ESA Geant4 R&D activities

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Space Environments
and Effects Section
European Space Agency
ESTEC

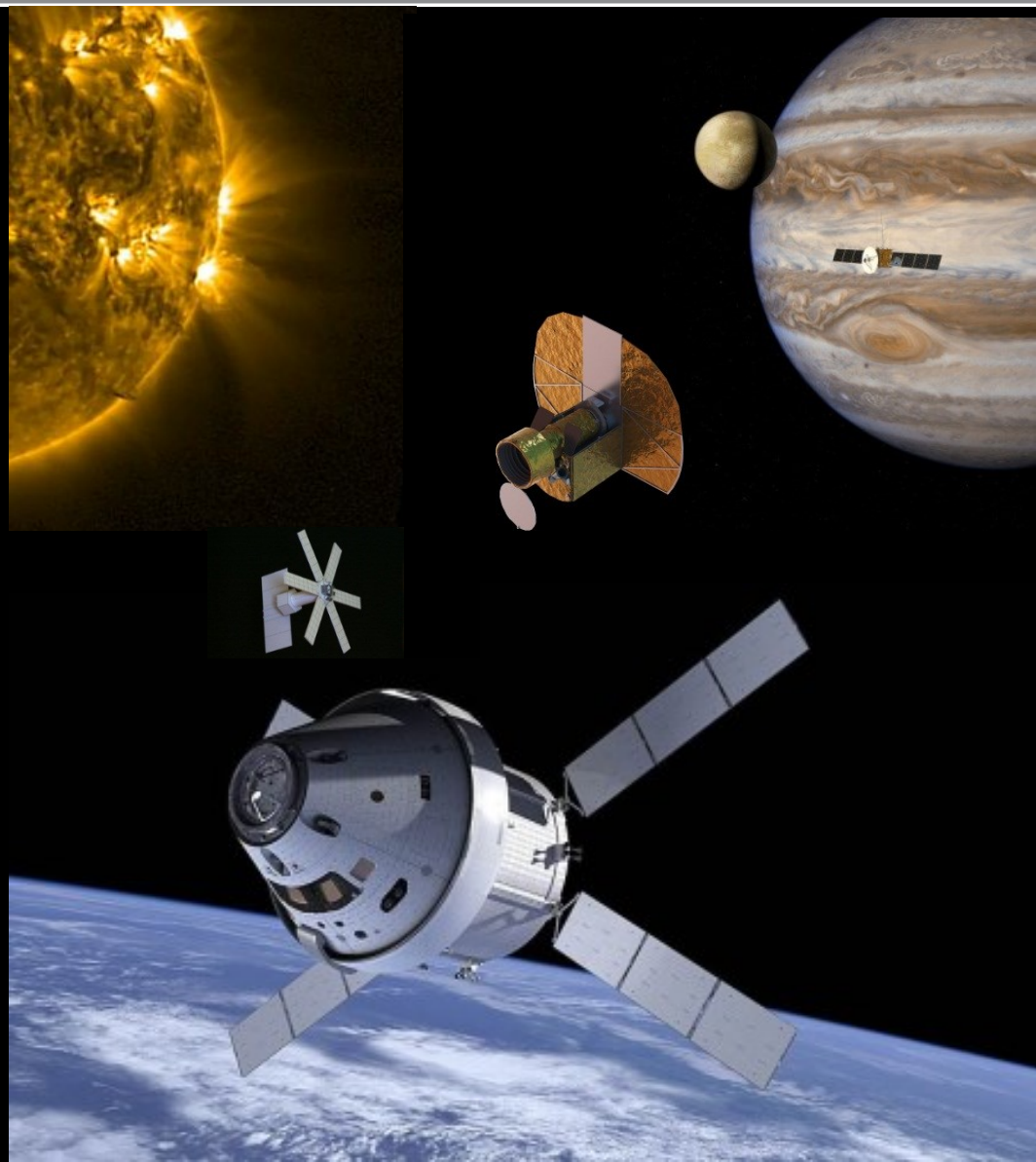
Geant4 Space Users' Workshop, **Barcelona**, 4 March 2013

Contents

- ESA Programmes outlook
- Radiation engineering tools
- (Some) ongoing and planned R&D activities
- Radiation monitoring activities
- Outlook and Conclusions

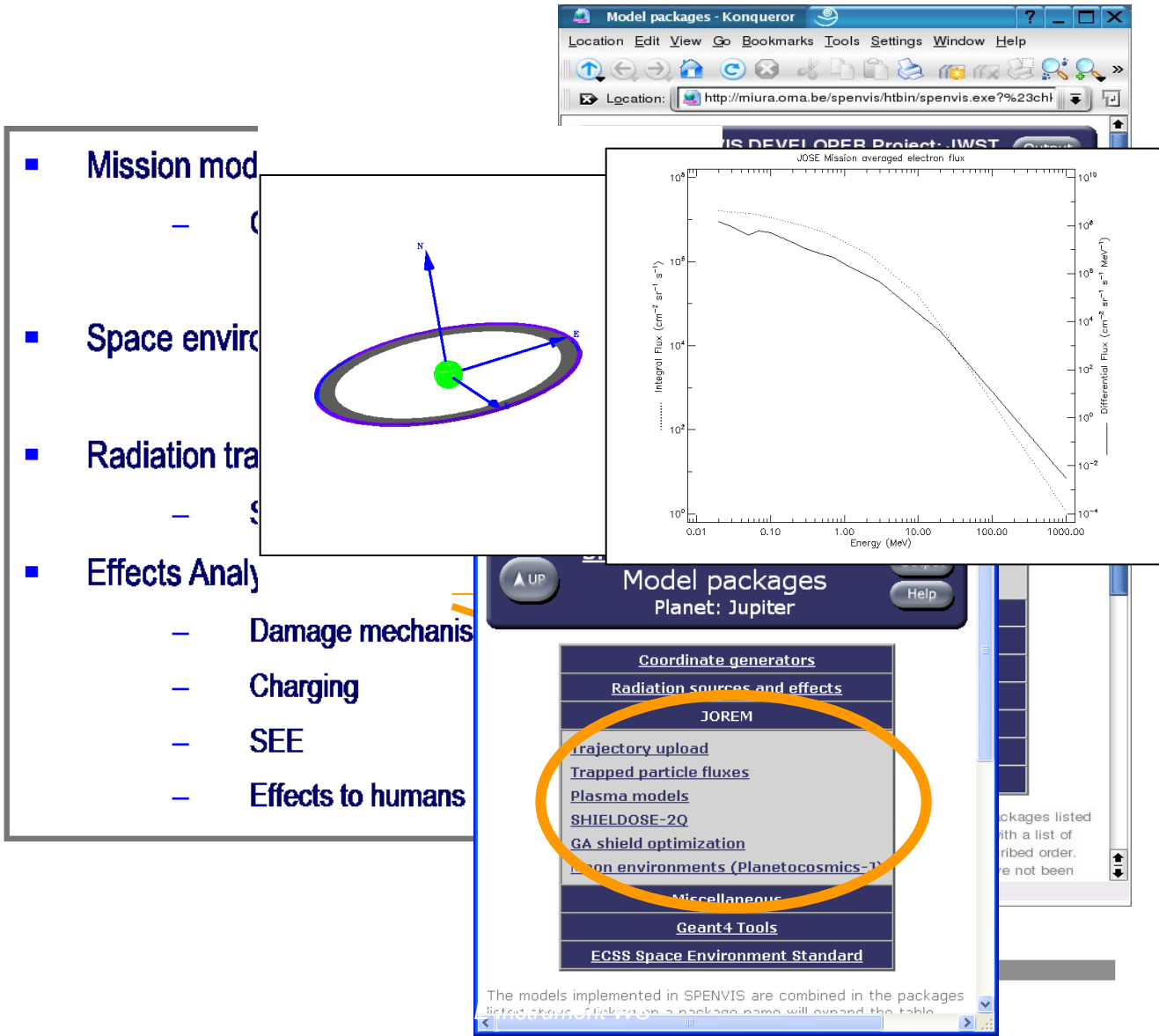
ESA Programmes Outlook (in context of particle interactions)

- Demanding Science missions
  - ✓ In preparation: JUICE, SO
  - ✓ Under study: LOFT, Cheops, ExoMars,…
- Human missions:
  - ✓ ESA will construct service module for Orion (needs high immunity from radiation effects)
  - ✓ Preparation for missions beyond LEO (shielding, biological effects)
- Earth observation missions with considerable on-board processing (susceptibilities, especially SEE)
- Telecom and Navigation (Galileo) in highly severe outer radiation belt environment



