Image Credit:ESA

SHA
Space Hazards Applications, LLC

Models and Applications for Assessing Space Weather Hazards to Satellites from Earth to the Moon

J.C. Green, T.P. O'Brien, R. Quinn, A. Kellerman, A. Boyd, S. Claudepierre, J. Likar, Y. Shprits, I.Parker, D. Turner, C. Keys, D. Pitchford

GOAL

To provide a suite of easy to access applications that give the unique real time and retrospective space weather hazard to specific satellite systems along any satellite orbit.

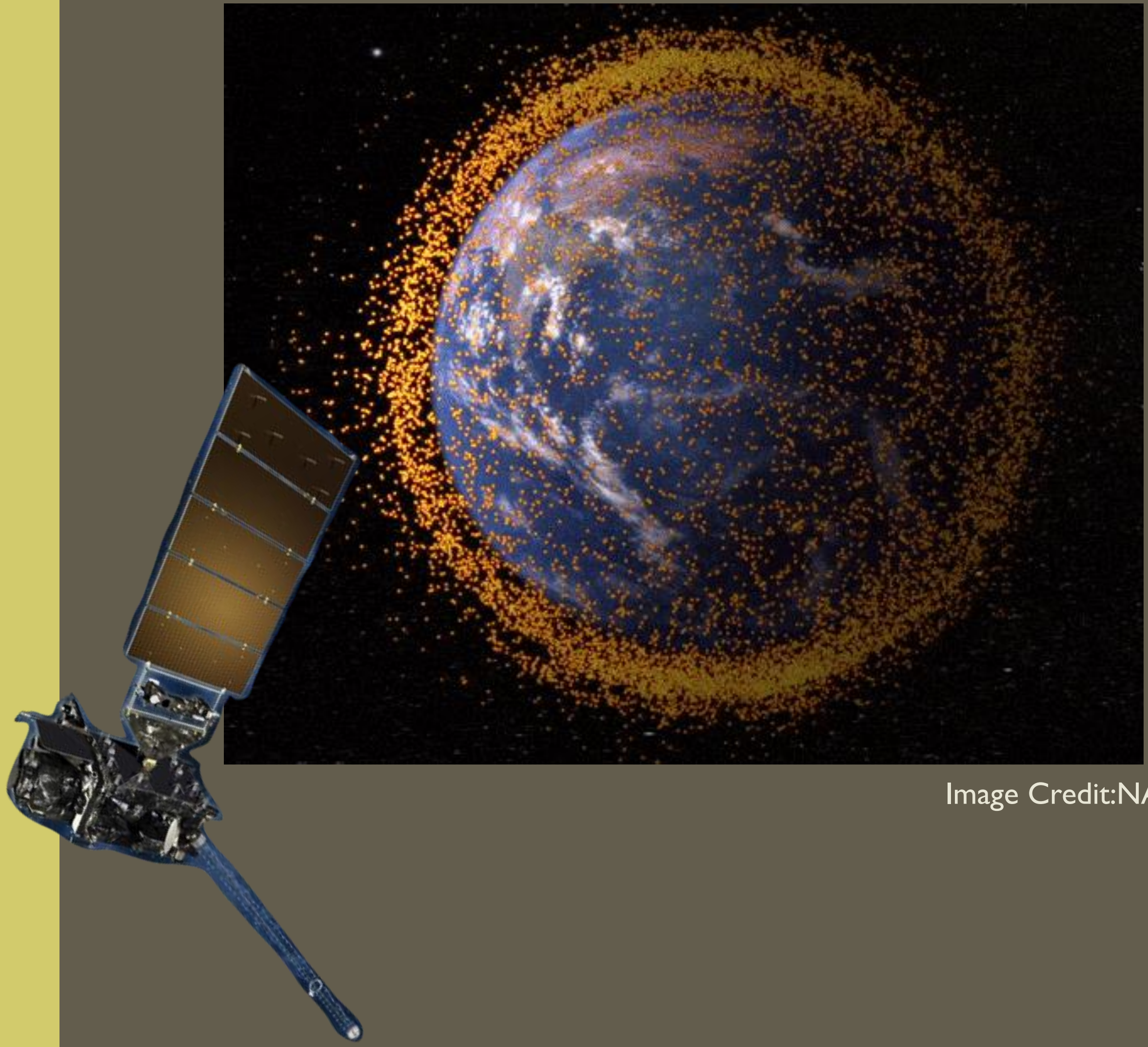
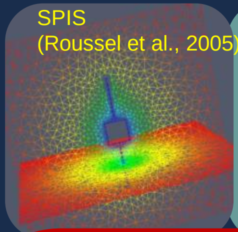


Image Credit:NASA

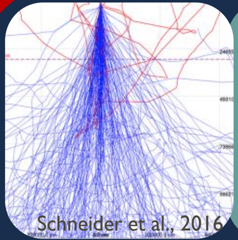
Particle Radiation Hazards



SPIS (Roussel et al., 2005)

Surface Charging:
Charged particles collect on satellite surfaces producing high differential voltages, electrostatic discharges, and electromagnetic interference.

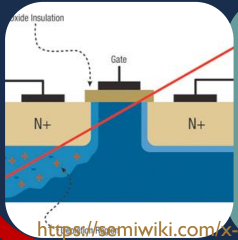
Low energy protons /electrons



Schneider et al., 2016

Internal Charging:
Energetic electrons accumulate in dielectrics (circuit boards, cable insulators) and on ungrounded metal (spot shields, connector contacts) leading to damaging discharges.

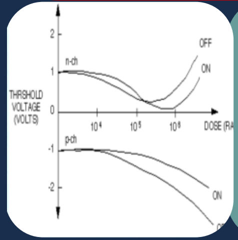
High energy electrons



Single Event Upsets:
Energetic ion passage through microelectronic device node causes catastrophic device failure, latent damage, or uncommanded mode/state changes.

High energy protons/ions

https://semiwiki.com/x-subscriber/silvaco/3604-single-event-upsets/

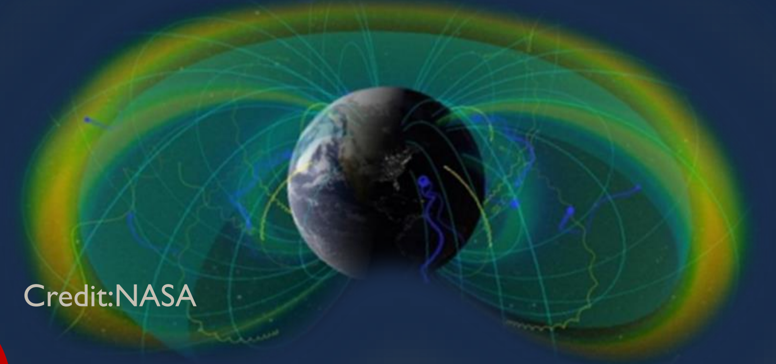


NASA ASIC Guide

Total Dose:
Energy loss when proton/electrons pass through microelectronic devices causing degradation and reduced performance that accumulates over mission (or step-wise during high dose rate events).

High energy protons electrons

Regions



Credit:NASA

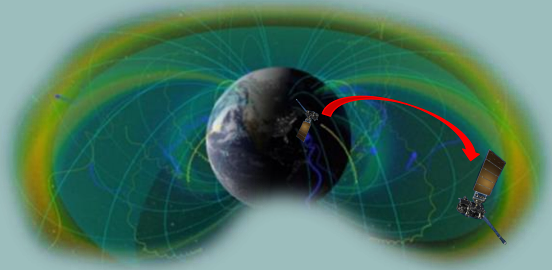
Magnetosphere

Moon

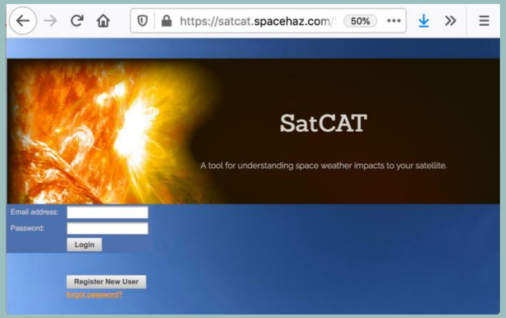
Models And Applications

Internal Charging

SHELLS-hires Electron Radiation Belt Model

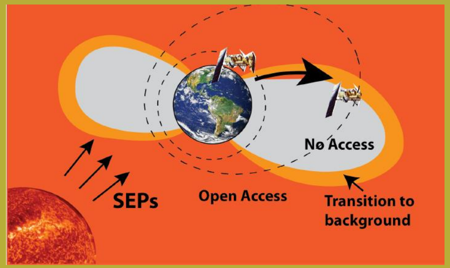


Satellite Charging Assessment Tool

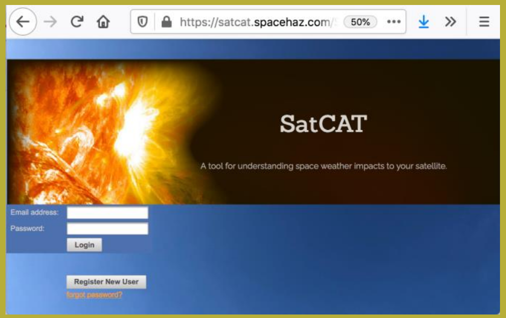


Single Event Effects

Solar Particle Access Model (SPAM)

