

Geant4 Radiation Shielding and Effects Analysis in SPENVIS: Past And Present, and Future Trends

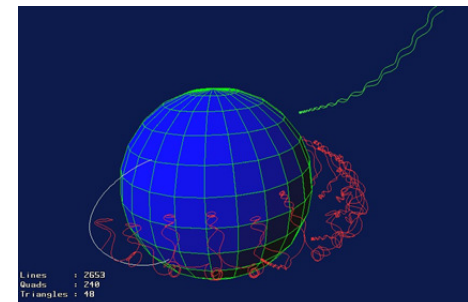
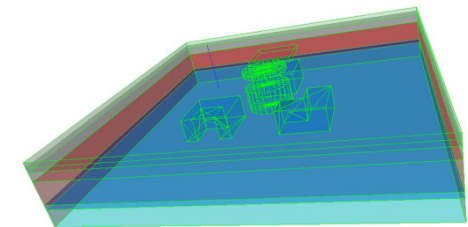
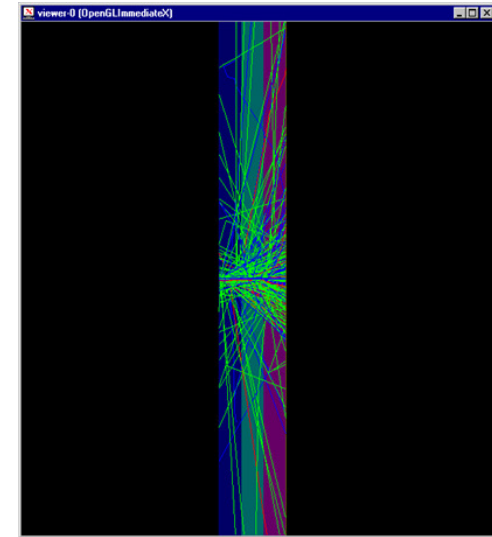
Pete Truscott, *Kallisto Consultancy*

Ruthlessly exploiting the work of kind friends and colleagues, including Fan Lei (RadMod Research), Daniel Heynderickx (DH Consultancy), Ana Keating and Patricia Goncalves (LIP), Laurent Desorgher (PSI)

With the help of the SPENVIS Team: Michel Kruglanski, Erwin De Donder, Neophytos Messios, et al

Sponsored and codeveloped by: Giovanni Santin, Hugh Evans, Petteri Nieminen, Eamonn Daly (ESA/ESTEC)

SPENVIS Workshop, Brussels, 23rd May 2013





Outline

1. Geant4 background
2. Geant4-based tools in SPENVIS
3. What are the challenges of these tools and potential solutions?
4. Where is Geant4 heading and the future of Geant4/SPENVIS?



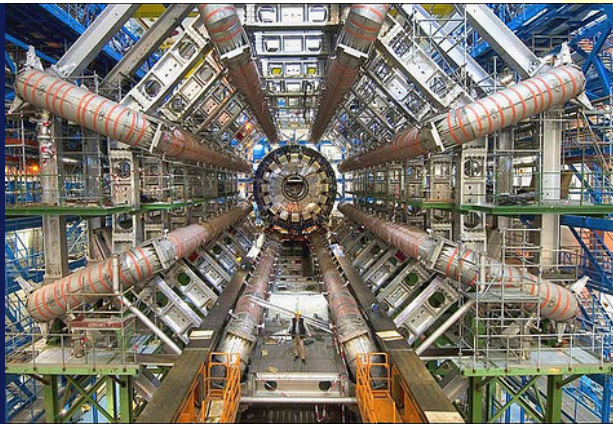
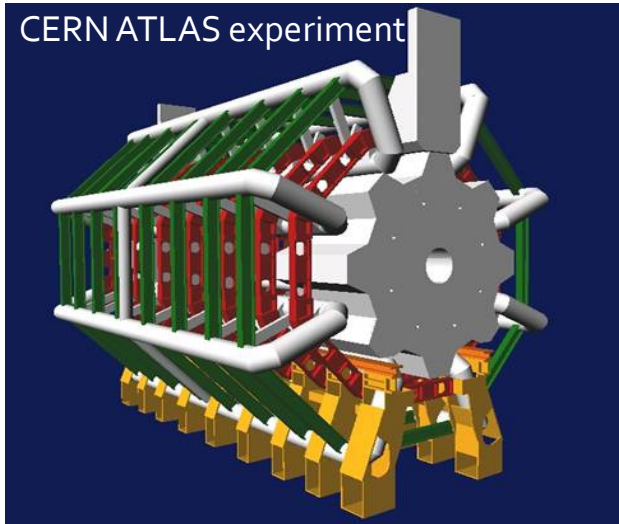


Geant4 Background: The Virtues

- Began life in ~1993/94 as CERN Project RD44, to improve on Geant3
- First production release in December 1998
- Current version is 9.6 patch 1
- Comprehensive Monte Carlo simulation of all particles in 3D geometries
- Variety of physics models covering:
 - Electromagnetic
 - hadronic (nuclear)
 - decay processes
 - treatment over 1PeV to ~100eV (and to thermal energies for neutrons)
 - Electric and magnetic fields
- This toolkit continues to be supported through HEP, medical physics, space, *etc* communities as applications and requirements grow - **new physics, new tools, new validations**
- Implementation in C++ - aids enhancement of code through class inheritance

