

LEO Radiation, Its Effects on Electronics and Mitigation Approaches, A Primer

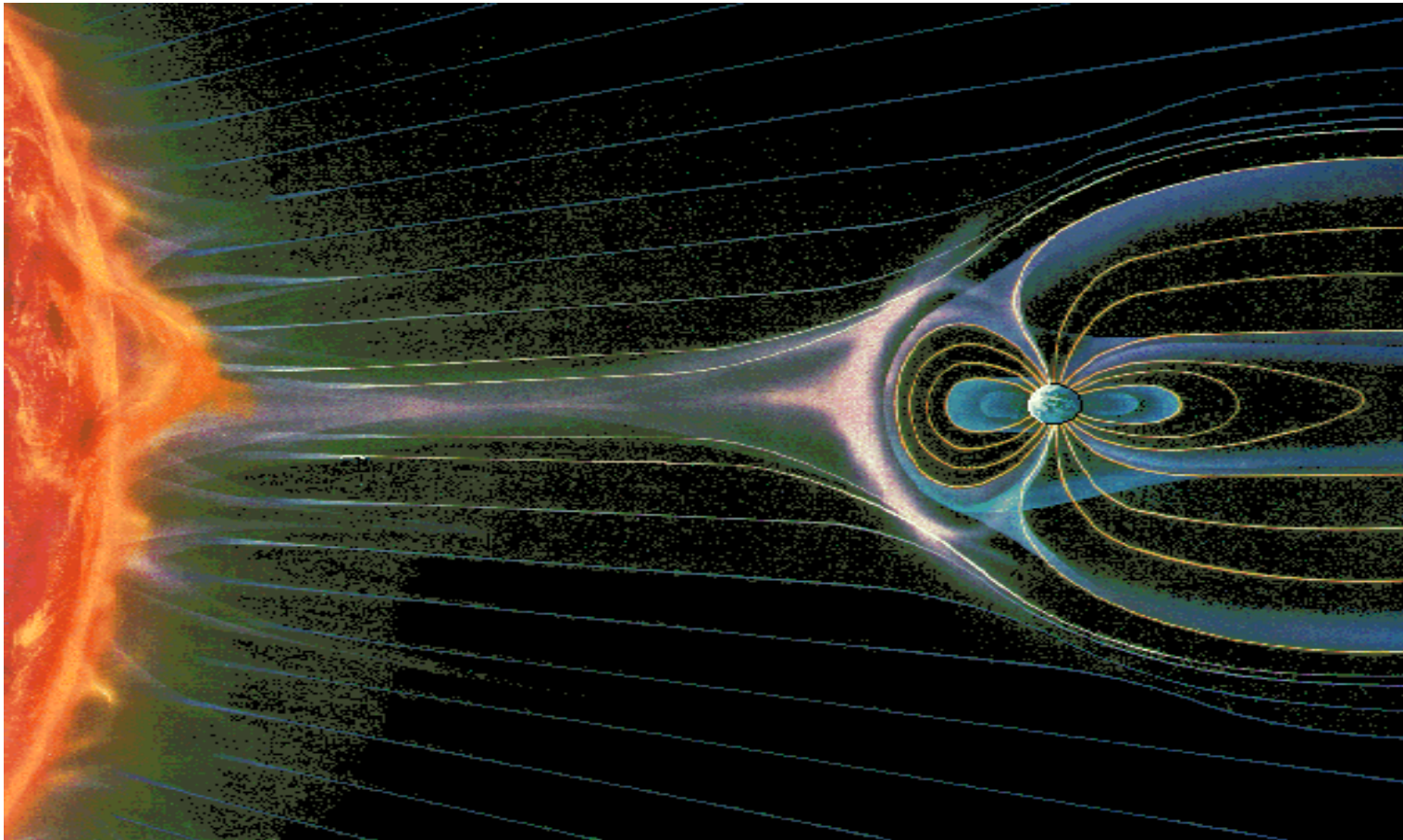
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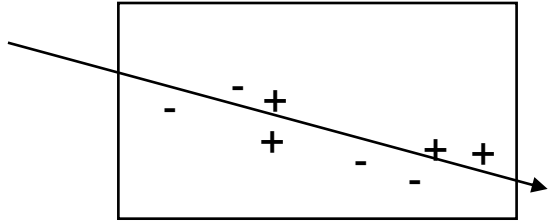
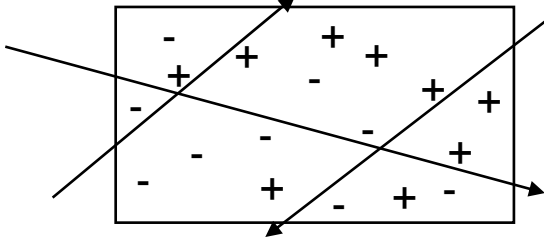
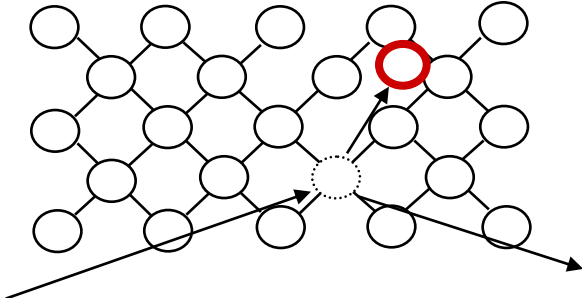
Background taken by Boeing PicoSat CSTB1 using its 1cm aperture imager

