AFRL Space Environment Research for Ops & Design

AFRL HERITAGE | 1917–2017

100 YEARS OF U.S. AIR FORCE SCIENCE & TECHNOLOGY

7 September 2017

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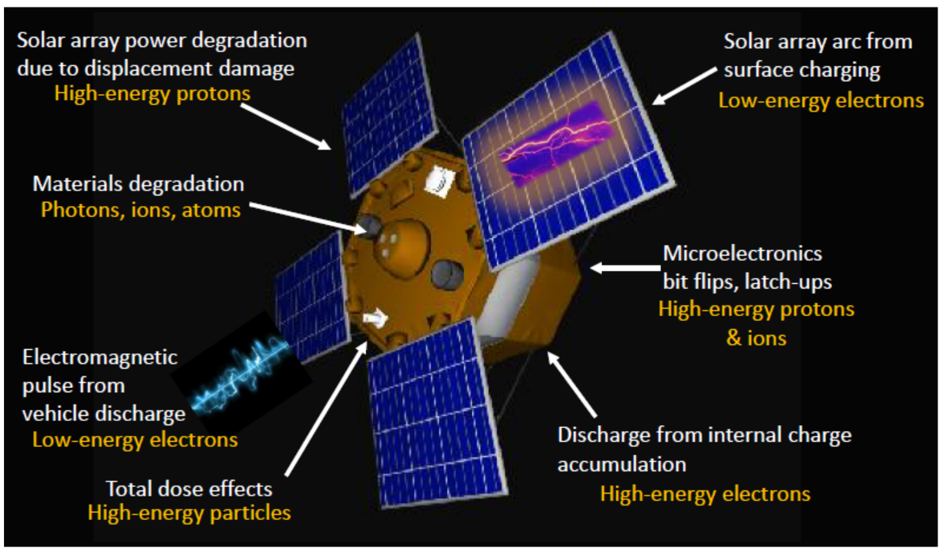
Integrity ★ Service ★ Excellence

AFRL Research to Ops/Design

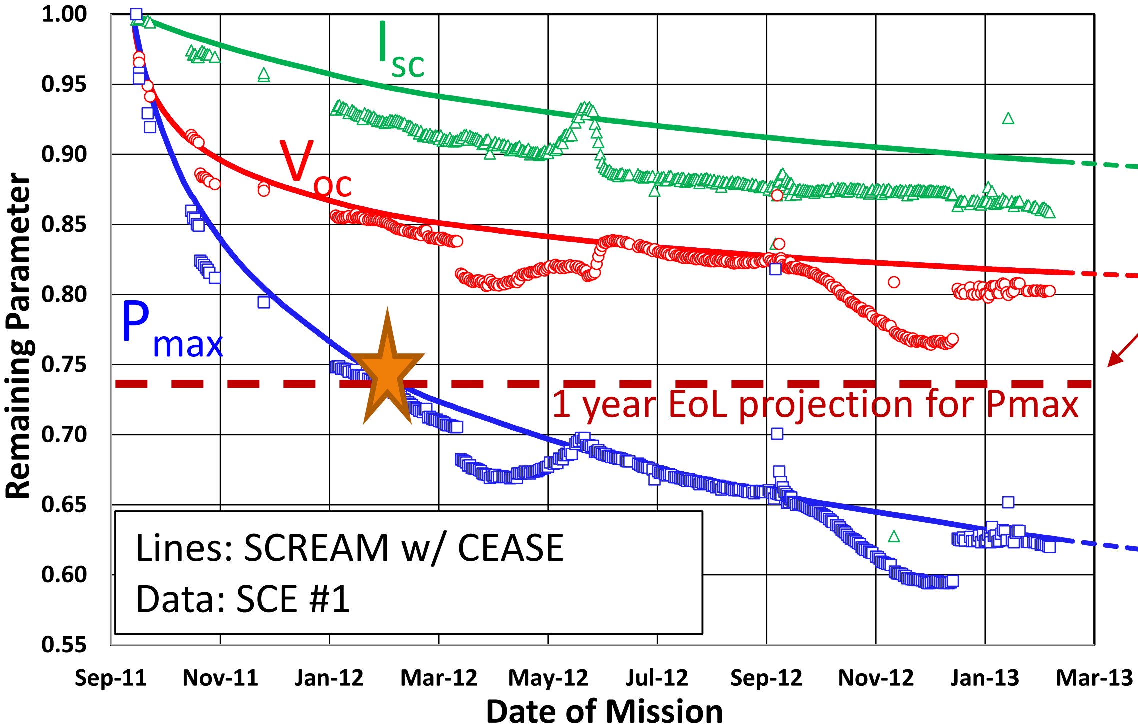
The following subset of AFRL's space environment research efforts illustrates what we identify as bearing on operations and design



