Coatings and Surface Treatments for Space Applications

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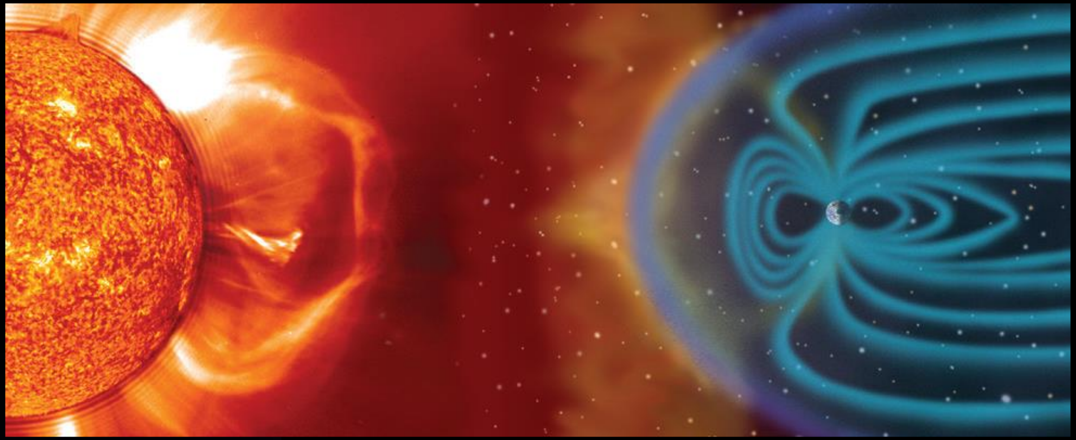
Space Environment

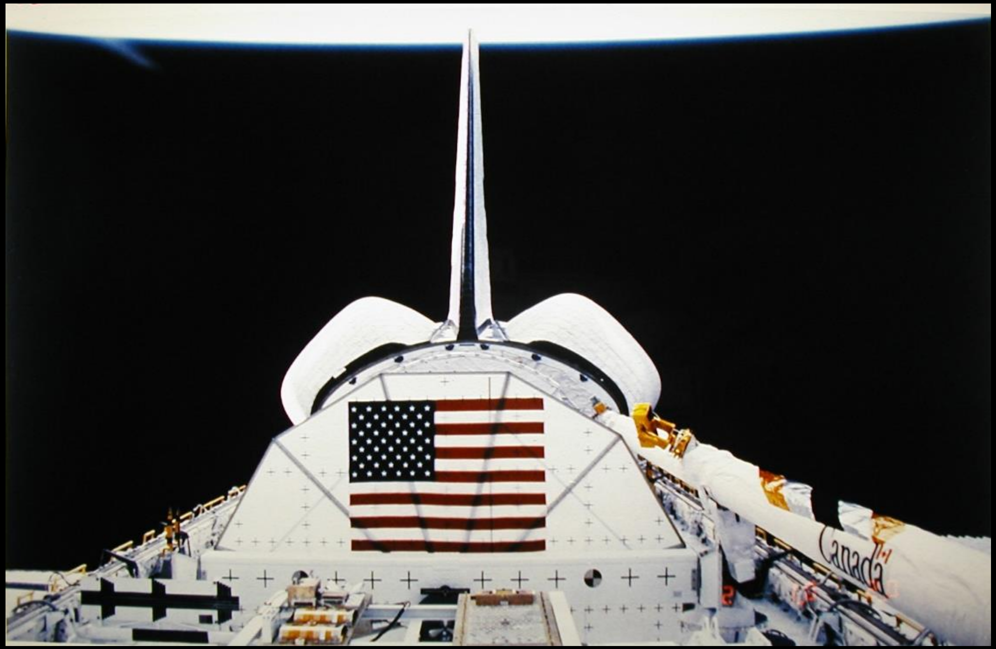
- Solar radiation (ultraviolet (UV), x-rays)
- Charged particle radiation (electrons, protons)
- Cosmic rays (energetic nuclei)
- Temperature extremes & thermal cycling
- Micrometeoroids & orbital debris (space particles)
- Atomic oxygen (AO) (reactive oxygen atoms)
- Planetary dust and wind
- Reactive atmospheres



