8-11-2016

CubeSat Space Environments Effects Studied in the Space Survivability Test Chamber

JR Dennison
Utah State Univesity

Gregory Wilson
Utah State University

Alex Souvall
Utah State University

Ben Russon
Utah State University

Katie Gamaunt
Utah State University

Recommended Citation

Dennison, JR; Wilson, Gregory; Souvall, Alex; Russon, Ben; and Gamaunt, Katie, "CubeSat Space Environments Effects Studied in the Space Survivability Test Chamber" (2016). 30th Annual AIAA/USU Conference on Small Satellites. *Posters.* Paper 45.
https://digitalcommons.usu.edu/mp_post/45

CubeSat Space Environments Effects Studied in the Space Survivability Test Chamber

JR Dennison, Gregory Wilson, Alex Souvall, Ben Russon, and Katie Gamaunt

Material Physics Group, Physics Department, Utah State University

Overview

The Utah State University Materials Physics Group (MPG) has developed an extensive versatile and cost-effective pre-launch test capability for verification and assessment of small satellites, system components, and spacecraft materials. The facilities can perform environmental testing and component characterization related to typical CubeSats—including performance of radiation damage, solar arrays, electronics, sensor and memory components, and structural integrity—in a cost effective way.

CubeSats are particularly susceptible to environmental-induced modifications, which can lead to deleterious or catastrophic consequences. This is increasingly important as small satellites—with minimal shielding due to reduced mass and size constraints and reliance on more compact and sensitive electronics—have longer mission lifetimes and make more diverse, complex and sensitive measurements. The current push to expand deployment of CubeSats beyond LEO, into even more demanding environments where modest relief due to shielding by the Earth's magnetosphere is absent (such as polar or GEO orbits), can further exacerbate these problems. Testing of small satellites is therefore critical to avoid such problems.

Space Environment Characteristics

The Space Survivability Test (SST) chamber simulates several critical characteristics of the space environment: electron flux, ionizing radiation, photon flux, temperature and neutral gas environment. Figures 2 shows representative electron spectra for several common environments. The solar UV/Vis/NIR spectrum is shown in Fig. 3. The range of electron, ionizing radiation, and photon sources are shown above the environmental flux graphs. Samples are in a low density particle environment, using a vacuum or controlled neutral gas environment down to ~10^{-6} Pa. Temperature can be maintained for prolonged testing from ~60 K to ~450 K. This chamber does not yet simulate ions, plasma or atomic oxygen.

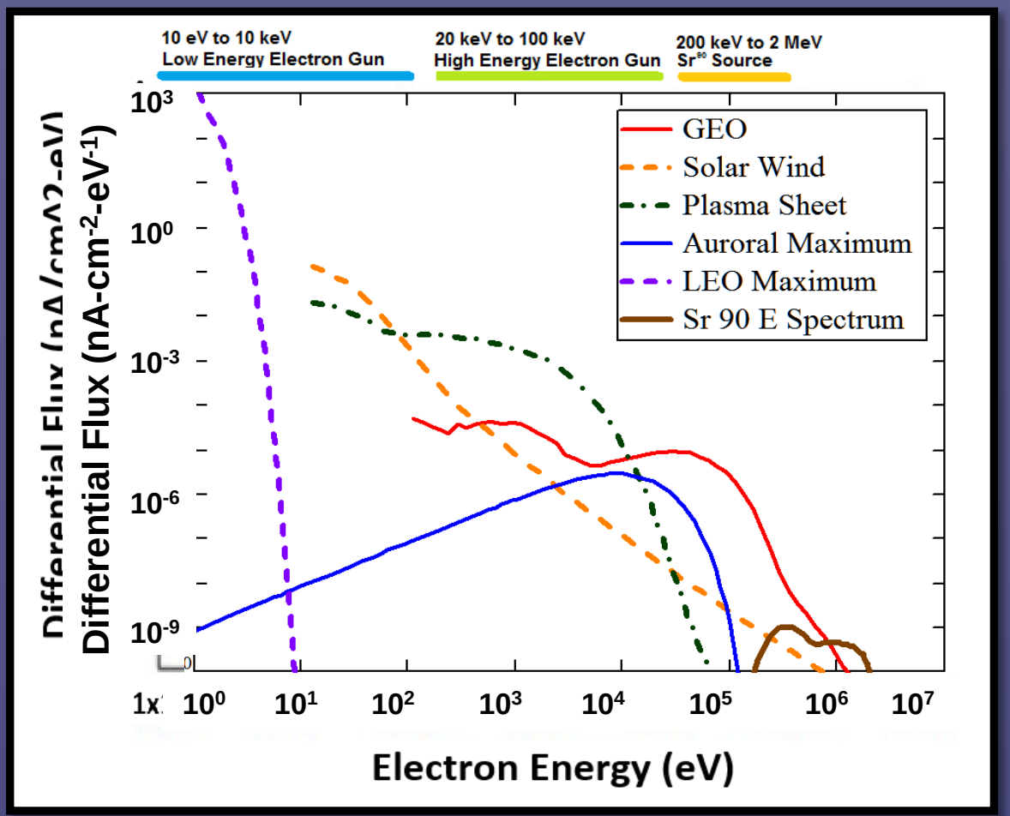


Fig. 1. Typical Space Electron Flux Spectra. Bars show source ranges.

