GRAN SASSO
SCIENCE INSTITUTE

SCHOOL OF ADVANCED STUDIES

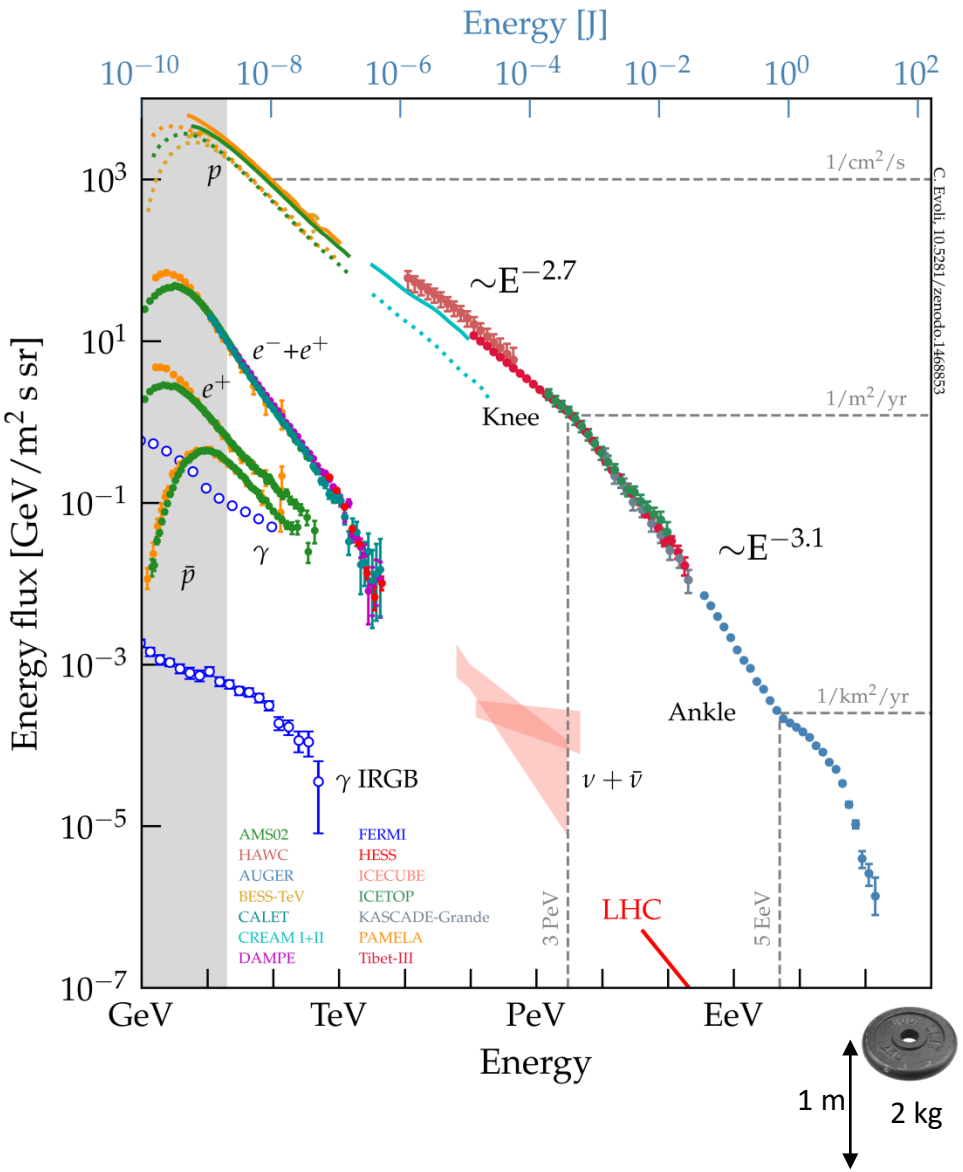
Radiations from the Universe: experiments

