Modelling the space radiation environment

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ESA / ESTEC

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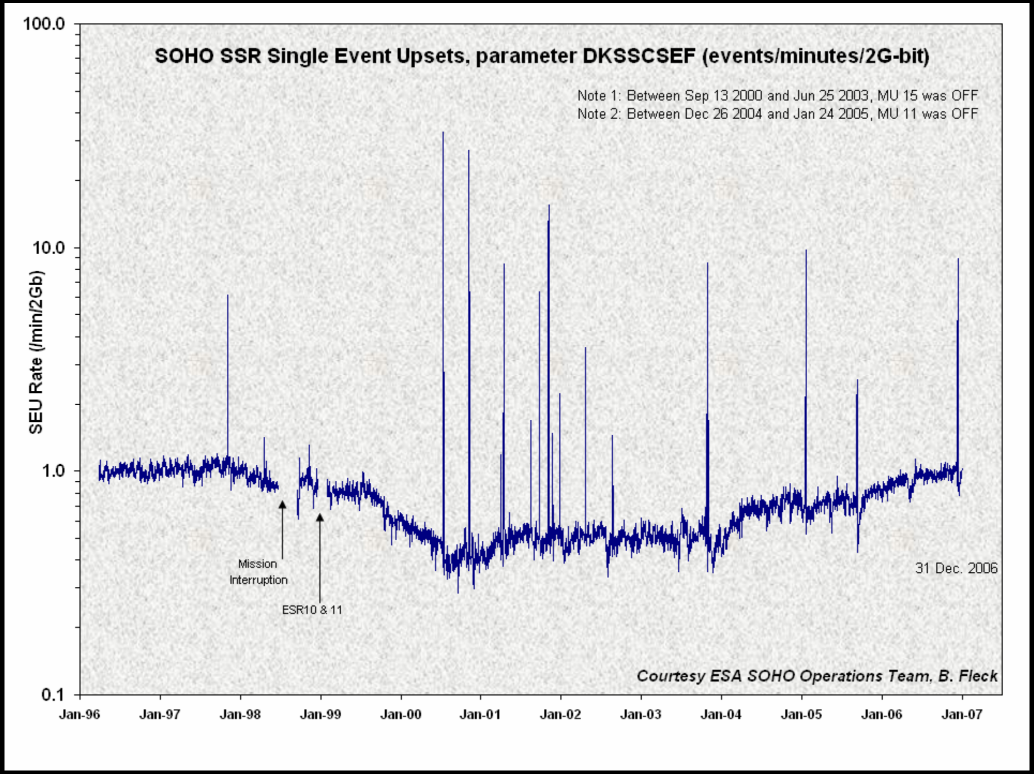
Single Event Effects



Outline

- Radiation sources
- SEE modelling
- From space environment to LET and SEE rates

The Space Radiation Environment

(Extra) Galactic and anomalous Cosmic Rays

Protons and Ions

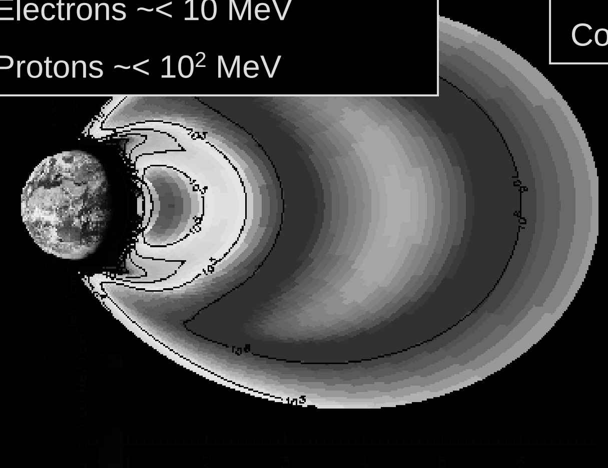
$\langle E \rangle \sim 1$ GeV, $E_{max} > 10^{21}$ eV

Continuous low intensity

Trapped radiation

Electrons ~< 10 MeV

Protons ~< 10^2 MeV

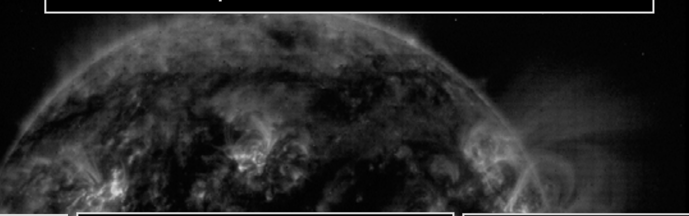


Solar radiation

Protons, some ions, electrons, neutrons, gamma rays, X-rays…

Softer spectrum

Event driven – occasional high fluxes over short periods.



Others

Jovian electrons

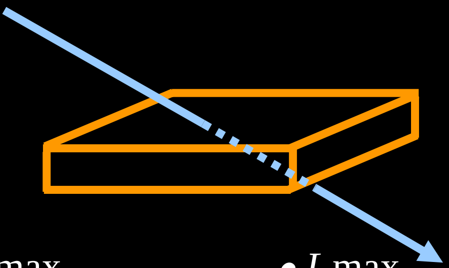
Man-made sources

…

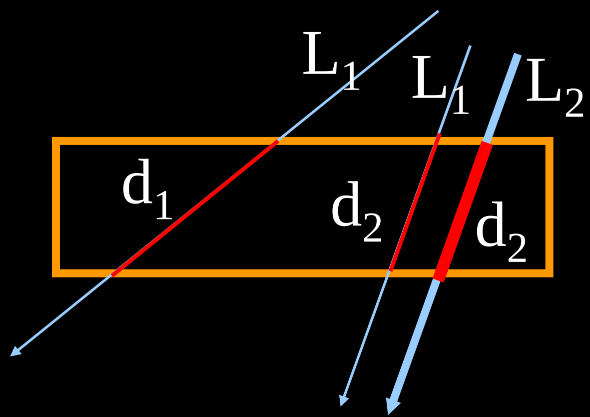
Effects

Single Event Effects	Degradation	Charging	Background	Threats to life
Trapped and solar protons GCR and solar heavy ions Neutrons	TID: Trapped protons and electrons, solar protons NIEL: protons, electrons	Electrons	All particle species	Solar protons Heavy ions

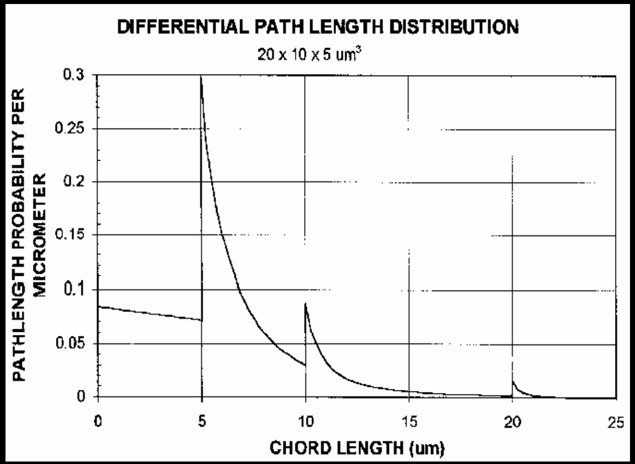
SEE: basic mechanisms



$$U = S/4\int_{Ec/L\max}^{l\max} p(l) \int_{Ec/l}^{L\max} f(L)\,dL\,dl$$



If d x LET > Q_c , get upset



Simplifications / Assumptions !