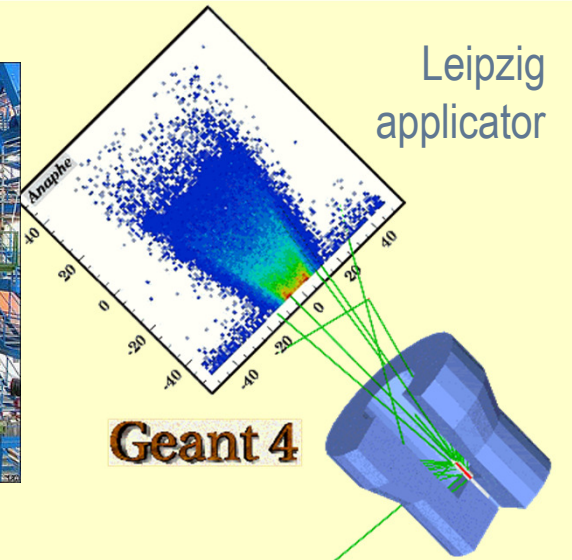
Geant4 Applications

CERN ATLAS experiment

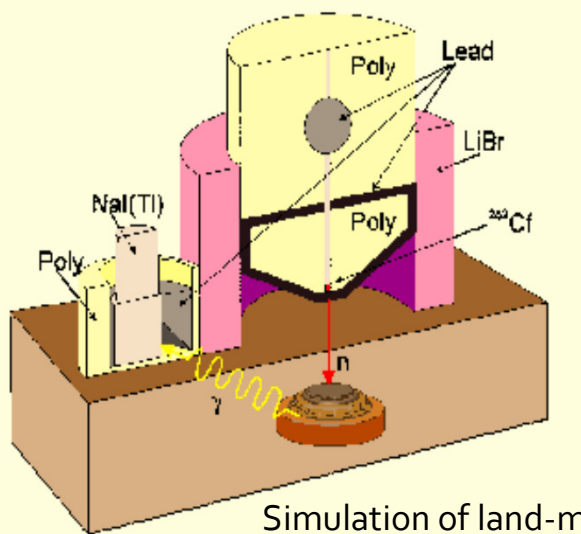


Leipzig applicator

Geant 4



Dosimetry for superficial brachytherapy

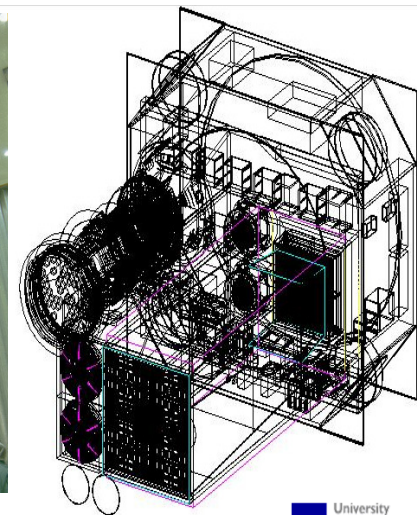


Simulation of land-mine detection by DRDC Suffield

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ESA INTEGRAL Gamma Ray Telescope

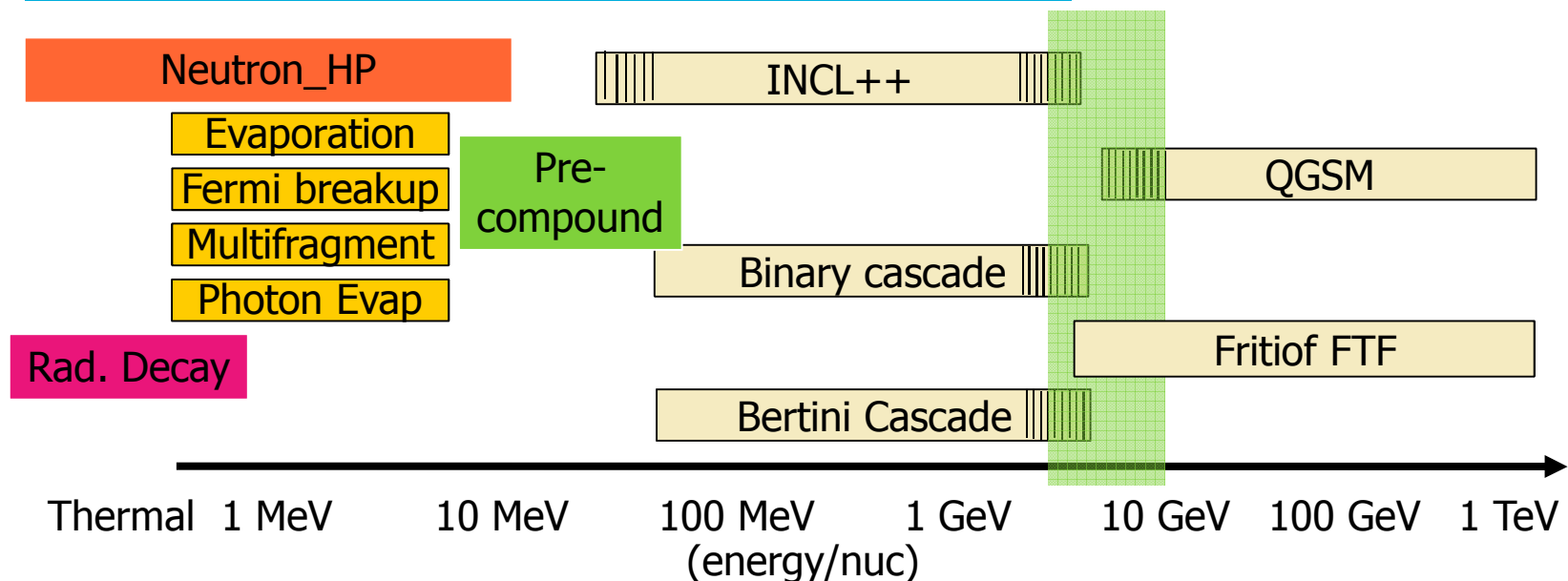


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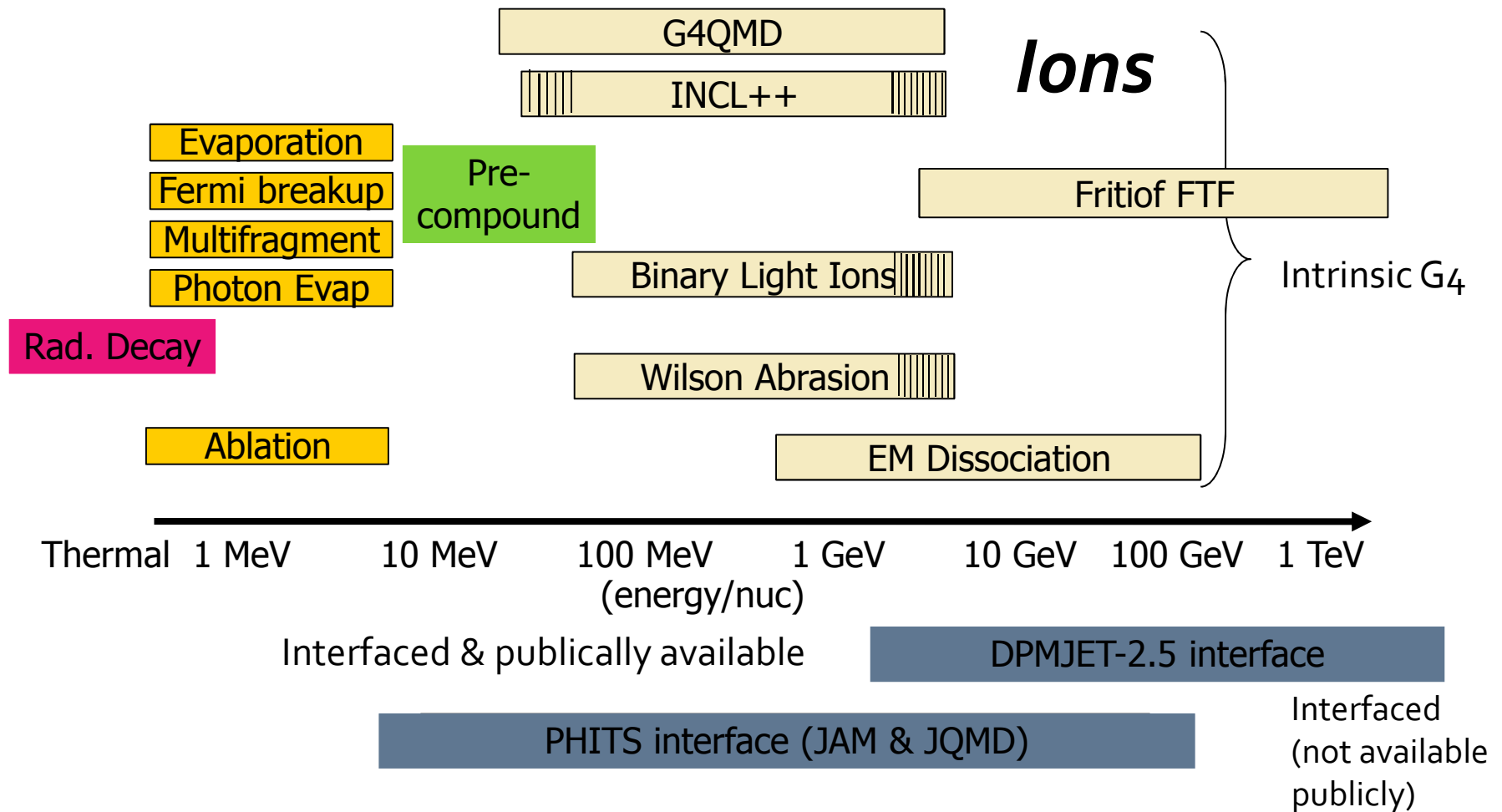
Geant4 Nucleon-nuclear interactions

