Atomic Oxygen Environment, Effects and Simulation

Sharon K. R. Miller

NASA Glenn Research Center, Cleveland, OH 44135
sharon.k.miller@nasa.gov

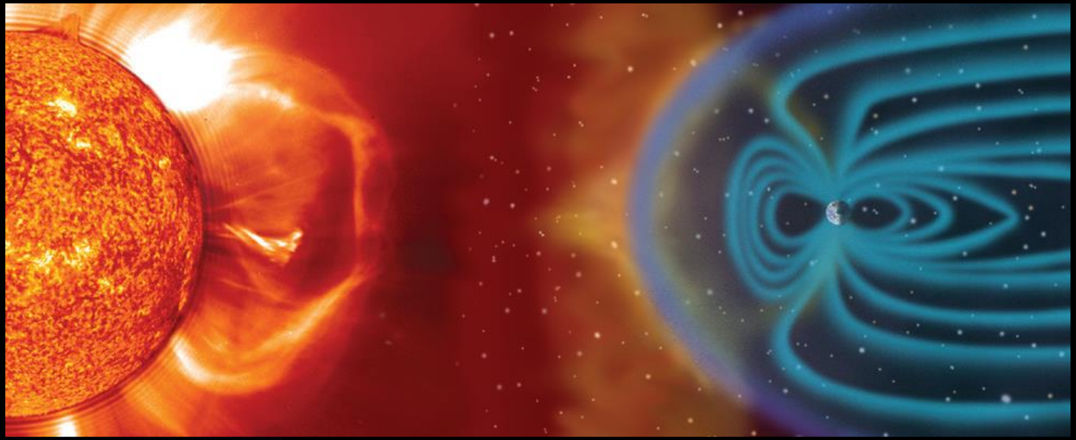
Bruce A. Banks

SAIC at NASA Glenn Research Center, Cleveland, OH 44135

Applied Space Environments Conference (ASEC), Oct. 9-13, 2023

Space Environment

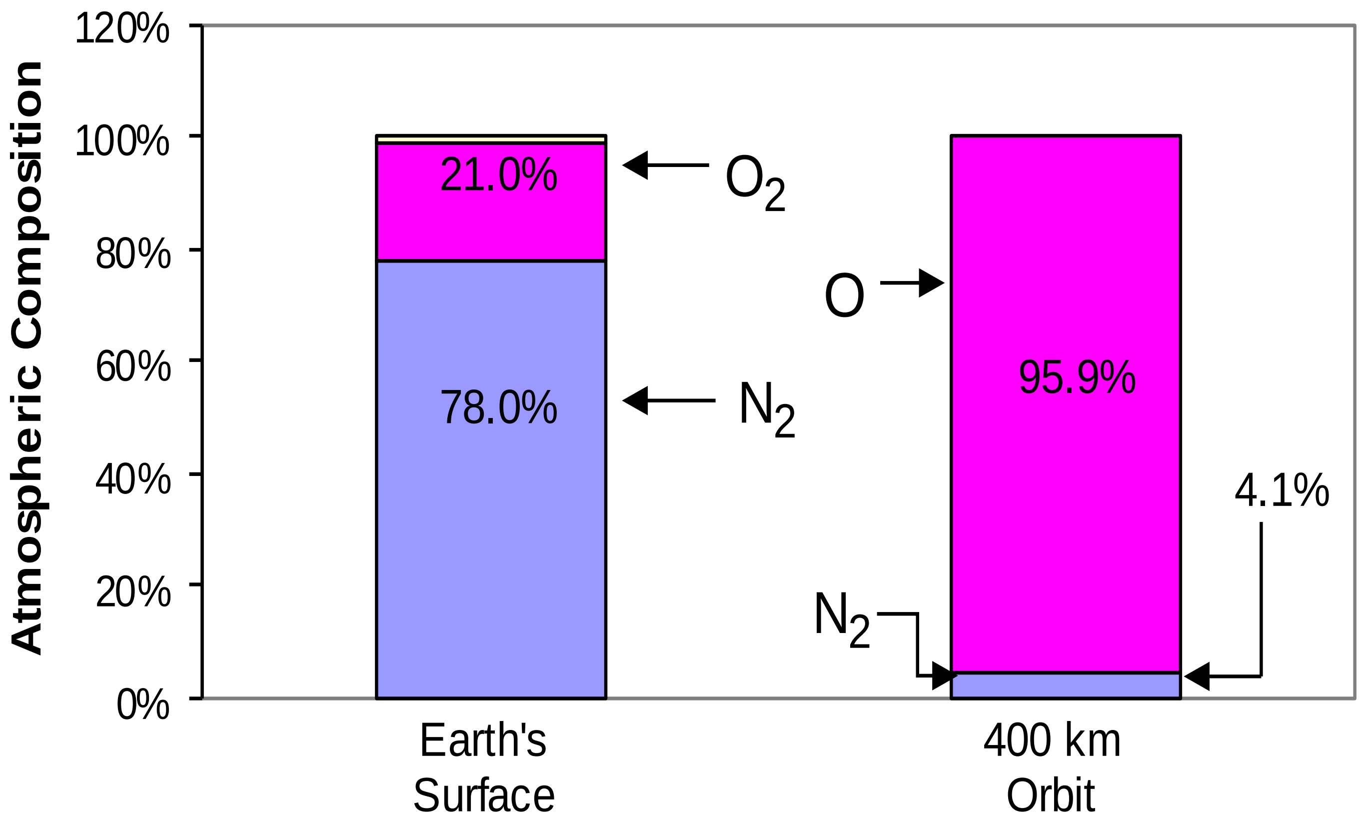
- Solar radiation (ultraviolet (UV), x-rays)
- Charged particle radiation (electrons, protons)
- Cosmic rays (energetic nuclei)
- Temperature extremes & thermal cycling
- Micrometeoroids & orbital debris (space particles)
- Atomic oxygen (AO) (reactive oxygen atoms)
- Planetary dust and wind
- Reactive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



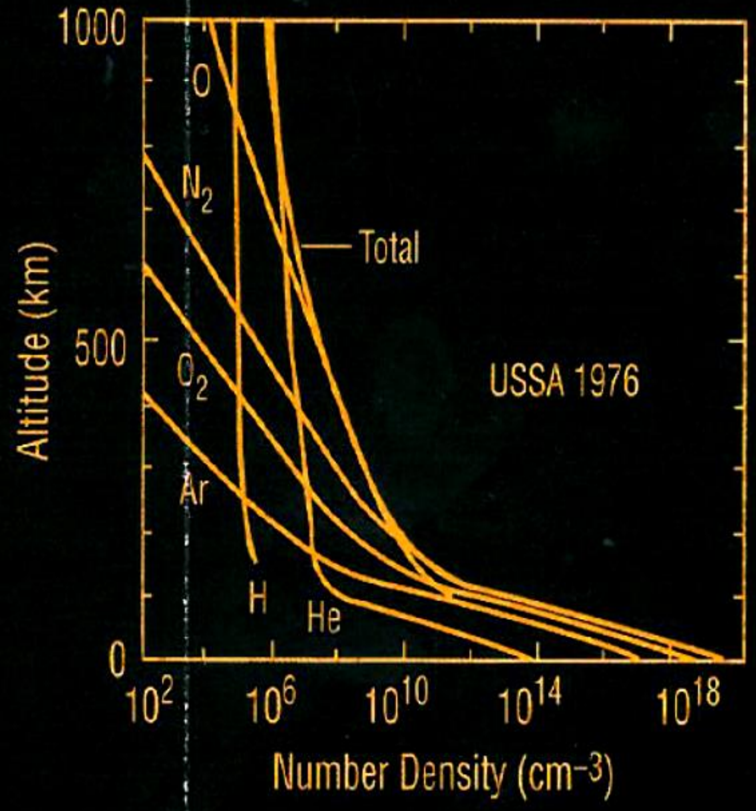
Art Image of solar flares and solar wind, NASA Image

