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

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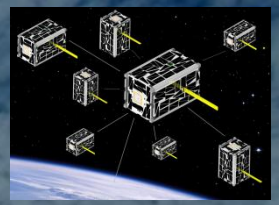
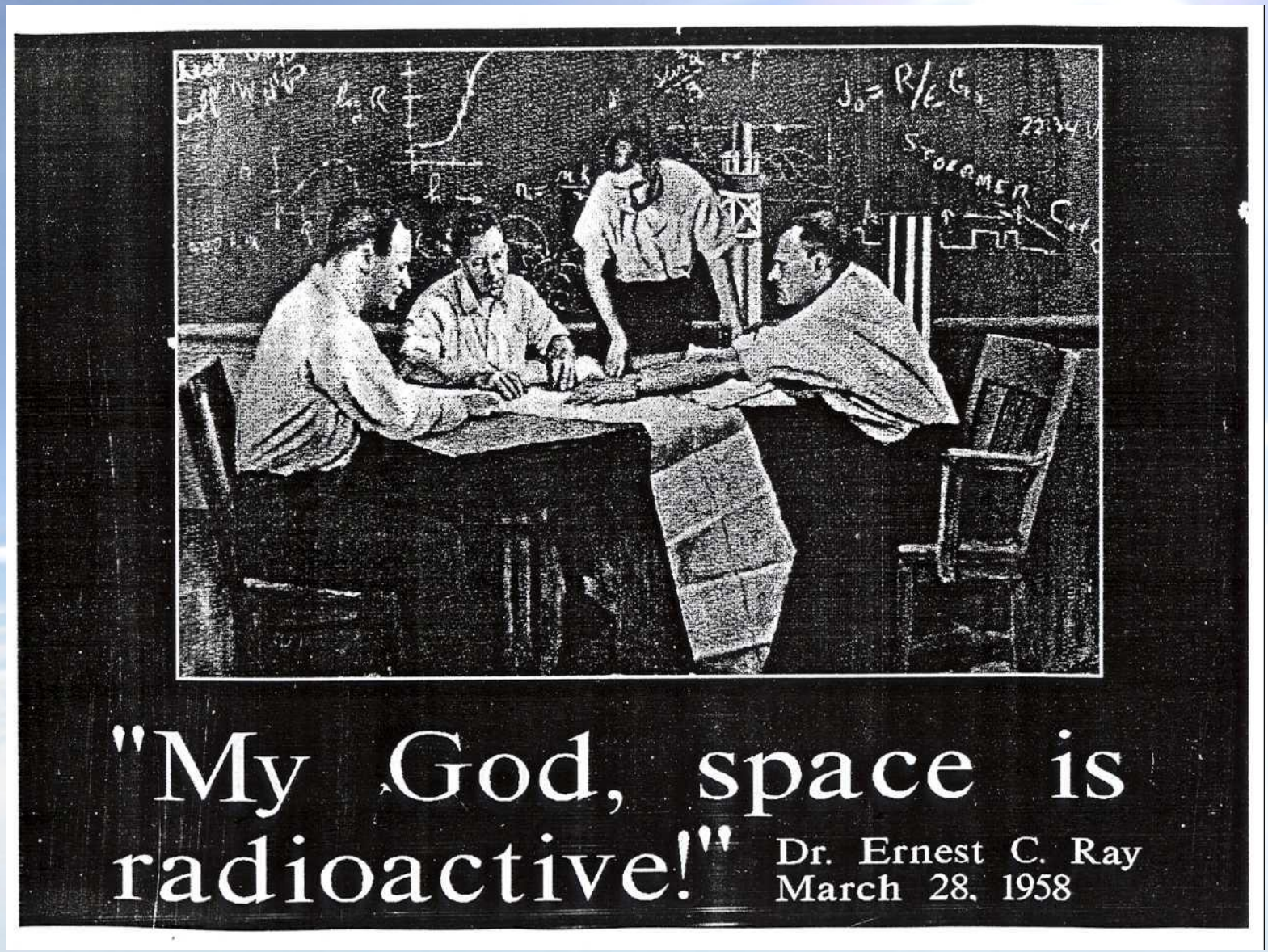
27th Annual AIAA/USU
SmallSat Conference
August 29, 2013



Introduction

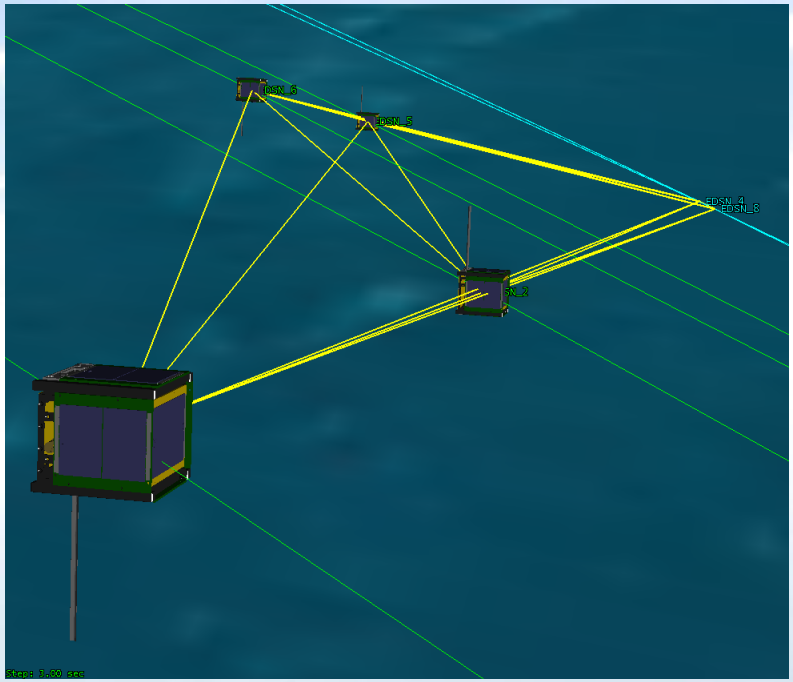
- EDSN Mission
- Instrument Motivations
- Mission Objectives
- Instrument Design
- Instrument Characterization
- Instrument Testing
- Mission ConOps
- Mission Status
- Future Work

Introduction



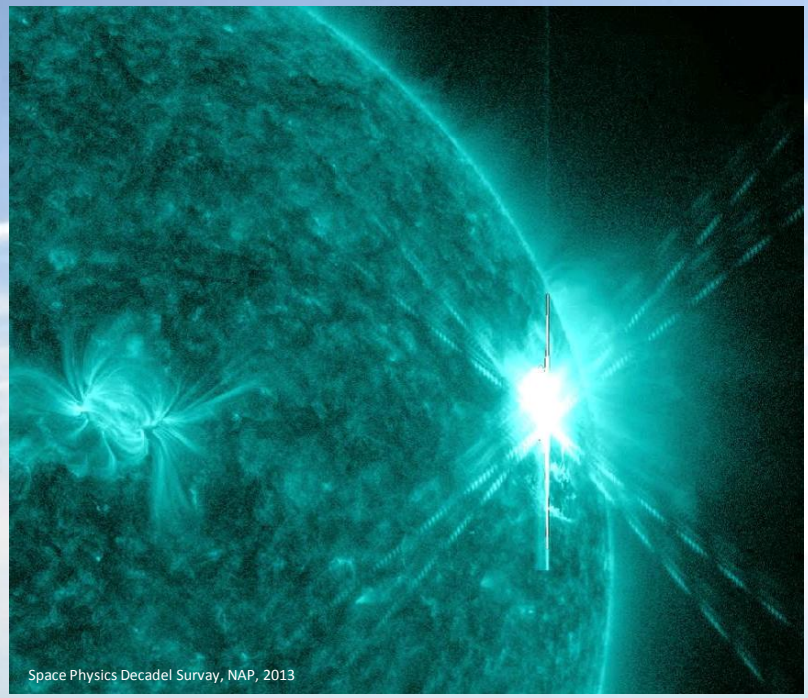
EDSN Mission

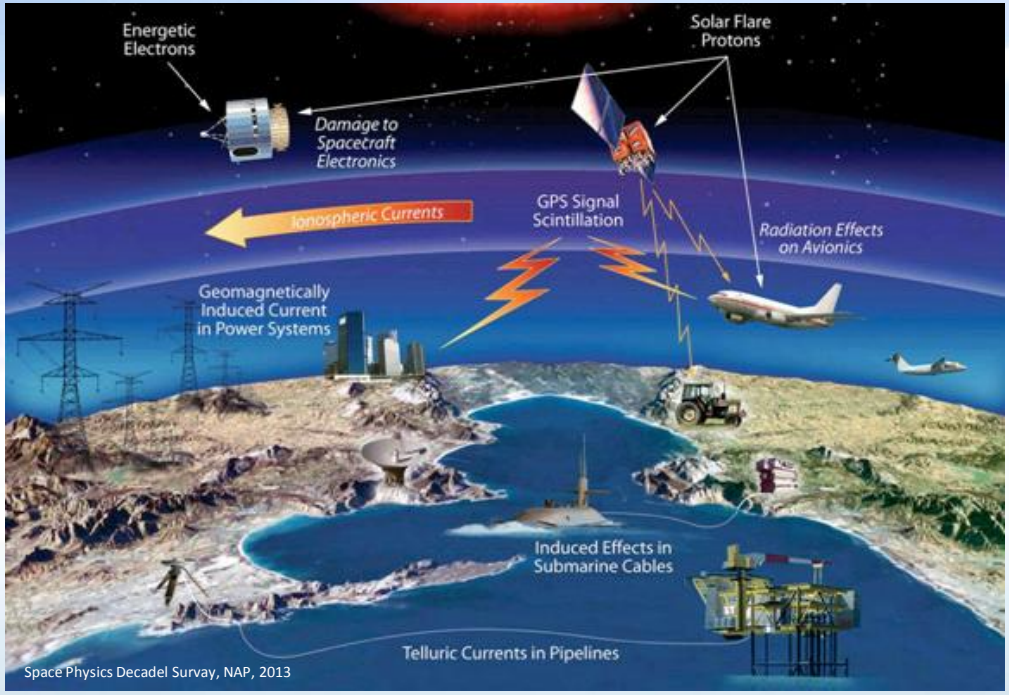
- Edison Demonstration of Satellite Networks
  - Multi-node network of 8 identical satellites
  - CMD and DWNLNK accomplished through a single “parent” which sends and receives data from the rest of the “siblings.”
  - Any of the 8 satellites can become the “parent.”
  - Active attitude control through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



EPISEM Motivations

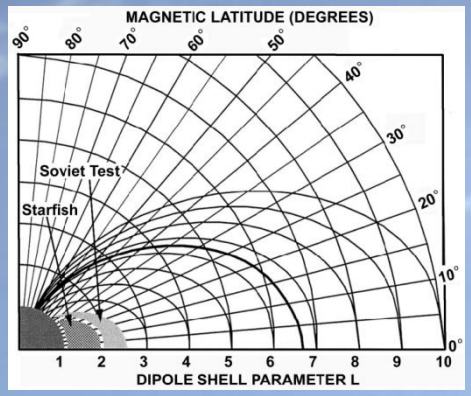
- 2003 Space Physics Decadal Survey:
  - Multipoint measurements are needed in the ionosphere, where global changes occur on short time scales and small spatial scales.
- 2013 Space Physics Decadal Survey:
  - The study of the heliophysics system requires multipoint observations to develop understanding of the coupling between disparate regions and to resolve temporal and spatial ambiguities that limit scientific understanding.