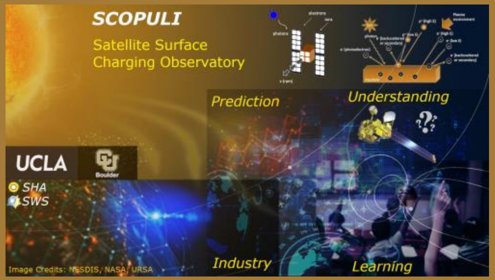


Satellite Hazard Assessment Tool



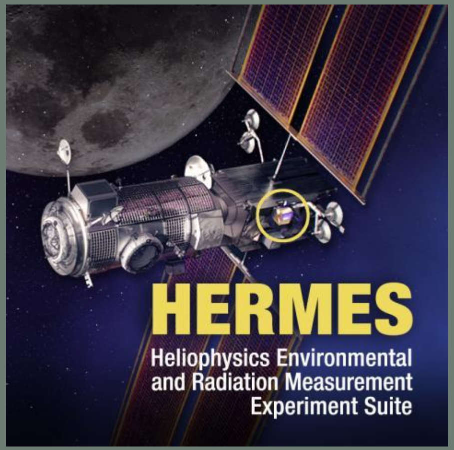
Surface Charging

SCOPULI



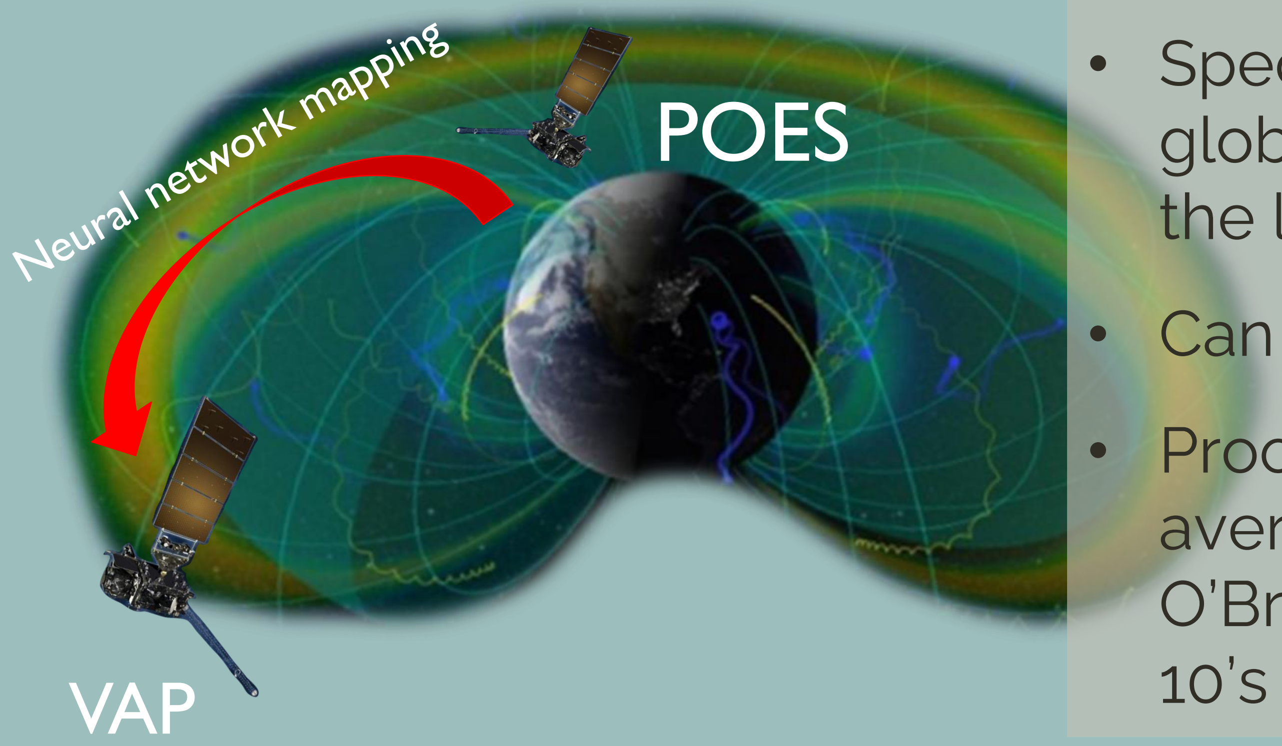
Lunar Impacts

NASA HERMES Interdisciplinary Science Team



Internal Charging: SHELLS-hires Model

SHELLS-hires
Electron radiation belt model that extends sparse data coverage



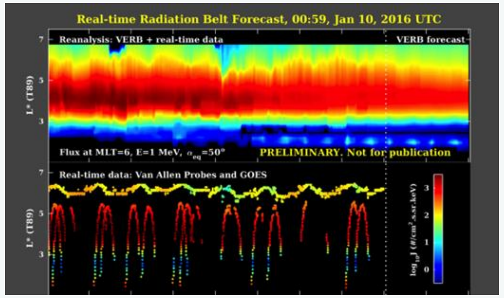
- Neural network learns the mapping from low (POES) to high altitude (VAP) electron fluxes
- Specifies electron flux in near real time globally with just low altitude data based on the learned mapping
- Can produce a historical climatology
- Proof of concept developed based on daily averaged POES data [Claudepierre and O'Brien]. SHELLS-hires runs at a cadence of 10's of minutes [Boyd et al., 2023]

Internal Charging: SatCAT Application

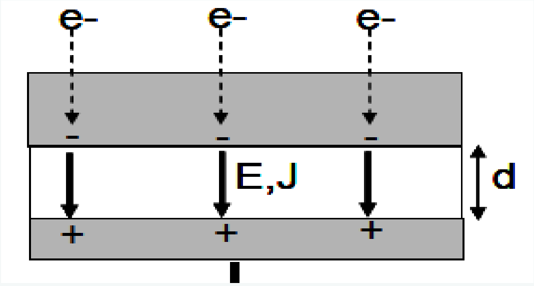
- Online interactive web application allows users to generate, display, and analyze a unique accumulated charge time-line for any user chosen satellite, shielding, and materials

- Provides a timeline of the hazard over the whole mission and updates in real time

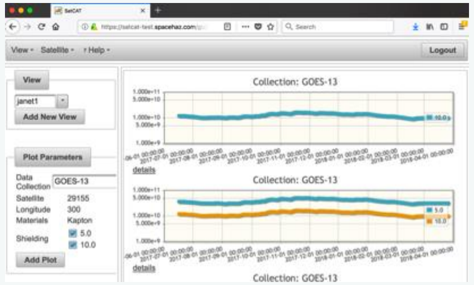
Environment → Engineering Effect → User Interface /Application



