
Radiation Environments (and Derived Requirements)

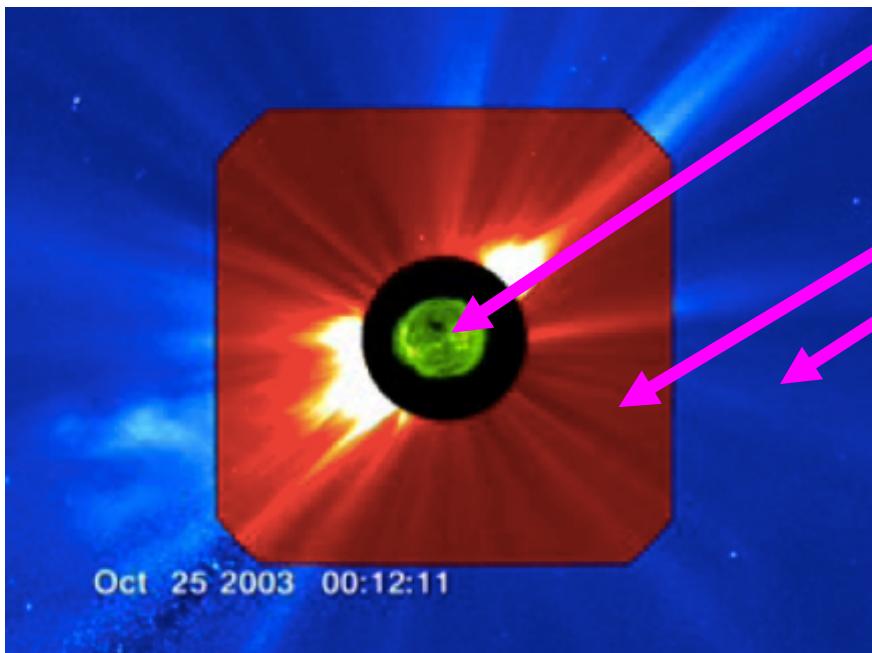
Robert A. Reed
Vanderbilt University



Outline

- Introduction
- Interaction of Radiation with Matter
- Radiation Environments and Derived Mission Requirements

Radiation Events in Space-Based Imagers



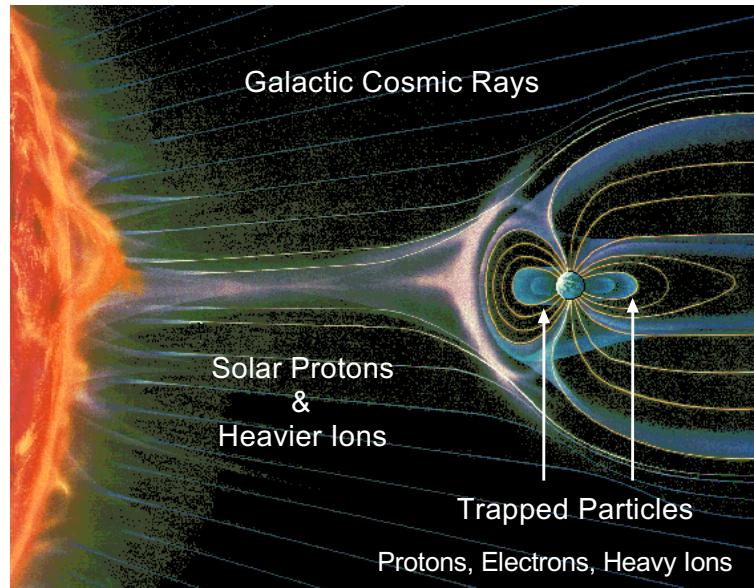
Extreme ultraviolet Imaging
Telescope

The Large Angle and
Spectrometric Coronagraph:
- C2 coronagraph
- C3 coronagraph.

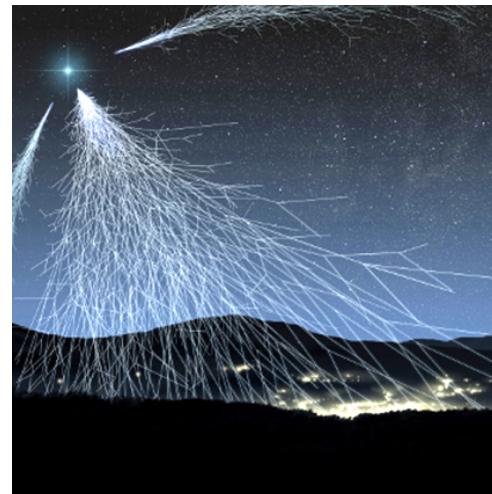
Solar & Heliospheric Observatory (SOHO)

http://www.nasa.gov/mpg/61466main_eitlasco_fall2003_320x240.mpg

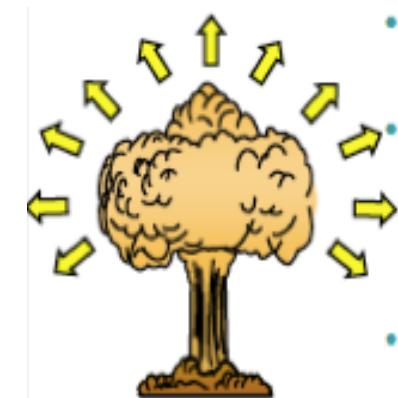
Radiation Environments



Nikkei Science, Inc. of Japan, image by K. Endo

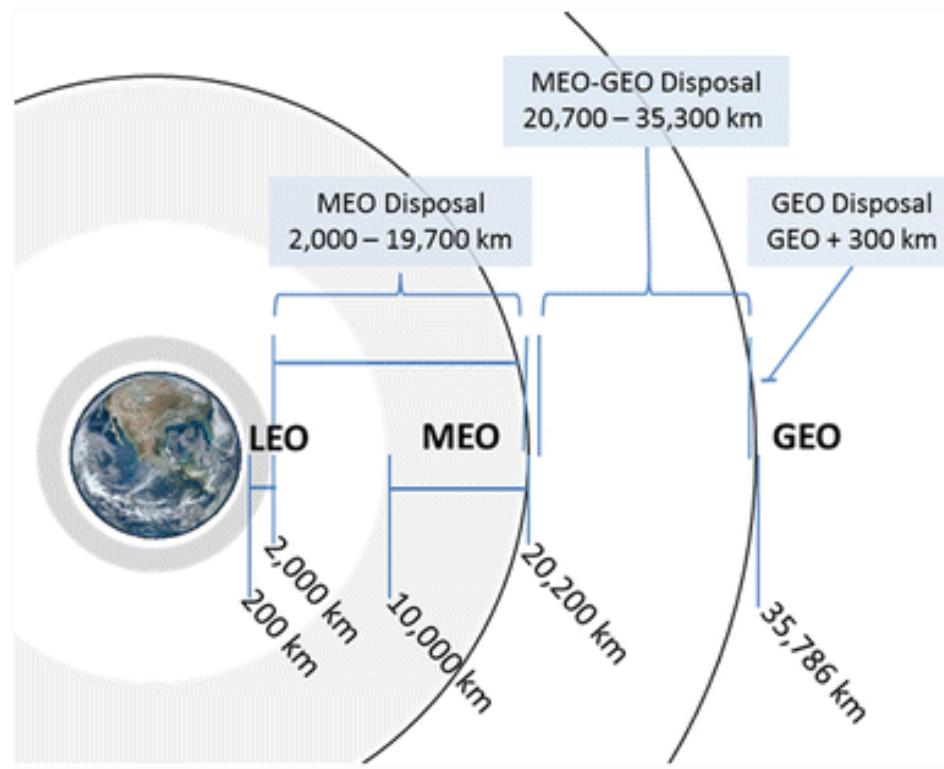


<https://www.ura-hq.org/>



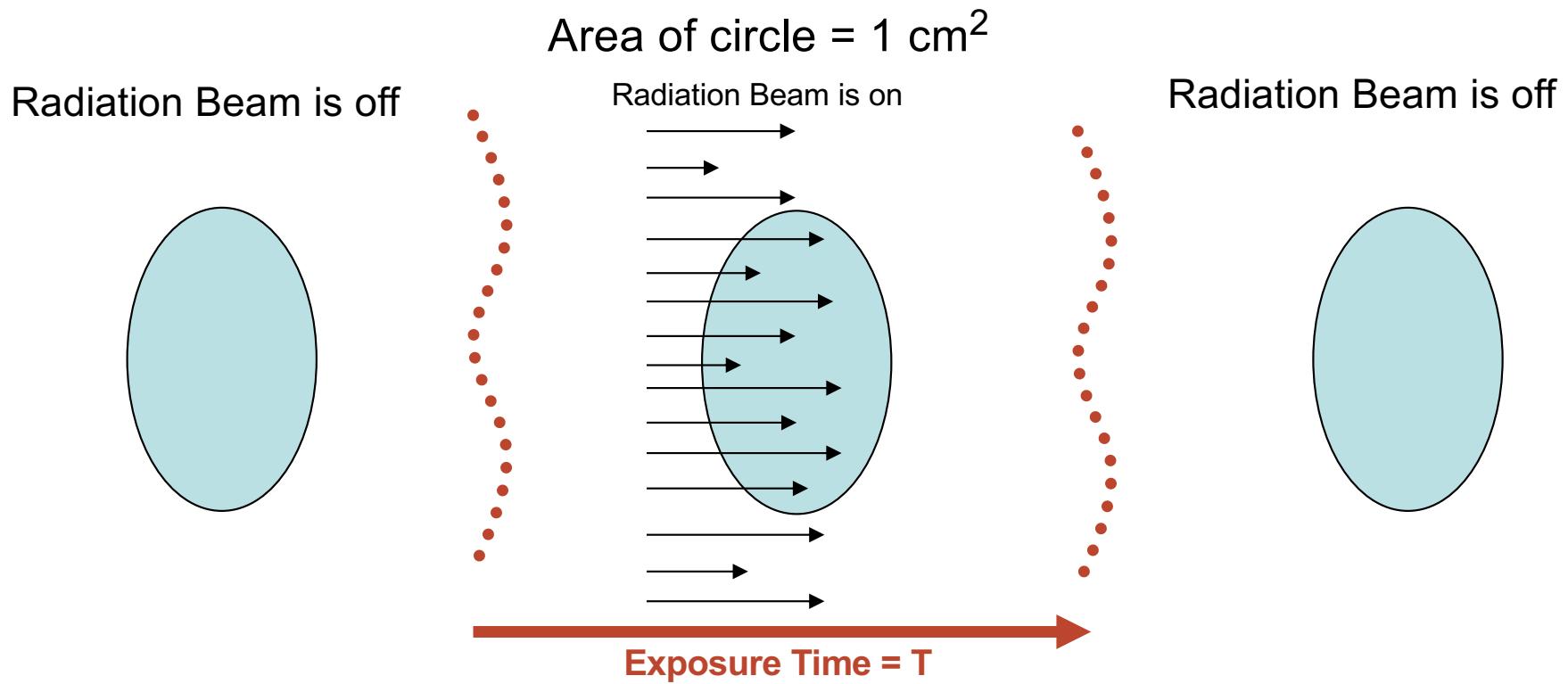
J. Franco, Chemical,
Biological, Radiological,
and Nuclear Survivability
Conf., May 18, 2011

Different Earth Orbits



Each mission will have a different set of radiation requirements

Flux and Fluence Defined



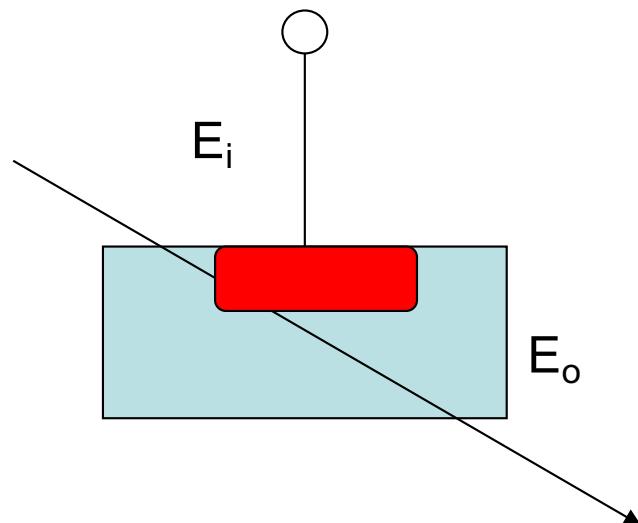
Flux = # particles hitting the 1 cm² circle per second [particles/(cm² s)]

