Simultaneous multi-point space weather measurements using the low cost EDSN CubeSat constellation

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Introduction

- EDSN Mission
- Instrument Motivations
- Mission Objectives
- Instrument Design
- Instrument Characterization
- Instrument Testing
- Mission ConOps
- Mission Status
- Future Work
"My God, space is radioactive!"  
Dr. Ernest C. Ray  
March 28, 1958
EDSN Mission

- Edison Demonstration of Satellite Networks
  - Multi-node network of 8 identical satellites
  - CMD and DWNLNK accomplished through a single “parent” which sends and receives data from the rest of the “siblings.”
  - Any of the 8 satellites can become the “parent.”
  - Active attitude control through magnetorquers and reaction wheels
  - On board GPS receiver and S-band Comm system
  - Samsung Galaxy smartphone as CDH
EPISEM Motivations

• 2003 Space Physics Decadal Survey:
  – Multipoint measurements are needed in the ionosphere, where global changes occur on short time scales and small spatial scales.

• 2013 Space Physics Decadal Survey:
  – The study of the heliophysics system requires multipoint observations to develop understanding of the coupling between disparate regions and to resolve temporal and spatial ambiguities that limit scientific understanding.
EPISEM (above) will measure omnidirectional integral flux concurrently at each spacecraft.

POLAR/SAMPEX (left) evaluated electron flux at large spatial and temporal distributions.

Spatial variations may occur at scales undetectable by a large spatial distribution.

Temporal variations may occur over periods of minutes to hours.
Mission Objectives

How are the spatio-temporal distribution and temporal variability of penetrating electrons and high-energy protons characterized?

- Previous correlations show distributions that appear isotropic in nature when lag time is less than one day, across large spatial/temporal distributions.
- Small spatial/temporal scales accomplished with co-temporal measurements across the EDSN array.

EPISEM will provide the first measurements of coherence at small spatial and temporal scales.
Mission Objectives

What are the fundamental exposure rates of spacecraft avionics to radiation from penetrating electrons and high-energy protons in Low Earth Orbit?

- EPISEM provides constant radiation measurements for each identical spacecraft
- Single event upsets on all or each spacecraft may be correlated to the radiation flux measured by each EPISEM.

- 54% in the South Atlantic Anomaly
- 26% in the Polar Regions
- 20% Galactic Cosmic Rays

- What are the temporal dependencies?
- What are the small scale spatial dependencies?

SEUs in the MOPITT instrument aboard TERRA
March 2000 to January 2003

ASEN-5335 Lectures, Jeff Forbes, University of Colorado
Instrument Design

- Employs a thin-walled Geiger-Müller tube located inside the spacecraft structure.
- Detects penetrating beta/gamma radiation from energetic particles above a certain energy threshold.
- Specific energy threshold is different for electrons and protons.

Incoming radiation knocks electron off of the Neon fill gas
Neon becomes Ne+ and free electron avalanches toward anode

Anode: ~550V

Requires <100 mW of power draw at 8.4V
Hard-coded serial numbers for all units
Reports last 60 seconds of counts at 1 second time resolution
Characterization

- Plateau curves completed twice for each instrument.
  - After GM tube installed and before shipment (prior to staking / coating).
- High voltage monitor circuit calibrated against a high voltage probe to reduce circuit measurement error.
  - 2nd order curve-fit approximation
- Each board tested using the same procedures.
- Test results compared to ensure no large outliers between boards.

**Flight Board Rt = 2000, Temp = 25C**

![Graph showing average count per second vs. voltage.]

- Three Test Average
- Plateau Range
- Linear (Plateau Range)

\[ y = 0.0246x + 135.46 \]
\[ R^2 = 0.3417 \]

**Error in High Voltage Monitor Circuit**

![Graph showing deviation from measured value vs. high voltage setting.]

- Deviation from measured value, after conversion equation applied

August 16, 2013  AIAA/USU SmallSat Conference
Characterization

Final Plateau Curve Slope

Turn On Voltage

High Voltage Ripple

IBATTat700V
IBATTat300V
**Characterization**

EPISEM measures omnidirectional integral flux in counts per second per throughput (GF or $A\Omega$).

- EPISEM: LND71320 Tube, $A\Omega = 1.94 \text{ cm}^2*\text{sr}$
- Explorer-1: Anton302 Tube, $A\Omega = 17.4 \text{ cm}^2*\text{sr}$
- Omnidirectional flux ($\phi_{\text{part}}$) = count rate / ($\xi*A\Omega$)

EPISEM detects particles with energy greater than some threshold energy.

- $E > E'$
- Found using the CSDA range.
- Approx to the average path length traveled.
- Rate of loss at every point along particles path assumed to be equal to total stopping power.
- Density Cu = 9.0 g/cm³, Density Al = 2.7 g/cm³
- Bottom/Side Entry -> 2 MeV e- and 25 MeV p+

Integral flux, $I(E)$:

$J$ is a particle flux in counts$^{-1}$sec$^{-1}$cm$^{-2}$sr$^{-1}$

$J$ has a variation in energy $J(E)dE \propto E^{-\gamma}dE$

EPISEM measures integral flux $I(E)$ above a certain kinetic energy $J = -dI/dE$

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**Top of Stack Entry**

<table>
<thead>
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<th>Material</th>
<th>$E'$ for e- (MeV)</th>
<th>$E'$ for p+ (MeV)</th>
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<td>S-Band Patch</td>
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<tr>
<td>Router Assembly PCB</td>
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</tr>
<tr>
<td>S-Band Heatsink</td>
<td>Aluminum</td>
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<tr>
<td>MHX2420 Shield</td>
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<td>Geiger Tube Wall</td>
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<td><strong>Total Thicknesses</strong></td>
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<tr>
<td><strong>Total Thicknesses</strong></td>
<td>Al</td>
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Testing

TVAC chamber test:
- Hot soak at 50°C
- -40°C to 40°C cycles

High Altitude balloon flight:
- Flight had two other detectors
- Maximum altitude of 28 km

Suspected heavy ion strike from measurements with a silicon detector set to a threshold of >40 MeV
Science Data Collection:
Current baseline is 30 min data runs, once per day.
On-board propagator used for location targeting

S-band Crosslink/Downlink:
“Siblings” crosslink to “Parent”
“Parent” downlinks during pass
Santa Clara Ground Station

HAM community packets for E1P/HRBE:
One packet = 150 bytes
25,000 HAM packets received total.
Points represent number of packets received when the satellite is at that particular location.

EDSN’s round robin-beacon structure.
ConOps

- Targets of interest
  - L-shell conjunctions: RBSP, BARREL
  - Flares, CME’s, solar proton events
- South Atlantic Anomaly passes

Flare initially blamed for the Galaxy IV satellite failure
Mission Status

• All instruments delivered to Ames
  – QA inspection passed
  – 8µC, Cs-137 radiation source procured at Ames
  – Awaiting pre and post integration performance tests

• Launch mid-2014 on ELaNA VII
Questions?

Acknowledgements
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Ehson Mosleh
Backup Slides
Fabrication
Fabrication
Fabrication

- All circuit boards cleaned, cleaned, and then cleaned again
- Boards staked and coated before final testing and shipment
Fabrication

• Mounted and packaged in an aluminum shipping container
• Double-wrapped in alumaloy
• Packaged and shipped in lots of two to four
Design Iterations
Design Iterations
Space Weather

Customer Growth
SWPC Product Subscription Service

- Sunspot Number
- Number of Customers

Start of Subscription Service

- Customers
- Solar Cycle