GRAN SASSO
SCIENCE INSTITUTE

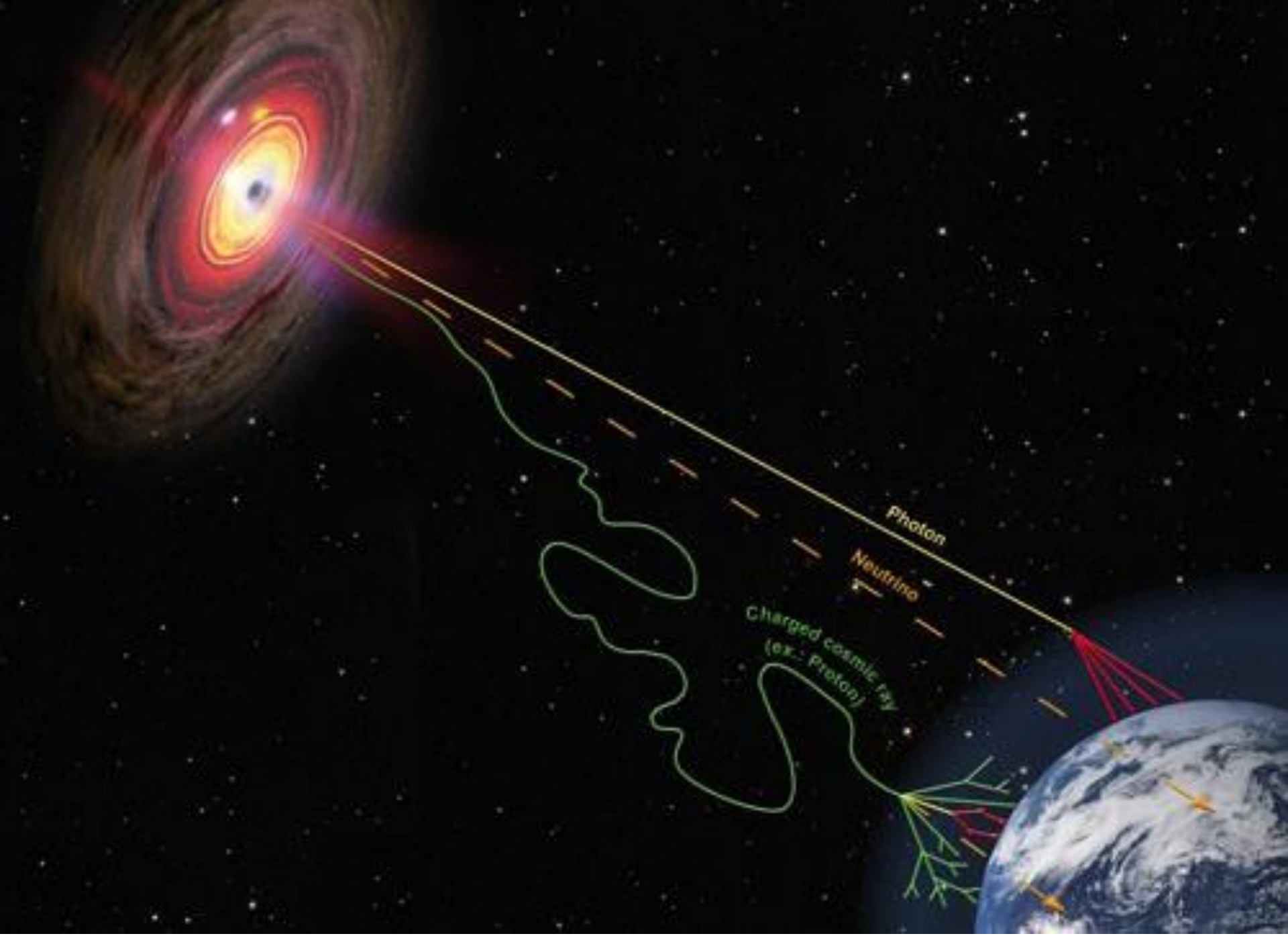
SCHOOL OF ADVANCED STUDIES

Radiations from the Universe: experiments

Ivan De Mitri
on behalf of the HE-EXP group
(about 20+5 people)

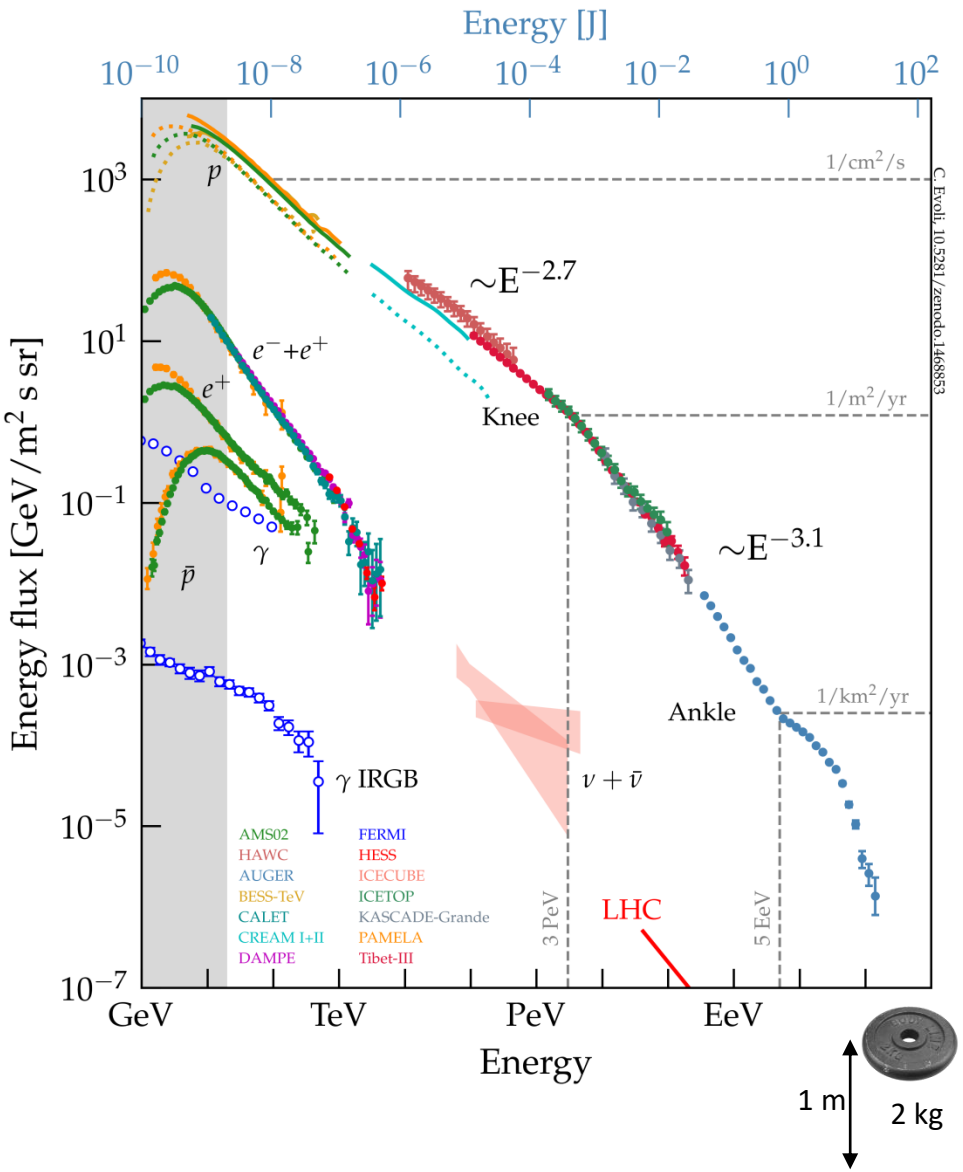
12th GSSI Science Fair
L'Aquila, February 17, 2026

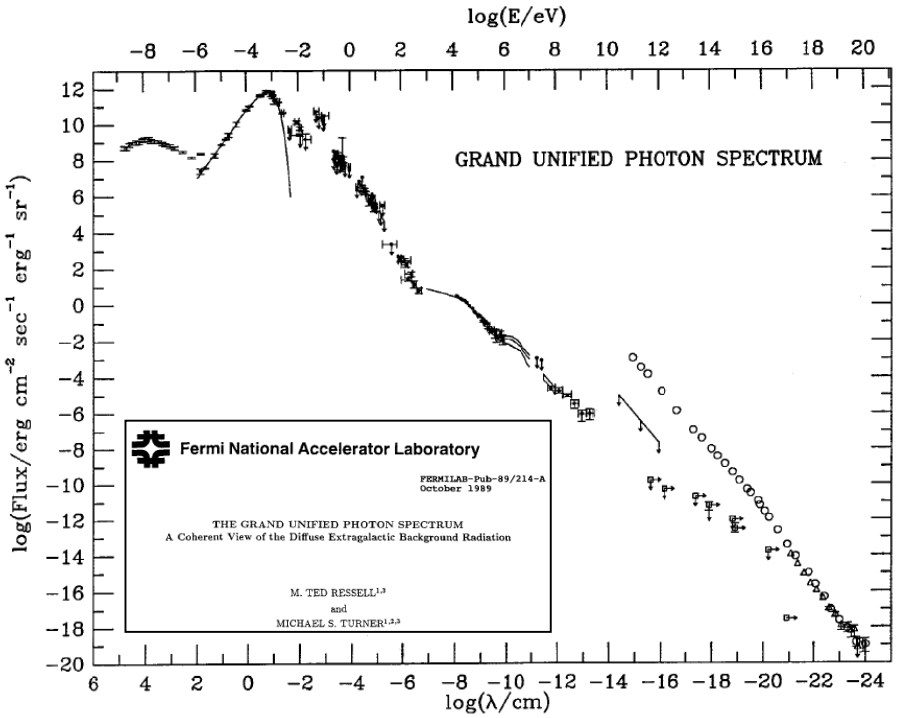
www.gssi.it

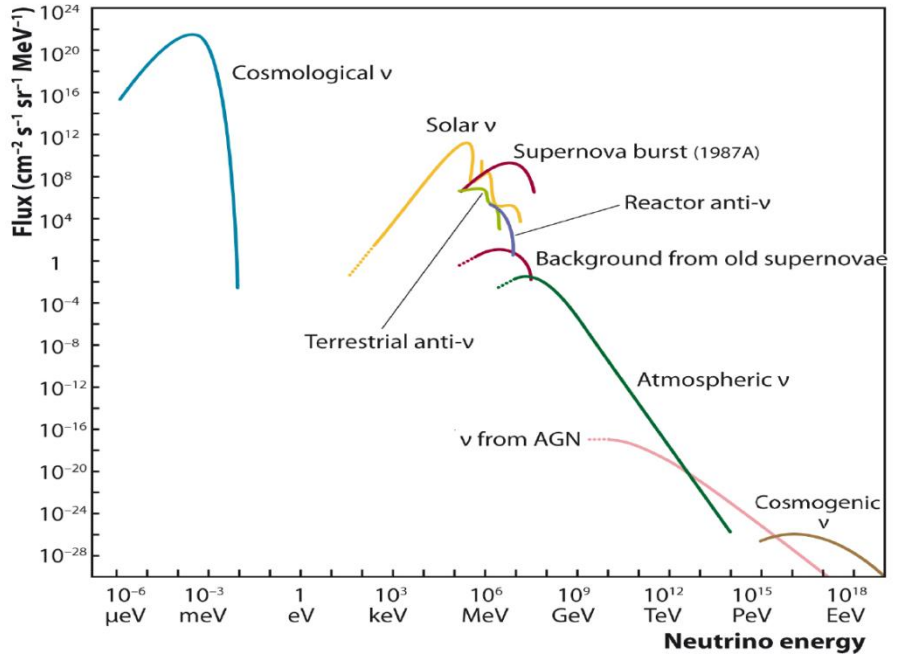

Photon
Neutrino
Charged cosmic ray
(ex.: Proton)

Detectors… from deep underground to space

Our landscapes(s)







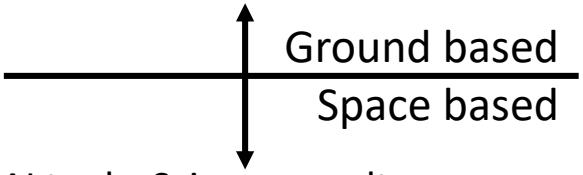
Ongoing activities at GSSI-LNGS-UNIVAQ

AUGER

Currently upgrading the detector. Atmosphere monitoring . Data analysis. Experimental results.
Phenomenological studies and theory development/assessment.

CTA

Construction of the first telescopes. Atmospheric monitoring



DAMPE

On orbit since December 2015. Data analysis. Standard SW and AI tools. Science results.

HERD

Design optimization ongoing. To be installed on the Chinese Space Station in 2029.

NUSES

New observational techniques (atmo-Č,…) and new technologies (SiPM, …) in space (UHE neutrinos, Low energy CR, GRB detection, interdisciplinary applications,…)
Payload integration ongoing at LNGS. Launch in 2027.

PBR / Suborbital flights

New techniques for (ultra)high energy EAS detection form high atmosphere

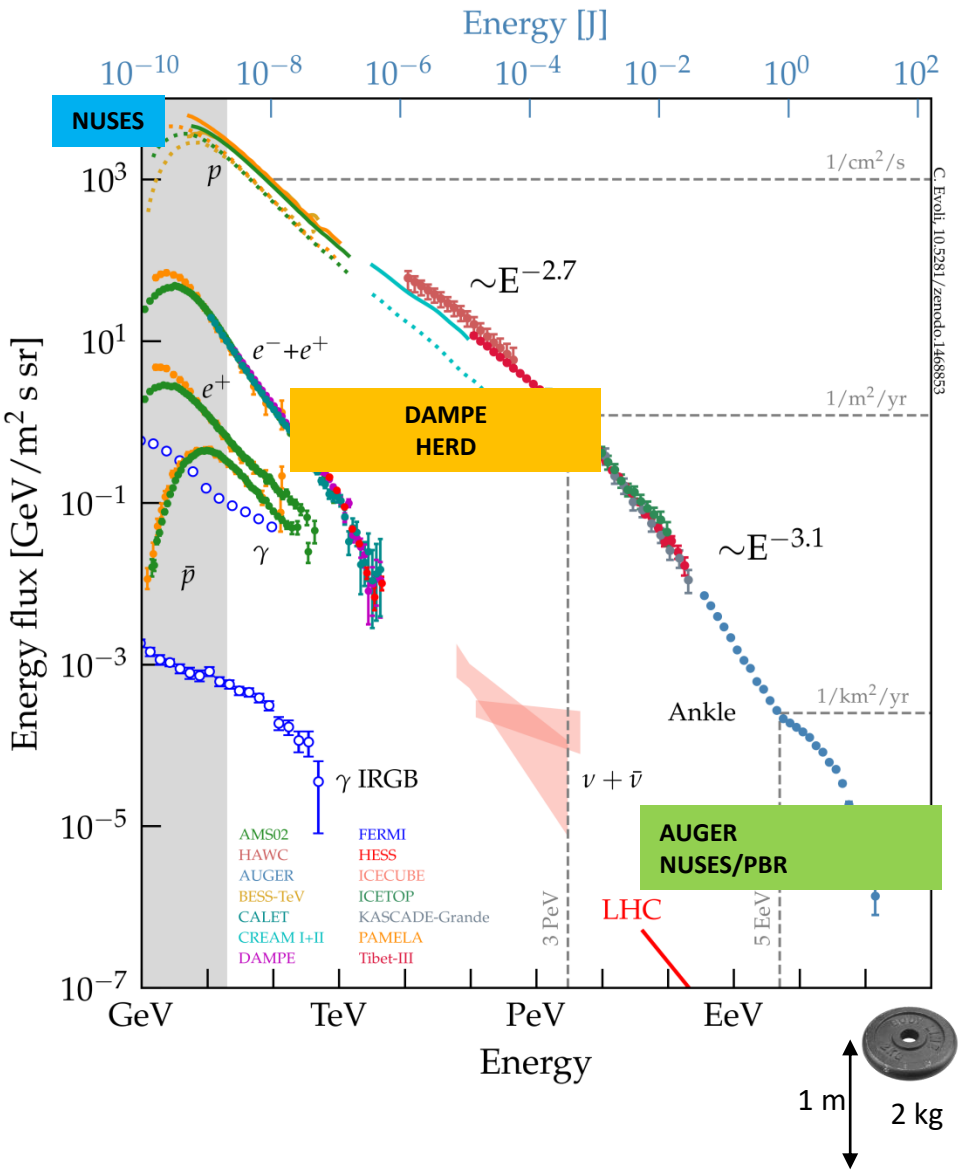
CRYSTAL EYE / WINK

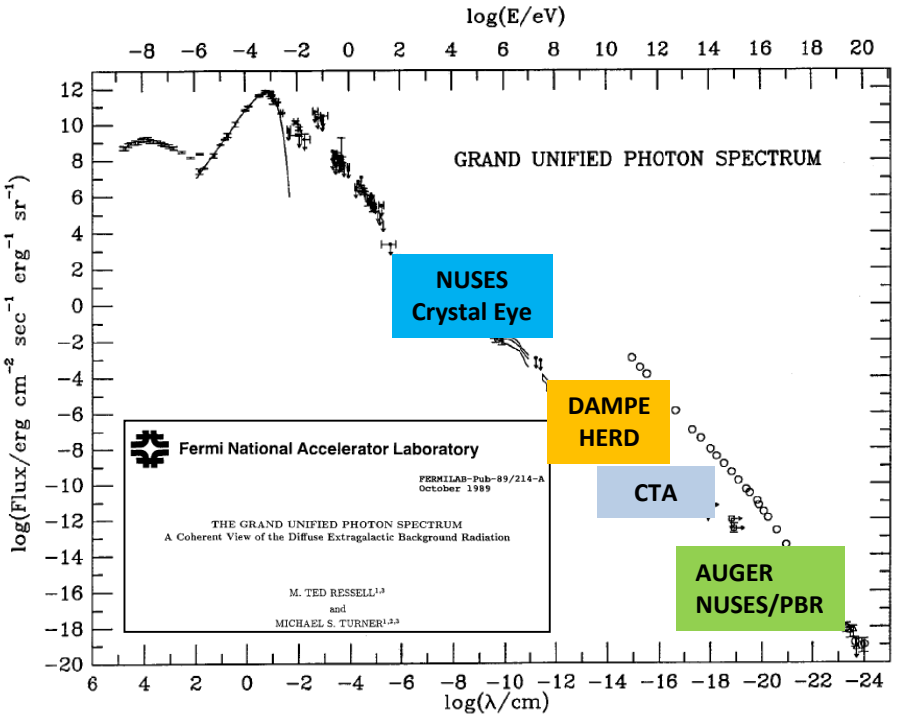
Wide field GRB monitor with pointing capability. Covering the MeV gap (0.1-30 MeV).
Wink to fly onboard Space Rider in 2027. Full scale prototype funded with PNRR funds.

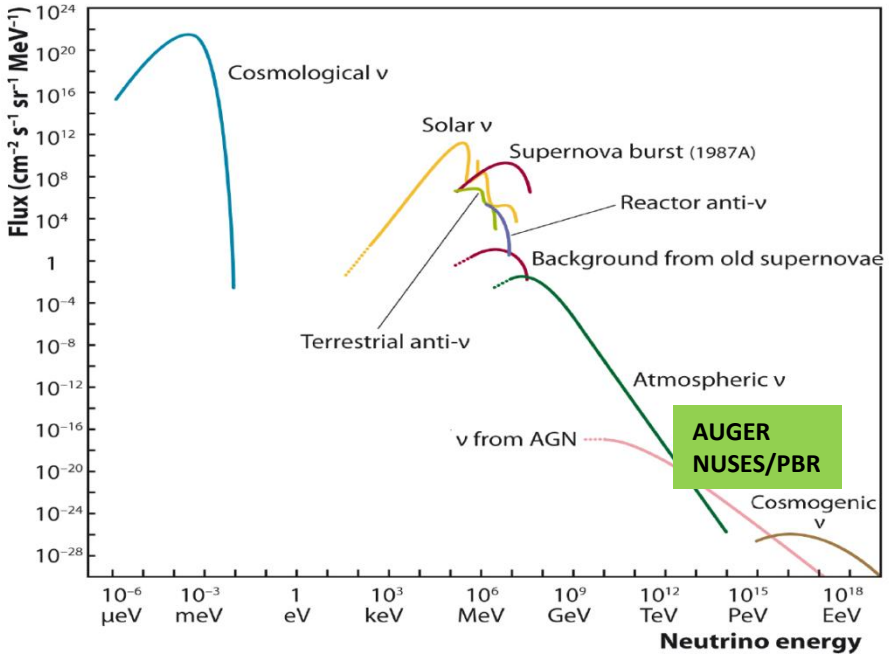
SpaceItUp!

