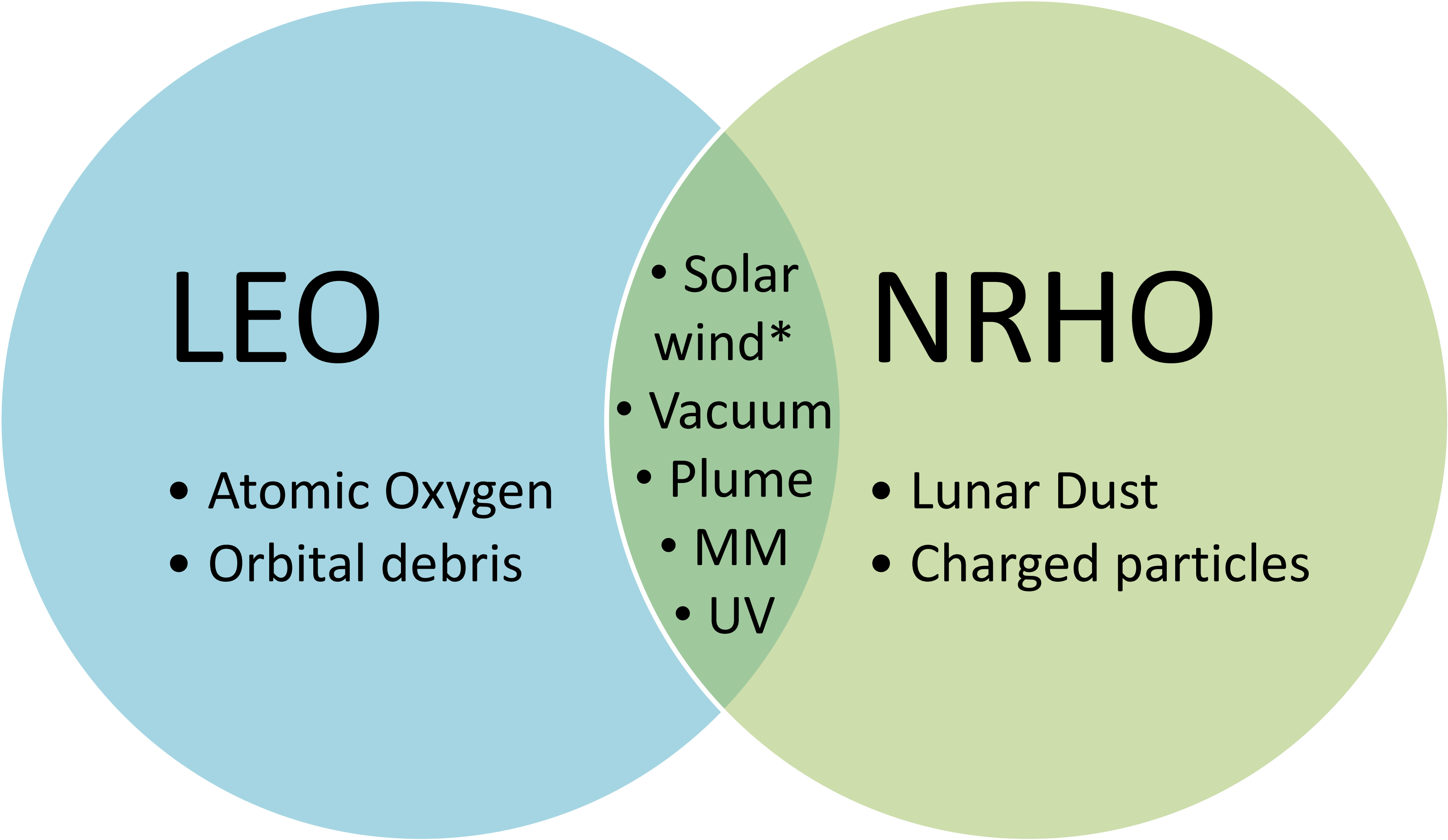

<u>Note:</u>
All incident thermal radiation is classified as Solar or IR
Solar energy is between 250 and 2500 nm and all other thermal radiation is classified as IR

# Introduction


Contamination of thermal control surfaces seen on ISS Expedition 22 (NASA)

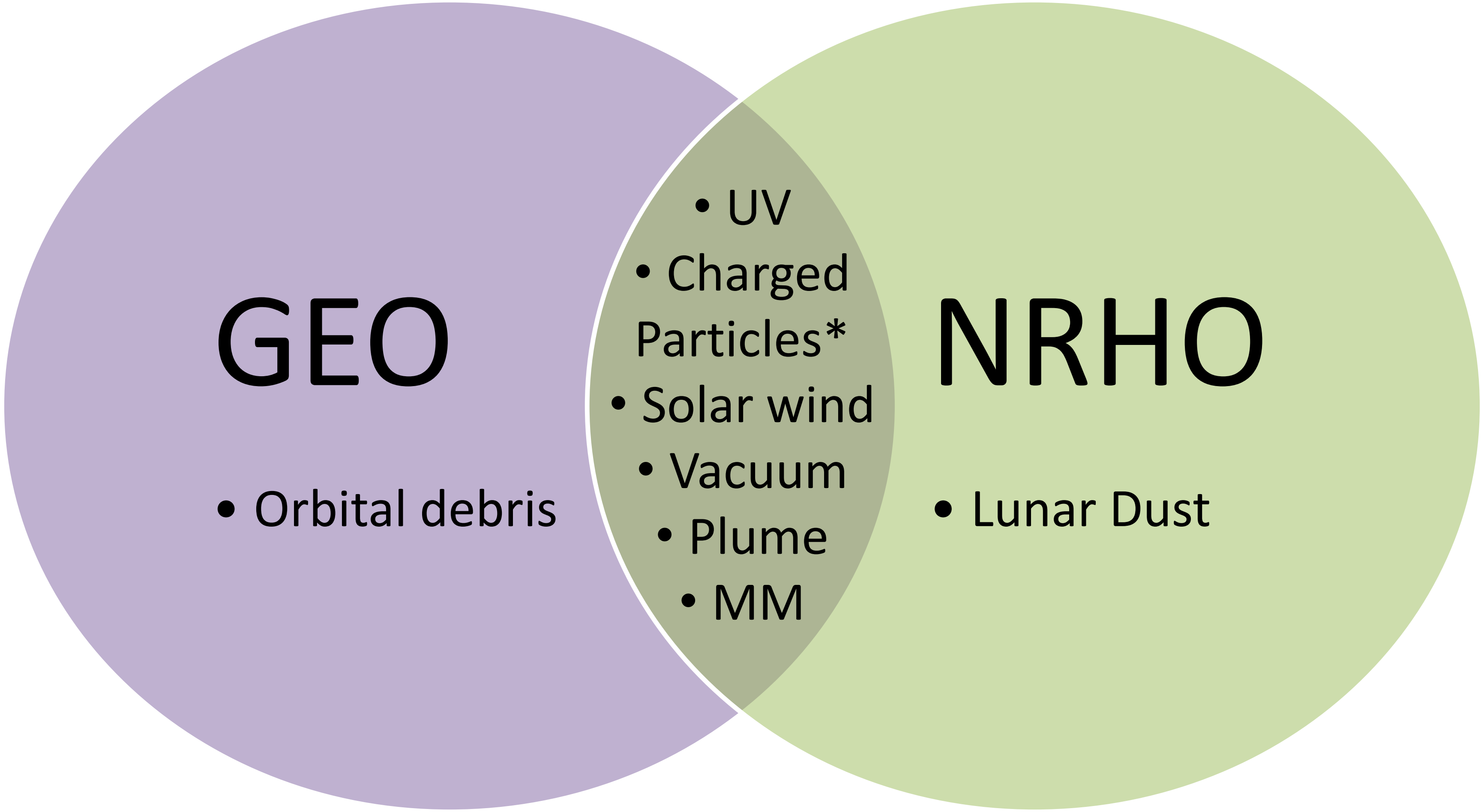
- **Tuning of optical properties is an important tool for passive thermal management, but materials and optical coatings degrade in the space environment**
- **Amount of degradation varies by material and environment**
  - $\alpha_{BOL} \neq \alpha_{EOL}$; $\varepsilon_{BOL} \neq \varepsilon_{EOL}$
  - Choose materials and a design which promote good performance during lifetime
- **NRHO is a relatively unknown space environment- nothing has flown in this orbit before**
  - Must understand how this environment will affect degradation of materials and coatings
  - Most EOL data is pertaining to Lower Earth Orbit (LEO) or Geostationary Earth Orbit (GEO)