Space Physics Decadel Survay, NAP, 2013

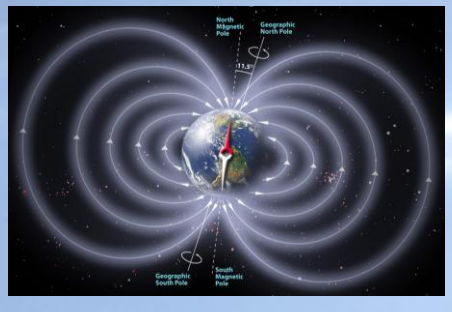


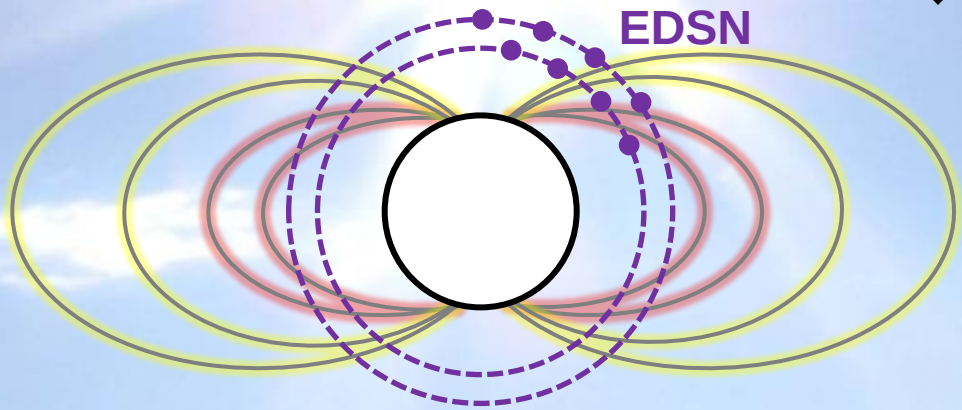
Space Physics Decadel Survay, NAP, 2013

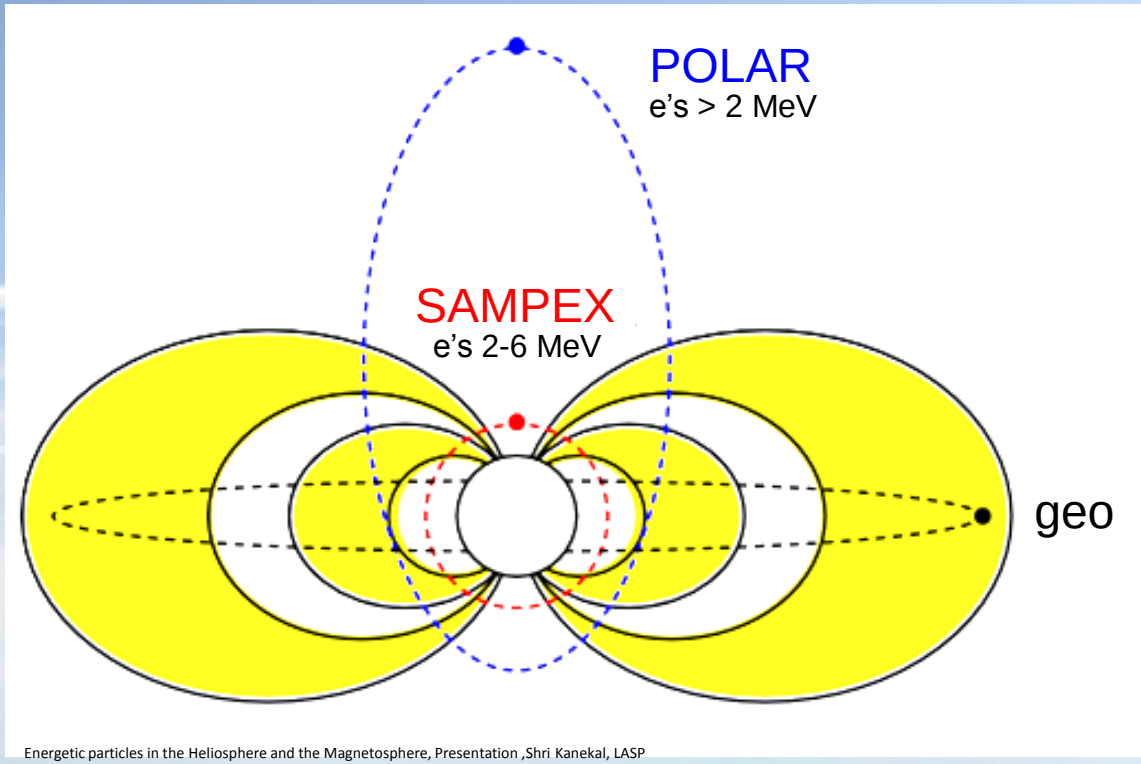
EPISEM Motivations



L-shell Concept







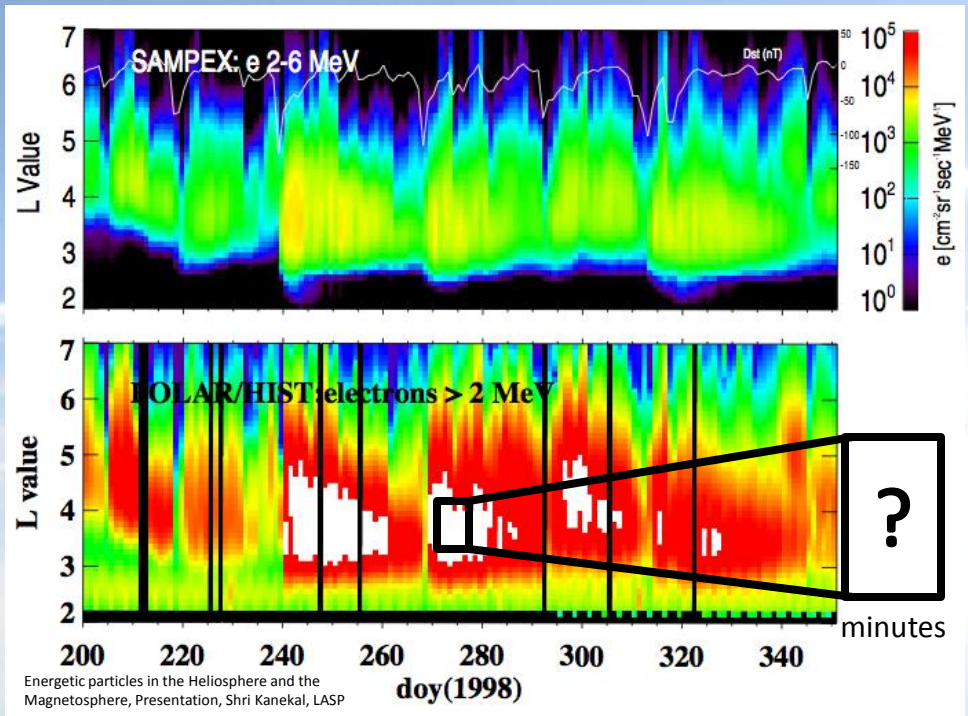
Energetic particles in the Heliosphere and the Magnetosphere, Presentation ,Shri Kanekal, LASP

- EPISEM (above) will measure omnidirectonal 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.

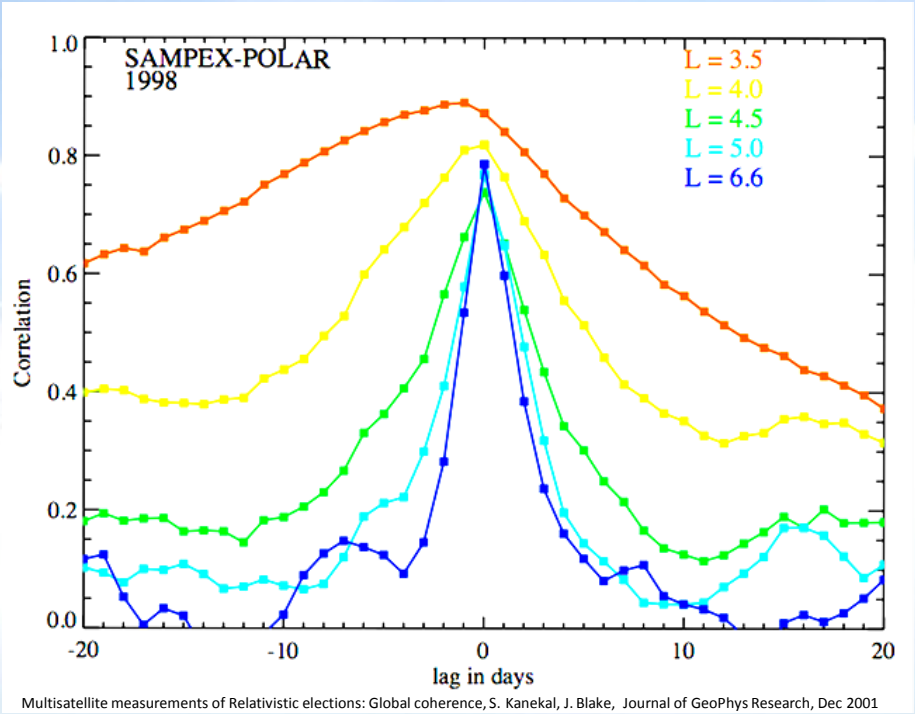
Mission Objectives

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.



Energetic particles in the Heliosphere and the Magnetosphere, Presentation, Shri Kanekal, LASP



Multisatellite measurements of Relativistic elections: Global coherence, S. Kanekal, J. Blake, Journal of GeoPhys Research, Dec 2001

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

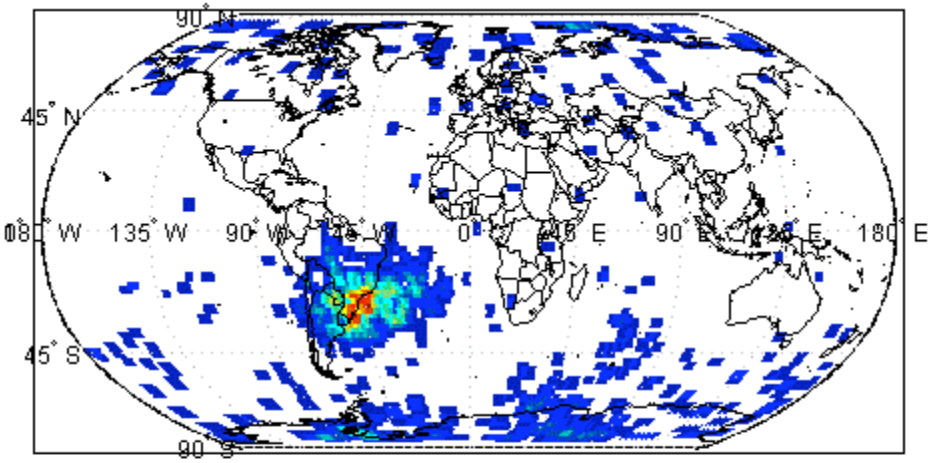
Mission Objectives

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?

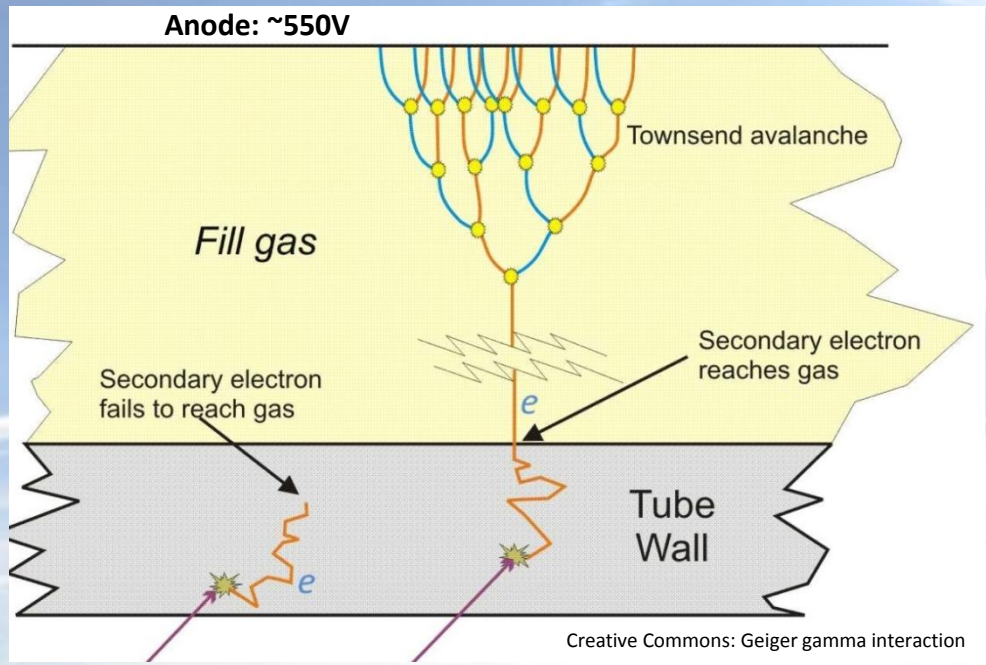


SEUs in the MOPITT instrument aboard TERRA March 2000 to January 2003

ASEN-5335 Lectures, Jeff Forbes, University of Colorado

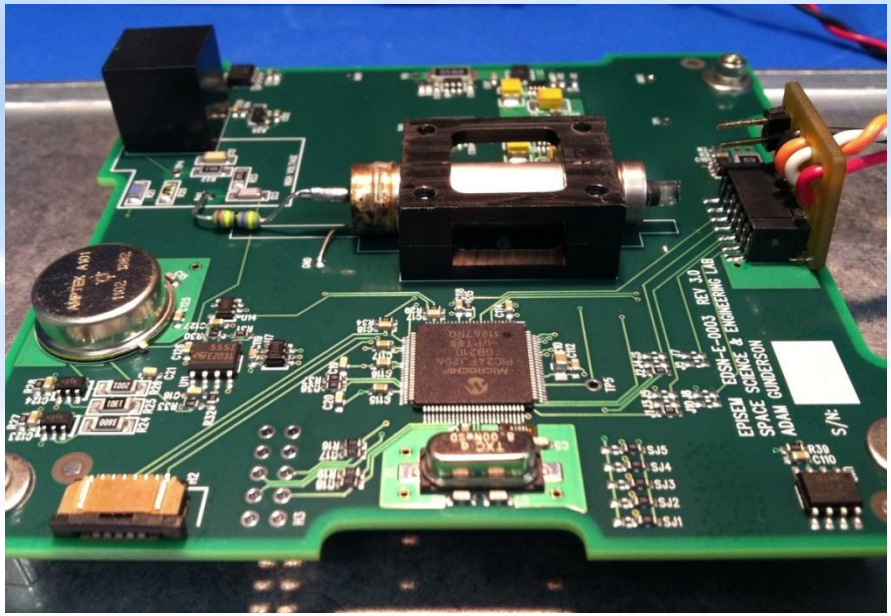
Instrument Design

- Employs an thin-walled Geiger-Müeller 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.



