Atomic Oxygen and Vacuum Ultraviolet Radiation Simulation Chamber at California Polytechnic State University, San Luis Obispo

Cal Poly Aerospace Engineering

National Geographic's 5th Happiest City in America (2018)

Cal Poly Strategic Plan

Learn by Doing at Cal Poly involves aspects of both "experiential learning" and "discovery learning." Experiential learning is an active learning process in which students learn from the experience of testing ideas and assumptions. In experiential learning faculty members set out clear activities with defined learning objectives that students need to meet. Discovery learning involves the process of a student learning for herself or himself in problem solving situations.

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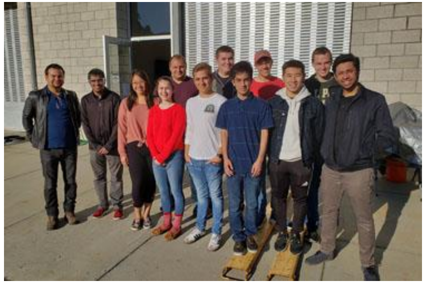
LABORATORY
Cal Poly Aerospace Low Speed Wind Tunnel
Undergraduate Computer Lab
Propulsion Lab
Department Lecture Room
Space Environments and Testing Lab
Structures Lab
CubeSat/PolySat Lab
Computational Fluid Dynamics Lab
Conference Room

In-Class Activities

Clubs & Student Organizations



Cal Poly In the Industry

Some Familiar Faces

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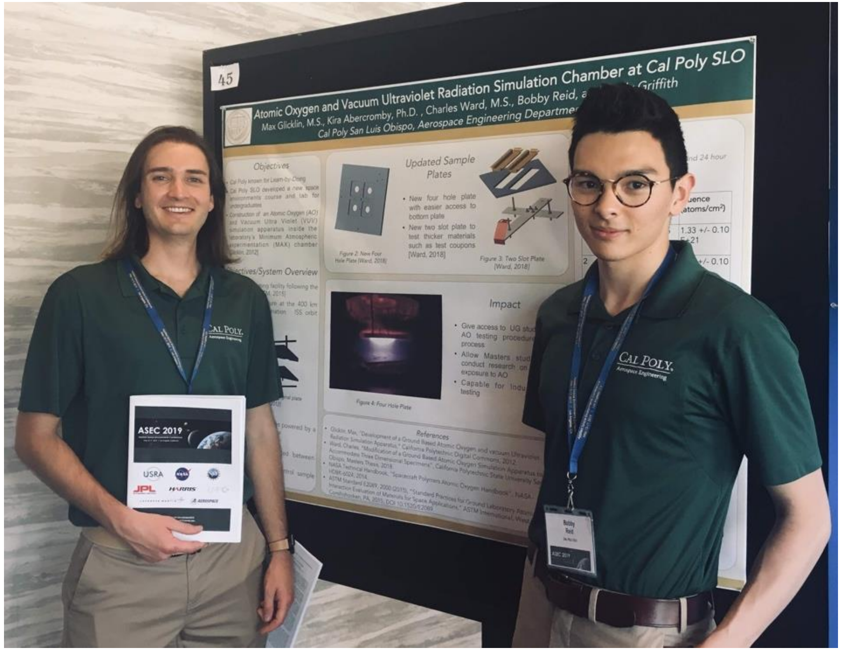
Atomic Oxygen and Vacuum Radiation Simulation Chamber at Cal Poly SLO



