7th Geant4 Space Users' Workshop
Seattle, 18-20 Aug 2010

Status of ESA Geant4 R&D activities

Giovanni Santin*, Petteri Nieminen

Space Environments and Effects Analysis Section
European Space Agency
ESTEC
** on loan from RHEA Tech Ltd*

Geant4 support to ESA programmes

Mixture of R&D and applications, targeting the major Programme domains

Accuracy

- Physics (nanodosimetry, electron transport, secondaries from inelastic, ion interactions)

Usability issues

- User experience (tool availability, scripting, GUI, web access, Windows)

Speed:

- Exchange formats: Geometry (GDML, CAD/TCAD), data I/O
  Scoring in micro- or nano-volumes in macroscopic S/C

Better understanding of engineering practices and margins

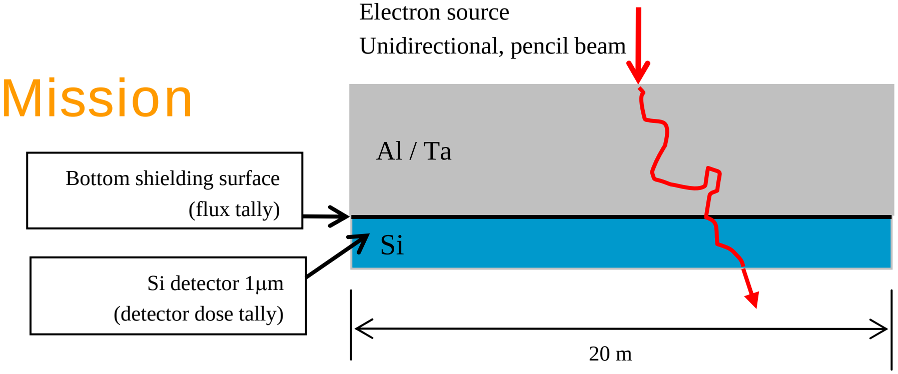
- Need to identify problems, quantify uncertainties

Science and Exploration

EJSM

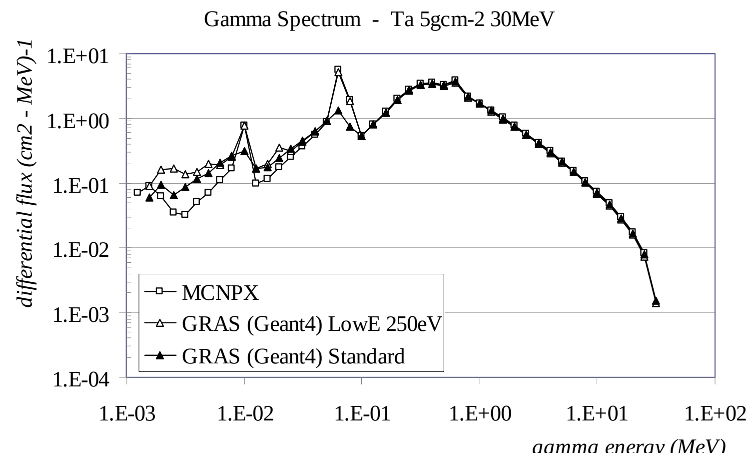
Europa Jupiter System Mission

- Combined missions
  - JEO – NASA-led
  - JGO – ESA-led



- Harsh e^- dominated environment

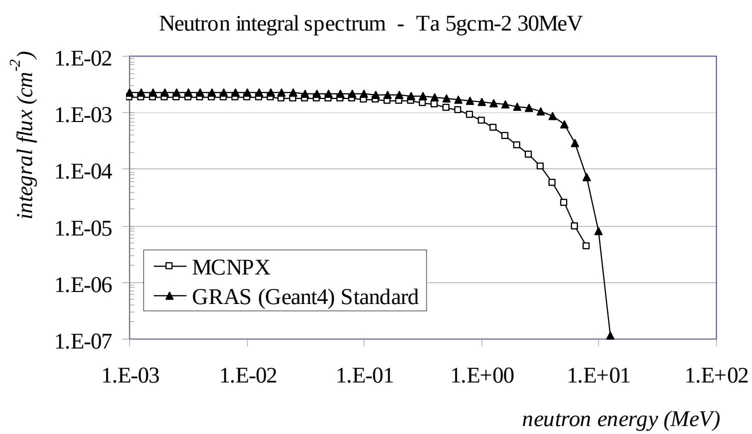
- Prediction capabilities of Geant4 and MCNPX
  - From single materials to multi-layered shielding options
  - Mono-energetic e- and realistic spectra
  - TID, electron, gamma and also neutron fluxes



- Selection of input parameters and models for Geant4 non-trivial

- Agreement generally good, with some notable differences

- Providing benchmarks for potential instrument providers to validate their own choice of transport tools



See talk by S.Kang (JPL)

JORE^{2}M^2

Jupiter Radiation Environment & Effect Models and Mitigations

- http://reat.space.qinetiq.com/jorem/

- Engineering tools for the prediction of the environment and effects/mitigation analysis
- Proton and electron flux-maps in B-L* space for the complete Jovian environment
- Development of models for the energetic ion environment (helium, carbon, oxygen and sulphur)

Of relevance here:

- Review of radiation effects analysis tools (not only Geant4-based)

- Implementation of updated version of PLANETOCOSMICS
  - trapped particle radiation incident upon the Galilean moons
  - including consideration of the Jovian and local fields.

- New tool based on genetic algorithms and MULASSIS
  - optimisation of radiation shields in combined e^- and proton environment.

ESA contract

(QinetiQ, Onera, DHC)

ELSHIELD

Energetic Electron Shielding, Charging and Radiation Effects and Margins

See talk by S.Ibarmia

- Analysis of problem areas in energetic electron penetration and interactions in S/C and P/L
- Tools: improve usability and physics modelling
- Validation of developments (also dedicated testing campaigns)
- Relationships with pre-flight testing and design margins

  Benchmarking and analyses to identify systematic deviations between simulation tools and engineering analysis processes performed as part of radiation hardness assurance and EMC assurance

