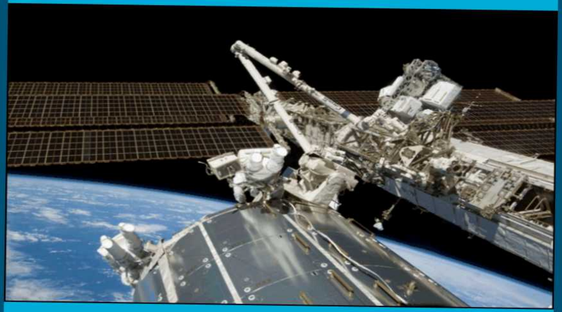
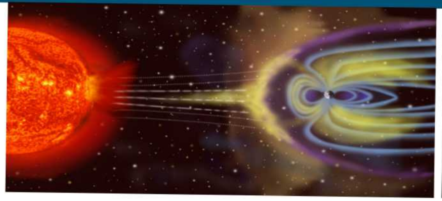
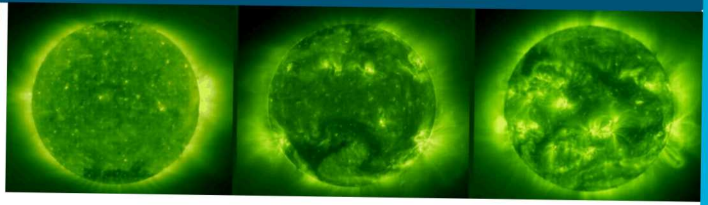
SAND2018-5900C

Introduction to the Space Radiation Environment







PRESENTED BY

Paul Thelen

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Introduction

The space environment contains various sources of radiation

Radiation interacts in unique ways with matter

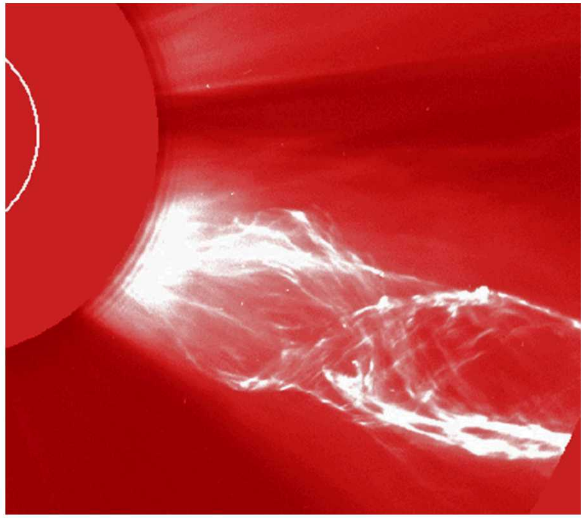
Radiation effects can have detrimental results on electronics if not properly mitigated

Need to understand …

- The space radiation environment
- Radiation effects on matter
- How to mitigate radiation effects

… In order to:

- Design radiation tolerant electronic components and integrated circuits
- Design a robust spacecraft
- Predict performance degradation and/or potential failure of systems in space



From SOHO -- Solar and Heliospheric Observatory

Agenda

Environment
- Galactic Cosmic Rays
- Solar Particle Events
- Van Allen Belts

Effects
- Total Ionizing Dose
- Single Event Effects
- Displacement Damage
- Spacecraft Charging

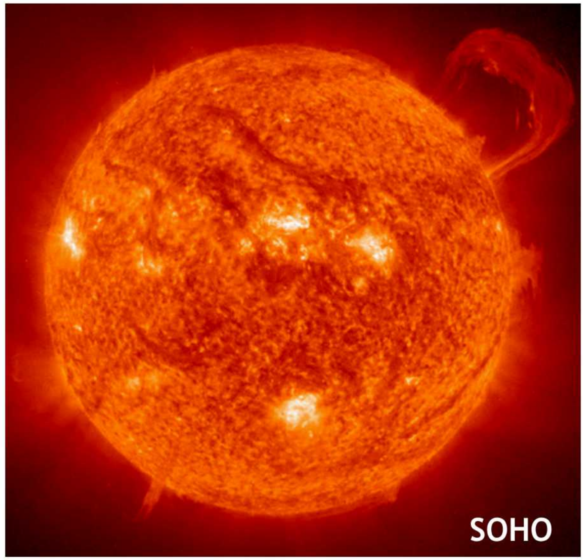
Environment Intro – The Sun

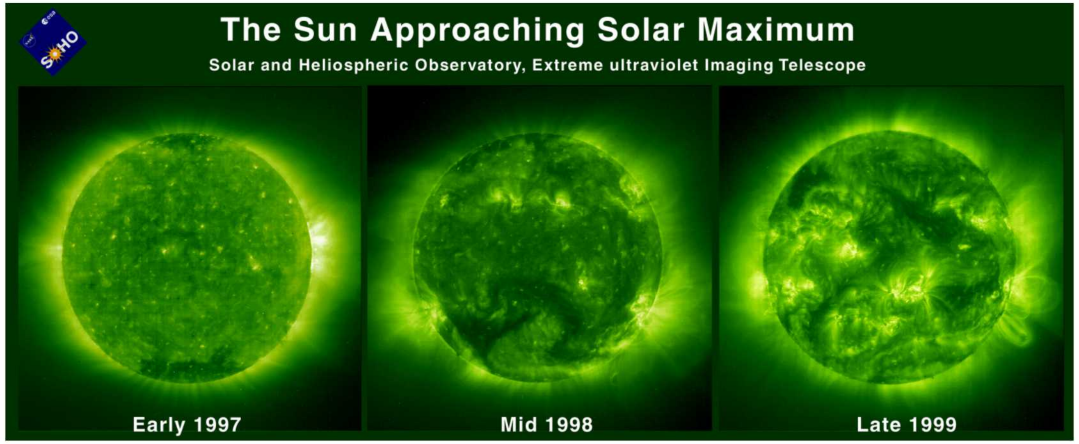
The sun is the main source of radiation in our solar system

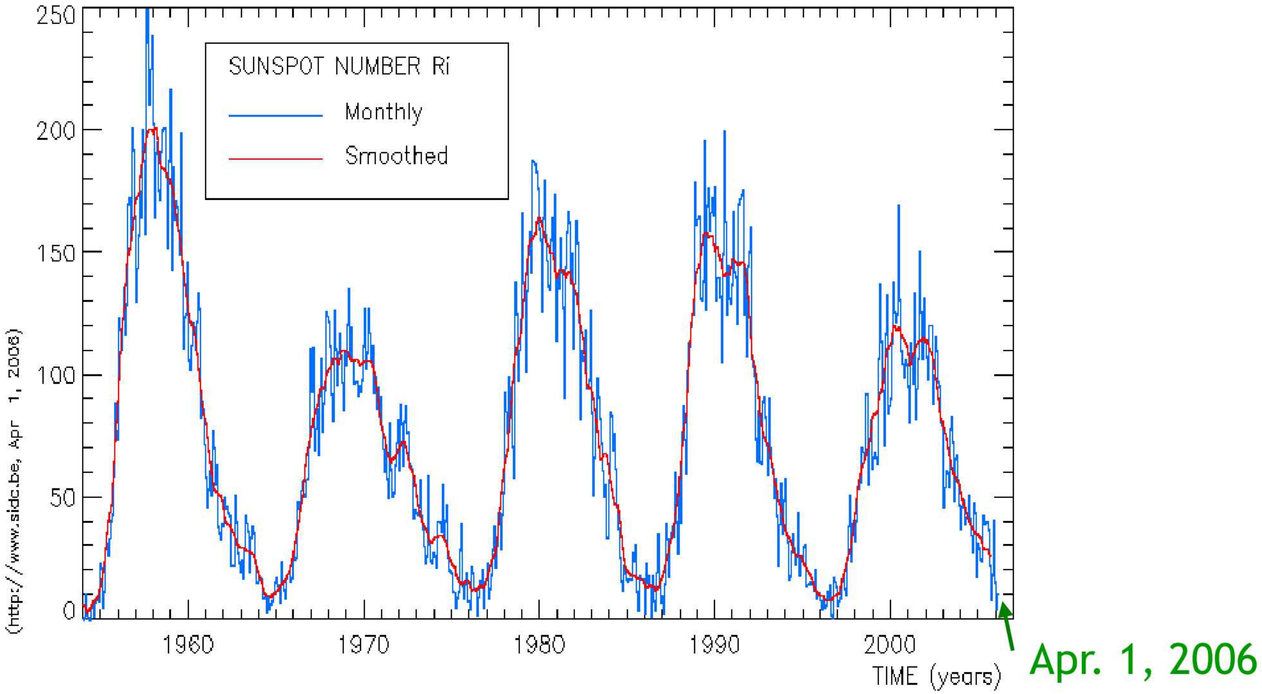
Follows an 11 year cycle of low to high activity (based on changes in magnetic field)

How do we know about the cycle?