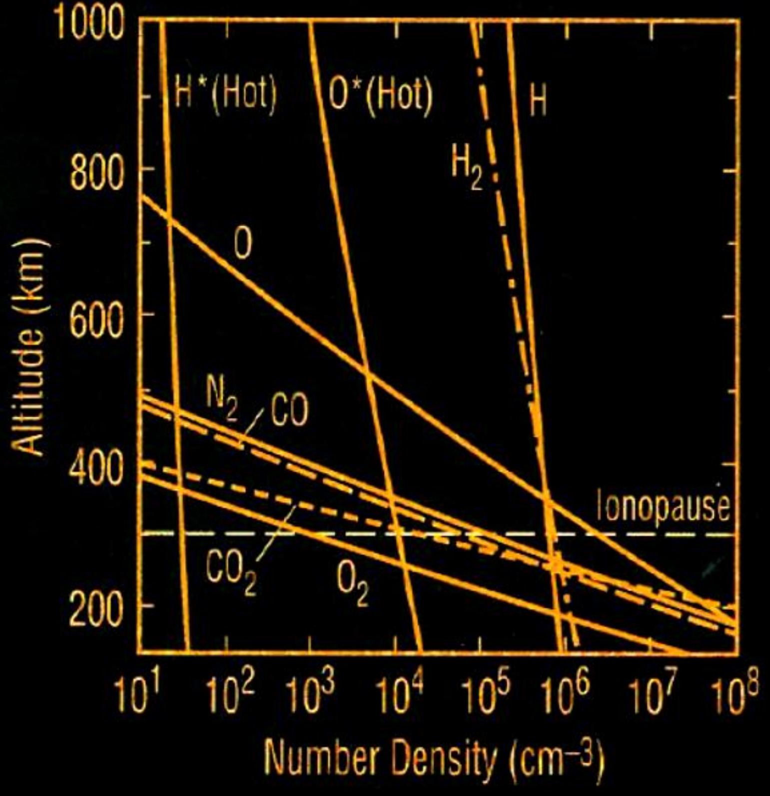
Moon from ISS, NASA Image

Atmospheric Composition



Atmospheric Comparison Between Earth and Mars





Graphs from NASA JPL

Mars Atmosphere Density Profiles

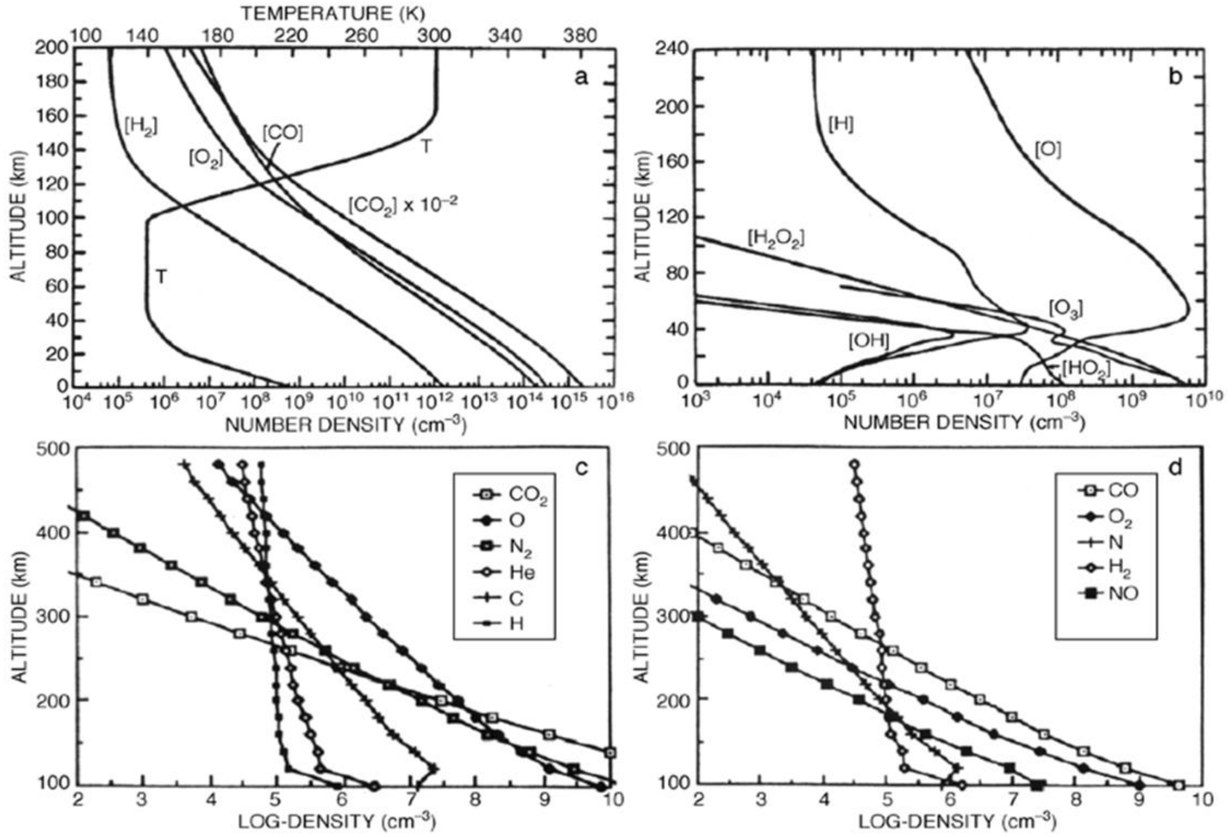
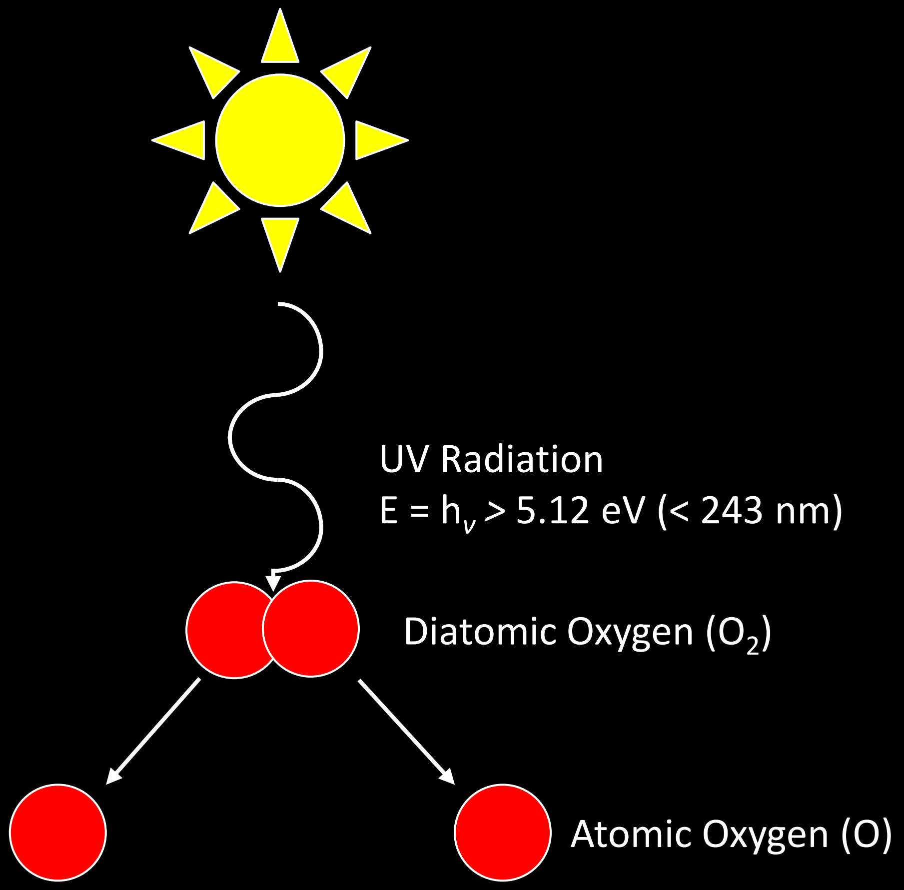


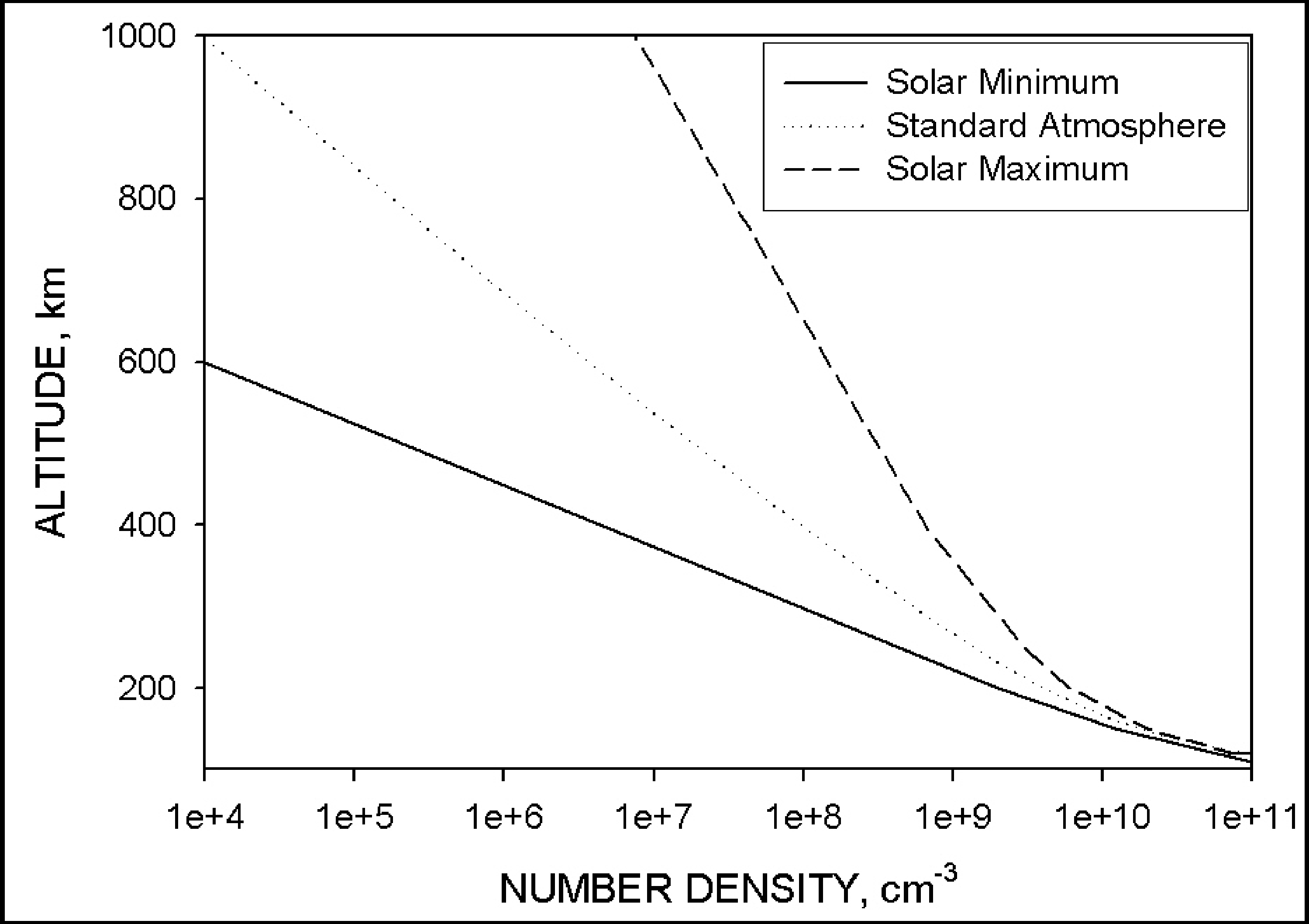
Figure 4-2. Martian Atmospheric Density Profiles for Various Constituents. a) CO_2, CO, O_2, and H_2 in an altitude range between 0 and 200 km, b) O, H, OH, H_2O_2, and O_3 from 0 to 240 km, c) CO_2, O, N_2, He, C, and H between 100 and 500 km and d) CO, O_2, N, H_2, and NO between 100 and 500 km.