# LEO vs. NRHO




*LEO is protected by Earth's magnetic field from radiation, so the solar wind is worse in NRHO than in LEO

# GEO vs. NRHO




*GEO includes the Van Allen Belts, which means radiation would be higher in the GEO environment than in the NRHO environment

# Degradation Sources in the NRHO Environment

# NRHO Environment

## Natural Environments

- UV
- Solar Wind
- Galactic Cosmic Rays (GCRs) and Solar Particle Events (SPEs)
- Vacuum
- Micrometeoroids

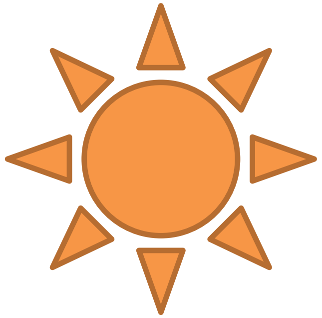
## Induced Environments

- Plume Impingement
- Venting
- Foreign Object Debris (FOD)
- Lunar Dust
- Crew Interaction

# Radiation and Charged Particles

- **UV**
  - Same as LEO
  - Causes some darkening (increase in absorptivity)
  - Will occur on surfaces that see the sun
  - Testing
    - Measured in equivalent solar hours (ESH), which are the number of hours that the particular surface would be exposed to sunlight during the mission
    - Materials can be tested to the expected mission ESH
    - One hour of ground testing can be equivalent to a maximum of 3 ESH, so for a 3 year mission, UV testing would take at least 1 year
    - Should be done with the capability of measuring in vacuum (oxygen would cause bleaching, negating some UV impacts)
- **Galactic Cosmic Rays (GCRs) and Solar Particle Events (SPEs)**
  - High energy, could cause subsurface damage or pass through completely
  - Mainly going to affect electronics and crew systems
  - Not usually a factor for thermal materials

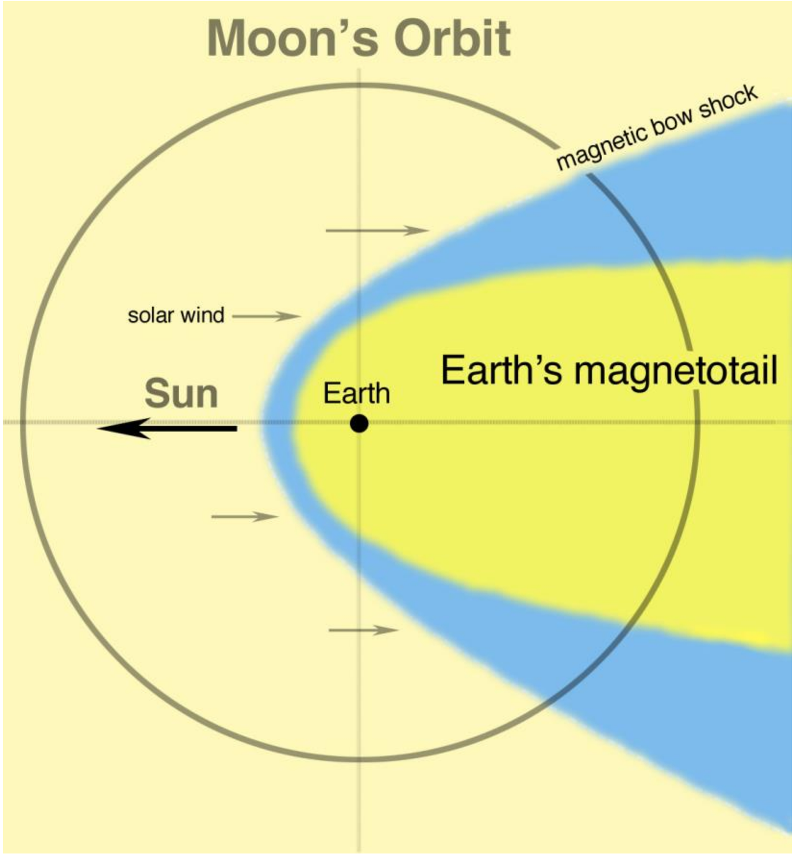
# Radiation and Charged Particles



- **Solar wind**
  - Continuous flow of mostly low energy charged particles from the sun
  - No longer protected by Earth's magnetic field in LEO, but radiation not as harsh as in GEO environment
  - Low energy protons & electrons unable to penetrate spacecraft, but deposit energy on the surface, causing darkening and increase in absorptivity
  - Testing
    - Submit material samples to expected energy levels and proton and electron fluence for the mission and determine effects on optical properties
      - Testing timeline for solar wind is on the order of weeks, depending on mission lifetime
      - Can be done at same time as UV testing
      - Energy levels and fluence tables for NRHO provided in SLS-SPEC-159 Rev G
- **Electrically dissipative surfaces are recommended in NRHO to reduce risk of electrostatic discharge (ESD) events**

# Magnetotail

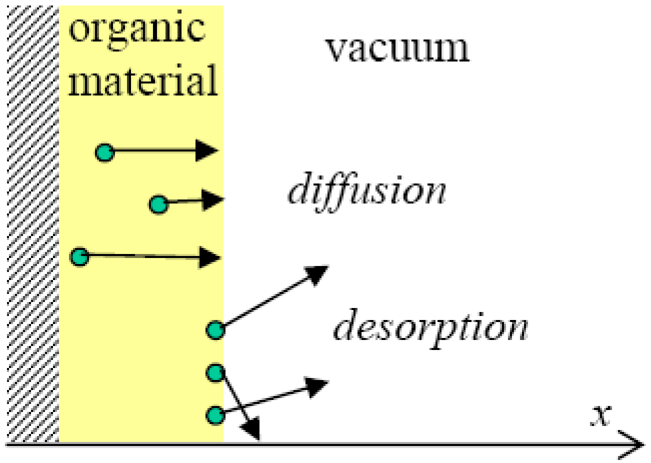
- **The magnetotail is a broad elongated extension of a Earth's magnetosphere on the side away from the sun**
- **The moon passes through Earth's magnetotail every 27 days or so**
- **Transit lasts ~6 days**
  - Relativistic electrons due to magnetotail magnetic reconnection
    - Between 10 MeV to 20 MeV
  - Decreased solar wind density
    - Bow shock, shells of higher proton fluence with lower density between
  - Size of magnetotail at lunar distance is anywhere from ~10 to 35 Earth diameters (Akay, Kaymaz, and Sibeck, 2013)