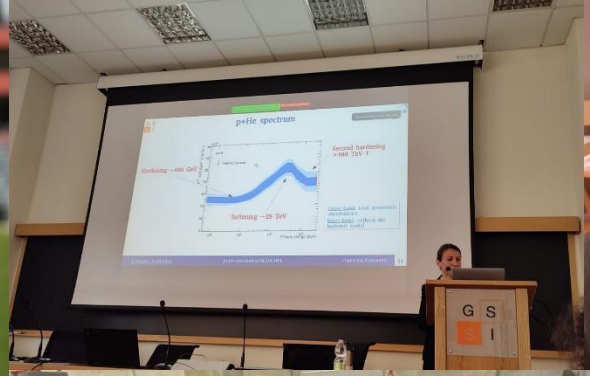
ASI national program. R&D activity for novel space-based radiation detectors

Our landscapes(s)

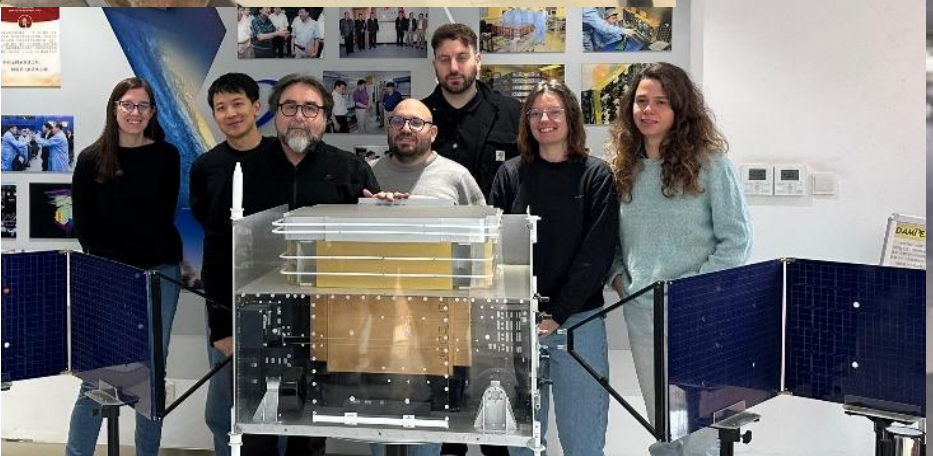






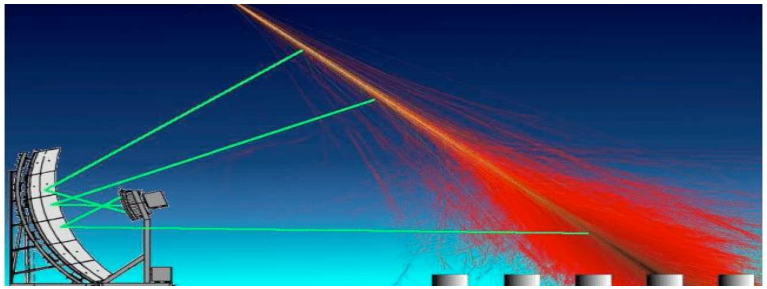

p+He spectrum
Softening ~25 TeV

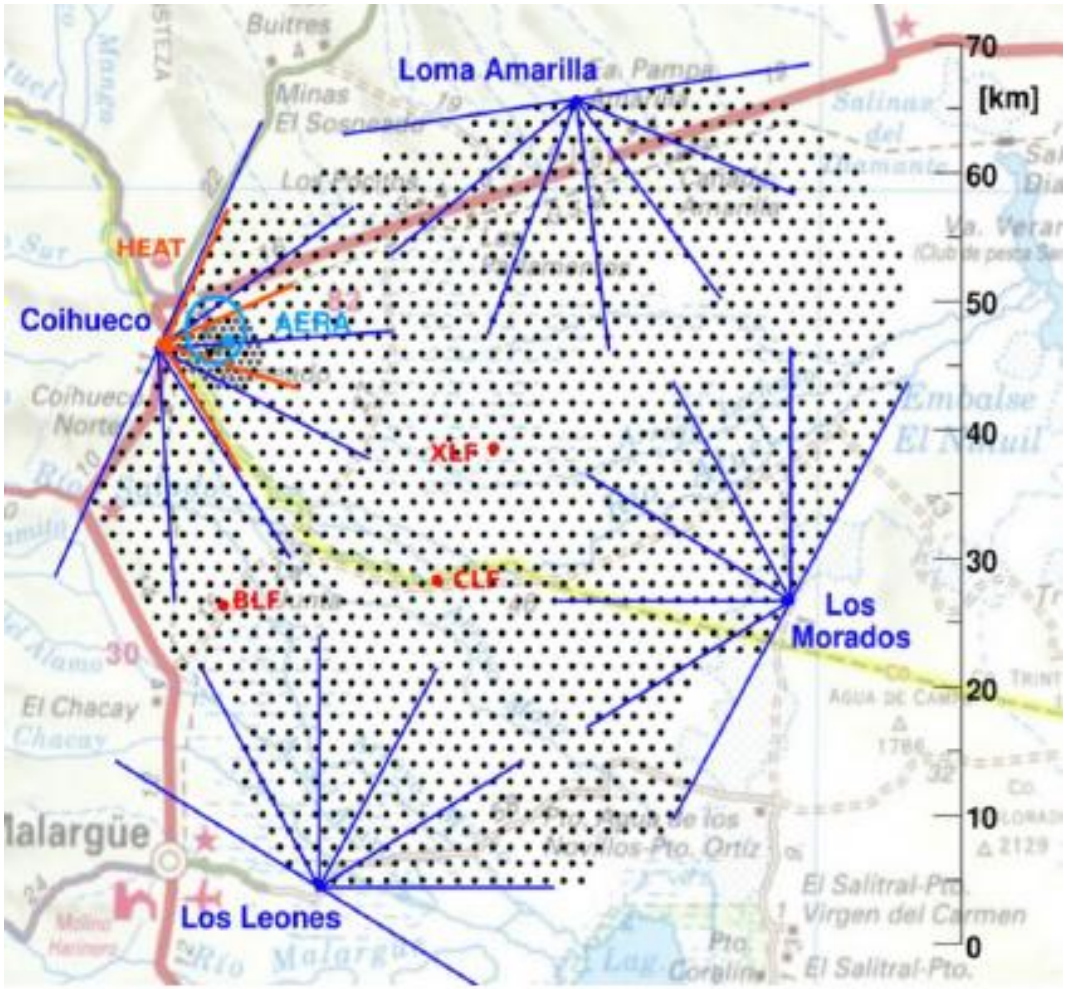

Dimitrios Kyratzis



The Pierre AUGER Observatory

- Malargue (Arg, 35°S), 1400 m a.s.l.
- E range: 10^{17} eV – 10^{21} eV
- Multi-detectors, hybrid reconstruction
- **Surface Detector** array (SD)
  - Sampling EAS particles at ground
  - 1670 WC tanks, 1500 m spacing, 3000 km^2.
  - SD-750, SD-433 (→ ~10^{16} eV)
- **Fluorescence Detectors** (FD)
  - EAS longitudinal profile
  - 24 Telescopes in 4 sites + 3 HEAT



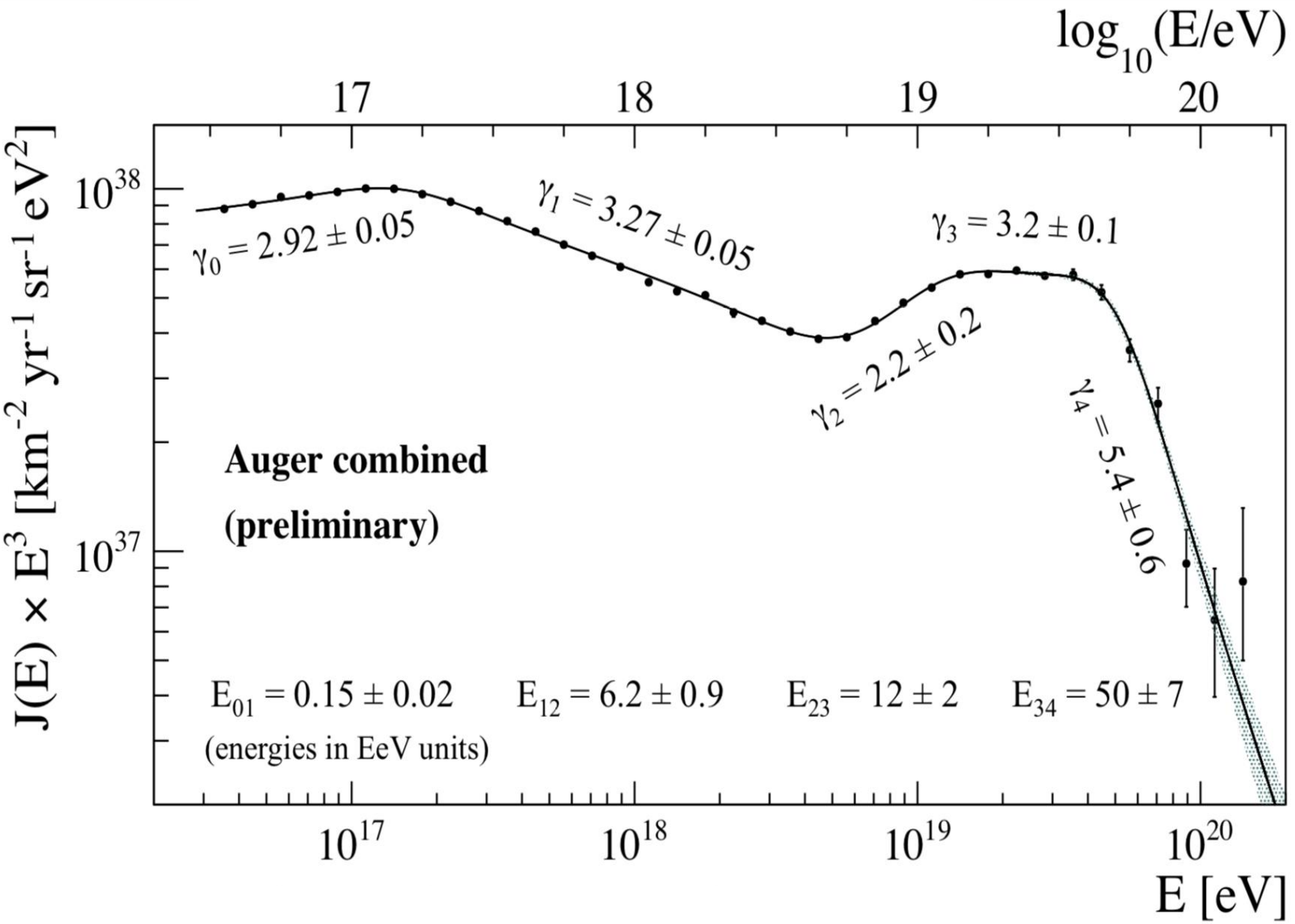


Surface Detector
1670 Water Cherenkov tanks
3.6 m diameter , 1.2 m depth
3 9'' PMTs + 1 Small 1'' PMT

Plus a Scintillation detector on top

Fluorescence Detector
6 telescopes /eye x 4 eyes
3.6 x 3.6 m2 spherical mirrors
80x80 cm2 cameras
440 PMTs, 30x30 deg2 FoV
+ HEAT telescopes

AUGER: the UHECR energy spectrum



AUGER: the arrival directions

Auger Coll., Science (2017), APJ (2018)

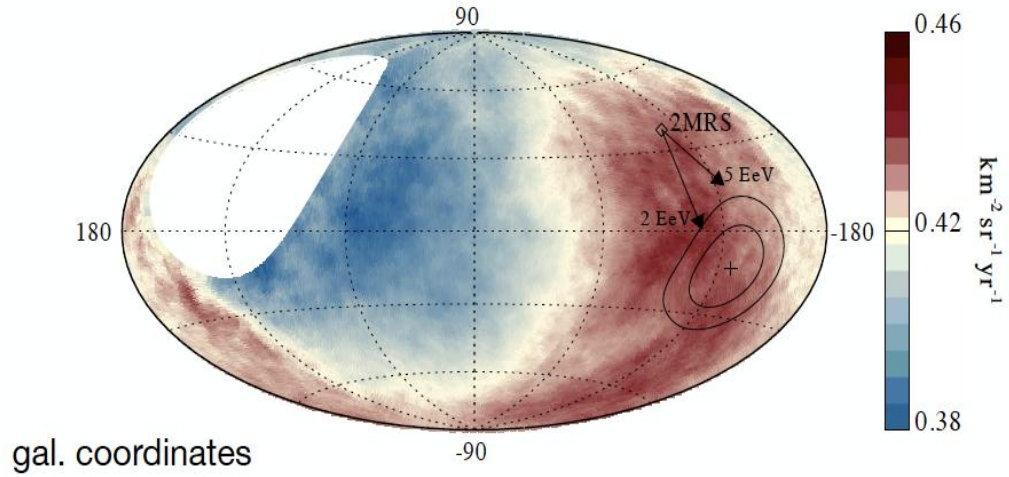
physicsworld TOP 10 BREAKTHROUGH 2017

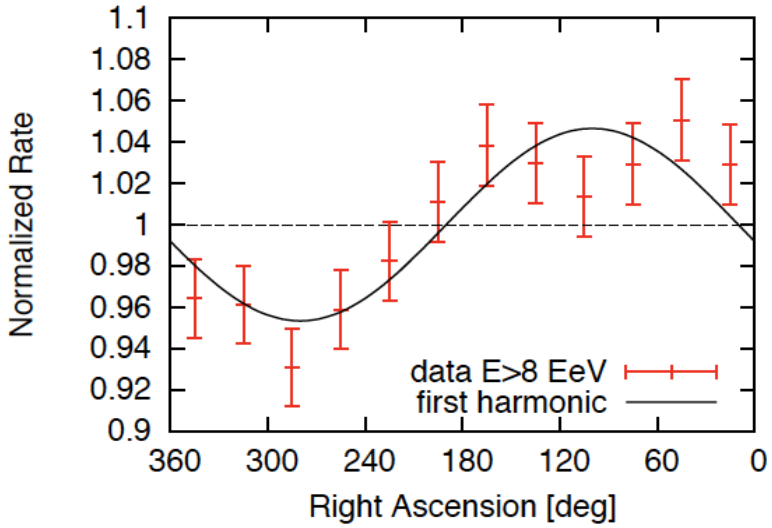
COSMIC RAYS

Observation of a large-scale anisotropy in the arrival directions of cosmic rays above 8×10^{18} eV

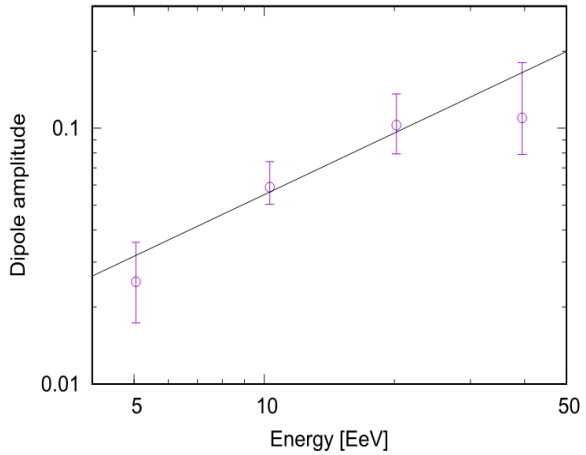
The Pierre Auger Collaboration*†

Cosmic rays are atomic nuclei arriving from outer space that reach the highest energies observed in nature. Clues to their origin come from studying the distribution of their arrival directions. Using 3×10^4 cosmic rays with energies above 8×10^{18} electron volts, recorded with the Pierre Auger Observatory from a total exposure of 76,800 km^2 sr year, we determined the existence of anisotropy in arrival directions. The anisotropy, detected at more than a 5.2σ level of significance, can be described by a dipole with an amplitude of $6.5^{+1.3}_{-0.9}$ percent toward right ascension $\alpha_d = 100 \pm 10$ degrees and declination $\delta_d = -24^{+12}_{-13}$ degrees. That direction indicates an extragalactic origin for these ultrahigh-energy particles.





The Astrophysical Journal, 868:4 (12pp), 2018 November 20



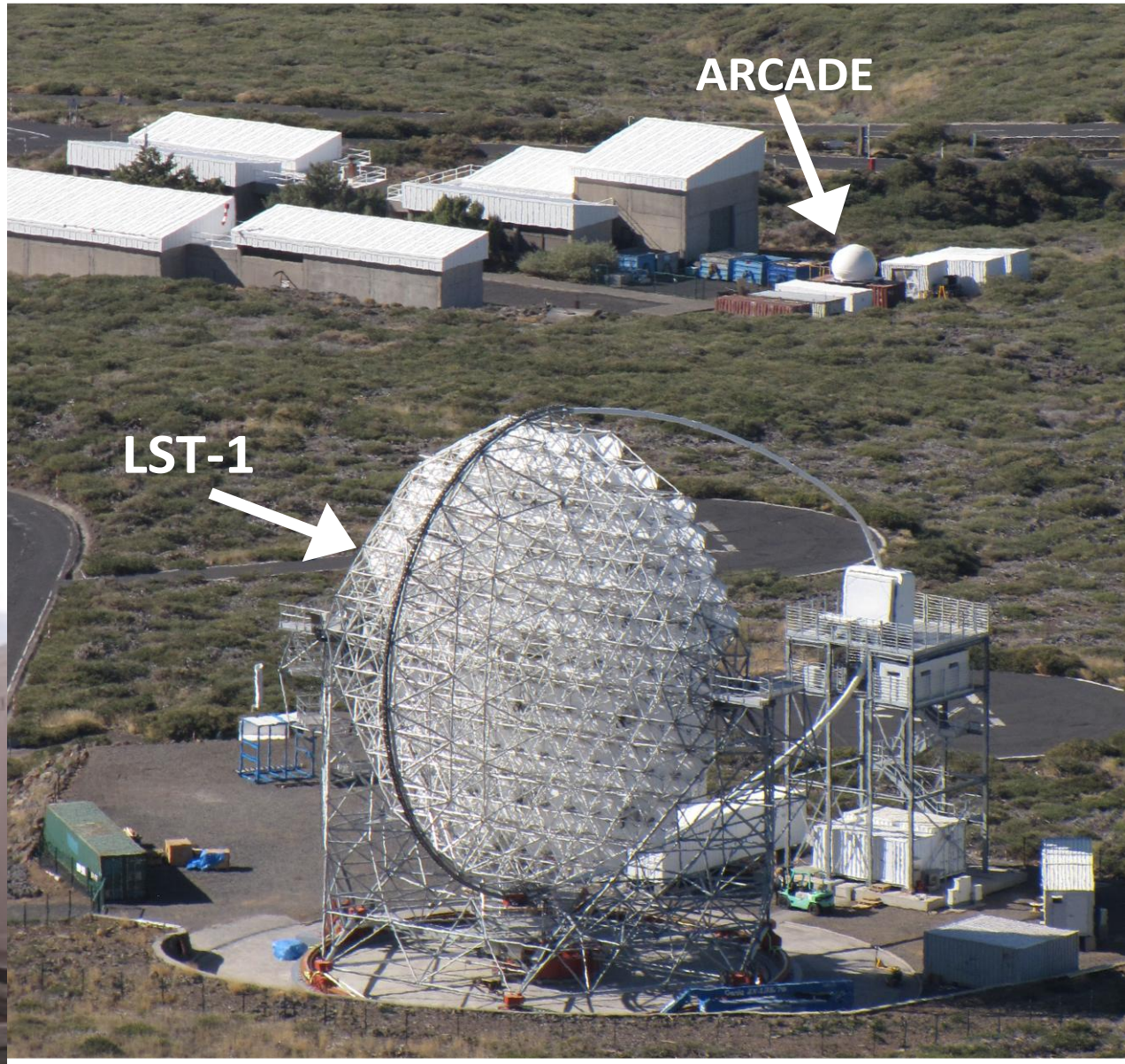
The Cherenkov Telescope Array: CTA

cta cherenkov telescope array **ARCADE Raman lidar**

INFN Istituto Nazionale di Fisica Nucleare
Sezione di Torino
Sezione di Napoli
Gruppo Collegato GSSI L'Aquila