VERB

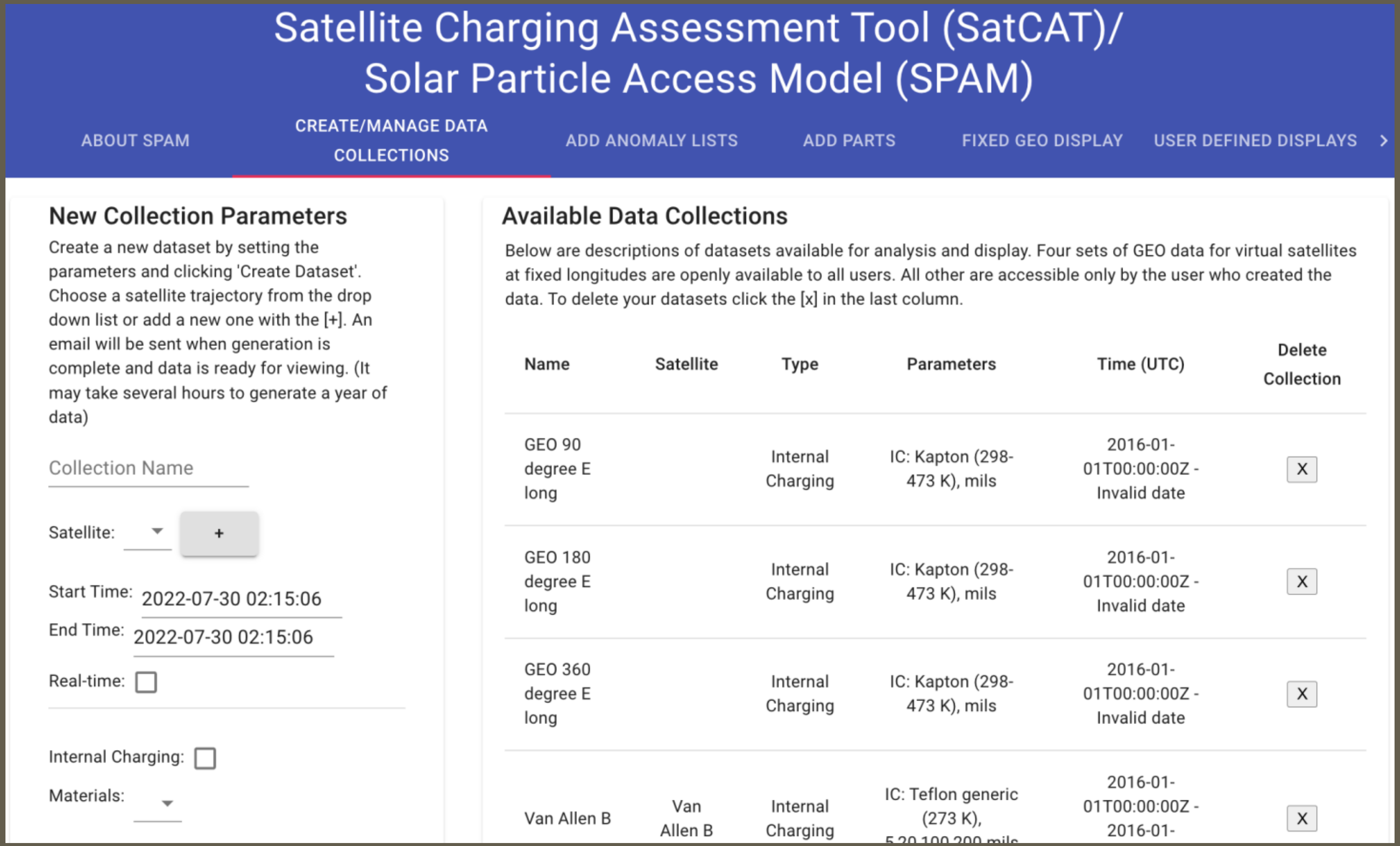


Bodeau, 2010



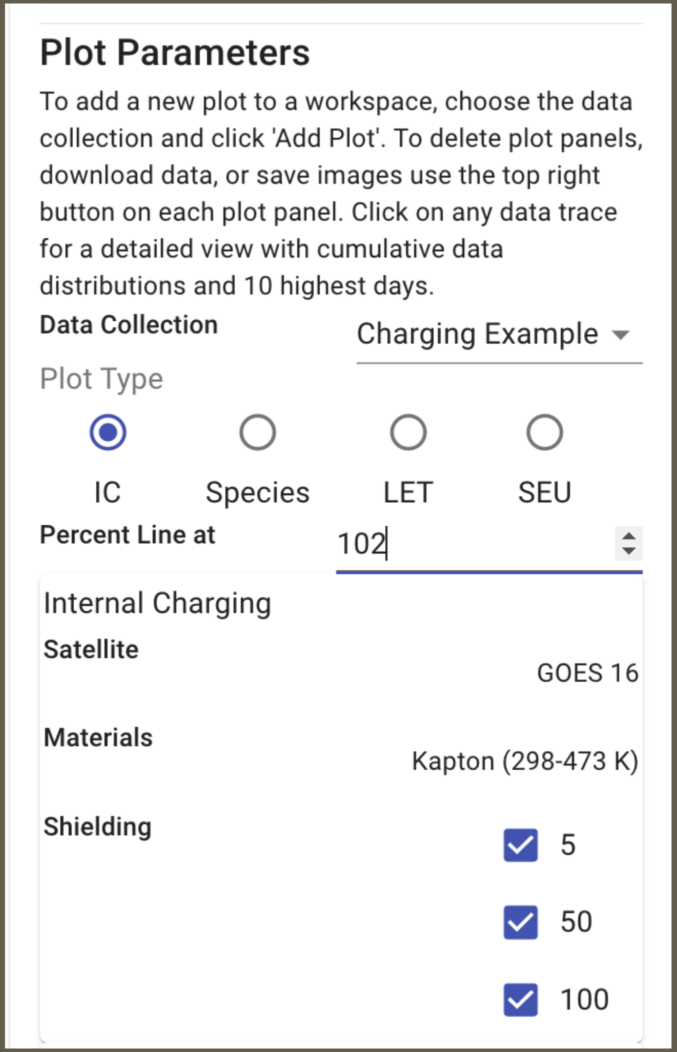
Internal Charging: SatCAT

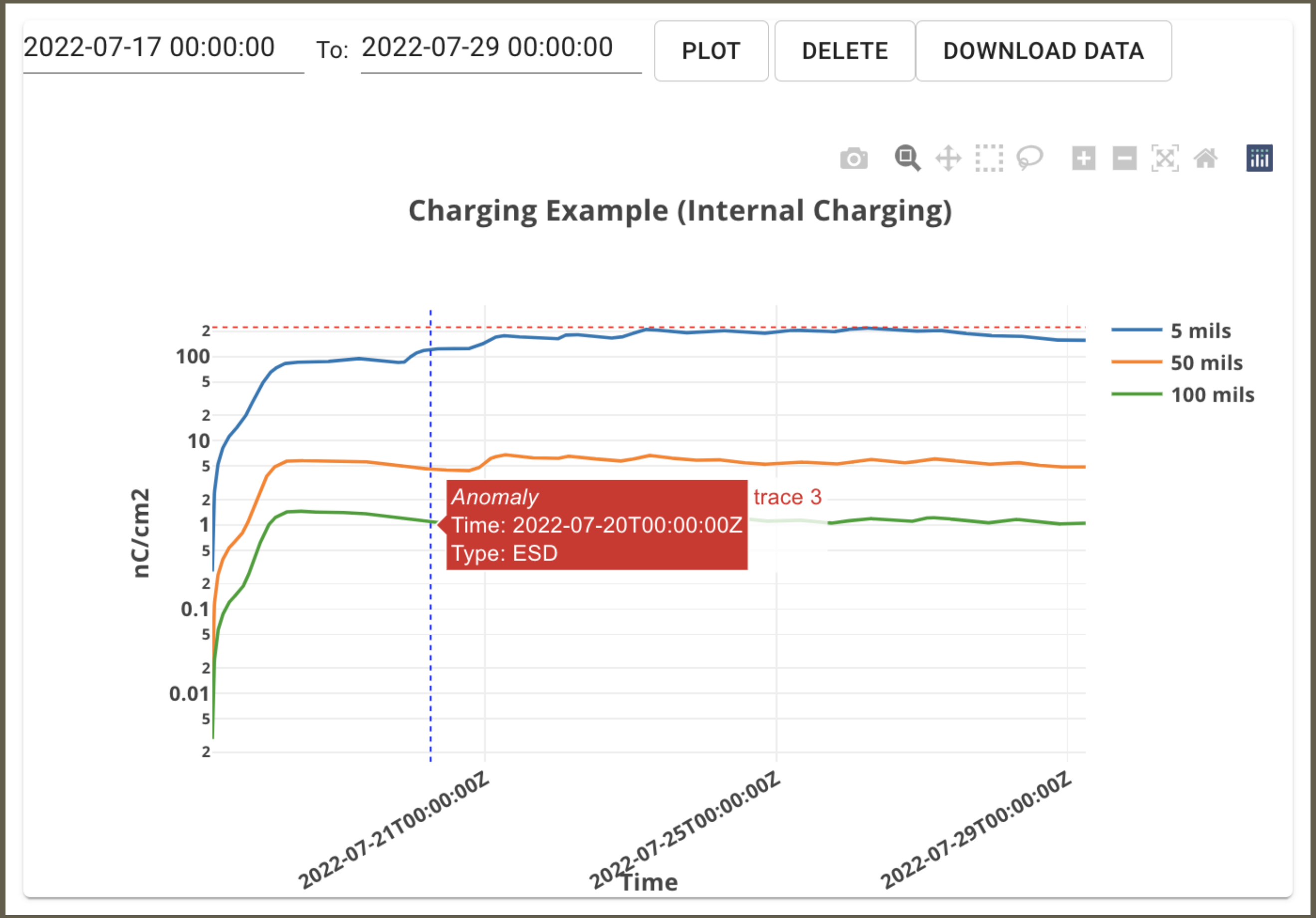
Easy to use online interface



- Create a dataset by filling in selections on the left panel
- Existing datasets are shown on the right
- Choose a satellite
- Add start and stop time (or real time updates)
- Choose the material of the component
- Add different shielding layers
- The tool collects TLE’s, creates the trajectory, gets the electron flux from VERB, translates to internal charge for material and shielding layers, and stores in a database for display and download

Internal Charging: SatCAT





Data along with anomaly times can be displayed within the app or downloaded for analysis

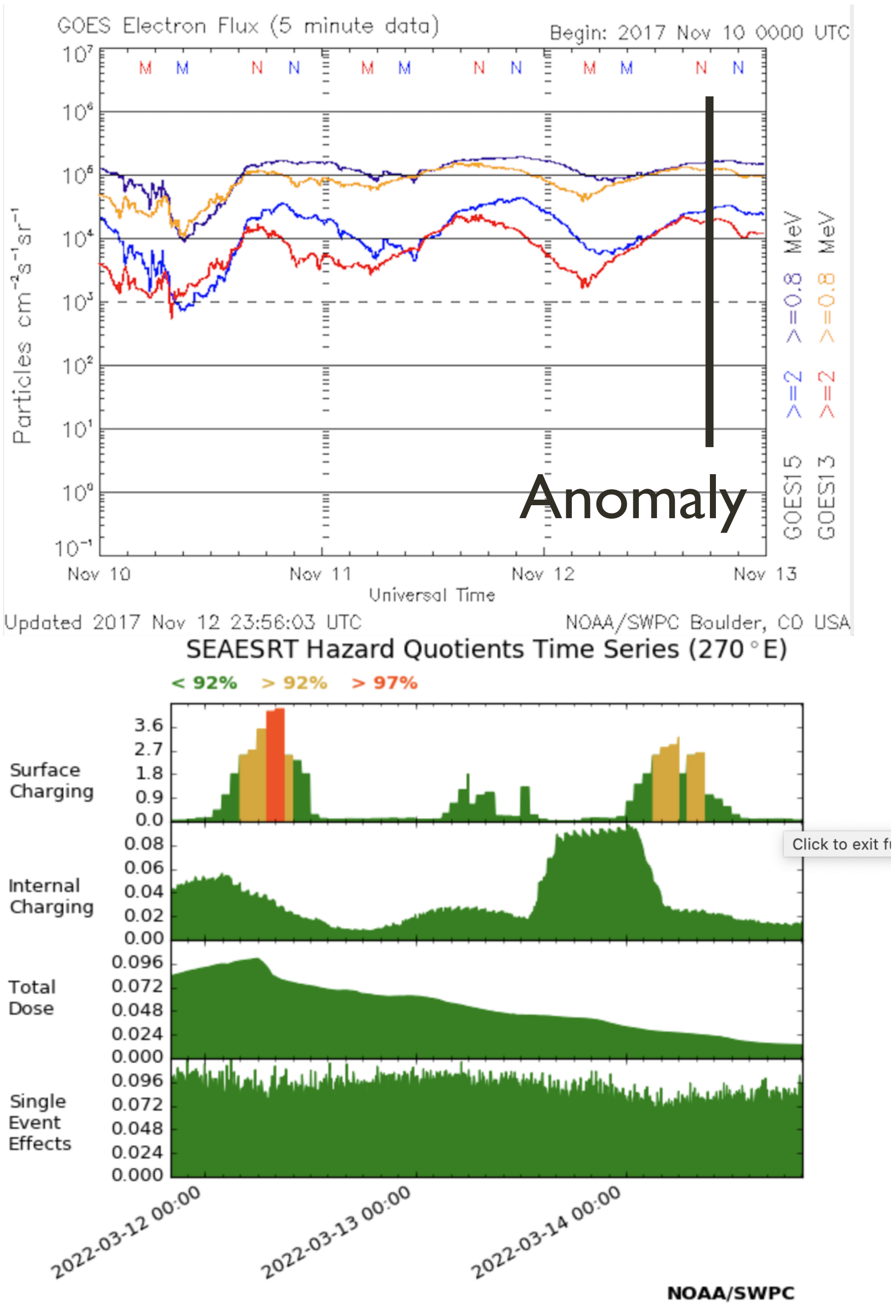
SATCAT

Van Allen Probes anomalies

VAP B transceiver POR 2017-11-12 17:34:15

Analysis tools available from SWPC

1) GOES electron fluxes
   - On Nov 12th fluxes were above the threshold
   - Fluxes had been elevated for several days
   - Not clear how GOES flux translates to GTO orbit
2) SEAESRT
   - Provides hazard quotients (Likelihood of an anomaly at this time relative to overall)
   - Only available for 3 days so post-anomaly assessment is not possible