- Increased magnetic activity leads to increase sunspot number and increased solar particle events (SPE)
- Increased SPE deflect cosmic rays which decreases Carbon-14 production in Earth's atmosphere
- Decrease carbon-14 shows up in tree rings







SIDC – Solar Influences Data Analysis Center

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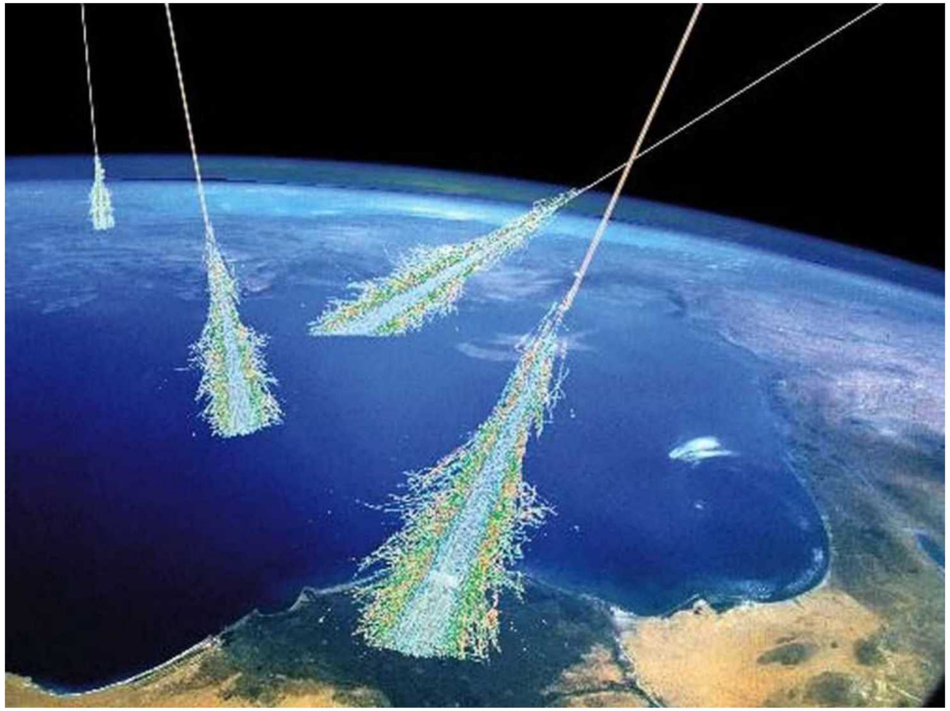
Galactic Cosmic Rays

Galactic Cosmic Rays (GCR) are

- Low flux – low rate of interaction with a device
- Extremely high energy (GeV and higher), thus potentially can deposit a lot of energy into a device
- Mostly hydrogen and helium, although can be comprised of any element
- Probably originated from supernovas
- Deflected by solar activity