CETEMPS DSFC
Università degli Studi dell'Aquila
Dipartimento di Scienze fisiche e chimiche
CETEMPS

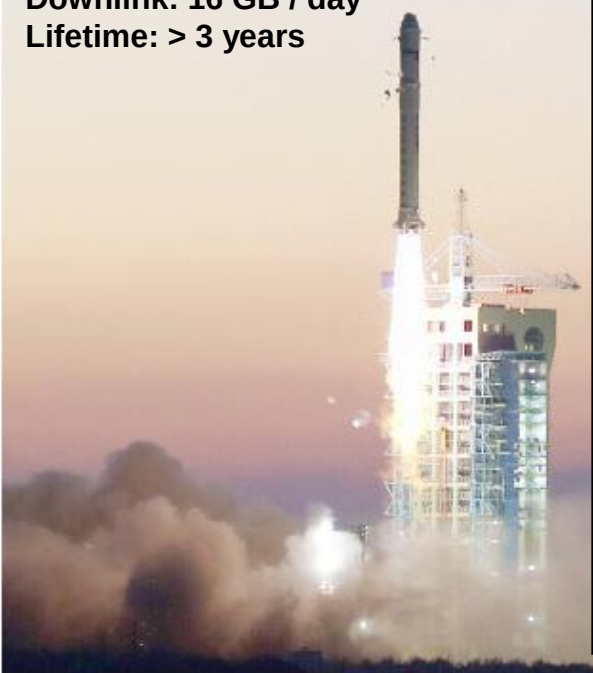
Università degli Studi di Napoli Federico II
Dipartimento di Fisica «Ettore Pancini»

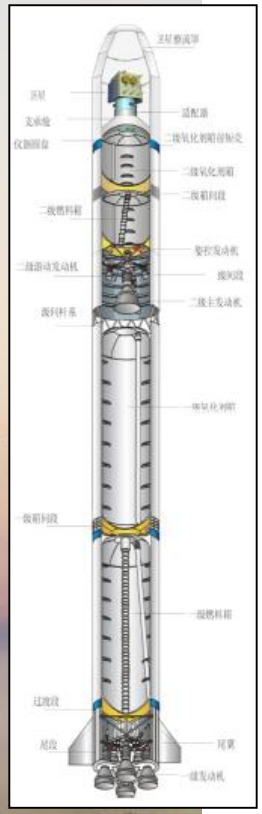


DAMPE: the mission

Launched on Dec. 17, 2015
From the Juquan Space Center
Gobi desert
CZ(LM)-2D rocket

Mass: 1850 kg (scientific payload 1400 kg)
Power : 640 W (scientific payolad 400 W)
Orbit: sun syncronous
Altitude: 500km
Inclination: 97.41°
Period: 95 minutes
Downlink: 16 GB / day
Lifetime: > 3 years





8th International DAMPE workshop, GSSI , December 2018

Three major scientific goals

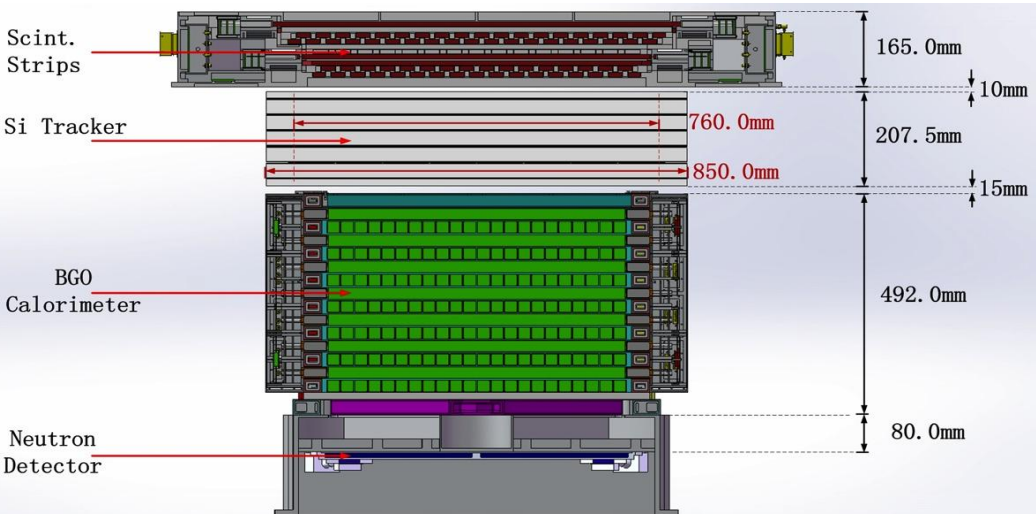
Cosmic ray physics

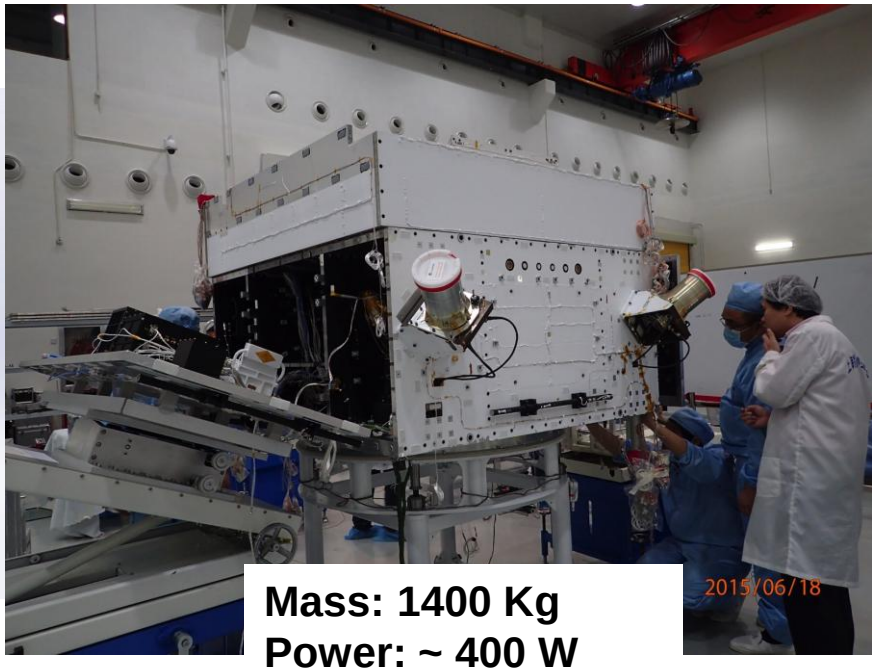
γ-ray astronomy

Dark matter indirect detection

DAMPE: the detector

	DAMPE	AMS-02	Fermi LAT
e/γ Energy res.@100 GeV (%)	**1.5**	3	10
e/γ Angular res.@100 GeV (°)	0.1	0.3	0.1
e/p discrimination	10^5	10^5 - 10^6	10^3
Calorimeter thickness (X_0)	**32**	17	8.6
Geometrical accep. (m^2sr)	**0.29**	0.09	1





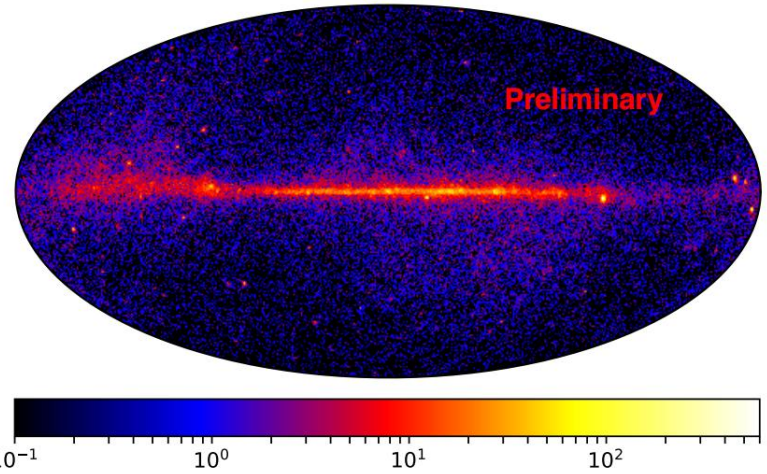
Mass: 1400 Kg
Power: ~ 400 W
Livetime: > 3 years

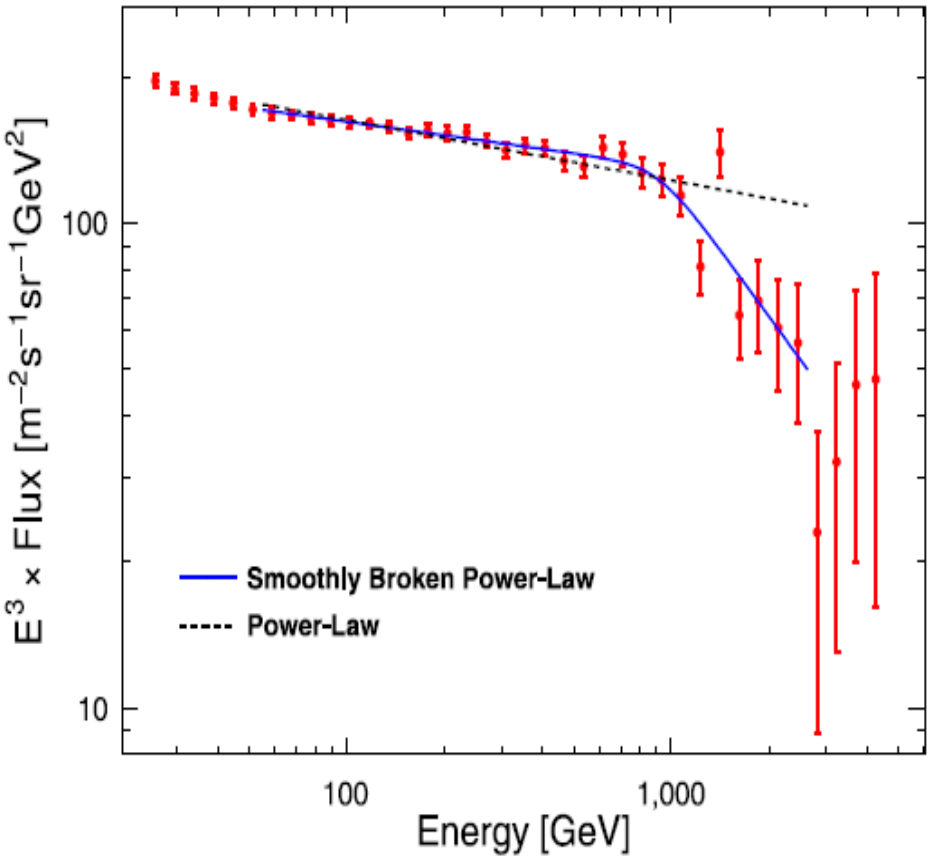
DAMPE: some science results

LETTER nature International weekly journal of science
doi:10.1038/nature24475

Direct detection of a break in the teraelectronvolt cosmic-ray spectrum of electrons and positrons

DAMPE Collaboration*

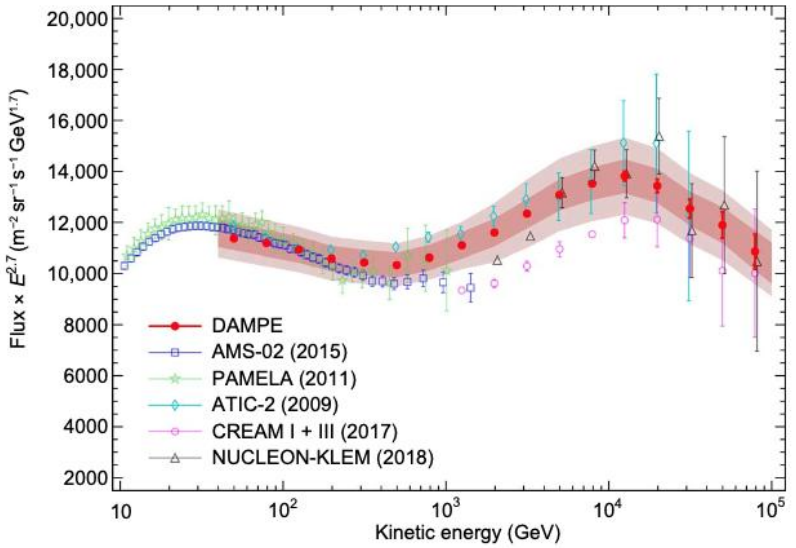




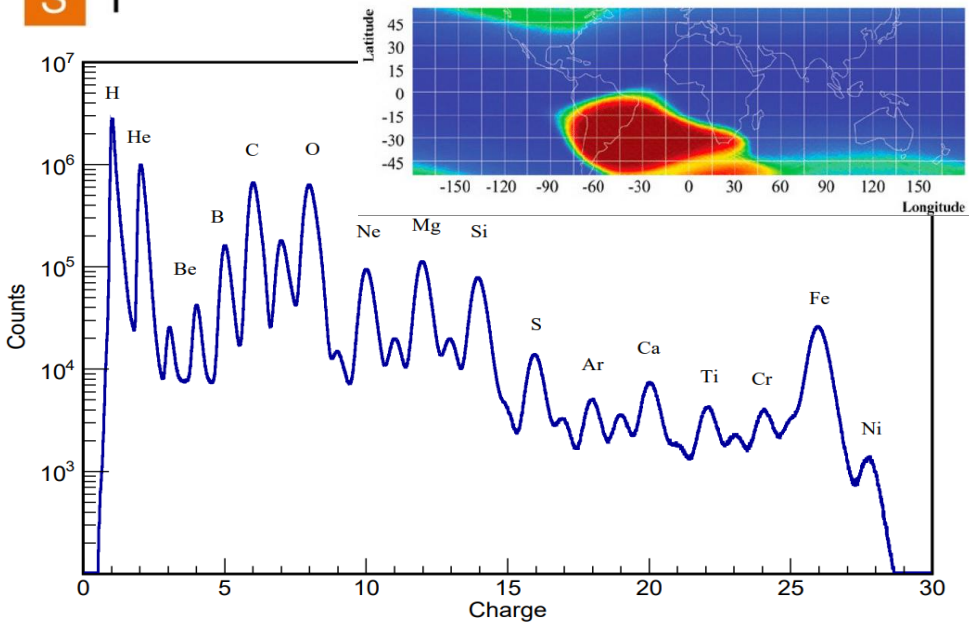
SCIENCE ADVANCES | RESEARCH ARTICLE

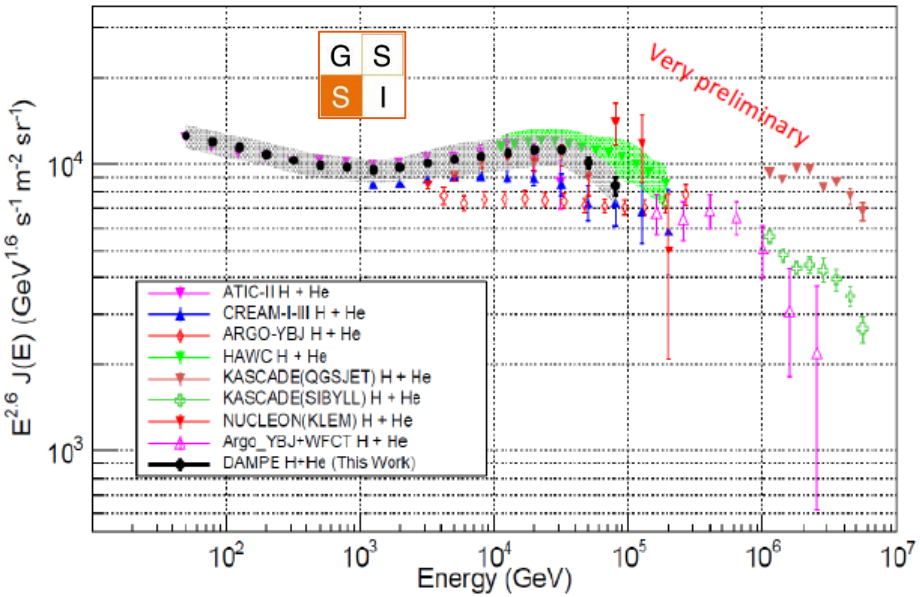
PHYSICS

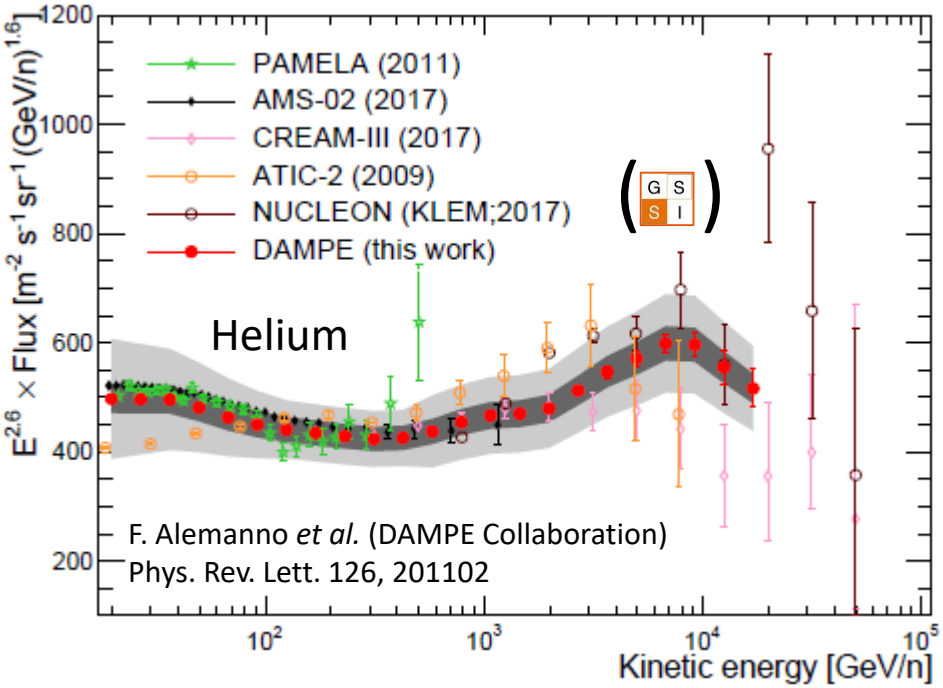
Measurement of the cosmic ray proton spectrum from 40 GeV to 100 TeV with the DAMPE satellite



