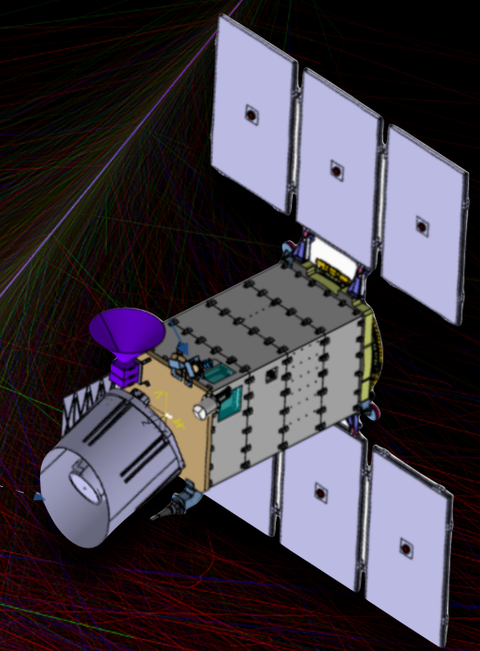
JOINT ANNUAL MEETING OF THE SWISS PHYSICAL SOCIETY AUSTRIAN PHYSICAL SOCIETY

Friday 8 September 2023



The NUSES space mission

C. Trimarelli, L. Burmistrov, M. Heller, T. Montaruli

On behalf of the NUSES Collaboration

1. Université de Genève

UNIVERSITÉ DE GENÈVE

The NUSES Collaboration

NeUtrino and Seismic Electromagnetic Signals

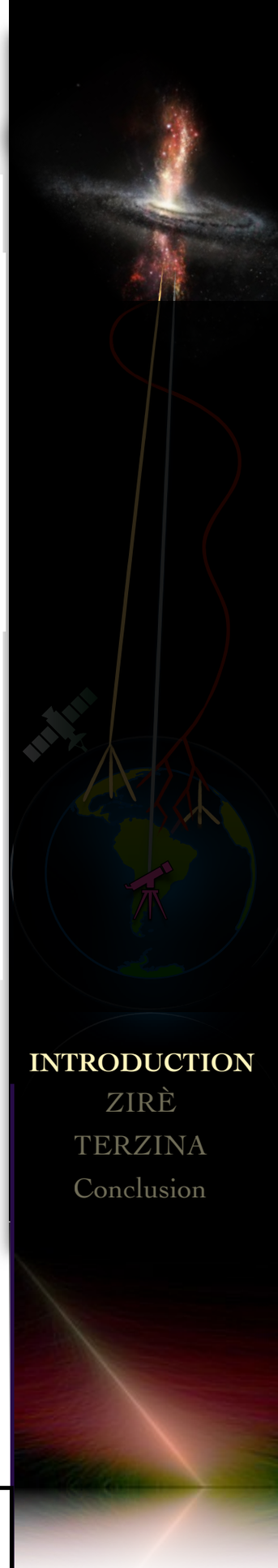
- Gran Sasso Science Institute (GSSI)
- INFN – Laboratori Nazionali del Gran Sasso
- Università dell'Aquila (UnivAQ)
- Università di Roma "Tor Vergata" & INFN-Roma2
- Università di Torino & INFN Torino
- Università di Trento & INFN-TIFPA
- Università di Bari & INFN Bari
- Università di Padova & INFN Padova
- Università di Napoli & INFN Napoli
- Università del Salento & INFN Lecce
- University of Geneva
- University of Chicago
- Pennsylvania State University
- CRESST/NASA Goddard Space Flight Center
- University of Maryland

G S S I

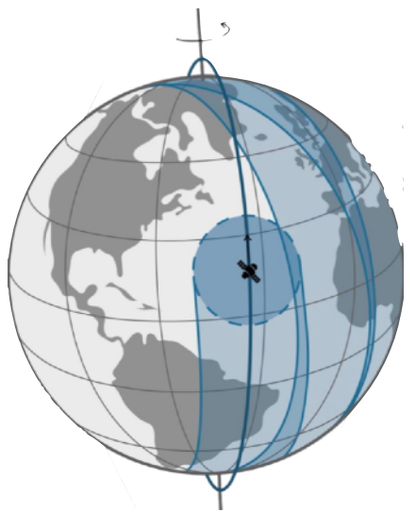
INFN

ThalesAlenia Space — a Thales / Leonardo company

Agenzia Spaziale Italiana

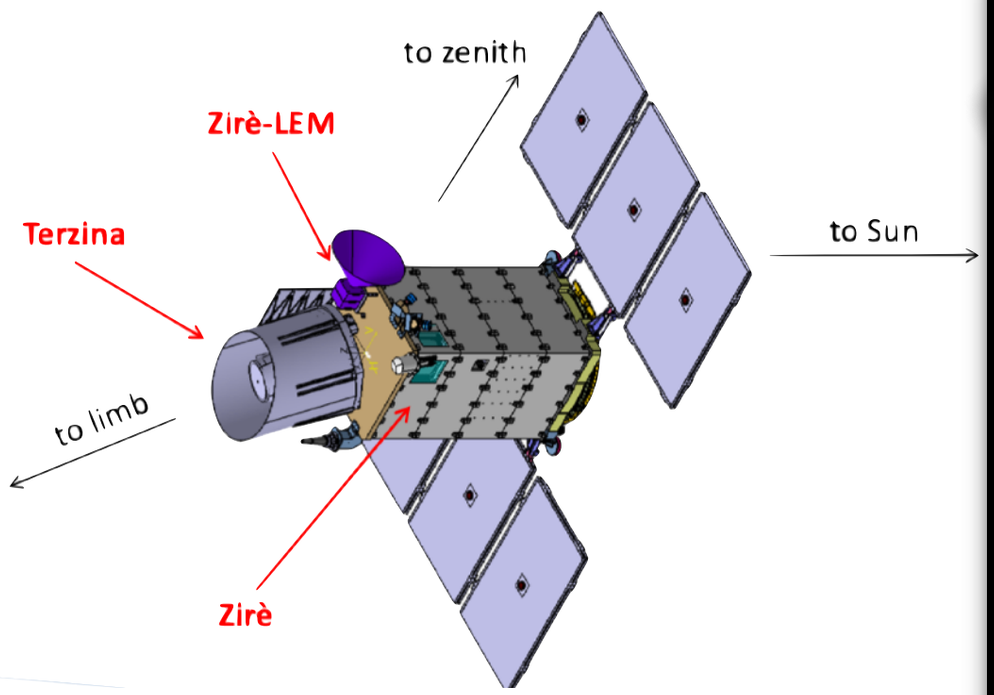


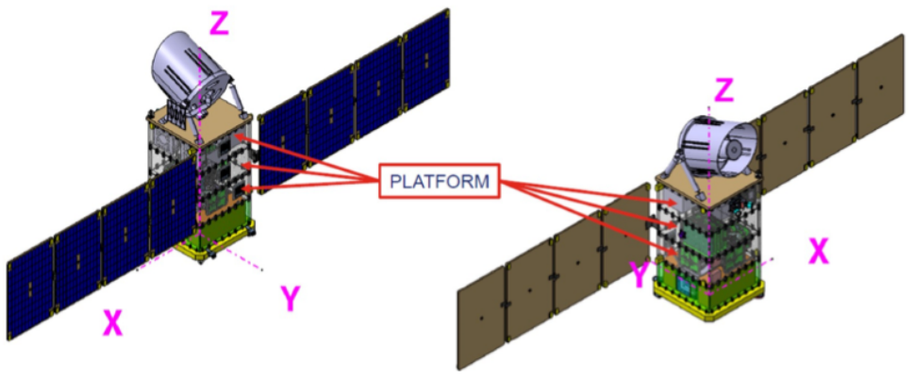
The Spacecraft



NIMBUS (New Italian Micro BUS) new Platform concept for low orbit microsatellites (LEO) which foresees a modular approach relying on standard trays.

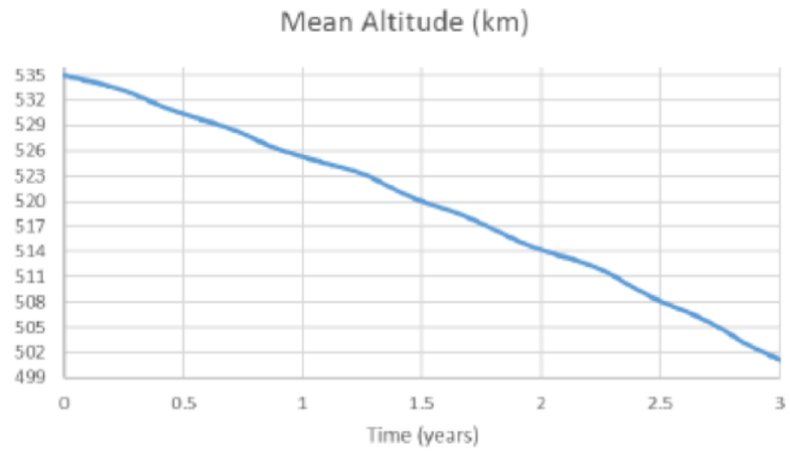
- Ballistic mission (no propulsion for orbital control)
- Weight: <150 kg

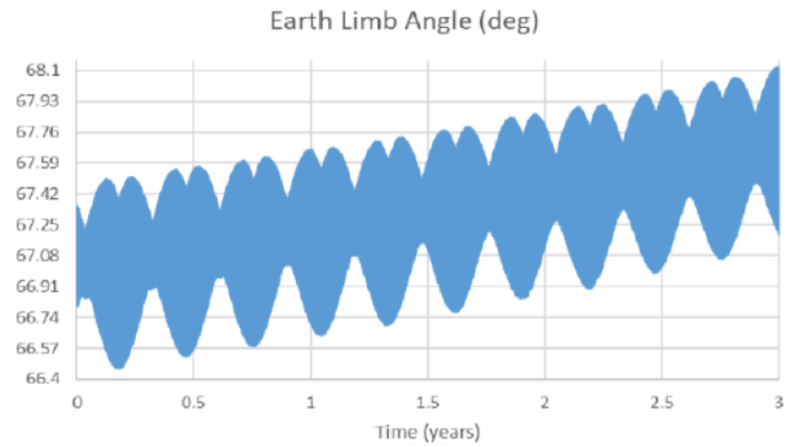




Low Earth Orbit (LEO) with high inclination, sun-synchronous orbit on the day-night border (BoL altitude 535 Km, inclination = 97.8°, LTAN = 18:00);

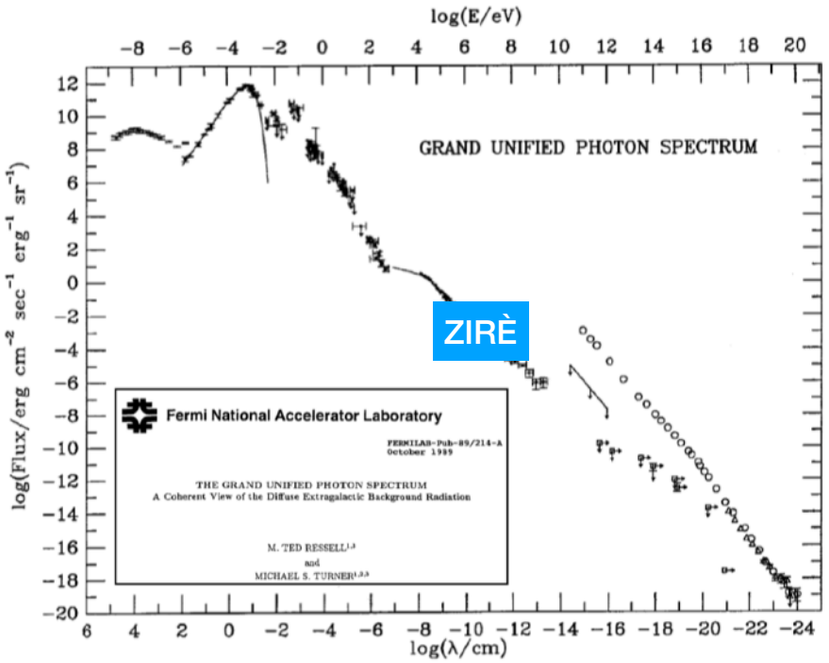
Lifetime	3y
Orbit	Low Earth Orbit (LEO), sunsynchronous orbit on the day-night border
Mean Altitude	550 km
Inclination	97.6 deg
LTAN	18:00:00

