Geant4 related analyses at ESA

G.Santin*, P.Nieminen, E.Daly, A.Mohammadzadeh, H.Evans*
Space environment and effects section – TEC-EES
ESA / ESTEC

** RHEA Ldt*

Geant4 Space Users' Workshop 2004
Vanderbilt, Nashville, TN, USA

Particle transport simulations in the space environment domain

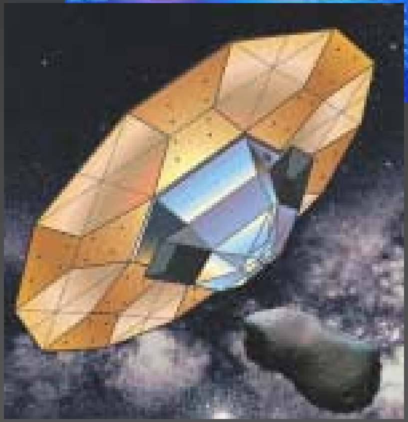
- Interaction of environment particles with spacecraft structure and detectors
  - Primaries, secondary particle production
  - Dose estimation (Ionising, Non-Ionising)
- Microscopic effects description
  - Charge balance, SEE, displacement damage,…
- Space environment modeling
  - Trapped radiation (Earth, Mercury,…)
  - Atmospheric showers (Earth, Mars,…)
- Scientific detector studies (signal extraction, background estimation,…)

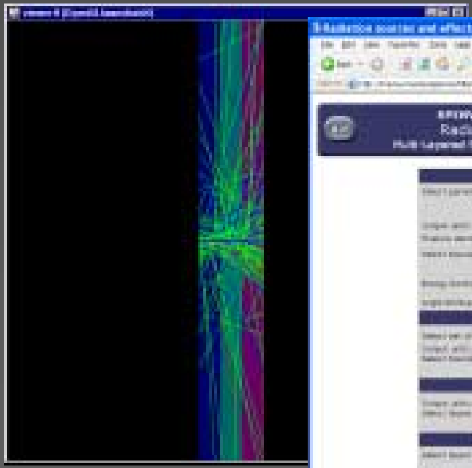
- Result uncertainties
  - Simulation engine models
  - Component parameterisation
  - Geometry model approximations
  - Systematics from the space environment models
- ESA is trying to address all these aspects
  - In-house work
  - External contracts

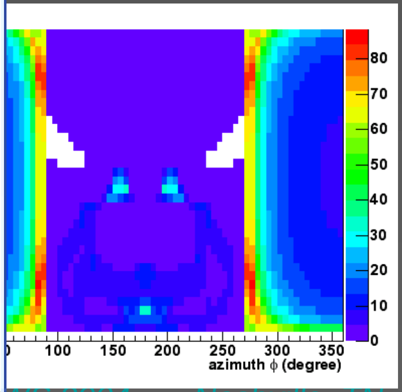
- MC tool requirements
  - Physics description → proton, electron, ion, neutron, pion, gamma (+X-ray), optical photons
  - Wide energy range
  - Geometry description (I/O, flexibility)
- Geant4 chosen by ESA as standard simulation toolkit for particle transport
  - Becoming adequate for the description of the relevant phenomena

Mission simulation and engineering tools

- "Applications" targeted at a specific mission or problem
  - Mission analyses
    - Degradation, background, charging
    - Examples: XMM, GAIA, Smart-2
  - Radiation monitors: design and calibration
    - SREM, MRM
- Simulation "engineering tool" development
  - Shielding optimisation
  - Radiation effects to detectors/components
  - More detailed tools as new standard
  - SSAT, MULASSIS, NIEL





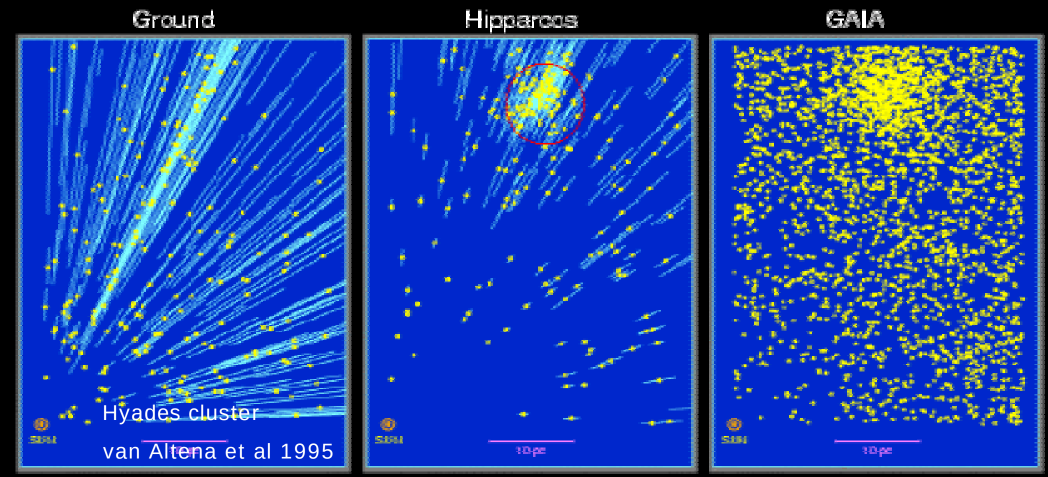


The GAIA mission

- Multi-epoch survey of the central regions of galaxies with high spatial resolution and multicolor photometry

- Successor to ESA's Hipparcos satellite (1989-'93)
  - a factor of more than 100 improvement in accuracy
  - a factor 1000 improvement in limiting magnitude, and
  - a factor of 10000 in the number of stars observed