Credit: Simon Swordy (U. Chicago), NASA

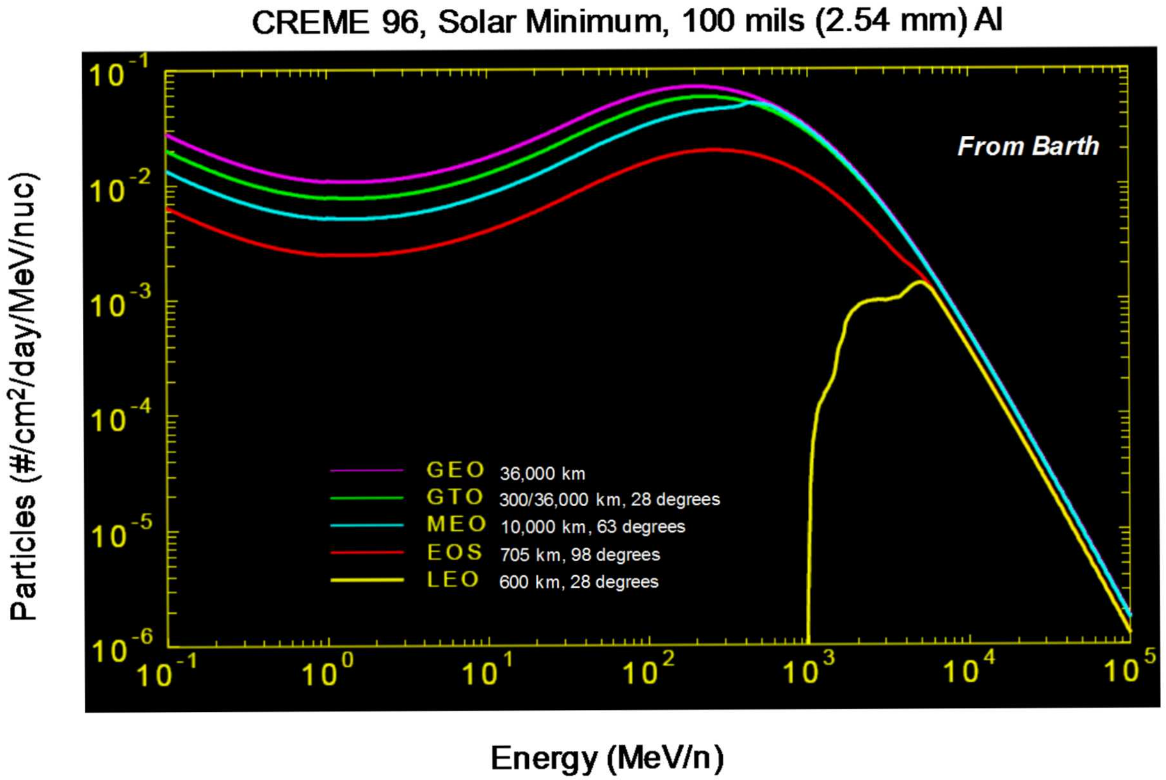
Supernova Remnants

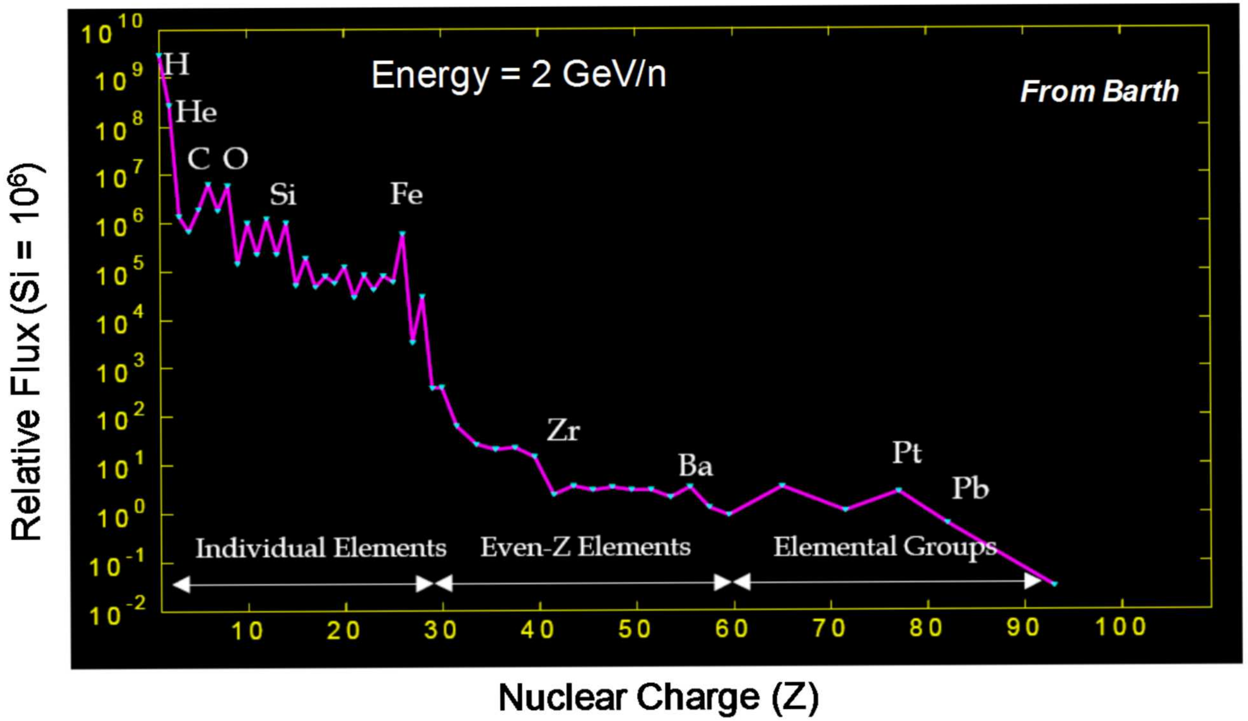
Cygnus Loop

N 63A

Steady, low-flux, very high energy

Galactic Cosmic Rays





Solar Particle Event

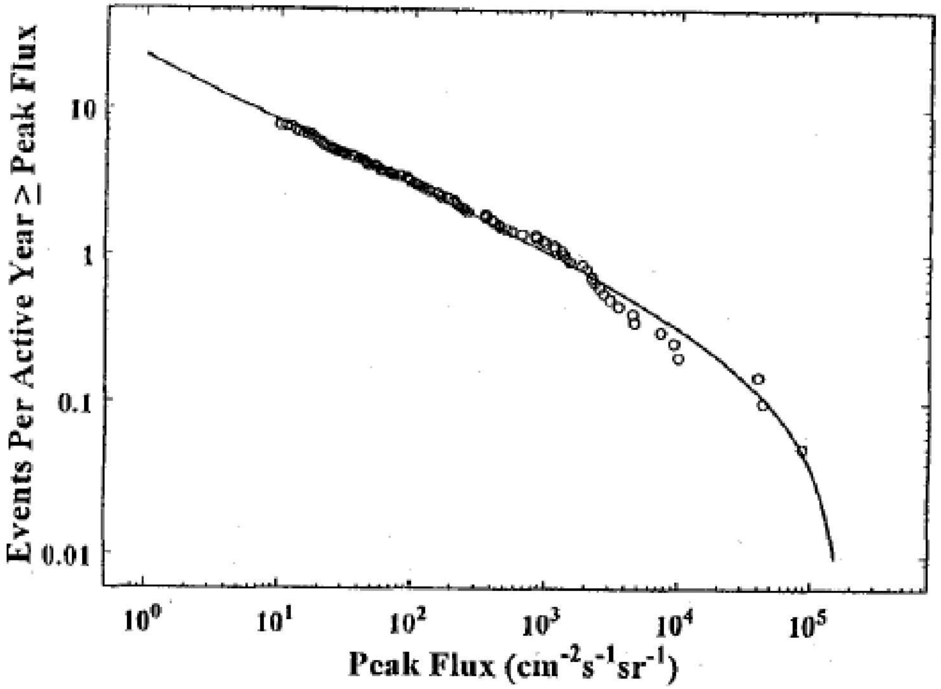
Solar Particle Events (SPE) are material ejected from the sun due to its magnetic field

More SPEs during solar maximum in 11 year cycle

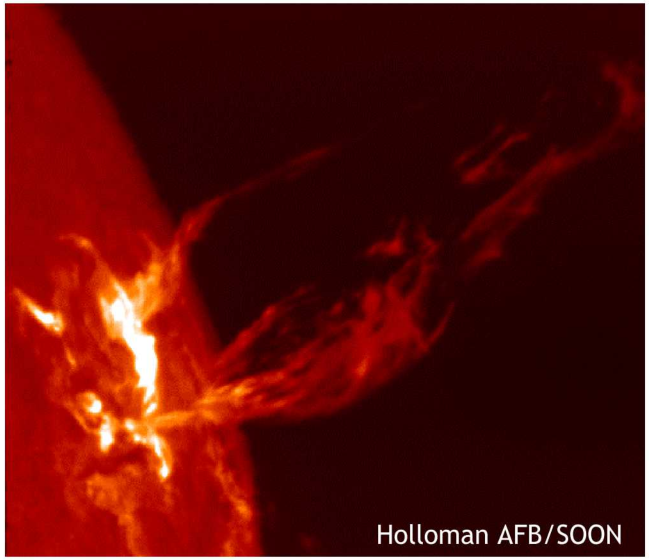
SPEs last hours to days

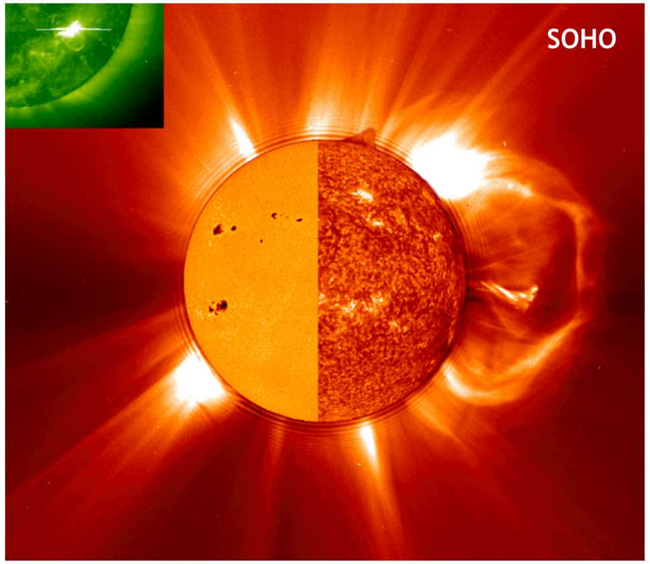
SPEs are coronal mass ejections and solar flares

Large events are less frequent (right)



M.A. Xapsos, "Probability Model for Peak Fluxes of Solar Proton Events, IEEE TNS Vol.45, p. 2948, 1998

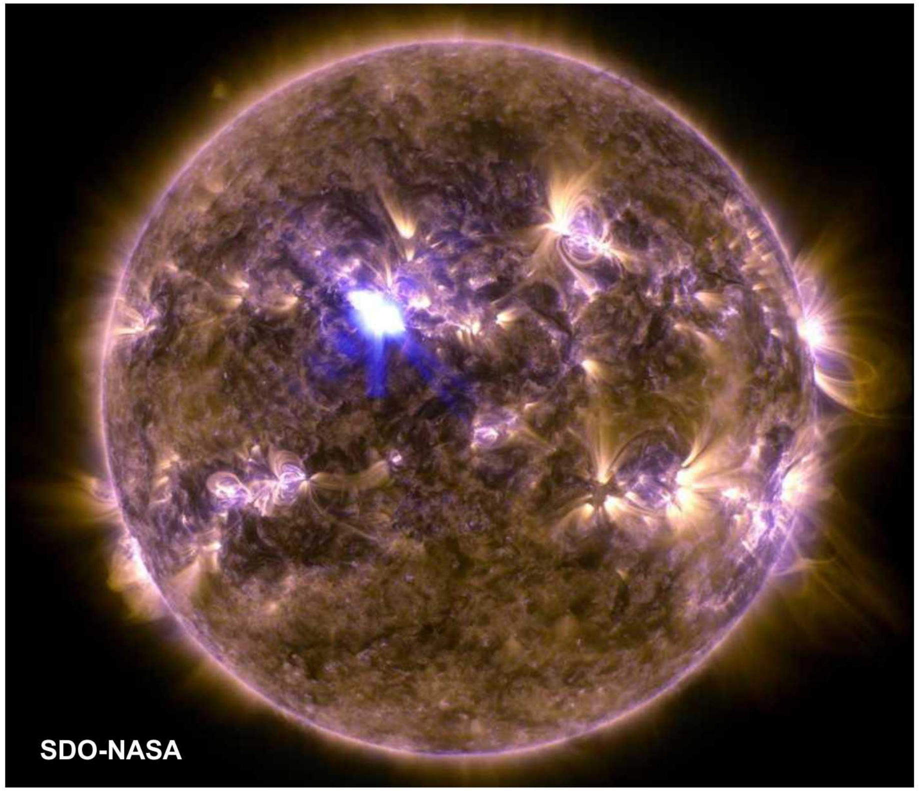




Cyclic, with random/violent events, high flux, high energy

Solar Particle Event

Composite false-color
Extreme-UV image of the Sun



Proton flux data taken by the GOES 13 satellite – data at Space Weather Prediction Center website

