Spring 4-2-2012

Simulation Chamber for Space Environment Survivability Testing

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NCUR 2012 national conference on undergraduate research WEBER STATE UNIVERSITY OGDEN · UTAH MARCH 29-31, 2012

Space Environment Effects

Before After

The space environment can modify materials and cause detrimental effects to satellites. Some of these effects are change in reflectivity and emissivity, which lead to changes in thermal, optical, and charging properties. If these are severe enough the spacecraft will not operate as designed.

The key to predicting and mitigating these deleterious effects is the ability to accurately simulate space environment effects through long-duration, well-characterized testing in an accelerated, versatile laboratory environment.

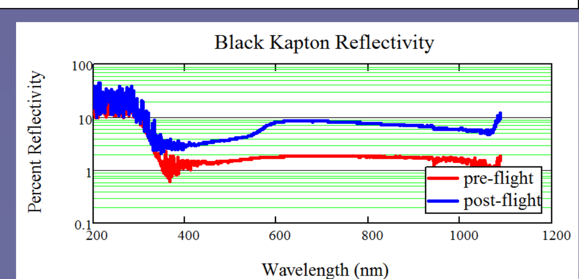
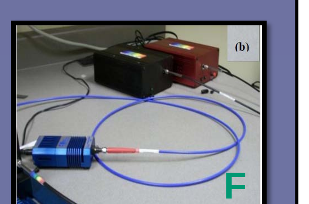
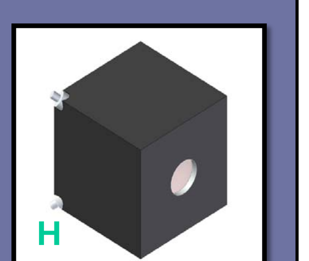


Fig. 6. (Top) Damaged Solar Panel due to overcharging. (Middle/Bottom) Photographs and UV/VIS/NIR spectra comparing pre- and post-flight samples from SUSpECS II

In Situ Analysis Capability





UV/VIS/NIR Reflectivity-Two fiber optic spectrometers (F) measures reflectivity of UV/VIS/NIR (200-1080 nm) NIR (858-1700 nm) ranges with <1 nm resolution.

Integrating Sphere-A 2.5 cm diameter integrating sphere (H) can be extended over the samples with a retractable probe linear translation stage (T). The sample stage can be rotated to position different samples under the probes. Light from a deuterium/W-halogen calibrated light source enters the integrating sphere through one fiber optic connection; reflected light from the sample exits through another fiber optic to spectrometers.

IR Emissivitty-Measured with retractable probe (4 μm to 15 μm) (G) mounted on probe translation stage. .

Calibration Samples-*In situ* high and low reflectivity/emissivity calibration standards (N) are mounted behind the probe translation stage.

Light Flux-Continuously monitored with *in situ* photodiodes (I) on sample stage (M) equipped with filters to separately monitor NIR, VIS, UV intensities. Exterior sensor feedback used to regulate the solar simulator intensity.

Electron Flux-Continuously monitored with *in situ* Faraday cup (J) on sample stage (M).

Temperature-Monitored with platinum RTDs (K).

Pressure--Absolute pressure monitored with Convectron and ion gauges (Y). Partial pressure measured with a Residual Gas Analyzer (Z).

Versatile Sample Holder Design

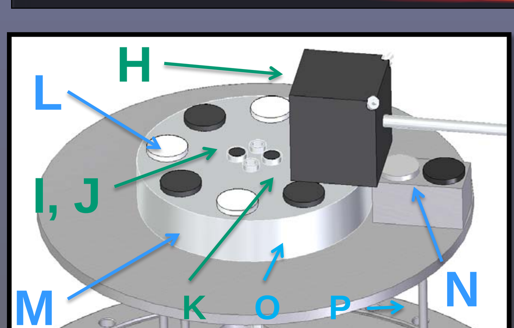


Fig. 7. View of Sample Carousel and Probe Translation Stage.

Sample Stage-Sample stage (M) connected to 355º rotary feedthrough (S) to position samples under probe translation stage (T) and enhance flux uniformity by periodic rotation. Sample stage shown has six 2.5 cm diameter samples (L) plus flux sensors (I,J,K); alternate configurations have up to one 10 cm diameter sample. Uniform temperature over ~100 K to 450 K controlled using attached cryogenic reservoir (P) and resistance heaters (O). Large thermal mass helps maintain stable thermal.