Graphs Courtesy of Hank Garrett, NASA JPL

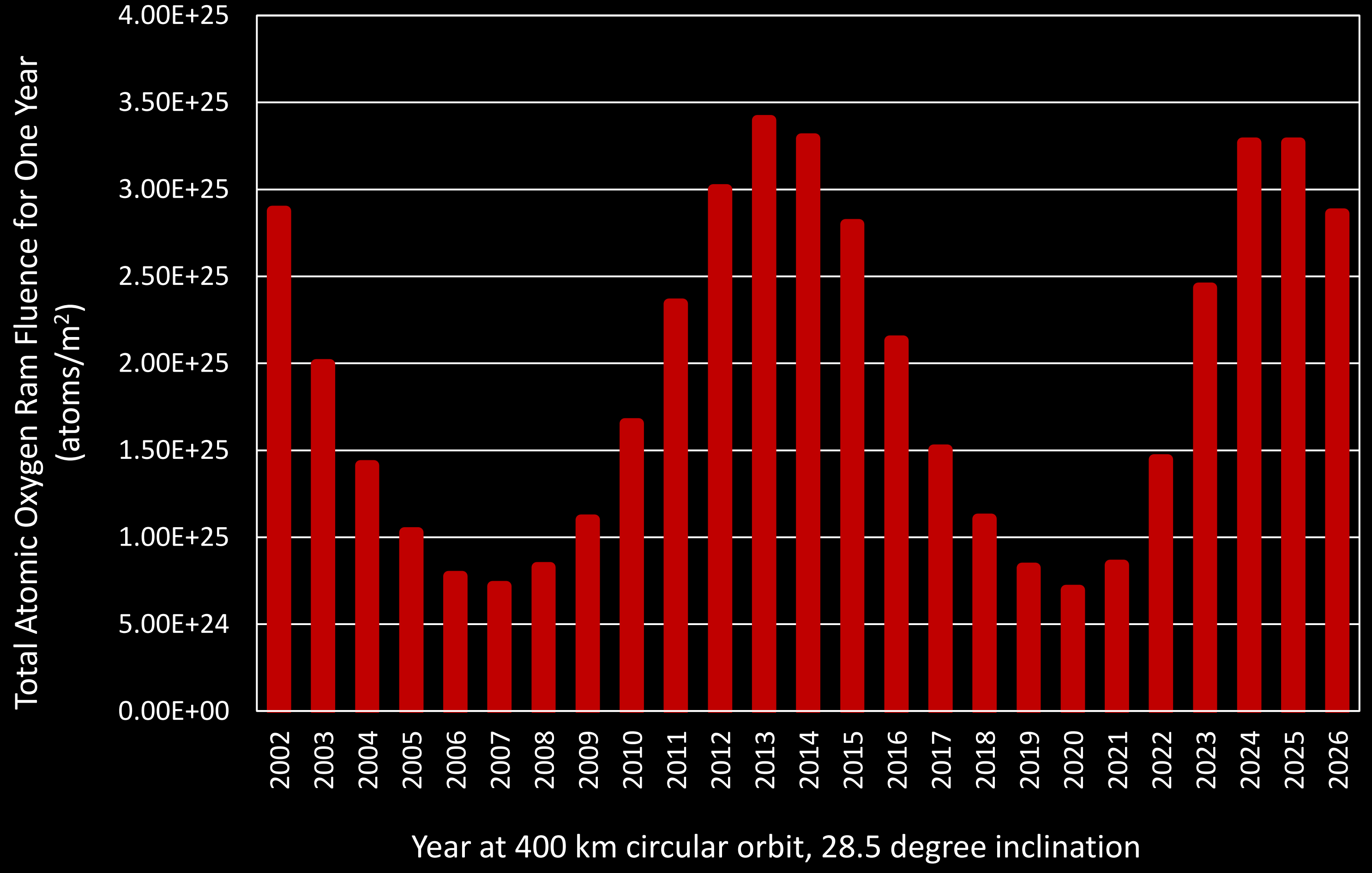
Atomic Oxygen Formation by Photodissociation



Atomic Oxygen Earth Atmosphere Number Density Dependence Upon Solar Activity

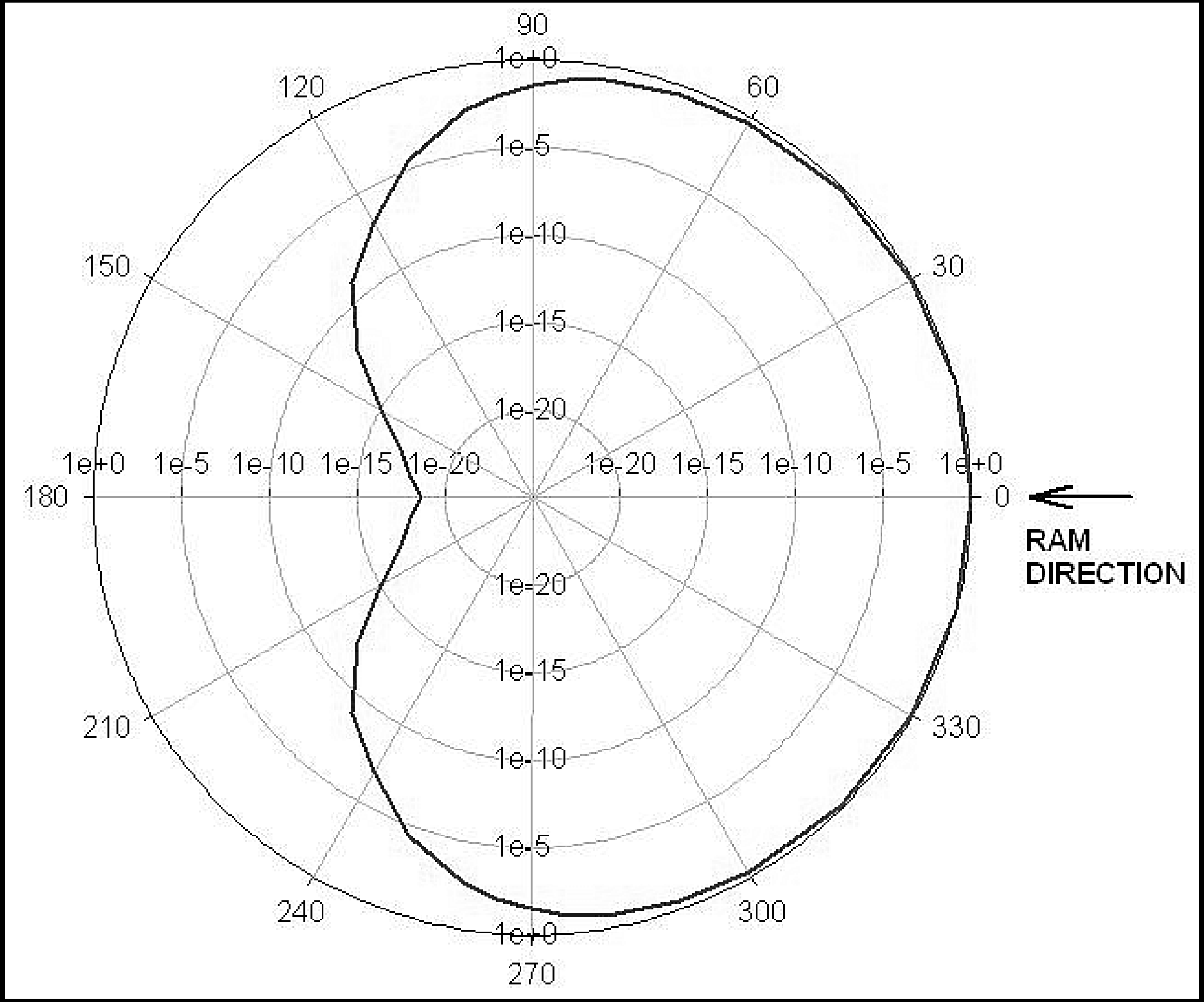


Solar Cycle Caused Variation in Level of Atomic Oxygen in Low Earth Orbit at 400 km