Art Image of solar flares and solar wind, NASA Image

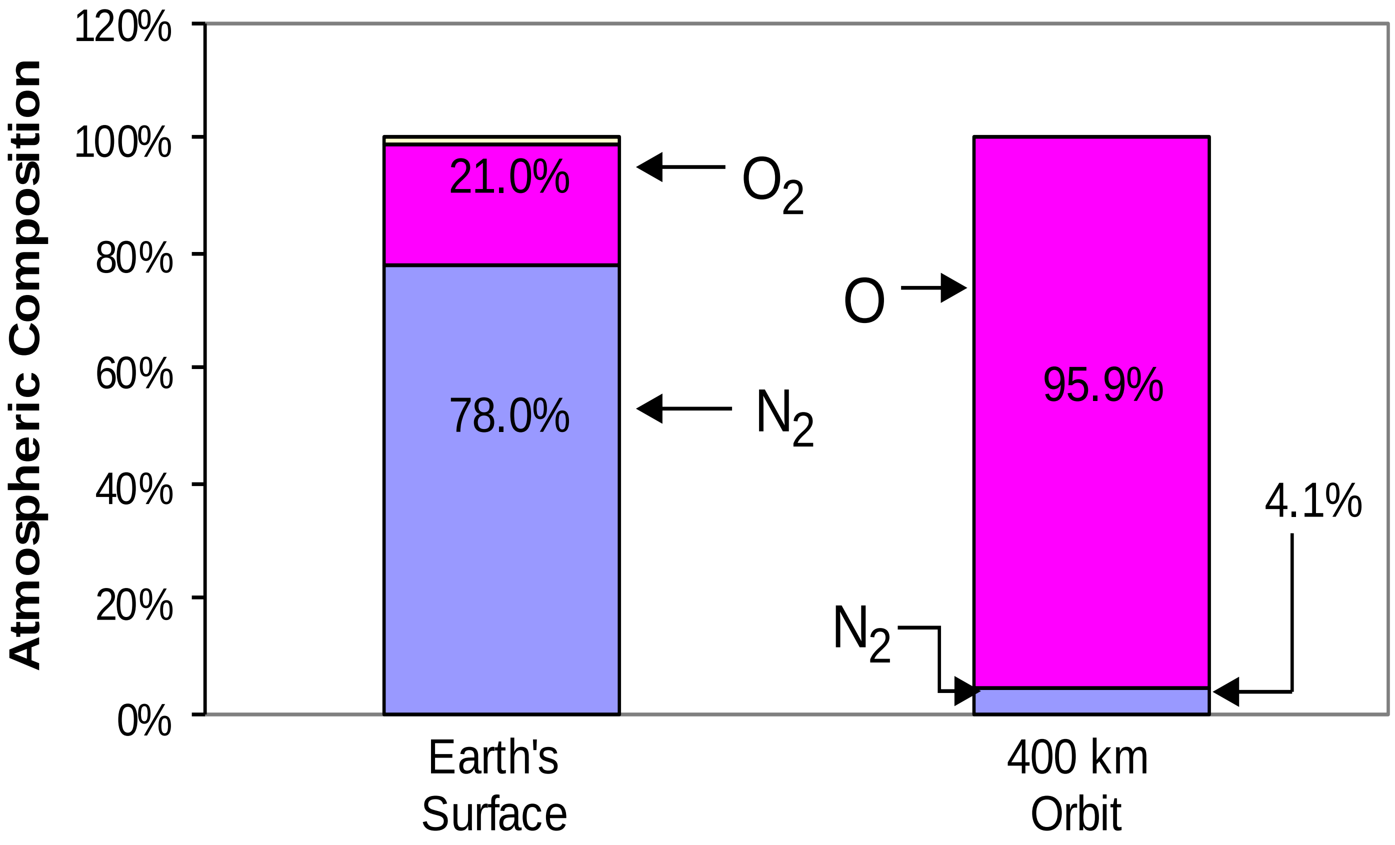
Moon from ISS, NASA Image

Environment Interaction Visible on Space Shuttle Tail Section

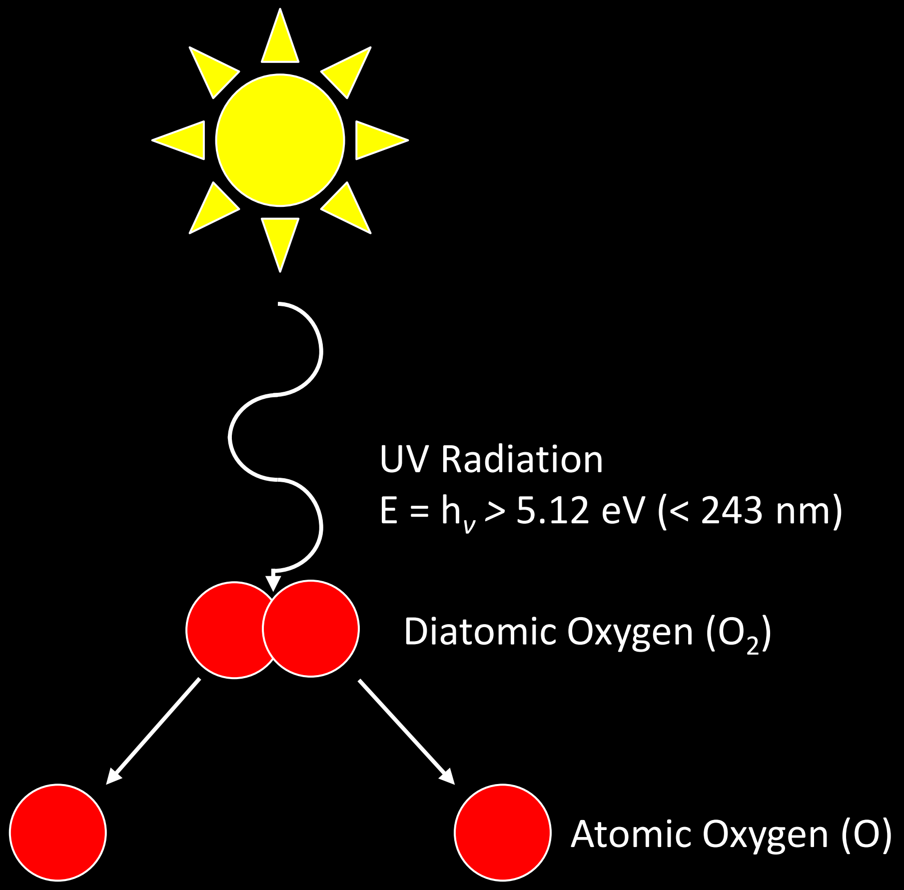


NASA Images of Space Shuttle, standard photo and time lapse photo

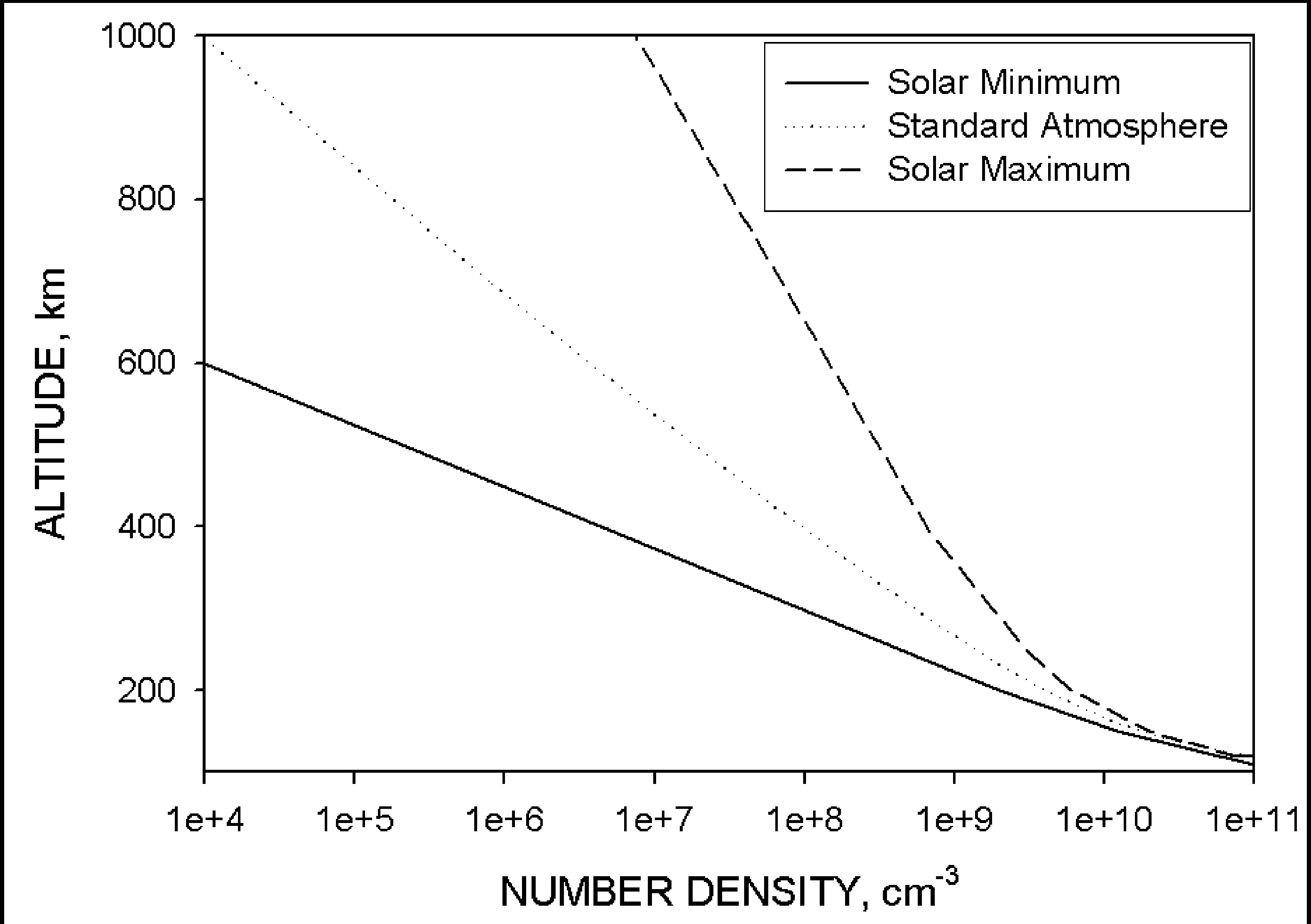
Atmospheric Composition



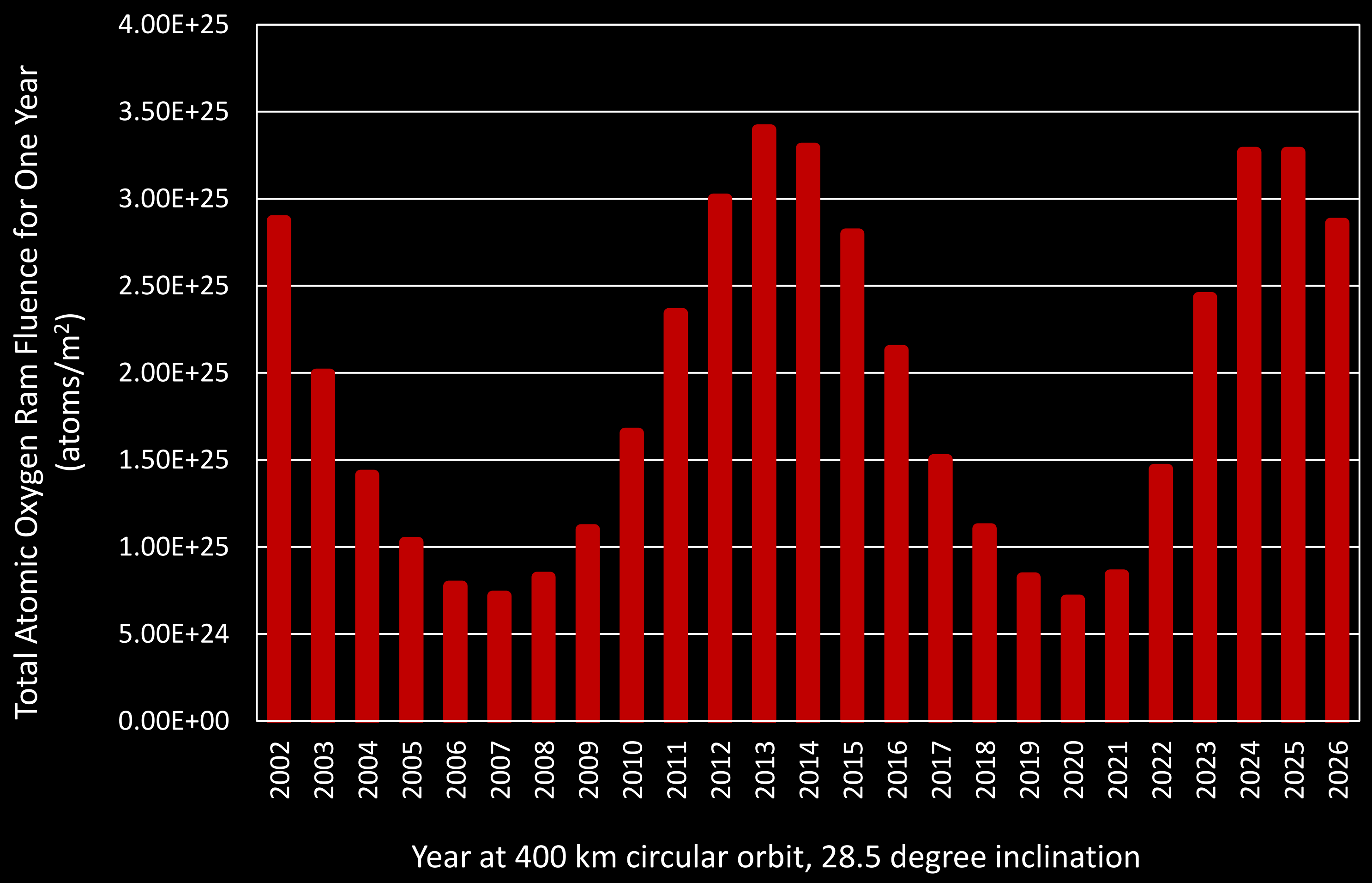
Atomic Oxygen Formation by Photodissociation



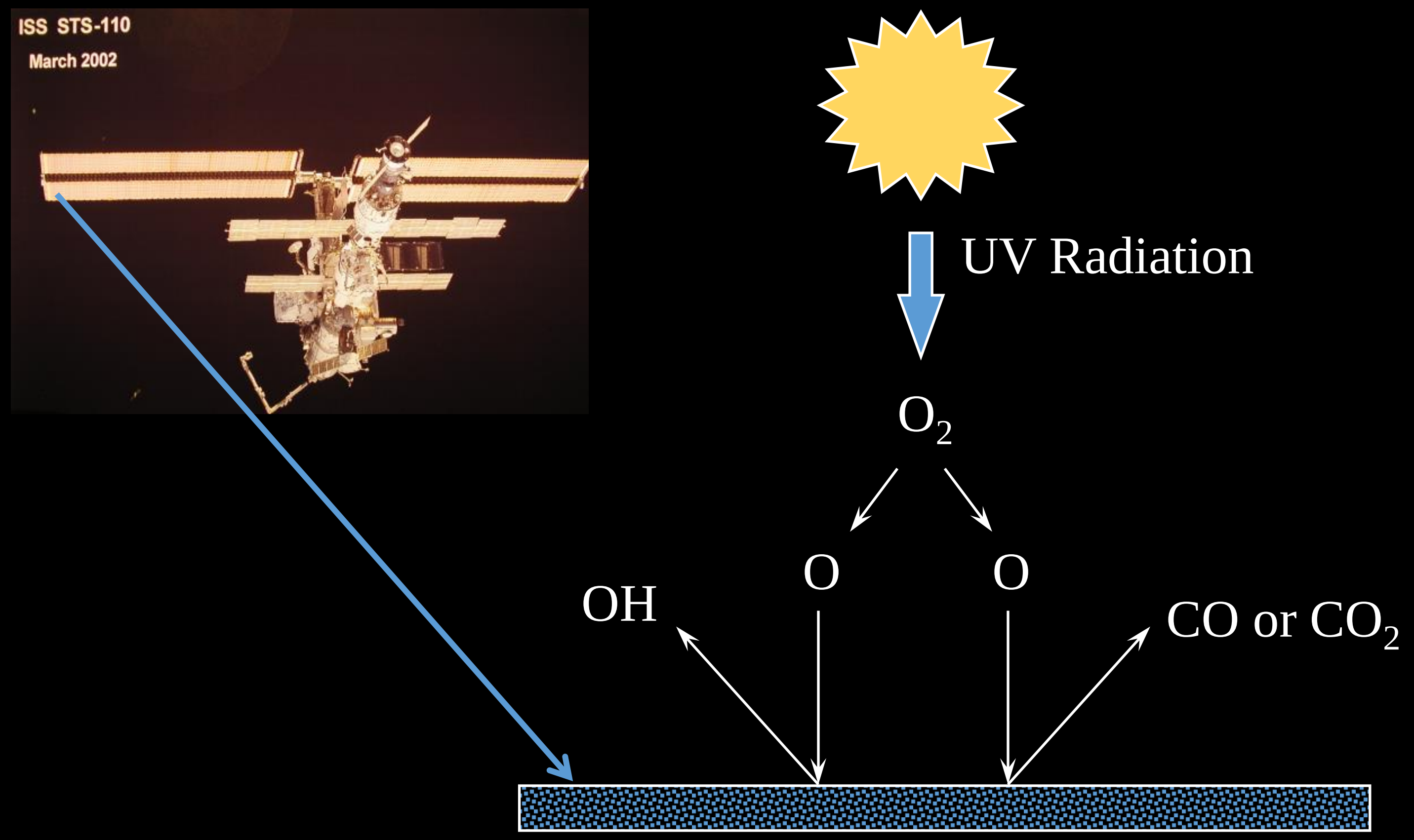
Atomic Oxygen Earth Atmosphere Number Density Dependence Upon Solar Activity

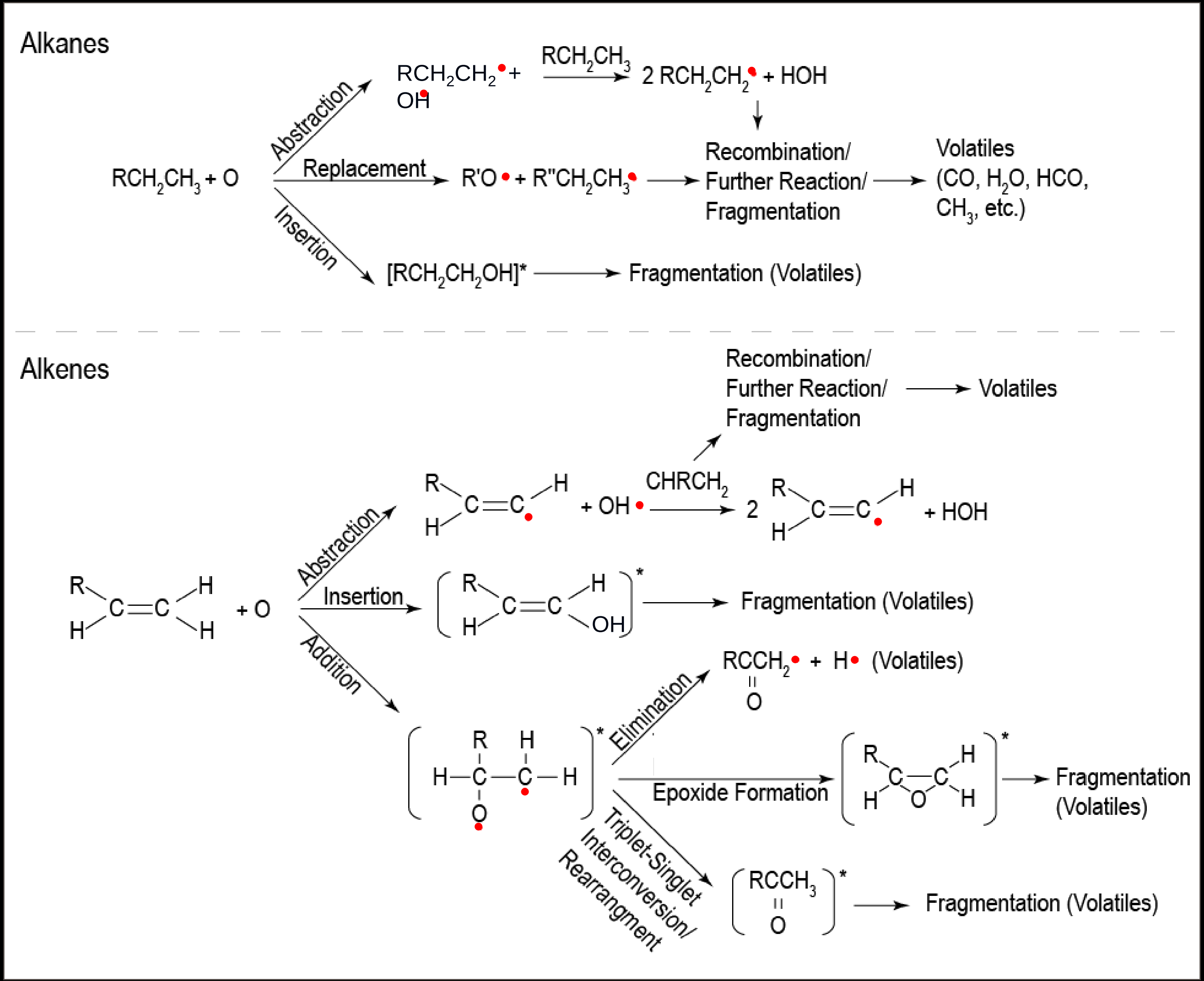


Solar Cycle Caused Variation in Level of Atomic Oxygen in Low Earth Orbit at 400 km



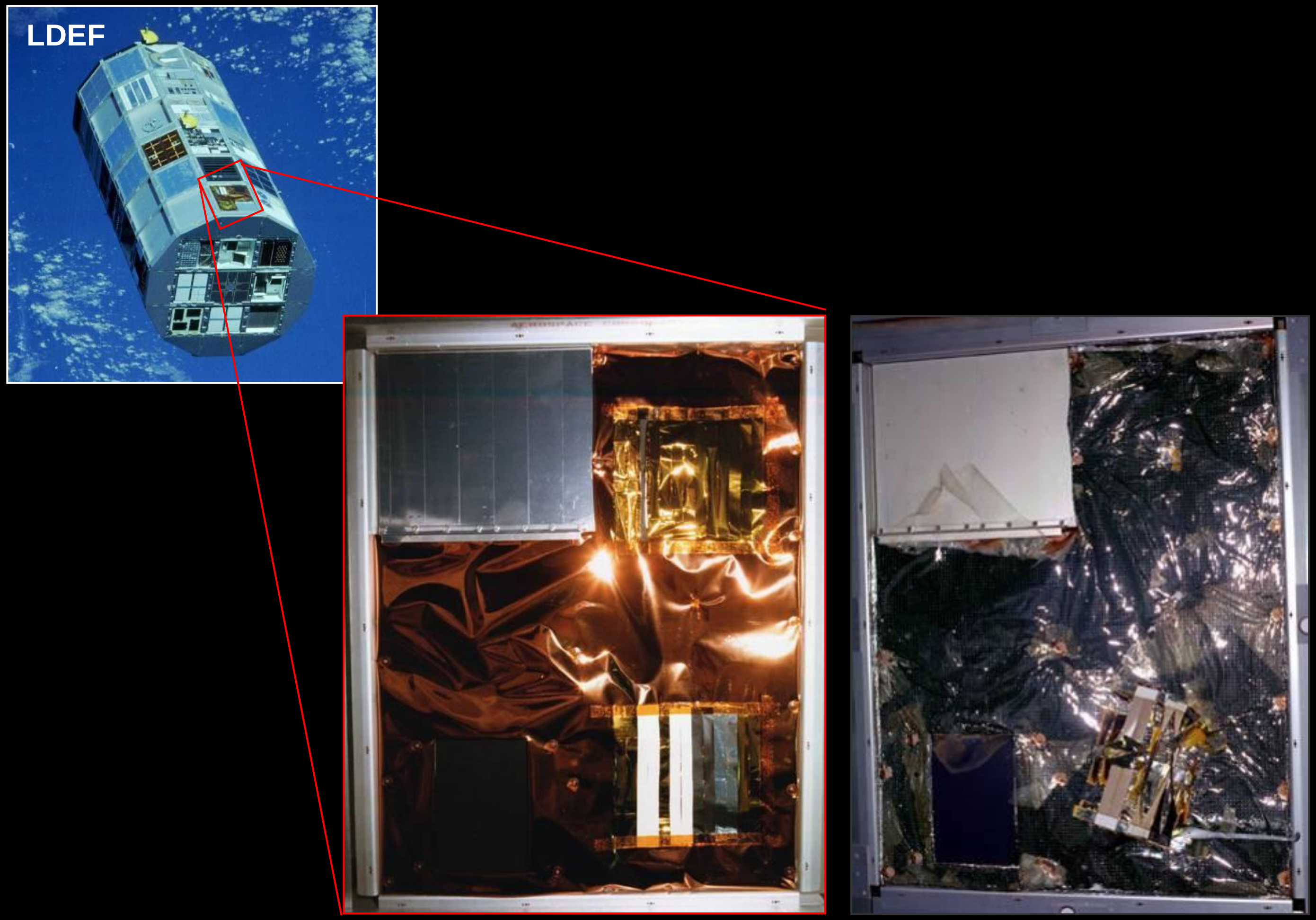
Basic Atomic Oxygen Interaction with Organic Surfaces





de Groh, K. K., Banks, B. A., Miller, S. K. R., and Dever, J. A., Degradation of Spacecraft Materials (Chapter 28) in Handbook of Environmental Degradation of Materials, Myer Kutz (editor), William Andrew Publishing, 2018.

What Can Atomic Oxygen Do to Spacecraft?



