SPENVIS Tutorial: Radiation models in SPENVIS and their accuracy

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Outline

- Radiation environments
- Sources of model uncertainties
- Running radiation models in SPENVIS
- Interplanetary radiation models
- Planetary radiation models

R… …nts

- Interpla…
  - Cosmi…
  - Solar …
  - Shield… …es
  - Secon… …ing
- Planeta…
  - Earth, …
- Mars en…

Coordinate generators

Radiation sources and effects

Radiation sources

Trapped proton and electron fluxes

Trapped proton flux anisotropy

Short-term solar particle fluxes (only for SEU)

Long-term solar particle fluences

Galactic cosmic ray fluxes

Shielded flux

Solar cell radiation damage

Damage equivalent fluences for solar cells (EQFLUX)

NIEL based damage equivalent fluences for solar cells (MC-SCREAM)

Long-term radiation doses

Ionizing dose for simple geometries

Non-ionizing energy loss for simple geometries

Effective dose and ambient dose equivalent

Single event effects

Short-term SEU rates and LET spectra

Long-term SEUs and LET spectra

Spacecraft charging

Atmosphere and ionosphere

Magnetic field

Meteoroids and debris

Miscellaneous

Geant4 Tools

ECSS Space Environment Standard

Model uncertainties

- Difficult to quantify given the large number of contributing factors
- For most models at best a qualitative uncertainty is provided (e.g. "a factor 2").
- Contributing factors:
  - Errors in underlying data
  - Undersampling of the environment
  - Modelling assumptions
  - Propagation of uncertainties
  - The SPENVIS user!

Data error sources

- Instrument calibration and cross-calibration
- Instrument limitations:
  - Resolution in time, energy, species, …
  - Saturation, dead time effects
  - Channel contamination
  - Systematic errors
  - Unknown errors
- Data post-processing:
  - Poor specification of coordinate systems
  - Conversion to magnetic coordinates
  - Inadequate or missing quality information

Environment undersampling

- Datasets are necessarily limited in time
  - For SEP modelling: less than 4 solar cycles of quality data. Are these cycles representative?
  - Earth radiation belts: 50 years of data, but of very variable quantity and not always easy to intercompare, and no continuous full spatial coverage.
- Spatial coverage is limited by orbit type
  - Oversampling of covered spatial regions
  - Undersampling of most of the environment space
  - Interpolation, extrapolation and weighting are needed
  - Radiation belts require multiple simultaneous missions (e.g. RBSP and PROBA V/EPT).

Modelling assumptions

- The physics of the radiation environments is not fully understood, necessitating simplifications and assumptions.
- Boundary conditions and driving parameters are not always known or agreed on. Even if they are, data to quantify them is not always available.
- Models need to be validated with independent quality datasets.

User responsibility

- SPENVIS aims at accurate and correct model implementation, and at easy interfacing between applications.
- Some users are very inventive and find ways to mis-use the models.
- Others don't read the help pages...
- Don't take anything for granted! For instance, if more than one model is available, compare them to appreciate the variations between them.