- Clearly proton-nuclear and neutron-nuclear interactions are important for space and terrestrial SEE environments.
- A number of different theory-based and empirical data-based models exist in Geant4 to treat these events

Existing Geant4 Hadron-nuclear final state models



Existing Geant4 Nuclear-Nuclear Final State Models (Heavy ions)



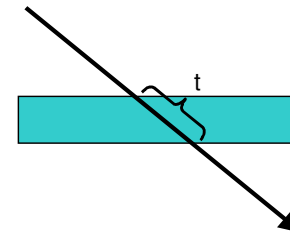
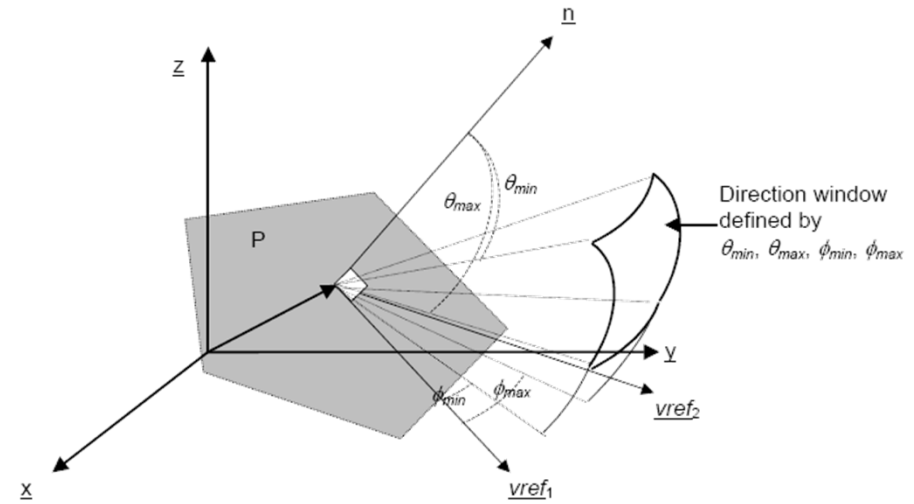
Geant4 Background: The Vices

- It is a toolkit:
 - Geant4 philosophy considers it the responsibility of the user to write the application and the develop post-processing tools
 - Need for applications like MULASSIS, SSAT, GRAS
- Although there is extensive documentation, it's a long and steep learning-curve
 - This is particularly true for understanding which physics models should be used
- Toolkit interfaces are subject to change, in cases without notice.

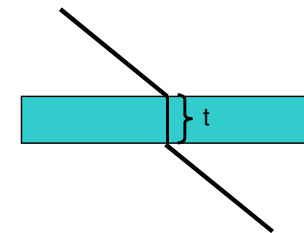
For users who are more familiar with windows shrink-wrapped or "download-and-play" software
Geant4 appears positively user-hostile!!

Sector Shielding Analysis Tool (SSAT)

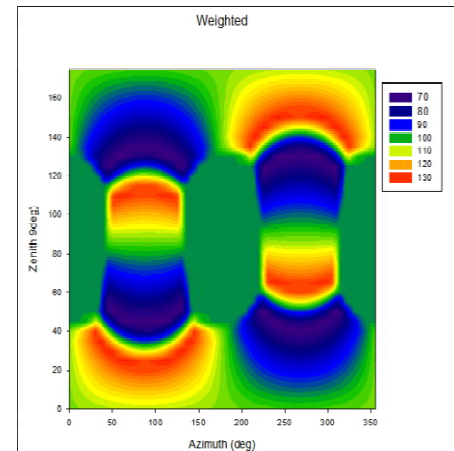
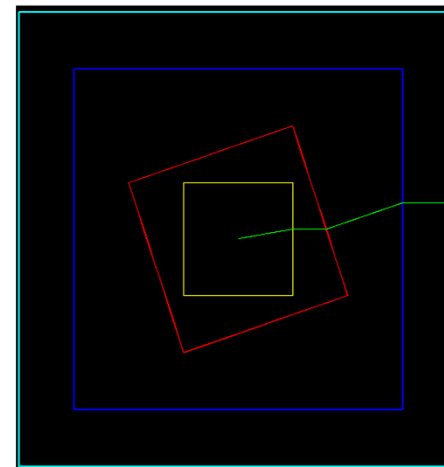
- Geant4-based sector analysis software
- “Geantino” only flags boundary crossings without treatment of physics)
- 3D geometry (Geant4, GDML)
- Extremely flexible controls compared with most SSA tools
 - Define “look window”
 - Reference vectors for local coordinate system at point of interest
 - Sample in even intervals of ϕ and either even intervals of θ or $\cos\theta$
- Norm, slant, weighted analysis