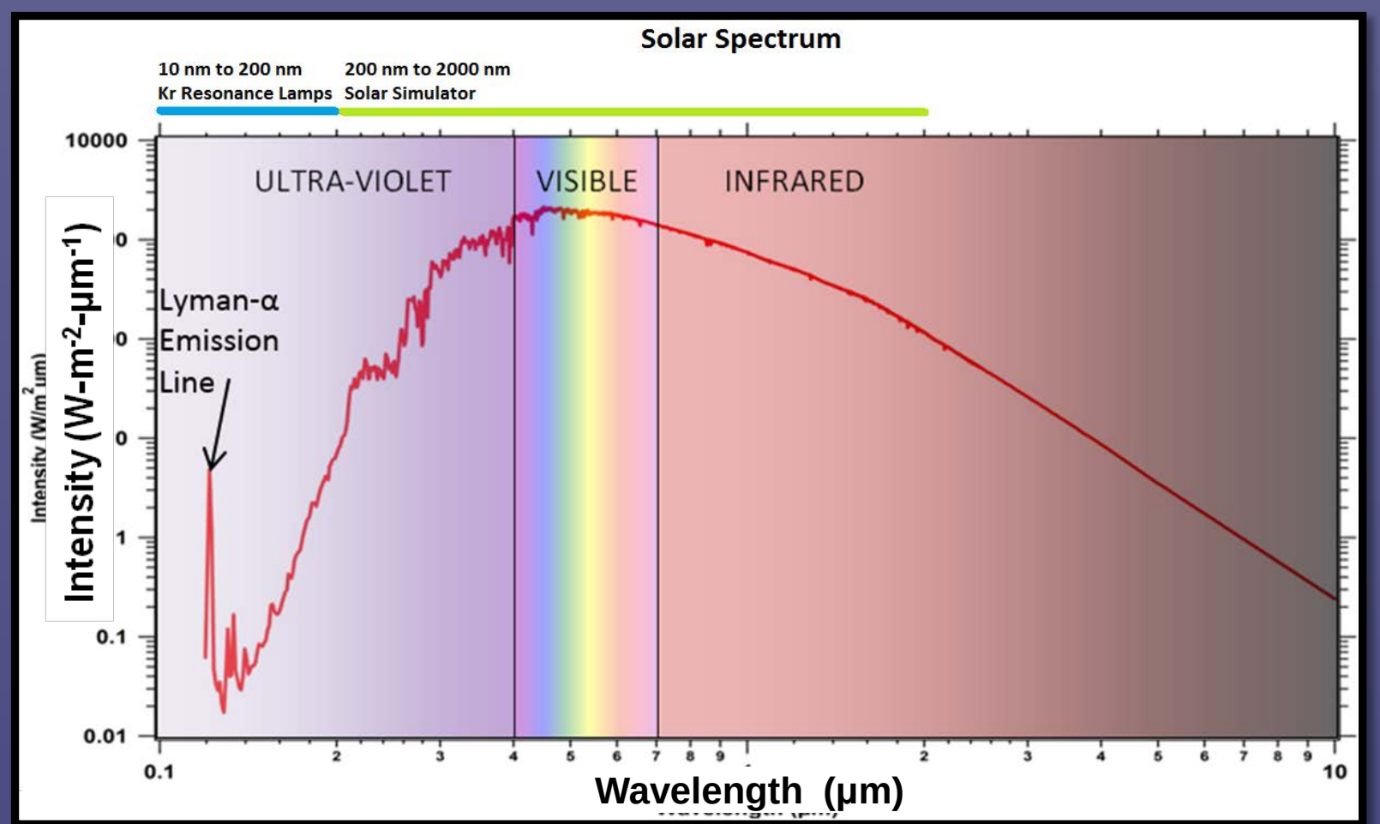


Fig. 32 AM0 Solar Electromagnetic Spectrum. Bars show source ranges.