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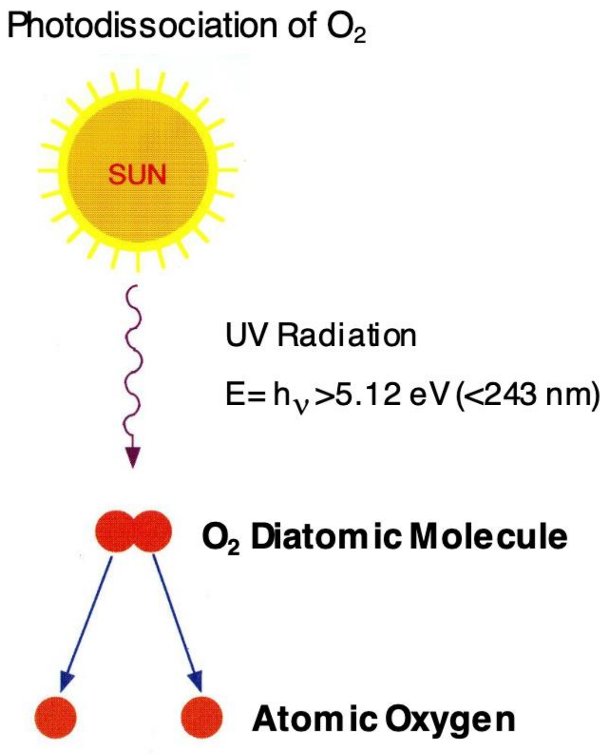
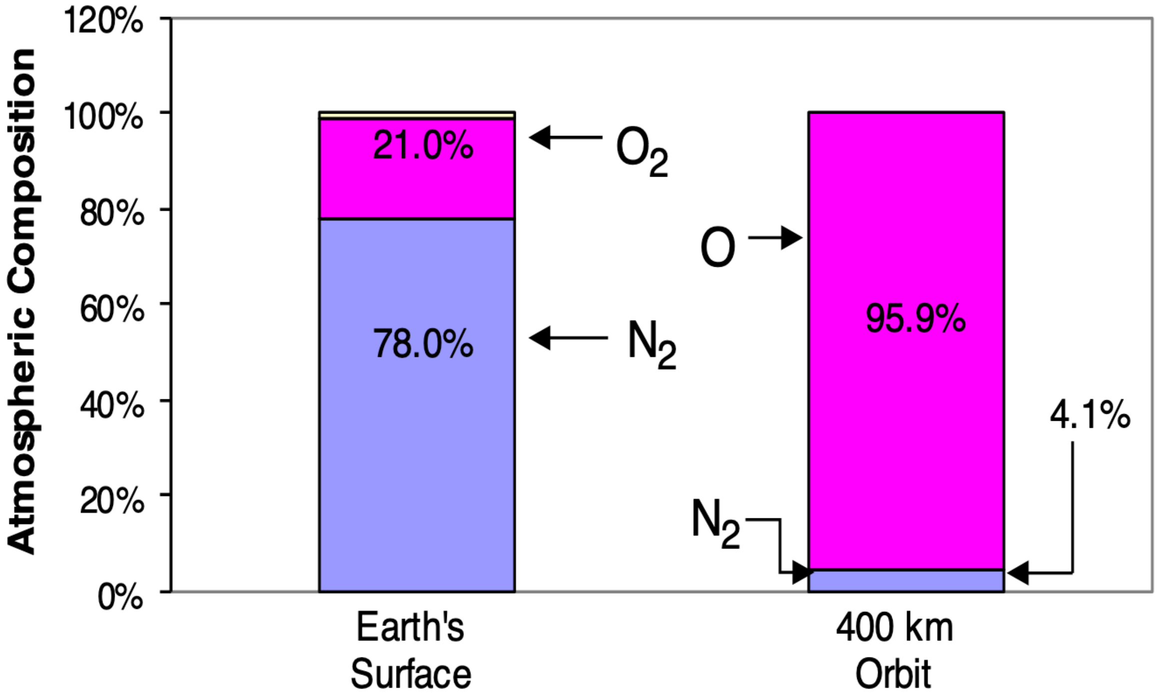
Atomic Oxygen Overview

- Atomic Oxygen (AO): monatomic oxygen atoms
  - Created by photo-disassociation of diatomic oxygen by UV radiation



AO is the dominant species between 180 km and 675 km[1]



Atomic Oxygen Overview

- Average ram energy in LEO ~ 4.5 eV
- Corrosive to organic S/C materials due to high collision energy-–high enough to break bonds

