Bologna, 22-24/06/2022 – Forum della Ricerca Sperimentale e Tecnologica in INAF

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DI ASTROFISICA

IAPS ISTITUTO DI ASTROFISICA
E PLANETOLOGIA SPAZIALI

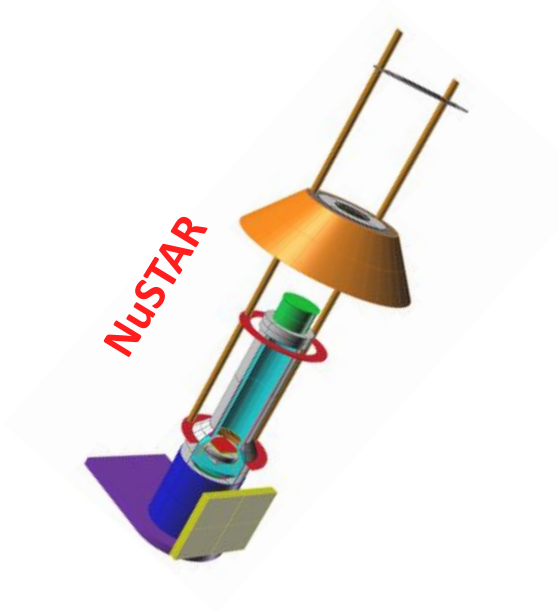
Tecnologie informatiche allo IAPS

Simone Lotti e Romolo Politi

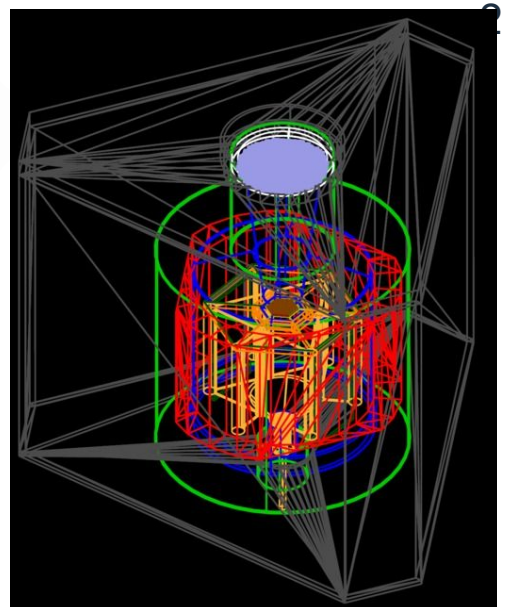
in rappresentanza di tutto il personale coinvolto nelle attività

Geant4 activities at IAPS

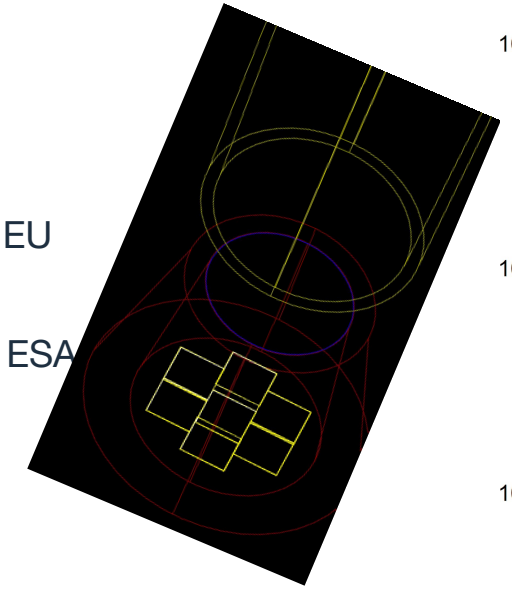
- Several X-ray missions reproduced
- Years long collaboration with Geant4 developers
- Mass models used for several purposes:
  - GCR background estimation and analysis (Athena – **IAPS responsibility**)
  - Detector calibration, design analysis and improvement (Athena – **IAPS responsibility**)
  - Response matrices generation (Athena, XMM-Newton - AHEAD2020 EU contract)
  - Soft protons impact analysis (Athena, XMM-Newton - AREMBES ESA CTP contract, AHEAD2020 EU contract)
  - Polarization detection capabilities (NuSTAR)
- Creation, experimental validation, and upgrade of the Space Physics List to be included in the next Geant4 version (AREMBES and EXACRAD, ESA CTP contracts, AHEAD2020 EU contract)
- Experimental validation of physical processes (EXACRAD, ESA CTP contract)
- Development of an advanced example for the Geant4 collaboration (AREMBES CCN2)