TAS-E led consortium

G4AI,

TRAD,

INTA,

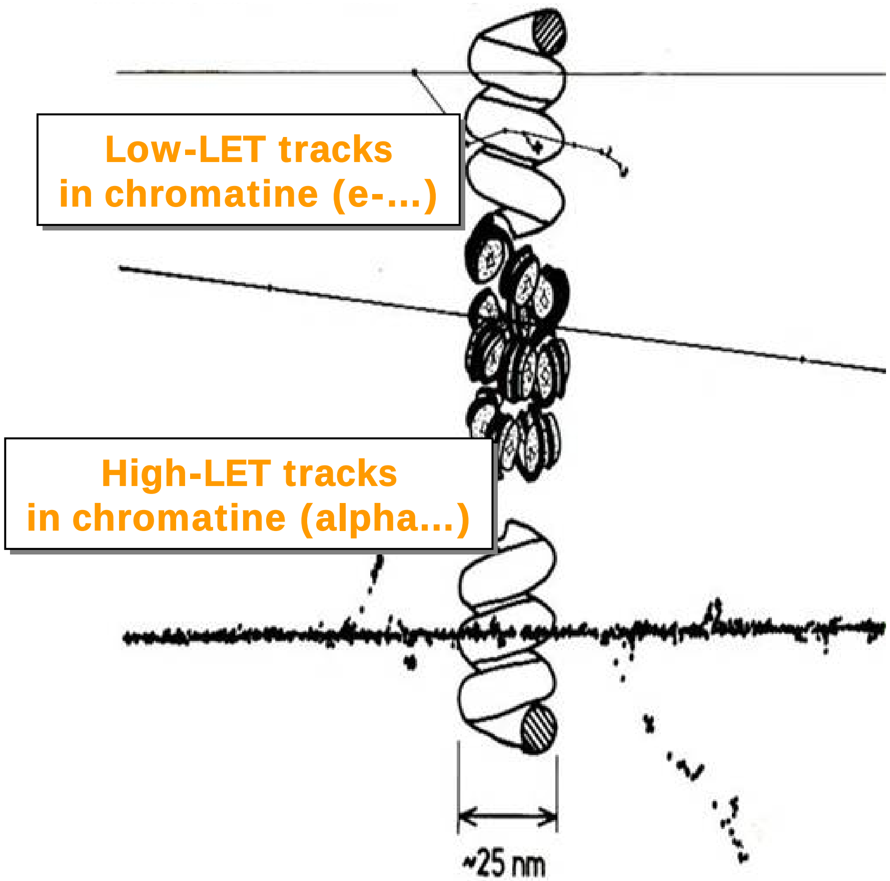
DHC,

ONERA,

Artenum,

TAS France

Geant4-DNA



- Adapt Geant4 for simulation of interactions of radiation with biological systems at cellular and DNA level
  - "Nanodosimetry" domain
  - Prediction of early DNA damages (~1us after irradiation)
- New ESA TRP activity
  - "Physics Models for Biological Effects of Radiation and Shielding" http://geant4.in2p3.fr/spip.php?rubrique14
  - Consortium led by CNRS/IN2P3/CENBG (S.Incerti)

S.Incerti should be in this room…

Physics stage :

Physics models summary

	e	p	H	α, He+, He
Elastic scattering	**> 8.23 eV** **Screened Rutherford** **> 8.23 eV** **Champion**	-	-	-
Excitation	**8.23 eV – 10 MeV** **Emfietzoglou**	**10 eV – 500 keV** **Miller Green** **500 keV – 100 MeV** **Born**	-	**Effective charge scaling from same models as for proton**
Charge increase / decrease	-	**1 keV – 10 MeV** **Dingfelder**	**1 keV – 10 MeV** **Dingfelder**	
Ionisation	**11 eV – 1 MeV** **Born**	**100 eV – 500 keV** **Rudd** **500 keV – 100 MeV** **Born**	**100 eV – 100 MeV** **Rudd**	

Color code:

- Model using interpolated data tables

- Analytical model

Physics stage:
Models now available in Geant4-DNA

- Applicable to liquid water only, the main component of biological matter (for the moment…)
- Can reach the eV limit
  - 8.23 eV lower energy limit for excitation
  - Compatible with molecular description of interactions
- Purely discrete
  - Simulate all elementary interactions on an event-by-event basis
  - No condensed history approximation
- Models can be purely analytical and/or use interpolated data tables (e.g. cross sections)
- Extensions on-going
- Large domain of applications in perspective: radiobiology, radiotherapy/hadrontherapy, radioprotection for aerospace & astronautics, exobiology…
- Synergies with nanodosimetry in micro-electronics

Radiation effects analysis

- Tools, interfaces, physics developments

Engineering use: Geant4 tools in SPENVIS

SPENVIS DEVELOPER Project: PROBA1_SREM

Model packages

Planet: Earth

UP | Output | Help

- Coordinate generators
- Radiation sources and effects
- Spacecraft charging
- Atmosphere and ionosphere
- Magnetic field
- Meteoroids and debris
- Miscellaneous
- **Geant4 Tools**

General models

- Multi-Layered Shielding Simulation (Mulassis)
- Geant4 Radiation Analysis for Space (Gras)
- Geant4-based Microdosimetry Analysis Tool (GEMAT)
- Sector Shielding Analysis Tool (SSAT)

Planet specific models

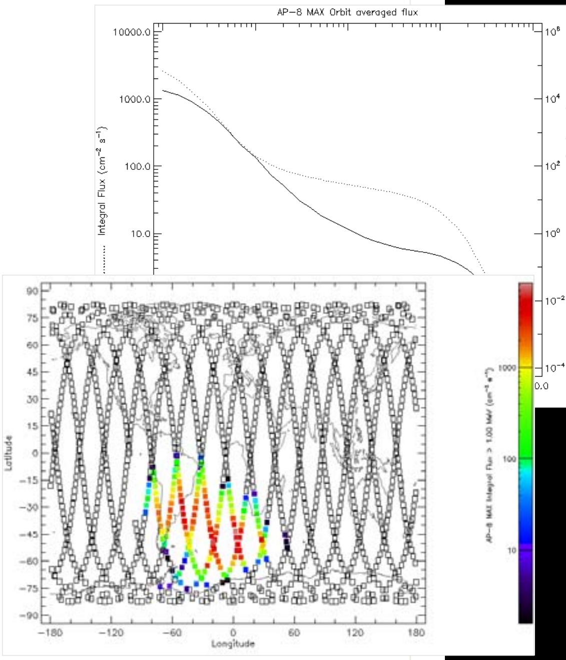
- Magnetocosmics
- Planetocosmics

Common settings

- Definition of source particles
- Definition of physical models
- User defined materials
- Geometry definition tool

ECSS Space Environment Standard

The models implemented in SPENVIS are combined in the packages listed above. Clicking on a package name will expand the table with a list of models. Some model suites have to be executed in a prescribed order. Model links will not be available when pre-required runs have not been executed yet. Most models run on both a spacecraft trajectory and a geographical coordinate grid. Clicking on the coordinate generator links and returning to this page toggles between the two sets of coordinates. The model links will adapt to the choice of coordinates.



PROBA-1 environment

3-D radiation analyses in SPENVIS

SPENVIS DEVELOPER Project: PROBA1_SREM
Geant4 tools
Geant4 Radiation Analysis for Space (Gras)

UP | Output | Help

Gras is a Geant4-based tool that provides a general space radiation analysis for 3D geometry models. Gras is a complex tool, so please consult the help page before using it.

Status	Settings	Remarks
defined	Source particles	Trapped, proton
defined	Geometry	GDML
defined	Analysis parameters	Fluence
Advanced settings		
not required	Material definition	----
default	Region cuts-in-range	---
defined	Physical models	Standard EM, Hadron
defined	GDML definition	upl, GDML file analysis

Create macro

Model developed by

esa

SPENVIS DEVELOPER Project: PROBA1_SREM
Geant4 tools
GDML definition

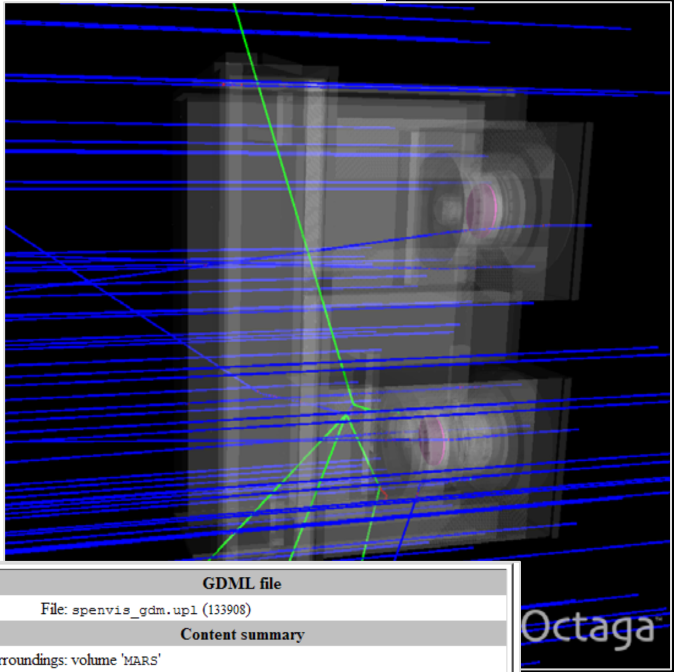
UP | Output | Help

GDML files are used by Geant4 applications to describe the user geometry. Inside SPENVIS, GDML files can either be uploaded or generated by the Geometry definition tool

Source:	new file upload
Title:	SREM
File:	C:\Documents and Settings\neophytos\Desktop\srem_ Browse...

