Reverse Monte Carlo tools in FASTRAD®

P. POURROUQUET, J.C. THOMAS, P.F. PEYRARD
(TRAD, Labège, France)
R. ECOFFET, G. ROLLAND (CNES, Toulouse, France)

http://www.fastrad.net

OUTLINE

- **The FASTRAD software**
  - Radiation CAD Interface
  - Dose Calculation
  - Post-Processing Analysis

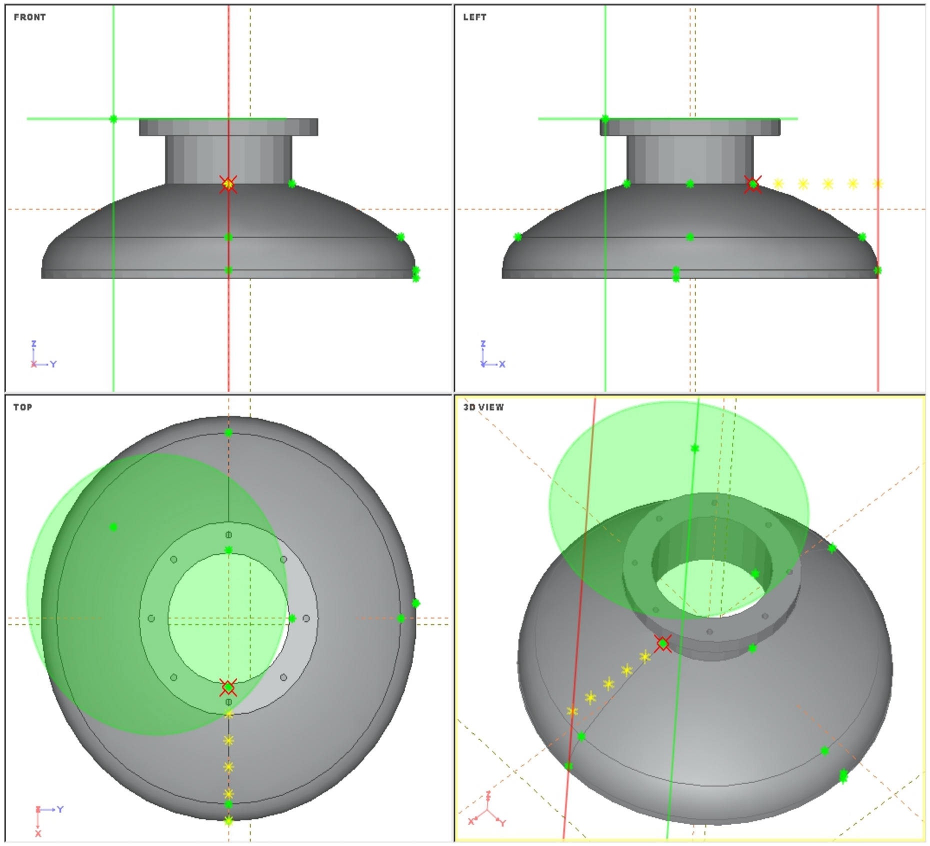
- **The Monte Carlo module**
  - Direct Method
  - Reverse Method

- **Results and validations**

The FASTRAD Software

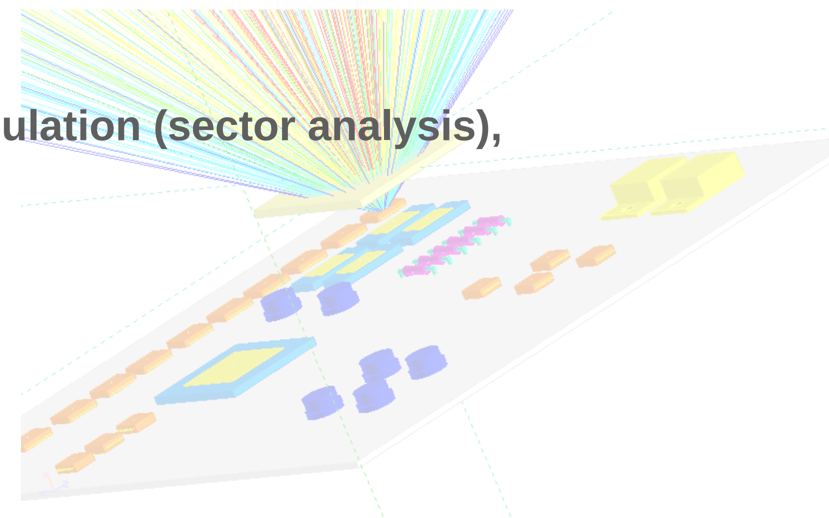
FASTRAD – Radiation CAD Interface

- **Import / Export CAD capability**
  - STEP/IGES format (CAD tools standard),
  - STEP SPE format (space CAD model)
- **Geometry modeler**
  - Complete and intuitive geometry toolkit,
  - Shape reconstruction
- **Data input for 3rd party calculation tools**
  - GEANT4 (CERN)
  - NOVICE (EMPC)



- **2 complementary calculation modules**
  - **Ray-tracing,**
  - **Monte Carlo Algorithm.**