Fluence = total # of particles hitting the 1 cm² circle in time T [particles/cm²]

Effects of Radiation Interactions

- Energy loss by primary particle produces:
 - Temporary Effects
 - Permanent Effects
- Both can be a result of:
 - A single pulse of energy deposition over a short period of time
 - Single event effects (SEEs)
 - Or an accumulation of several energy deposition events
 - Total ionizing dose (TID)
 - Displacement damage dose (DDD)

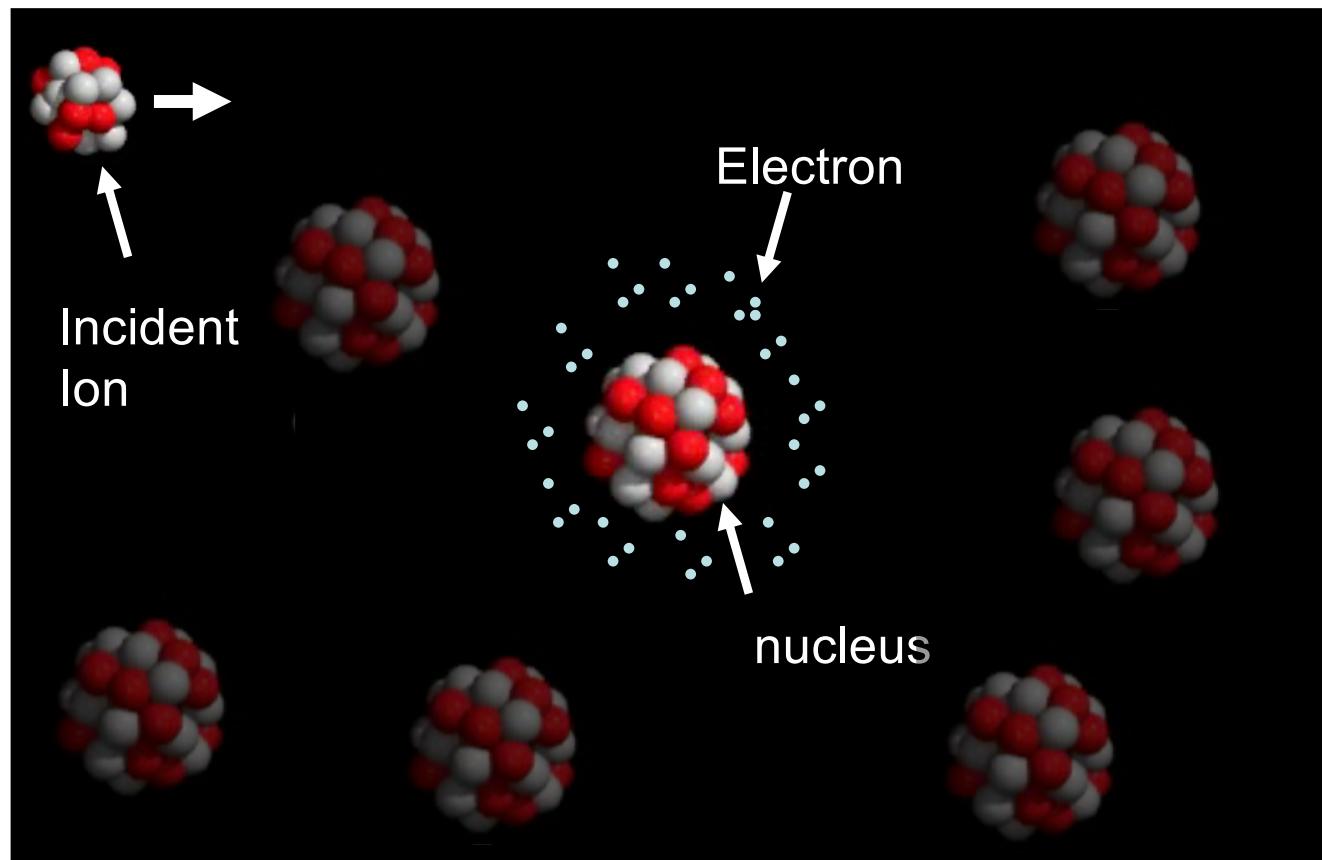
For example: Linear
Energy
Transfer



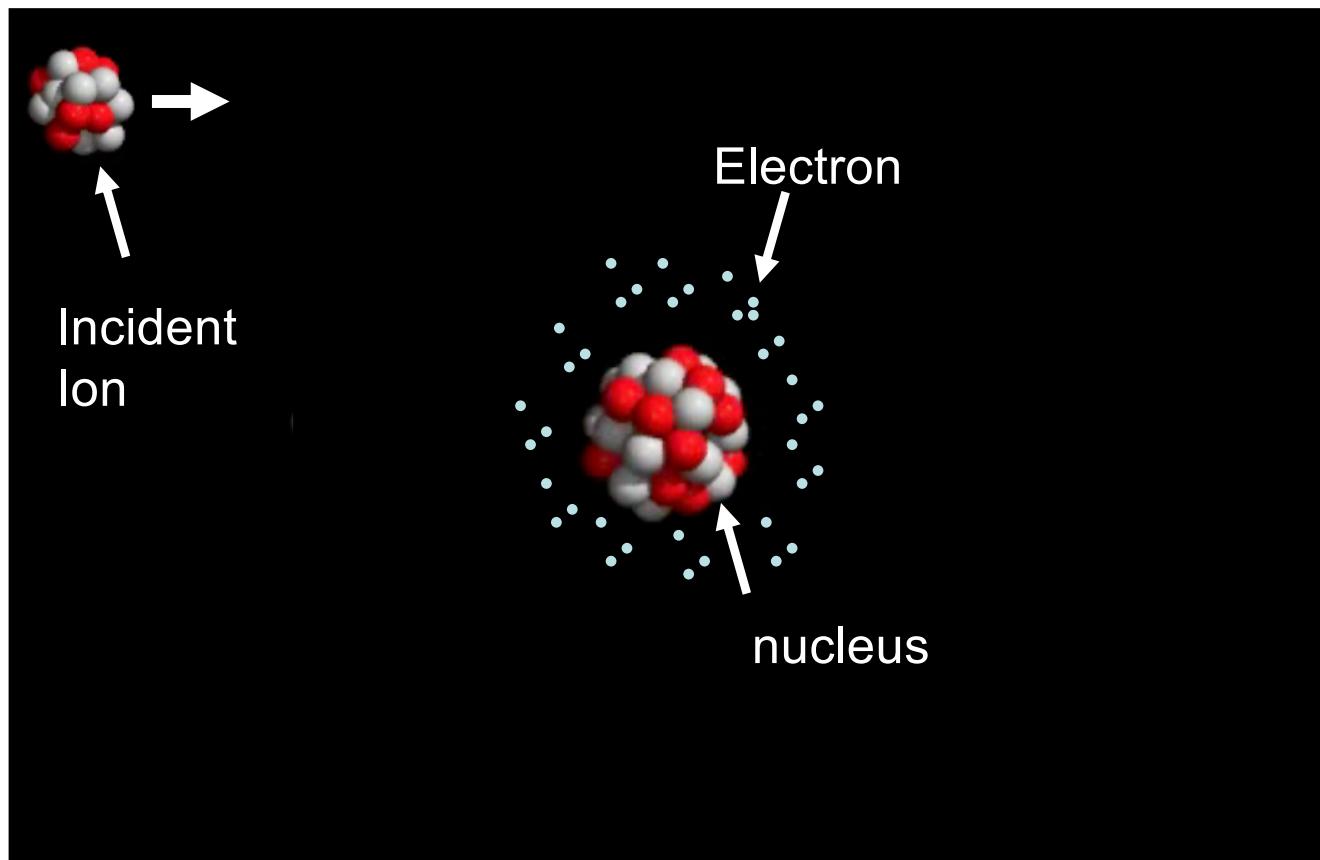
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- Introduction
- **Interaction of Radiation with Matter**
- Radiation Environments and Derived Mission Requirements