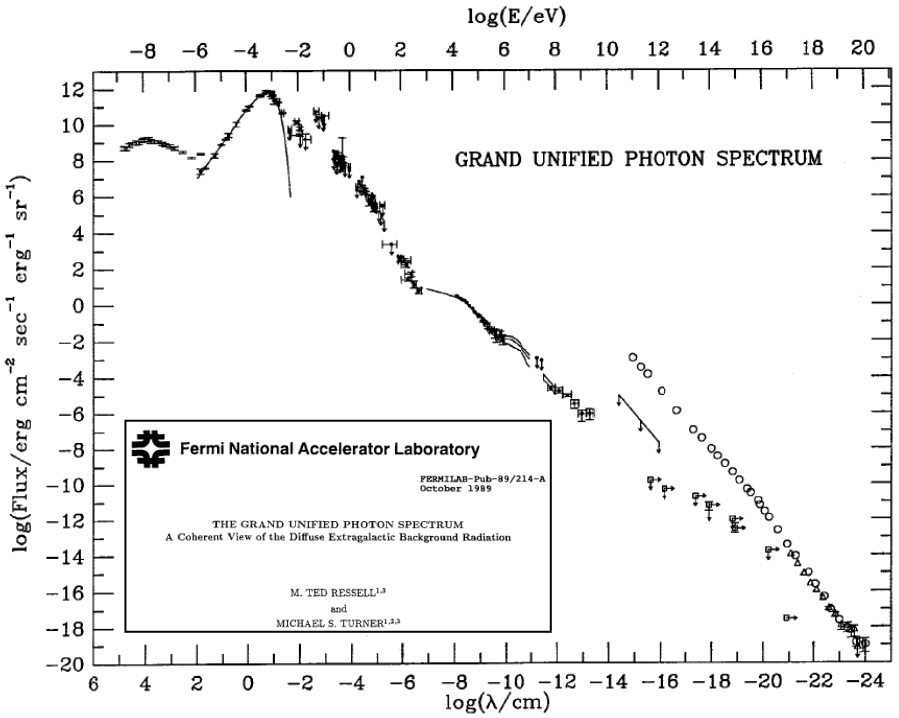
Ivan De Mitri

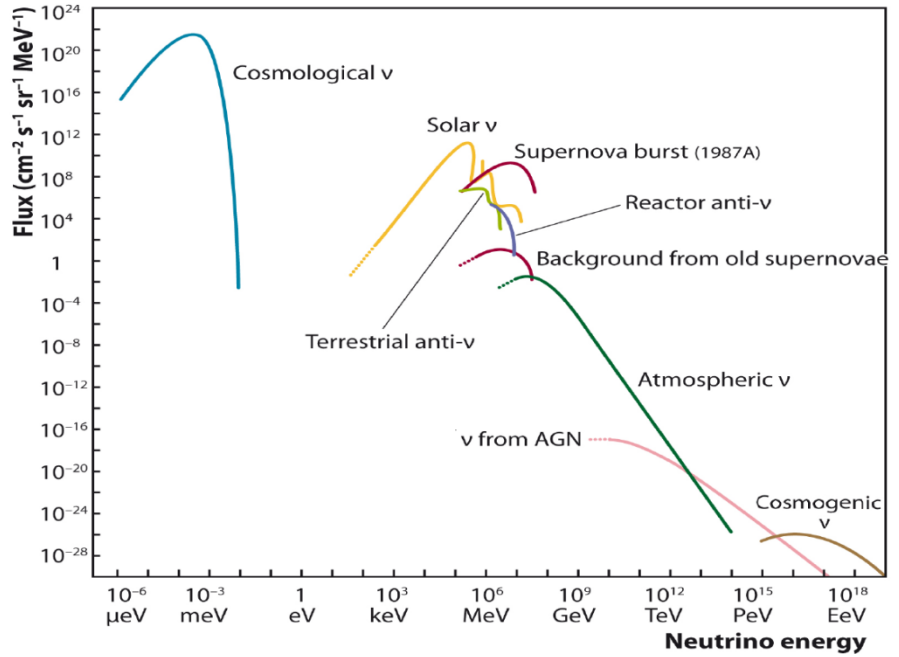
7th GSSI Science Fair
L'Aquila, March 2, 2021

www.gssi.it

Our landscapes(s)







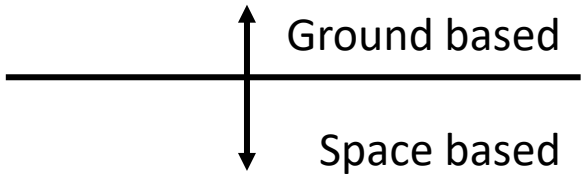
Ongoing activities at GSSI-LNGS-UNIVAQ

AUGER

Currently upgrading the detector. Atmosphere monitoring . Data analysis. Science results.