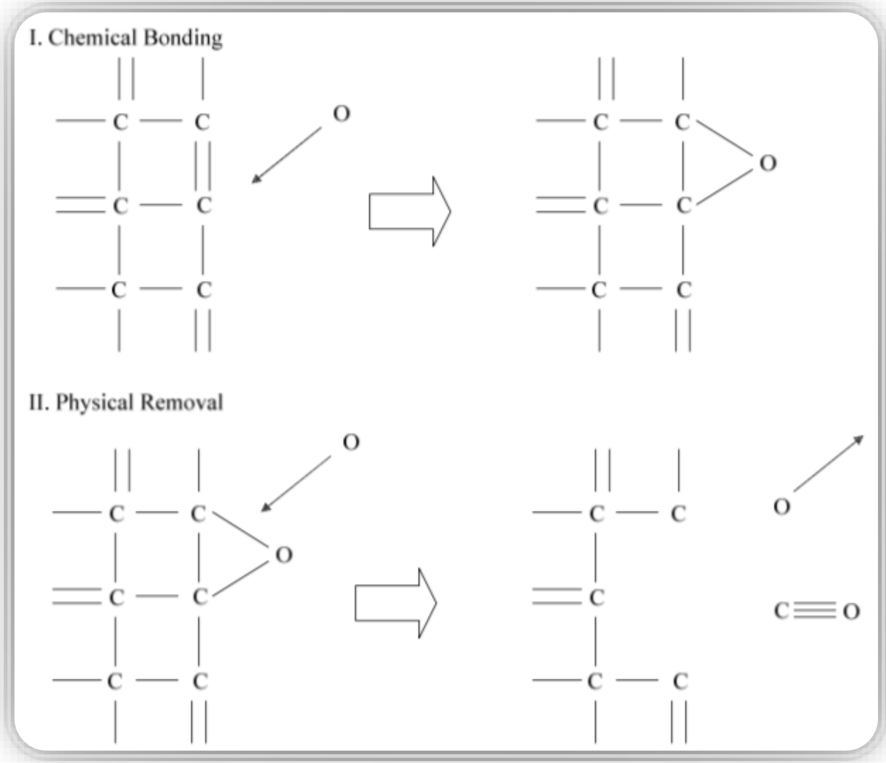
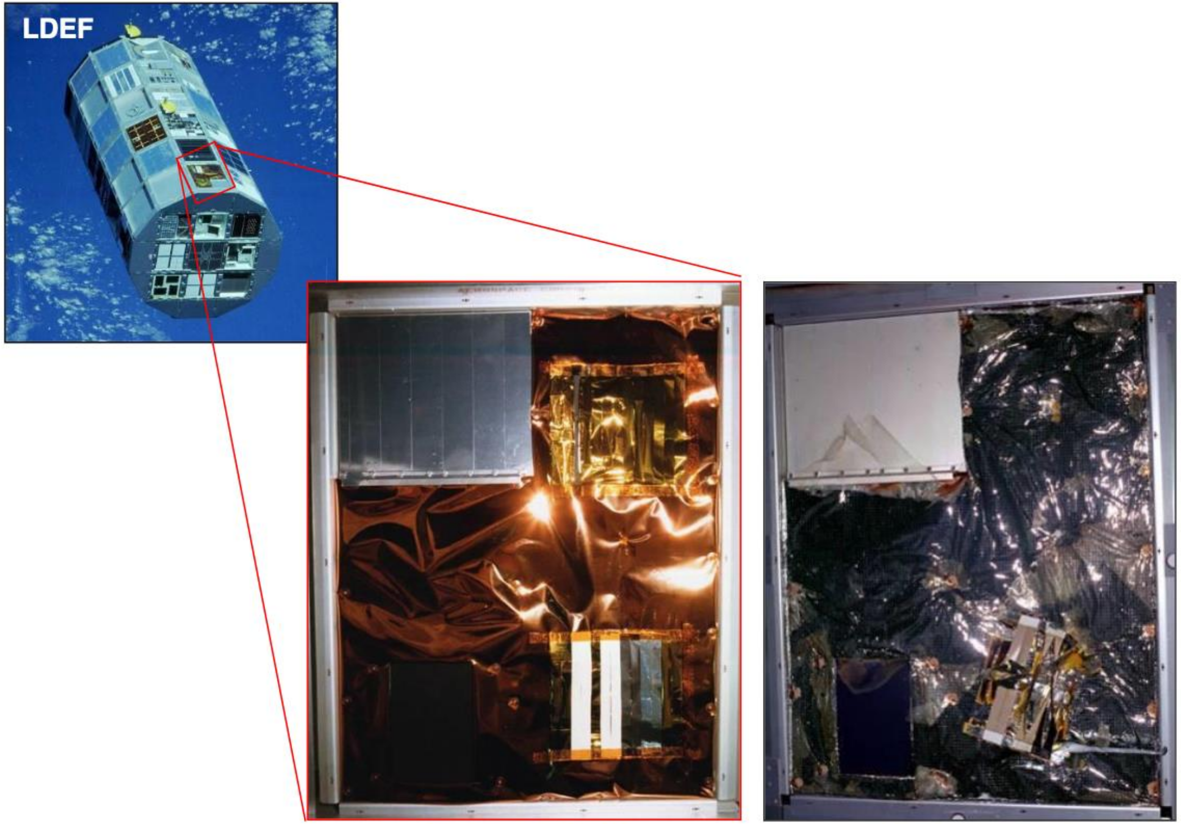