Creative Commons: Geiger gamma interaction

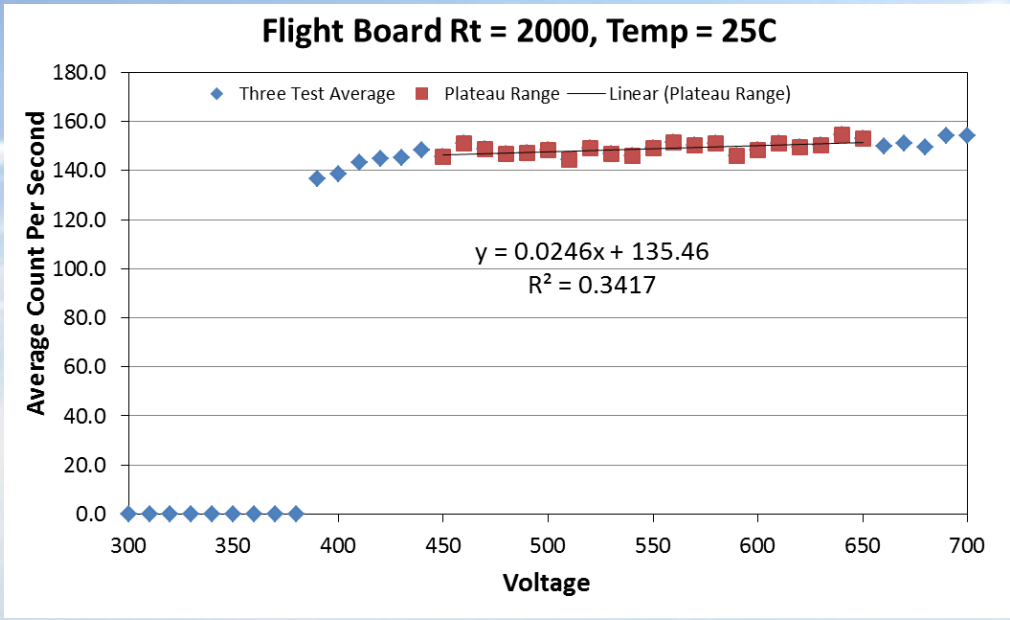
- Incoming radiation knocks electron off of the Neon fill gas
- Neon becomes Ne+ and free electron avalanches toward anode

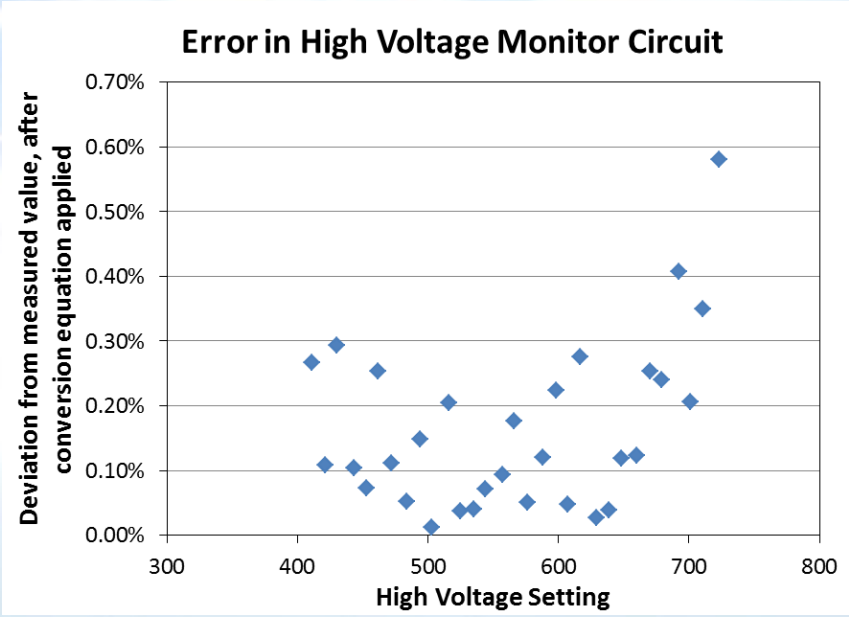


- Requires <100 mW of power draw at 8.4V
- Hard-coded serial numbers for all units
- Reports last 60 seconds of counts at 1 second time resolution

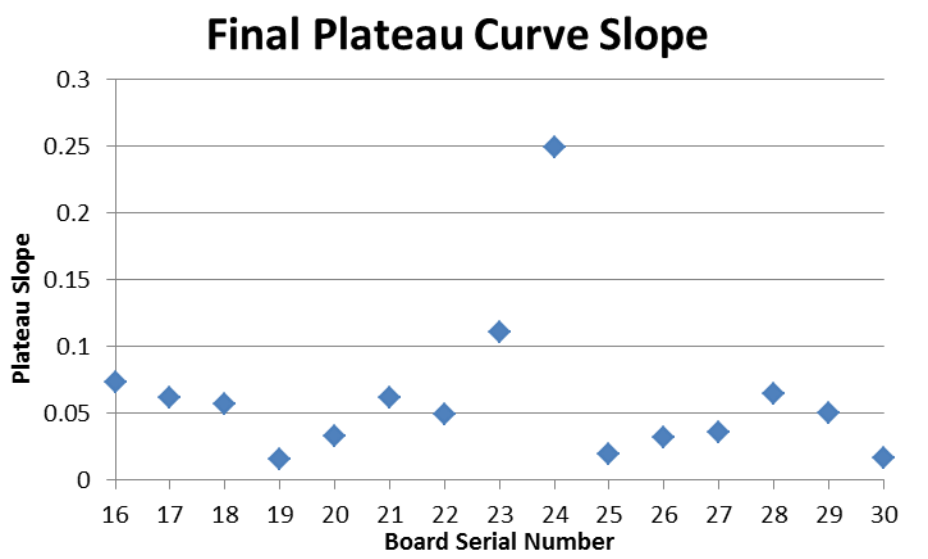
Characterization

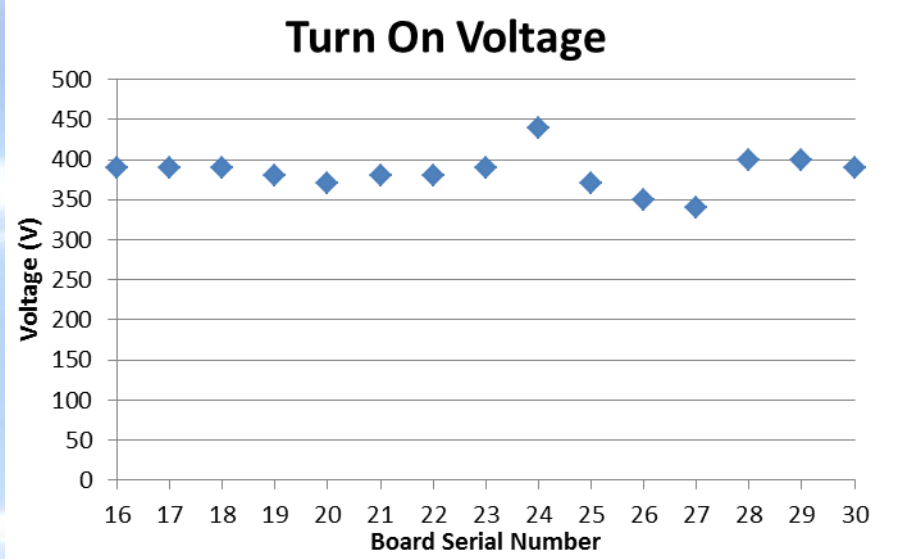
- Plateau curves completed twice for each instrument.
  - After GM tube installed and before shipment (prior to staking / coating).
- High voltage monitor circuit calibrated against a high voltage probe to reduce circuit measurement error.
  - 2nd order curve-fit approximation
- Each board tested using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

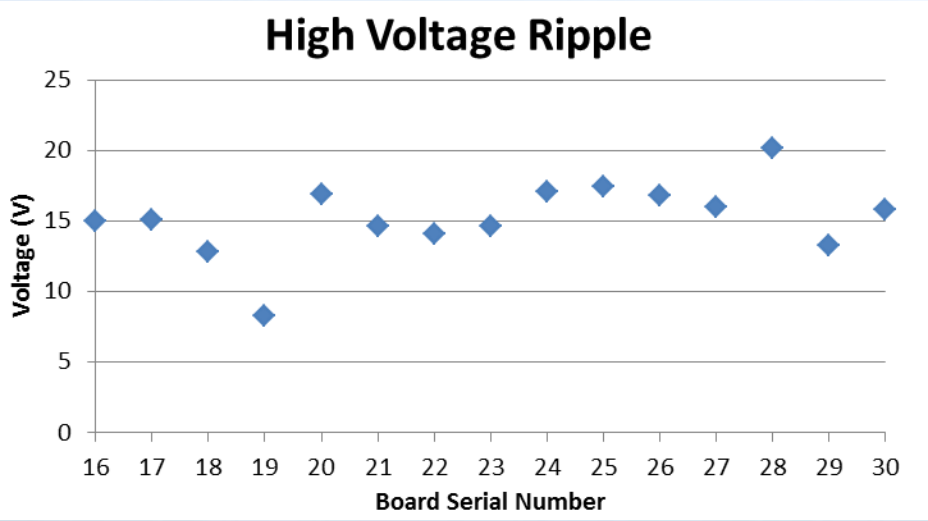


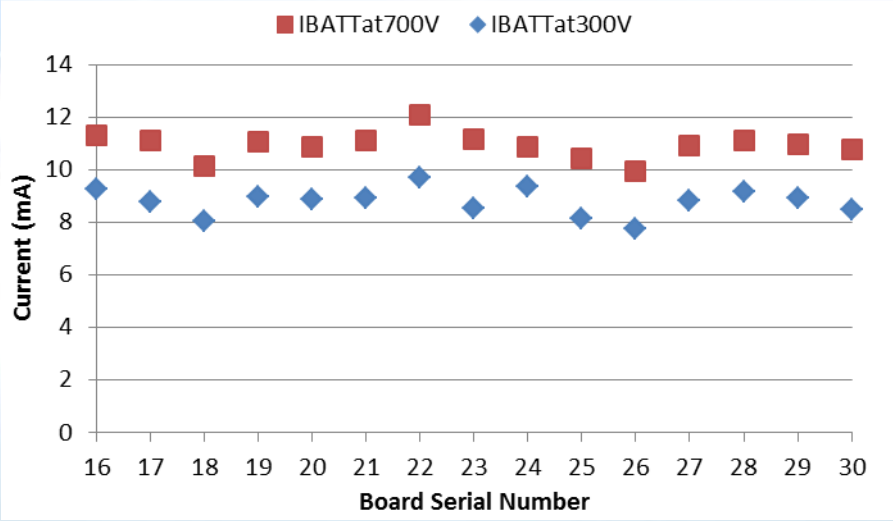


Characterization





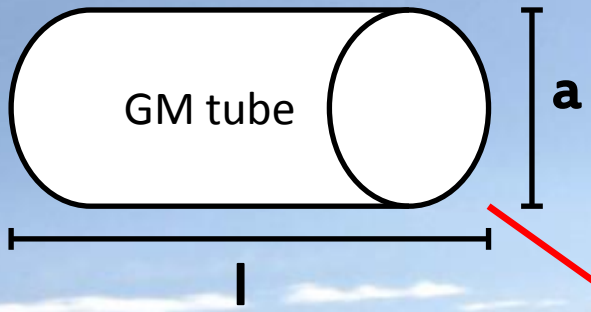




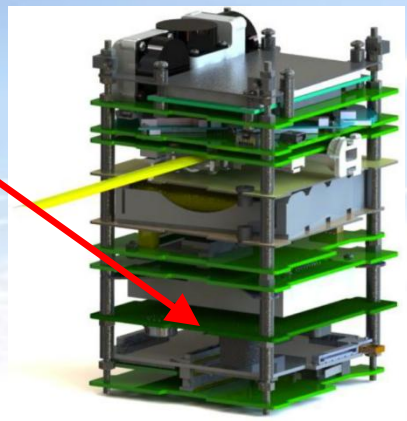
Characterization

EPISEM measures omnidirectional integral flux in counts per second per throughput (GF or AΩ).