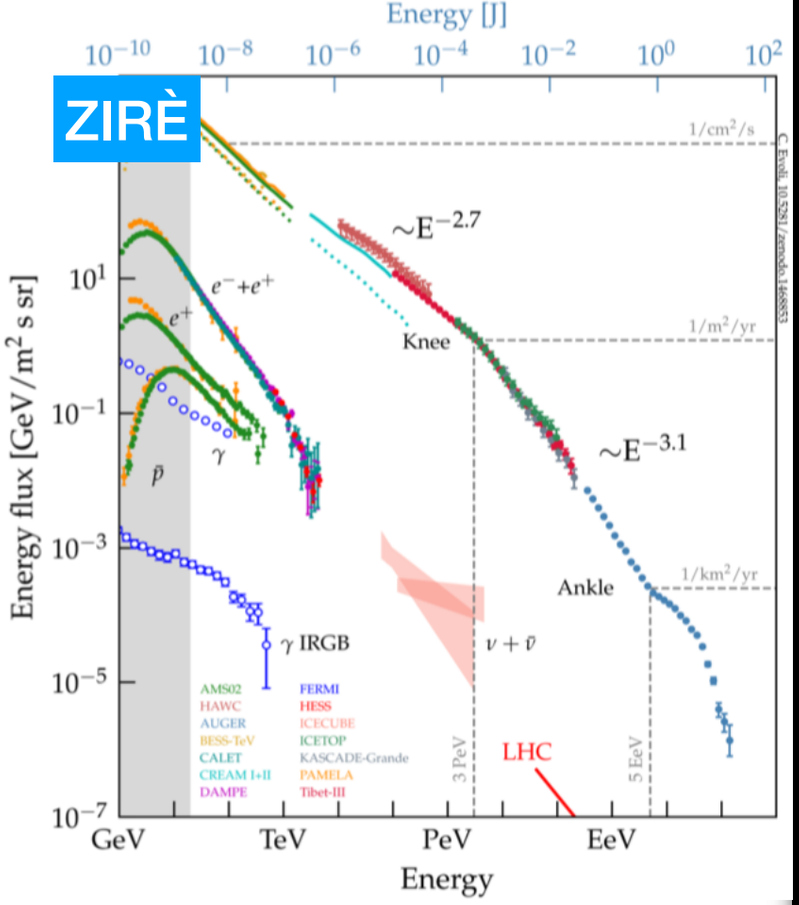




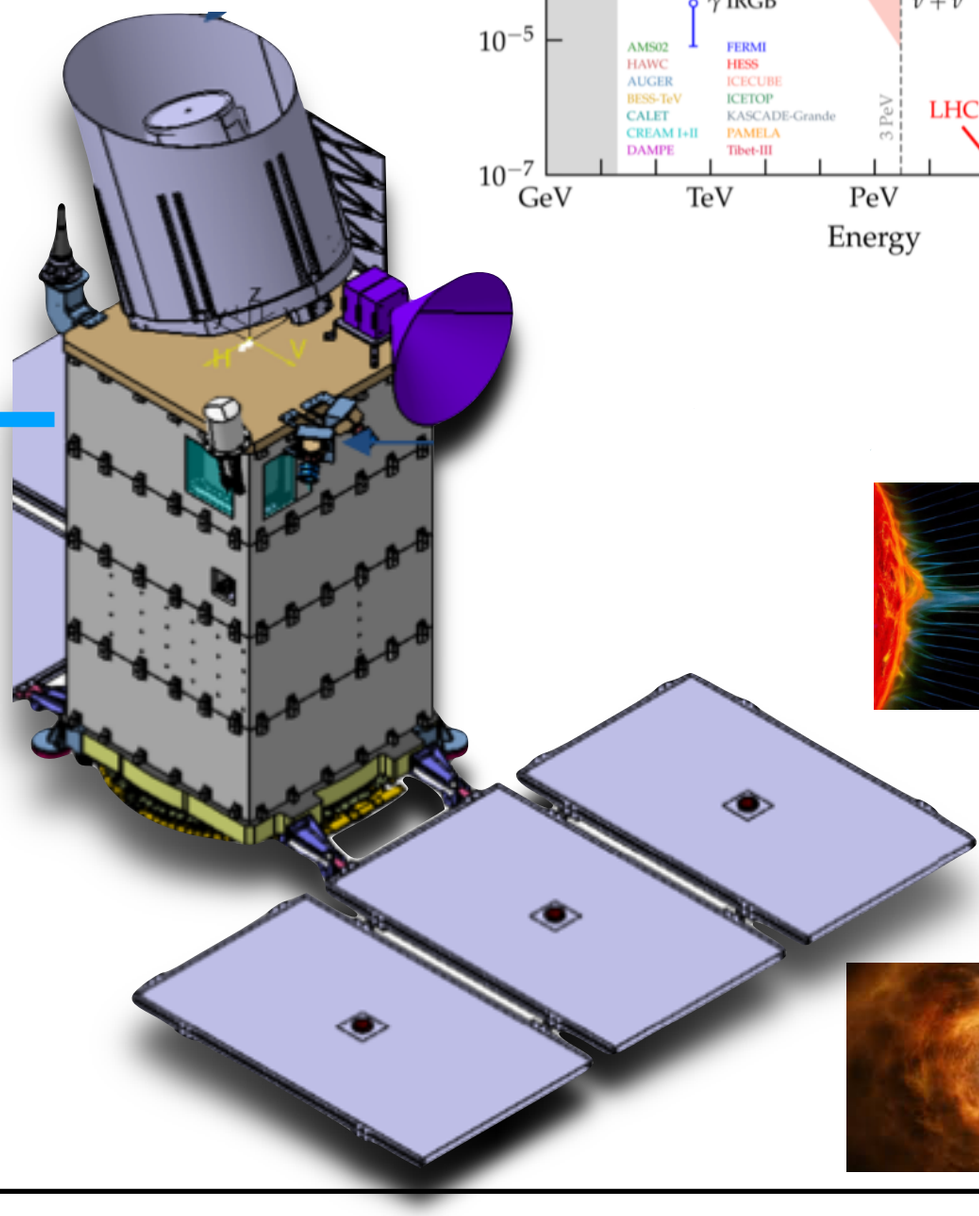
Payloads

The NUSES satellite will host two instruments:





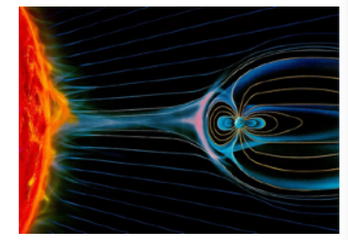
ZIRÈ



- Monitoring of low energy (<250 MeV) Cosmic Ray fluxes to study **Van Allen belts**, **space weather** and **lithosphere-ionosphere-magnetosphere** couplings;

- Detection of 0.1 MeV – 10 MeV photons for the study of **transient** (GRB, e.m. follow up of GW events, SN emission lines,…) and **steady gamma sources**.

https://pos.sissa.it/444/139/



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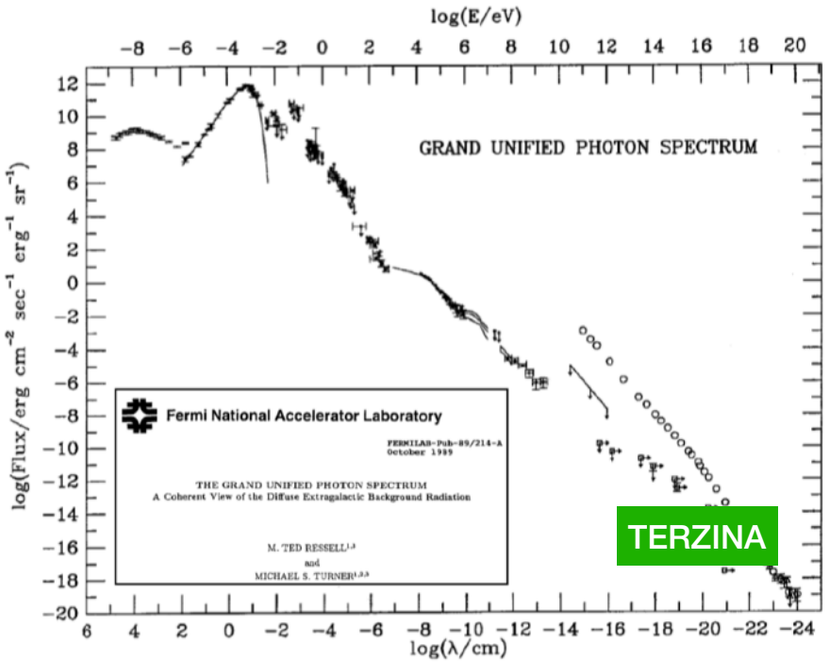
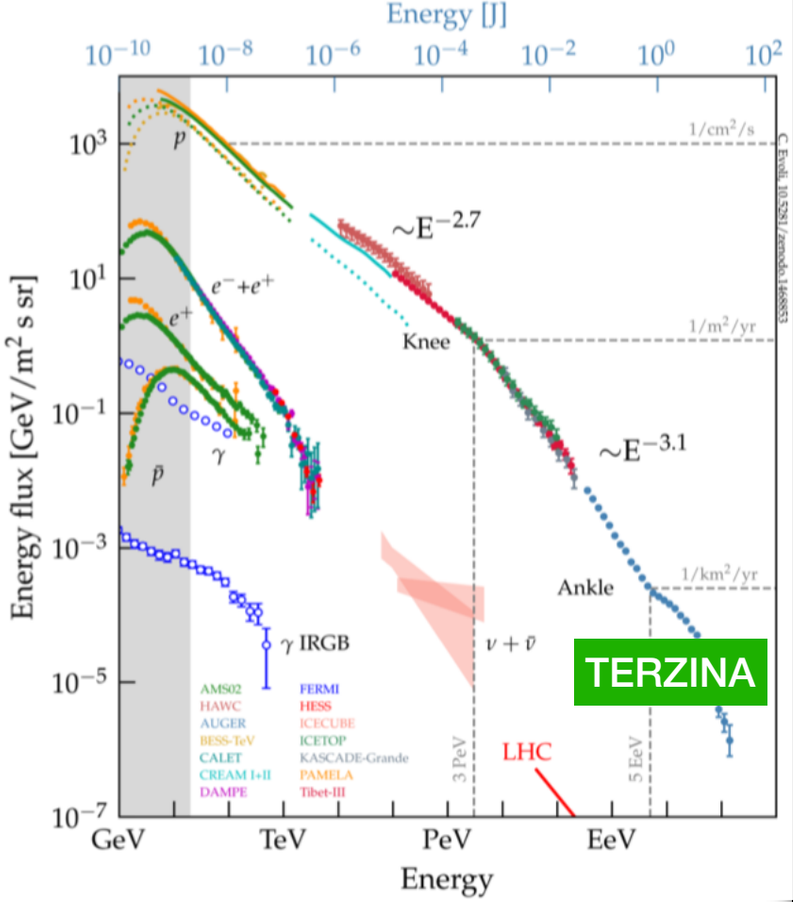
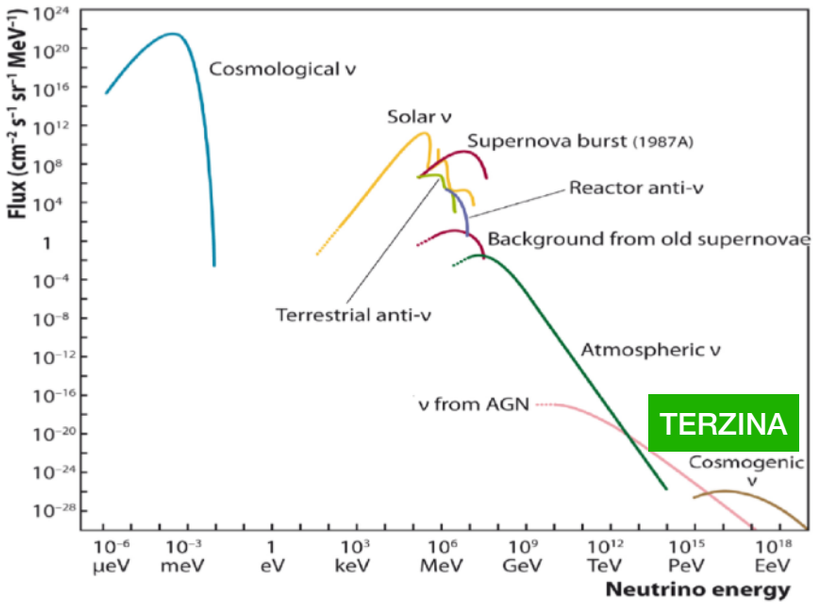
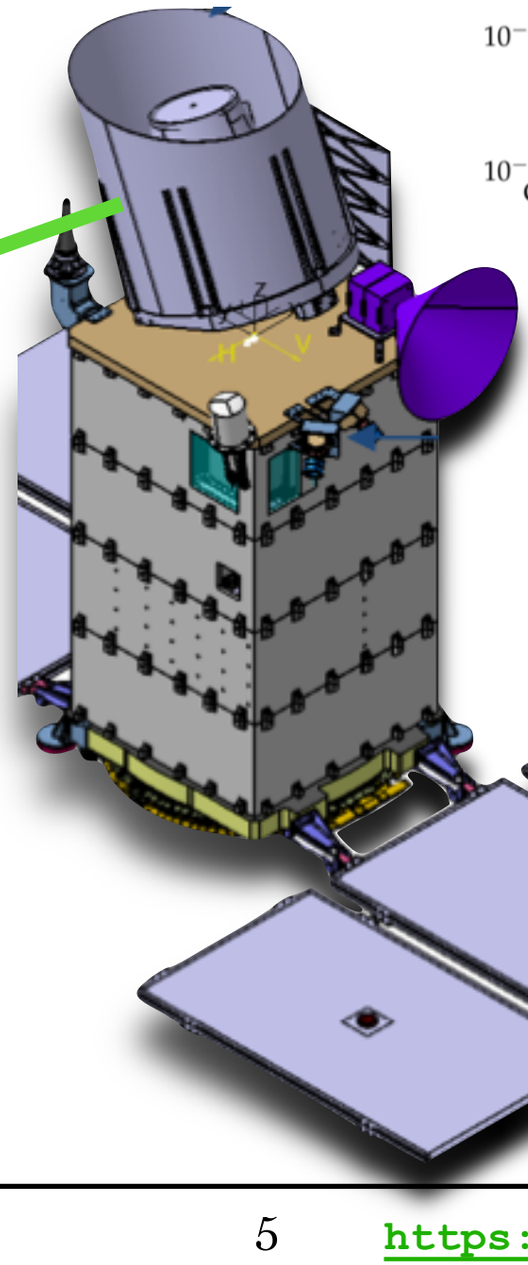