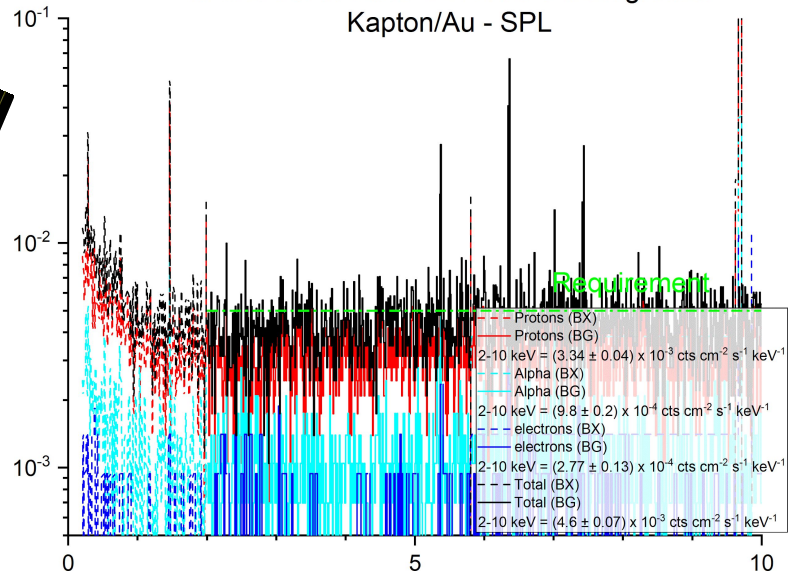
Athena X-IFU



XMM-Newton



In and out of band GCR X-IFU background
Kapton/Au - SPL



Geant4 activities at IAPS

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Geant4 simulations at IAPS (IXPE)

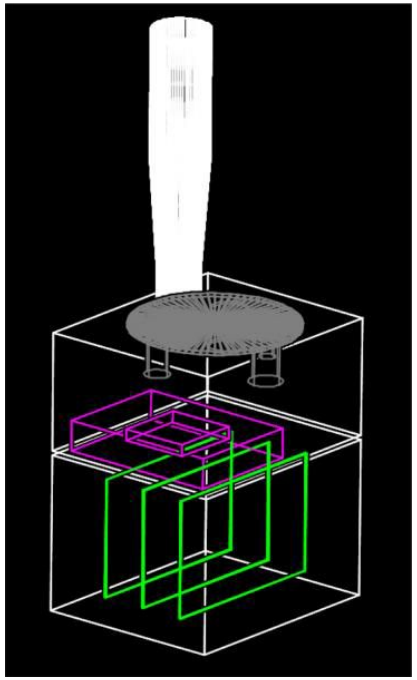
GEANT4 simulations performed within IXPE:

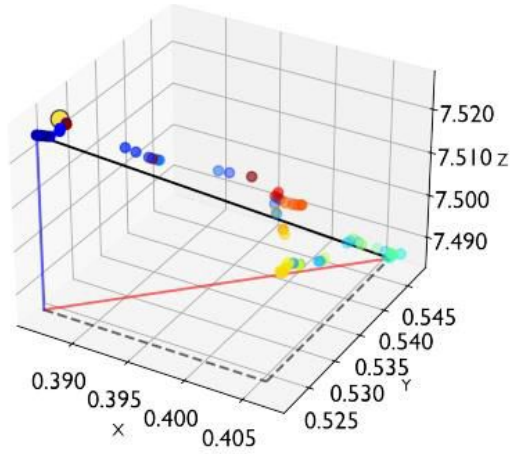
- Study IXPE background [F. Xie et al., Astroparticle Physics 128 (2021) 102566]
- Optimize a weighted schema to improve IXPE polarimetric performances [A. Di Marco et al., The Astronomical Journal, 163:170 (9pp), 2022]
- Study for Machine learning software to reconstruct photoelectron tracks in IXPE's GPD

GEANT4 laboratory's activity performed in 2021 for students of University of Rome "La Sapienza" on the optimization and study of gas mixtures for photoelectron polarimeters

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





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Geant4 simulations for polarimetry at IAPS

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IXPE launch, APOD 2021-12-22

The SPENVIS platform

The Space ENVironment Information System (SPENVIS) is an ongoing ESA online platform (https://www.spenvis.oma.be/) compiling a large suite of models/tools to describe the space environment and its effects upon materials. Several Geant4 and Geant4-based tools have been fully incorporated, especially to the aim of dosimetric studies. The SPENVIS orbit generator has recently been extended to planets other than the Earth.