Diagram of the AO Erosion Process[1]



Prior to Flight

After 5.8 years in LEO

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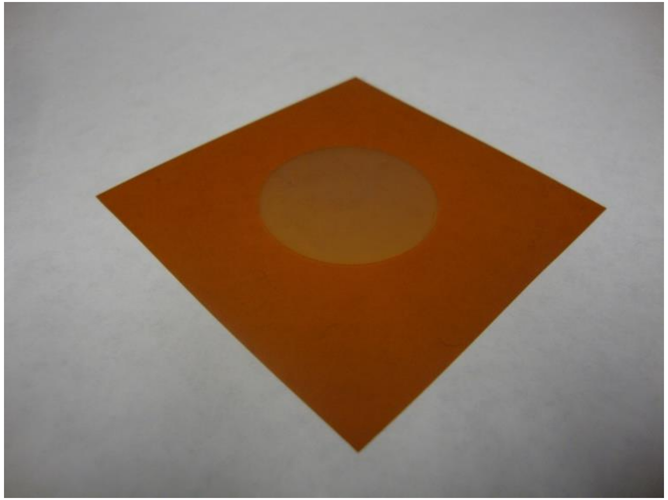
AO Material Testing

- Placing materials on orbit to collect empirical data is possible and has been done
  - Extremely costly, time-consuming, and cannot provide accelerated testing for long-term durability predictions
  - Need for the development of ground-based simulation facilities.
- The most common methods use either Radio Frequency, RF, microwave, or laser energy to disassociate diatomic oxygen into AO.
- The best current method for creating AO at ground facilities include plasma ashers, continuous or pulsed lasers, gridded or grid-less ion sources or microwave electron resonance sources



Kapton HN sample following 24-hour exposure testing[1]

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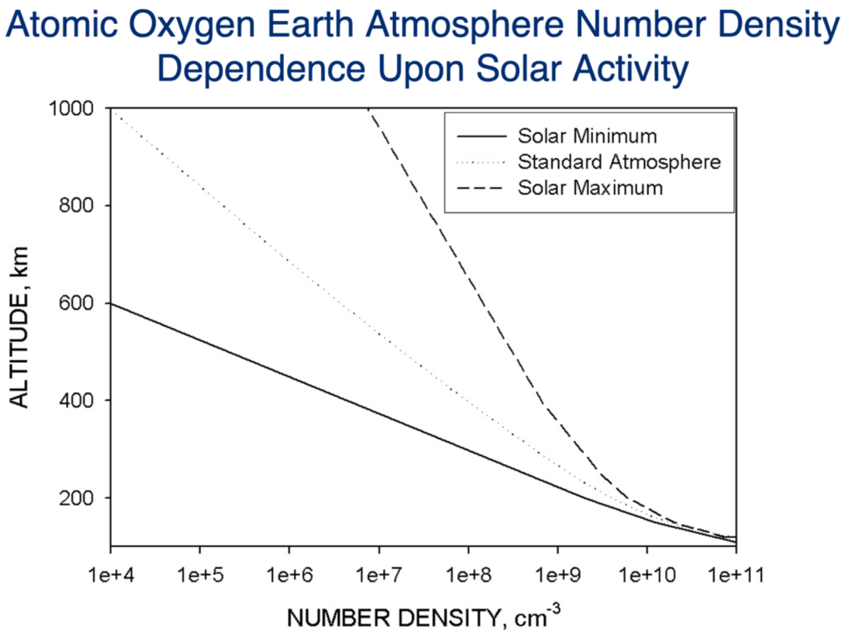
Plasma Ashers

- Create thermal energy plasma around 0.1 eV–far below the AO orbital energy of 4.5 eV
- Low cost and high simplicity
- Produces AO plasma that is characteristically different from orbital AO-–still generates material erosion qualitatively similar to orbital AO
- Require a considerably higher flux to produce equal levels of oxidation