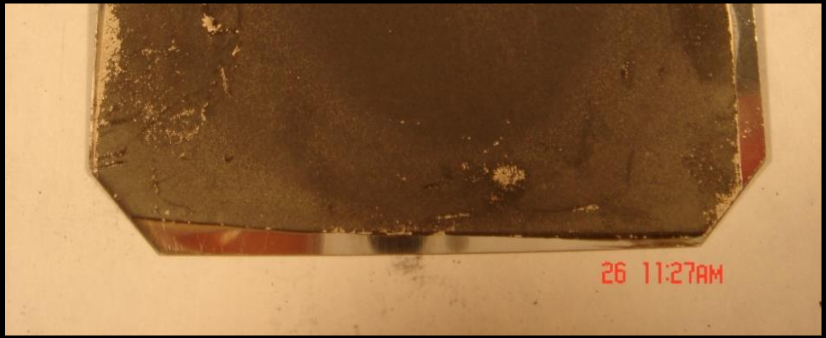
Prior to Flight

After 5.8 years in LEO

Mirrored Silver Back of Solar Cell
Prior to and After Exposure to Atomic Oxygen

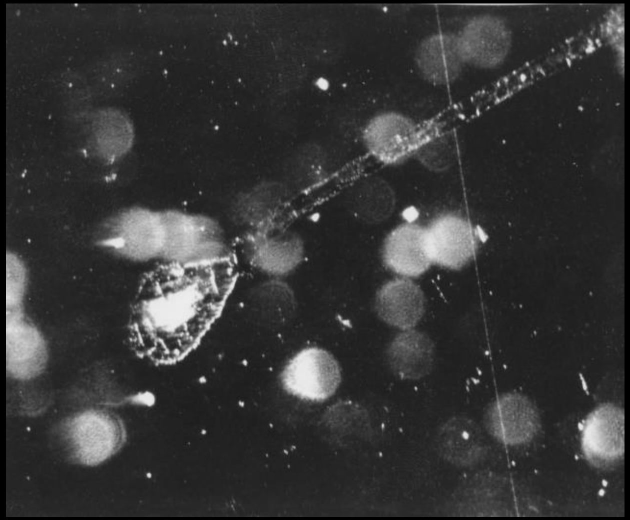
As Received

After Exposure to an AO Effective Fluence of $2x10^{21}$ atoms/cm^2



Oxidative Cracking of Silicone

DC 93-500 Silicone
Exposed to LEO Atomic Oxygen on STS-46
Fluence = 2.3 x 10^{20} atoms/cm^2



Pre-flight

Post-flight

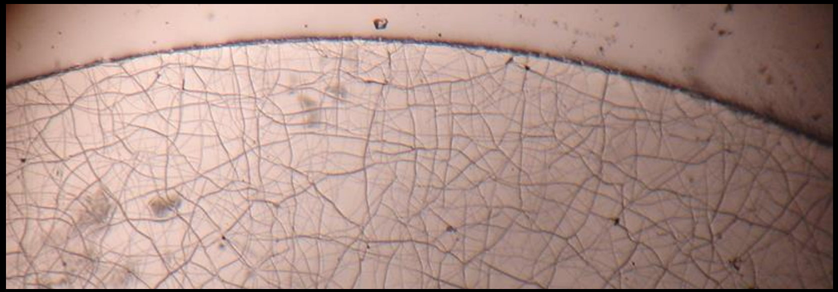
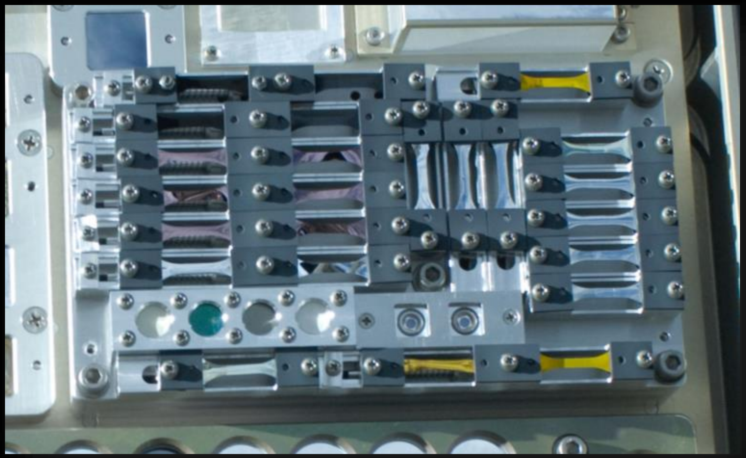


Chart From Kim K. de Groh, NASA GRC

Stress Dependent Atomic Oxygen Erosion of Black Kapton XC

Polymers Exposed Under Stress on Materials International Space Station Experiment (MISSE) 6

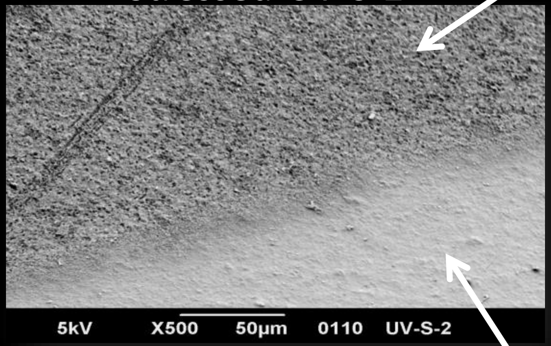


Stressed (left) and Unstressed (right) Black Kapton XC

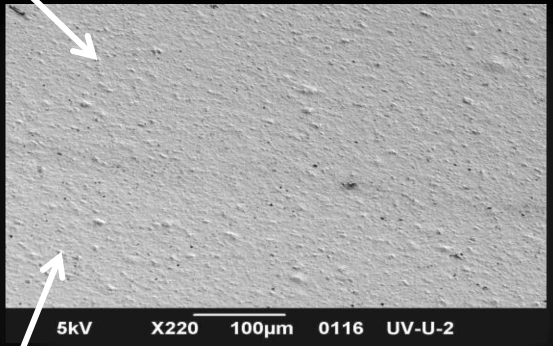
- Stress level: Force/Area = ~4000psi (2.76e7 N/m^2)
- Strain = Stress/Modulus = 4000 psi/480000 psi (3.3e9 N/m^2) = ~0.008
- For Kapton XC this represents ~3 % of the maximum strain and ~24% of the tensile strength

Exposed

Stressed UV-S-2



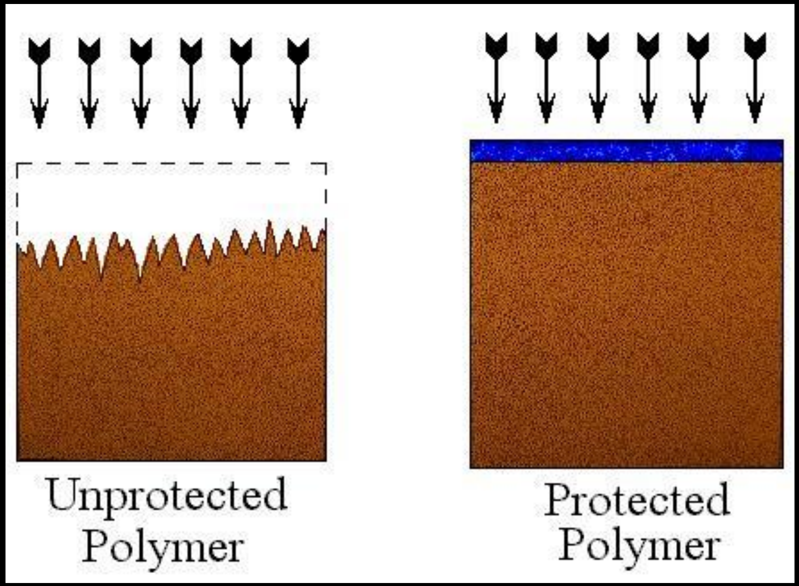
Unstressed UV-U-2



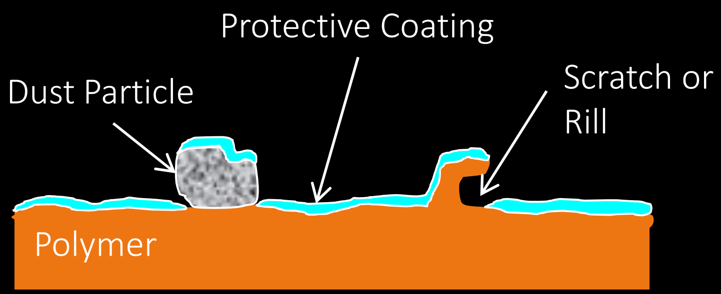
Under Mount

Kapton XC experienced a factor of 4 higher erosion rate under tension

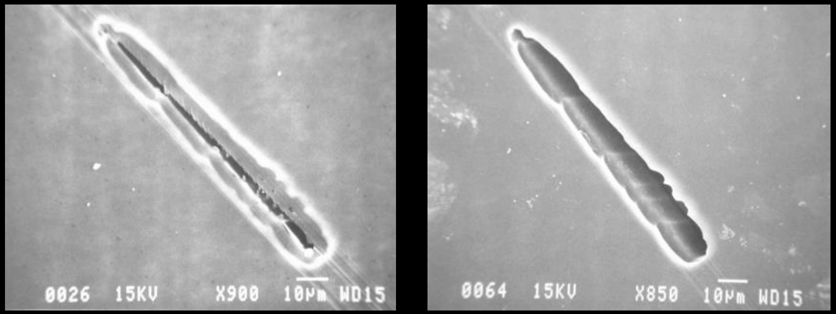
Atomic Oxygen Mitigation Using Protective Coatings



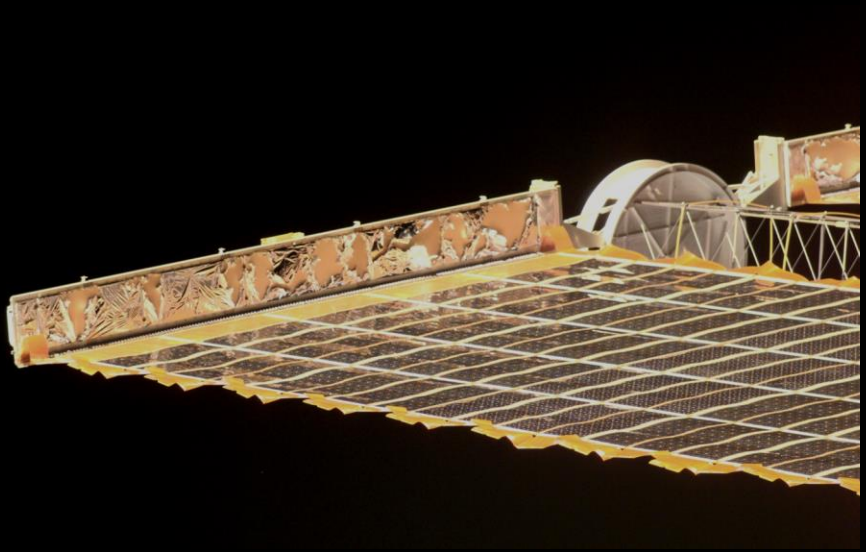
Imperfections in Thin Film Coatings

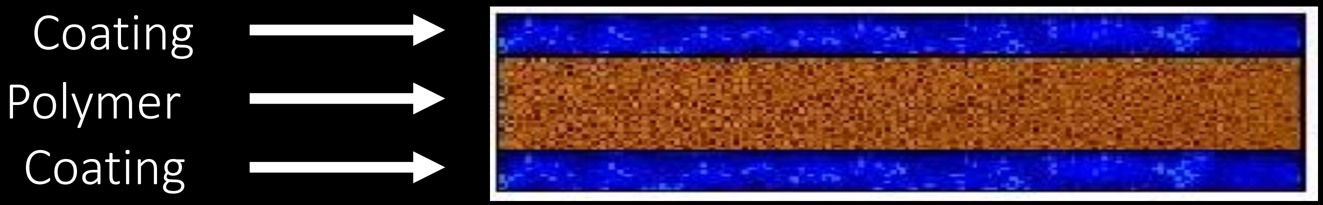


Aluminized Kapton Flown on LDEF



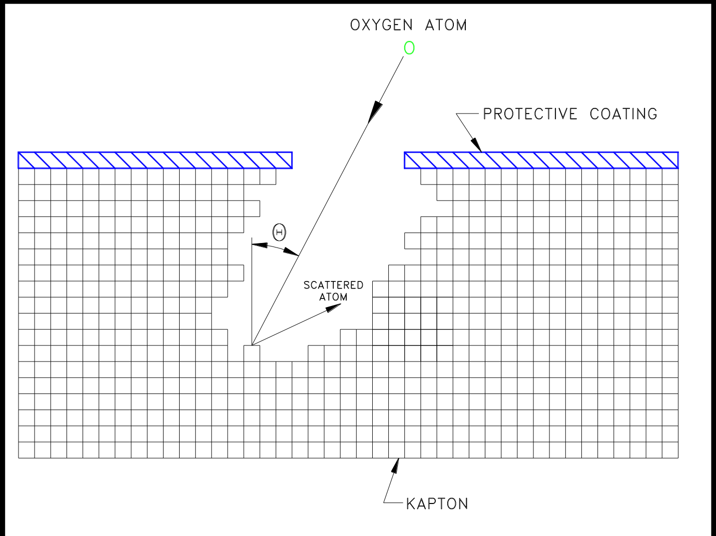
Blanket Box Cover Failure of Aluminized Kapton Observed on ISS

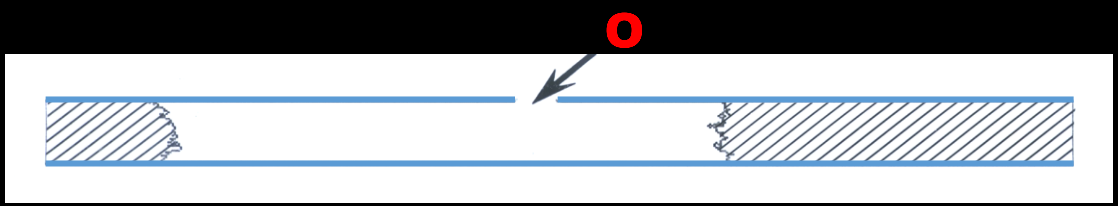




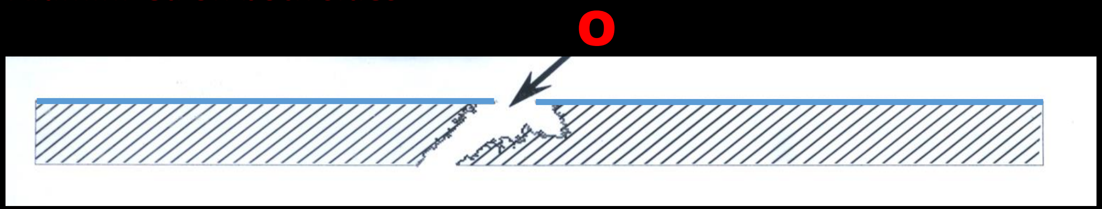
Monte Carlo Computational Model Predictions

- 2-D Computational modeling of atomic oxygen erosion of polymers based on observed in-space results
- Takes into account:
  - Energy dependence of reaction probability
  - Angle of impact dependence on reaction probability
  - Thermalization of scattered oxygen atoms
  - Partial recombination at surfaces
  - Atomic oxygen scattering distribution functions
- Modeling parameters tuned to replicate in-space erosion