- EPISEM: LND71320 Tube, AΩ = 1.94 cm^2*sr
- Explorer-1: Anton302 Tube, AΩ = 17.4 cm^2*sr
- Omnidirectional flux (ϕ_{part}) = count rate / (ξ*AΩ)



$$A\Omega = (\pi/4)(a*l)(1+a/2l)$$



Integral flux, I(E):

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

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

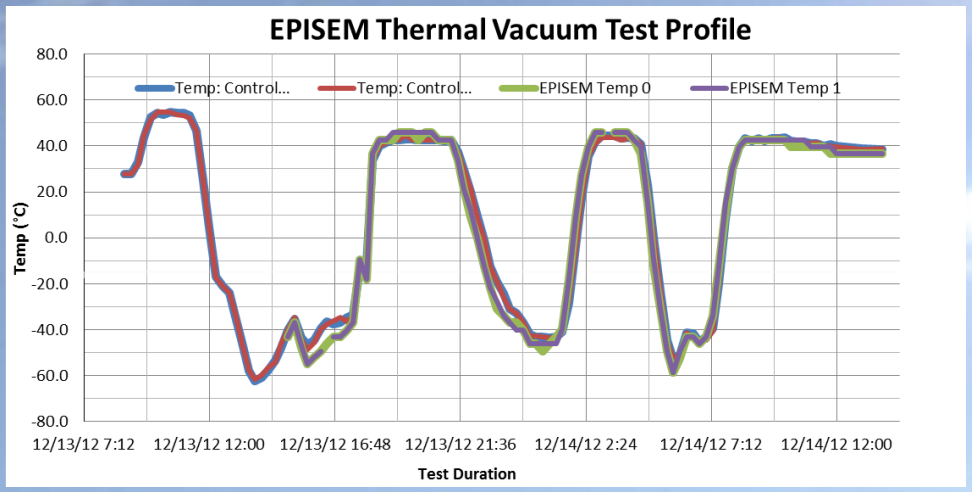
EPISEM measures integral flux I(E) above a certain kinetic energy $J = -dI/dE$

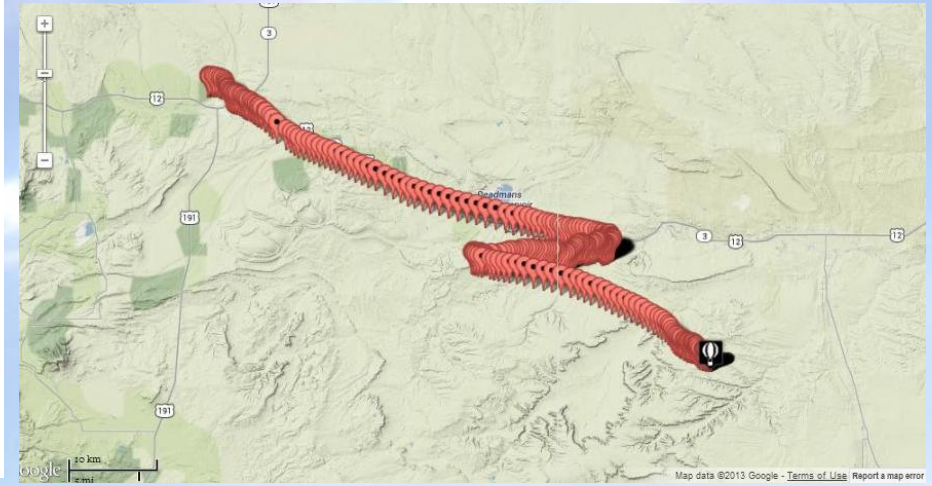
EPISEM detects particles with energy greater than some threshold energy.

- 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/cm^3, Density Al = 2.7 g/cm^3
- Bottom/Side Entry -> 2 MeV e- and 25 MeV p+

Top of Stack Entry	Material	E' for e- (MeV)	E' for p+ (MeV)
S-Band Patch	Copper	2.00	25.00
Router Assembly PCB	Copper	2.00	25.00
S-Band Heatsink	Aluminum	4.50	13.00
MHX2420 Shield	Aluminum	4.50	13.00
MHX2420 PCB	Copper	2.00	25.00
ACS PCB	Copper	2.00	25.00
Phone PCB	Copper	2.00	25.00
EPS PCB	Copper	2.00	25.00
18650 Liions	**Various**	**8.00**	**60.00**
Stensat Radio PCB	Copper	2.00	25.00
GPS Aluminum Housing	Aluminum	4.50	13.00
GPS Card	Copper	2.00	25.00
GPS Heatsink	Aluminum	4.50	13.00
GPS Interface PCB	Copper	2.00	25.00
EPISEM PCB	Copper	2.00	25.00
Geiger Tube Wall	Aluminum	0.08	2.20
Total Thicknesses	**Copper**	**20.00**	**95.00**
Total Thicknesses	**Aluminum**	**1.75**	**27.50**

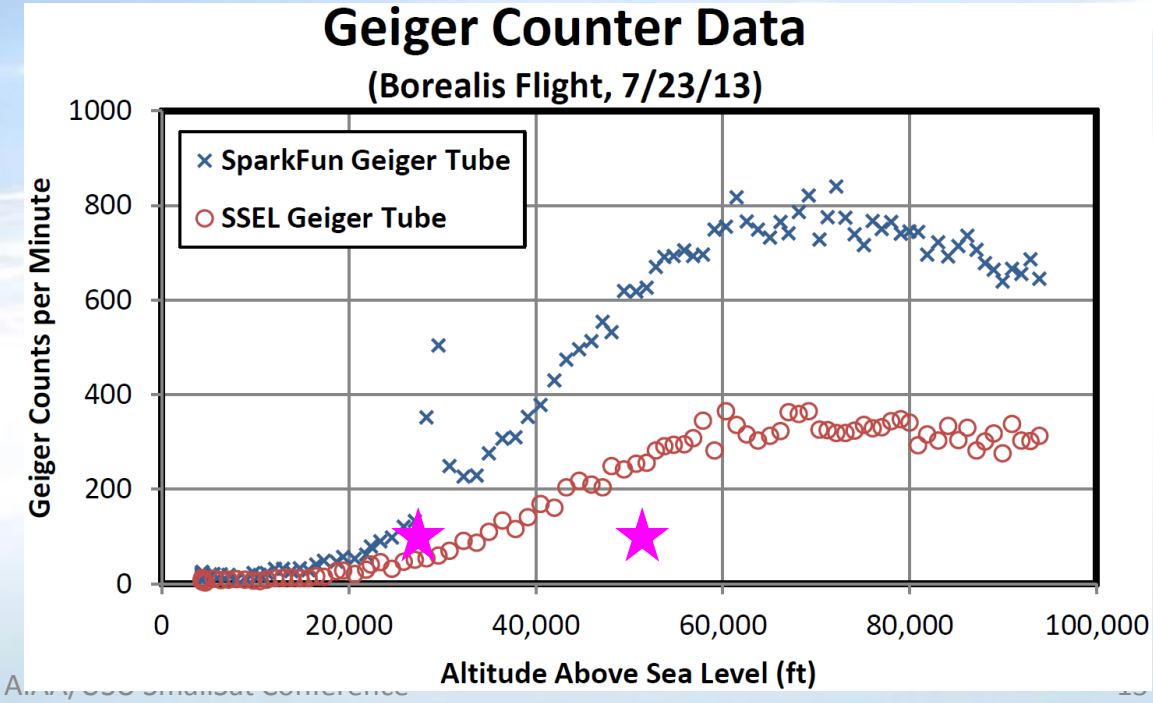
Testing





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

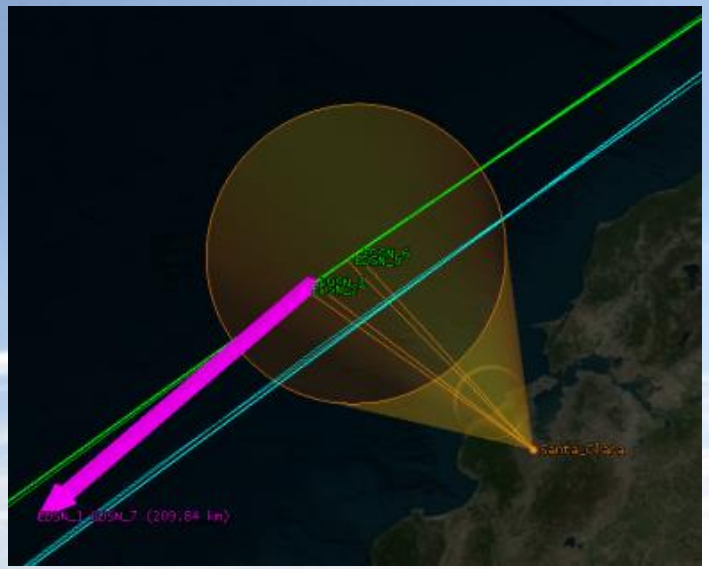


ConOps

Science Data Collection:

Current baseline is 30 min data runs, once per day.

On-board propagator used for location targeting

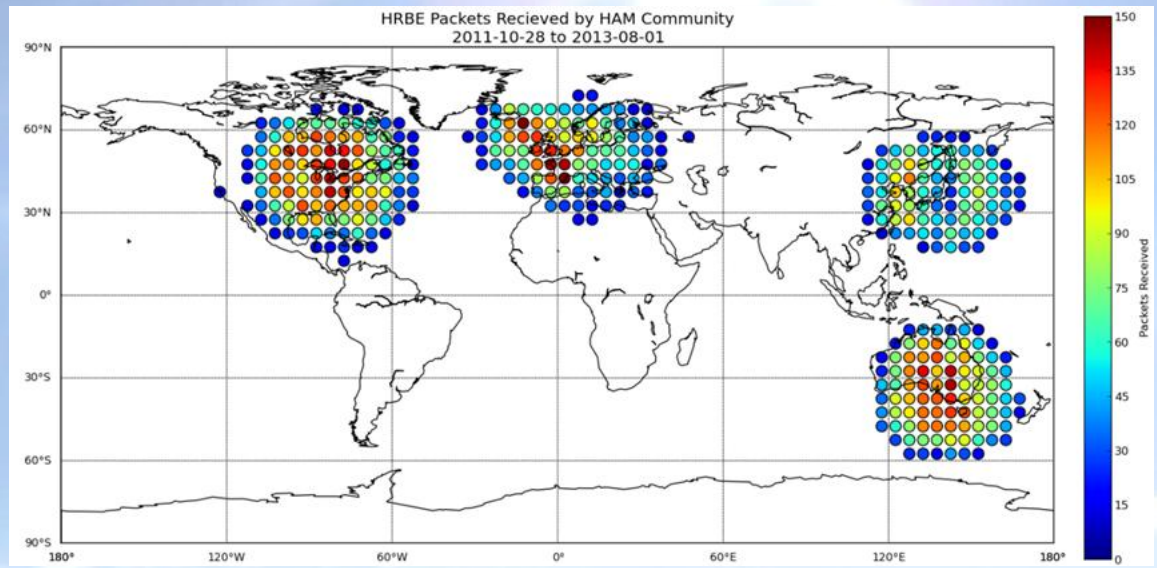


S-band Crosslink/Downlink:

"Siblings" crosslink to "Parent"

"Parent" downlinks during pass

Santa Clara Ground Station



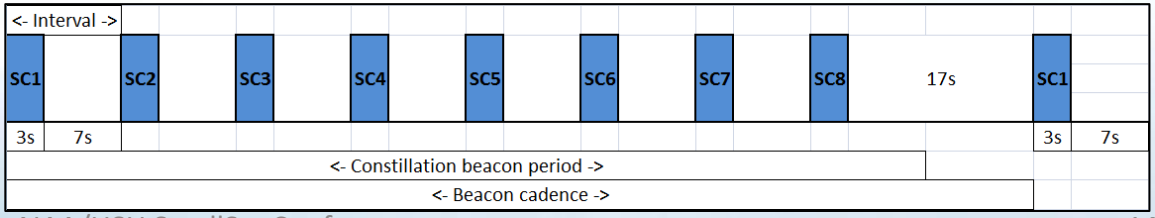
HAM community packets for E1P/HRBE:

One packet = 150 bytes

25,000 HAM packets received total.