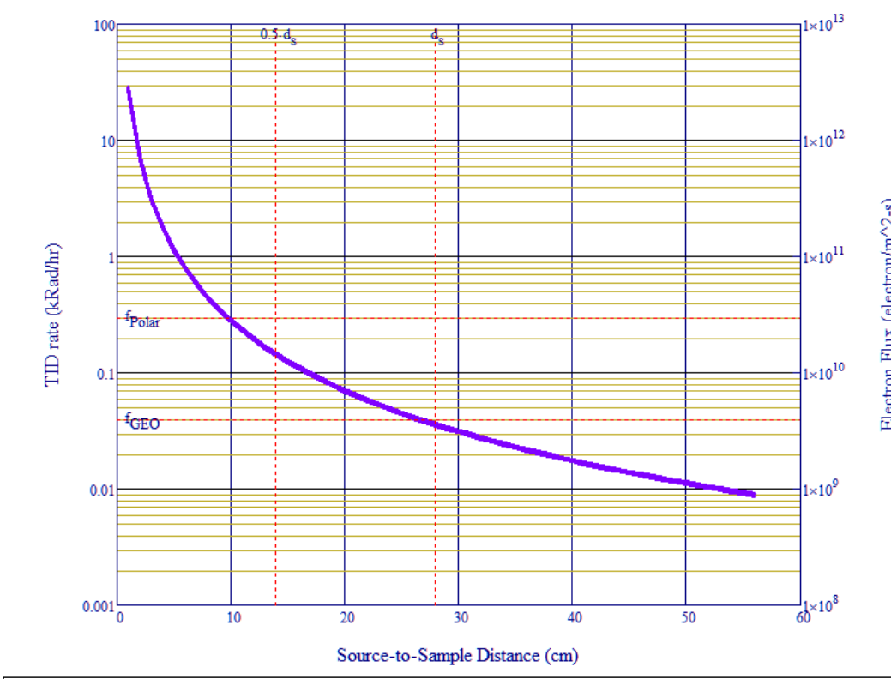
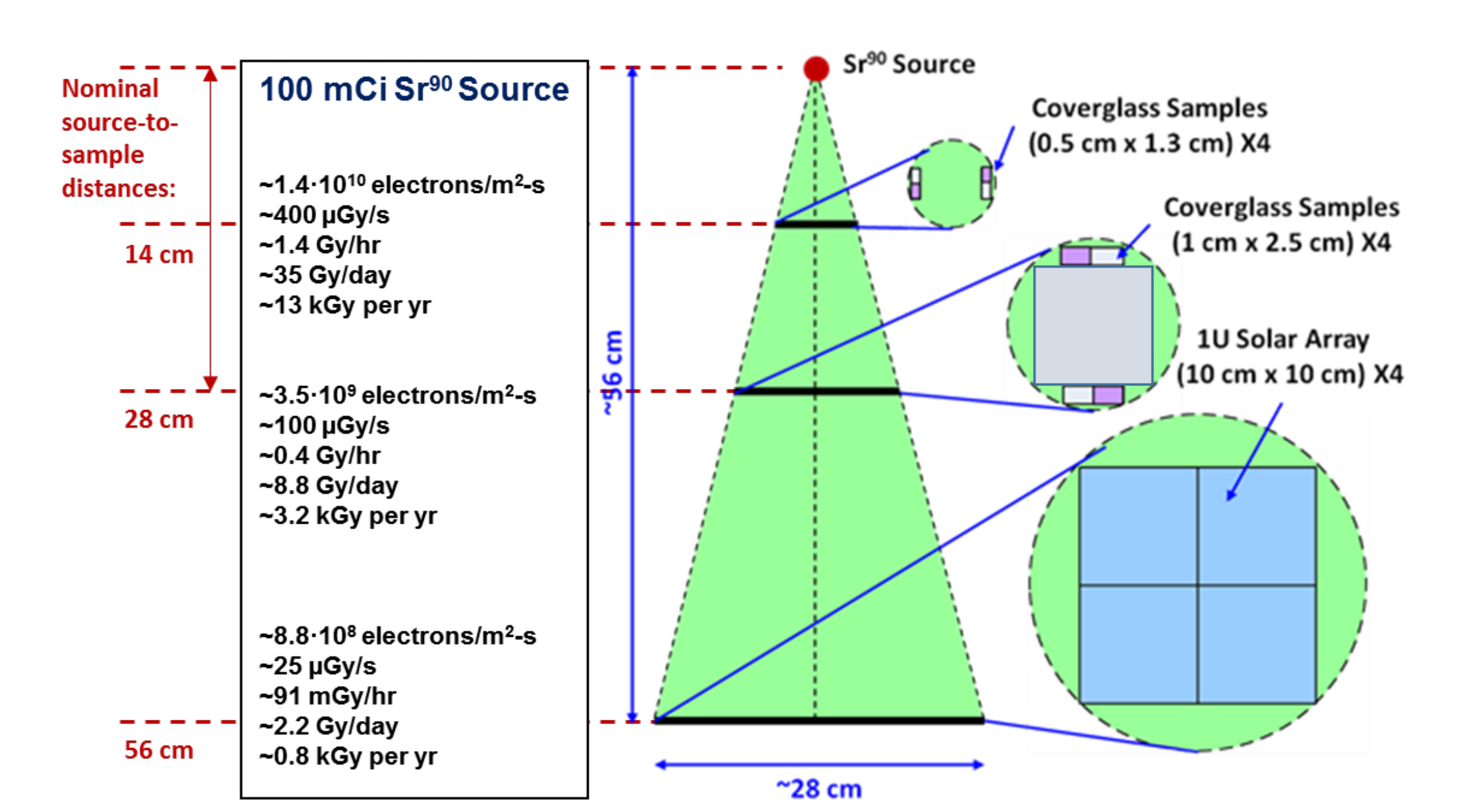


Fig. 3. Typical Space Electron Flux Spectra. Bars show source ranges.

Table I. Typical total ionizing dose levels in space environments (surface dose/year)

Orbit	Annual Dose	Primary Source
Earth Orbits (nearly all from trapped particles)		
LEO (ISS-Shuttle)	~ 2 krad	Protons
MEO	~ 100 krad	Protons and Electrons
GEO (GOES)	~ 10 krad	Electrons
Transfer (CRRES)	~ 50 krad	Protons and Electrons
Polar	~ 100 krad	Protons and Electrons



100 mCi Sr^{90} Source

~$1.4\cdot10^{10}$ electrons/m²-s
~400 μGy/s
~1.4 Gy/hr
~35 Gy/day
~13 kGy per yr