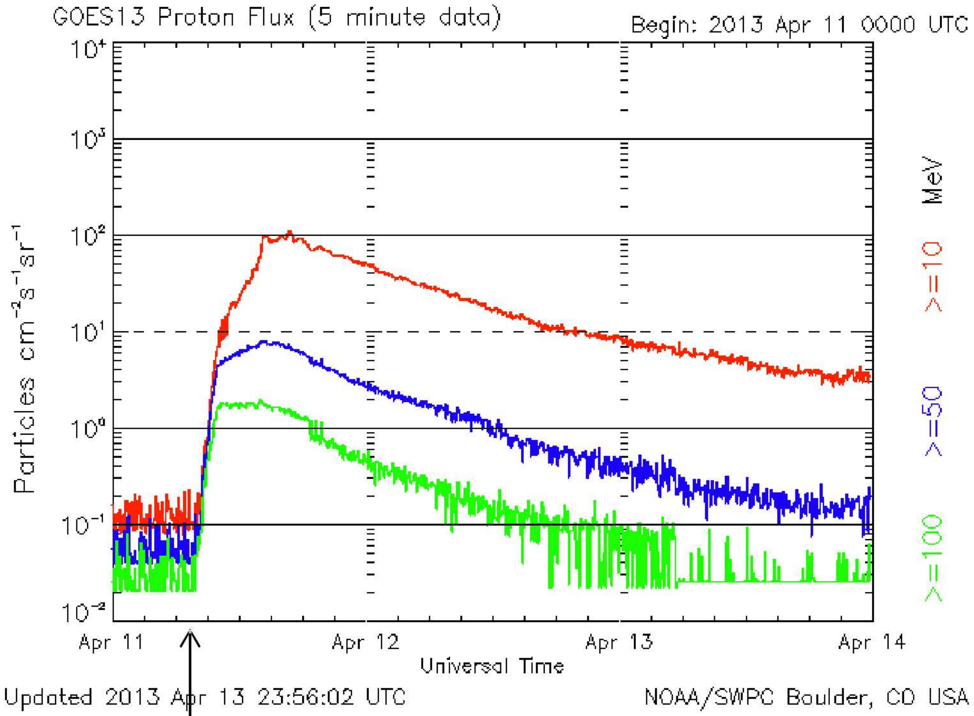


Image of solar flare
taken at 0711 UTC 4/11

Van Allen Belts

Earth's magnetic field traps electrons and protons

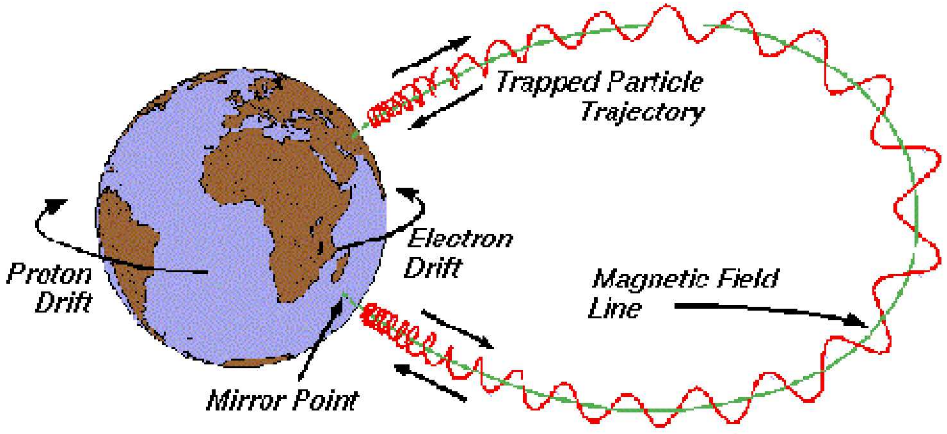
Captures particles from solar wind/solar events and GCR interactions in atmosphere