Density of energy deposition: LET

$$\frac{dE}{dx} = -\frac{4e^4 z^2 N_A Z}{mv^2 A} B_i$$

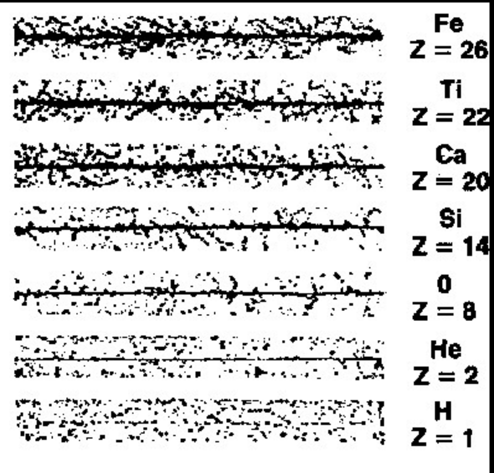
z : ion charge number

Z : material charge number;

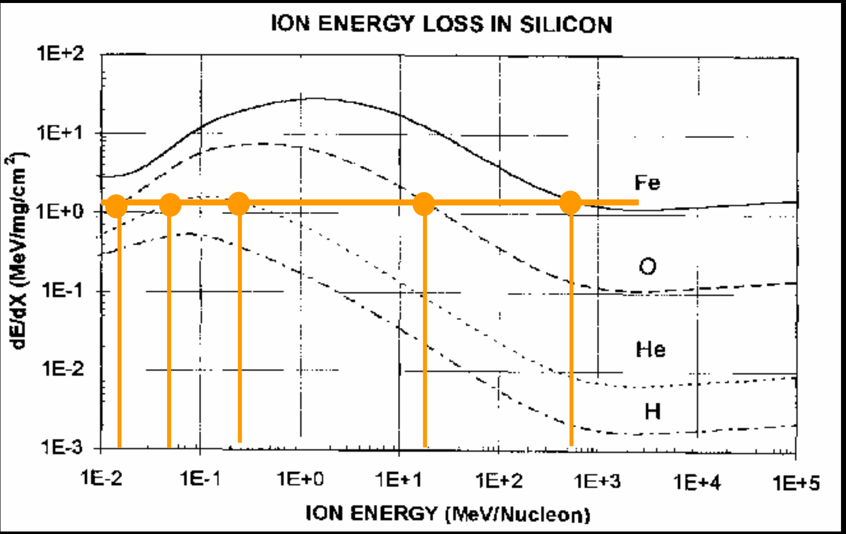
N_A : Avogadro's number;

A : Material atomic number

B_i : material dependent correction



Cosmic ray ion tracks in a photographic emulsion.

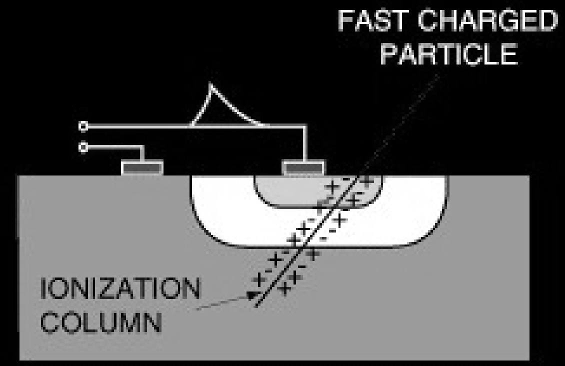


- LET function of ion energy
- Exploited for tests at ion accelerators

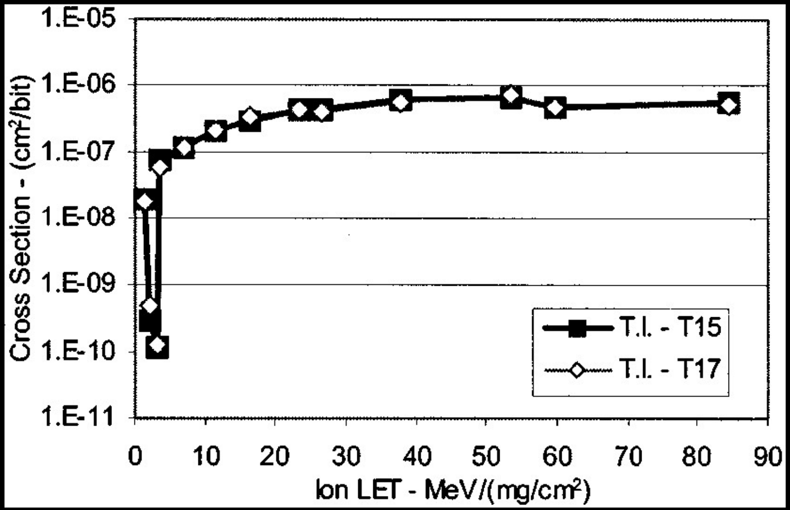
Simplifications / Assumptions !

Ion induced SEUs

- High LET → sufficient to deposit more than critical charge
- SEU induced via direct ionisation

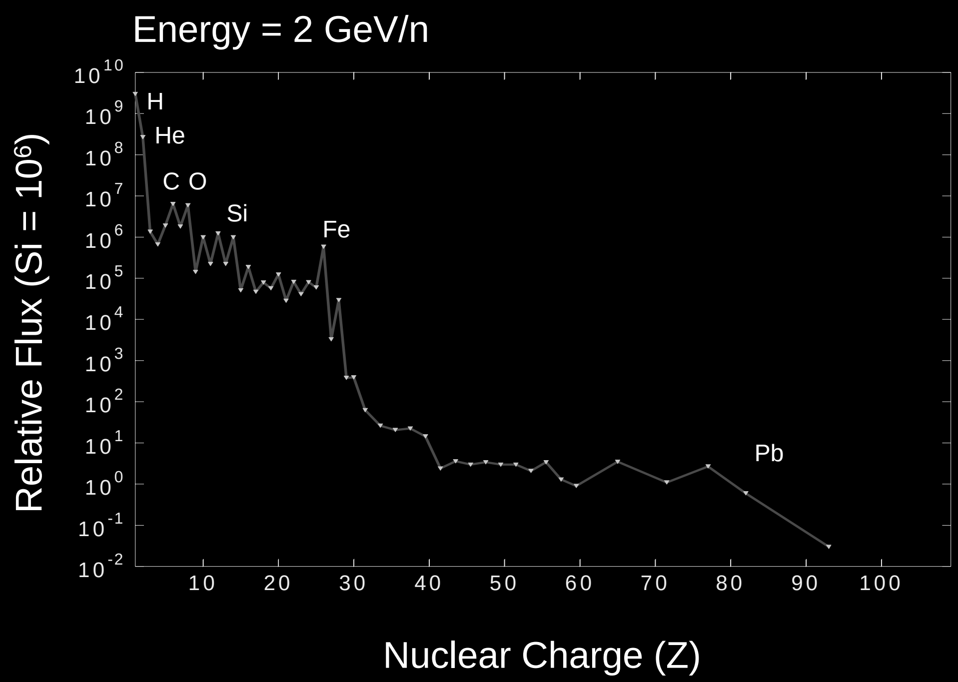


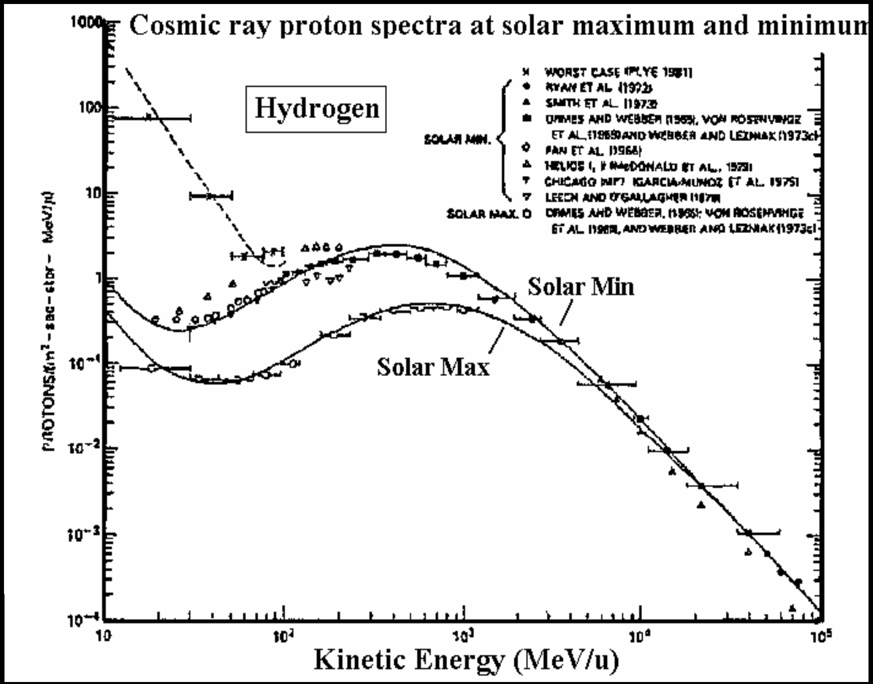
- SEU Cross Section expressed as function of proton energy