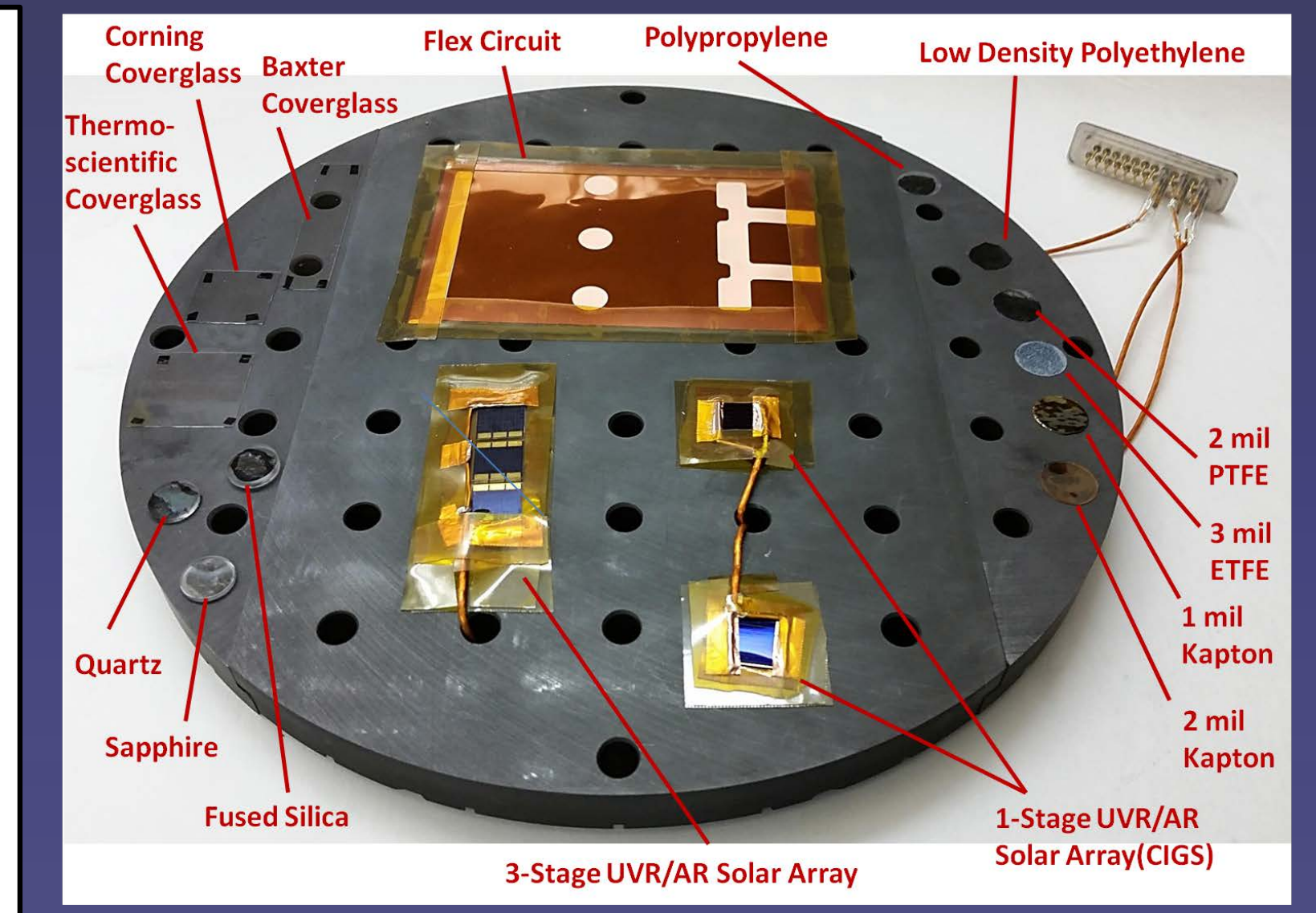
~$3.5\cdot10^{9}$ electrons/m²-s
~100 μGy/s
~0.4 Gy/hr
~8.8 Gy/day
~3.2 kGy per yr

~$8.8\cdot10^{8}$ electrons/m²-s
~25 μGy/s
~91 mGy/hr
~2.2 Gy/day
~0.8 kGy per yr

Space Environment Effects and Radiation Testing

Radiation testing of Arduino Board COTS parts. *In situ* tests are run on parts during irradiation with simultaneous tests on identical control hardware. Periodic tests include:

- CPU diagnostics relayed via USB connection.
- μSD card memory read/write tests.
- Bluetooth and WiFi communication.
- Sensor tests with fixed sources for reproducible, periodic, variable stimuli for magnetic Hall, temperature, photocell, IR, & acceleration sensors.



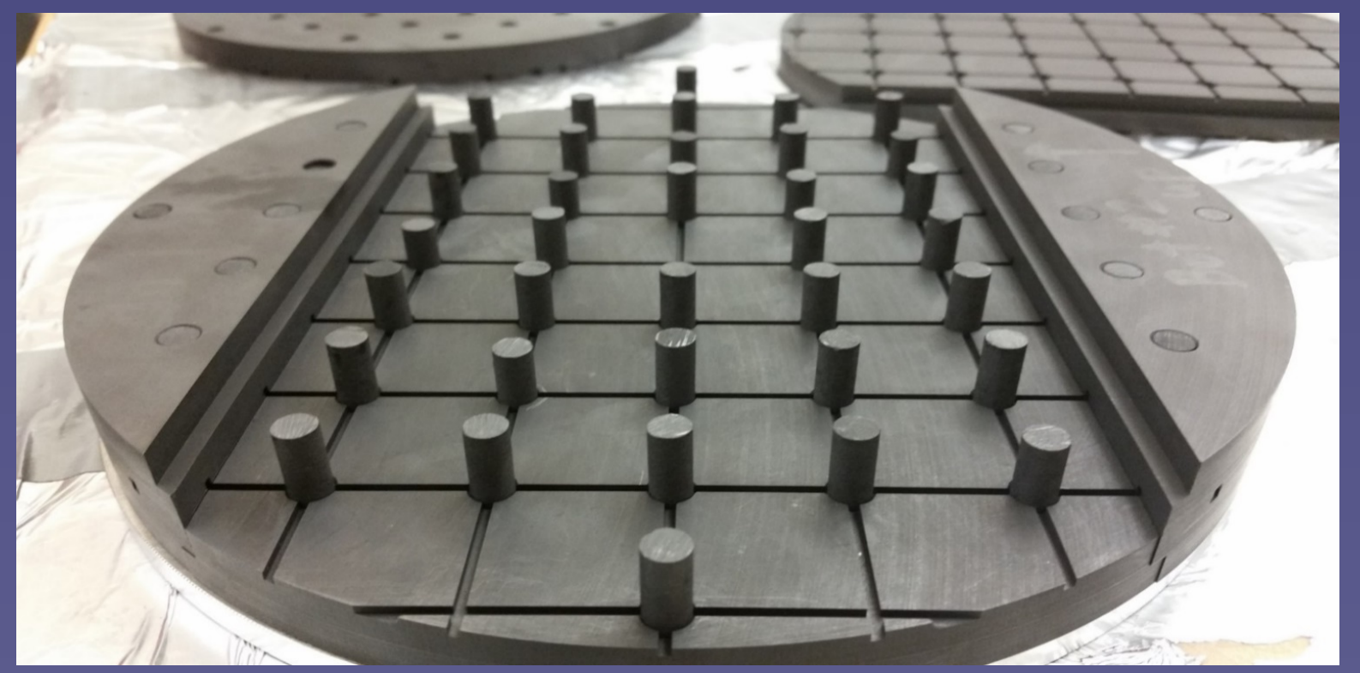
Degradation studies of common spacecraft materials (coverglass, quartz, sapphire, fused silica PI, LDPE, PTFE, ETFE).