TERZINA

Pathfinder for future missions devoted to UHE **cosmic ray** with $E > 100\,\mathrm{PeV}$ and Earth-skimming UHE **neutrino** detection demonstrator through space-based atmospheric Cherenkov light detection.



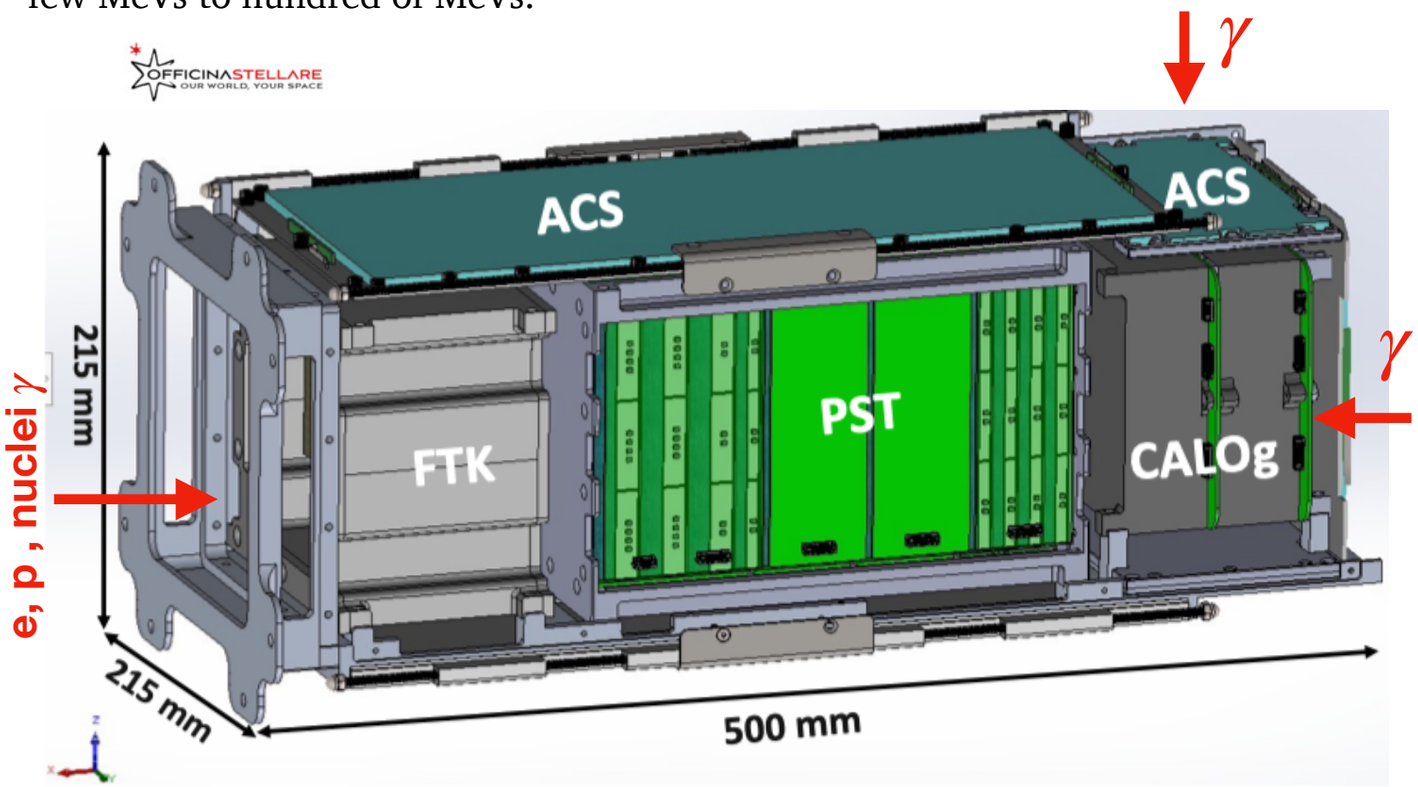


https://pos.sissa.it/444/391/

https://arxiv.org/abs/2304.11992

ZIRÈ design

The ZIRÈ detector will be devoted to the measurement of Cosmic Rays (mainly electrons and protons) in the energy range from few MeVs to hundred of MeVs.



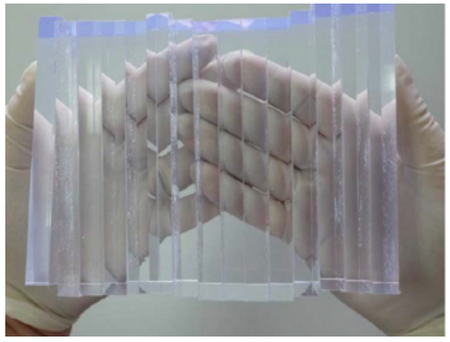
FTK (Fiber TracKer): N.3 X-Y modules made of scintillating fibers read out by linear arrays of SiMs **for track reconstruction of charged particles**

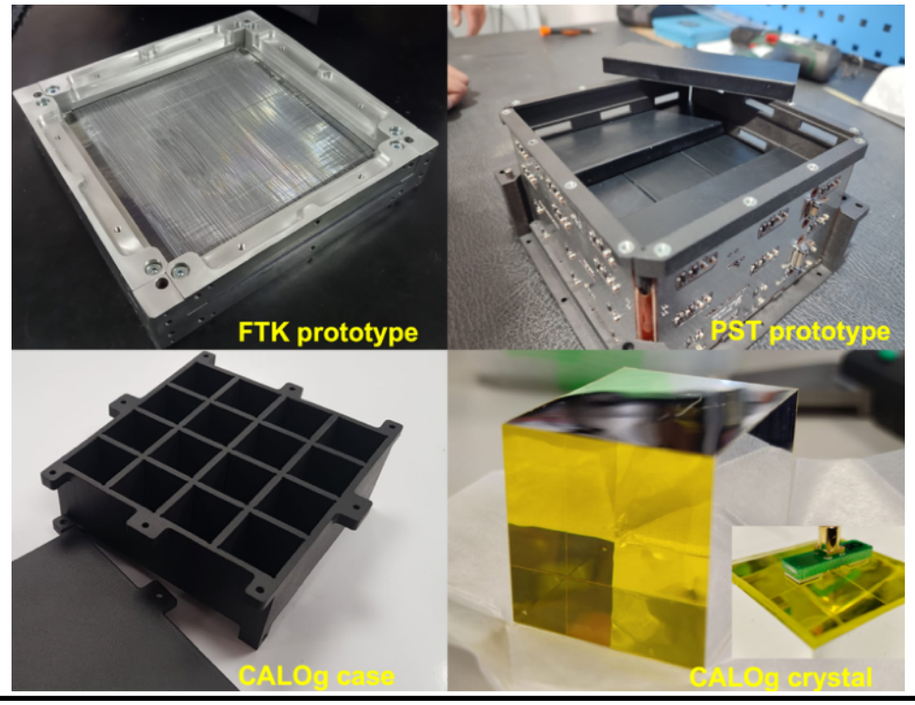
PST (Plastic Scintillator Tower): N. 32 layers X-Y modules made of scintillating tiles read out by two sets of SiPMs of different sensitive area used **for particle identification**

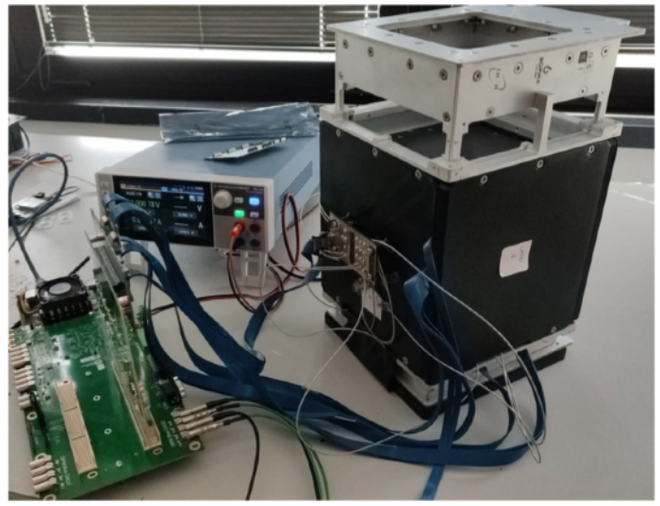
CALOg: N.2 4x4 matrices of LYSO (GAGG) crystals read out by three sets of SiPMs of different sensitive area used **for energy measurements of the incoming CR induced events** and **for the detection of low energy gamma-rays** entering from two windows suitably placed on its sides