R.Harboe Sørensen et al, IEEE-TNS, 2002

Cosmic Ray ions

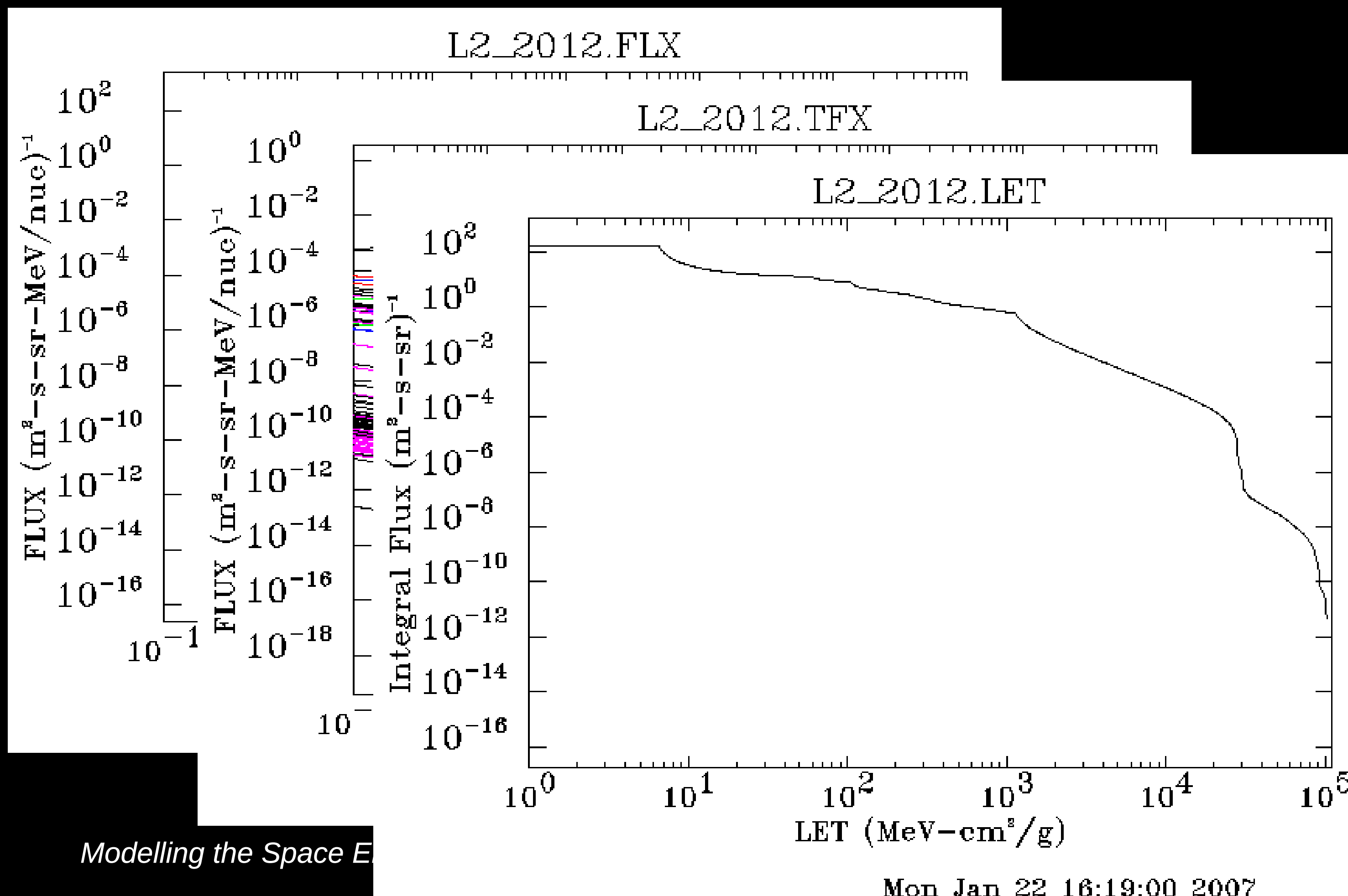




Adams (NRL reports in “CREME series”)

LET integral spectrum

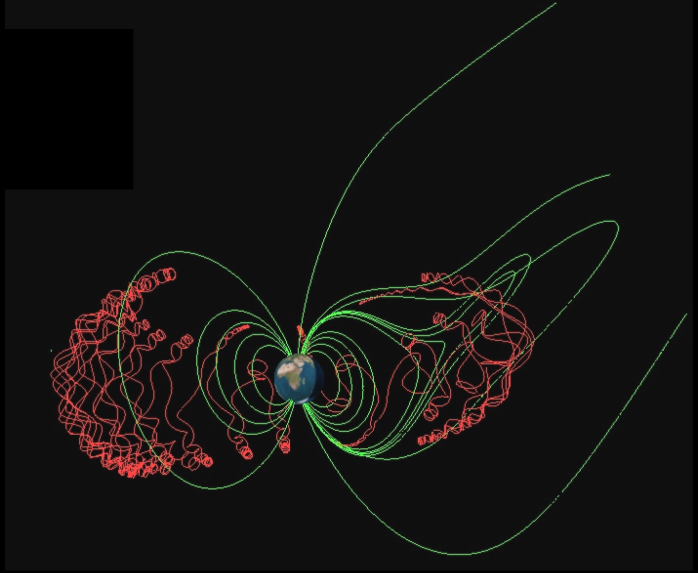
- Combines all ions into one curve
- Total number of particles with a given LET (so combines slow low-Z ions with fast high-Z ions)

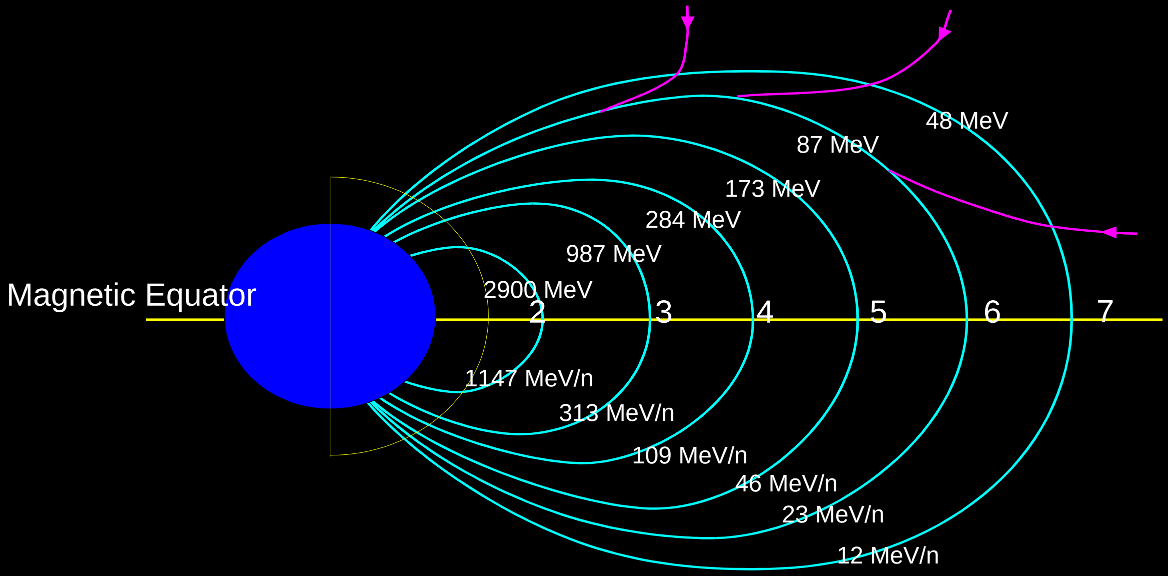


- Provides direct ionisation component only!