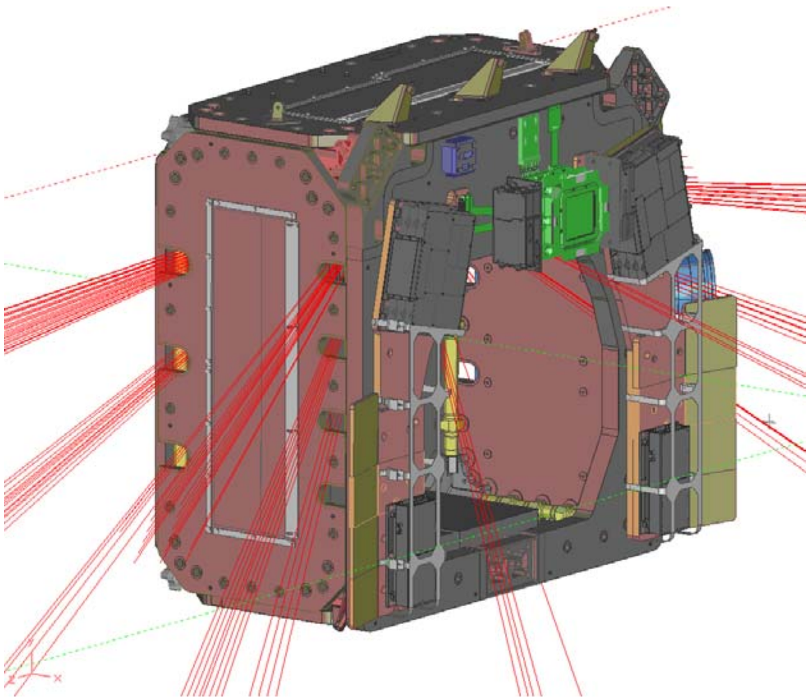
- **Ray-tracing**
  - **A well-known method for fast dose calculation (sector analysis),**
  - **But problems may appear with:**
    - very dense or very light materials,
    - electrons (light charged particles) .



- **Monte Carlo**
  - **Partnership with CNES since 2005,**
  - **Better results accuracy thanks to a more realistic transport,**
  - **Details of this method in a few slides…**

- **Ray-tracing Visualisation**
  - Ray visualisation according to the mass shielding distribution,
  - Shielding impact on dose deposition.

- **Shielding assistant**
  - Point at the design weaknesses,
  - Helpful to place additional shielding for critical parts.



CNES courtesy

The Monte Carlo module

Monte Carlo module

- **MC algorithms for electrons and photons**
  - Energy range (1 keV – 10 MeV)
  - On-going electron validation up to 1GeV

- **Physical processes taken into account**
  - Multiple scattering,
  - Ionisation,
  - Bremsstrahlung photon creation,
  - Photoelectric effect,
  - Compton diffusion,
  - Materialisation.

Direct Monte Carlo

- **Realistic Particle transport**
  - From source to model limits or total energy loss,
  - Secondary particle tracking (electrons and photons).

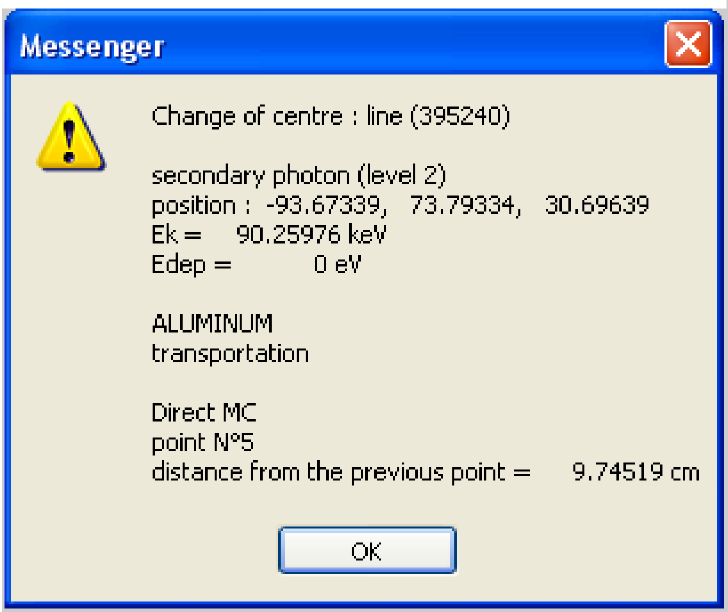
- **Large variety of available sources**
  - External isotropic environment (space environment),
  - Circular beam (irradiation test or medical devices),
  - Isotropic emission from the surface of a volume (nuclear).