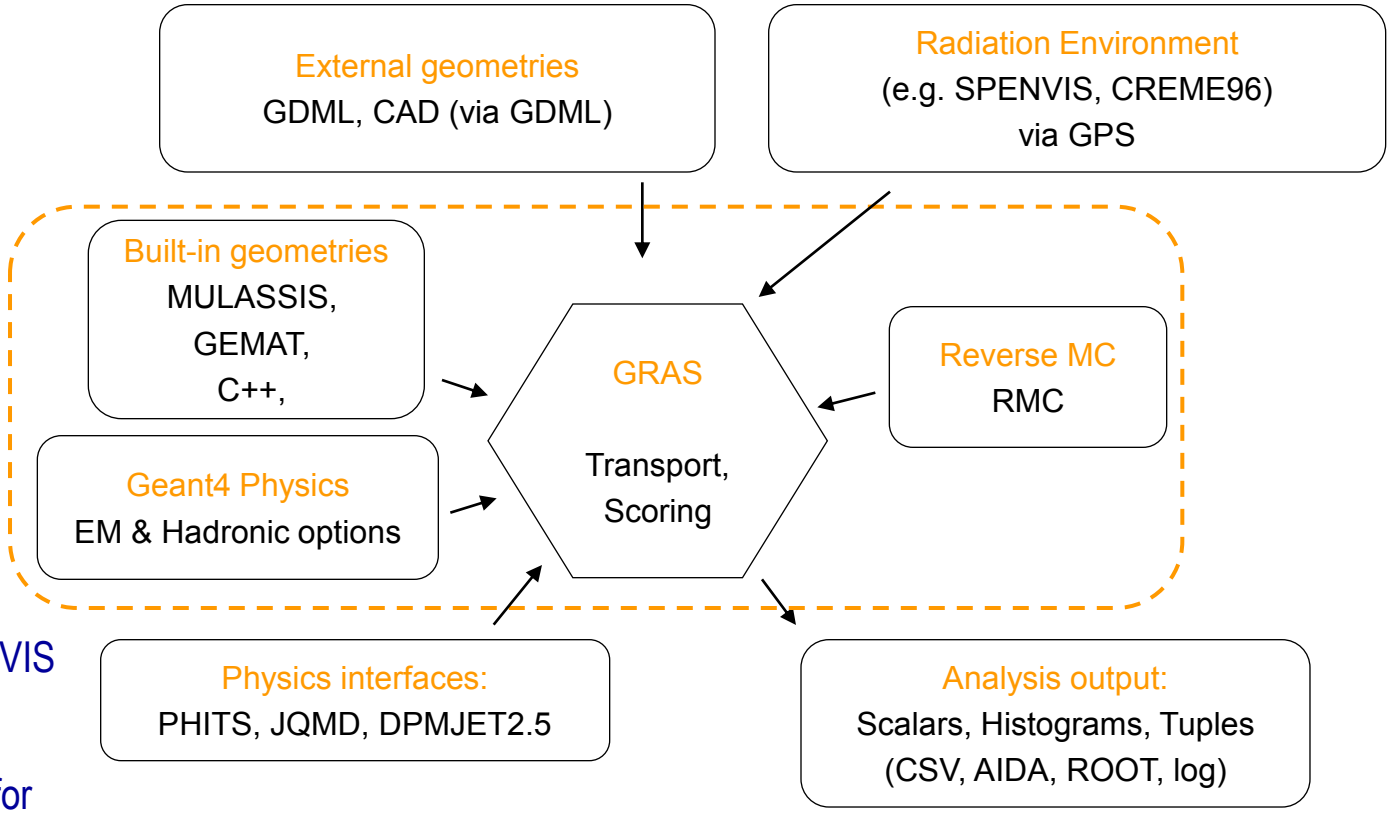
Radiation Engineering tools: SPENVIS

- Models and tools for the space environments effects analysis
- Web Interface
- A range of Geant4-derived tools and models
- Recent additions of Jupiter-related models and tools to target the JUICE mission under “JOREM”: JOSE environment, shielding assessment
- 10,000th registered user on 26 February 2013!
- Under development: Next Generation of the system ‘(“SPENVIS-NG”)
- See presentation on Tuesday by Neophytos Messios



Geant4 tool integration: GRAS

- 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
- Currently GRAS v3.1, trial version available in SPENVIS as of March 2013
- Increasingly the baseline for much of ESA analyses
- Reverse MC: See talk by Laurent Desorgher Tuesday morning

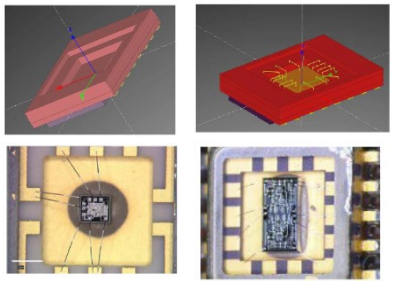


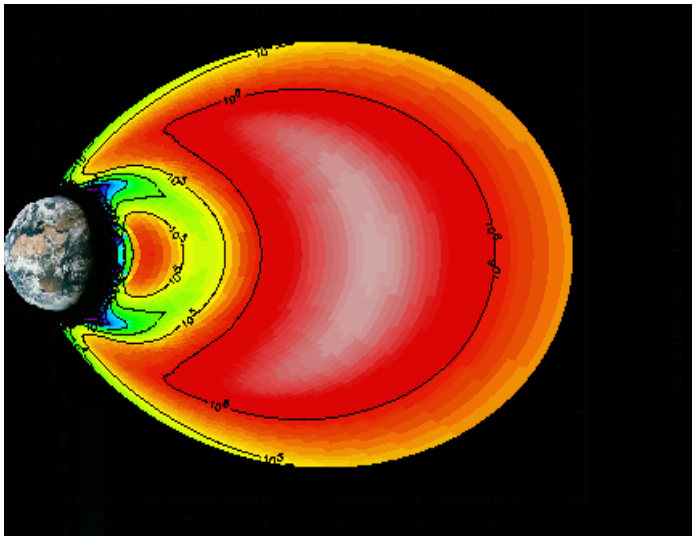
G Santin, V Ivantchenko et al, IEEE Trans. Nucl. Sci. 52, 2005

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

ELSHIELD

Energetic Electron Shielding, Charging and Radiation Effects and Margins



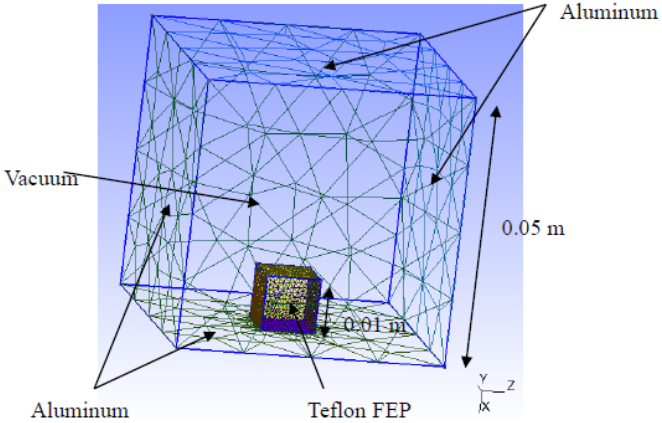


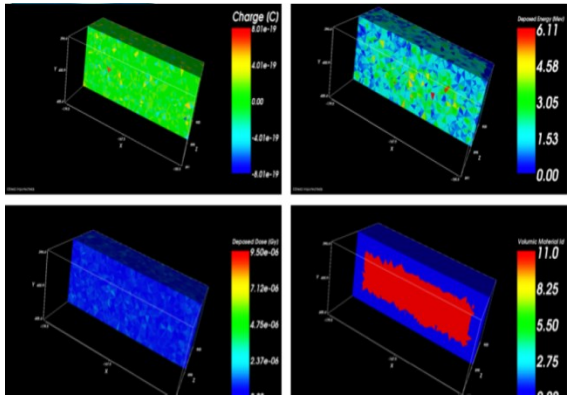
- Analysis of problem areas in energetic electron penetration and interactions in S/C and P/L
- Tools: Improved usability and e.m. physics models
- Validation of developments (also dedicated testing campaigns)
- Relationships with pre-flight testing and design margins
- Benchmarking and analyses to identify systematic deviations between simulation tools and engineering analysis processes performed as part of radiation hardness assurance and EMC assurance
- See presentation by Sergio Ibarmia Tuesday morning