- Characterizing transient environments for anomaly forensics
  - CEASE III, RHAS, REMS
- Nowcasts and forecasts of the environment for operations
  - ADAPT
  - SPE forecasting & mapping
  - GEO flux mapping in LT
- Environment climatology for spacecraft design and mission planning
  - AE9/AP9-IRENE
- Testing and improving designs to minimize vulnerabilities
  - SCICL, spacecraft charging studies

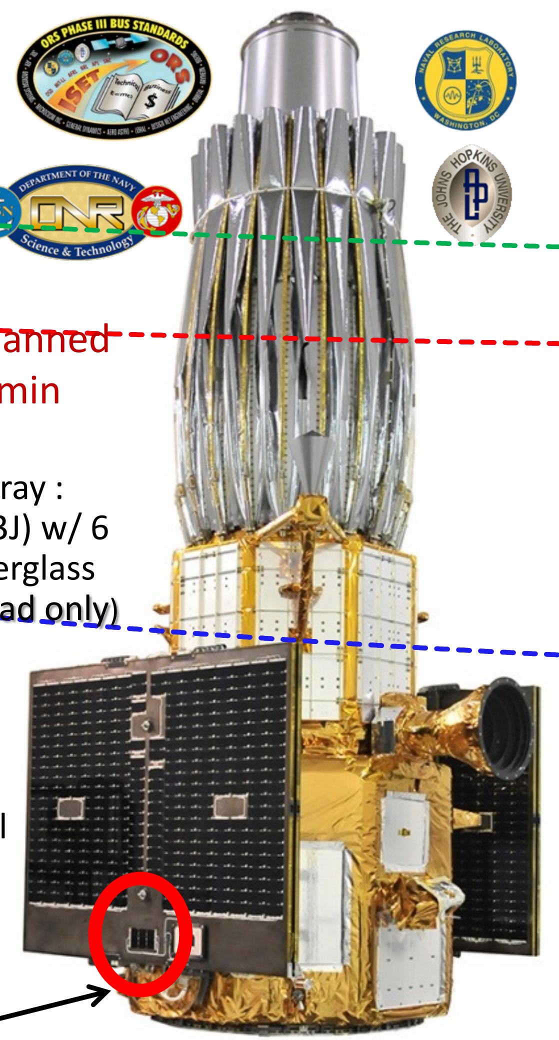
TACSAT-4 Solar Cell Degradation

Solar Cell Experiment #1 Results[1]



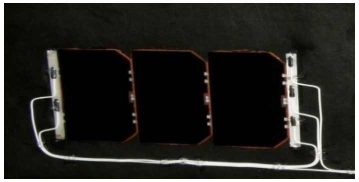
Mission planned using AP8min

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
- Found to result from 1-10 MeV slot protons

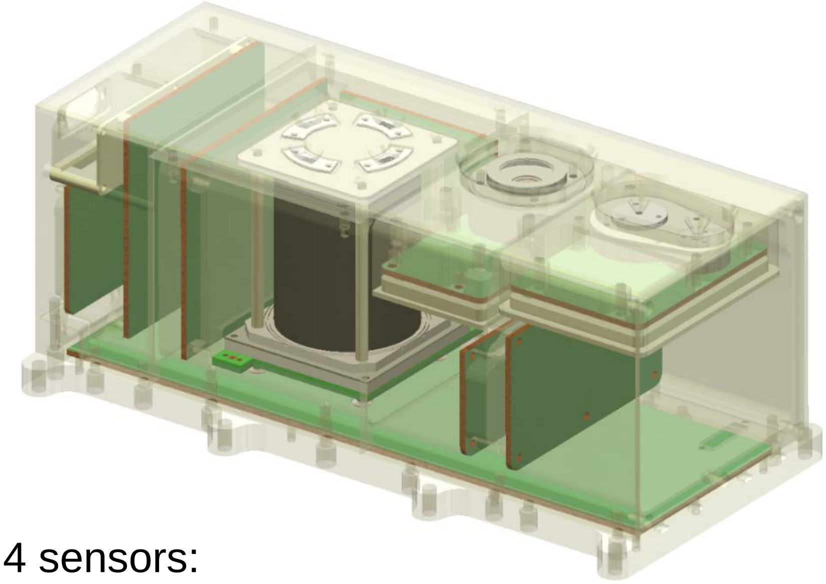
SCE #1 : Emcore BTJM (3J) 3-cell string w/ 6 mil CMG coverglass (full IV curves)