IRENE model testing

Though currently provided for evaluation purposes only, data-driven IRENE AE9/AP9 models for particles stably trapped in the Earth's radiation belts (RBs) have been integrated into SPENVIS. Long-term proton flux spectra from the HEPD particle detector (CSES/Limadou mission) in the South Atlantic Anomaly (SAA) have been successfully compared with (IGRF-supported) AP9 counterpart from SPENVIS, revealing HEPD as as a reliable in-flight instrument to improve most recent RB model accuracy.

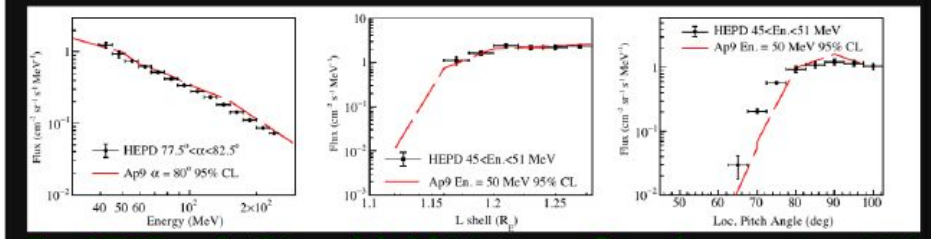
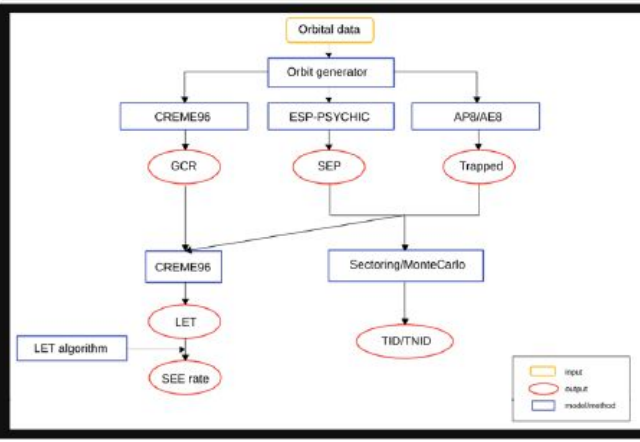


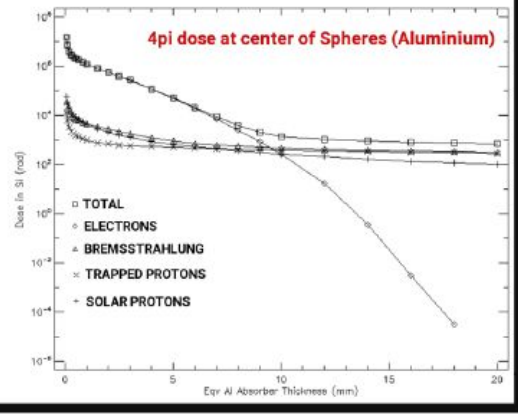
Fig: HEPD and AP9-modeled SAA proton fluxes between Aug 2018 and Dec 2020 [Martucci et al. (2022), Phys. Rev. D **105**, 062001].

Radiation modeling for Commercial Off-The-Shelf (COTS) parts

Within collaborations with ASI/INFN/SMEs, SPENVIS has been undergoing extended use to produce a redundant 1oo2-architecture electronic mainboard based on System-On-Chip COTS devices, so as to obtain a TRL5 system for safety-critical applications at Low Earth Orbit (LEO). ECSS-tailored environmental requirements have included definition of primary radiation components at LEO, counting worst-case effects from solar modulation in. Long-term dosimetry (SHIELDOSE-2Q modeled TID; no NIEL since mostly relevant for optoelectronic devices) has been modeled for radiation-ageing purposes. Proton-induced single-event effects are currently under evaluation.