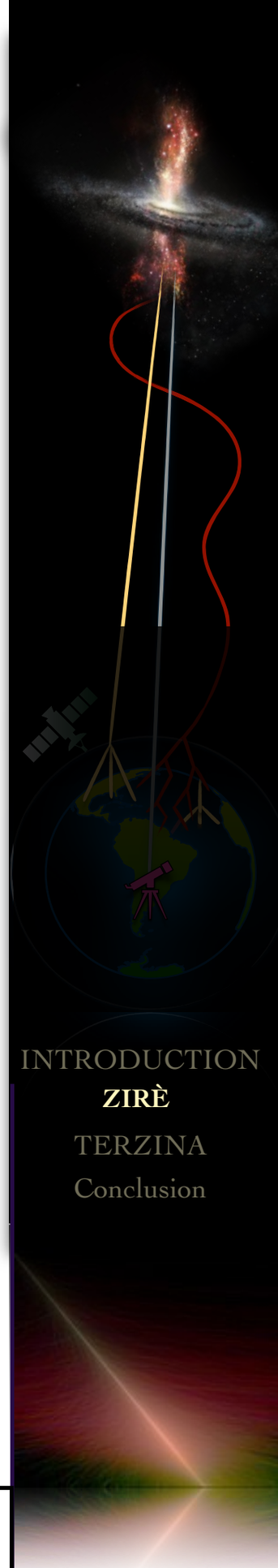
ACS (Anti-Coincidence System): a VETO for charged particle induced events made of plastic scintillator tiles and read out by SiPMs

A small prototype of the Zirè detector, **Zirèttino**, has been built-up for calibrations and tests with sources, cosmic rays and particle beams









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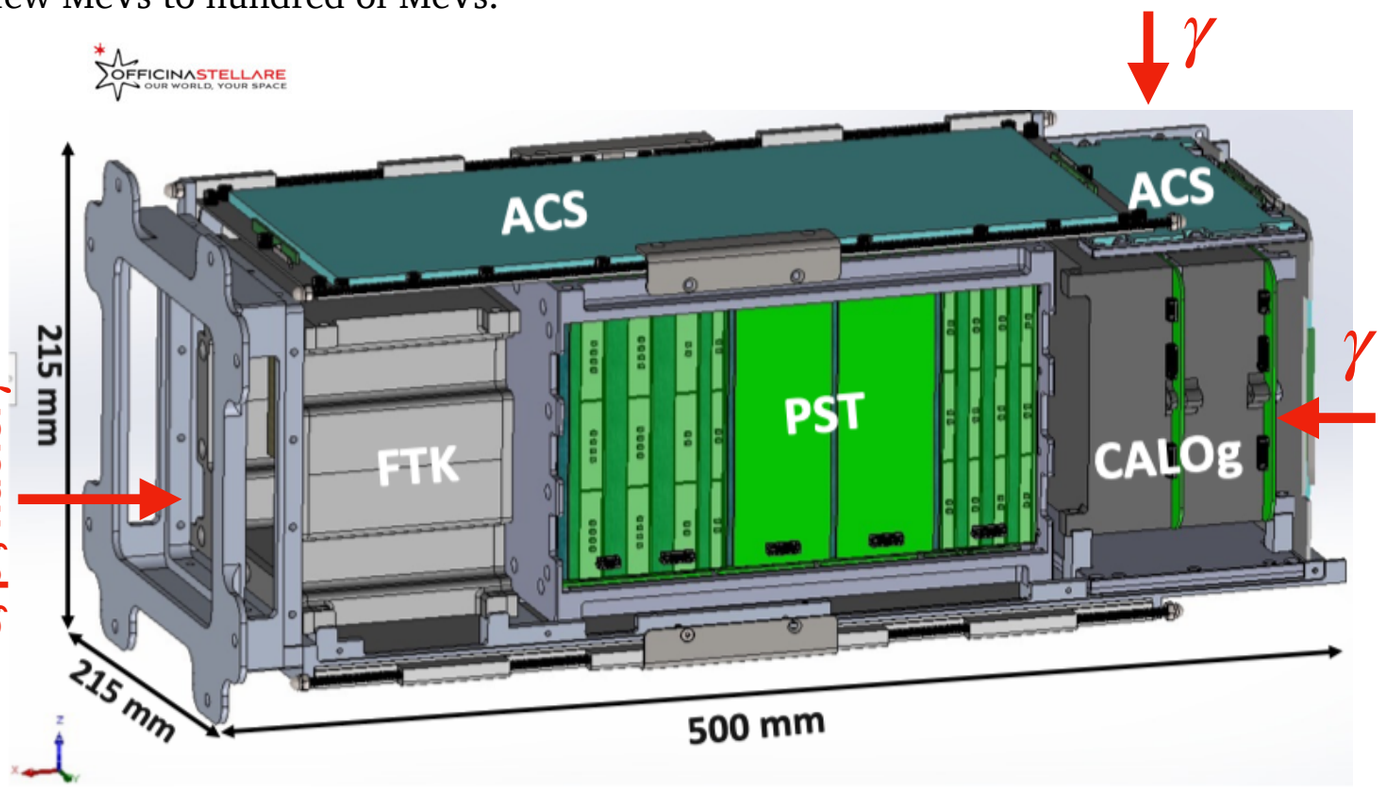

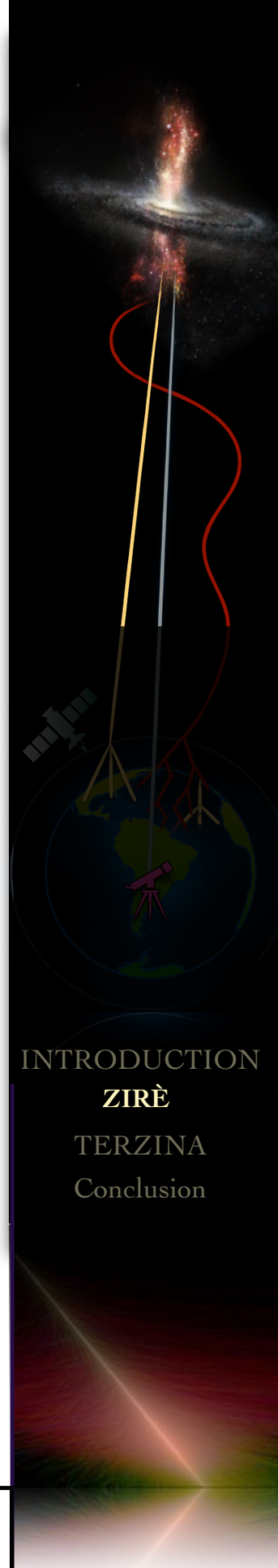

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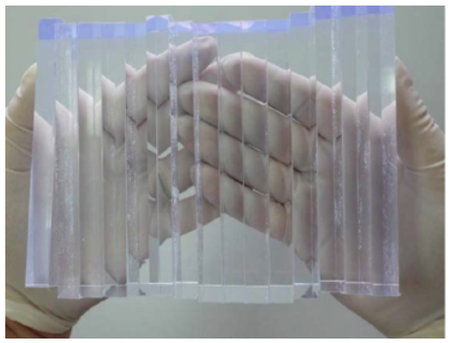
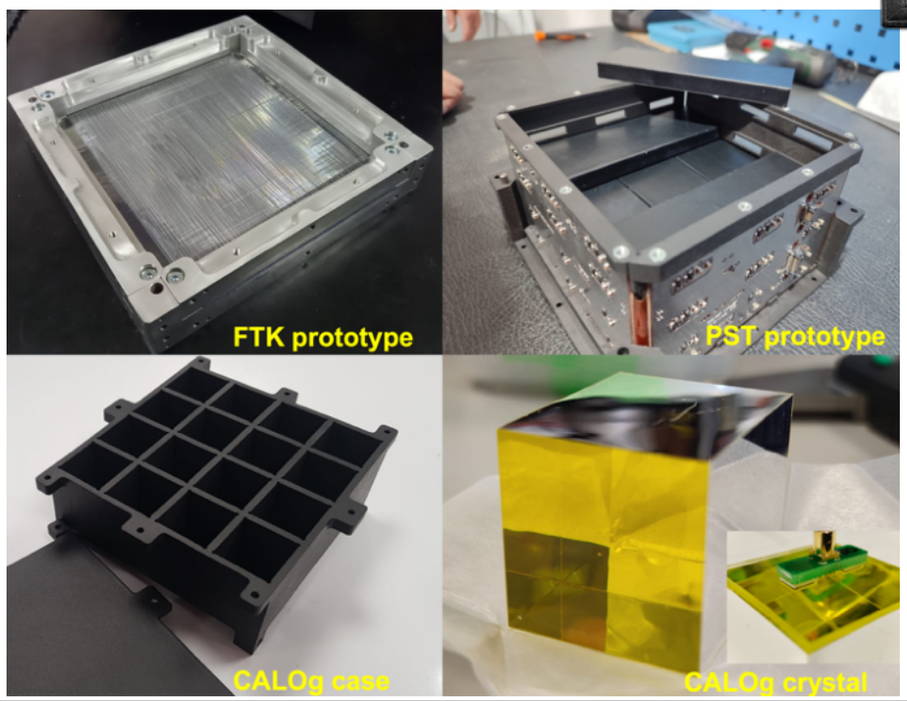
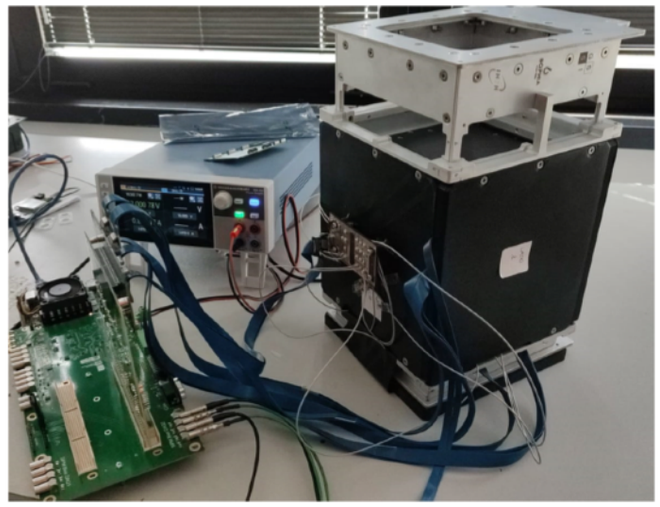
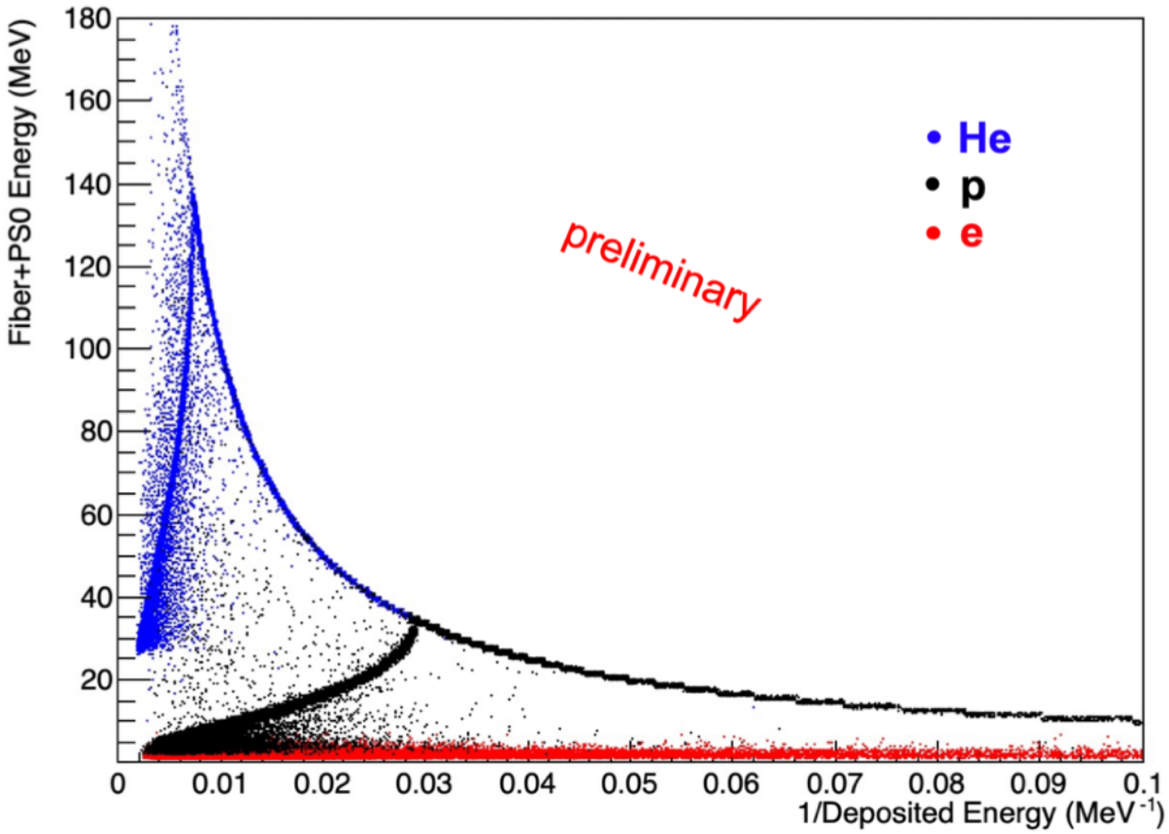
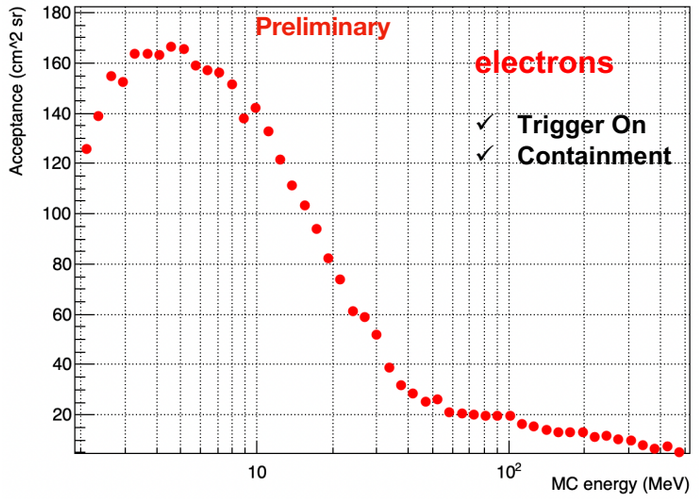


