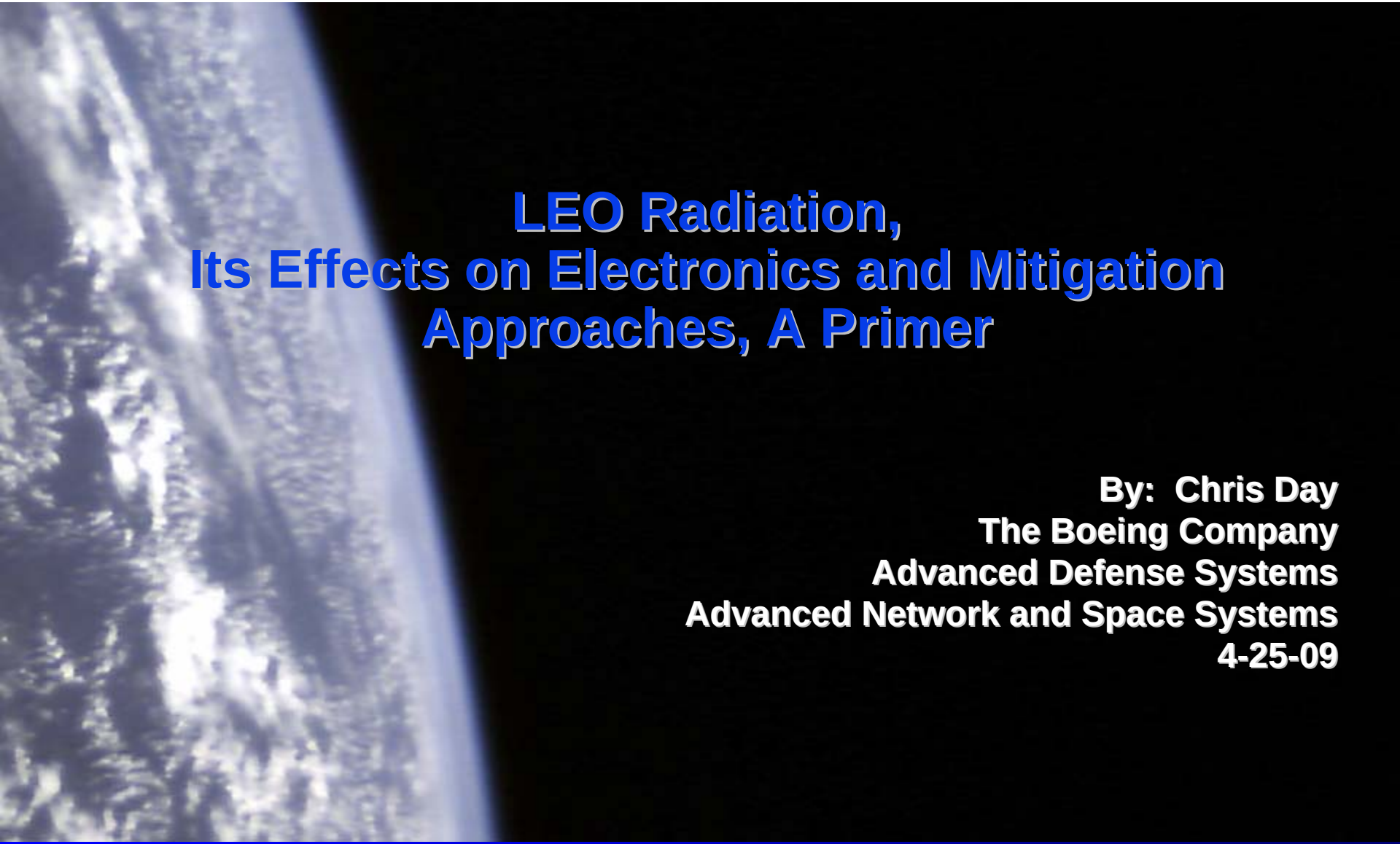

LEO Radiation, Its Effects on Electronics and Mitigation Approaches, A Primer

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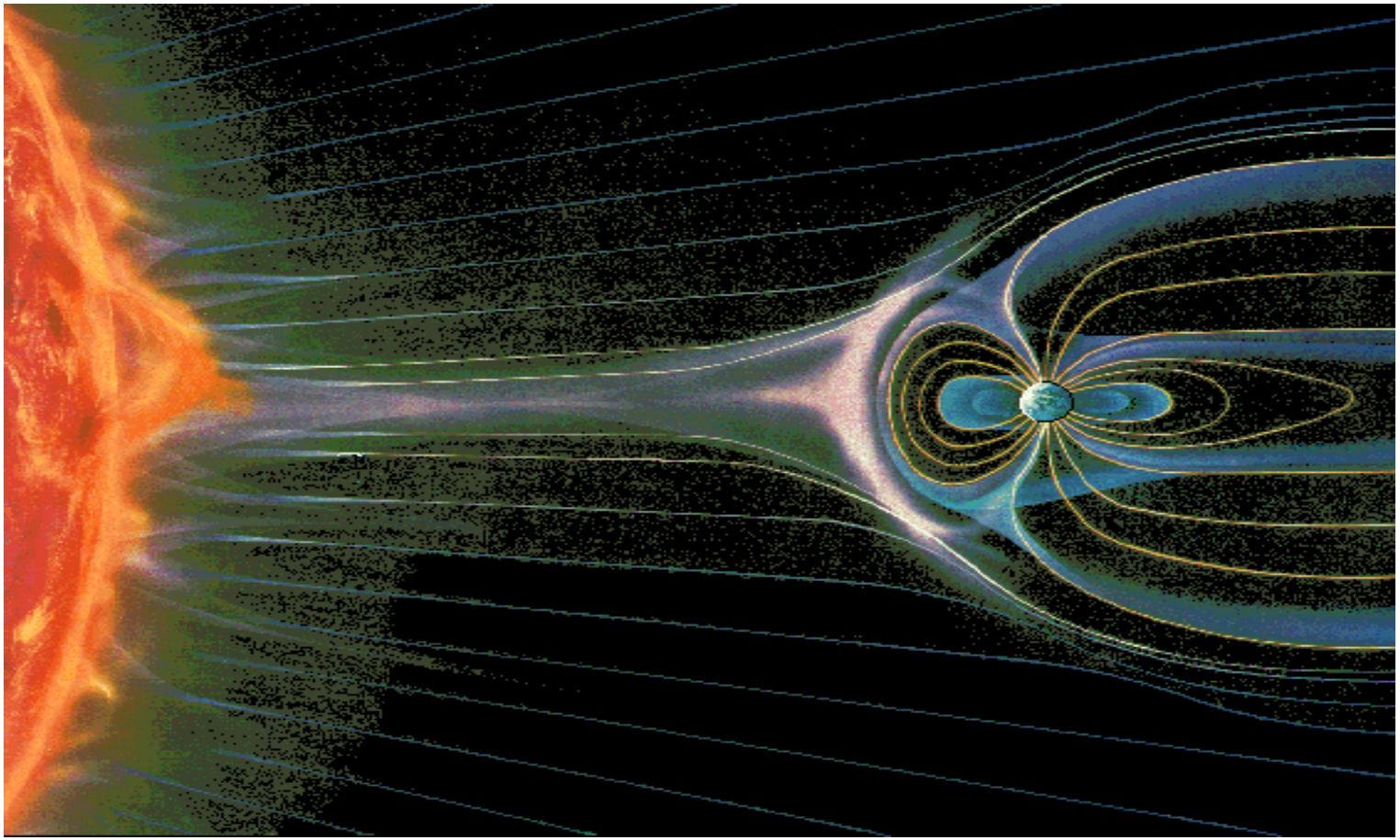
4-25-09

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

