Development of a Universal Small-Satellite Payload

FOR ON-ORBIT CHARACTERIZATION AND EVALUATION OF NOVEL RADIATION SHIELDING MATERIALS

SMALL SPACECRAFT TECHNOLOGY PROGRAM

Avery Brock [1]

The RADSET Team:

NASA Ames - Engineering:
Luke Idziak[2] PM, Malachi Mooney-Rivkin[3], Alejandro Salas[2]

NASA Glenn - Science:
Susan Y. Wrbanek, John D. Wrbanek

With support from:

Kayla Delrosario – Cal-Poly SLO

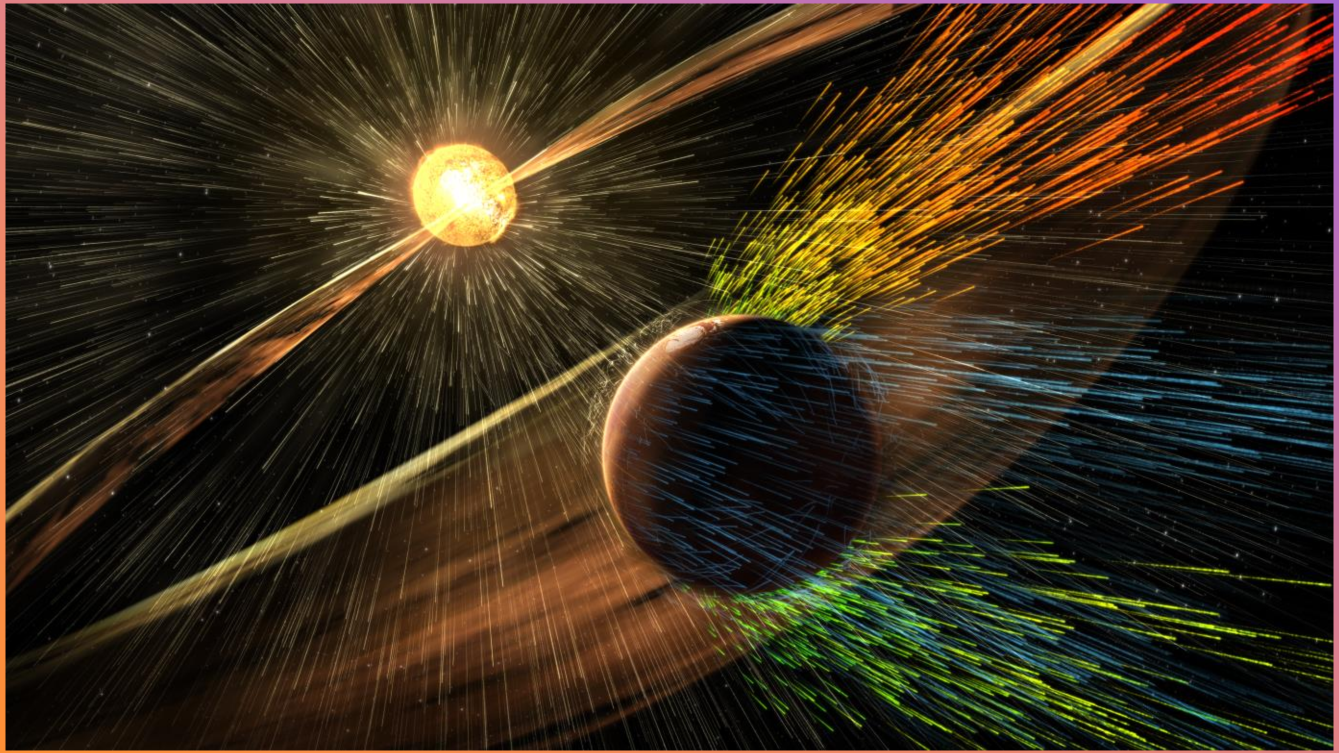
Jennifer Lalli, Ben Woods – NanoSonic Inc. Pembroke VA

Ivan V. Khodyuk, John Fiala – CapeSym Inc. Natick MA

[1]KBR Wyle Services LLC, Houston TX
[2]Axient LLC, Colorado Springs CO
[3]Metis Technology Solutions LLC, Houston TX

OUTLINE

- Space Weather & Small Spacecraft
- Shielding Materials
- Sensor Selection
- Payload Design
- Mission Expectations



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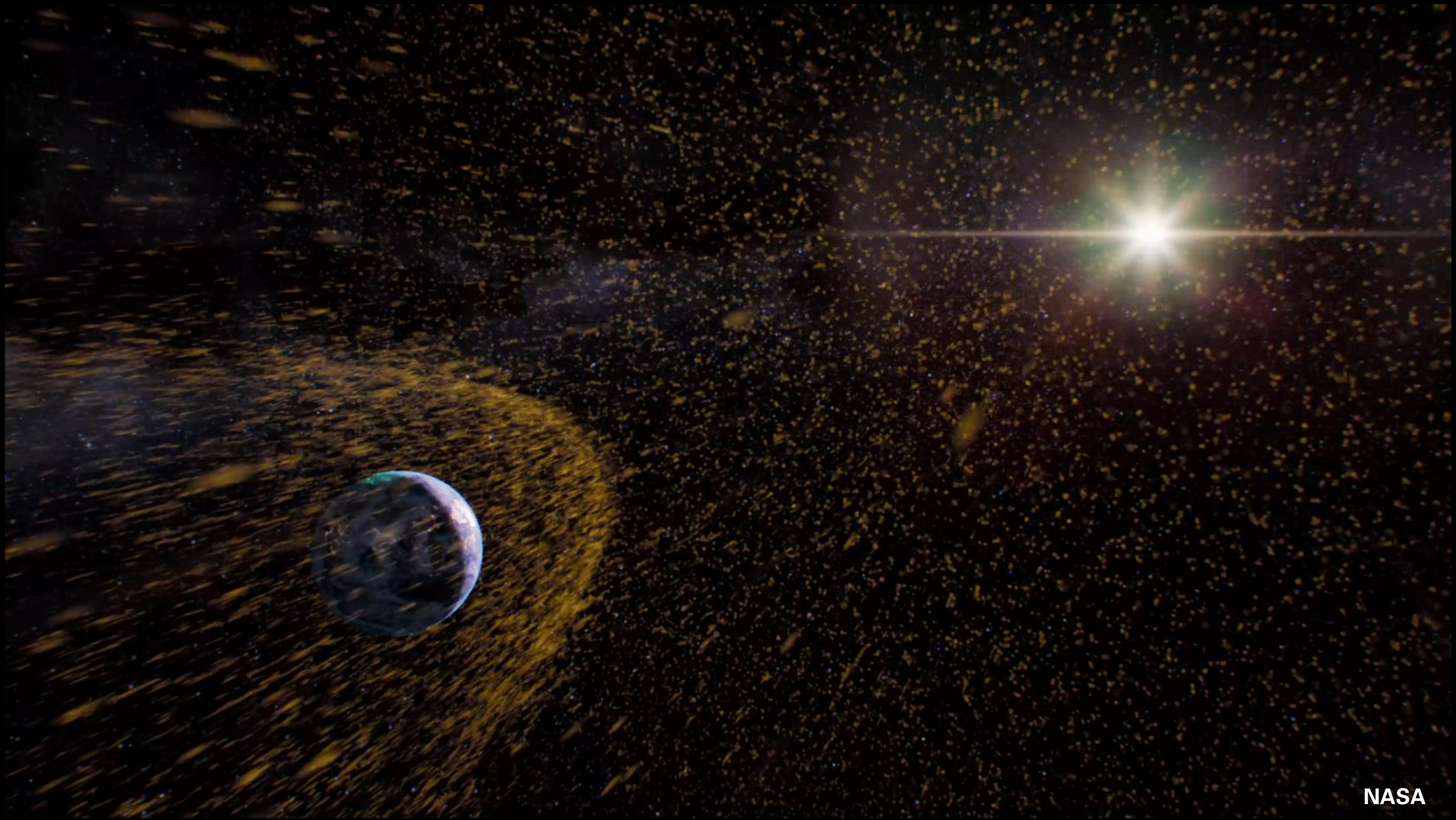


