

Space Radiation Impacts to Satellites

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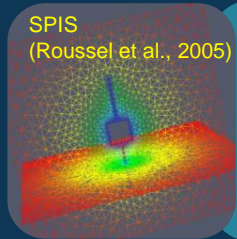
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Small Satellite Conference Aug 04, 2020



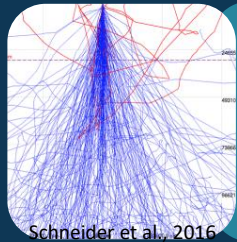
The Threat

Space radiation damages components causing system/mission loss or limitation



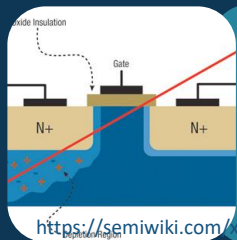
Surface Charging:

Charged particles collect on satellite surfaces producing high differential voltages, damaging arcs (electrostatic discharges), and electromagnetic interference.



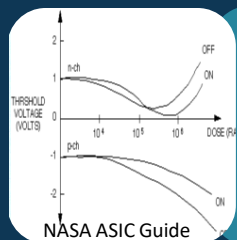
Internal Charging:

Energetic electrons accumulate in interior dielectrics (circuit boards, cable insulators) and on ungrounded metal (spot shields, connector contacts) leading to electrical breakdown and discharge in the vicinity of sensitive electronics.



Single Event Upsets:

Energetic ion passage through microelectronic device node causes instantaneous catastrophic device failure, latent damage, or uncommanded mode/state changes requiring ground intervention.

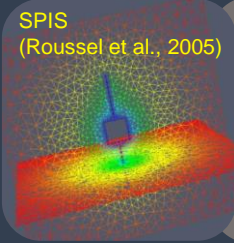


Total Dose:

Energy loss (deposited dose) from proton/electron passage through microelectronic device active region accumulates over mission (or step-wise during high dose rate events) causing device degradation and reduced performance at circuit or system level.

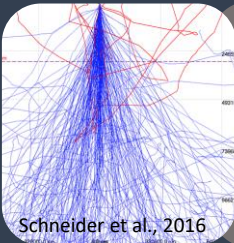
The Mitigation

Sound design may prevent some space radiation impacts



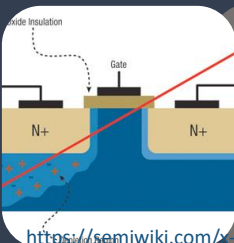
Surface Charging:

NASCAP-2K, SPIS, MUSCAT can be used to model surface charging using ISO worst case environments



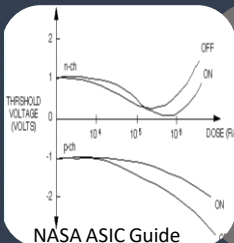
Internal Charging:

IRENE/AE9, Novice, Numit, FASTRAD can be used to simulate electron flux internal charging over mission or for specific systems. Follow NASA-HDBK-4002 guidelines



Single Event Upsets:

CREME96, CREME-MC, Novice, IRENE/AP9 SEE effects kernel can be used to calculate SEE upset rates for components and shielding.



Total Dose:

IRENE/AE9/AP9, Novice, FASTRAD

LEO/MEO Issues

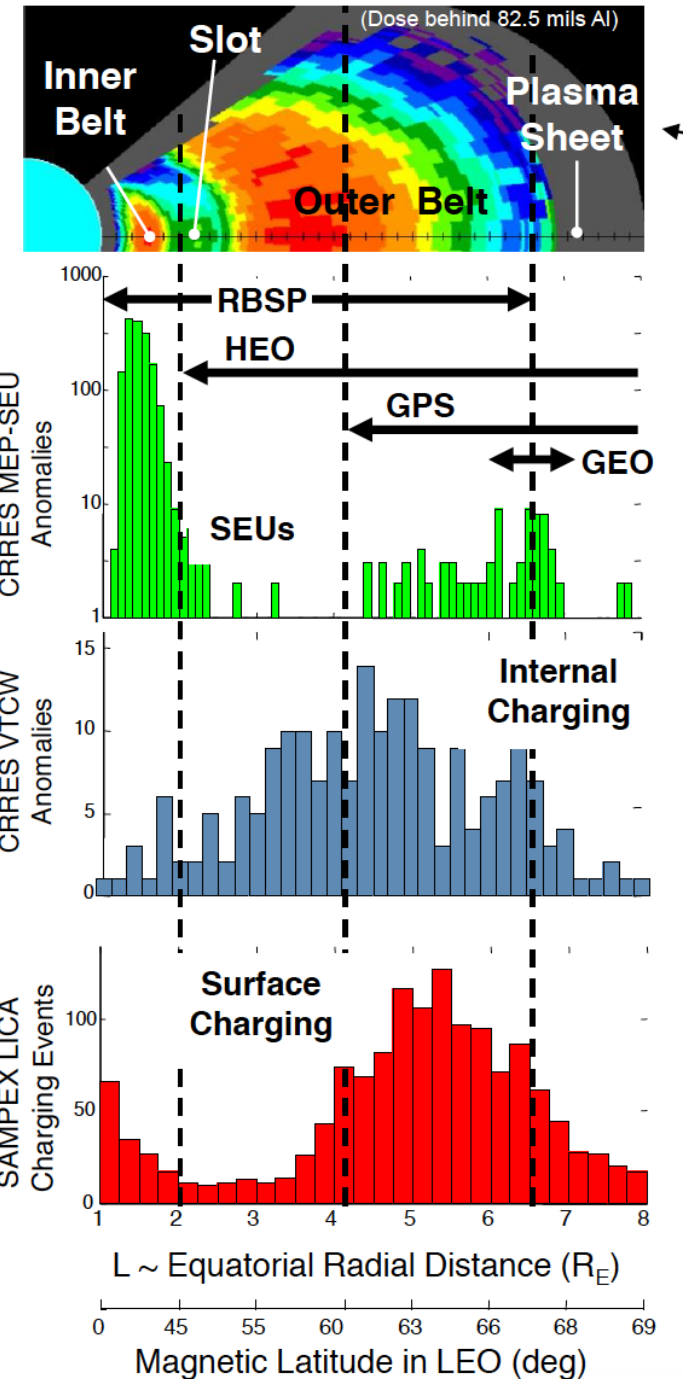
Occurrence of anomalies depends on orbit/location

SEUs
Surface Charging

} MOST COMMON

Internal Charging
Total Dose

} LESS COMMON



Anomaly Attribution/Forensics

No single space weather indicator can explain all issues at all locations

SEU

Cause: >10 MeV protons/heavy ions
Steady trapped population near Earth
Sporadic events related to solar activity (flares, CMEs)
Galactic Cosmic Rays

Total Dose

Cause: Long duration intensification of the radiation environment

Each are caused by different particle populations enhanced at different times in different locations

Surface Charging

•Cause: ~10s keV electrons
Occurs during substorms (Sporadic (every ~3 hours) reconfiguration of Earth's magnetic field)

Internal Charging

Cause: >100 keV electrons
Occurs during storms (Days long global change of Earth's magnetic field structure)

LEO/MEO SEUs

Stably trapped proton belt

Proton belt forms a torus shaped region around Earth

Protons reach low altitudes (<2000 km) only in South Atlantic Anomaly magnetic field distortion

Peak fluxes vary by ~ 2 over solar cycle

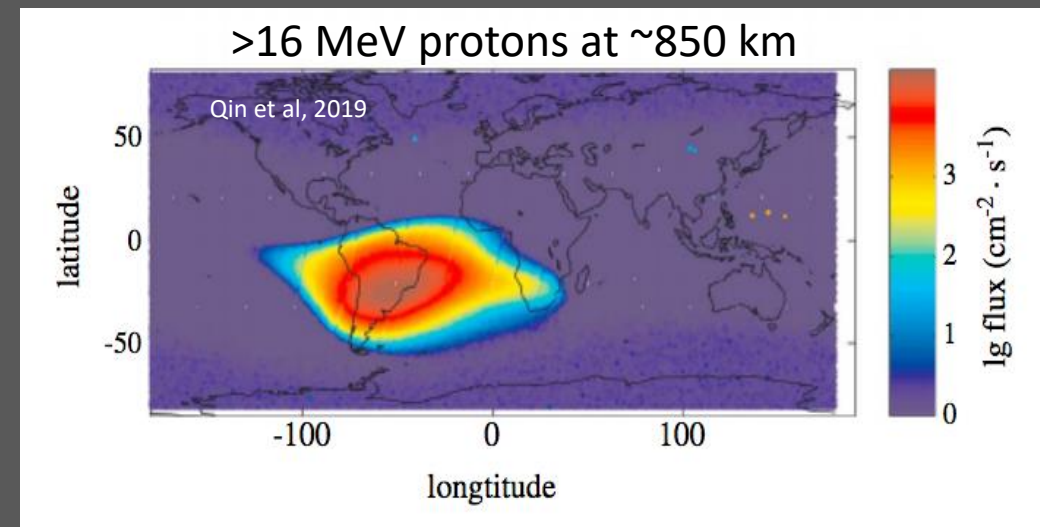
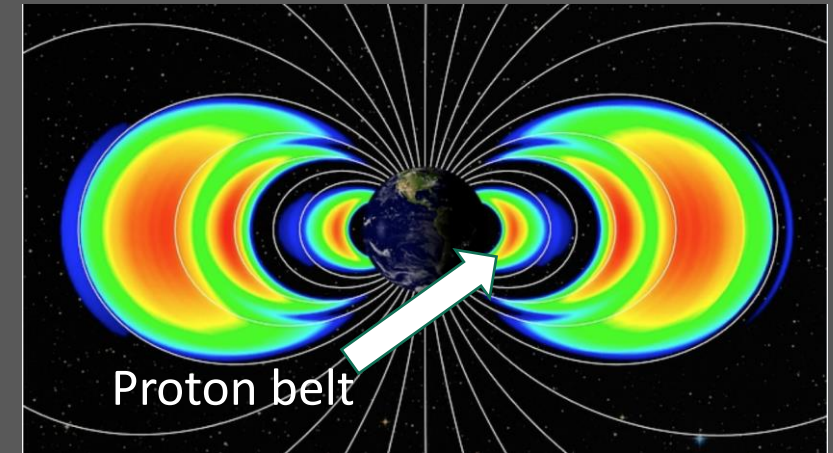
There is always some probability of an anomaly occurring in the SAA