Advances Space Systems

Radiation Near Earth

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

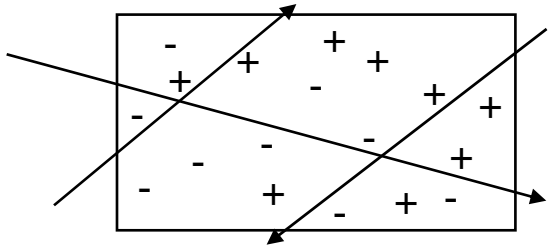
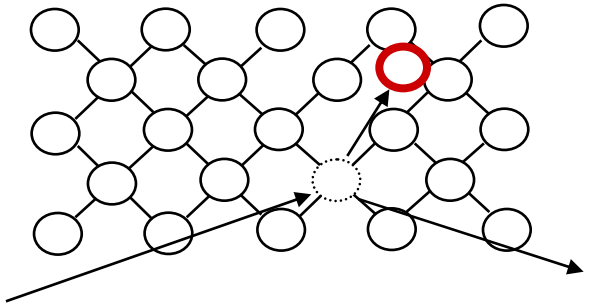
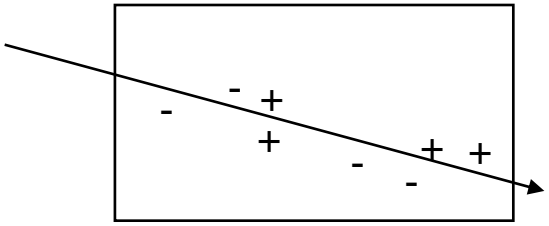