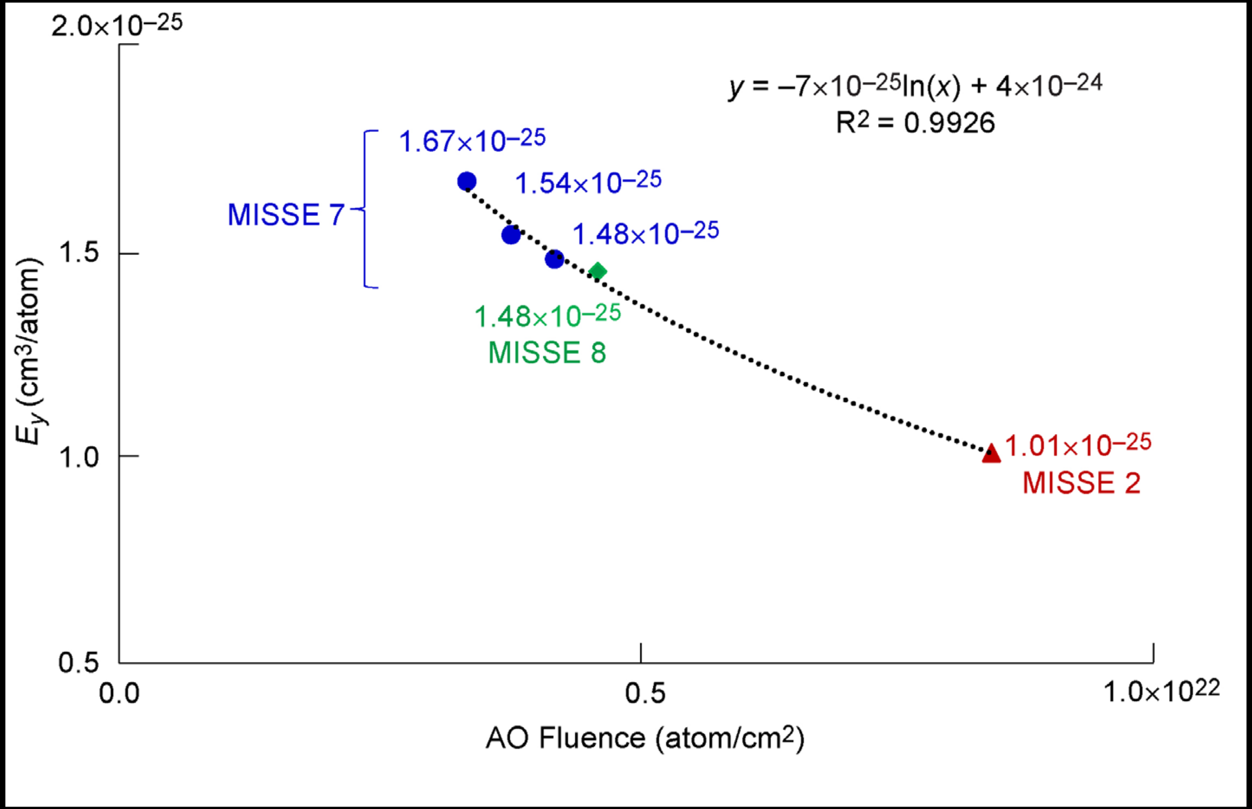
Aluminized on both sides

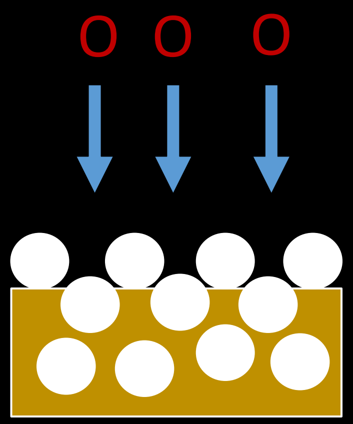


Aluminized on exposed side only

Atomic Oxygen Mitigation Using Fillers

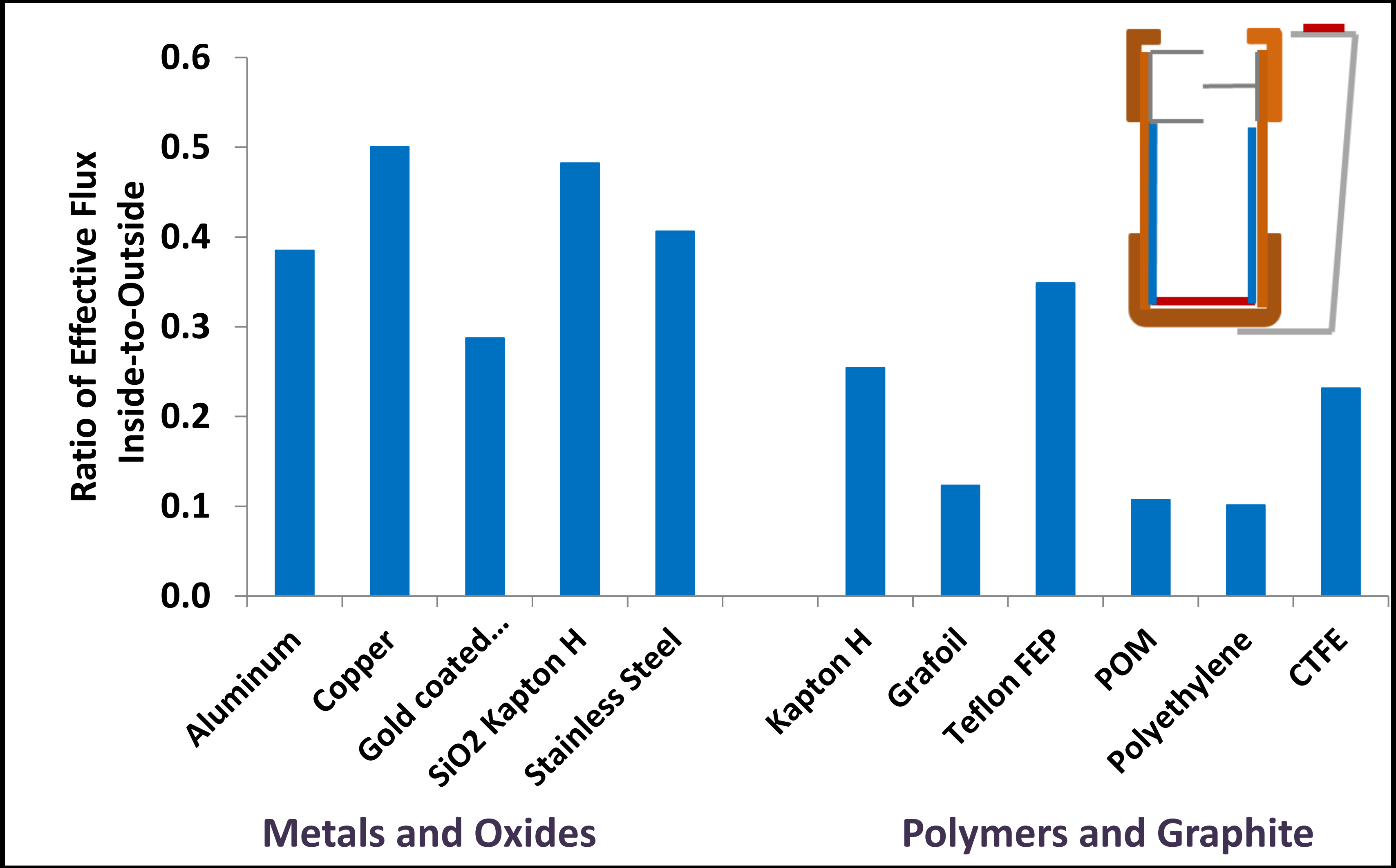
Erosion Yield Versus Atomic Oxygen Fluence for White Tedlar





Kim K. de Groh and Bruce A. Banks, Atomic Oxygen Erosion Data from the MISSE 2-8 Missions, May 2019, NASA TM-2019-219982

Atomic Oxygen Mitigation Using Getters

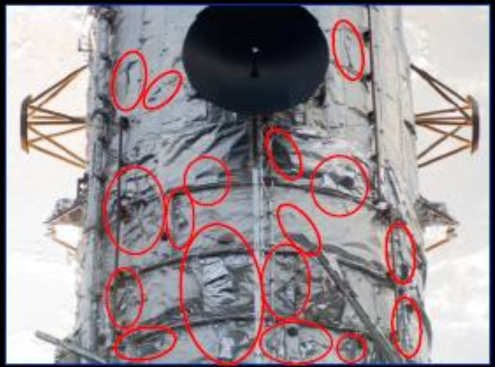


Space Environment Induced Degradation

Hubble Space Telescope (HST)

Radiation induced embrittlement & cracking of HST Teflon multilayer insulation (MLI)

Servicing Mission 2 (SM2)
6.8 years of space exposure

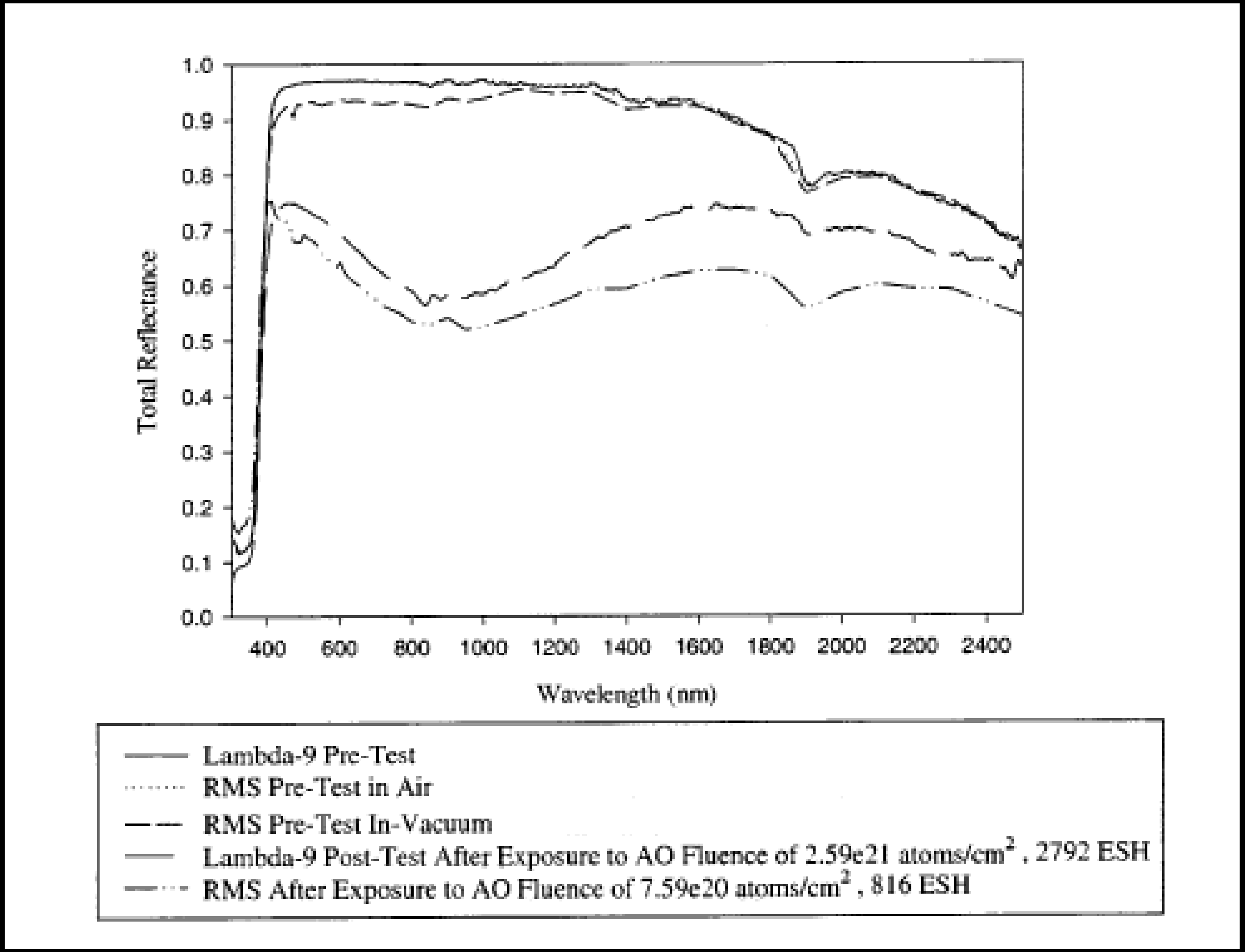


Servicing Mission 4 (SM4)
19 years of space exposure

SM4 replacement of severely degraded Bay 8 MLI
19 years of space exposure

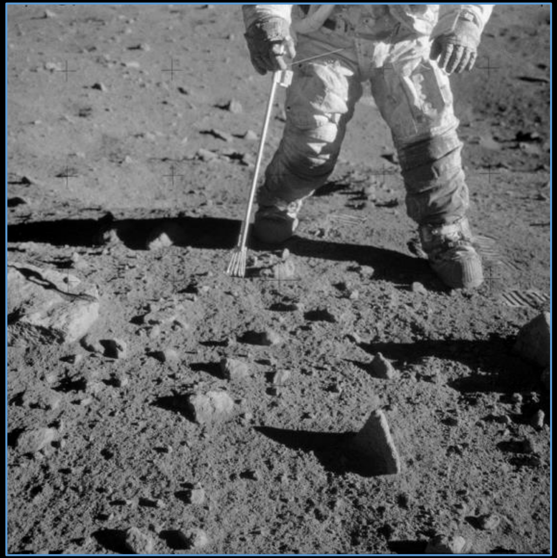
Chart from "Durability of Polymers in the Space Environment" Presentation by Kim de Groh, NASA GRC

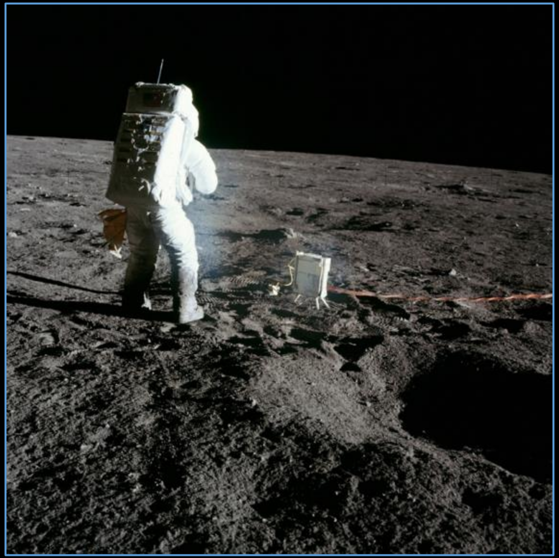
White Silicate Based Thermal Control Paint Reflectance with UV and AO Exposure



Lunar Dust Issues During Apollo

"We must have had more than a hundred hours suited work with the same equipment, and the wear was not as bad on the training suits as it is on these flight suits in just the eight hours we were out" – Pete Conrad –Apollo 12 –from the Apollo 12 Technical Crew Debriefing, December 1, 1969





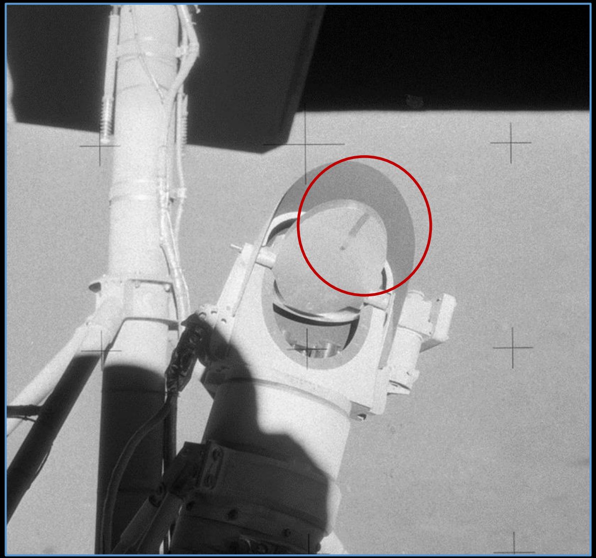


Image on the left is of Pete Conrad's suit on the lunar surface during an Apollo 12 EVA, showing dust accumulation on gloves, lower legs and boots, center image is a photo of Alan Bean taken by Pete Conrad, the blue haze in the center was on multiple images and attributed to dust on the camera lens, image on the right is of the TV mirror on Surveyor III after Pete Conrad wiped the surface with a gloved finger (area in circle). - *Photos courtesy of NASA Apollo 12 Image Library*