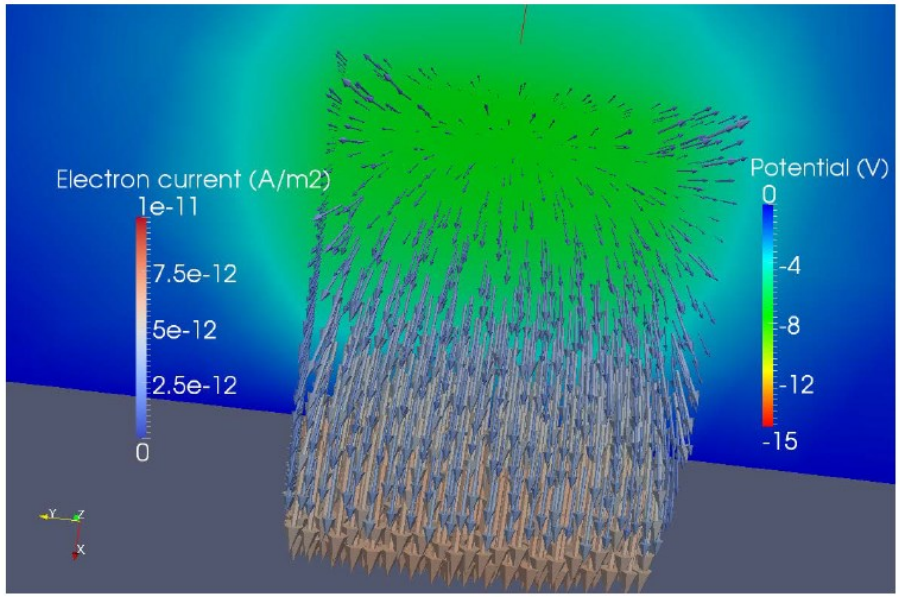
ThalesAlenia Space
INTA
TRAD Tests & radiations
DH Consultancy
ONERA The French Aerospace Lab
Geant4 Associates International
Artenum, Paris Science & Groupware

ELSHIELD 3D internal charging tool

- New 3D deep charging analysis capability, based on novel interfaces between CAD, SPENVIS, FASTRAD, Geant4 / GRAS particle transport, SPIS and circuit solvers

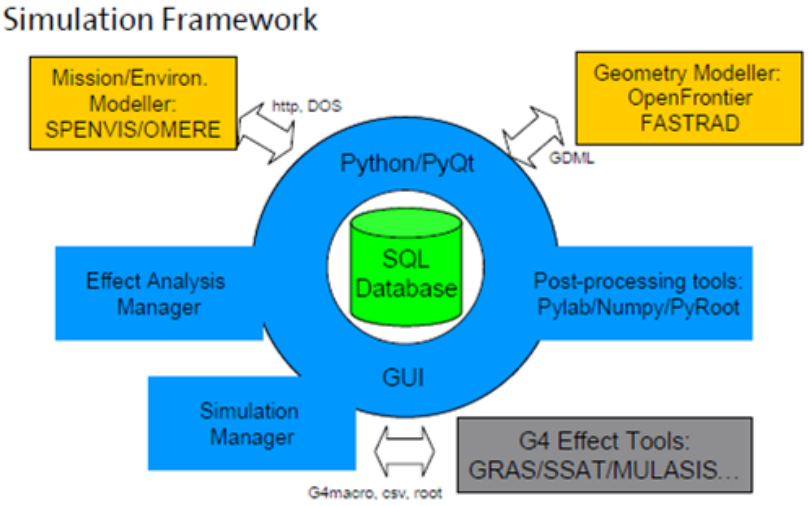


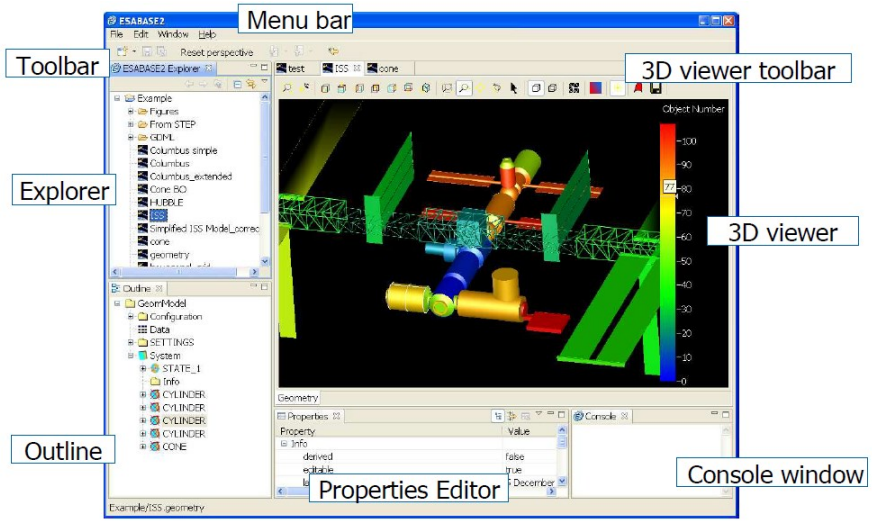




REST-SIM Simulation Framework

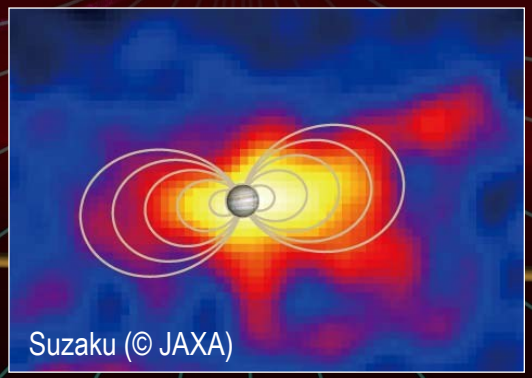
- Mission specification and environment modeller
- S/C and P/L geometry modeller
- Effects analysis tools
  - Geant4-based applications (GRAS, SSAT, MULASSIS)
- Simulation manager
- Post-processing manager
  - Visualisation, plots
  - Response matrices / formulae / algorithms
- See Tuesday's presentation by Fan Lei
- "Follow-on" activity CIRSOS, focusing on collaborative aspects, in ESA ITT (emits.esa.int)

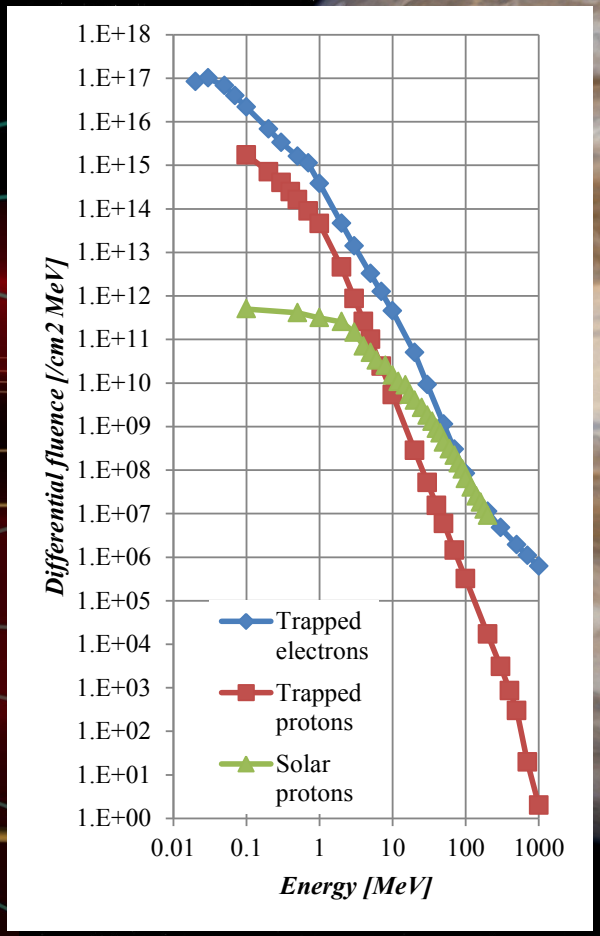




ESA Cosmic Vision L-Class mission JUICE (JUpiter ICy moons Explorer), aka Laplace