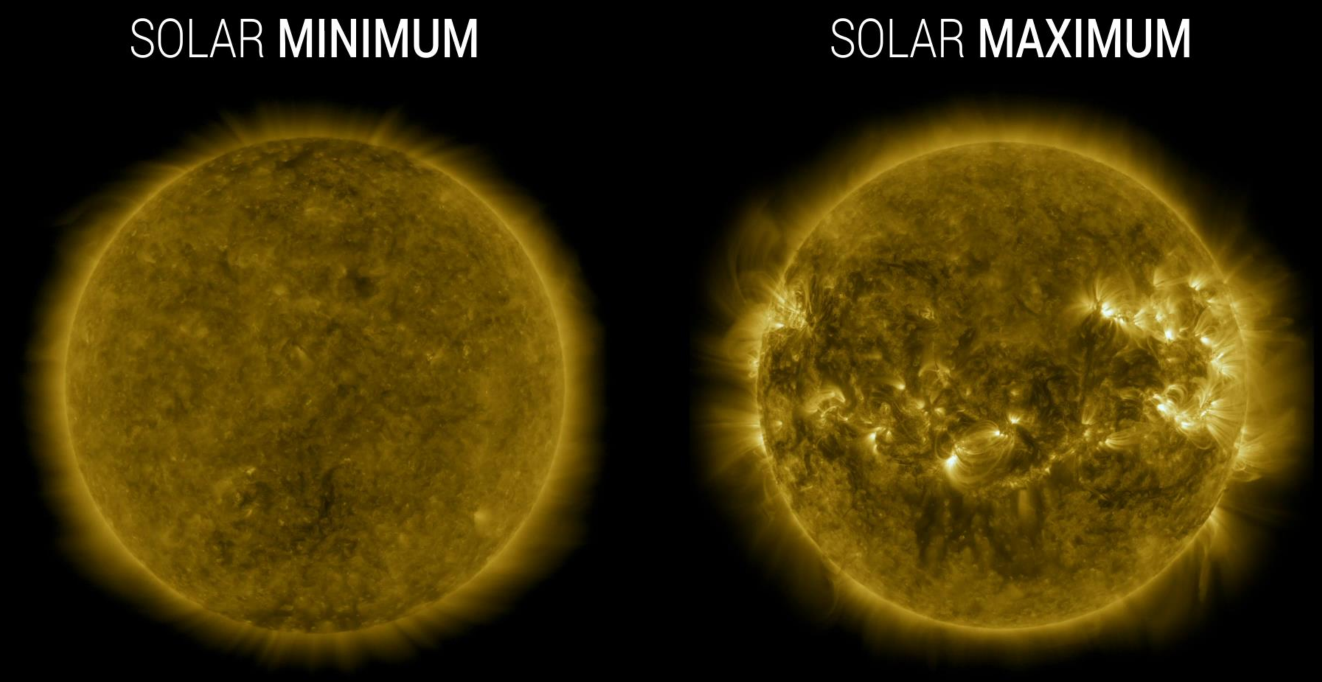
Primary Space Ionizing Radiation Components:

- Electrons
- Protons
- Alpha Particles
- Heavy Ions
- Neutrons
- X-Rays
- Gamma Rays

Energies from MeV to GeV

Significant Interplay with Planetary and Solar Fields Makes Modeling Difficult

Space radiation is difficult to replicate on earth due to the variety of particles and magnitude of energies present



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Solar Particles Travel Along Solar Magnetic Field Lines

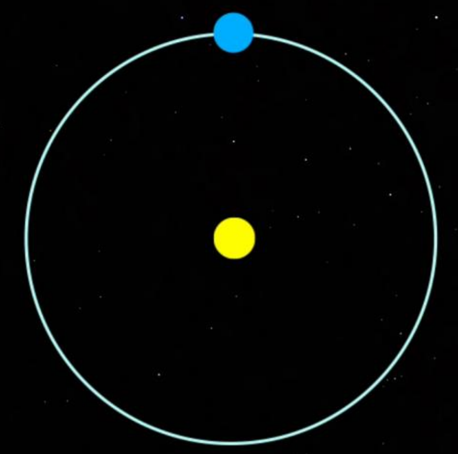
Modeling, Warning, and Prediction handled by NOAA Space Weather Prediction Center

Can cause radio blackouts and increase spacecraft drag

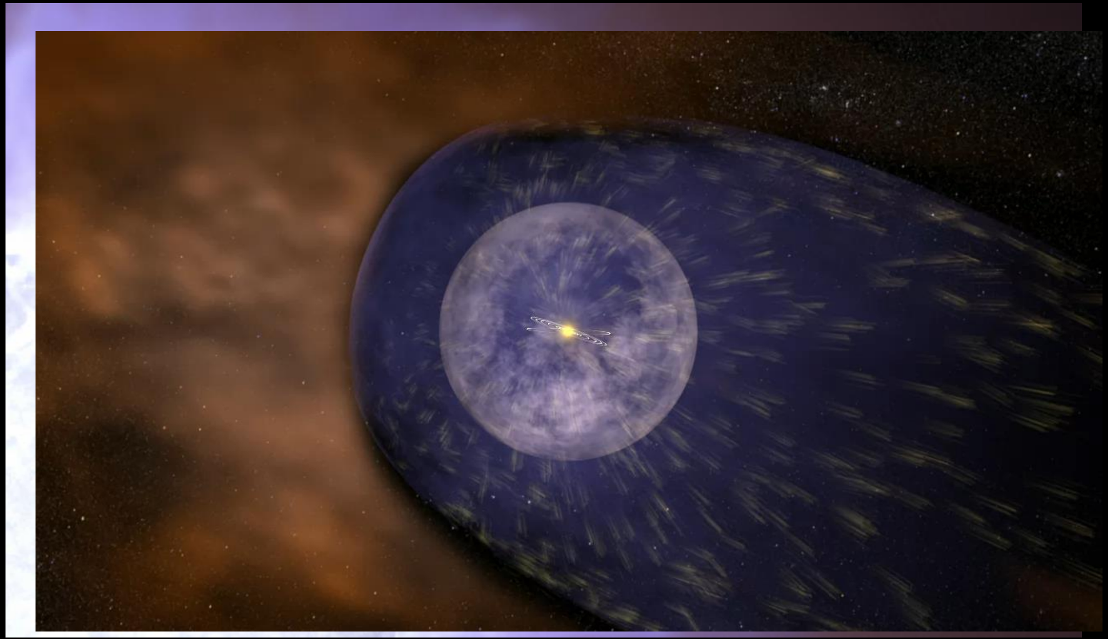
Solar Cycle 25

More active than predicted

- Solar Flares, High-Speed Wind Streams, Coronal Mass Ejections (CME)
- Release Solar Energetic Particles (SEP, Primarily Protons)
- X-Rays



NASA's Goddard Space Flight Center

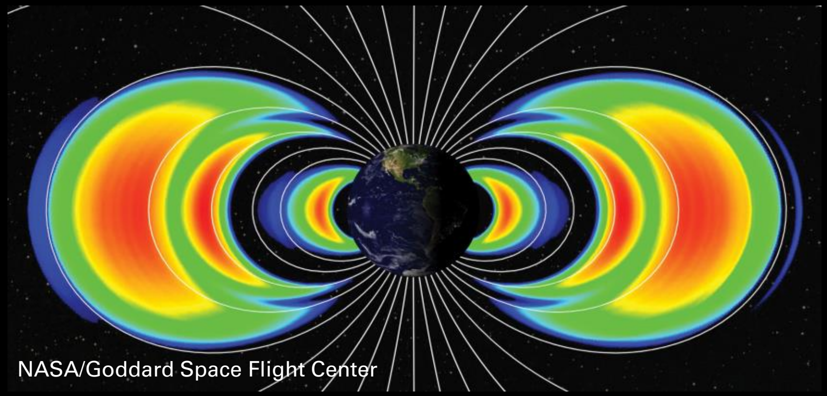


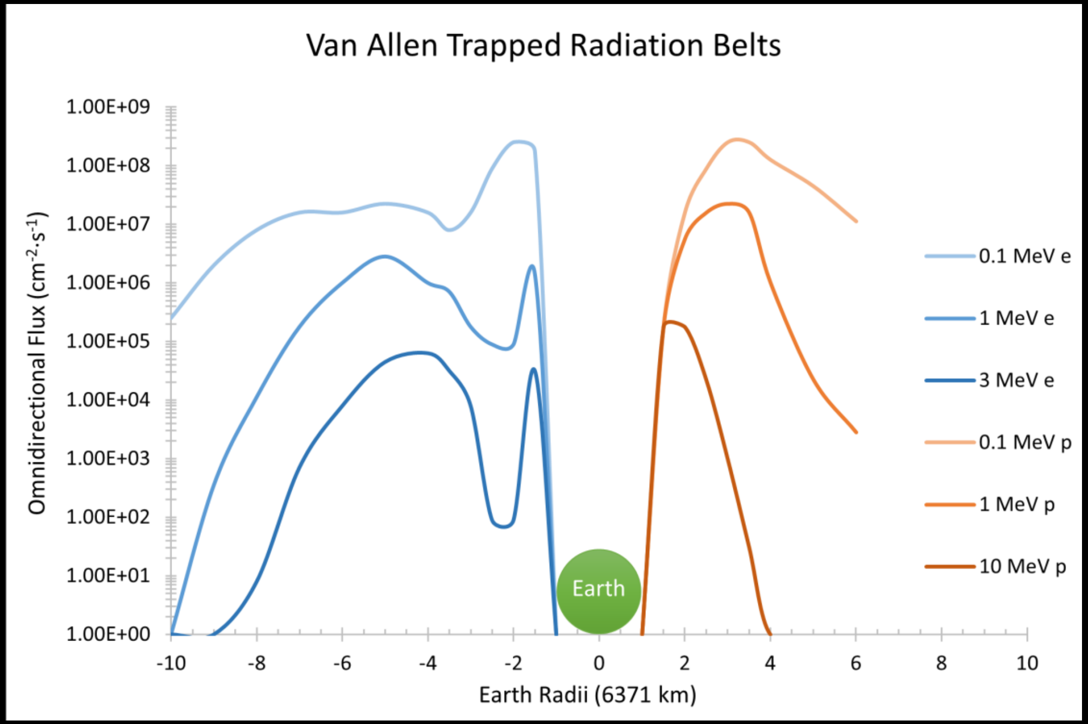
SA's Goddard Space Flight Center Conceptual Image Lab

NASA's Goddard Space Flight Center Conceptual Image Lab

The heliosphere deflects galactic cosmic radiation, but the solar magnetic poles can pull particles into the solar system

Increase in solar activity expands the heliosphere as local solar winds increase, hypothetically reducing the ratio of SEPs to GRCs, though this cannot currently be predicted