- Target for the launch: 2010
  - L2 orbit



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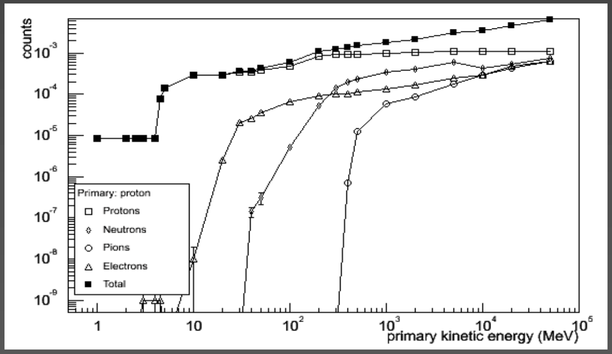
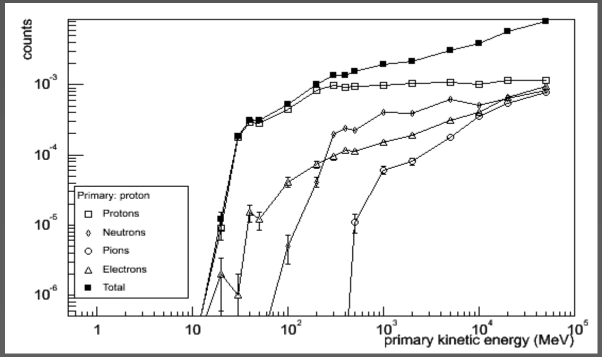
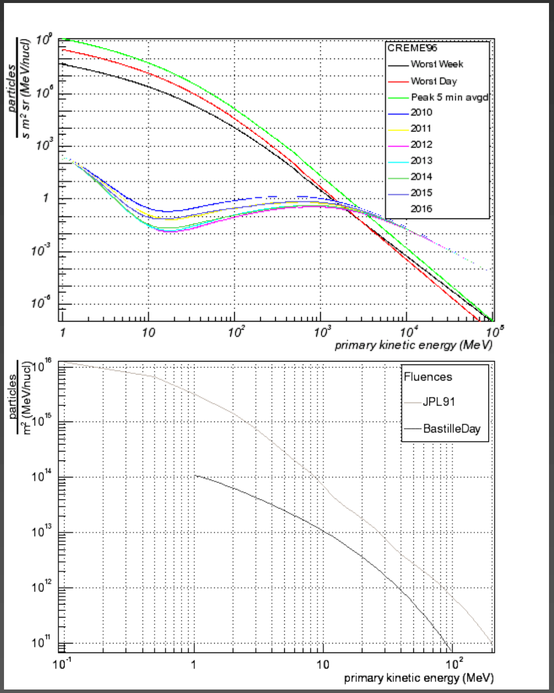
GAIA
Focal plane radiation analysis

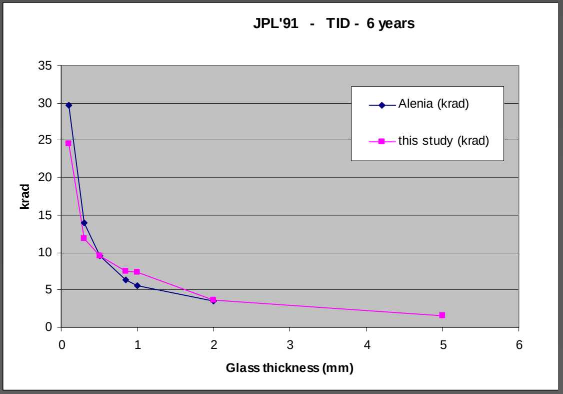




- Protons spectra relevant for the L2 radiation environment
  - "Flare" model environment
    - CRÈME'96 (worst week/day, peak 5 min)
  - Quiet time environment
    - CRÈME'96 model (2010-2016)
  - 6 year mission total proton fluence
    - JPL'91, 90% confidence level
  - Individual solar events
    - Examples of real data spectra
    - NOAA database
    - Bastille day event



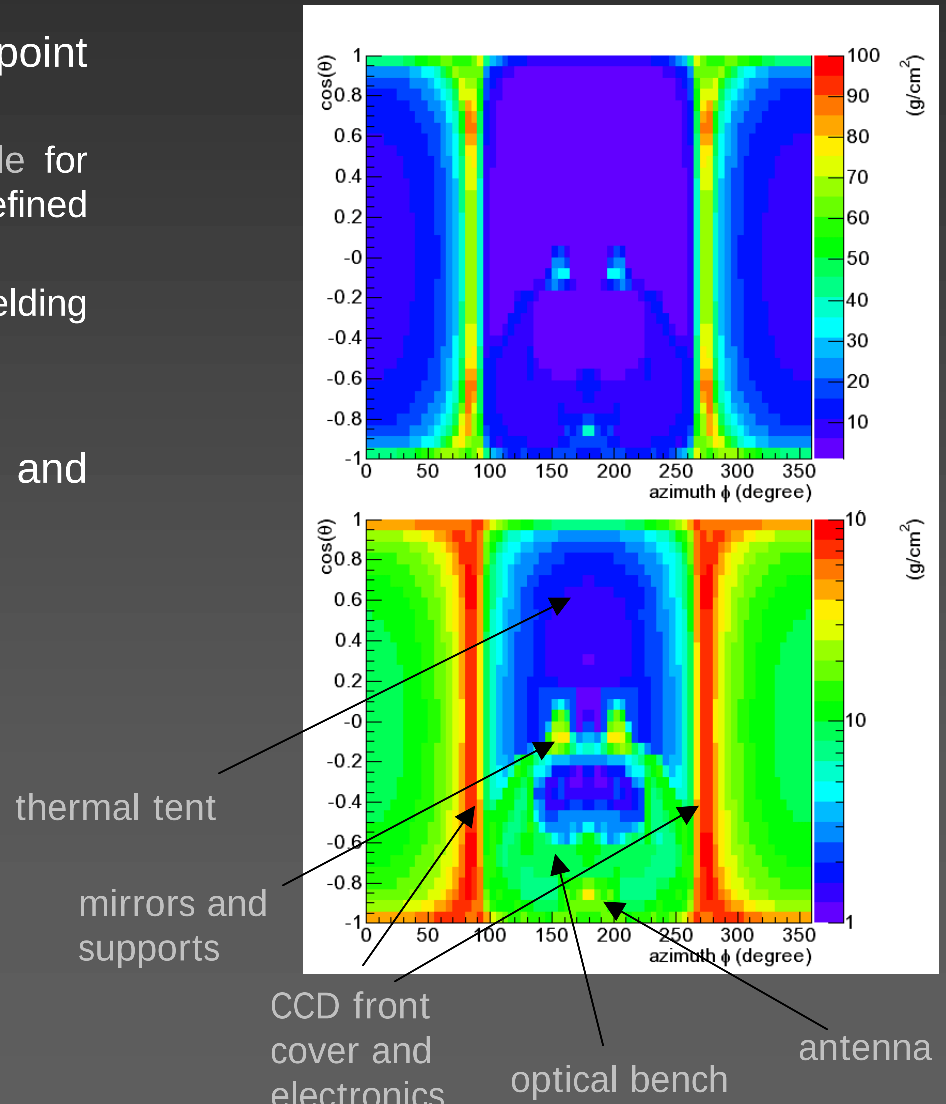
- Optical plane CCD shielding optimisation
  - Cover thickness
  - Glass protection
- Ionising and Non Ionising dose
  - Degradation during the 6 year mission



