esa

ESA STATUS REPORT

Marco Vuolo, G.Santin,P.Nieminen

ESA/ESTEC and RHEA System

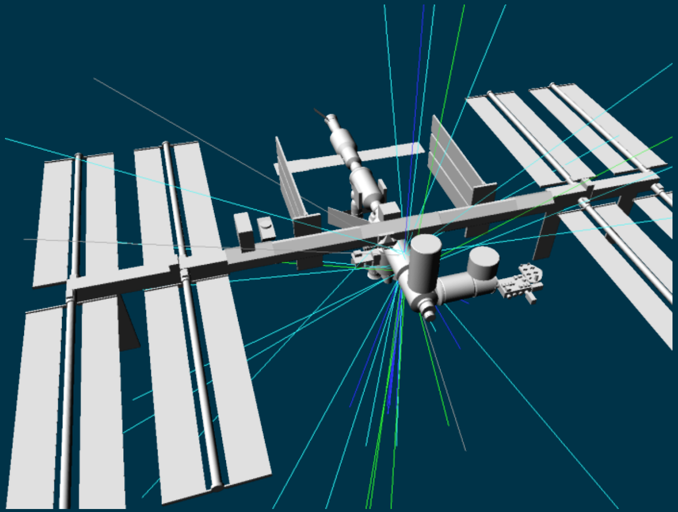
Outline

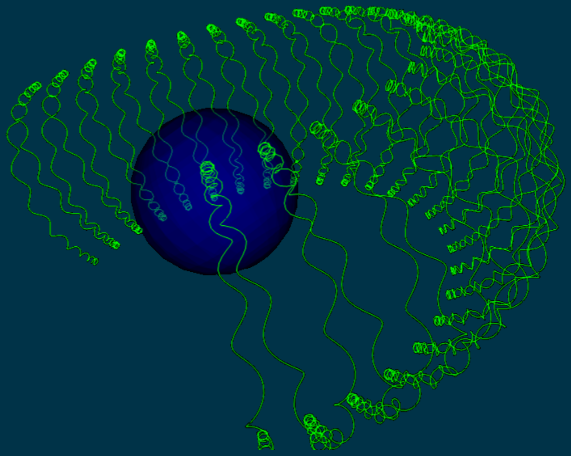
- ESA projects and Geant4 support
- Tool developments
- Perspectives

Xylokastro, Korinthia, Greece
21 October 2019

Summary

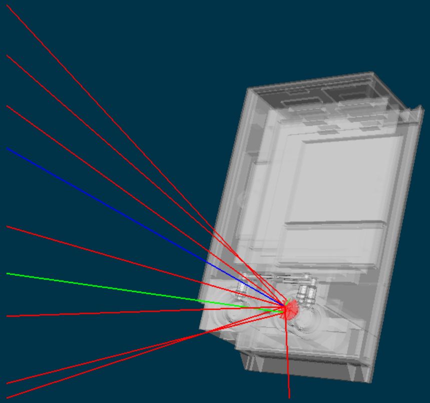
- Overview on ESA Geant4 based tools and recent achievements
- ESA Science Missions support:
  - ✓ JUICE (Materials selection, geometry debugging, code validation, SEE, etc.)
  - ✓ ATHENA (particle background study, AREMBES, EXACRAD)
  - ✓ Additional ESA Cosmic Vision missions
- Updates on ESA Radiation Monitors and recent developments
- R&D Activities using ESA G4 tools (G4G, ROSSINI …)
- Additional topics of interest

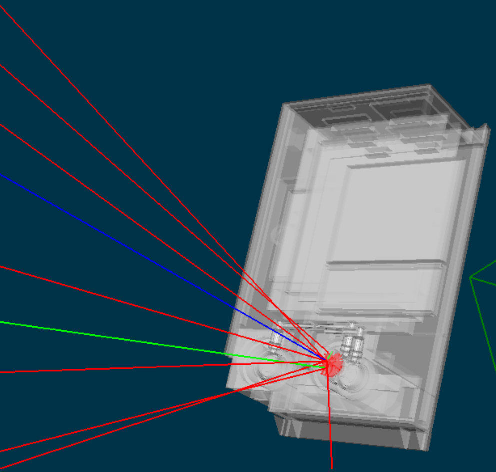


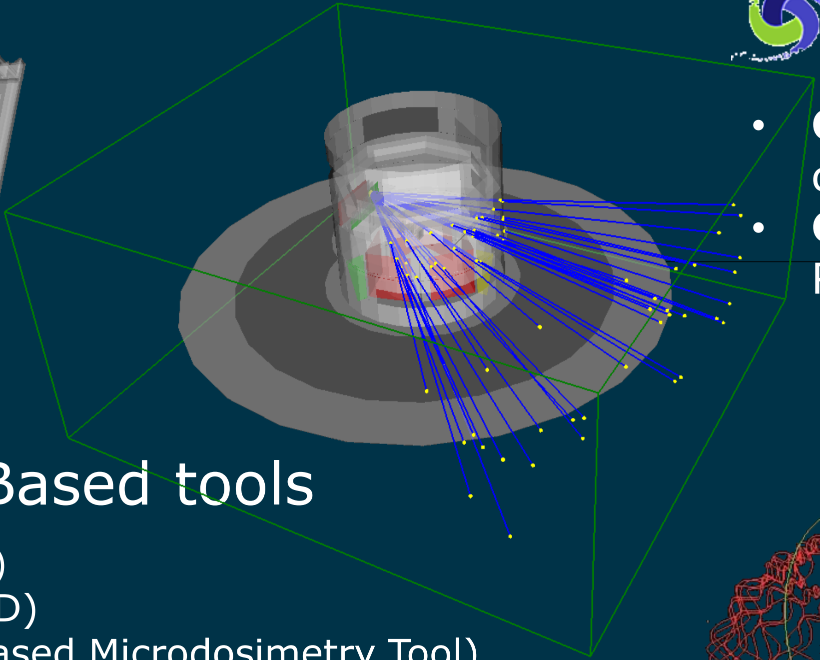


Overview on ESA Geant4 based tools and recent achievements

ESA G4 BASED TOOLS



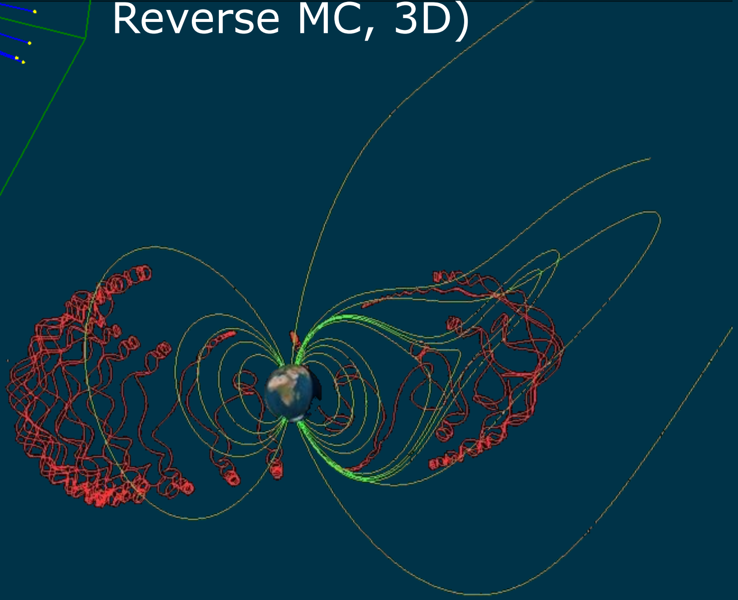




- **Geant4**: 20+ year in the collaboration
- **GRAS** (Forward and Reverse MC, 3D)

ESA Geant4 Based tools

- **SSAT** (Ray Tracing)
- **MULASSIS** (MC, 1D)
- **GEMAT** (Geant4-based Microdosimetry Tool)
- **MAGNETOCOSMICS** (magnetosphere simulations)
- **ATMOCOSMICS** (atmosphere simulations)
- **PLANETOCOSMICS-J** (Extension to planets and moons)



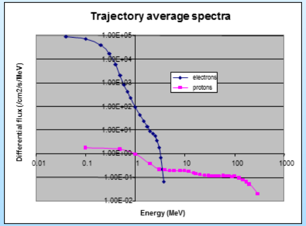
http://space-env.esa.int/index.php/geant4-radiation-analysis-for-space.html

By L. Desorgher , PSI, CHUV

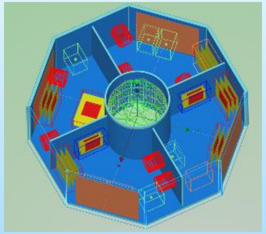
Geant4 Radiation Analysis for Space (GRAS)

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 v4.0
- Available through the ESA Space Software Repository: https://essr.esa.int/



Radiation Environment
(e.g. SPENVIS, CREME96)
via GPS



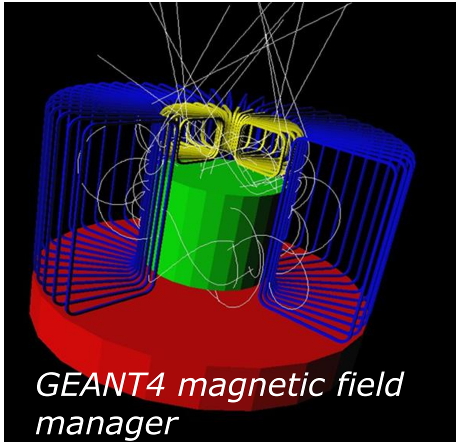
External geometries
GDML, CAD (via GDML)

Built-in geometries
MULASSIS, GEMAT, C++

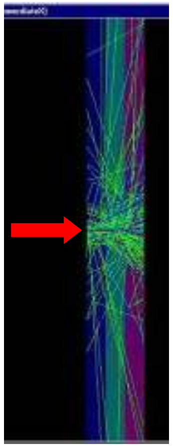
Geant4 Physics
EM & Hadronic options

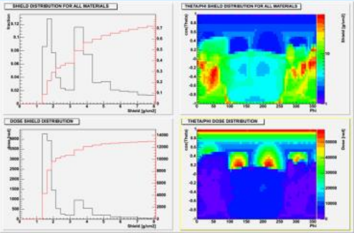
GRAS
Transport, Scoring

Reverse MC
Adjoint physics



GEANT4 magnetic field manager

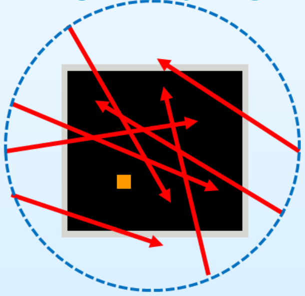


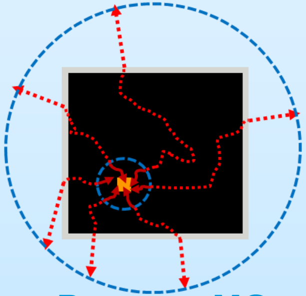


Analysis output:
- Scalars, Histograms, Tuples (CSV, AIDA, ROOT, log)
- Several modules available:

Dose, Dose eq., Fluence, Niel, LET, Step by Step, Detector, Charge

Forward MC





Reverse MC

- **Adjoint Monte Carlo:**, based on *reverse tracking*
- *Reverse MC method more rapid than forward by orders of magnitude*

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

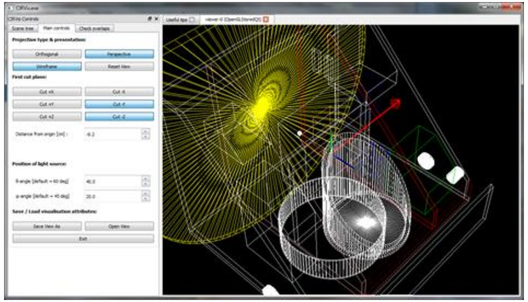
CIRSOS (Collaborative Iterative Radiation Shielding Optimization System)

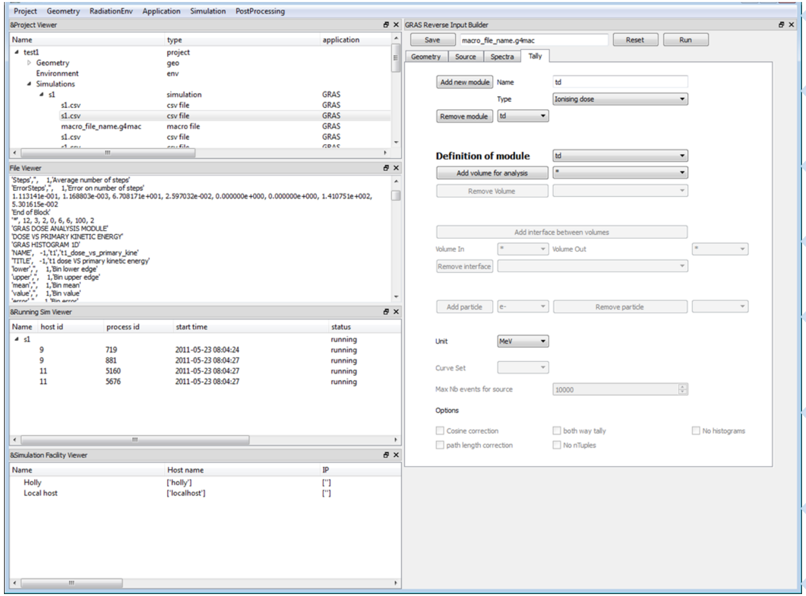
- **Multi-user collaborative radiation analysis**, I/F to SPENVIS & OMERE, **CAD through GDML** export by FASTRAD & ESABASE2
- **Job management on local PC and remote clusters**
- Local or remote DB
  - Geant4 based analysis tools:

-Ray Tracing (SSAT)

-Forward and Reverse MC (GRAS)

  - Geometry and Environment from the DB
  - Parametric analysis
  - Full control of Geant4 physics

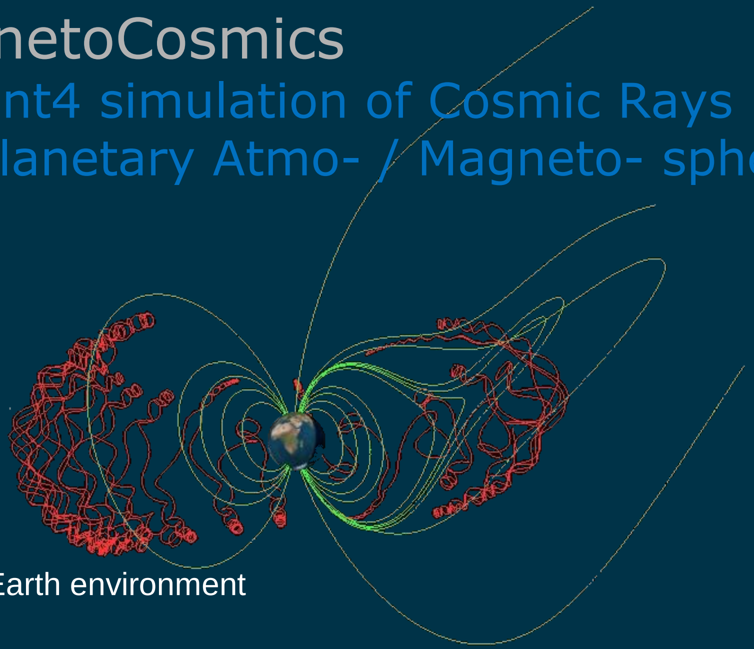


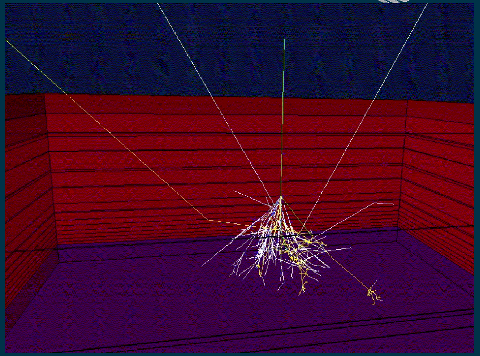


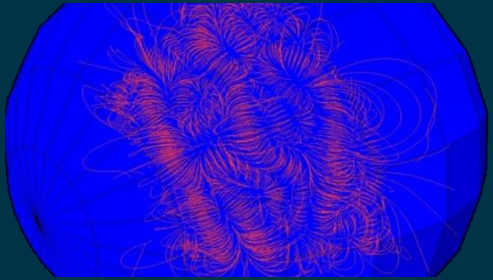
- Environment (link to Spenvis, Omere)
- Geometry (GDML, G4 visualization)
- Physics
- FMC, RMC, SSAT
- Tallies, Scoring
- Parametric analyses, Multi-stage simulations, Multiple source
- Jobs management on clusters
- Post processing, Python console

PlanetoCosmics

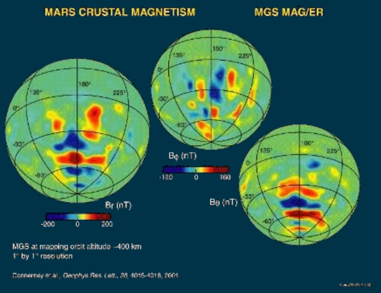
Geant4 simulation of Cosmic Rays in planetary Atmo- / Magneto- spheres







- Originally for Earth environment
- Extended to
  - Mars (local magnetic fields)
  - Mercury
  - Jupiter
  - Jovian moons
- Possible future development
  - Saturn, Uranus, etc.



Geant4 implementation L. Desorgher, Space IT

http://cosray.unibe.ch/~laurent/planetocosmics/

SPENVIS

The Space Environment Information System

SPENVIS Project: THESEUS
Model packages
Planet: Earth

UP | Output | Help

esa

SPENVIS is ESA's SPace ENVironment Information System
- WWW interface to models of the space environment and its effects
- Cosmic rays, radiation belts, solar energetic particles, plasmas, gases and microparticles

- Damage-equivalent fluences for solar cells (EQFLUX).
- Ionising dose (SHIELDOSE).
- Damage-equivalent proton fluences and non-ionising energy loss (NIEL).
- Single-event upset rates in micro-electronic devices.

Coordinate generators

Radiation sources and effects

Radiation sources

- Trapped proton and electron fluxes — Standard models
- Trapped proton flux anisotropy
- Solar particle peak fluxes (only for SEU)
- Solar particle mission fluences
- Galactic cosmic ray fluxes
- Shielded flux

Solar cell radiation damage

- Damage equivalent fluences for solar cells (EQFLUX)
- NIEL based damage equivalent fluences for solar cells (MC-SCREAM)

Long-term radiation doses

- Ionizing dose for simple geometries
- Non-ionizing energy loss for simple geometries
- Effective dose and ambient dose equivalent

Single event effects

- Short-term SEU rates and LET spectra
- Long-term SEUs and LET spectra

Spacecraft charging

Atmosphere and ionosphere

Magnetic field

Meteoroids and debris

Miscellaneous

Geant4 Tools

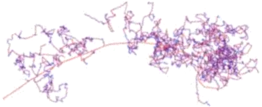
ECSS Space Environment Standard

Geant4 tools:
- Multi-Layered Shielding Simulation (Mulassis)
- Geant4-based Microdosimetry Analysis Tool (GEMAT)
- Sector Shielding Analysis Tool (SSAT)
- Magnetocosmics
- Planetocosmics
- GRAS

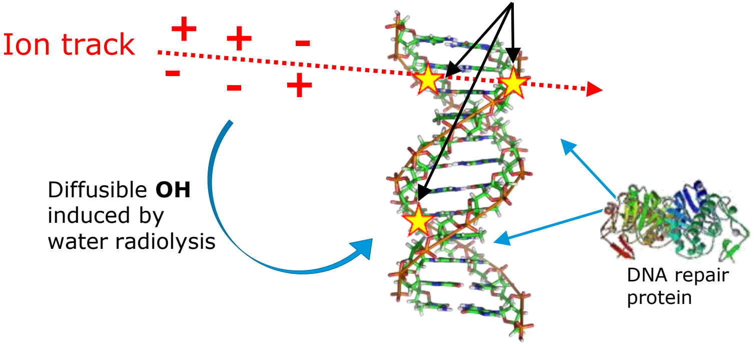
BIRA-IASB

https://www.spenvis.oma.be/

Geant4-DNA

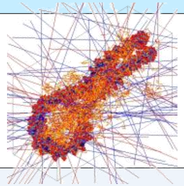


The Geant4 general purpose particle-matter Monte Carlo simulation toolkit is being extended with processes for the **modeling of early biological damage induced by ionising radiation at the DNA scale**. Such developments are on-going in the framework of the Geant4-DNA project, originally initiated by the European Space Agency/ESTEC.