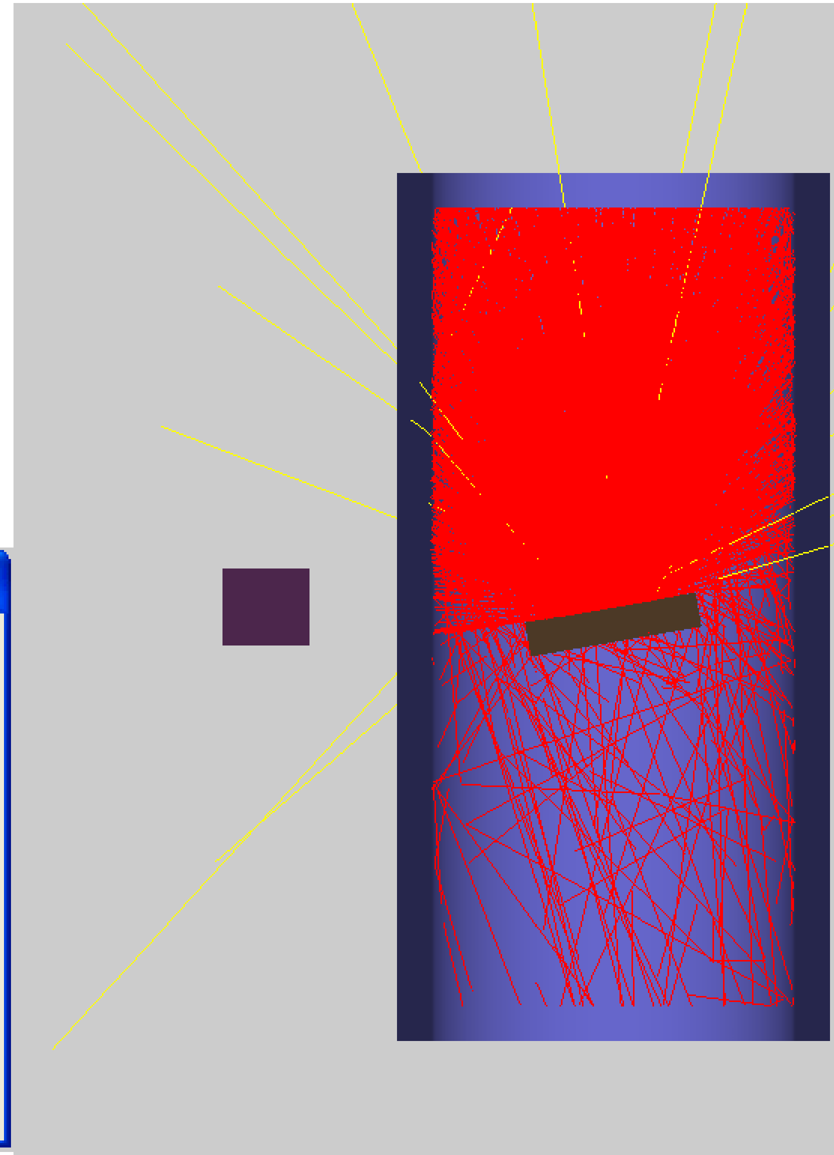
- **Calculation Results in Sensitive Volumes (SV)**
  - Energy and dose deposition,
  - Fluence of transmitted particles.

- **Drawback for space calculation**
  - Huge computational time when the size of the Sensitive Volume is much smaller than the model size => need for a biasing method : the **Reverse Monte Carlo**

Visualisation

- **Trajectory visualisation**
  - **Trajectory view of all particles tracked during the simulation**
  - **Information on each particle step**