Ionization

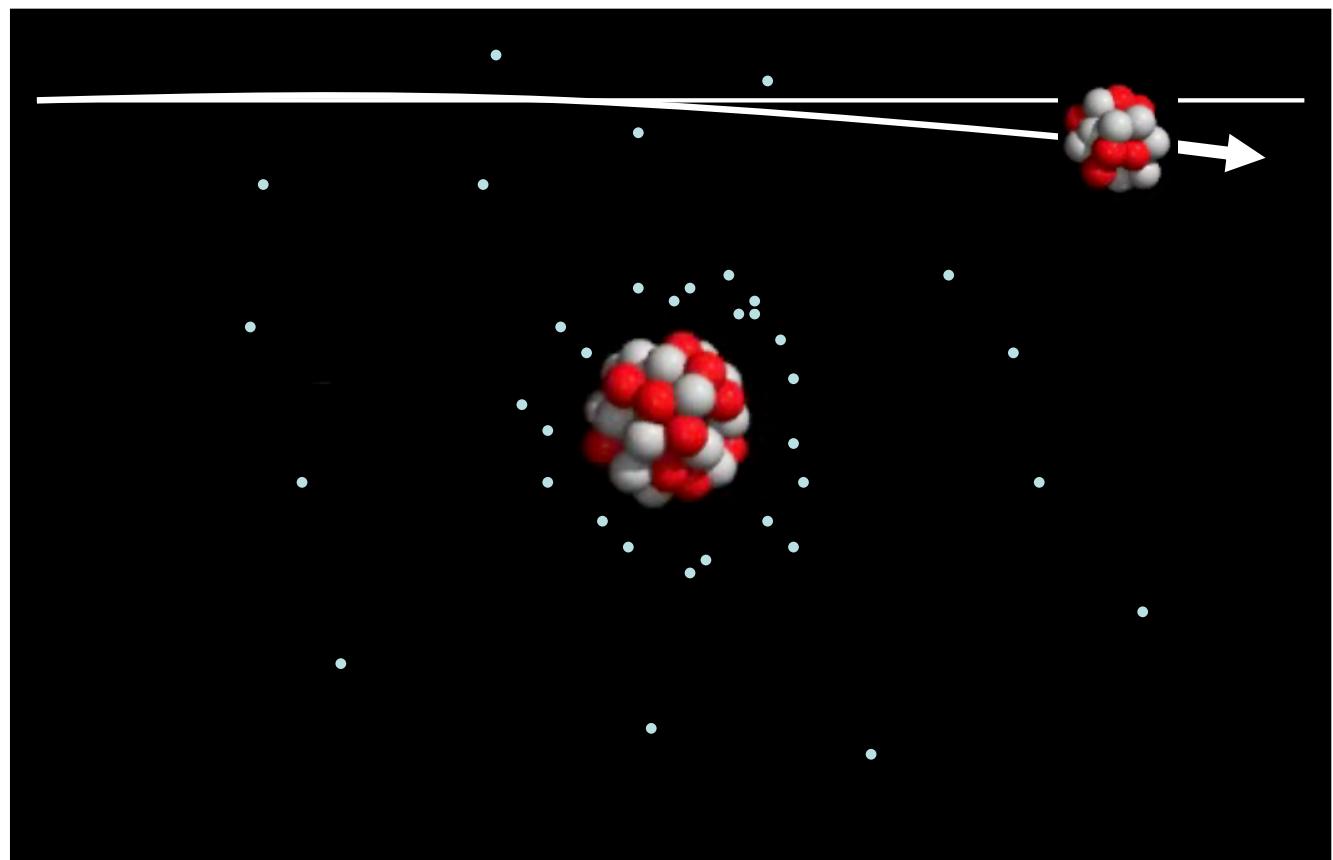


Ionization

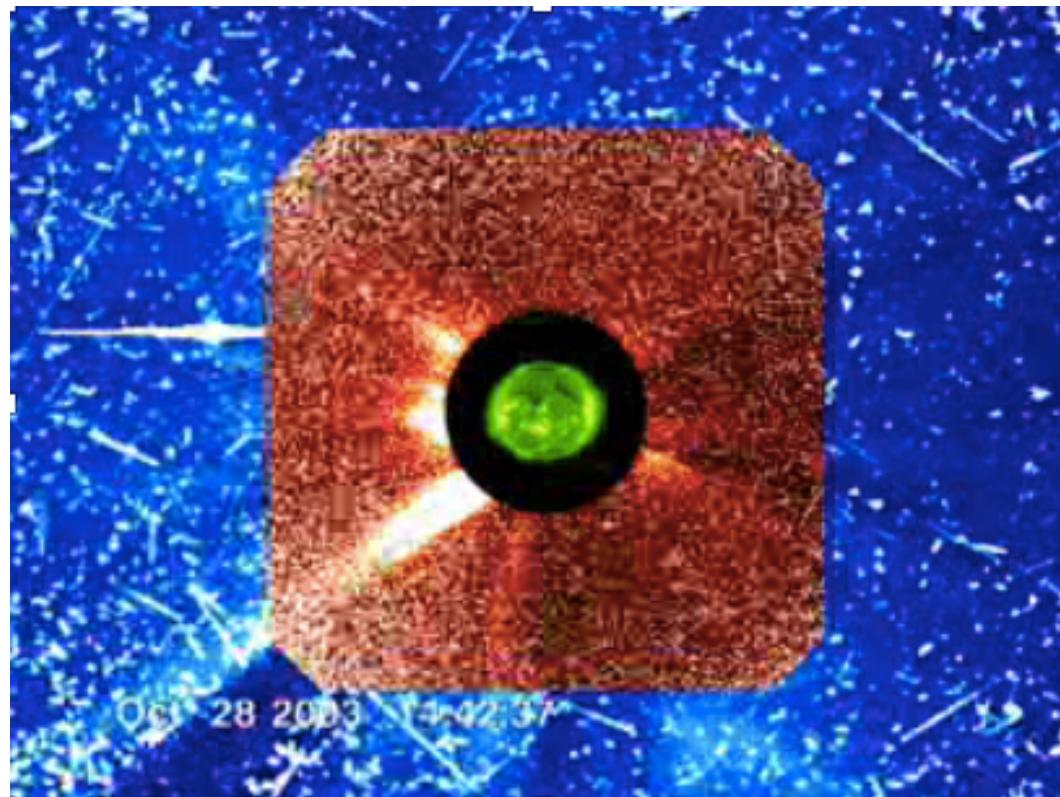


Electronic Stopping – Stopping Force - Ionization

- Electromagnetically scattering (charge particles attract and repel each other)
- Ionization of the target atoms electrons
- Rogue charge can produce temporary or permanent effects in electronics



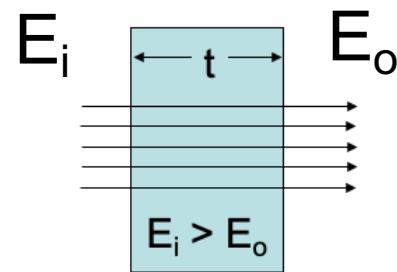
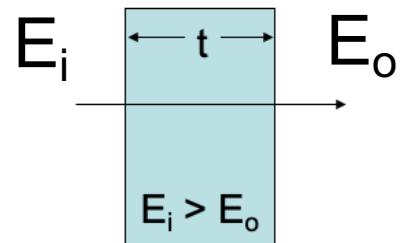
Example of Effects from Ionization



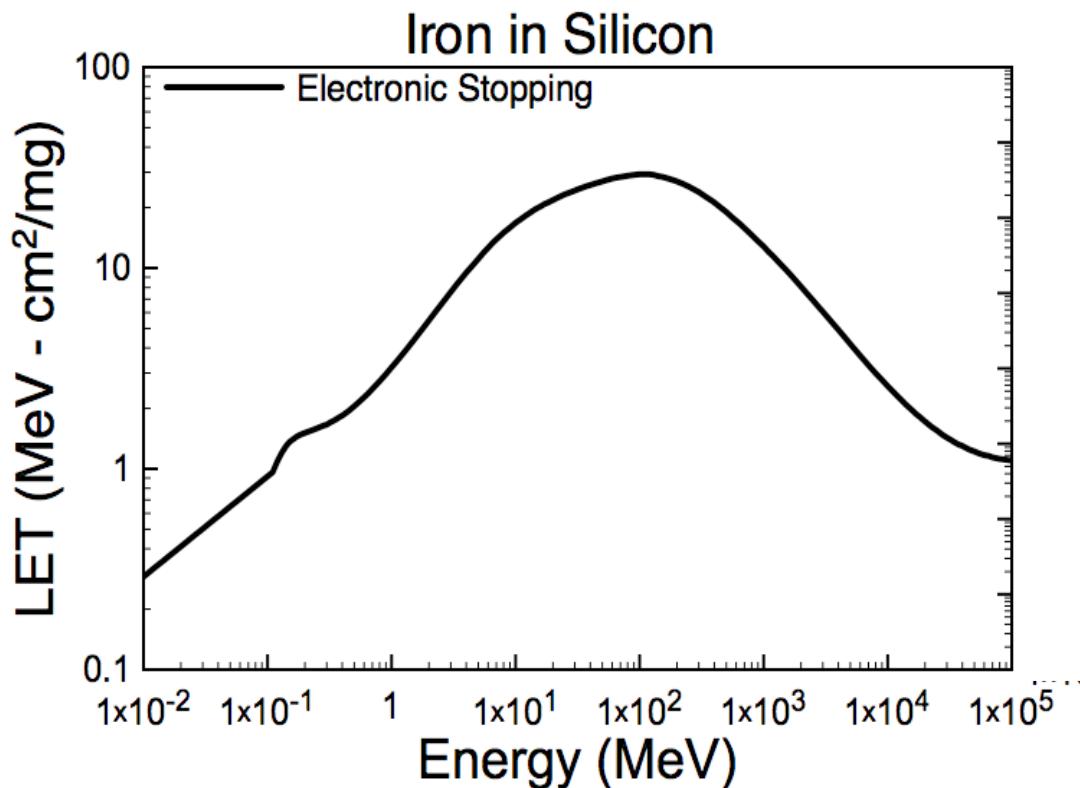
Single Event Effect

Metrics of Interest for Ionization

- Mean energy loss (E) per path length (x)
 - Stopping Force
 - Stopping Power
 - **Linear Energy Transfer (LET)**
- Single pulse of energy deposition
 - $LET = -\rho \frac{\Delta E}{t}$ [MeV-cm²/mg] or $-\rho \frac{dE}{dx}$
(Note MeV are units of energy)
 - Single Event Effect
- Accumulation of several pulses:
 - Total Ionizing Dose (TID) = $k * LET * Fluence$
 - Typically expressed in units of “rad”
 - k = proper unit conversion