Janet Barth http://radhome.gsfc.nasa.gov/radhome/papers/apl_922.pdf

Relevant Radiation Sources in LEO

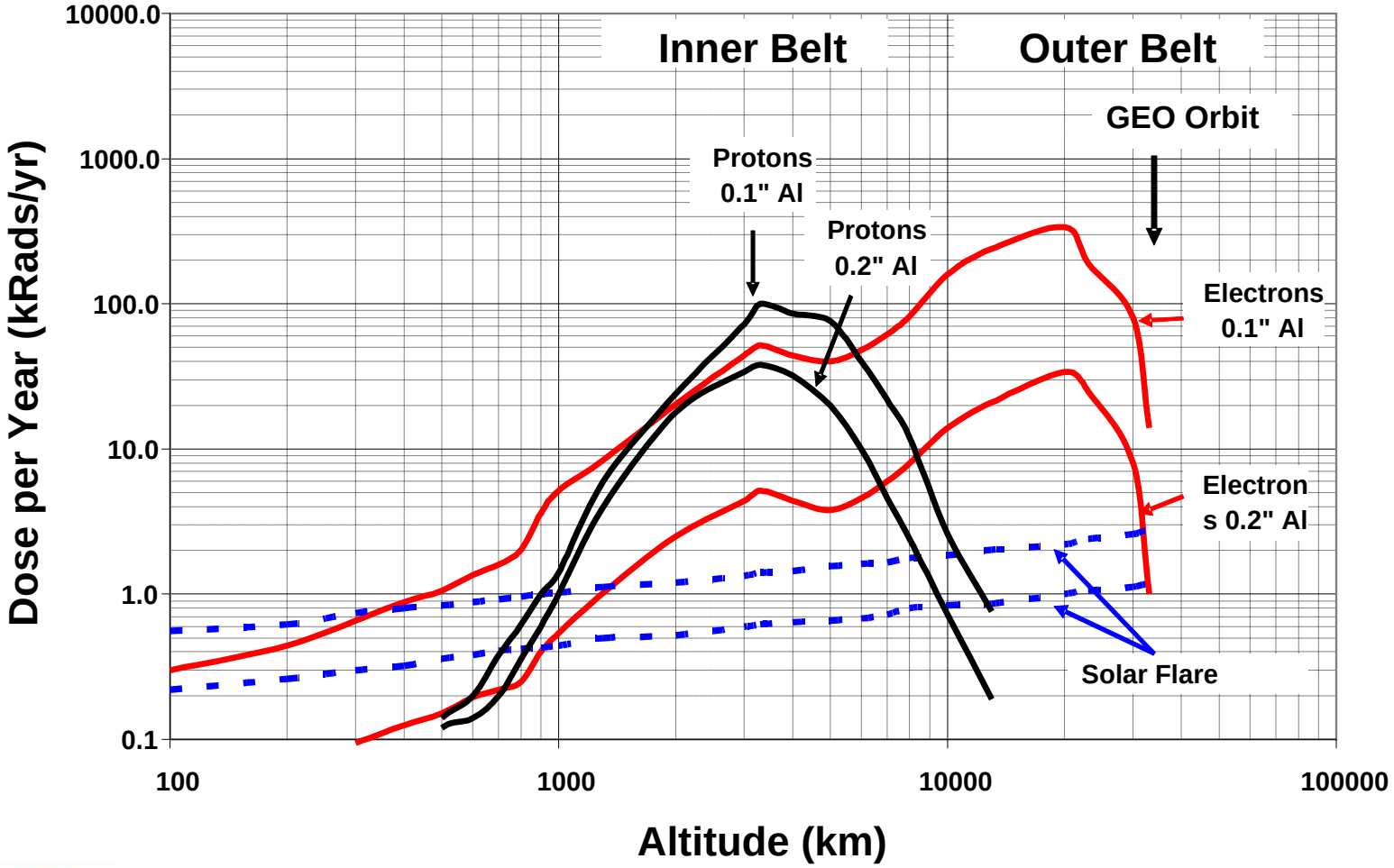
Particle	Charge	Source	Energy	Effects
Electrons	-	Rad Belts	0-7 MeV	TID
Protons	+	Rad Belts, Solar flares	0-400 MeV	SEE, TID
Heavy Ions	+/-	Cosmic Rays, Solar Flares	> 10,000 MeV	SEE
Gamma Rays	0	Deep space	>100keV	SEE, TID
X-Rays	0	Solar Flares	<120keV	SEE, TID
UV	0	Sunlight	<124eV	Solar Cell Degradation