Acknowledgements/References

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•Dennison, J R, "Charge-Enhanced Contamination and Environmental Degradation of MISSE-6 SUSpECS Materials," IEEE Transactions on Plasma Science, February 2012, Vol. 40
•Dennison, J R and Dyre, James S., "Proposal to Perform Survivability Testing of Radiator Coatings for Solar Probe Plus", May 27, 2011.
•Swaminathan, Prasanna V., "Measurements of Charge Storage Decay Time and Resistivity of Spacecraft Insulators," Masters Thesis, Utah State University, Logan, UT 2004.

Abstract

A vacuum chamber was designed and built that simulates the space environment making possible the testing of material modification due to exposure of solar radiation. Critical environmental components required include an ultra high vacuum (10-9 Torr), a UV/VIS/NIR solar spectrum source, an electron gun and charge plasma, temperature extremes, and long exposure duration. To simulate the solar spectrum, a solar simulator was attached to the chamber with a range of 200nm to 2000nm. The exposure time can be accelerated by scaling the solar intensity up to four suns. A Krypton lamp imitates the 120 nm ultraviolet hydrogen Lymann alpha emission not produced by the solar simulator. A temperature range from 100K to 450K is achieved using an attached cryogenic reservoir and resistance heaters. An electron flood gun (mono-energetic, 20 eV to 15keV) is calibrated to replicate solar wind at desired distances from the sun. The chamber maintains 98% uniformity of the electron and electromagnetic radiation exposure relative to the center. The chamber allows for a cost-effective investigation of multiple small-scale samples. An automated data acquisition system monitors and records the reflectivity, absorptivity, and emissivity of the samples throughout the test. An integrating sphere and an IR absorptivity/emissivity probe are used to collect this data. The system allows for measurements to be taken while the samples are still under vacuum and exposed to radiation. With these accurate simulations we can closely predict the material's behavior in near proximity to the sun. This information is vital in determining materials for satellites, probes, and any other spacecraft .

Experimental Test Chamber Design

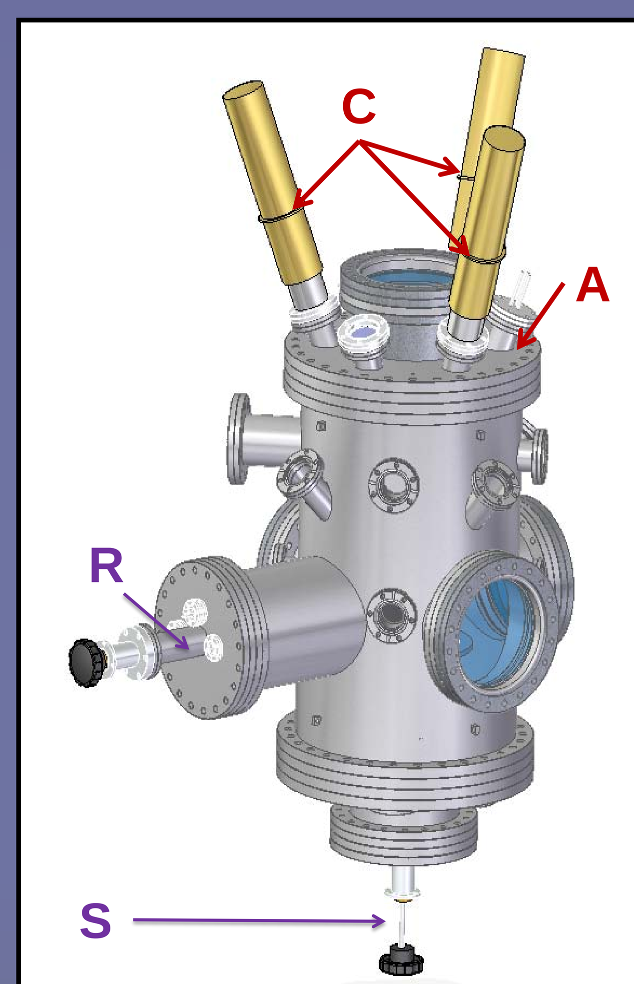


Fig. 1. Chamber Exterior View.