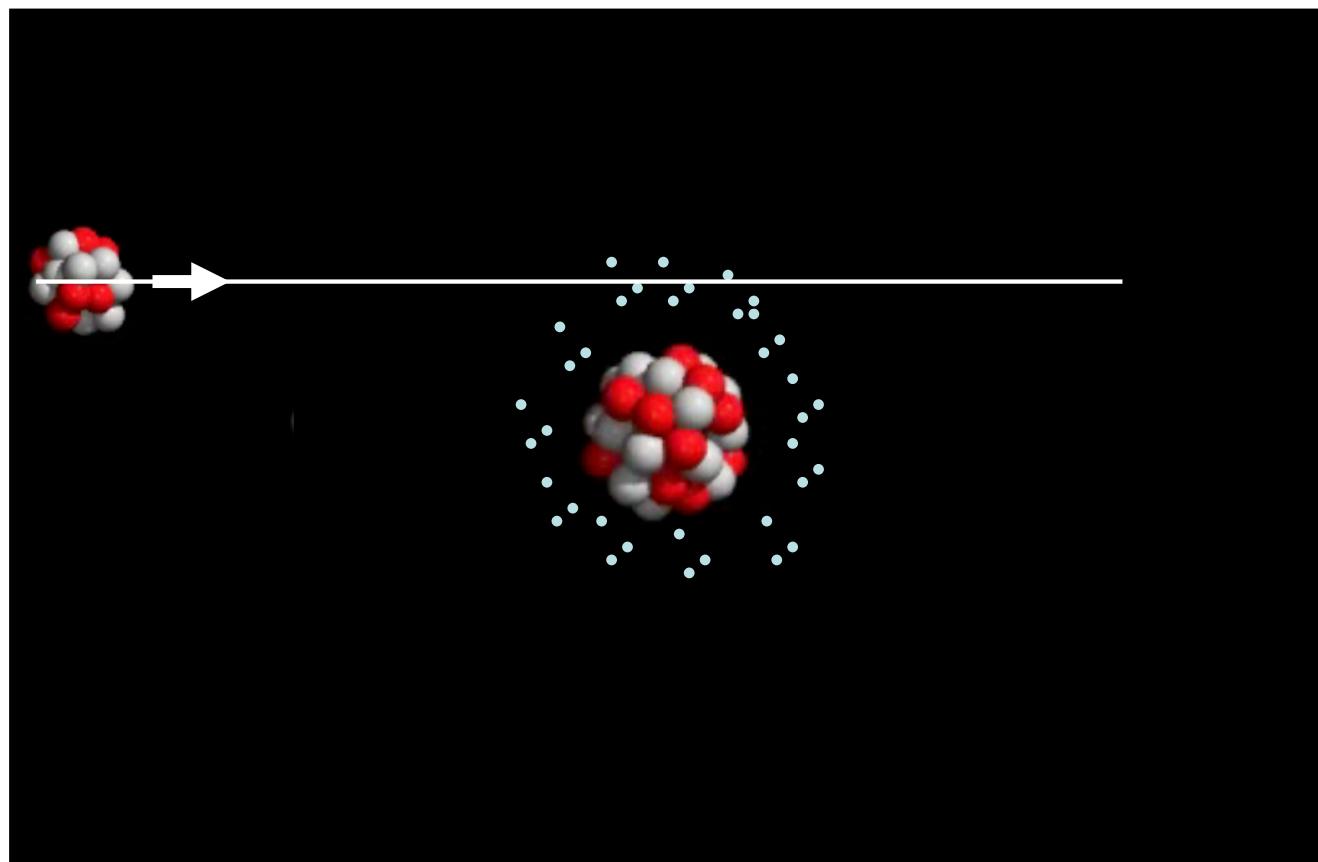


A Plot of LET



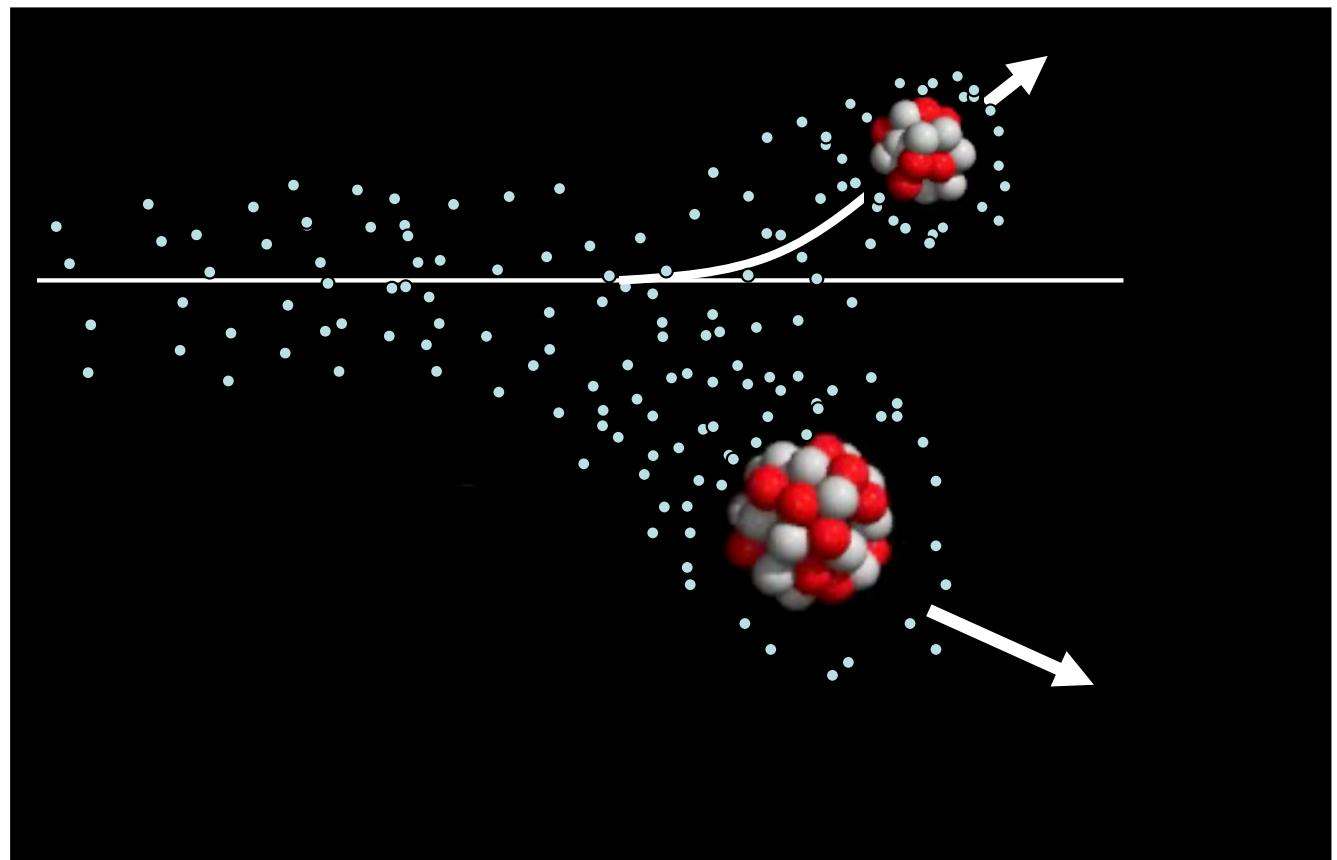
- Similar trend over energy occurs for all ions in all target materials
- Lower mass incident particle in Silicon, Lower LET
- Iron incident on Higher mass material, Higher LET

Nuclear Stopping (Elastic)

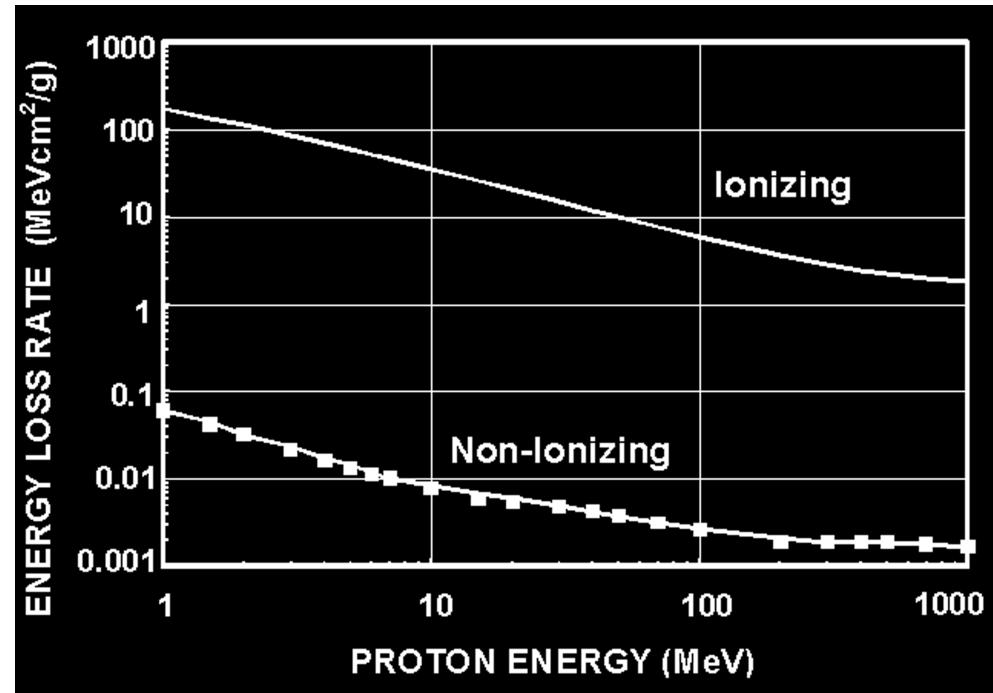
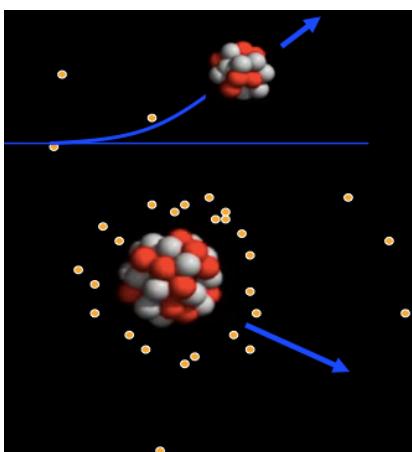
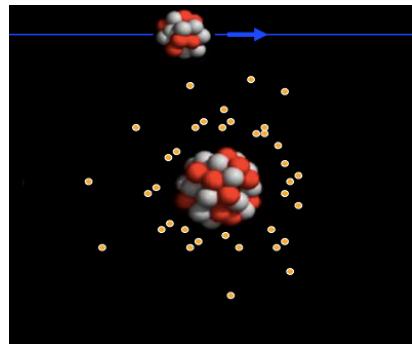


Nuclear Stopping - Recoil of Target Atom

- Coulomb collisions between the ion and the atom
- Displaced target atom can produce permanent effects in electronics
 - Can be annealed to recover functionality
- Rogue charge is also generated
- Other interactions that cause displaced atoms
 - Nuclear reaction
 - Fission



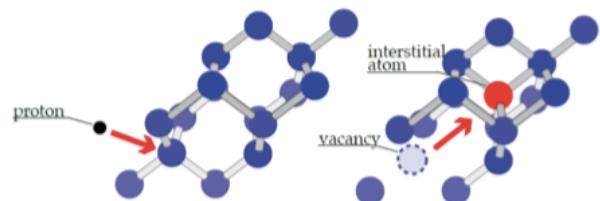
Metrics of Interest for Nuclear Forces



C.J. Dale et al., "A Comparison of Monte Carlo and Analytic Treatments of Displacement Damage in Microvolumes, IEEE TNS, Vol. 41, 1994.

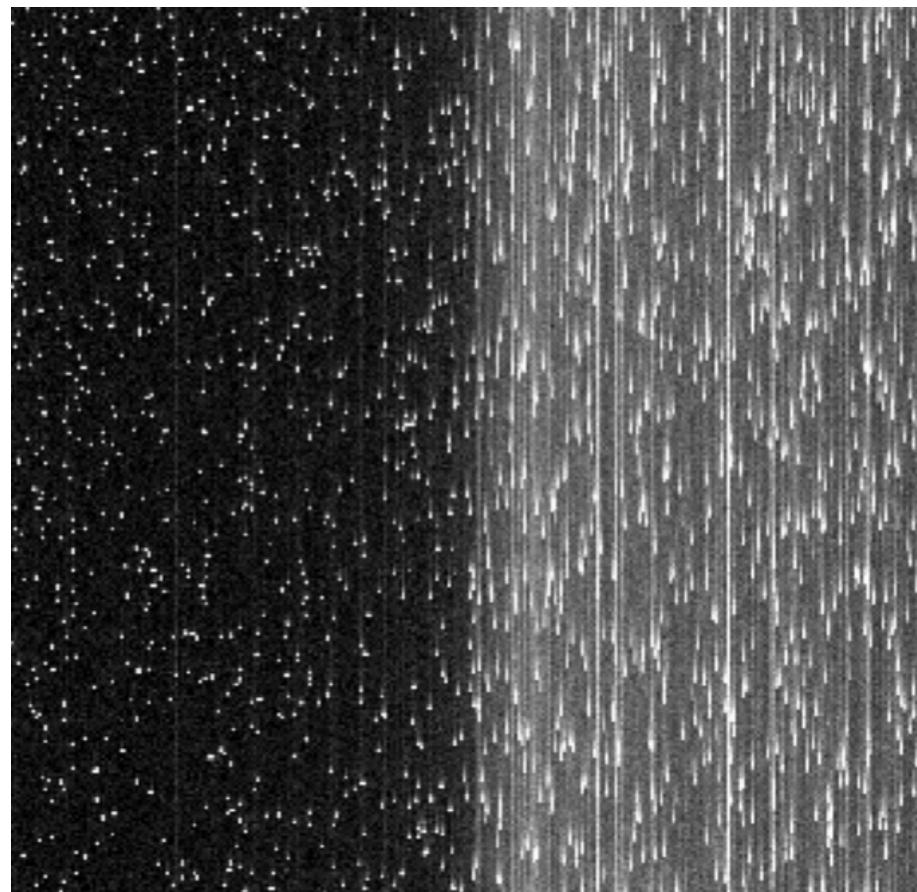
$$\text{Displacement Damage Dose (DDD)} = \text{NIEL} * \text{Fluence [MeV/g]}$$

Displacement Damage in an Imagers



Si displacement damage

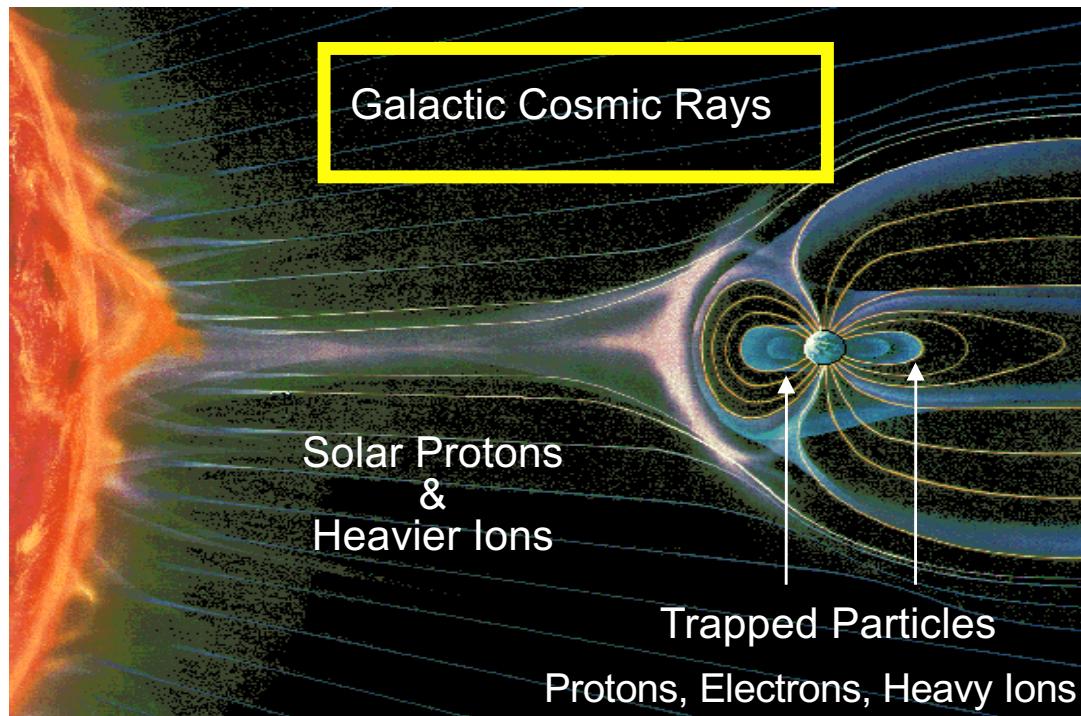
- Displacement damage in the silicon lattice
- Produces places where charge is temporarily trapped and later released
- Exposure for two DDDs