SATCAT

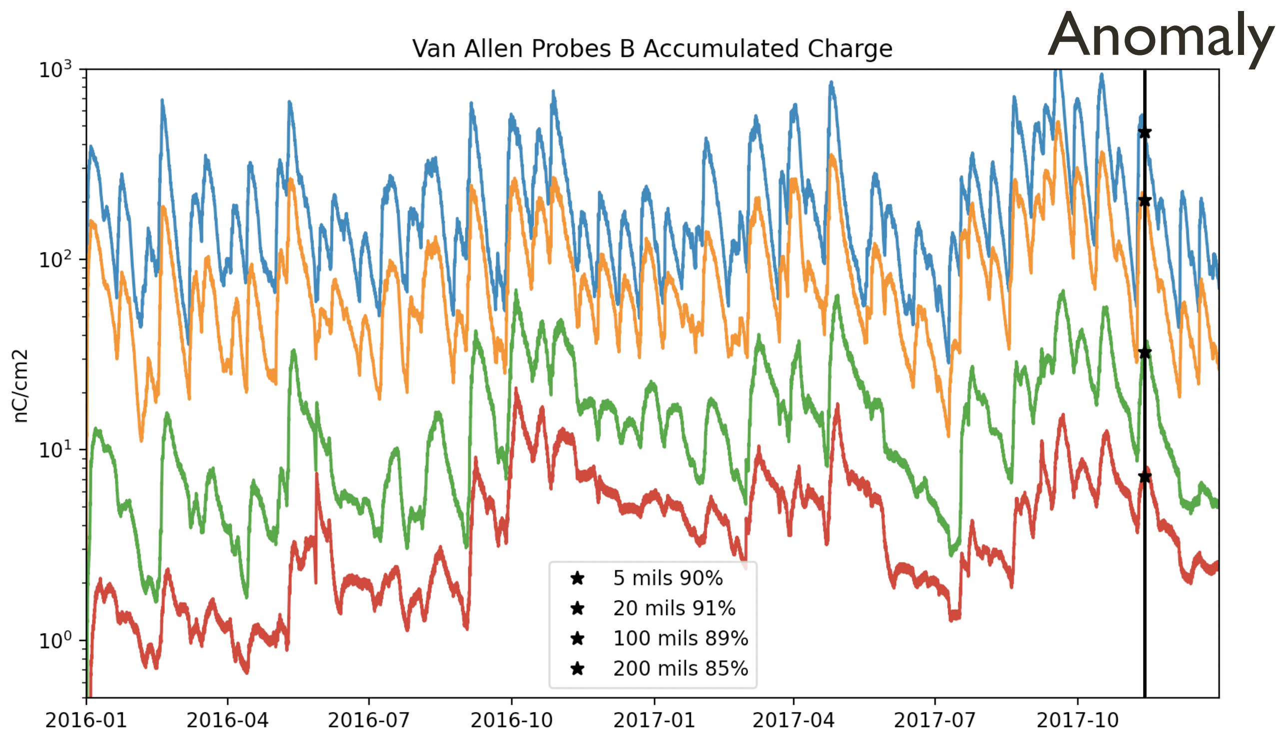
Van Allen Probes B

<u>Teflon material (2 day decay)</u>

Generated datasets of internal charging levels from 2016-2018 for 5,20,100,200 mils along the Van Allen probes B trajectory.

Charging would have been at the 91% level for lightly shielded (20 mils) Teflon.

Shielding (mils)	Material and decay constant	Charging level
5	Teflon generic (t = 2.2d)	90%
20	Teflon generic (t = 2.2d)	91%
100	Teflon generic (t = 2.2d)	89%
200	Teflon generic (t = 2.2d)	85%



SATCAT

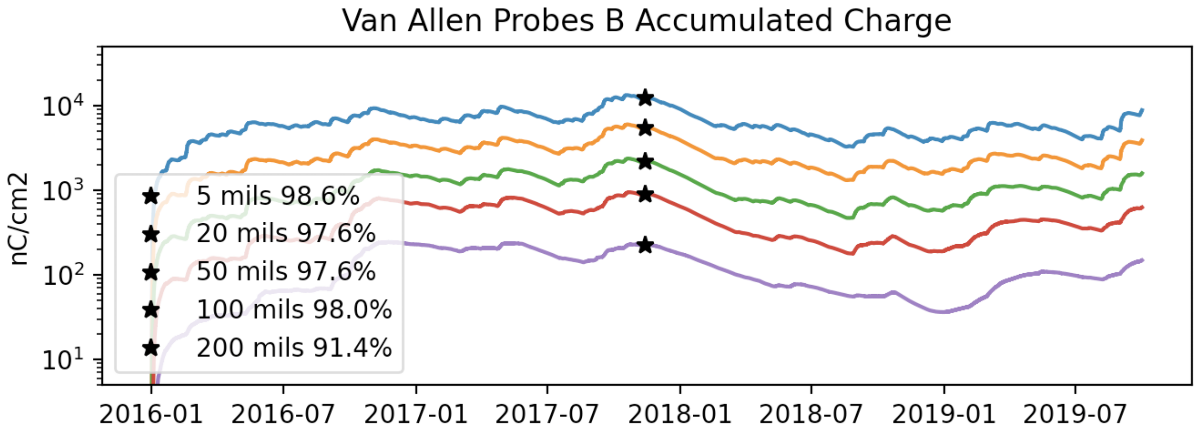
Van Allen Probes B

<u>Tefzel material (82 day decay)</u>

Generated datasets of internal charging levels from 2016-2019 for 5,20,50,100,200 mils.

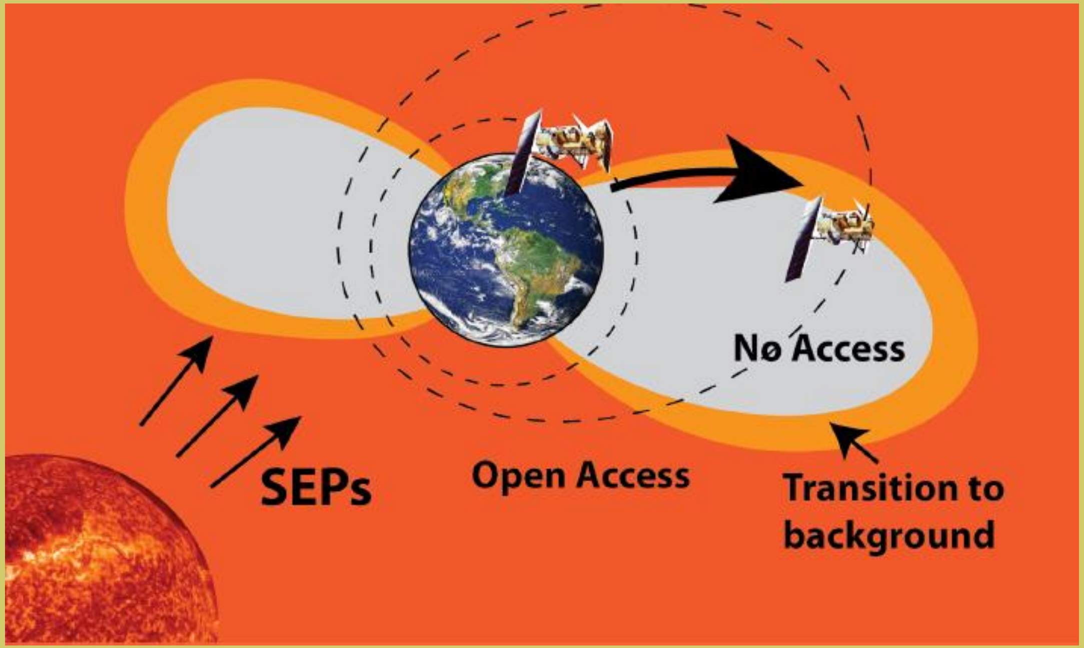
Charging would have been at the 98-99% level for Tefzel with shielding 5-100 mils.

Shielding (mils)	Material and decay constant	Charging level
5	Tefzel (t = 82 d)	99%
20	Tefzel (t = 82 d)	98%
50	Tefzel (t = 82 d)	98%
100	Tefzel (t = 82 d)	98%
200	Tefzel (t = 82 d)	91%



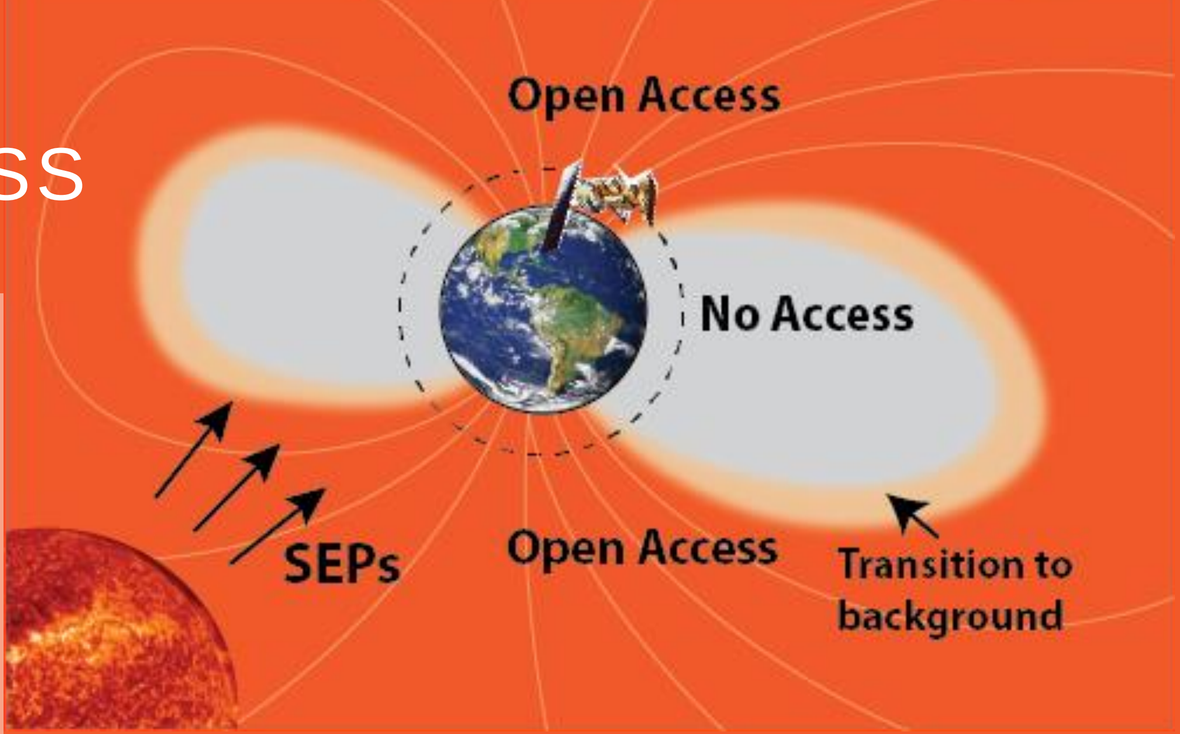
Single Event Effects: SPAM Model

Solar Particle
Access Model (SPAM)