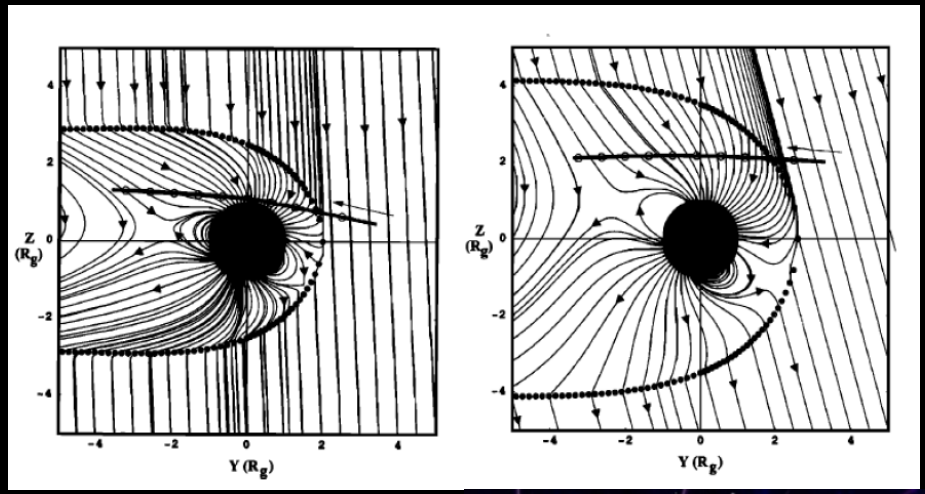
- Launch planned for 2022
- Giant Jovian magnetosphere and e- radiation belts up to several tens of MeV
- Protons, ions also present
- Substantial shielding and background issues
- Intensive ESA work, including Geant4
- 11 science instruments selected 21 February 2013
- See JUICE PEP presentation by Stefan Karlsson later today

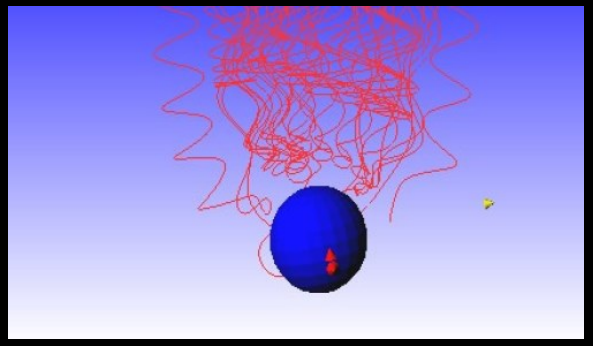


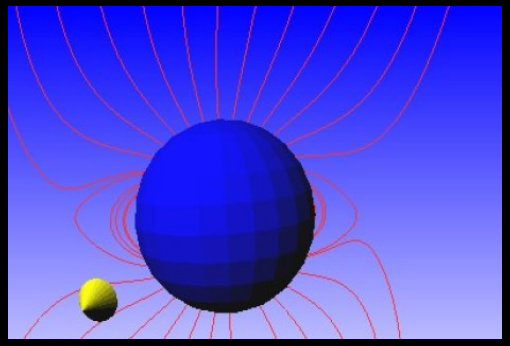


Ganymede Radiation Environment Engineering Tool (GREET)

- Early work by L. Desorgher (SpaceIT), 2008 for Europa
- Modification of the local radiation fluxes especially for Ganymede → engineering implication!
- Ganymede-specific model due in mid-2013 by RadMod Research, Kallisto Consultancy and DHC
- Computationally intensive → GRID
- See talk by Pete Truscott today afternoon





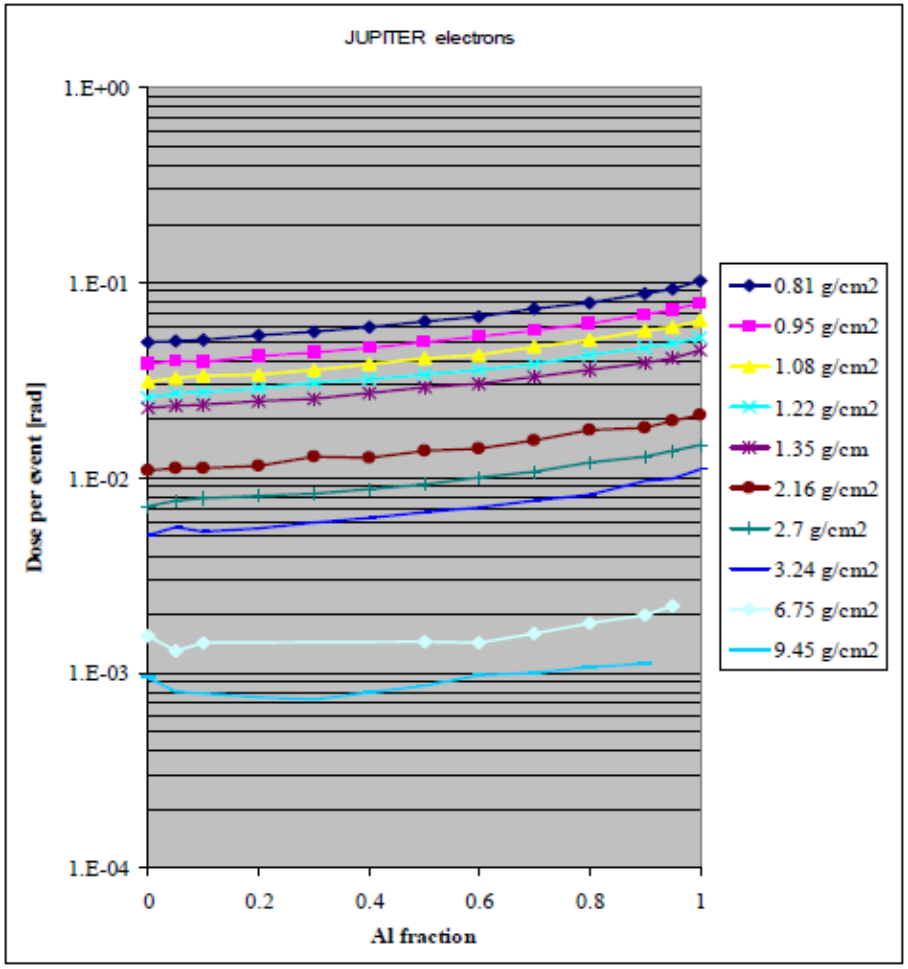


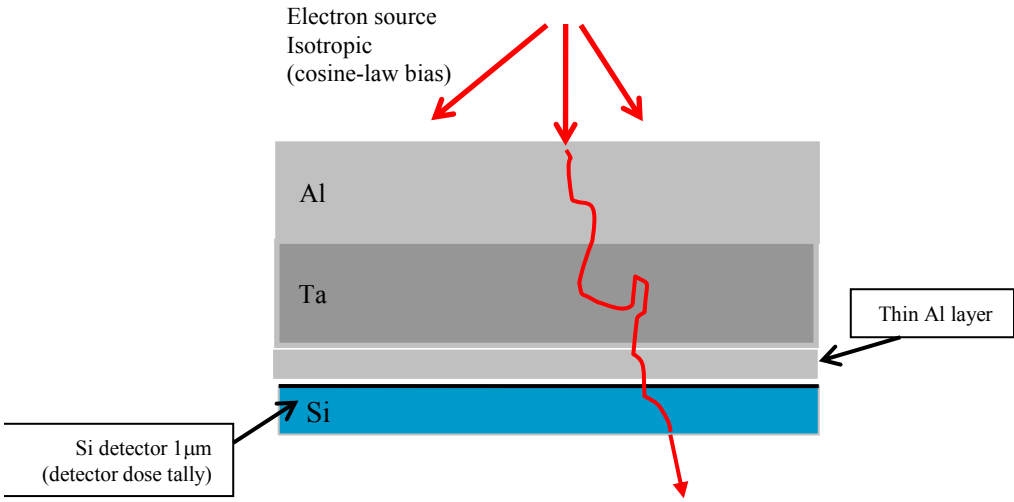
PLANETOCOSMICS-J

P. Truscott, D. Heyndericks, R. Nartallo, Fan Lei, A. Sicard-Piet, S. Bourdarie, J. Sorensen and L.Desorgher, "Application of PLANETOCOSMICS to Simulate the Radiation Environment at the Galilean Moons", Vol. 5, EPSC2010-808, 2010

Graded shielding material effectiveness at Jupiter (JUICE)

Ref.: TEC-EES/2010.613 /GS/1.0





- Maximum dose reduction factor ~2
- For a given dose: mass saving for pure Ta vs. pure Al factor ~1.5
  - E.g.
    3.24 g/cm2 (Al) ~ 2.16 g/cm2 (Ta),
    and
    1.22 g/cm2 (Al) ~ 0.81 g/cm2 (Ta)
- General message:
  Rescaling to Aluminium not satisfactory

Physics Models For Biological Effects of Radiation and Shielding (contribution to "Geant4-DNA" project)

- ESA activity, with main focus on physics stage, completed in 2012
- «BioRad 2» kicked off end of 2012, with focus on derived parameters for human space flight
- The Geant4-DNA project as such is much wider
- See Geant4-DNA presentation by Sébastien Incerti Tuesday morning

How can Geant4-DNA model radiation biology ?