	Earth's RBs	SEP events	GCRs
Prymary composition	Electrons (< 10 MeV) dominating in the outer belt. Protons (< 400 MeV) dominating in the inner belt.	Mostly low-E electrons & protons. Rare higher-E protons & heavy ions.	98% hadrons: 87% protons, 12% α, 1% heavy ions. 2% leptons (e^-/e^+).
Effect of solar modulation	Change in atmospheric scale height & EW proton anisotropy. Creation of temporary belts at SOL MAX.	Probability of SEP frequency and magnitude: high at SOL MAX, low at SOL MIN.	$\leq 1 \frac{Gev}{n}$ component of flux anticorrelated to solar activity.
Effect of geomagnetic field	Inner edge of IRB encountered in SAA.	Cutoff rigidity function of GMLat.	Cutoff rigidity function of GMLat.
Modeling	Electrons: AE8 (empirical; ECSS standard), with AE9 refinement. Protons: AP8 (empirical; ECSS standard), with AP9 refinement.	Cumulated (7yr+) solar proton fluence: ESP (ECSS standard). Solar proton worst-case peak fluxes: CREME96 (ECSS standard).	ISO15390 (ECSS standard), CREME96.
Damage on electronics	TID, SEEs and TNID from protons basically in SAA. TID from electrons at high LATs.	TID and TNID (protons and electrons). SEEs (protons and low-E heavy ions).	Mostly SEEs at high LATs.





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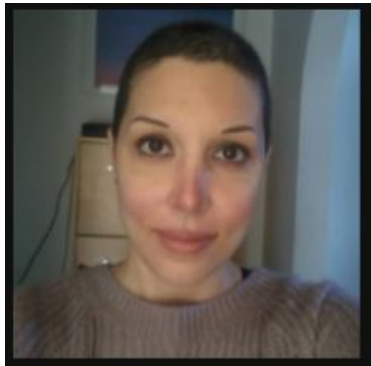

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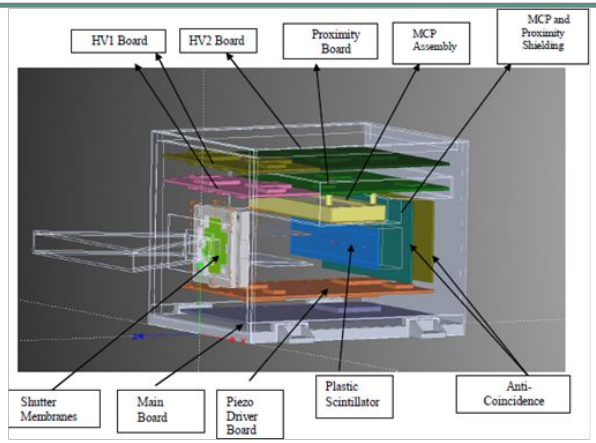
Geant4 activities for study of ENA sensors

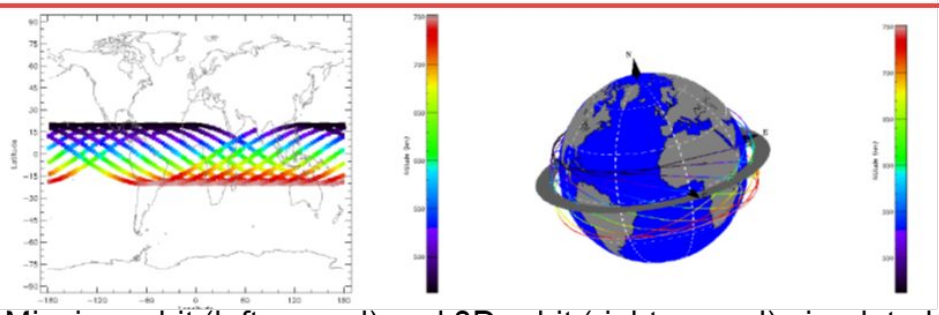
Geant4 and some tools based on Geant 4, like Spenvis (ESA's SPace ENVironment Information System) platform and the FASTRAD tool (a 3D CAD Tool For Radiation Shielding Analysis) has been used at IAPS in last decade for study of background signal and shielding strategy of different ENA (Energetic Neutral Atoms) detectors.

In particular studies have been performed for SERENA/ELENA instrument on board of BepiColombo mission and for other ENA proposed instruments like ENAMISS (Energetic Neutral Atoms Monitor on the International Space Station) and GENIE (Ganymede's and Europa's Neutral Imaging Experiment).



GENIE geometry for shielding strategy studies with FASTRAD tool

At the moment we are working on phase A of SWEATERS (Space WEAther Ena Radiation Sensor) instrument concept and preliminary studies of a possible space orbit and the analysis of radiation environment (i.e Galacic Cosmic rays and Solar Particles at different altitudes) around the spacecraft are done by SPENVIS platform.