Primary Effects of Dust on Extra-Vehicular Activity (EVA) Systems Based on Apollo Mission Logs

- Vision Obscuration
- False Instrument Readings
- Coating and Contamination
- Loss of Traction
- Clogging of Mechanisms
- Abrasion
- Thermal Control Problems
- Seal Failures
- Inhalation and Irritation

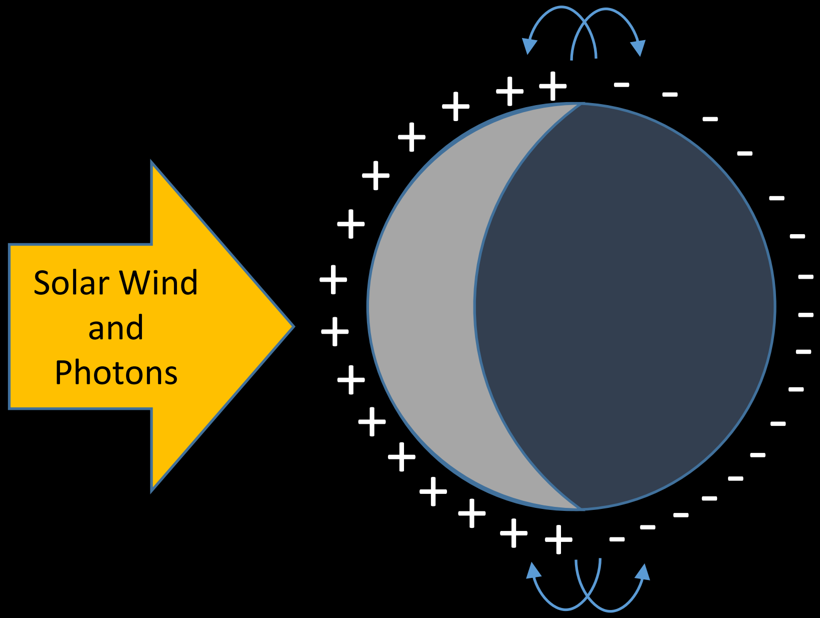
Gaier, J.R. “The Effects of Lunar Dust on EVA Systems During the Apollo Missions”, NASA TM-2005-213610/Rev1, (2005)

Gene Cernan Covered in Lunar Dust
NASA Apollo Image Library

Lunar Dust Adhesion and Wear

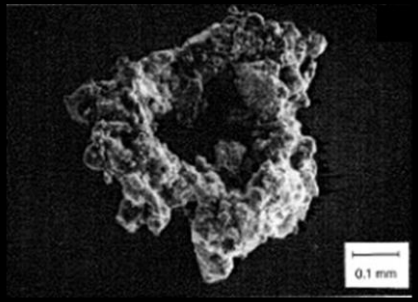
Image from Clementine Spacecraft-NASA

Electrostatic



Triboelectric

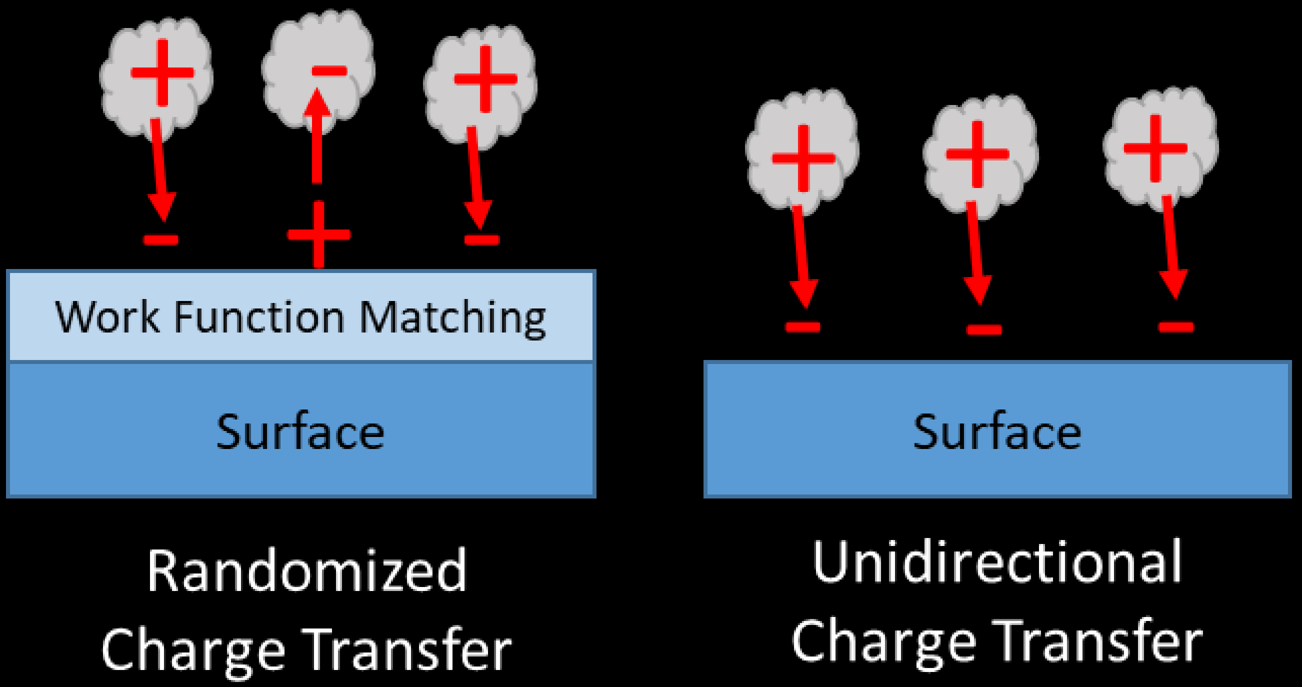
Apollo 12 Image Library-NASA



SEM Image of Lunar Soil Agglutinate
NASA S87-38112

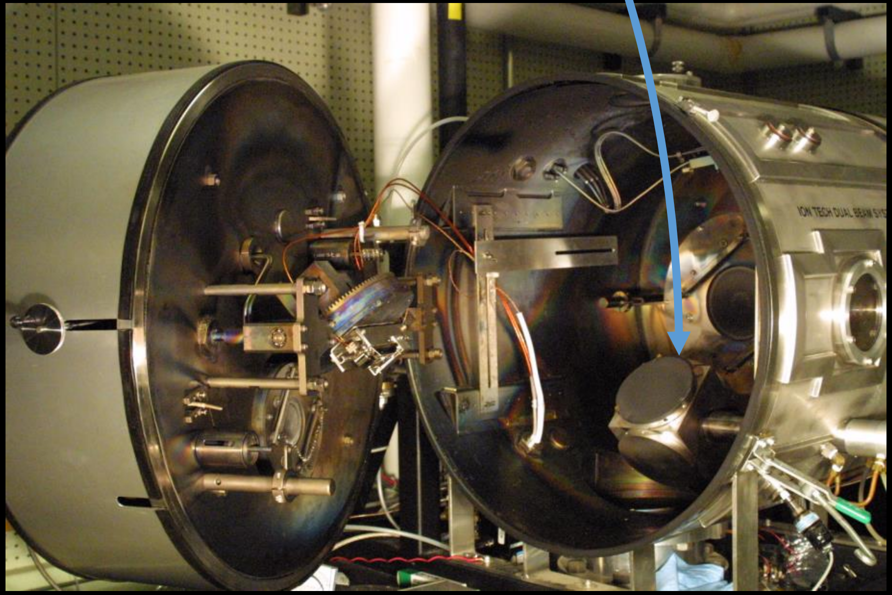
A portion of the leg of Harrison Schmitt's Apollo 17
Pressure Garment Assembly –NASA from Gaier 2009

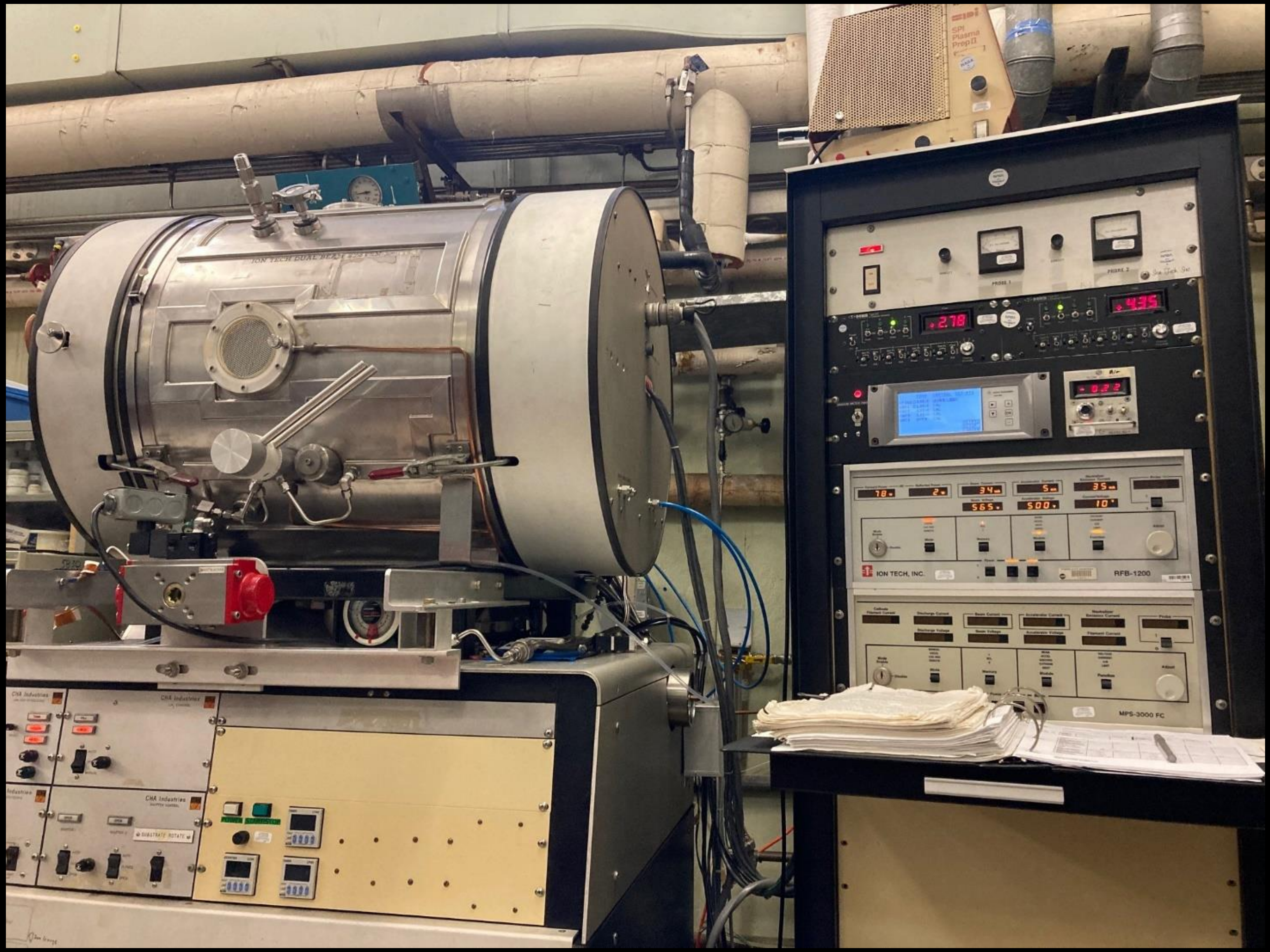
Work Function Matching Coatings for Passive Dust Mitigation



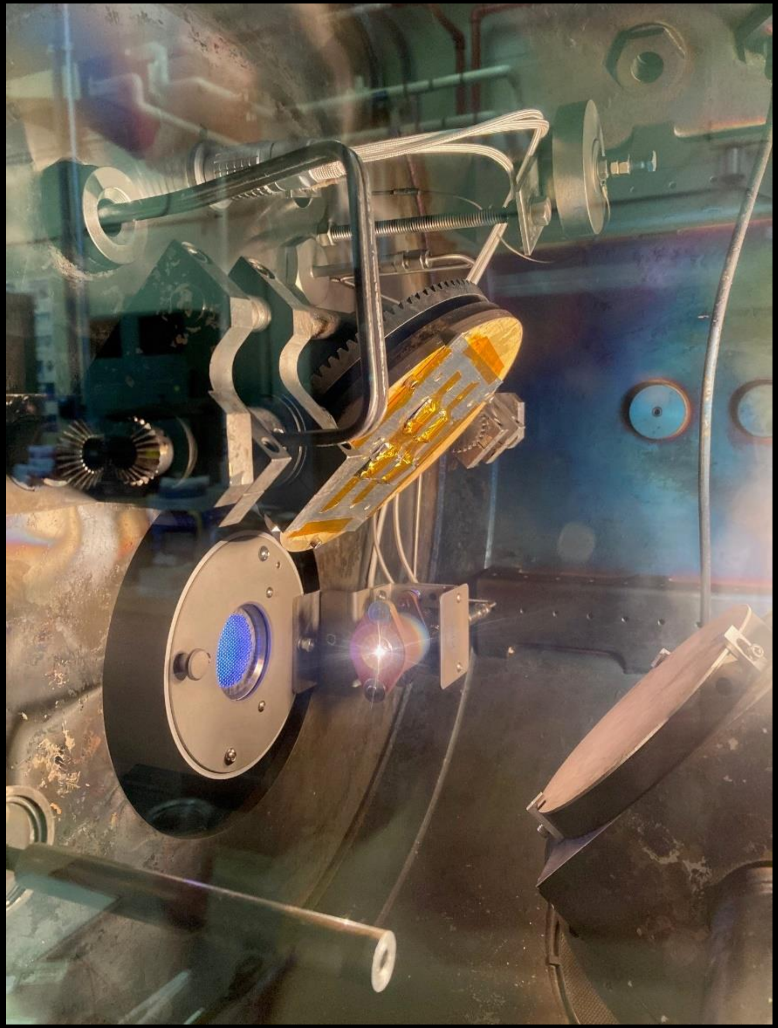
Work Function Matching Coating Preparation