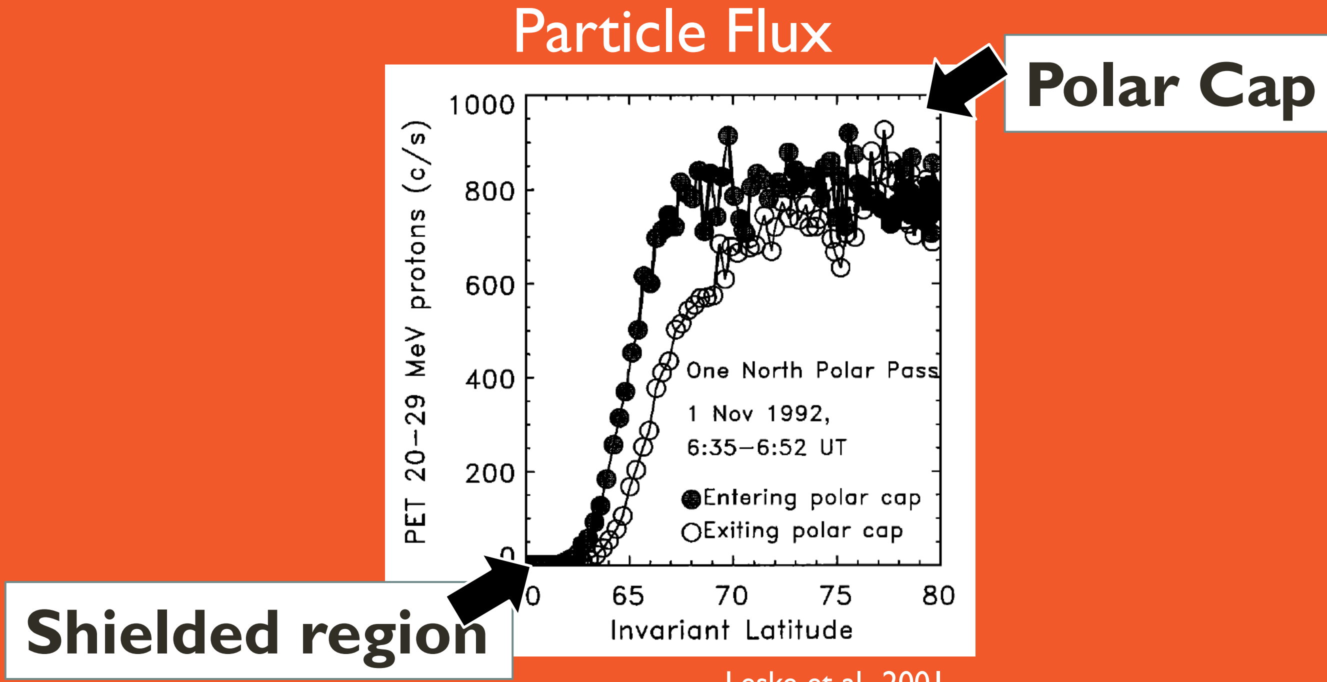


An empirically derived data driven model for mapping solar particle flux throughout the magnetosphere for satellite anomaly monitoring and attribution

SOLAR PARTICLE ACCESS



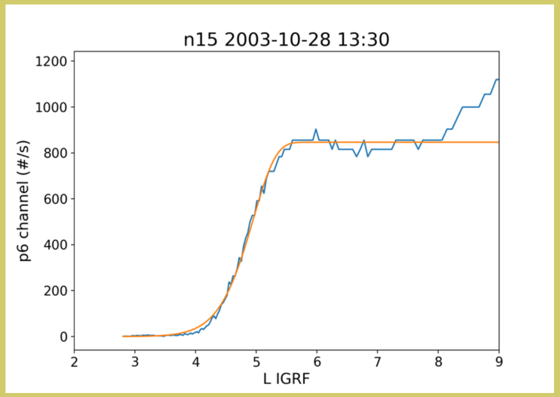
- Some regions are shielded as ions are deflected by Earth's magnetic field.
- Polar orbiting MEO/LEO satellites will pass in and out of high flux regions.
- Monitoring the threat from these ions requires knowledge of where they have access or are deflected.
- Access regions change as the magnetic field is distorted by the oncoming solar wind.

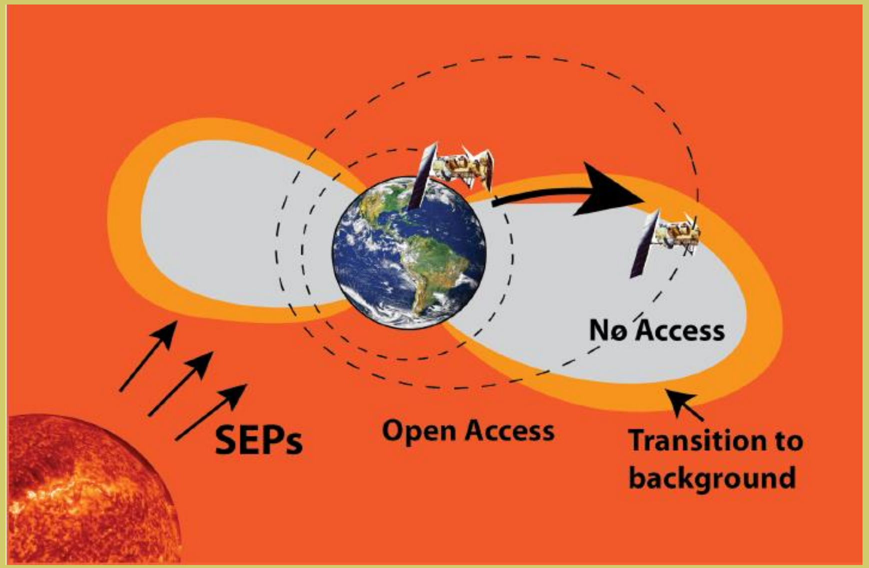


Leske et al., 2001

Single Event Effects: SPAM Model

POES proton flux





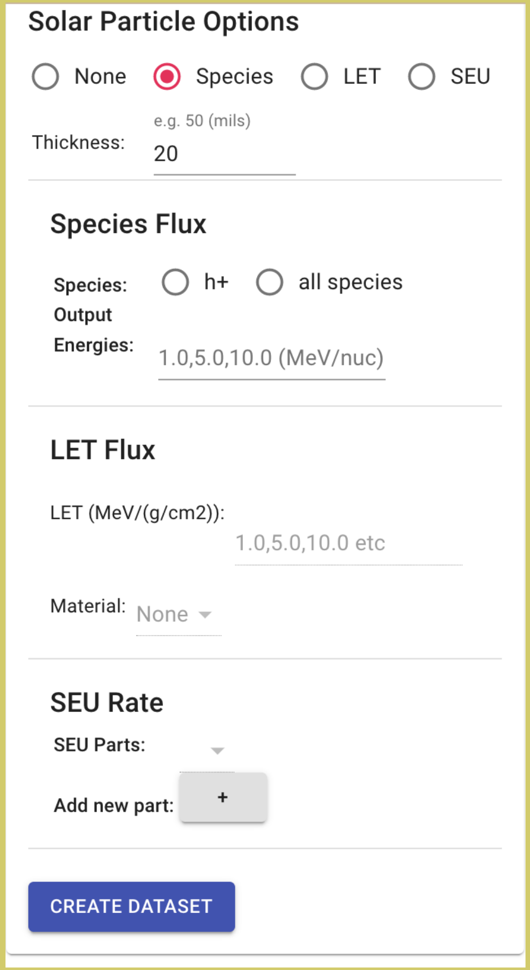
SPAM defines SEP access using real time observations of ions in Low Earth Orbit (POES/MetOP)

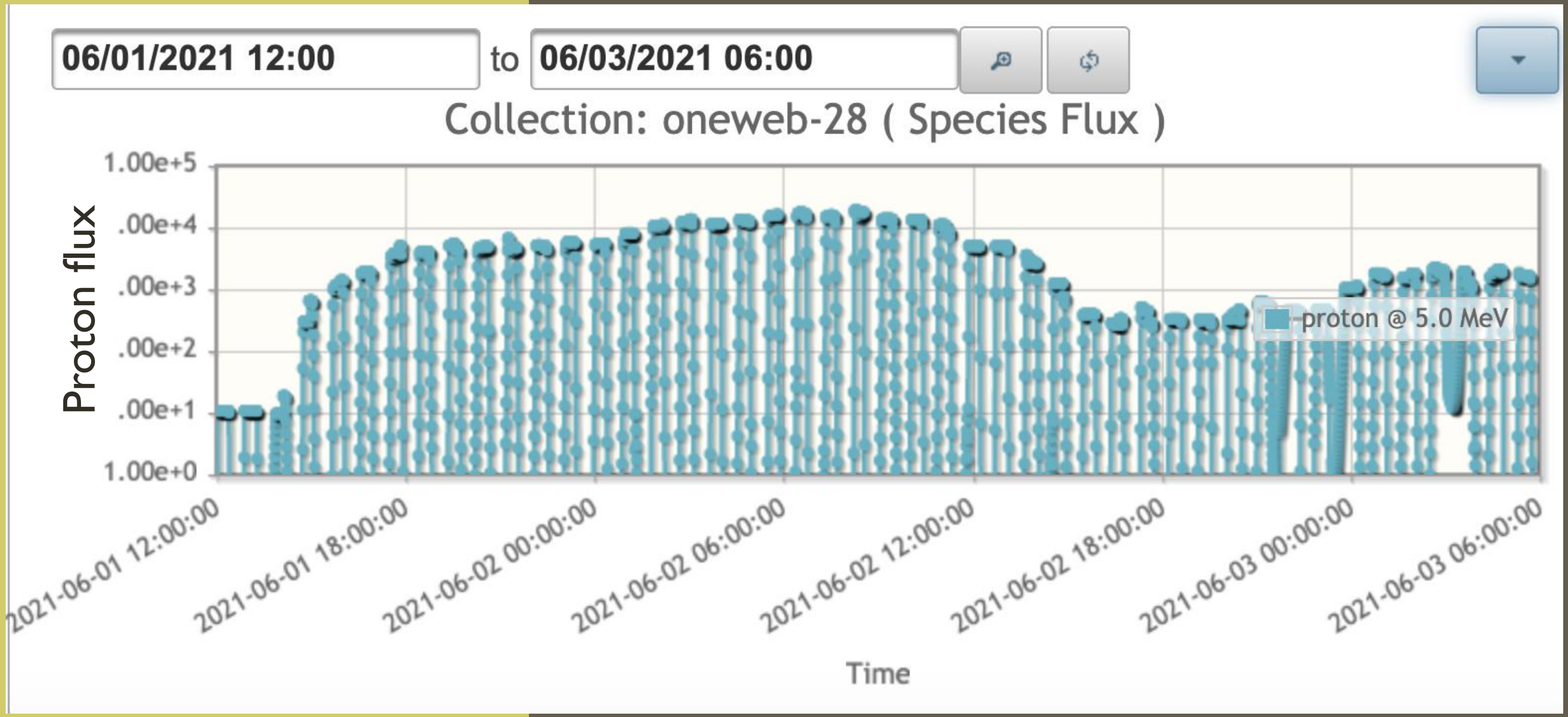
Empirically maps each POES/MetOp pass through the cutoff regions to:

- All Magnetic Local times
- All altitudes
- All ion species

Translates to LET spectrum and SEU rate

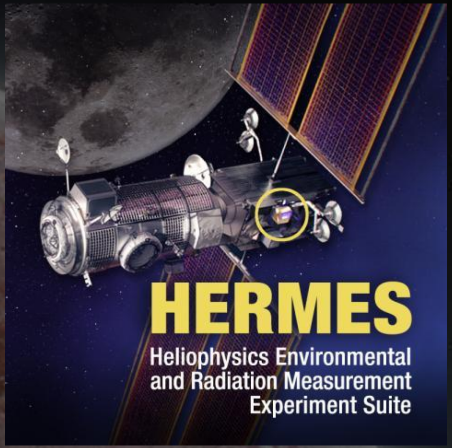
SATCAT/SPAM





Example using SPAM to show the proton flux expected along a Oneweb satellite orbit had it been in orbit during the Halloween 2003 storms when one of the most intense proton events occurred

Lunar Models And Applications



Goal:

1) To understand/model the space particle environment encountered as the moon orbits Earth

2) Create a prototype awareness tool to specify and predict the environment, its impacts, and the hazard to space systems

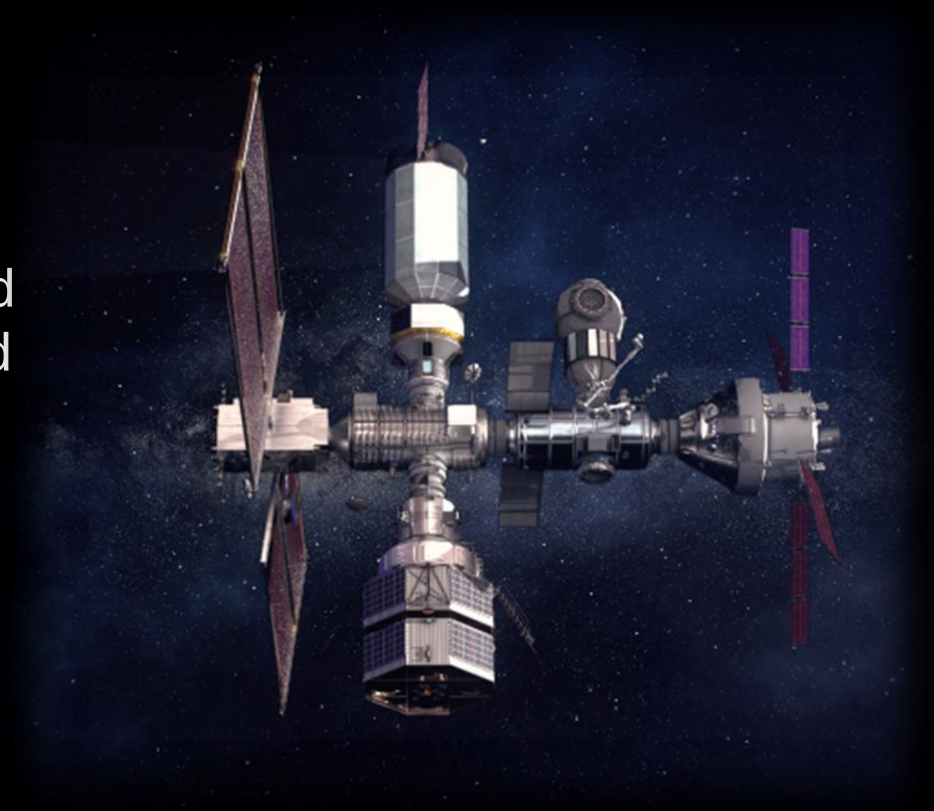
   - Surface charging, internal charging, SEE

Image: Andrew McCarthy/Connor Matherne

Lunar Surface Charging

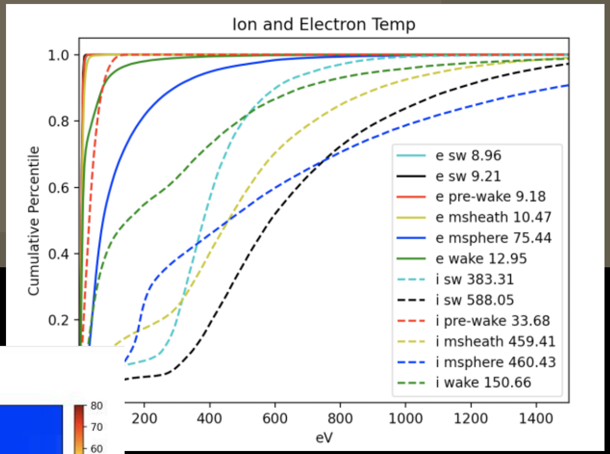
Statistical plasma model

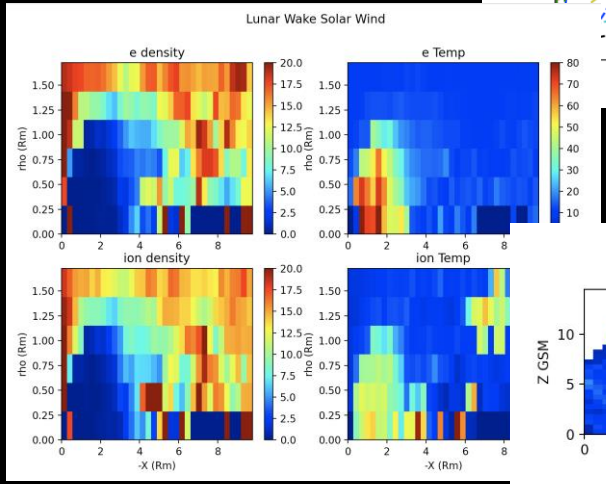
- Use Themis/Artemis data to create statistical representation of plasma environment at the moon (similar to DSNE but with better resolution)
- Use Nascap and Gateway design to specify charging and create a look-uptable to go from environment to expected charging
- Assess sensitivity of charging to surface properties
- Implement a real time application that would give charging potentials based on lunar location

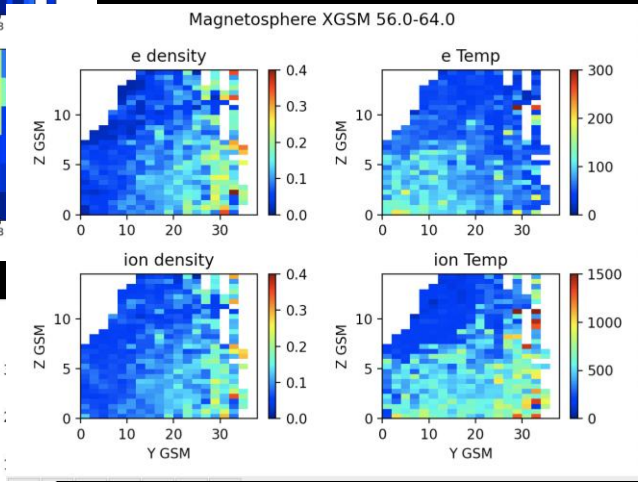


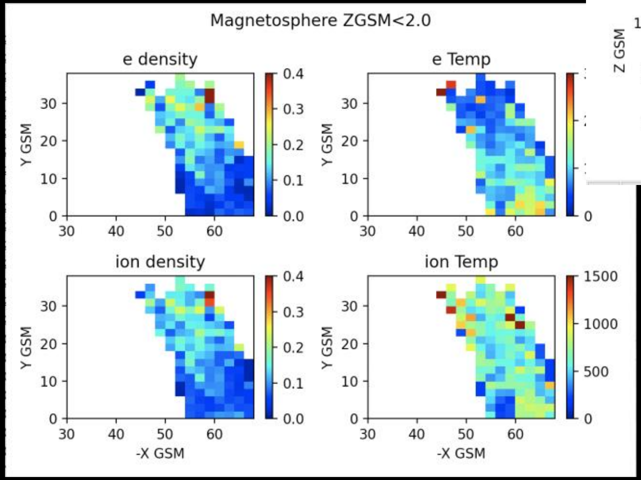
SURFACE CHARGING MODEL

1. Defined plasma regions (using a Gaussian mixture model)
2. Created cumulative distribution functions of electron and ion density/temperature in each region
3. Refined the statistics further for certain regions
   - Lunar Wake in each region (distributions for x and rho bins)
   - Magnetosphere (distributions for X,Y,Z GSM)
4. Defined where those regions occur along the lunar orbit
5. Simple statistical model that can give the most likely plasma region that you are in (with percentages) for any X,Y,Z, and the full distribution of the plasma encountered at that location for the last 10 years (based on THEMIS)