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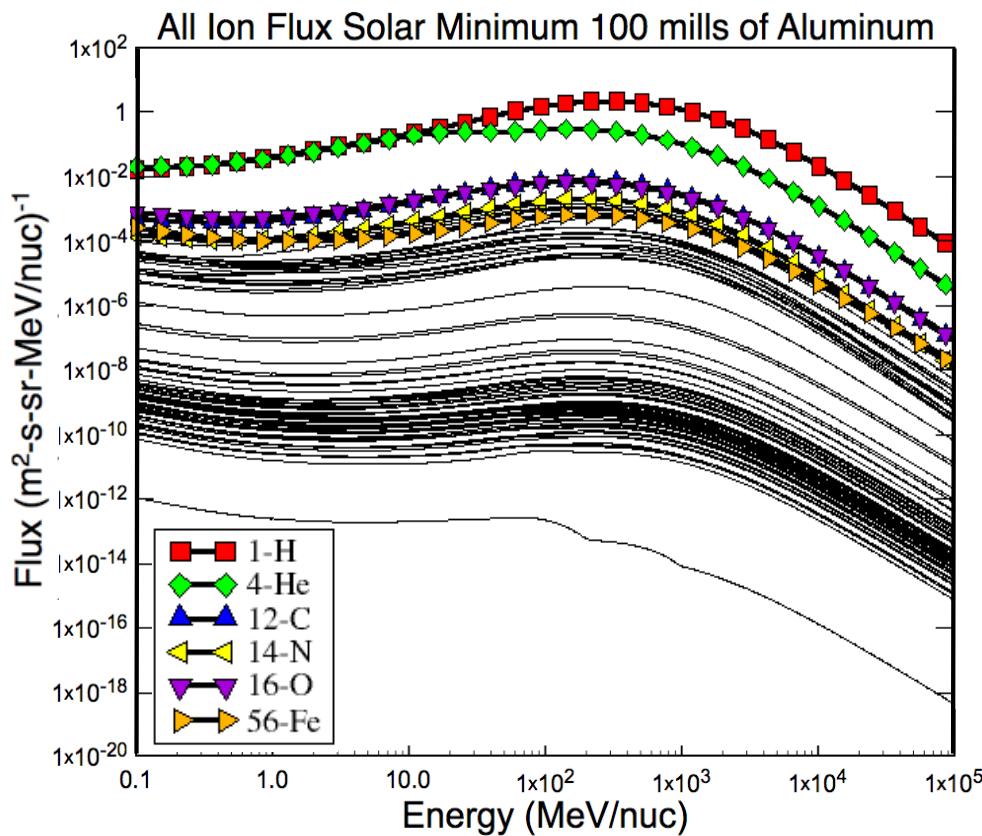
Space Radiation Environment



Nikkei Science, Inc. of Japan, image by K. Endo

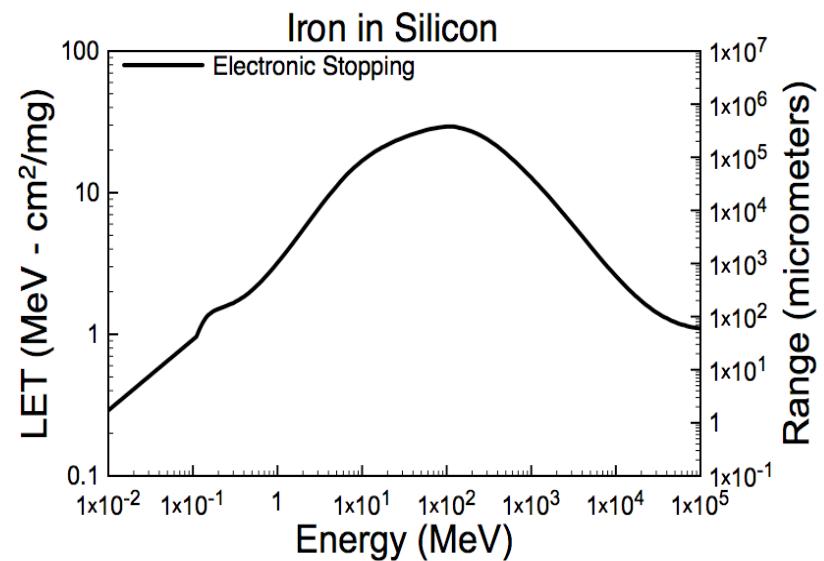
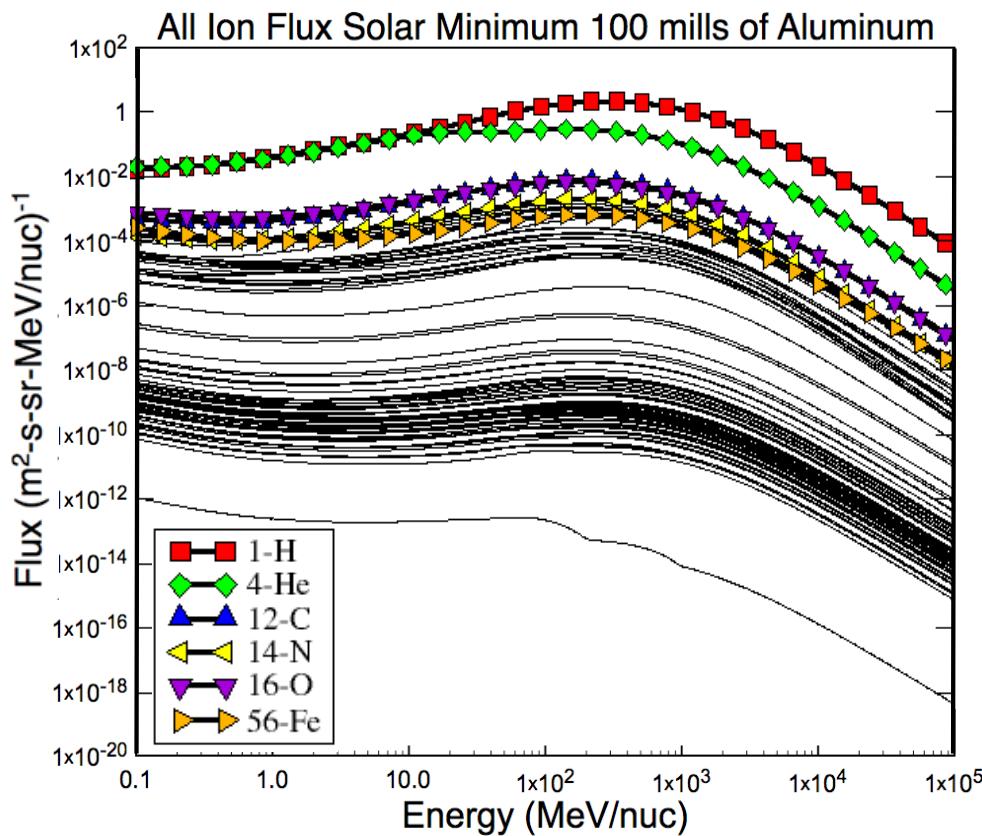
Galactic Cosmic Rays

Typically only important for SEE



Galactic Cosmic Rays

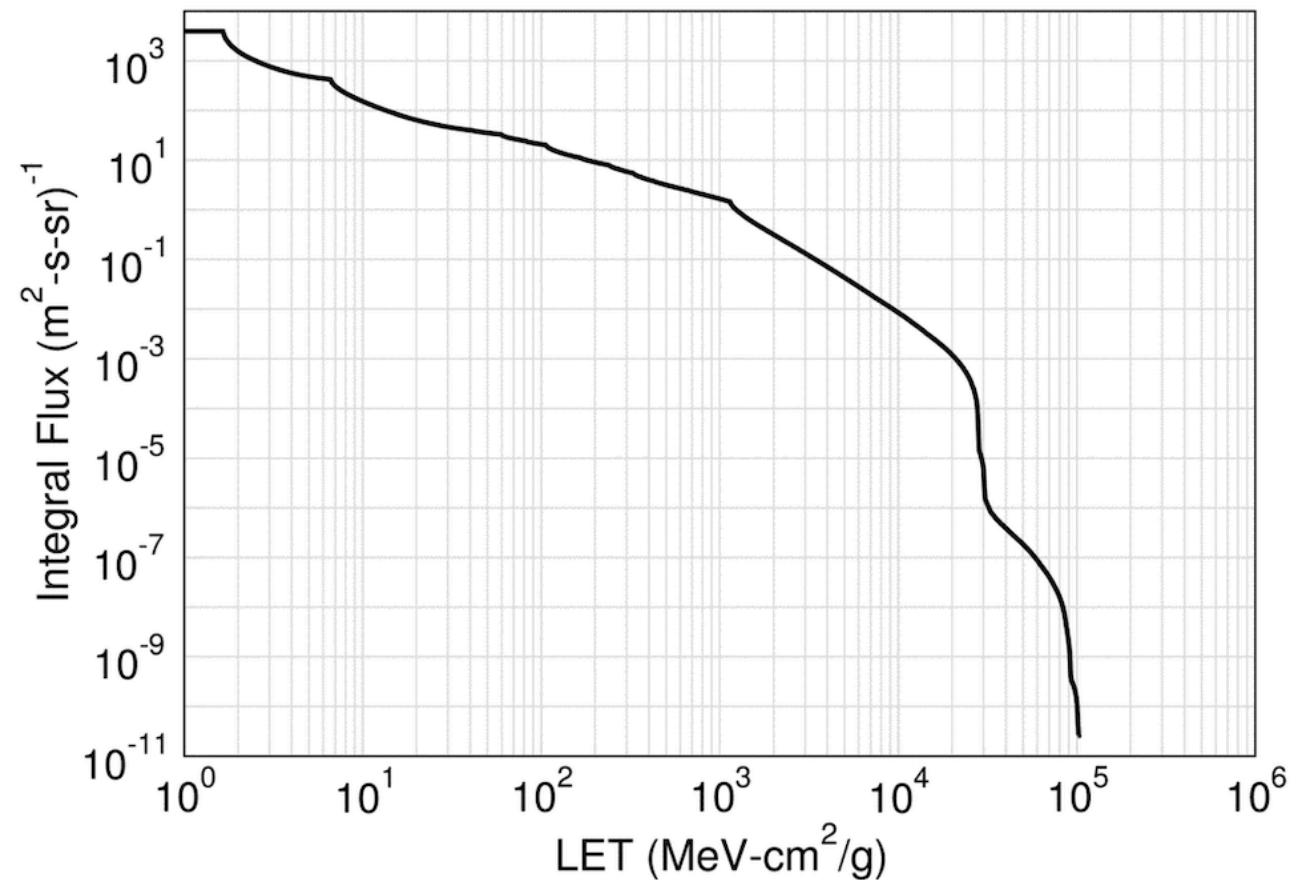
Typically only important for SEE



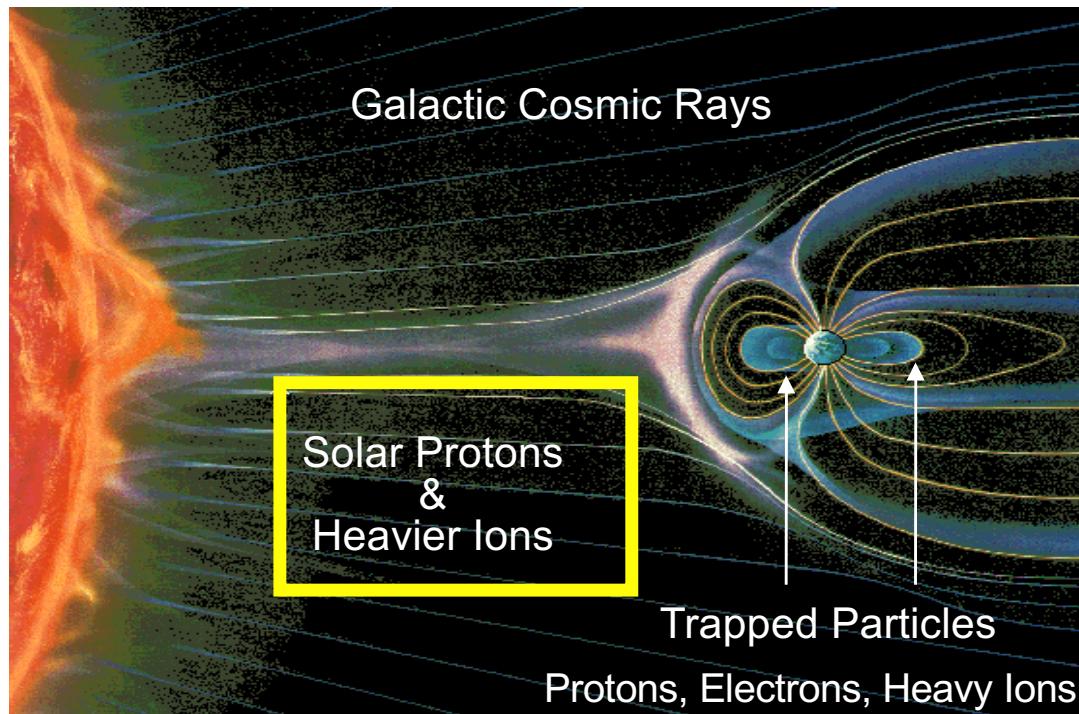
- Lower mass incident particle in Silicon, Lower LET
- Iron incident on Higher mass material, Higher LET