Pre- and post-irradiation characterization of optical transmission, conductivity, surface composition and morphology. fused silica,

Radiation testing of flexible solar panels for CubeSats from Vanguard Space Technologies with in situ IV measurments to determine efficiency loss as a function of radiation dose.

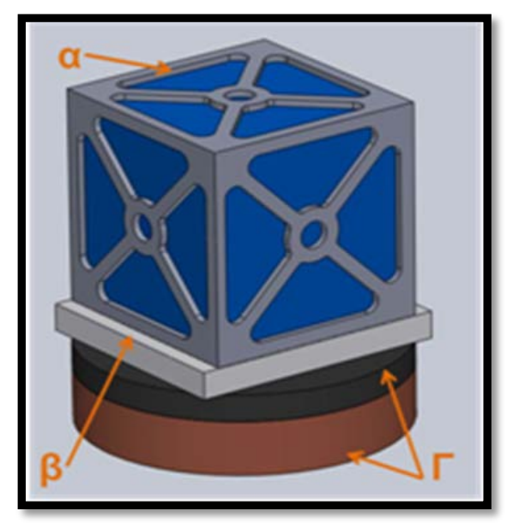
Shielding for reduced radiation

- •Channeled Graphite Bilayer (inhibits beta radiation from leaving SST chamber)
- •Graphite Plugs
- •Stainless Steel substrate (Shields Bremsstrahlung x-rays)



In situ monitoring

IV curves of flexible solar panels for CubeSats are measured *in vacuu* during irradia-tion whilst mounted on the sample stage.

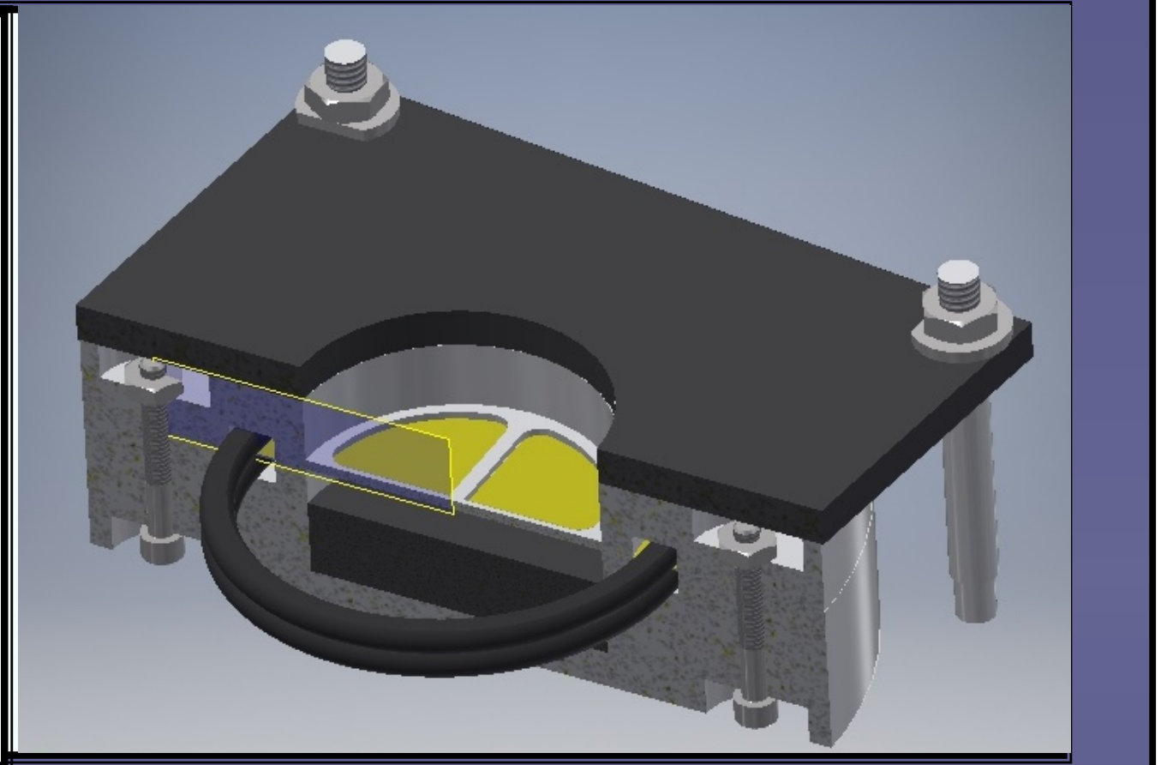


Biological Test Chamber

A small test chamber has been designed for biological testing, with 1 atm pressure within the main UHV chamber. The Al window has high transmission of the Sr^{90} β radiation. It is constructed with low-Z materials to minimize bremsstrahlung radiation.

Initial experiments include testing space radiation effects on of seed germination and genetic mutation of single cell organisms.

We gratefully acknowledge design support from Takuyuki Sakai, Shusuke Okita, Midori Modikawa, Akihiro Nagata, Yuta Takahasi, and Takahiro Shimizu of Tsukuba University for the biological test chamber.



Space Survivability Test Chamber

Fig. 4. Cutaway View with Source Beams.