Particles travel back and forth, trapped for years

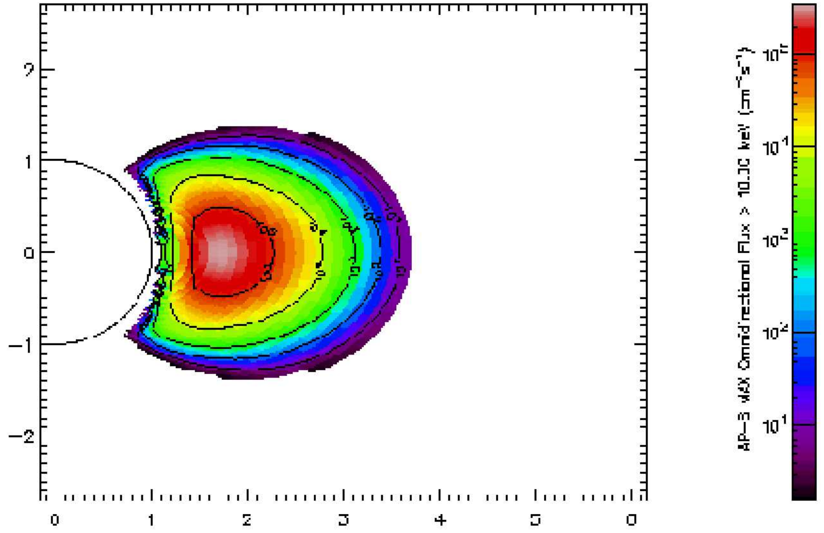
Belts dip very close in south Atlantic

Proton energy: 100 keV to 100 MeV+

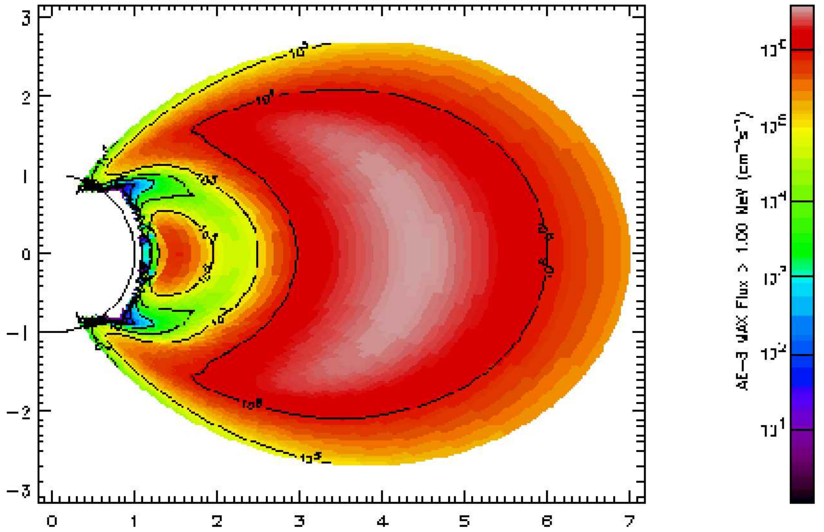
Electron energy: 10 keV to 10 MeV+



SPENVIS website



Trapped Proton Belt AP-8 MAX integral proton flux >10 MeV

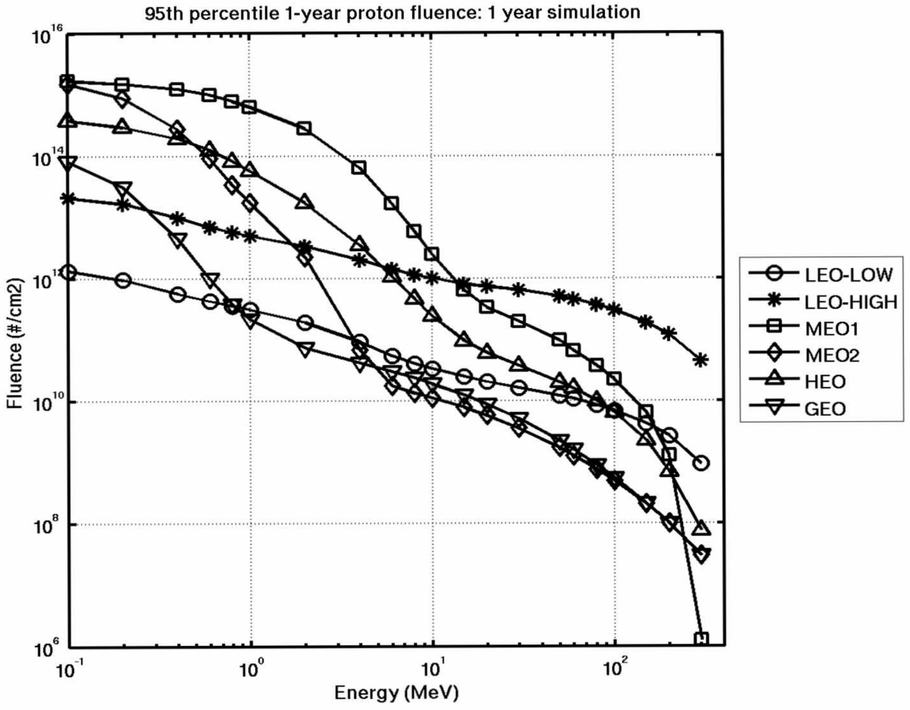


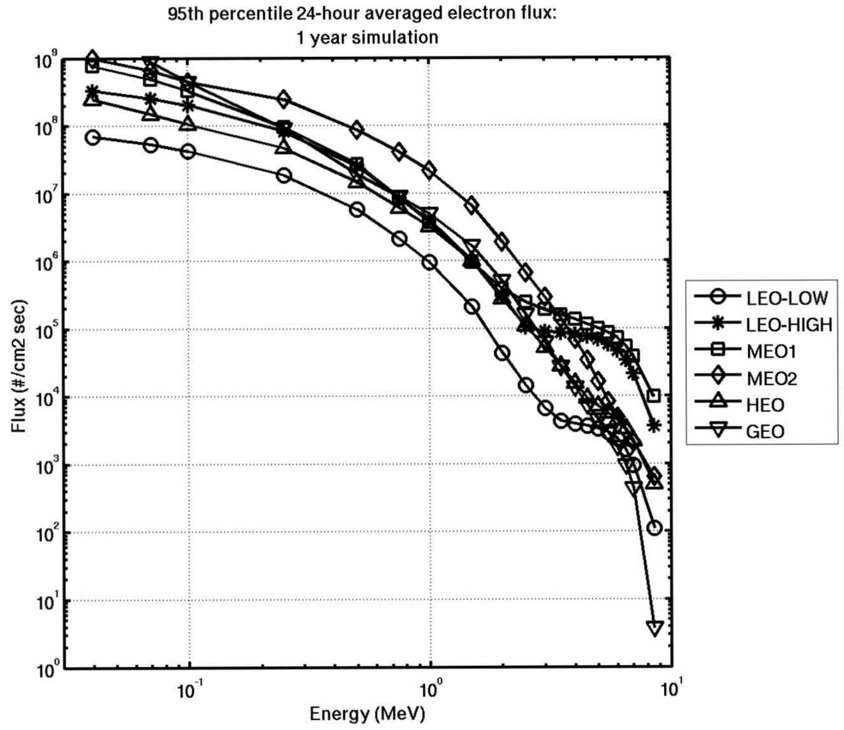
Trapped Electron Belt AE-8 MAX integral electron flux >1 MeV

Steady, low energy, very high flux

Van Allen Belts

From Mark Johnson, Aerospace Corp





Orbit	Altitude	Inclination
	km	degrees
LEO-LOW	≤800	All
LEO-HIGH	≤2000	All
MEO1	8062	0
MEO2	20200	55
HEO	1000 to 39478	63.4
GEO	35870	0

Complex. Need model for high fidelity of specific orbit

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Mechanism, Effect, Mitigation

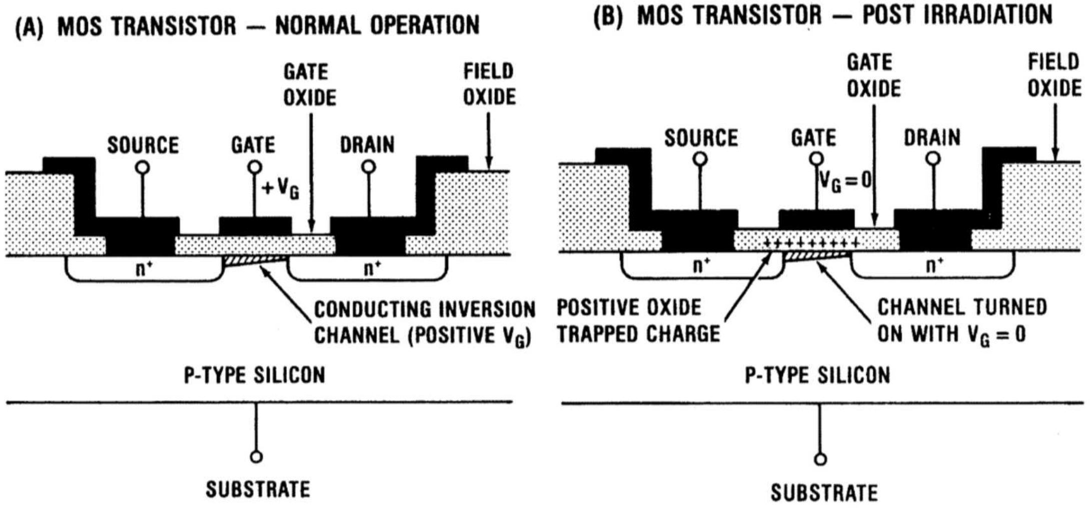
Total Ionizing Dose (TID)

Protons and electrons will ionize electronics (the effect is most prevalent in MEO)

Constantly accumulated slowly over time

Some charge will be trapped

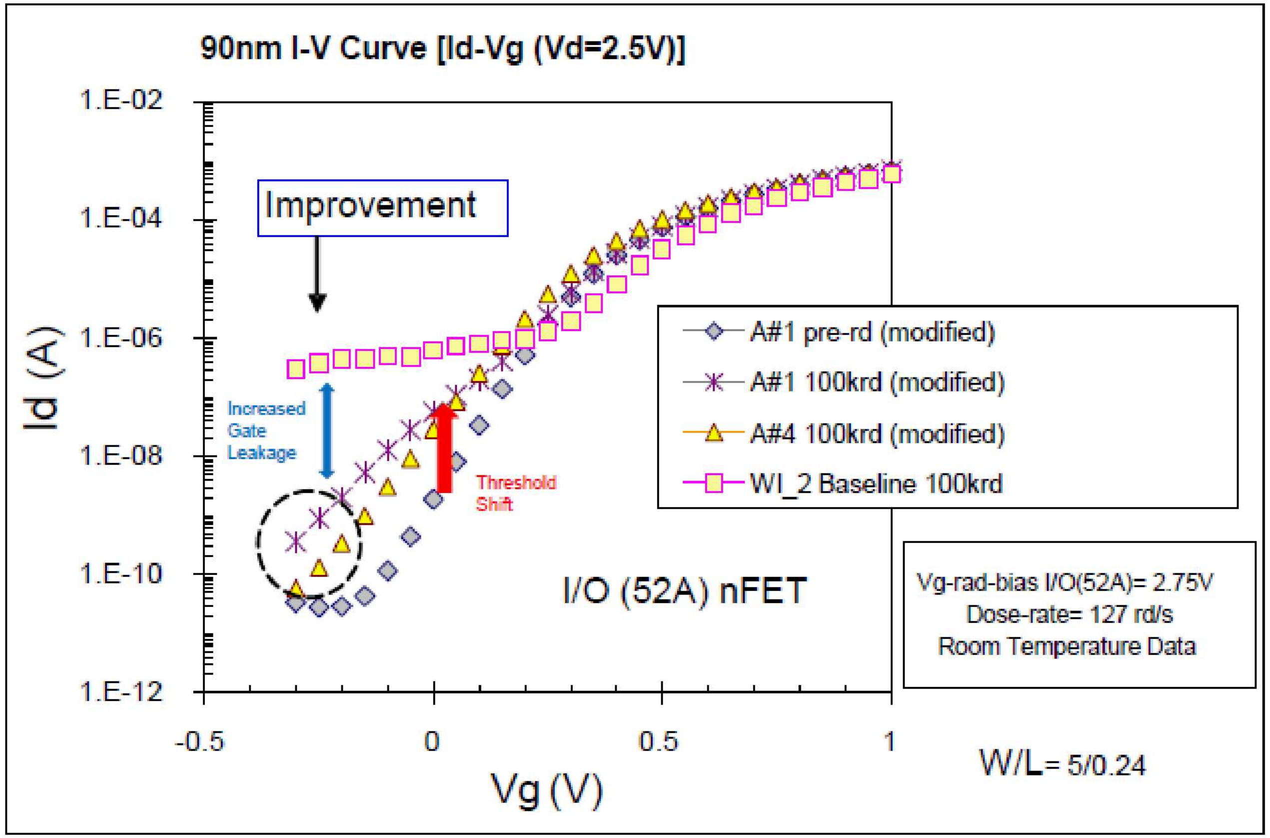
Leads to various effects
- Threshold shifts
- Leakage currents
- Timing changes
- Functional failures