LET Spectrum – Typical Requirement for GRC Induced SEEs

- LET spectrum combines all the particles in the space environment into one, simple spectrum
- Summing of the flux for each species and energy that has an LET within a defined range of LET values

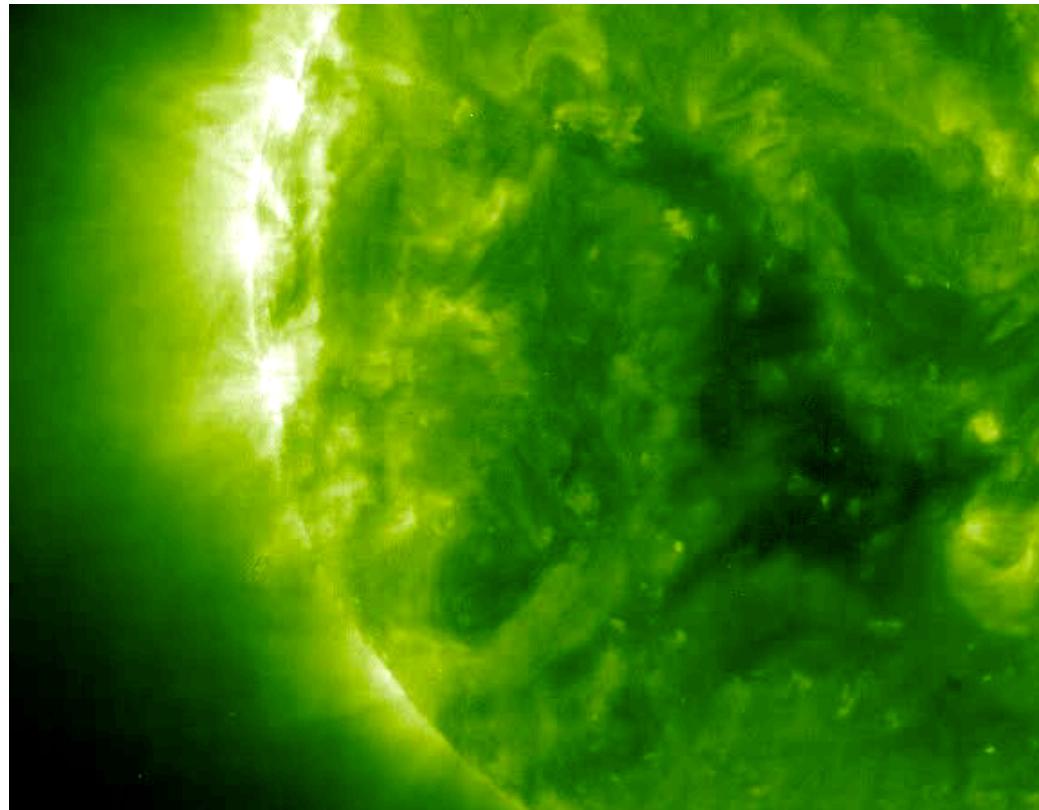


Space Radiation Environment



Nikkei Science, Inc. of Japan, image by K. Endo

Solar Particle Events

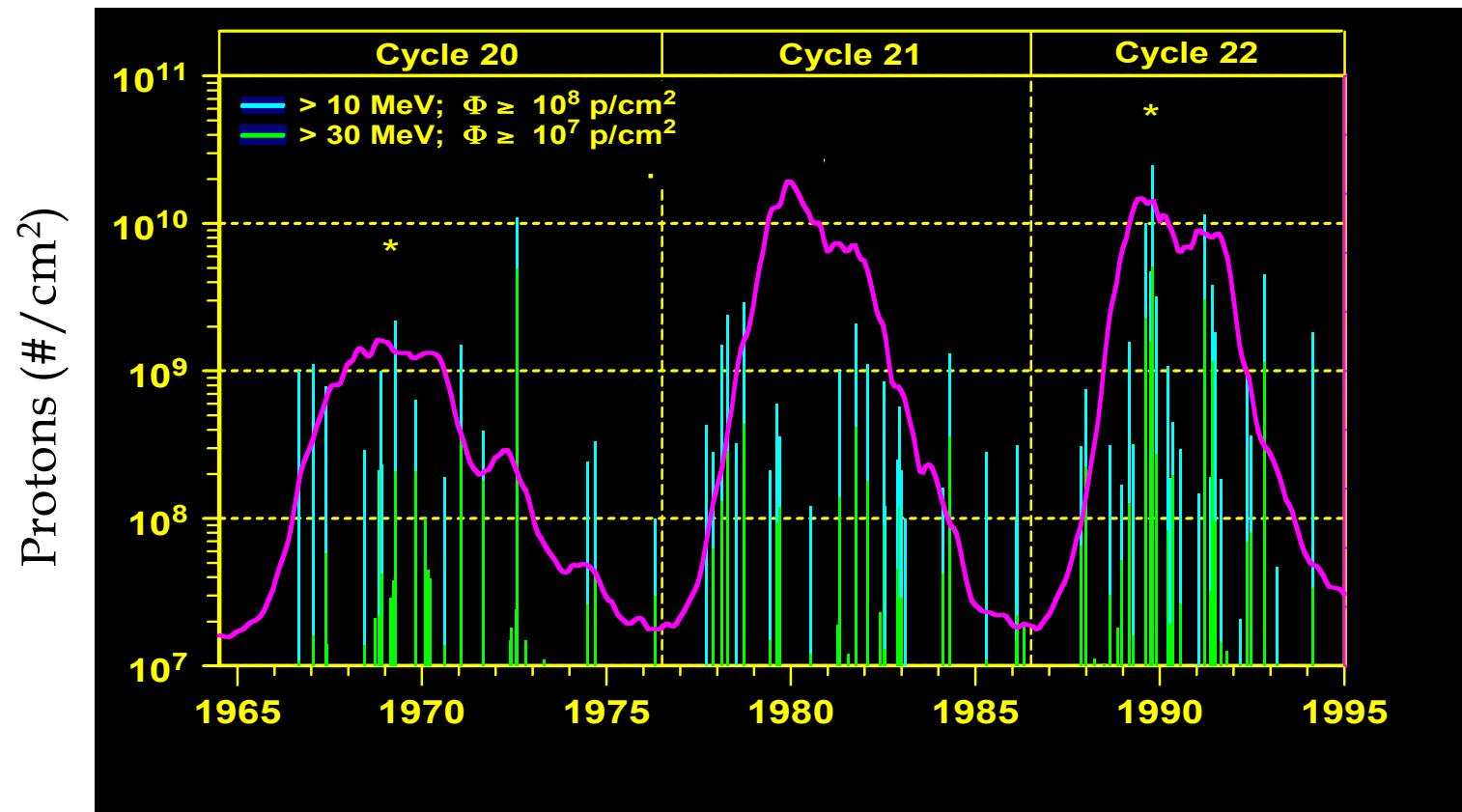


Can produce SEEs, TID, and DDD

WWW.NASA.GOV

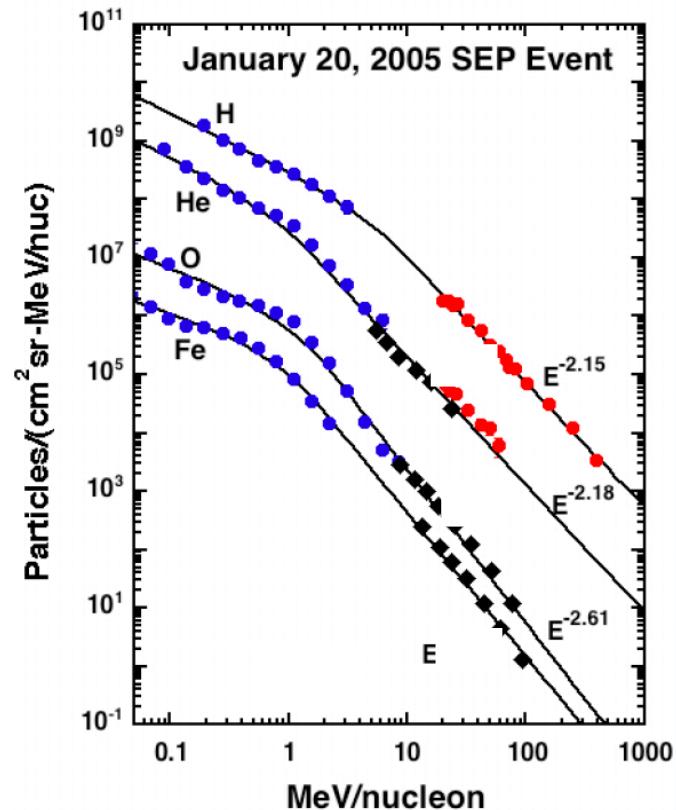
Solar Proton Events

Proton Event Fluence



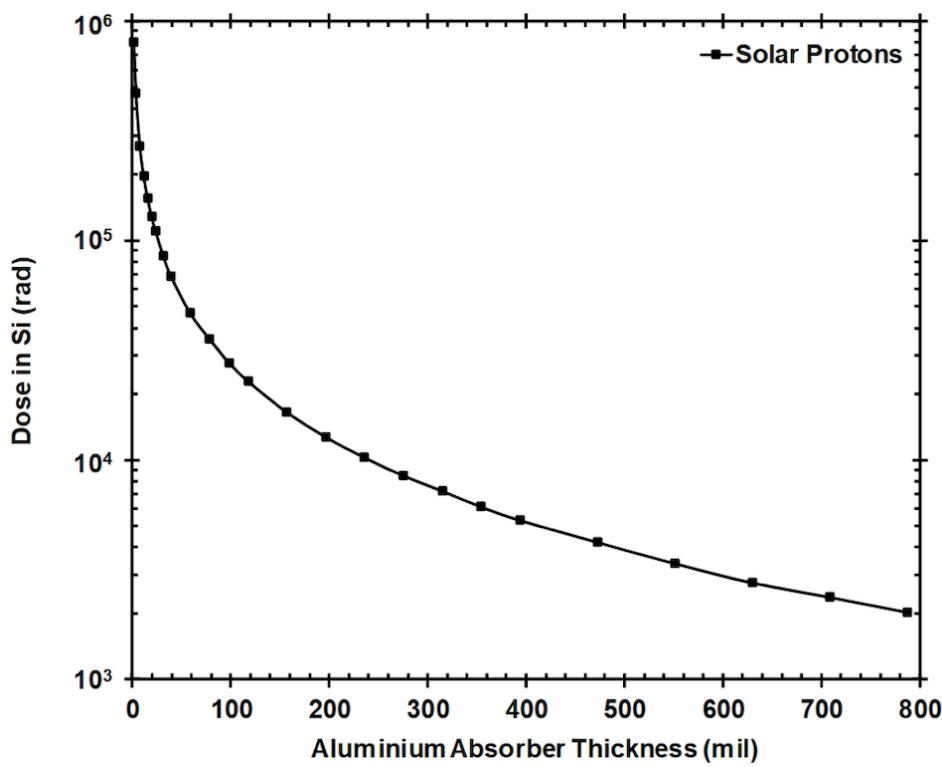
Solar Event Spectra

- Solar spectra varies from one event to the next
- Coronal Mass Ejection
 - Dominated by protons
 - SEE and DDD (nuclear interactions)
 - TID (ionization)
- Certain events contain increased heavy ion ($Z>2$) component
- These types of spectrum are used to define SEE requirements