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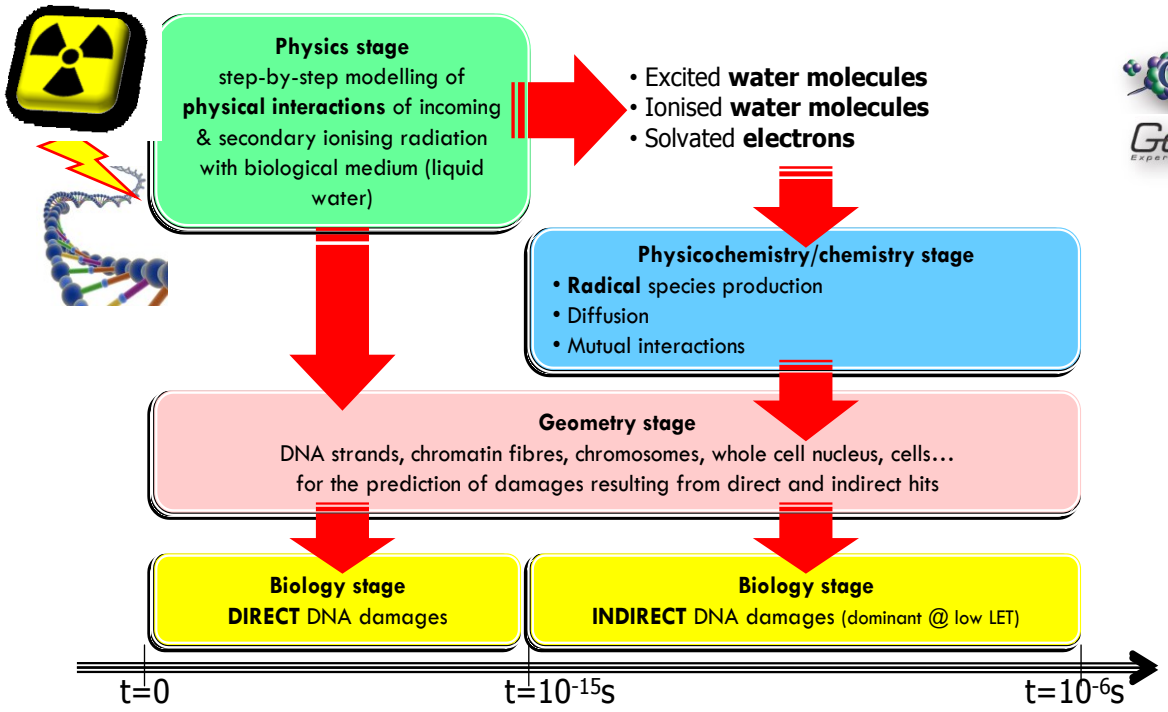
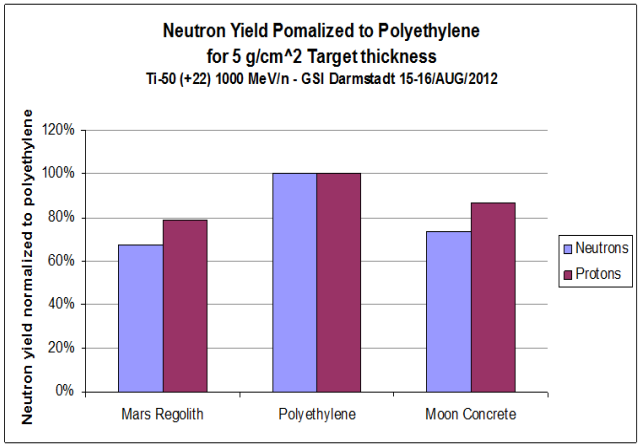
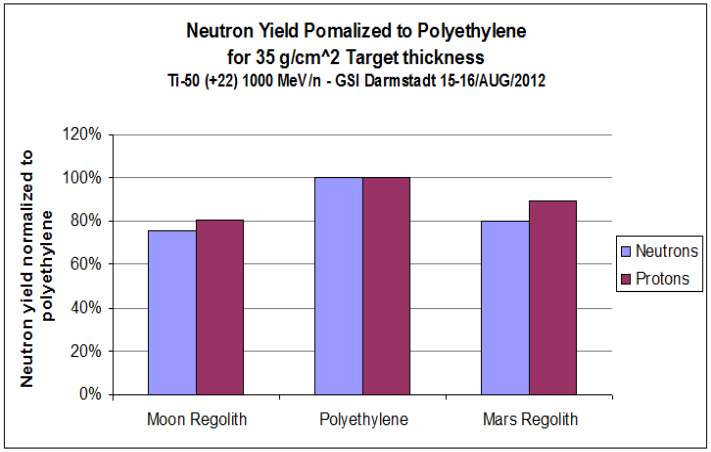


Radiation Shielding by ISRU and Innovative Materials for EVA, Vehicles and Habitats (ROSSINI)

- Activity kicked off with TAS (Torino), GSI and SpaceIT in November 2011
- Goal: Design, develop, build and test innovative passive shielding solutions to be adopted in future human exploration missions
- Testing at GSI, targeting GCR range of particle Z and energies (~1 GeV/n Iron)
- Simulation framework developed based on Geant4, in combination with FLUKA
- Evaluation of radiation doses absorbed in human tissue, given the particle species energy spectra observed behind the shields considered
- Guidelines for design and use of eventual shielded refuges on lunar/planetary surfaces, habitats and deep space missions