CTA

Construction of the first telescopes. Atmospheric monitoring



DAMPE

On orbit since December 2015. Data analysis. Science results.

HERD

Design optimization ongoing. To be installed on the Chinese Space Station in 2026.

CRYSTAL EYE + GRAAL

Prototype construction. To fly onboard Space Rider in 2022.
ESA call: Gamma Ray Astronomy and Astrophysics on the Lunar surface.

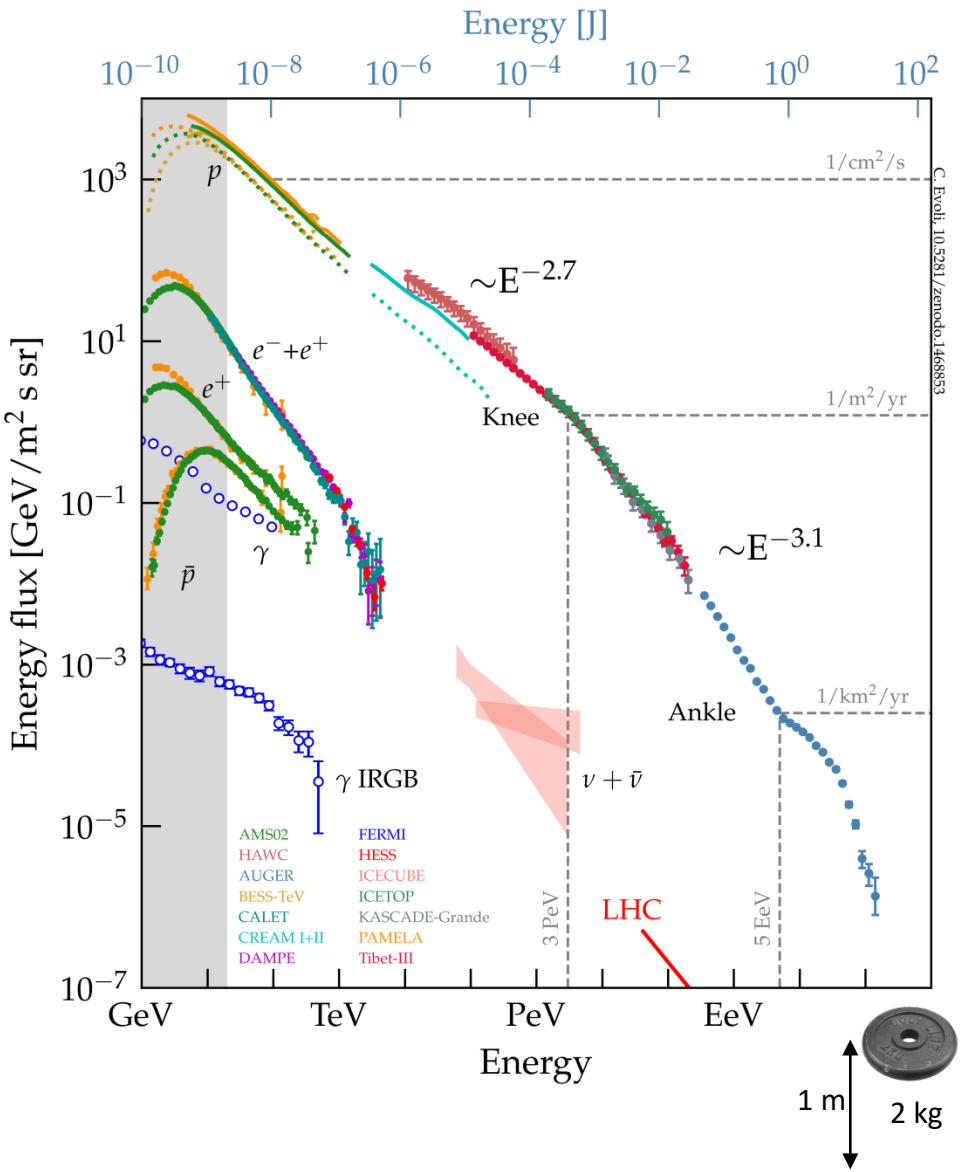
NUSES

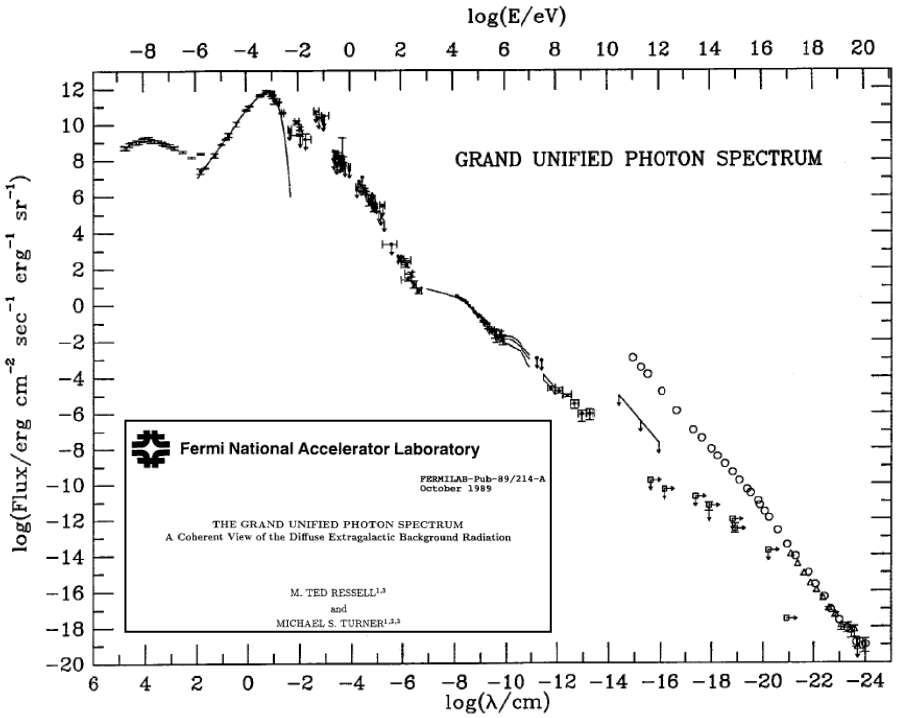
R&D activity to start. Pathfinder for new technologies in space.

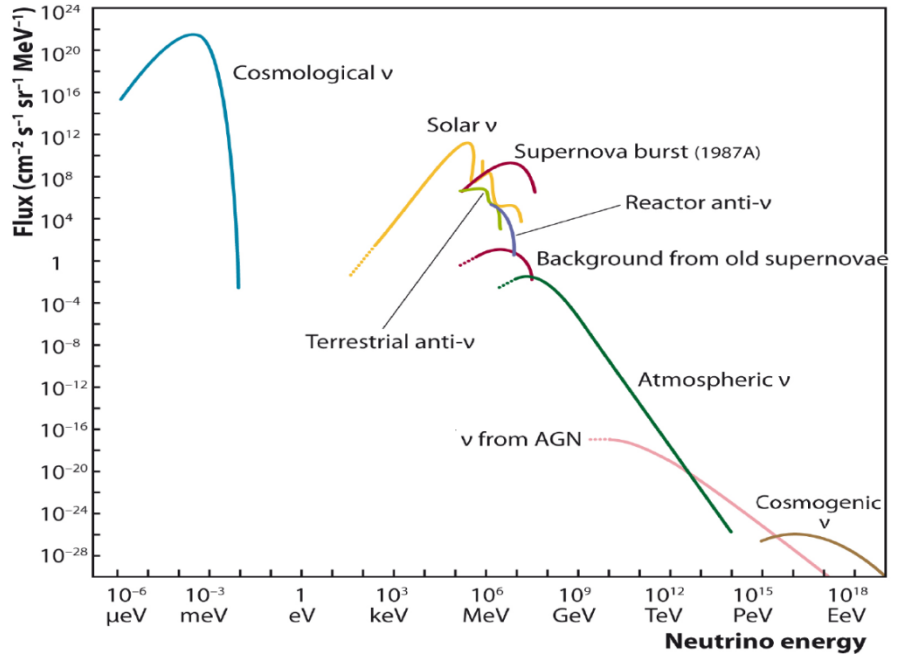
(POEMMA)

Design optimization ongoing. It is one of the selected projects by the NASA call for medium size missions. Final selection for phase A next year.