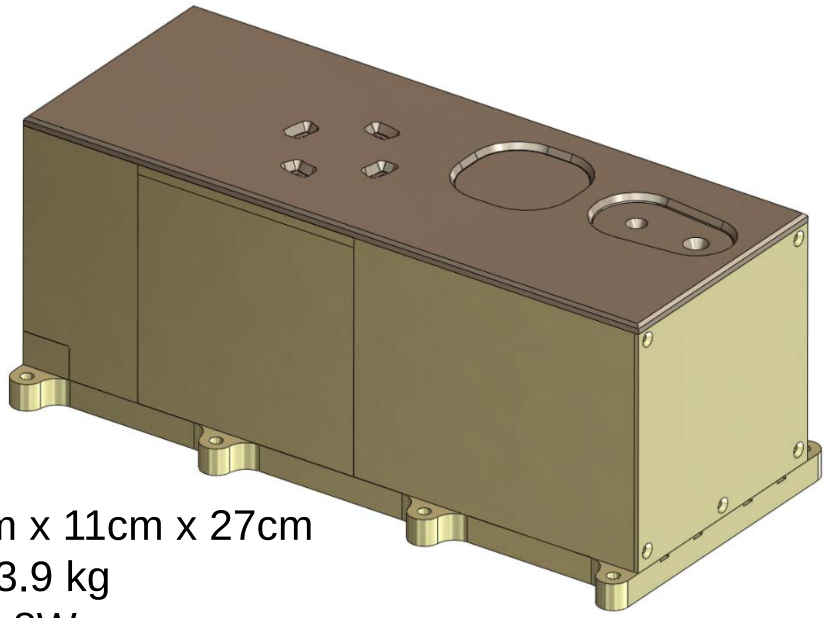


1. P.P Jenkins et al., "TACSAT-4 Solar Cell Experiment: Two Years in Orbit." 10th European Space Power Conference, Noordwijkerhout, NL, 14 Apr 2014.

CEASE-3

- Anomaly assessments often require local environment data
- Energetic charged particle sensors will need to be carried on new AF satellites
- CEASE-3 has been designed for this role—
  - Characterize particle hazards driving dose, SEE, internal charging effects
  - Minimize burden on host spacecraft

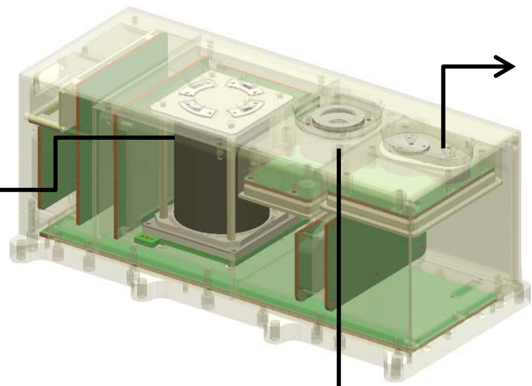




4 sensors:
ESA with 4 look directions
3 Silicon charged-particle detectors
Energy range, electrons: 50 eV – 5 MeV
Energy range, protons: 2 MeV – 100 MeV

Size:
11cm x 11cm x 27cm
Mass: 3.9 kg
Power: 8W

CEASE-3 Sensor Breakdown



Spiral ESA

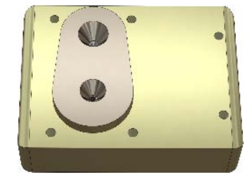
Electrostatic Analyzer

4 independent look directions w/ additional background sensor

Measures:
e- .05- 40 keV
Fluxes up to 2.5×10^{15} electrons/cm^2 s MeV

LEPET/MEPET

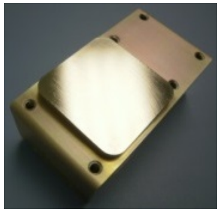
Two 2-element detector telescopes
Passive collimation
Anti-coincidence logic



Measures:
p+ 2 – 17 MeV e- 0.1- 2 MeV (combined range)
Fluxes: electron = 5.4×10^{10} /cm^2 s MeV
proton = 4.2×10^{7} /cm^2 s MeV