Sputter target made from simulant with chemistry closest to Mare Crisium

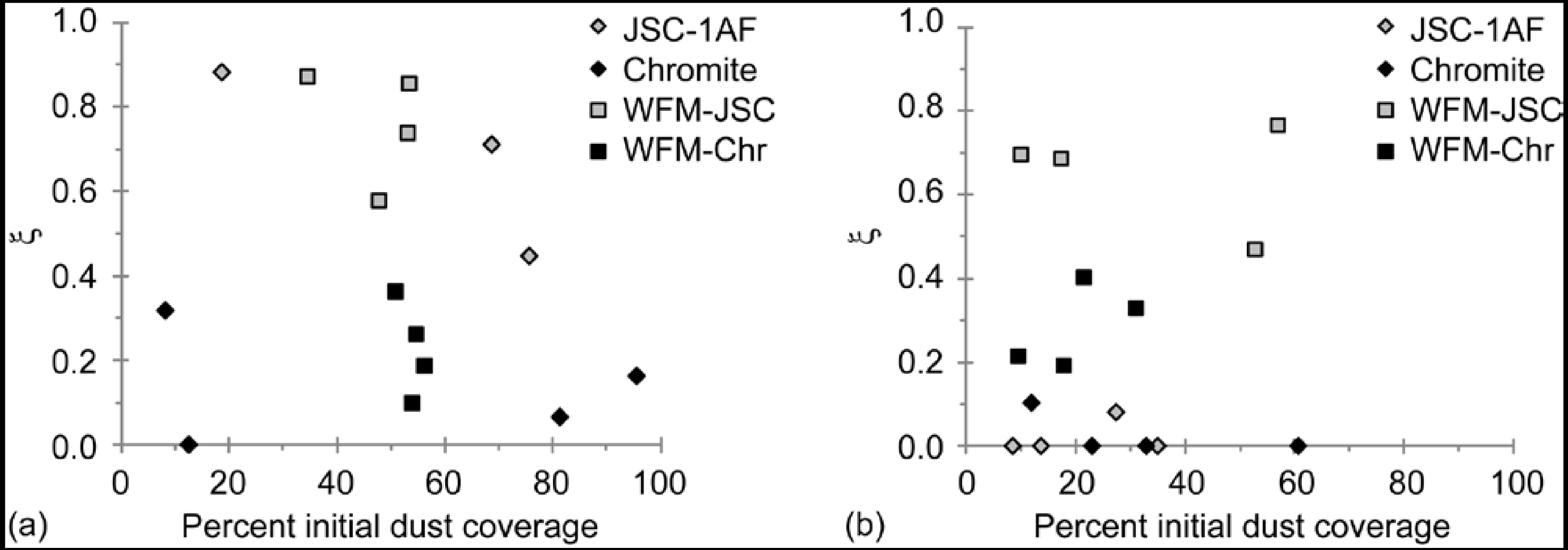




Work Function Matching Coating Preparation



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

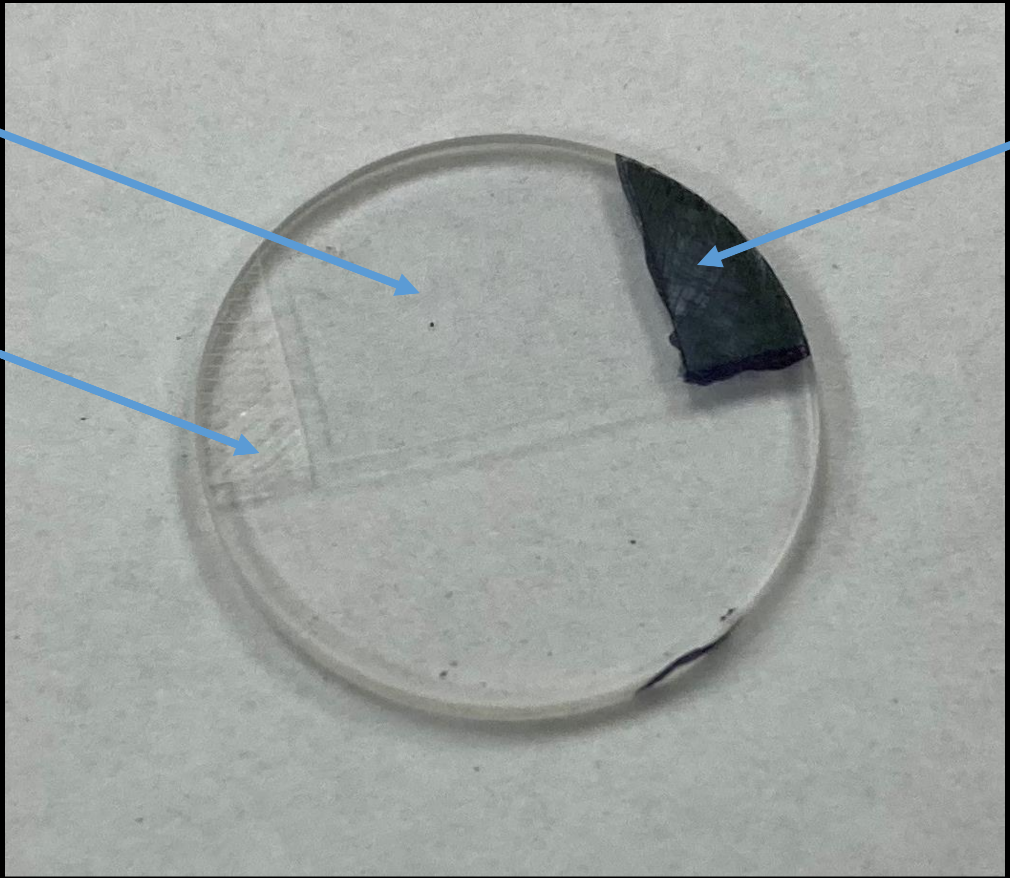


Dust removal efficiency, ξ, calculated for pristine and workfunction matching coated (a) AZ93 and (b) AxFEP using JSC1-AF and Chromite simulants for dusting. (From Gaier, J.R., Waters, D.L., Misconin, R.M., Banks, B.A and Crowder, M. “Evaluation of Surface Modification as a Lunar Dust Mitigation Strategy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

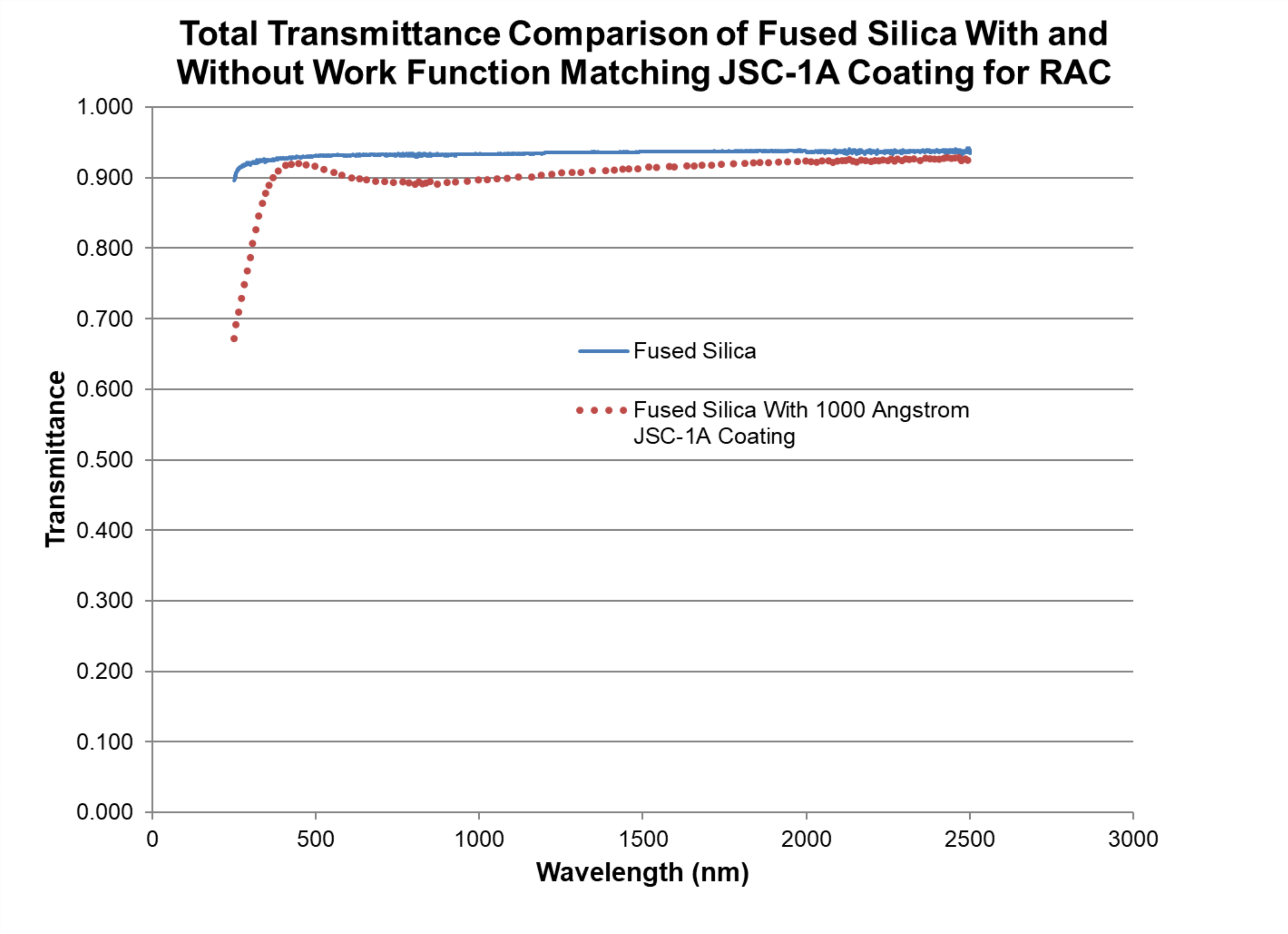
Work Function Matching Coating on Upper Marked Half of Fused Silica Disk for RAC

Work Function Matching Coating (1000 Å) on Top Half

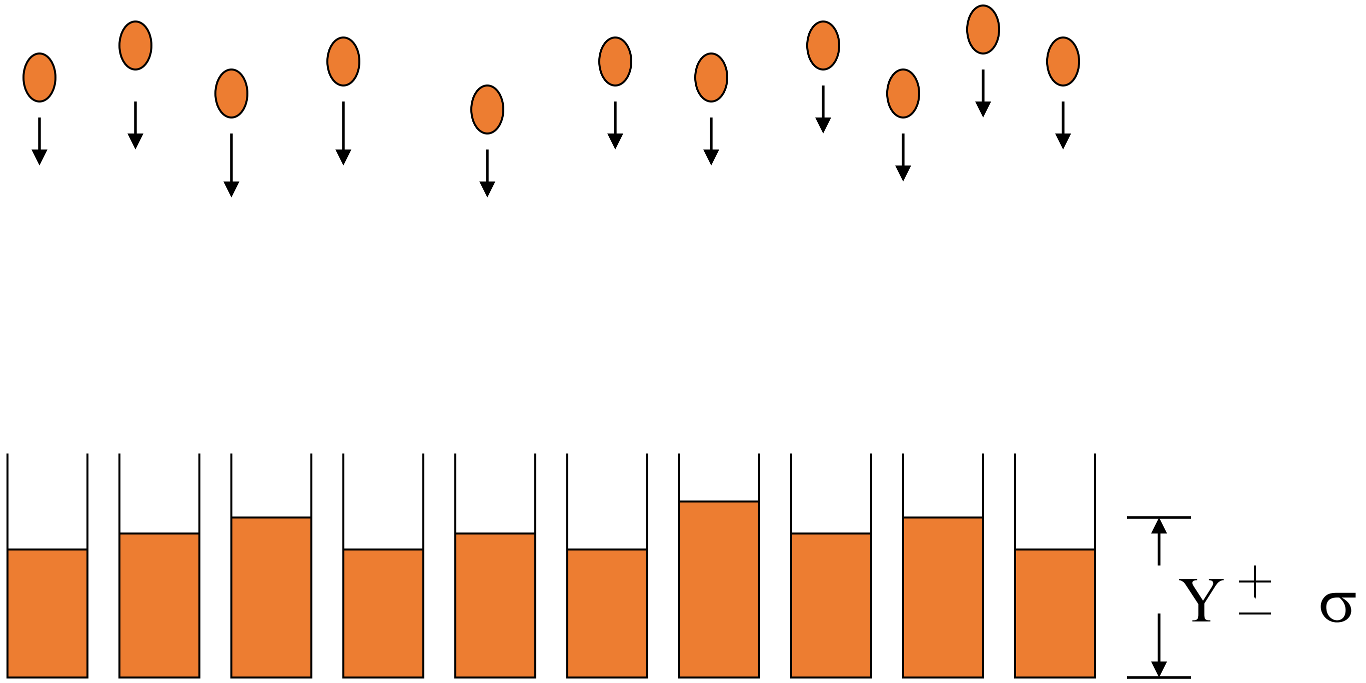
Section of Fused Silica with Hash Marks Applied by Diamond Scribe Prior to Work Function Matching Coating (to distinguish coated and uncoated halves in camera images when on the lunar surface)



Section of Fused Silica with Hash Marks Applied by Diamond Scribe then Overcoated with Black Ink Prior to Work Function Matching Coating (to distinguish coated and uncoated halves in camera images when on the lunar surface)

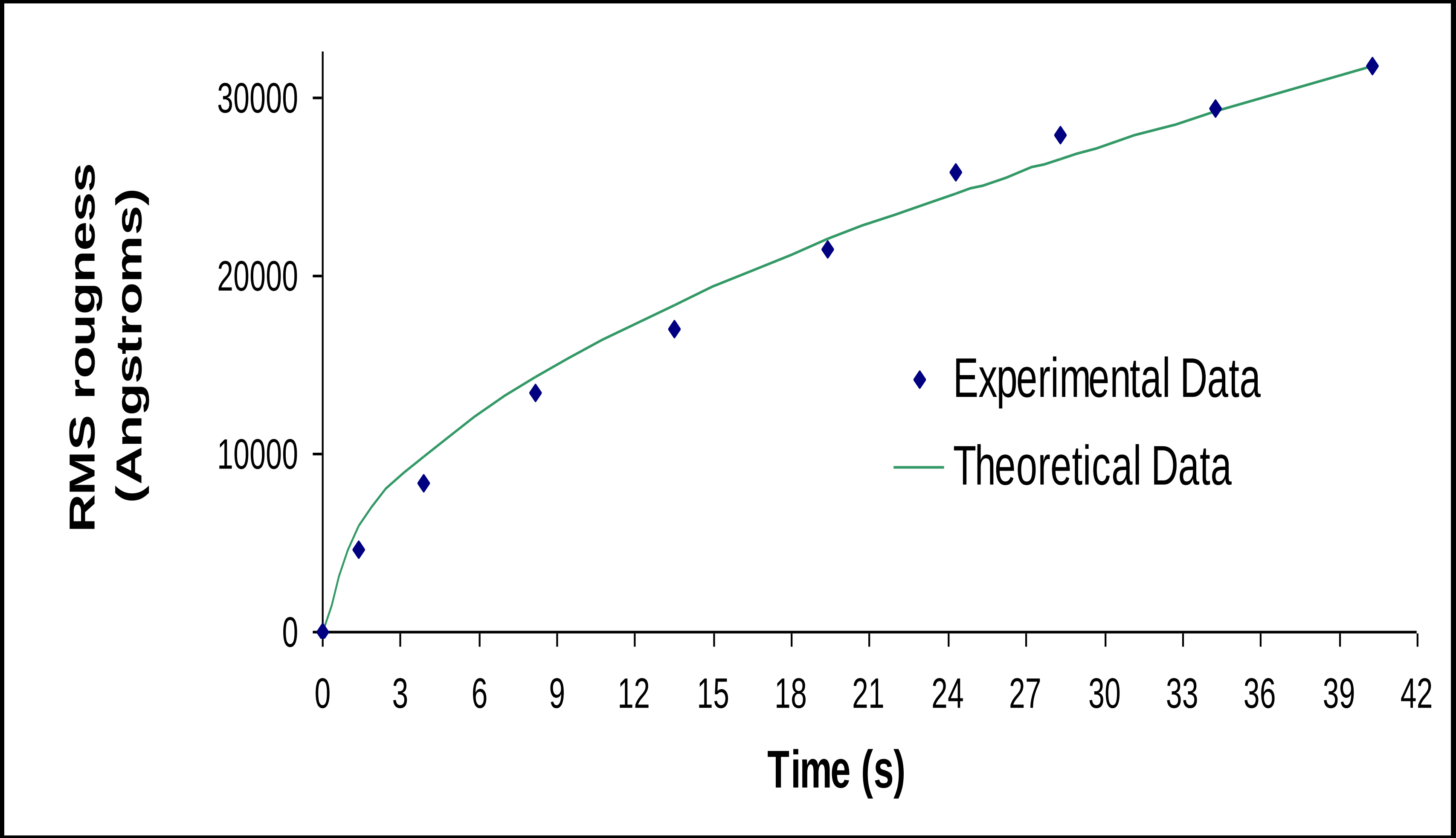

Total Transmittance Comparison of Fused Silica With and Without Work Function Matching JSC-1A Coating for RAC
Transmittance
Wavelength (nm)
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
0
500
1000
1500
2000
2500
3000
Fused Silica
Fused Silica With 1000 Angstrom JSC-1A Coating

