DTU Satellite Systems and Design Course
Space Environment

Flemming Hansen
MScEE, PhD
Technology Manager
Danish Small Satellite Programme
Danish Space Research Institute

Phone: 3532 5721
E-mail: fh@dsri.dk

Downloads available from:
http://www.dsri.dk/roemer/pub/Cubesat

Overview of the Space Environment

External Factors

Residual atmosphere (up to ≈800 km) - Drag causes orbit decay and reentry

Trapped protons - Degrades materials and electronic components, causes single-event effects in semiconductor components.

Trapped electrons - Degrades materials and electronic components

Solar protons from flares - Degrades materials and electronic components, causes single-event effects in semiconductor components.

Cosmic rays - causes single-event effects in semiconductor components.

Solar radiation: IR, Visible, UV, X-Ray - Degrades materials

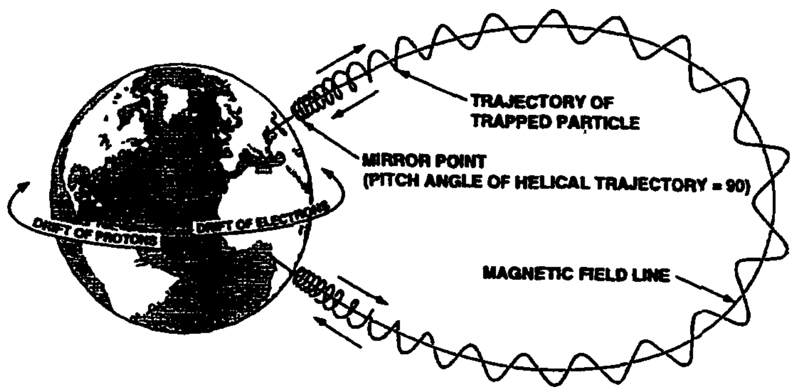
Plasma from magnetic substorms - Causes spacecraft charging

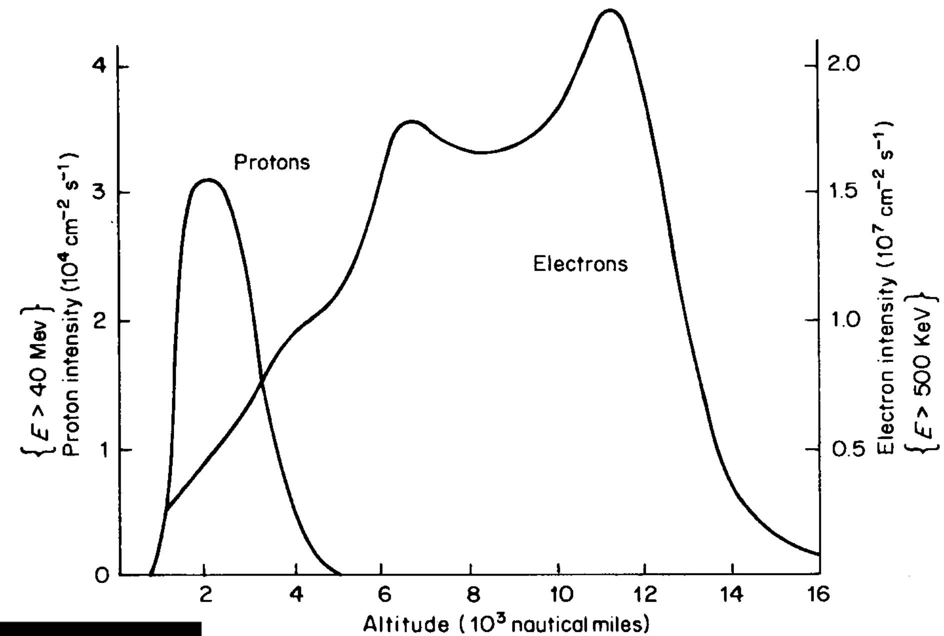
Atomic oxygen - Erodes exposed surfaces

Local Factors

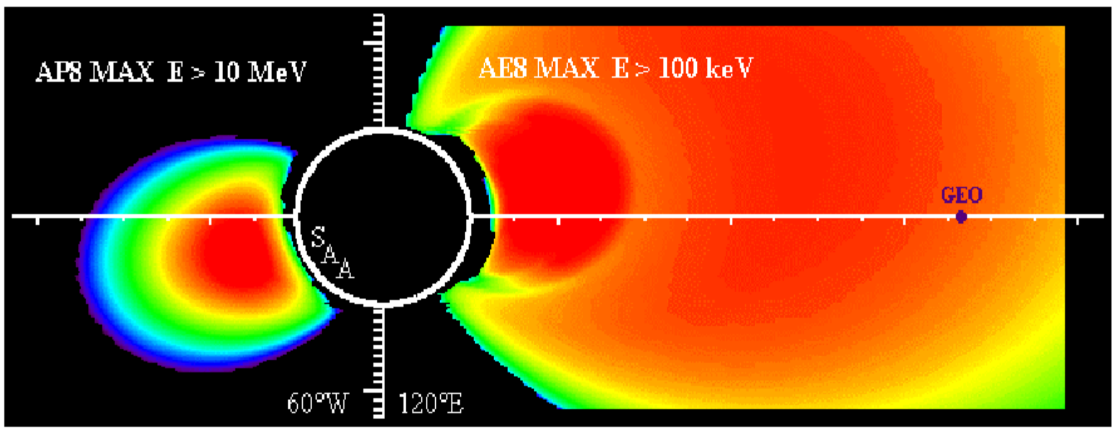
Outgassing - Deposits on cold surfaces, e.g. optical apertures.