Geomagnetic shielding

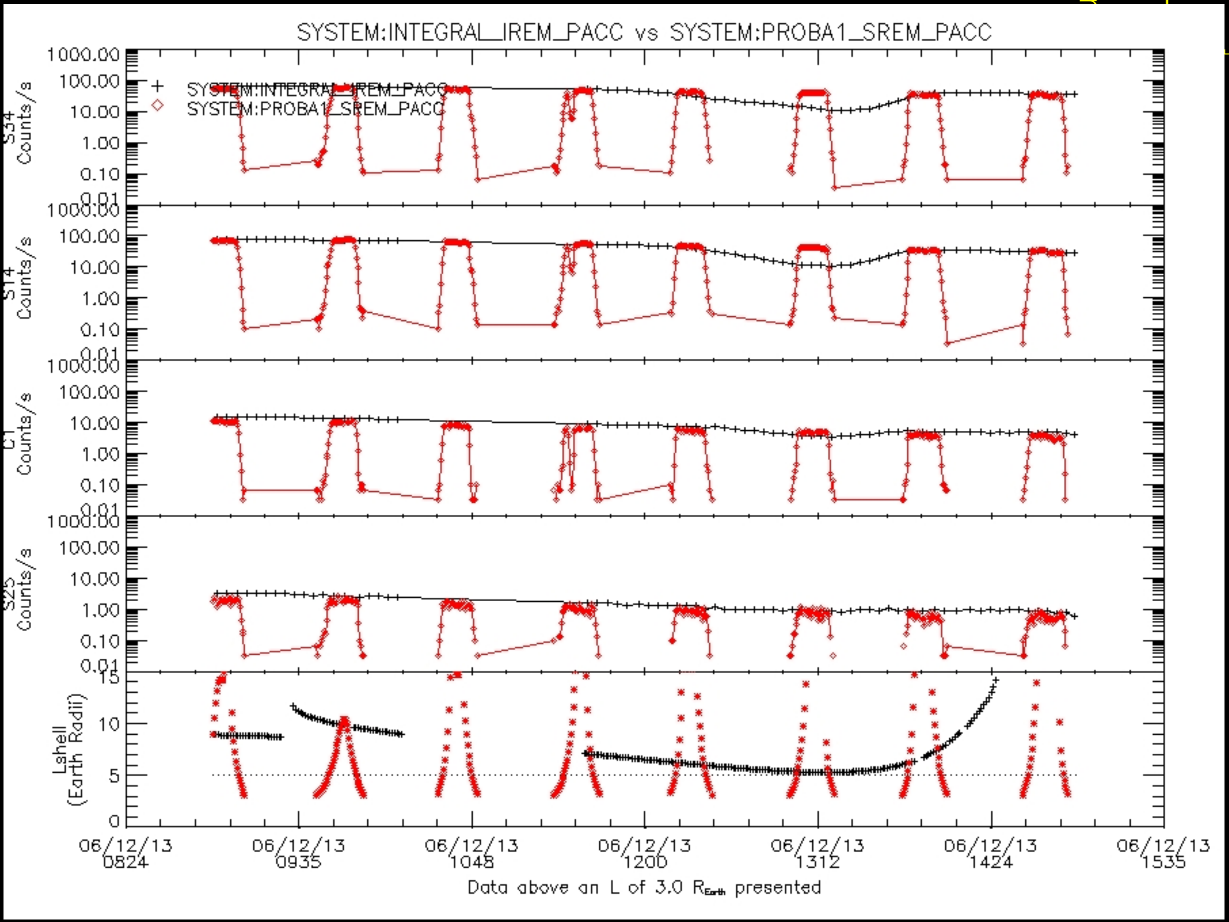
- Within the magnetosphere
- Størmer theory: regions allowed or forbidden depend on the particle Rigidity (momentum/unit charge)

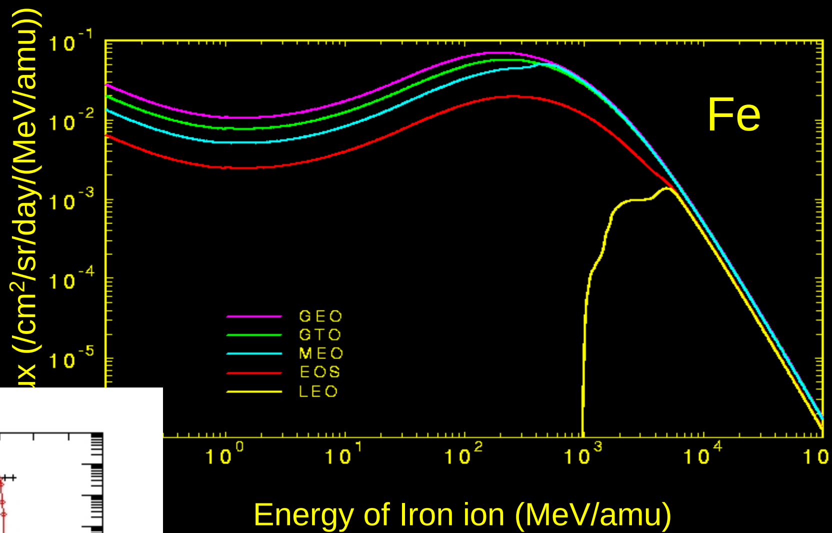




after Stassinopoulos

Geomagnetic shielding (cont.)





SREM

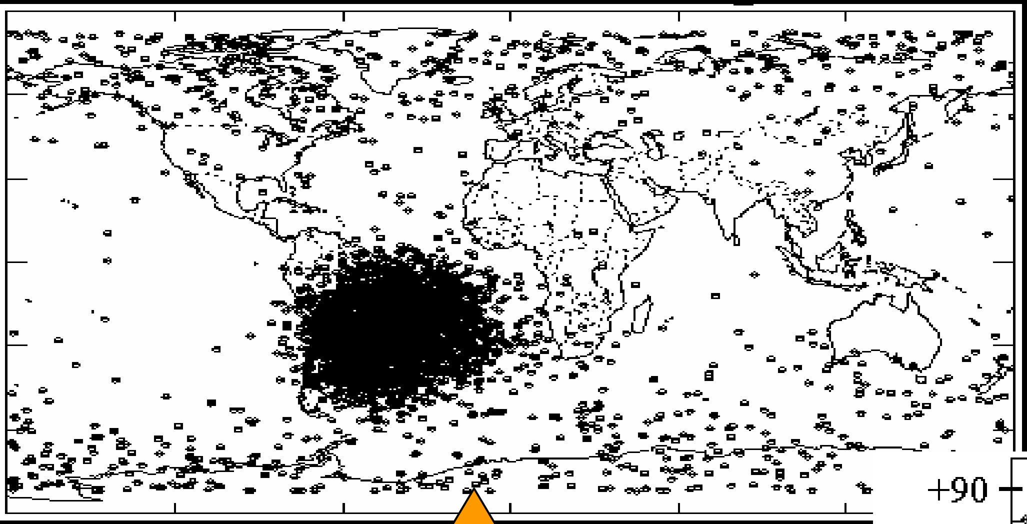
(ESA Standard Radiation Environment Monitor)