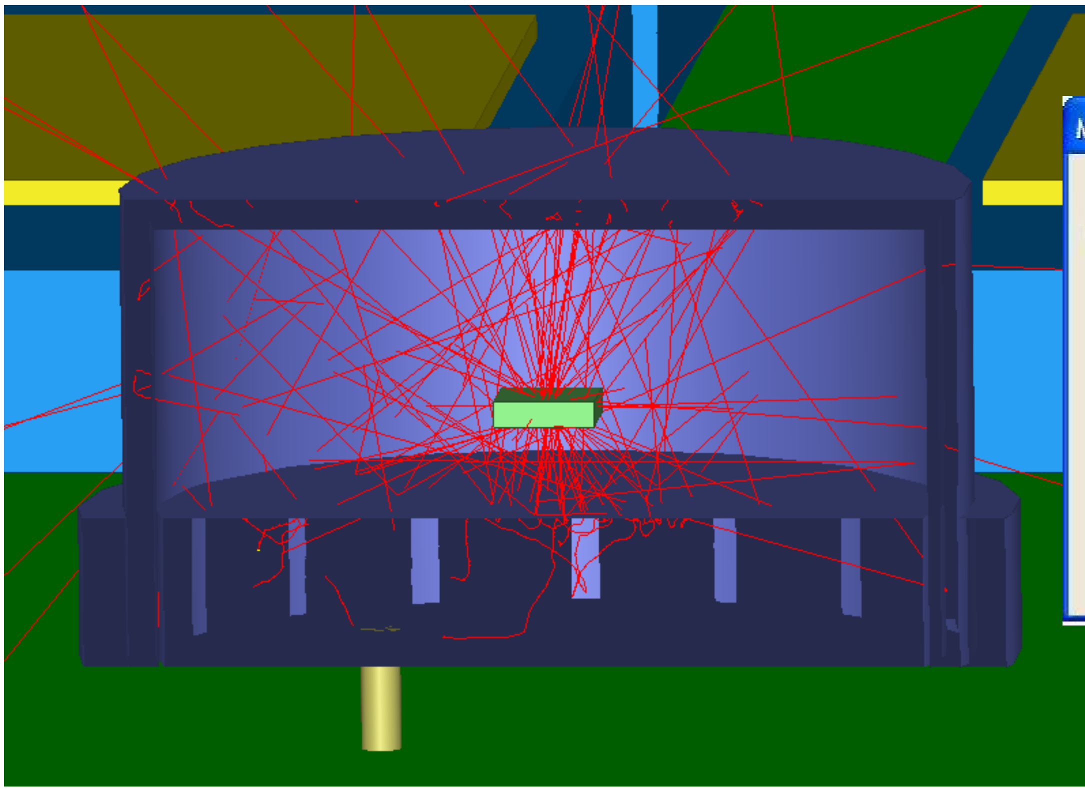


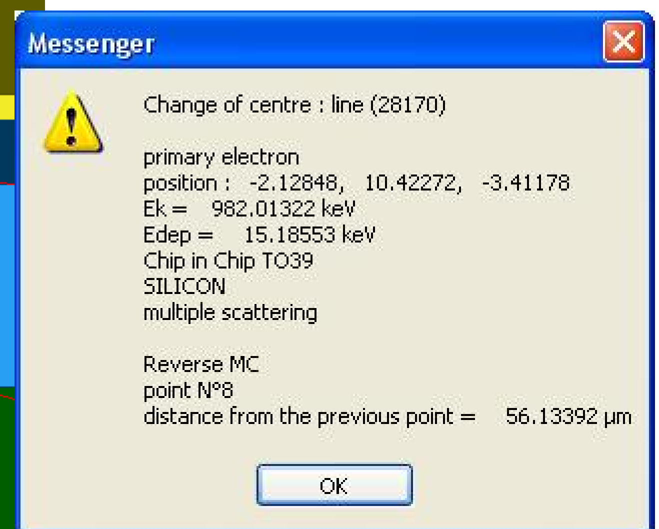
Reverse Monte Carlo

- **General principle**
  - Backward tracking from SV up to the source area (external and isotropic).
  - Estimate of each backtracked particle weight.
  - Particle source : user-defined electron spectrum => tracking of primary electrons and secondary photons (Bremsstrahlung).
- **Sensitive Volumes**
  - Physical volume in your model => Forward tracking inside SV for energy deposition calculation,
  - Point detector => tabulated data for energy deposition in Silicon.
- **Calculation results in the SV**
  - Energy and dose deposition,
  - Fluence of transmitted particles.

Visualisation

- **Trajectory visualisation**
  - **Trajectory view of all particles tracked during the simulation**
  - **Information on each particle step**





Results and Validations

Reverse Monte Carlo Validations

Validations performed using NOVICE (EMPC):

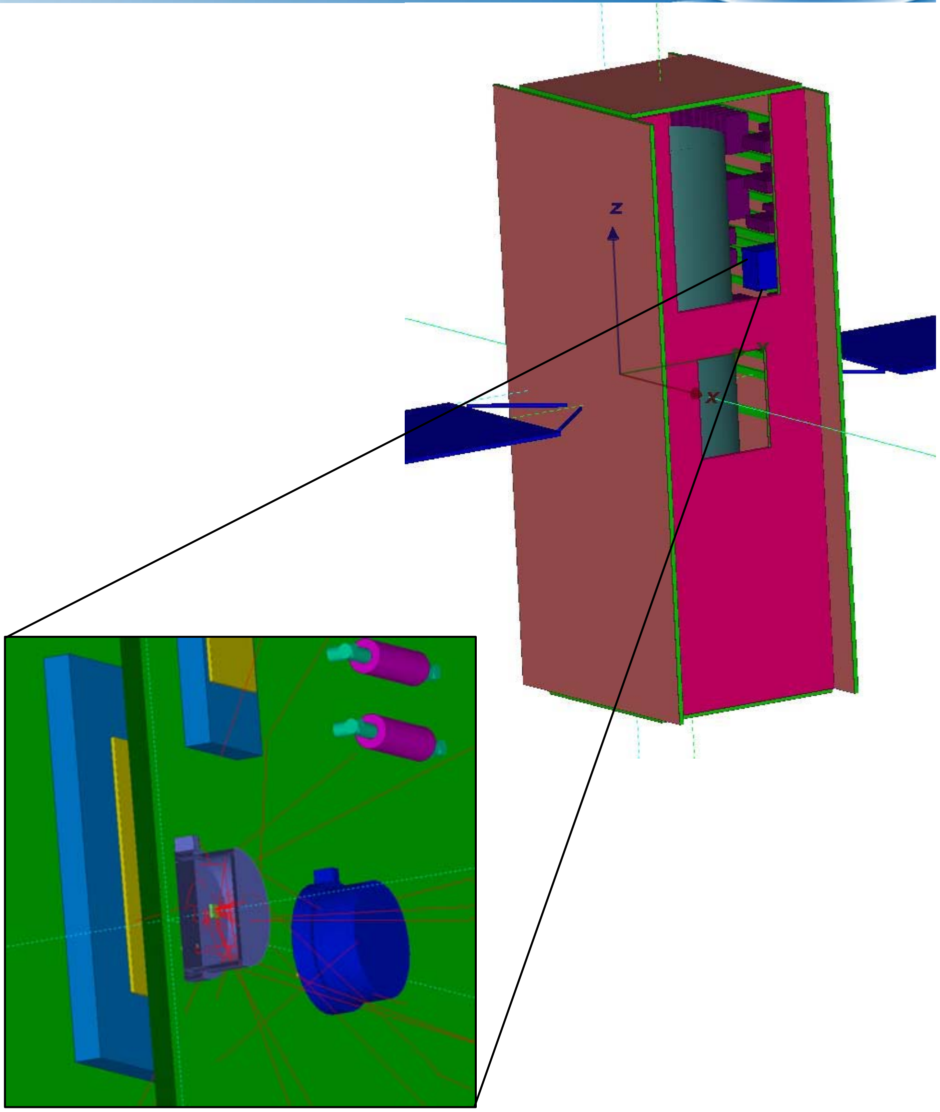
- **Electron flux at geosynchronous orbit**
  - Realistic satellite model,
  - Total dose due to electrons and Bremsstrahlung photons.