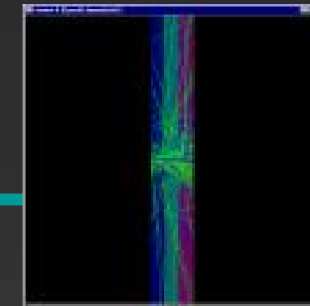
GAIA Sector Shielding Analysis Tool (SSAT)

- Ray tracing: from a user-defined point within a Geant4 geometry →
  - shielding levels (fraction of solid angle for which the shielding is within a defined interval) and
  - shielding distribution (the mean shielding level as a function of look direction).
- It utilizes geantinos
- Provides both global shielding and shielding from single materials

- GAIA: view from the CCD surface

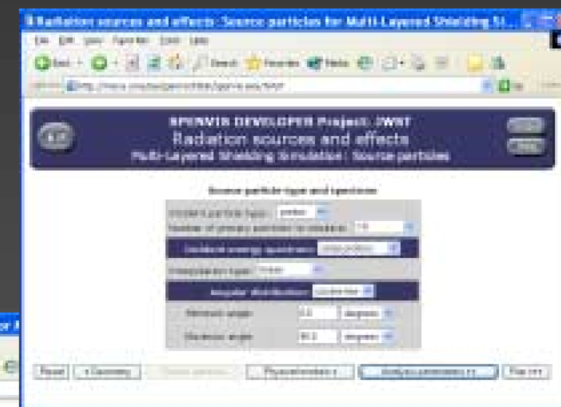


MULASSIS:
MUlti-LAyer Shielding Simulation Software



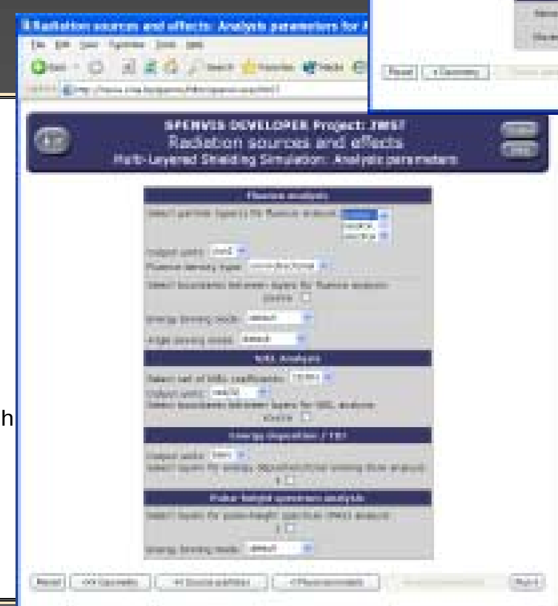
- User Requirements
  - Increasing mass → secondaries more and more important
  - Difficult with analytical models or look-up table approach (SHIELDOSE)
  - Detailed radiation effects analysis in a multi-layer geometry

  - User-friendly (to non C++ programmers)
  - Basic Space-Environment options included



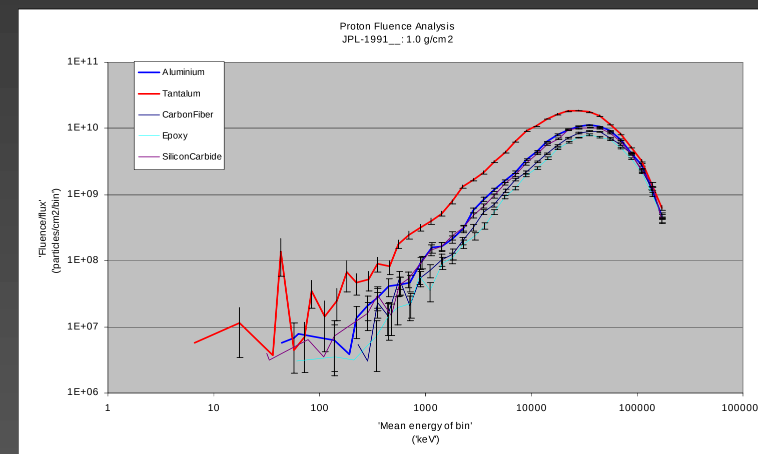
- WWW tool, Geant4 based, for shielding calculations
- Integrated into SPENVIS with a WWW interface
- Source code and precompiled executables downloadable
  - Local interactive use for high statistics applications