Points represent number of packets received when the satellite is at that particular location.

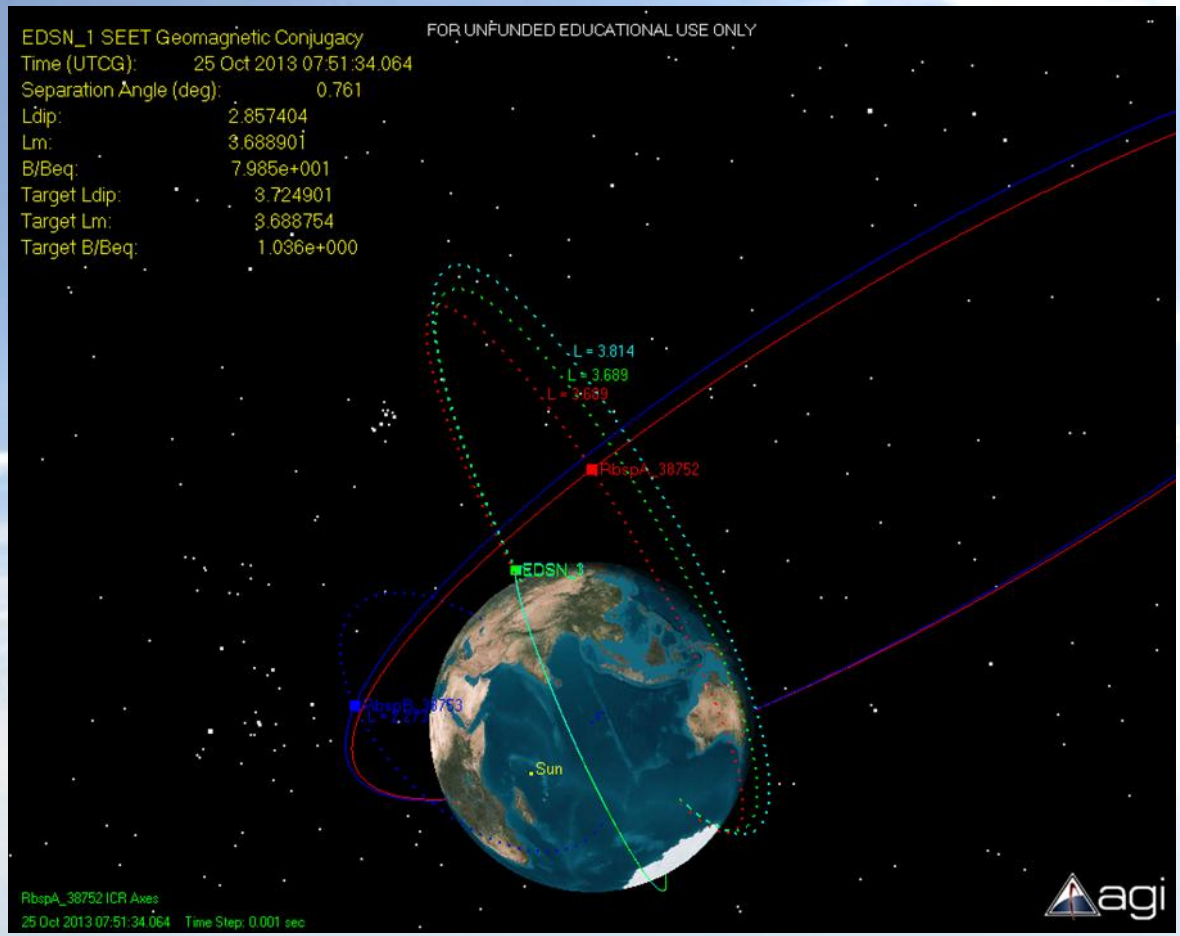
EDSN's round robin-beacon structure.

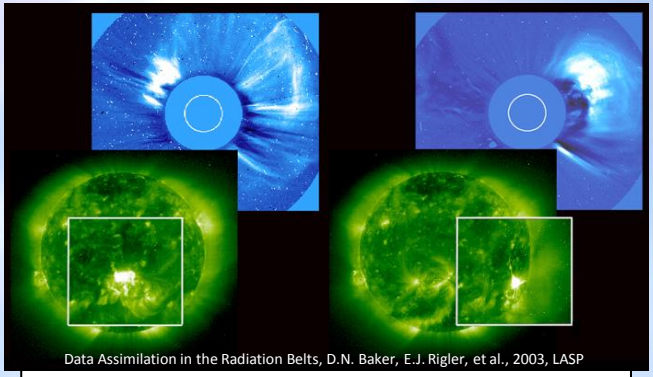


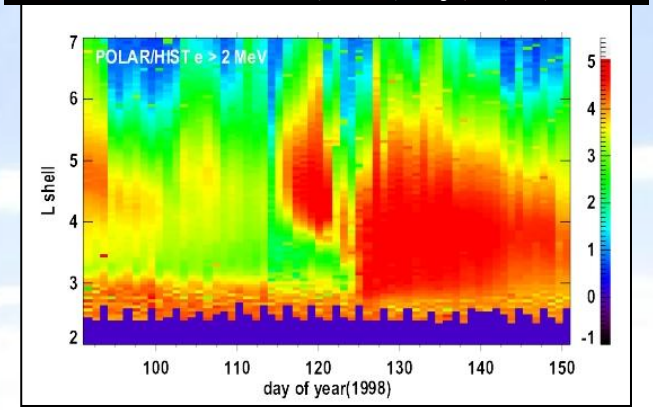
ConOps

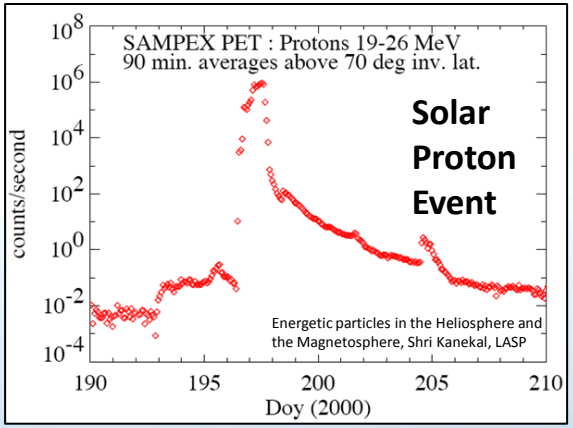
- Targets of interest
  - L-shell conjunctions: RBSP, BARREL
  - Flares, CME's, solar proton events
- South Atlantic Anomaly passes

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

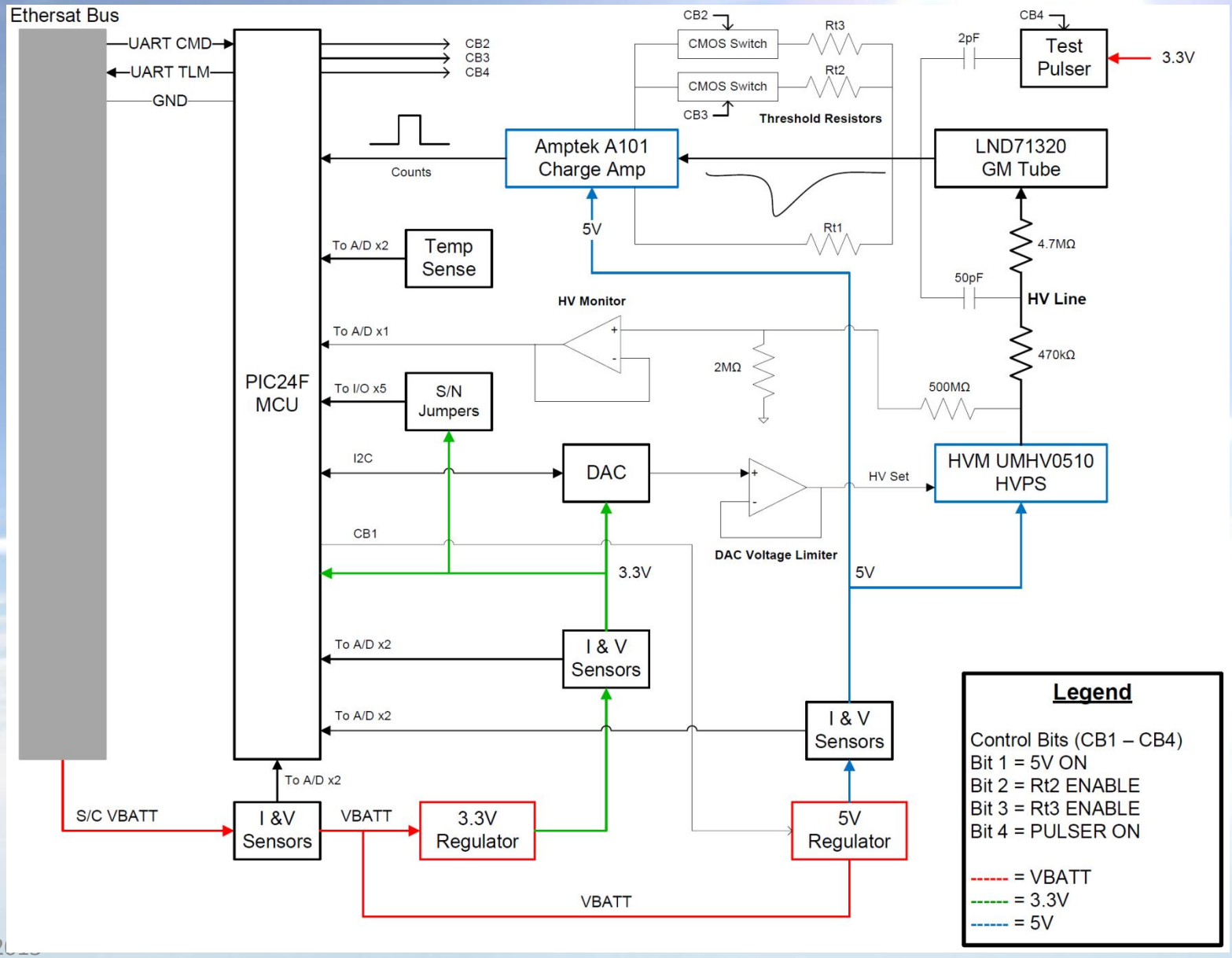
Questions?