Running radiation models

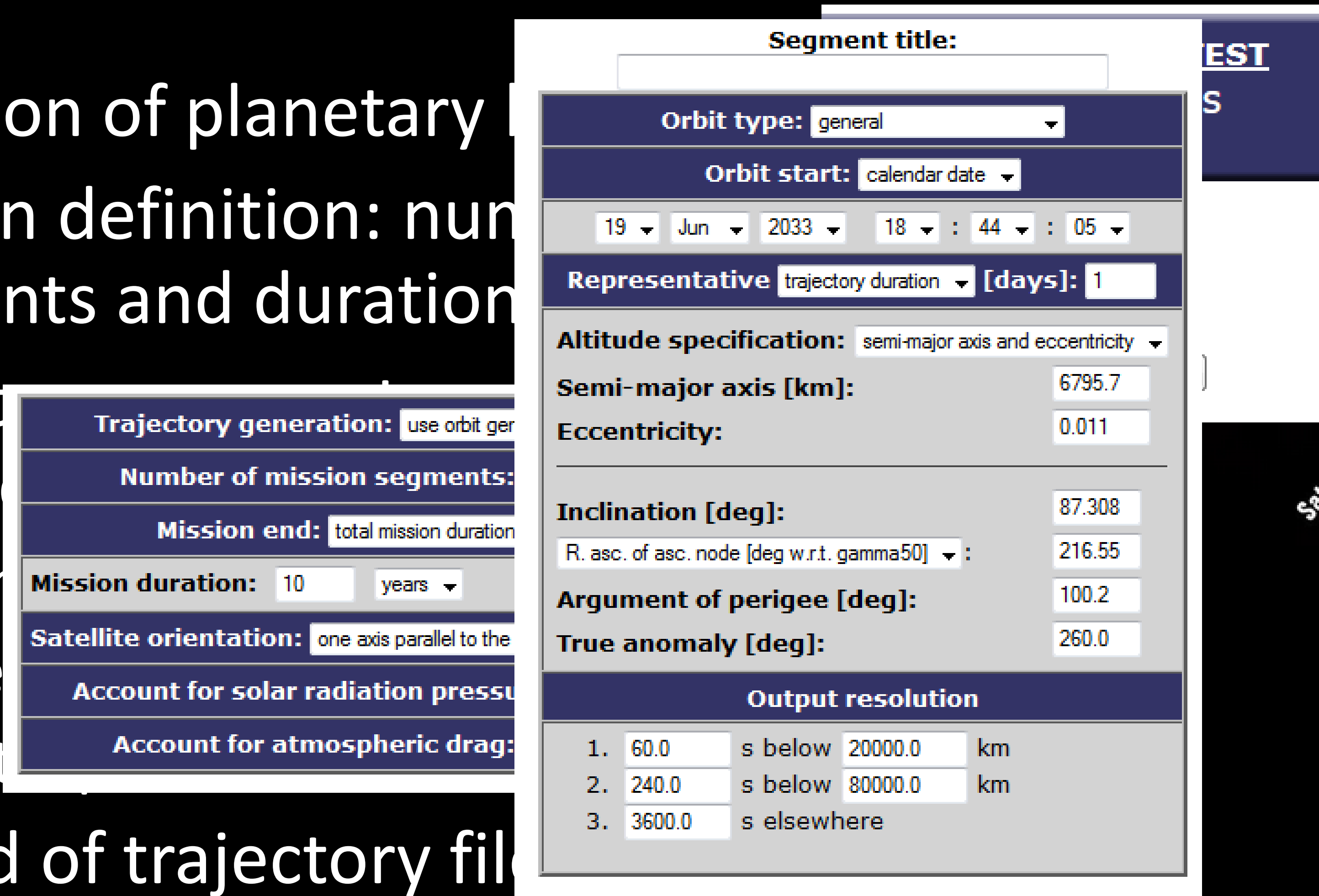
- Define a set of coordinates
  - Spacecraft trajectory
    - Sampling of radiation belts
    - Magnetic shielding cut-off for CR and SEP models
  - Coordinate maps: single point, profile, 2D map
- Select the appropriate model, set parameters and run.
- Model outputs
  - Point by point spectra, transmission functions, …
  - Trajectory and mission averages
  - CSV files (VOTable in SPENVIS-NG)
  - Plots of spectra, time series, maps, 3D views, …

Spacecraft trajectories

- The *mission* concept: a series of consecutive trajectory segments, specified by start time and duration or stop time.
- For each segment a representative trajectory is defined and generated: the minimum number of orbits to cover the environment.
- Radiation model outputs are scaled up to segment lengths and summed to provide total mission quantities (except for the statistical SEP models).
- Outputs are provided for each segment and for the total mission.

Trajectory specification

- Selection of planetary l
- Mission definition: nun segments and duration
- Traject param
  - Segm
  - Traje
  - Orbit
- Upload of trajectory fil