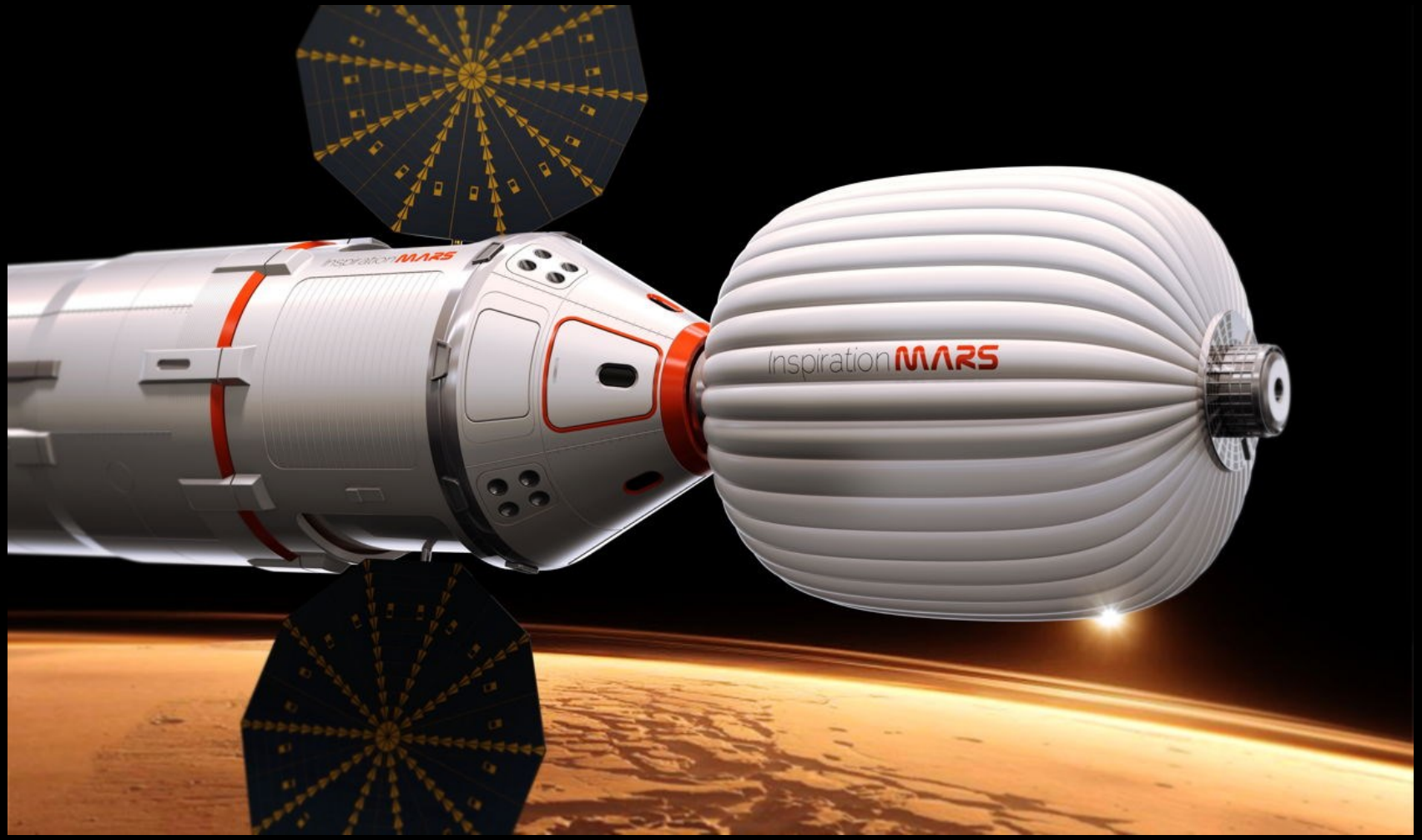




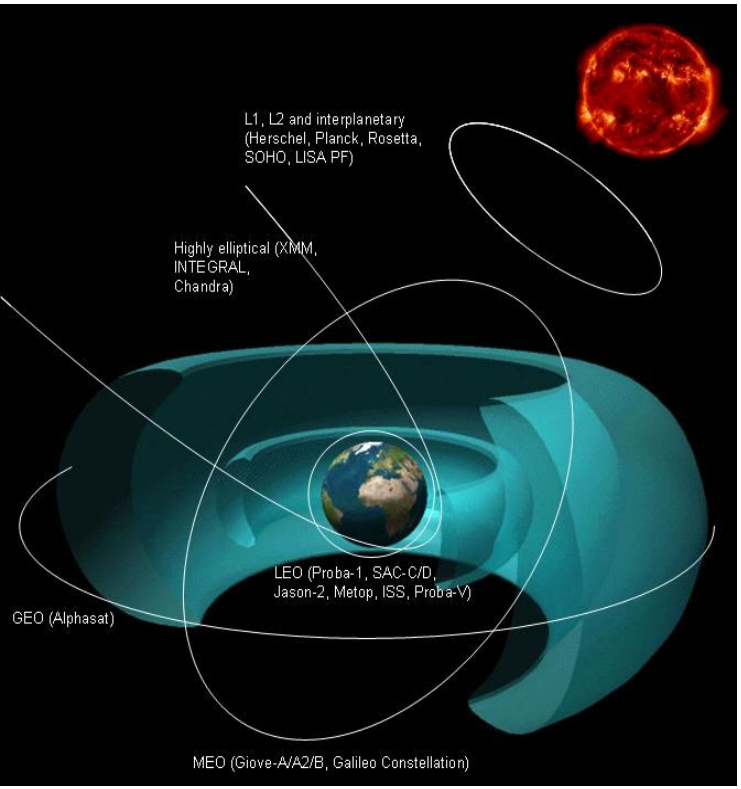
GSI experimental campaign December 2012:

Ti-50 at 1 GeV/n

Deep space mission radiation issues…

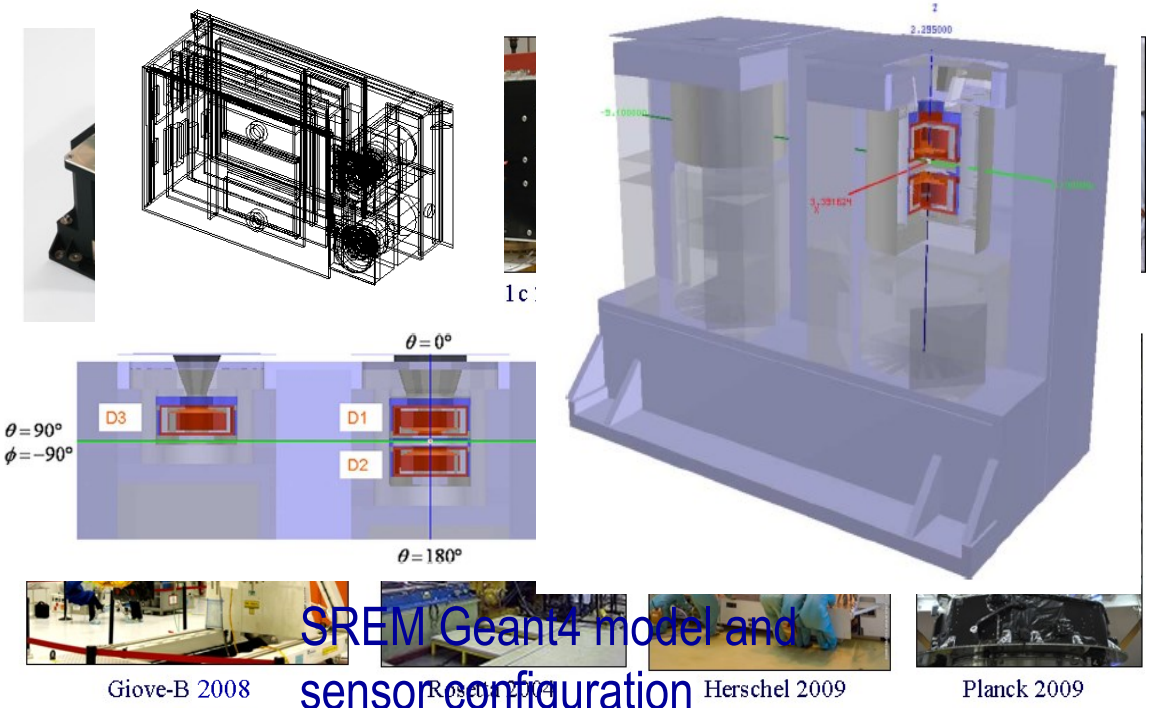


Radiation monitors: SREM



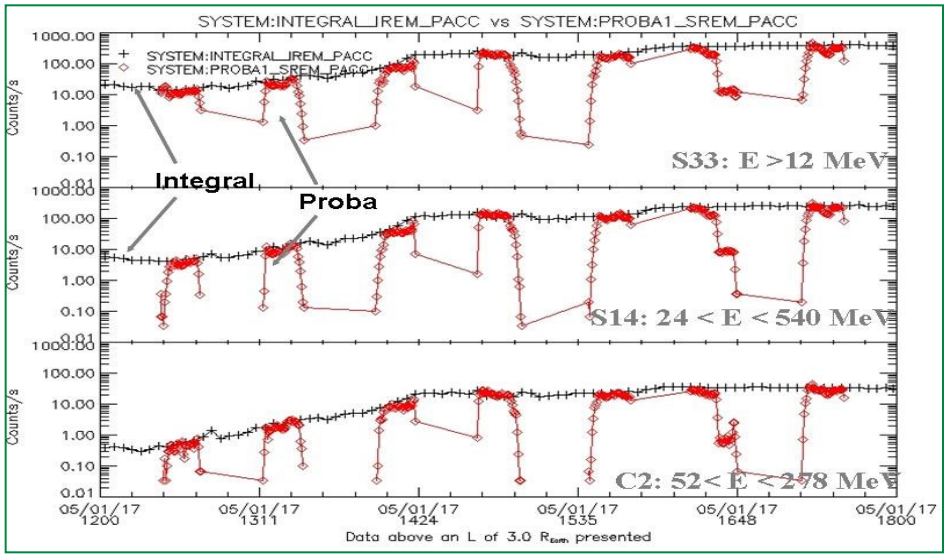
Part of a constellation of various European radiation monitors

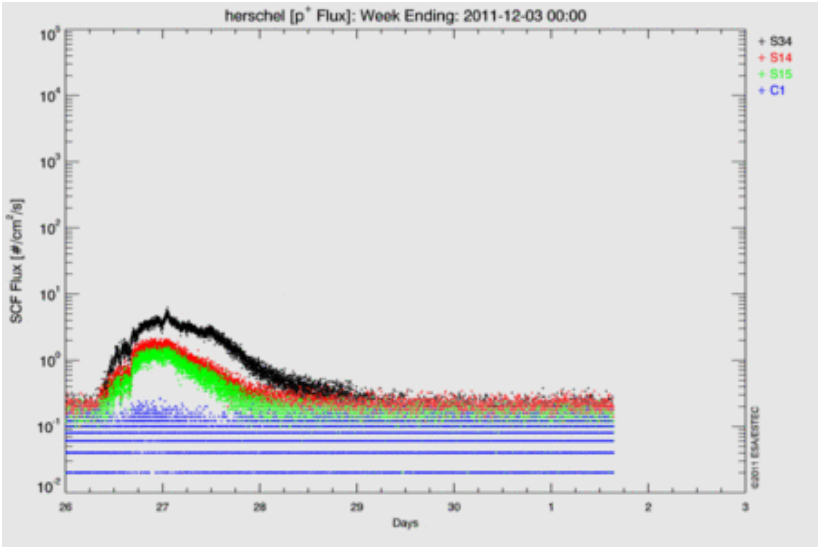
SREM – ESA's Standard Radiation Environment Monitor (1996-)