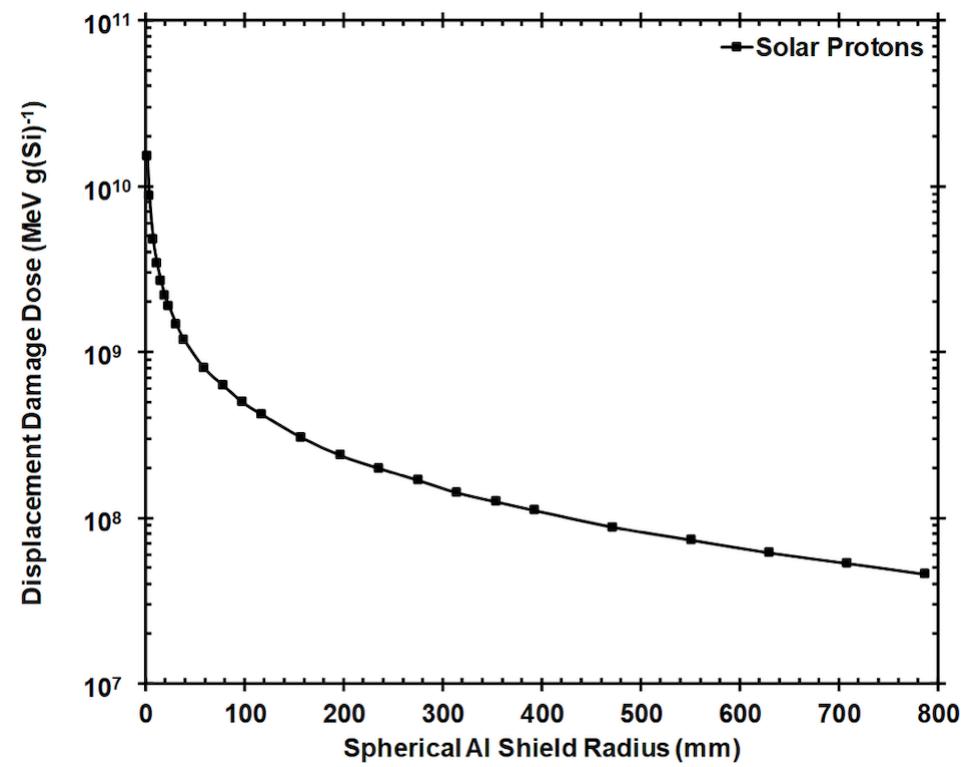


Typical requirements for TID and DDD for a spacecraft at GEO

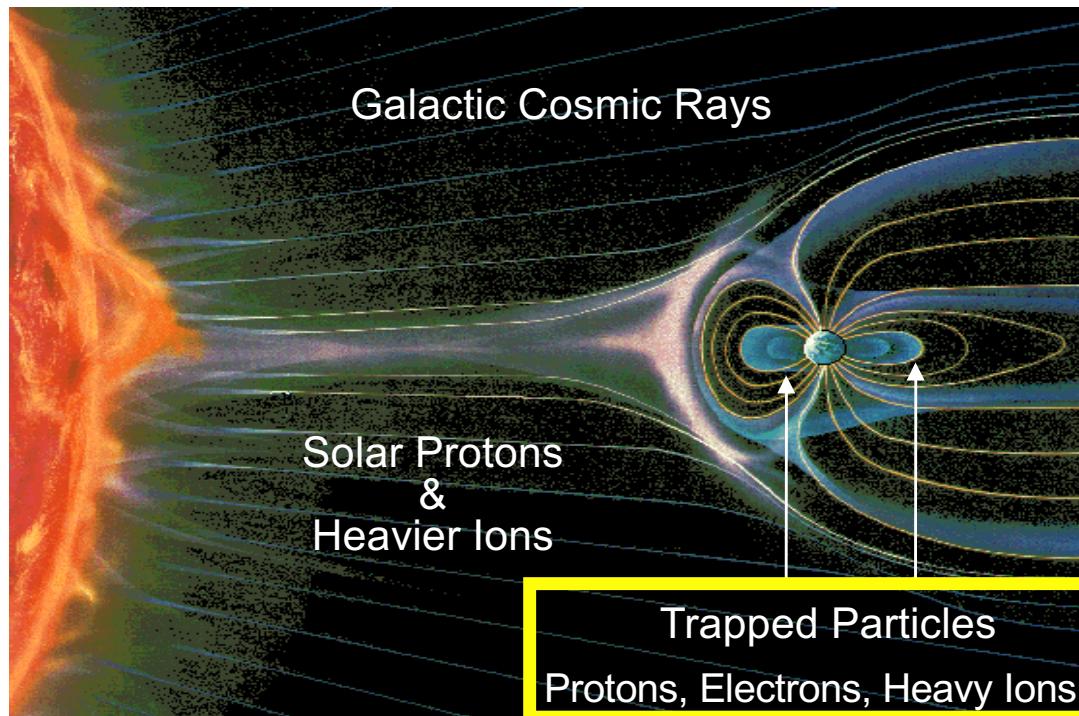
Total Ionizing Dose



Displacement Damage Dose

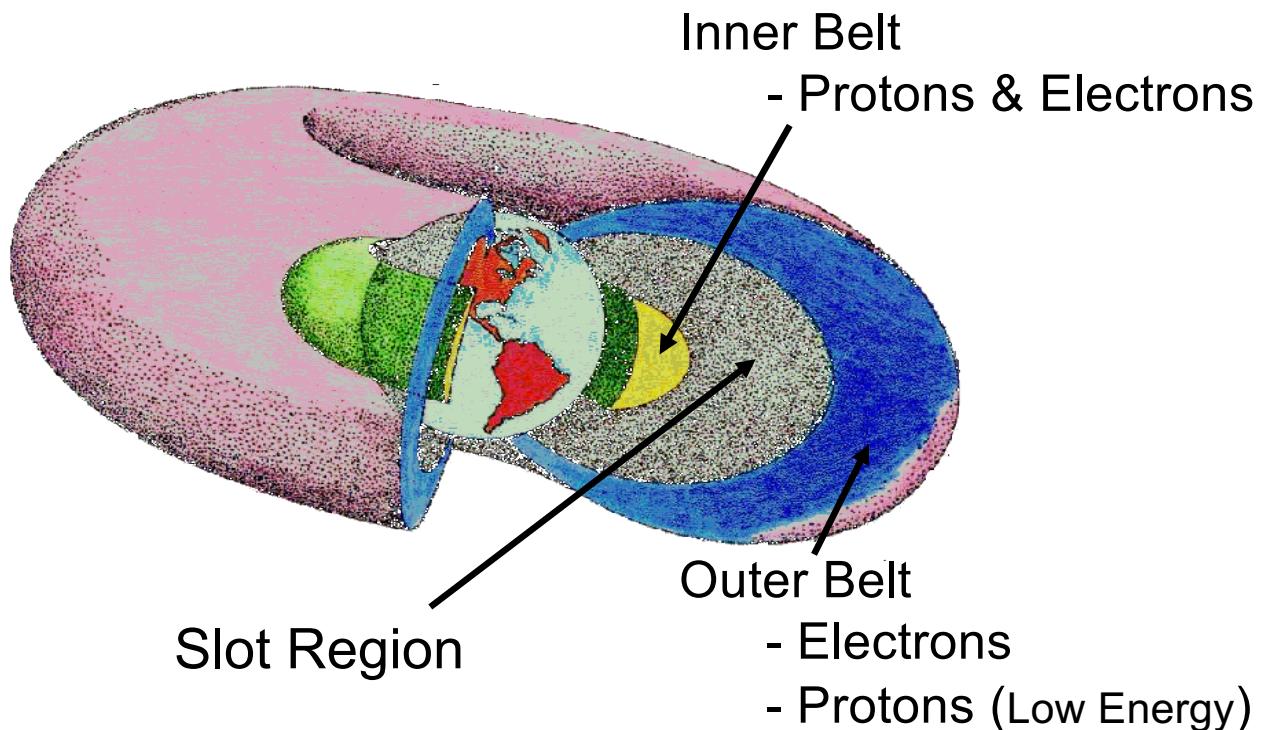


Space Radiation Environment



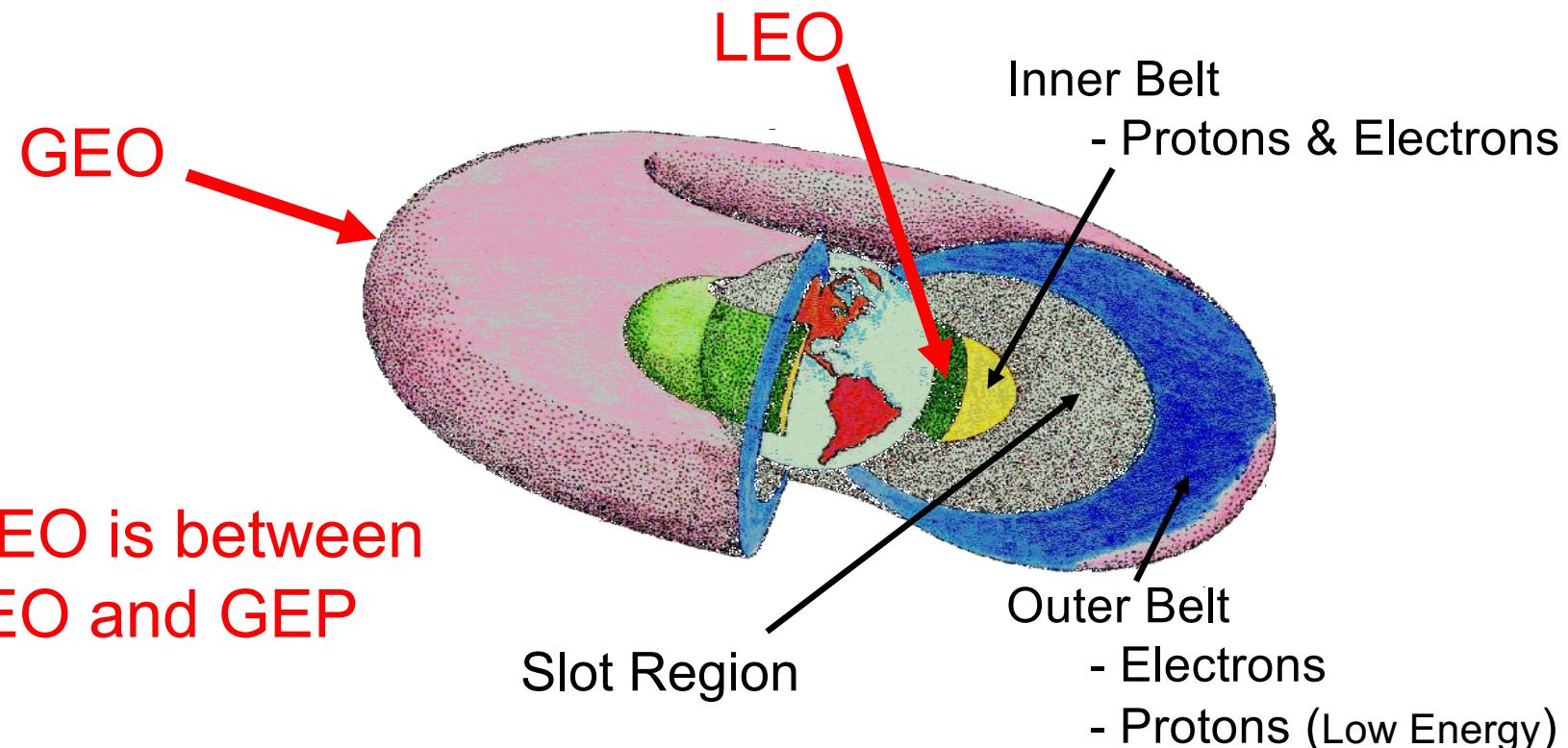
Nikkei Science, Inc. of Japan, image by K. Endo