Reset | Save >>

© ESA



GDML file

File: spenvis_gdm.upl (133908)

Content summary

Surroundings: volume 'MARS'
material 'vacuum'
Statistics: 8 material(s)
125 unique volume(s)
24 empty volume(s)

Stucture overview

Structure:
- MARS (VACUUM)

```
+1.00 +0.00 +0.00 +0.00
+0.00 +1.00 +0.00 +0.00
+0.00 +0.00 +1.00 +0.00
+0.00 +0.00 +0.00 +1.00
```

  - SBAL (VACUUM)

```
+1.00 +0.00 +0.00 +33.00
+0.00 +1.00 +0.00 -30.00
+0.00 +0.00 +1.00 -70.60
+0.00 +0.00 +0.00 +1.00
```

    - C2W1 (ALUMINUM)

```
+1.00 +0.00 +0.00 -1.00
+0.00 +1.00 +0.00 +0.00
+0.00 +0.00 +1.00 +17.10
+0.00 +0.00 +0.00 +1.00
```

    - C2V1 (ALUMINUM)

```
+1.00 +0.00 +0.00 -1.00
+0.00 +1.00 +0.00 -60.00
+0.00 +0.00 +1.00 +17.10
+0.00 +0.00 +0.00 +1.00
```

Sector Shielding Analysis Tool SSAT

- Ray tracing: from a user-defined point within a Geant4 geometry
- NORM, SLANT and MIXED tracing

SHIELDING

- shielding levels

  fraction of solid angle for which the shielding is within a defined interval

  global and from single materials

- shielding distribution

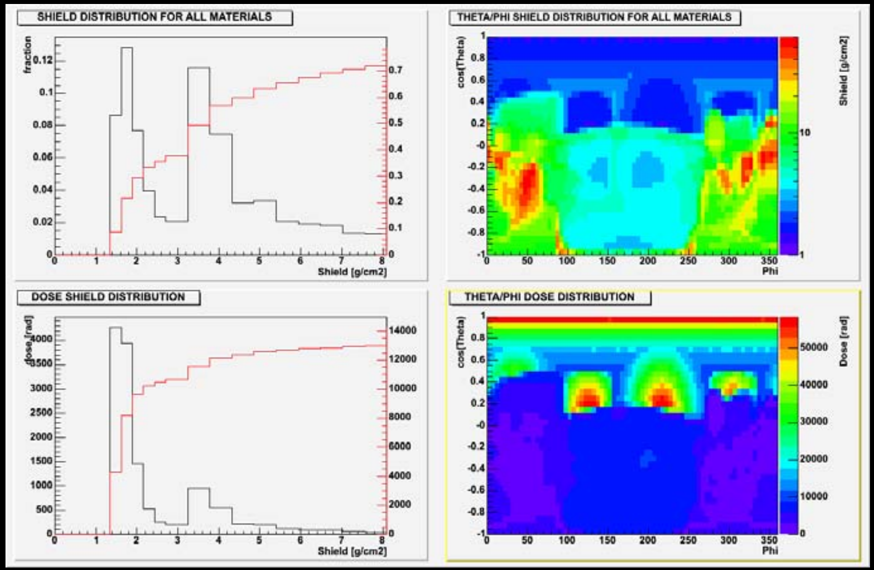
  the mean shielding level as a function of look direction

- It utilizes geantinos

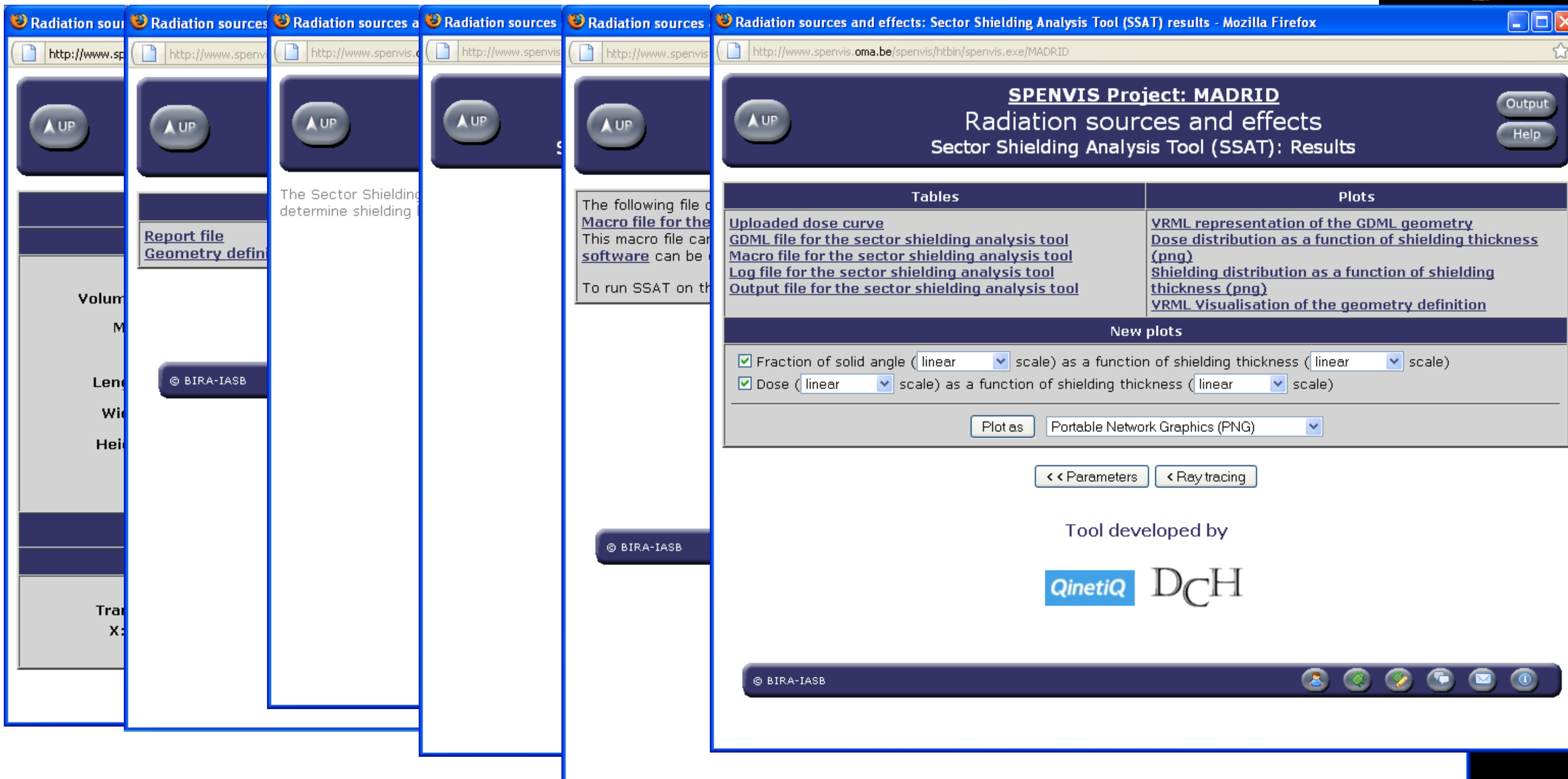
See e.g. talks by S.Ibarmia, F.Garcia (tomorrow morning)

DOSE

- Estimate of the dose at a point
  - Based on external Dose-Depth curve e.g. SHIELDOSE-2
  - Ray-by-ray dose calculation
- Results:
  - Total dose
  - Dose-Depth profile
  - Dose directionality