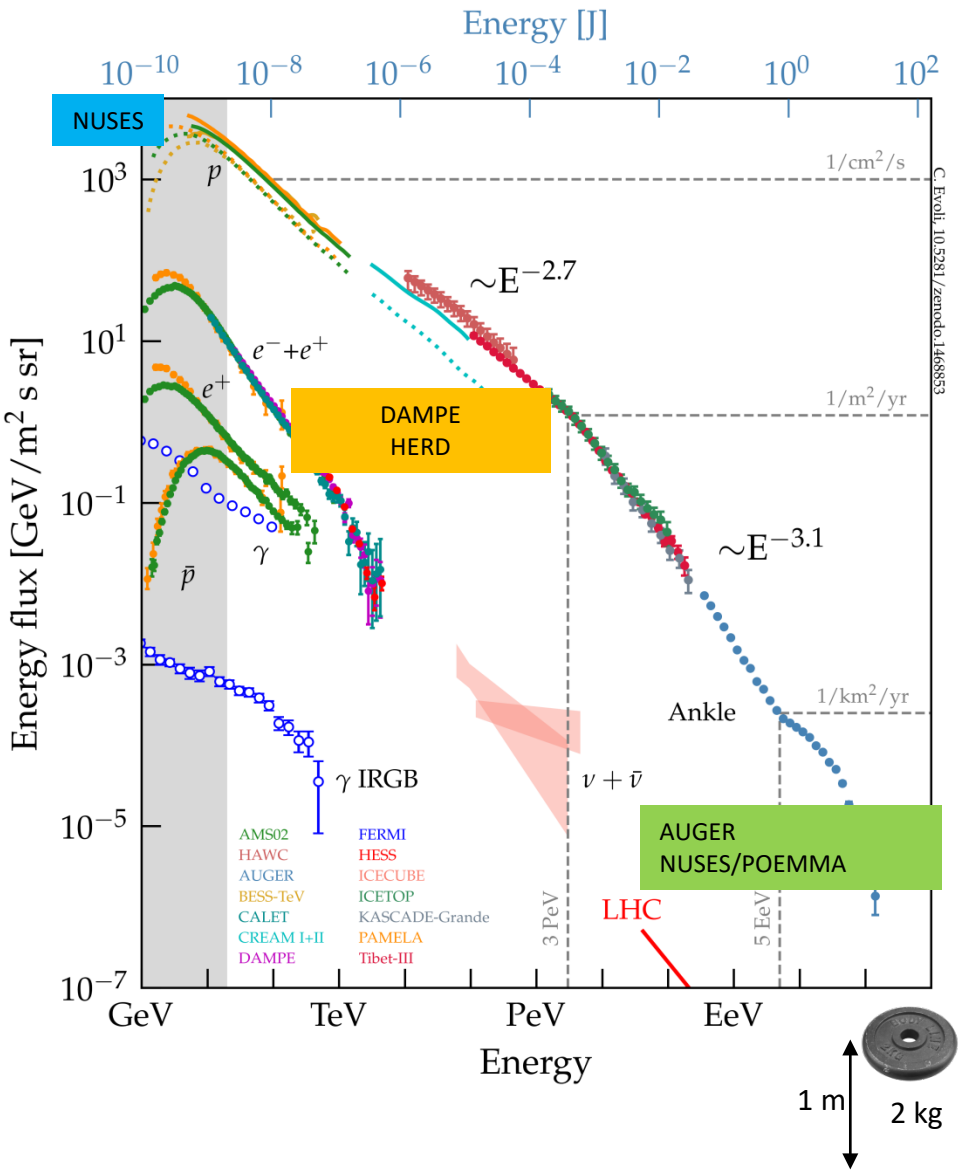
Our landscapes(s)