Van Allen Proton and Electron Belts



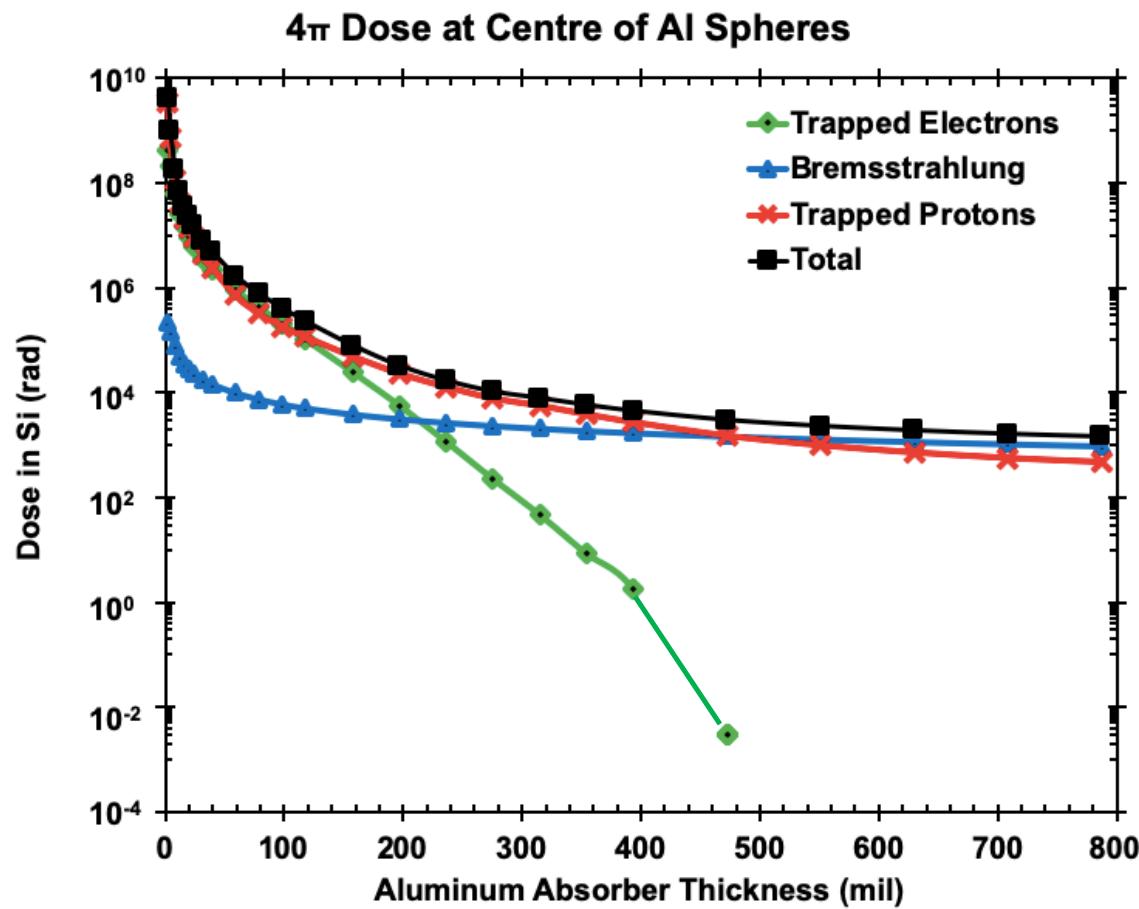
Can produce SEEs, TID, and DDD

Van Allen Proton and Electron Belts



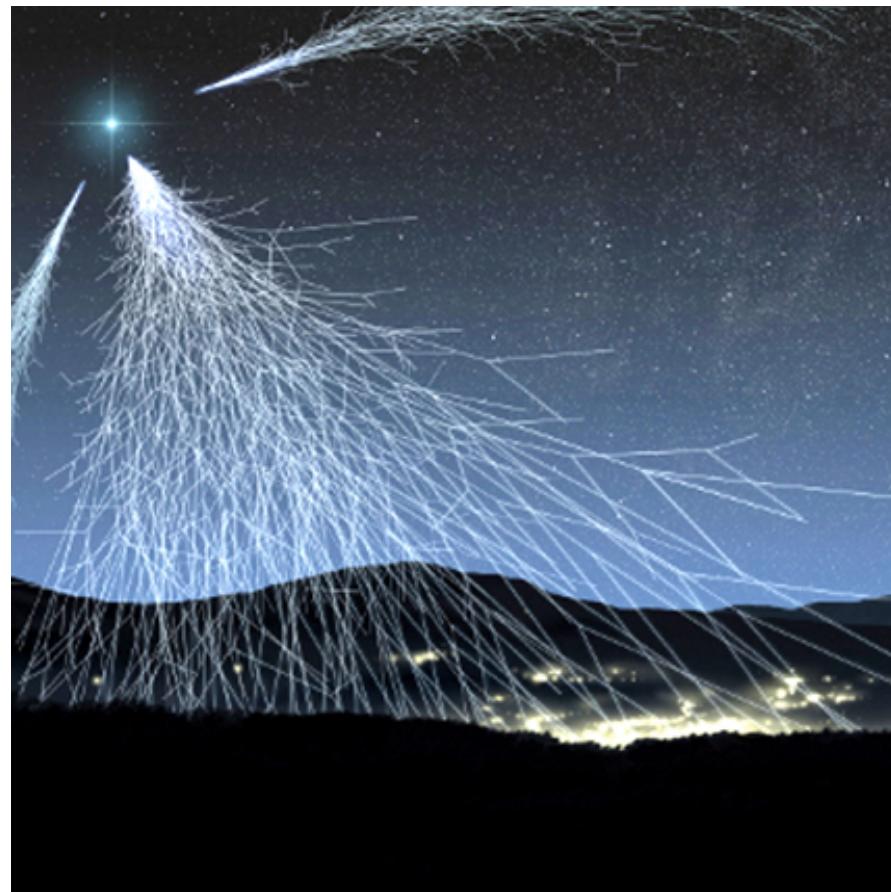
Can produce SEEs, TID, and DDD

Comparison of TID requirements for a spacecraft at MEO



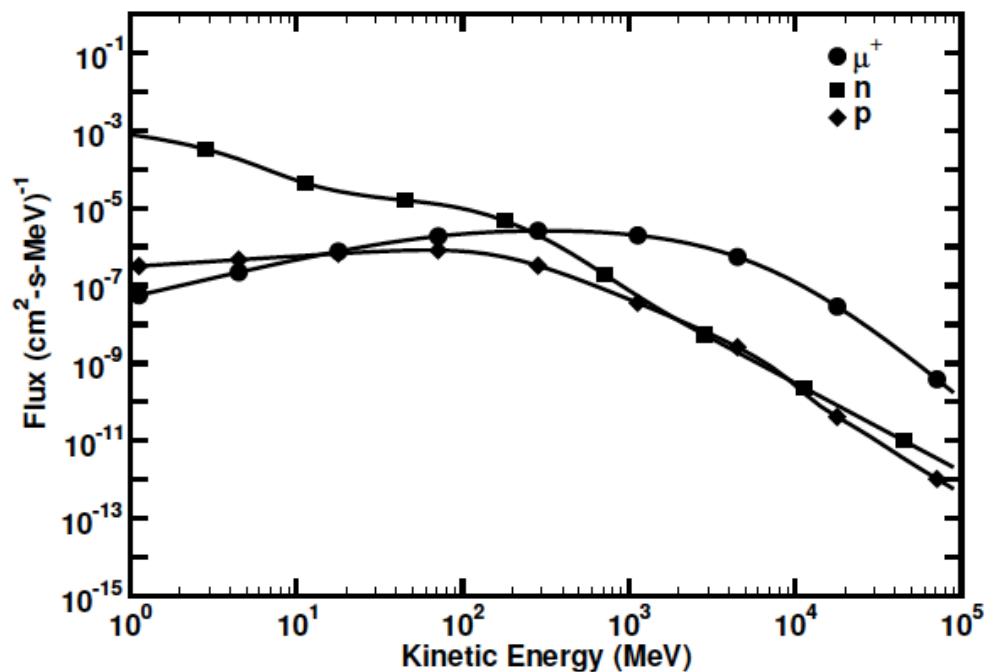
Note: Bremsstrahlung is photon production during electron energy loss

Terrestrial Radiation Environments



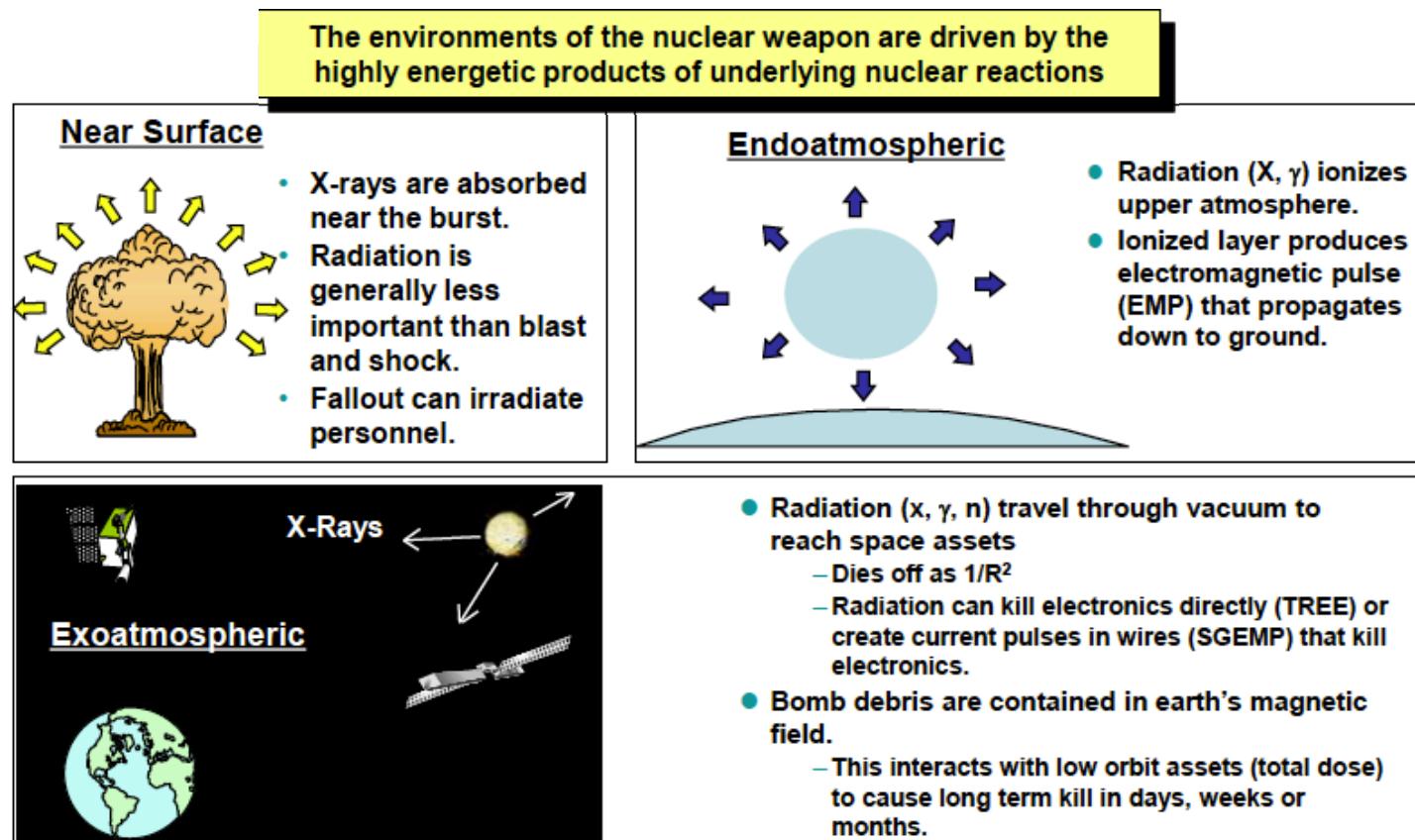
Terrestrial Particle Environment

- Particle showers produced from interaction of GCR ions with the atmosphere
- Flux depends on strongly altitude
 - Denver, CO has higher flux than Hawthorne, NY
- Primary concern is SEE



(Unclassified)

Radiation Output of Nuclear Weapons



Conclusions

- Key interactions of radiation with matter
 - Ionizing energy lose (LET)
 - Non-ionizing energy lose (NIEL)
- Models are used to predict the space environment
 - Orbit dependence
 - Shielding dependence
 - Time dependence (launch date and mission duration)
- Mission requirements are derived from the output of these model
 - LET flux spectrum (SEE)
 - TID versus shielding
 - DDD versus shielding