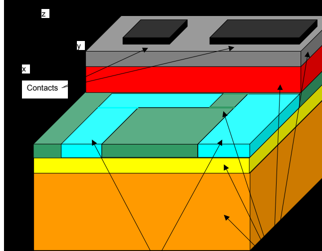
SSAT now SPENVIS ray-tracer engine



- Ray-tracing analysis addresses engineering needs
  - Quick assessment of effects to micro- or nano- scaled devices in macroscopic spacecraft models

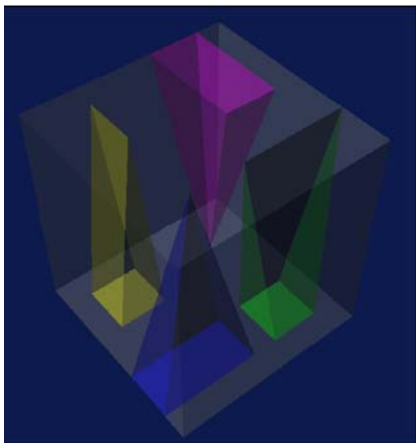
- Proton ray-tracing results are usually not too far from full MC
- Electron results: comparison with full MC shows case-by-case variations with both under- and over- prediction of dose, with no easy answer on strategy

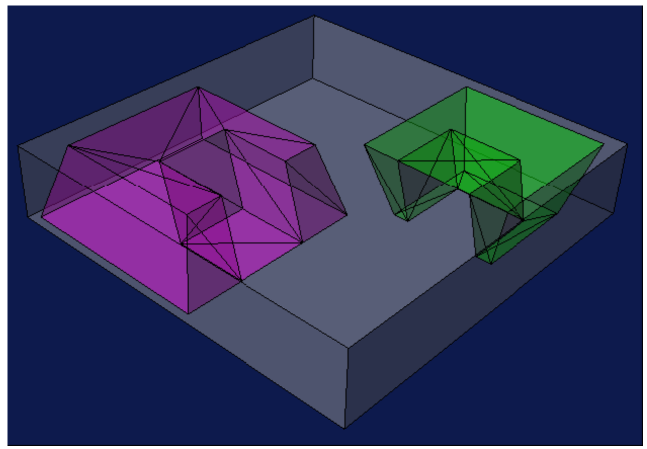
Single Event Effects: GEMAT



Geant4-based Microdosimetry Tool

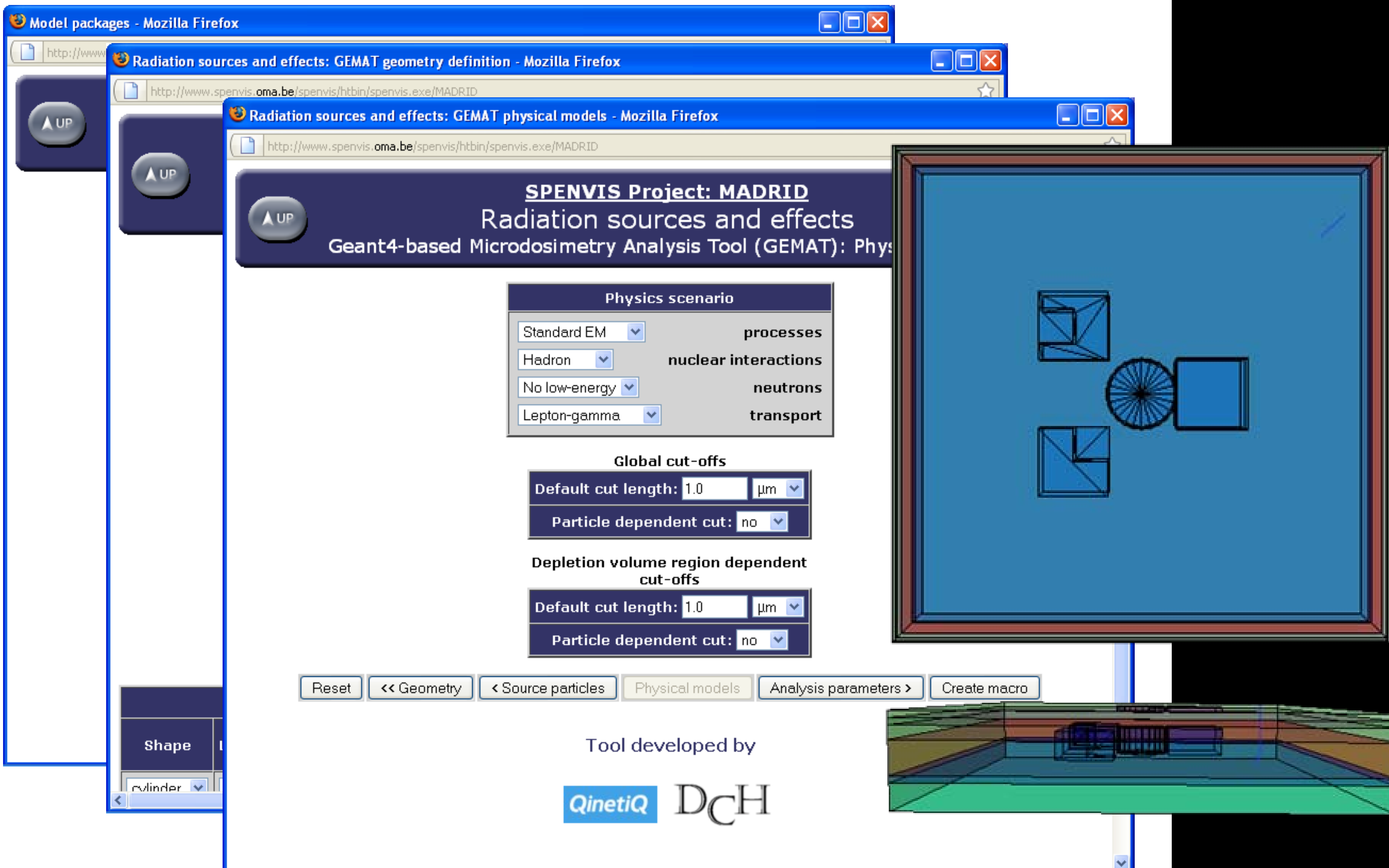
- Microdosimetry in geometries representing features of a semiconductor device (transistor/junction geometries)





- Analysis includes
  - Single Event Effects (SEE)
    - User-input collection "efficiencies" for different regions
    - Charge Collection Analysis (CCA, GRAS analysis module) includes diffusion equation for charge transport outside drift volumes
  - Simultaneous energy deposition in several sensitive regions (MBU)
- Has been recently integrated into SPENVIS

GEMAT through SPENVIS



DESMICREX

Radiation effects in deep sub-micron technologies

- Usage of technologies below 100 nm in space for European missions is actively pursued with combined efforts of Space Agencies
- Circuit designers challenged with evolving susceptibility to SEEs and possibly other effects traditionally not observed with larger size CMOS technologies

Objectives

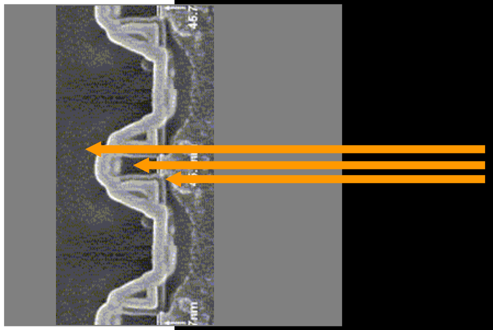
- Develop simulation framework enabling IC designers to characterize the impact of radiation effects on integrated circuits using DSM technologies

  → TCAD / SPICE interfaces, novel algorithms, etc
- Identify new effects and trends, and design countermeasures