**Credit:** Tim Stubbs/University of Maryland/GSFC

# Vacuum

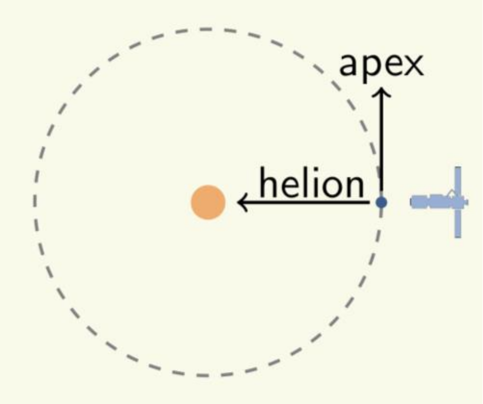
- **Vacuum exposure causes outgassing and contamination**
  - Outgassing is the release of a gas that was trapped inside a solid
  - These outgassed products can recondense on external surfaces causing contamination
  - Outgassed product can also be ionized by solar UV and then electrostatically reattracted to the vehicle
- **NRHO**
  - Solar wind is not as effective at carrying away particles from surface as atmosphere which would be present in LEO- this could cause increase in contamination degradation
  - Contamination could be a very significant source of degradation in NRHO

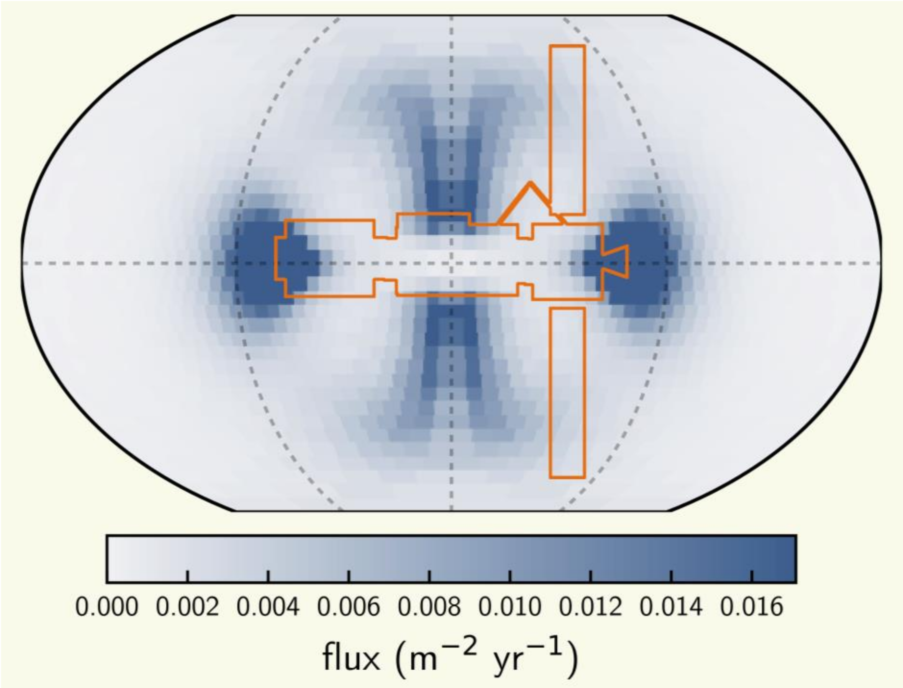



(Roussel et al., 2009)

- **Mitigated by design or material choice**
  - Choose materials that are low-outgassing
    - Even if a material is “low outgassing” if there is a large quantity it can still cause problems
  - Limit line of sight- arrange so that they are not nearby contamination sensitive surfaces
  - Total mass loss (TML) of less than 1% is standard, confirmed with Vacuum Stability test (ASTM-E595)
  - Collected Volatile Condensable Materials (CVCM)- standard amount that might re-condense on a surface is limited to about 0.1%
  - ASTM-E1559 more sophisticated test that estimates contamination on sensitive surfaces

# Micrometeoroids




(Moorhead, 2019)

- **Earth and Moon encounter approximately the same population of meteoroids**
- **Gravity and size of Earth and Moon affect the local meteoroid environment**
  - Meteoroid Engineering Model (MEM) 3.0 predicts meteoroid flux and includes NRHO environment (Moorhead, 2019)
- **Meteoroid directionality is not random- flux will be different on different surfaces**
- **NRHO doesn’t have the luxury of radar tracking for large MM- can’t be avoided like ISS**
- **Potential to punch holes in solar cells or radiators**
  - Unlikely to be significant for thermal surfaces
  - Probably won’t affect selection of material, but may affect performance over time

# Synergistic Effects

- **UV and AO combined on Beta cloth has a cancelling effect, known as AO scrubbing**
  - With only UV Beta cloth will yellow and absorptivity will increase
  - Lots of data out there already for UV ONLY effects, this data can still be used
- **UV/charged particles could have some interaction, material dependent**
  - Photolytic deposition- chemical decomposition caused by light or electromagnetic radiation
- **Enhanced outgassing and contamination due to spacecraft charging and UV**

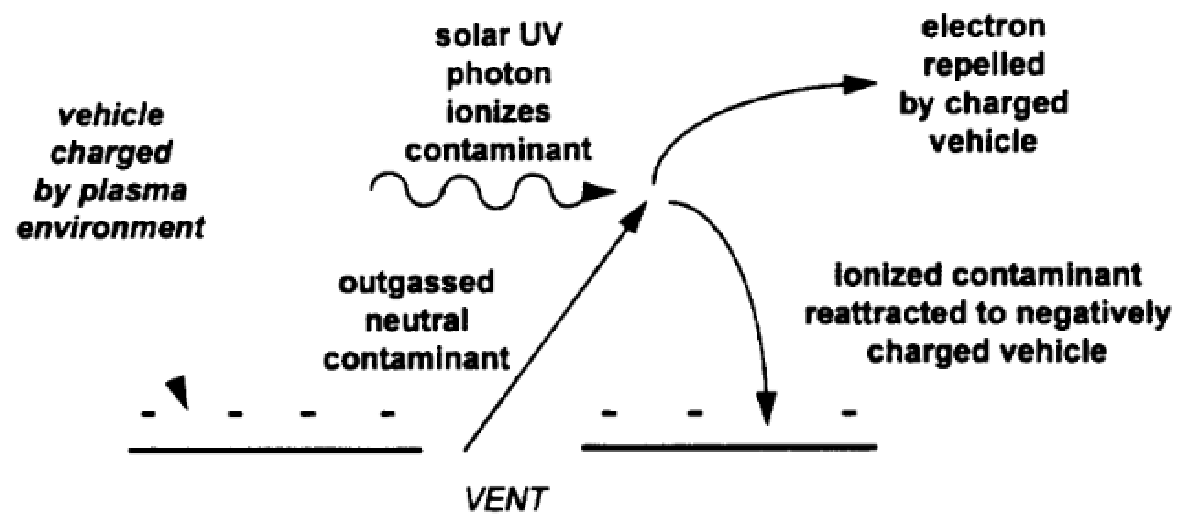


Figure 2-14. Electrostatic reattraction of ionized contaminants.