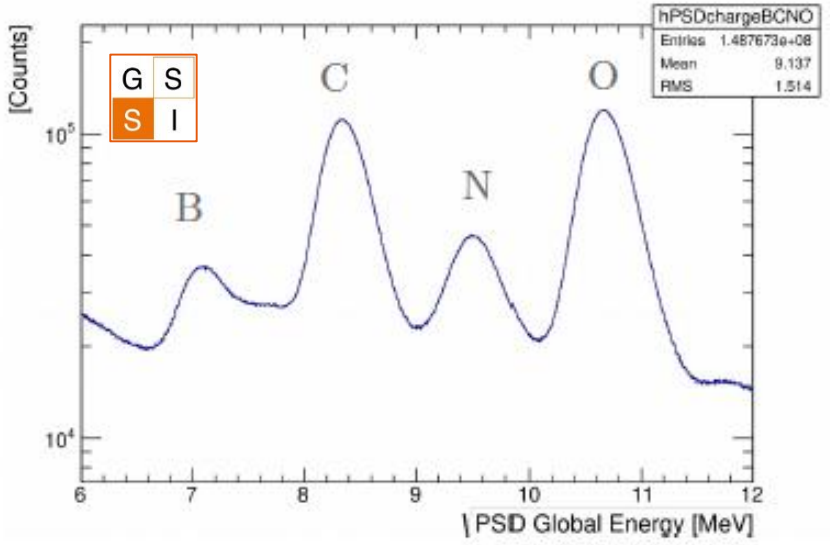
DAMPE: some science results





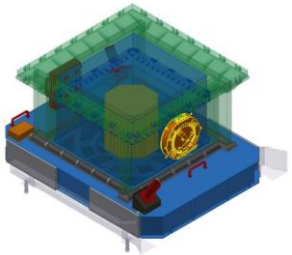


F. Alemanno *et al.* (DAMPE Collaboration)
Phys. Rev. Lett. 126, 201102

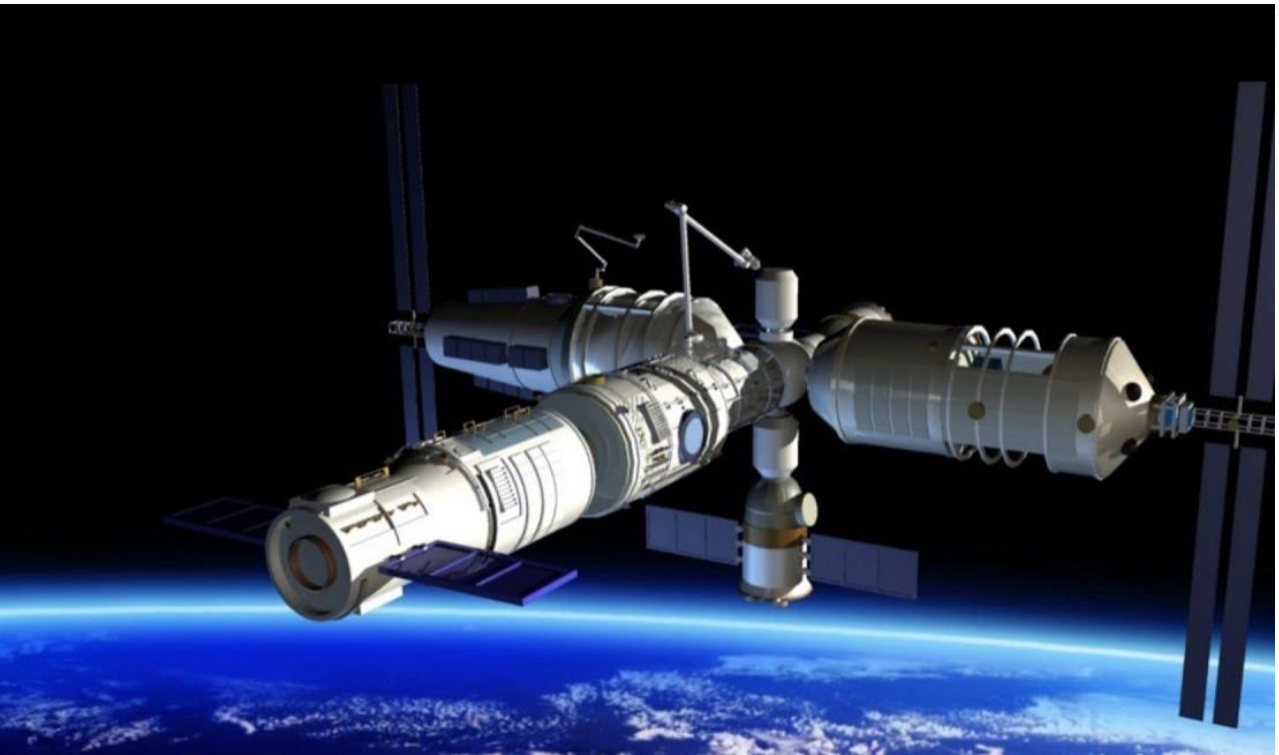


HERD: High Energy Radiation Detector

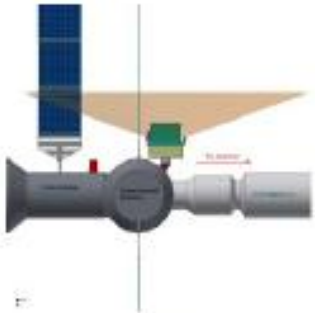
- HERD, a China-led mission with a key European contribution led by Italy, is proposed by IHEP as an astronomy and particle astrophysics experiment onboard the China's Space Station, which is planned for operation starting around 2029 for about 10 years.



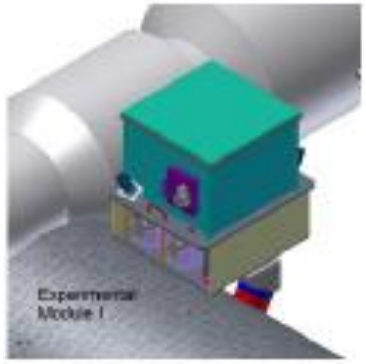
- Main Science goals
  - Precise cosmic ray spectra and composition up to the "knee"
  - Gamma-ray astronomy and transient studies (flaring, e.m. follow, …)
  - Electrons spectra (and anisotropy) up to tens of TeV
  - Indirect dark matter searches with high sensitivity



(a) Top view

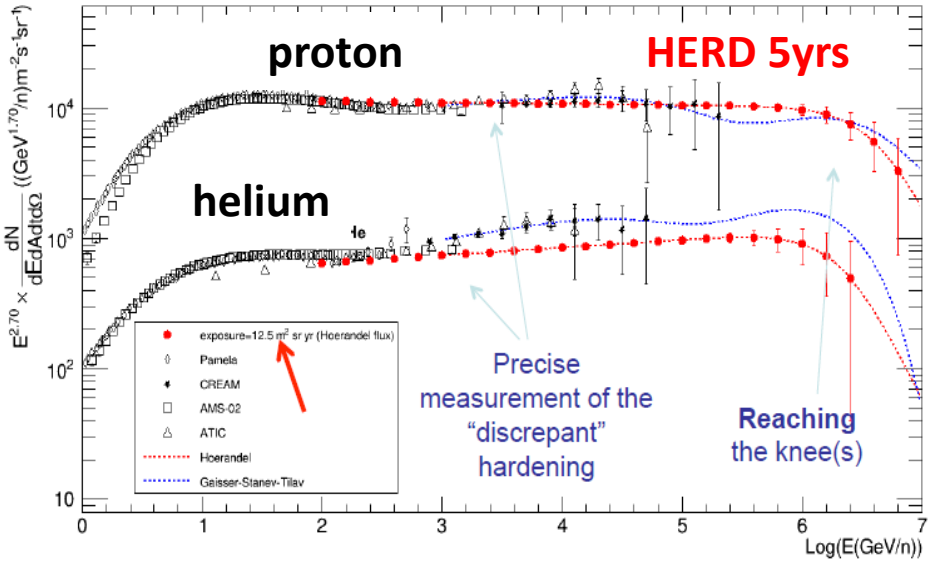


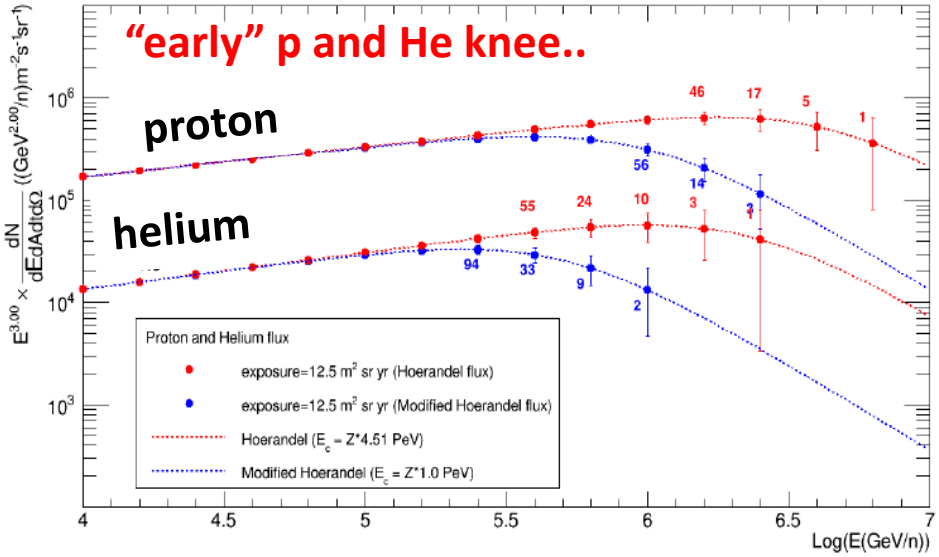
(b) Side view

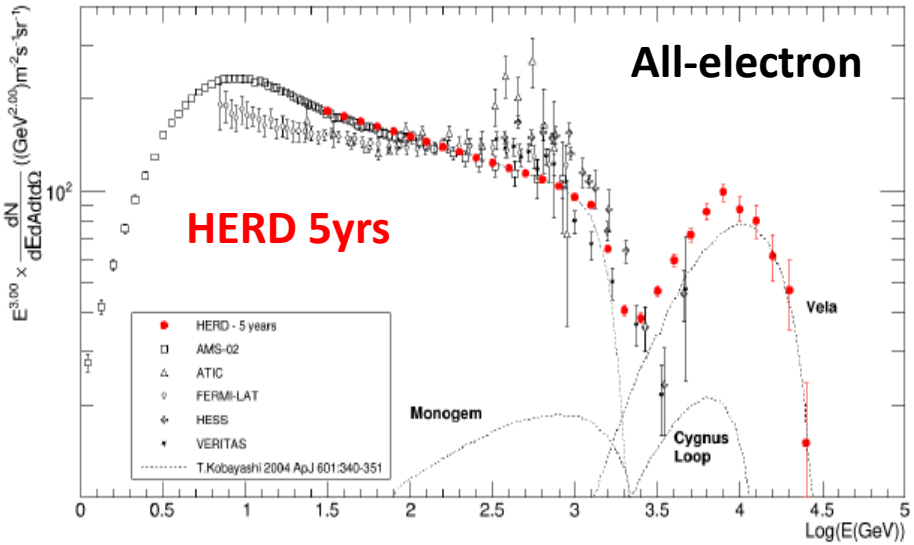


(c) Oblique view

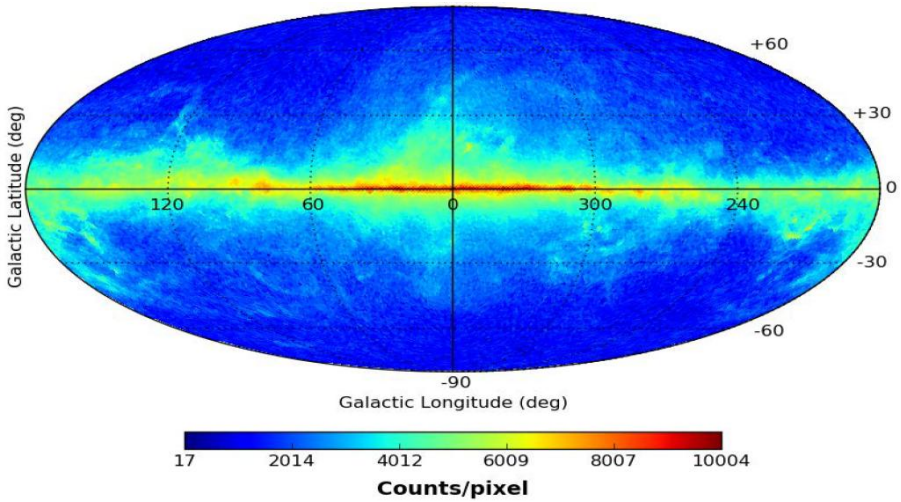
HERD: some performance plots (1)







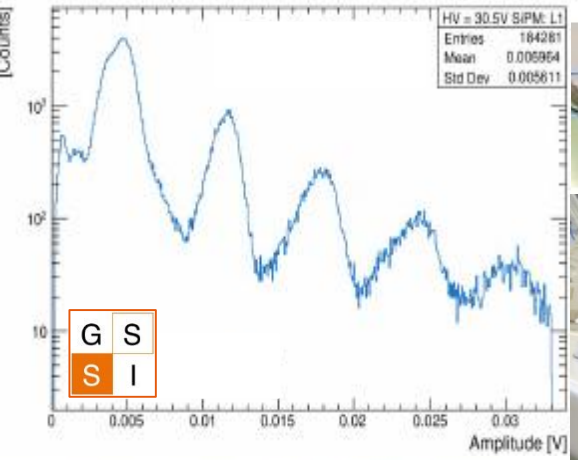
HERD 5yrs, photon map, E_γ > 1GeV

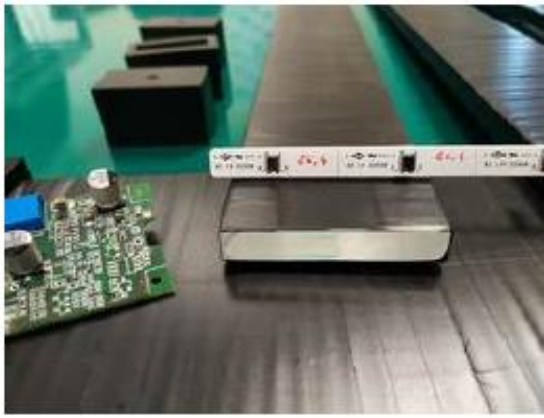


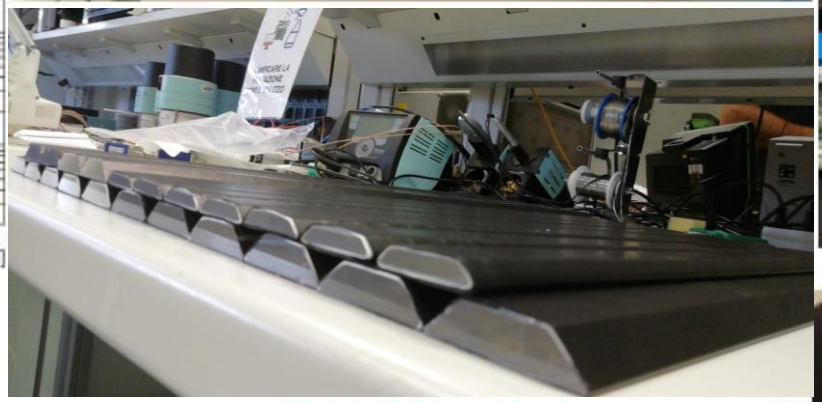
HERD: PSD R&D activity at GSSI

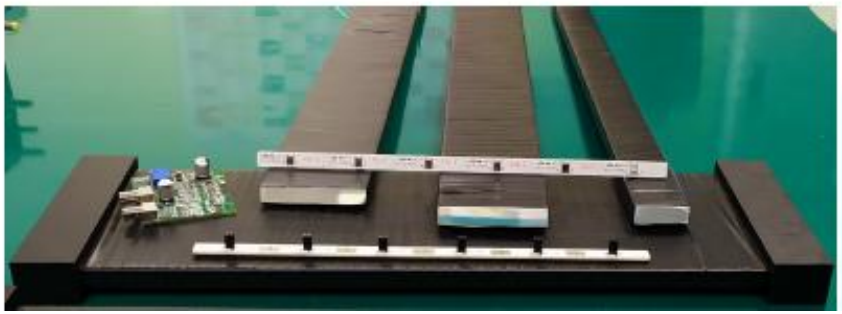
Configuring various scintillator bars coupled with AdvanSiD/Hamamatsu SiPMs.

- Purification, wrapping and coupling procedures carefully carried out at GSSI – LNGS
- Specifically used: [50 x 3 x 1 cm³] bars coupled with 1 SiPM/side
- Ongoing measurements also include: [50 x 6 x 1 cm³] bars coupled with 2 SiPMs/side
- Collaboration with other institutes in Italy in order to determine the optimal geometry.









THE **NUSES** SPACE MISSION

Italian led mission conceived as a **pathfinder** for **new observation methods and technologies** in the study of high and low energy radiations from space **enabling new sensors and tools**

60+ persons from many institutions.

Large **expertise** (and **synergies**) from space missions/R&D: AMS, DAMPE, FERMI, LIMADOU, GAPS, HERD, PAMELA, SPB, newASTROGAM, POEMMA, …

Participating Research Institutes:

- Gran Sasso Science Institute
- INFN Laboratori Nazionali del Gran Sasso
- Università dell'Aquila
- Università di Torino and INFN Torino
- Università di Trento and INFN-TIFPA
- Università di Bari, Politecnico di Bari and INFN Bari
- Università di Padova and INFN Padova
- Università "Federico II" and INFN Napoli
- Università del Salento and INFN Lecce
- University of Geneva
- Columbia University
- NASA Goddard Space Flight Center
- Pennsylvania State University
- New York University Abu Dhabi

Other Industrial Partners:

OFFICINASTELLARE OUR WORLD, YOUR SPACE

Nuclear Instruments

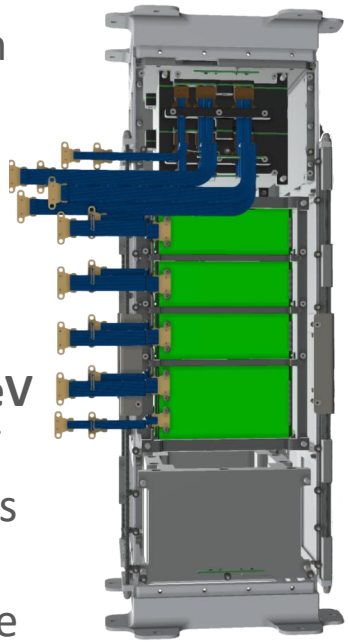
FONDAZIONE BRUNO KESSLER

GRAN SASSO TECH

NUSES: **TWO PAYLOADS**

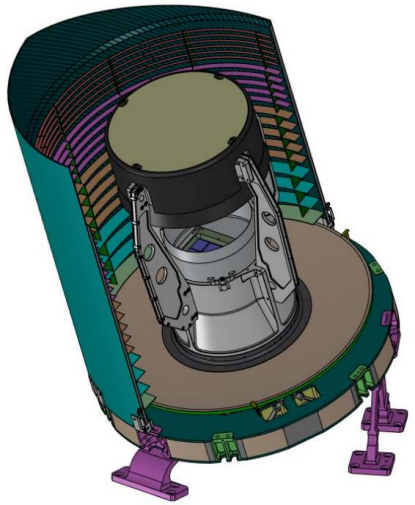
Zirè

- **Measure the flux (E<300 MeV) of cosmic e^-, p** and light nuclei of solar/galactic origin;
- Study of the cosmic radiation variability (Van Allen belt system);
- Possible correlation with seismic activity due to **Magnetosphere-Ionosphere-Lithosphere Coupling** (MILC);
- Detection of **0.1 - 50 MeV** photons for the study of transient gamma sources **(GRBs)**;
- Paving the way for future **applications of new technology** (SiPM, Fiber Tracker, GRB detection…);



Terzina

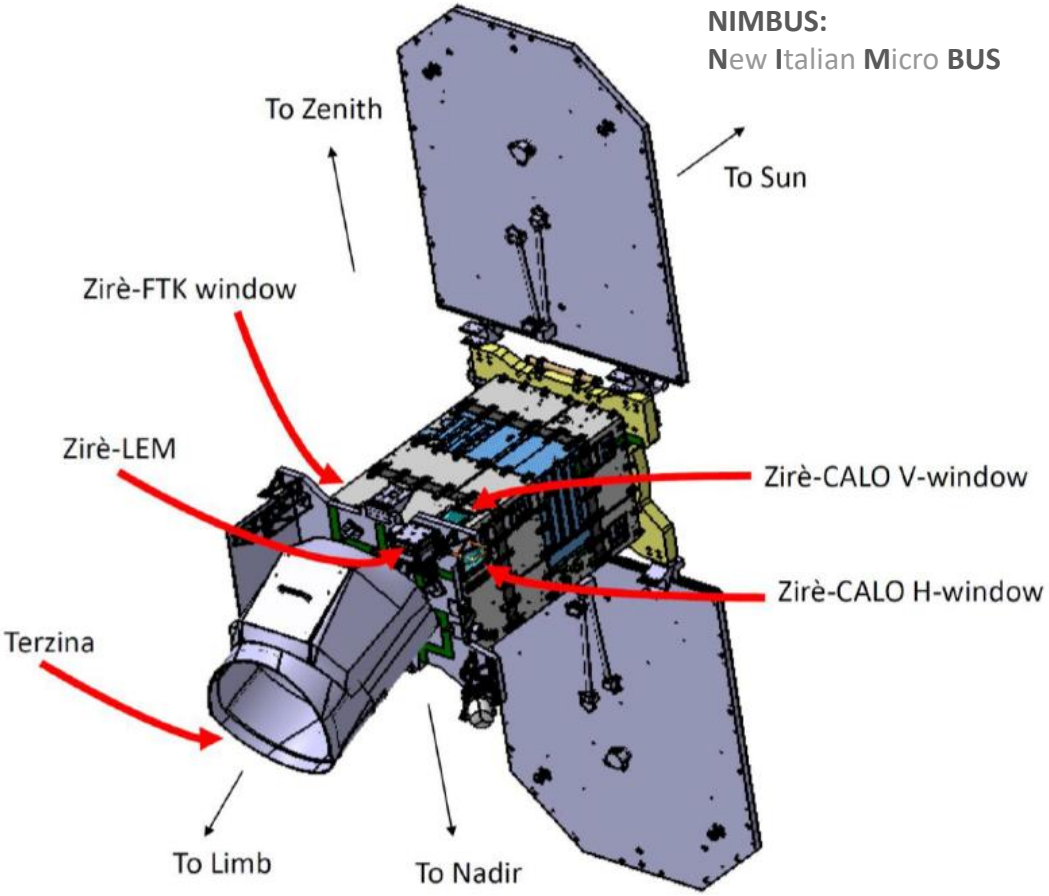
Pathfinder for future missions devoted to **UHE cosmic rays and neutrino** astronomy through **space-based** detection atmospheric **Cherenkov light** induced by Extensive Air Showers (EAS) with $10^{16.5}$ – $10^{18.5}$ eV

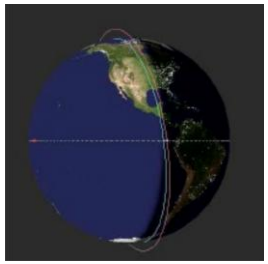


New Technologies and approaches
Development of new observational techniques, testing new sensors (e.g. **SiPM**) and related electronics, DAQ, onboard AI, for space missions. New solutions for the satellite platform.