Earth's Radiation Belts





Trapped Protons **Trapped Electrons**



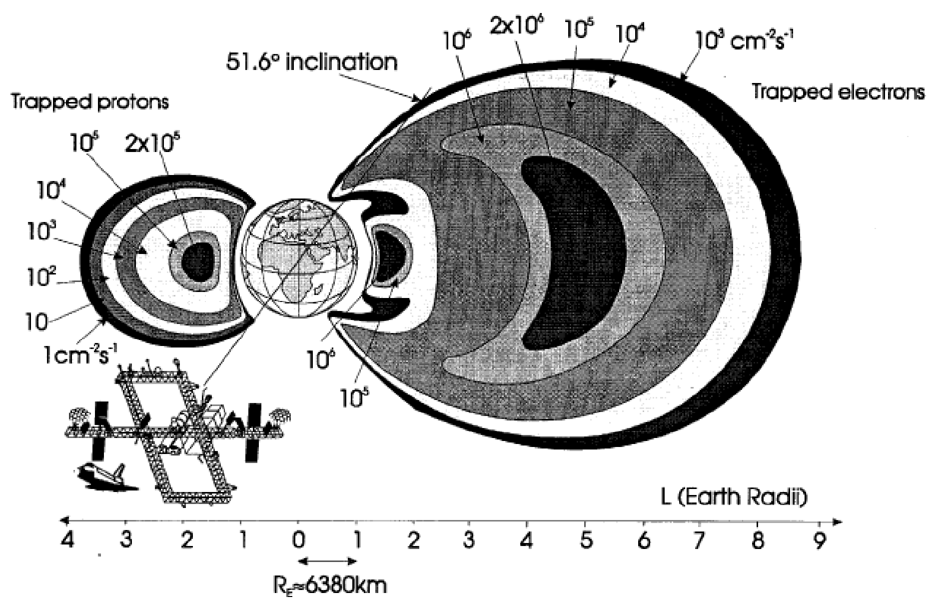
Charged particles + Magnetic field

$$\mathbf{F} = q\,(\mathbf{v} \times \mathbf{B} + \mathbf{E})$$

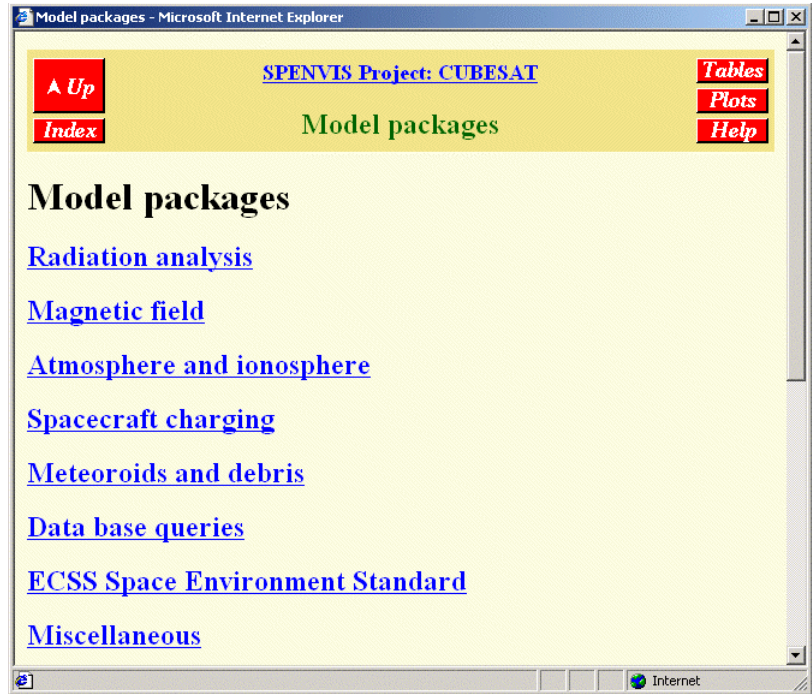
- gyration, bound and drift motions
- electrons: 100 keV - 10 MeV
- protons: 1 MeV - 400 MeV
- ions: Helium, Oxygen

Effects of High-Energy Charged Particles in the Space Environment

- **Biological effects (Prolonged exposure of astronauts in MIR and International Space Station)**
  - ➔ **Shielding, return to ground in case of majorsolar flares**
- **Degradation of materials and semiconductors by ionization and lattice displacements**
  - ➔ **Materials selection, radiation hardening, shielding**
- **Single-Event Upsets in computer memory cells**
  - ➔ **Error Detection and Correction (EDAC), radiation hardening**
- **Radiation background (Increased noise level in CCD, X-ray and gamma-ray detectors)**
  - ➔ **Radiation hardening, shielding, select orbit outside or inside radiation belts, disable payload while passing through radiation belts**



Calculation of Effects of Ionizing Radiation in the Space Environment

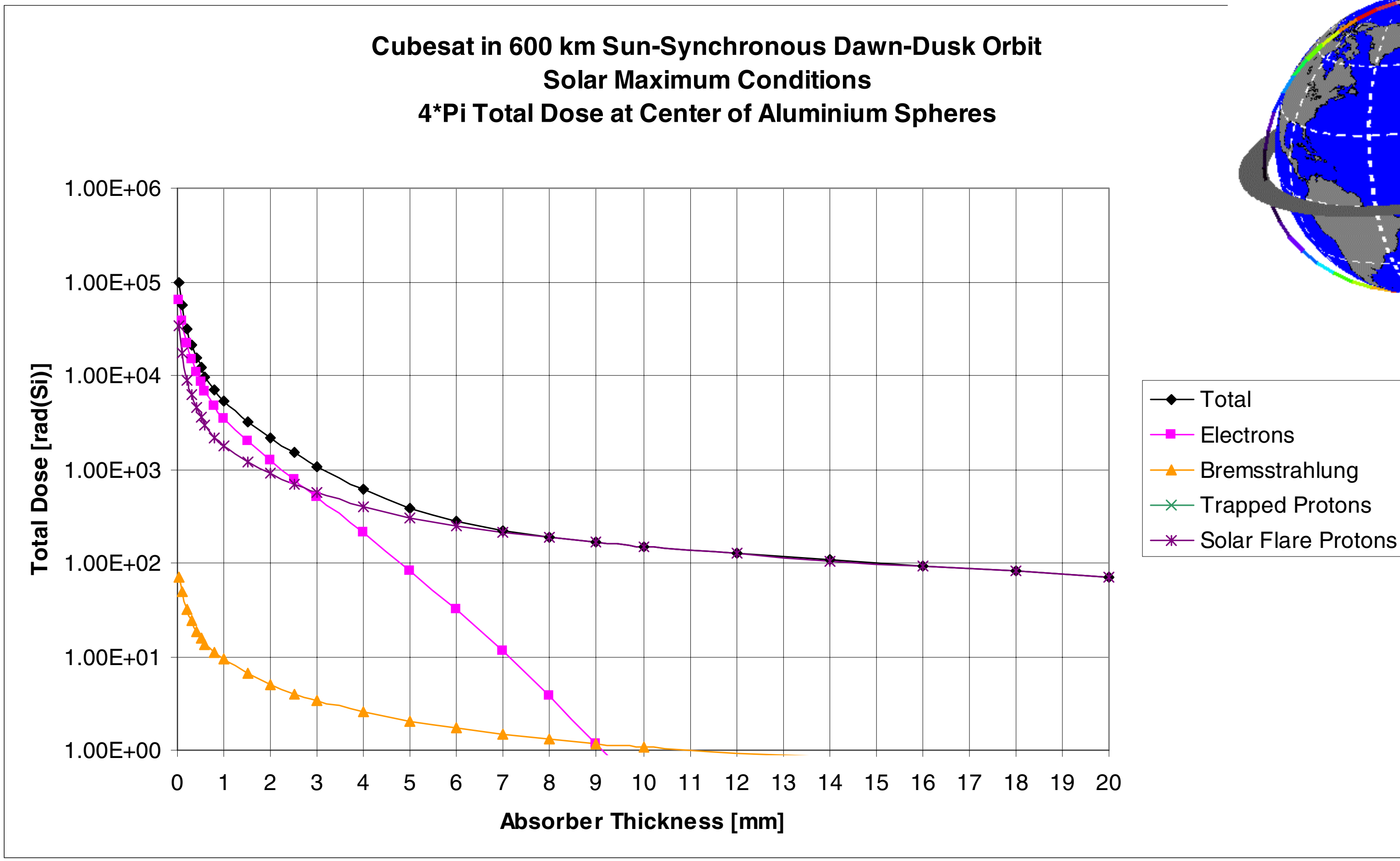


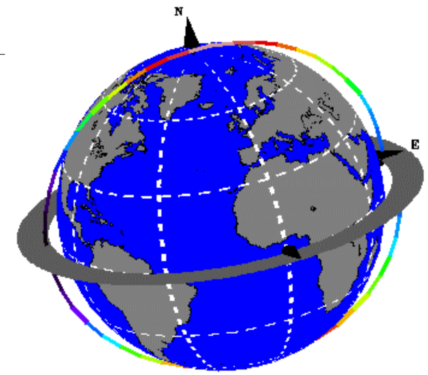
ESA has created a web-facility - SPENVIS that gives the user acess to a number of useful modeling and calculation resources – see SPENVIS opening vindow at right

You have to be a registered user to gain access to the facility.