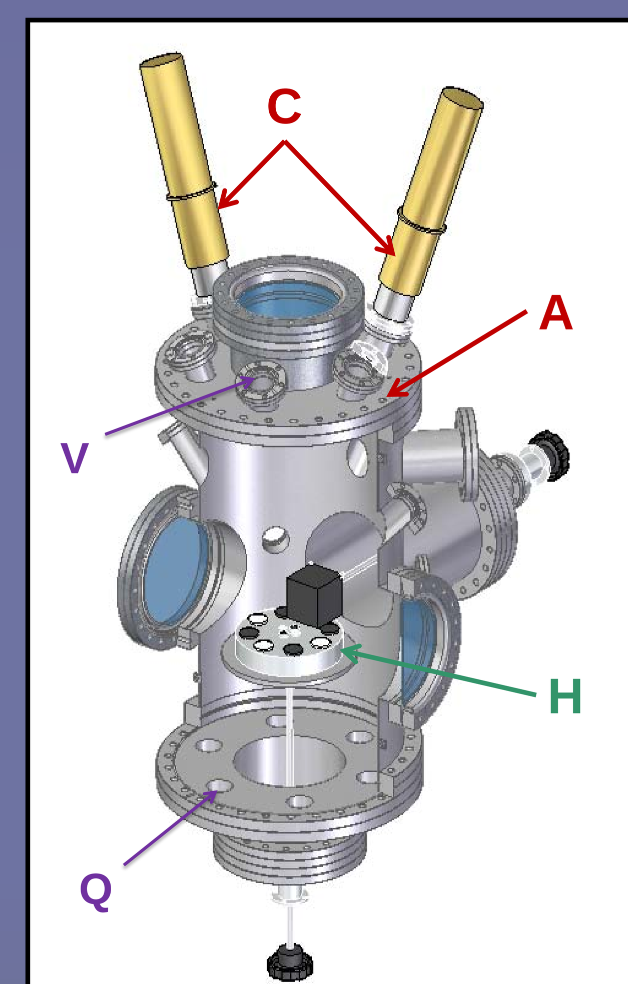


Fig. 2 . Chamber Vertical Cutaway View.

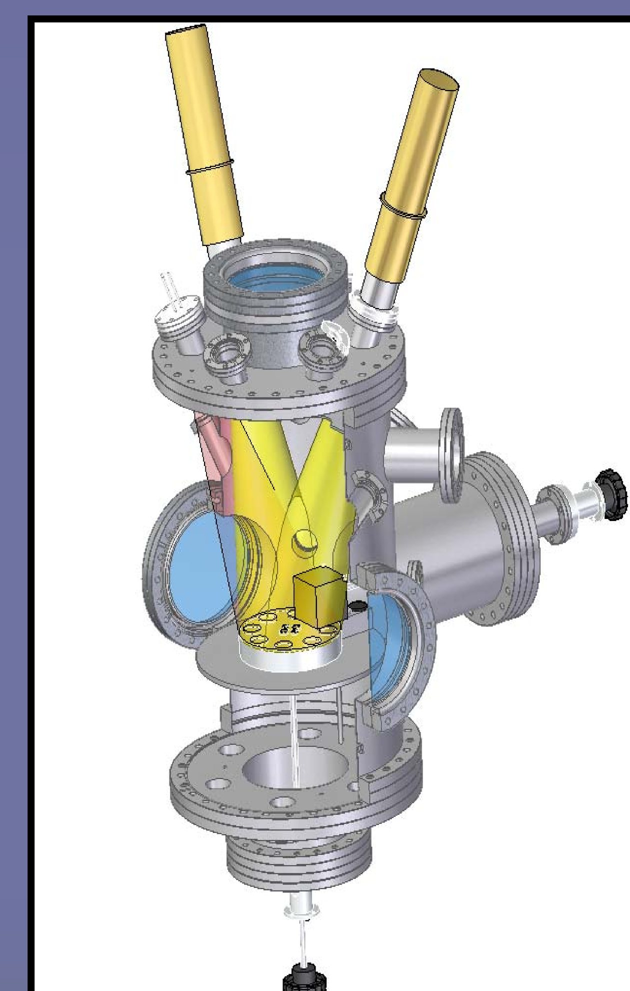


Fig. 3 Cutaway View of Beam Trajectories.