(Tribble et al., 1996)

# NRHO Environment

## Natural Environments

- UV
- Solar Wind
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- Vacuum
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## Induced Environments

- Plume Impingement
- Venting
- Foreign Object Debris (FOD)
- Lunar Dust
- Crew Interaction

# Contamination- Plume, Venting, Particle

- **Plume ejecta**
  - Plumes from engines of spacecraft or visiting vehicles can cause contamination that damages optical properties
    - Non-volatile residue build-up on surface
    - Chemical reactions with partially reacting products
    - Plume erosion- can cause a sand-blasting effect, relatively small, will probably be within noise/margin
  - Mitigated by design- arrange so plumes are not impinging on contamination sensitive surfaces
- **Venting**
  - Vented air from airlock, vented gaseous or liquid wastes
  - Gasses will likely dissipate
  - Water based liquids could be more of a problem, especially with dissolved substances
  - Contaminants on a surface facing the sun may get baked off, but not necessarily on the space-facing side
- **Particulates and Foreign Object Debris (FOD)**
  - Brought from Earth or caused by damage to spacecraft in orbit
    - Example: paint flakes, dust

(Soares et al., 2015)

# Lunar Dust

- **Lunar dust may be found in the natural NRHO environment- see backup charts for details**
  - Lunar dust due to induced environmental effects are a greater unknown
- **Unknown how lunar dust in orbit will be affected by lander and other surface activities**
  - Potentially more dust kicked up into NRHO after lunar landings
- **Lunar dust could be brought back to NRHO via Ascent Vehicle**
  - Unknown how dust would transfer from one surface to the next
- **Currently unknown how lunar dust might adhere to thermal surfaces or how it might impact thermal performance**
  - Could adhere and obscure surface, degrading thermal performance by degrading optical properties or providing thermal insulation
  - Could abrade surface and damage optics
  - Some instruments on Apollo 16 and 17 showed degraded heat rejection capabilities due to dust coverage and subsequent overheating (Gaier & Jaworske, 2007)
  - Unknown if percent coverage would be 0.01% or more
    - 12% coverage of a Z93 radiator is estimated to increase alpha by 50% (Gaier, Siamidis, and Larkin 2010)
  - Very difficult to predict dust coverage at this time- Type of dust, size distribution, shape, etc.

# Crew Interaction

- **Astronauts can cause damage to external surfaces during EVA**
- **EVA capability adds many requirements for material selection**
  - Astronaut safety
    - Sharp edges
    - Hazardous materials
    - Touch temperature maintained (a/e ratio)
  - Durability
    - Withstand kick loads
    - Peeling and delamination
    - Tearing of insulating blankets
    - Flaking or shattering could cause particulate which can lead to further damage to surfaces and mechanisms, and could result in sharp edges
  - Visibility
    - Colored handrails for translation path, labeling on exterior, etc.
    - Specularity/glint requirements - could interfere with astronauts vision

Gold anodized aluminum handrails as seen in spacewalk on January 2020 (NASA)

# Material Options

# Materials by Function

Solar Arrays

Radiators

MLI

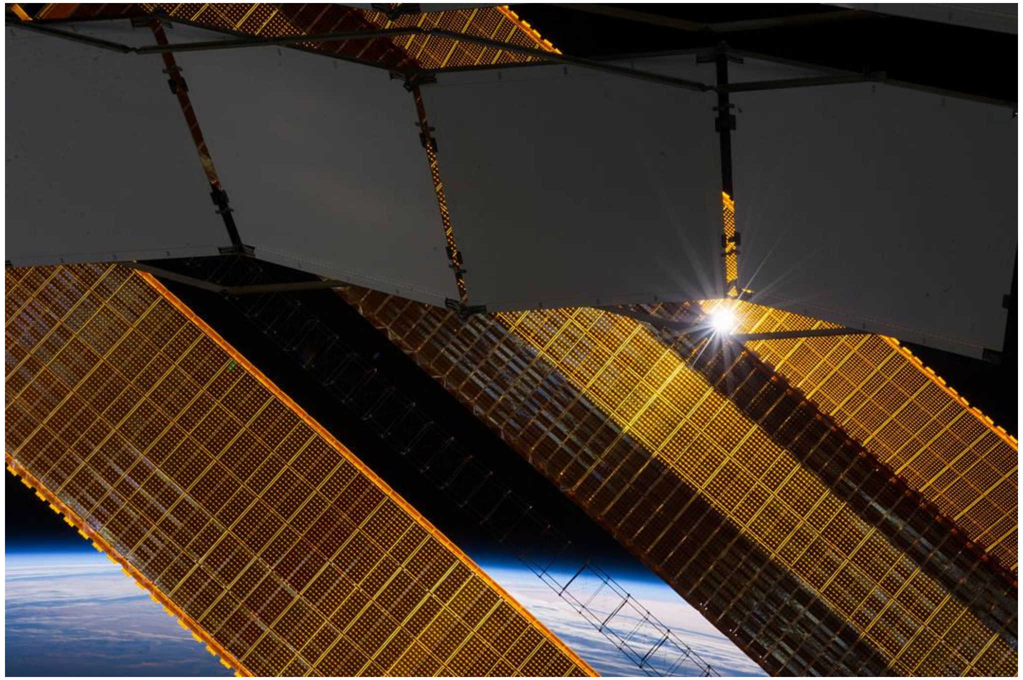
Structure

Cameras, Star Trackers, & Windows

Credit: NASA

# Materials- Solar Arrays

- **Degradation**
  - Some degradation on solar cells, but power team should have a profile of power loss vs time
    - Degrades due to radiation
  - Degradation due to UV photolytic deposition
    - UV causes chemical reaction with contaminants on the surface
  - Impacts from lunar dust are still unknown
  - Typically solar cells run warm
- **Materials**
  - Cover glass that is usually very stable
    - Fused silica
    - Microsheet glass
      - Cerium doped borosilicate cover glass
  - Solar cells vary widely by manufacturer

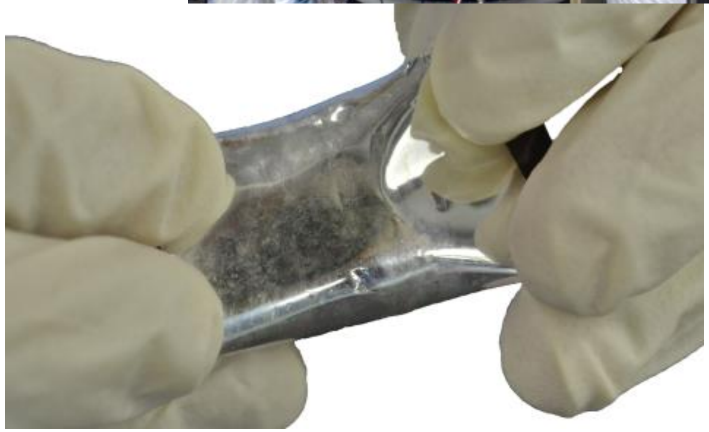


ISS solar arrays and radiator January 2014 (NASA)

# Radiator Options- OSR

- **OSR is a second surface mirror - cover glass made of quartz over metallized reflecting layer**
  - Reflecting layer is most commonly aluminum, silver or gold
    - Aluminum is most resilient material and has good optical properties
    - Silver is the best reflector but is susceptible to AO degradation
    - Gold is the least used option because of its relatively high absorptivity
- **Emissivity ~ 0.8, absorptivity is very low (~0.08 to 0.13)**
- **Lowest a/e ratio of all options and most favorable for performance**
- **Very stable to most degradation sources, but susceptible to contamination**
- **Delicate, requires experienced processing**
- **Limited to flat surfaces**
- **Expensive, heavy (3-5 mil glass, up to 7.5 mil)**
- **Newer thin film and flexible versions may be an option**
  - Degradation will likely be affected- would require testing

