Energetic Particle Sensors for Anomaly Attribution and Environmental Specification (CEASE & RHAS)

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Chad Lindstrom[1],
Stuart Huston[2] ,
W. Robert Johnston[1]

1. Air Force Research Laboratory, Space Vehicles Directorate.
2. Atmospheric and Environmental Research, Inc.

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Atmospheric and Environmental Research

Motivation

Current Approach:

1. Design for Robustness
   - Designs and components have heritage and/or testing to env. specifications
   - **Requires good environmental models – what do we design to?**

Most of the time this works, but occasionally the space particle environment still causes anomalies

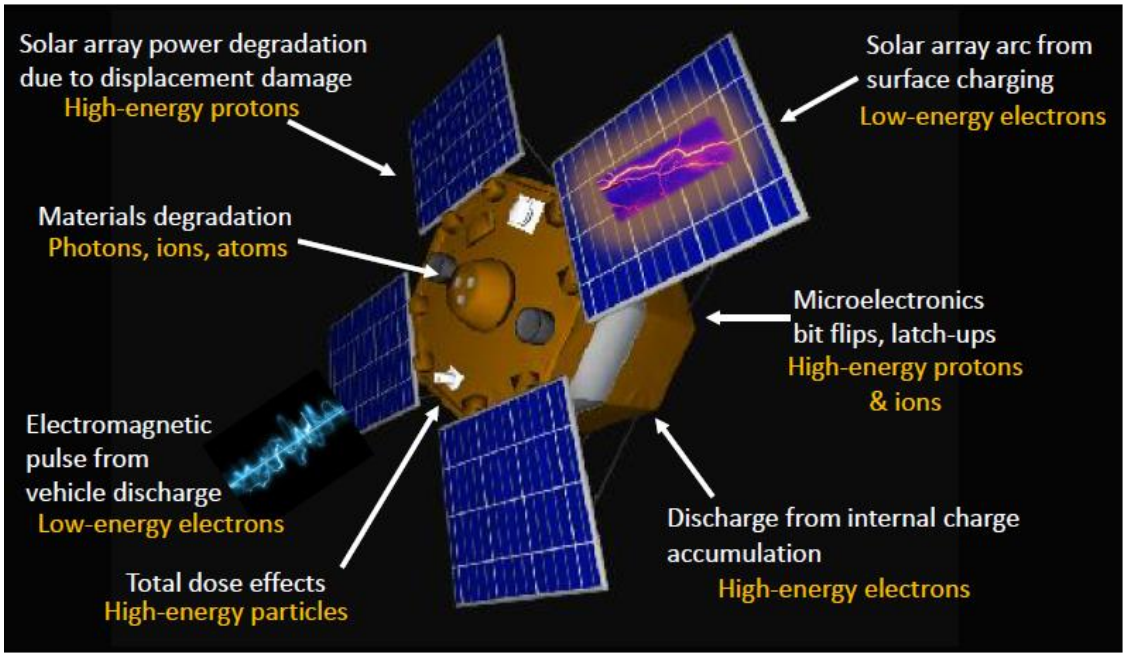
First time occurrences

2. Anomaly Attribution
   - Isolate anomaly to particular subsystem
   - Determine source of anomaly based on understanding of subsystem that is affected
   - **Particle environment is often not considered until source of last resort**

Can be time critical!

3. Impact to Operations & Mitigation
   - Accurate knowledge of cause enables best assessment and mitigation strategy

Various Ways Space Particle Environment Can Affect Satellites



Often we don't have actionable data on the particle environment

What is a "good" energetic particle sensor for anomaly attribution?