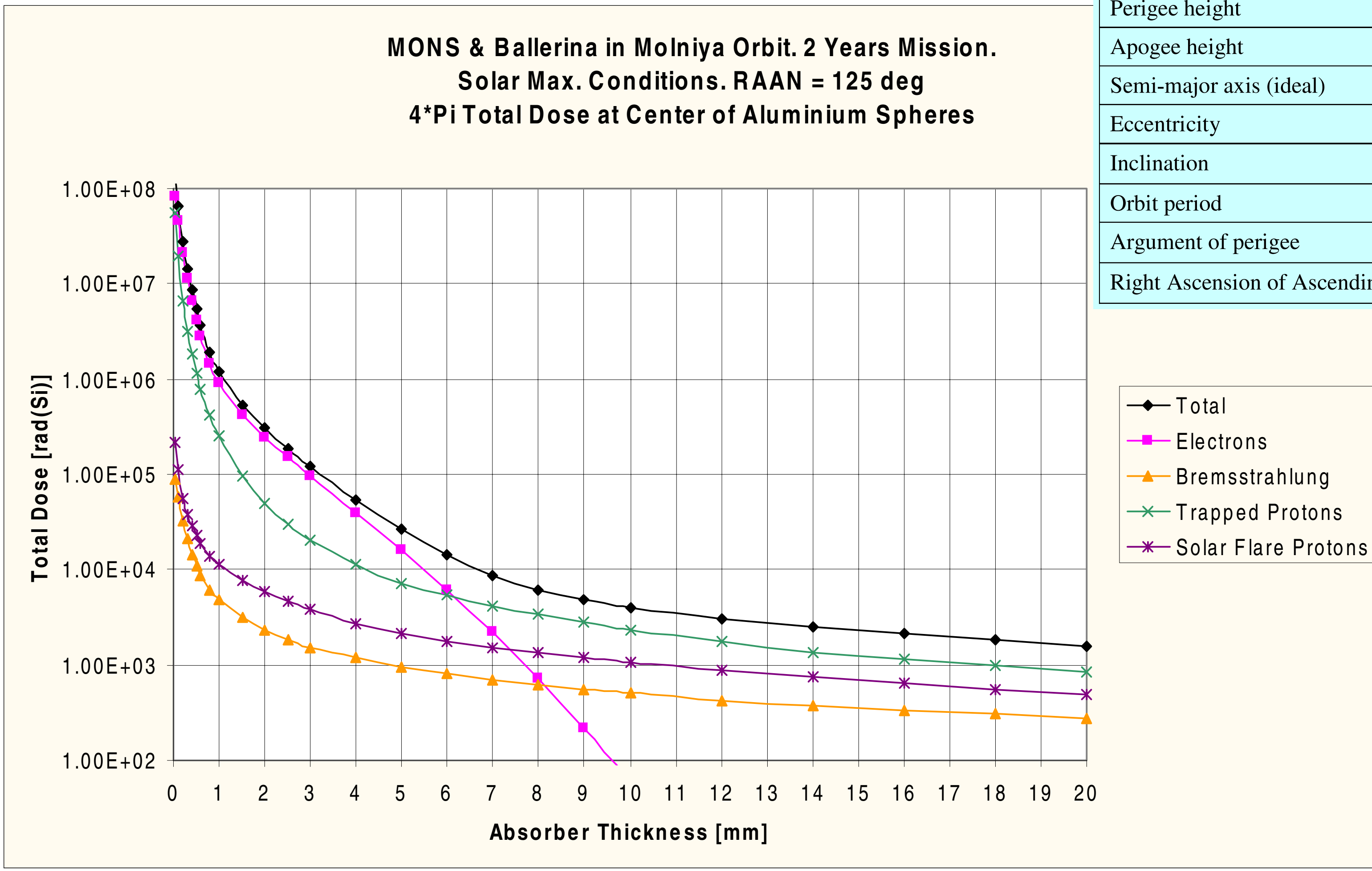
http://www.spenvis.oma.be/spenvis/

Radiation in Syn-Synchronous Polar Low Earth Orbit

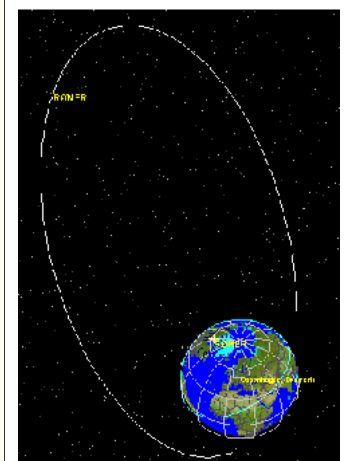




Radiation in Molniya Orbit (RØMER)

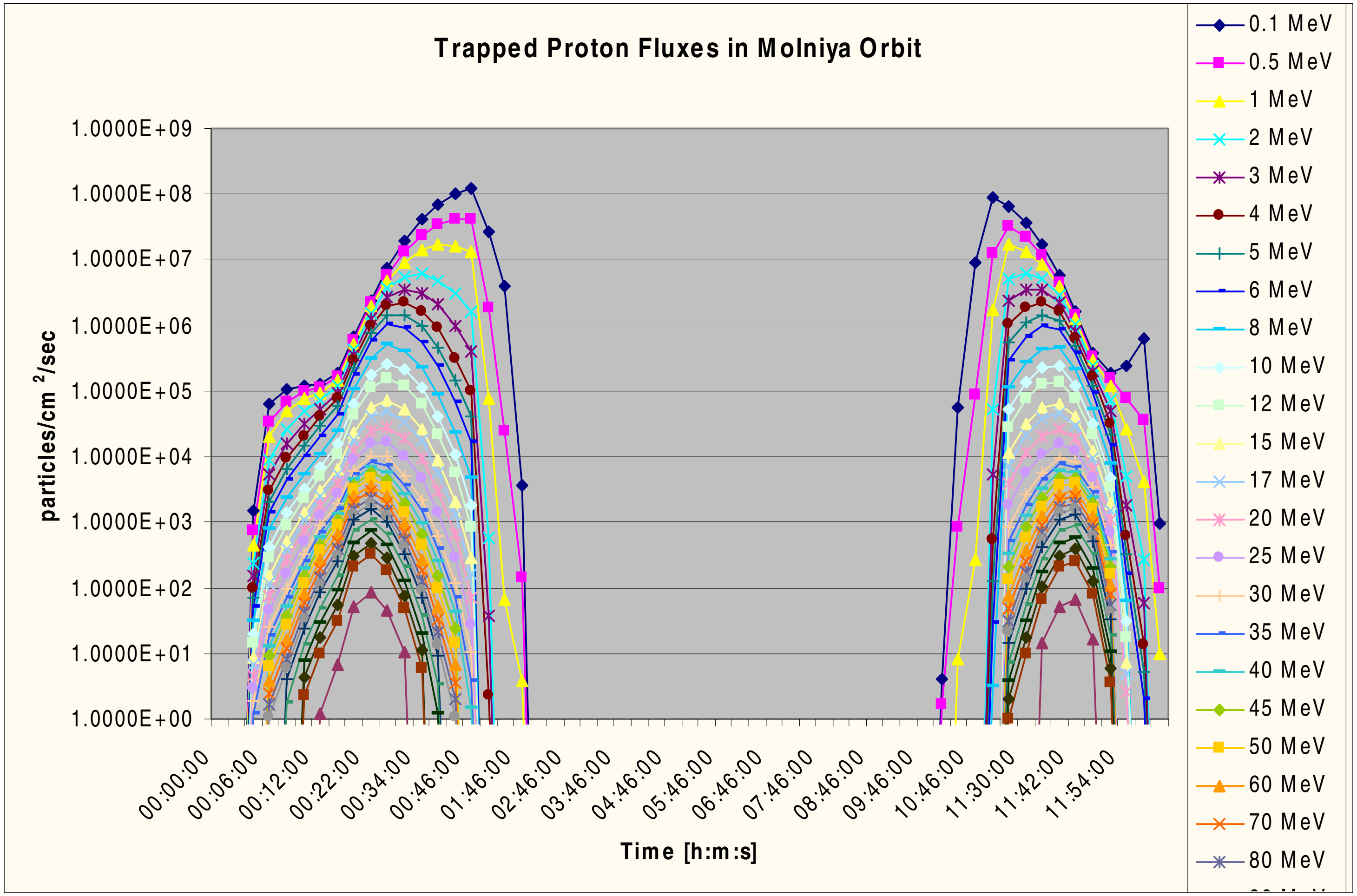


Perigee height	600 km
Apogee height	39767 km
Semi-major axis (ideal)	26561.764 km
Eccentricity	0.737286
Inclination	63.4°
Orbit period	11 hours 58 min
Argument of perigee	270°
Right Ascension of Ascending Node	293°