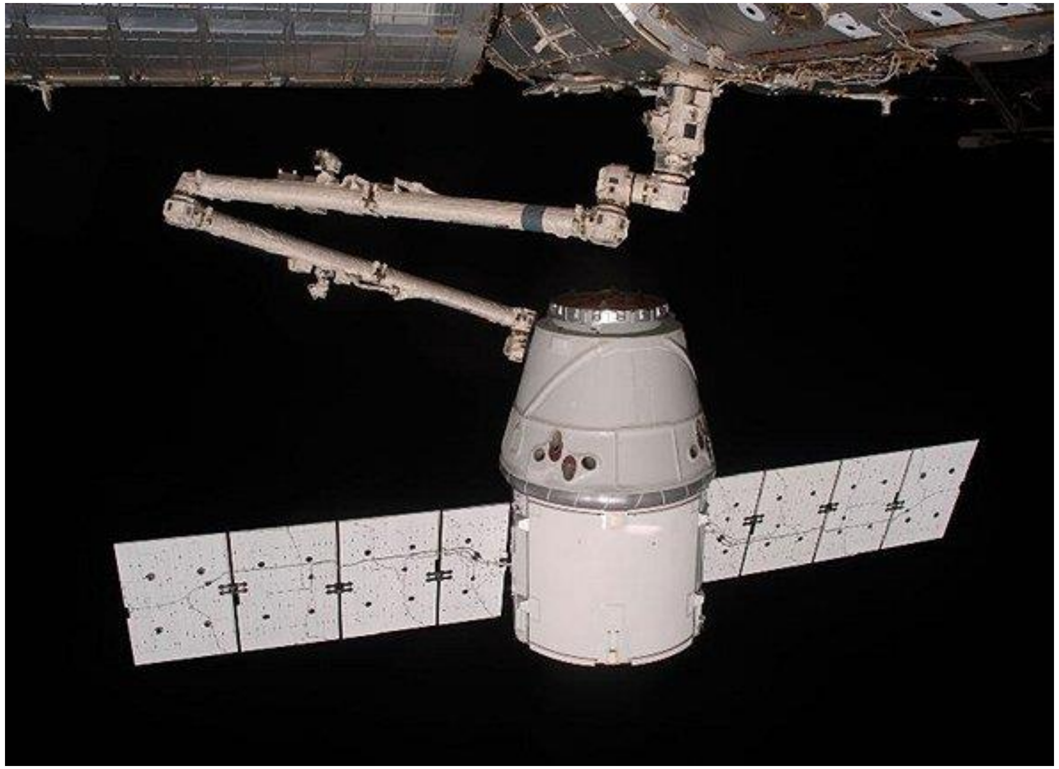
MESSENGER Mercury-bound NASA spacecraft used 70% OSRs with 30% solar cells on it's solar panels (NASA)



(Consorzio C.R.E.O, 2012)

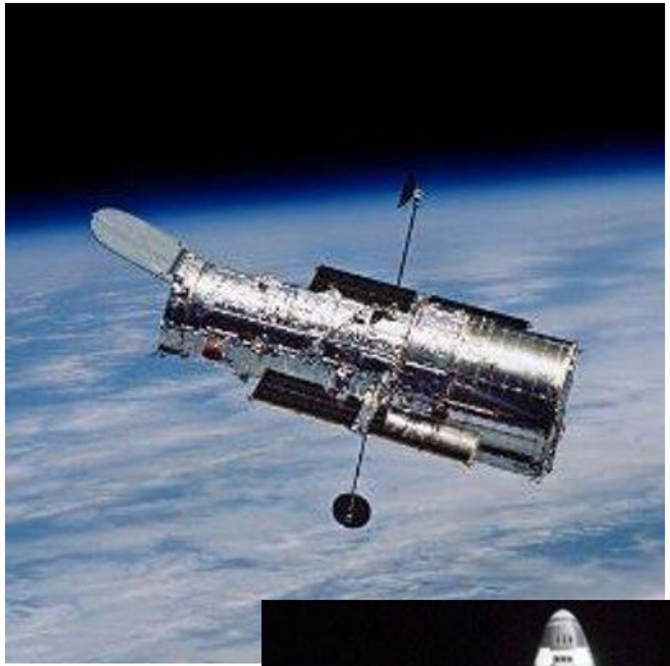
# Radiator Options- White Paint

- **Emissivity ~ 0.89 to 0.94, absorptivity ~ 0.2**
- **Sensitive to**
  - UV
  - Solar wind
  - Contamination
- **Silicone coating**
  - Potential outgassing problems, higher degradation due to radiation
  - Easy to apply because it is a smooth paint, fairly durable and rugged
  - Alion DS 13, used by JPL, electrically dissipative
  - Aptek 2719, electrically dissipative
- **Silicate coating**
  - More difficult to apply than silicone coatings, but stable, reliable, sticks to most hardware
  - Alion Z93C55, well characterized, electrically dissipative
  - Aptek 2711, electrically dissipative, no radiation/solar wind testing yet



View from the International Space Station of the SpaceX Dragon spacecraft as the robotic arm moves Dragon into place for attachment to the station May 25, 2012. (NASA)

# Radiator Options- Silver Teflon with ITO



Hubble Silver Teflon (NASA)

Space Shuttle Orbiter used Silver Teflon inside the bay doors (NASA)

- **Lower performance than OSR and some white paints**
- **Used frequently in LEO (Shuttle, Hubble, etc)**
- **Lightweight and low cost**
- **Degrades in radiation, tends to peel under thermal cycling, and AO conditions**
- **Indium Tin Oxide (ITO)**
  - Thin, optically transparent coating that is electrically dissipative
  - ITO is delicate and can rub off easily
  - Verification of continuous ITO film layer is difficult

# Radiator Options- Oxide Composite System

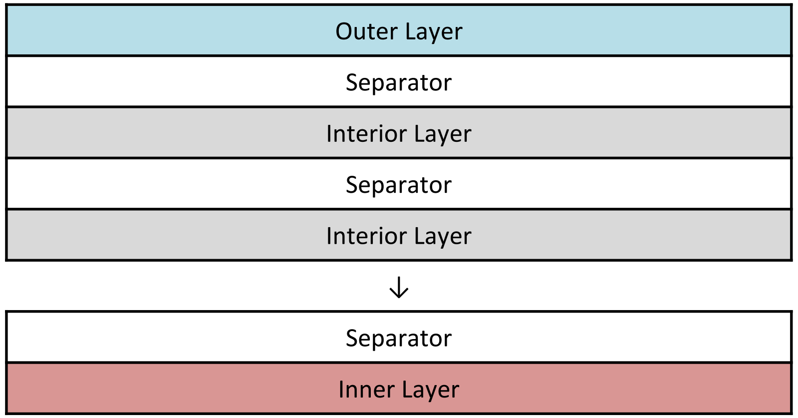
- **Reduced emissivity (0.6-0.7)**
- **More stable than Teflon, especially from UV and solar wind**
- **Silver/Aluminum as reflective layer (vapor deposited on hardware or films)**
- **Thickness about 2.5-2.6 microns total, 2.3 is oxides**
  - Aluminum oxide (~1.9 micron) + silicon oxide (0.4-0.6 micron)
- **Fabrication through electron beam evaporation**
- **Can apply to non-planar surfaces**
- **Surface roughness affects absorptivity**
- **May need additional coating for electrical dissipation**

| |
|---|
| 550 nm $SiO_2$ |
| 2000 nm $Al_2O_3$ |
| 150 nm Ag |
| 100 nm $Al_2O_3$ |
| Substrate (Hardware or Film) |