Mission orbit (left pannel) and 3D orbit (right pannel) simulated by Orbit Generator tool in Spenvis.

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Machine Learning/Deep Learning

Laboratory ⟷ Space Mission

Machine Learning techniques are applied to mineral identification via reflectance spectra using some laboratory dataset between mineral end-members and their mixtures, having as a variable the grain (or particle) size. An Intelligent Agent is programmed to recognize specific spectral properties and their variability taking into account the limits of retrieving this information.

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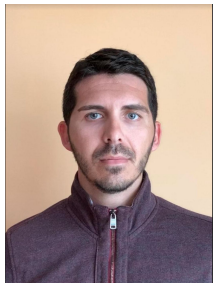
Deep Neural Networks for Surface Composition Reconstruction



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We examine a tentative proxy method to derive the elemental and mineralogical composition of the regolith of Mercury from in situ measurements of its neutral exosphere through the use of deep neural networks (DNNs). For this we developed a multivariate regression (MVR) supervised feed-forward DNN architecture whose inputs are the exospheric densities and proton precipitation fluxes measured in mock-up orbital runs through simulated Hermean exospheres in view of the analysis of data from the SERENA.

Machine Learning Applications in Space Plasmas

At IAPS Machine Learning approaches are applied in the field of Space Plasmas and Space Weather forecast.
The IAPS-Group activities in this field can be so summarized:

- Artificial Neural Networks (ANNs) for geomagnetic indices' forecast with application to Space Weather;
- Statistical Models and Machine Learning methods devoted to the forecasting of Solar Energetic Proton events;
- Machine Learning methods (clustering tools) to disentangle different plasma species in measurements of ion spectrometers.

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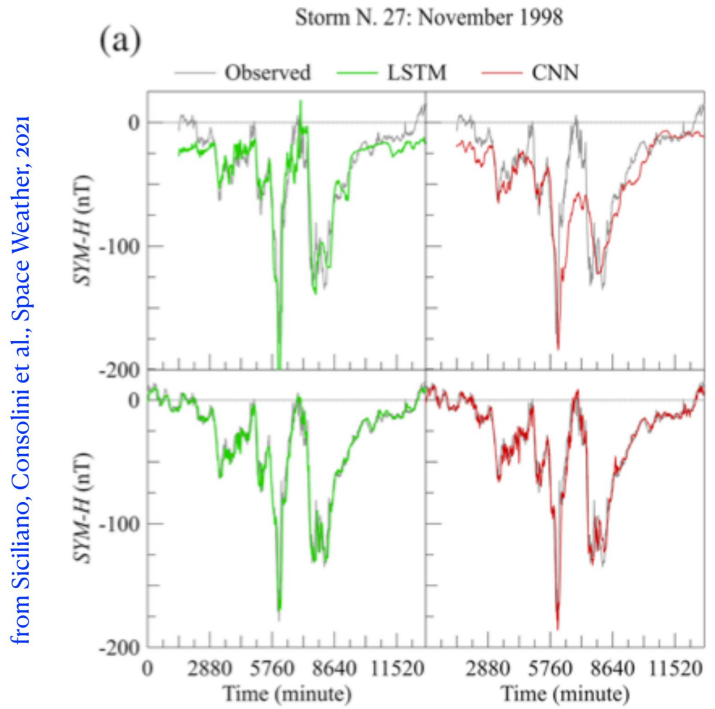
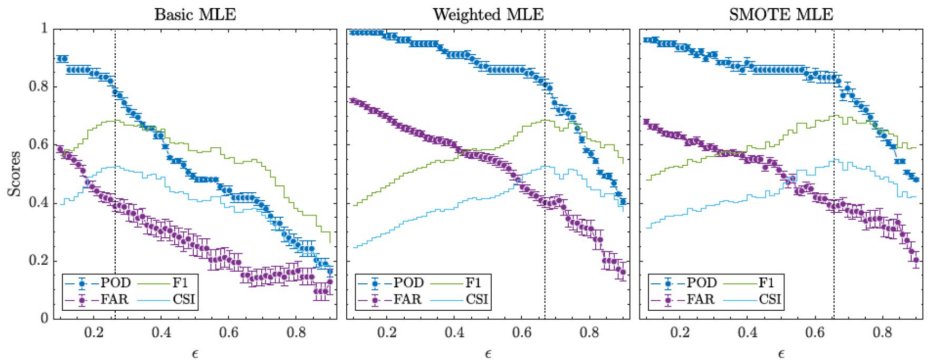