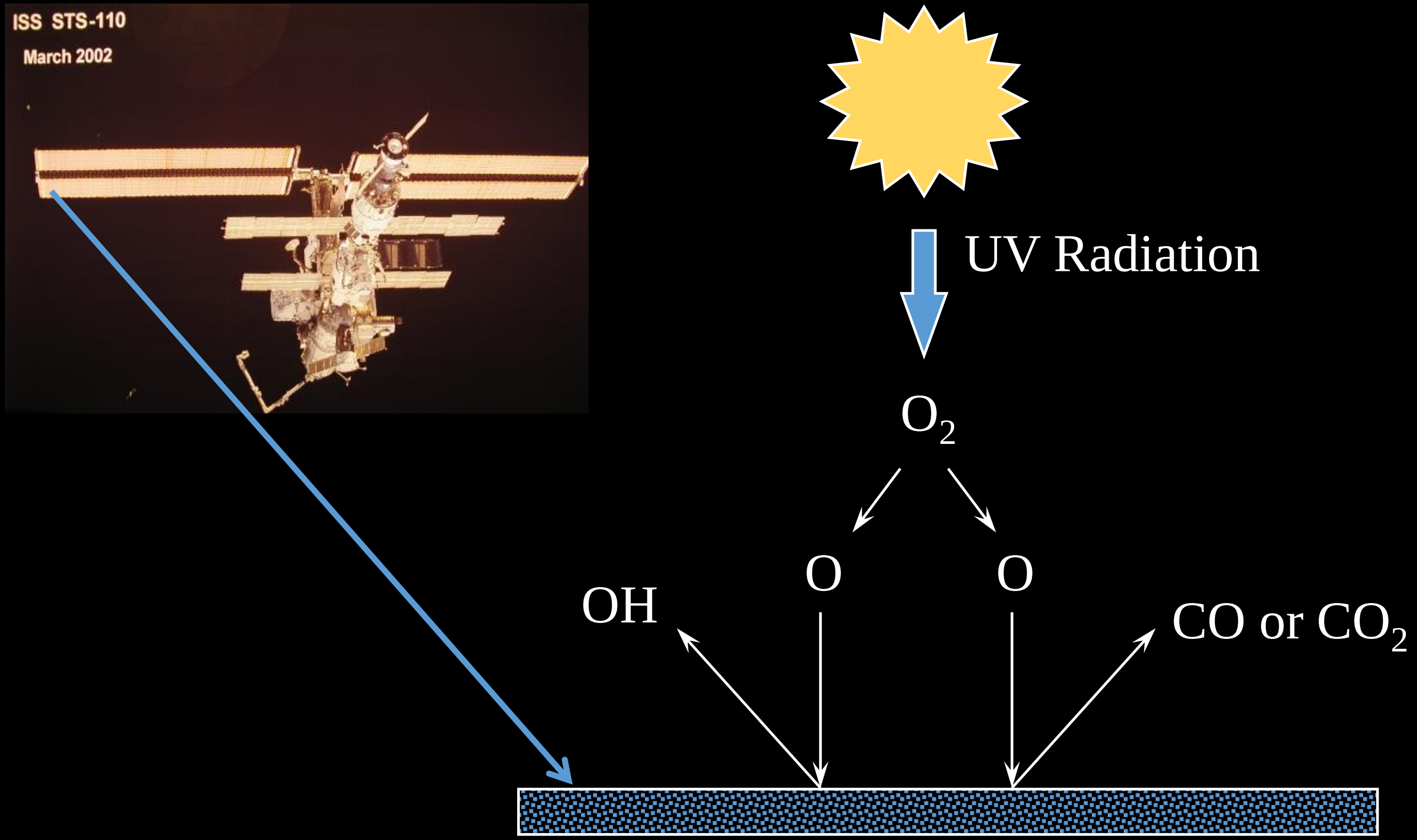


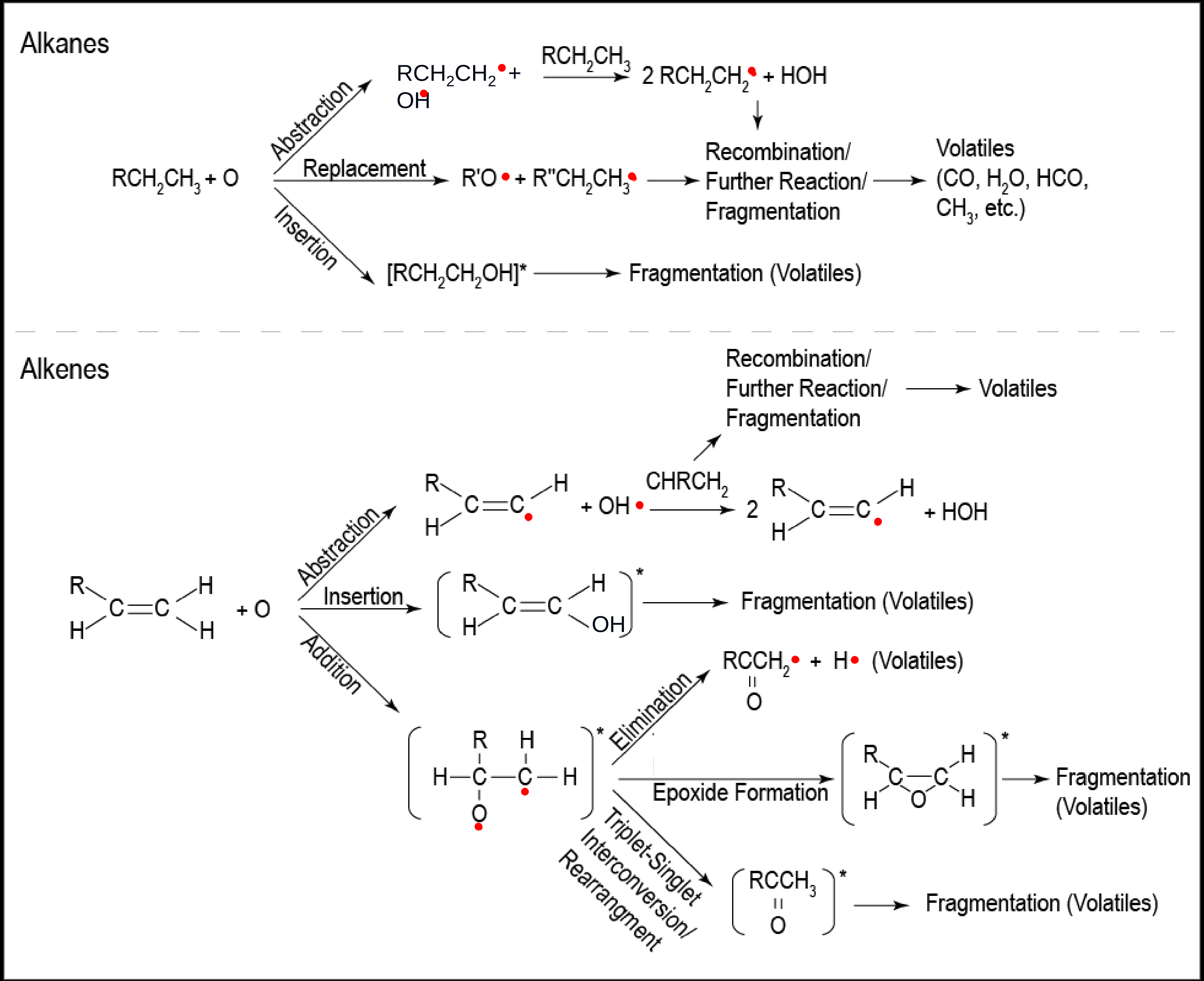
Logarithmic Polar Plot of Atomic Oxygen Arrival Flux

(400 km Earth orbit at 28.5º inclination and 1000 K thermosphere)