# Materials- Multilayer Insulation (MLI)

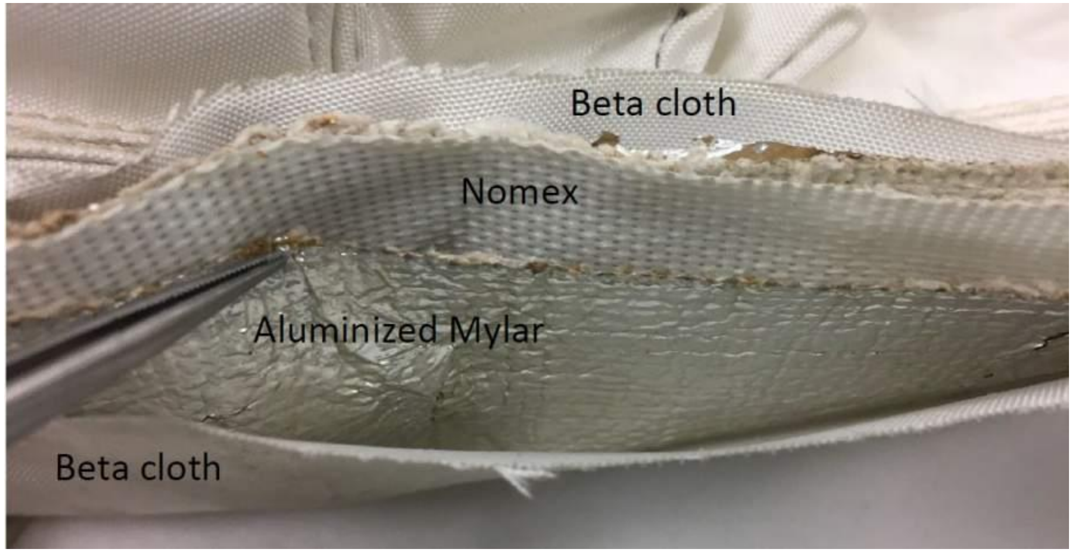
- **MLI uses many layers of low emissivity films as heat transfer barriers**
- **Purpose**
  - Minimizes radiation through adding reflective layers
  - Minimizes conduction through reducing contact between layers
- **Other**
  - Micrometeoroid protection
  - AO protection
  - Plume impingement protection

MLI blanket installation on TIRS instrument January 2012 (NASA)



# Materials- MLI Outer Layers

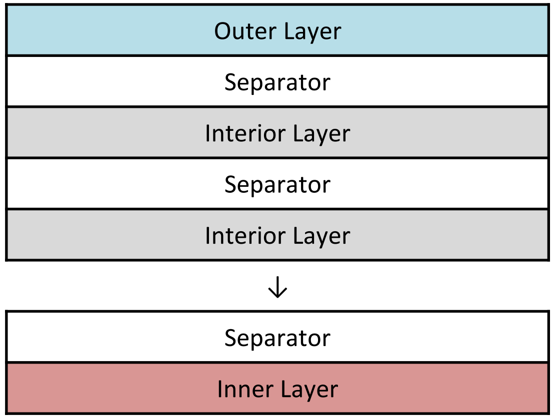
- **Silver Teflon - nominal**
  - Very low a/e ratio
  - Teflon loses mechanical strength over time and should be backed with Kapton or beta cloth
- **Aluminized Kapton - nominal**
  - Lightweight, relatively delicate, generates particulates
- **Beta cloth**
  - AO resistance, durable, MMOD protection
  - Heavy
  - Substantial degradation- can turn black after several years in GEO
    - AO causes bleaching effect which counteracts darkening from UV and contamination in LEO
- **Germanium Black Kapton (GBK)**
  - Electrically dissipative
  - Minimizes glint
  - Degrades quickly in storage and due to handling
- **Stamet**
  - Similar to GBK, but better ground handling performance
- **Astroquartz**
  - High temperature
  - Durable, offers MMOD protection
  - Heavy
- **ITO can be applied over other surfaces like silver Teflon to improve charge dissipation if needed**



Credit: National Air and Space Museum

# Materials- MLI Other Layers

| Layer | Material | Notes |
|---|---|---|
| **Interior (multiple layers)** | Aluminized, Silvered or Goldized<br>• Kapton<br>• Mylar<br>• Polyester<br>• Teflon<br>• Kevlar | Goldized is more expensive but lower emissivity<br>Mylar is most common but should not be used over 250°C, it is also flammable<br>Kevlar for MMOD protection<br>Teflon when very low a/e ratio needed |
| **Separator** | Dacron, Nomex, Nylon, Silk, Tissueglass, Dexiglass, Astroquartz | Astroquartz is best used for high temperatures |
| **Inner** | Kapton reinforced with aramid (Nomex or equivalent), laminated Nomex, Kevlar, Kapton, etc, or same as interior layers | Kevlar for MMOD protection |




**Low emissivity coating used most for interior layers is aluminum- doesn't tarnish like silver and is relatively inexpensive and available in a variety of thicknesses and base materials**

# Materials- Structure

- **Most of the surfaces will be covered by radiators or MLI, but not all**
- **On ISS this was usually anodized aluminum, surfaces had to last for 30 yrs without refurbishment**
  - Example: Truss, electronics boxes, handrails
  - Resistant to AO
- **In a location where predictable temperature is critical, could use a material with a static/predictable a/e of 1 and then design around it**
  - Many coatings could provide this property, even though it is not optimized, it would be relatively stable over the lifetime
    - Black coating, like Polyurethane Aeroglaze Z307 from Socomore or Epoxy BR127-NC ESD
  - ISS used black surface coating (black anodized) on the pressurized mating adapter (PMA) to provide predictable temperature which was important for docking

# Materials- Structure

## Bare Aluminum

- Tends to get hot in sun exposure and would likely need some sort of corrosion protection

## Anodized Al

- a/e<1, could meet touch temp requirements
- Anodized Al is not electrically dissipative, but could add ITO to surface
- Not generally recommended for open large areas
- Optical properties vary widely due to processing, but can be customized for application
- Generally aluminum oxide coating does not outgass, but colored anodize could depending on processing

## Alodine/Iridite conversion coating

- Provides corrosion protection
- More conductive than Anodize
- Not scratch resistant

## Polyurethanes and silicone coatings (paints)

- Would change color and increase absorptivity over lifetime
- a/e would probably not increase over 0.75 at EOL
- Could use electrically dissipative coating

## Primers

- Provides some protection, makes other coatings adhere better
- Could be electrically dissipative

## Composite structures

- Can fly without any coating on them (depending on thermal requirements)
- Some coatings do not adhere well to composites, especially with temperature cycling

# Materials- EVA path

- **Including EVA in the design adds many requirements to protect the safety of the astronauts and to ensure the spacecraft performance is not reduced by crew interaction**
- **EVA Path Materials**
  - Strong concern with OSRs taking a kick load and becoming sharp edges if damaged
  - White paint- can sometimes flake due to handling, even a brush by an astronaut could cause damage to surface and release of particles which can contaminate other surfaces or impede mechanisms
  - Moderate concern with Silver Teflon- ITO could possibly be brushed off by crewmember
  - Anodized Aluminum with good, well controlled properties and coated with ITO could be a good option for EVA paths in NRHO
  - Handrails on EVA translation path are usually Gold Anodized for visibility
  - MLI can tear due to crew interaction- consider using more durable materials such as beta cloth or astroquartz

Gold anodized aluminum handrails as seen in spacewalk on January 2020 (NASA)

# EOL Properties

# Estimating EOL Properties

- **Start with BOL absorptivity and emissivity**
  - Sometimes this already includes expected degradation that may occur pre-flight, but it may not
- **Measurement and thickness uncertainties**
- **Determine degradation due to solar wind over lifetime**
  - Testing conditions: Solar wind fluence at that distance + magnetotail fluence
- **Determine degradation due to UV over lifetime**
  - Testing conditions: Should not change from LEO/GEO, measured in-vacuo
- **Determine degradation due to potential contamination**
  - Estimate contamination environment
    - Dependent on design (line of sight of outgassing materials, thrusters, could be worse if in view of sun)
  - Testing conditions: evaluate based on requirements
- **Include damage from transit between launch to NRHO (could have damage from atomic oxygen fluence, etc)**
- **Look for potential synergistic effects**
- **Add up all uncertainties and degradations to the BOL property**