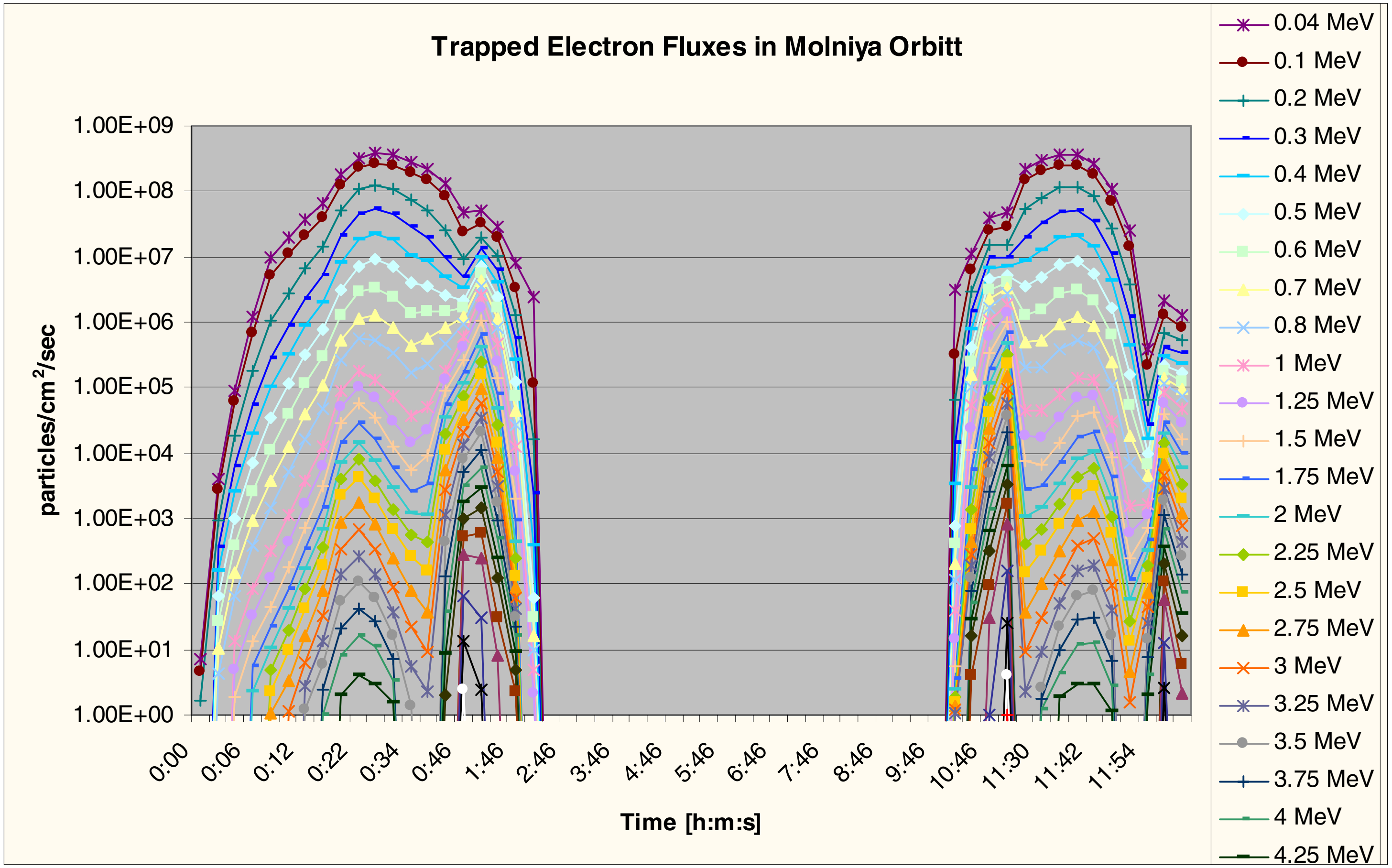


DSRI

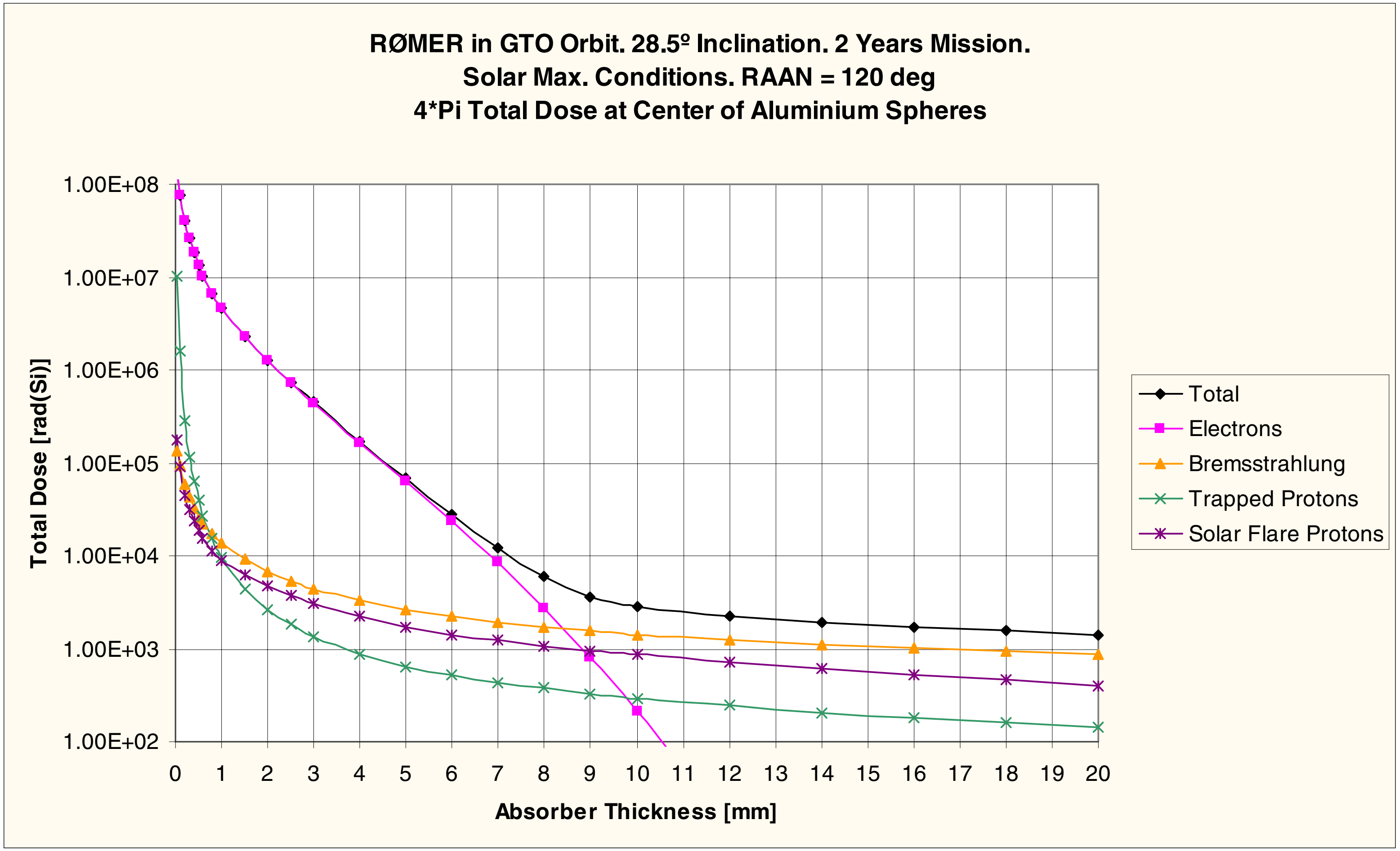
Radiation Environment in Molniya Orbit - Trapped Proton Fluxes Along Orbit