Rectilinear propagation
“slant” method

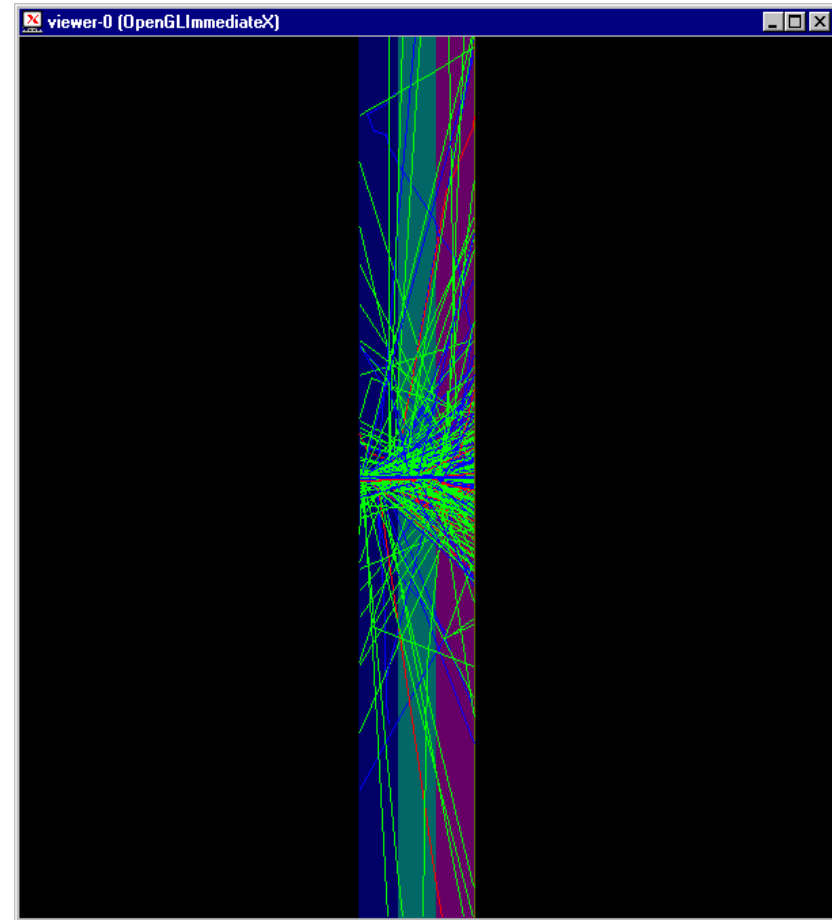


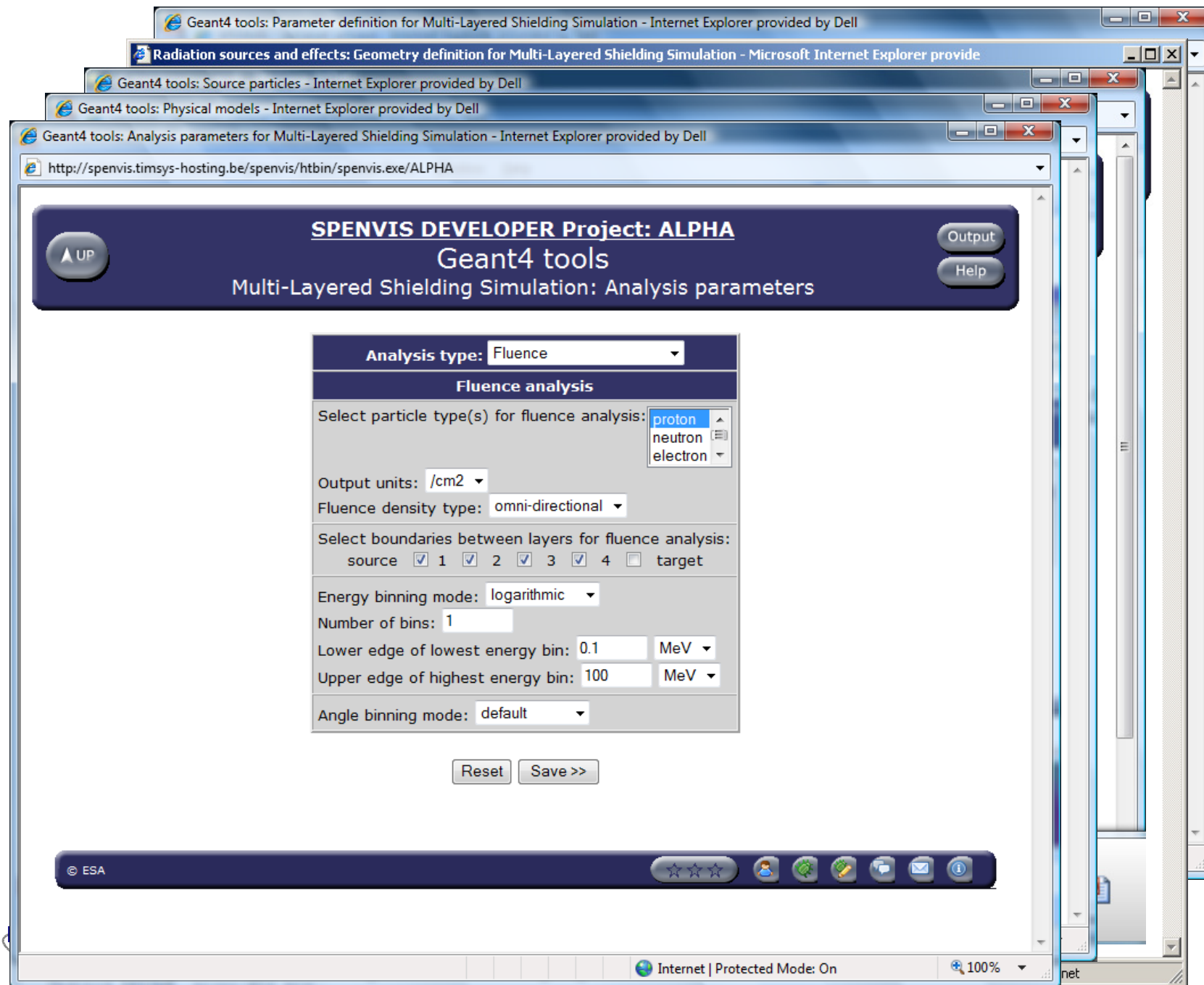
Propagation by diffusion
“norm” method



Multi-Layered Shielding Simulation Software (MULASSIS)

- Geant4 application to allow radiation analysis for 1D geometries (slab & sphere)
- Provide Shieldose-type information with the physics of G4
- SPENVIS or standalone versions (incl. MS Vista)
- Simple specification of geometry (comprising any materials), source particle, physics, and analysis:
 - TID, DD, fluence, energy-deposition spectra
- Graded shielding analysis for electron/ γ sources to shielding properties of concrete and boronated polythenes to neutrons <20MeV
- SPENVIS Jupiter sections include Genetic Algorithm shield optimiser, GARSO





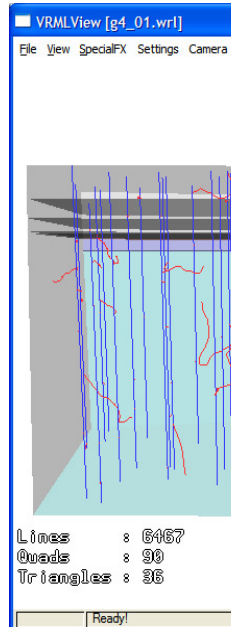
GEMAT

- Treats any Geant4 incident particle

- Potential species

- Calculate energy distribution

- Can get different thresholds for EDA



Radiation sources and effects: GEMAT geometry definition - Internet Explorer provided by Dell

http://www.spenvis.oma.be/htbin/spenvis.exe/EXAMPLE

Layer definition

Layer surface dimensions: default

Number of layers: 5

Layer number	Material Edit	Thickness (units)	Visualisation colour
Layer 1	silicon_dioxide_fused_quartz	2.0 μm	grey
Layer 2	silicon dioxide (fused quartz)	0.1 μm	grey
Layer 3	silicon_dioxide_fused_quartz	0.01 μm	grey
Layer 4	silicon	0.1 μm	yellow
Layer 5	silicon	2.0 μm	white