Solar Event: Dec 2006

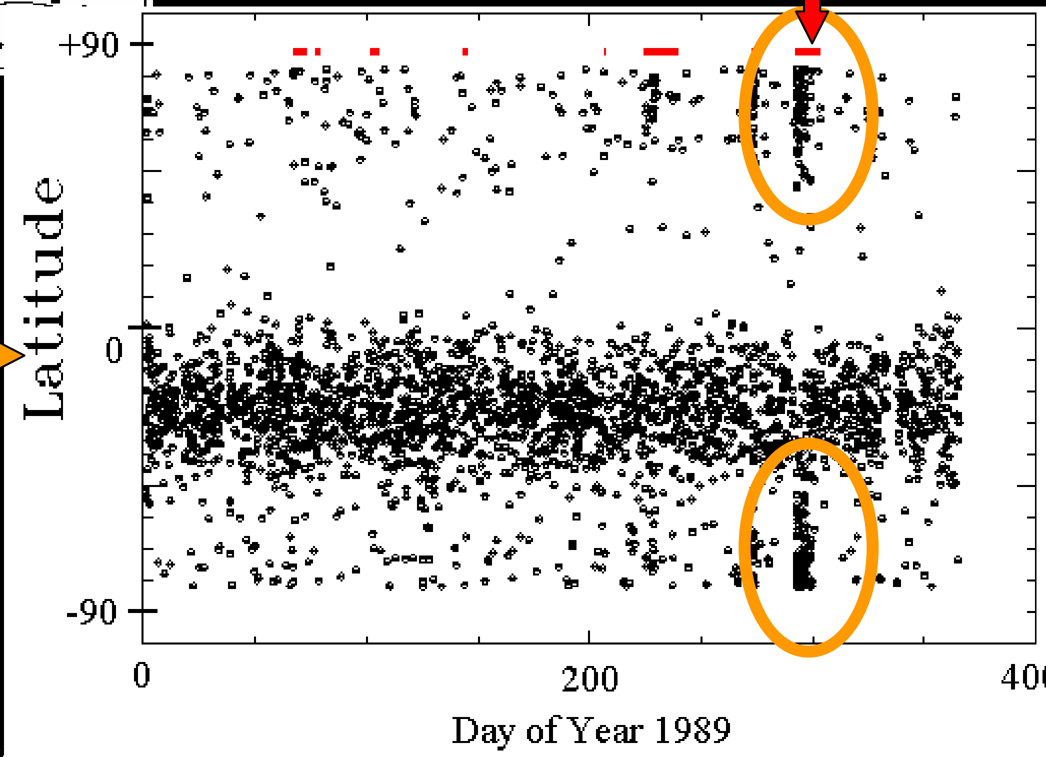
Counts on

Integral VS Proba

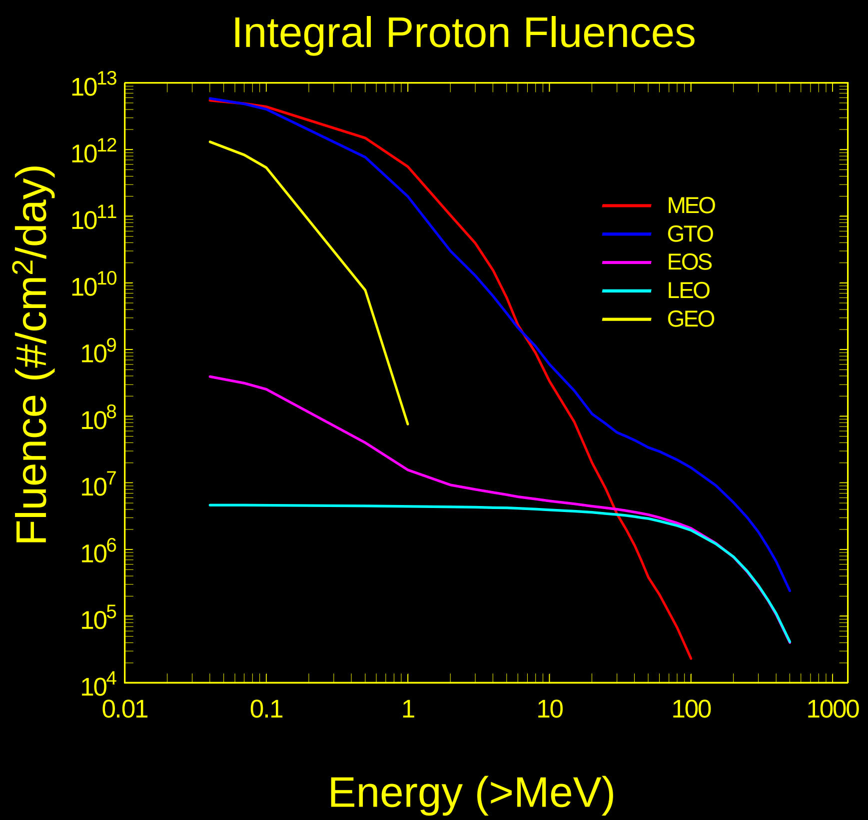
SEU counter on UoSAT-3

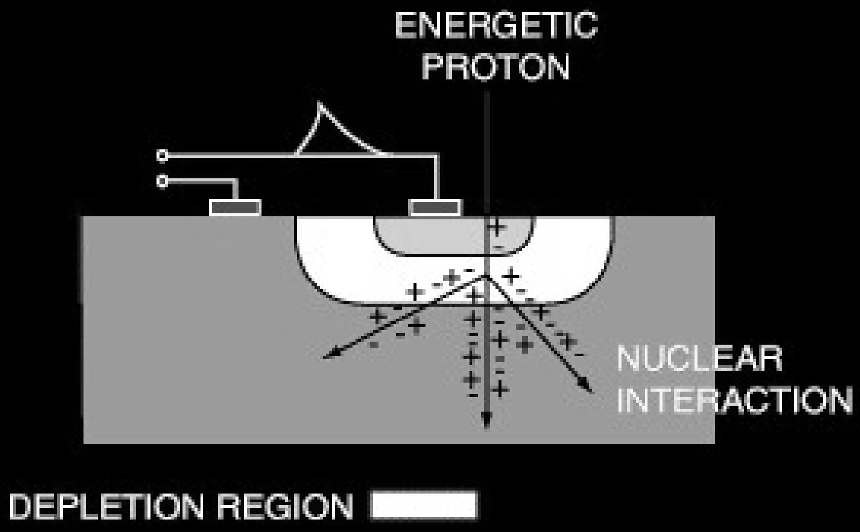


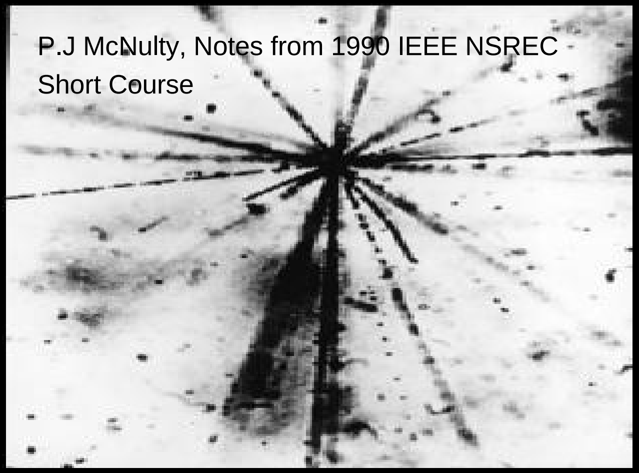
- World map
- Time behaviour



Proton induced SEUs



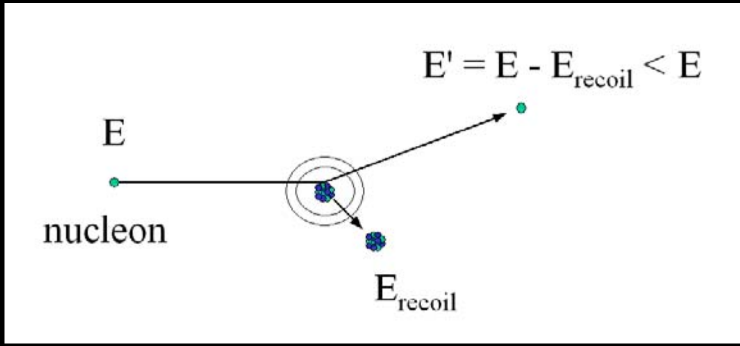


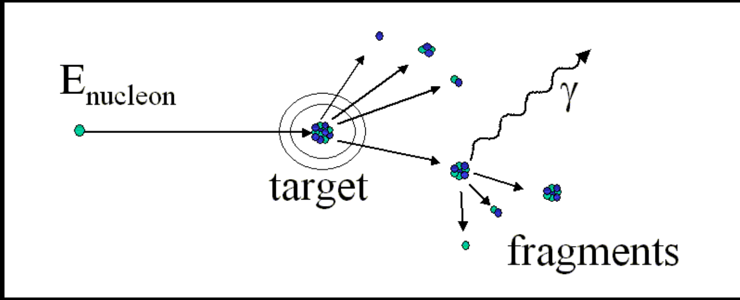


- AP8-MAX spectra

Nuclear collisions

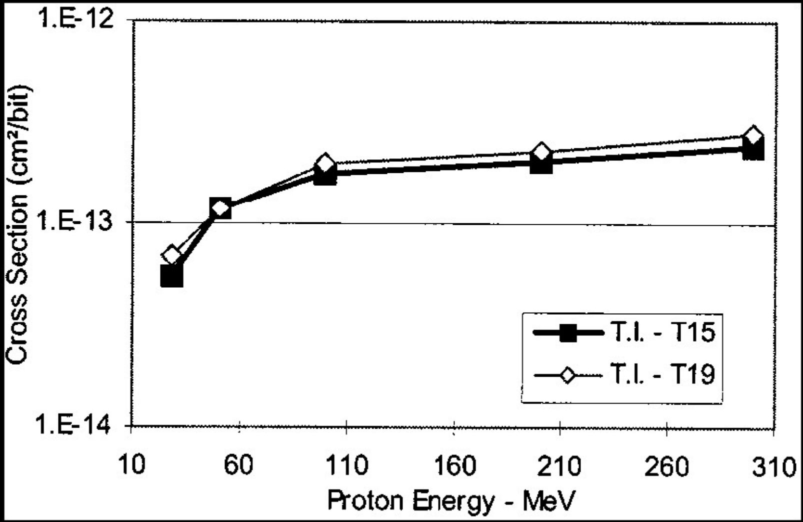
- Nuclear interactions in / near sensitive regions
  - Recoil nuclei from elastic
  - Nuclei fragments, gamma, neutrons from inelastic