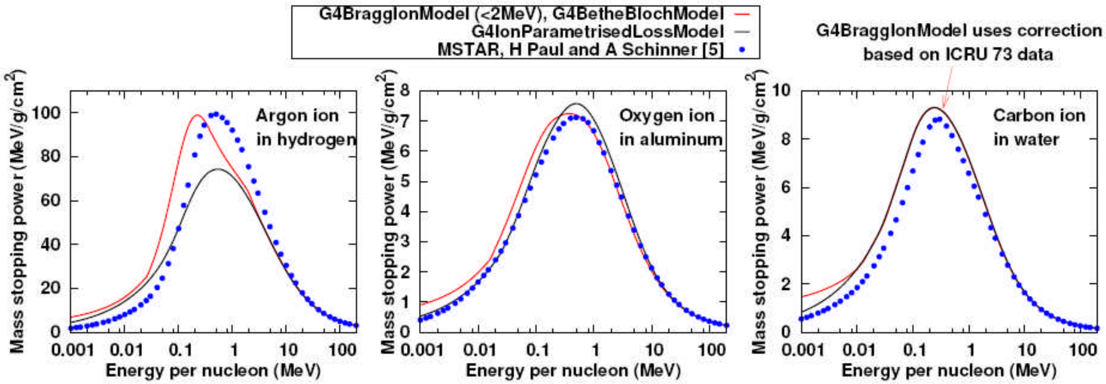
- Consortium

Physics development examples: Ions

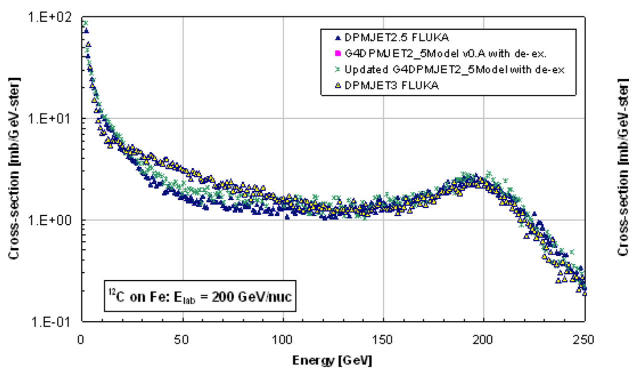
- Impact e.g. on
  - SEE ground testing of EEE components
  - Shielding, recoil and fragment ion contribution to SEE, dose



- ICRU-73 tabulated stopping powers (PASS code results)



- DPMJET-II.5 model in Geant4
  - Interface to DPMJET-II.5 event generator
  - Cross sections



V. Ivantchenko

A.Lechner

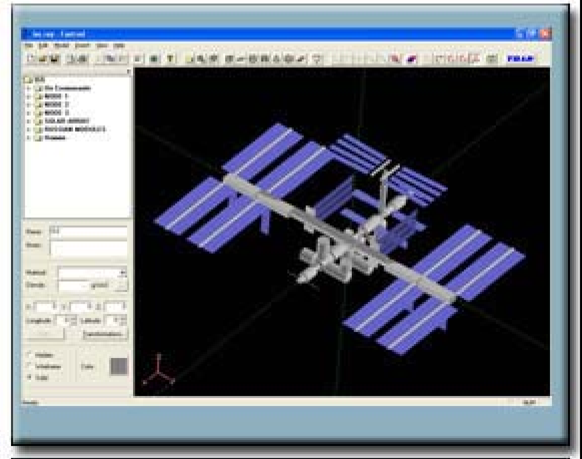
P.Truscott

(QinetiQ)

Modelling speed in 3-D realistic S/C

http://www.trad.fr

http://www.etamax.de



Modèle de la station internationale sur FASTRAD

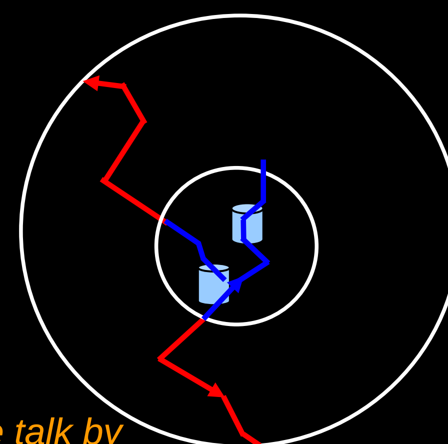
CAD geometry interface

- CAD STEP and IGES interface (and normal 3D models)
  - via external 3D modelling tools tools
  - Direct GDML output for Geant4
- FASTRAD, ESABASE2

Speed: Reverse MC

Requirement from space industry

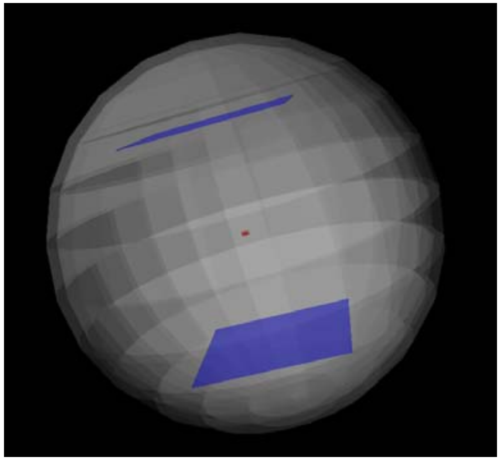
- Tallying in sub-micron SV inside macroscopic geometries
- Reverse tracking from the boundary of the sensitive region to the external source
  Based on "adjoint" transport equations
- Computing time focused on tracks that contribute to the detector signal



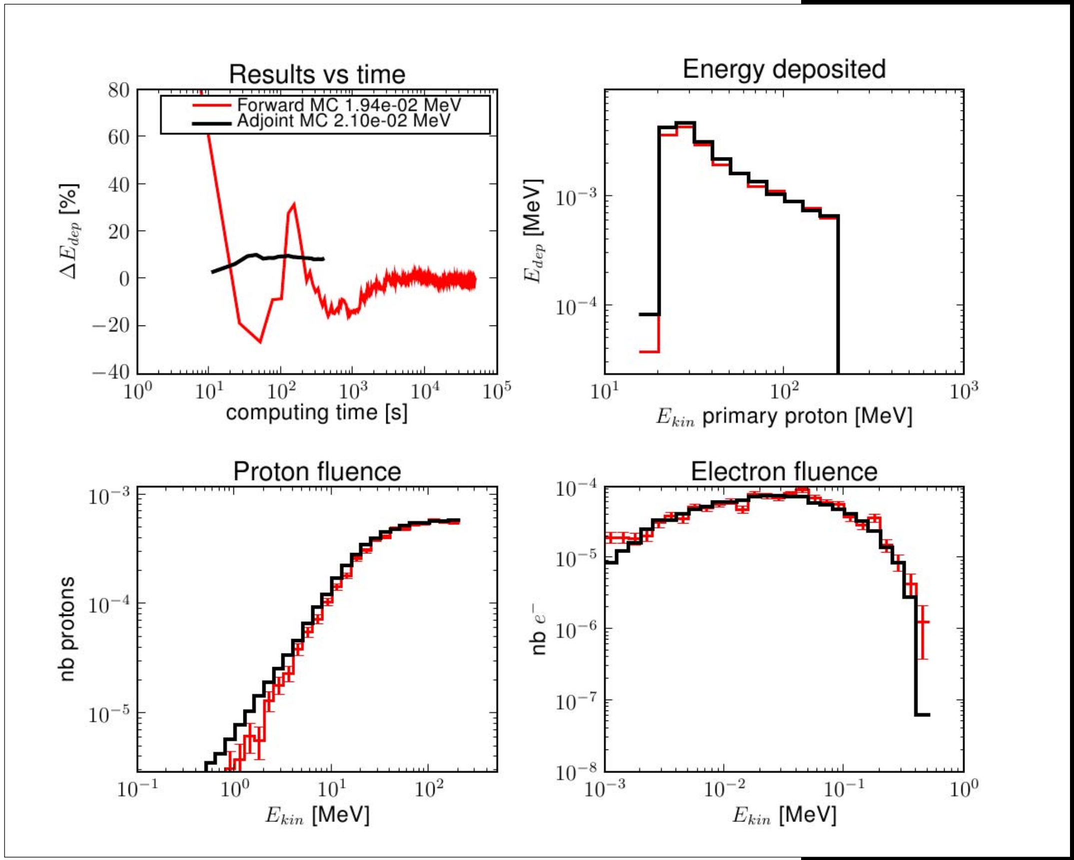
See talk by

L.Desorgher (Space IT)

