Geant4 simulations for the design, verification and calibration of ground experiments and space missions

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CSN5 Forum della Ricerca Sperimentale e Tecnologica in INAF – 23 Giugno 2022 Bologna
Lighting talks

Geant4 in INAF

- Geant4 [1] is an open-source toolkit library for Monte Carlo particle transport simulations at high energies (from few eV), developed by CERN and maintained by a large, international collaboration. A widely used simulation software for designing, verifying and calibrating high-energy space-borne instrumentation and on-ground experiments.

- INAF has become a leading institute for developing Geant4 applications for the X-ray and Gamma-ray background simulation, instrument response definition, shielding optimisation and performance characterisation of high energy missions and instruments.

- INAF coordinates the background simulation activities for both the Athena instrument international consortia, the Athena magnetic diverter simulation group, the THESEUS XGIS and HERMES instrument background, response matrix and sensitivity simulation and the simulation of the IXPE and eXTP background. INAF has also led the ESA funded CTP projects AREMBES and EXACRAD for the X-ray radiation effect analysis and minimisation of the Athena mission, and INAF researchers are coordinating Geant4 simulations activities within the European HORIZON2020 AHEAD2020 project and contributing to the simulations of either accepted or under proposal COSI, XRISM and ASTROGAM projects.

- **We present here some examples of the INAF's central role in the development of Geant4 applications, also to highlight the coordination among the several contributing institutes (OAS, IAPS, IASF-Mi, IASF-Pa) as the critical factor in helping share internal knowledge and boost the scientific results.**

- Scheda INAF: Geant4 simulations of high energy missions and experiments (GEANT4-SIM)

https://schede.inaf.it/consulta/mostra?selezione=60897ddba8c56d19096844c9

Geant4 simulation frameworks and physics validation

- **BoGEMMS** (Bologna Geant4 Multi-Mission Simulator) [2]
  - developed at OAS
  - Geant4-based framework for the development of configurable and astronomy-oriented simulations for the scientific performance of X-ray and Gamma-ray missions and experiments
  - used for the simulation of Simbol-X, NHXM, XMM-Newton, ATHENA, ASTROGAM, COSI, AGILE, HITOMI

- **AREMBES** (ATHENA Radiation Environment Models And X-Ray Background Effects Simulators) [3]
  - ESA funded ITT with **IAPS Piship, coordinators and members from IAPS, IASF-Mi, OAS, IASF-Pa**
  - L1 and L2 space radiation environment models
  - validation and upgrade of the Geant4 physics library for space applications (SPL) and implementation of new Geant4 physics models
  - Development of a multi-purpose framework for radiation effect simulations

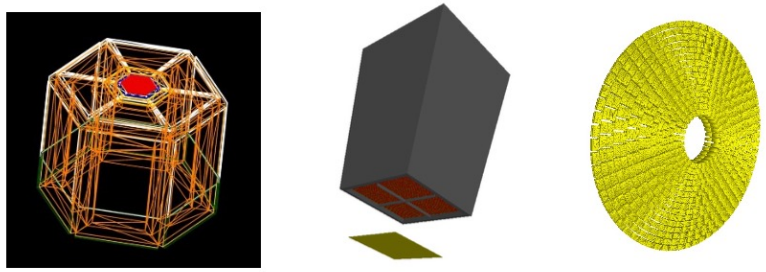
- **EXACRAD** (Experimental Evaluation of ATHENA Charged Particle Background from Secondary Radiation and Scattering in Optics) [4]
  - ESA funded ITT with **IASF-Milano Piship, coordinators and members from IAPS, IASF-Mi, OAS**
  - Geant4 physics library validation of ATHENA background inducing processes:
  - Low energy (< 300 keV) proton scattering at grazing angles
  - Production of low-energy (<100 keV) secondary electrons from hadronic processes
  - Electron backscattering (< 1 MeV)

- **AHEAD2020** EU contracts:
  - **Coordinators and members from IAPS, IASF-Mi, OAS, IASF-Pa**
  - Low energy proton scattering Geant4 simulation
  - XMM-Newton and ATHENA proton response matrix simulation