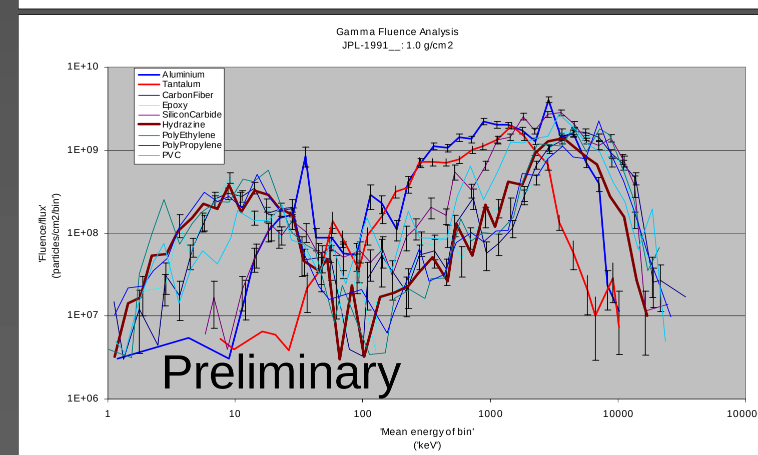
```
# Remove the default geometry
/geometry/layer/delete 0

# Now build a new geometry
# First define two new materials. There are 4 predefined
materials
# 1: Vacuum 2: Air 3: Aluminium 4: Silicon
/geometry/material/add GenericPlastic C-H2 1.3
/geometry/material/add BGO Bi4-Ge3-O12 7.13
/geometry/material/add SiliconOxide Si-O2 2.65
/geometry/material/list

# There are five layers in geometry
# The format is: add position materialName colourIndex th
unit
/geometry/layer/add 0 Aluminium 1 5. mum
/geometry/layer/add 1 GenericPlastic 2 3. mm
/geometry/layer/add 2 SiliconOxide 3 1. mum
/geometry/layer/add 3 Silicon 4 0.1 mm
/geometry/layer/add 4 BGO 4 1.0 cm
/geometry/layer/list 0
```



Bepi Colombo shielding analysis

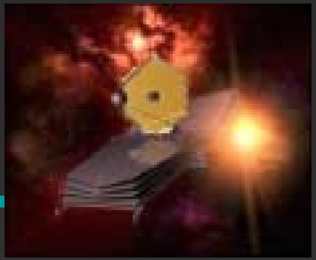
- Mission in early design phase
- Material shielding performance study
  - With the MULASSIS tool
  - In the radiation environment along the mission to Mercury (model)
  - For a list of selected solar particle events



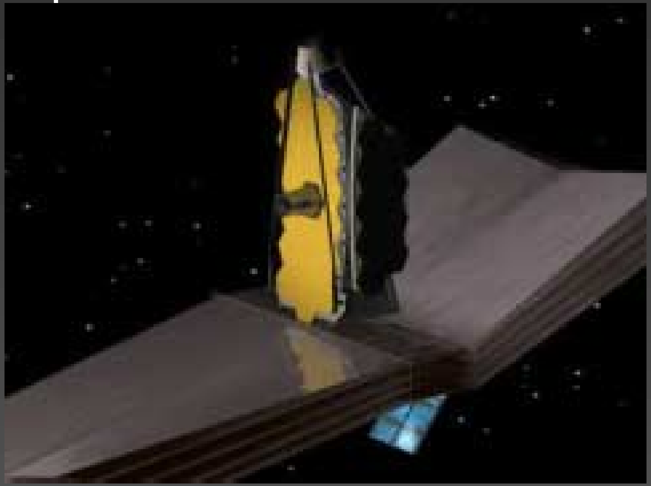


- Similar MULASSIS analysis for Man2Mars

James Webb Space Telescope JWST

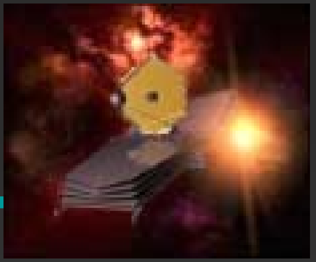


- NASA mission, Successor of Hubble Space Telescope
  - US, Canada, Europe collaboration
  - Launch 2011, L2 orbit
  - Mirror diameter 6.5 m
  - Deployable sun-shield
  - Mass ~ 6 tons