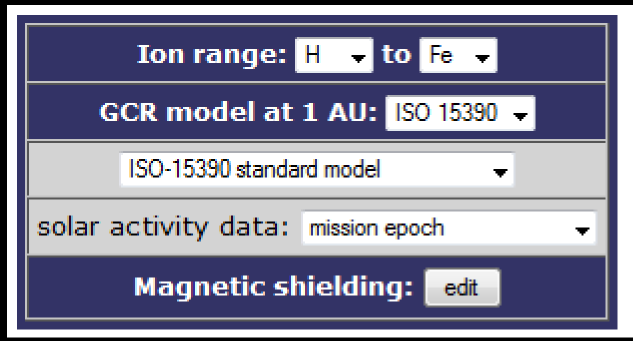


Interplanetary radiation models

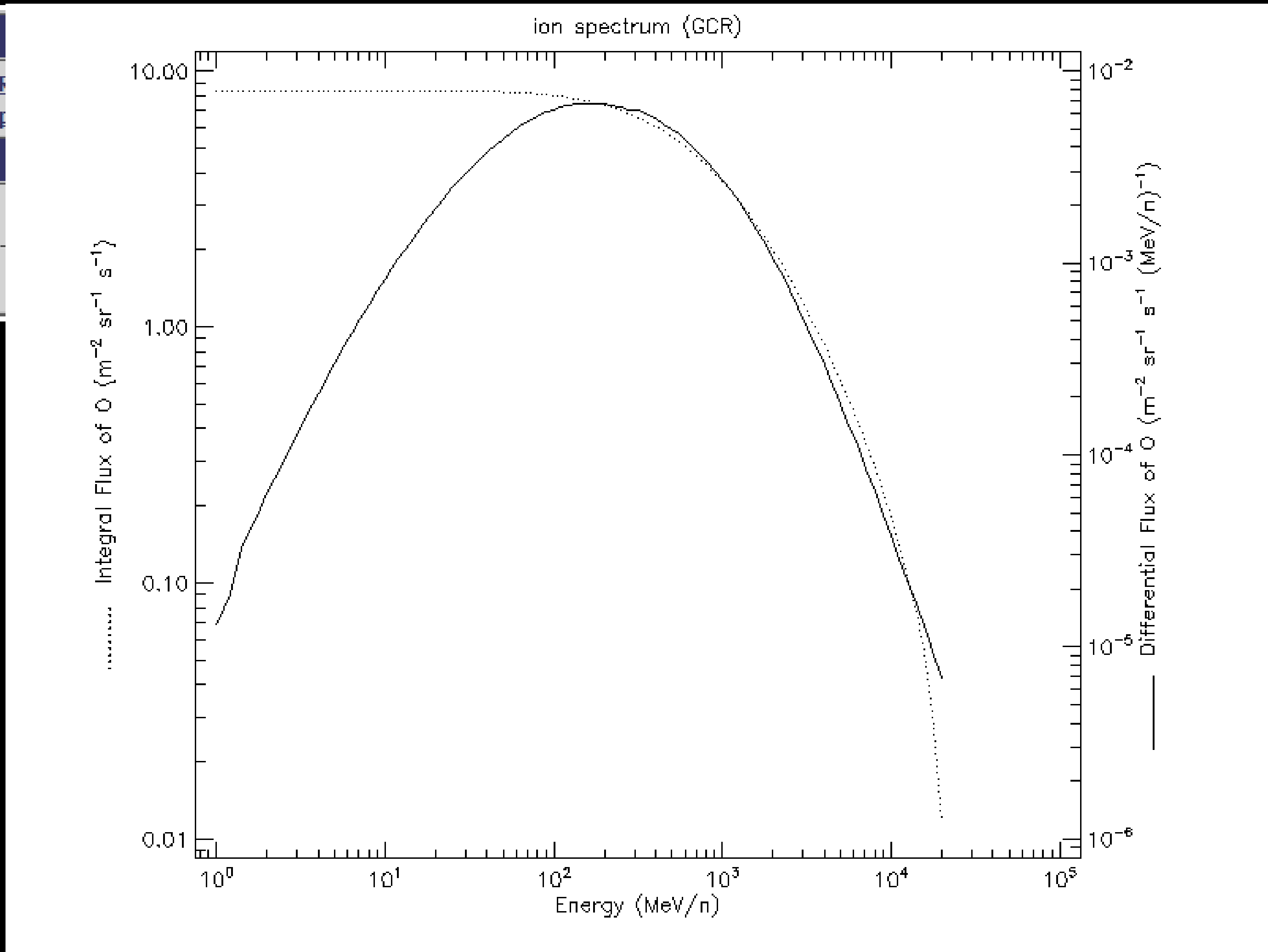
- Galactic and anomalous cosmic ray fluxes
- Solar Energetic Particle fluences
  - Specified in terms of a confidence level
  - Cumulative fluence
  - Worst case event fluence
- Solar energetic particle fluxes
  - Energy spectra for representative historic events
  - Worst day or week, peak flux
- To be used in combination with magnetic shielding models
- SEP Fluxes and fluences are given at 1 AU. SPENVIS scales with r^{-2} for distances < 1 AU.