HEPET

5-element, actively-collimated telescope

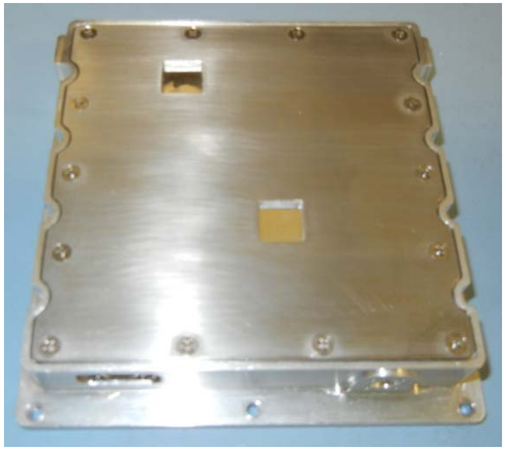


Measures:
p+ 25 – 100 MeV; e- 2- 5 MeV
Fluxes: electron = 5.8×10^{7} /cm^2 s MeV
proton = 2.4×10^{4} /cm^2 s MeV

IMPROVEMENTS:

Two additional sensors: ESA, with 4 look directions, and additional particle telescope
Higher flux ranges and count rates
Broader energy range with more channels
Higher reliability instrument – 15 year lifetime
2 units currently being developed for 2019 launch
Design will be transitioned to industry by 2020

Radiation Hazard Awareness Sensor (RHAS)



Mechanical
- 490 grams
- 12.7cm x 13.7cm x 2.5cm 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)

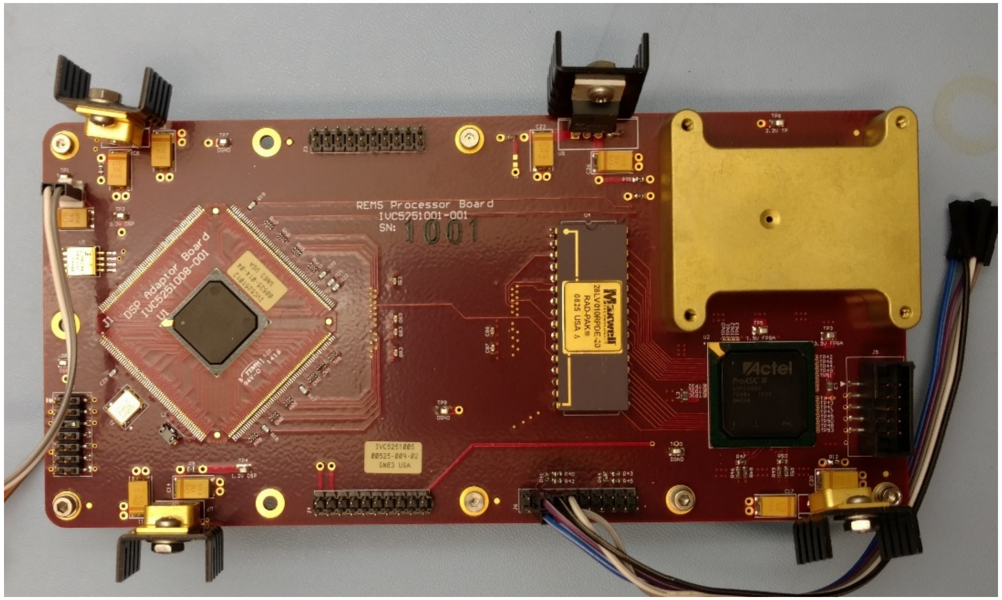
Channels:
- Dos1 (54 mils eq. Al) [>1.1 MeV e-, >16 MeV p]
- Dos2 (100 mils eq. Al) [>1.9 MeV e-, >24 MeV p]
- Dos3 (390 mils eq. Al) [>6.0 MeV e-, >47 MeV p]

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

REMS Instrument

- REMS is a next generation sensor for space weather monitoring, based on the CERN Timepix chip
- Intended for Small Sat platform
- Developed by Invocon under AFRL sponsored Phase II SBIR



- Sensor chip and software incorporate several advanced features over standard silicon detectors
  - Pixelated detector with 256 x 256 pixels; sensor active area = $2 cm^2$
  - Particle Type discrimination (electrons, protons, helium, heavy ions)
  - Incident angle resolution (over 450 angle bins in a 115° full angle)
  - Energy range: 10 keV to 1 MeV for electrons; 100 keV to 100 MeV for protons