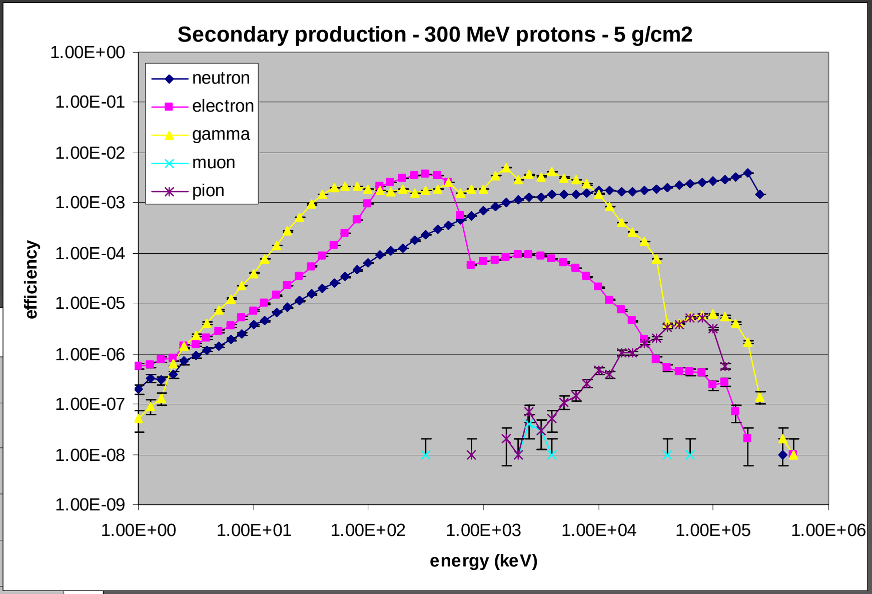


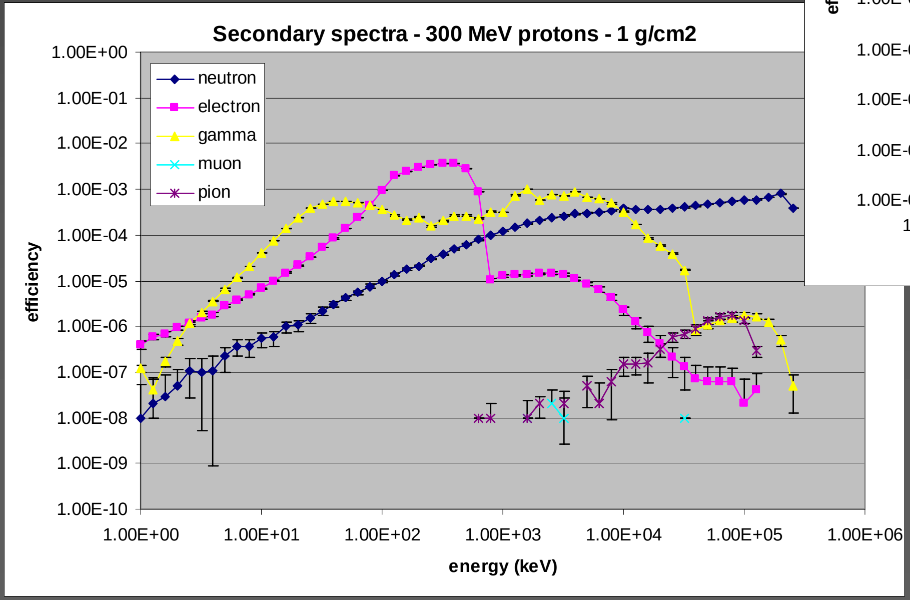
- Instruments
  - 0.6 – 28 um (far visible – mid-infrared light)
    - Visible – Near IR Camera (NIRCam)
    - Near-IR Multi Object Spectrograph (NIRSpec)
    - Mid-IR Camera Spectrograph (MIRI)
- NIRSpec – Near InfraRed Spectrometer
  - European responsibility
  - mercury cadmium telluride (HgCdTe) detector
  - Multi object → Micro-shutter array (MSA) or other solutions

James Webb Space Telescope SiC Shielding effects



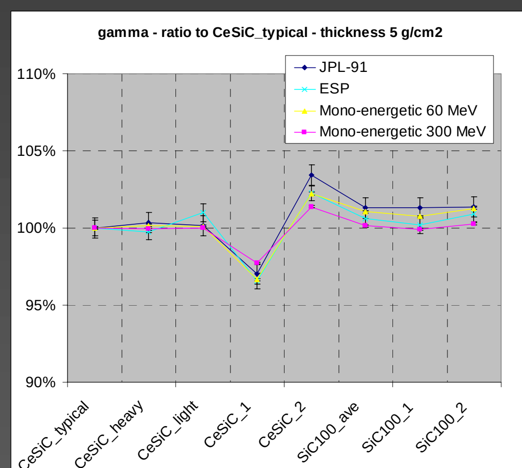
- First investigation of secondary production from the shielding
  - SiC structure, ~10's of mm
- MULASSIS simulations
  - Solar protons: JPL'91, Xapsos
  - Monoenergetic source
- Secondary fluence after shielding