Cosmic ray models

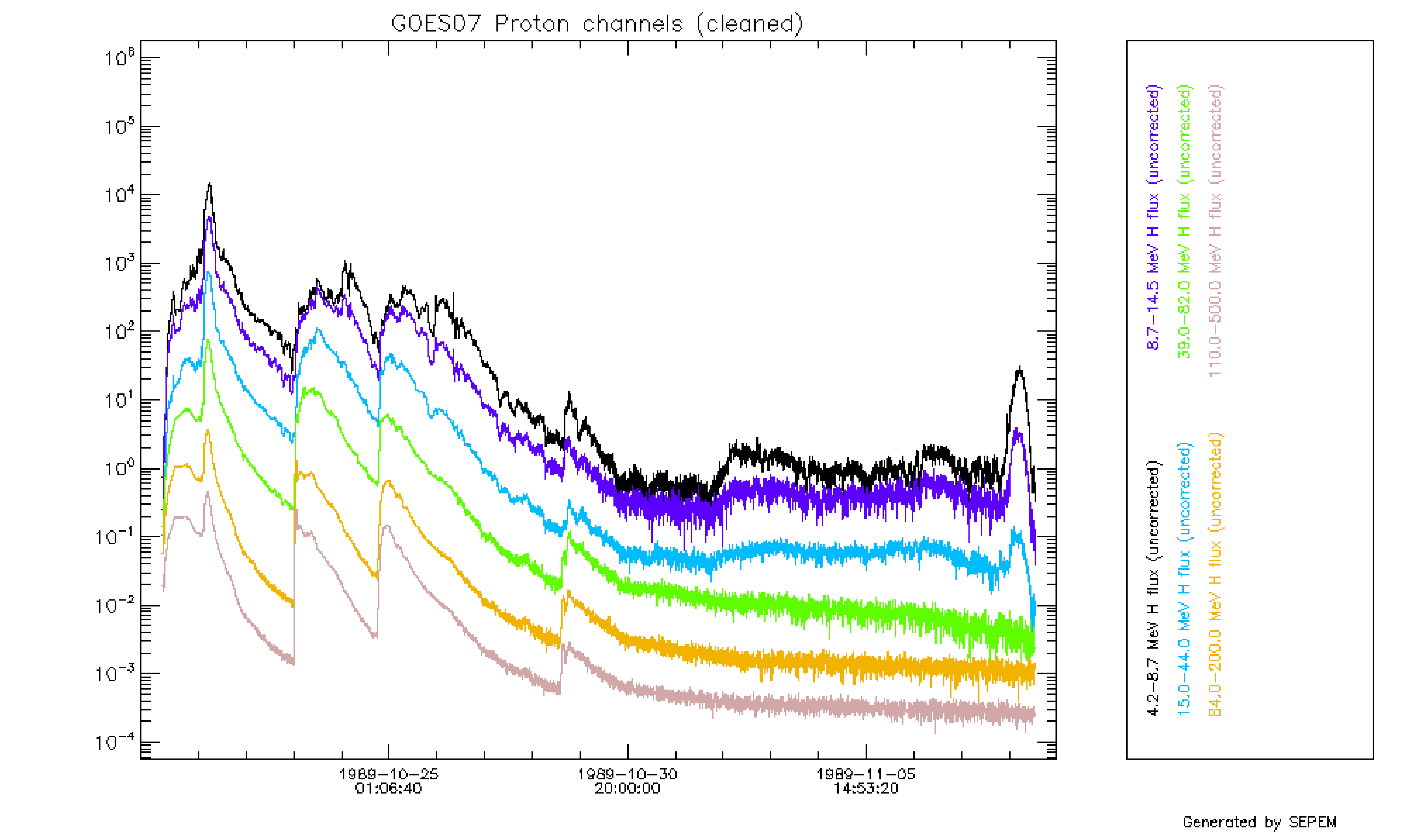
- Models available in SPENVIS
  - ISO 15390 (Nymmik MSU model): no ACR
  - Nymmik 1996: extension of ISO 15390 below 10 MeV/nuc (ACR?)
  - CREME96: Nymmik 1992 model for 1986-1987 solar minimum plus ACR
  - CREME86: GCR + ACR, sinusoidal solar cycle modulation
  - Badhwar-O'Neill model to be added in SPENVIS-NG
- Model parameters
  - Ion range (1-92)
  - Solar cycle phase
  - CREME86 model version