Include ☐ particle tracks in visualisation

Contact volumes

Number of volumes: 3

Shape	Layer	Material Edit	X	Y	Radius	Half X	Half Y	V half X	V half Y	Units	Colour
cylinder	2	copper	5	-5	2					μm	dark red
box	2	copper	5	5		2	2			μm	dark red
L shape	2	copper	-5	5		2	2	1	1	μm	dark red

Depletion volumes

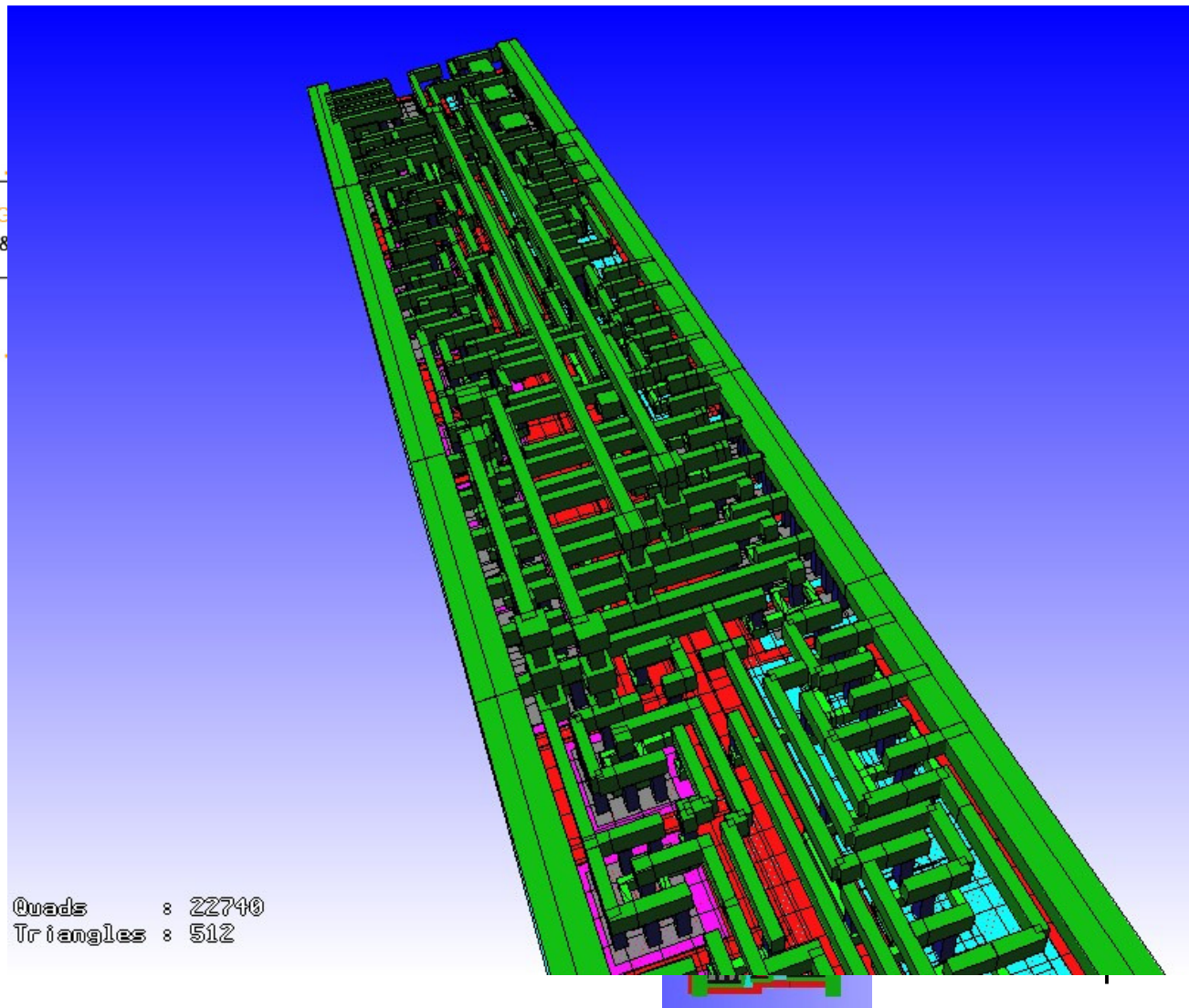
Number of volumes: 3

Shape	Layer	Material Edit	X	Y	Radius	Half X	Half Y	V half X	V half Y	Delta	Units	Colour
cylinder	4	silicon	5	-5	2					0.0	μm	cyan
box	4	silicon	5	5		2	2			0.0	μm	cyan
L shape	4	silicon	-5	5		2	2	1	1	0.0	μm	cyan

Reset Geometry Source particles > Physical models >> Analysis parameters >>> Create macro

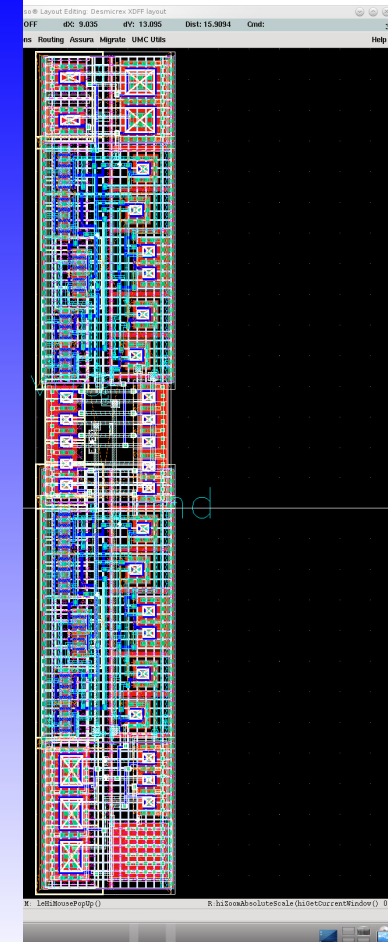
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GRAS - Geant4 Radiation Analysis for Space