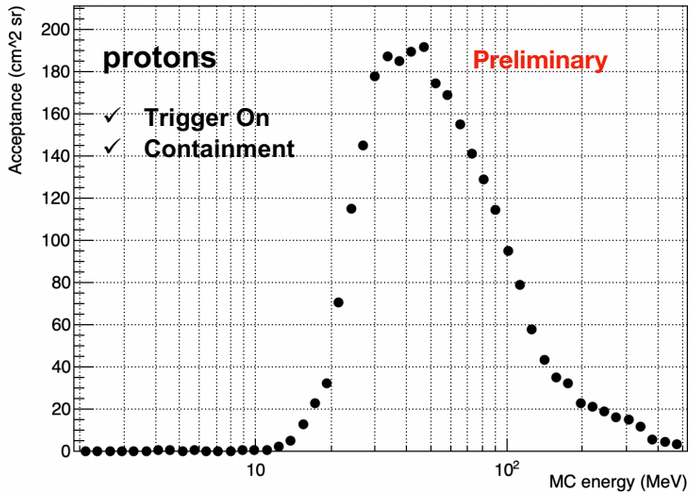




ZIRÈ Geant4 simulations

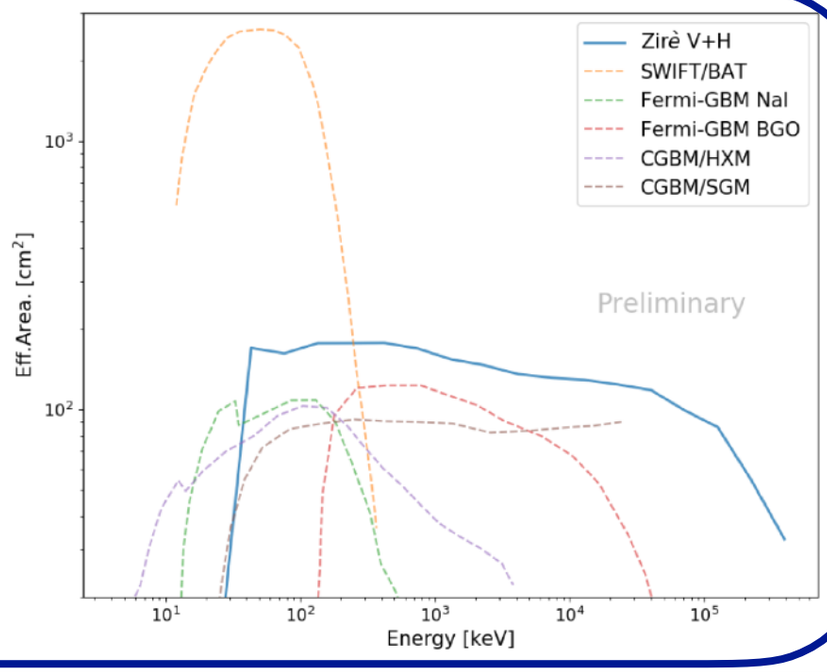


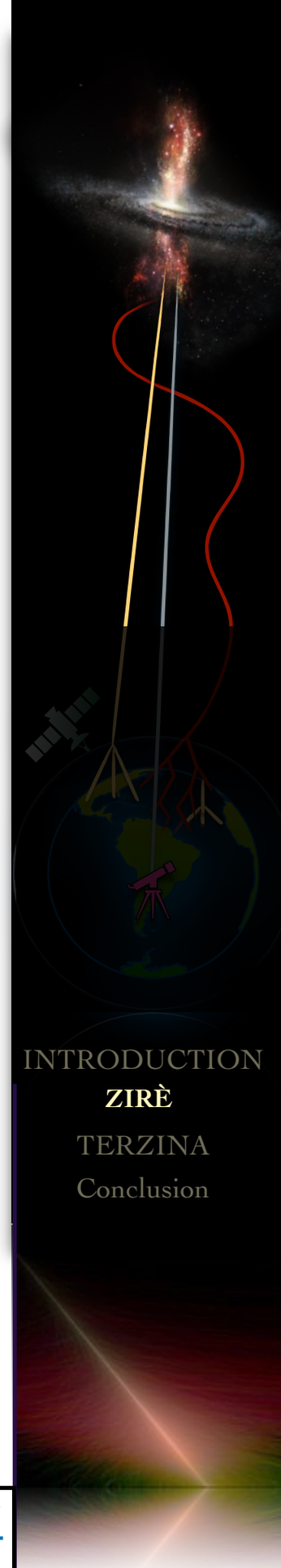




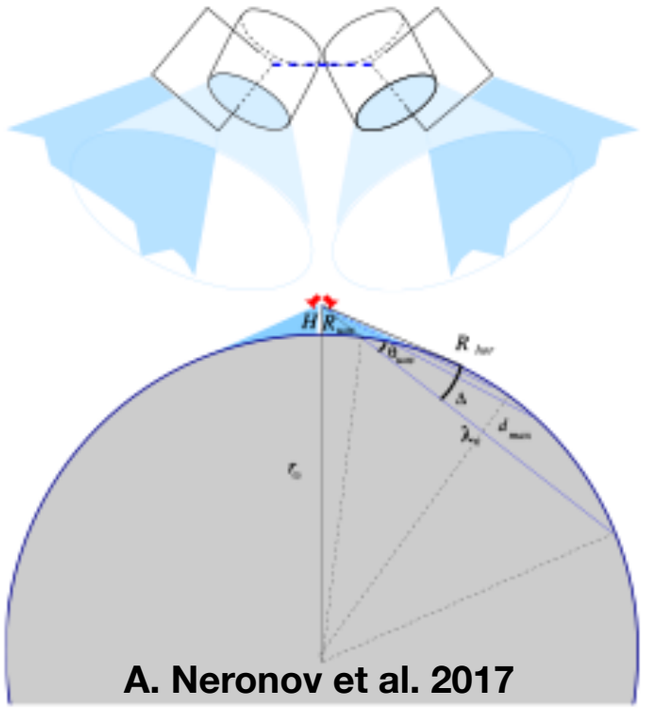
Low energy gamma rays between 10 keV-50 MeV with CALOg sub-detector

- Two windows surrounding the CALOg are included in the design for this purpose;
- A preliminary estimate of the effective area is obtained from dedicated GEANT4 simulations;
- The plot shows the summed effective area for both windows impinged by normal incident photons.





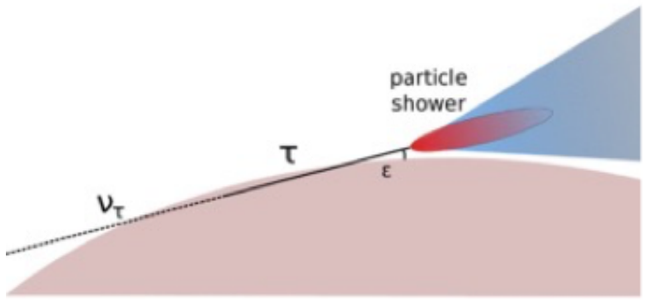
TERZINA Cherenkov emission observed from space



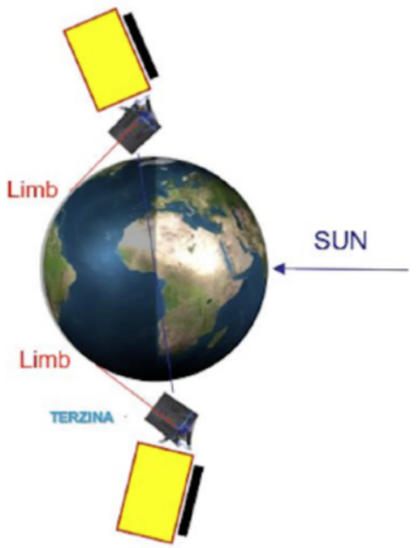
Looking at the atmosphere limb:

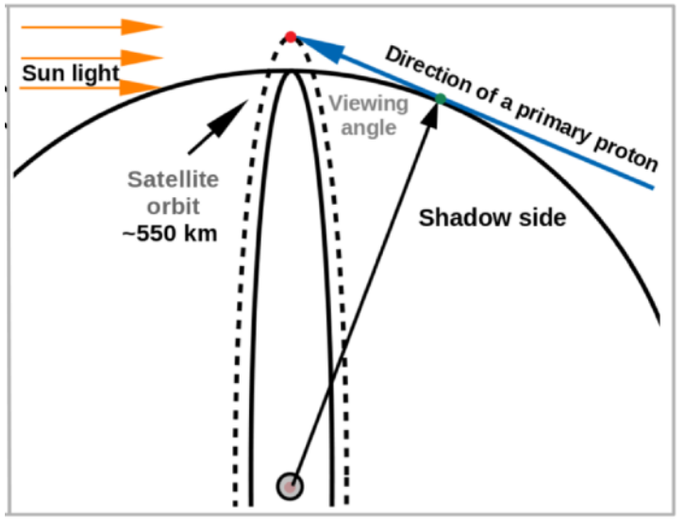
- **Just below:** to observe tau and muon neutrinos of > few PeV energy can be detected as Earth-skimming associated to up-going EAS. The Cherenkov emission of these cascades provides a unique signal for space based (LEO) instruments.