AFRL among the first to attempt to answer this with the Compact Environmental Anomaly Sensor (CEASE) developed in mid-1990's:

Size, weight, and power (SWAP)
Cost
Capability (Particle Species, Energetic Coverage, & Channels)

Effort focused to a large extent on finding right mix of these quantities

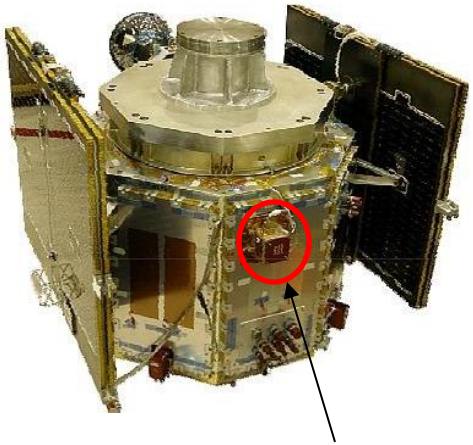
Experience with CEASE has shown importance of other issues:

Ease of data interpretation/logistics – How easy is it to process its data, relate it to anomalies, and get the right information in the decision maker's hands?

Accuracy and reliability – Can the data be trusted when its most needed?

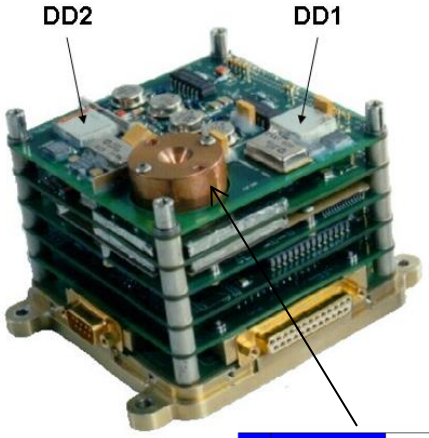
Range of operating environments – Can the instrument work over a wide variety of conditions?

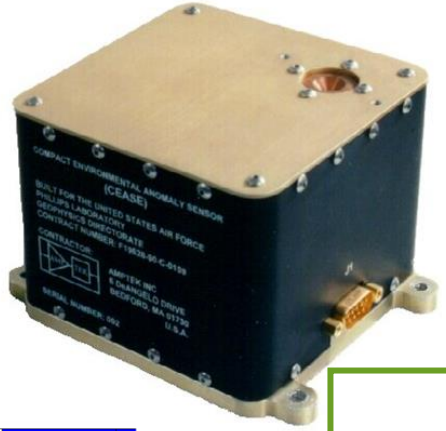
Data can also be used to improve environmental specifications

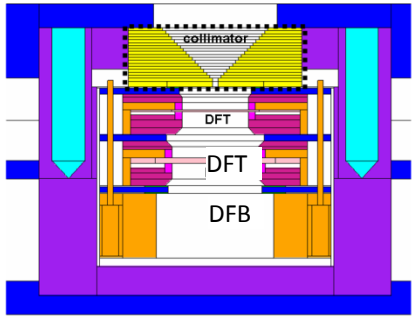


CEASE on TACSAT-4

Compact Environmental Anomaly Sensor (CEASE)







Particle Telescope

Vital Statistics

- Mass: 1 kg
- Power: 1.2 W
- Size: 10 x 10 x 8 cm

Particle Detectors

- 2 Dosimeters (Heavy and Light Shielded)
- Two element particle telescope
- SEE sensor
- Nominally 1-80 MeV protons, 0.05-3 MeV e^-
- CEASE II adds electrostatic analyzer for low energy electrons

CEASE Instrument Functions

- Provide real-time warning of space environmental hazards
- Assist satellite operators in investigating anomalies
- If spacecraft resources allow, collect detailed radiation environment data for research and input to specification and forecast models

AMP TEK | Compact Environmental Anomaly Sensor Space Radiation Alarm | CEASE

Assurance Technology Corporation

CEASE Flight History

Mission	Orbit	Launch	Status	Notes
TSX-5	LEO (410 x 1710 km, 69° inc)	Jun 2000	Ended in 2006	B.K. Dichter et. al demonstrated excellent correlation between SEE type anomalies and CEASE data; Data has been extensively used in AE9/AP9 v1.0.
DSP-21	GEO	Aug 2001	10+ years in operation	First CEASE II with electrostatic analyzer; Used in AE9/AP9 validation
SES-12	GEO	Activated Jun 2010	Operational CEASE II	First commercial operation of CEASE
TACSAT-4	HEO (700 x 12050 km, 63°)	Sep 2011	Completed mission in 2013	Identified elevated proton levels responsible for accelerated solar degradation; Proton data is one of key upgrades in AP9 v1.2
DSX	MEO (6000 x 12000 km, 45° inc)	Late 2015	CEASE I Integrated	Final CEASE I unit will be part of comprehensive science suite to measure MEO particle populations