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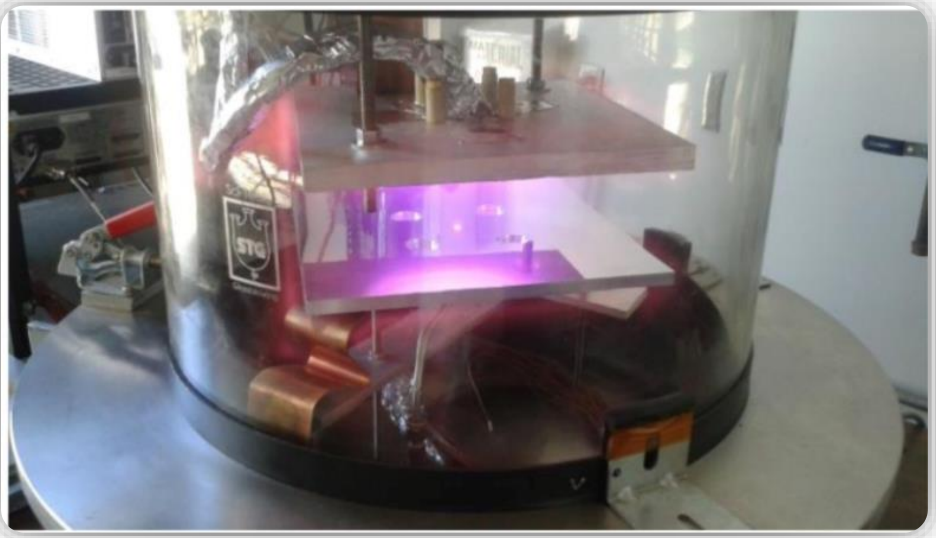
Minimum Atmospheric Experimentation (MAX) Chamber



AO Plasma Production During 24-Hour Exposure Test[5]

- Developed in 2011, completed in 2012 as a Masters thesis by Max Glicklin.
- Incorporated into mandatory curriculum for AERO students with a concentration in astronautics.
- Also used for research efforts in for numerous senior projects and masters' thesis

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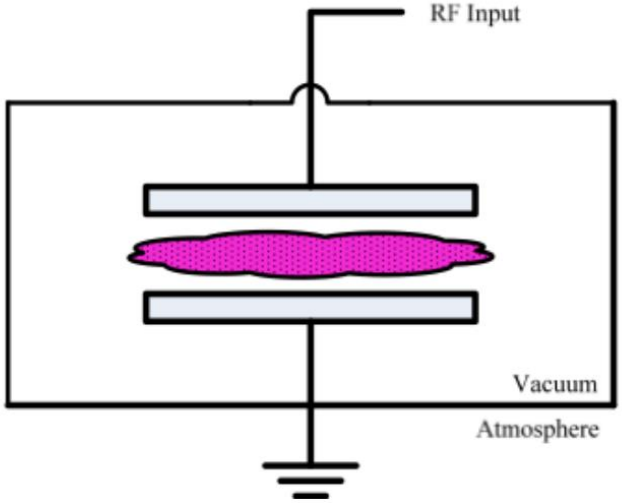
Original System

- Atomic oxygen is produced through a capacitively coupled plasma system
  - Low cost, easy to construct
- Two parallel electrodes powered by a 13.56 MHz RF generator
- RF electrode has 15.24cm diameter
  - Confined by dark space shield, which constrains AO generation to the desired exposure area
- Atmospheric air is injected between the electrodes and provides the diatomic oxygen to generate the AO



Simple schematic of a capacitively coupled plasma system[1]

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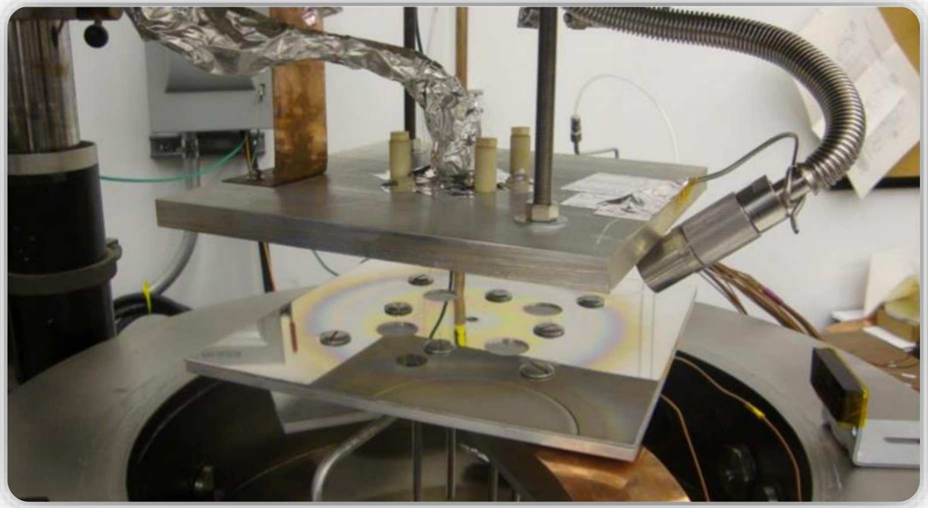
Original System