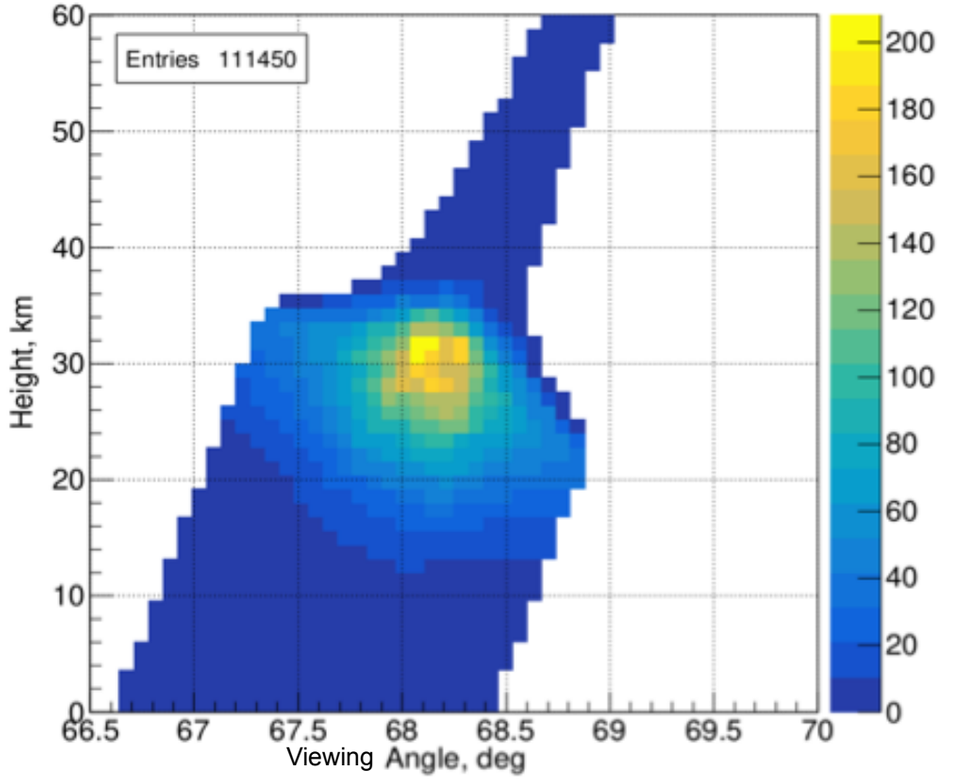
- **Just above**: Similar signals are produced by HE cosmic rays (> 100 PeV) impinging the atmosphere from above the Earth's limb.

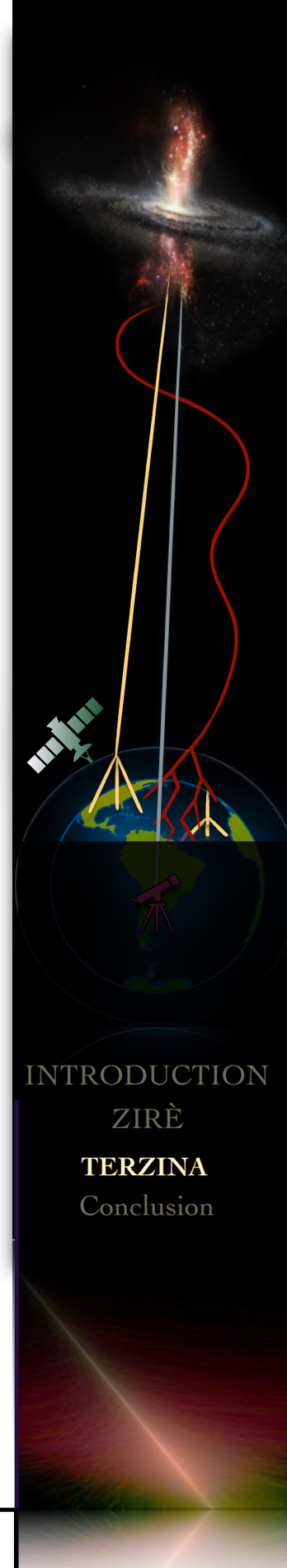


Most contributing layers of the atmosphere around altitudes 20 - 40 km



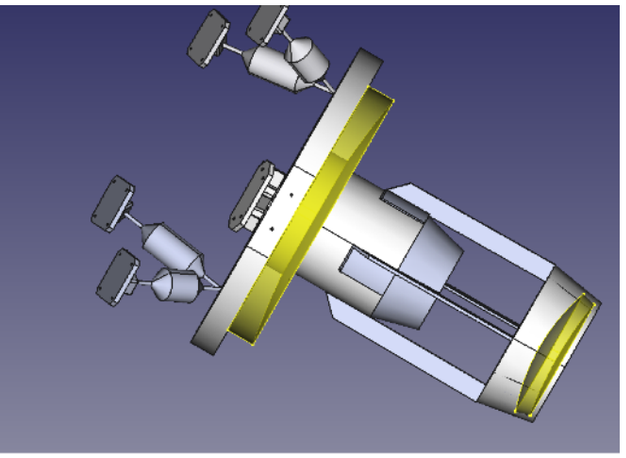


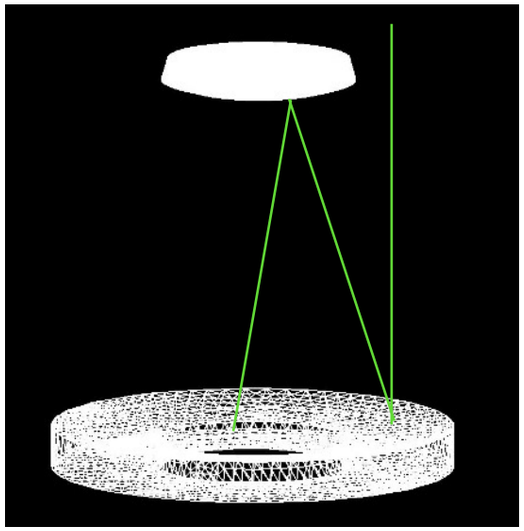


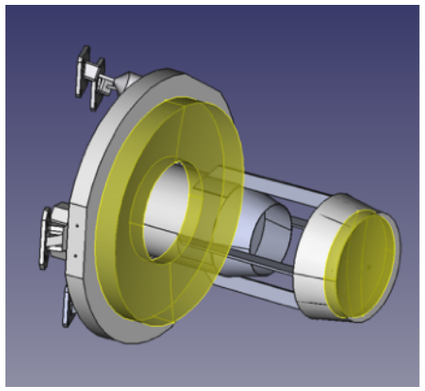


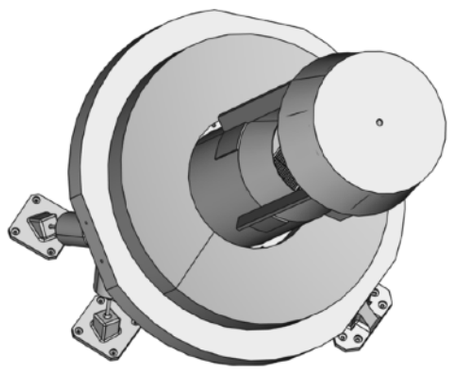
TERZINA Telescope

Inside: Mirrors

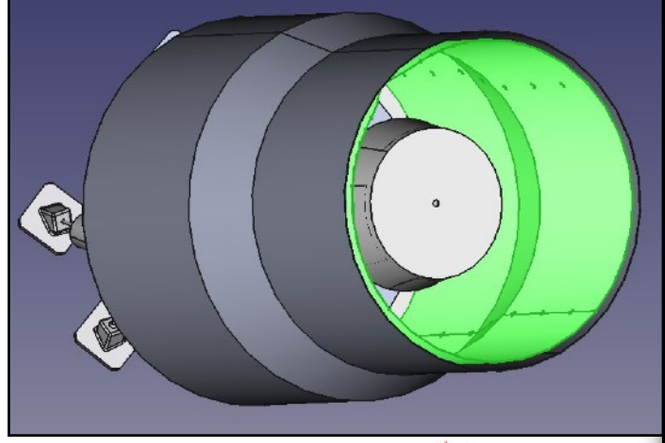




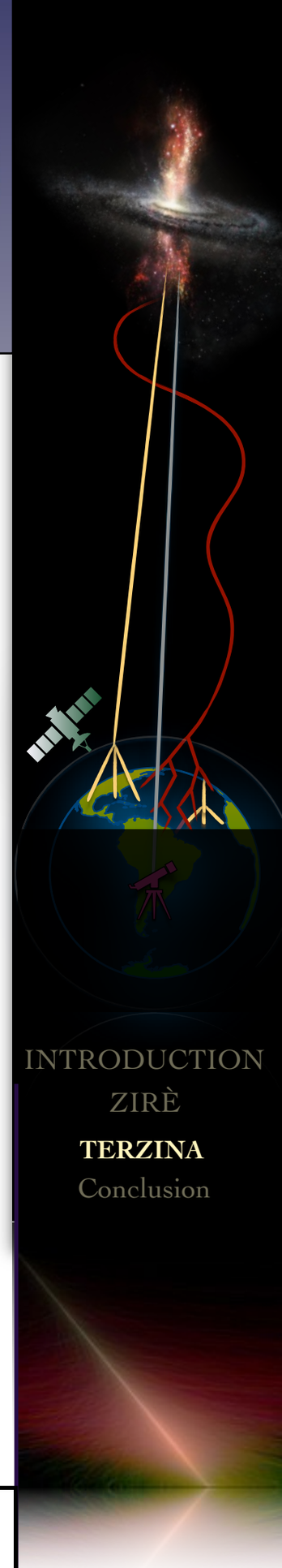




- Schmidt-Cassegrain optics
- Equivalent focal length $F_L = 925\,\text{mm}$
- Telescope Field of View: 7.2° along the Earth's limb and 2.9° across it
- Point spread function (PSF): < 1 mm
- Effective area of the telescope: 0.1 m^2
- M1 and M2 parabolic mirrors

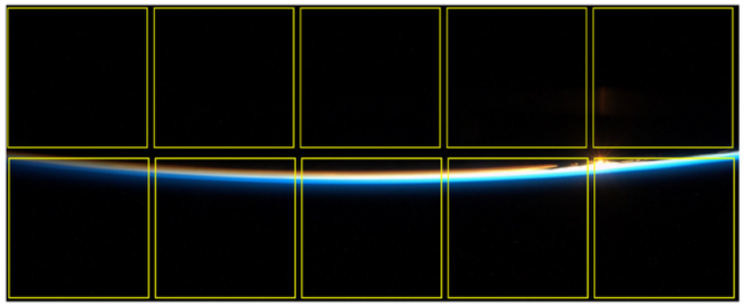


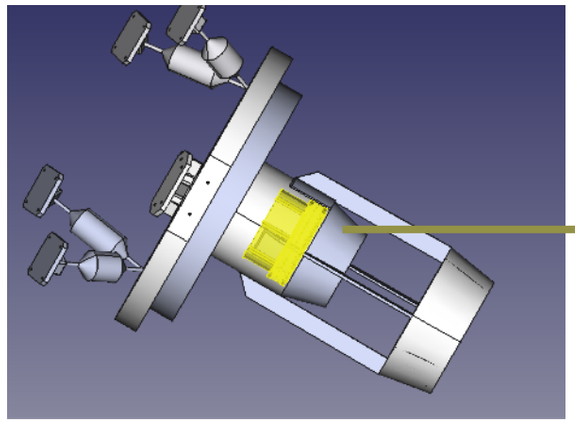
60x60x50 cm^3
Terzina total weight ~35 kg