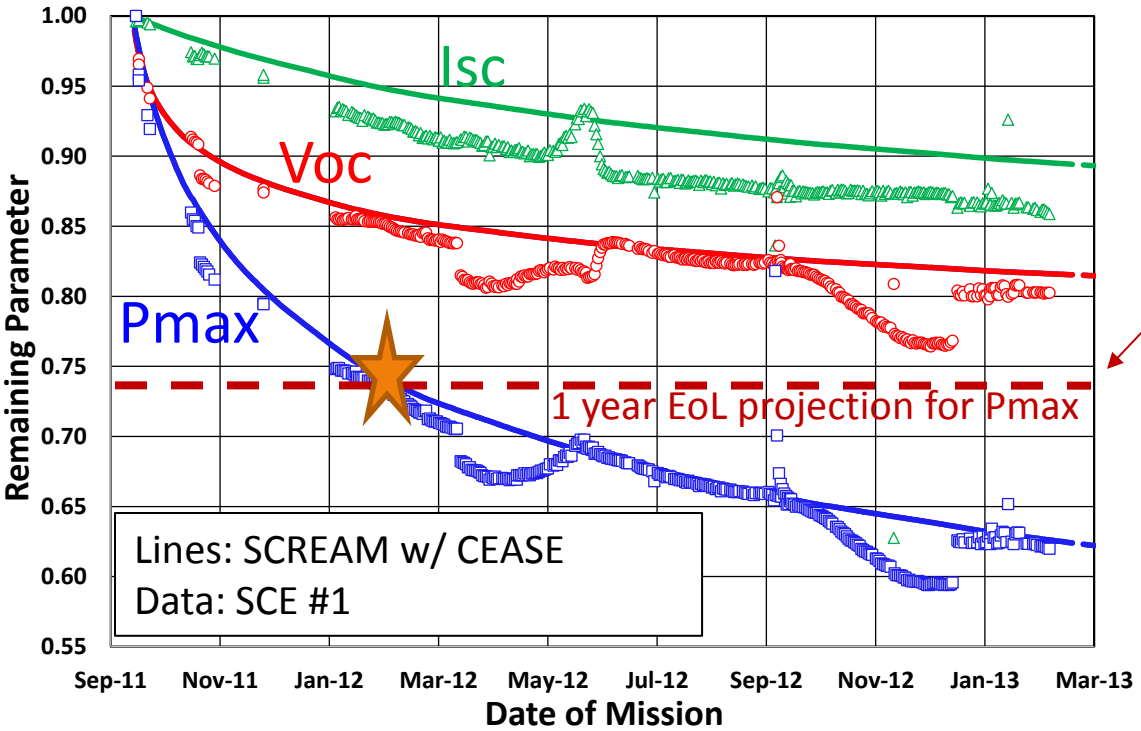
Extensive flight history has provided AFRL and its partners with a unique perspective

TACSAT-4 in particular is an important example of anomaly attribution

TACSAT-4 Solar Cell Degradation

(Effects of 1-10 MeV Slot Protons)

Solar Cell Experiment #1 Results[1]

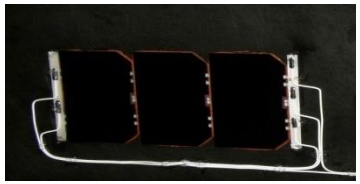


Mission planned using AP8min

Power Array : Emcore ATJ (3J) w/ 6 mil CMG coverglass (current at load only)

- Rapid degradation cause for alarm!
- SCREAM w/CEASE explained results and enabled projections of effects on ops

SCE #1 : Emcore BTJM (3J) 3-cell string w/ 6 mil CMG coverglass (full IV curves)



1. P.P Jenkins et al., "TACSAT-4 Solar Cell Experiment: Two Years in Orbit." 10th European Space Power Conference, Noordwijkerhout, NL, 14 Apr 2014.