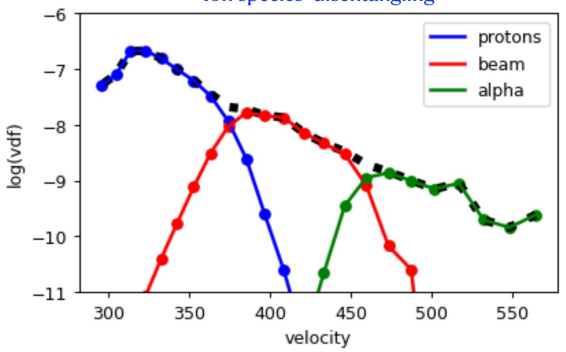
from Siciliano, Consolini et al., Space Weather, 2021

Solar Energetic Particles' forecast



from Stumpo, Laurenza et al., Space Weather, 2021

Ion species' disentangling



from De Marco et al., submitted, 2022

Sviluppo di metodologie ed expertise per pipeline di elaborazione dati

L'attività proposta si propone l'obiettivo di sviluppare metodologie ed expertise per la gestione di pipeline complesse di elaborazione dati, con particolare riferimento (ma non esclusivamente) a procedure dedicate rispettivamente alla determinazione orbitale di precisione e alla riduzione dati di strumentazione accelerometrica. Tali metodologie dovrebbero coprire l'intero ciclo di vita delle pipeline (progettazione, sviluppo, testing, debugging, deployment, ...), con l'obiettivo precipuo di permettere una efficace integrazione in esse di codice già sviluppato e disponibile.

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Arxes: new HPC tools for multi-physics studies of planet formation

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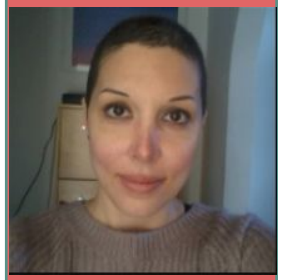
The Arxes planet formation team at INAF is involved into multiple space missions (NASA mission *Juno*, ESA missions *Ariel*, *Juice*, *Bepicolombo*) as well as national and international projects spanning the study of the Solar System, circumstellar discs and exoplanets. To support these activities, the Arxes and LAPD teams jointly developed and are continuosly enhancing *Mercury-Arxes* and *Debris,* HPC codes parallelized and vectorized with OpenMP to fully take advantage of modern cpu architectures. Mercury-Arxes is an n-body code incorporating multi-physics libraries that implement planet migration, the effects of aerodynamic drag and disk self-gravity on planetary bodies embedded in circumstellar disks, and the mass and radius evolution of forming planets (Turrini+2019; Turrini+2021). Debris is a statistical collisional code that allows for simulating the collisional cascade in planetesimal disks and estimating the production of dust in debris disks and circumstellar disks (Turrini+2019; Bernabò+2022). Both codes are currently undergoing porting from OpenMP to OpenACC and the first release of Mercury-Arxes adapted to GPU computing is already being used for scientific investigations.


Simone Lotti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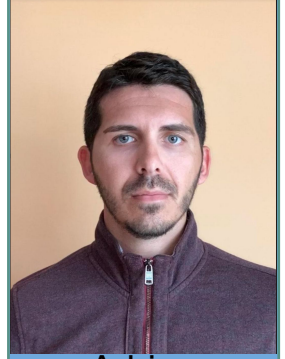
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Sergio Fonte


Claudio Macculi

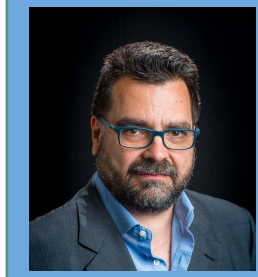

Rosanna Rispoli

GEANT4

ML/DL

HPC/HTC


Giuseppe Consolini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Alessandro Di Marco


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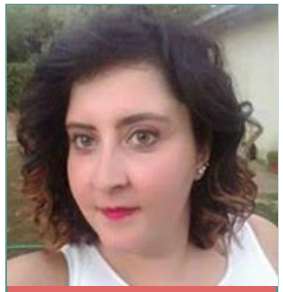
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