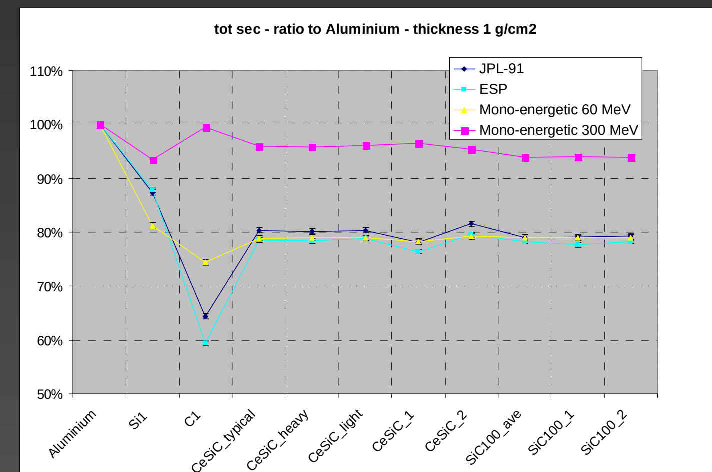


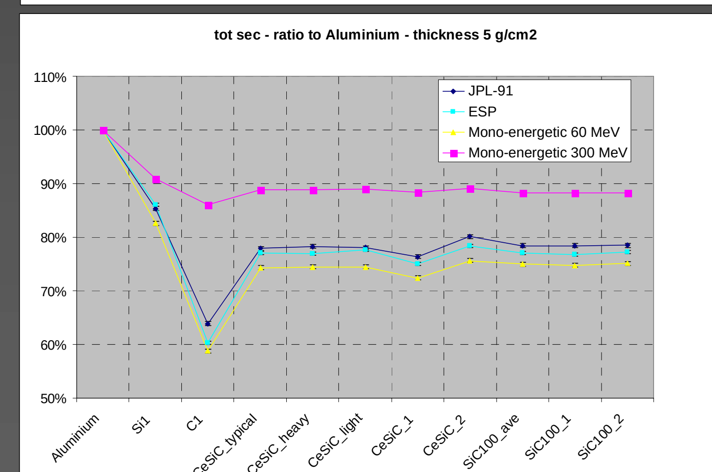


James Webb Space Telescope
SiC Shielding effects

- Precise comparison of different Silicon Carbide manufacturing techniques
  - Total secondary production “efficiency”
  - Comparison to Aluminium
  - Comparison among SiC’s





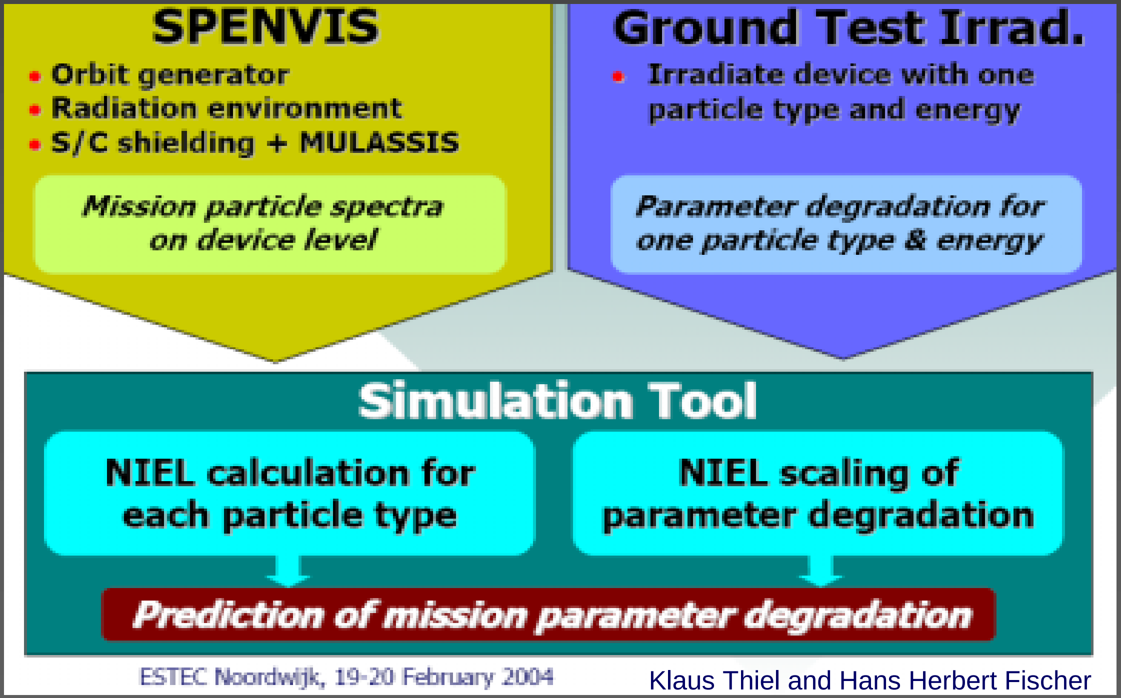


- Results are precise and behave as expected, but depend on cross section and secondary production validation
  - Open issue

Displacement Damage Effect Tool (1)

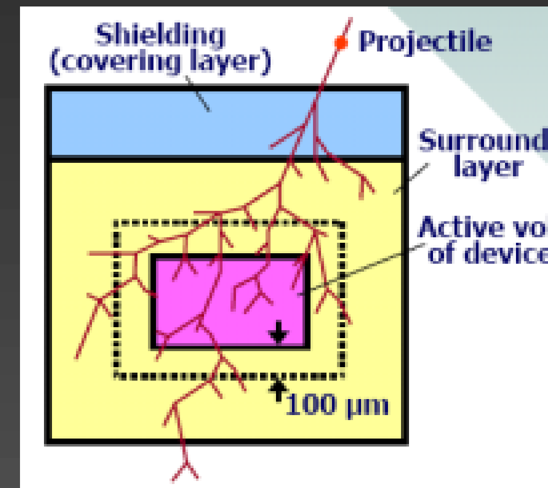
- Nuclear Chemistry Dept., University of Köln, Germany
  - contract with ESA / ESTEC / TEC-QCA
- Aim: Simplify the space qualification procedure for new electronic deviced used in space missions
  - Calculate the displace damage effects in semiconductors induced by NIEL during a space mission
  - Estimate the resulting performance degradation of electronic circuit components

- Independent modules
  - From Rad.Env. Specs to NIEL
    - via G4 particle transport
  - From NIEL to parameter degradation
    - via ground irradiation tests

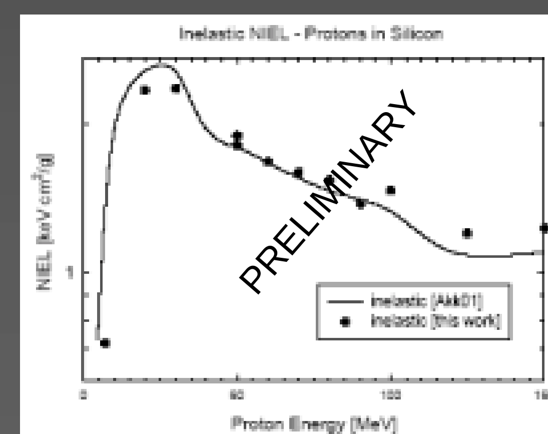


Displacement Damage Effect Tool (2)