NUSES: **CONFIGURATION AND ORBIT**

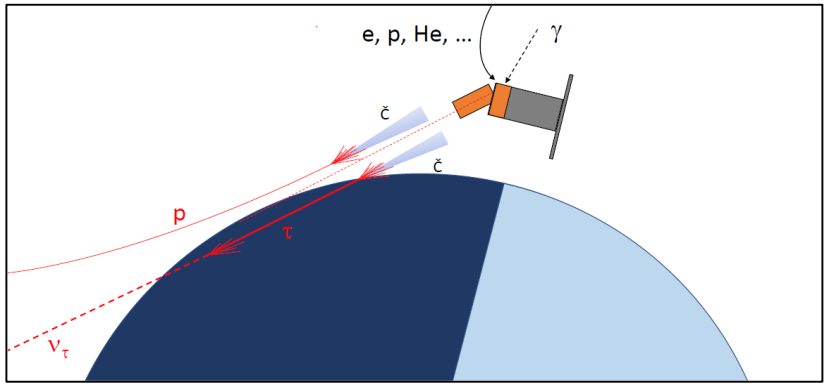
NIMBUS:
New **I**talian **M**icro **BUS**

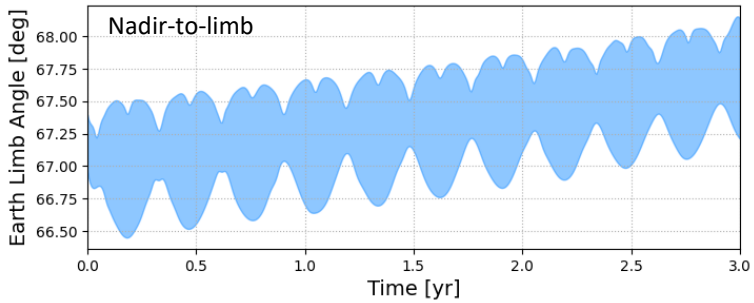




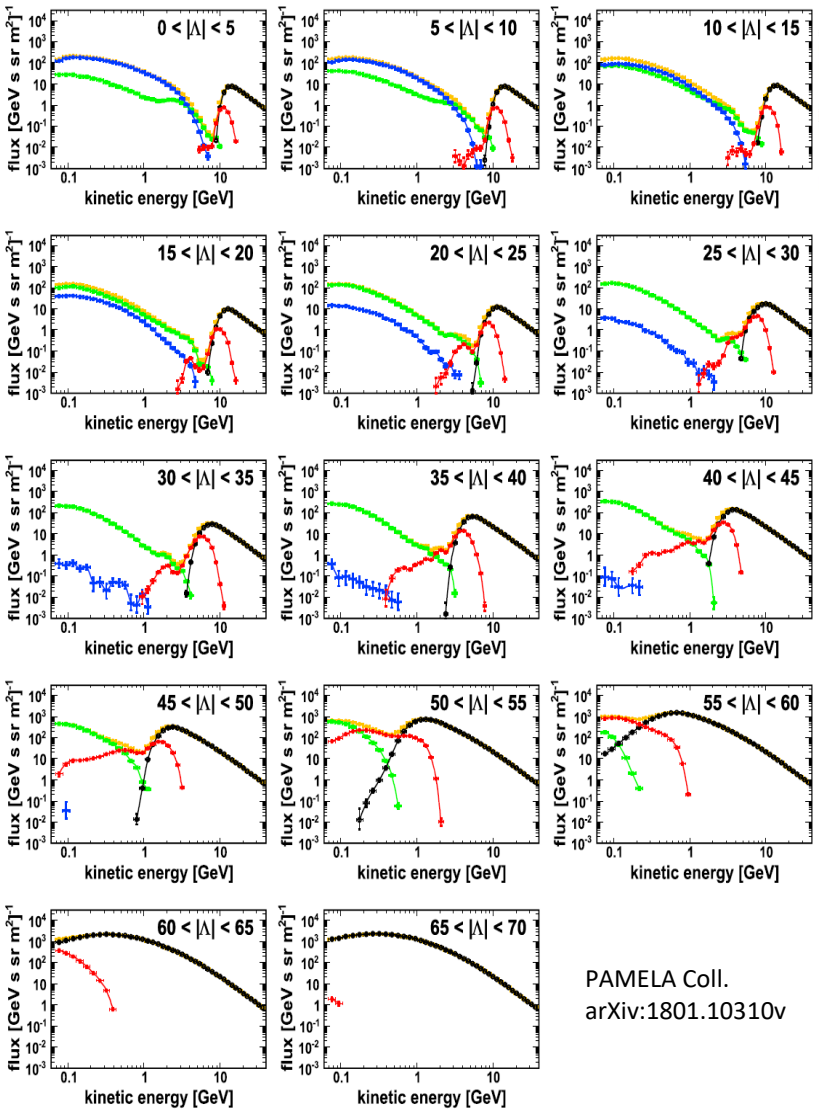
Low Earth Orbit (LEO) with high inclination, **sun synchronous orbit on the day-night border.**

- Altitude ~550 km
- Inclination = 97.8 deg
- LTAN = 18:00

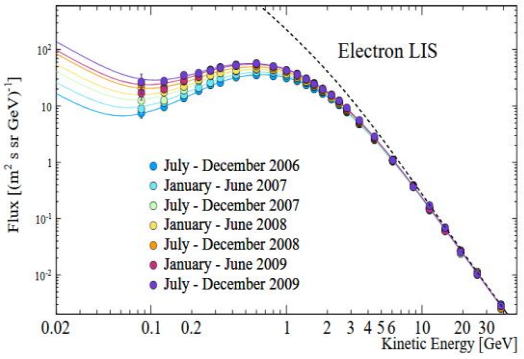


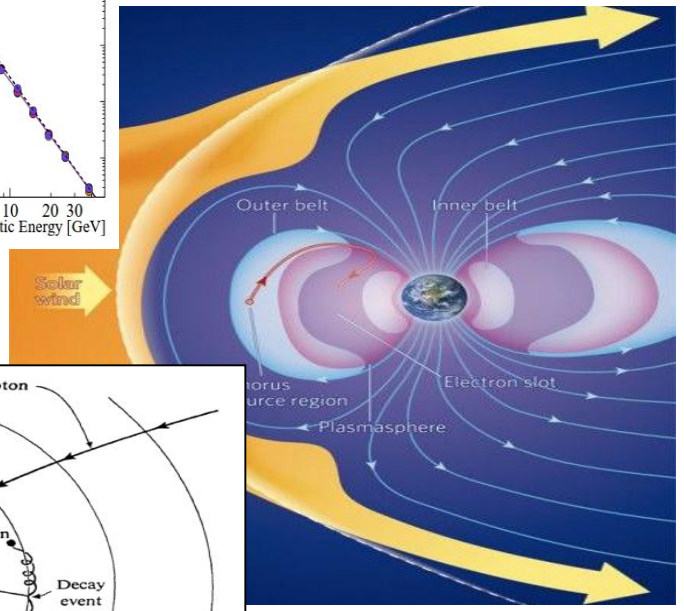


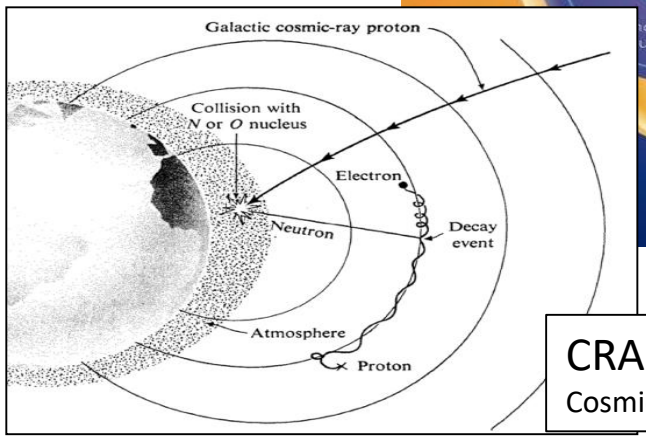
Zirè: **Low energy cosmic rays and MeV photons**



PAMELA Coll.
arXiv:1801.10310v







CRAND

Cosmic Ray Albedo Neutron Decay

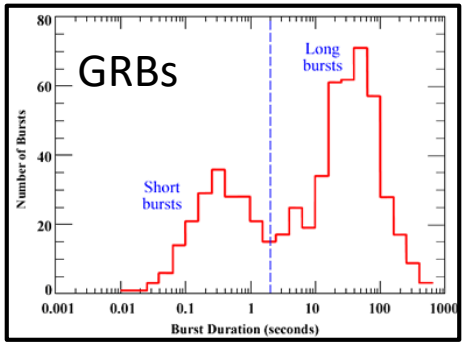
Belt type	Composition	Rigidity [MeV/n]	Filling mechanisms	L	Residence time [d]
Van Allen (inner)	p e^-	$0.1-100$ $0.01-1$	$n \to pe^-\overline{\nu}_e$, external belts	< 2.5	$10-1000$
Van Allen (outer)	e^- p	$1-10$ $0.1-1$	solar wind	> 2.5	$1-10$
SAMPEX	N^{+x}, O^{+x}, Ne^{+x}	10 $10-100$	Anomalous CR	2	$10-100$

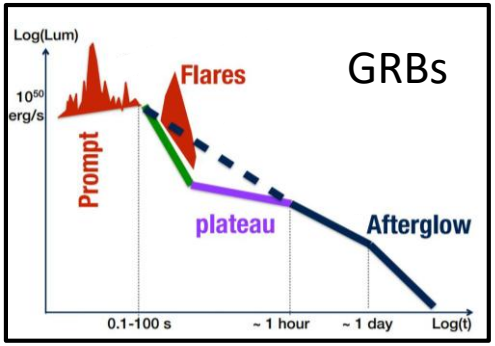
Zirè: **Low energy cosmic rays and MeV photons**

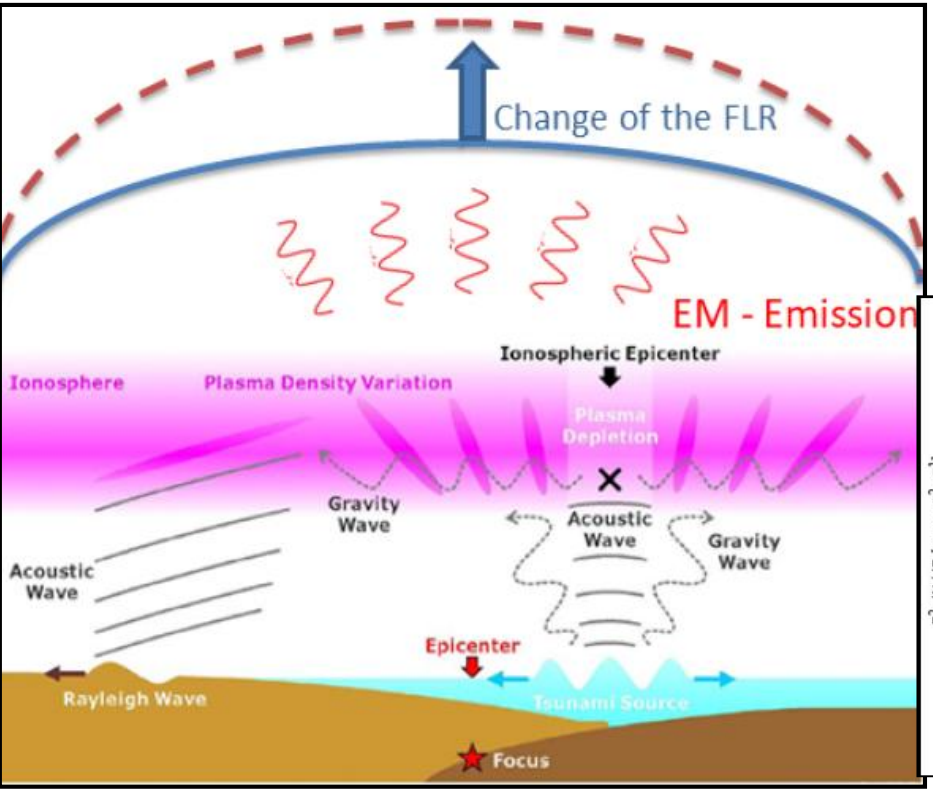
Magnetospheric
Ionospheric
Lithospheric
Coupling

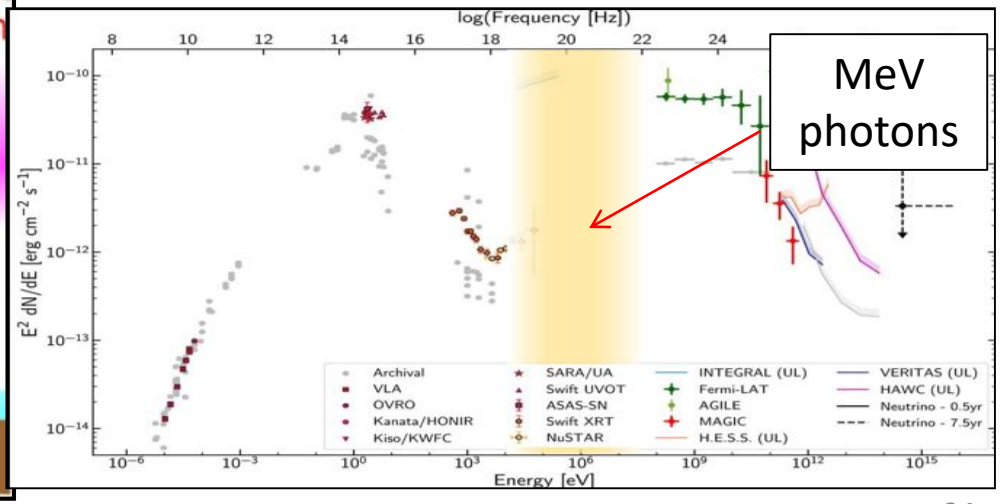
Electrons and protons

Transient
gamma ray
sources







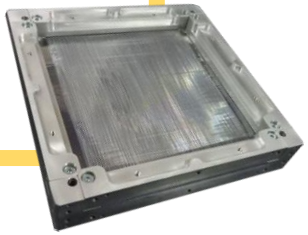


Zirè: **LAYOUT**

FTK, PST, ACS and CALOg are all readout by SiPM sensors

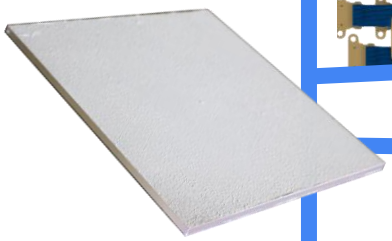
Fiber TracKer (FTK)

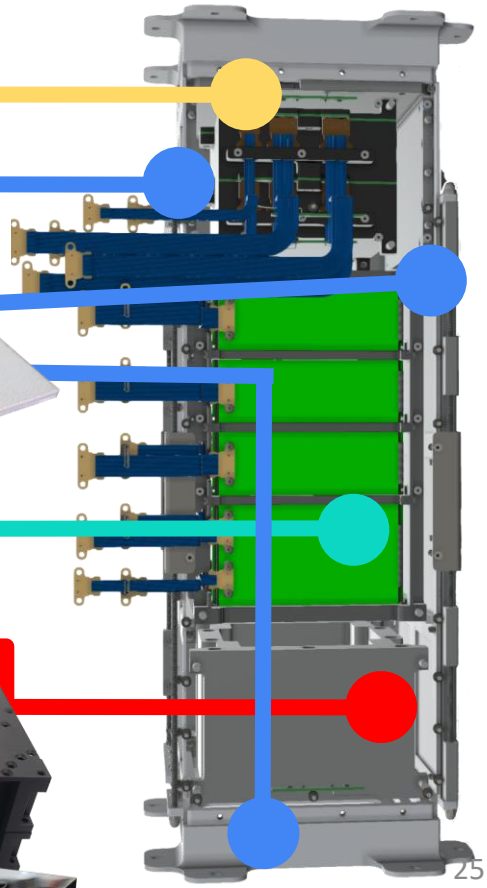
3 double layer XY modules of fibers to be used for track identification.



Anti-Coincidence System (ACS)

9 PS layers surrounding the detector.





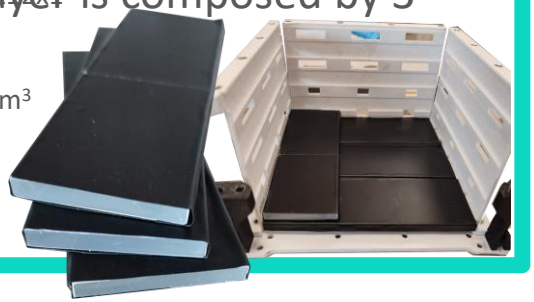
Plastic Scintillator Tower (PST)

Tower of 32 Plastic Scintillator layers.

Each layer is composed by 3 bars.