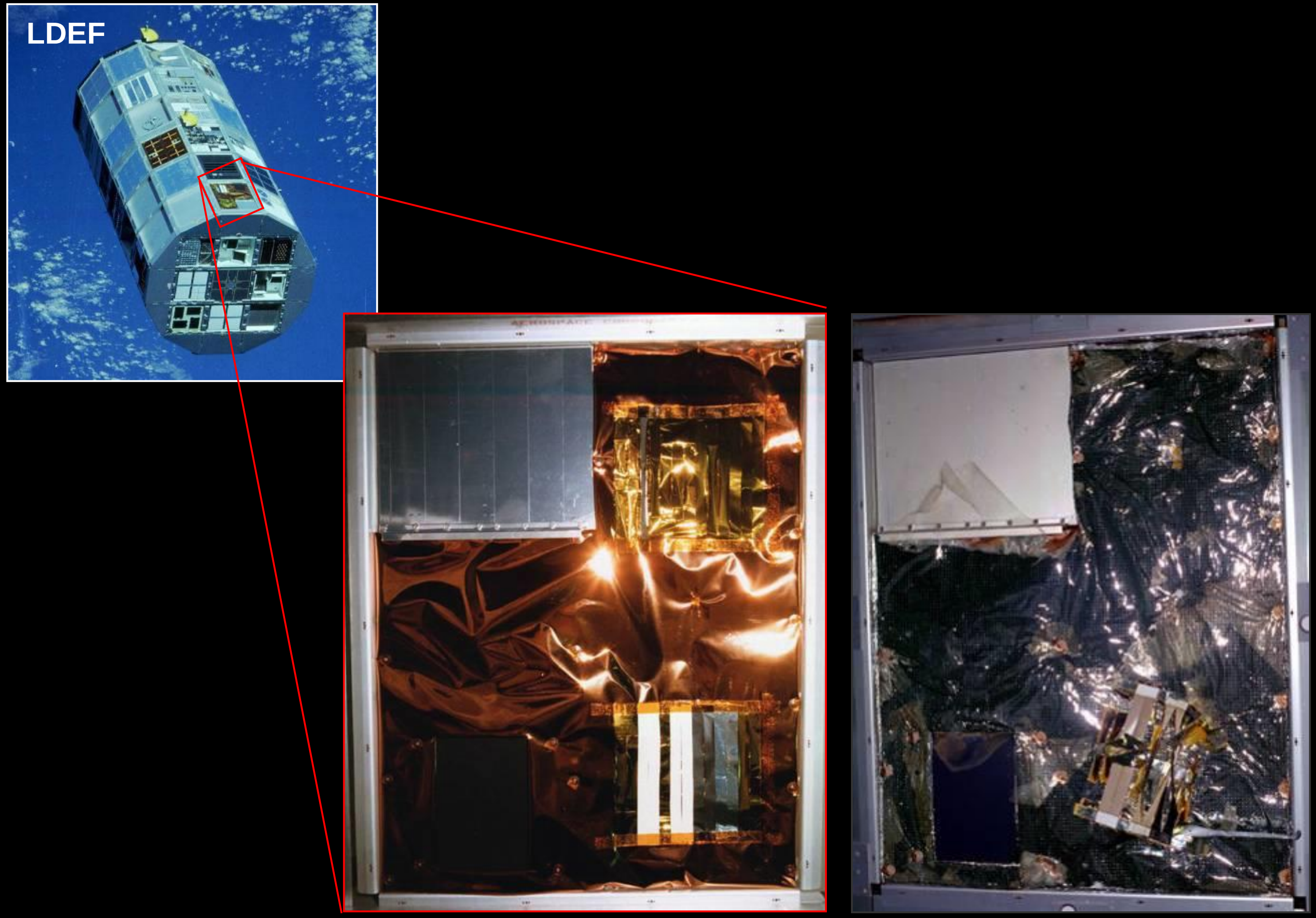
Basic Atomic Oxygen Interaction with Organic Surfaces





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?



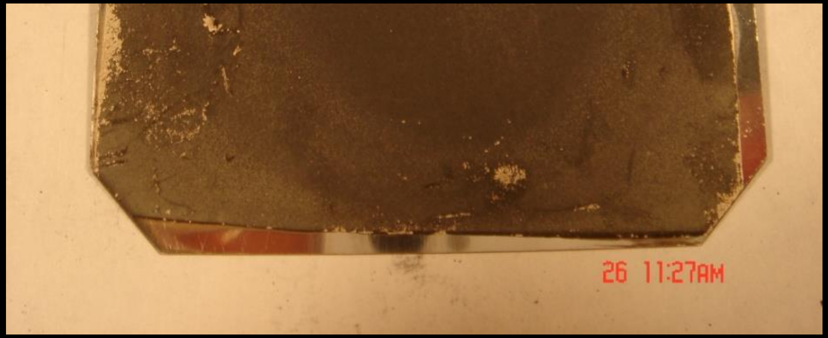
Prior to Flight

After 5.8 years in LEO

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

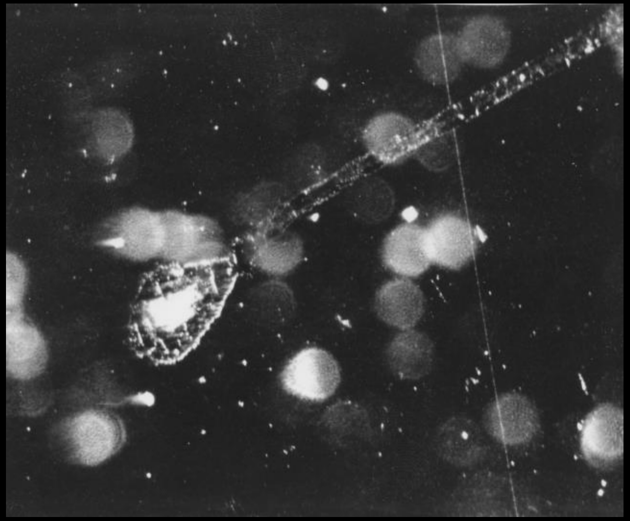
As Received

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

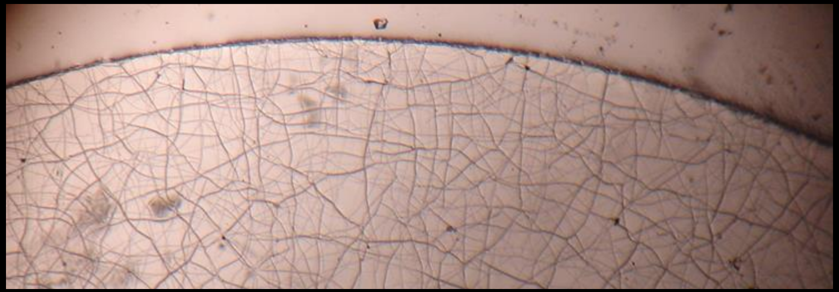
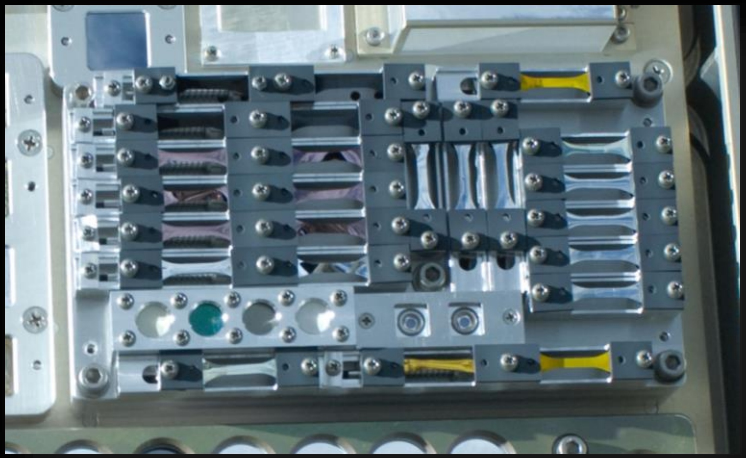


Chart From Kim K. de Groh, NASA GRC

Stress Dependent Atomic Oxygen Erosion of Black Kapton XC

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

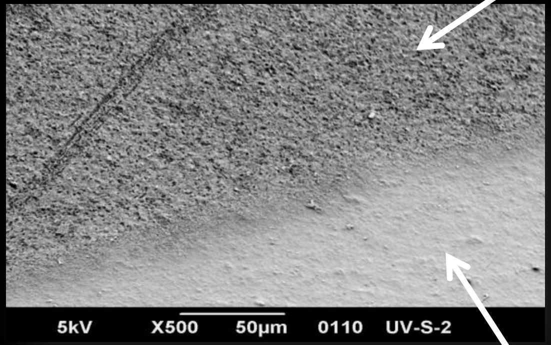


Stressed (left) and Unstressed (right) Black Kapton XC

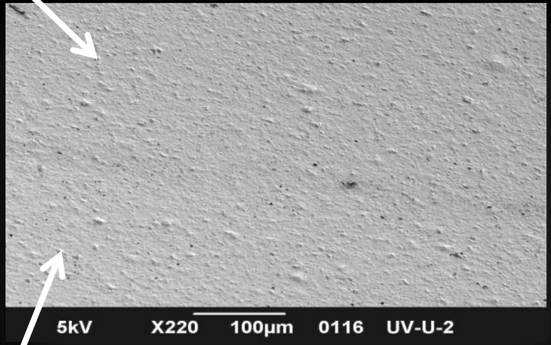
- Stress level: Force/Area = ~4000psi (2.76e7 N/m^2)
- Strain = Stress/Modulus = 4000 psi/480000 psi (3.3e9 N/m^2) = ~0.008
- For Kapton XC this represents ~3 % of the maximum strain and ~24% of the tensile strength