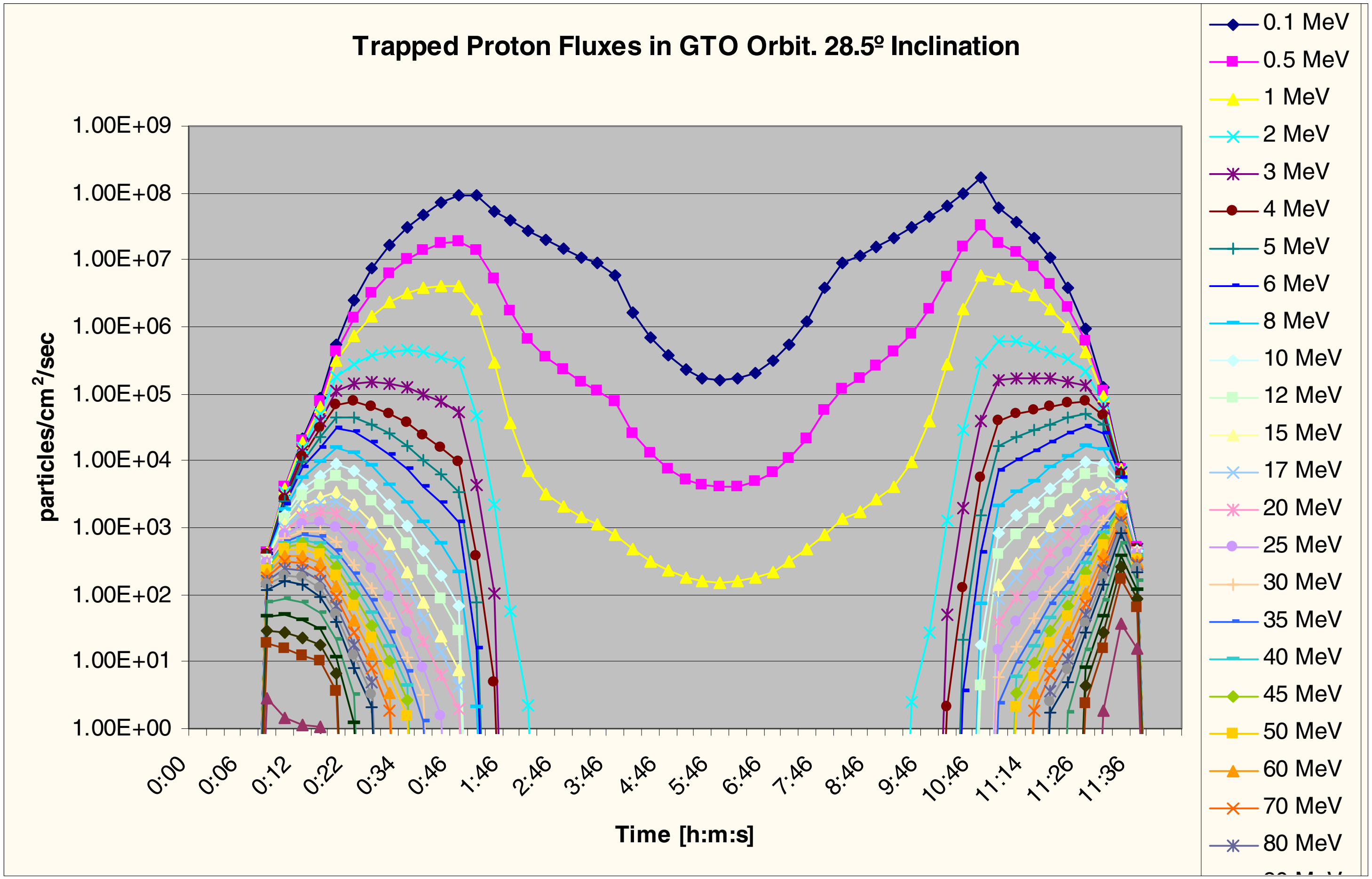
Radiation Environment in Molniya Orbit - Trapped Electron Fluxes Along Orbit



Radiation Environment in Geostationary Transfer Orbit, 28.5° Inclination



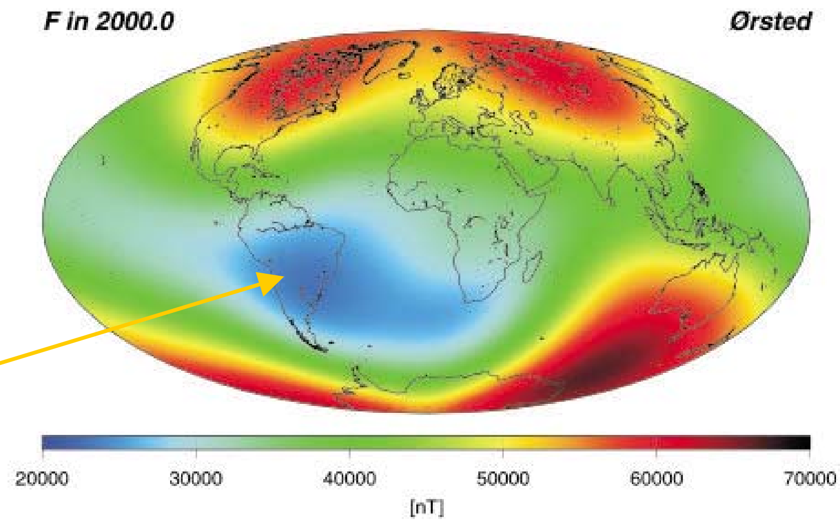
Radiation Environment in Molniya Orbit - Trapped Proton Fluxes Along Orbit



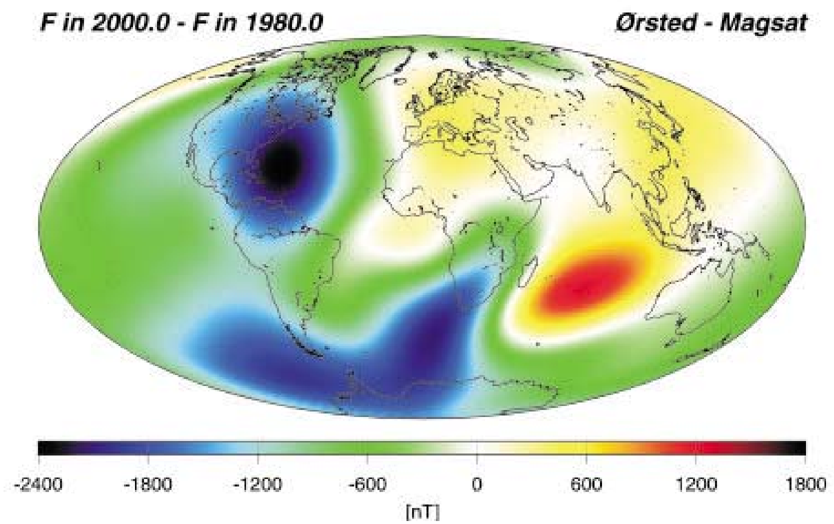
ØRSTED Magnetic Field Model

Today's Field

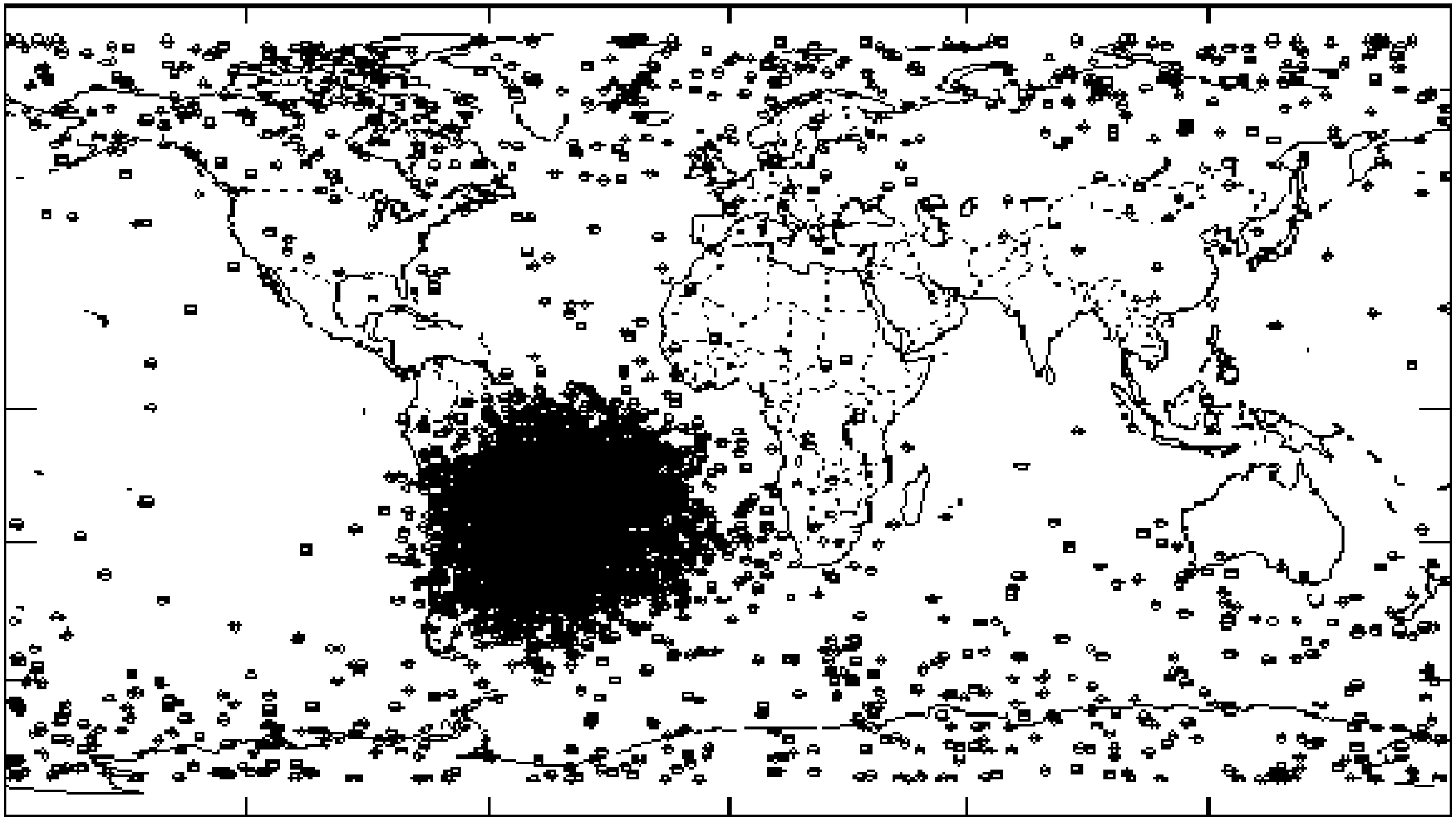
South-Atlantic Anomaly (SAA)