Air Force Data Assimilative Photospheric Flux Transport (ADAPT) Model

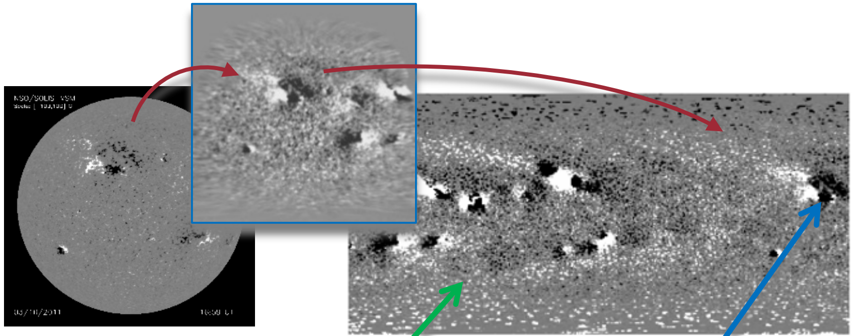
The ADAPT model generates global solar photospheric magnetic field maps.

ADAPT generates 1 to 7 day future forecast maps using flux transport that accounts for known surface flows in the solar photosphere:

- *differential rotation, meridional circulation, supergranular diffusion*

Global maps are utilized to drive:

- Coronal & solar wind models used to forecast the solar wind and Coronal Mass Ejection (CME) arrival times
- Empirical models to forecast of $F_{10.7}$ and XUV/EUV/FUV irradiance 1 to 7 days in advance for thermospheric modeling



Example ADAPT Global Solar Magnetic Map

Weak Field Sum

Strong Field Sum

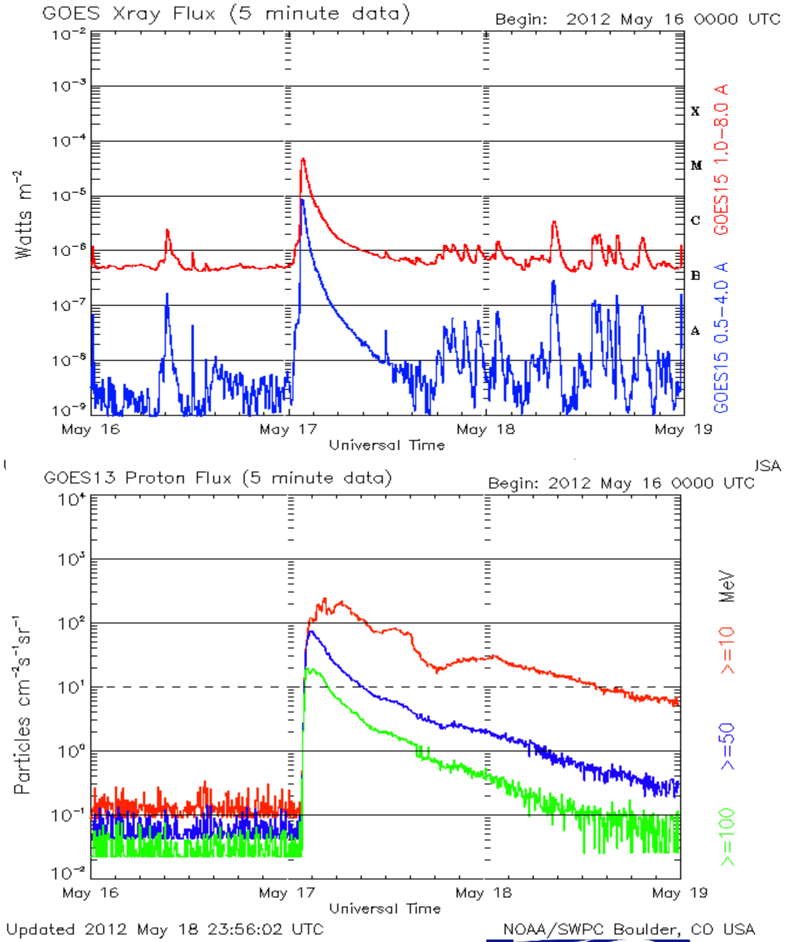
$$F_{model} = m_0 + m_1 S_P + m_2 S_A$$

Real-Time Automated SEP Forecast System

Developing a three-step SEP forecasting system to be used to supply solar input to a spacecraft radiation environment model (spacecraft charging, SEUs):