Exposed

Stressed UV-S-2



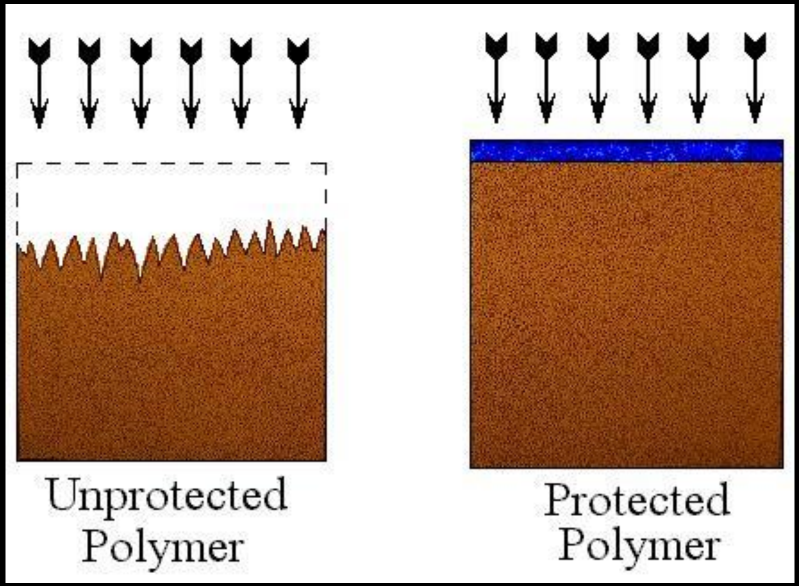
Unstressed UV-U-2



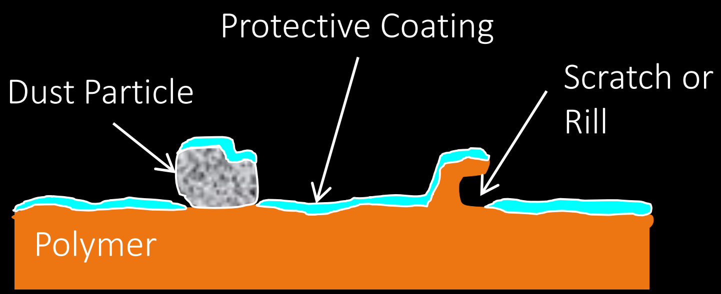
Under Mount

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

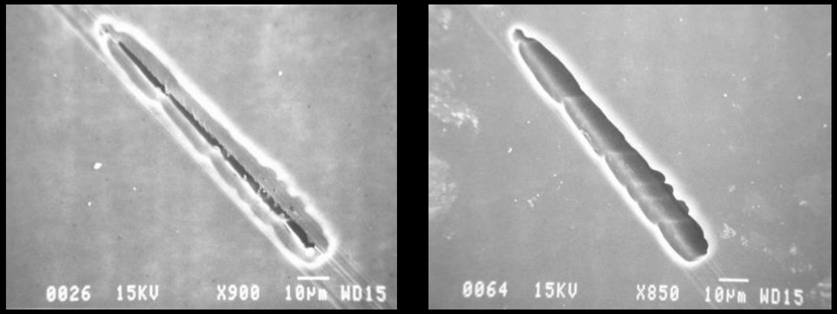
Atomic Oxygen Mitigation Using Protective Coatings



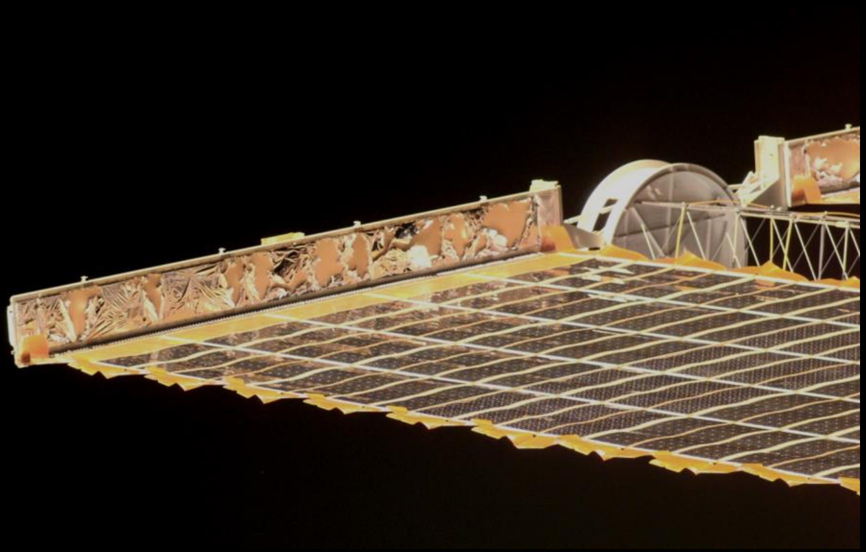
Imperfections in Thin Film Coatings

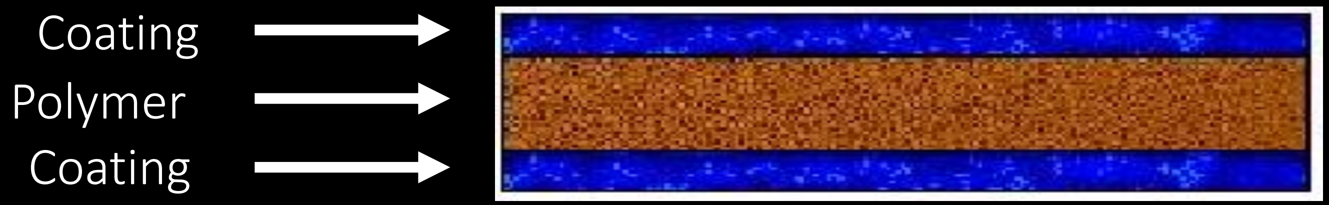


Aluminized Kapton Flown on LDEF



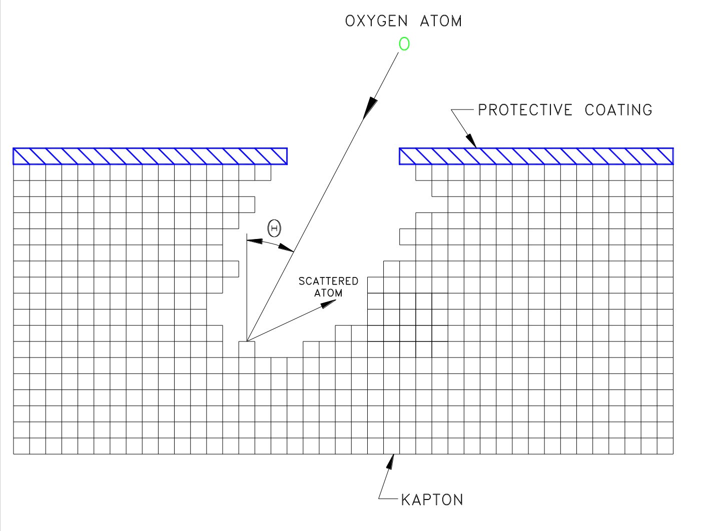
Blanket Box Cover Failure of Aluminized Kapton Observed on ISS

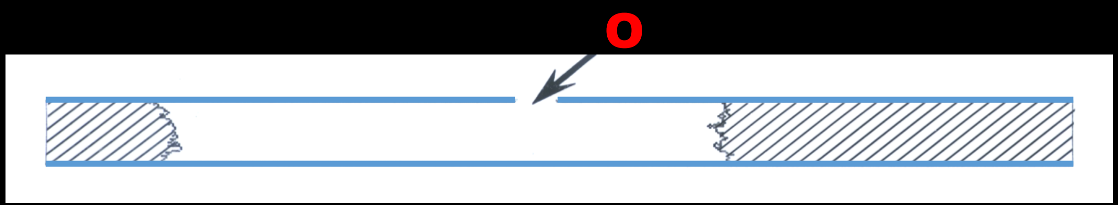




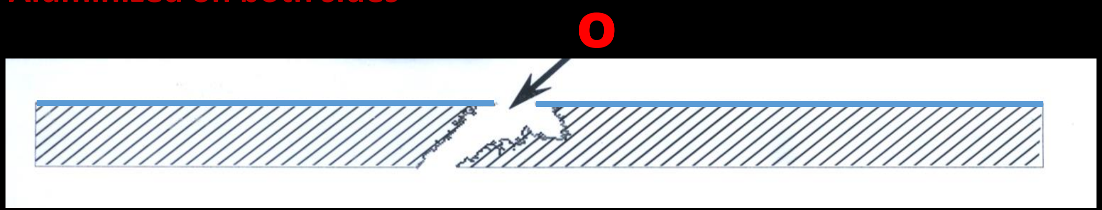
Monte Carlo Computational Model Predictions