Timeline Showing Challenges of Attribution

Sep. 2011 — Launch

Oct. 2011 — AFRL notices apparent enhanced proton flux at L~ 2.5-3.1 but questions exist because CEASE response historically was not trusted below proton energies of 15 MeV. NRL operations team notified about this finding.

Nov. 2011 — NRL SCE scientists contact AFRL with questions about environment. Crash effort begun to provide proton spectra required to drive SCREAM

Dec.-Jan. 2011 — Initial results from CEASE proton spectra appear promising. However, a new problem appears of a strong dropout in proton fluence. Speculation is it is associated with sensor look direction.

Feb.- June 2012 — Speculation that dip is associated with look direction is confirmed. AFRL unfolds effects of look direction on fluence spectra and first quantitative estimates show good agreement with SCE #1.

Sep. 2012 — TACSAT-4 operations begins limited usage of SCREAM/CEASE results to estimate potential impact on future operations. Results are first presented to community at NSREC.

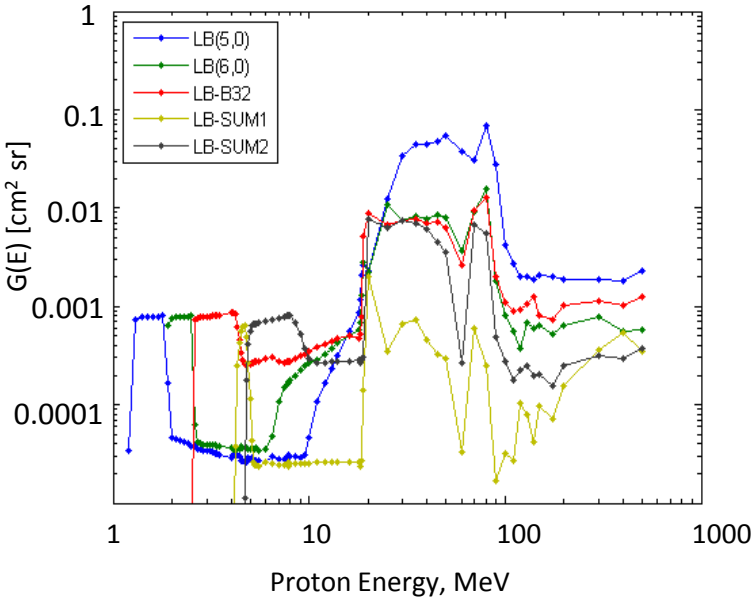
Sep. 2013 — TACSAT-4 successfully ends its mission after 2 years on orbit

Jul. 2014 — AP9 version 1.2 released with fully cleaned and cross-calibrated CEASE data from TACSAT-4 among improvements

What have we learned from this experience about what makes a good energetic particle sensor for anomaly attribution?

Importance of Accuracy & Reliability of Particle Data

CEASE response for 1-10 MeV protons



Significant concerns existed about CEASE's ability to measure 1-10 MeV protons

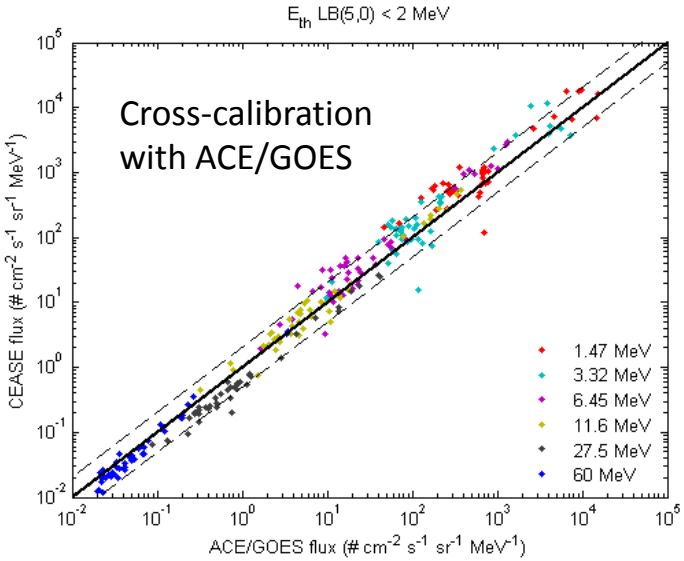
CEASE observes counts

Response

Proton flux

$$C_i = \int_0^\infty G(E)\, j_{iso}(E)\, dE$$

CEASE channels at these energies required careful analysis since they respond most strongly to high energy protons