- NIEL module
  - Projectile and target specific calculation
    - Microscopic approach: MC simulation of the cascade step by step in the vicinity of the active volume, or
    - Lindhard partition function

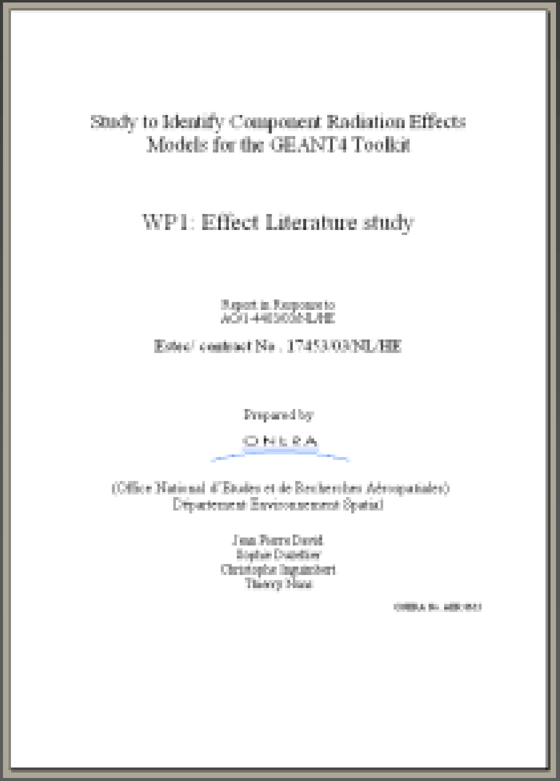


  - For protons, MC-NIEL will be available after the implementation of the binary Coulomb scattering process in Geant4
    - (now only statistical treatment in MSC)
  - Some Geant4 bugs have been found, analyzed, and reported to the Geant4 team.
- Graphical User Interface (GUI)



New Geant4 models for space applications

- Study to Identify Component Radiation Effects Models for the GEANT4 Toolkit
  - Effect Literature study
- Investigation of potential radiation effects to components
  - Dose / <u>SEE</u> / NIEL
- Quantitative selection criteria
  - based on general, technical, and Geant4 issues
- On-going work
  - Model detailed study
- Follow-on work
  - Implementation of selected models


Study to Identify Component Radiation Effects Models for the GEANT4 Toolkit

WP1: Effect Literature study

Report in Response to

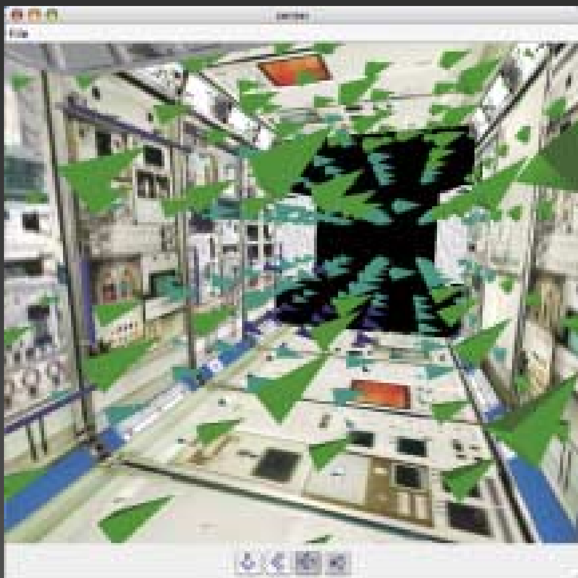
Estec/ contract No . 17453/03/NL/HE

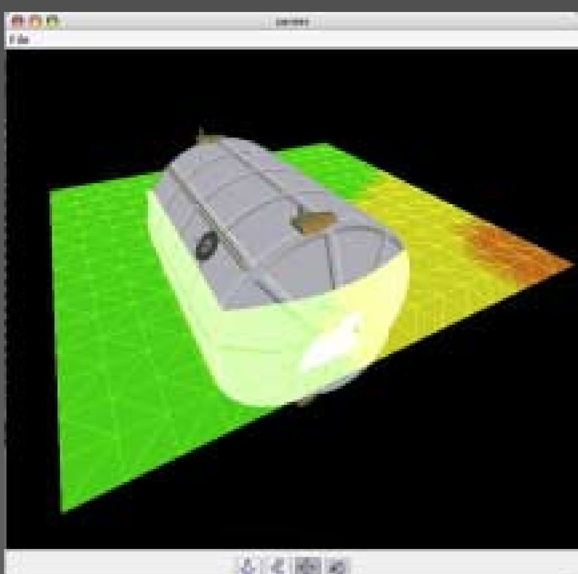
Prepared by

ONERA

(Office National d'Etudes et de Recherches Aérospatiales)
Département Environnement Spatial

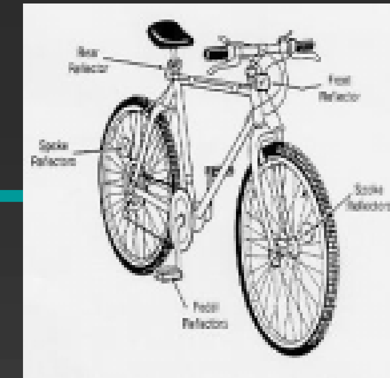
DESIRE - RadVis





- DESIRE RadVis will be used to visualise radiation flux and dose data resulting from the DESIRE project
  - rapid and easily compressible manner
  - improve radiation awareness of astronauts and ground personnel at ESA.
- 3D visualisation of radiation flux and dose levels in and around the module
  - It will also calculate and display the total combined dose contributions of the input data
- Developed using Java and Java3D technology
  - Designed for use on desktop PCs running Windows
  - Will also support stereoscopic rendering on more exotic display systems and using other operating systems