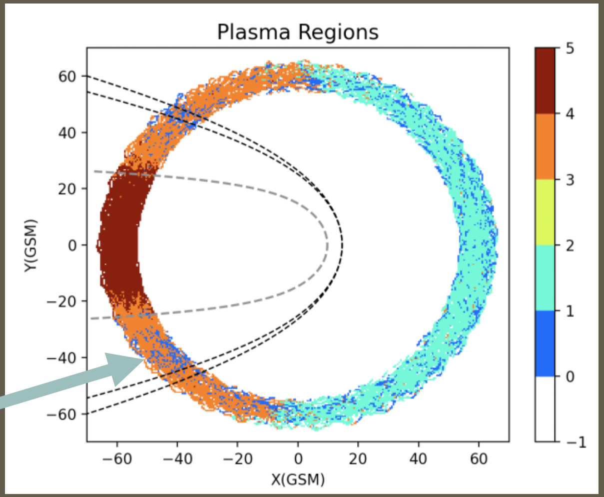


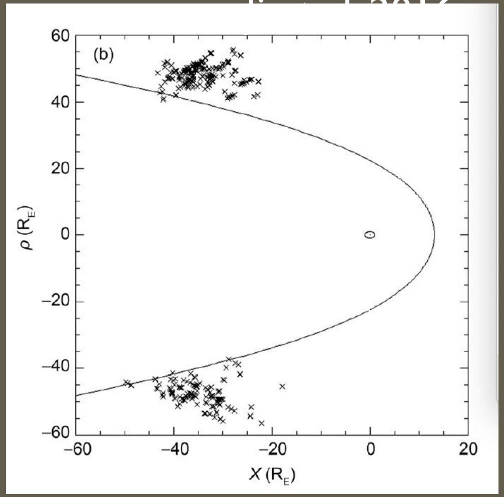


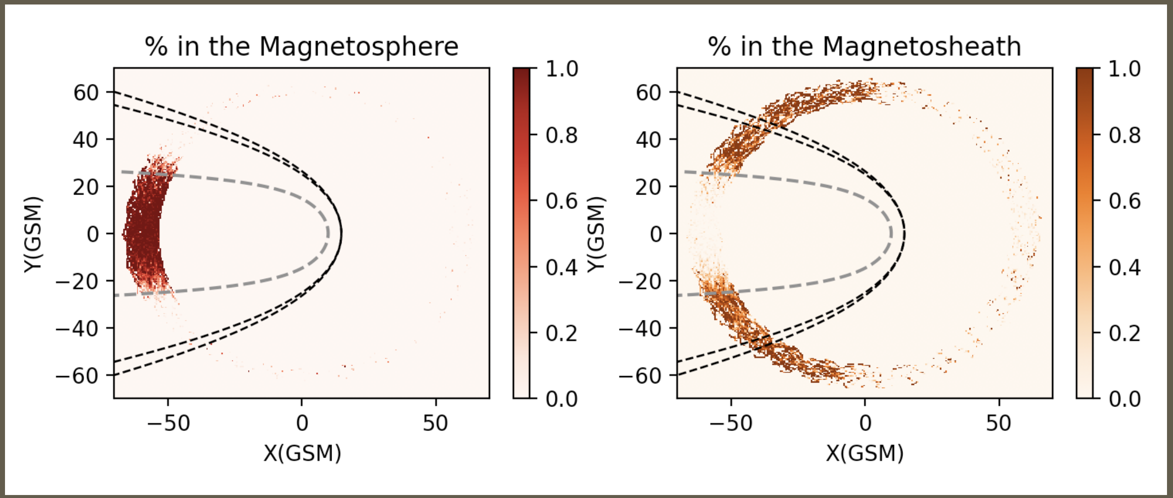
Surface Charging: Statistical Lunar Plasma Model

Location of plasma regions

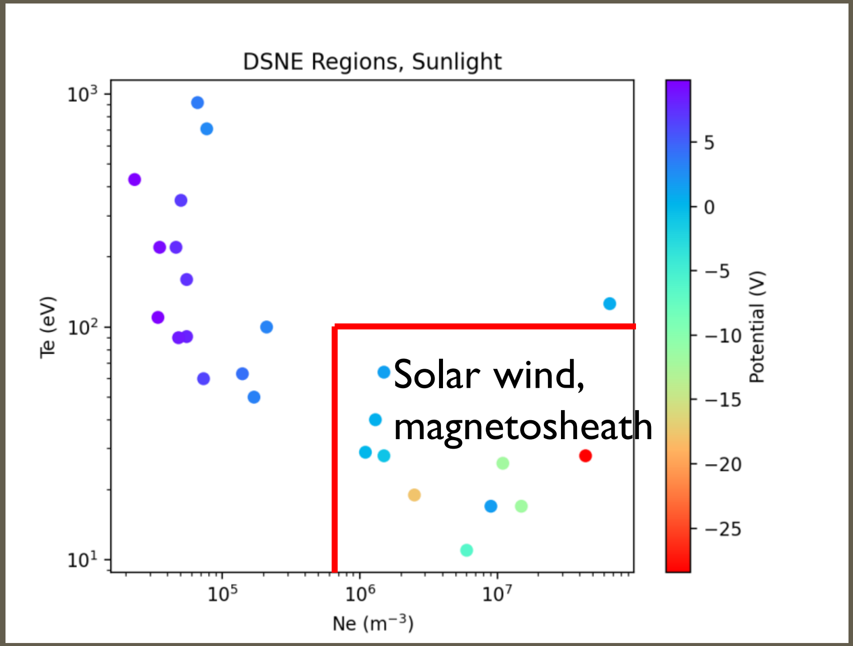
- Magnetosphere is well defined
- Magnetosheath type plasma region extends outside model bow shock (Chao et al 2002)
  - Is consistent with recent bow shock identification study using Artemis (Ji et al, 2016)



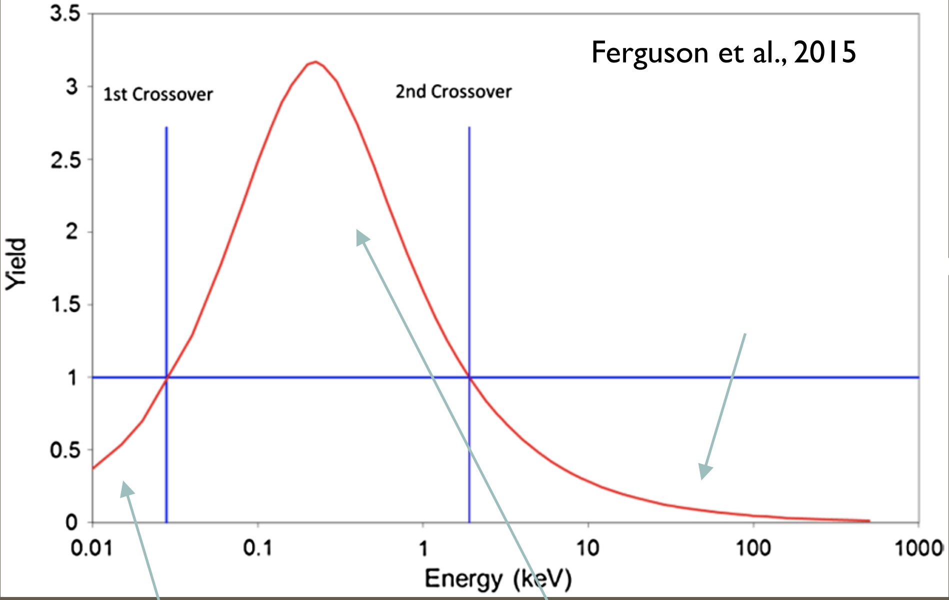




NASCAP Potentials



Typical Secondary Electron Yield



egat

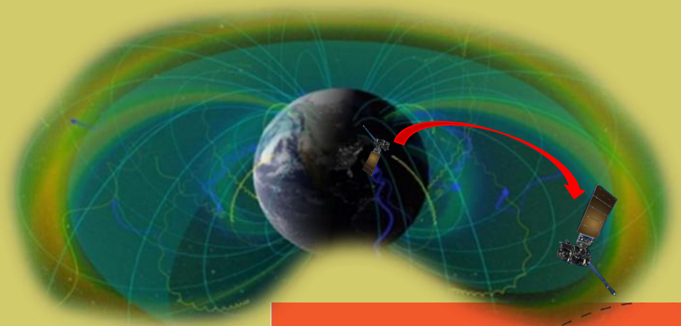
Negative and large differential potentials

- Occur in solar wind and magnetosheath (not plasmasheet)
- *low temperature* and *high density*
  (T_e < 100 eV, N_e > 10^6 m^{-3})
- Likely due to the secondary electron yield of materials used

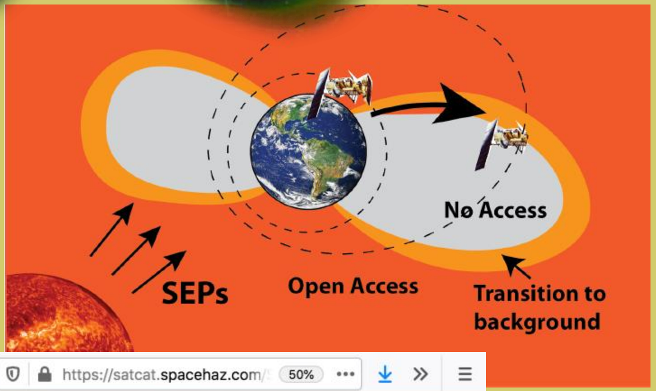
Lots of low energy electrons (i.e. low T) will charge negative

Moderate energy electrons will charge positive

SUMARY

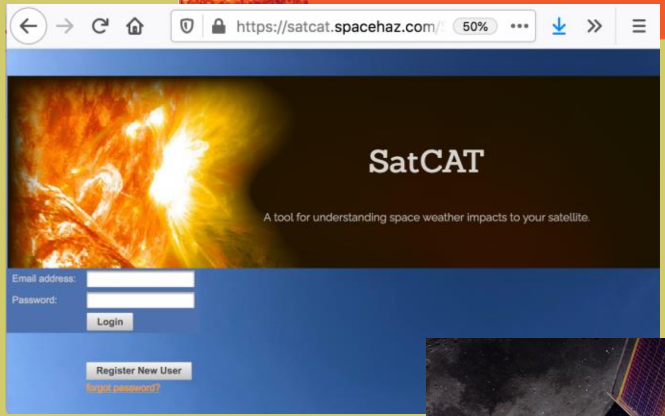


We've developed a suite of easy to access models and applications for understanding unique real time space weather impacts to satellite systems.