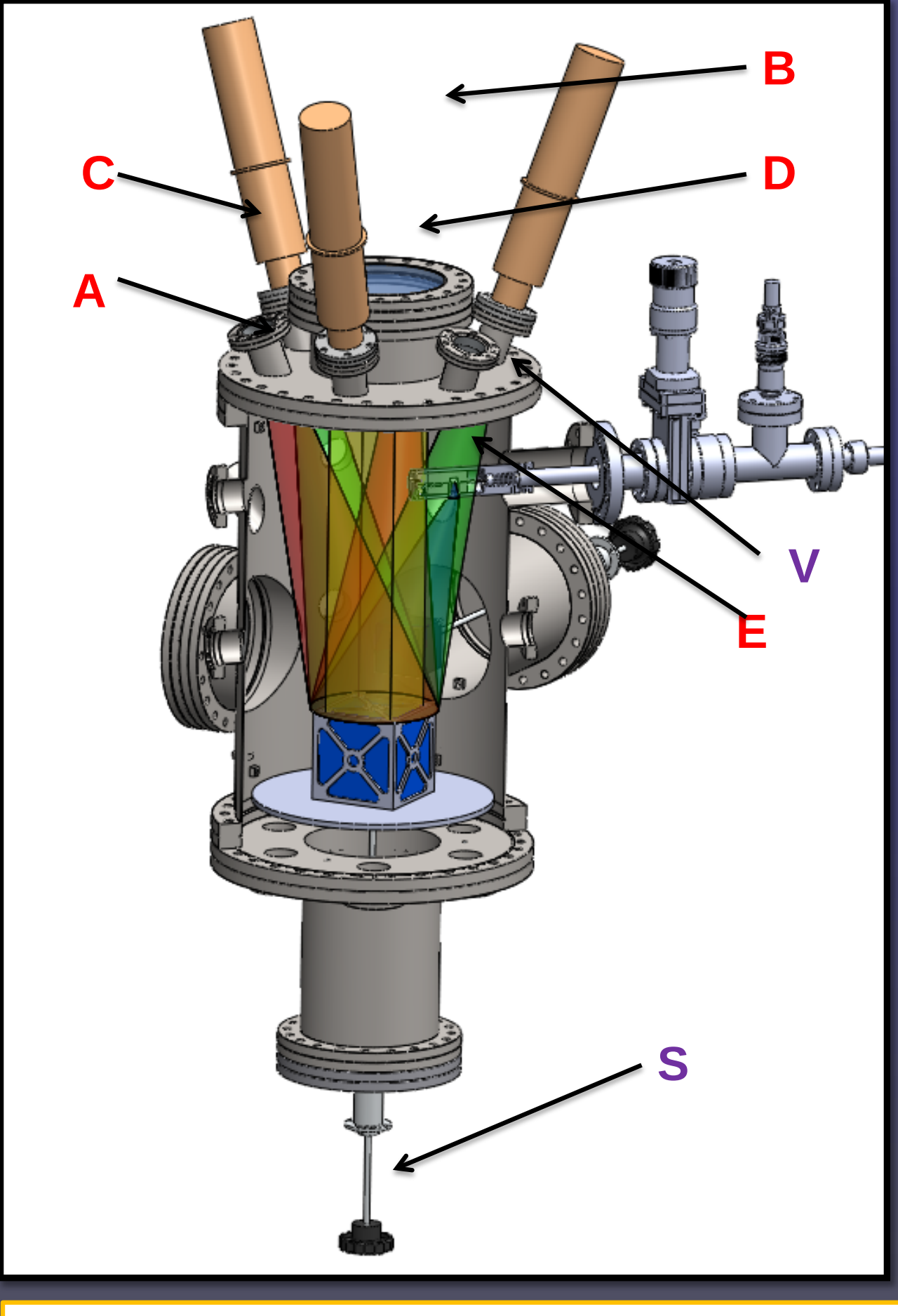
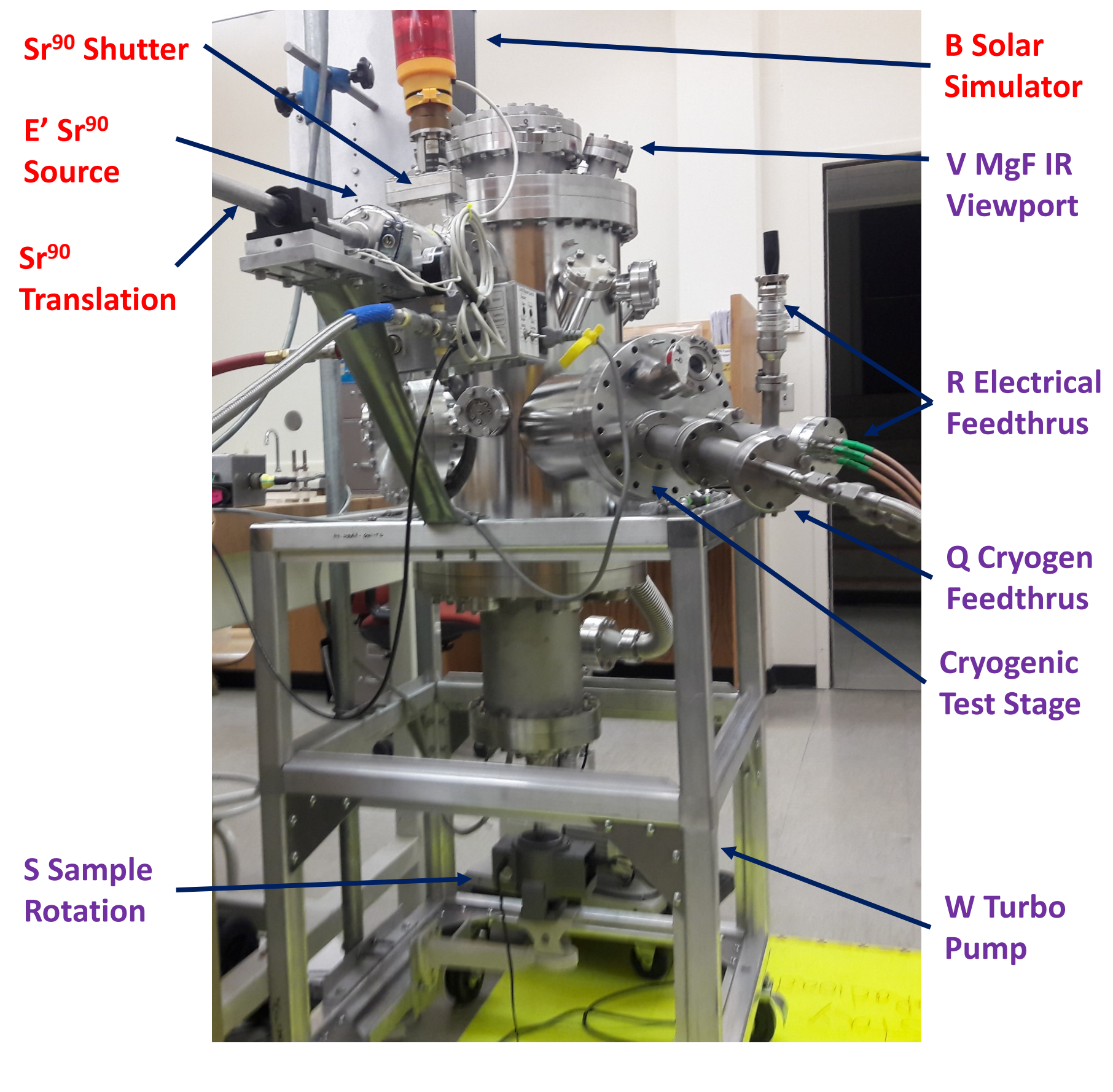