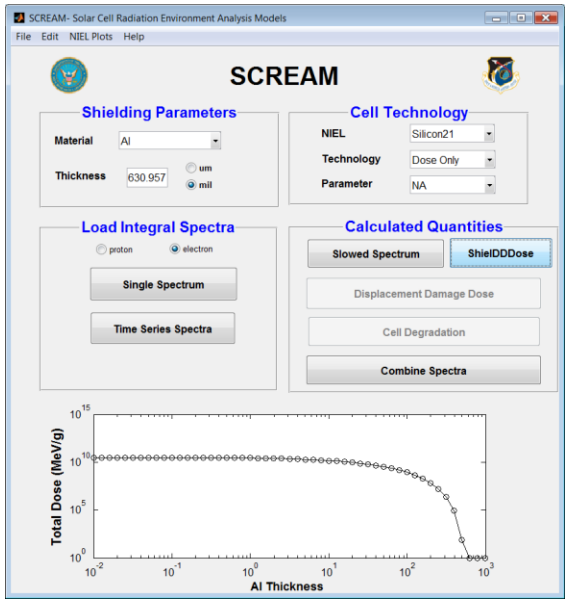


Ultimately, excellent performance achieved for soft spectra

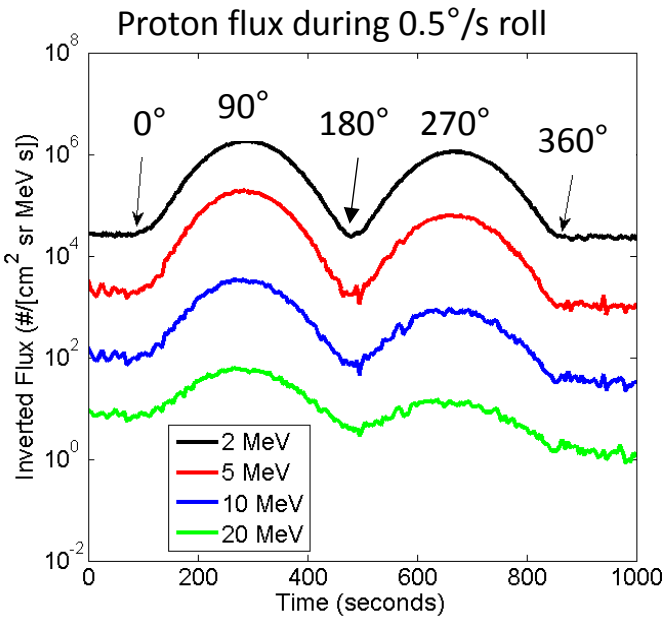
- Biggest factor in slowing down confidence in attribution analysis
- Understand limitations of the sensor (models and calibrations critical to achieving this)

Logistics and Ease of Data Interpretation

NRL's SCREAM *(Solar Cell Radiation Environment Analysis Models)* required spectra to do assessment



Problems existed in initially getting attitude data but ultimately proved critical in analysis



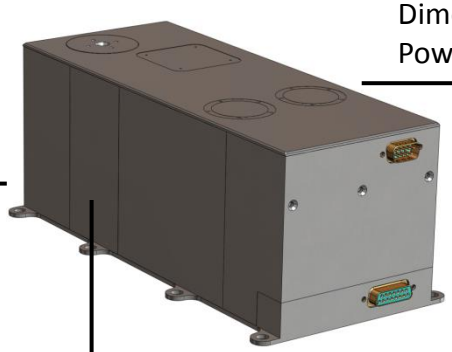
- Understand what is required to drive attribution software from sensor
- Be able to quickly generate particle spectra as it is the basis for most advanced analysis

- Information flow both from and to the spacecraft operations center is critical to performing timely anomaly attribution