Data Analysis for Space applications



- Moving from “toolkit” to “tool” for specific cases and analyses
  - Long standing discussion…
  - Caveat’s
    - G4 too rich and complex to be entirely closed in a “tool” envelope
  - Nevertheless…
    - MULASSIS is a first specific example
- Space Analysis Module (→ SPAM)
  - Preliminary phase
  - Other G4 Space users are probably doing the same
  - Some results can be useful to the G4 community if generic enough
- Open issues
  - Interface to analysis tools
    - ROOT, AIDA compliant tools,…
    - G4 independence of specific analysis solution is strategically right
    - Clear view of status and evolution for some of these tools is essential
  - Interface to geometry
    - GDML or C++ or…
    - Adoption of GDML by G4 is very appreciated
    - Standard tools to interact with a generic geometry are needed
      - Sensitive volume
      - Visualization

Tentative summary of issues emerged

- Physics
  - Medium energy proton physics
    - Gap in the range 5-10 GeV ?
  - Ion physics: Cumulative effects (Dose) and SEE
    - Extension to heavy ions ?
    - Validation of existing models for light ions ?
  - NIEL: Coulomb scattering contribution

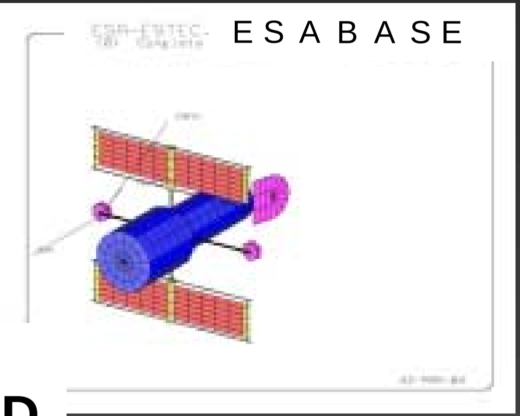
- Geometry description

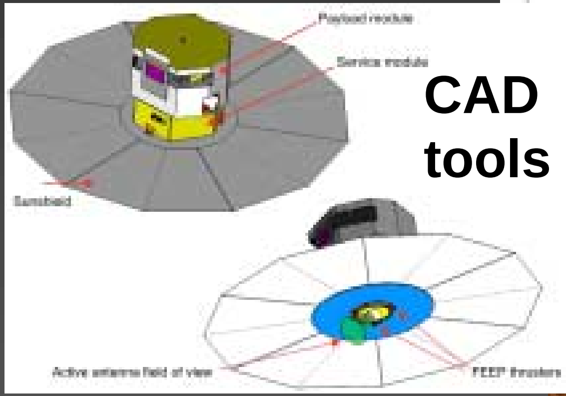
- Analysis
  - Standard extraction of relevant information for typical simple cases

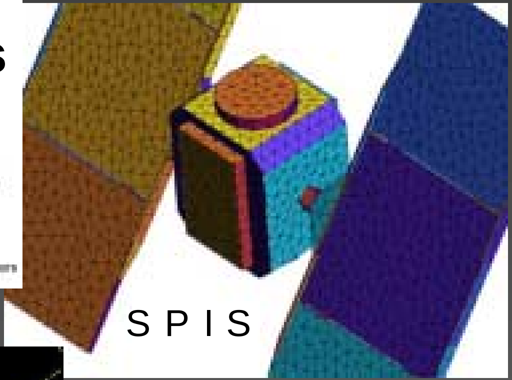
- Shielding and Micro-dosimetry
  - Reverse Monte Carlo?
  - Biasing
    - Present limitations, future upgrades

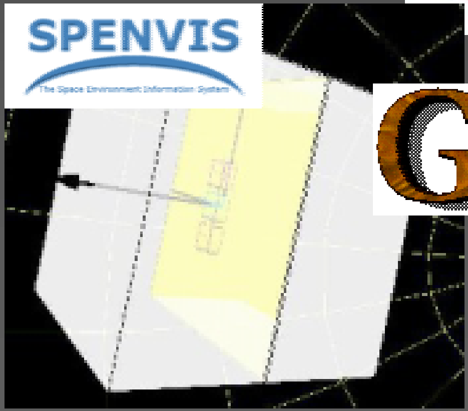
Radiation environment and effects Tools harmonisation

- Input
  - Geometry
    - STEP for Space Environment
    - GDML
      - SPENVIS
- Space Environment
  - Common Data Format (CDF)
- Output
  - Analysis tools
    - AIDA
  - Geometry









G4 Space Users' web page

- Gathering the experience of the various groups around the world
- Updates with news users w/ link to relevant sites
- Collection of topics, interesting papers
  - Quite extensive list
  - Please send me an e-mail if you want to be included
- Link to space related tools
  - SSAT, MULASSIS, …
  - Any other?
- Suggestions?

Conclusions

- Successful application of G4 Monte Carlo techniques for the estimation of the HE Radiation Environment effects on satellites
  - Environment models
  - Radiation effects on components and detectors
  - Complete mission analyses and engineering tool development

- Geant4 description of spacecraft-particle interaction suitable for manned and un-manned mission analysis
  - Assessed EM physics performance
  - New promising hadronic models need
    - validation for protons
    - validation and extension for ions

- Need for engineering tools (G4-based) is always valid

- Geant4 Space Users' world community
  - ESA still maintains the web page with users, topics, relevant papers

- Fruitful interaction with the Geant4 collaboration

- ESA Round Table on Radiation effects software R&D
  - ESA/ESTEC, The Netherlands, June 7th 2004