Changes Since 1980



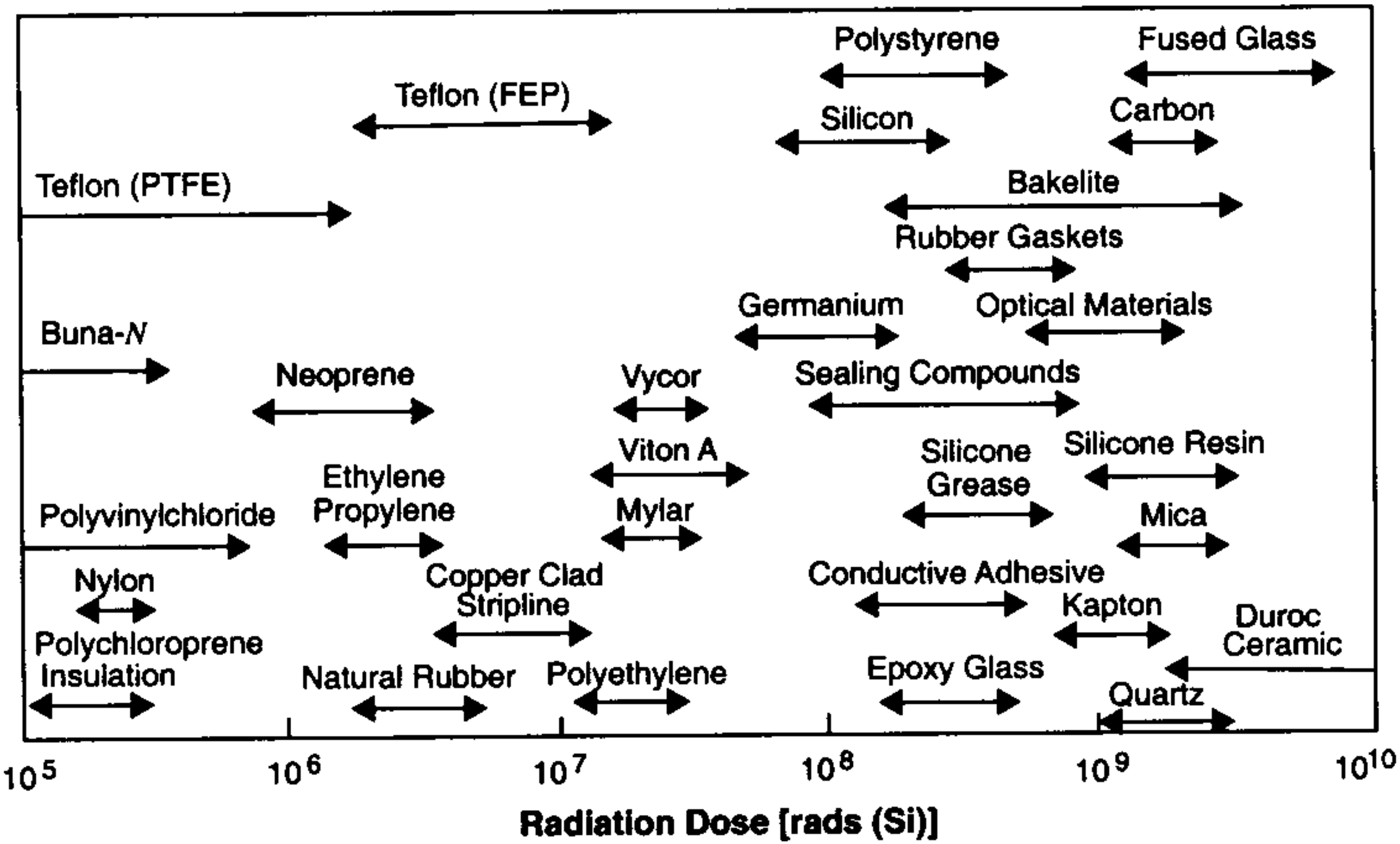
Effects of South-Atlantic Anomaly



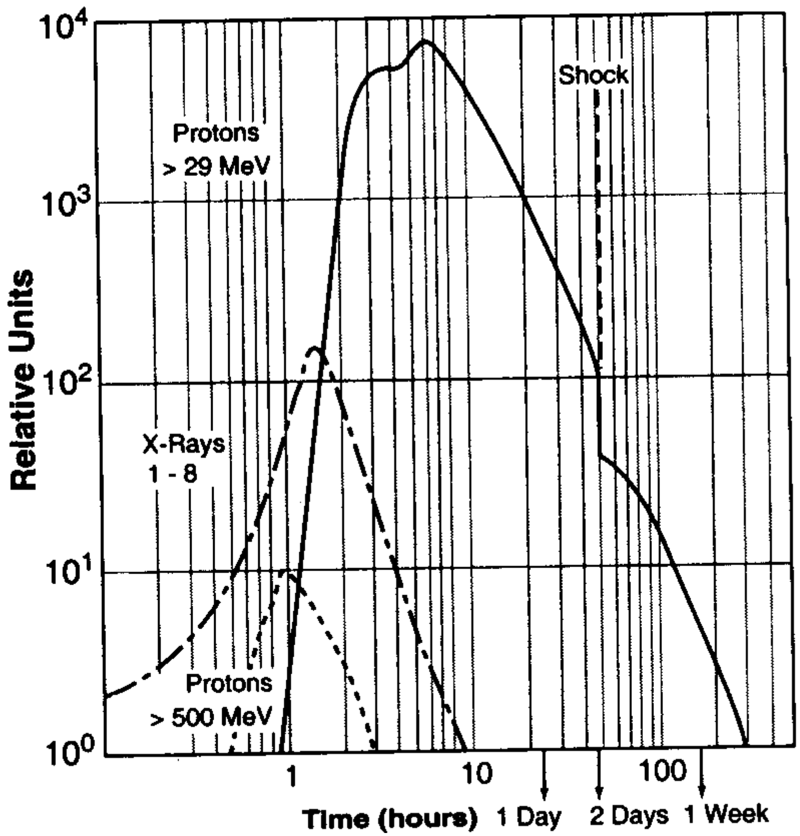
UoSAT-3 Single-Event Upsets

DSRI

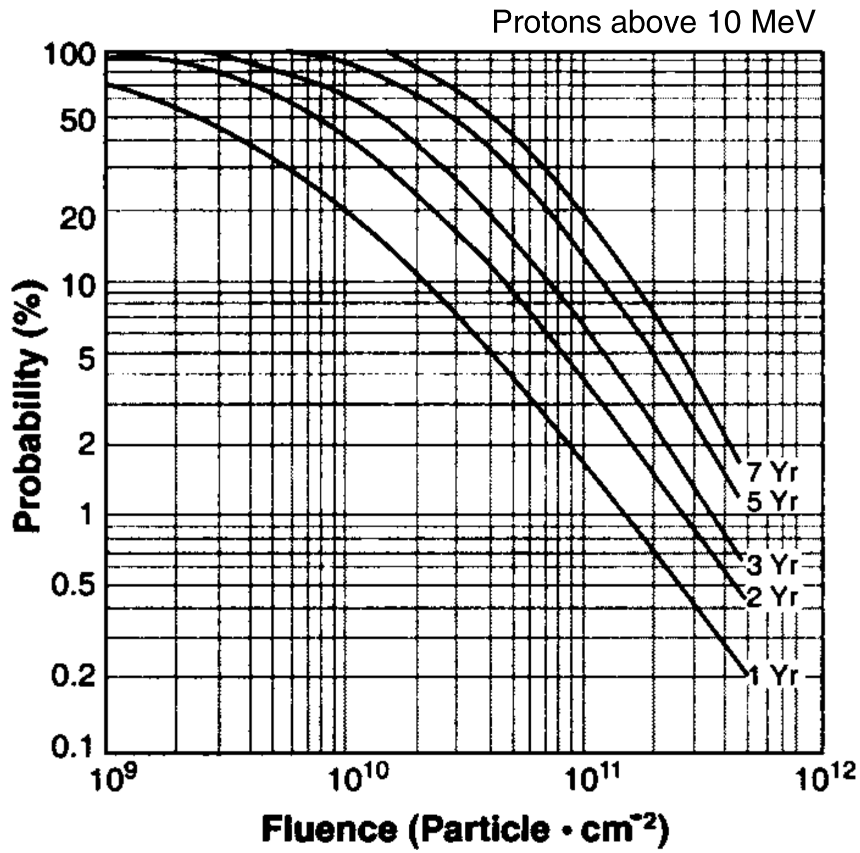
Radiation Dose Tolerance of Materials



Solar Flares

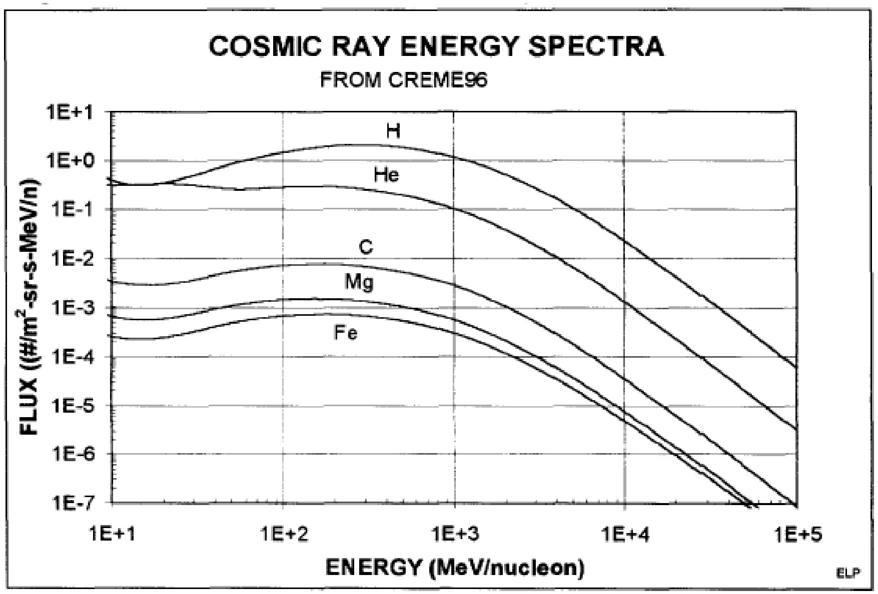


Major Solar Flare

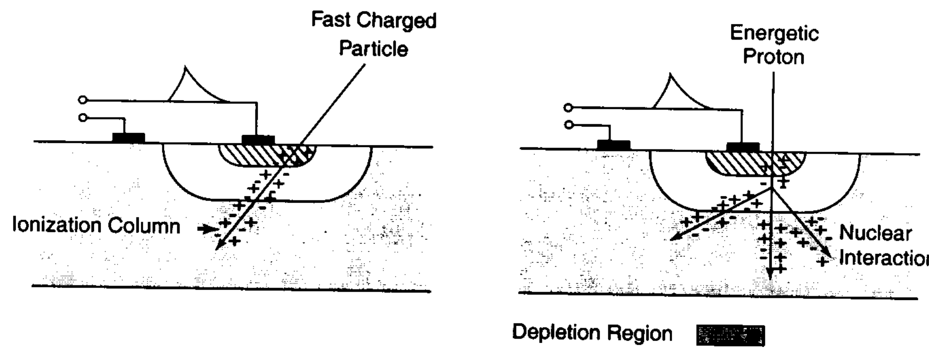


Probability of exceeding a given fluence level for various mission durations

Cosmic Rays

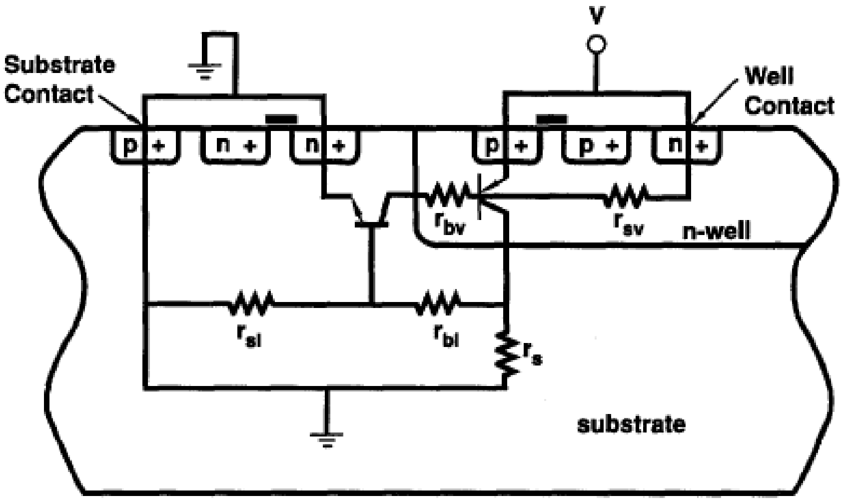


Cosmic ray species vs particle energy

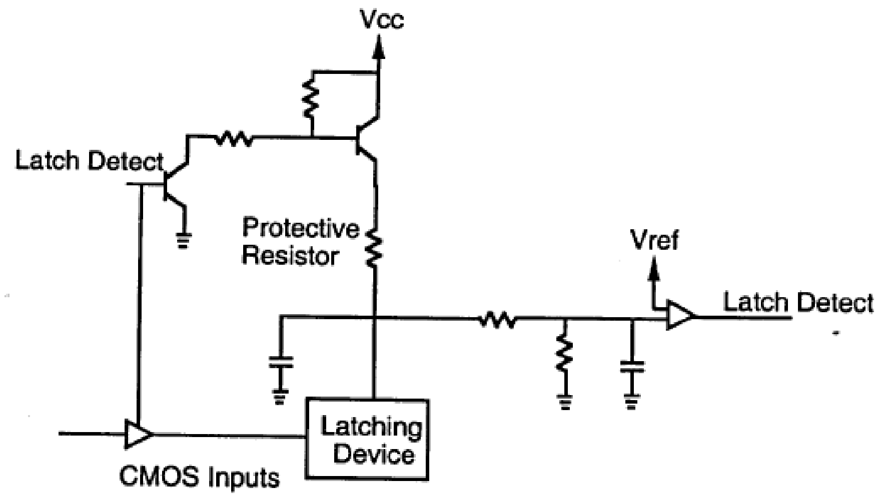


Effect of high-energy charged particle in integrated circuit

Single-Event Latch-Up



Two-transistor model for latch-up in CMOS device showing parasitic elements



Latch-up protection circuit for ADSP-2100 digital signal processor

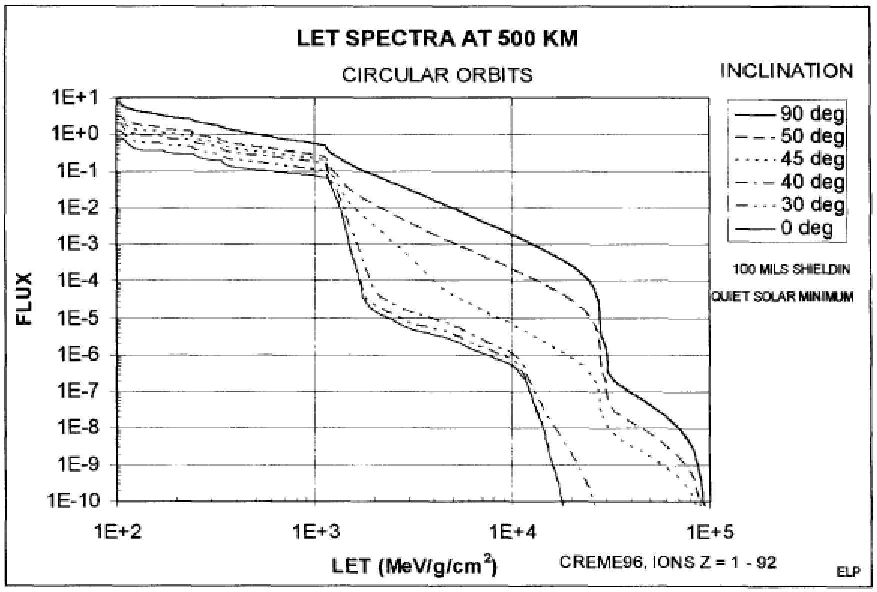