- SEU Cross Sections expressed as function of proton energy





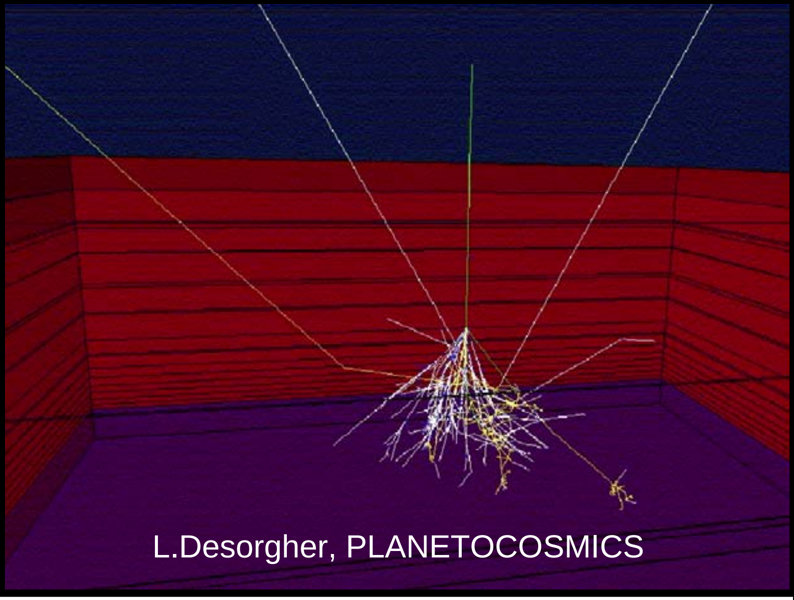
Open issues

- Physics: double differential cross sections
  - Main recoil &
  - Energy and angular distribution of (high-LET) fragments
- Detailed modelling of the vicinity of the sensitive device
  - Geometry
  - Materials



R.Harboe Sørensen et al, IEEE-TNS, 2002

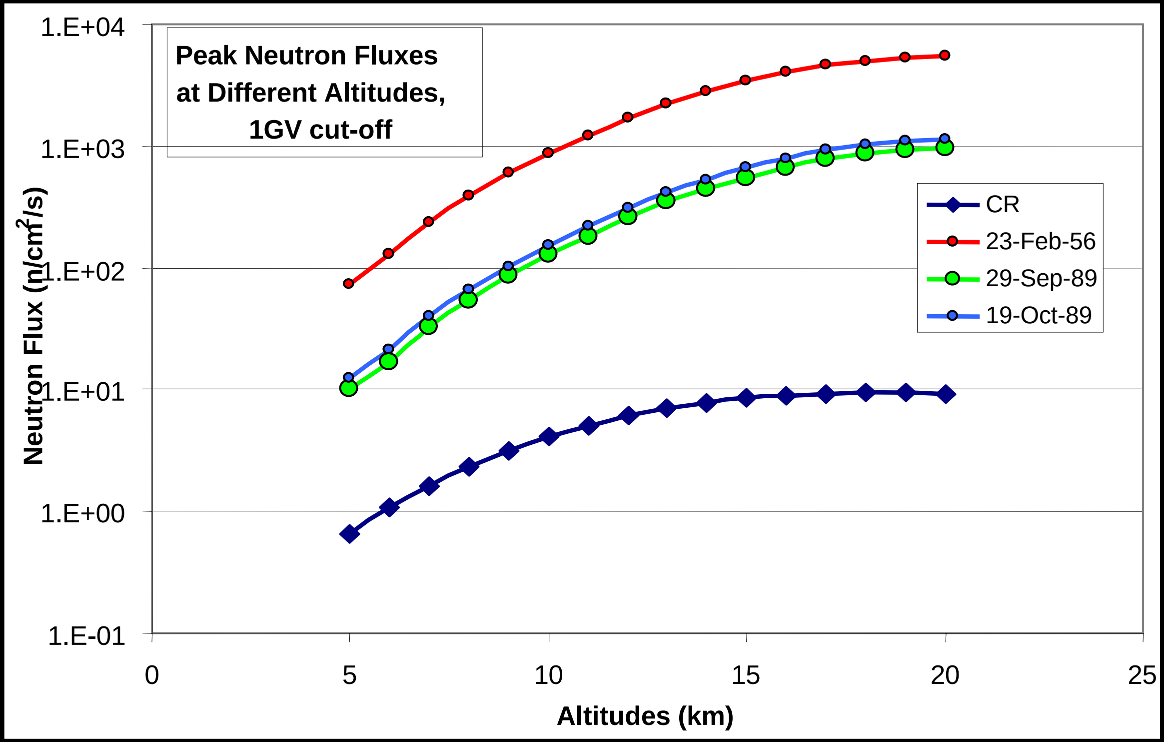
Atmosphere effect
Neutrons



Primary radiation interacts in high atmosphere
→ secondary radiation

Neutron production relevant to

- LEO (e.g. Shuttle)
- Avionics
  - Reliability
  - Dose to crew
- SEE on ground!