Cosmic ray model output

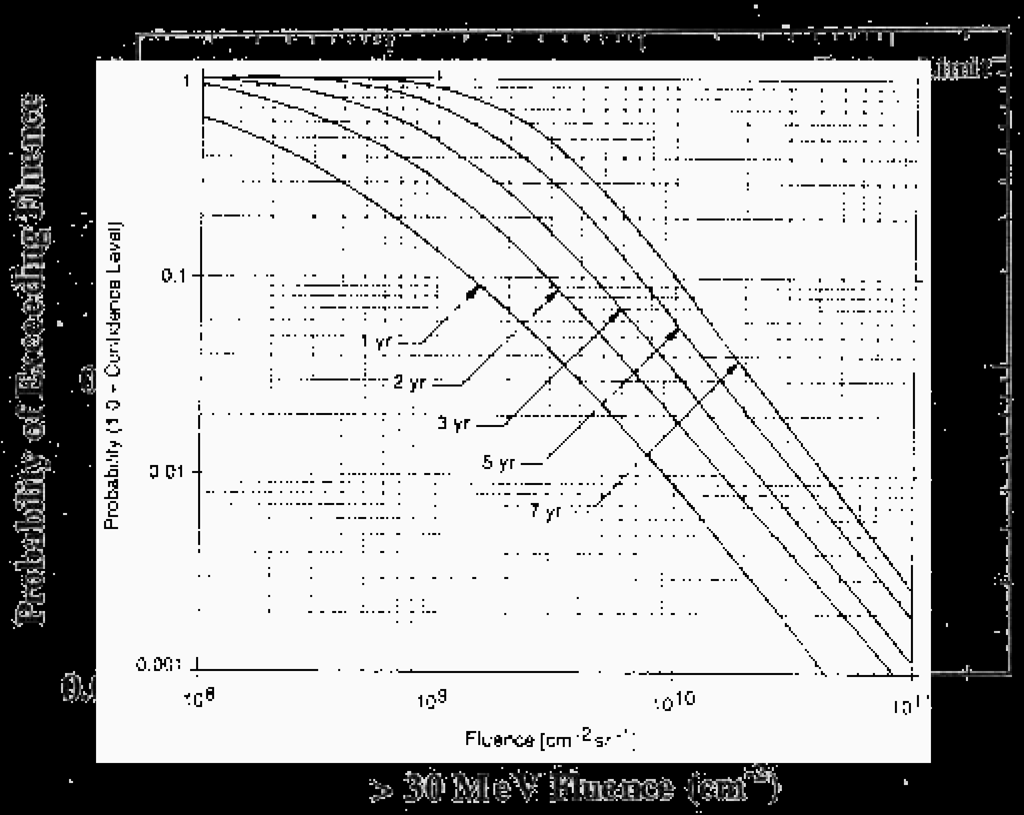


Short term SEP fluxes



SEP fluence models in SPENVIS

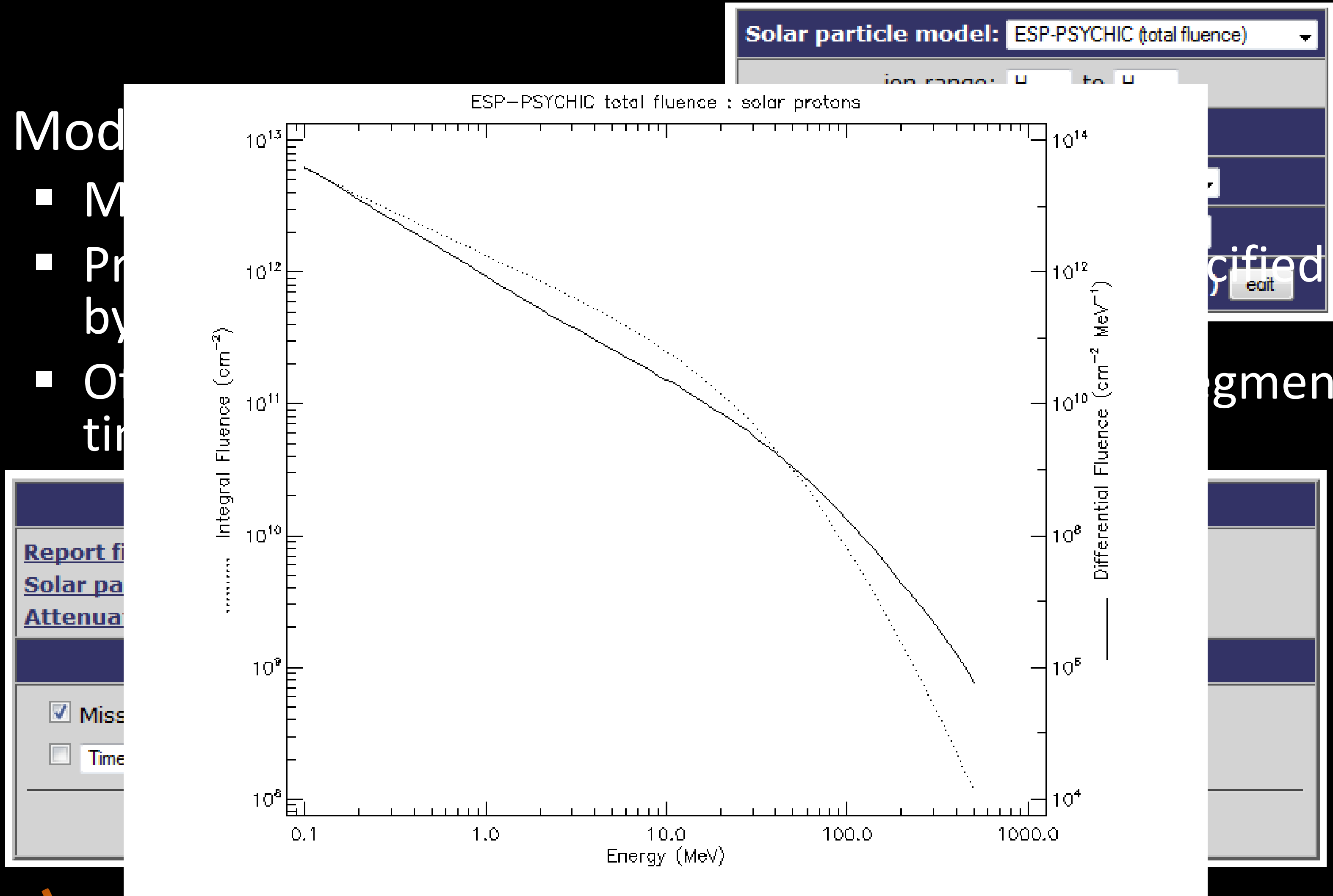
- King (19 … solar max and min
- JPL : log … only
- Rosenqv … ES-8 data
- Emission …
  - Event … py
  - Missic
  - Solar
- PSYCHIC … bles
- SEPEM (… implem …