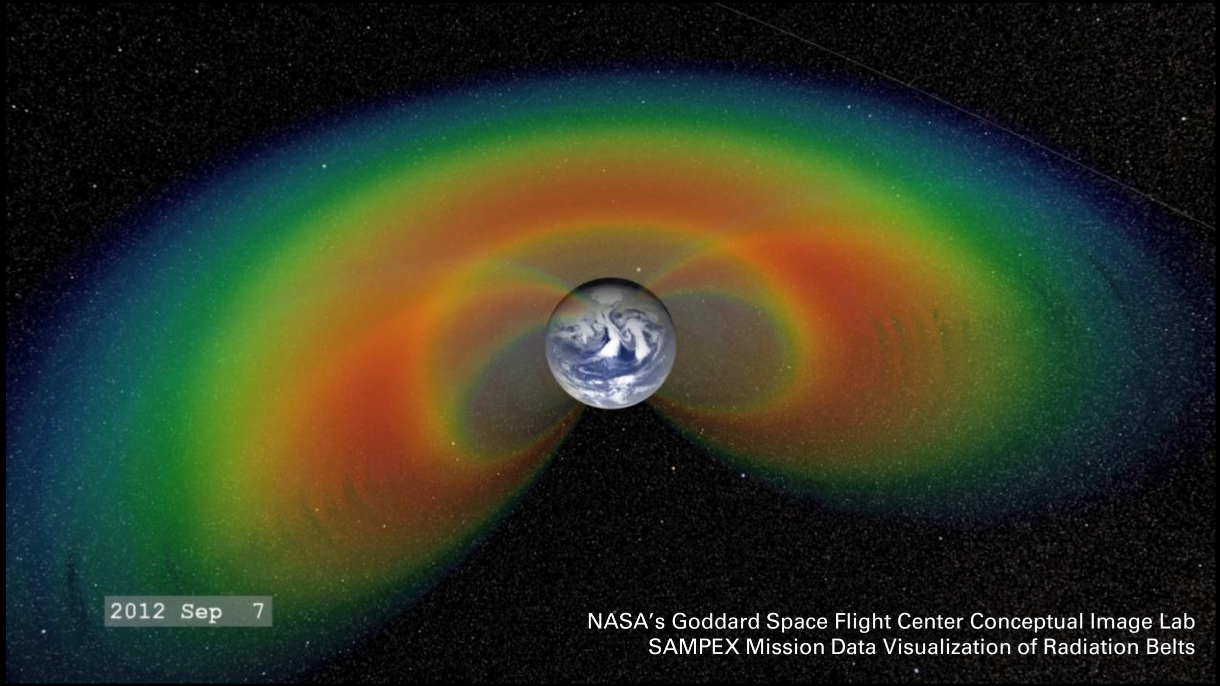
Charged Particles Become Trapped by Planetary Magnetic Fields

- Particles, primarily electrons and protons, spiral along field lines from pole to pole
- Present on all planets with magnetic fields

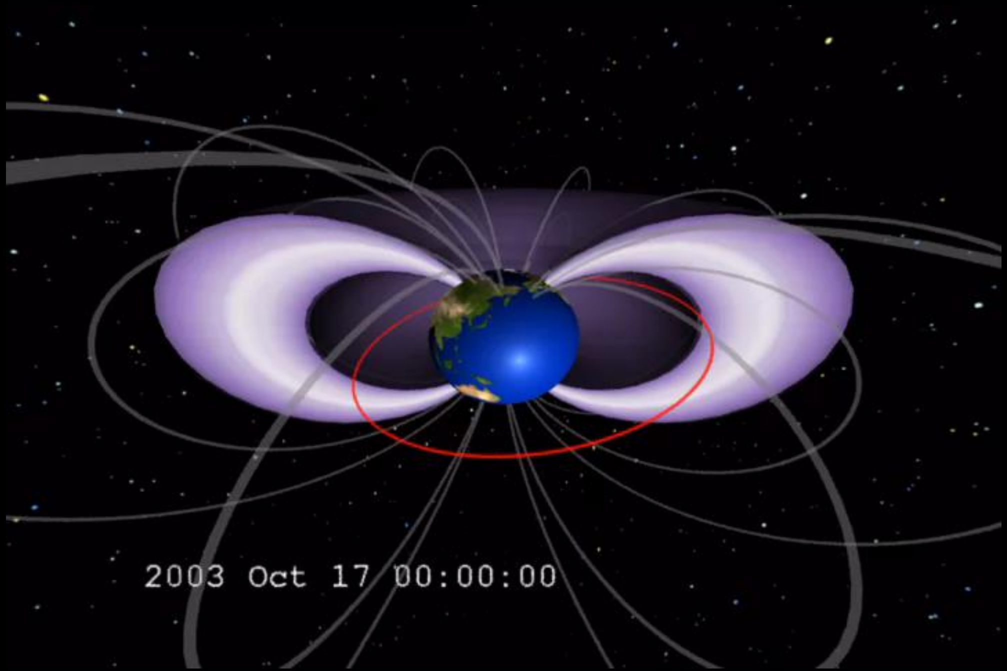
Earth has inner and outer radiation belts (Van Allen Belts)

- Inner Belt:
  - Ionosphere to 2.5 Earth Radii
  - Primarily protons > 10MeV
- Outer Belt:
  - 3-10 Earth Radii
  - Primarily electrons 1-10MeV

Primary Concern for LEO Spacecraft



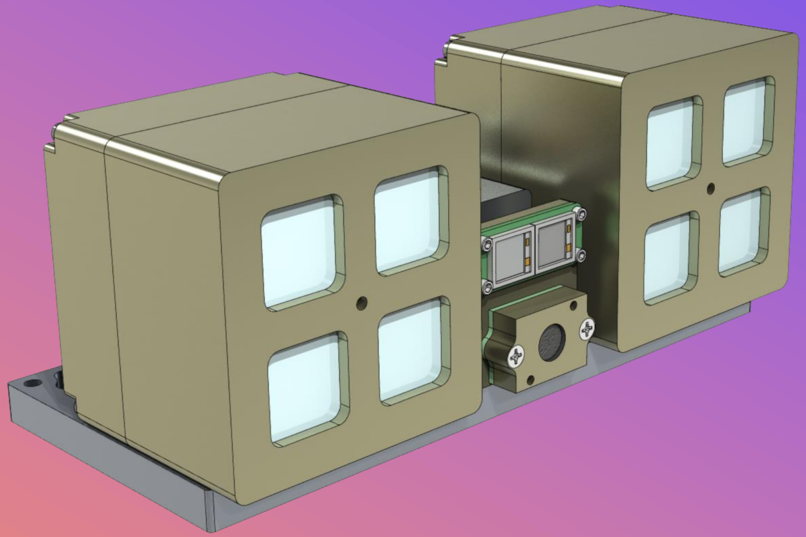
NASA's Goddard Space Flight Center Conceptual Image Lab
SAMPEX Mission Data Visualization of Radiation Belts



NASA/Goddard Space Flight Center Scientific Visualization Studio

Variations and interplay between solar and geomagnetic activity can drastically impact the radiation environment seen by spacecraft. Sudden solar storms can wreak havoc on spacecraft control and communications. Radiation exposure can shift dramatically.

SHIELDING MATERIALS AND PAYLOAD



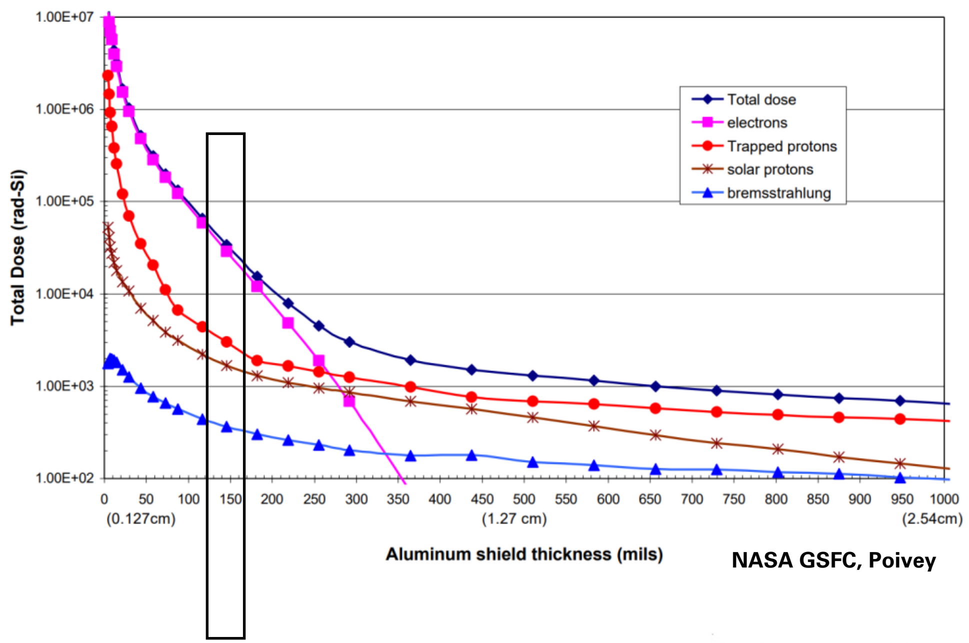
Shielding in spacecraft is to primarily protect electronics, increasing reliability, longevity, and capability of small spacecraft missions.