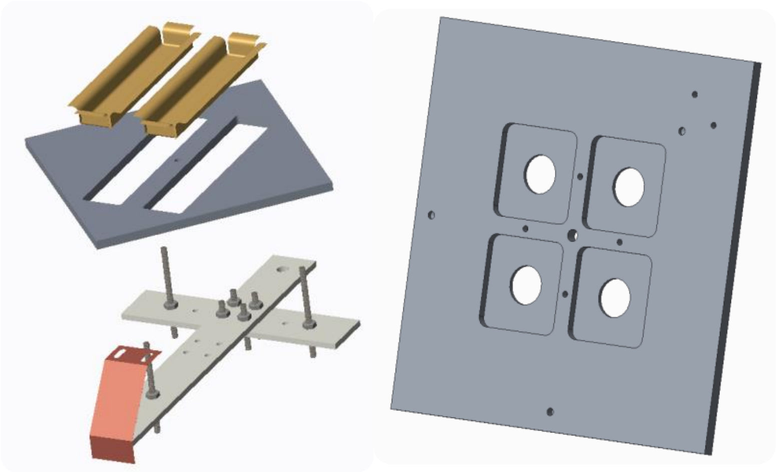
- Electrode gap distance of 7.62 cm
- Chamber pressure of 175 +/- 10 mTorr,
- Input power of 125 W
- Original system was intended to be used for testing on thin film materials.
  - Four 2.54 cm diameter holes equally distributed in the exposure area.
- VUV light source incorporated into the system to study the synergistic effects of radiation and AO



Original Sample Plate with VUV Deuterium Lamp[1]

System Updates

- Plates were redesigned to allow for testing of larger samples and increase the ease of access to the samples.
- Electrode gap kept the same as the original system but entire system was raised to provide more room for researchers to insert samples.
- A second plate option was added: the original four-hole plate and a new, deeper two-slot plate.
- Both plates machined from 0.95 cm thick 6061 aluminum plate with a mirror finish.



Updated four-hole plate and the new two-slot plate[4]

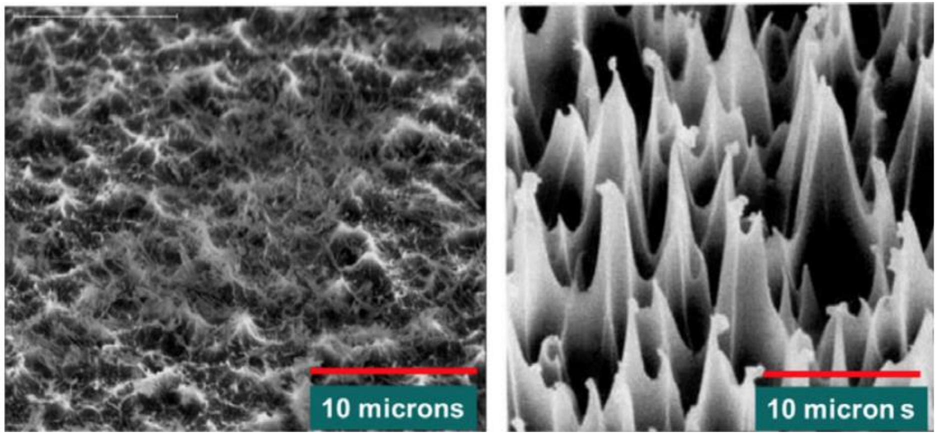
System Output

Sample Location	Flux (atoms/cm^2/s)	Fluence (atoms/cm^2)
1	1.54 +/- 0.05 E+16	1.33 +/- 0.10 E+21
2	1.61 +/- 0.05 E+16	1.39 +/- 0.10 E+21
3	1.58 +/- 0.05 E+16	1.37 +/- 0.10 E+21
4	1.63 +/- 0.05 E+16	1.40 +/- 0.10 E+21