Internal charging

- SHELLS-hires model, SatCAT application

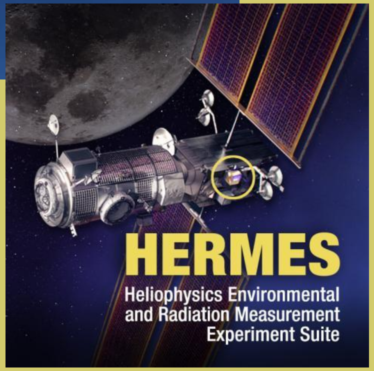


SEE

- SPAM model, SPAM/SatCAT application

Lunar Orbit

- surface charging environment and impacts



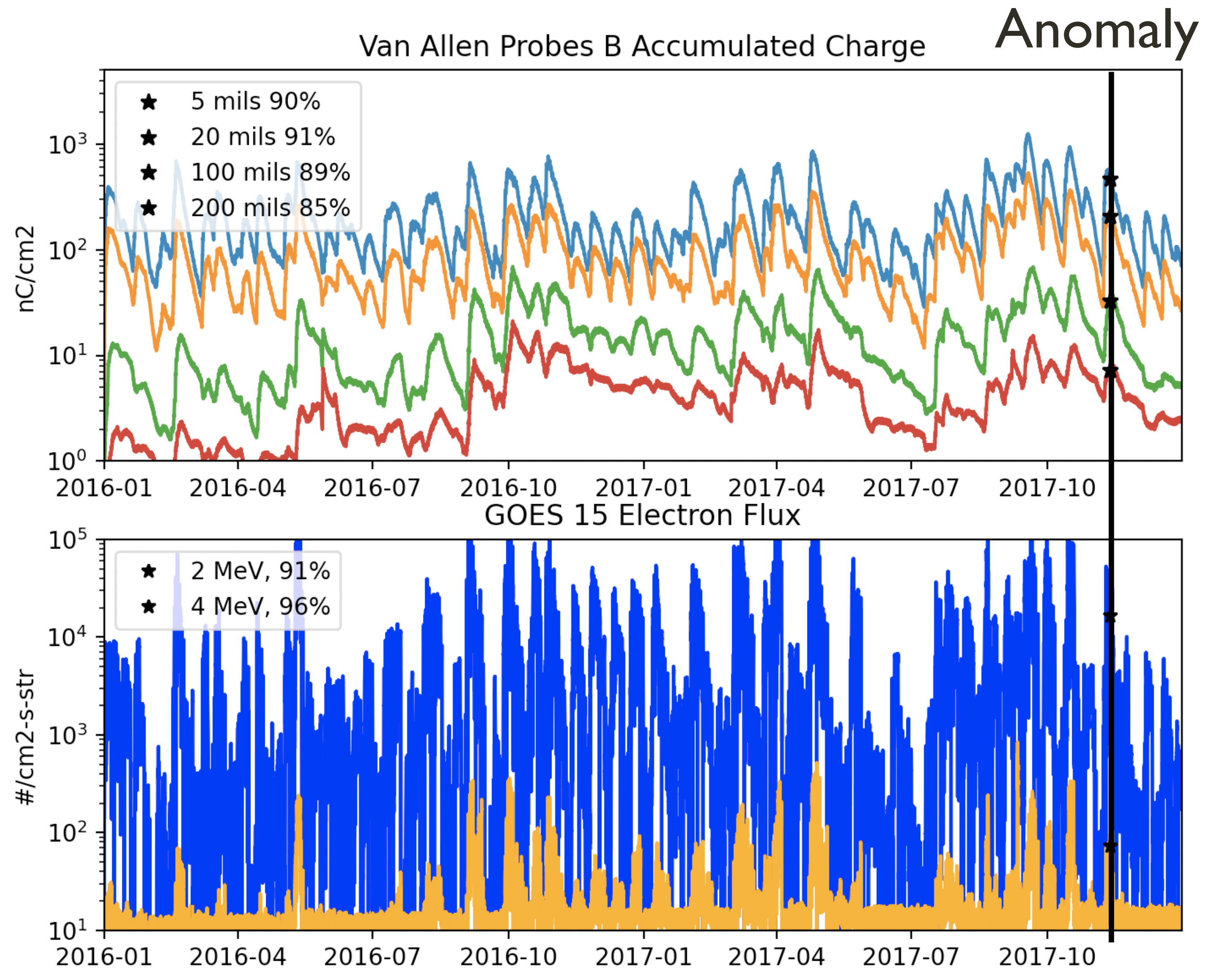
SATCAT

Van Allen Probes B

Comparing SatCAT charge to GOES fluxes

GOES electron fluxes were high
- 2 MeV flux 91% level
- 4 MeV 96% level

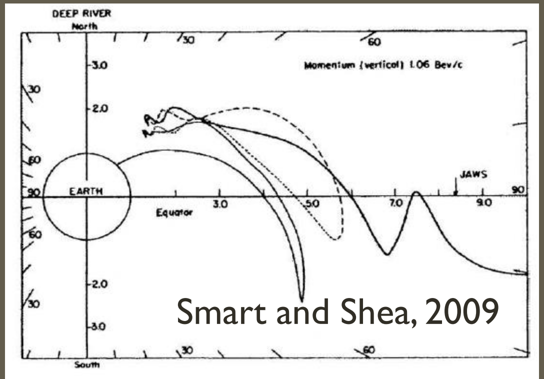
Inferences would have to be made about the flux at GTO and how the changing energy spectrum is affecting the system

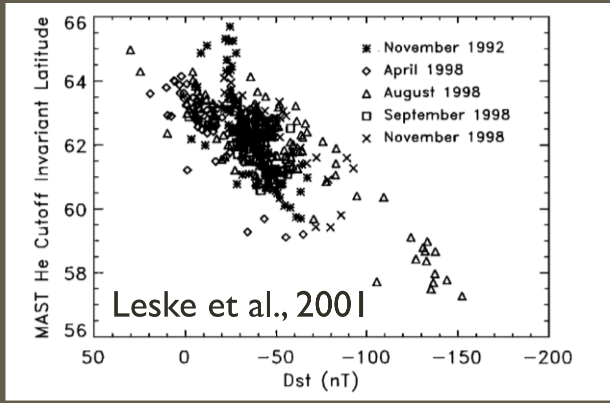


WHY SPAM?

Current models:

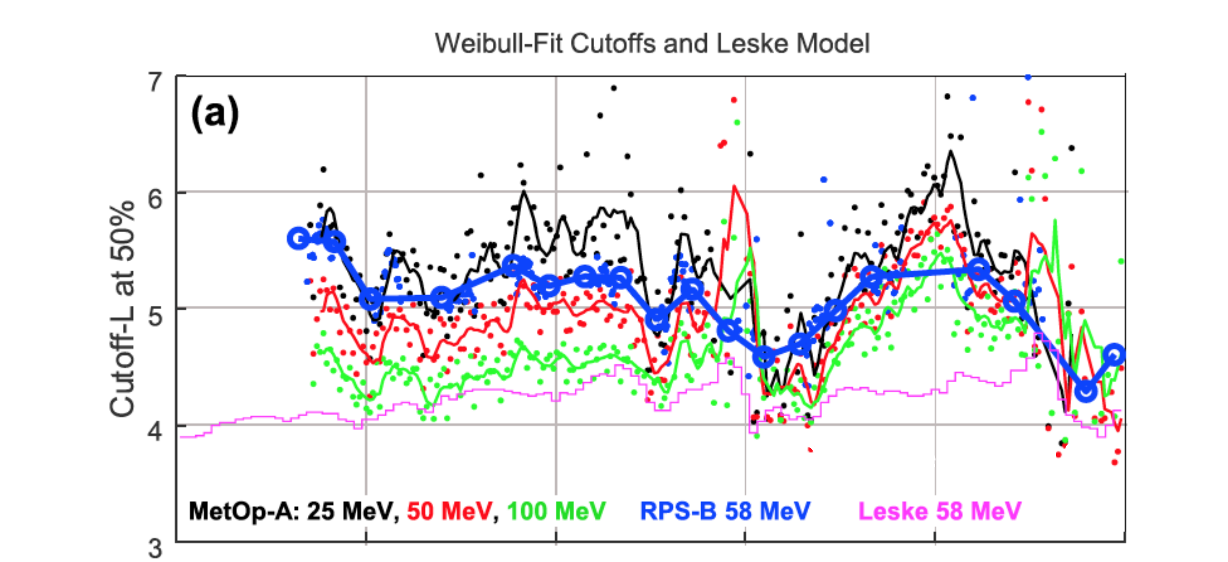
- Physics based: trace particle trajectories
- Statistical: Define average locations based on past event





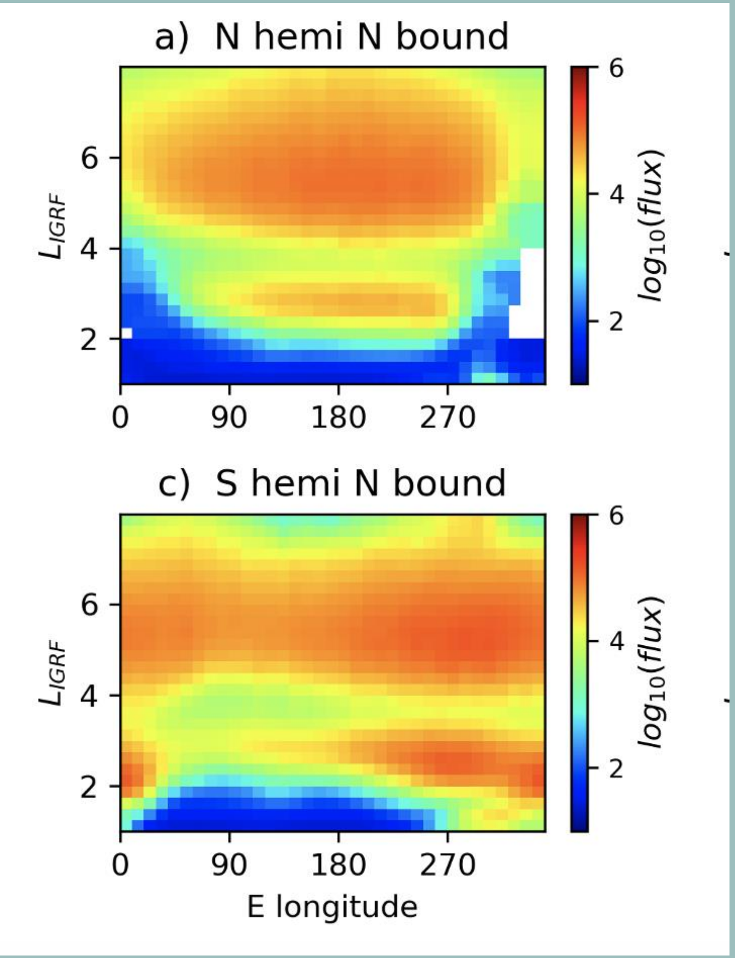
Issues:

- Don’t capture dynamic variations
- Don’t apply to all latitudes and altitudes.
- Give single cutoff locations that don’t describe how the flux increases across the boundary which is important for satellite impacts.
- Not easily accessible to satellite operators.



Internal Charging: SHELLS

POES electron fluxes vary with longitude



- SHELLS-hires
  - Removes orbital variations by mapping each POES pass to a consistent longitude using statistical asynchronous regression [Green et al., 2020]
  - Updates ~10's of minutes (L=3-6.3)
  - Alex Boyd et al., updating to extend to larger L
- Could be used for data assimilation input to predictive physics models such as VERB
- Working on implementation at CCMC

https://github.com/poes-metop-sem/poes_metop_sem/tree/master/src/SHELLS