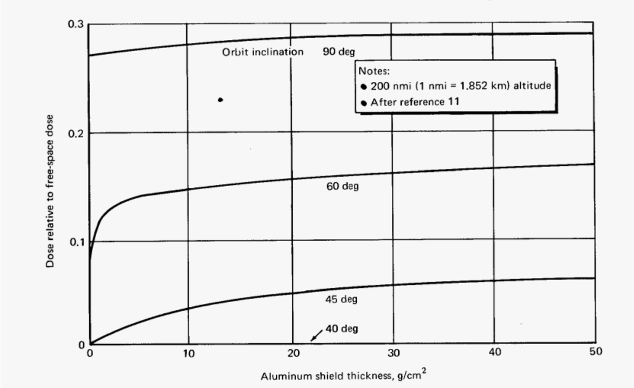
Aluminum is currently the go-to for spacecraft shielding due to relative effectiveness, low density, low-cost, and machinability.

100mils of aluminum is the current standard from the Apollo era and is used as a general reference for material comparison and equivalency to attenuate the most dangerous proton radiation levels.

Most LEO small spacecraft use aluminum structure and don't fly additional shielding as TID is usually less than 1krad/year (below ~900km, AE8 model).

Total dose at the center of Solid Aluminum Sphere
ST5: 200-35790 km, 0 degree inclination, three months





NASA SP-8054, 1970

NASA JSC

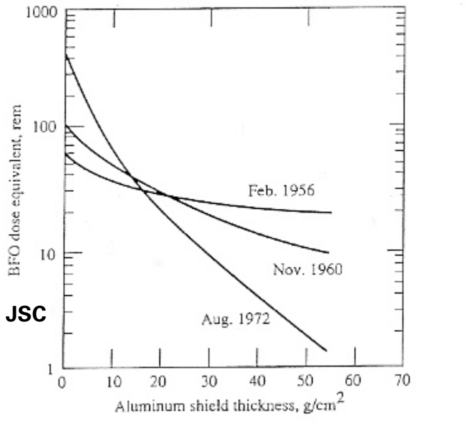


Figure 9. Shielding effectiveness for three of the largest solar proton events.

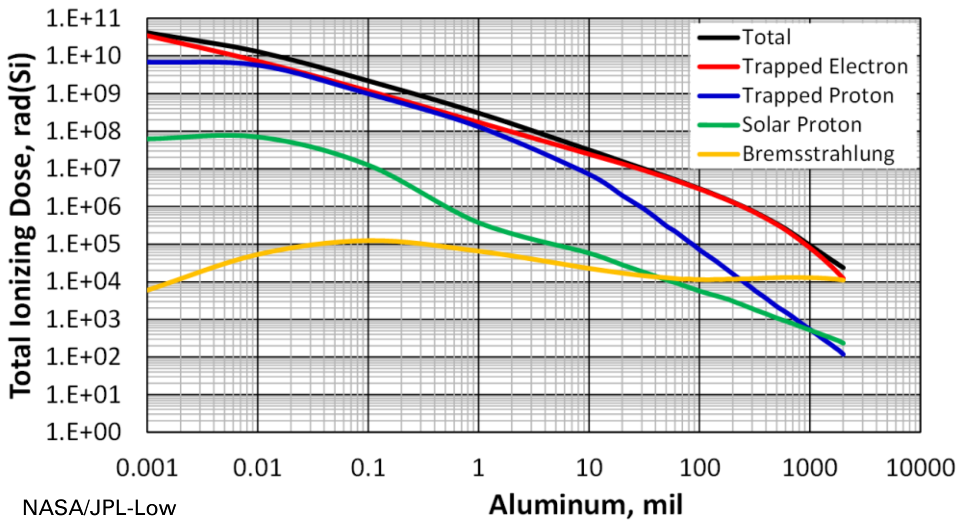
Mission to Europa, must survive Jupiter's incredible radiation belts:

- Designed to reduce mission TID to 150krad/s (Si)
- Internal electronics hardened to 300krad

9.2mm Aluminum-7075 Vault with 1.3mm Tantalum Ta10W Connector Panels and Plates

NASA/JPL-Caltech
Europa Clipper Vault Plate
1.3mm Tantalum Ta10W
(Al-7075 9.2mm eq)

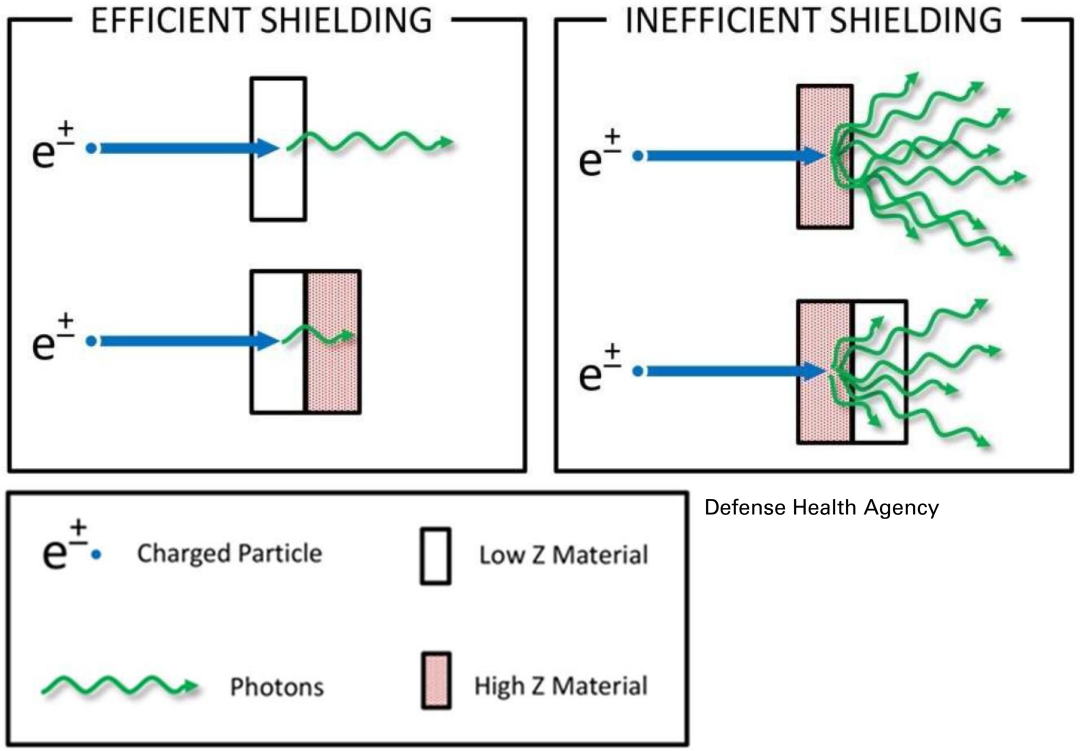
NASA/JPL-Caltech
Europa Clipper Vault 9.2mm (362mil) Al-7075
~1.4mx1.4mx1m, 150kg estimate



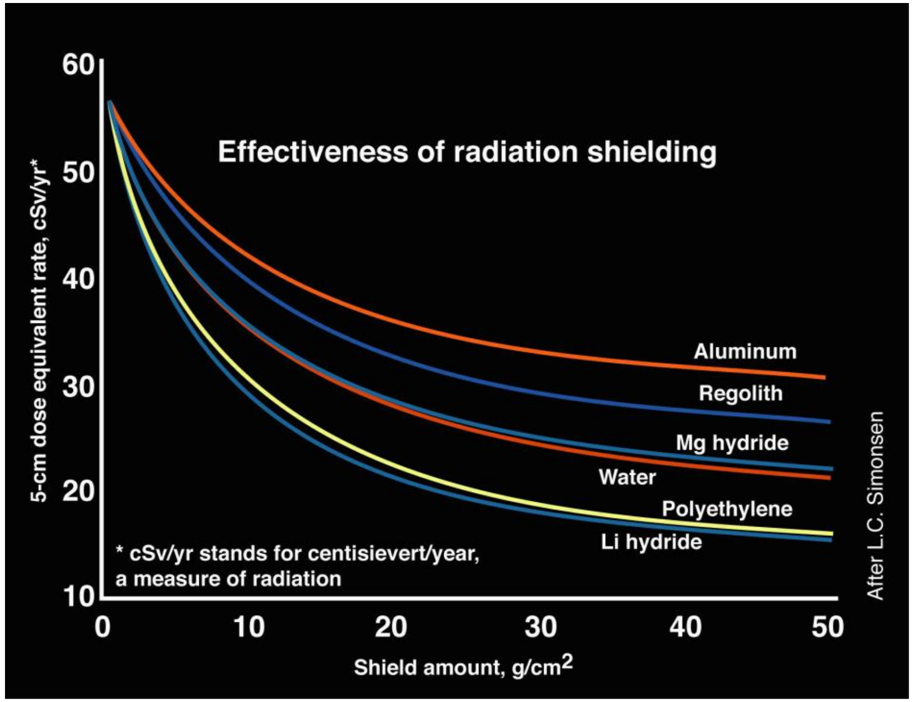
NASA/JPL-Low

No single material can shield effectively against multiple radiation types:

- Metals don't shield well against electron flux and can create secondary particles, but shield against electric fields
- Plastics and composites reduce secondary particles but can require large volumes to shield effectively due to low mass