- Model output: fluence spectrum for given confidence level

SEP fluence model runs

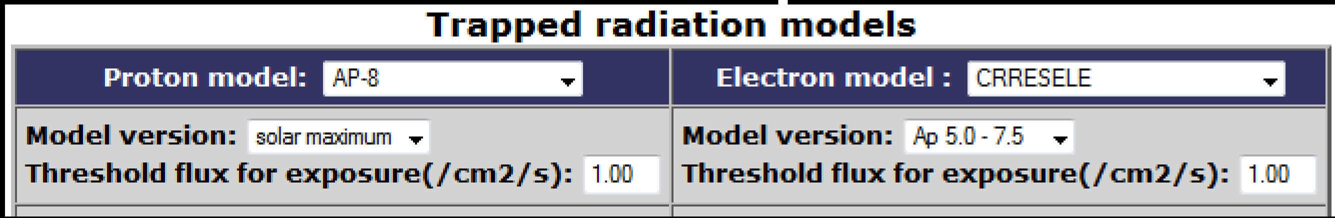
- Mod
  - M
  - Pr … cified by
  - O … egment ti



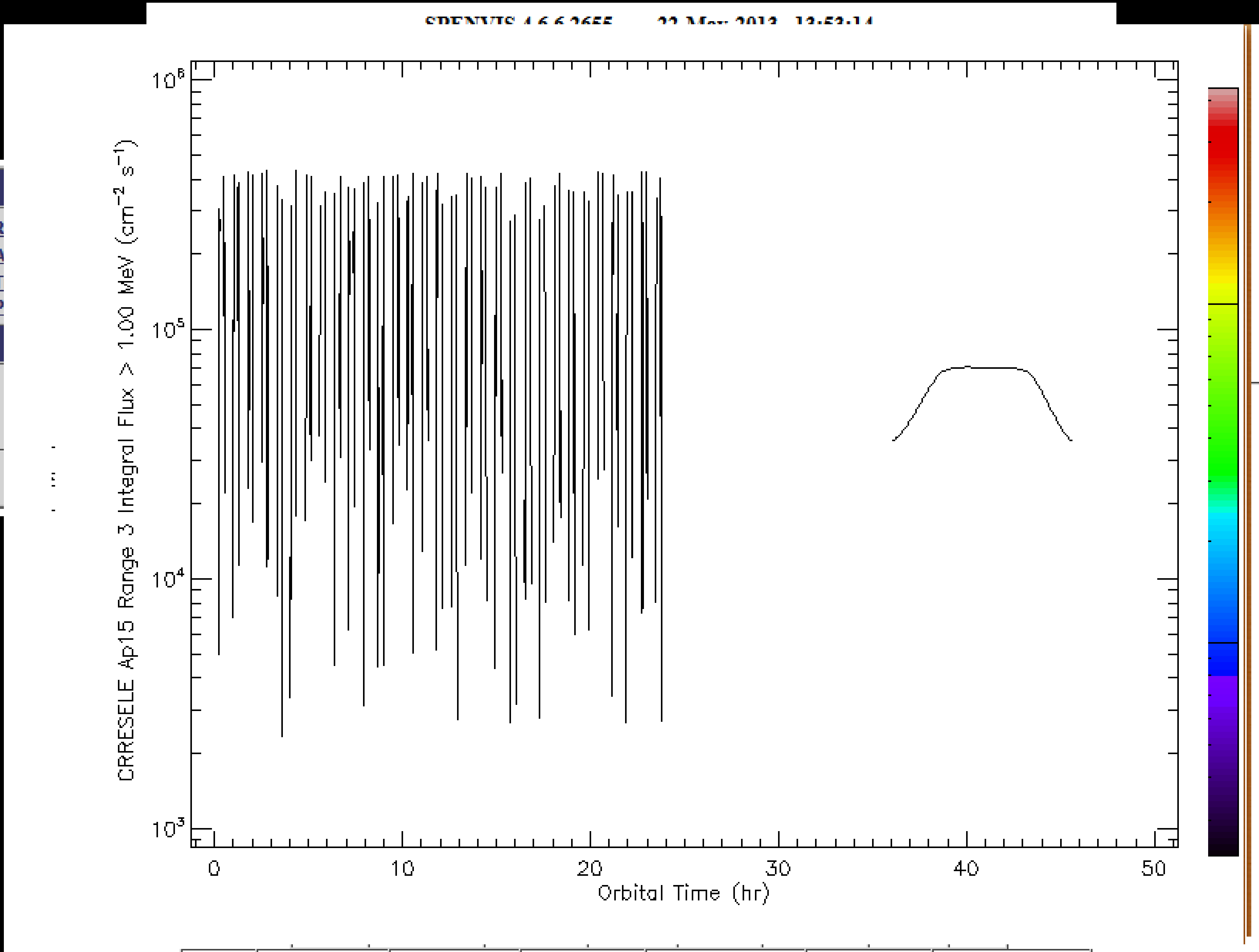
Radiation belt models: Earth

- AP8/AE8 for protons/electrons
  - Static models: rudimentary separation in solar min/max
  - Covers the complete radiation belts
  - Badhwar-Konradi model for low altitude directional flux
- CRRESPRO, CRRESELE
  - Dynamic models: quiet/active for protons, A_{p15} levels for electrons
- SAMPEX/PET solar min model for LEO (<600 km)
- IGE-2006/POLE (International Geostationary Electron model, Particle ONERA-LANL Environment): statistical model for the GEO electron environment