- **Electron flux of Jovian environment**
  - Range of electron energy from few keVs to 1 GeV
  - Transmitted electron flux in the optical lenses of a Star Tracker.

- **Quasi mono-energetic electron flux**
  - Narrow peak around 1 MeV,
  - Comparisons with actual irradiation test.

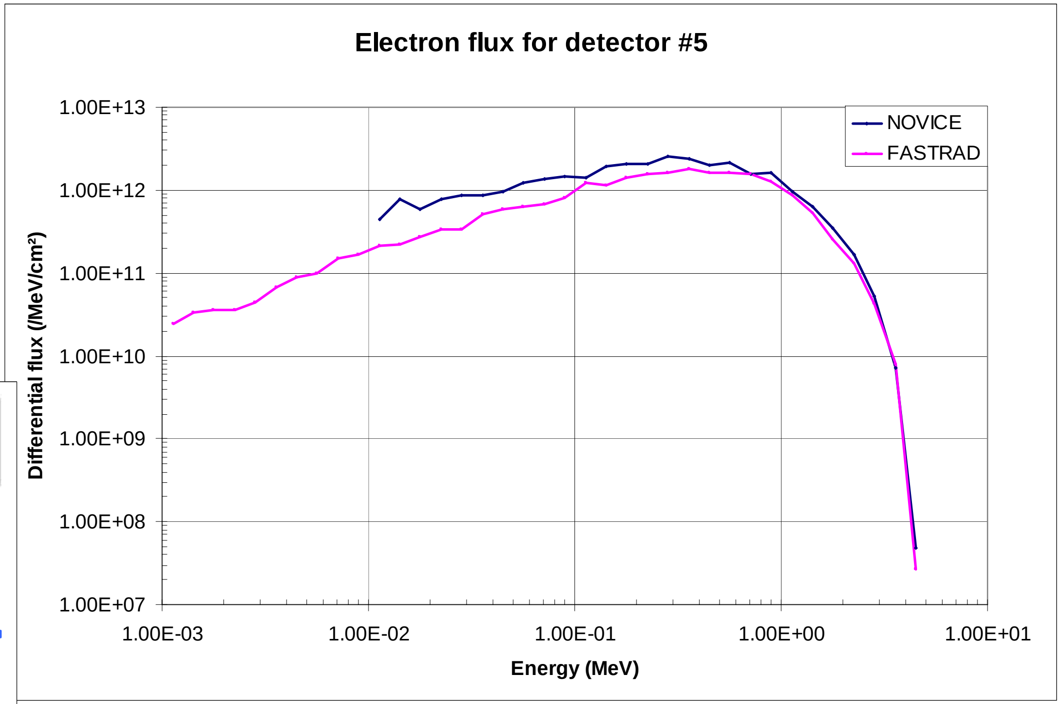
Total dose at Geosynchronous orbit

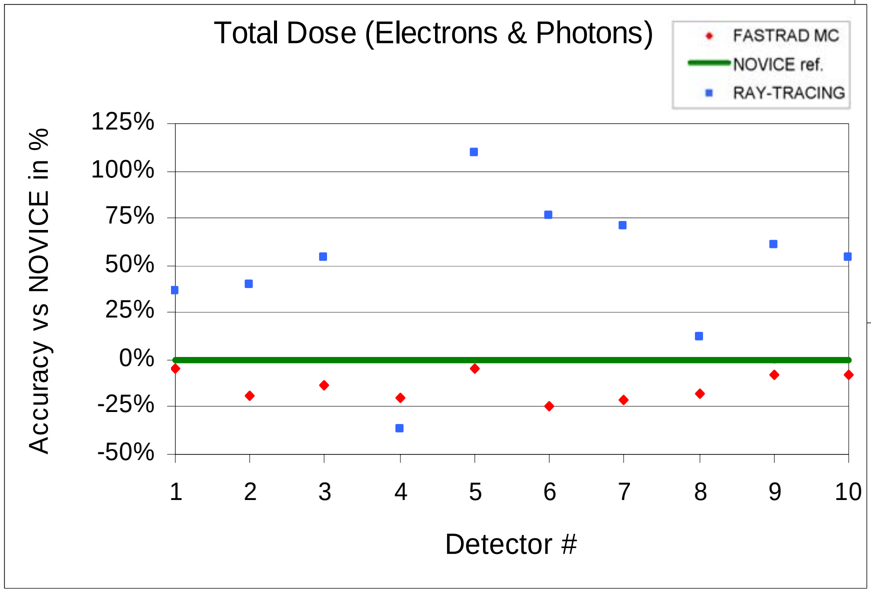
- **Complete Spacecraft**
  - Satellite structure,
  - Electronic units,
  - Component packages.
- **Geostationary environment**
  - Electron flux up to 5 MeV
- **Results**
  - Total deposited dose (primary electrons and Bremsstrahlung photons)
  - Electron transmitted fluence at component chip level