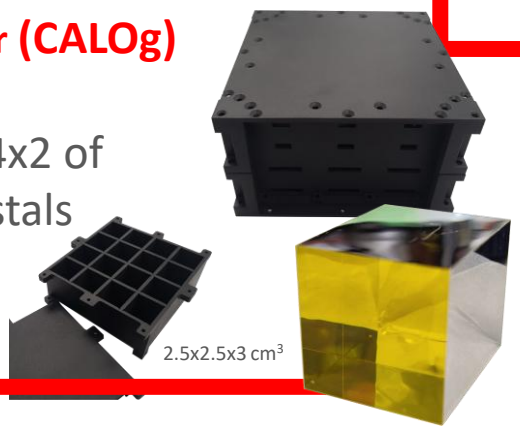
6 layers: 4x4x1 cm^3

26 layers: 4x12x0.5 cm^3



Calorimeter (CALOg)

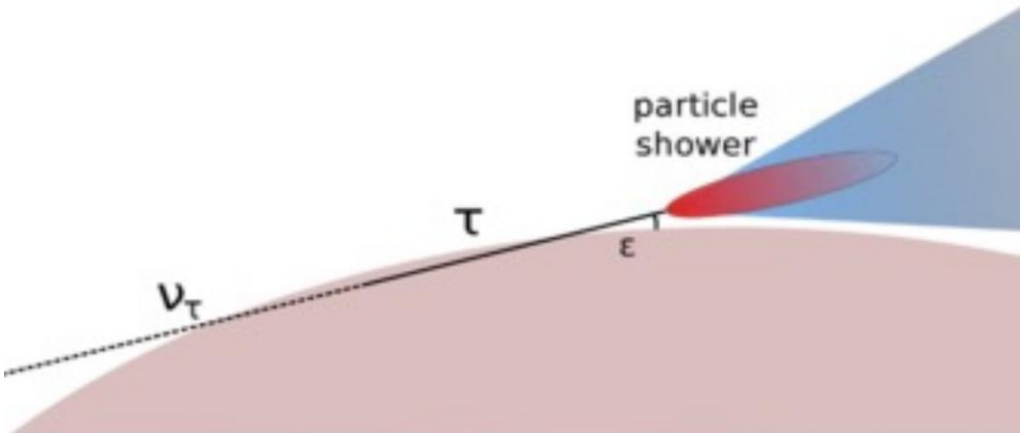
Matrix 4x4x2 of GAGG crystals



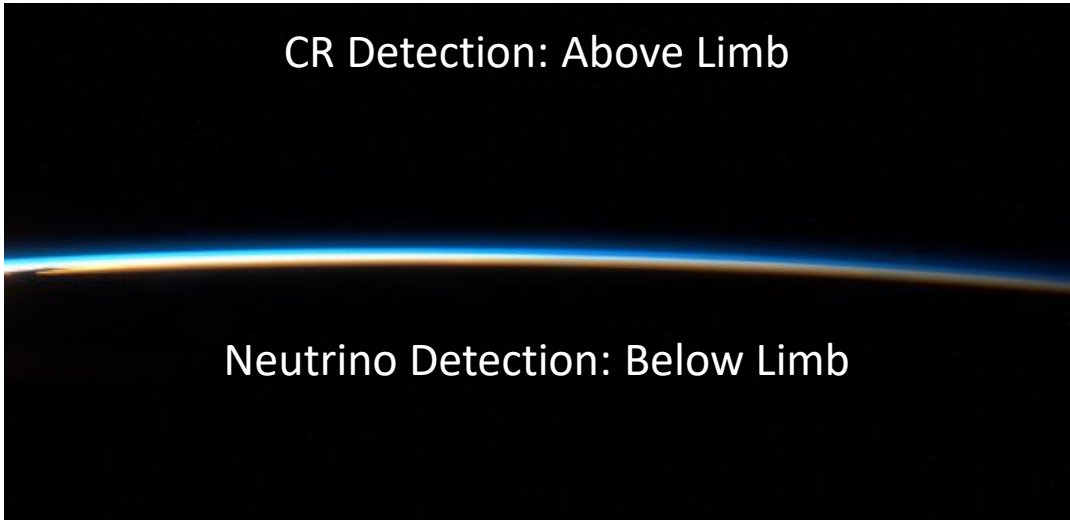
2.5x2.5x3 cm^3

25

The observation of **astrophysical neutrinos** at energies > **10 PeV** can be achieved by detecting EAS produced by Earth skimming events. The Cherenkov emission of these cascades provides a **unique signal for space based (LEO) instruments**.



Similar signals are produced by high energy cosmic rays (**CR)** impinging the atmosphere from **above the Earth's limb**. Thus, also CR with E>10 PeV can be observed through EAS's Cherenkov emission from space. This provides a useful **reference/calibration signal**.

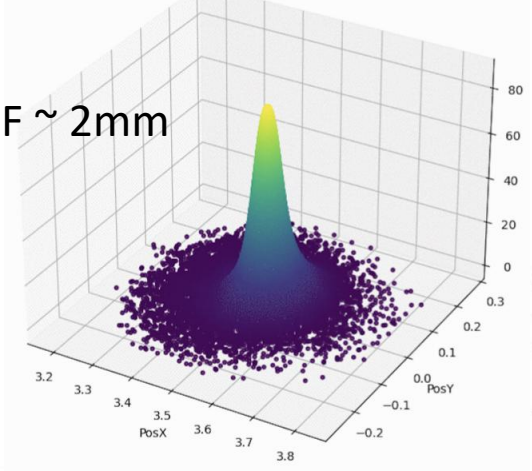


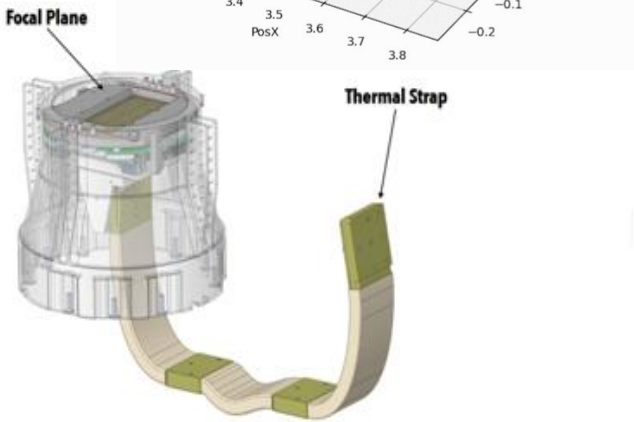
Terzina: **Layout**

A double mirror telescope composed by:
- the structural (mechanics) and thermal control (TC) assembly
- the optical head unit
- the focal plane assembly (FPA)
- the front-end electronics (FEE) and data acquisition (DAQ) boards

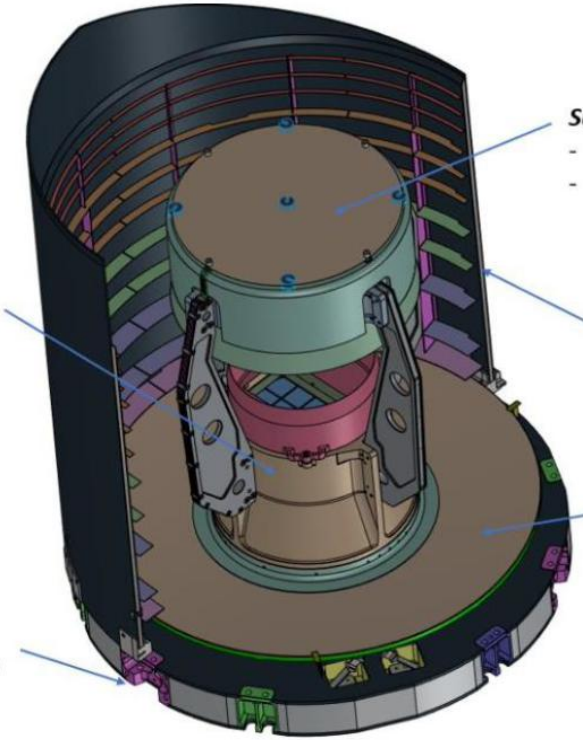
Schmidt-Cassegrain (Ritchey-Chrètien) compact system with:
- M1: hyperbolic mirror
- M2: corrector lens with coated external surface acting as aspherical mirror

Equivalent focal length F_L	925 mm
Field of View (FoV)	7.2° x 2.9°
Point spread function (PSF)	~ 2 mm < Pixel size
Effective area	0.1 m^2
Shadowing	8 %





Central support tower:
- *FPA support*
- *M1 baffle for stray-light rejection*
- *Titanium gr.5 and bolted joints to withstand low temperature*



Secondary mirror assembly
- *Invar36 mirror cell*
- *M2 heating system*

External baffle:
- *stray-light rejection*

Primary mirror assembly
- *Invar36 mirror cells*

Optical bench
- *M1 heating system*

Terzina: **The Focal Plane Assembly (FPA)**

SiPM based camera, consisting of,

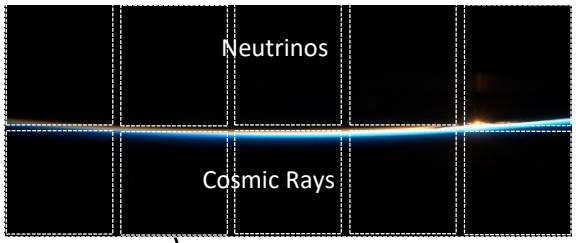
- 8 x 8 SiPM arrays
- 2 rows w/ 5 arrays per row
- Total: 640 pixels (channels)
- Array Area: 25.3 x 25.4 mm^2
- Array Eff. Area: 24.0 x 24.0 mm^2

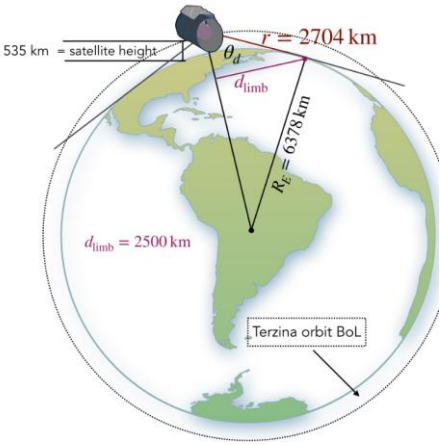
SiPMs connected to a PCB providing:

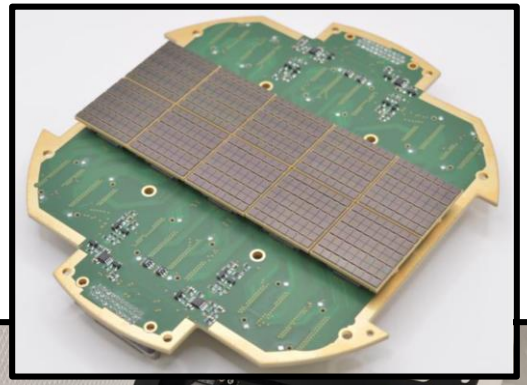
- bias HV
- signal routing to a DAQ board
- temperature & radiation sensors
- LED pulser

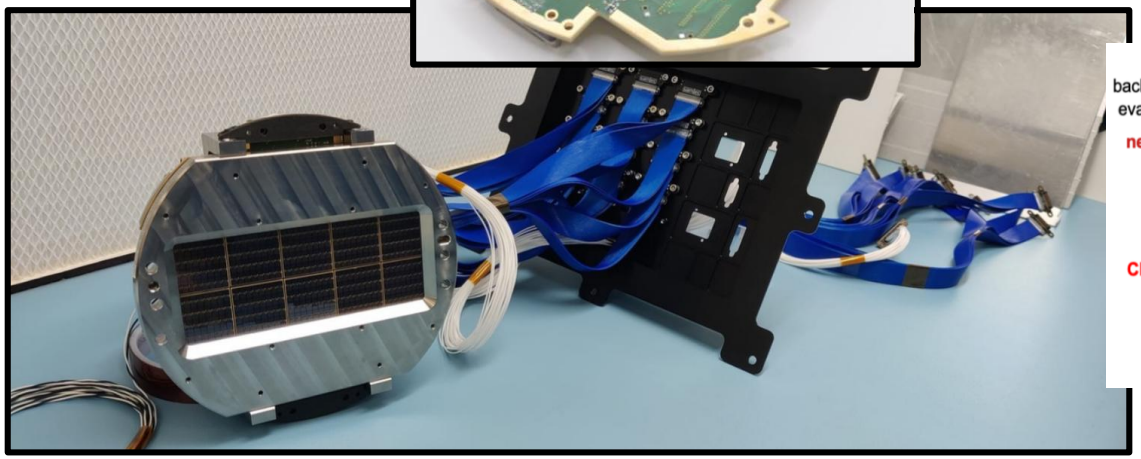
SiPM Information:

- Size: 2.9 mm x 2.6 mm
- FoV = atan(r_{SiPM} / F_L) ~ 0.18° x 0.16°
- DCR ~ 50 kHz / mm^2
- OCT ~ 7%
- PDE @ 450 nm ~ 50 %
- V_{BD} = 32.6 V

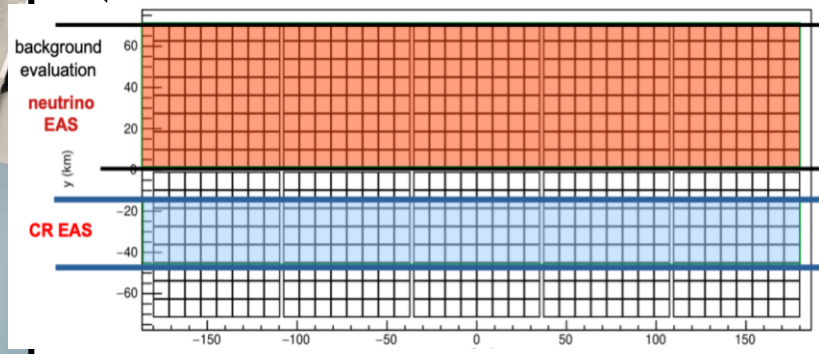








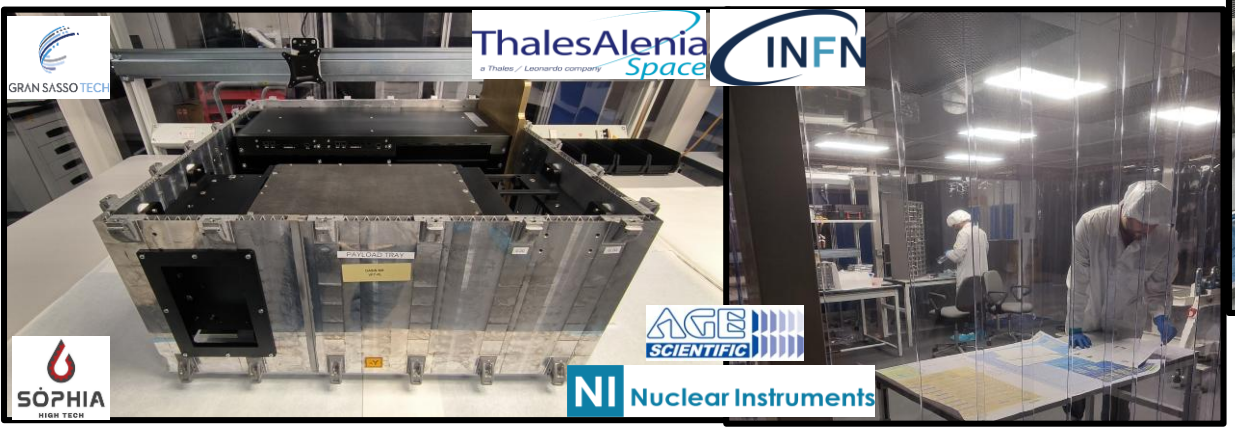
Camera plane with projection on the Earth (total area 360 x 140 km^2)

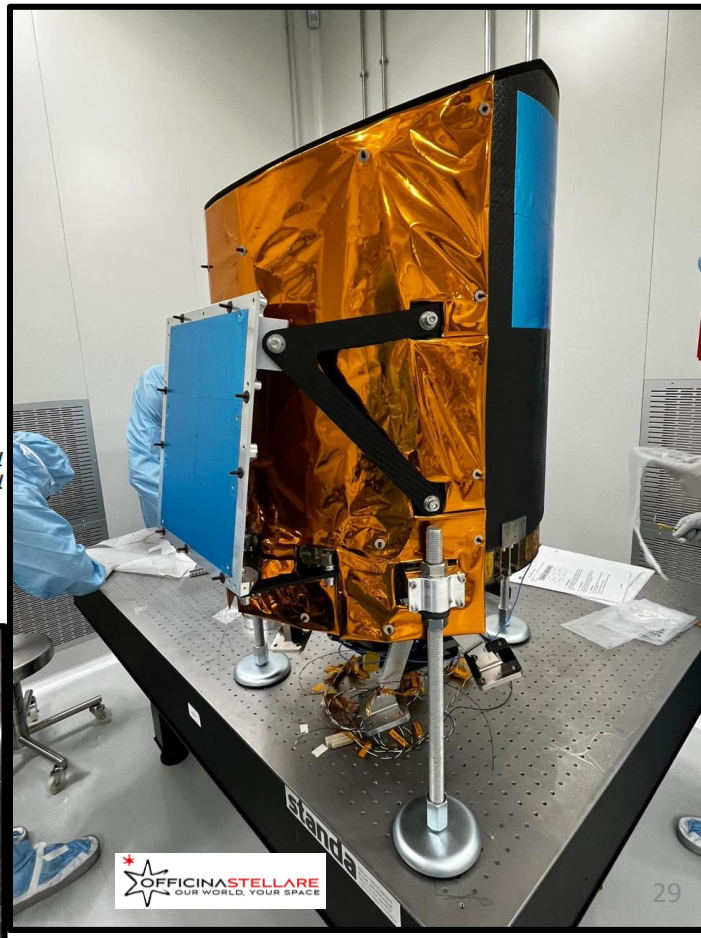


NUSES: Integrating EQM → FM

Device in P/L	SM	STM	EQM	PFM	S/C Location	P/L
Ziré Instrument	X	-	X	X(3)	Tray	**Ziré P/L**
Electronics Unit (EU)	X	X(1)	X	X(3)	Tray	
LEM	X	-	X(2)	X(3)	Top Panel	
Terzina OTA (Optical Telescope Assembly)	-	X	-	X	Top Panel	**Terzina P/L**
Terzina FPA (Focal Plane Assembly)	-	X	X	X	Top Panel	
Terzina OHU (OTA+FPA+TCA(Thermal Control Assembly))	-	X	-	X	Top Panel	

Table 1. Details of all the models developed for the NUSES payload. (1) EU undergoes Technological Qualification, (2) LEM-EQM not fully representative, (3) PFM Zirè P/L includes Tray+Top Panel+Thermal Assembly.