Physical stage
step-by-step modelling of physical interactions of incoming & secondary ionizing radiation with biological medium (liquid water)

- Excited water molecules
- Ionised water molecules
- Solvated electrons



Physico-chemical/chemical stage
- **Radical** species production
- Diffusion
- Mutual chemical interactions

Geometrical models
DNA strands, chromatin fibres, chromosomes, whole cell nucleus, cells…
for the prediction of damage resulting from direct and indirect hits

DIRECT DNA damage

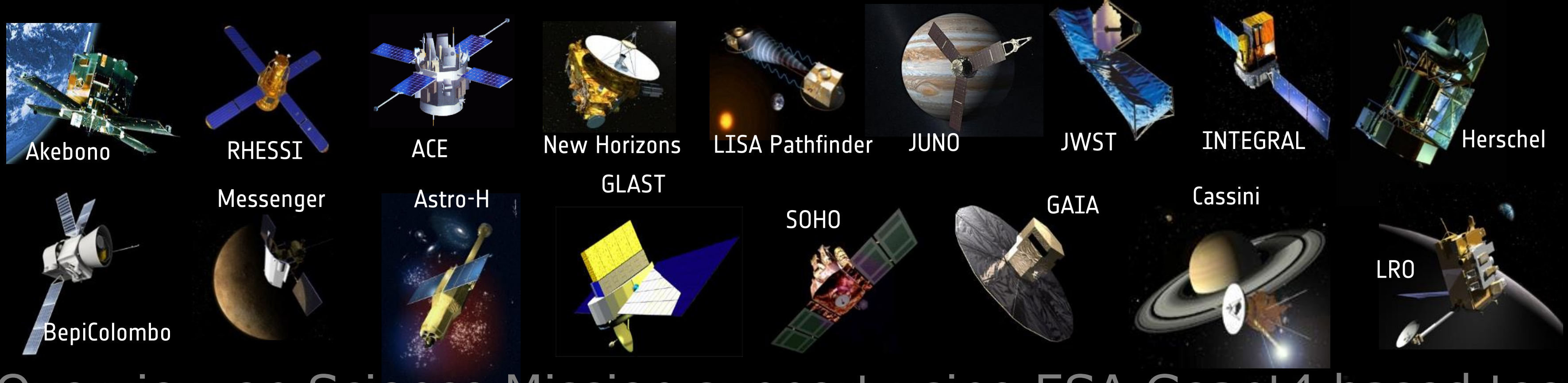
INDIRECT DNA damage

repair

$t=0s$ $t=10^{-15}s$ $t=10^{-6}s$

Sébastien Incerti, CNRS / IN2P3 / CENBG

http://geant4-dna.org

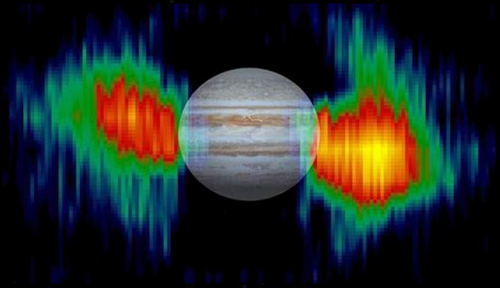


Overview on Science Mission support using ESA Geant4 based tools

SCIENCE MISSION SUPPORT

JUpiter Icy moons Explorer (JUICE)

- JUICE is the first large-class mission in ESA's Cosmic Vision 2015-2025 programme.
- Planned for launch in 2022 and arrival at Jupiter in 2029,
- It will spend at least three years making detailed observations of the giant gaseous planet Jupiter and three of its largest moons, Ganymede, Callisto and Europa.



Cassini (NATURE 2002)

Very intense magnetic field

- Jupiter rotational period 9 h 56 min
- Plasma torus and radiation belts wobble due to 7° tilt between Jupiter rotational and magnetic axes

Hostile radiation environment

- Trapped electrons with energies >100MeV
- Intense, energetic, variable, difficult to predict

Design driver for JUICE platform and payload

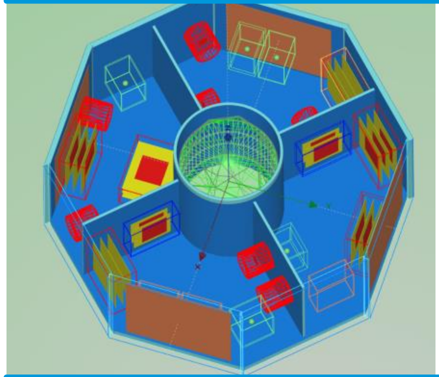
- Sensor / component **degradation**
- High **background** noise for science instruments
- **Electron-induced SEE**

Broad range of radiation analysis activities (TID, charging, DD, noise, SEE) for platform and instruments, **including Geant4 and GRAS**

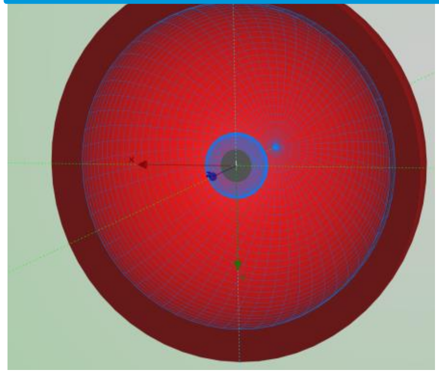
JUICE Geant4 related activities

- Radiation Shielding design: Vaults for sensitive electronics including **High-Z materials**
- RMC Tests and comparisons: Geant4 has crucial role in **design and/or validation** of both FASTRAD and NOVICE.
- Electron **back scattering** studied to explain some discrepancies between sectoring analysis and MC
- **Electron-induced Single Event Effects** studies (Maris Tali, RADECS 2016 IEEE Trans Nucl Sci, 2017):
    - Not a big issue @ Earth, but potentially @ Jupiter
    - Low energy ->direct ionization, Higher energies -> nuclear interactions
    - <u>Gamma-nuclear and electro-nuclear processes</u>
    - Need of <u>**BIASING** techniques</u> implementation into GRAS (started)

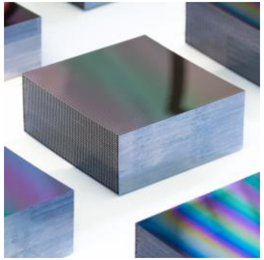
TEST Spacecraft for sharing info



Sphere: 1mm Pb+4mm Al + Si det (0.5 mm r)



ESA Cosmic Vision L-class mission Athena



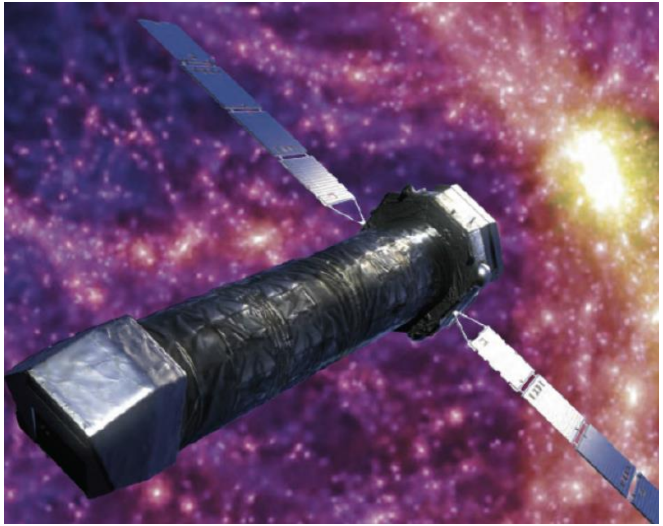
ATHENA (Advanced Telescope for High Energy Astrophysics)

Primary goals:
- Mapping hot gas structures and determining their properties
- searching for supermassive black holes

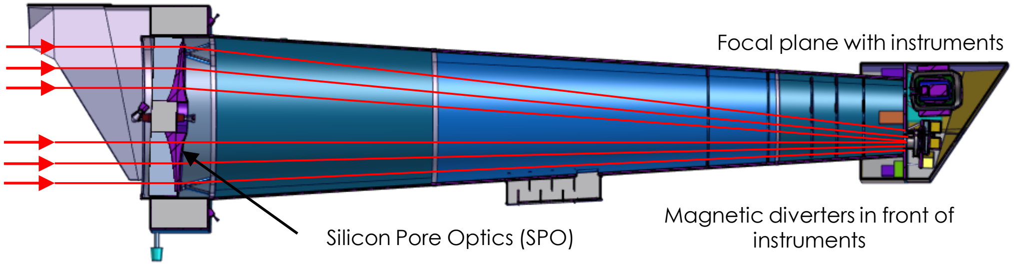
Launch 2028, with mission duration of 5 years
- Halo orbit around L2 (or possibly L1)

Mirror:
- Silicon Pore Optics

Two instruments:
- X-Ray Integral Field Unit (X-IFU), 0.3-10 keV
- Wide Field Imager (WFI), 0.1-12 keV

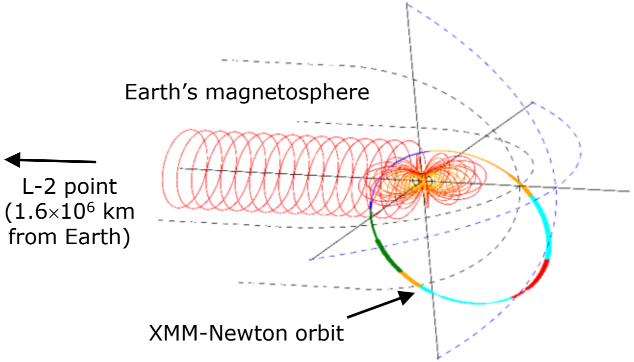


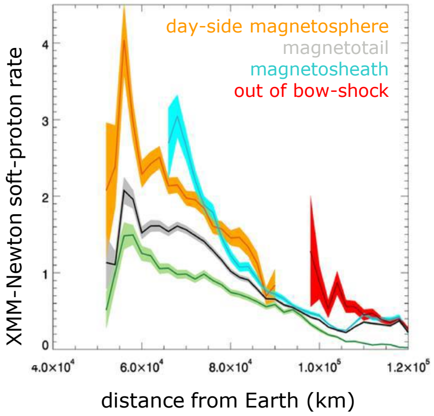
Soft protons focusing in Athena:

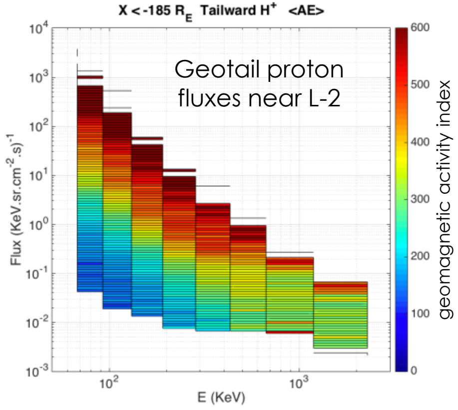


Particle background in the ATHENA X-ray telescope

- **AREMBES** (Athena Radiation Environment Models and x-ray Background Effects Simulator) :
  - Analysis of particle background in XMM-Newton data, measurements by Geotail, ACE and Wind spacecraft.
  - Development of a software simulator based on Geant4, capable of addressing all the background issues that the ATHENA mission will experience during its lifetime.
- **soft protons:** 10 keV to 100 keV energy range (“soft” compared to energetic particles causing SEE, TID, NIEL...)
  - ➢ potential limitation for astrophysical observations that require low background
  - ➢ ½ of XMM-Newton observations affected by “soft-proton flares”
  - ➢ ATHENA will operate at L-2 Lagrange point – new environment for X-ray telescopes