CREME suite

De facto standard model for CR ion fluxes

Solar protons?

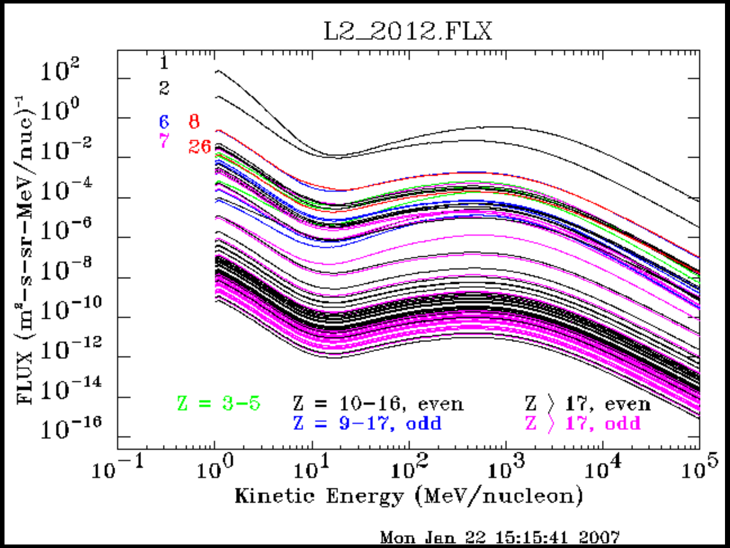
CREME86

- Ions: 8 models, based on limited measurements
- SPE: based on various flare models including Aug 1972

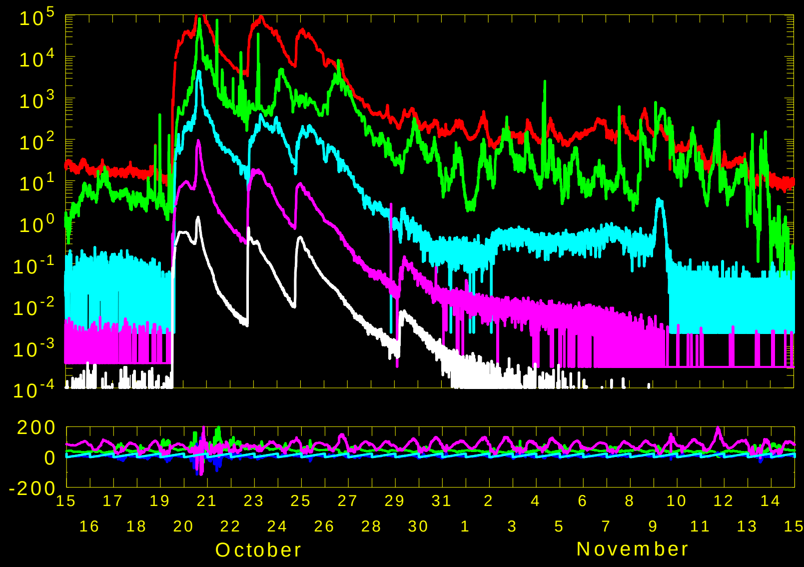
CREME96

- Ions: 3 models, based on IMP-8 data

- Solar Particle Event model
  - Based on October 1989 Event
  - Average over Worst Week, Worst Day, Peak of Event
  - Is it a good model?

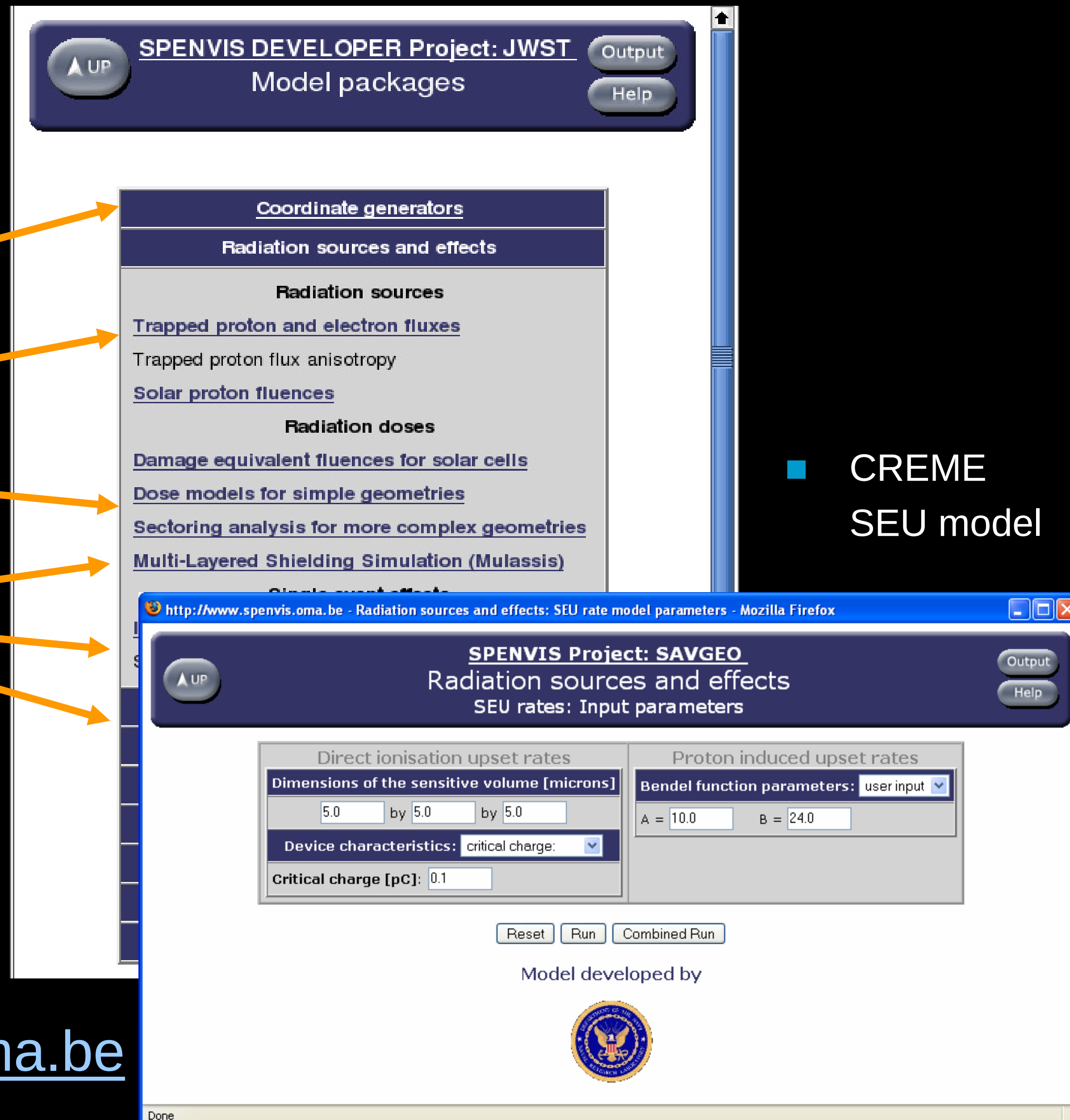


October 1989 SPE - GOES



SPENVIS as analysis framework

- Mission model
  - Orbit, S/C attitude
- Space environment models
- Radiation transport
  - S/C geometry
  - Simulation engine
- Effects Analysis
  - Damage mechanisms
    - TID
    - NIEL
  - Fluence
  - Charging
  - SEE
  - Effects to humans