Kallisto
Consultancy

radiation

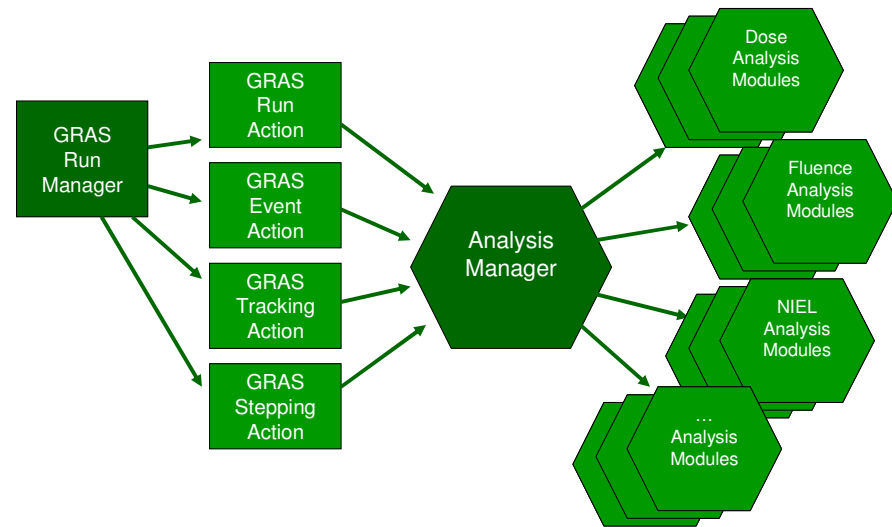


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GRAS - Geant4 Radiation Analysis for Space

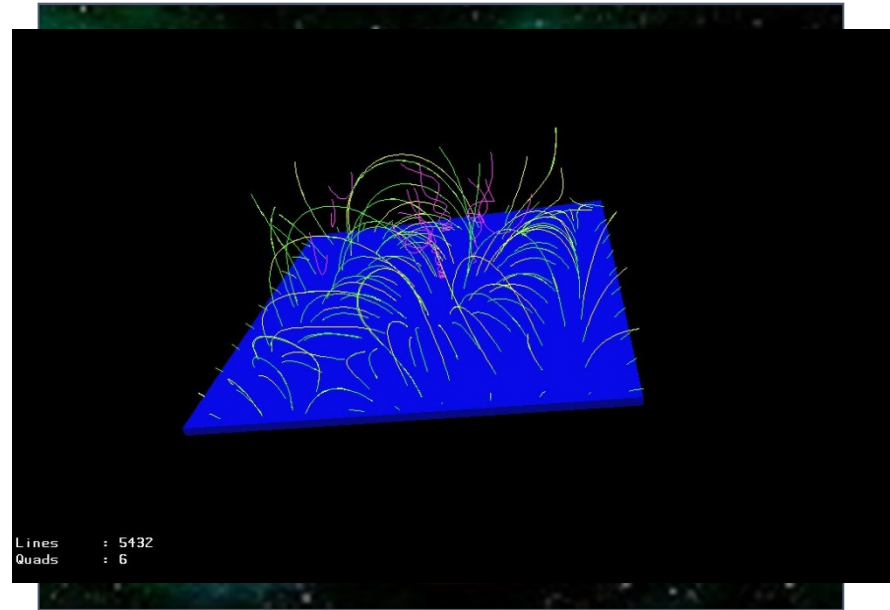
- Can be used to assess variety of radiation parameters through analysis modules: outputs TID, TNID, particle fluence/flux, energy deposition, path-length distributions, PH energy-deposition spectra (PHS), radiological dose (dose equivalent and equivalent dose)
- Charge collection model from GEMAT
- CSV + AIDA + ROOT output as well as Geometry Visualisation output
- Open source
- Disadvantages:
 - Still relatively complex to use



(images courtesy of Giovanni Santin)

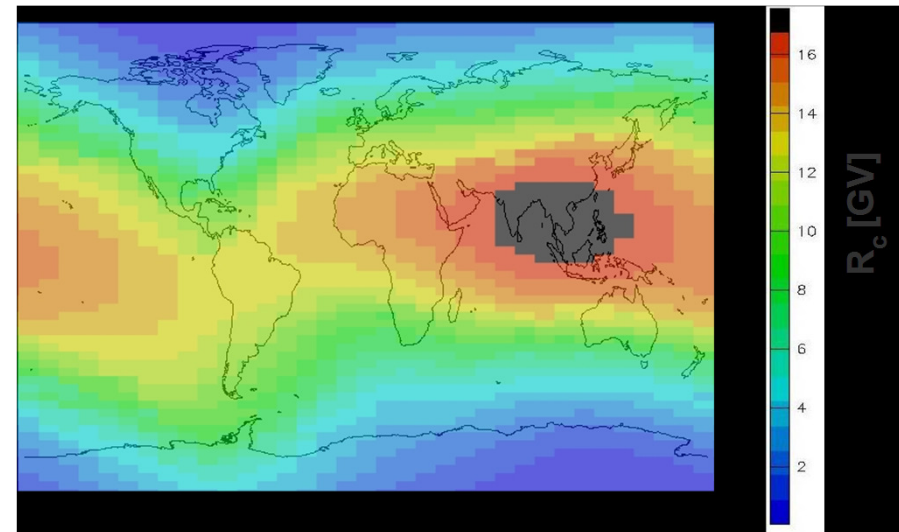
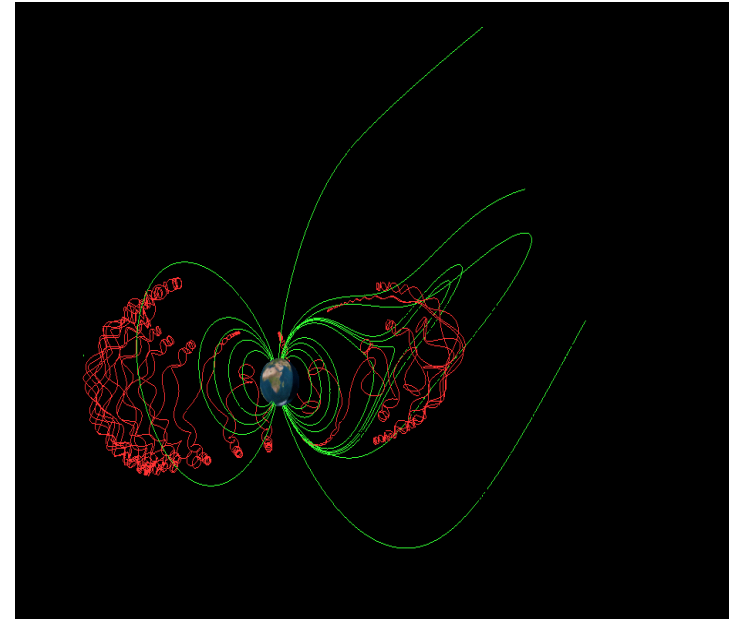
Detailed Mars Energetic Radiation Environment Model (dMEREM)