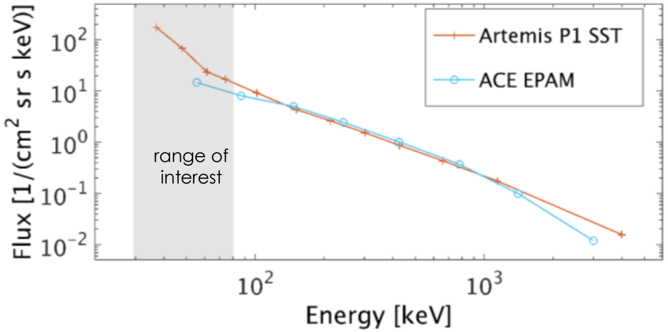




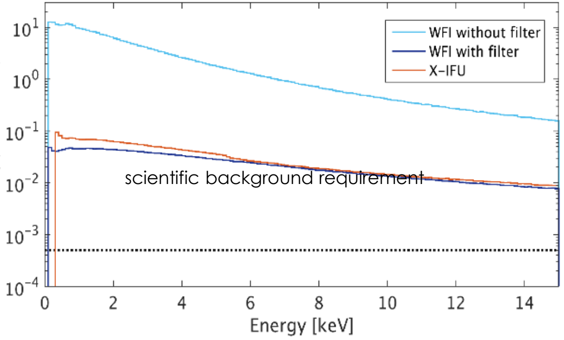
Particle background in the ATHENA X-ray telescope

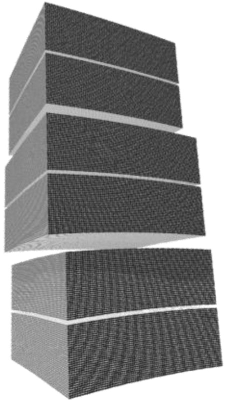
Soft Proton Fluxes in and Around the Earth's Magnetotail, D. Budjas et al. ,March 2017 IEEE Transactions on Plasma Science PP(99):1-7

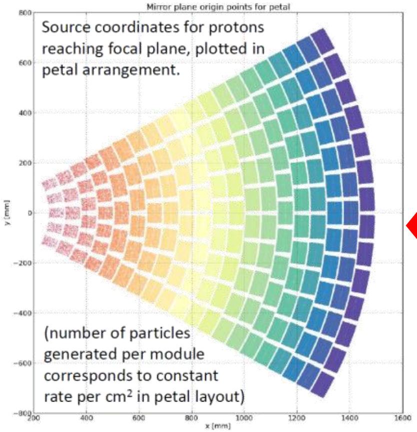
90% worst-case spectra for solar (from ACE) and solar + Earth magnetotail (from Artemis) proton flux

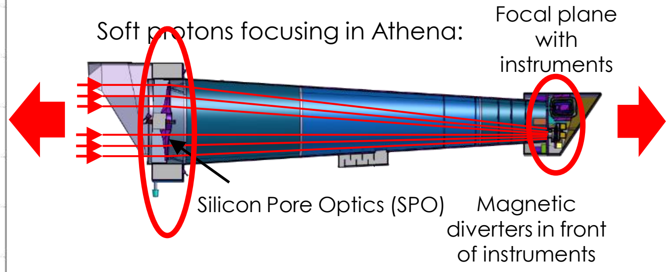


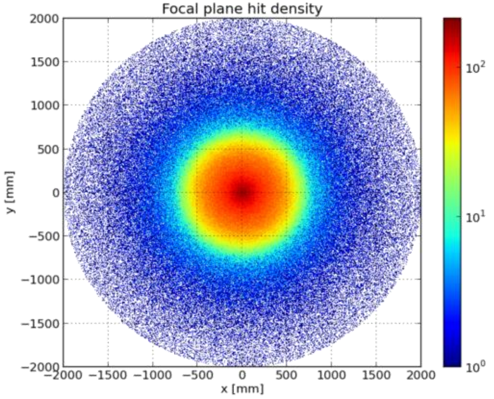
estimate of soft-proton background in Athena X-ray detectors without magnetic diverters







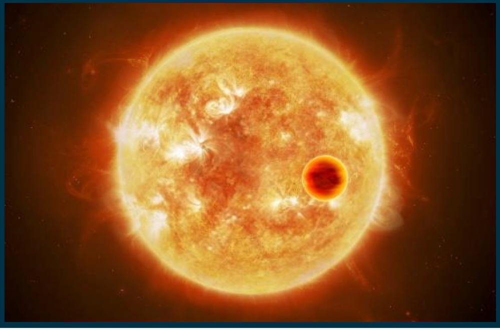




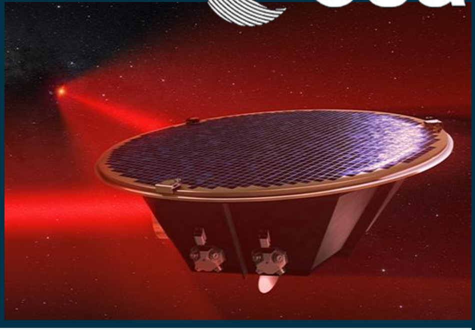
Future missions in ESA's Cosmic Vision programme

ARIEL, the Atmospheric Remote-sensing Infrared Exoplanet Large-survey

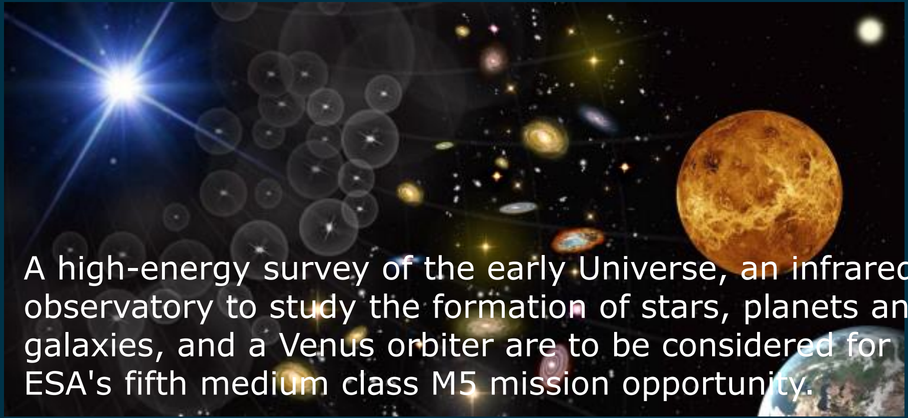
M4



LISA is a space-based observatory of gravitational waves consisting of a constellation of three spacecraft, with launch planned for 2034 L3



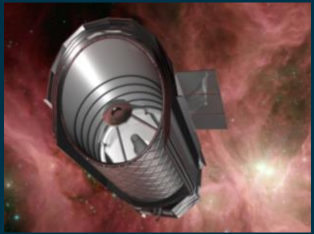
M5 selection:



A high-energy survey of the early Universe, an infrared observatory to study the formation of stars, planets and galaxies, and a Venus orbiter are to be considered for ESA's fifth medium class M5 mission opportunity.

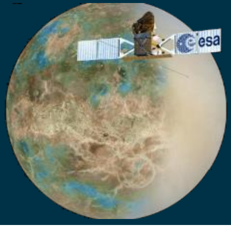
THESEUS:

Transient High Energy Sources and Early Universe Surveyor



SPICA:

Space Infrared Telescope for Cosmology and Astrophysics



EnVision:

Venus high-resolution radar mapping and atmospheric studies

Updates on ESA Radiation Monitors and recent developments

ESA RADIATION MONITORS UPDATES

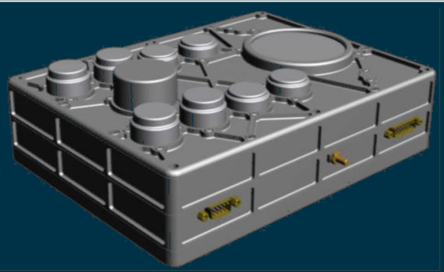
*Reported dates are indicative (each project requires years of development, testing and mission preparation)

Overview of past ESA Radiation Monitors

Contraves(RUAG→TAS-CH),PSI (CH)

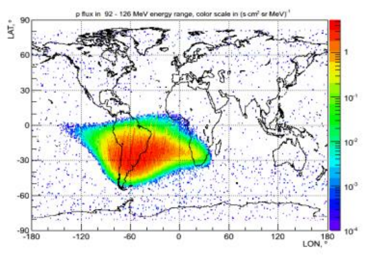
Flights on STRV-1c, **Proba-1, INTEGRAL**, Rosetta, Giove-B, Herschel and Planck

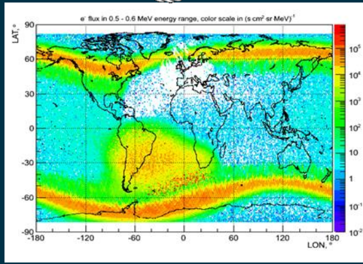
SREM Standard Radiation Environment Monitor



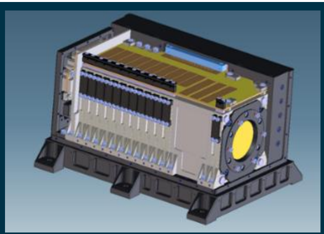
- RUAG (→TAS-CH), QinetiQ (UK)
- 2 Galileo FOC s/c equipped with the Environmental Monitoring Unit (EMU)
- Flying as 'SEDA' on two Himawari (Japan) satellites in GEO

EMU Environment Monitoring Unit





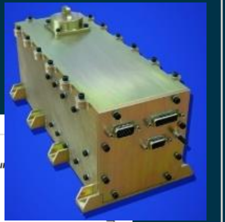
- UCL/CSR, QinetiQ Space, BISA, B.USOC (B), ASRO (FIN)
- Flying on Proba-V since May 2013