Geant4 applications

ATHENA

- X-IFU GCR background estimation and analysis, detector calibration, design analysis and improvement (IAPS responsibility) [5]
- X-IFU and WFI soft proton impact analysis and response matrix generation (OAS and IAPS responsibility) [6]
- Charged particle diverter scientific assessment (OAS responsibility)



ATHENA X-IFU (left), WFI (center), SPO (right)
X-ray microcalorimeter, Wide field X-ray imager and spectrometer and X-ray mirror
ESA X-ray large mission
Launch 2030s

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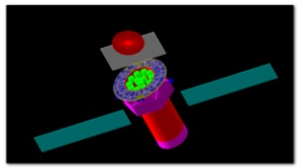
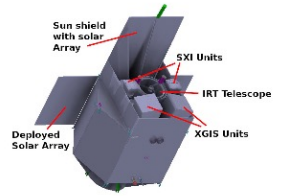
HERMES, eXTP, THESEUS (OAS responsibility)

HERMES
Constellation of 7+1 CubeSats
with high energy detectors
Launch ~2023

- Monte Carlo simulation of background sources [7]
- Response matrix determination
- Design optimisation



eXTP
Chinese-European mission
LAD/WFM instruments
Currently in phase B



THESEUS
XGIS instrument
ESA-M5 candidate mission

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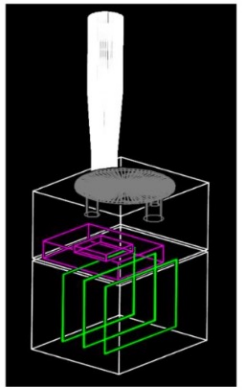
IXPE (IAPS responsibility)

- Study of the IXPE background and improvement of the polarimetric performances [8, 9]
- Machine learning software to reconstruct photoelectron tracks in IXPE's GPD

- GEANT4 activity within HypeX PRIN:
  - Performances and gas mixture optimization for future photoelectron polarimeters with a 3D track reconstruction
  - Optimization of a 3D track reconstruction algorithm



IXPE
NASA imaging X-ray polarimeter
Launched on Dec. 2021

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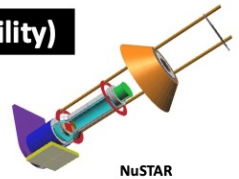
NuSTAR (IAPS responsibility)

- Polarization detection capabilities



NuSTAR
NASA X-ray focusing telescope
Launched on Jun. 2012

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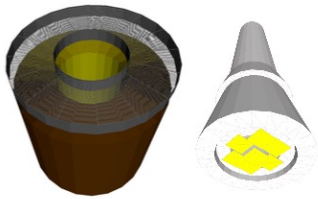
XMM-Newton

- Soft proton induced background and proton response matrix (OAS responsibility) [10]



XMM-Newton X-ray mirror (left) and EPIC/MOS (right)
ESA X-ray focusing telescope
Launched on Dec. 1999

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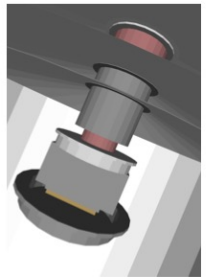
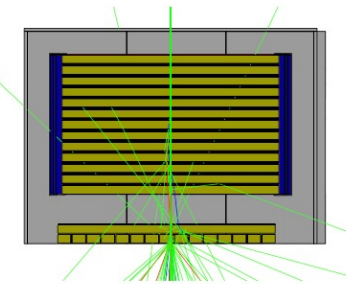
HITOMI, AGILE, ASTROGAM, COSI (OAS responsibility)

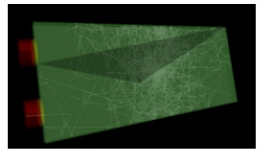
- HITOMI/SXS background simulation and validation
- AGILE PSF simulation and validation with in-flight observations [11]
- ASTROGAM performance simulation in the pair regime
- Design and simulation of the COSI anticoincidence system



HITOMI/SXS
JAXA LE and HE mission
Launched on 2016, 1 month operation



AGILE/GRID
ASI gamma-ray mission
Launched on Apr. 2007



COSI/ACS prototype
NASA Compton Spectrometer and Imager
Launch 2026

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