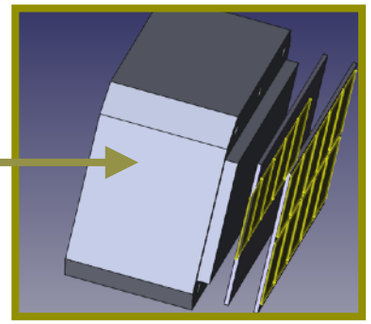


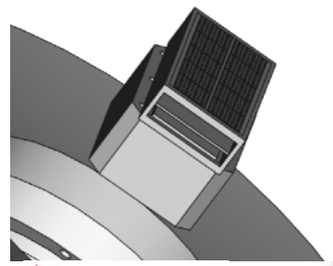
TERZINA Telescope

Inside: FPA







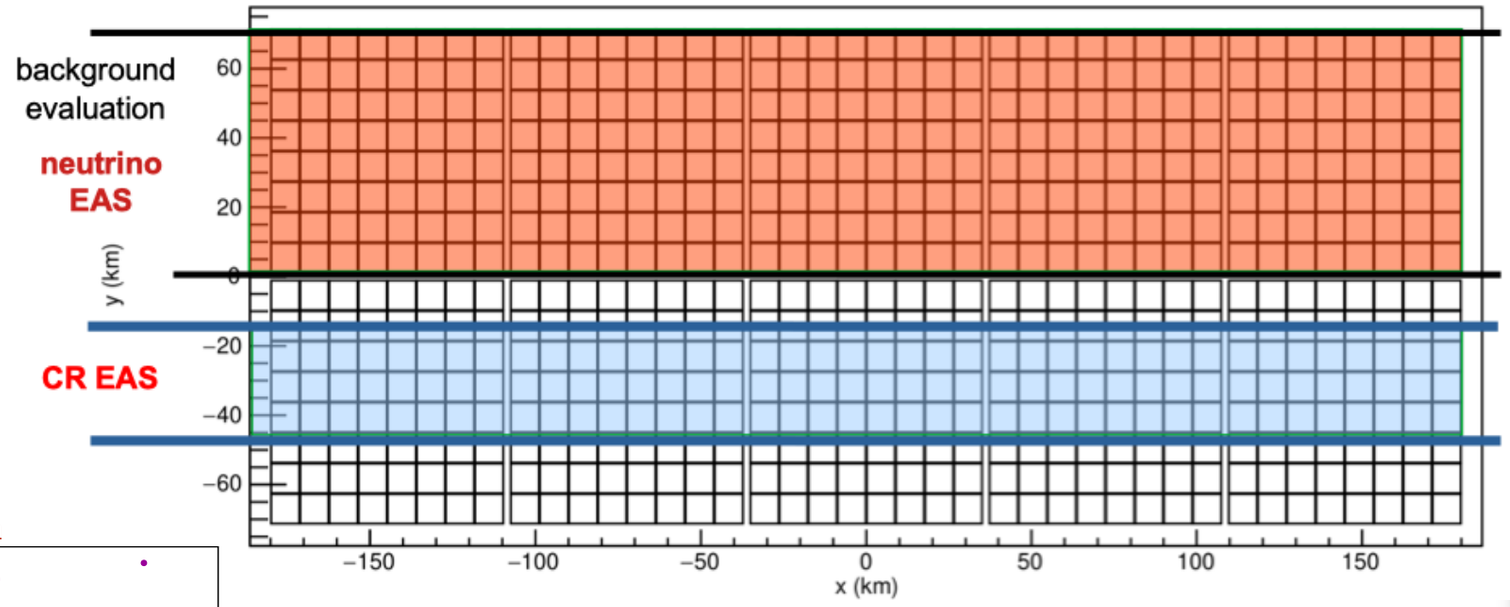


SiPM arrays 8x8 pixels
5x2 = 10 SiPM arrays
(8x8) x 10 = 640 pixels

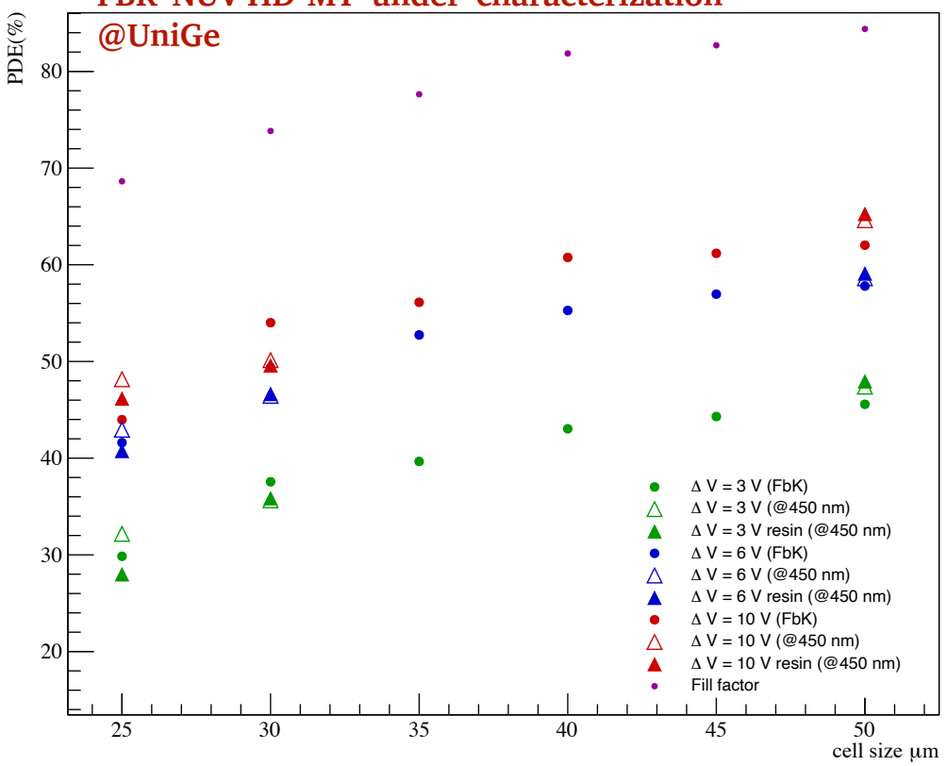
Array dim: 24.9 mm x 24.9 mm

- Pixel: 2.3 mm x 2.7 mm
- Field of View per pixel
  FoV = $\arctan(r_{SiPM}/F_L) \simeq 0.18°$
  (with $r_{\mathrm{SiPM}} \simeq 3$ mm)

Camera plane with projection on the Earth (total area 360x140 km²)



FBK NUV-HD-MT under characterization @UniGe



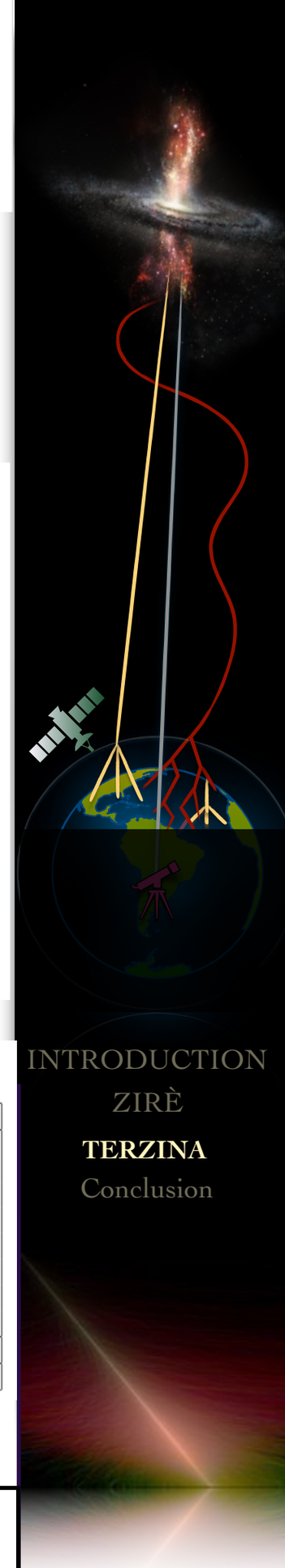
Simulations are performed assuming NUV-HD-LowCT for different SiPM typical values (for 35 µm cell-size) DCR ~100 kHz/mm^2 , AP ~5%, CT ~ 5%–20% and PDE ~ 50%–60%.

FONDAZIONE BRUNO KESSLER

Table 2. SiPM: expected characteristics.

	NUV-HD	NUV-HD-MT*
V_{bd} @ 23°C, V	32.6	32.6
V_{over}, V	6	6
$V_{operation}$ @ 23°C, V	38.6	38.6
PDE, % @ 400 nm	50	50
DCR, kHz/mm	77	77
CT, %	16	~7
DCT, %	3.5	~1
Power per channel, µW**	<6.25	~6.25
*MT - Metal Trench		
** Beginning of Life of the satellite		

https://arxiv.org/abs/2304.11992



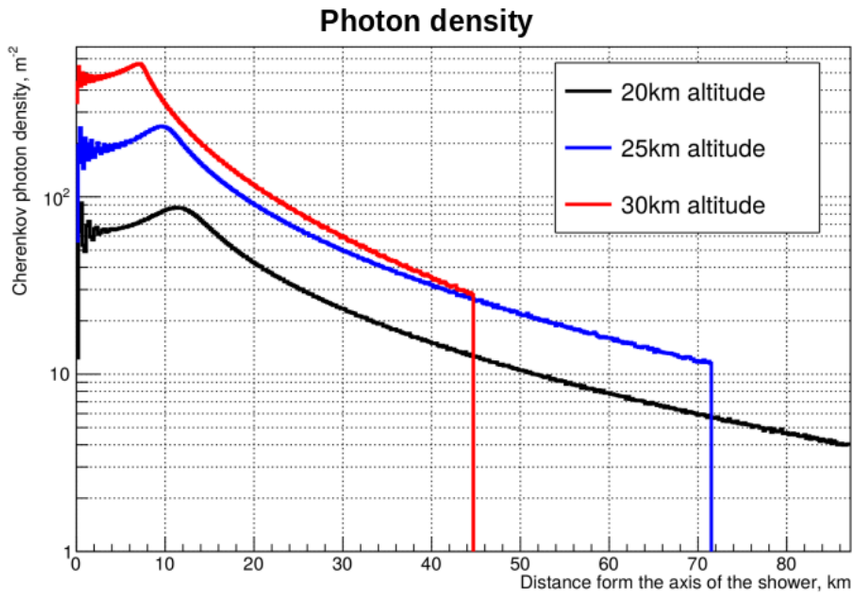
TERZINA Simulation Pipeline

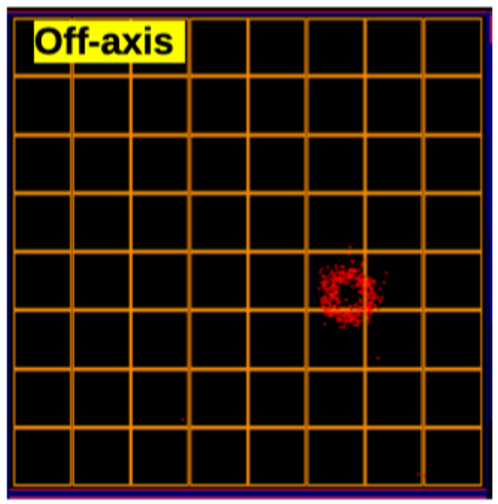
Preliminary and optimistic scenario

Track Fast sim	~10^{13} simulated events	Fast simulation of the tracks to choose detectable candidates
EASCherSim	~10^{5} simulated events	Monte Carlo simulation of the UHECR and photon propagation