CEASE III/RR Instrument Overview

CEASE III/RR Solid Model

RR = Risk Reduction

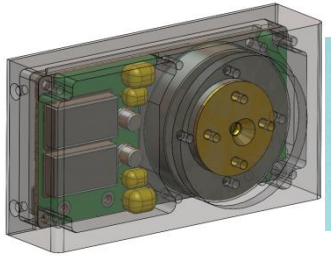


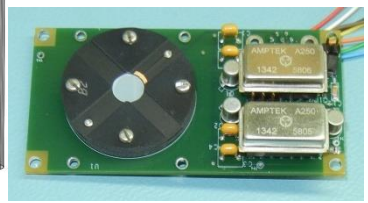
Dimensions: 10x10x25 cm Weight: 3.3kg

Power: 8 W max avg; 10 W peak

Designed to minimize changes necessary for follow on Class A operational instrument

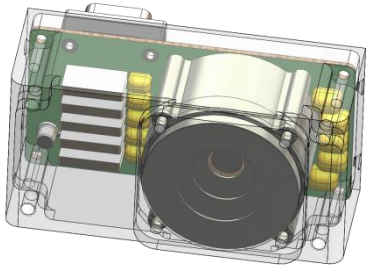
LEPET (Low Energy Proton Electron Telescope)

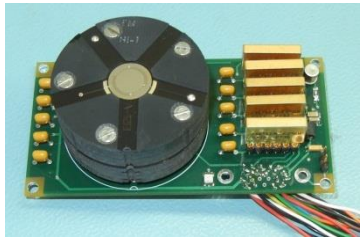




2 solid-state detectors measure incident proton fluxes from 3 – 12 MeV; electron fluxes from 0.05- 1 MeV

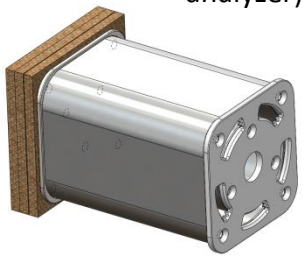
HEPET (High Energy Proton Electron Telescope)





5 solid-state detectors measure incident proton fluxes from 15 – 200 MeV; electron fluxes from 1- 4 MeV

ESA (Electrostatic analyzer)