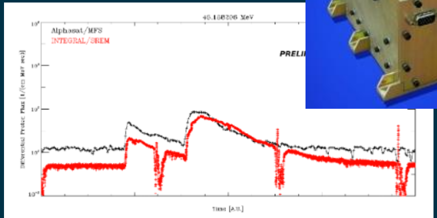


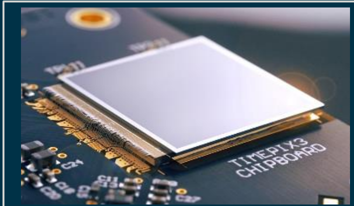
EPT Energetic Particle Telescope

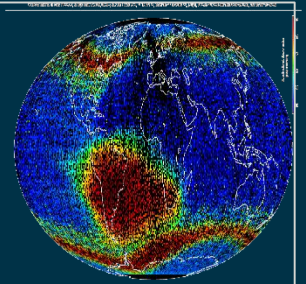
MFS Multifunctional Spectrometer

- EFACEC (P), LIP (P)
- Flying on AlphaSat (Inmarsat-4A F4) on GEO (July 2013 on), data analysis ongoing
- Similar instrument ("BERM") to be flown on BepiColombo







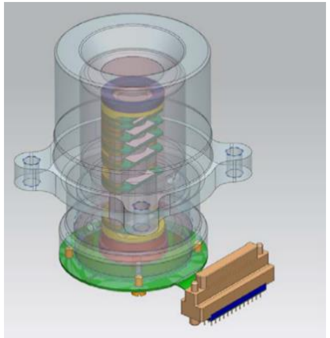


- IEAP CTU, CSRC (CZ)
- TimePix-based (CERN) imaging sensor
- One-chip demonstrator launched on Proba-V

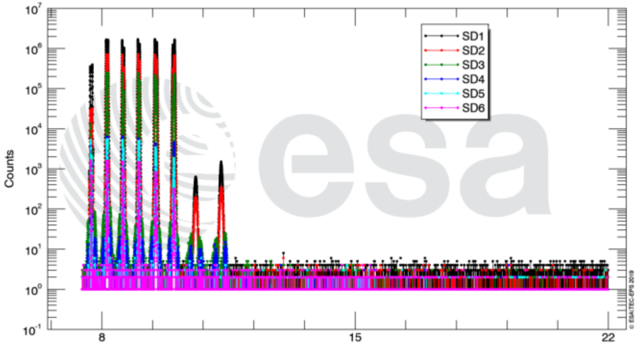
SATRAM Space Application of TimePix Radiation Monitor

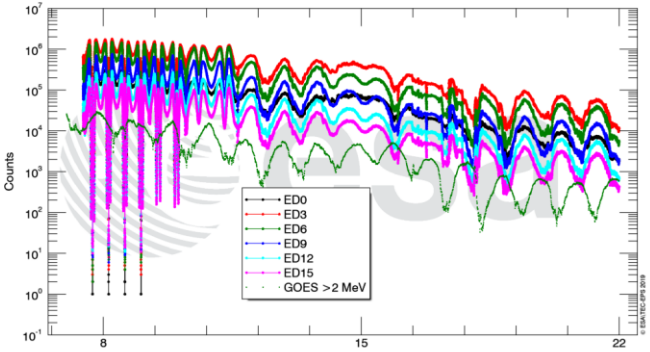
Next Generation Radiation Monitor (NGRM)

- TAS-CH, PSI (CH), IDEAS (N), EREMS (F), ONERA (F)
- Intended as follow-on for the SREM: Batch approach
- Mass 1.5 kg, power 2.5 W
- Dimensions 150 x 133 x 69 mm^3
- Two sensor heads, one for protons and heavy ions, the other for electrons
- Modular interface
- Flying on EDRS-C (GEO)
- Next flights : MetOp-SG, MTG and Sentinel-6.



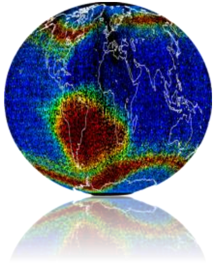
Following the successful launch of the European Data Relay System (EDRS-C) spacecraft on 6 August 2019, the first radiation environment data from the onboard Next Generation Radiation Monitor (NGRM) instrument have been received.



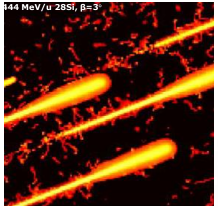


http://space-env.esa.int/index.php/ESA-ESTEC-Space-Environment-TEC-EPS/articles/NGRM_First_Data.html

Miniaturisation



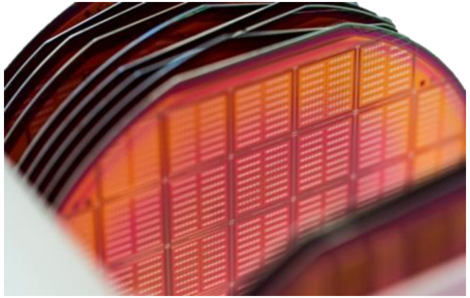
Miniaturised Radiation Monitor (MIRAM)



- IEAP CTU, CSRC (CZ)
- Mass <150 g, power <1 W
- TimePix3-based (CERN) imaging sensor
- Dosimeter for accumulated total dose + particle identification
- Status report TEC-EPS FPS Dec 2019, end of the project 2020

SpacePix 2

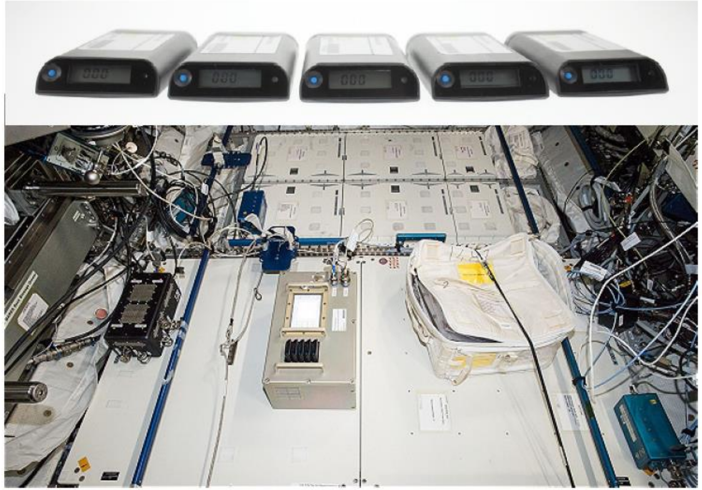
- FNSPE CTU, ESC Aerospace (CZ)
- Pixelated monolithic detector 180 nm SoI based on the X-chip03 development (FNSPE CTU)
- Expected 64x64 pixels, pixels pitch 50 μm or 100 μm
- Kicked off in 02/2019 - End of the project 2021



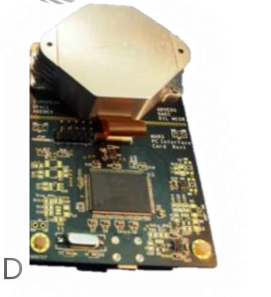
Personal Active Dosimeters - EAD & MIDAS

European Astronaut Dosimeter (EAD)

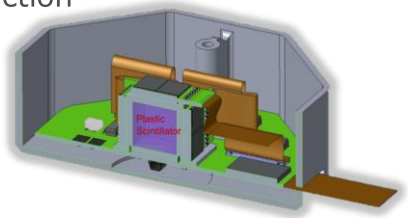
- DLR (DE), Mirion (FI), Tyndall (IE), PTB (DE), Seibersdorf Labor (AT)
- Active monitoring of astronaut radiation exposure
- Central unit (R/O, recharge), mobile units
- Flown to ISS, selected for Orion EM1 (5+2 units)



Highly Miniaturised ASIC Radiation Detector (MIDAS)

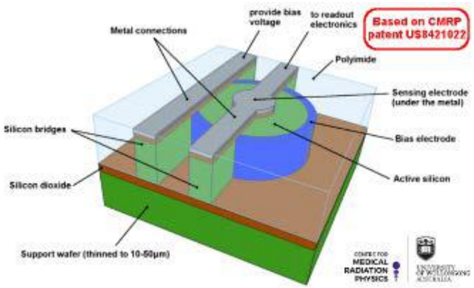


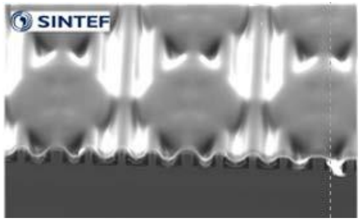
- ADVEOS, Uni.Cyprus, GEAC, Demokritos (GR)
- GCR ion discr. based on ASICs MAPS technology
  - ✓ 32 x 32 matrix, 105.5 um pixel pitch, coinc./track reco
  - ✓ Dynamic range: 0.5fCb-5 pCb (80db)
  - ✓ Pixel power <100 nA @ 1.8V, embedded A/D converter
- Scintillator/SiPM based fast neutron detection



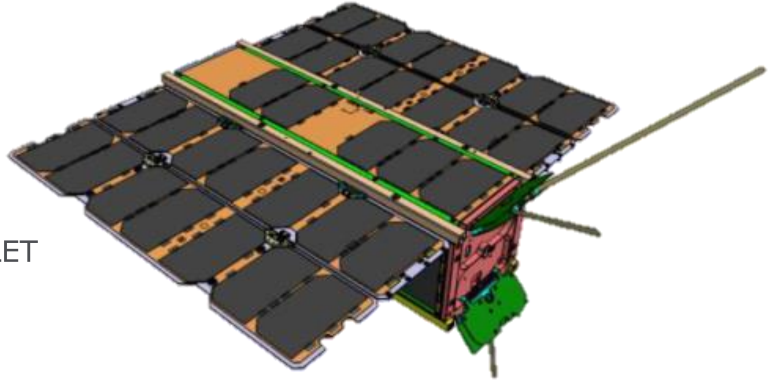
Tissue equivalent microdosimetry

- SINTEF (NO), Uni Wollongong
- 3D Silicon “mushroom” tech



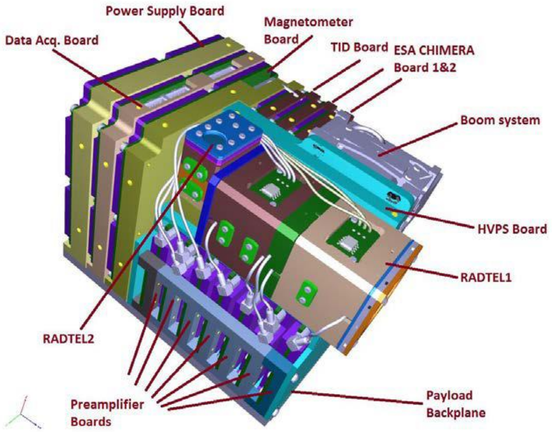


In Orbit Demonstrator



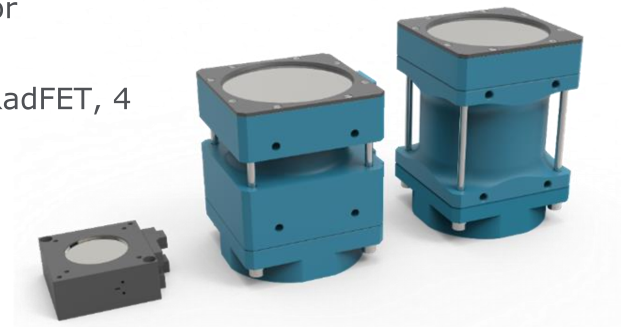
RadCube: 3U cubesatby C3S (HU)