Fig. 5 SST Chamber. Configured for electrostatic discharge testing.



Sample Stages

(Above) 21 cm diameter sample stage (M) connected to 360º rotary feedthrough (S) to enhance flux uniformity by periodic rotation. The standard breadboard allows versatile sample configurations. (Left) 1U CubeSat mounted on sample stage. (Right) Stage with thermal control and linear translation stage with *in situ* characterization probes.

Radiation Sources

A High Energy Electron Gun
A′ Low Energy Electron Gun
B UV/NIS/NIR Solar Simulator
C FUV Kapton Discharge Lamps
D Air Mass Zero Filter Set
E Flux Mask
E′ Sr^{90} Radiation Source

Analysis Components

F UV/VIS/NIR Reflectivity Spectrometers
G IR Emissivity Probe
H Integrating Sphere
I Photodiode UV/VIS/NIR Flux Monitor
J Faraday Cup Electron Flux Monitor
K Platinum Resistance Temperature Probe

Sample Carousel

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

Chamber Components

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

Chamber Components

α CubeSat
β CubeSat Test Fixture
Γ Radiation Shielding
Δ COTS Electronics
ε Rad Hard Breadboard
η COTS Text Fixture
Θ Electron Gun

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 Source

SEEM Space Environment Test Facility

Unique capabilities for simulating and testing potential environmental-induced modifications of small satellites, components, and materials are available at the Material Physics Group's (MPG) Space Environment Effects Materials (SEEM) test facility. Their new versatile ultrahigh vacuum Space Survivability Test (SST) chamber [2] is particularly well suited for cost-effective tests of multiple small scale materials samples over prolonged exposure to simulate critical environmental components including: the neutral gas atmosphere/vacuum, the far UV through near IR solar spectrum, electron plasma fluxes, and temperature. Testing is available for a 10 cm X 10 cm CubeSat face sample area (maximum sample area of 16 cm X 16 cm or 20 cm diameter), with exposure to within <5% uniformity at intensities for >5X accelerated testing. A Sr^{90} β-radiation source produces a high-energy (~200 keV to >2.5 MeV) spectrum similar to the GEO spectrum for testing of radiation damage, single event interrupts, and COTS parts [2]. An automated data acquisition system periodically records real-time environmental conditions—and *in situ* monitoring of key satellite/component/sample performance metrics and characterization of material properties and calibration standards—during the sample exposure cycle [5].

Electron Flux

A high energy electron flood gun (A) (20 keV – 100 keV) provides ≤5 X 10^6 electrons/cm² (~1pA/cm² to 1 μA/cm²) flux needed to simulate the solar wind and plasma sheet at more than the 100X cumulative electron flux. A low energy electron gun (A') (10 eV-10 keV) simulates higher flux conditions. Both have interchangeable electron filaments.

Ionizing Radiation

A 100 mCi encapsulated Sr^{90} radiation source (E') mimics high energy (~500 keV to 2.5 MeV) geostationary electron flux (see Fig. 2) [2].

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. Source uses a Xe discharge tube bulbs with >1 month lifetimes for long duration studies.

Far Ultraviolet Flux

Kr resonance lamps (C) provide FUV radiation flux (ranging from 10 to 200 nm) at 4 times sun equivalent intensity. Kr bulbs have ~3 month lifetimes for long duration studies.

Temperature

Temperature range from 60 K [4] to 450 K is maintained to ±2 K [3].