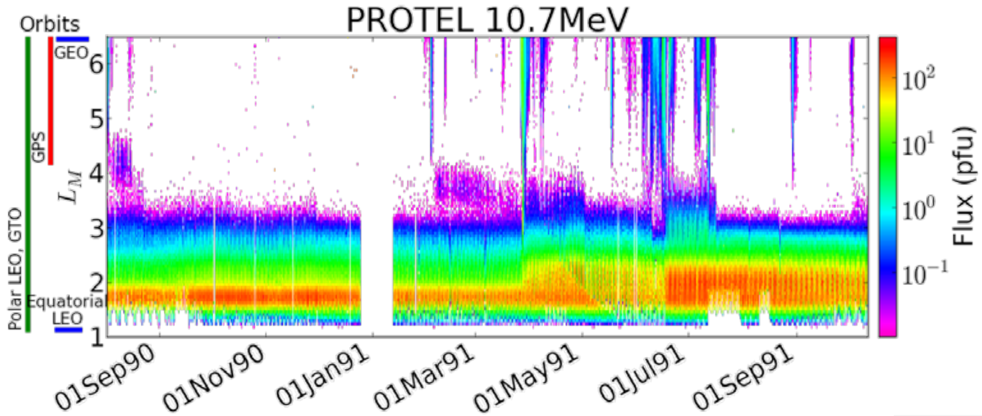
1. **Before any solar event**: Early (next 24 hours) SEP event probability forecast based on Falconer's "free-energy proxy" tool (used by NASA/SRAG)
2. **Once a solar flare (> M2) occurs**: Multi-stage flare-based dynamic SEP event forecast initialized using AF/NOAA (Balch) database of GOES X-ray and SEP events. This forecast then needs to be "aged" as time passes (developed by Kahler et al 2015) depending on flare location.
3. **At SEP onset**: Dynamic forecast of expected peak intensity, spectrum and timescale (under development).

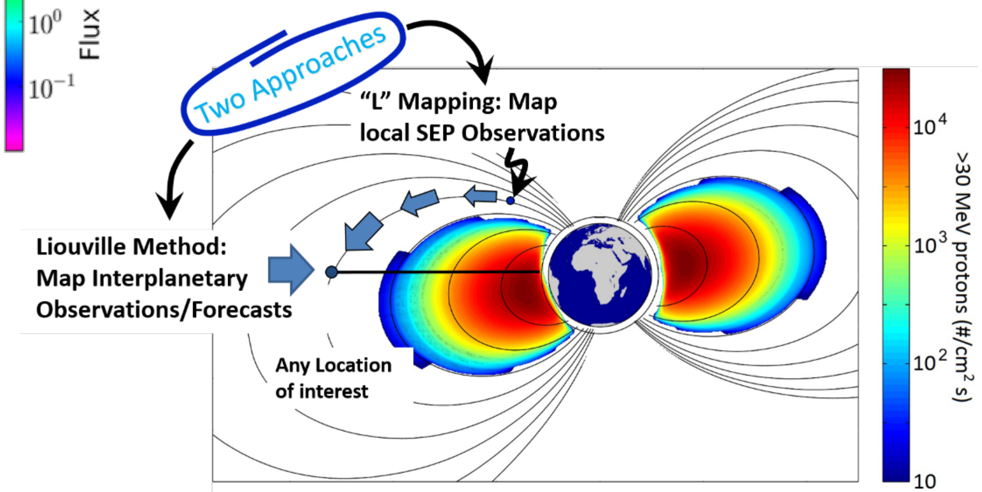
System is completely automated using publicly-available real-time datasets.



Kahler and Ling (2015), Dynamic SEP Event Probability Forecasts, *Space Weather*, 13:665+