- AE8-MIN update with CRRES/MEA data (Vampola)
- To be added in SPENVIS-NG: AP9/AE9, slot radiation environment model (SRREM project), Ganymede environment models (GREET project)

Earth RB model parameters

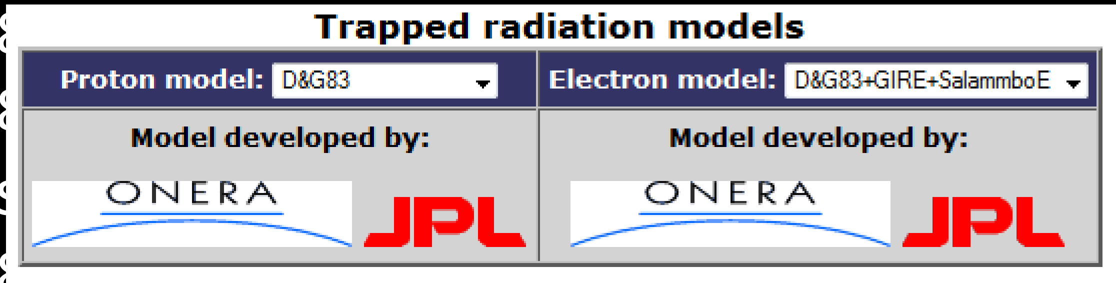


- AP-8/AE-8
  - Solar MIN/MAX
  - Local time variation for AE-8
  - Apply confidence levels for AE-8 (based on AE-4)
- CRRES
  - CRRESPRO: quiet or active model
  - CRRESELE: A_{p15} range, average model or maximum model
- IGE-2006/POLE
  - Model version (IGE-2006, POLE-V2, POLE-V1)
  - Model type: lower, mean or upper flux


SPENVIS 4.6.6.2655 22 May 2013 13:53:14
CRRESELE Ap15 Range 3 Integral Flux > 1.00 MeV (cm⁻² s⁻¹)
Orbital Time (hr)