Trapped Charge in a MOS transistor
T.R. Oldham, and F.B. McLean, "Total Ionizing Dose Effects in MOS Oxides and Devices," *IEEE Trans. Nucl. Sci.*, vol. 50, no. 3, p. 483, June 2003.

COTS may fail 5-20 krad
Rad hard parts can survive much higher doses (100 krad, 300 krad, etc.)

TID Example



nFET TID Damage
From Bruce Wilson, DTRA

TID Mitigation

Shielding

- Shielding can reduced TID of a given part
- If a part cannot meet TID requires for a given orbit/depth combination, shielding can supplement
- High-Z material has a better aluminum equivalence, and makes for a better shield to weight ratio in general

Part Selection

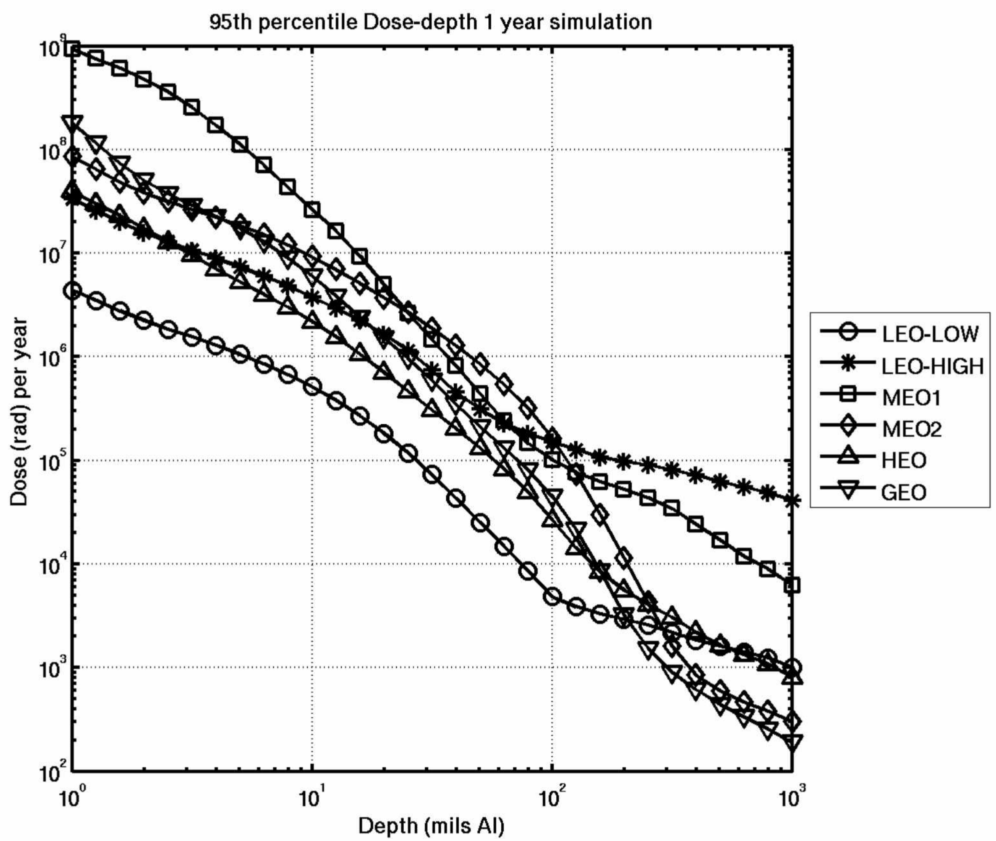
- Rad hardened/Rad tolerant parts are almost always referring to TID hardened
- Select parts that are radiation tolerant/hardened against space radiation

Design

- Parts deeper in the space vehicle receive lower TID due to shielding from other components

Orbit Selection

- TID varies with orbit (right)



From Mark Johnson, Aerospace Corp

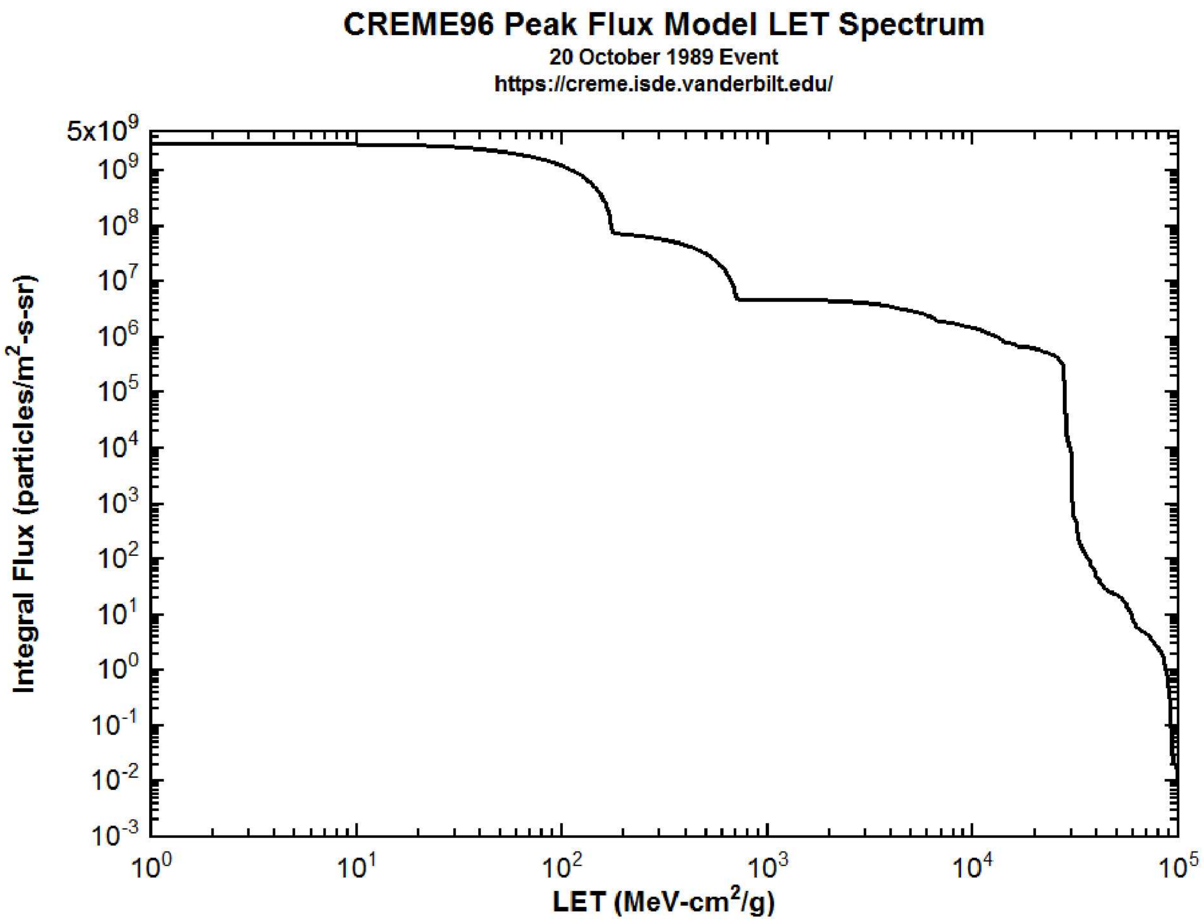
Single Event Effects

Protons, heavy ions and electrons deposit energy in semiconductor material

Neutrons may induce reactions that indirectly deposit charge

Depending on linear energy transfer (LET) of particle, various effects are possible