SEP Specification/Forecast Throughout Geospace

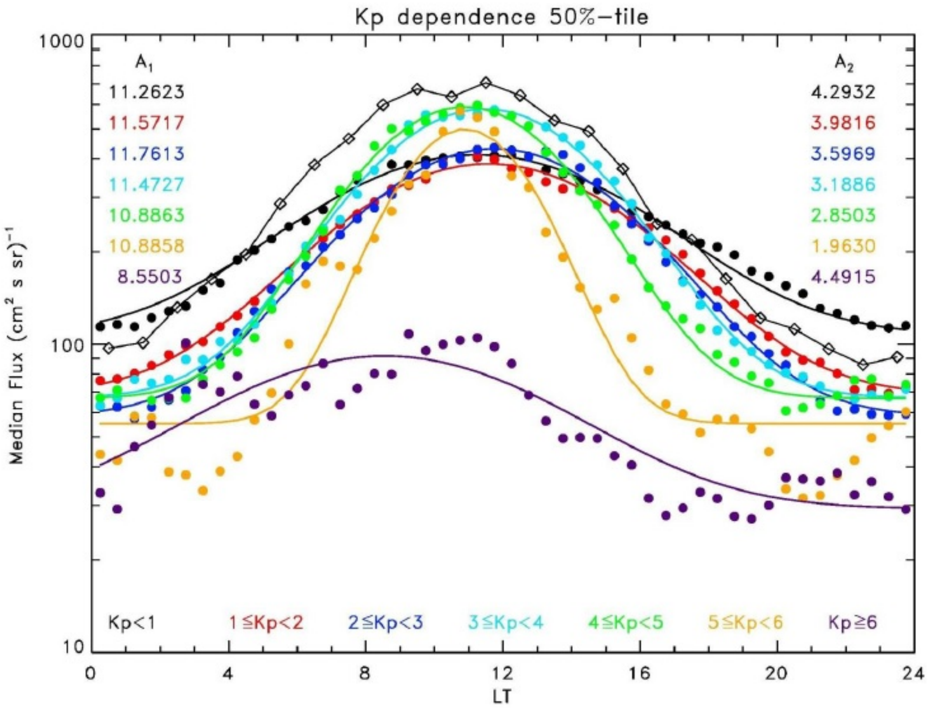




- Objective: develop magnetic mapping and apply to SEP observations, yielding real-time estimate of solar proton fluxes at any location in Geospace
- Currently developing and testing alternate approaches to mapping including (if appropriate) determination of magnetic cutoffs

GEO flux mapping in LT

- Model for predicting >2 MeV electron fluxes throughout GEO ring based on GOES data
  - Parameterized by Kp and local time
  - Optimally uses last 6 hrs of GOES data
- Tests from 1998-2009 GOES data yield PE>0.6 in 68% of cases, PE>0.8 in 24% of cases

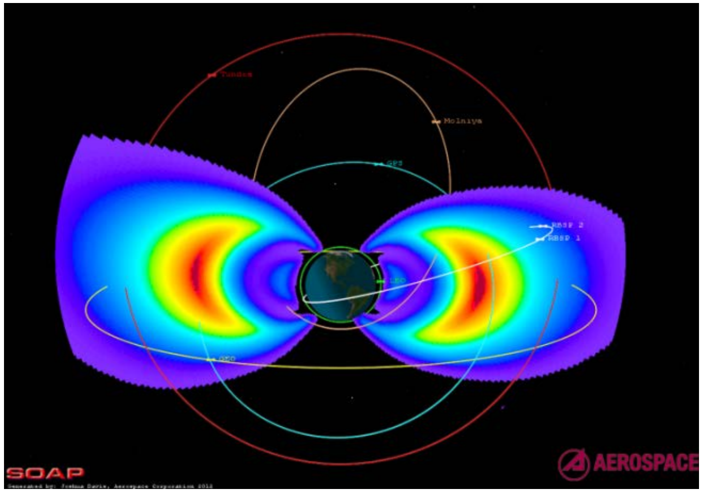


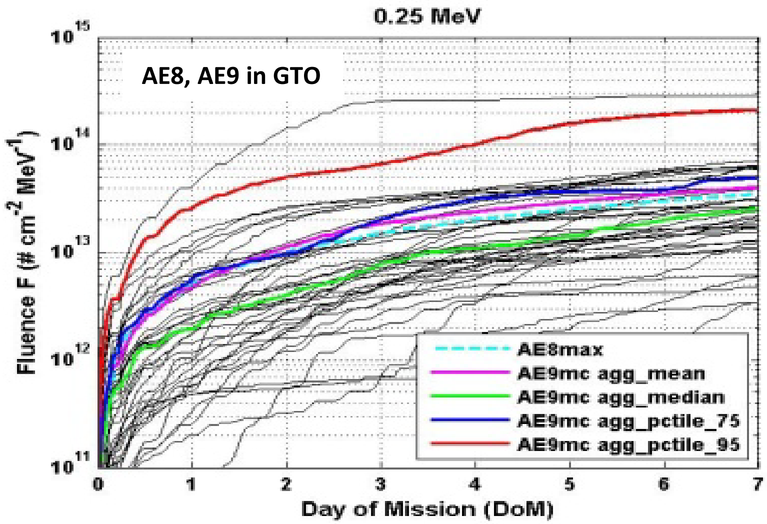
Su, Y.-J. et al. (2014), Specification of >2MeV electron flux as a function of local time and geomagnetic activity at geosynchronous orbit, *Space Weather*, 12:470-486

AE9/AP9-IRENE

- AE9/AP9/SPM specifies the natural trapped radiation environment for satellite design and mission planning, supporting all orbits with statistics for confidence intervals