Legend of Components

Radiation Sources
- A Electron Gun
- B UV/VIS/NIR Solar Simulator
- C FUV Krypton Discharge Lamps
- D Air Mass Zero Filter Set
- E Flux Mask

Sample Carousel
- L Samples
- M Rotating Sample Carousel
- N Reflectivity/Emissivity Calib. Standards
- O Resistance Heaters
- P Cryogenic Reservoir

Chamber Components
- Q Cryogen Vacuum Feedthough
- R Electrical Vacuum Feedthrough
- S Sample Rotational Vacuum Feedthrough
- T Translational Vacuum Feedthrough
- U Sapphire UV/VIS Viewport
- V MgF UV Viewport
- W Turbomolecular/Mech . Vacuum Pump
- X Ion Vacuum Pump
- Y Ion/Convectron Gauges—Pressure
- Z Residual Gas Analyzer—Gas Species

Analysis Components
- F UV/VIS/IR Reflectivity Spectrometers
- G IR Emissivity Probe
- H Integrating Sphere
- I Photodiodes–UV/VIS/IR Flux Monitor
- J Faraday Cup–Electron Flux Monitor
- K Platinum Resistance Temperature Probe

Instrumentation (Not Shown)
- Data Acquisition System
- Temperature Controller
- Electron Gun Controller
- UV/VIS/NIR Solar Simulator Controller
- FUV Kr Resonance Lamp Controller
- Spectrometers and Reflectivity Light

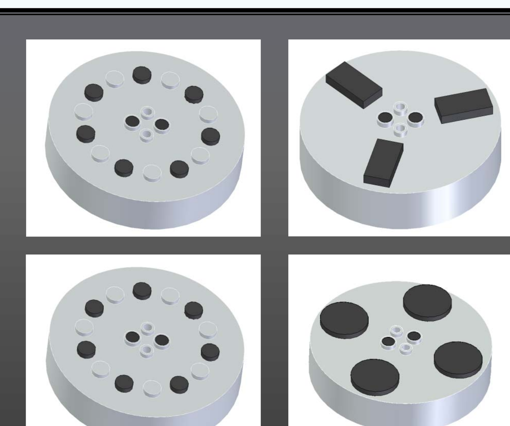
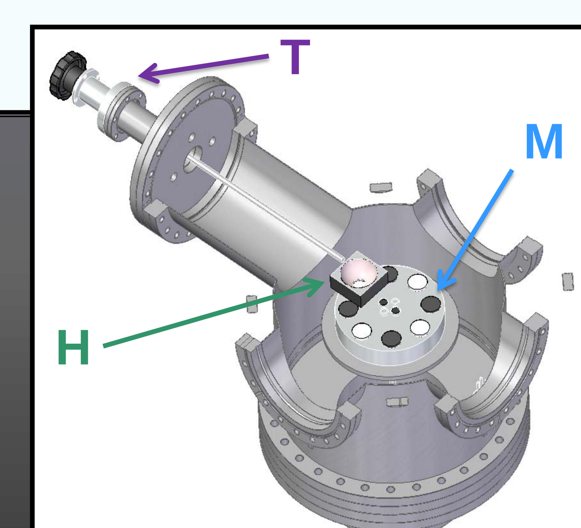


Fig. 4. (Right) Sample Level Cutaway View

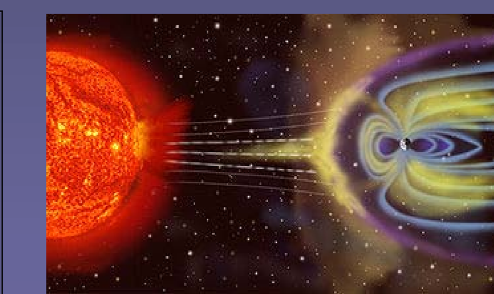
Fig. 5. (Left) The sample stage can be reconfigured for various sample sizes.

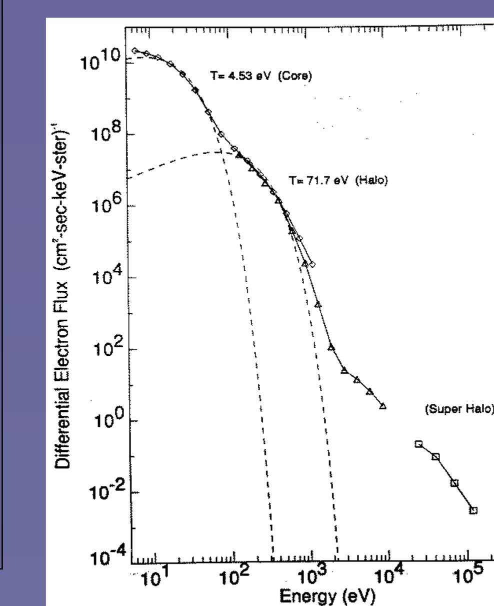
(Not Shown) The chamber can be reconfigured as a radiation source for other test chambers by removing the sample stage flange and bolting the upper source components to other SDL/USU chambers.