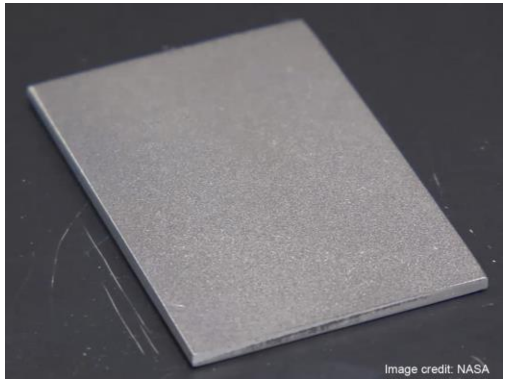
Defense Health Agency



Increasing the density of low-Z materials with doping, or layering materials creates shielding referred to as 'graded-Z'

This class of material yields much greater performance than single-material shields

GRADED-Z DEMO: SHIELDS-1 MISSION



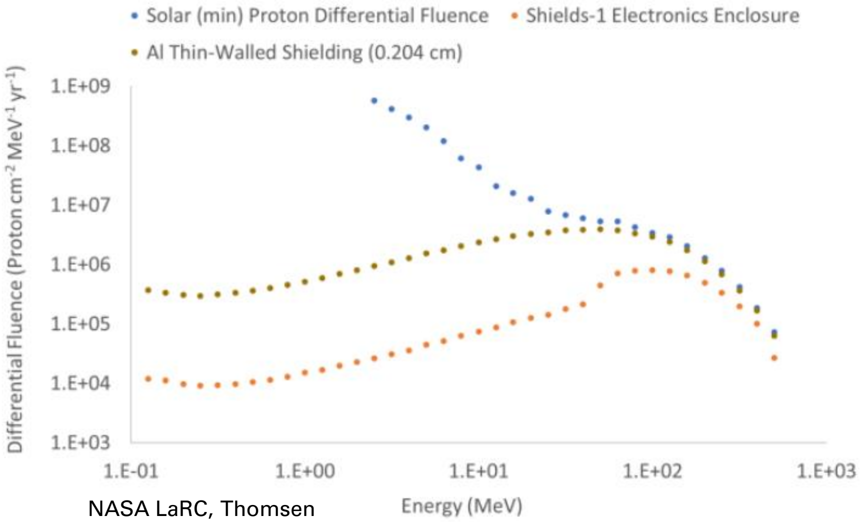
Tantalum/Tungsten Coated Aluminum Graded-Z 2.04-2.54mm thick

3U Cubesat Launched December 2018, 500km, 85-degree Orbit ~475km Current Attitude

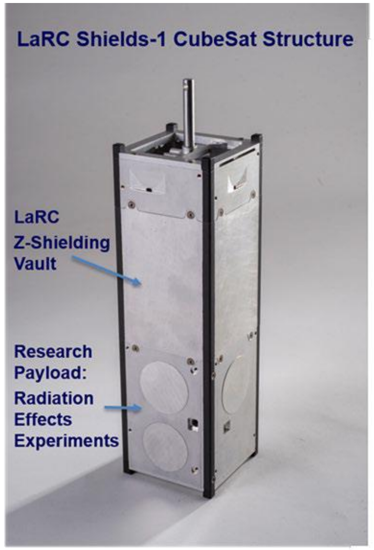
NASA Langley 'thin Z-shielding' IP: Titanium and Tantalum Diffusion Bonding on Aluminum

All-metallic shielding to enable thermal and electrical conductivity

Demonstrated increased shielding efficacy in an aluminum equivalent volume, equivalent aluminum would be twice as thick



NASA LaRC, Thomsen



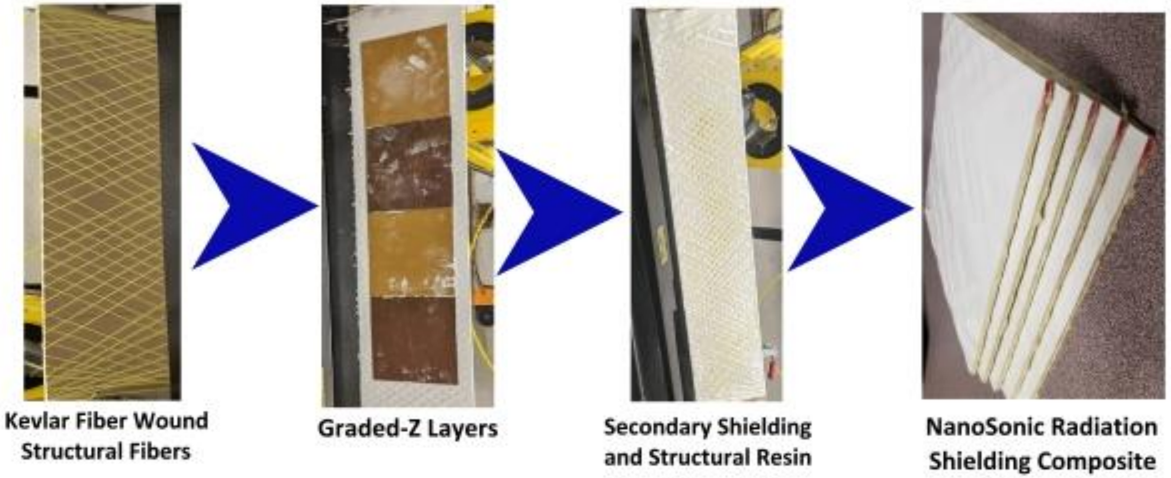
NASA/JPL

NASA S3VI Webinar on SHIELDS-1

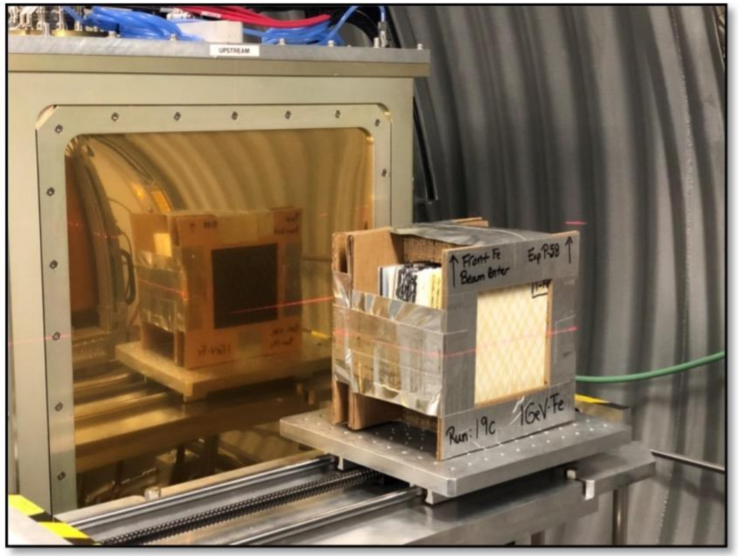
NOVEL CANDIDATE MATERIAL: NANOSONIC COMPOSITE

Small Spacecraft Technology Program Material of Interest:

- NASA SBIR Developed Composite from NanoSonic
- Wound Kevlar and Boron Nitride providing structure and impact protection
- Ground testing showing efficacy against electrons, protons, and iron ions
- Attenuates X-rays and gamma rays
  - Attenuation 71% higher than polyethylene without secondary radiation
- 50-Year SEP & GCR simulated structural survival