Reverse MC: comparison VS forward Protons, simple geometry



- Proton source
  - [0.1keV, 200MeV]
  - E^{-1} spectrum



- Difference in total computed dose <~5%
- Reverse MC method more rapid than forward by orders of magnitude

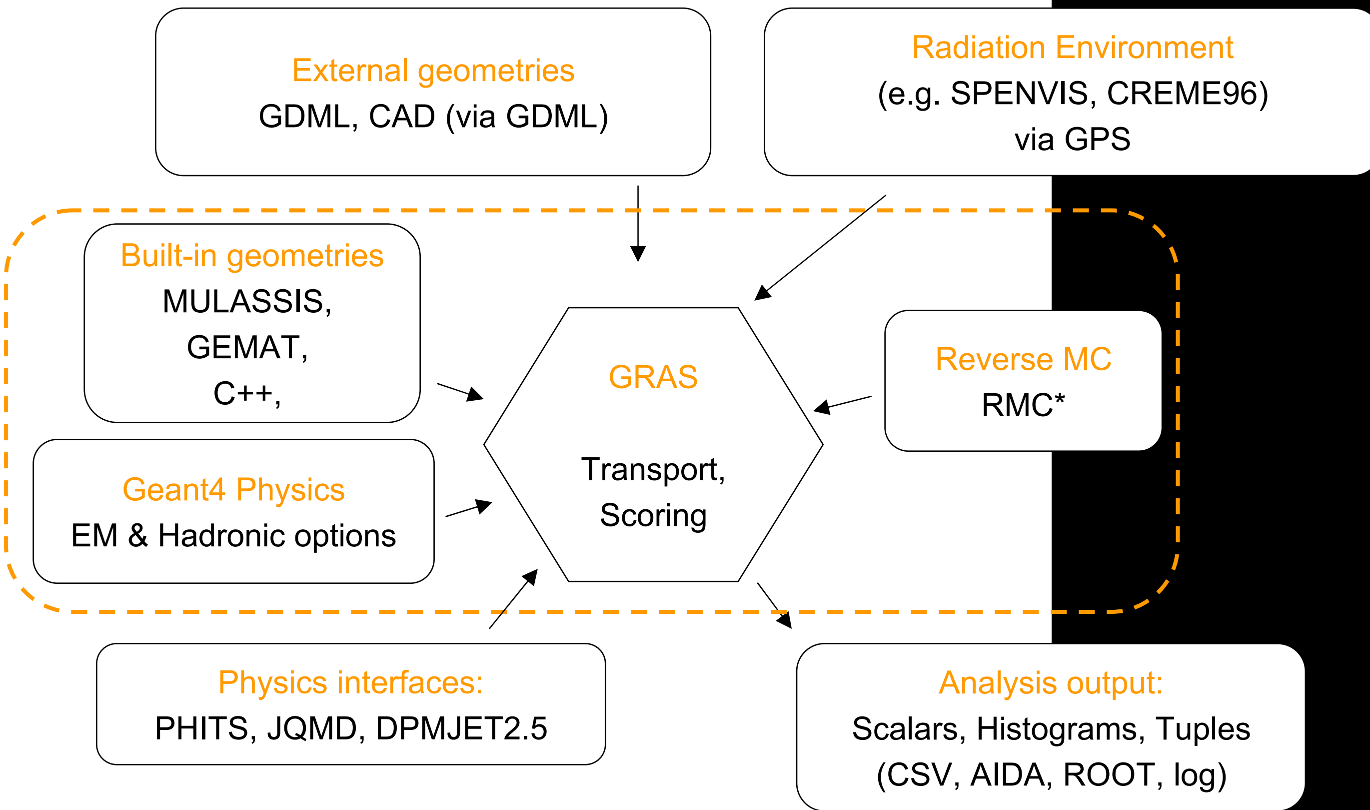
See talk by

L.Desorgher (Space IT)

Geant4 tool integration: GRAS

Requirements:

- Ready-To-Use tool
  - Multi-mission approach
- Quick assessments
  - Ray-tracing ↔ MC
  - 1D ↔ 3D
  - EM ↔ Hadronics
  - LET ↔ SV details
- Modular progress
  - Open to collaborations and contributions



G Santin, V Ivantchenko et al, IEEE Trans. Nucl. Sci. 52, 2005

http://space-env.esa.int/index.php/geant4-radiation-analysis-for-space.html

** in progress*

GRAS: script driven

Santin et al, RADECS, 2005

Geometry

1

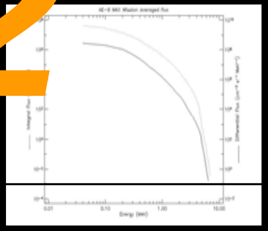
Parameters for
built-in geometries
or
External files

```
/gras/geometry/type gdml
/gdml/file geometry/conexpress.gdml
```

Source

2

RADIATION
ENVIRONMENT



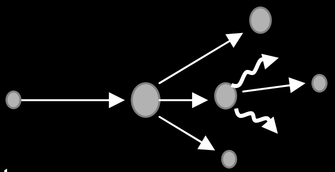
```
/gps/pos/type Surface
/gps/pos/shape Sphere
...
/gps/ang/type cos
/gps/particle e-

...
```

Physics

3

Physics lists

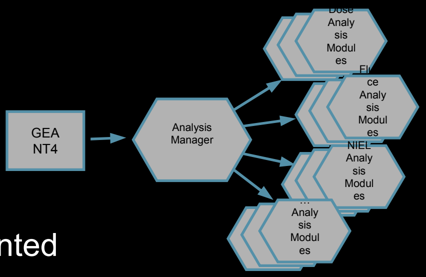
or single components



```
/gras/phys/addPhysics em_standard_opt3
/gras/phys/addPhysics QGSP_BIC_HP
/gras/phys/addPhysics raddecay

/gras/physics/setCuts 0.1 mm
/gras/physics/stepMax 0.01 mm
```