- Applications:
  - Spacecraft design
    - Directional flux considerations e.g. for ISS
    - Considerations for extended delivery legs
  - Mission planning (e.g. orbit selection)
- Development needs:
  - Models and model products (SEPs, solar cycle reanalysis, LEO/loss cone gradients, …)





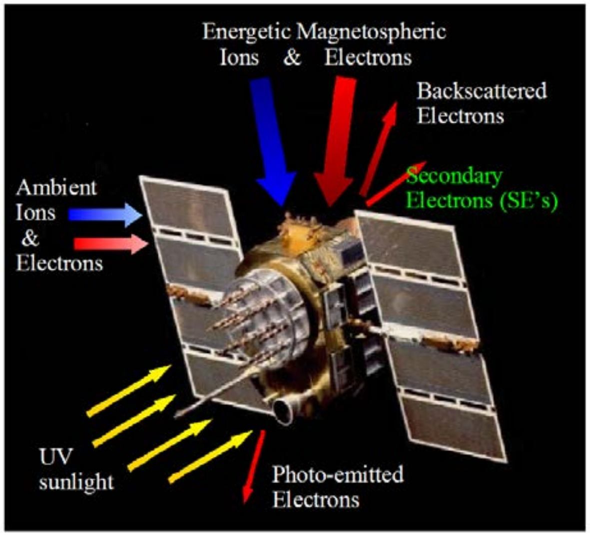
Spacecraft Charging and Instrument Calibration Lab (SCICL)

SCICL—a one-stop shop for detailed spacecraft charging studies

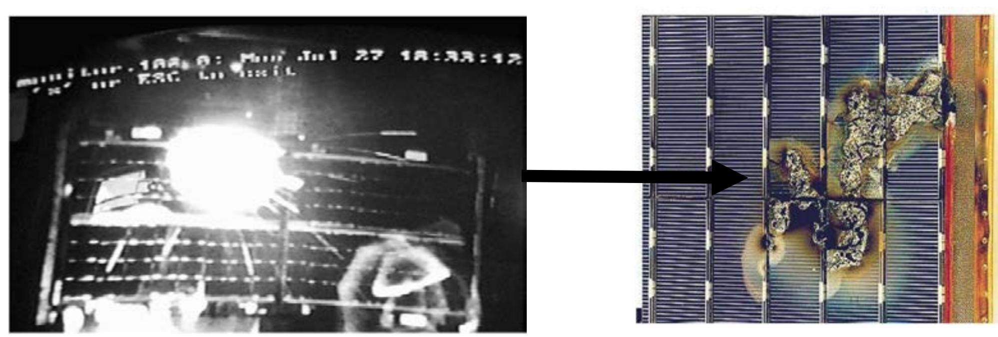
- Mumbo and Jumbo large vacuum chambers
  - Simulation of electron, photon, ion fluxes
  - Sensor calibration
- Support facilities including bell jar, electronics lab, and
- Class 1000 Clean Room
  - Dry box storage for flight hardware

- **Component testing in flight-like conditions**
- **Material aging**
- **Surface/internal charging testing**
  - **ISO 11221**

Spacecraft Charging Studies



- Balance between input/output charge fluxes yields **Frame Potential** for spacecraft as a whole and **Differential Potentials** for individual dielectric surfaces
- **Differential potentials** between conductors and dielectrics lead to **high electric fields** and **arcing** - material breakdown (deep-dielectric discharge), surface vacuum arcs, or catastrophic **sustained arcs**



- Identified two populations of sustained solar array arcing events in commercial GEO satellites—one from severe charging LT environment, one from eclipse entry/exit
  Ferguson et al. (2017), "1997-2002 solar array string failures revisited," *J. of Spacecraft and Rockets*, 54:542+.
- Led round-robin testing determining that durations of arcing events are driven by multiple plasma species Hoffman et al. (2014), "AFRL round-robin test results…" *IEEE Trans. Plasma Sci.*, 43:3006+.
- Preliminary positive results using Arecibo to detect arcing in GPS solar arrays
  Ferguson et al. (2017), "Ground-based surveillance campaign…", *J. of Spacecraft and Rockets*, 54:566+.

Summary

AFRL's applied space environment research covers the range from the nature of geospace hazards to how designers and operators can cope with them

- Forecasting and nowcasting of particle hazards
- Climatology models for design
- Hazard mitigation technology
- Design standards
- Materials testing
- Compact sensors for anomaly assessment