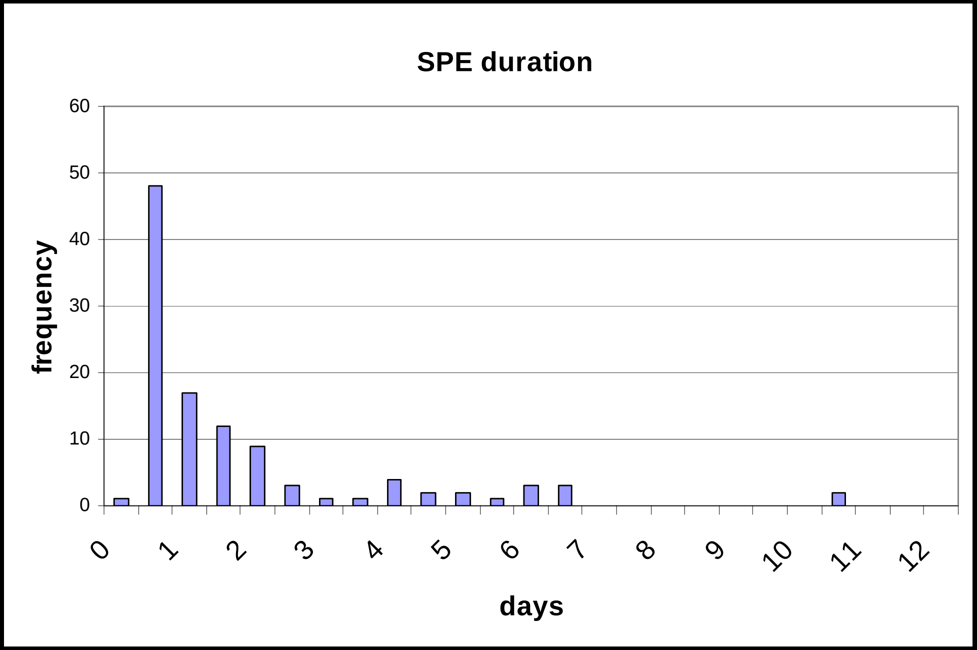
- CREME SEU model

http://www.spenvis.oma.be

Modelling SPEs

- Variability in
  - Energy spectrum
  - Composition (ion species content)
  - Duration
  - Solar cycle intensity

- Need to set-up database of events and accumulate data for decades



L.Rosenqvist and A.Hilgers, Sensitivity of a statistical solar proton fluence model to the size of the event data set, Geophys. Res. Letters, 2003

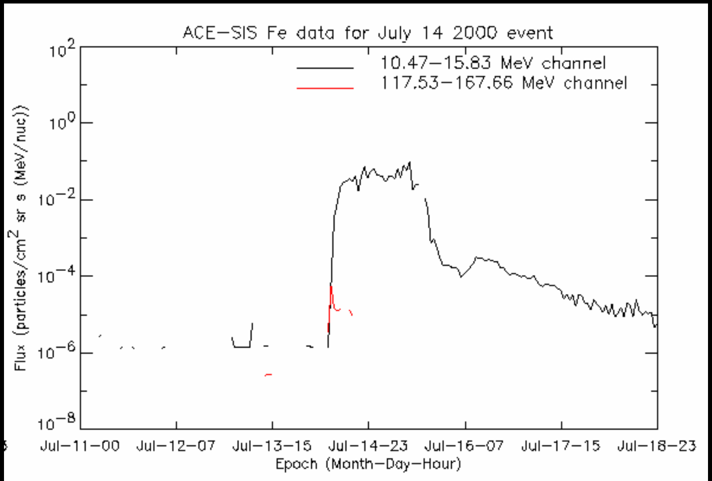
L.Rosenqvist et al., Toolkit for Updating Interplanetary Proton-Cumulated Fluence Models, J. of Spacecraft & Rockets 42, 6, Nov–Dec 2005

From environment to LET ?

S.Esteve Hoyos et al. (IEEE TNS, 2004)

- De-facto standard SPE models (i.e. CREME96 WW, WD, P5M) based on only one event

- Attempt to re-compute LET spectrum
  - SEU rates using datasets of particle fluxes
  - Compare with SOHO SSR SEU rate data



- Insufficient environment information
  - Limited ion species and energy range
- Limited coverage during SPE
  - Environment data gaps and saturation
- Shielding information lacking detail
  - Available for parts only, no detailed S/C
- Unreliable in-flight data
  - Saturation of SEU counters during SPE

Recommendation of flying LET monitor

- Simple, low cost compared to flux detectors

Modelling SEUs

Charge collection

- Collection efficiency
- Interplay of physics and SV geometry

MBU

- Charge injection in multiple cells
- Charge diffusion to multiple junctions
- Charge injection in device circuitry

→ Need detailed modelling
Monte Carlo transport
+ Charge Collection

COTS components: poor visibility of manufacturing

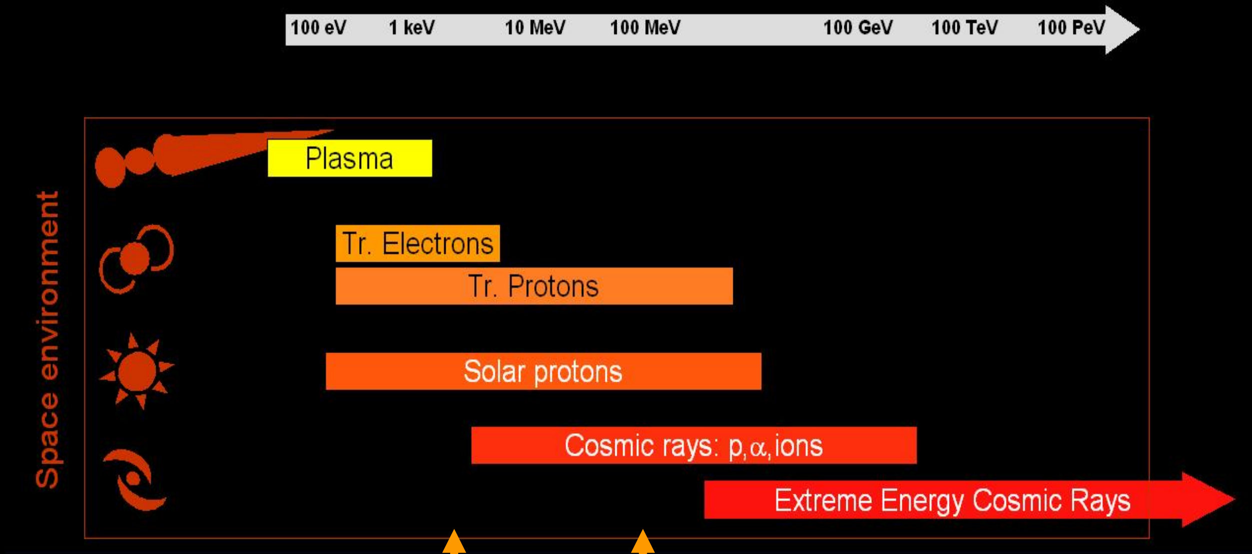
New physics

- Track structure from different ion species
- Nuclear interactions
- Microdosimetry spectra in shrinking devices (< 100 nm)

→ Monte Carlo modelling?

→ Data: SEPC monitors?

From testing to prediction



SEU calculation is a combination of test data and environment modelling

- Energies at ground testing facilities

  → Simulations complement ground testing by extrapolating results to real spectra to

  - Interpret and Predict on orbit behavior
  - Understand and Design new technologies

Problem areas

- Interpretation of tests
  - "Effective LET" e.g. with tilted samples
  - Samples: thinning, packaging,…
  - Beam conditions
  - Complex devices (SEFI, etc)
- Modelling of S/C and module shielding around devices

Summary

- SEU problems increasing
  New component problems appearing

- Modelling key to extrapolate tests
  and understand in-flight data

- Data during Solar Proton Events not satisfactory
  will need continuous update

- Test and in-flight monitor data vital
  LET, microdosimetry monitors to complement flux detectors

http://space-env.esa.int