- RadMag: Radiation monitor, MTA EK (HU)
- Measurements Protons, electrons, heavy ion LET
- SEE testing (CHIMERA boards)
- Magnetic field (w/ boom)
- Phases B2-F kicked off in March 2017
- Target orbit 500-600 km SSO, 3 year life time



Evolution:

- **RadMag2** development (started 2018) for the ESA SSA Distributed Space Weather Sensor System(D3S)
- **PRETTY (AT):** radiation payload (4 RadFET, 4 FGDOS)



GRAS simulations for Radiation Monitor design

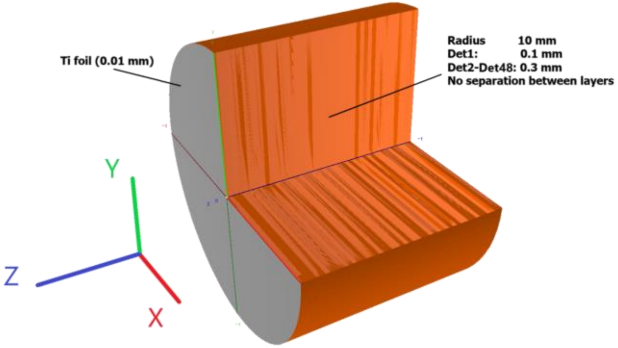
The "D3S RadMag" example by mtaEK

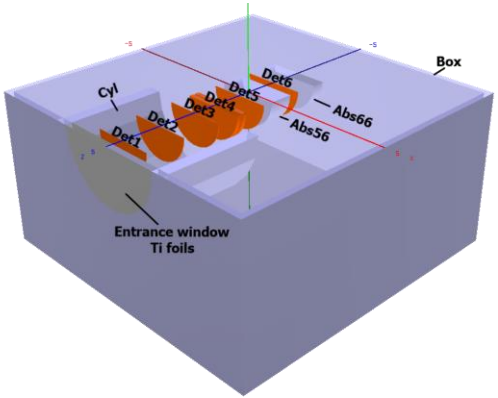
The activity aims to develop a complex instrument package combining the cosmic ray and magnetic field measurement capability for space weather service and directly applicable in the Distributed Space Weather Sensors System (D3S) concept of ESA.

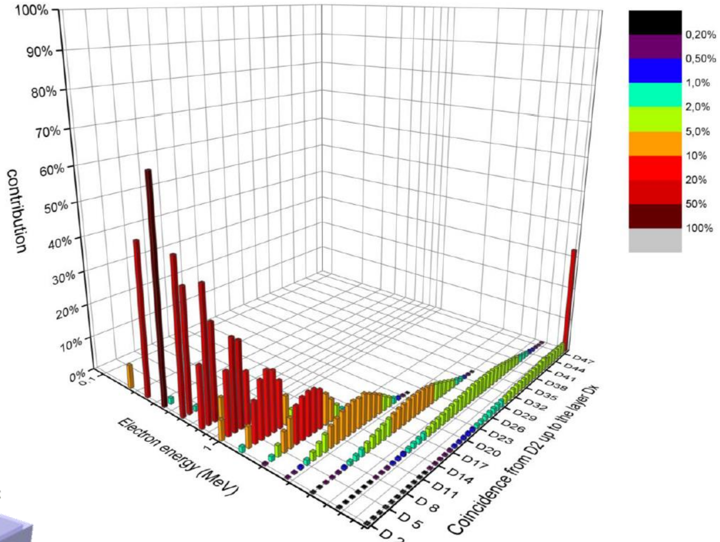
- 1D slab geometry
- Species separation efficiency
- Identification of important layers

⇒

- Real design
- Absorber materials
- Channels definition







D2-Dx coincidence histogram for electrons

Credit: A.Hirn and B.Zabori (MTA EK)

esa

Overview on ESA R&D activities and studies which involve the ESA G4 tools

RECENT R&D ACTIVITIES

G4G – Geant4 Greece

Geant4-based Particle Simulation Facility in Greece for Future Science Mission Support

- IASA - Institute of Accelerating Systems & Applications
- National Centre of Scientific Research “Demokritos”
- National Technical University Of Athens
- University of Ioannina

The objective is to establish a **strategic, complementary, long-term** capability as a key resource for space science-related simulation of particle “radiation” interactions with the payloads and systems, both for future missions and to aid data analysis from past and operating missions.

Main tasks:

REVIEW of existing Geant4 ESA developments

- Analysis and Improvement of Particle Transport and Effects Models for Electromagnetic Interactions
- Review of Particle Transport and Effects of Models for Hadronic Interactions

- ESA Geant4 tools general improvements and new implementation (GRAS Multi-Threading, etc.)
- Improvements and extension for Planetocosmics-J
- Reverse Monte-Carlo improvements and validation for simulation speed-up
- ATHENA, JUICE and LISA related radiation analyses and tools development
- New Geant4 applications for SPENVIS
- New advanced examples for the Geant4

Applications: Shielding materials studies and codes validation

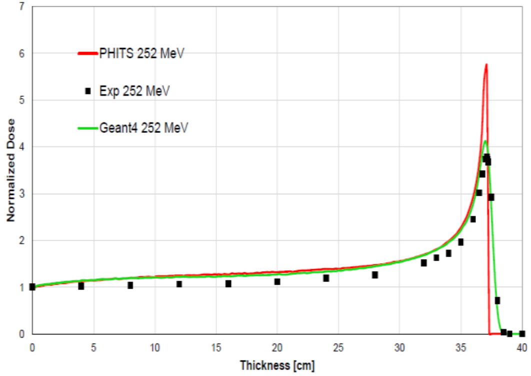
ROSSINI 1-2-3: Radiation Shielding by ISRU and Innovative Materials for EVA, Vehicles and Habitats (2011-2019…)

- ELSHIELD: Energetic Electron Shielding, Charging and Radiation Effects and Margins
- RAPRO: Evaluation of Lighter and More Efficient Radiation Protection for Electronic and Sensitive Parts
- MUSRAS: MUltiScreen RAdiation Shielding
- E^2RAD: Energetic Electrons Radiation Assessment Study
- ESA internal activities and R&D

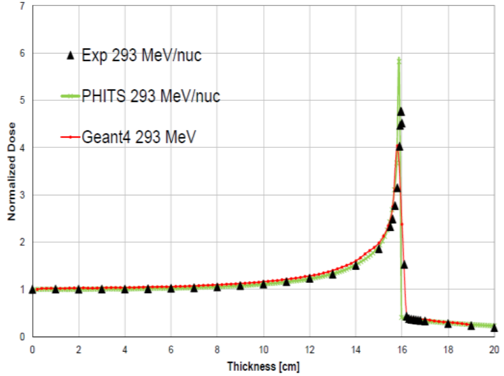
* *in-situ resource utilisation*

ROSSINI 1-2-3

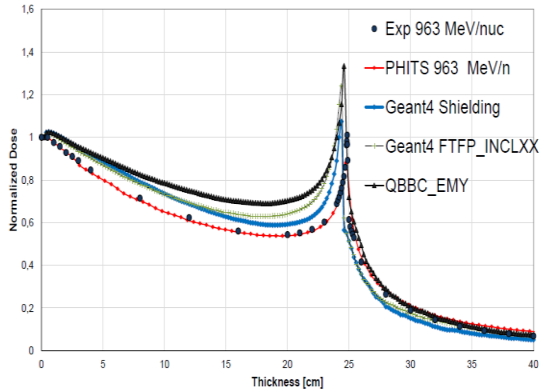
PHITS, Geant4 vs NSRL Experimental Data
H in HDPE



PHITS, Geant4 vs NSRL Experimental Data
^{12}C in HDPE

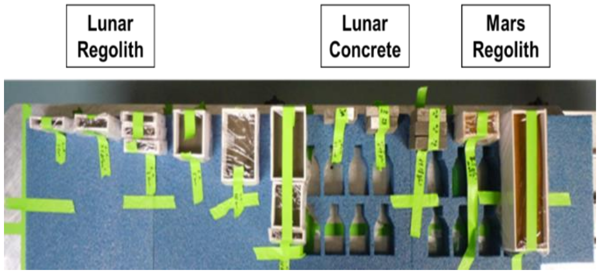


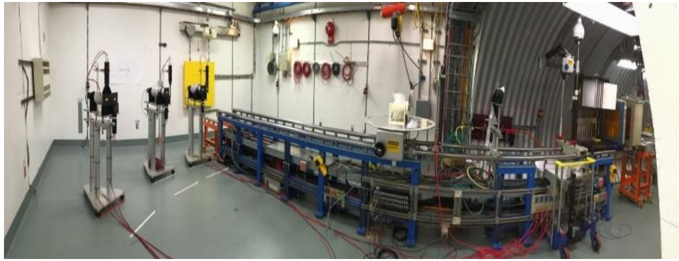
PHITS, Geant4 vs NSRL Experimental Data
^{56}Fe in HDPE



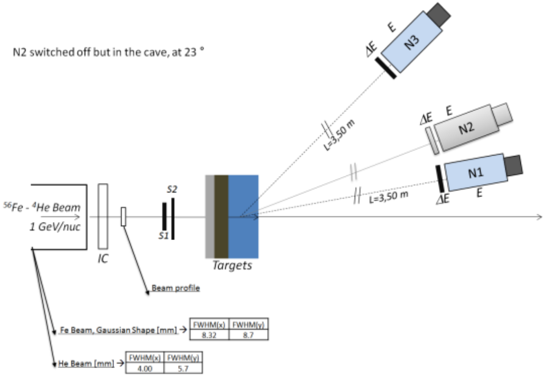
Radiation tests including: dose reduction, beam fragmentation, lateral scattering, microdosimetry

Simulations against experimental data and 3D simulations done with GRAS/Geant4 and PHITS