- 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

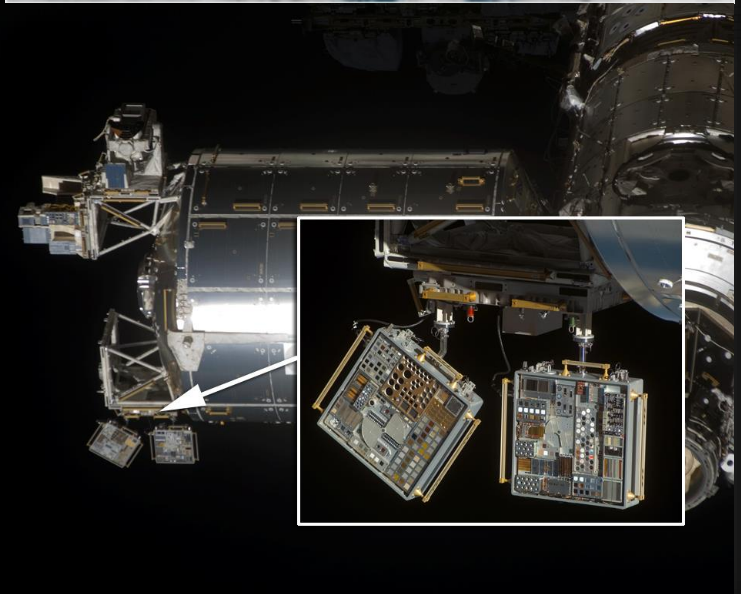


Aluminized on exposed side only

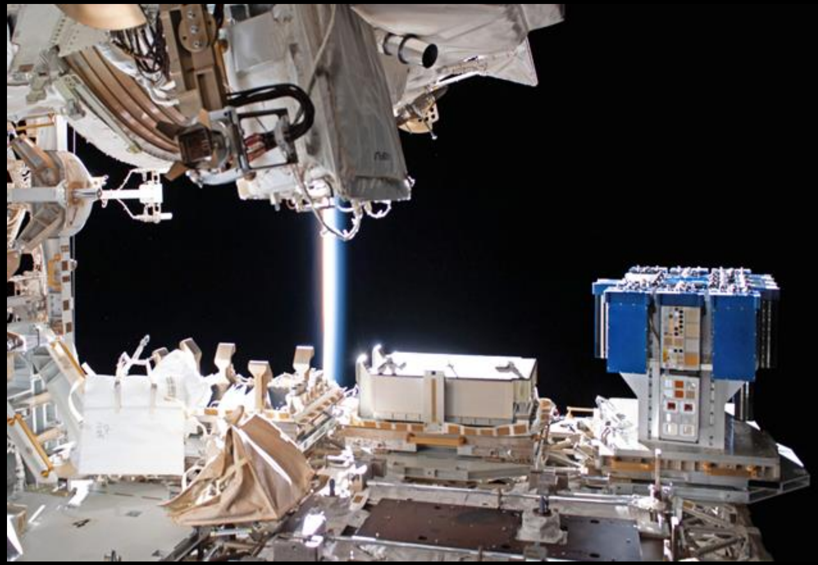
Material Testing in Low Earth Orbit

Long Duration Exposure Facility (LDEF)

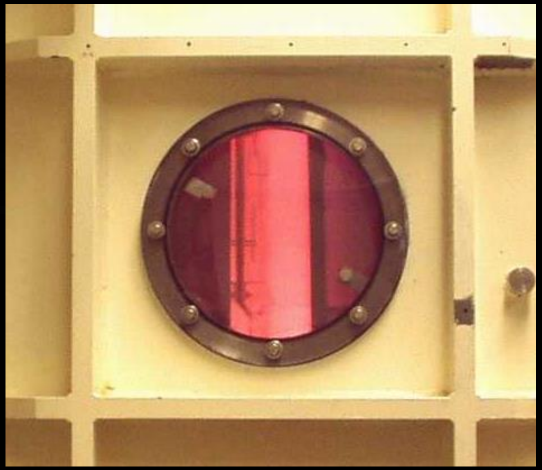
Materials International Space Station Experiment (MISSE)

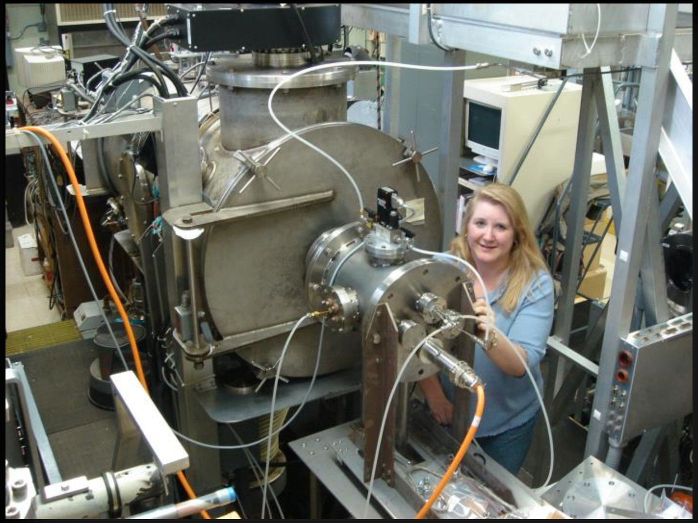


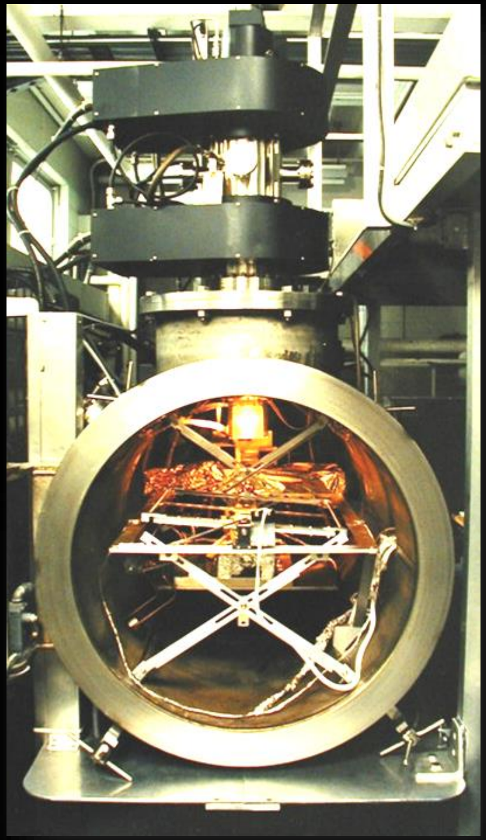
Wake Side of MISSE Flight Facility



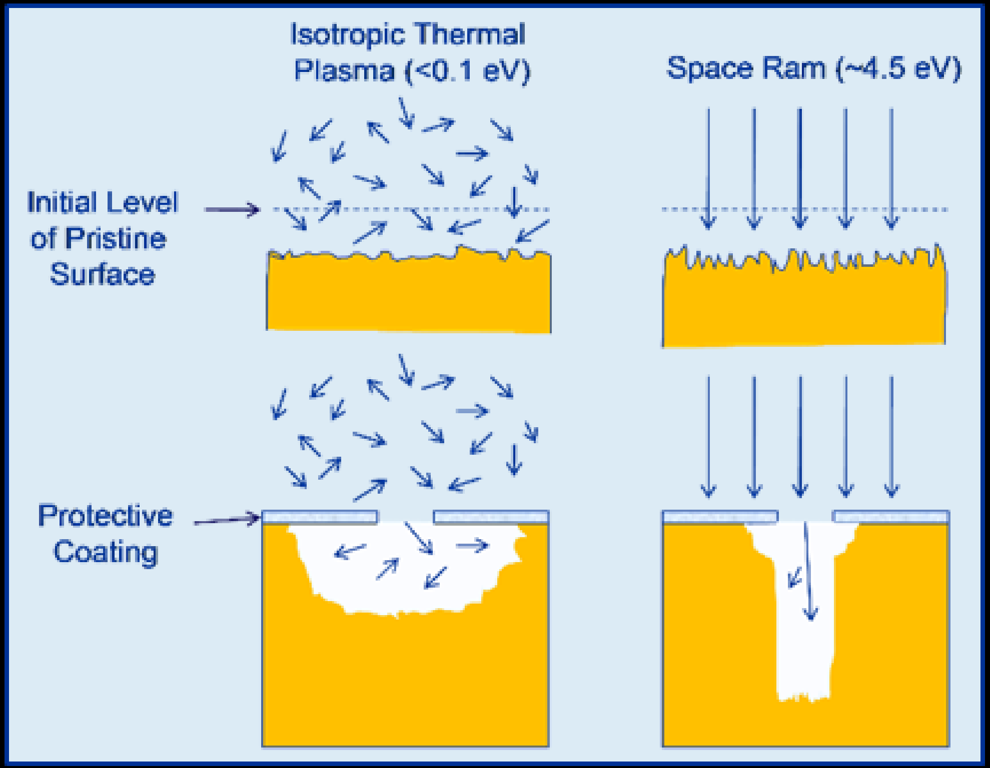
Material Testing in Ground-Based Simulation Facilities