- dMEREM is a Geant4-based application to simulate GCR and SEP (protons and heavier ions) X-ray, and energetic e^- propagation through the Martian atmosphere and soil
- Based on an extension of work of Keating & Desorgher with MARSREC and PLANETOCOSMICS codes
- Treats point locations above/within Martian atmosphere or subsurface, and for Phobos and Deimos
- Propagation of all secondary particles including protons & heavier ions, neutrons, e^- , γ /X-rays, $\mu^\pm$, $\pi^\pm$, as well as more exotic particles
- Dual parton model (DPMJET-2.5) enhancement to Geant4 for nuclear-nuclear interactions 5- 10^{11} GeV/nuc
- Accumulates particle fluxes and energy spectra, dose equivalent and effective dose, and particle LET spectra for Si & H₂O
- Treats internal magnetic fields, relevant to energetic electrons



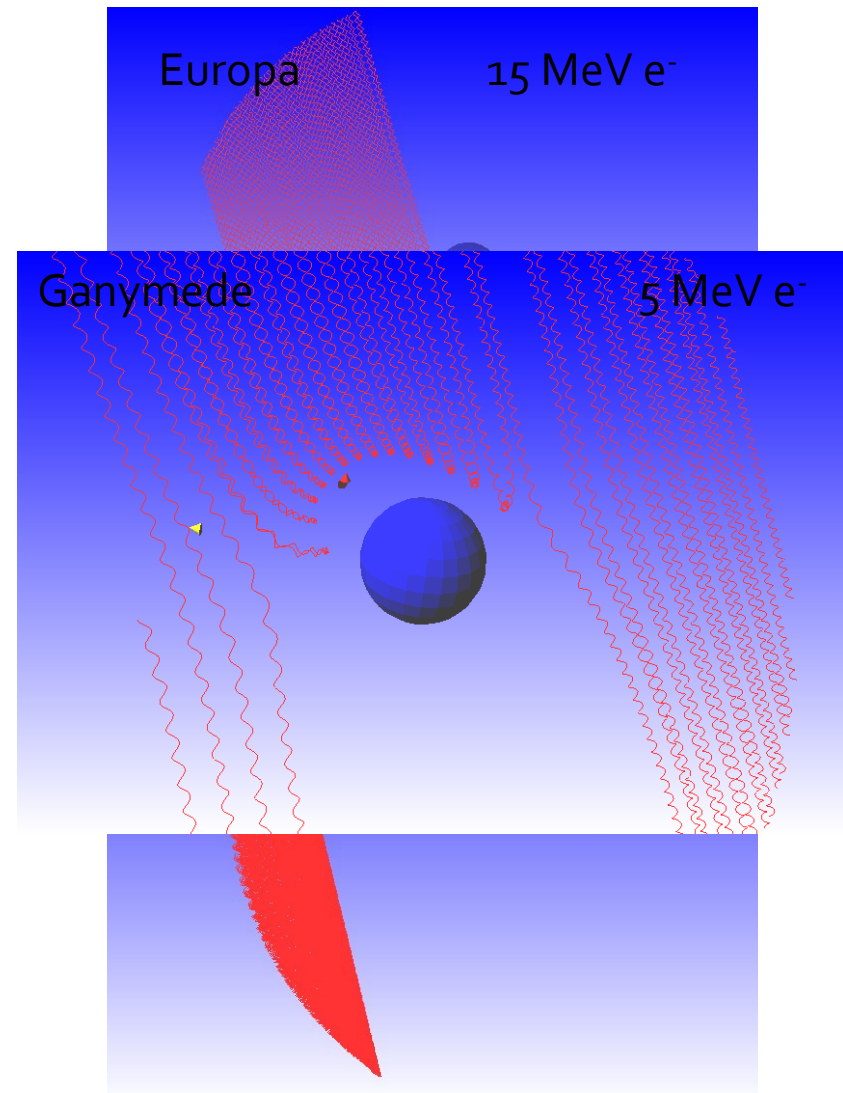
PLANETOCOSMICS

- Geant4-based 3D radiation simulation software developed by Laurent Desorgher for full-planetary simulation for Univ Bern / ESA
- Application for simulation of shielding effects of magnetic field, atmosphere and soil
 - Forward propagation: particle flux and energy deposition analysis
 - Backward propagation: rigidity cut-off analysis
- Treats any Geant4 incident particle and any material
- Mercury, Earth, Mars and Jupiter fields treated
 - Mercury – simple 300nT dipole
 - Earth – IGRF + Tsyganenko 89, 96, 01
 - Mars - Crustal models of Purucker *et al* and Cain *et al*



PLANETOCOSMICS-J Galilean Moon Environment Tool

- Adaptation of PLANETOCOSMICS to simulate Jupiter's trapped particle interactions with Io, Europa, Ganymede and Callisto
- Includes
 - particle bounce and curvature+ ∇B drift of guiding centre in rotating Jovian field
 - $\mathbf{v} \times \mathbf{B}$ forces from moon's intrinsic and induced fields
- Shows how moon can help mitigate Jupiter's radiation environment



How Popular are the SPENVIS Geant4 Tools?

- MULASSIS does seem to be run the most frequently
- Statistics of SPENVIS model runs in May 2010 shows
 - 22% MULASSIS related
 - 8% SSAT related

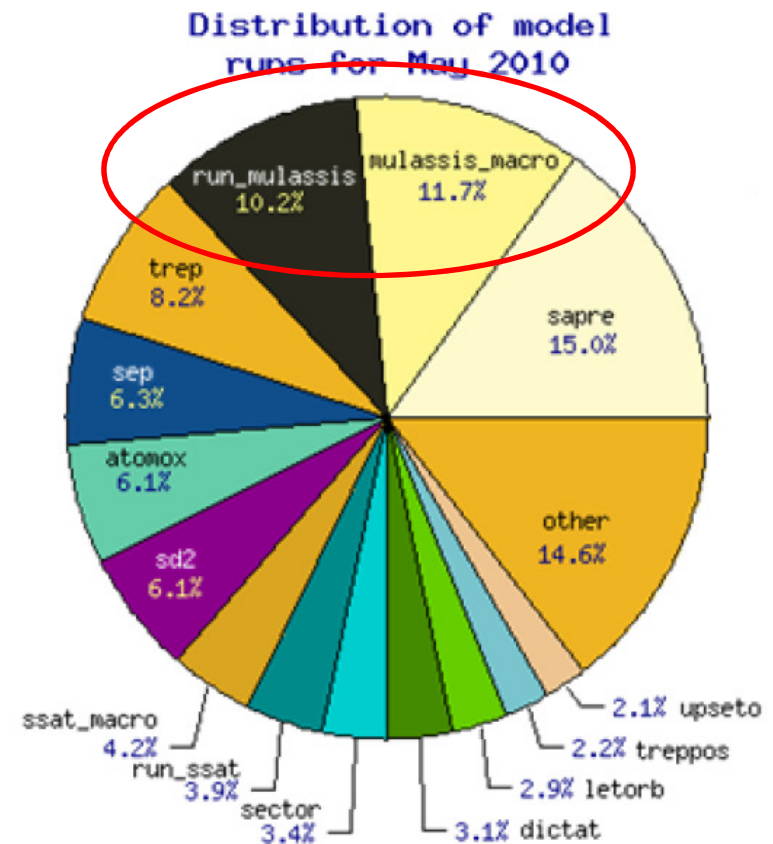


Figure from M Kruglanski, SPENVIS Workshop, 2010

The Challenges: The Need For Speed ... or better interfaces

- Paradigm for Geant4 Monte Carlo simulations conflicts with SPENVIS approach for other tools (e.g. SHIELDOSE-2, NIEL)
 - In the majority of cases, simulations should be performed on local computer
 - Additional complexity → user errors
- Users frequently ask why there is limit of just a few minutes for MULASSIS runs, response is:
 - Download software and run with macro
 - Purchase a SPENVIS CD-ROM
- Scope for considering multi-thread solutions?
- If not, consider better “hand-shaking” solutions between SPENVIS Server and Geant4 client, and client-side control of S/W?