Results

Deposited dose and transmitted fluence comparisons against NOVICE



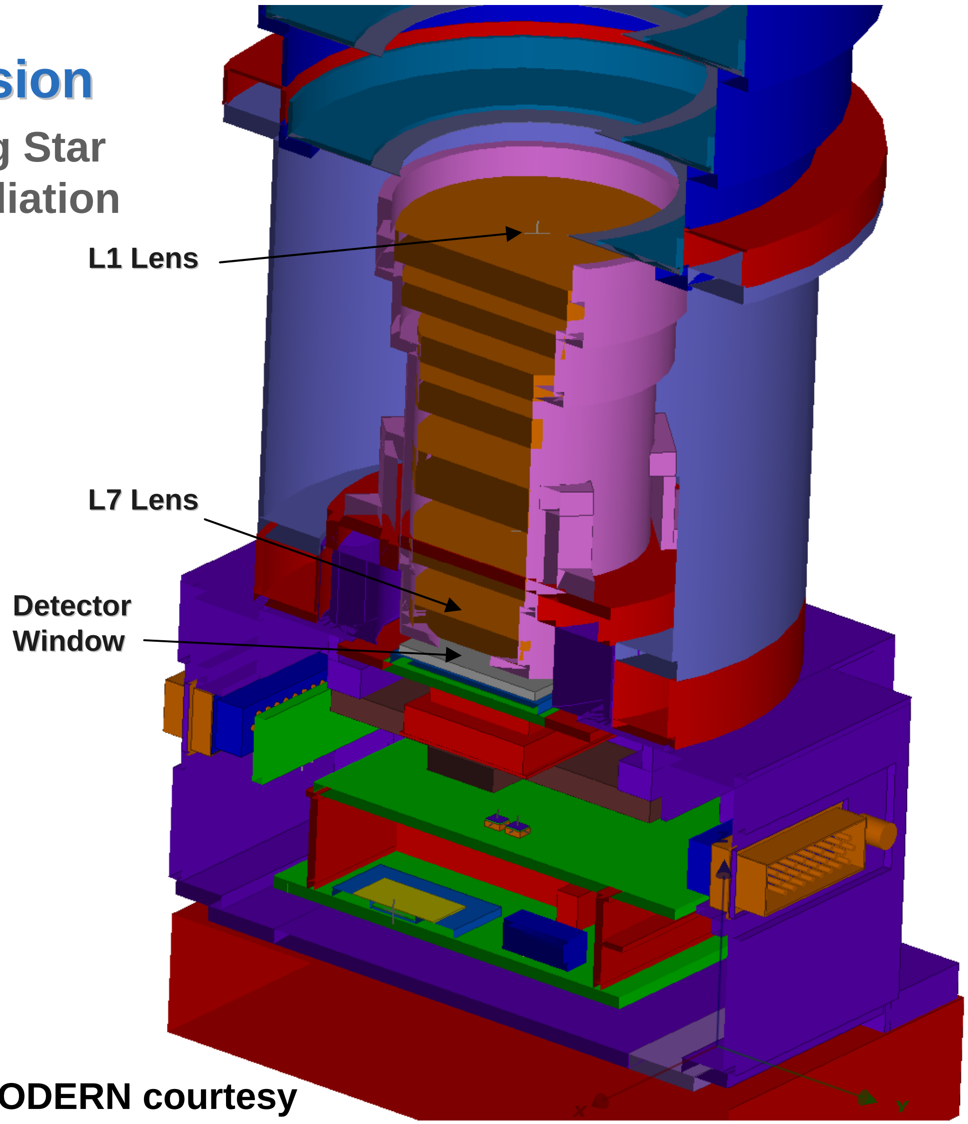


Transmitted flux in Jovian environment

- **Star Tracker for Laplace mission**
  - ESA funded study for evaluating Star Tracker performance in high radiation environments,
  - SODERN's Hydra Star Tracker modeled in FASTRAD,