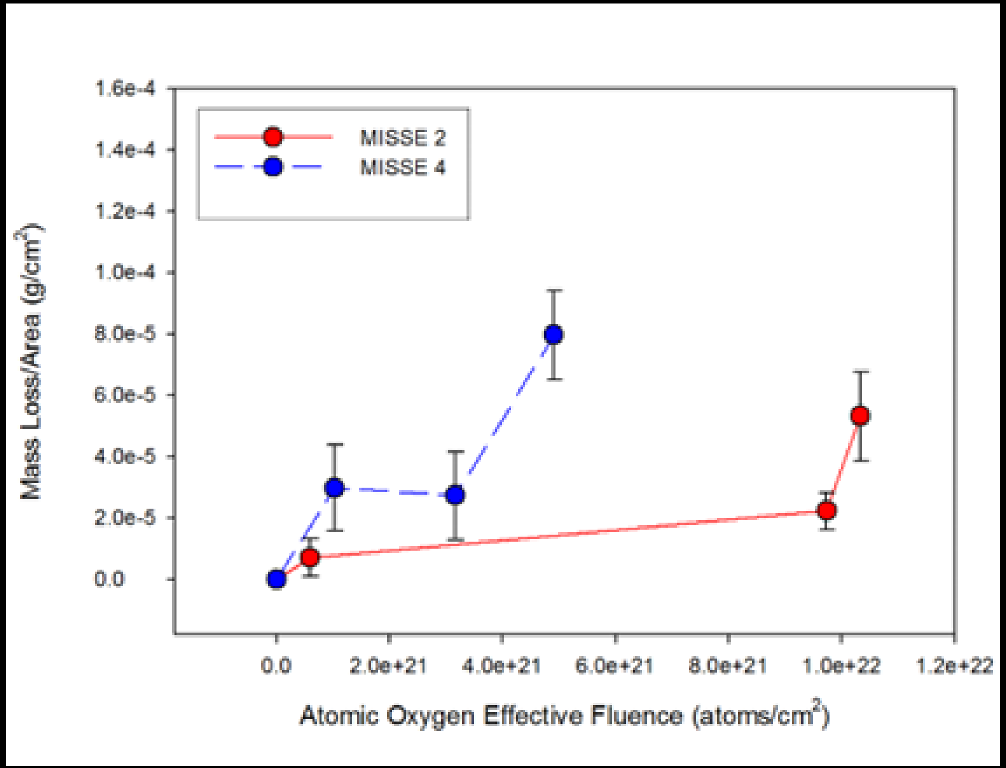






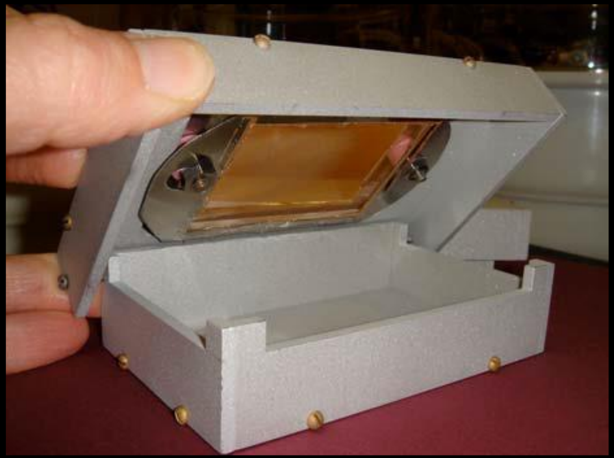
Difference in Erosion Rates Between Ground-Based and Space Exposure Due to Energy of Incoming Atoms for Coated Polymers

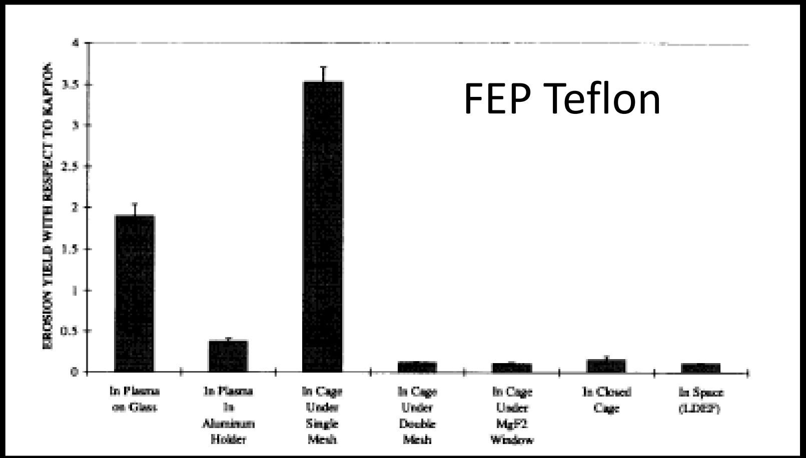


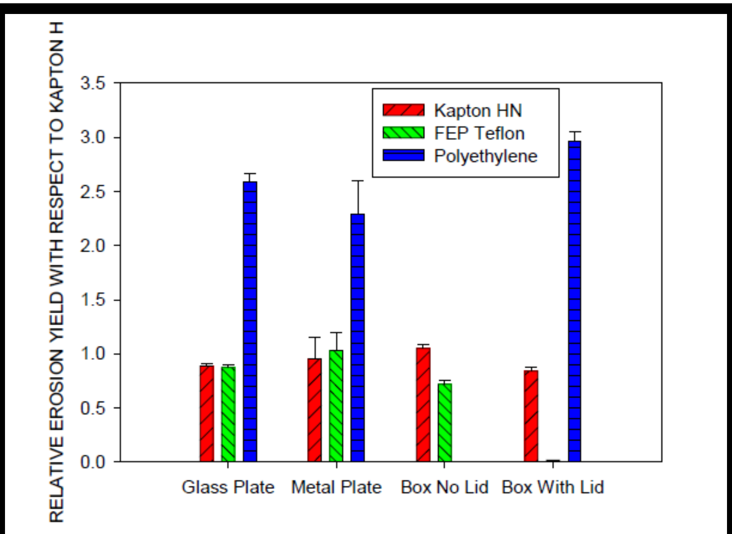


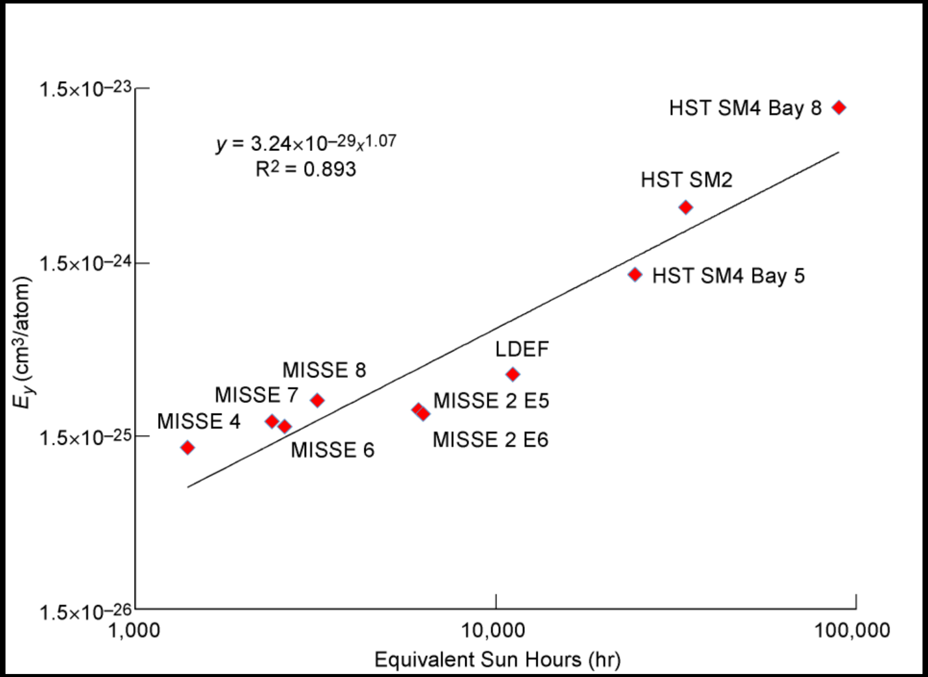
Coated Kapton samples exposed to ground-based isotropic atomic oxygen prior to and after flight. Central slope region represents loss during MISSE flight. Ground based isotropic system about 18 times more reactive than in LEO for a protected polymer

Difference in Erosion Yield for FEP Teflon in Combined Environments for Ground and Space









Erosion yield versus solar exposure (ESH) for FEP Teflon flown on various missions. Graph from de Groh, K.; and Banks, B. "Atomic Oxygen Erosion Data From the MISSE 2–8 Missions"; NASA TM 2019-219982. May, 2019

Summary

- Atomic oxygen is present in the upper atmosphere of many planetary bodies and is created by dissociation of oxygen by ultraviolet radiation from the sun
- The amount of atomic oxygen arriving at a spacecraft surface depends on the solar cycle and orientation
- Atomic oxygen is very reactive and can cause changes in optical, thermal and mechanical properties of materials
- The degree of erosion can depend on the presence of other environmental and induced factors
- It is important to consider the total environment that materials will be exposed to when testing materials in space or in ground-based systems