Radiation terms

Term	Description	Units	Diagram
Total Ionizing Dose (TID)	Density of Energy Deposition	Rad	
Displacement	Displaced Atoms, one catagory of TID effect	Equivalent Number of Standard Particles/cm^2	
Linear Energy Transfer (LET)	Energy per Unit Length	MeV/mg/cm^2	

Levels of radiation in space, a point example

Dose (kRads/yr) vs Altitude at 90 Deg



Some of the Effects of radiation on Electronics

- **Single Event Upset (SEU)** (SMAD, 3rd edition, p220)
  - A "bit flip"
  - Causes data corruption
  - No permanent damage
- **Single Event Latchup (SEL)** (SMAD, 3rd edition, p220)
  - Part does not operate correctly
  - Causes excessive current flow
  - Can permanently damage component or power supply
- **Single Event Functional Interrupt (SEFI)** (http://ieeexplore.ieee.org/iel4/5668/15177/00698915.pdf?arnumber=698915)
  - Interrupts normal component operation
  - Non-permanent failure: power cycle or re-initialize component to restore operation
- **TID effects** (http://radhome.gsfc.nasa.gov/radhome/papers/slideshow10/SC_NSREC97/sld004.htm)
  - Accumulated effect of long term radiation damage
  - Increases component current consumption
  - Decreases component performance: high leakage current, low gain, etc.

Mitigation Approaches

- **Shielding** (various CubeSat group web sites)
  - Reduces TID and somewhat reduces Single Event Effects (SEEs)
  - Aluminum and copper are often used for bulk shielding
  - Tantalum used for spot shielding (Google Tantalum ic shielding)
- **Rad-hard parts selection** (used by NASA for decades)
  - SEE specification
  - TID testing
  - Rad-hard (or Rad-tolerant) by design
- **Redundancy** (used by NASA for decades)
  - Redundant circuits
  - Triple Mode Redundancy (TMR)
  - Code redundancy
- **Error detection and correction (EDAC)** (http://neos.fontismedia.com/euro_em/files/e375.pdf)
  - Detects single and multiple bit errors
  - Corrects one or more bit errors
  - Forward Error Correction
- **Memory scrubbing** (http://ieeexplore.ieee.org/iel5/9780/30846/01430145.pdf)
  - Periodically read and correct data

Mitigation Approaches

- **Limit current or Turn off circuits with excessive current consumption** (Harsh Environments, Maurer, et al.)
  - 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**
  (http://mae.pennnet.com/display_article/293824/32/ARCHI/none/ONEWS/1/Researcher-develops-method-of-forecasting-space-radiation-hazards,-safeguarding-astronauts/)
  - Lowers chance of damage from radiation events
- **Part de-rating and increase operating margin**
  (http://www.jhuapl.edu/techdigest/td2801/Maurer.pdf)
  - 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)
    - http://news.cnet.com/More-solar-flares-warm-satellite-concerns/2100-1033_3-5098950.html
  - Radiation effects are reduced when electronics are powered off

References to Radiation Environment Information

- **Minimalist Recovery Techniques for Single Event Effects in Spaceborne Microcontrollers. By Douglas Caldwell**
  - http://www.cs.ucla.edu/~rennels/dougdiss.pdf
- **Ionization and plasma**
  - http://cindispace.utdallas.edu/DMSP/
- **Nuclear and Space Radiation Effects Conference**
  - http://www.nsrec.com/
- **Very thorough presentation on the space radiation environment**
  - http://radhome.gsfc.nasa.gov/radhome/papers/slideshow10/SC_NSREC97/index.htm
- **Very thorough paper on radiation effects and mitigation**
  - http://www.jhuapl.edu/techdigest/td2801/Maurer.pdf
- **Born to fail – Embedded.com, Dec 12 2002**
  - http://www.embedded.com/www.embedded.com/columns/showArticle.jhtml?articleID=9900877
- **Chris Day's Masters Thesis**
  - **On file at Cal Poly Library (On the internet???)**
- **Harsh Environments: Space Radiation… By Maurer, et al.**
  - http://www.jhuapl.edu/techdigest/td2801/Maurer.pdf
- **White papers on space technology**
  - http://www.maxwell.com/microelectronics/technical-support/white-papers.asp