Development of Surface Roughness from Spatially Independent Addition or Removal on Surfaces

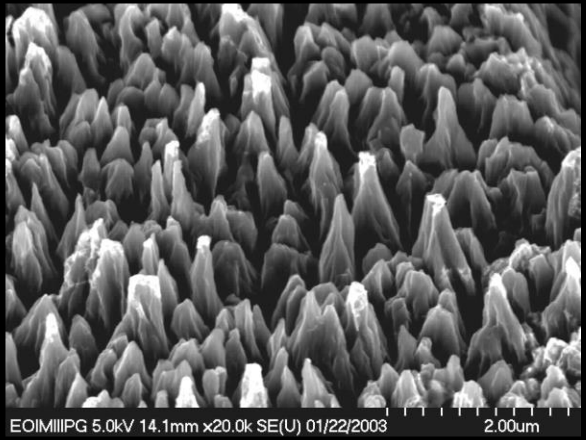


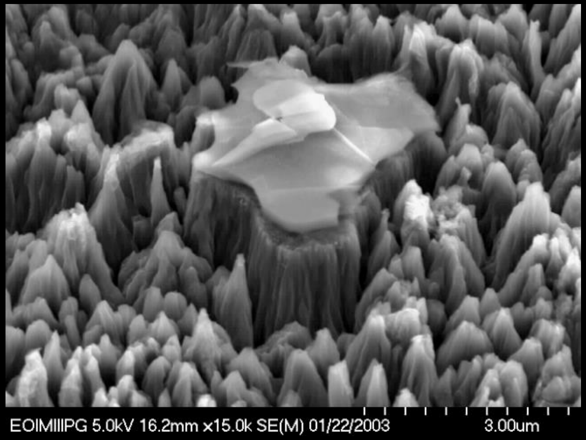
- **Roughness, σ ,obeys Poisson statistics**
- **Roughness grows as square root of treatment time**

Development of Surface Roughness of Grit Blasted Glass



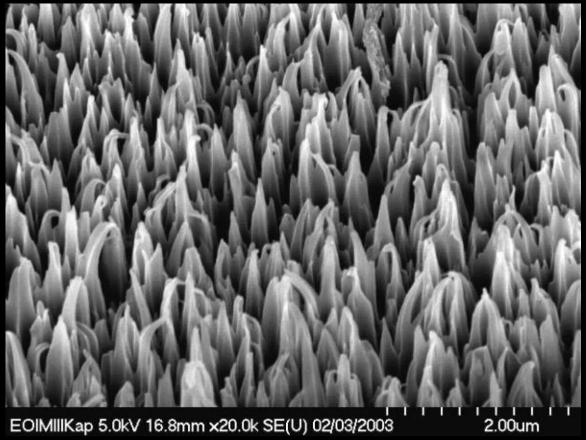
Directed Atomic Oxygen Erosion in LEO

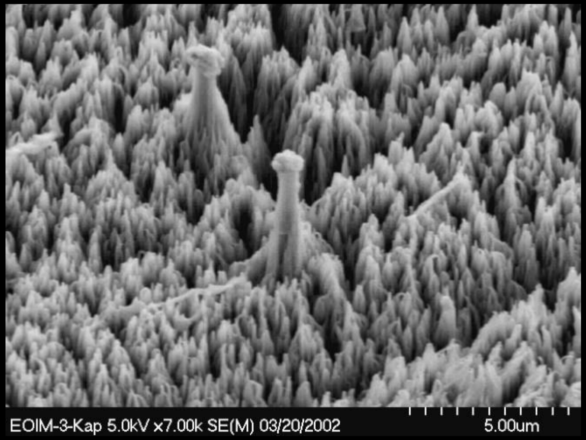




EOIM III Pyrolytic graphite

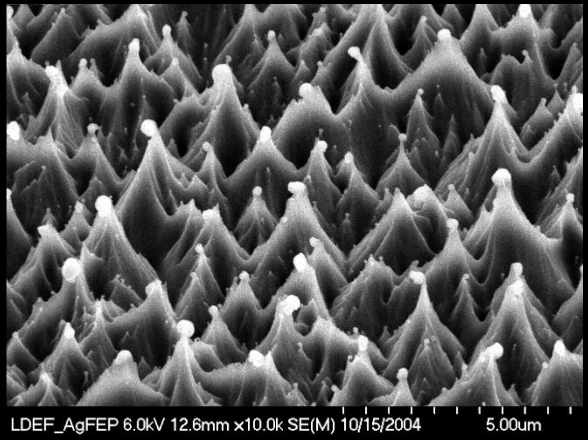
AO F= 2.3×10^{20} atoms/cm^2

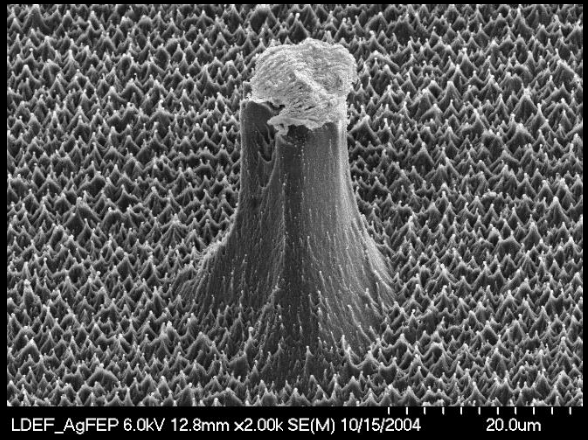




EOIM III Kapton H

AO F= 2.3×10^{20} atoms/cm^2

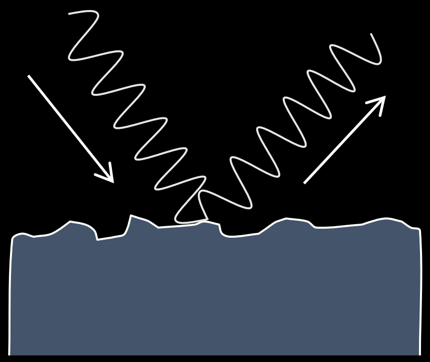




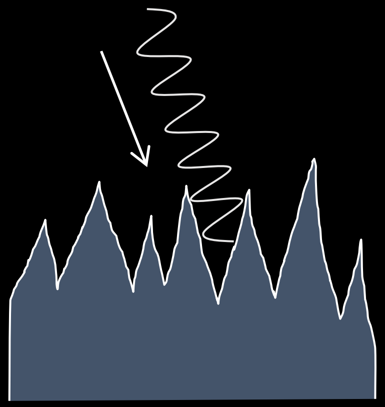
LDEF Teflon FEP

AO F= 7.78×10^{21} atoms/cm^2

Effect of Texture on Absorptance



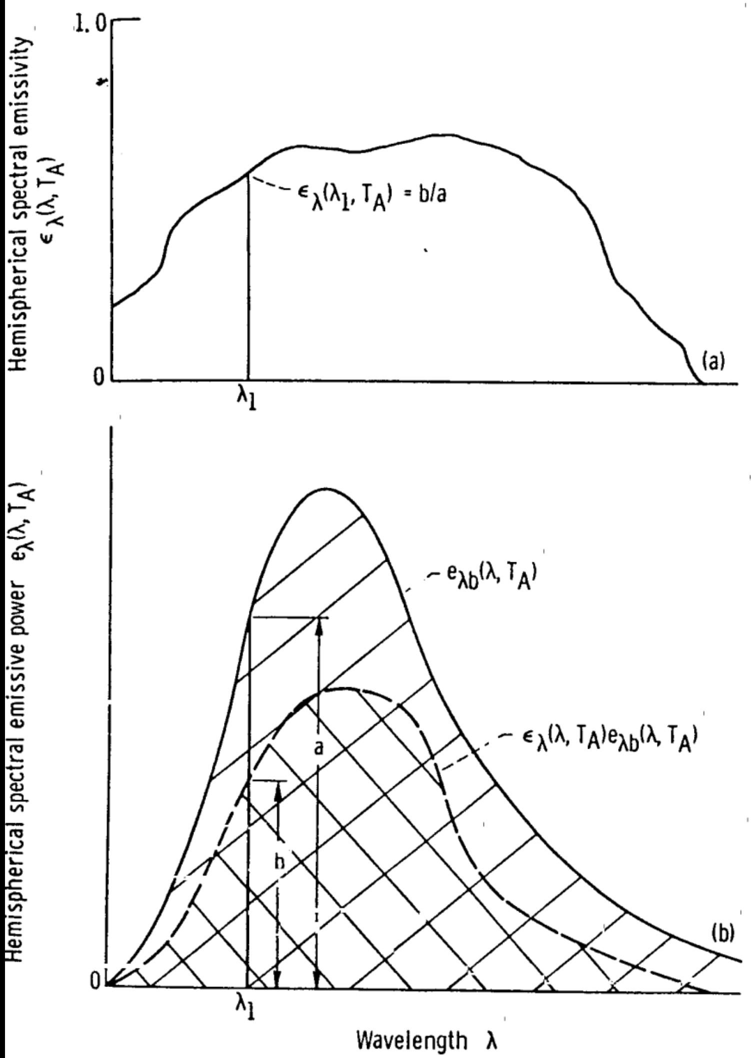
α is Low
$\lambda > \sigma$



α is High
$\lambda < \sigma$

Where σ = surface texture

Thermal Emittance Calculation



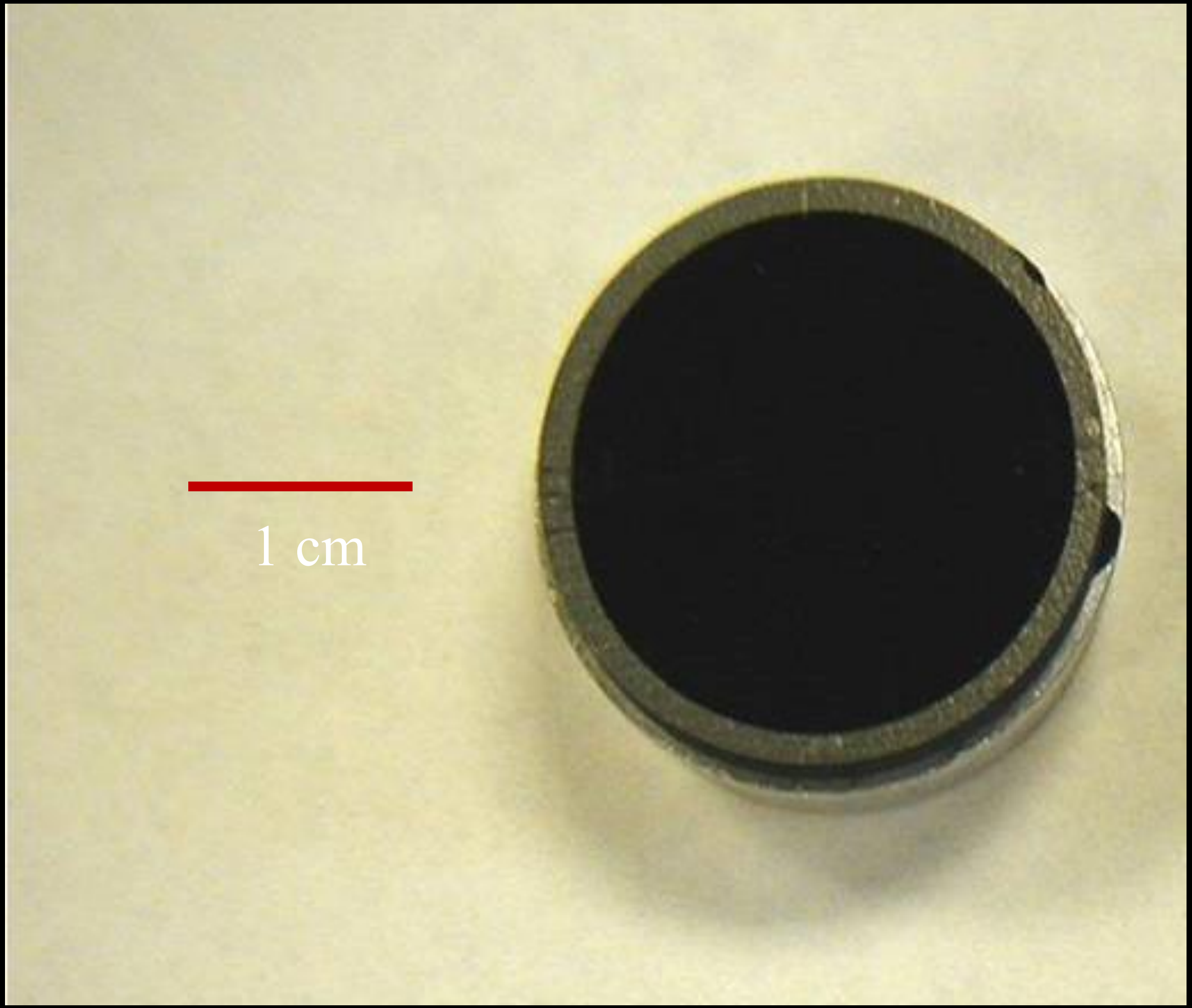
$$\epsilon(T_A) = \frac{\int_0^\infty \epsilon_\lambda(\lambda, T_A)\, e_{\lambda b}(\lambda, T_A)\, d\lambda}{\sigma T_A{}^4}$$