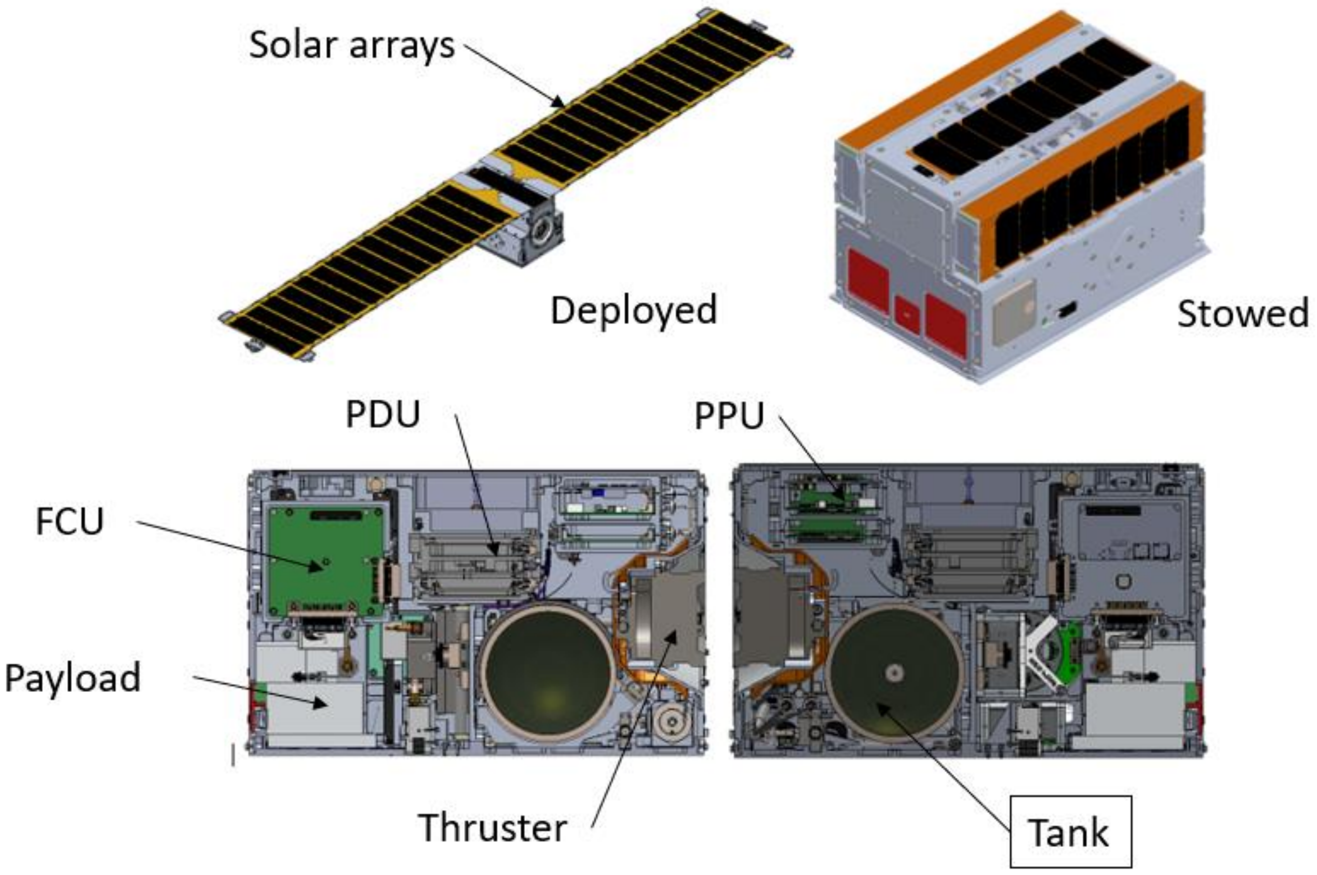


NanoSonic, Public Release



ExoTerra Courier 12U CubeSat
Expected Launch NET Q1 2026
Climb and Descend Between 600-800km

- 'Halo' Hall Effect Thruster
  - 650-1400s ISP 4-33mN
  - 1270m/s ΔV @ 5mN for 12U
- Fold-Out Solar Arrays
  - NASA SBIR Phase II Developed
  - 160W/kg, 200W-1kW Scalable
- Radiation Tolerant Electronics
  - GaN-Based Power Plants
  - >100krad Design
- 2U Front Forward-Facing Payload
  - 28V 5W Continuous Power
  - >20W Available when thruster is not active
  - RS485 Host Communication



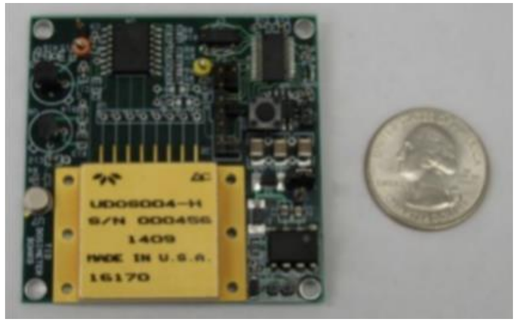
ExoTerra, Public Release

Flight-Tested Radiation Sensors suitable for SmallSats:

Total Ionizing Dosimeters:
- Teledyne uDOS Silicon Target Dosimeters
- SHIELDS-1, BioSentinel (considered, not flown), Van Allen Probes, LRO
- Yields dose integral but doesn't allow for evaluation of particles or have a fast response

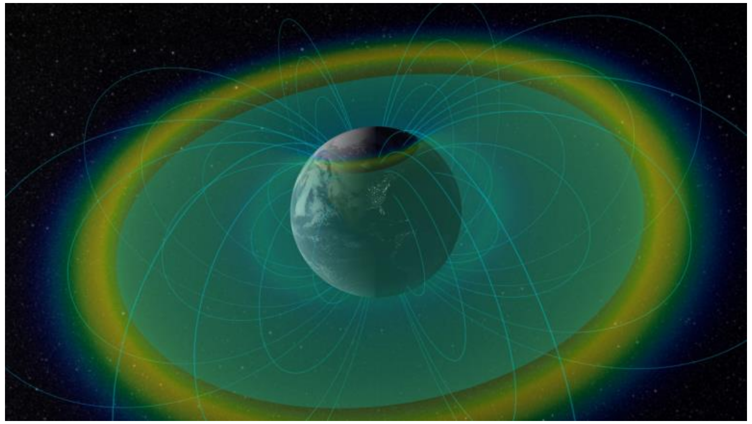
PIN-Diode Geiger Counter:
- Teviso BG Series Pulse Discriminator
- Nepal SanoSat-1, TechEdSat-11, CERN
- Fast response but cannot discern energy levels

Scintillator:
- Enables detection of energy level and particle types to better understand shielding effectiveness against different types of radiation
- Readout electronics can be complicated



BioSentinel uDOS Dosimeter Test Board, NASA

Sun Sensing:
- Desire to have sun angle and incident energy sensors to evaluate particle types and energy compared to sun angle and luminance
- Validate field models and extend high-energy particle detection

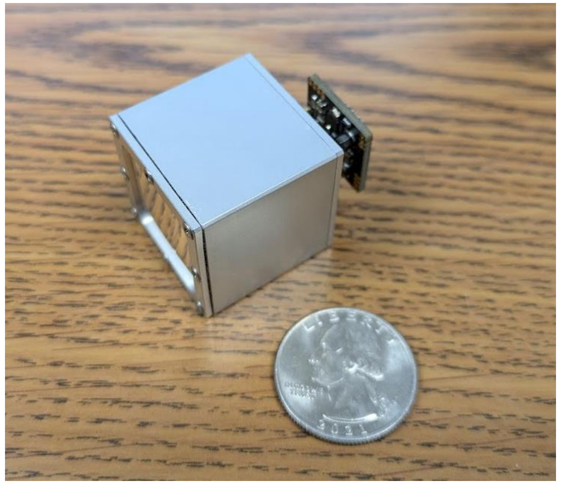


NASA's Goddard Space Flight Center Conceptual Image Lab

Custom Scintillator Module:

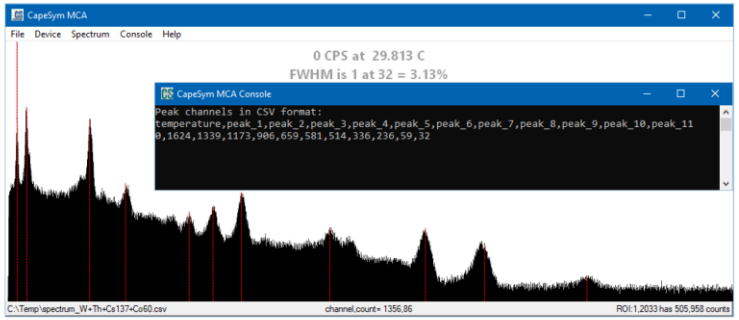
- CapeSym (CapeScint) miniaturized spectroscopic detector modules
- DoE NNSA SBIR Developed for space applications
- Multichannel Analyzer with bias supply
- 20mm cubic Cesium-Iodide crystal on Silicon Photomultiplier array
- Customized with metalized Mylar windows to improve low-energy response

- 28x28x40mm^3 Modules, 75g, 150mW
- 5keV-12MeV Range, 1keV resolution, <6% Error



CapeScint CSI-20c-SiPM-T Module, Public Release

CapeScint CpaMCA v1.5.7, Public Release



Example Sensor Output

Sun Sensor PIN Diodes:

Hamamatsu <u>S2044 2-D PSD</u>

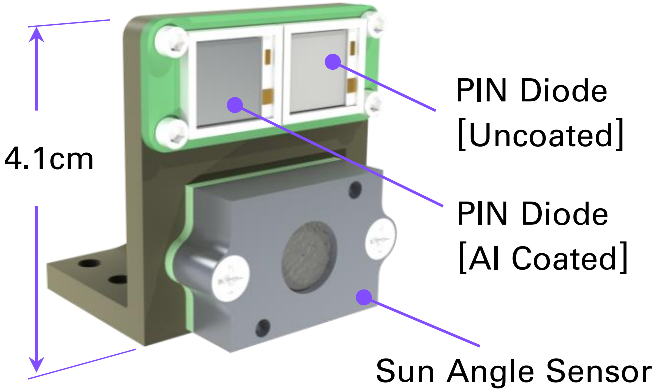
- Sun Angle sensing

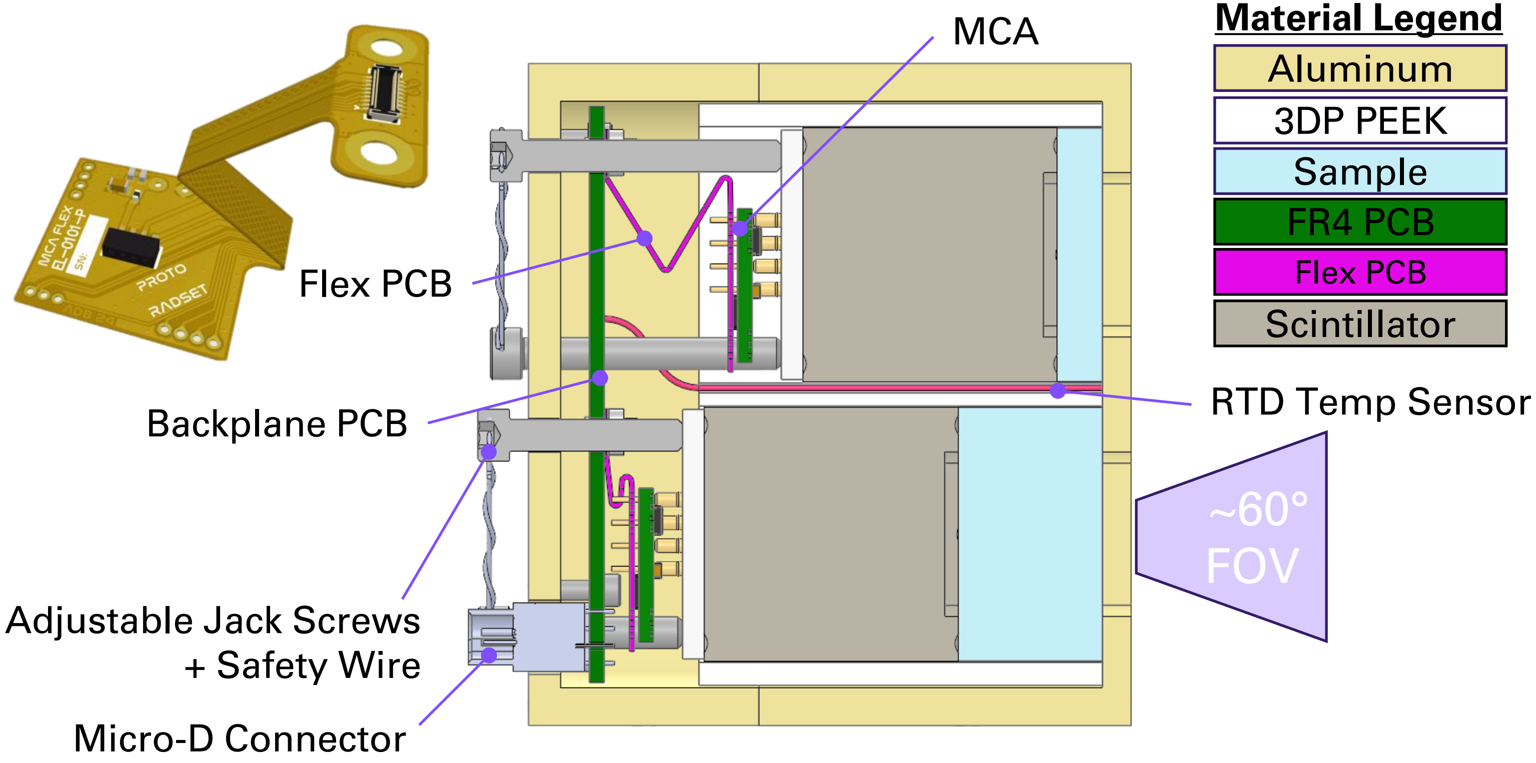
Hamamatsu <u>S13993</u> unsealed large-area aluminum-coated photodiode

- Direct radiation detection

Hamamatsu <u>S3590-09</u> unsealed large-area photodiode

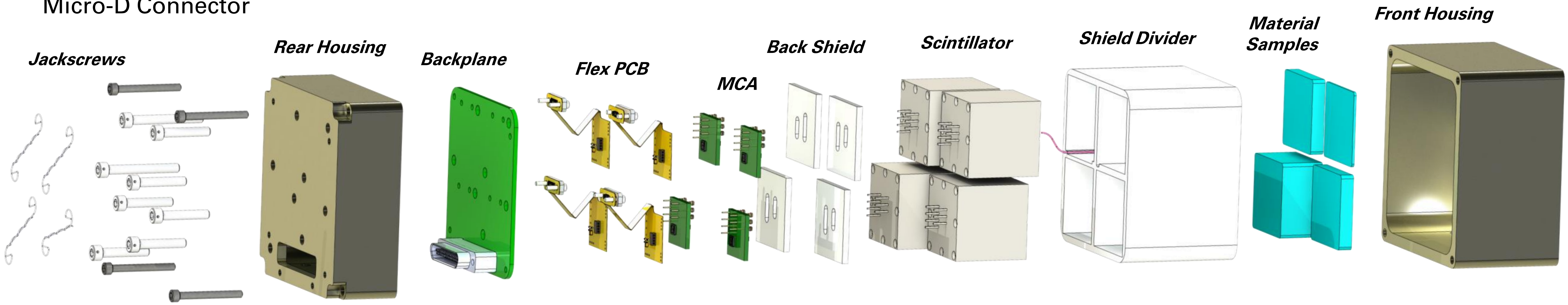
- General incident energy measurement





1U Sensor Quartet Module:

- 73x73x73mm^3 cube holding four 28x28mm sample coupons, accepts material up to 16mm thick
- 165mil Aluminum 7075, 100mil printed PEEK shielding
- Four scintillator modules, RTD sample temperature sensor, all digitizing and power electronics
- 5-12VDC Power, SPI & I2C over LVDS, and USB interface on single Micro-D



A Re-Configurable Payload for ‘U-Class’ Spacecraft

Detector Assembly

- Four detector-sample pairs per ‘Quartet’
- Approx. 22x22mm^2 exposed sample area
  - Approx. 60° FOV [0.84 Sr], dependent on sample thickness

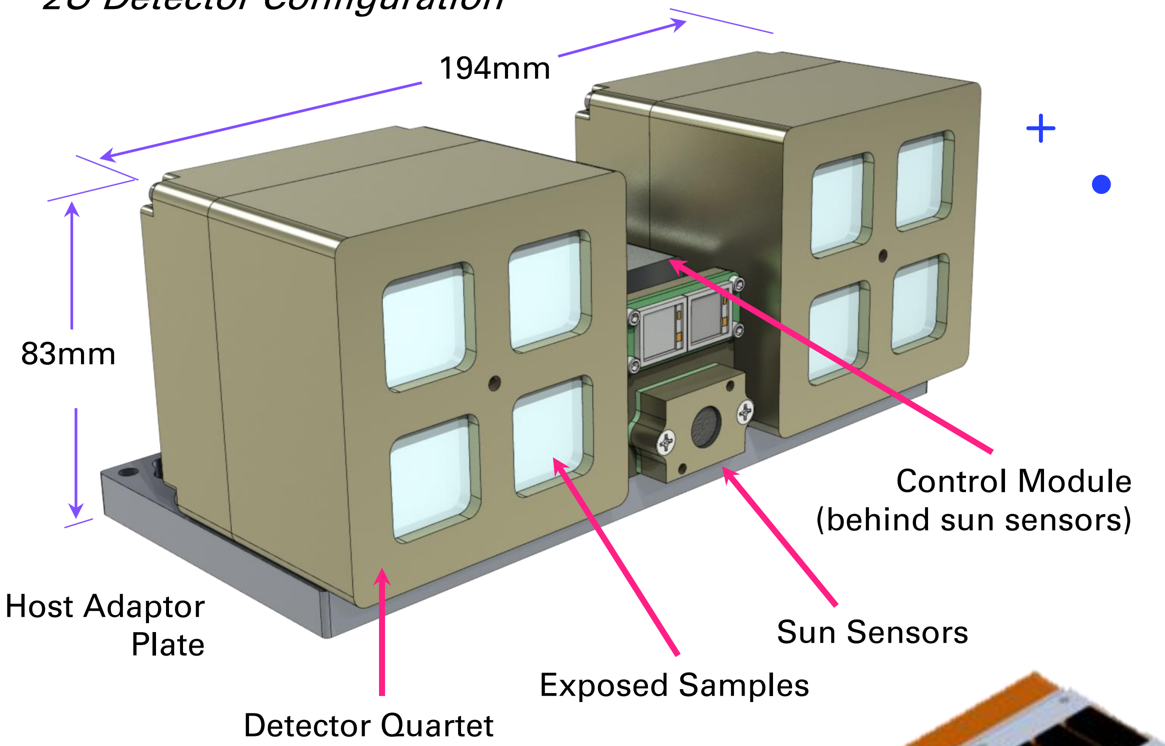
Payload Configured as 2U Exo-Terra Payload

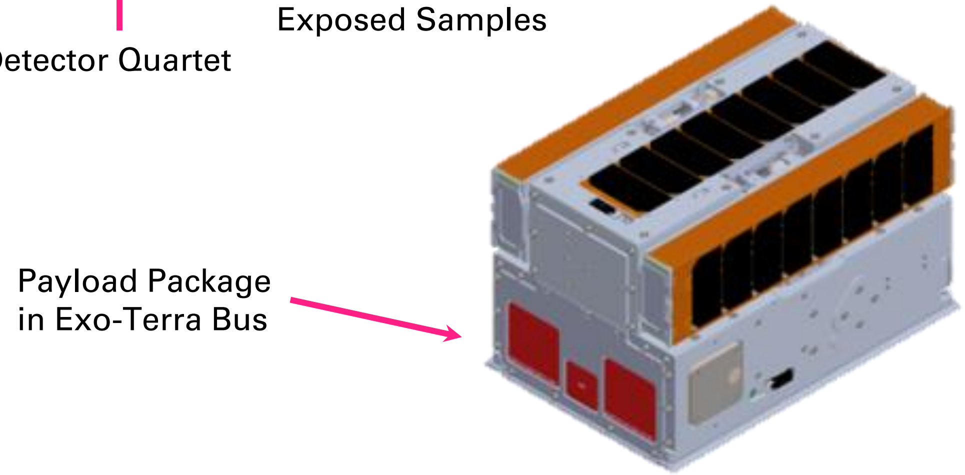
- 2x Quartets integrated on S/C adaptor plate
- Ram-oriented in S/C along Ion thruster vector
- Ports in S/C preserve view for material coupons & auxiliary sensors