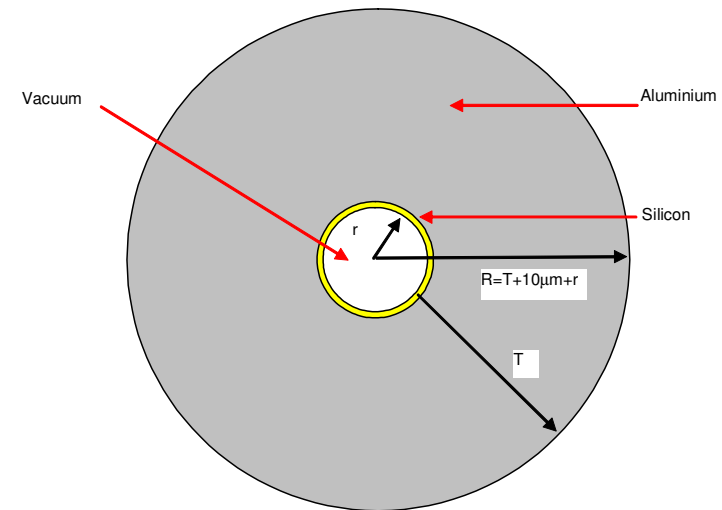


Easy-to-Use (& Easy-to-Misuse) Geant4/SPENVIS Tools

- Despite attempts to simplify the tools and user interface, the reliance on Geant4 and MC creates extra complexity which users do not expect
 - A greater amount of forethought before commencing a simulation, which the standard tool operators do not expect
 - Be prepared to throw your first (and even second) MC results in the bin without looking at them
 - It's rare that people read the documentation first
- Examples of misuse
 - "I cannot understand what XXXXX expects to get out of a 100 electron simulation [using MULASSIS] with thickness of 2 cm - we cannot babysit individual users"
 - Example case in 2011, someone used MULASSIS looking at energy deposition events from very low-energy ions with nuclear interactions switched on and off – differences interpreted as signs of influences of nuclear interactions in FET, even though no nuclear physics models were operating in very low energy regime

Easy-to-Use (& Easy-to-Misuse) Geant4/SPENVIS Tools

- Examples of misuse
 - Normalisation factors cause users no end of problems – results are often in error by factors of 2 or 4
 - Spherical shield model – there are cases where users make inner target radius $\sim 1/100$ of shield, and complain of errors without spotting the poor statistics
 - Running 10^4 particle histories (without biasing) when the spectrum flux intensity changes by 10^5 or 10^6



Easy-to-Use (& Easy-to-Misuse) Geant4/SPENVIS Tools

Possible solutions?

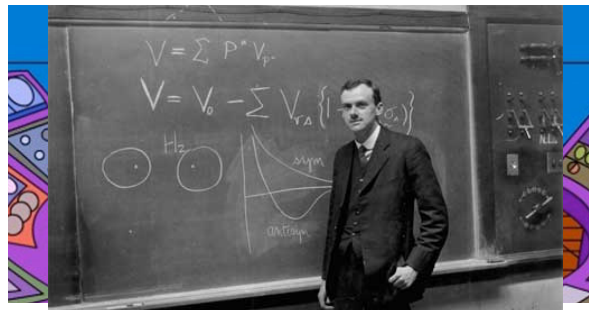
- Simplify the software as much as possible:
 - Even if the same S/W is used for different applications with different physics, let them appear to the user as different tools to novice users?
- Retain Help Pages but augment with
 - Series of instructional videos on how to use S/W, what the calculation is doing, and what goes into the normalisation factors
 - Information about common mistakes (text pages, video, or pop-up help?)
- Don't create GUI interfaces to complex tools which cannot be operated sensibly in SPENVIS (or make them accessible only to "Extreme" Users)
 - PLANETOCOSMICS-J, GARSO fall into category, and possibly dMEREM
 - Create data interfaces to allow tools to use SPENVIS outputs
 - Create http links from SPENVIS to locations to download S/W

Easy-to-Use (& Easy-to-Misuse) Geant4/SPENVIS Tools

Possible solutions?

- Where appropriate, move to fast tools which calculate using interpolation of Geant4 MC results
 - E.g. Cutoff rigidities, PLANETOCOSMICS-J → GREET Ganymede shielding tool, eMEREM, MFLUX
- Improve the software report output
 - Terminate runs when statistical accuracy is achieved rather than # particles, and warn when run terminated early
 - Explicit warnings to state when spectra are under-sampled
 - If simulation is under-sampled, point user to help or video documents

Engineering software to be "fool-proof" first requires an accurate specification of a "fool" and what level of foolishness he/she is capable of





Trends in Geant4 Relevant to Space applications

- Parallelisation of Geant4
 - Geant4-MT
 - GPU implementations for faster navigation
- Extension of low-energy EM physics
 - Originally development led by radiobiological effects groups
 - CEA recent work to treat e^- transport in Si down to 16.7 eV and possibly SiO₂ in due course
- Ions
 - Improved ion stopping power models in Geant4 for standard and exotic semiconductor materials (ESA RRMCM Project)
 - Importance of improved ion-ion collision models
- Reverse Monte Carlo and variance reduction
 - Significant developments under ESA projects on RMC
 - Whilst more efficient, options not straightforward to use



Conclusions

- Geant4 clearly provides powerful radiation tools underpinned with comprehensive physics simulation
- SPENVIS provides a wide range of Geant4-based tools that can be operated remotely through easy-to-use web-interfaces
 - MULASSIS
 - SSAT
 - GRAS
 - GEMAT
 - dMEREM
 - PLANETOCOSMICS, PLANETOCOSMICS-J
 - GARSO
- Model complexity introduces its own challenges
 - Users must take much greater care
 - Computational time
- Geant4 will continue to be supported and activity developed for foreseeable future and we should look to take advantage of the new features



Backup Slides





Geant4 Background

- Prior to ~2000, Monte Carlo simulation of space radiation and effects based on:
 - Geant3 (e.g. ESA, University of Southampton, etc)
 - EGS4 and ITS3 (for EM interactions only)
 - CALOR89 (HETC+FLUKA, MORSE, EGS4)
 - GCALOR (using Geant3 instead of HETC)