Space Environment Characteristics

There are certain characteristics of the space environment that are critical for a true simulation. These critical characteristics are electron flux, electromagnetic radiation, vacuum, and temperature. The electron flux is critical because the solar winds through space bombard spacecraft. The electromagnetic radiation has many critical aspects in itself. As can be seen in figure 10, the sun has a very broad range covering from the Visual/Infrared to Ultra Violet, specifically the Hydrogen Lyman Alpha emission at 121.6 nm. A vacuum simulation is critical because space is a vacuum, meaning very few particles. The temperature is critical because it changes drastically depending on proximity to the sun. Things not covered by this chamber are photons/ions, and atomic oxygen.





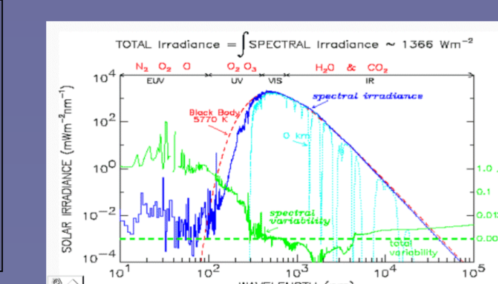


Fig. 8. (Top Right) Solar wind and Earth's magneto-sphere structure.

Fig. 9. (Right) Typical Space Electron Flux Spectra [Larsen].

Fig. 10. (Left) Solar Electro-magnetic Spectrum.

Space Simulation Capabilities

Versatile ultrahigh vacuum test chamber provides controlled temperature and vacuum environment with stable, uniform, long-duration electron and UV/VIS/NIR fluxes at up to 4 times sun equivalent intensities for accelerated testing for a sample area of 8 cm by 8 cm. Particularly well suited for cost-effective tests of multiple small scale materials samples over prolonged exposure.

Electron Flux—Electron flood gun (A) provides ≤5·10⁶ electrons/cm² (~1pA/cm² to 1 μA/cm²) flux needed to simulate the solar wind at more than the 100X cumulative electron flux. Mono-energetic energy range is ~0.05 to 15.00±0.01 keV. Gun provides a >98% uniform flux distribution over the full sample area, with "hot swappable" filaments for continuous exposure over the entire long duration testing. The electron gun was custom designed at USU after work by Swaminathan [2004].

Infrared/Visible/Ultraviolet Flux- A commercial Class AAA solar simulator (B) provides NIR/VIS/UVA/UVB electromagnetic radiation (from 200 nm to 1700 nm) at up to 4 times sun equivalent intensity for accelerated testing over an area of 80mmX80mm. Source uses a Xe discharge tube, parabolic reflector, collimating lens, and standard Air Mass Zero filters (D) to match the incident radiation spectrum to the solar spectrum. Xe bulbs have >1 month lifetimes for long duration studies.

Far Ultraviolet Flux- The Kr resonance lamps (C) provide FUV radiation flux (ranging from 10 to 200 nm) at 4 times sun equivalent intensity. Three lamps oriented 120º apart provide >98% flux uniformity. Lamp's emission lines reproduce the H Lymann-α line (121.6 nm) that dominates the solar FUV spectrum. Kr bulbs have ~3 month lifetimes for long duration studies.

Flux Mask-Flux mask (E) located near the chamber's top ports restricts the flux boundaries to the sample stage, limiting equipment exposure and reducing scattering to accommodate uniform exposure. Can be readily modified for different sample geometries.

View Ports- Solar simulator UV/VIS/NIR light passes through sapphire viewport (U). Krypton source FUV light passes through a Magnesium Fluoride window (V) . Additional viewports allow visual inspection.

Vacuum—Chamber uses standard mechanical and turbomolecular pumps (X) for roughing and an ion pump (Y) for continuous maintenance-free operation (base pressure <10⁻⁵ Pa).

Temperature---A temperature range from 100 K to 450 K is maintained to ±2 K by a standard PID temperature controller, using a cryogenic reservoir (Q) and resistance heaters (P) attached to a large thermal mass sample stage (M).