Vacuum

Ultrahigh vacuum chamber allows for pressures <10^{-7} Pa to simulate LEO

Electrostatic Discharge Test Fixture

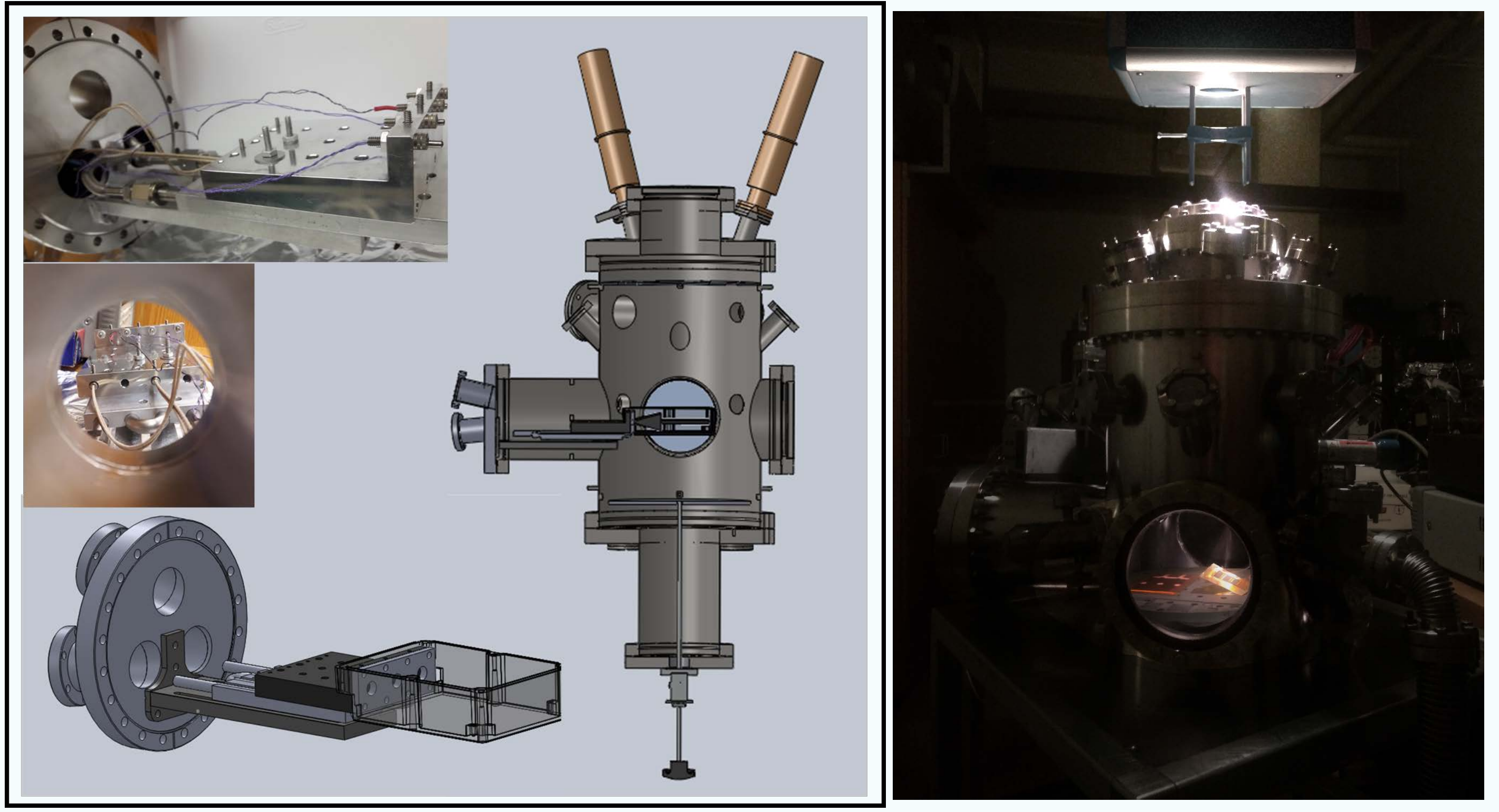


Fig. 6. Cutaway View of electrostatic discharge test fixture in SST chamber. Details show the electrically and thermally isolated test stage..

Acknowledgments, References & Tours

Partially supported by a Utah NASA Space Grant Consortium Faculty Research Infrastructure Program, USU Space Dynamics Laboratory IR&D award, and USU Undergraduate Research and Creative Opportunities Awards.

1) JR Dennison, John Prebola, Amberly Evans, Danielle Fullmer, Joshua L. Hodges, Dustin H. Crider and Daniel S. Crews, "Comparison of Flight and Ground Tests of Environmental Degradation of MISSE-6 *SUSpECS* Materials," Proceedings of the 11th Spacecraft Charging Technology Conference, (Albuquerque, NM, September 20-24, 2010).
2) JR Dennison, Kent Hartley, Lisa Montierth Phillipps, Justin Dekany, James S. Dyer, and Robert H. Johnson, "Small Satellite Space Environments Effects Test Facility," *Proceedings of the 28th Annual AIAA/USU Conference on Small Satellites*, (Logan, UT, August 2-7, 2014).
3) Robert H. Johnson, Lisa D. Montierth, JR Dennison, James S. Dyer, and Ethan Lindstrom, "Small Scale Simulation Chamber for Space Environment Survivability Testing," *IEEE Trans. on Plasma Sci.*, 41(12), 2013, 3453-3458. DOI: 10.1109/TPS.2013.2281399
4) Justin Dekany, Robert H. Johnson, Gregory Wilson, Amberly Evans and JR Dennison, "Ultrahigh Vacuum Cryostat System for Extended Low Temperature Space Environment Testing," *IEEE Trans. on Plasma Sci.*, 42(1), 2014, 266-271. DOI: 10.1109/TPS.2013.2290716
5) Amberly Evans Jensen, Gregory Wilson, Justin Dekany, Alec M. Sim and JR Dennison "Low Temperature Cathodoluminescence of Space Observatory Materials," *IEEE Trans. on Plasma Sci.*, 42(1), 2014, 305-310. DOI: 10.1109/TPS.2013.2291873
6) Ben Iannotta, "NOVA: Bright New Star for CubeSat Testing," Aerospace America, 24-26, June 2012.

Scan code to access accompanying paper and references, as well as other USU MPG articles.

SEEM Test Facility Tours
Wednesday 8/12/15 17:00
Thursday 8/13/15 14:00