Radiation Near Earth

- Particle radiation – mostly from the sun
- Earth's Magnetosphere deflects and focuses particles



Radiation Terms

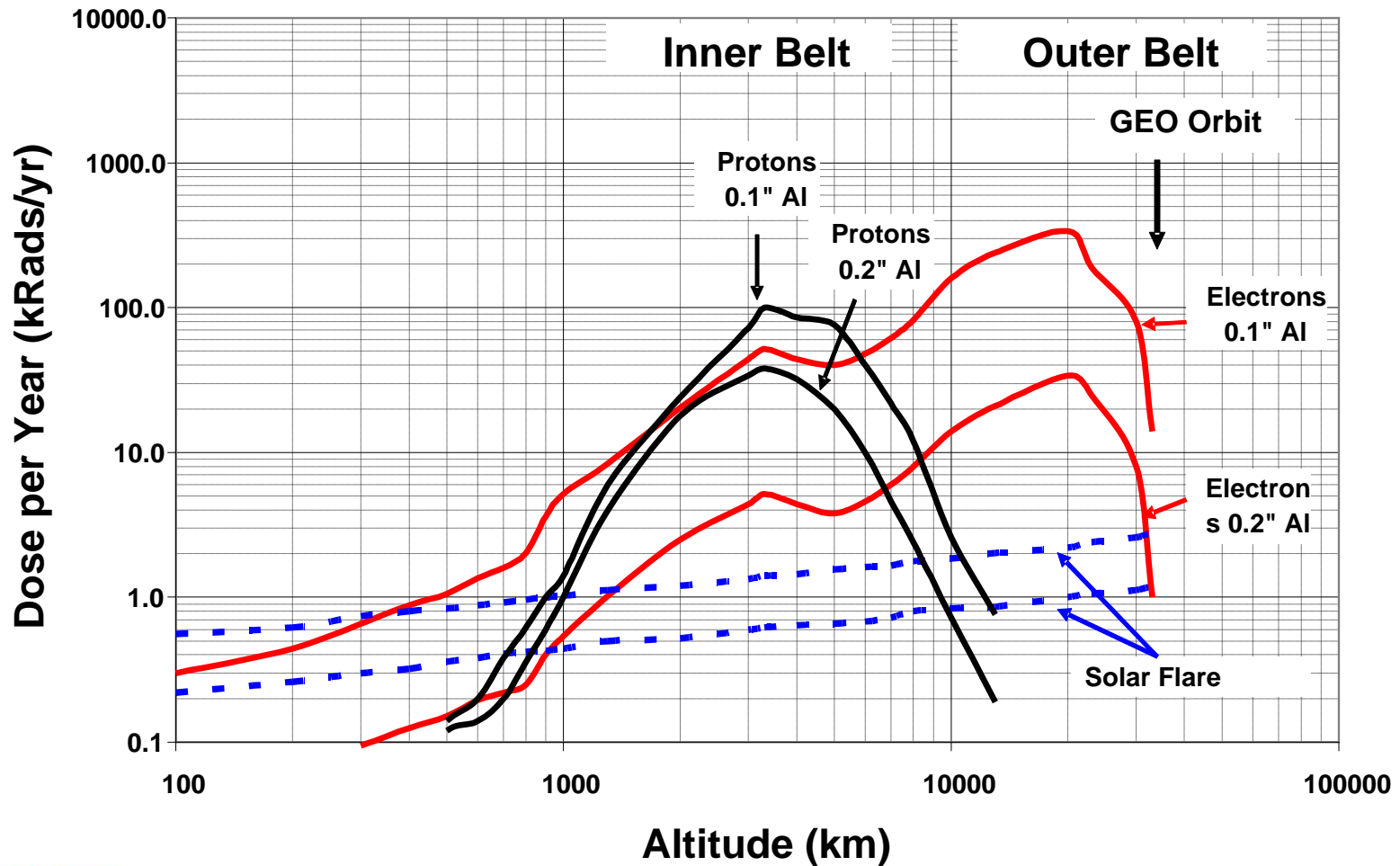
Term	Description	Units	Diagram
Linear Energy Transfer (LET)	Energy per Unit Length	MeV/mg/cm²	
Total Ionizing Dose (TID)	Density of Energy Deposition	Rad	
Displacement	Displaced Atoms, One Category of TID Effect	Equivalent Number of Standard Particles/cm²	