Fragmentation Set up – June 2016 - NSRL



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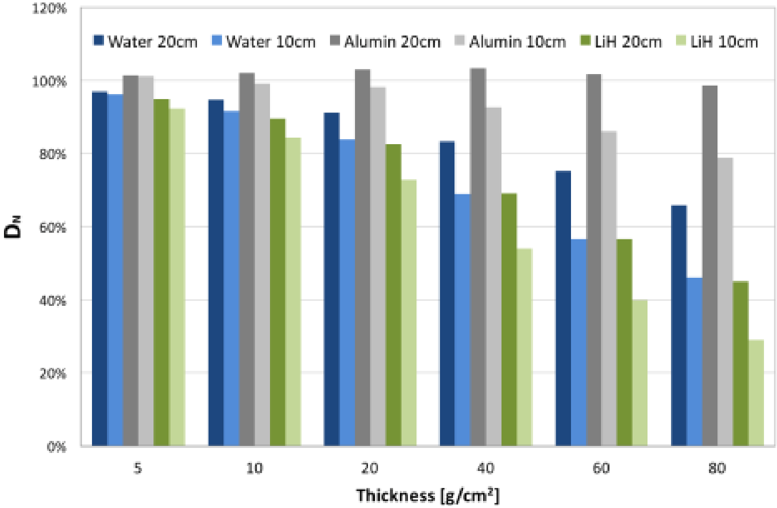
Trade-off 1D space environment simulations

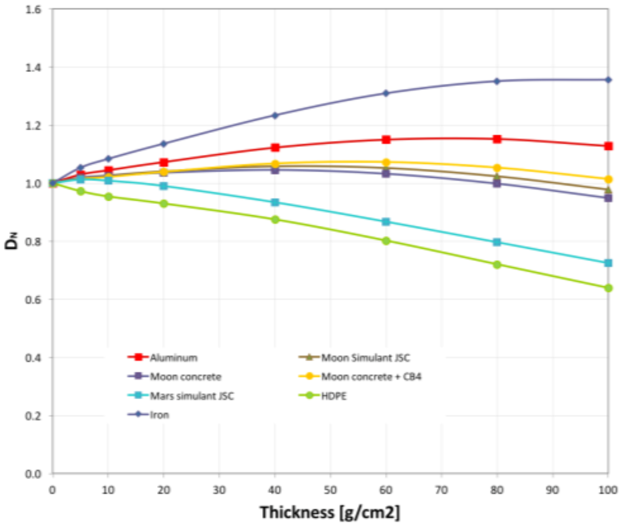
- 1D simulations, beam perpendicular to the target material surface
- Different sources modeled as 1D beam impinging on the target material
- Influence of detector and beam selection studied
- Single and multilayer materials

$$D_N = \frac{D_t}{D_0}$$

D_n varying simulations parameters for different materials

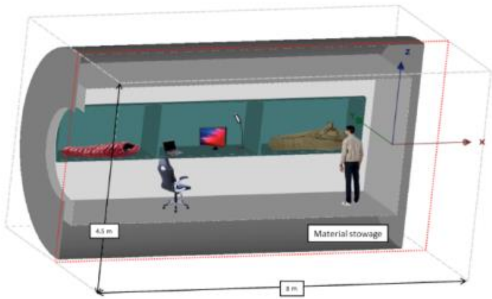


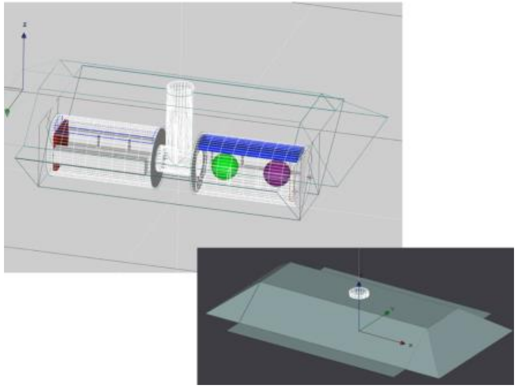
D_n varying thickness for different materials

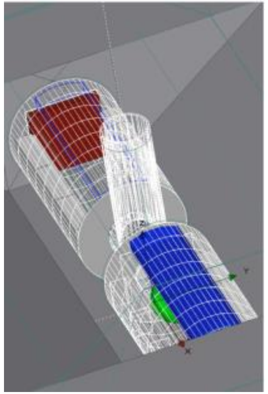


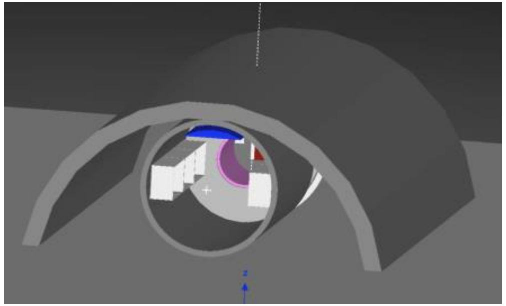
ROSSINI 2: exposure scenarios

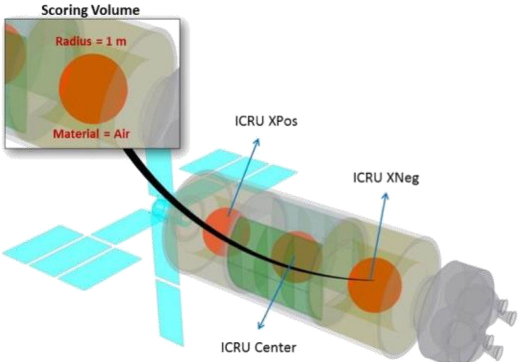
Moon habitats

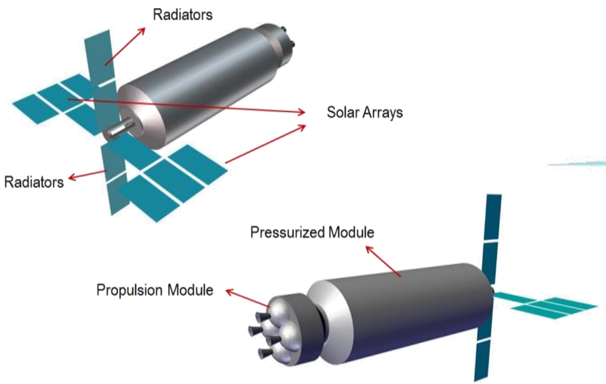


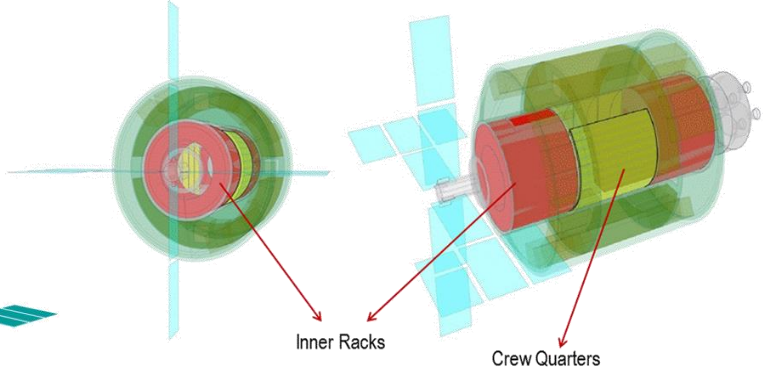












Deep-space habitats

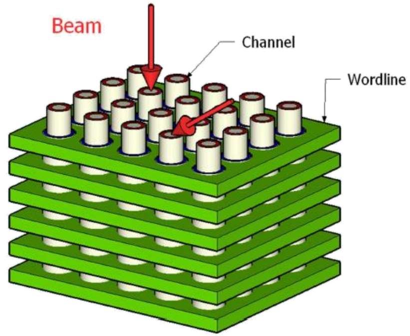
Effects of Heavy-Ion Irradiation on Vertical 3-D NAND Flash Memories

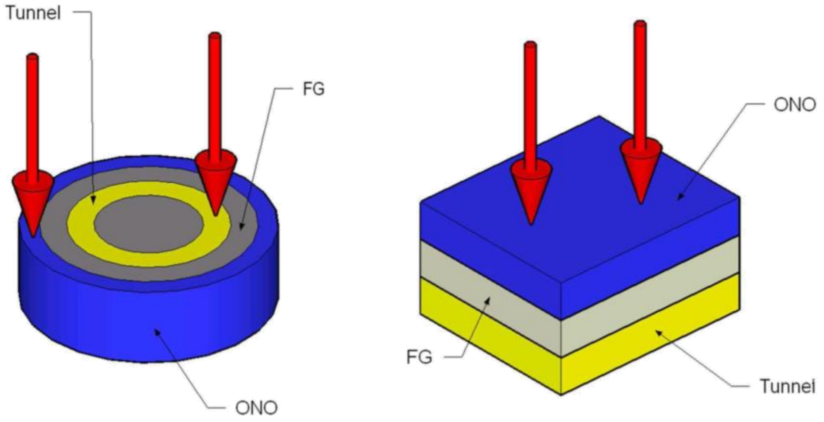
IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 65, NO. 1, JANUARY 2018

M. Bagatin, S. Gerardin, A. Paccagnella, S. Beltrami, E. Camerlenghi, M. Bertuccio, A. Costantino, A. Zadeh, V. Ferlet-Cavrois, G. Santin, and E. Daly

Technology Features:

- 3D NAND Flash have been introduced in the market. Thanks to the vertical structure, the same or better densities can be achieved with larger feature sizes and larger number of electrons per logic state with respect to planar samples.
- NAND flash memories are very appealing for solid-state data recorders, due to their large capacity, low cost per bit, and small power consumption.
- Their non-volatility minimizes data loss in the case of a single-event functional interrupt.
- Several concerns exist about the radiation sensitivity of floating gate (FG) memories in harsh environments.