- **Worst case electron flux**
  - Electron flux up to 1 GeV

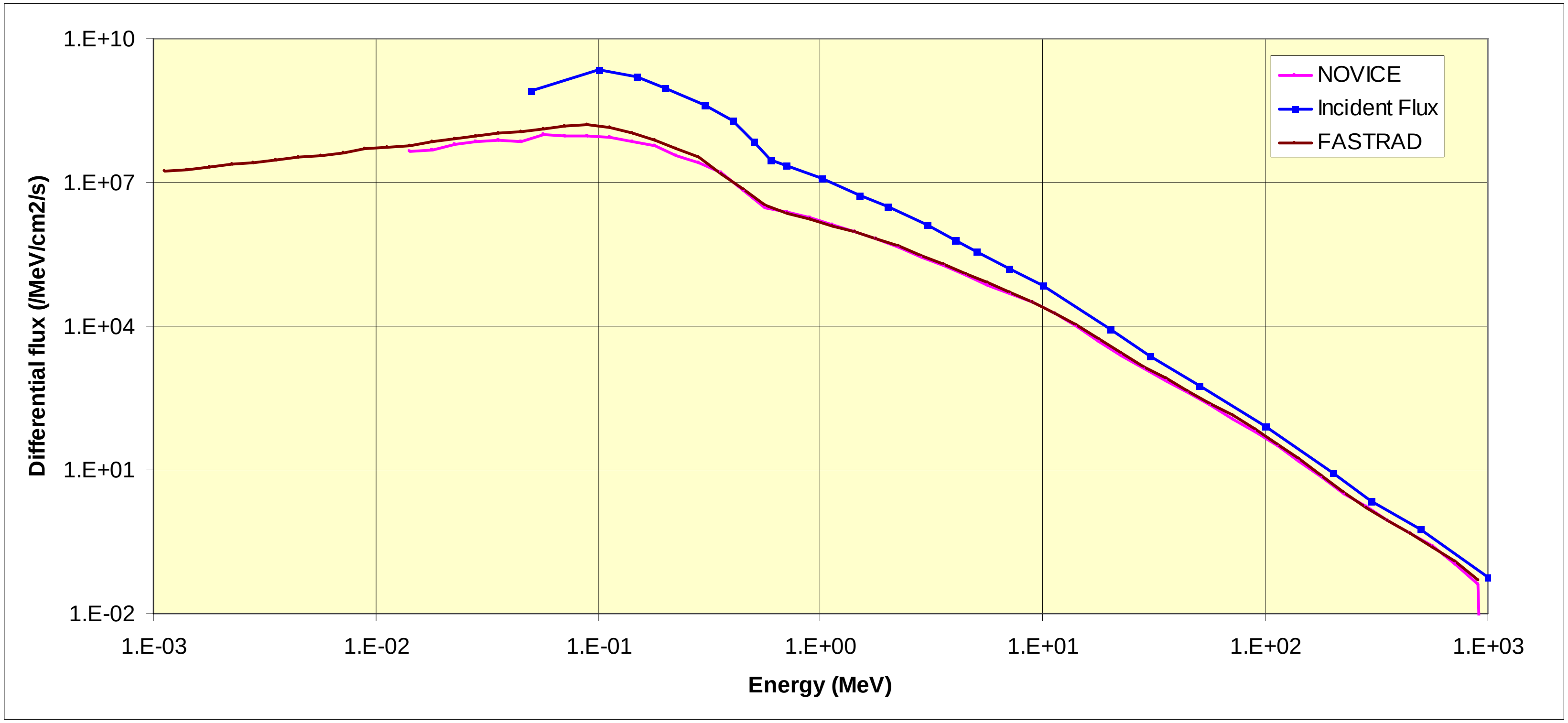
- **Results**
  - Transmitted electron flux on optical lenses