Typical Radiation Tolerences of Rad Hard and COTS Parts

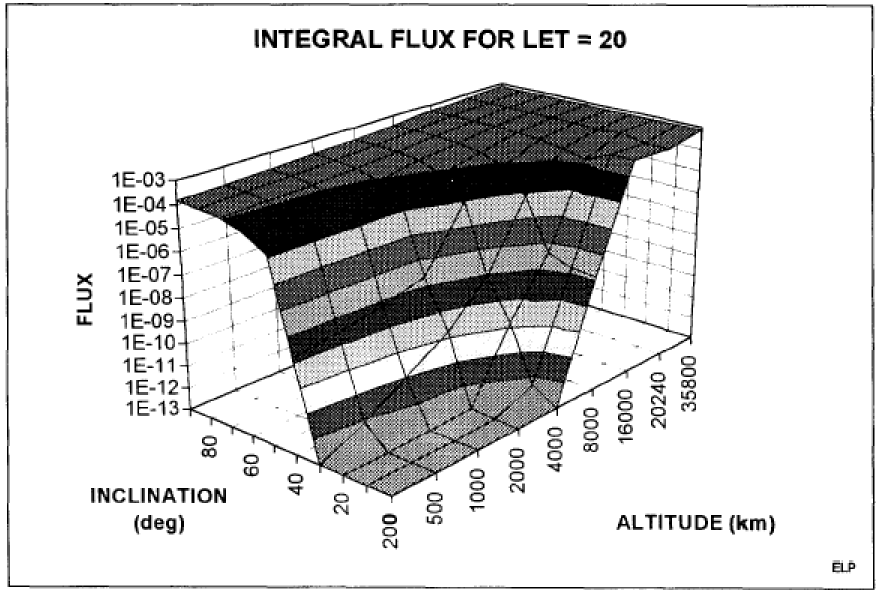
Characteristics	COTS	Rad Hard
Total Dose	10^3–10^4 rads	10^5–10^6 rads
Dose-Rate Upset	10^6–10^8 rads (Si)/s	$>10^9$ rads (Si)/s
Dose-Rate-Induced Latchup	10^7–10^9 rads (Si)/s	$>10^{12}$ rads (Si)/s
Neutrons	10^{11}–10^{13} n/cm^2	10^{14}–10^{15} n/cm^2
Single-Event Upset (SEU)	10^{-3}–10^{-7} errors/bit-day	10^{-8}–10^{-10} errors/bit-day
Single-Event Latchup/Single-Event Burnout (SEL/SEB)	< 20 MeV-cm^2/ mg (LET)	37-80 MeV-cm^2/ mg (LET)

- COTS characteristics may vary unpredictably from lot to lot and even within a lot.
- Higher margins and more testing (screening) are required with COTS usage, which will offset lower piece part costs.
- LET is Linear Energy Transfer threshold.

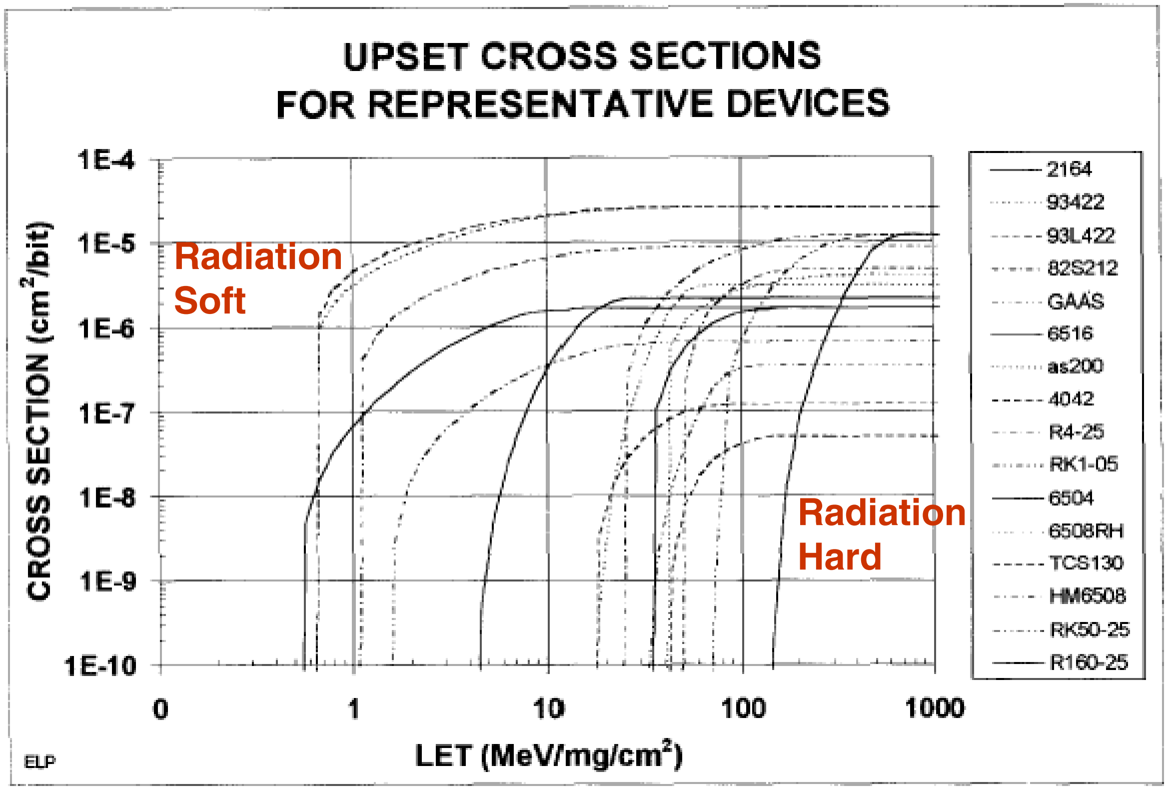
COTS: Commercial Off-the-Shelf (parts)

Linear Energy Transfer (LET) Spectra in Orbit





Single-Event Upset - Linear Energy Transfer Threshold



Single-Event Upset Protection Methods

Protection Method	Capability
Watchdog Timer	If not reset within the designed interval, perform some function (usually a system reset).
Redundancy	Two equivalent systems operate on the same data. If the two systems disagree, a system reset is performed.
Lockstep	Two devices in a system are clocked simultaneously, and which are provided common inputs. If the devices disagree, perform a system reset.
Voting	Use three or more devices to perform the same function. If one device disagrees with the rest, use the remaining devices to determine the next system state.
Repetition	A system must provide the same data more than once to perform some action. Used, for instance, to lower the risk of an inadvertent spacecraft command being executed.