Acknowledgements

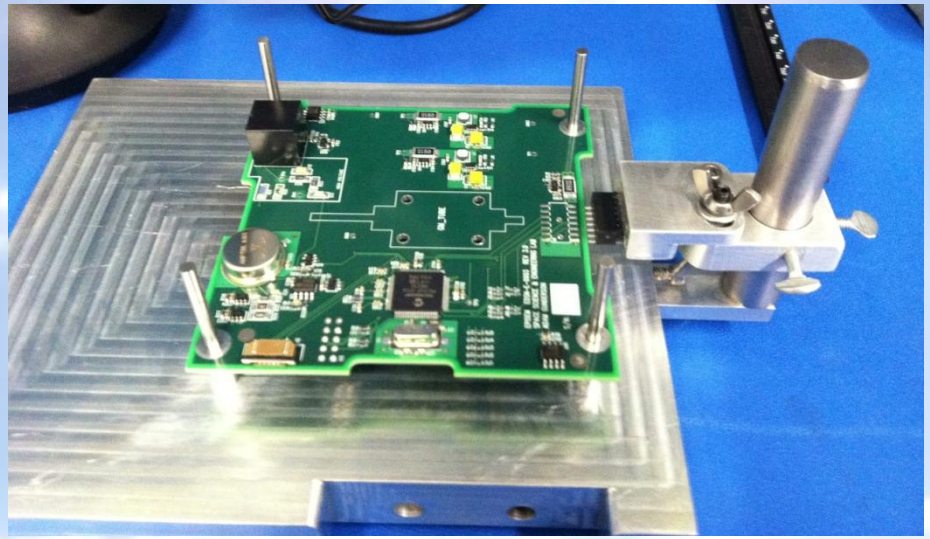
NASA Ames Research Center
Andrew Crawford, Matthew Handley, Jerry Johnson, David Klumpar, Larry Springer, Keith Mashburn, and Ehson Mosleh

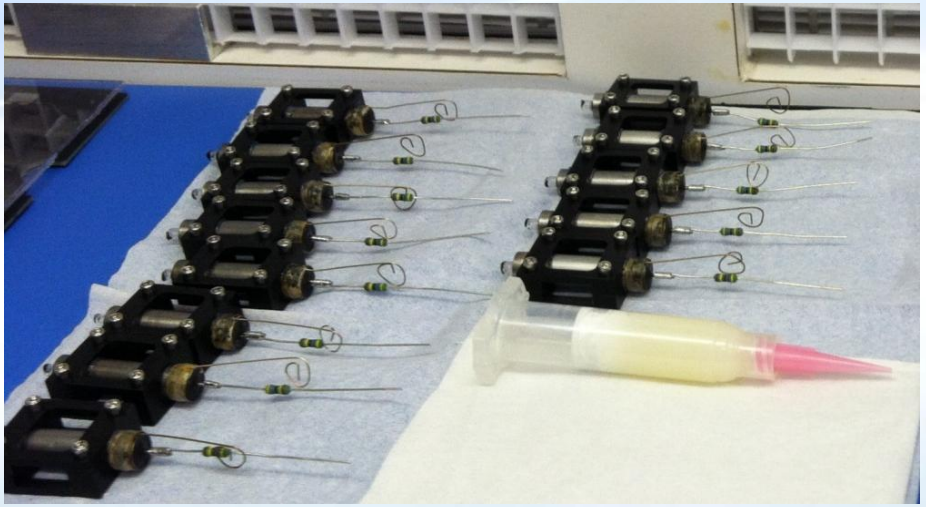
Backup Slides

Instrument Design



Fabrication





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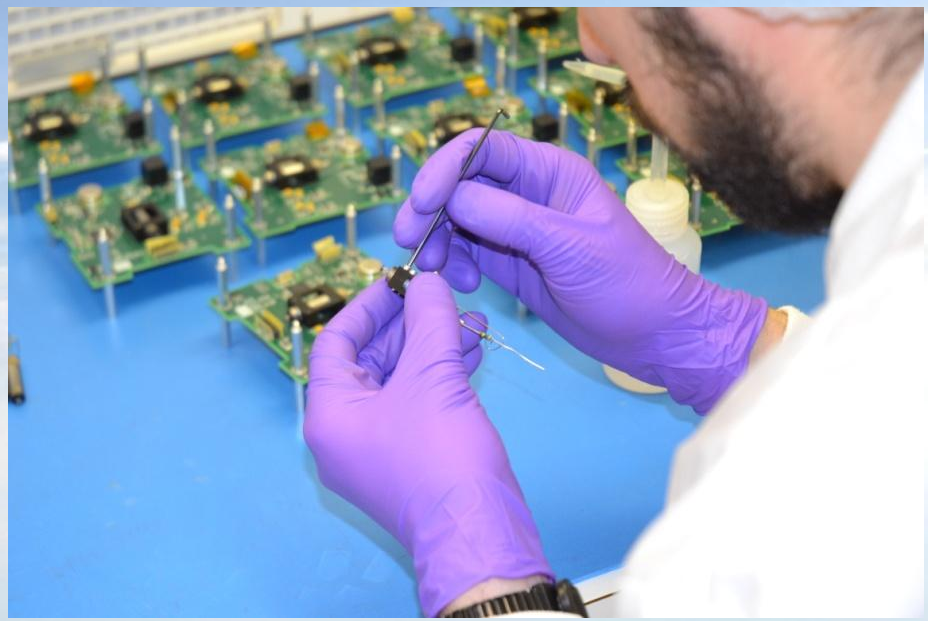

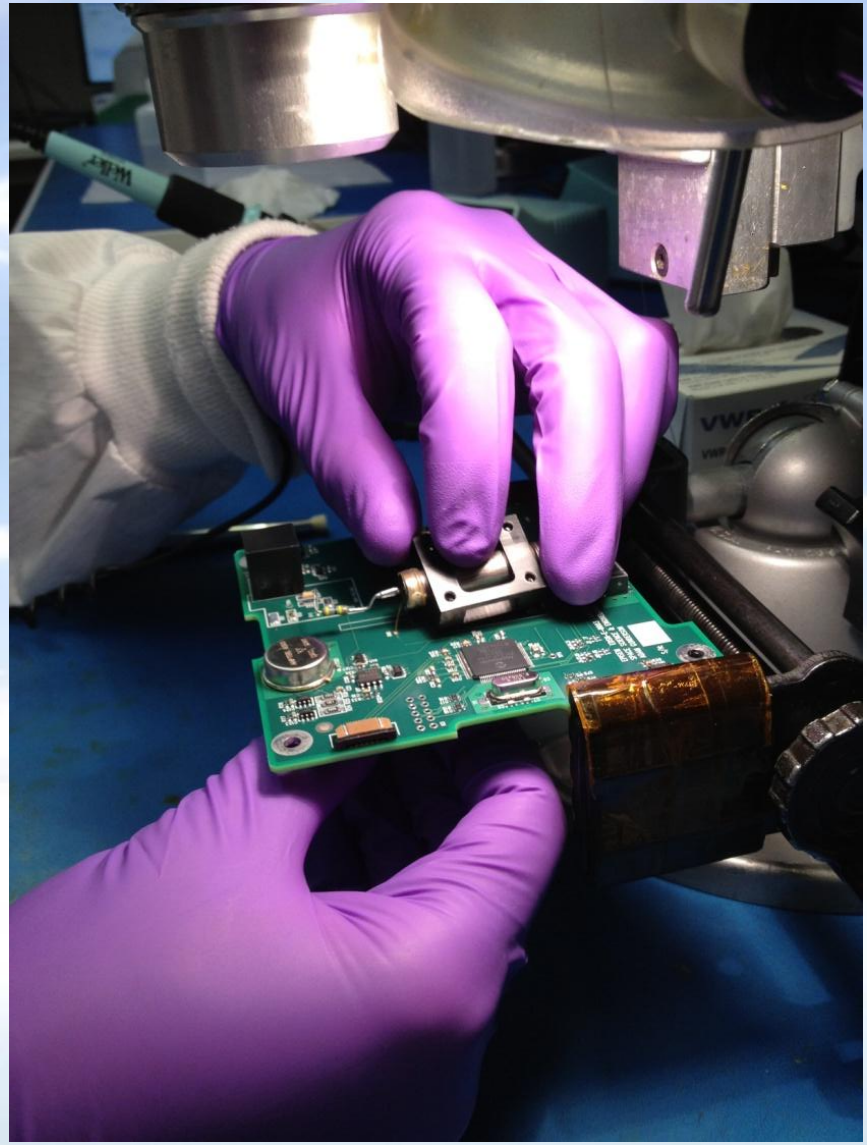

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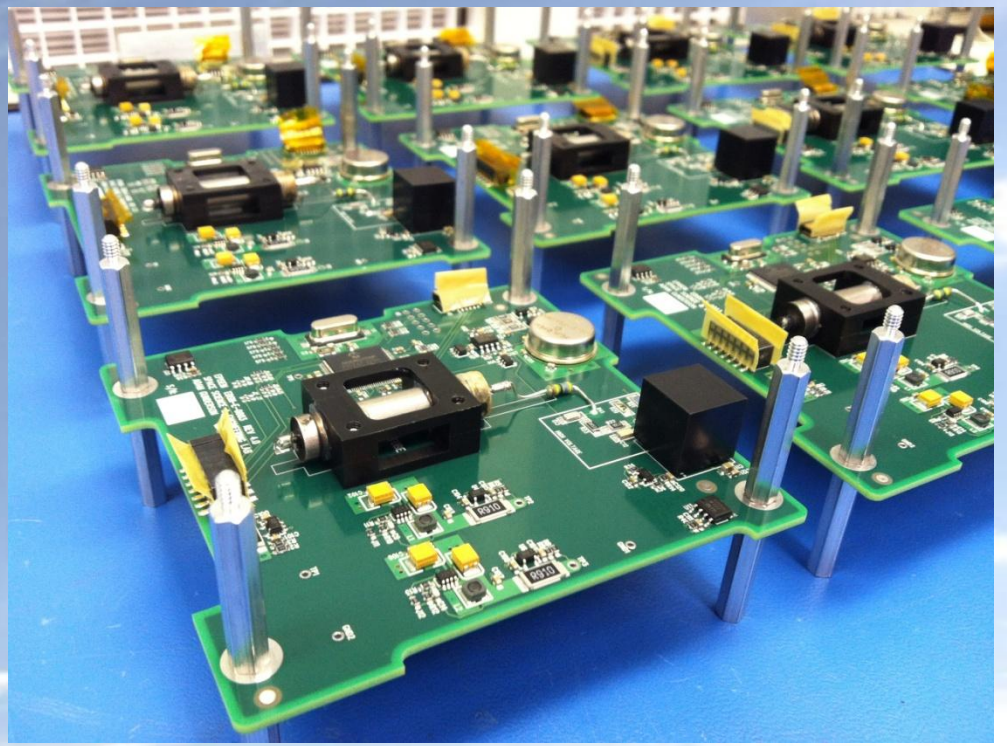
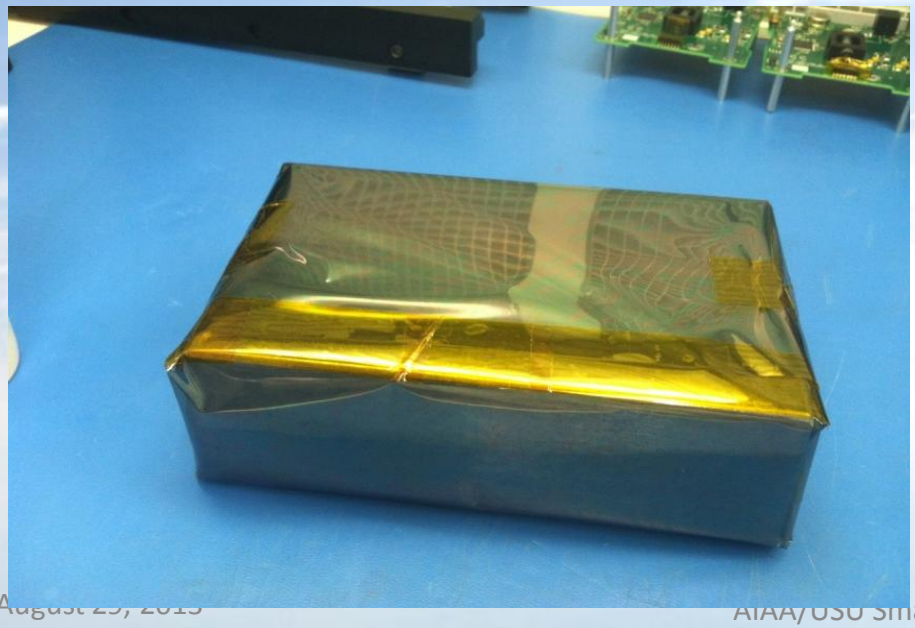
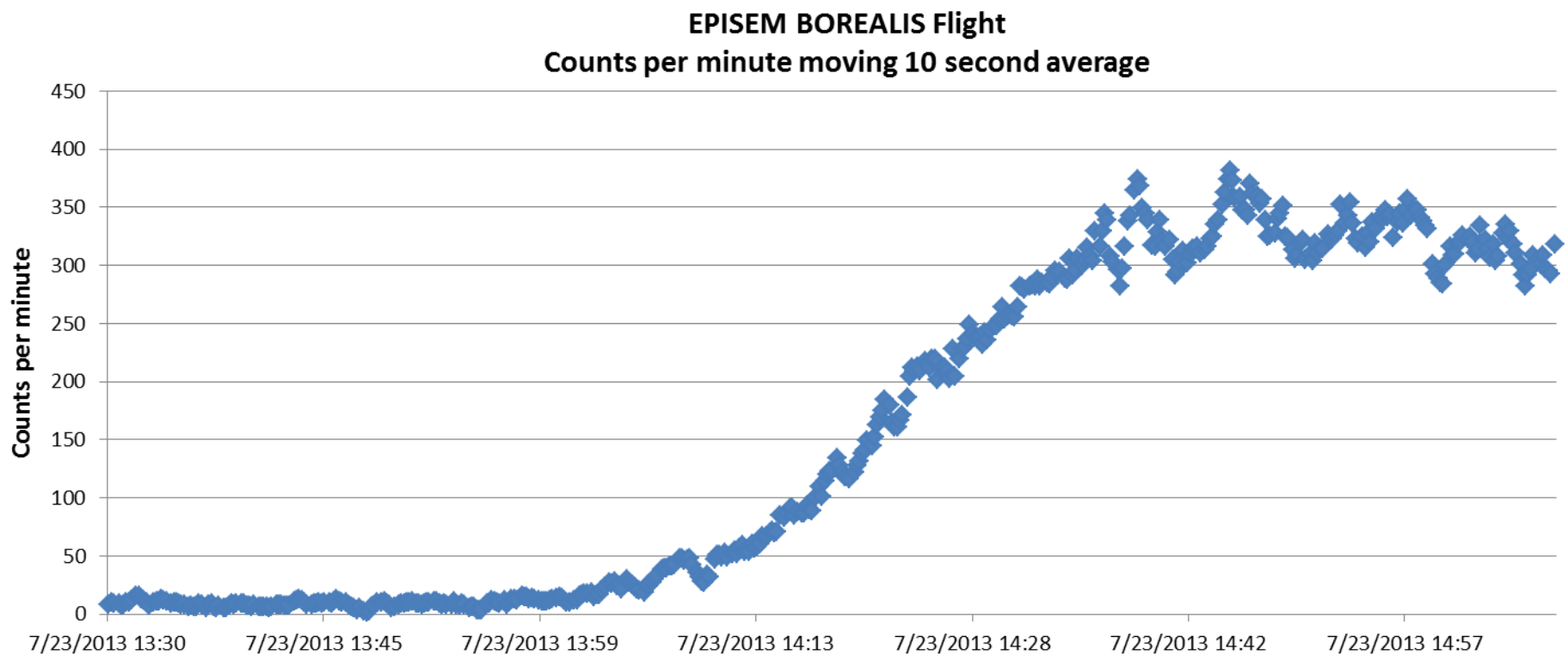