- Soft errors: Single Event Upset (SEU), Single Event Transient (SET)
- Hard errors: Single Event Latchup (SEL), Single Event Burnout (SEB), Single Event Gate Rupture (SEGR)



From Mark Johnson, Aerospace Corp

Soft Errors

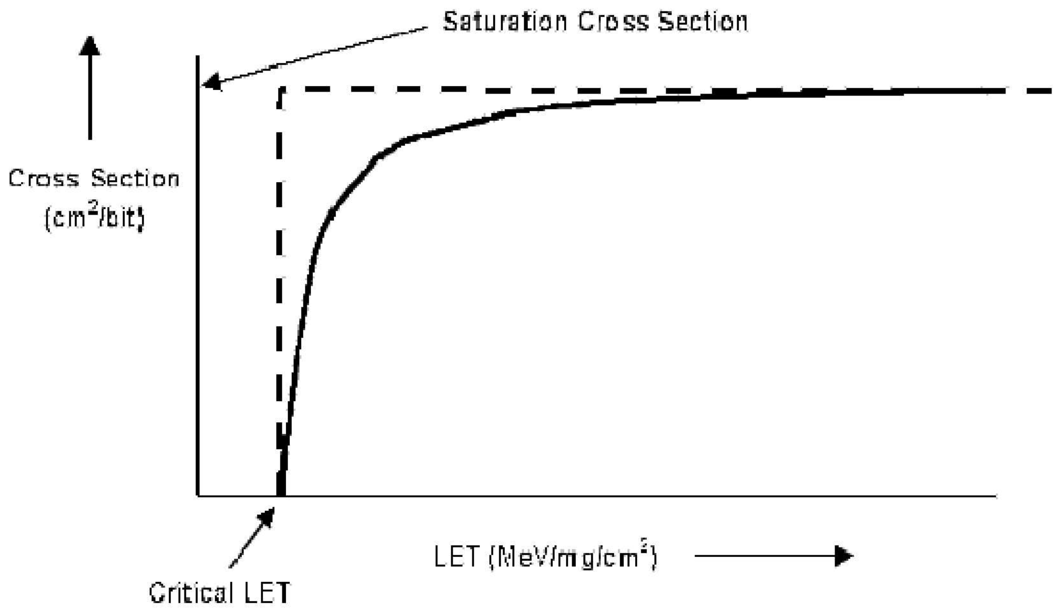
SEU is a state change in logic element (memory bit) induced from deposited charge

Requires some minimum, critical amount of charge

Thus, requires some minimum LET (usually a low value)

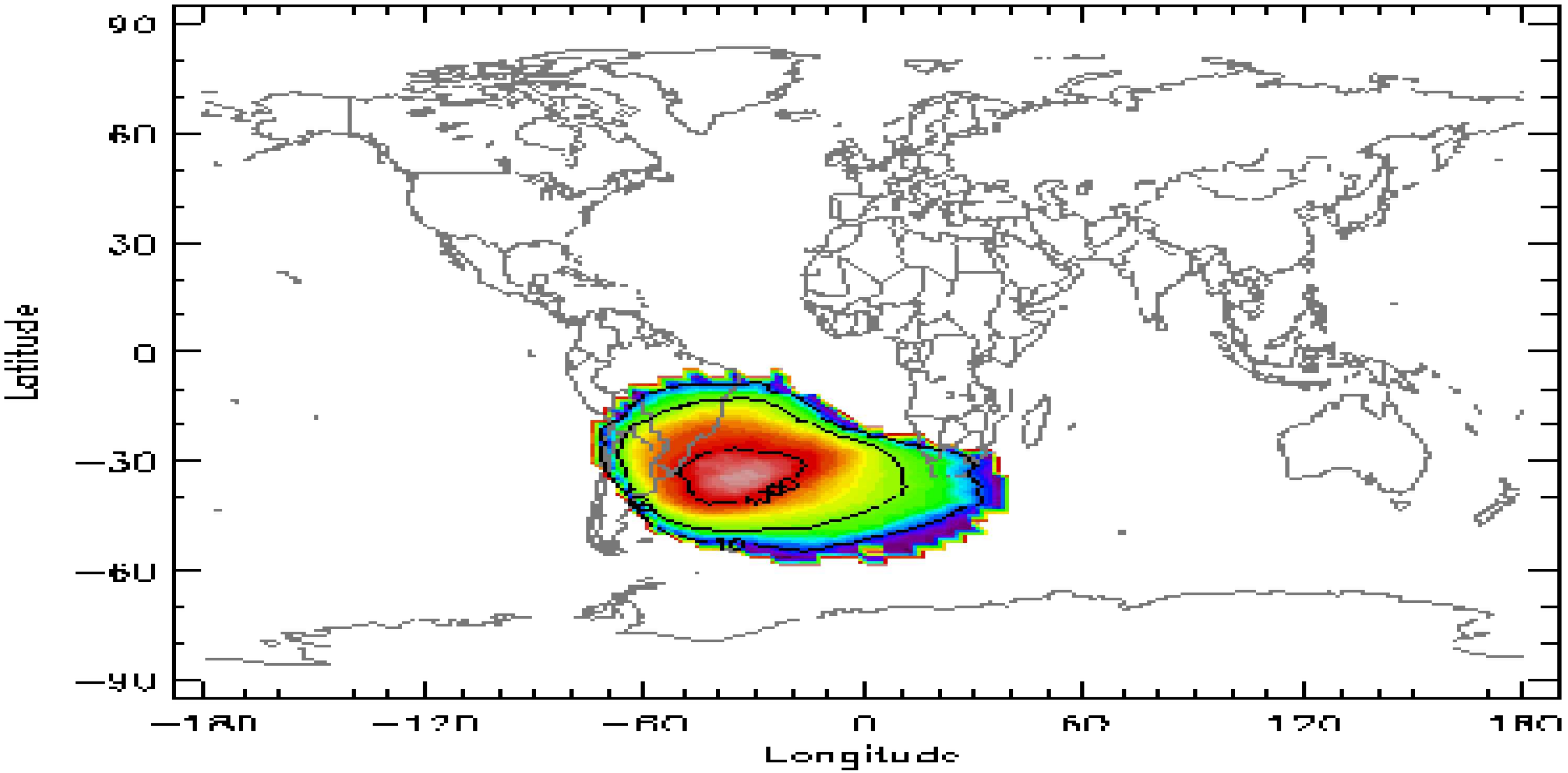
Mitigation:

- Error detection and correction (EDAC) through redundancy or other strategies. Higher rates make EDAC difficult (multiple bit upset - simultaneous)
- Part selection (requires higher LET for upset, lower upset cross-section/rate)
- Test – proton or ion source
- Orbit Selection (next slide)