WHERE

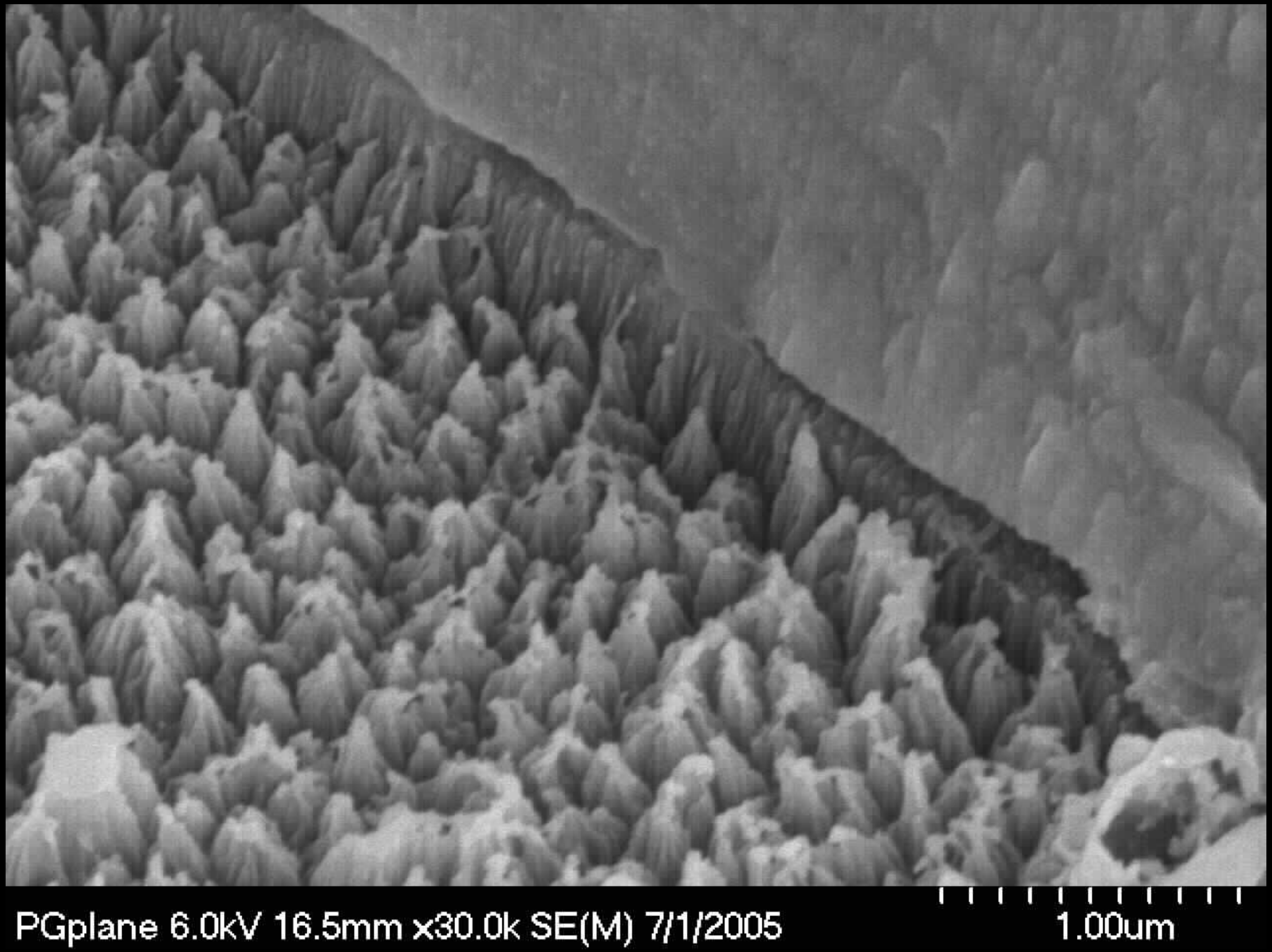
$$\epsilon_\lambda(\lambda, T_A) = (1 - \rho(\lambda, T_A))$$

Siegel R. and Howell, J. Thermal Radiation Heat Transfer, McGraw Hill, 1981

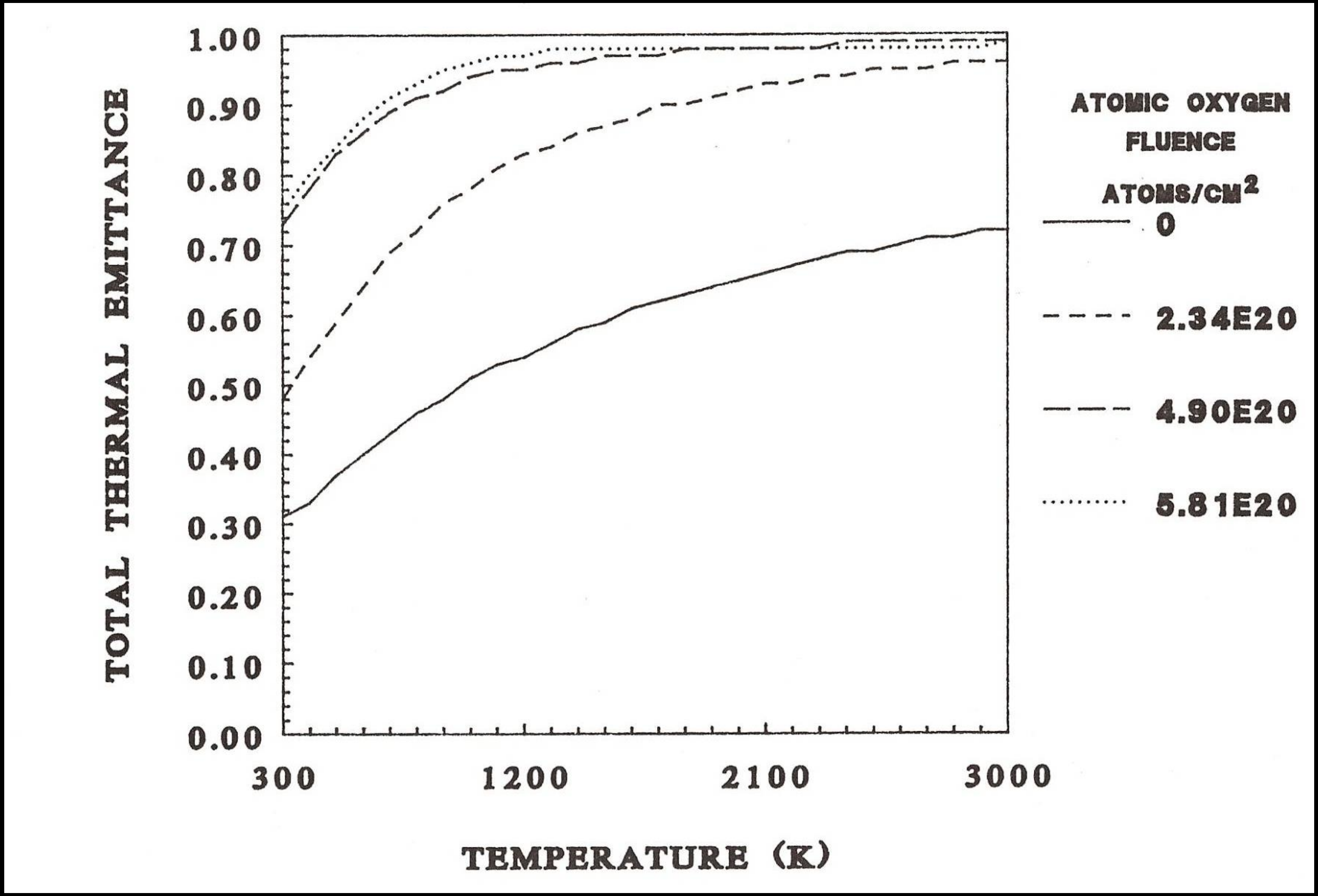
Atomic Oxygen Textured Pyrolytic Graphite from a Space Experiment



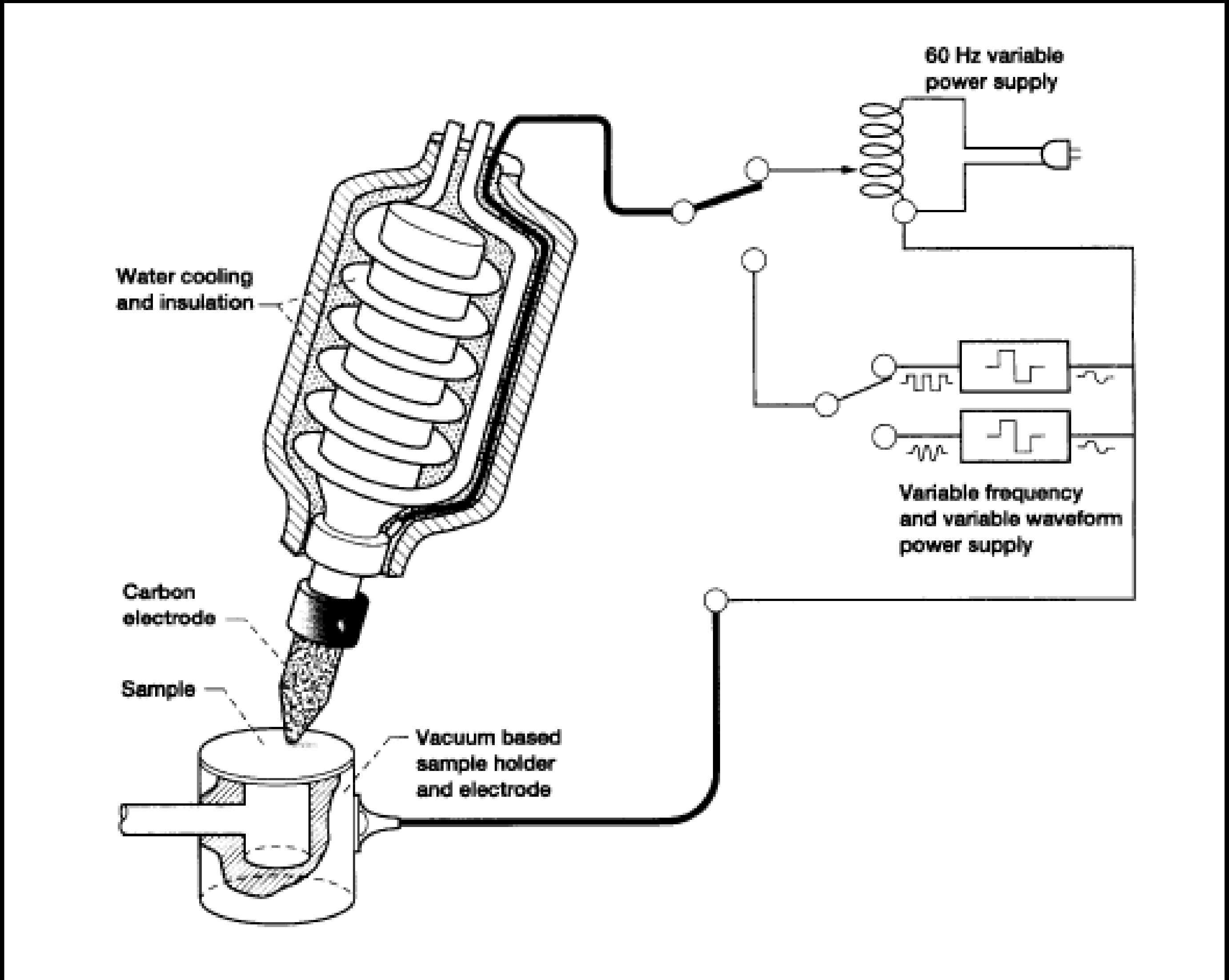
Atomic Oxygen Textured Pyrolytic Graphite (at the Edge of a Protective Coating) Made in the NASA Glenn End Hall Atomic Oxygen Facility



Carbon-Carbon Composite

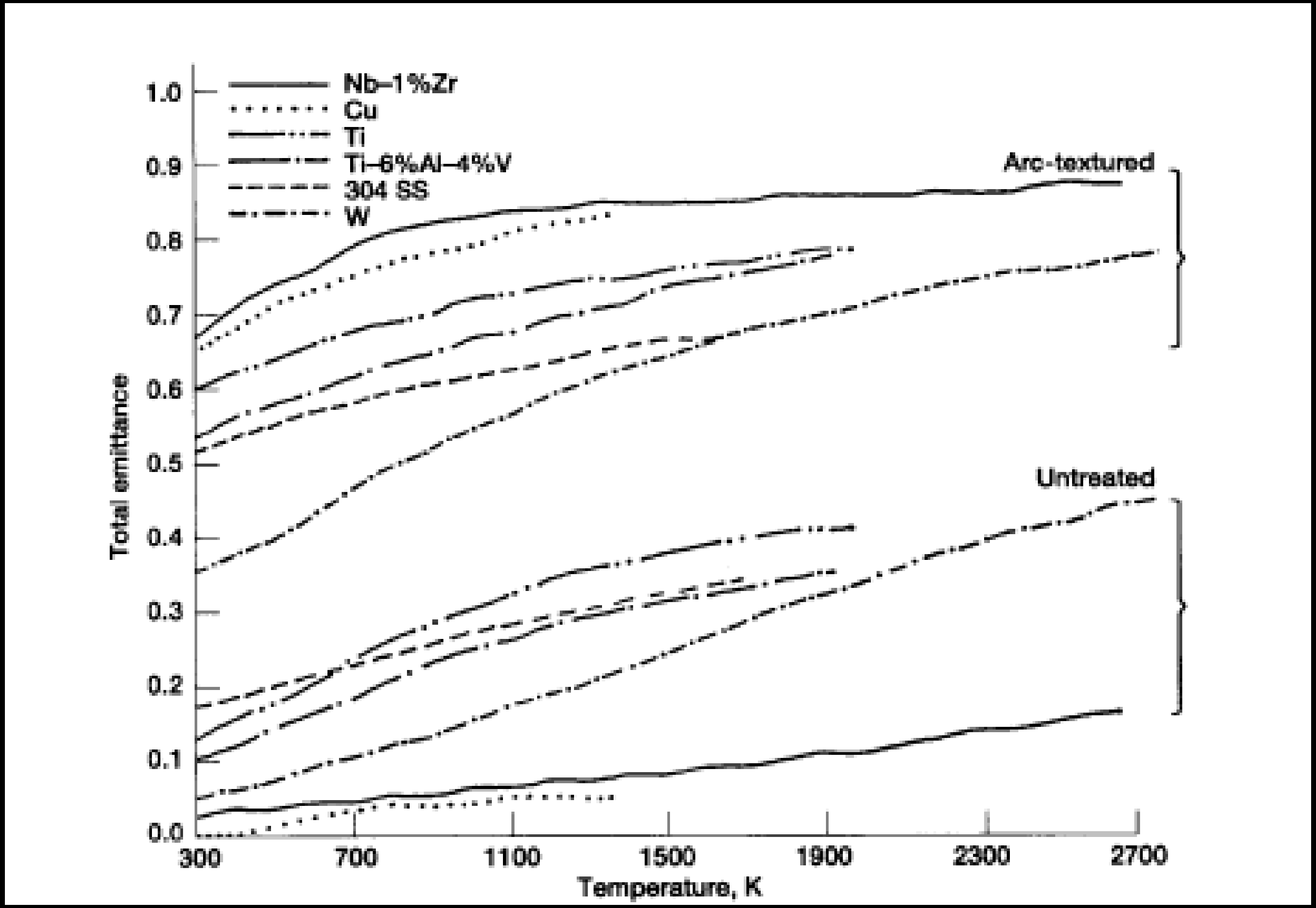


Arc Texturing of Metals



THERMAL EMITTANCE AT 322 K OF SANDED METALS PRIOR TO AND AFTER CARBON AND SILICON CARBIDE ARC TEXTURING				
Metal	Sanded and Untreated	Carbon Arc Textured	Carbon Arc Textured and Exposed to Atomic Oxygen	Silicon Carbide Arc Textured
6061-T6 Al	0.086	---	---	0.822
Cu	0.050	0.657	0.870	0.839
Ni	0.044	---	---	0.763
Nb-1% Zr	0.112	0.676	0.505	0.812
Type 304 Stainless Steel	0.146	0.511	---	0.600
Ti-6% Al-4% V	0.144	0.534	---	0.670
W	0.145	0.347	---	0.689

Emittance of Carbon Arc Textured Metals vs Temperature



Summary

- The space environment can affect material performance
- Coatings, material modification and surface treatments can improve performance in the space environment
- Space environment experience can lead to new techniques to enhance material performance