Analysis

4

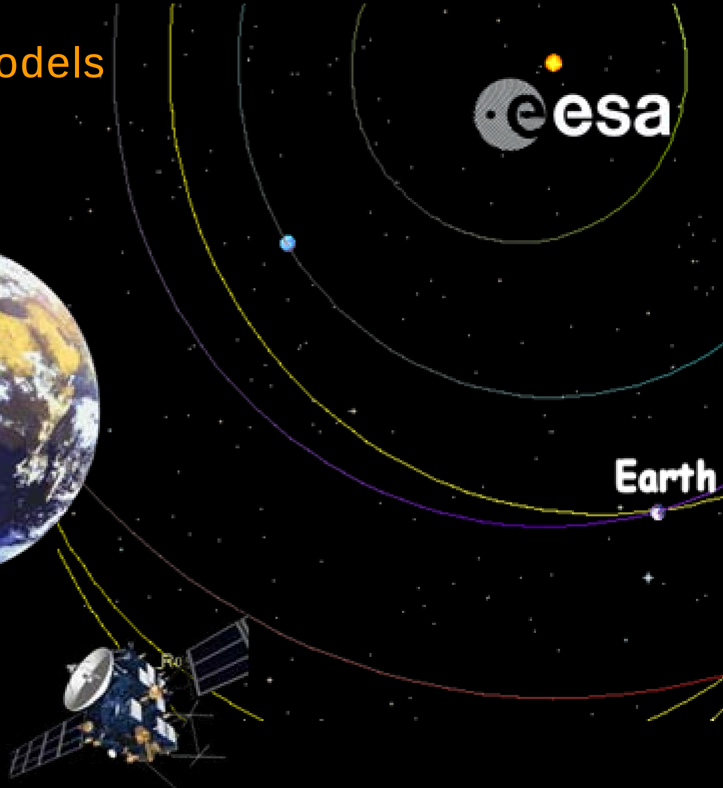


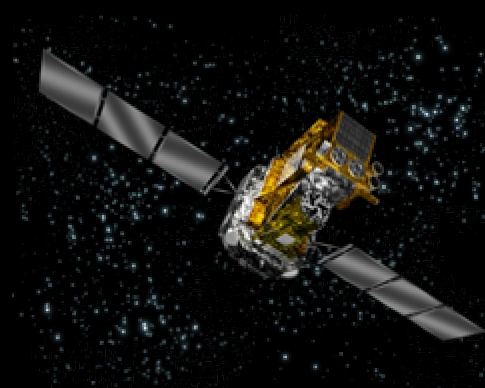
Object Oriented
scripting

```
/gras/analysis/dose/addModule doseB12
/gras/analysis/dose/doseB12/addVolume b1
/gras/analysis/dose/doseB12/addVolume b2
/gras/analysis/dose/doseB12/setUnit rad
```

Reducing uncertainties on radiation environment models

Radiation monitoring



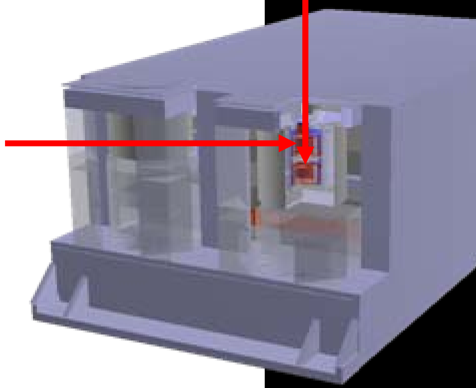


SREM

Standard Radiation Environment Monitor

- The same monitoring requirements apply to the other radiation environments (aircrew, medical staff,…)

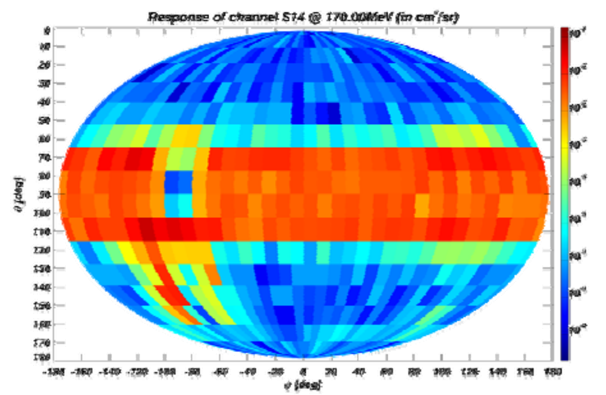
Radiation monitor design and calibration



SREM GRAS simulations

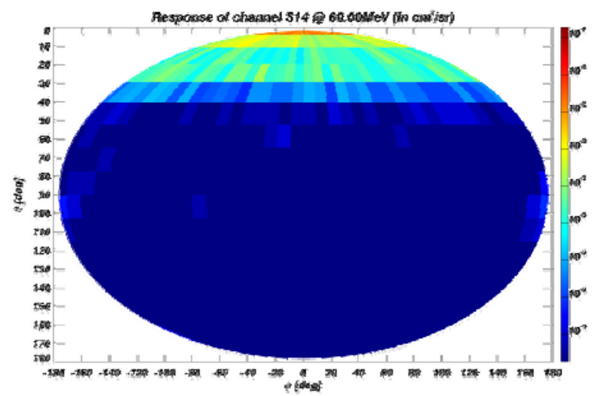
- Directional response function for all output channels
- Geant4 / GRAS simulations
- Inner Belt Anisotropy Investigations
  - AP-8 and Badhwar-Konradi pitch angle distribution model
  - Comparison with observations onboard PROBA-1
- Martin Siegl's Master's Thesis, 2009

  Siegl et al, IEEE TNS, 2010 (RADECS '09)



- Geant4 heavily used for design and calibration of new ESA radiation monitors, including
  - Standard Radiation Environment Monitor (SREM)
  - Energetic Particle Telescope (EPT)
  - Multi Functional Spectrometer (MFS)
  - Highly Miniaturised Radiation Monitor (HMRM)

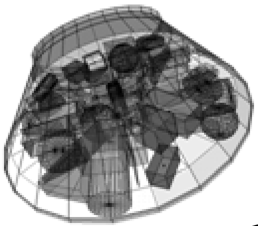
    see talk by E.Mitchell



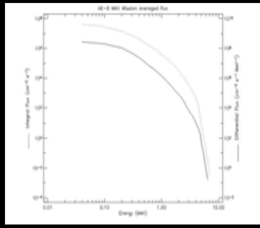
REST-SIM

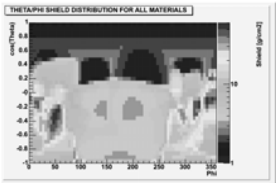
Geant4 for ESA Cosmic Vision

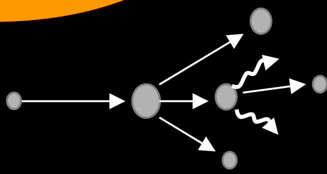
- Development of specific tools and capabilities for radiation effects analysis based on Geant4
- Enable quantitative analyses of the susceptibility of the proposed Cosmic Vision payloads to HEP radiation
- Greatly improved efficiency for integrated use through all project phases
  - for radiation effects tools
  - for geometry generation and exchange
  - for analysis case definition
- Continuous and smooth improvement of radiation analyses over entire mission design lifetime