SEUs are instantaneous

Attribution/Forensics

- Use AP9 to define location of anomaly relative to high flux along orbit

Stable Proton Belt



LEO/MEO SEUs

Sporadic Solar Energetic Particles

Stream from the sun and fill high latitude polar caps

Last days to weeks

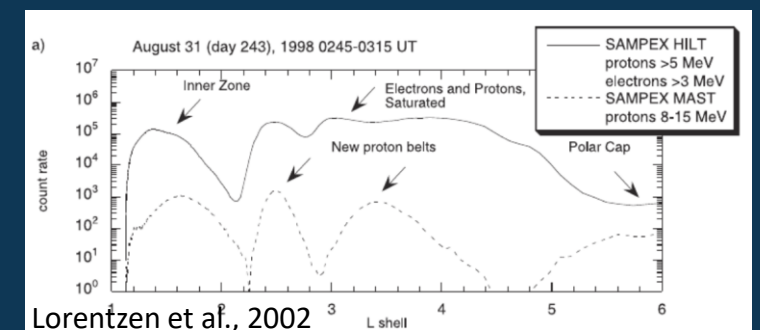
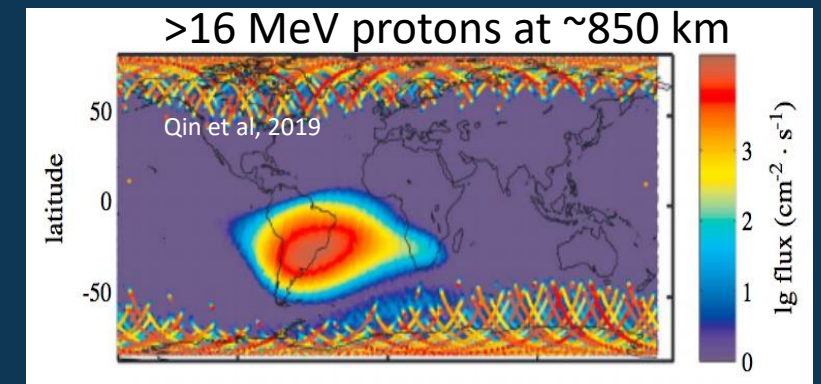
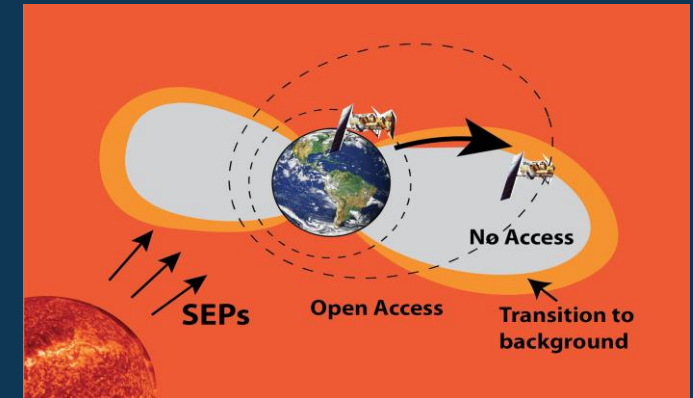
Some SEPs may be trapped and form a temporary new belt

None since Sep 2017

Attribution/Forensics:

- SWPC GOES proton plots and alerts indicate event in progress
- Human in the Loop Decision Tool [O'Brien et al. 2012]
- future Solar Particle Access Model (SPAM)