Sample 24-Hour Fluence[4]

Research Plans

- Low energy level plasma are omnidirectional and travel at low speeds.
  - Does not mimic erosion found on orbit
  - MAX cannot produce the impact energy found on orbit
  - Negate this by increasing the number density of AO particles
    - Some particles will have enough energy to replicate AO erosion according to the Maxwellian distribution
- There are complications associated with using erosion yield results from plasma ashers to predict performance in space.[4]
  - The relative ranking of erosion from asher data frequently does not prove to be reliable for predicting in-space results
  - Note:
- Objective: compare the capabilities of the two systems, namely the AO flux variance, erosion yields, depth of erosion, and erosion rate.

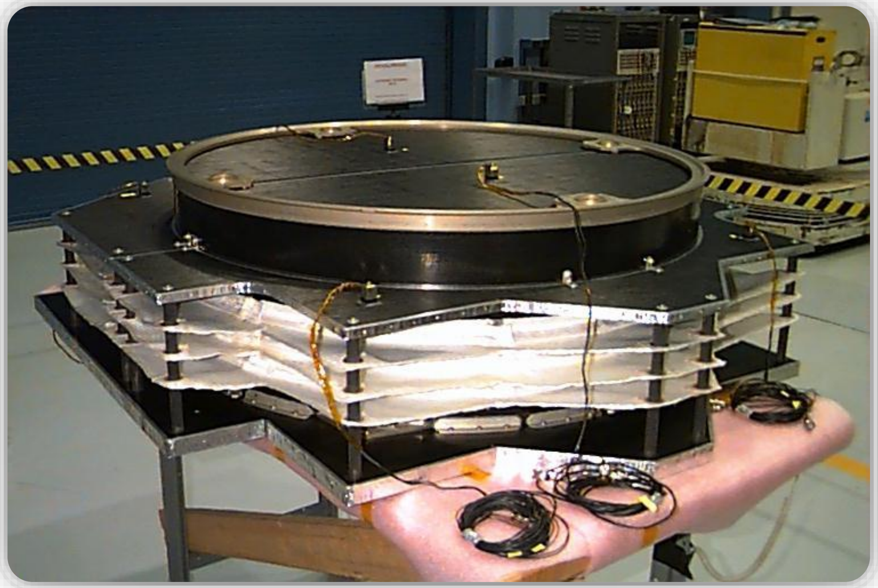


(a) (b)

Scanning electron microscope photograph showing surface roughness (pits and cones) of Chlorotrifluoroethylene after AO exposure in a (a) thermal energy plasma asher and (b) in LEO at ~4.5 eV [6]

Future Plans

- Refitting of VUV lamp to MAX to study the synergistic effects of VUV and AO on spacecraft material
- Degradation in the performance of Whipple Shields and MLI blankets following AO Degradation
- Evaluation of MLI Thermal Blankets before and after AO exposure
- Observation of the effects of AO exposure on electrical components



Whipple Shield On the NASA Stardust Probe[7]

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References

[1] Glicklin, Max J., “Development of a Ground Based Atomic Oxygen and vacuum Ultraviolet Radiation Simulation Apparatus,” California Polytechnic Digital Commons, 2012.

[2] “ECR (Electron Cyclotron Resonance) plasma source,” *ECR (Electron Cyclotron Resonance) plasma*

[3] Yokota, K., Tagawa, M., and Kleiman, J. I., “Atomic Oxygen Exposure Test Capabilities at Kobe University: Its Performance and Limitations,” 2019.

[4] Banks, B. A., *Simulation of the low earth orbital atomic oxygen interaction with materials by means of an oxygen ion beam*, Cleveland, OH: National Aeronautics and Space Administration, Lewis Research Center, 1989.

[5] Glicklin, M., Abercromby, K., Reid, B., Griffith, C., and Ward, C., “Atomic Oxygen and Vacuum Ultraviolet Radiation Simulation Chamber at California Polytechnic State University, San Luis Obispo,” 2019.

[6] Banks, B.A.,Kneubel, C.A., and Miller, S.K., *Atomic oxygen energy in low frequency hyperthermal plasma ashers*, Cleveland, OH: ..

[7] “STARDUST Nasa's Comet Sample Return Mission,” *NASA* Available: https://stardust.jpl.nasa.gov/photo/spacecraft.html#whipple.

Thank You Very Much