ConeXpress, R.Lindberg, ESA







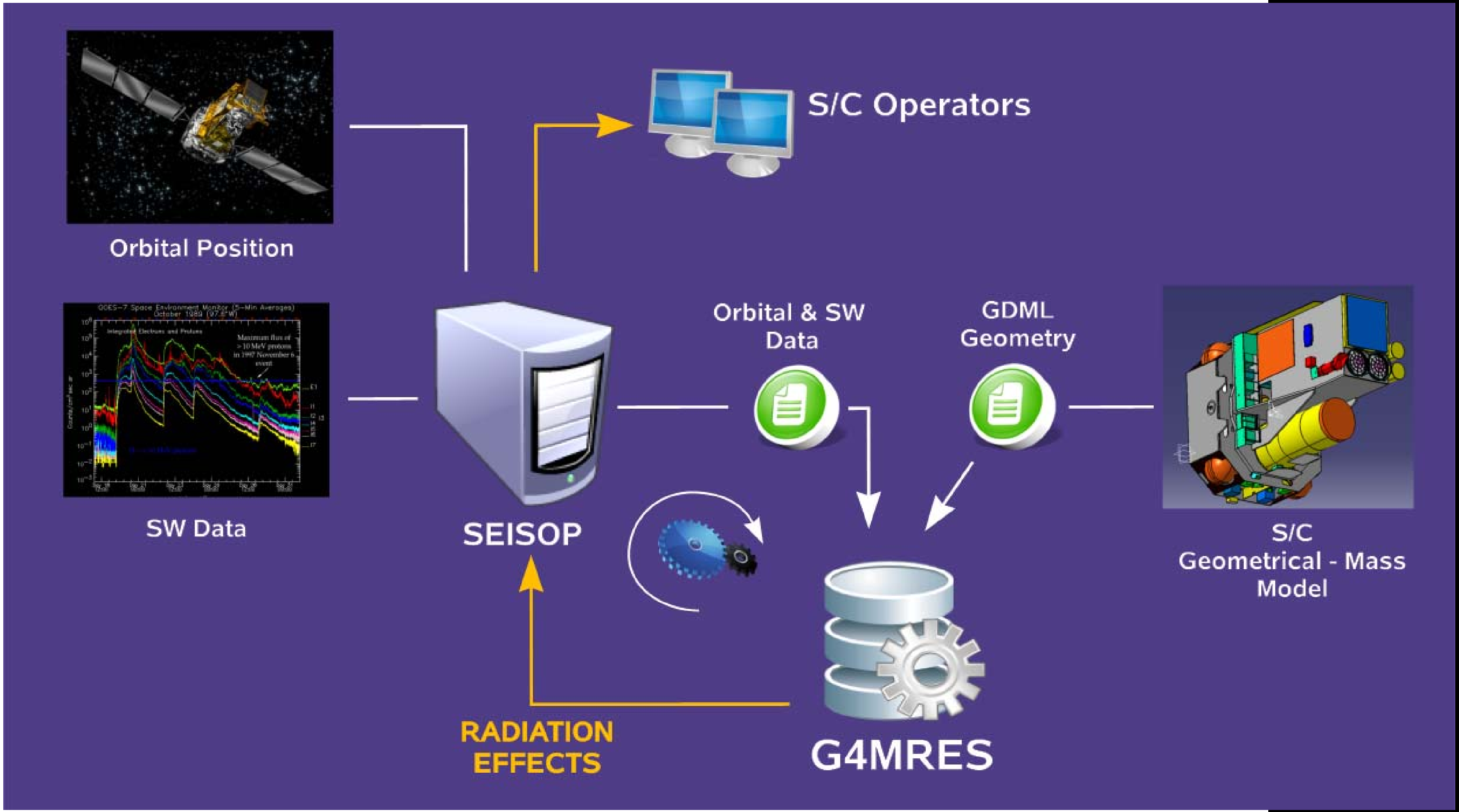
- Status
  - Task 1: Survey of CV mission technologies and susceptibilities √
  - Task 2: Requirements for radiation transport and effects analysis tools, and geometry generation/exchange √
  - Development of Framework — Ongoing
  - Application

http://reat.space.qinetiq.com/rest-sim/

SEISOP - G4MRES

"A Monte-Carlo plug-in tool to estimate real-time radiation effects on any S/C part"

See talk by S.Ibarmia



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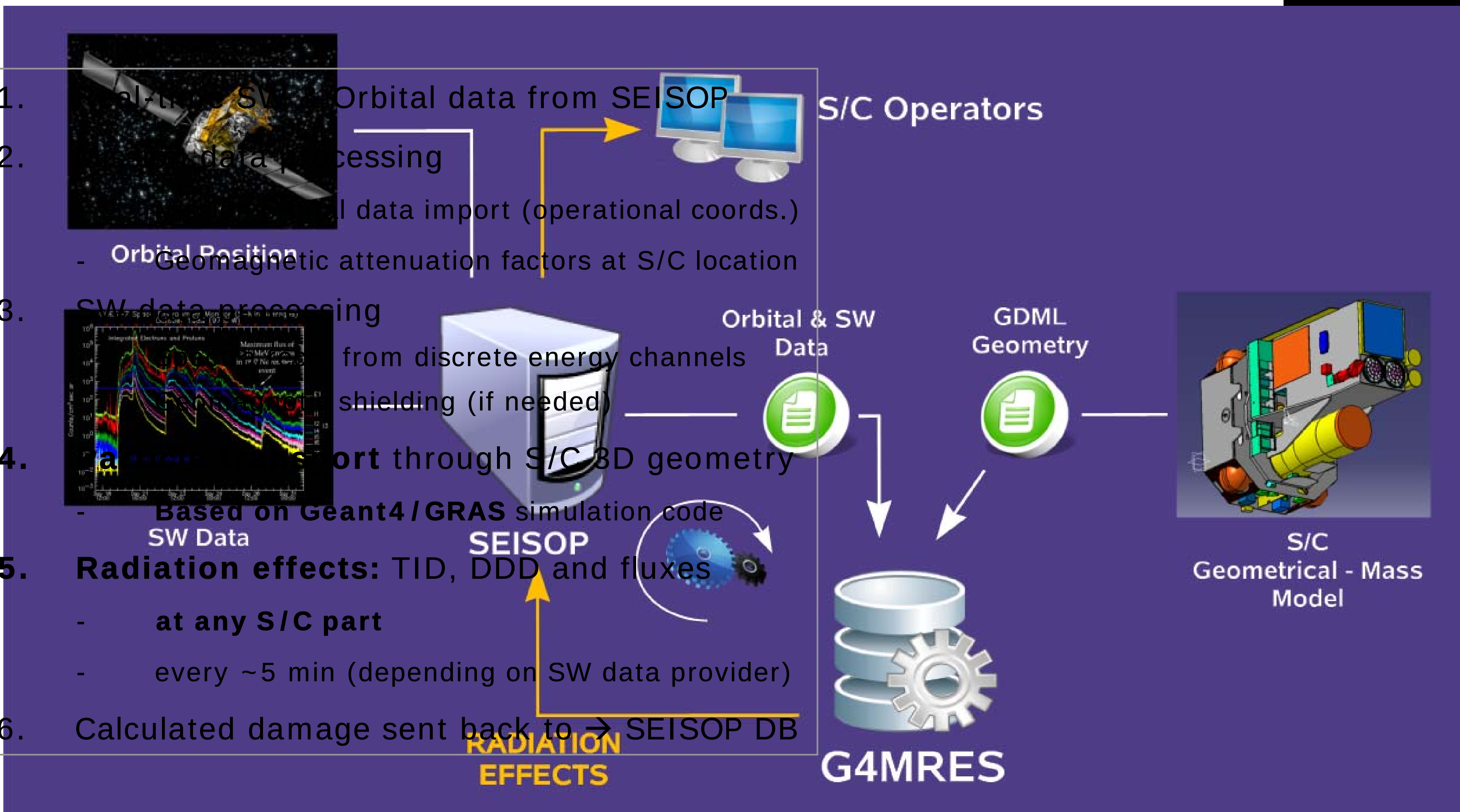

1. [illegible]al-time SW [illegible] Orbital data from SEISOP
2. [illegible] data p[illegible]cessing
   - [illegible]l data import (operational coords.)
   - Geomagnetic attenuation factors at S/C location
3. SW data processing
   - [illegible] from discrete energy channels
   - [illegible] shielding (if needed)
4. **[illegible]a[illegible]ort** through S/C 3D geometry
   - **Based on Geant4 / GRAS** simulation code
5. **Radiation effects:** TID, DDD and fluxes
   - **at any S/C part**
   - every ~5 min (depending on SW data provider)
6. Calculated damage sent back to → SEISOP DB

Summary, perspectives

- A number of R&D activities have come to completion
  - Reverse MC implementation for e-, gamma, protons, ions
  - CAD interface(s)
  - Ion physics (stopping power, hadronic interactions)

- Ongoing
  Mixture of R&D (physics, interfaces, tools) targeting the all ESA Programme domains
  - Physics accuracy for application in electron environments (Navigation and Jupiter)
  - Extension of capabilities for biological effects (DNA): low energy and chemistry
  - Augmented Geant4 SEE capability in SPENVIS, TCAD / SPICE framework for SEE
  - Ease of use: improved interfaces, integrated simulation frameworks

- Internal support to ESA missions (SEE, rad. monitors, Jupiter, …)

- Perspectives
  Upcoming R&D activities: items in ESA TRP programme selected soon
  - Single Event Effects: new mechanisms, physics phenomena, algorithms
  - Engineering interfaces
  - Computational speed for industrial applications

- International and inter-agency collaboration is welcome
  - Potential areas: basic developments, comparisons, (expt) validation