SODERN courtesy

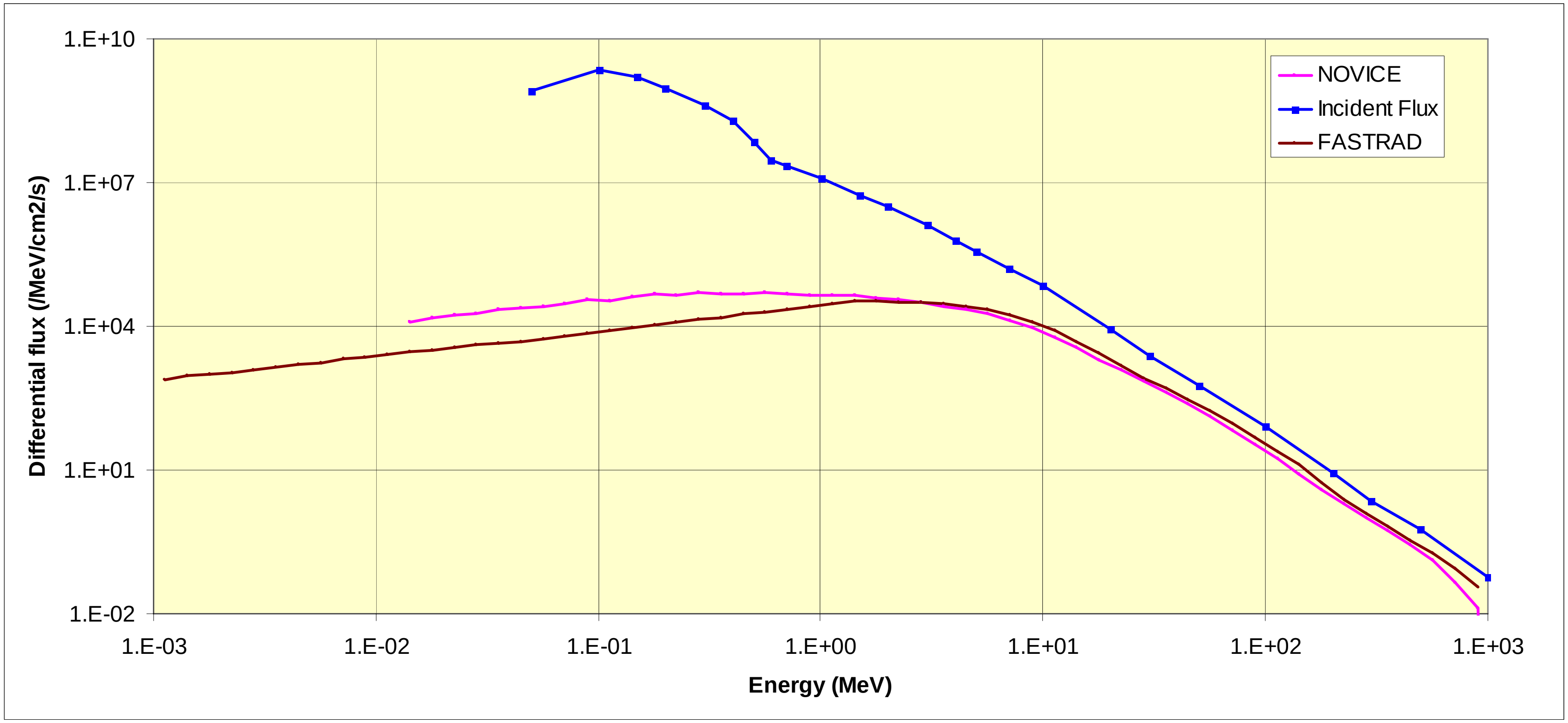
Transmitted flux in Jovian environment

- **Results and comparisons for L1 lens**



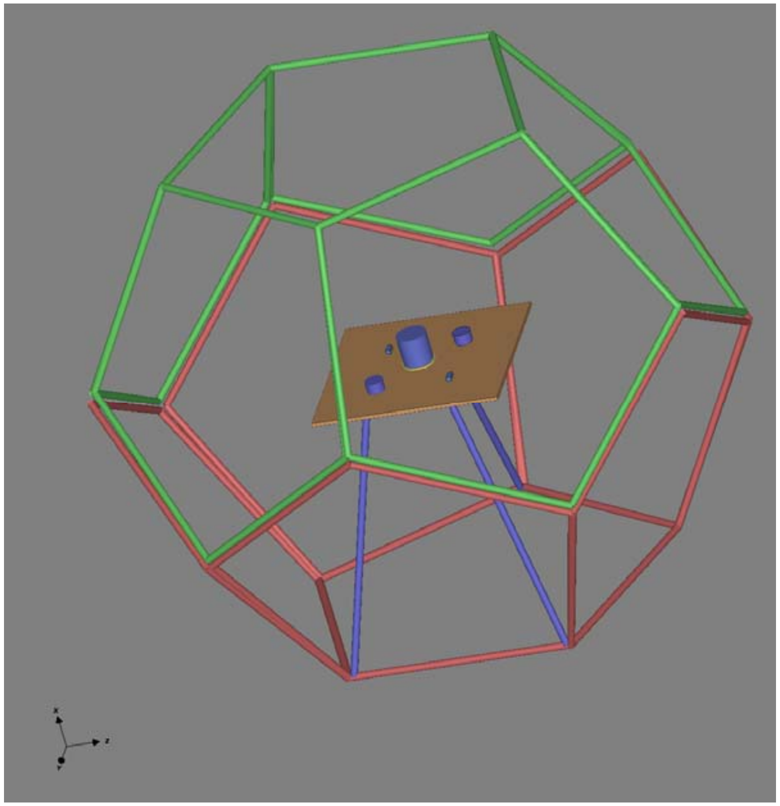
Transmitted flux in Jovian environment

- **Results and comparisons for L7 lens**



Quasi mono-energetic electron flux

- **Validation with an actual experiment**
  - Dodecahedron for an isotropic irradiation,
  - dosimeters under a 1 MeV electron irradiation beam.
- **Energy spectrum described as a narrow peak around 1 MeV using a Gaussian law**
- **Normalised results**
  - Deposited dose per particle, per cm^2



Quasi mono-energetic electron flux

- **Results and comparisons with NOVICE**

Components =>	TSD	HEXFET	Alanine Pellets
FASTRAD (rad(Si))	5.66E-09	1.22E-08	1.20E-08
NOVICE (rad(Si))	6.76E-09	1.20E-08	1.13E-08
Difference (%)	-16.31	1.45	5.99

- **Irradiation not fully completed**
  - First results seem to be in correlation with calculation.

Conclusion

- **Reverse Monte Carlo algorithm fully implemented in FASTRAD**
  - **Electrons and photons from 1 keV to 10 MeV (1GeV for electrons),**
  - **Dose and energy deposition calculation,**
  - **Transmitted flux calculation,**
  - **Particle trajectory visualisation,**
  - **Convergence study.**

- **Results validated against NOVICE**
  - **For every external spectrum type : Geostationary orbit, Jovian environment (high energy) and mono-energetic distribution.**
  - **For every calculation output : deposited dose, transmitted flux.**

- **Continuous development:**
  - **Constant improvement,**
  - **On-demand development for adaptation to user requirement:**
    - X-Ray inspection,
    - Bunker designer tool,
    - …