Relevant Radiation Sources in LEO

Particle	Charge	Source	Energy	Effects
Electrons	-	Rad Belts	0-7 MeV	TID
Protons	+	Rad Belts, Solar flares	0-400 MeV	SEE, TID
Heavy Ions	+/-	Cosmic Rays, Solar Flares	> 10,000 MeV	SEE
Gamma Rays	0	Deep Space	>100keV	SEE, TID
X-Rays	0	Solar Flares	<120keV	SEE, TID
UV	0	Sunlight	<124eV	Solar Cell Degradation

Levels of Radiation in Space, a Point Example

Dose (kRads/yr) vs Altitude at 90 Deg



Some of the Effects of Radiation on Electronics

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- **TID effects**

- Accumulated effect of long term radiation damage
- Increases component current consumption
- Decreases component performance: high leakage current, low gain, etc.

- **Single Event Upset (SEU)**

- A “bit flip”
- Causes data corruption
- No permanent damage

- **Single Event Functional Interrupt (SEFI)**

- Interrupts normal component operation
- Non-permanent failure: power cycle or re-initialize component to restore operation

- **Single Event Latchup (SEL)**

- Part does not operate correctly
- Causes excessive current flow
- Can permanently damage component or power supply

Mitigation Approaches

- **Shielding**

- Reduces TID and somewhat reduces Single Event Effects (SEEs)
- Aluminum and copper are often used for bulk shielding
- Tantalum used for spot shielding

- **Rad-hard parts selection**

- SEE specification
- TID testing
- Rad-hard (or Rad-tolerant) by design

- **Redundancy**

- Redundant circuits
- Triple Mode Redundancy (TMR)
- Code redundancy

- **Error detection and correction (EDAC)**

- Detects single and multiple bit errors
- Corrects one or more bit errors
- Forward Error Correction

- **Memory scrubbing**

- Periodically read and correct data

Mitigation Approaches

- **Limit current or Turn off circuits with excessive current consumption**
 - Reduces chance of damage from SEEs.
 - Removing power allows SELs to reset if permanent damage did not occur.
- **Turn off devices when not in use**
 - Lowers chance of damage from radiation events
- **Part de-rating and increase operating margin**
 - Reduces likelihood of some SEE
 - Increases longevity
- **Turn satellite systems off or change operating schedule in response to space weather**
 - Response to Coronal Mass Ejections (CMEs)
 - Radiation effects are reduced when electronics are powered off

References to Radiation Environment Information

Advanced Network and Space Systems

- **Minimalist Fault-Tolerance Techniques for Mitigating Single Event Effects in Non-Radiation Hardened Microcontrollers.** Douglas Caldwell's Ph.D. Thesis
 - <http://www.cs.ucla.edu/~rennels/dougdis.pdf>
- **CP2 CubeSat electronics design.** Chris Day's Masters Thesis
 - http://polysat.calpoly.edu/PublishedPapers/ChrisDay_thesis.pdf
- **Ionization and plasma data from DMSP**
 - <http://cindispace.utdallas.edu/DMSP/>
- **Nuclear and Space Radiation Effects Conference**
 - <http://www.nsrec.com/>
- **Radiation Environments Short Course**
 - http://radhome.gsfc.nasa.gov/radhome/papers/slideshow10/SC_NSREC97/index.htm
- **Space radiation, effects, and mitigation**
 - <http://www.jhuapl.edu/techdigest/td2801/Maurer.pdf>
- **Firmware failures and watchdog technology**
 - <http://www.embedded.com/www.embedded.com/columns/showArticle.jhtml?articleID=9900877>
- **White papers on space technology**
 - <http://www.maxwell.com/microelectronics/technical-support/white-papers.asp>