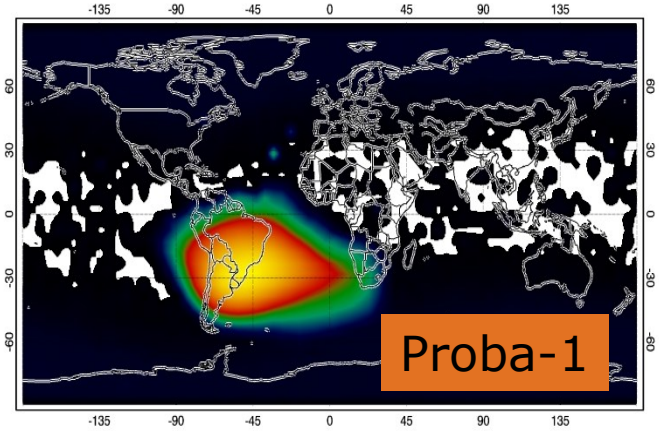


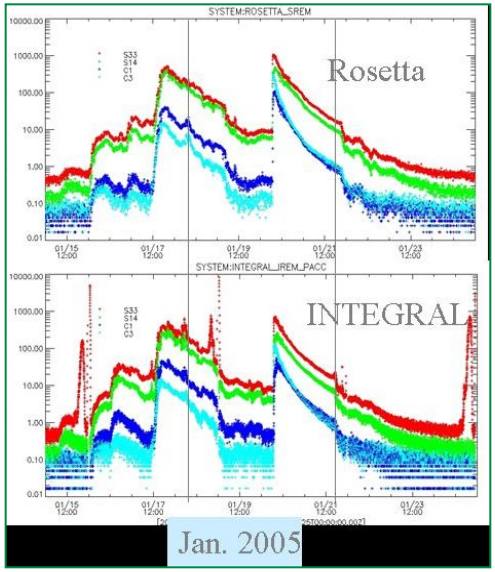
SREM Geant4 model and sensor configuration

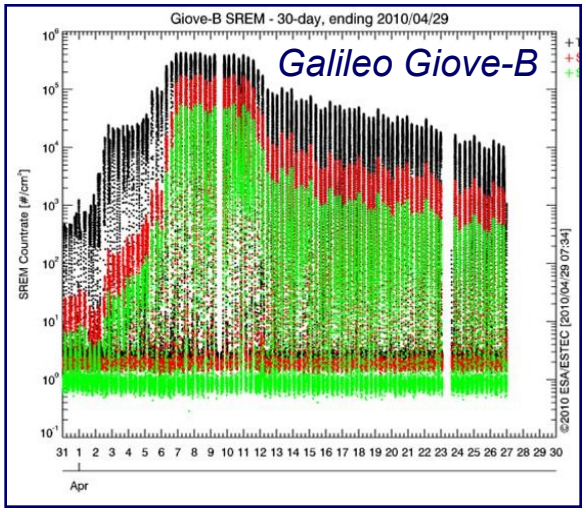
SREMs have returned a wealth of data









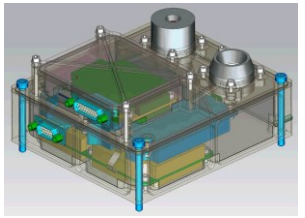


Next Generation Rad. Monitor (NGRM)

- Context:
  - SREM and other European units too large, old technology;
  - Agreement with member states for a “harmonised” European standard approach to a new generation
  - Funded under ESA GSTP programme, prime RUAG Switzerland
- Purpose:
  - Anomaly diagnosis;
  - Alarm functions and safeguarding critical systems;
  - Radiation effects diagnostics (e.g.SEE, payload support);
  - Characterizing the local spacecraft environment and updating models
- Activity:
  - Mass <1kg (SREM 2.5kg), power <1W (SREM 2.5W);
  - Easier interfaces (lower integration costs);
  - Performance → 24 channels e-, p+ discriminated, heavy ions by LET threshold. Geant4 optimisation
  - Min. lifetime 12 years in Galileo environment, 15 years in GEO
  - CDR in March 2013, PFM delivery early 2014
  - Identified needs in various Programmes (MTG, TIA, EOP, SSA…)

SREM

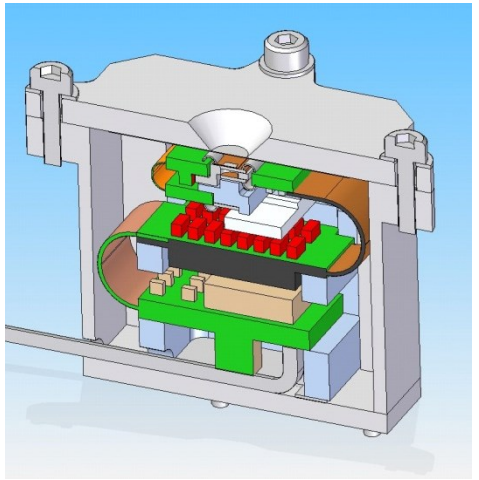
NGRM

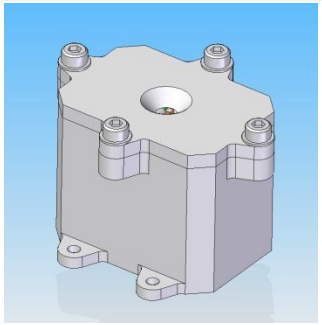


Highly Miniaturised Radiation Monitor (HMRM)

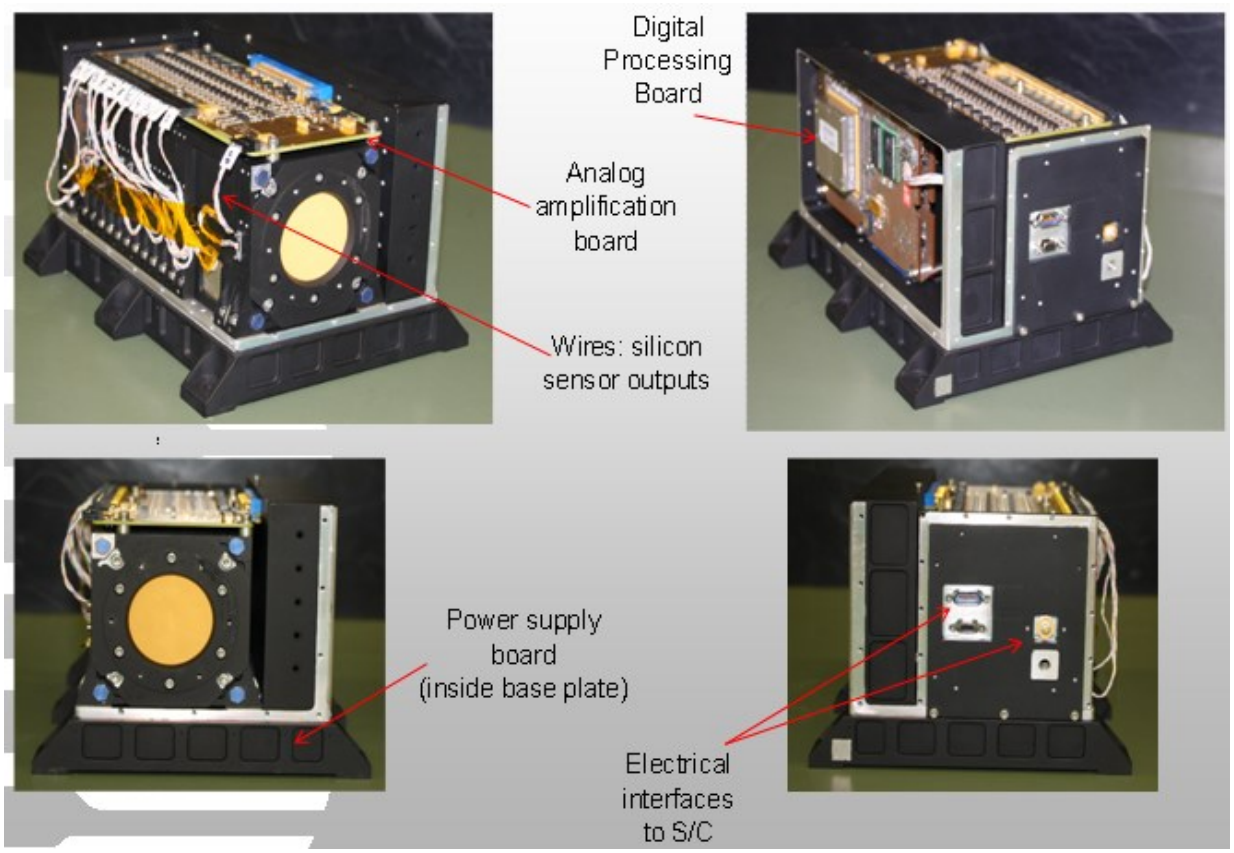
- Phase A-B TRP activity on-going (end Q4 2011 – flyable proto)
- Stack of four monolithic active pixel sensors (MAPS) interspersed with radiation shielding material;
- Extensive Geant4 design and optimisation
- Good particle identification efficiency;
- Integrated in an optimised shielded package together with all the ancillary components;
- Casing and aperture designed to restrict exposure to particles
- FPGA in prototype for data processing
- Prototype flight test on UK TECHDEMOSAT 2013
- Baseline design:
  - Power: ~ 200 mW
  - Size: ~ 12 x 25 x 20mm
  - Mass: ~ 30 g
- Single Chip option
  - to integrate in any electronics board, with more limited particle discrimination.