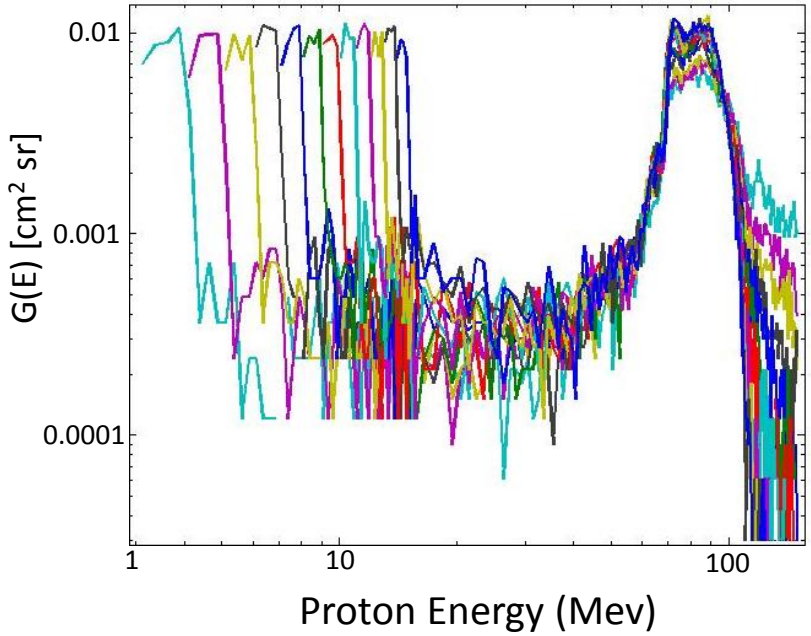


Two cylindrical ESAs measure electrons and ions from 100 eV to 50 keV

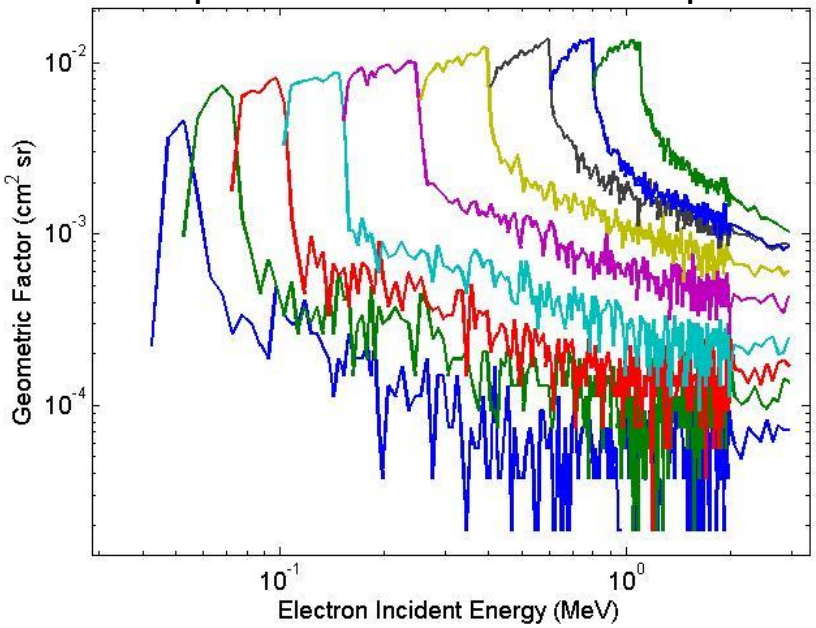
Focus has been on extending CEASE capabilities, accuracy, and reliability – not reducing SWAP and risk reduction unit's first planned flight is to GEO in 2017 (delivery early 2016)

Example of Anticipated Improvements Using LEPET

Computed LEPET Proton Response



Computed LEPET Electron Response



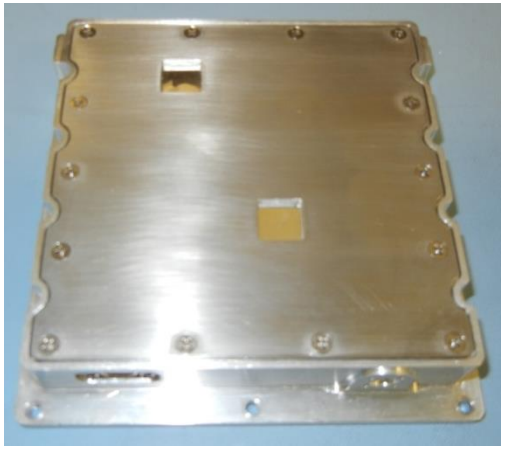
- Out-of-band background due to protons has been significantly decreased (10-100x)
- Much higher resolution channels (10-100x)
- Eliminates 0.2-1 MeV electron response dropout present in existing CEASE design
- Better statistics with larger geometric factor and higher maximum count rates

First flights primary objective is cross calibration with GOES for validation purposes

Radiation Hazard Awareness Sensor (RHAS)

Mechanical

- 490 grams
- 5”x5.375”x1” External Dimensions
- Al case – serves as camera lid as well as instrument
- Stainless steel lid and spacecraft wall used for differential shielding (mounted inside wall)



Channels:

- Dos1 (54 mils eq. Al) [>1.1 MeV e-, >16 MeV p]
- Dos2 (100 mils eq. Al) [>1.9 MeV e-, >24 MeV p]
- Dos3 (390 mils eq. Al) [>6.0 MeV e-, >47 MeV p]

Diagnostics:

- Temperature monitors (one for each dosimeter)
- On-orbit calibration
- Multiple data acquisition modes

Manifested on 2 identical GEO satellites intended for launch in 2017

Sensor emphasizes SWAP and cost over capability, accuracy, and reliability – question is whether the data is sufficient for simple, correlative type anomaly attribution?

Conclusion

Successful use of space particle detectors as hosted payloads for anomaly attribution requires designing sensors with an appropriate balance between:

Cost
Size, Weight, and Power
Capability
Establishing trust in data

These principles as well as experience with CEASE I & II are guiding the development of AFRL's CEASE RR/III and RHAS sensors