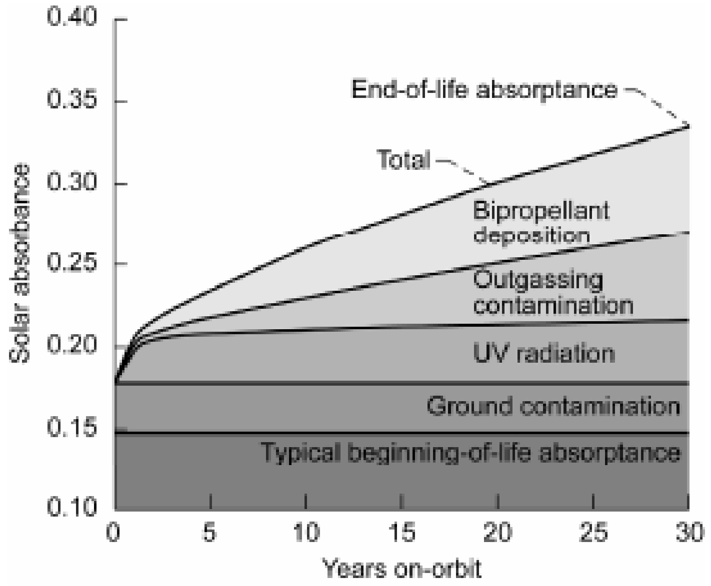



Figure 3.—Calculated change in the solar absorptance of Z-93P on International Space Station, with contributions separately identified.

(Jaworske et al., 2008)

# Coating Name (taken exactly from PROJECT supplied documents)
## Further info regarding coating (not taken from PROJECT supplied documents)

SURFACE LOCATION:
*(Internal or External or Both)*

Location of coating on spacecraft or instrument (taken from PROJECT supplied documents)

**NASA/TP-2005-212792 COATINGS HANDBOOK:**
- **Solar Absorptance:**
- **Normal Emittance:**

Measurements found in the Coatings Handbook for the listed coating or close substitute (listed as such)

| | α BOL | $\varepsilon_H$ BOL | 15 year α EOL | 15 year $\varepsilon_H$ EOL |
|---|---|---|---|---|
| From emailed chart | Values taken exactly from PROJECT supplied documents (NOT GSFC Coatings Committee meeting approved) | | | |
| Nominal Measured Values from TCR database | Values gathered from a thermal coatings reports (TCR) database search for the coating or close substitute (listed as such) | | | |
| Measurement Uncertainty | Uncertainty from instruments used to take thermal property measurements | | | |
| Environmental | Degradation from various environmental elements, usually explained further in the comments section | | | |
| Contamination | Degradation from contamination environment | | | |
| **Final approved GSFC Coatings Committee values** | | | | |

COMMENTS:

Cold case values

Hot case values

Values listed could be a range from low to high if coating is variable. Usually normal emittance measurements are supplied here (listed as such)

# Z93C55
## Conductive White Paint

| SURFACE LOCATION: |
| --- |
| *(External)* |

**NASA/TP-2005-212792 COATINGS HANDBOOK:**
- **Solar Absorptance: 0.14**
- **Normal Emittance:  0.94**

| | | | 15 year | |
| --- | --- | --- | --- | --- |
| | α BOL | $\varepsilon_H$ BOL | α EOL | $\varepsilon_H$ EOL |
| From source/testing | 0.167 | 0.905 | | |
| Measurement Uncertainty | N/A | +0.02 | +0.02 | -0.02 |
| Dehydration in Vacuum | -0.01 | | | |
| Thickness of Coating | | +0.01 | +0.01 | |
| UV/ Solar Wind | | | +0.06 | |
| Outgassing | | | +0.1 | |
| Venting | | | +0.01 | |
| EVAs | | | +0.01 | |
| Lunar Dust | | | +0.04 | |
| | **0.157** | **0.935** | **0.417** | **0.885** |

**COMMENTS:**
**Sometimes UV is measured at the same time as solar wind, sometimes it is separate**

*Warning: These are estimates based off of a literature search and should not be used without verification*

# Materials Requirements Summary

## Radiator Coatings

| | Z93* | Silver Teflon** | Z93C55 | Aptek 2711 | OSR** | CCAg** |
|---|---|---|---|---|---|---|
| BOL Absorptivity | 0.14 | 0.10 | 0.17 | 0.16 | 0.10 | 0.07 |
| BOL Emissivity | 0.92 | 0.79 | 0.91 | 0.92 | 0.80 | 0.6-0.7 |
| Specularity | ? | ? | ? | ? | Y | Y |
| Electrically Dissipative | N | N | Y | Y | N | N |
| Degradation Sensitivity | UV, Solar Wind, Contamination | UV, Solar Wind, Thermal Cycling, Contamination, Handling, AO | UV, Solar Wind, Contamination | UV, Solar Wind, Contamination | Contamination | Contamination |
| Use on EVA Path | N | Y | N | N | Y | Y |
| Flight Heritage | ISS<br>OSO-III<br>Mariner IV<br>Lunar Orbiter V | ISS<br>Hubble<br>SCATHA<br>Shuttle | SpaceX Dragon<br>GOES | MSL | Magellan<br>Messenger | DSCOVR<br>ISS- MISSE |

*AZ-93 is a distinct formulation made by AZ Technology
**Can be made conductive with ITO top thin film

# Materials Requirements Summary

MLI Outer Layers

| | Beta Cloth | Silver Teflon | Aluminized Kapton | Astroquartz | GBK | Stamet Black Kapton |
|---|---|---|---|---|---|---|
| BOL Absorptivity | 0.45 | 0.08 | 0.49-0.54 | 0.19-0.25 | 0.60 | 0.56 |
| BOL Emissivity | 0.8 | 0.76 | 0.71-0.81 | 0.6-0.86 | 0.82 | 0.83 |
| Temperature Stability | - | - | - | Stable at high temps | - | - |
| Specularity | ? | Y | Y | ? | N | N |
| Electrically Dissipative | N | N* | N* | N | Y | Y |
| Degradation Sensitivity | UV, Solar Wind, Contamination | UV, Solar Wind, Thermal Cycling, Contamination | Handling, UV, Solar Wind, Contamination | UV, Solar Wind, Contamination, dependent on fabric backing | Handling | Handling |
| Use on EVA Path | Y | N | N | Y | N | N |
| Flight Heritage | ISS | ISS<br>Hubble<br>Shuttle | SCATHA | Dawn<br>SCATHA | ISS- MISSE 7<br>SCATHA | ISS- MISSE 7<br>JUICE (not yet flown) |

*Can be made conductive with ITO or other coating on top

# Other Impacts to Material Choice

- **Touch temperatures**
- **Temperature stability**
- **Durability**
  - Kick loads
  - Micrometeoroids
  - Adhesion
- **Transit environments**
- **Ground exposure (corrosion, moisture, salt spray)**
- **Hazardous materials**
- **Particulate generation**
- **Color (for handrails or labeling)**

# Summary

- The NRHO environment is similar, but different from LEO and GEO environments and materials will not degrade the same ways
- Materials and coatings will have to withstand NRHO and will experience optical property degradation from UV, Solar Wind, Vacuum, Micrometeoroids, and possibly Lunar Dust, Plume Impingement, Venting, and Crew Interaction
- Most severe degradation in NRHO will be spacecraft dependent, but UV, molecular and particulate contamination, and solar wind are expected to be significant
- Materials and coatings should be selected by thermal optical property (BOL & EOL) and how well they meet all requirements
- Design of spacecraft should limit contamination by orienting sensitive surfaces away from higher outgassing sources, plumes, and vents
- EOL properties for NRHO can be estimated on the ground by a step-by-step process and adding margin