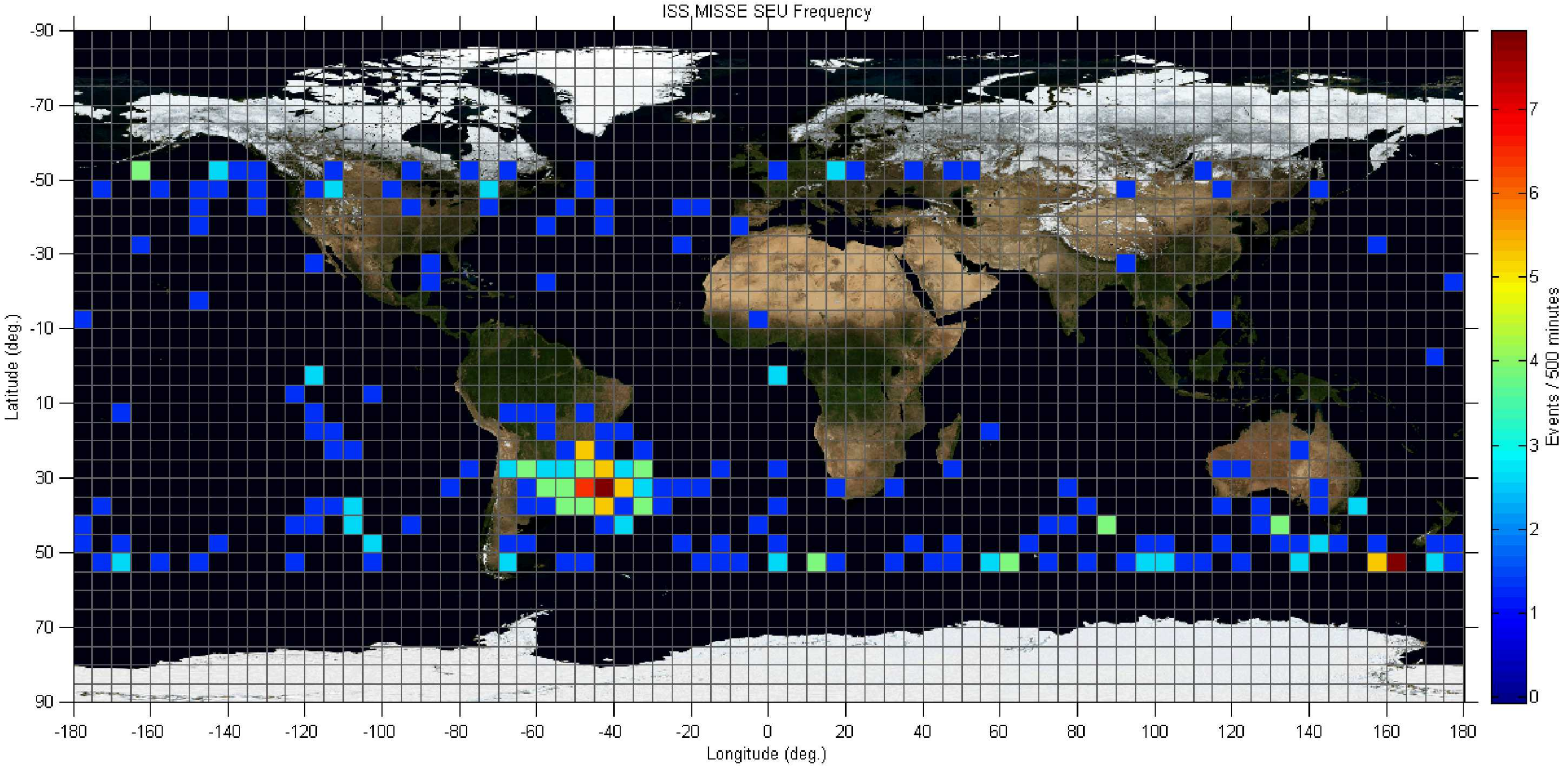
SPENVIS website

Soft Errors - AE-8 Trapped Proton E > 10 MeV at 500 km



Soft Errors

SEU Upset Rates in Xilinx Virtex FPGAs on SEUXSE/MISSE7A on the ISS



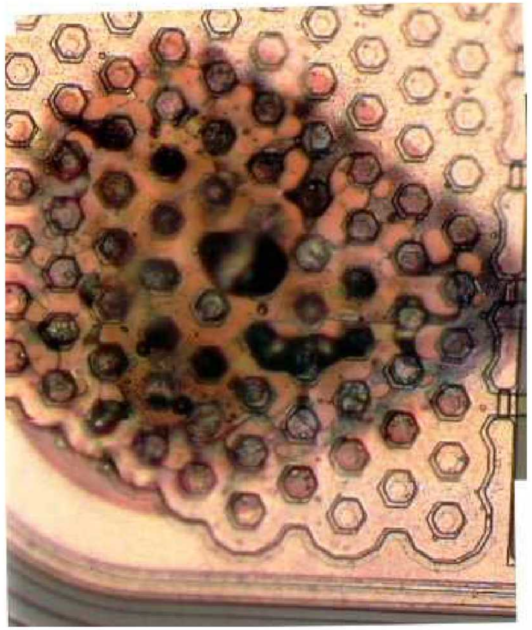
Hard Errors

Higher critical charge, but usually larger consequence

Often leads to high current modes that ultimate cause part failure

Mitigation:

- Part selection – (requires higher LET for event, lower event cross-section/rate)
- Test – ion source (to get higher LET)
- Detection of high current, circumvent and recover



From "Programmable Logic in the Space Radiation Environment", Kenneth A. LaBel, NASA Goddard Space Flight Center

Displacement Damage

Protons, electrons and neutrons will push lattice of electronics (especially prevalent in low-MEO/high-LEO)

Proton dominate

Constantly accumulated over time, leads to lattice vacancies and interstitials

Defects can become trapping/recombination sites

Leads to various effects

- Lower minority carrier lifetime
- Lower transistor gain
- Optical degradation

Mostly mitigated through part selection, if orbit is an issue

Spacecraft Charging

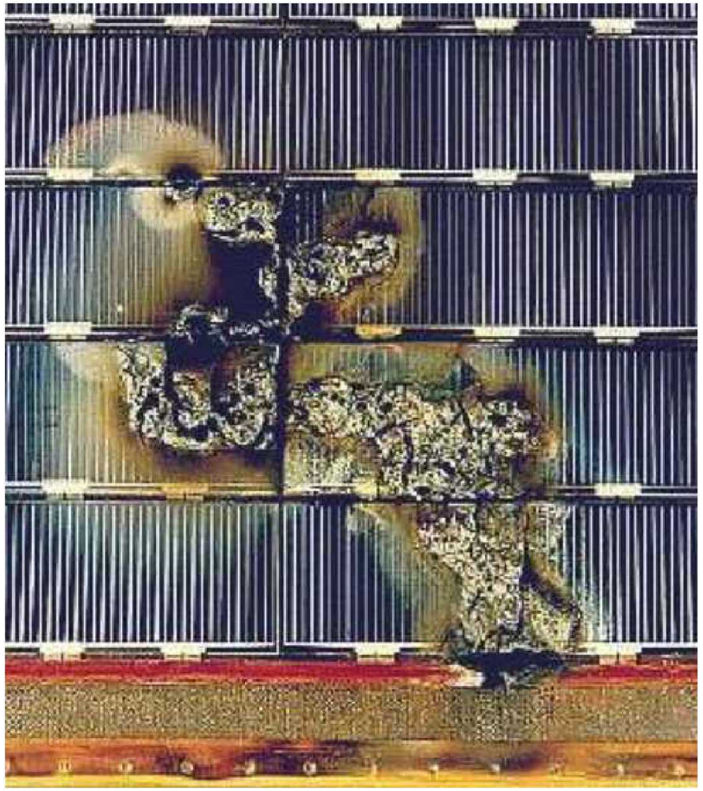
Electrons will accumulate charge on a spacecraft (especially when travelling through Van Allen belts (MEO)

Low energy electrons accumulate on surface, high energy may penetrate and collect internally (for example, in dielectrics)

Field build up and eventual electrostatic discharge (ESD) can cause function interruption or failure

Insulator charging is an important issue. If charge is collected faster than it is dissipated, it will eventually arc

Mitigation: Design and material selection, orbit selection



ESD Damage on Solar Array, NASA.

Conclusion

The space radiation environment is complex and has many components

The radiation can cause a variety of effects that may hinder a system's ability to perform its mission

We can design a system and model/predict radiation effects to minimize the risk of radiation issues