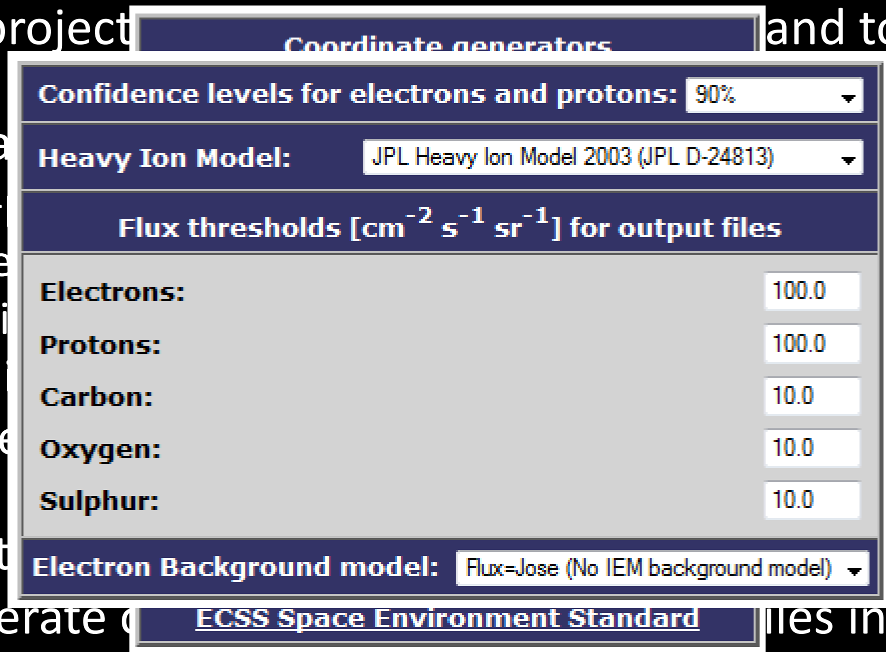
Radiation belt models: Jupiter

- Trapped radiation models
  - Divine & Garrett 83 (protons and electrons)
  - D&G83 + Salammbo (protons and electrons)
  - D&G
  - D&G
- Model s
  - D&G83: Voyager and Pioneer flybys
  - GIRE: extension with Galileo data
  - Salammbo: numerical transport code
- Models are run on spacecraft trajectories (only one mission segment), outputs are similar to Earth RB models.



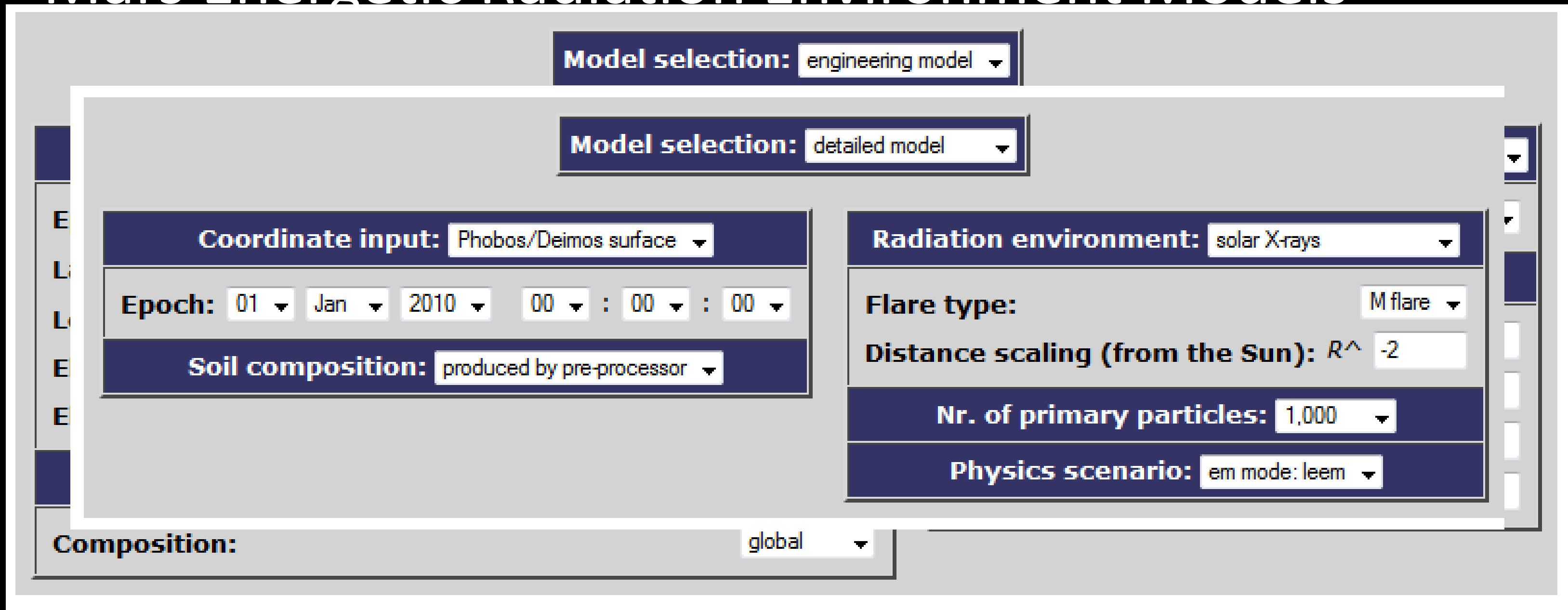
JOREM models

- Jupiter Radiation Environment and Effects Models and Mitigation (JOREM): ESA project … and tools for Jovian missions
- Jovian Specifica…
  - Based on re-… Galileo missions
  - Improved tre…
  - Includes basi… rcentile values)
  - Includes JPL …
- Interplanetary … ped under ESA contract)
- Divine & Garret…
- The models operate … iles in EME2000 coordinates.
- Planetocosmic-J simulations for the Galilean moons



Mars environment models

- Mars Energetic Radiation Environment Models



  - Two versions
    - Look-up tables generated with FLUKA for rapid analysis
    - Full Geant4 simulations for detailed studies