# Forward Work

- **Research NRHO-appropriate materials for use on cameras, star-trackers, and windows**
- **Gateway PTCS is estimating EOL properties promising materials**
  – See example shown for Z93C55
- **Testing of materials and coatings is needed to better estimate EOL properties for NRHO**
  – Ground testing- Solar wind, lunar dust, UV, crew interaction, thermal cycling, adhesion, specularity
  – In-situ testing- Lunar dust, contamination, solar wind, UV, etc

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- **Ray LeVesque (GSFC)**
- **Miria Finckenor (MSFC)**
- **John Alred (JSC)**
- **Boeing Space Environments**
- **David Gilmore (Aerospace Corporation)**

# Resources

- **SLS-SPEC-159**
- **Meteoroid Engineering Model (MEM) 3.0**
- **outgassing.nasa.gov**
- **MAPTIS**
- **https://wiki.jsc.nasa.gov/fod/index.php/Lunar_Dust_Testing**
- **Solar Wind/UV Testing**
  - Goddard Space Flight Center (Contact: Mark Hasegawa)
  - Marshall Space Flight Center (Contact: Miria Finckenor)
- **Lunar Dust Testing**
  - Johnson Space Center (Contact: Katy Hurlbert, Don Barker)

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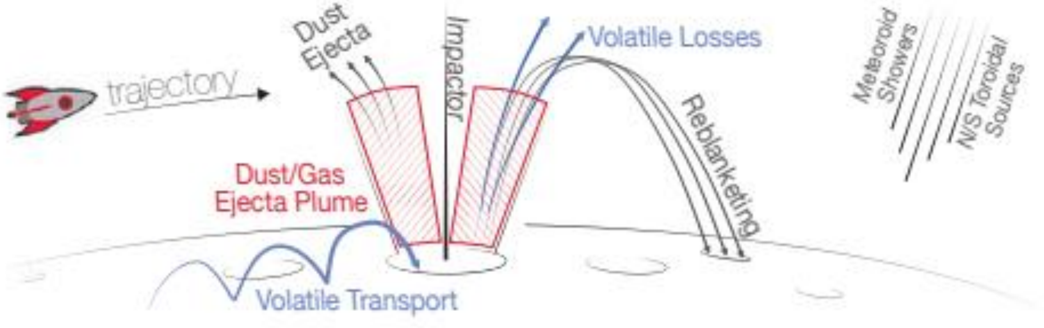
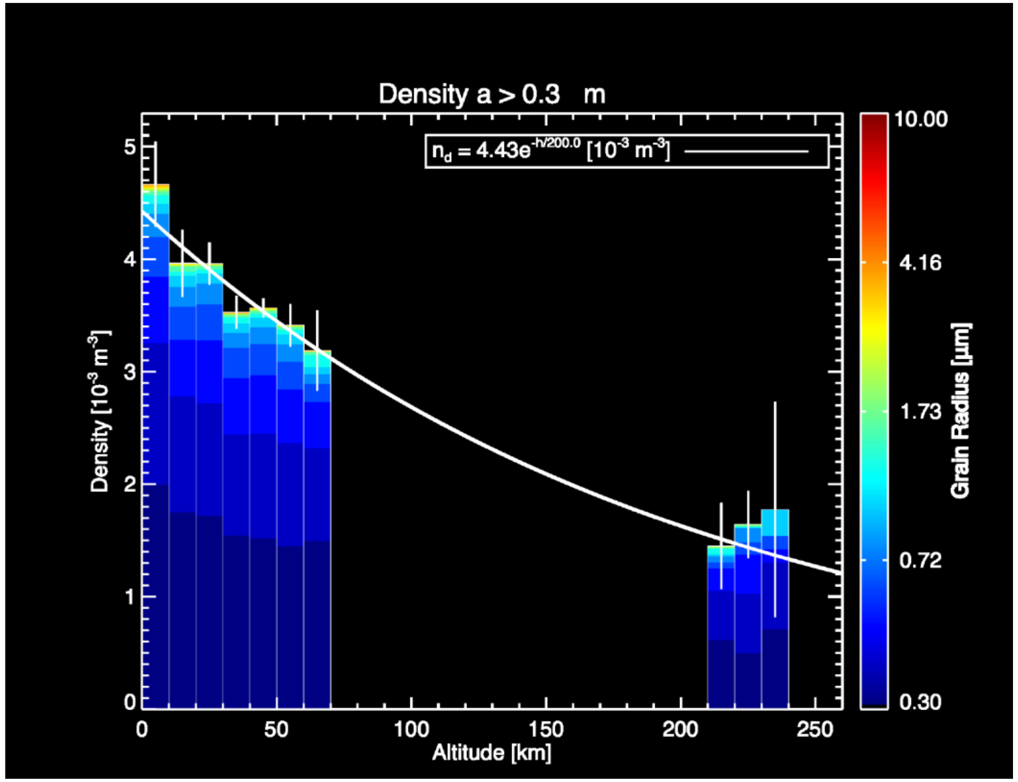
# Backups

# Lunar Dust- Natural Environment

- **Natural lunar dust in orbit concentration decreases exponentially the higher the altitude (LADEE)**
  - Average lunar dust density is predicted to be ~ 0.00245 [$10^{-3}$ /$m^3$] at 1500 km altitude
  - Might be a higher concentration of dust at the poles
    - (Horanyi et al., 2020)




(Horanyi et al., 2020)

# Lunar Dust Contamination

- **How much dust contamination will occur in NRHO?**
  - Natural dust in orbit + dust blown up from human activities + dust carried up with HLS
- **What do we need to know to test effects of lunar dust on optical properties?**
  - Adhesion (electrostatic, vibration)
  - Reasonable amount of dust coverage
  - Reasonable dust simulant (particle size, size distribution, optical property of dust, etc.)
- **Future work**
  - Similar studies were done for effect of Martian dust coverage on effective emissivity
    - Katy Hurlbert (JSC) has a proposal to do similar testing for lunar dust
  - Adhesion testing of dust on different materials has been proposed by Don Barker (JSC)

# Lunar Dust- Mitigation Technologies

- **Surface modification**
  - Ion beam surface treating to reduce surface energy (van der Waals forces) or electrostatic force (dependent on the material being treated)
  - Textured surface modification which decreases contact area between surface and dust particles, ultimately decreasing van der Waals forces
- **Lotus Dust Mitigation Coating**
  - Lightweight nano-texture dust mitigation coating that sheds dust particles utilizing anti-contamination and self-cleaning properties
- **Space Plasma Alleviation of Regolith Concentrations in Lunar Environment (SPARCLE)**
  - Low power, electrostatically based “gun-shaped probe”
  - Controls the charge transported to the dust covered surface to induce dust flow away from the surface towards another
- **Electrodynamic Dust Shield (EDS)**
  - Uses traveling electric fields to transport electrostatically charged dust particles along surfaces.
  - This field is generated by applying a series of varying high voltage signals on a set of electrodes embedded in a high dielectric strength material
    - Ex. 1: ITO on glass created for use on solar panels
    - Ex. 2: Copper on polyimide film painted on white paint
- **Electrostatic Lunar Dust Collector (ELDC)**
  - Low voltage electrostatic collector for collecting naturally charged lunar dust before deposition
  - Requires thousands of times smaller electric field strengths than the EDS
    - ELDC plates can be created out of ITO or IZO – both transparent and highly conductive

# Specularity

- **Specularity is of concerns for thermal engineers for two reasons**
  - Highly specular surfaces can reflect heat onto nearby surfaces
  - Impacts material choice because of glare to optically sensitive cameras, star-trackers, and even astronaut vision during EVAs