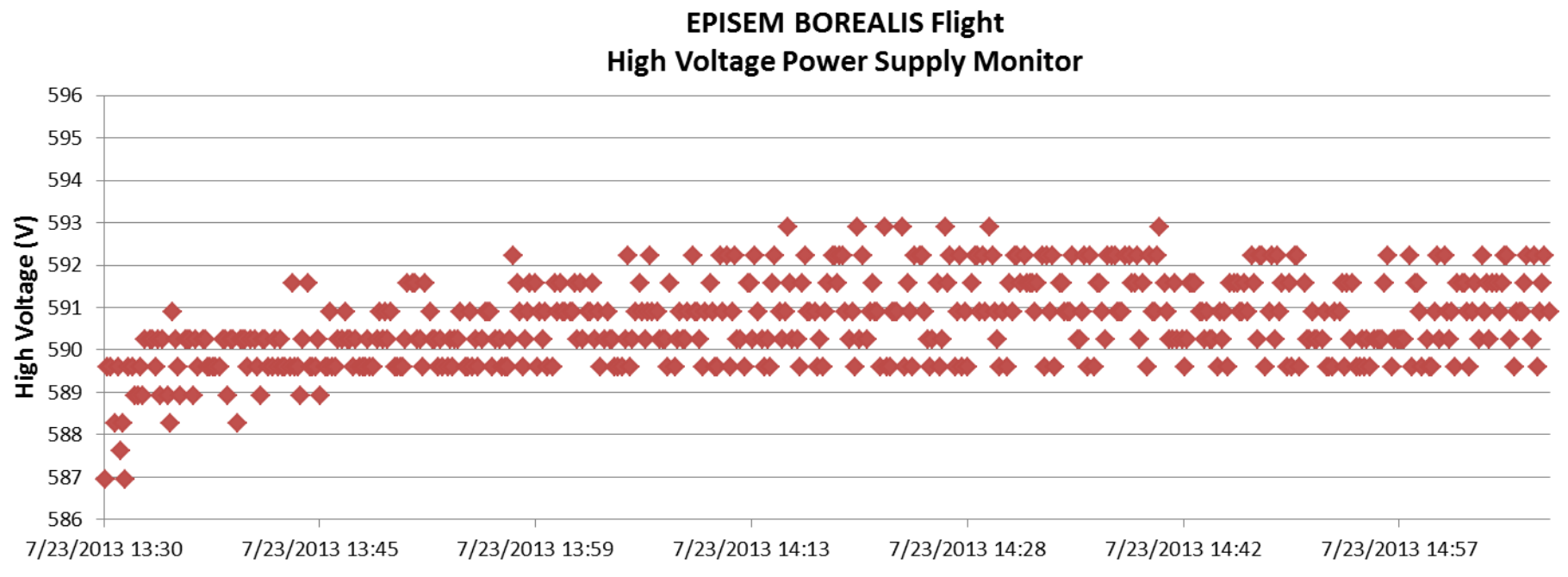
- All circuit boards cleaned, cleaned, and then cleaned again
- Boards staked and coated before final testing and shipment

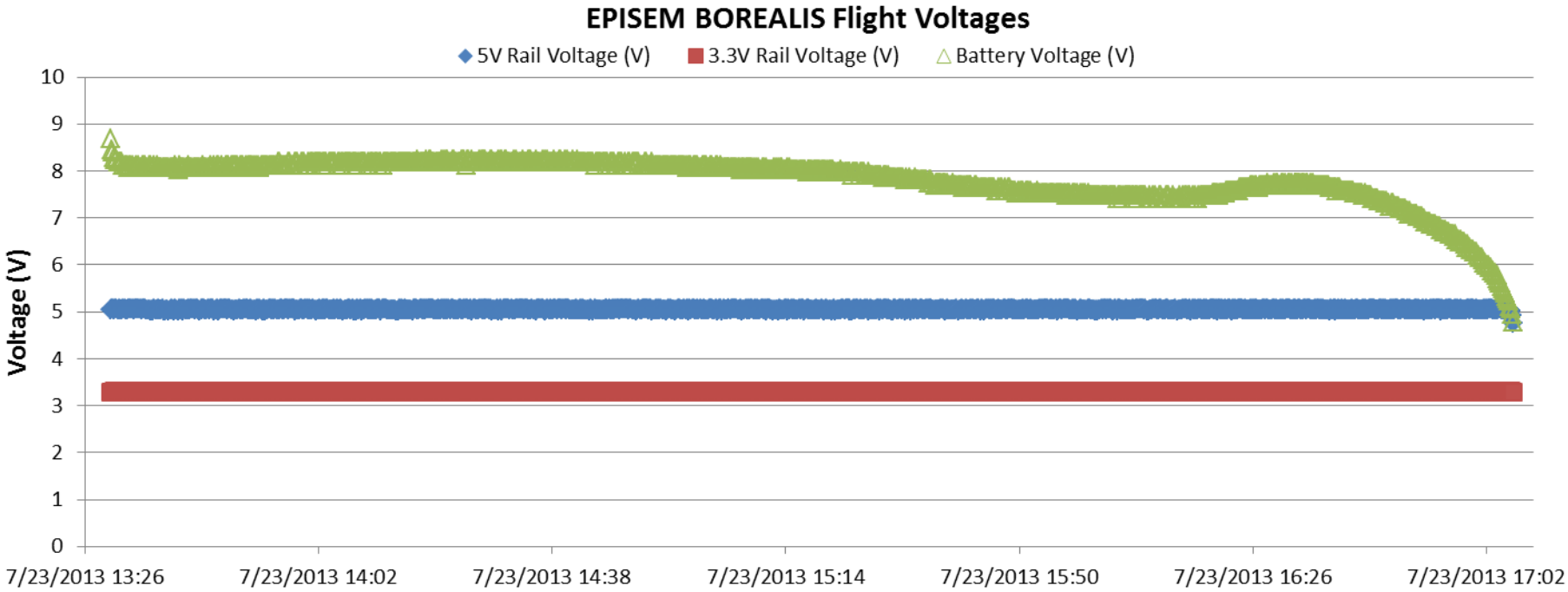
Fabrication

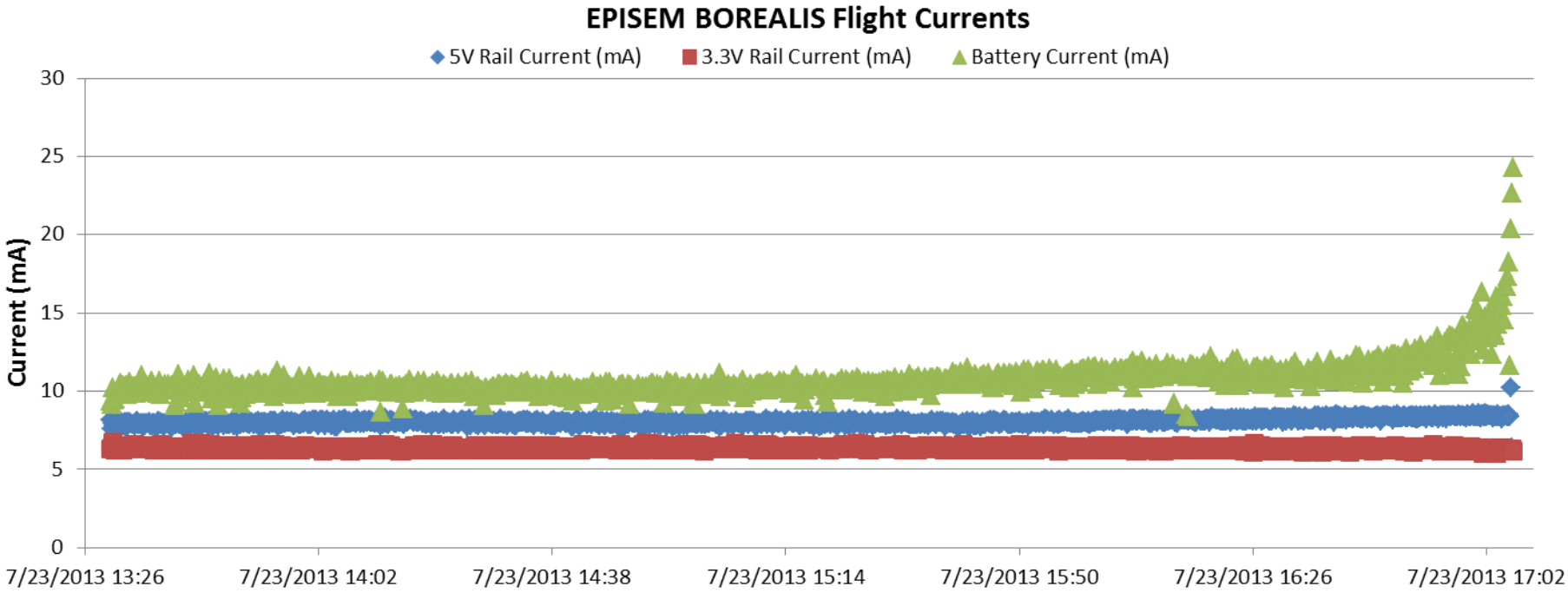
- Mounted and packaged in an aluminum shipping container
- Double-wrapped in alumaloy
- Packaged and shipped in lots of two to four