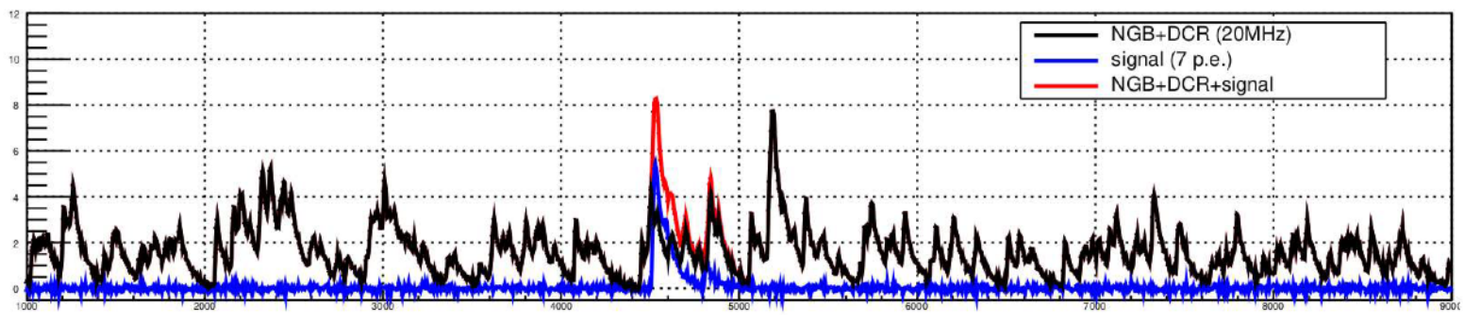
https://pypi.org/project/easchersim/1.1/

Geant4 photon	~10^{8} simulated events	Monte Carlo simulation of photon propagation to the telescope





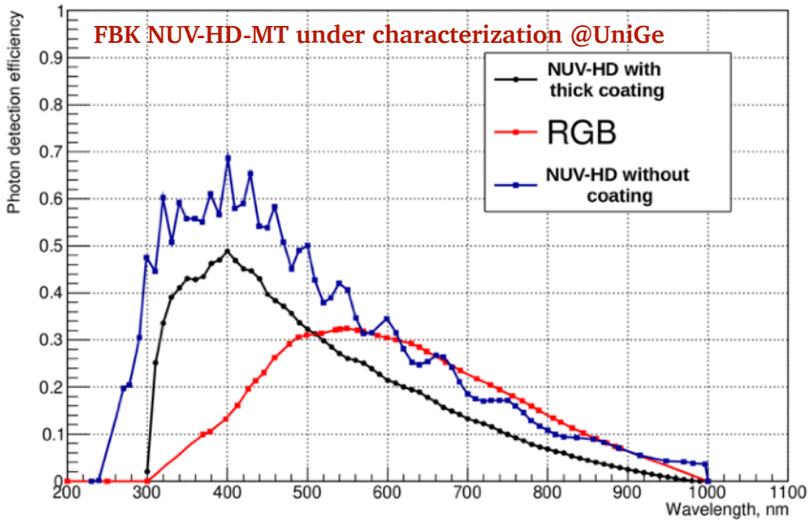
Digitization/wf. Sim	~10^{8} simulated events	Simulating the SiPM response

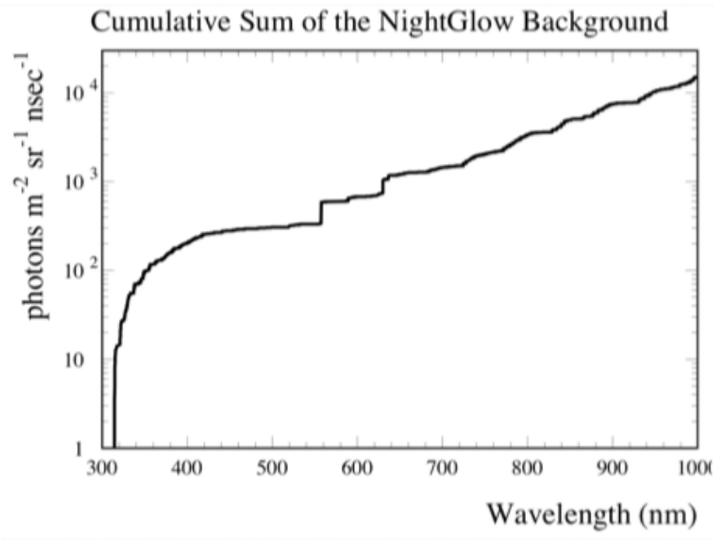


TERZINA Expected background and aperture

1) Background radiation consists on the **Night Glow Background (NGB)** (estimated with **SPENVIS**):

$R_{\text{pix}}^{\text{NGB}} = \eta \cdot \Delta\Omega \cdot \phi_{\text{NGB}} \cdot S \cdot PDE_{\text{eff}}$ $\quad S = 0.1\ \text{m}^2,\ PDE_{\text{eff}} = 0.1,\ \Delta\Omega \simeq (FoV_{\text{pix}})^2,\ \phi_{\text{NGB}} = 1.55 \cdot 10^4\ \text{m}^{-2}\text{sr}^{-1}\text{ns}^{-1},\ \eta = 6$

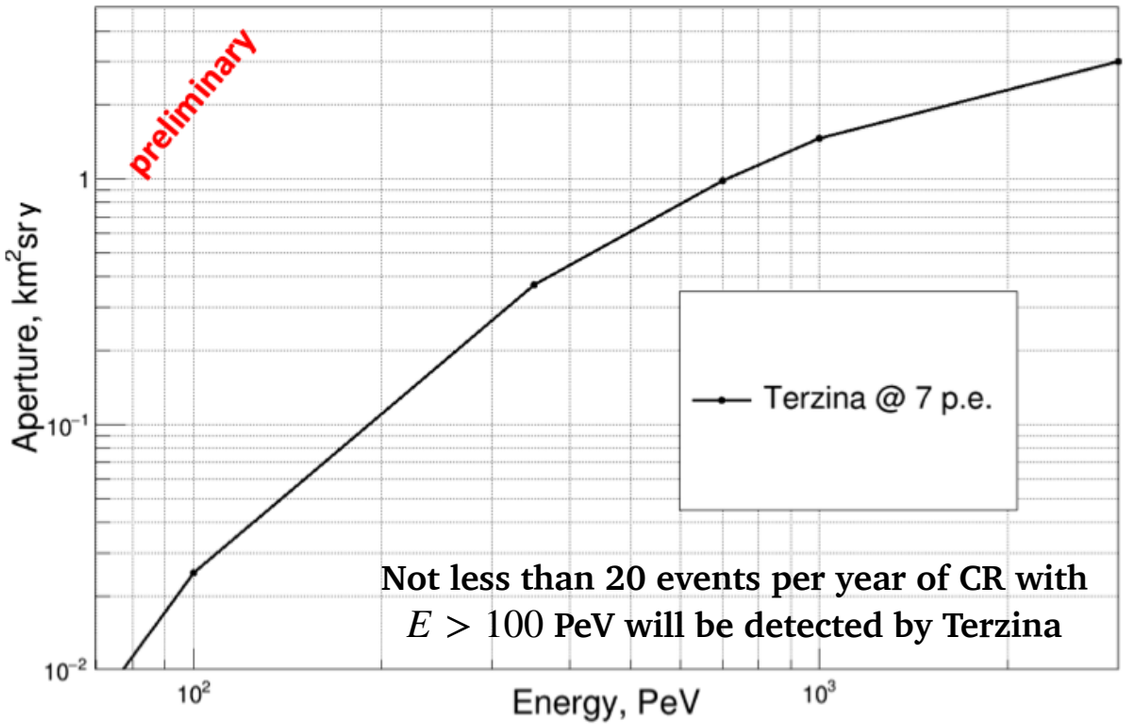




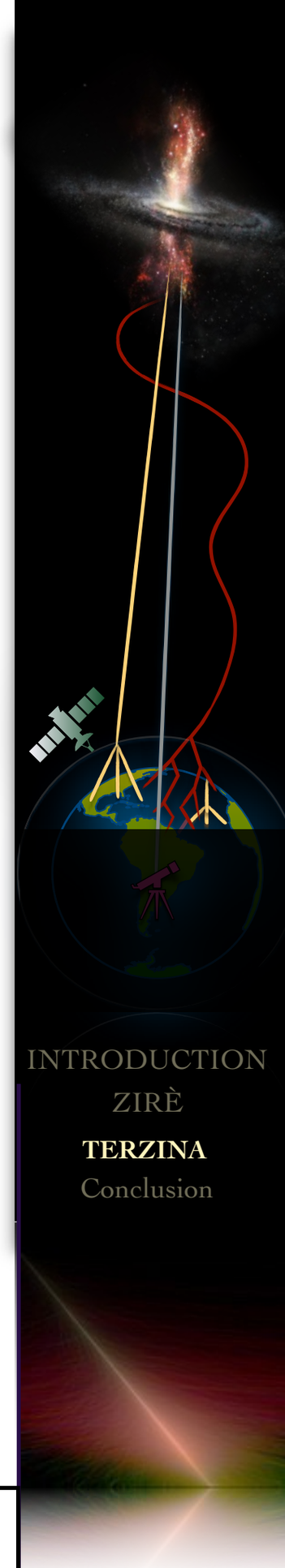
2) Sensors background: the in-orbit background produced on the FPA mimics events and produces a progressive sensor damage with an increasing of the **Dark Count Rate (DCR)** during the mission

>>The simulated combined background (per pixel) due to NGB and DCR is: 11 MHz

At BoL **NGB contribution** >> **DCR contribution**
At EoL **DCR contribution** >> **NGB contribution**



Preliminary and optimistic scenario



Conclusions and prospects

The NUSES space mission with its payloads is devoted to several scientific and technological goals:

- Observations of High Energy cosmic ray showers from space through Cherenkov signal and detection of HE neutrino by the Earth skimming geometry and Cherenkov light emission
- First observation of high energy cosmic ray showers from space through Cherenkov signal
- Flux measurements of electrons, protons and nuclei from few to hundreds of MeVs
- Looking for possible CR flux correlation with seismic activity and space weather phenomena
- Measurements of photons in the energy range 0.1-10 MeV for transient and steady gamma source detection (Earth Observation, TGF, etc …)
- Qualification of new technological (full SiPM technology) and observational approaches fundamental for future space missions

- **Full characterization of many SiPM devices (Static - Dynamic - Optical - Irradiation - Annealing)**
- First simulations of the detectors done and **currently under update using the final geometry and more realistic scenario (heavier nuclei, exact sensitive area, etc.)**
- Payload prototypes are now under construction and test

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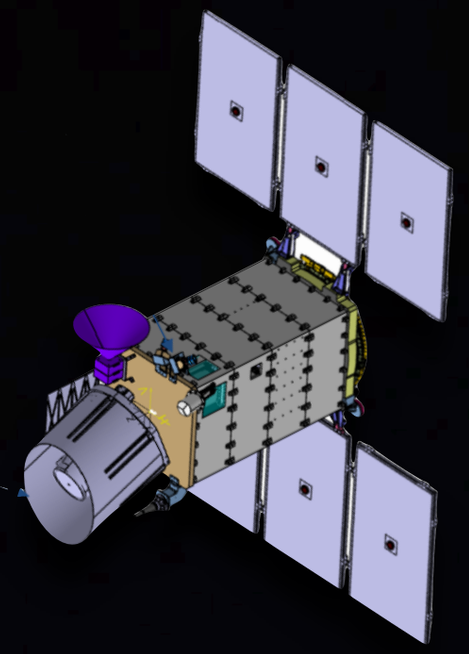

Thanks for your attention

ZIRÈ LEM On ACS layer

A specific ZIRÈ payload named Low Energy Module (LEM) designed for the detection of low energy **electrons** < 7 MeV and **protons** 3-50 MeV range with could provide a larger sensitivity for MILC studies.

Particle spectrometer for time resolved measurements of differential flux distribution of low-energy charged particles:
- 5 independent silicon detectors
- a plastic calorimeter
- 2 veto systems on top and the bottom of the instrument

- Good particle identification
- Particle direction measurement (within few degrees)
- Particle energy measurement (within few % resolution)
- High rate capability