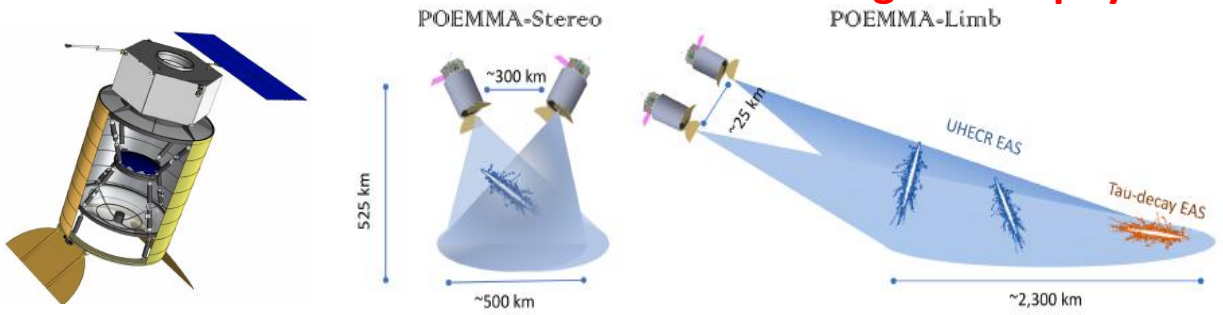


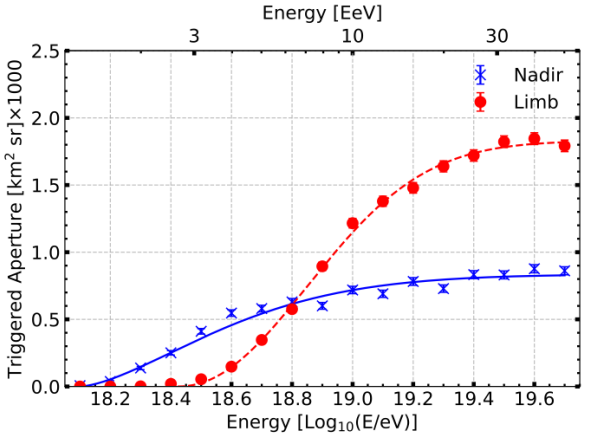


Launch 2027
Space X Falcon 9
Setting up the Mission Operation Center

PBR: POEMMA Balloon with Radio

POEMMA: Probe Of Extreme Multi-Messenger Astrophysics

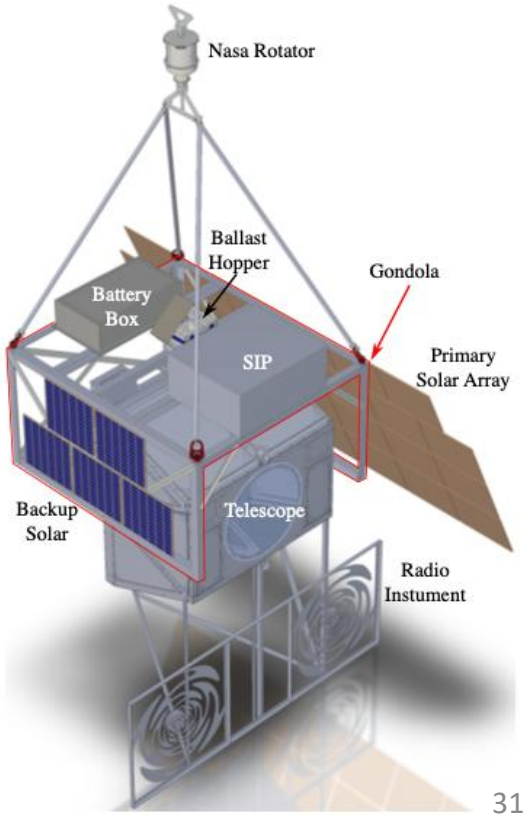




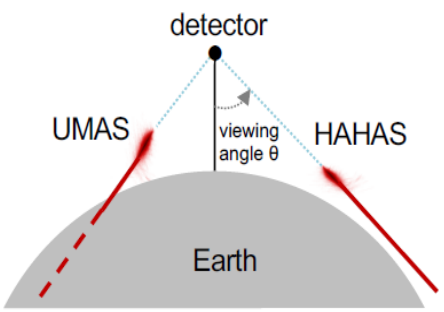
- Payload of NASA SPB with launch from Wanaka, NZ
- Target date: Spring, 2027
- Flight duration: more than 20 days

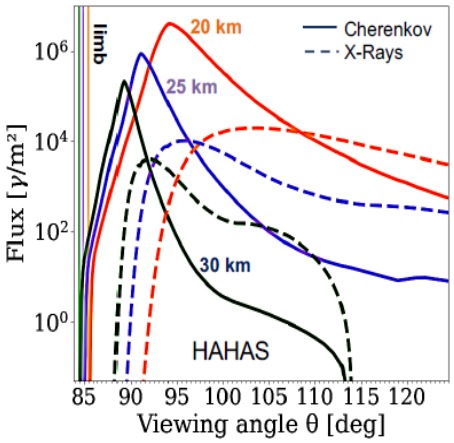
- 1.1 diameter Schmidt Optic Telescope with hybrid focal surface
- 2 radio antennas
- 1 IR camera (cloud monitoring)
- 1 γ/X- Ray detector (early shower development)

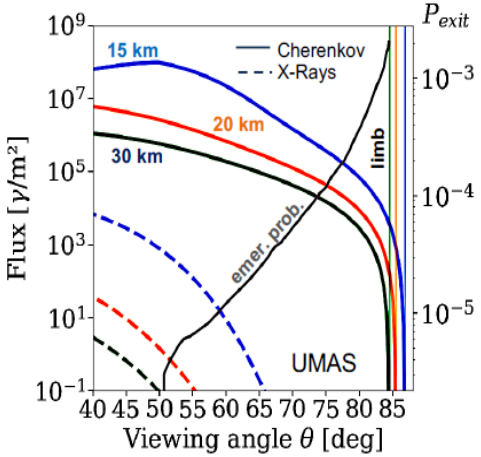
- Pointing:
  - 360° in azimuth via NASA provided rotator
  - Nadir to 10° above horizon in zenith

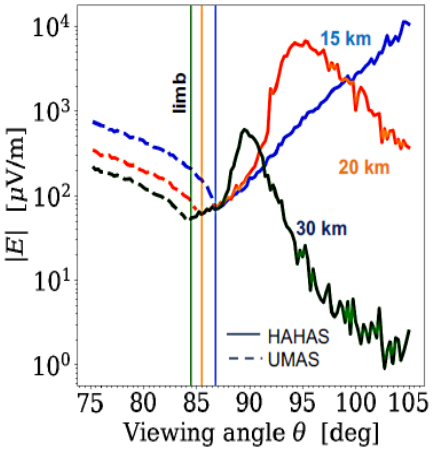


New Detection Concepts for High Energy Neutrinos



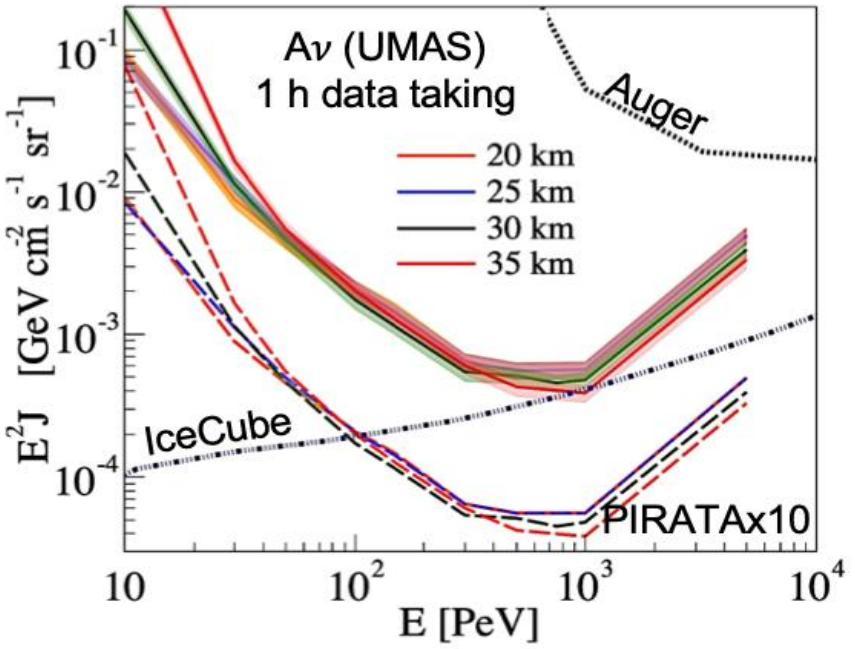




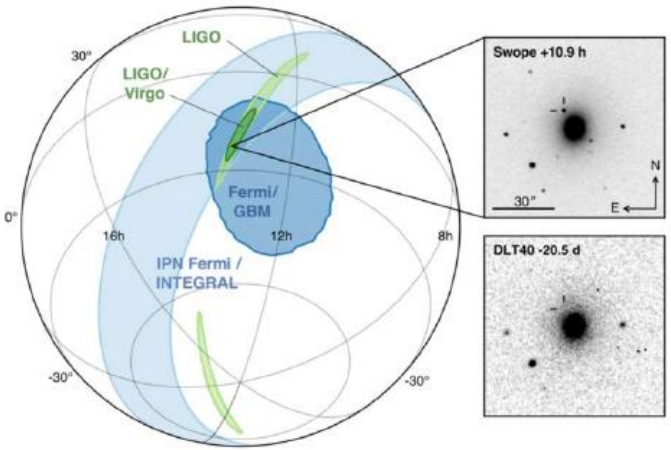


Calculations/simulations of Extensive Air Shower (EAS) radiative emissions in the radio, visible-UV and X-rays energy bands.

Study new detection techniques for the observation of high energy neutrinos from orbital and suborbital altitudes (NUSES-Terzina / PBR,…)

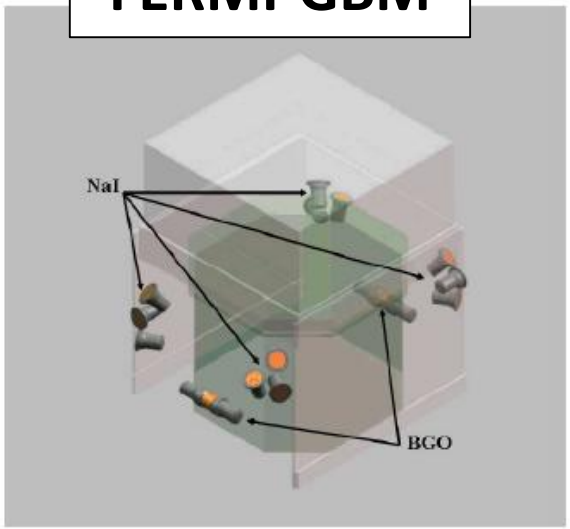


Crystal Eye: a sky monitor for X-rays and low energy γ-rays



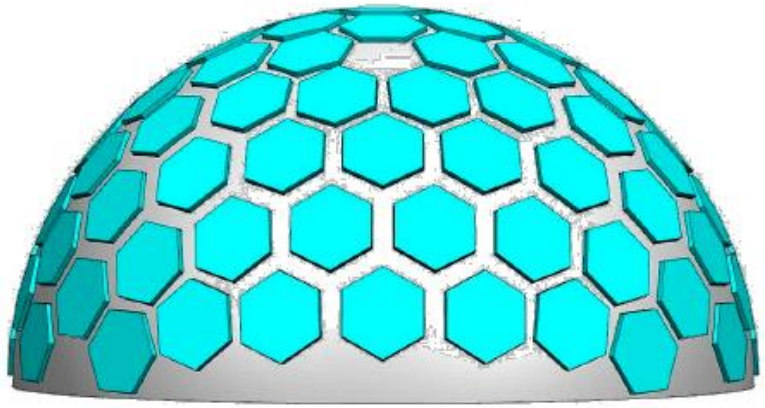
Multimessenger observation of
GRB170817
EM counterpart of GW event

FERMI-GBM



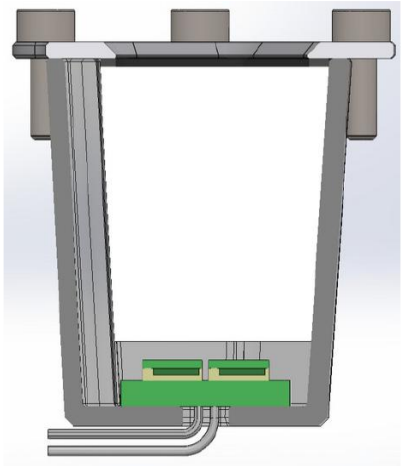
- All sky monitor
- **Low** resolution
- Triangulation on **12 pixels**
- Pixel diameter **12.7 cm**

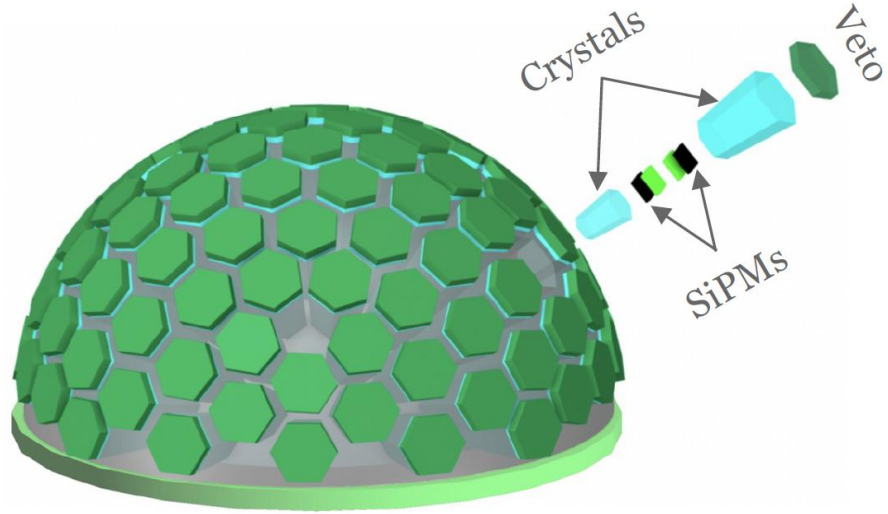
CRYSTAL EYE

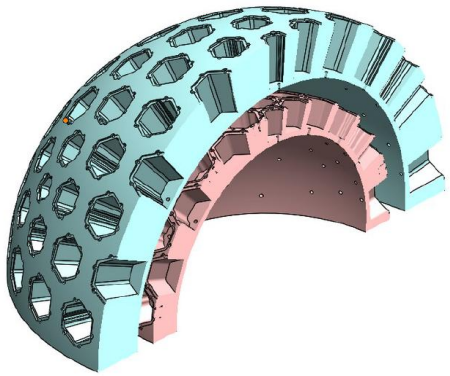


- All sky monitor
- **High** resolution
- Triangulation on **110 pixels**
- Pixel diameter **3.3 cm**

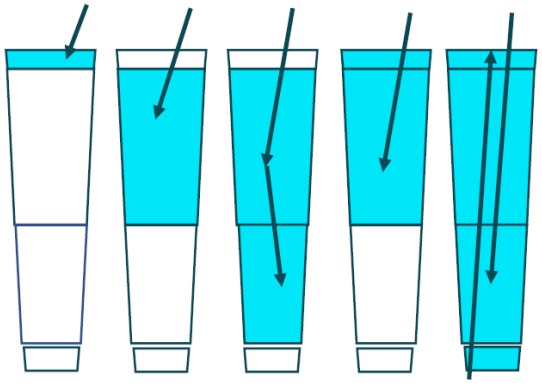
Crystal Eye: a sky monitor for X-rays and low energy γ-rays



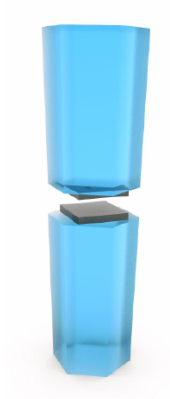




Detection of
10 keV - 30 MeV γ
All-sky Monitor



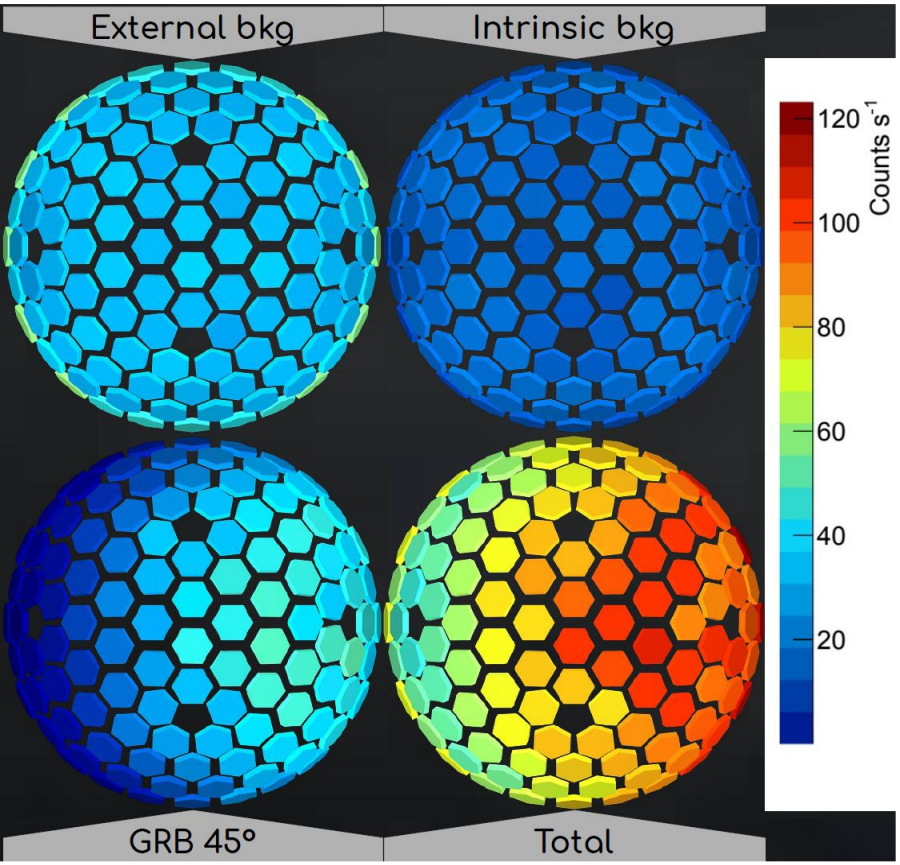
a – Down-going hard X-ray
b – Down-going LE g-ray
c – Down-going ME g-ray
d – Down-going LE charged particle
e – HE charged particle

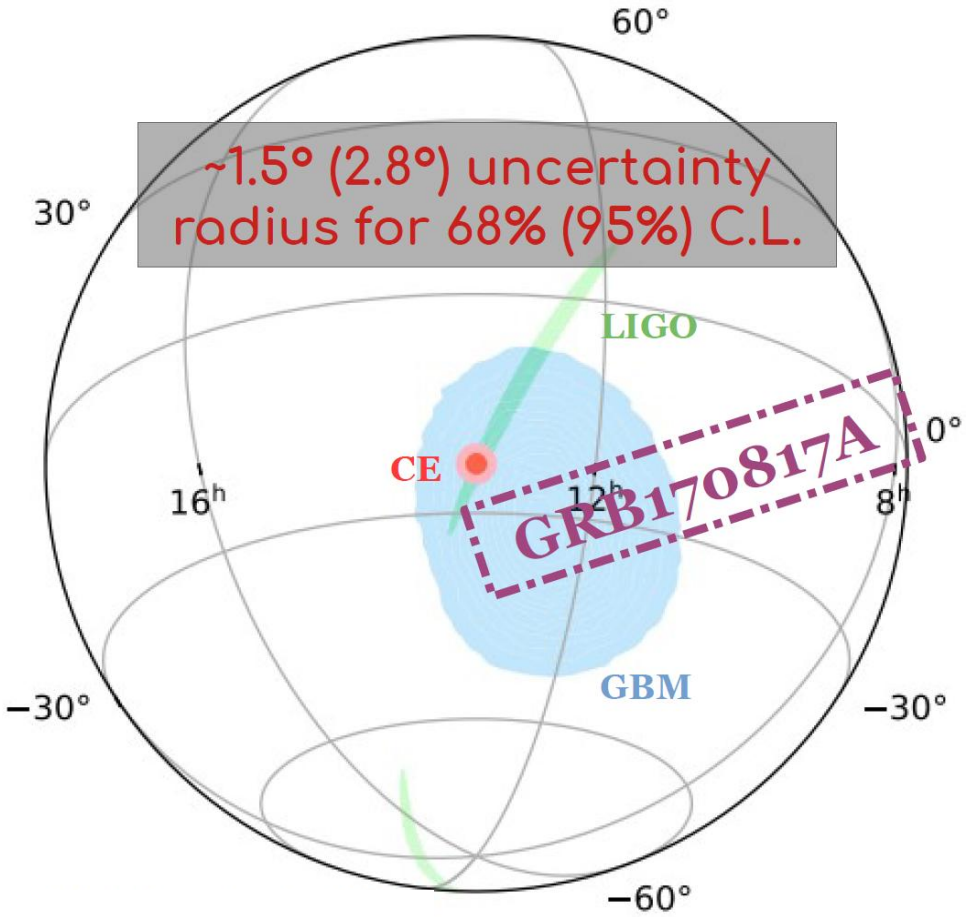


- **Pixel FOV:** 2.5°x2.5°.
- **LYSO+GAGG crystals**
- **Photodetectors:** 4x4 MPPC array
- **VETO** for charged cosmic-ray rejection.