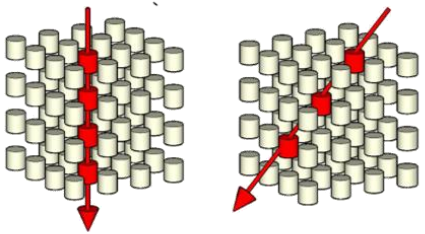


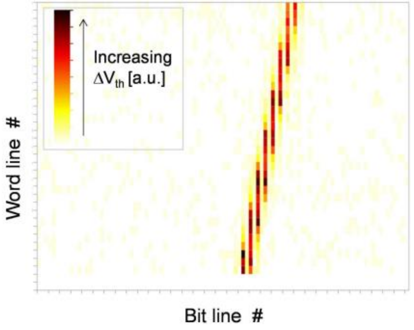


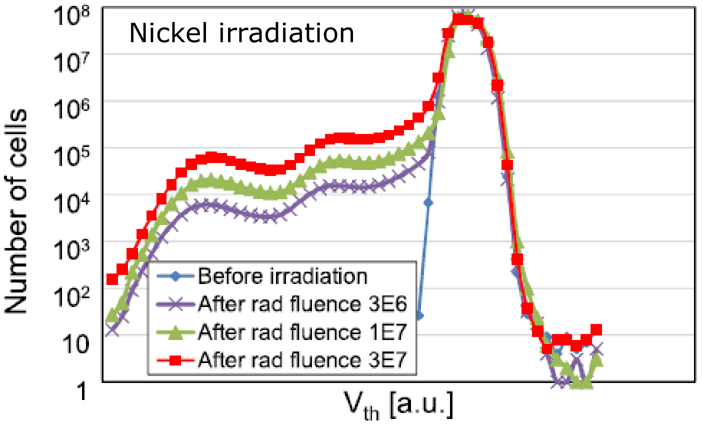
The **FG storage element** has a cylindrical annulus structure, and it is sandwiched between the **tunnel oxide** and the interpoly dielectric (**oxide–nitride–oxide, ONO**)

Effects of Heavy-Ion Irradiation on Vertical 3-D NAND Flash Memories

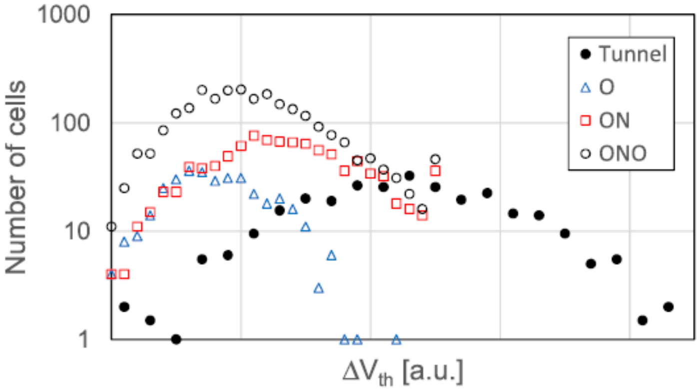
The threshold voltage of hit cells is the primary parameter to study since Vth is used to encode information and shifts are directly related to upsets.







- Two peaks caused by the existence of two sensitive volumes: the tunnel oxide and ONO.
- They can be struck independently, and a normal strike traverses them along the width (height) and not along the thickness.
- The cross-sectional area of the ONO at normal incidence is larger than that of the tunnel oxide.



Vth distributions after Monte Carlo Geant4 simulations with Ni ions, considering different sensitive volumes: tunnel oxide and one or more layers in the ONO blocking oxide.

G4EmLivermorePhysics and G4EmPenelopePhysics (similar results)

CERN-ESA bilateral cooperation framework

A new collaboration agreement between **CERN and ESA**, signed on **11 July**, will address the challenge of operating in harsh radiation environments, found in both particle-physics facilities and outer space.
The agreement concerns radiation environments, technologies and facilities with potential applications in both space systems and particle-physics experiments or accelerators.

The agreement identifies seven specific projects with high priority:

1 - High Energy Electrons Tests

2 - High Penetration Heavy Ions Tests

3 - EEE commercial components and modules (COTS) assessment strategy

4 - In Orbit Technology Demonstration

5 - Rad-Hard and Rad-Tol components and modules

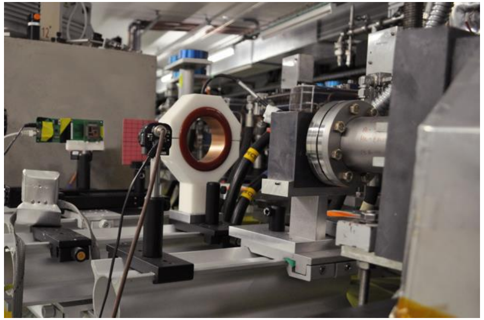
6 - Radiation Detectors, Monitors and Dosimeters

7 - Simulation tools for radiation effects

Achievements

- High-energy electron tests for the JUICE mission were performed in the CLEAR/VESPER facility to simulate the environment of Jupiter.
- Complex components were also tested with xenon and lead ions in the SPS North Area at CERN for an in-depth analysis of galactic cosmic-ray effects.
- These activities will continue and the newly identified ones will be implemented under the coordination of the CERN-ESA Committee on Radiation Issues.

*The results and related studies on irradiation of electronic components in VESPER/CLEAR during the past 3 years are mainly part of **Maris Tali's**(CERN, ESA, University of Jyvaskyla) **PhD thesis***



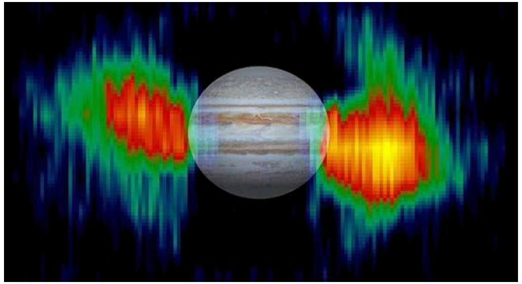
***200 MeV electron beam** for accelerator research; applied to studying possible impact of Jovian trapped electrons on ESA JUICE mission*

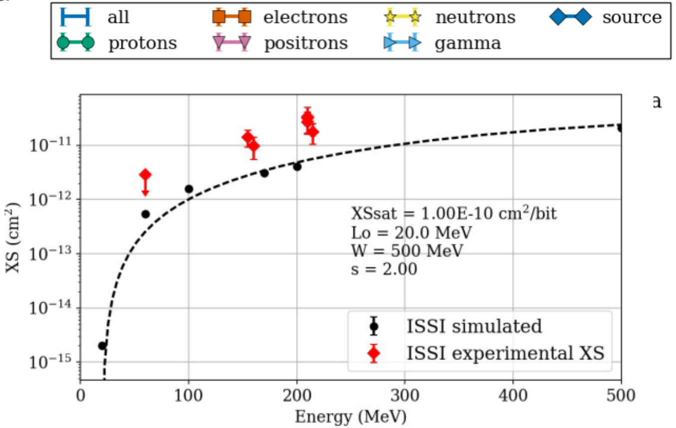
- M. Tali et al., "High-Energy Electron-Induced SEUs and Jovian Environment Impact," in IEEE Transactions on Nuclear Science, vol. 64, no. 8, pp. 2016-2022, Aug. 2017.
- M. Tali et al., "Mechanisms of Electron-Induced Single-Event Upsets in Medical and Experimental LINACs," in IEEE Transactions on Nuclear Science, vol. 65, no. 8, pp. 1715-1723, Aug. 2018.
- M. Tali et al., "Mechanisms of Electron-Induced Single-Event Latchup," in IEEE Transactions on Nuclear Science, vol. 66, no. 1, pp. 437-443, Jan. 2019.

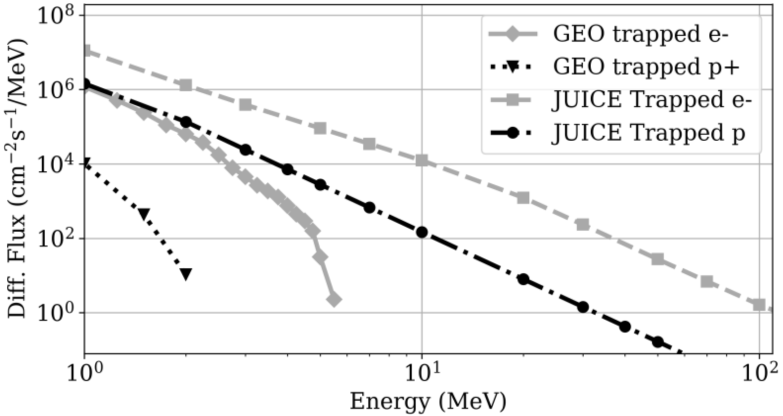
High-Energy Electron-Induced SEEs in the Jovian Environment

Main results from reference SEU Monitor testing:

- Electrons are capable of inducing SEUs in a component with a relatively large critical charge (~10fC) and with a cross section ~4 orders of magnitude lower that that from protons and neutrons
- The related basic mechanisms are electro and photo-nuclear interactions with silicon nuclei in sensitive region
- Main application: Jovian environment, where electron flux is intense and energetic, and large amount of photons are generated in the interaction of trapped electrons with spacecraft shielding







VESPER experiments showed for the first time that **high-energy electrons** are capable of inducing **destructive SEL events**

Topics of interest

- CAD-GDML interfaces (CSG and tessellated solids):
  - FASTRAD: TRAD
  - EDGE: Artenum
  - FreeCAD plugins:
    - **FreeCAD GDML module** - Werner Meyer and Keith Sloan
    - PSI version, also available online: http://polar.psi.ch/cadmc/converter/
  - Salome plugins (old developments)
  - CADMesh and GUIMesh: Python tool to convert STEP geometries into GDML as tessellated solids using FreeCAD libraries
- Biasing options : general example coming?
- Scoring -> 2D and 3D dose/flux maps (PHITS, FLUKA, Etc.)

Summary and outlook

All major ESA science missions continue to be major Geant4 users, through ESA developments or commercial tools. Geant4 is playing an important and strategical role in many ESA activities related to Space Environment and Effects.

Several ongoing or planned Geant4 related activities :

- **Support to scientific missions**
- **Radiation monitor developments**
- **Shielding materials**
- **Geant4 based tools review and improvement**
- **Geant4 physics models review development**
- **Future activity on RMC and geometry editors are foreseen**

ESA related activities to G4SUW 2019

- Persistency of Geant4 Phase-Space Information for Radiation Effects and Instrument Background Analysis
  - Pete Truscott (Kallisto Consultancy Ltd)
- AREMBES: Geant4 validation for X-ray space missions and G4 simulator development
  - Simone Lotti (INAF)
- Measurements and Geant4 simulations of the back-scattered electrons off ATHENA X-ray mirrors
  - Fan Lei (RadMod Research)
- Latest Updates of Grazing Angle Soft Proton Scattering on X-ray Optics
  - Sebastian Diebold (IAAT University of Tübingen)
- GEANT4 simulation Study of the MIDAS dosimeter/radiation monitor
  - Dr Christos Papadimitropoulos (Greek Atomic Energy Commission)
- The EXACRAD Project
  - Dr Silvano Molendi (INAF)
- Geant4 tools in SPENVIS: A user perspective
  - Neophytos Messios (BIRA-IASB)
- A comparative study of multiple scattering calculations implemented in general-purpose Monte Carlo codes
  - Prof. Michael Kokkoris (National Technical University of Athens), Dr Eleni Vagena (University of Ioannina), Dr Effrosyni Androulakaki (National Technical University of Athens), Prof. Nikolaos Patronis (University of Ioannina)
- Microdosimetry with Geant4 for Quality Factor estimates
  - Dr Ioanna Kyriakou (Medical Physics Lab, University of Ioannina Medical School, Greece)

Thank you!

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

Thanks for your attention!