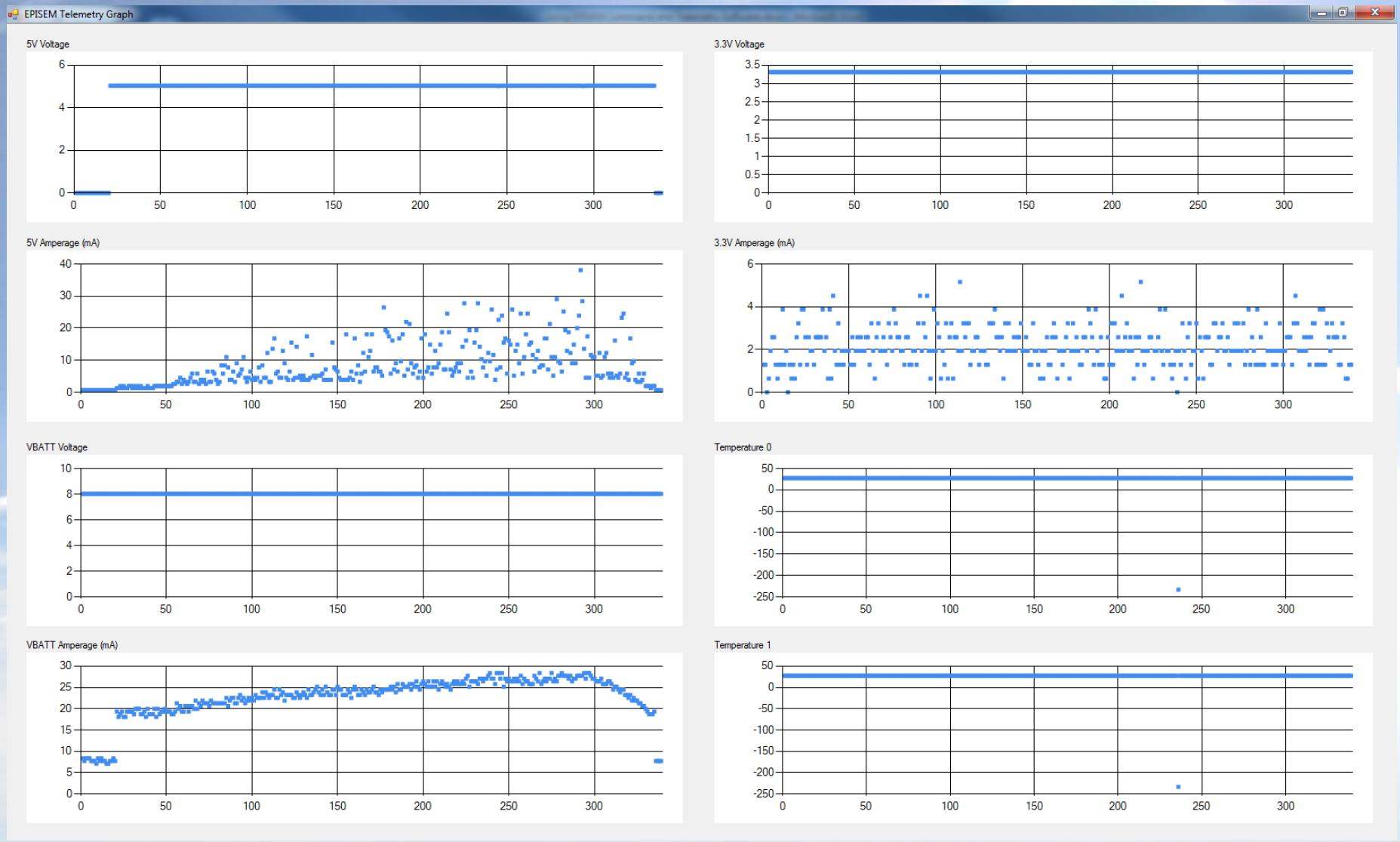

EPISEM BOREALIS Flight
Counts per minute moving 10 second average
Counts per minute
450
400
350
300
250
200
150
100
50
0
7/23/2013 13:30
7/23/2013 13:45
7/23/2013 13:59
7/23/2013 14:13
7/23/2013 14:28
7/23/2013 14:42
7/23/2013 14:57


EPISEM BOREALIS Flight
High Voltage Power Supply Monitor
High Voltage (V)
596
595
594
593
592
591
590
589
588
587
586
7/23/2013 13:30
7/23/2013 13:45
7/23/2013 13:59
7/23/2013 14:13
7/23/2013 14:28
7/23/2013 14:42
7/23/2013 14:57

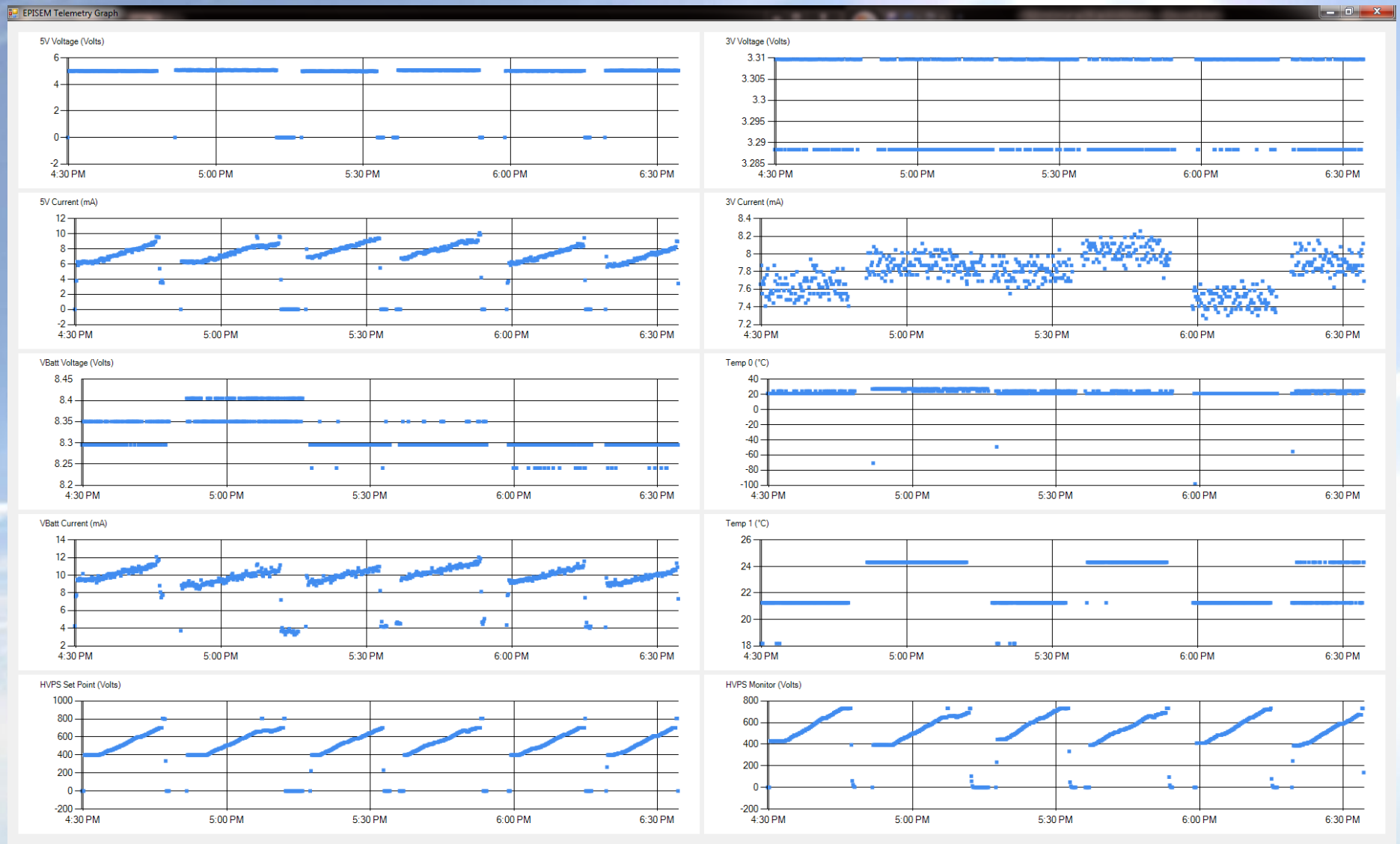
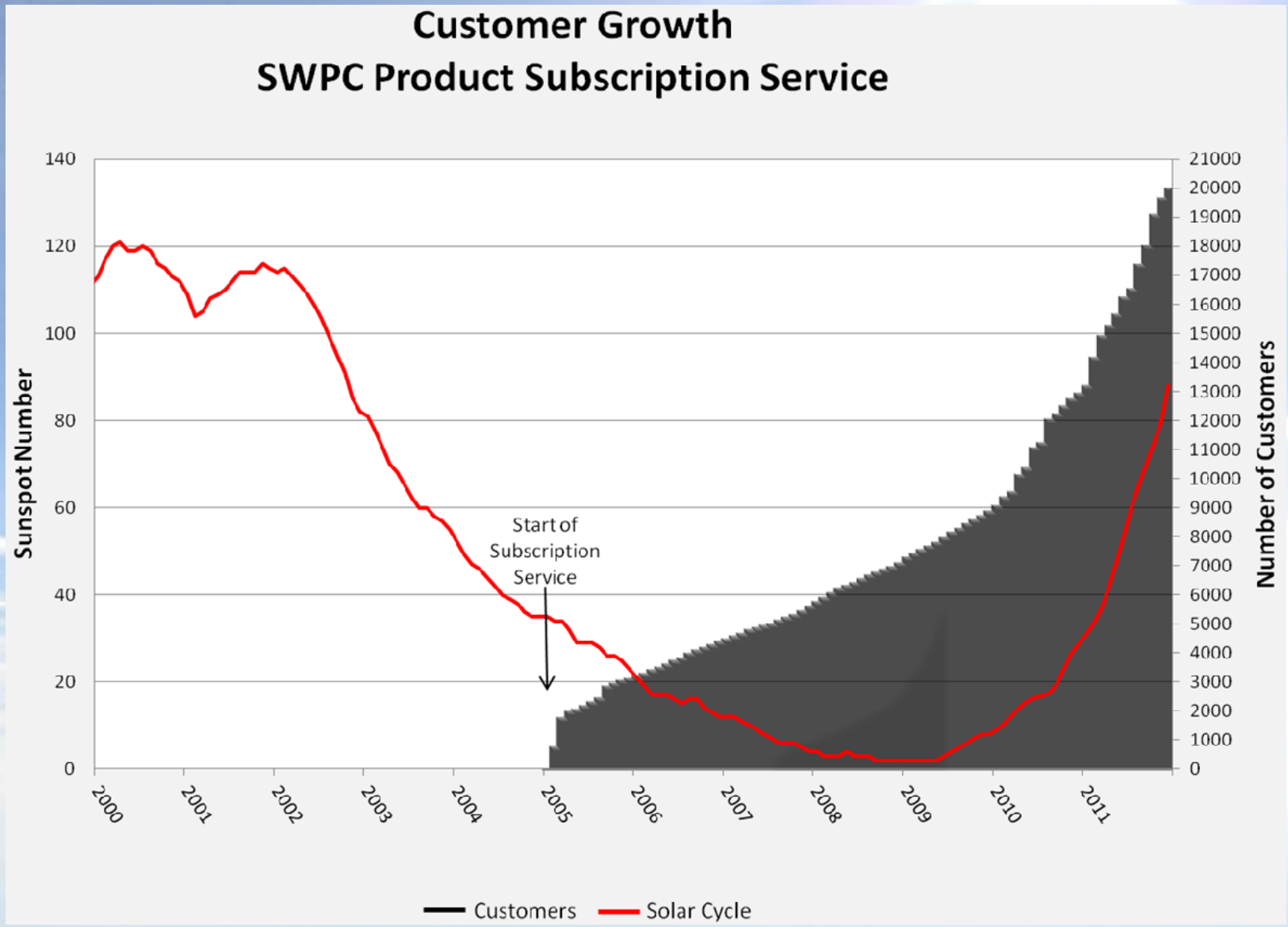

EPISEM BOREALIS Flight Voltages
5V Rail Voltage (V)
3.3V Rail Voltage (V)
Battery Voltage (V)
Voltage (V)
10
9
8
7
6
5
4
3
2
1
0
7/23/2013 13:26
7/23/2013 14:02
7/23/2013 14:38
7/23/2013 15:14
7/23/2013 15:50
7/23/2013 16:26
7/23/2013 17:02


EPISEM BOREALIS Flight Currents
5V Rail Current (mA)
3.3V Rail Current (mA)
Battery Current (mA)
Current (mA)
30
25
20
15
10
5
0
7/23/2013 13:26
7/23/2013 14:02
7/23/2013 14:38
7/23/2013 15:14
7/23/2013 15:50
7/23/2013 16:26
7/23/2013 17:02

Design Iterations



Design Iterations



Space Weather