Science & Technology Facilities Council
Imperial College London

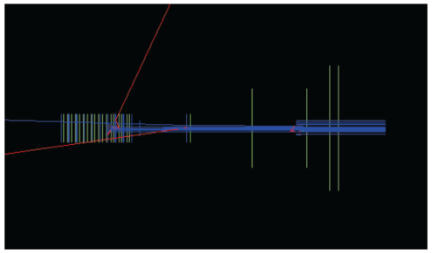




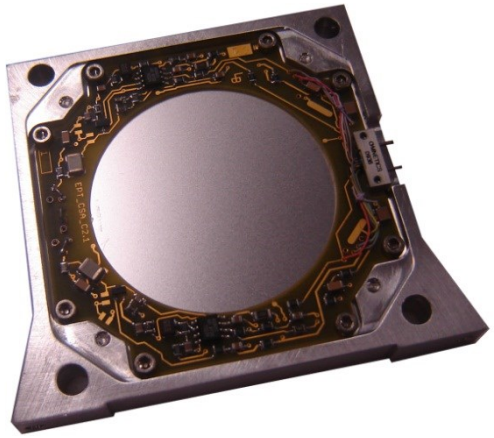
The Energetic Particle Telescope (EPT)



- Modular concept with high fidelity and very low particle cross-contamination
- Two dE/dx front sensors (Geant4)
- 9-12 “Digital Absorber Modules”
- Mass 3.5-5 kg, power < 6 W
- In-orbit calibration facility for radiation monitors
- Phase D completed ,and EPT integrated to host spacecraft Proba-V
- Proba-V due for launch in April 2013



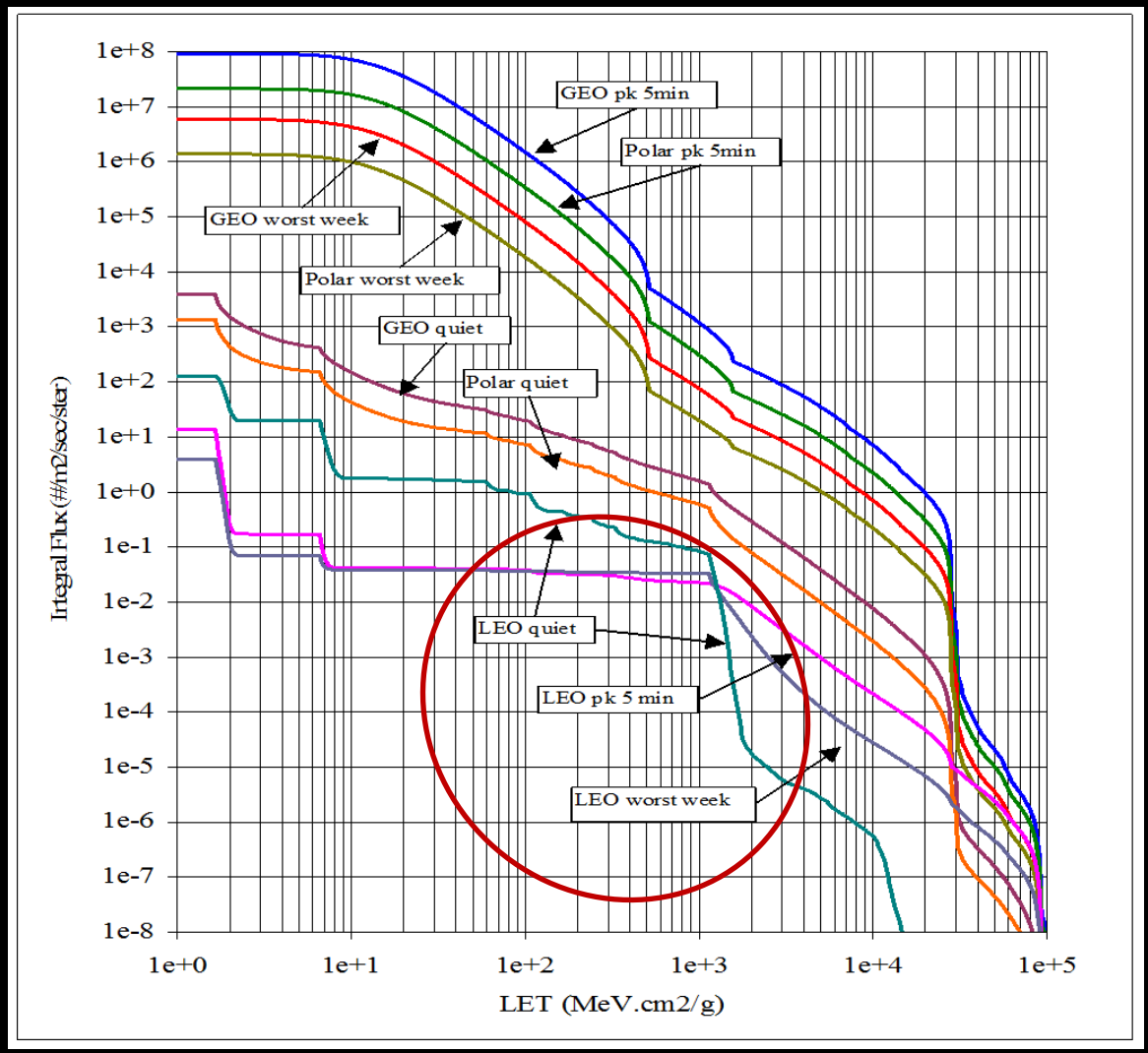
EPT design and validation with Geant4



EPT Digital Absorber Module

A brief note on SEE…

- Miniaturisation, drive towards COTS, circuit complexity
- Increasing susceptibility, especially at LEO (ref. EO and some new Science missions)
- Not all the anomalies or problems get reported. But it does not mean they are not there…
- Importance of improved tools, analysis capabilities and models
- Upcoming ESA TRP activity on high-E heavy ion SEE effects
- Feynman: "There is plenty of room at the bottom" → Room for MC SEE applications for the foreseeable future
- See the talks in the dedicated SEE sessions on Tuesday



The "old" LET paradigm

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

- Geant4/GRAS-based. See MINIMOS-NT presentation by Pete Truscott Tuesday afternoon

Outlook and conclusions

- A broad range of ESA R&D for Geant4-related developments and applications (REST-SIM and ELSHIELD, completed, ROSSINI and DESMICREX ongoing, BioRad 2 and GREET started, CIRSOS in ITT, heavy ion SEE in preparation, internal R&D plans including Geant4 kernel efficiency contribution,…)
- JUICE: Substantial demand for Geant4-related models, tools and applications
- A number of other future missions where MC capabilities are critical
- A number of radiation monitoring and data analyses activities on-going where Geant4 is used
- Importance of easy-to-use and rapid tools (e.g. inverse MC, GRAS, Web-based applications, SEE models and tools) for spacecraft and instrument development
- Physics accuracy however remains important (margins) → updates to the existing models, or creation of entirely new ones, as needed (e.g. MuElec)

Advertisement

- ESA Research Fellow (post-doc) candidates looked for JUICE-related radiation modelling and shielding analyses work at ESA / ESTEC Space Environments and Effects Section.
- For more information check http://www.esa.int/About_Us/Careers_at_ESA/Postdoctoral_Research_Fellowship_Programme (description of the application process) and contact Petteri.Nieminen@esa.int