Control Module & Interface:

- Embedded Linux Microprocessor
- 28VDC & RS-485 Host Interface via Micro-D
  - Compatible with 6-60VDC Bus Supply
  - RS-232 Serial Compatible
  - 4W Operating Power Requirement

2U Detector Configuration





28x28mm Sample Coupons:

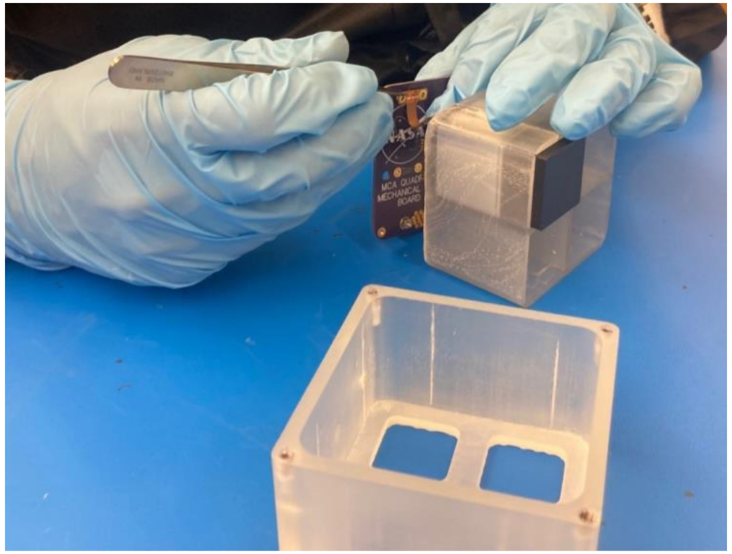
NanoSonic Graded-Z Composite Mk1	NanoSonic Control Composite	Ionizing Radiation Energy Sensor	Non-Ionizing Energy Sensor	100mil UHMWPE	NASA Chitin Melt Bio-Shielding
NanoSonic Graded-Z Composite Mk2	100mil Aluminum 7075 Model Control	Sun Angle Sensor		No-Material Control Sensor Control	NASA Graded-Z Aerogel

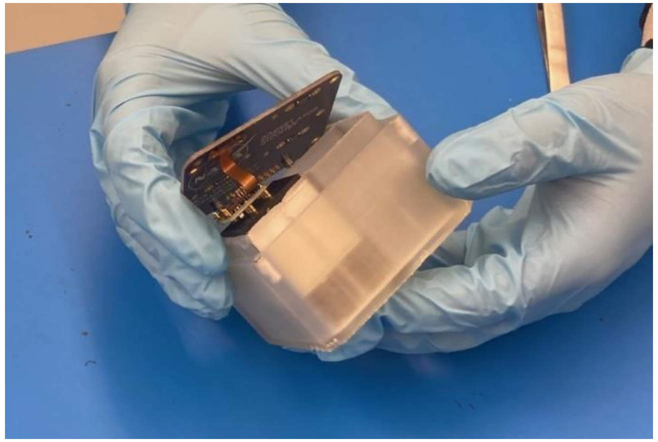
NanoSonic Test Quartet (1U):

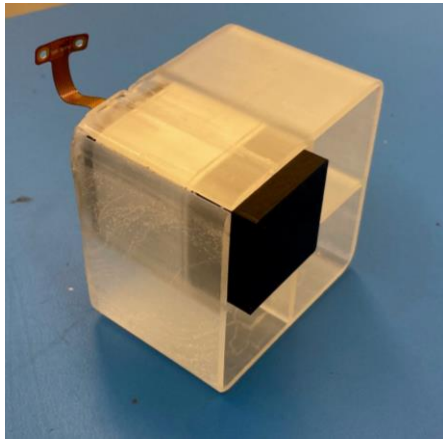
- TRL Advancement of SBIR Material
- Evaluation of material revisions efficacy
- Aluminum Standard Sample
  - Model verification against control

NASA Test Quartet (1U):

- Initial testing of Chitin Melt material
- TRL Advancement of Graded-Z Aerogel
- Polyethylene Standard Sample
  - Model verification against Aluminum







Mechanical Model Fit-Check:

- SLA-Printed models assembled with mechanical PCBs and flight-spare sensors
- Assembly process experimentation to optimize design for integration
  - Utilize additional surface-mounted standoffs
  - Assemble sensors and PCBs prior to mechanical housing integration

Next Steps

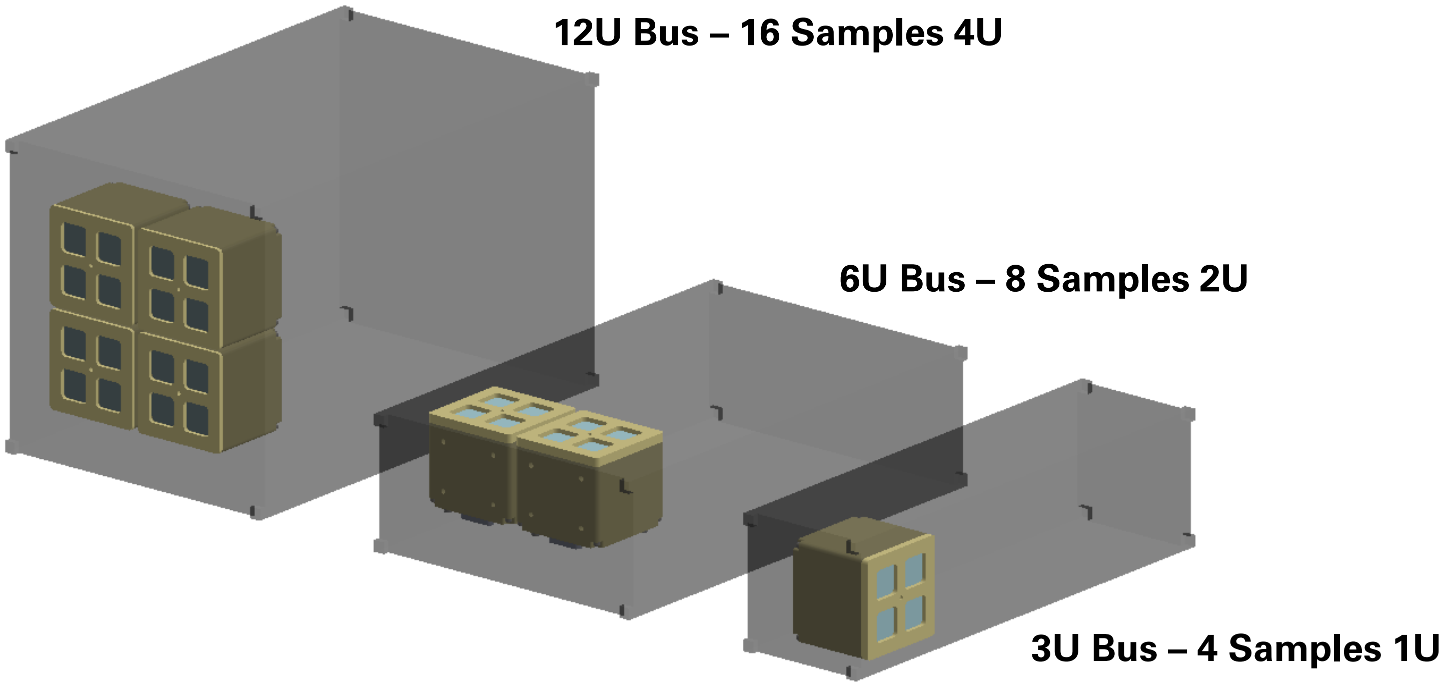
- Flight Unit Assembly & Integration
- Environmental Testing
    - Beam testing; Establish bias/sensitivity benchmarks for each detector
    - Qualification TVAC/Vibe (ARC)
    - Spacecraft-level acceptance testing (ExoTerra)

ExoTerra Launch NET Q1 2026

- Additionally/Alternatively:
    - Candidate payload for ARC TechEdSat-14 (2026)
    - SSTP/JSC R5 Spacecraft
    - Scalable SWaP/Comm permits various missions of opportunity

CONOPS

- Reporting of each sensor's spectrum
    - Correlate with temperature, sun sensor, and spacecraft ADCS data
- Configure integration periods and thermal compensation of sensors during checkout
- Possible onboard data processing/peak finding for dynamic adjustment during space weather events



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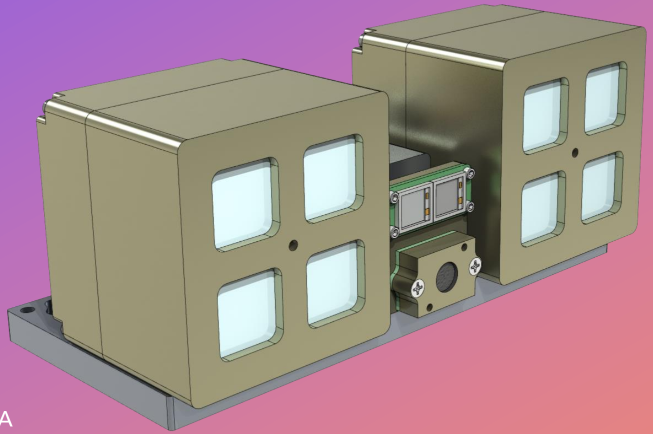
AMES RESEARCH CENTER

SPACEFLIGHT DIVISION
NASA AMES RESEARCH CENTER



NASA

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