Solar Energetic Particles



LEO/MEO SEUs

Galactic Cosmic Rays

High energy ions from outside our solar system

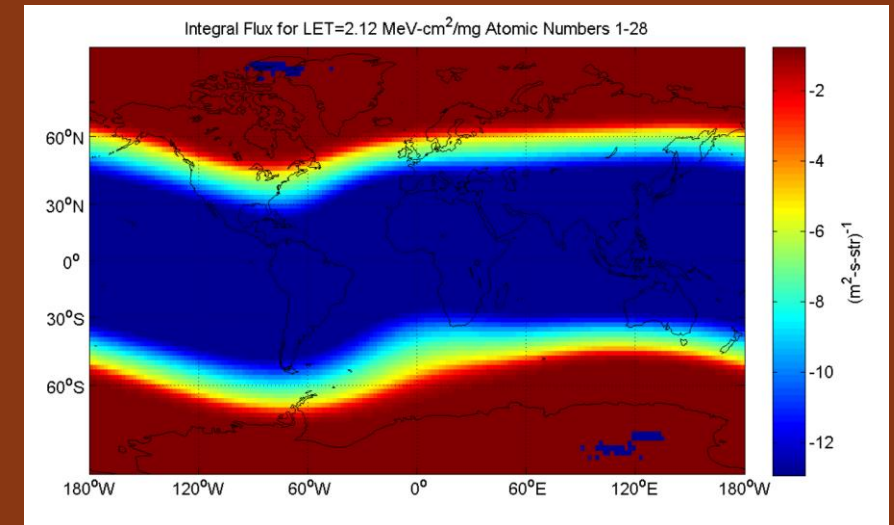
Always present at high latitudes at low levels

Anti-correlated with solar cycle

Attribution/Forensics:

- Statistical access regions from tools such as CREME96

Galactic Cosmic Rays



Green et al, 2010

LEO/MEO Surface Charging

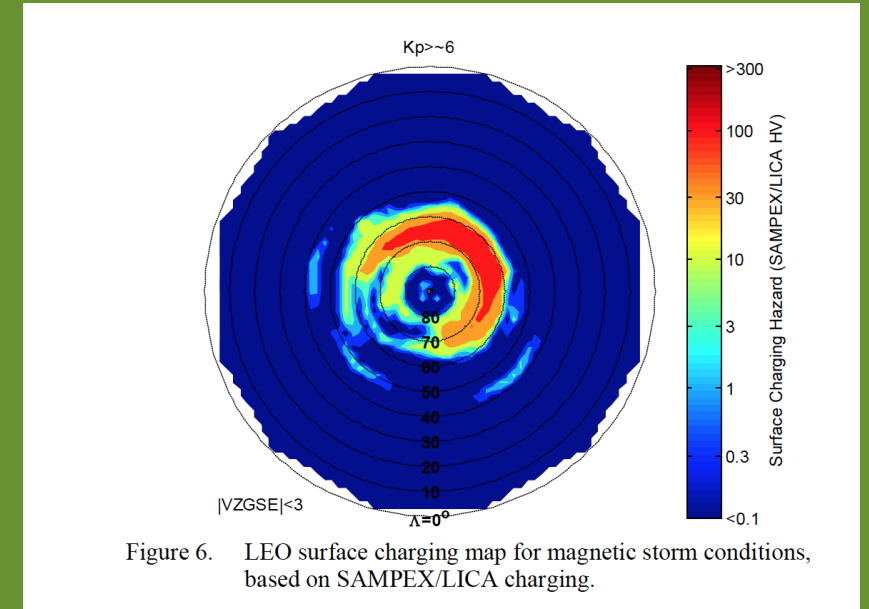
Auroral electrons

Caused by energetic electrons accelerated in high latitude auroral regions

Attribution/Forensics:

- SEAES tool developed by Aerospace indicates likelihood of charging at LEO but is not publicly available
- Human in the Loop Decision Tool [O'Brien et al. 2012]

Auroral electrons



O'Brien et al, 2009

Extreme Events

The US Space Weather Action Plan (SWAP) Phase 1 created an initial report on radiation benchmarks for extreme events

- <https://www.sworm.gov/publications/2018/Space-Weather-Phase-1-Benchmarks-Report.pdf>
- Gives some extreme event flux values for SEPs and GCRs

Work is underway to refine the benchmarks and deliver a Phase II report



NATIONAL SPACE WEATHER STRATEGY AND ACTION PLAN

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Summary

Four different issues caused by space radiation

- Surface charging, internal charging, SEUs, and total dose

Two major concerns at LEO

- SEUs and surface charging

SEUs

- Stably trapped proton belt (constant, low latitude)
- Solar Energetic Protons (sporadic, high latitude)
- Galactic Cosmic Rays (constant, high latitude)

Surface charging

- High latitude auroral regions