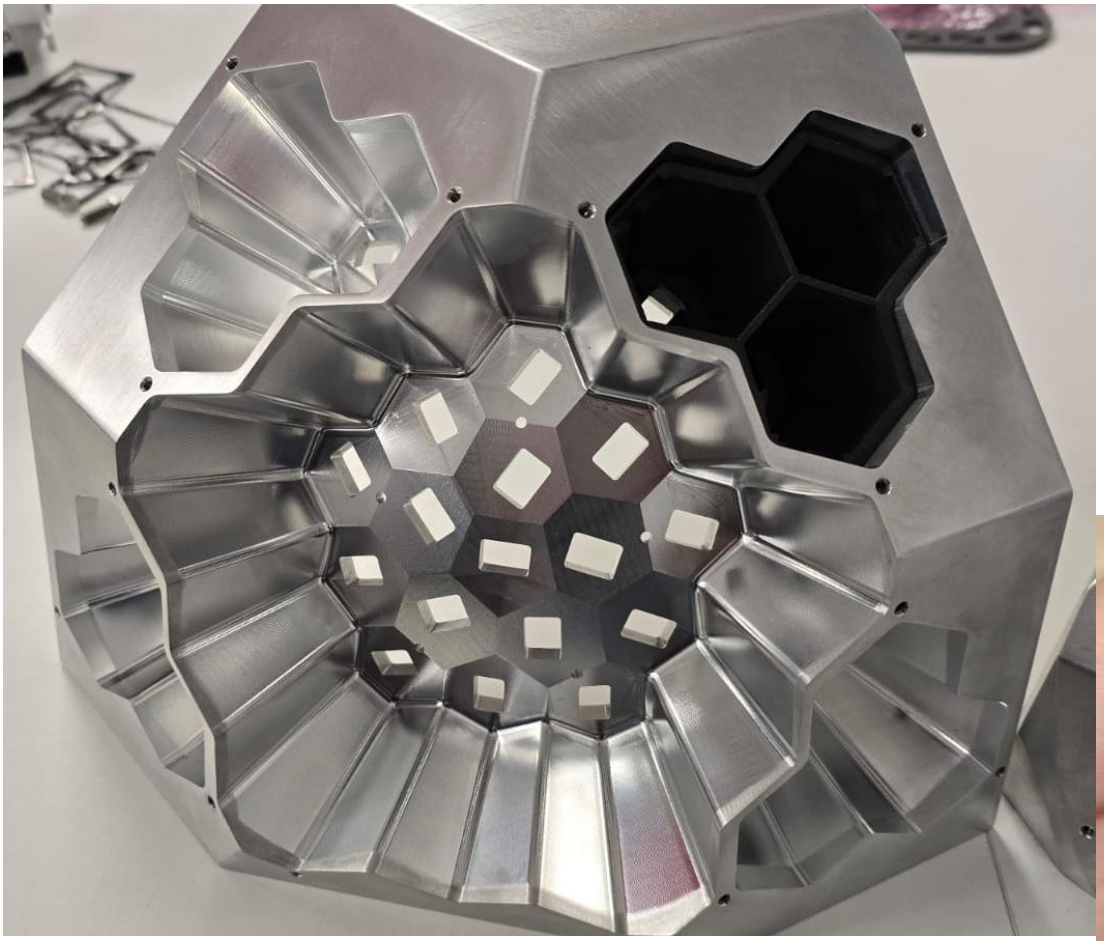
Crystal Eye: GRB sky localization

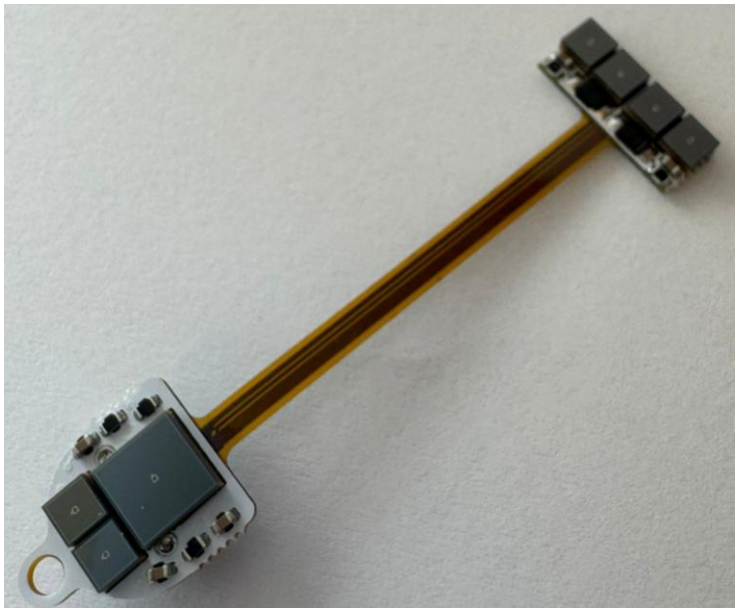
Use the signal distribution over the detector and smart SW tools to identify the position in the sky and send alarms to the community

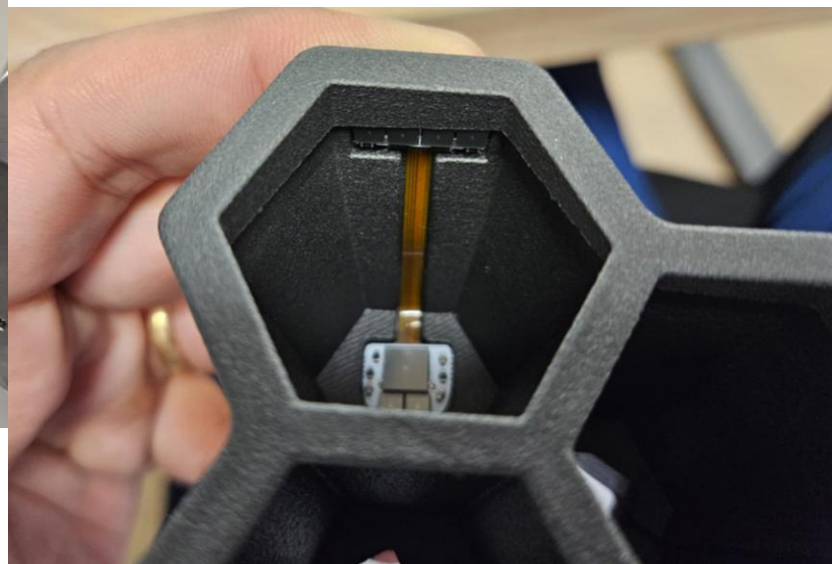




Crystal Eye:
Mechanics and SiPM readout

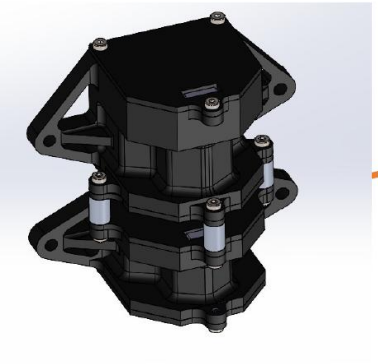


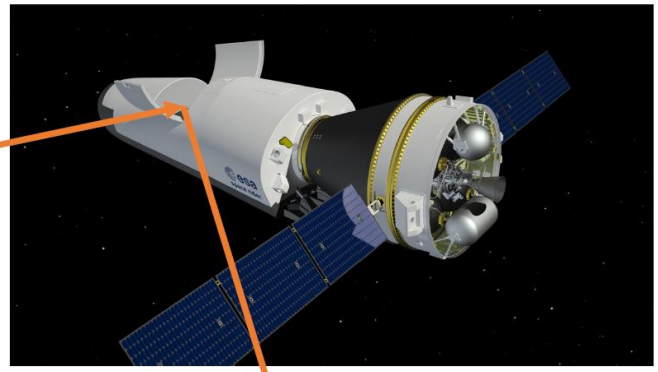




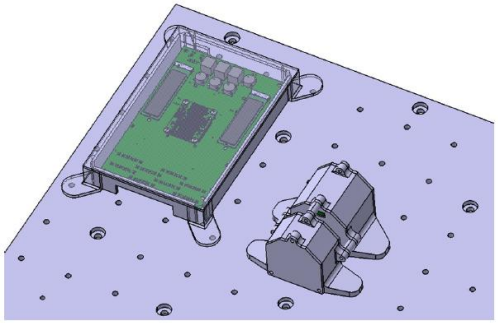
Wink: a Crystal Eye pathfinder

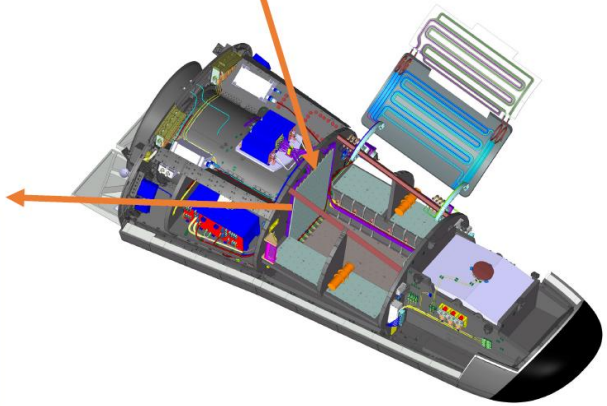
WINK consists of 3 Crystal Eye pixels and its operations will validate the Crystal Eye technology observing deep space and Earth.

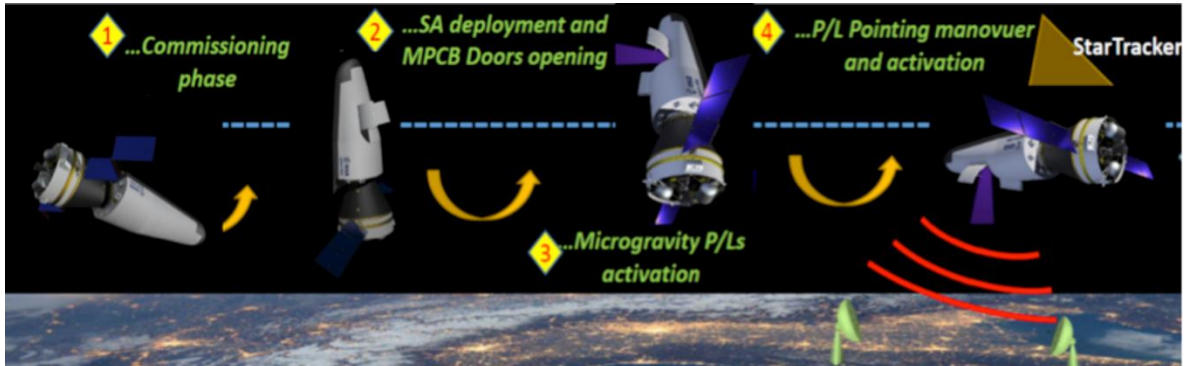




Number of pixels: 3
Material: LYSO
Photodetectors: SiPM-array
Weight: 2kg
Power consumption: < 15 W
FOV: 30°





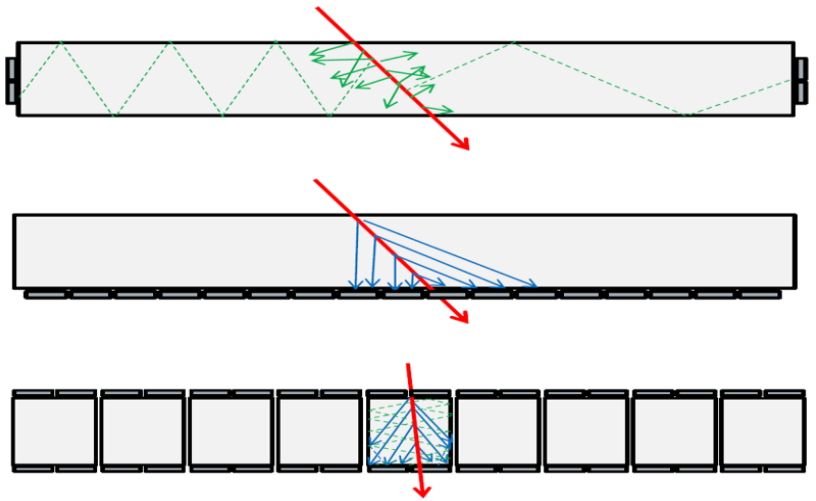


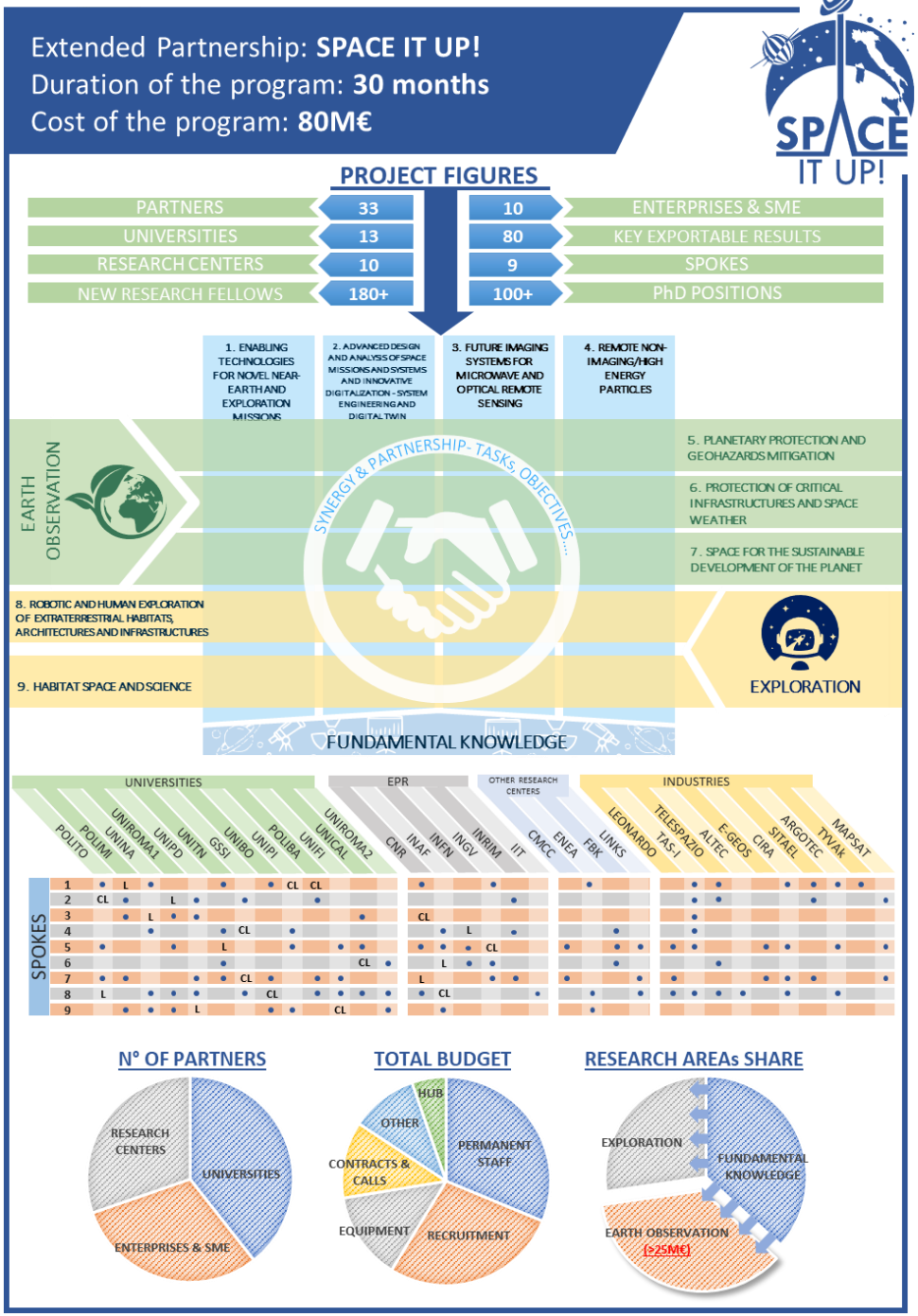
Space It Up ! @GSSI……..

Setting up novel (space-based) radiation detectors

Detector innovations with new solutions for:
- particle identification:
  Cherenkov detection for electron tagging
- photon tagging: duly segmented active veto systems
- optical coupling: space qualified materials
- low power electronics
- high dynamic range
- radiation hardness and damage mitigations

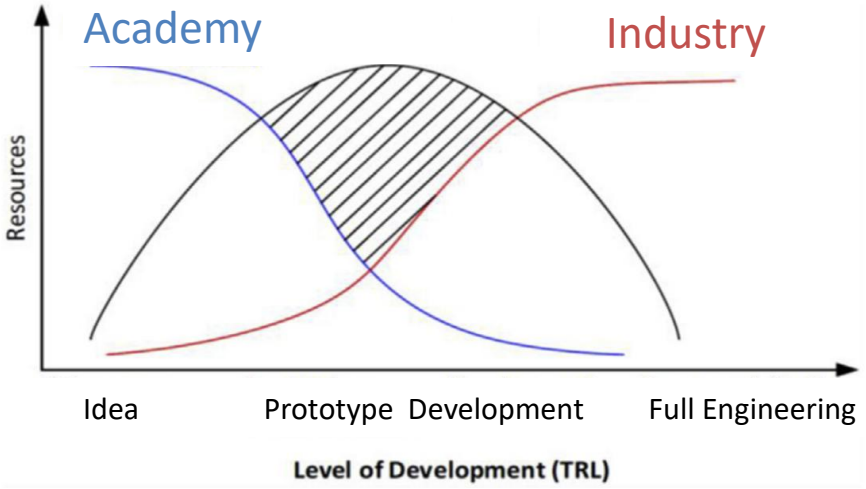
Example: Use PMMA with wavelenght shifter to enhance the number of detected Cherenkov photons and then tag electrons wrt non relativistic nuclei





Space and Earth innovation Campus (SEIC) funded under PNRR

- 23 partners lead by GSSI
- 3,500 square meters infrastructure
- Total grant: 19 Meuro in three years




DURING AN IMPORTANT CALL WITH ESA...
WHAT DOES IT MEAN THERE IS NO LAUNCHER???
Ivan De Mitri
WHO SHOULD LAUNCH THE SATELLITE?
ME?!? SGRUNT !
LATER AT GSSI...
...TO CONCLUDE, WE DON'T HAVE A LAUNCHER
IMPOSSIBLE!
DON'T WORRY GUYS! I HAVE A SOLUTION!
SEE... THIS IS THE CRYSTAL EYE IN ORBIT...
THE END

HE Short Courses

TH

HE-1: Particle acceleration in astrophysical plasma

Pasquale Blasi (GSSI & INFN LNGS)

During the course I will dive into the discussion of the physical processes that lead to particle acceleration in astrophysical environments. I will present possible connections with the origin of cosmic rays as well as with the energisation of particles responsible for the production of high energy radiation and neutrinos in sources such as supernova remnants, active galactic nuclei and gamma ray bursts. The course is of theoretical nature, with a discussion of phenomenological implications.

HE-6: Gamma and neutrino emissions from high energy sources

Paolo Lipari (Università di Roma La Sapienza & INFN Roma1)

Theoretical aspects of gamma and neutrino emissions. Connections with multi wavelength and multi-messenger observations. Study of the atmospheric neutrino flux.

HE-7: UHECR theory

Roberto Aloisio (GSSI & INFN LNGS)

Theoretical overview of acceleration and propagation processes of Ultra High Energy Cosmic Rays.

HE-8: Plasma physics around astrophysical compact objects

Elena Amato (INAF Osservatorio di Arcetri)

Pulsars as unipolar inductors and pair creation in its magnetosphere. Force-free solution for the outflow from an aligned rotator: the pulsar equation and the Blandford-Znajeck mechanism for energy extraction from a rotating black hole. MHD and radiation modelling of pulsar wind nebulae and particle acceleration.

HE-9: Accretion power in astrophysical systems

Emanuele Sobacchi (GSSI & INFN LNGS)

Eddington luminosity. Equations of hydrodynamics. Sound waves. Rayleigh-Taylor and Kelvin-Helmholtz instabilities. Bondi model of spherical accretion. Shakura-Sunyaev model of accretion discs. Magnitude of viscosity (phenomenological alpha prescription). Equations of magneto-hydrodynamics. Magnetorotational instability. Physical origin of viscosity in accretion discs.

EXP

HE-2: Data analysis techniques in HE Astroparticle Physics

Pierpaolo Savina (GSSI & INFN LNGS)

Review of the main techniques for data reconstruction from ground and space based cosmic ray observations. Specific data analysis case studies, taken from current experiments, will serve as a foundation to provide an overview of various techniques. A focus will be also given to the use of multivariate analysis and machine learning methods.

HE-3: High Energy Radiation Measurements (Laboratory course)

Adriano Di Giovanni (GSSI & INFN LNGS), Felicia Barbato (GSSI & INFN LNGS)

Silicon-based light detectors. Readout and DAQ systems. Applications to space-based experiments. Tracking systems: measurement of observables and diagnostics. This is a laboratory course: lectures will mostly be held at the Gran Sasso National Laboratory (LNGS).

HE-4: Gamma and neutrino telescopes

Nicola M. Mazziotta (INFN Bari), Maurizio Spurio (Università di Bologna)

Space and ground based telescopes for gamma and neutrino observations: detection techniques and data analysis/simulations tools. Review of the latest results and future projects.

HE-5: Front-end and readout electronic systems for High Energy Astroparticle Physics

Felicia Barbato (GSSI & INFN LNGS), Adriano Di Giovanni (GSSI & INFN LNGS)

Waveforms and signal processing. Front End electronics. Review of electronics systems for signal conditioning. Signal charge collection in low power regimes. Data processing and decoding. Radiation hardness. Specific examples on space-based detectors. Hands-on sessions with signal simulation tools.