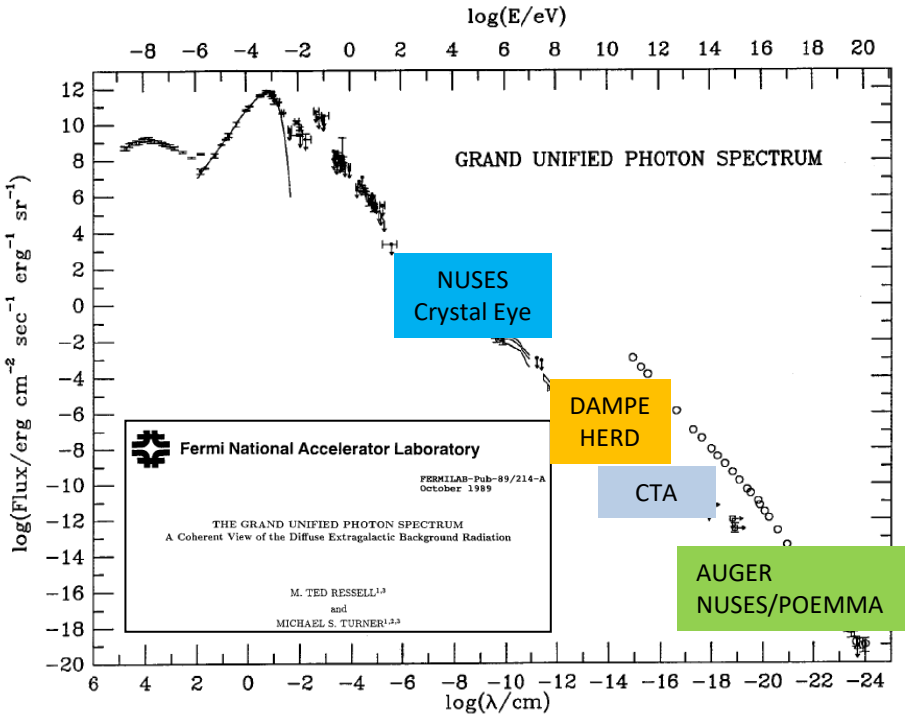


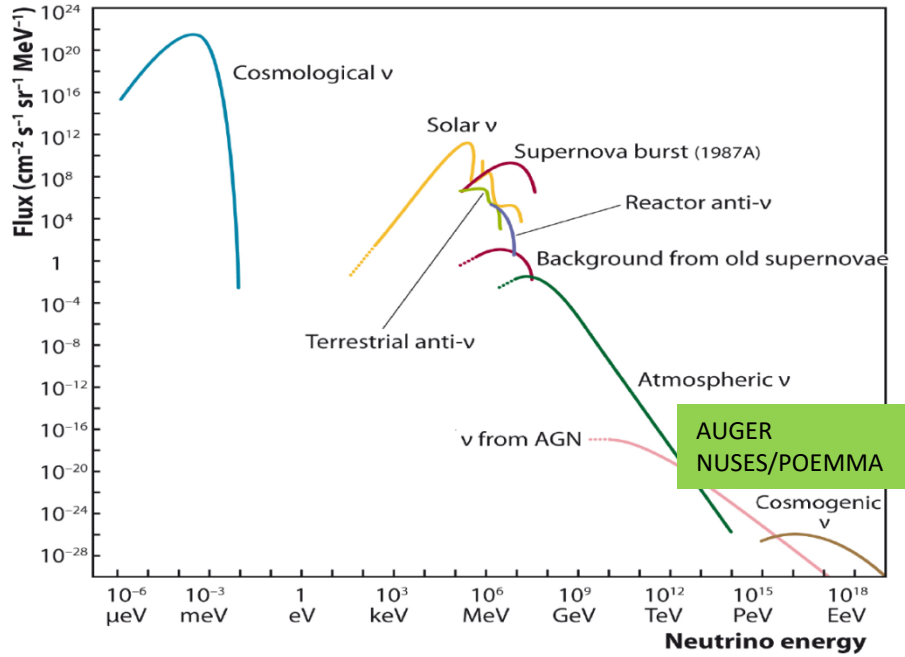




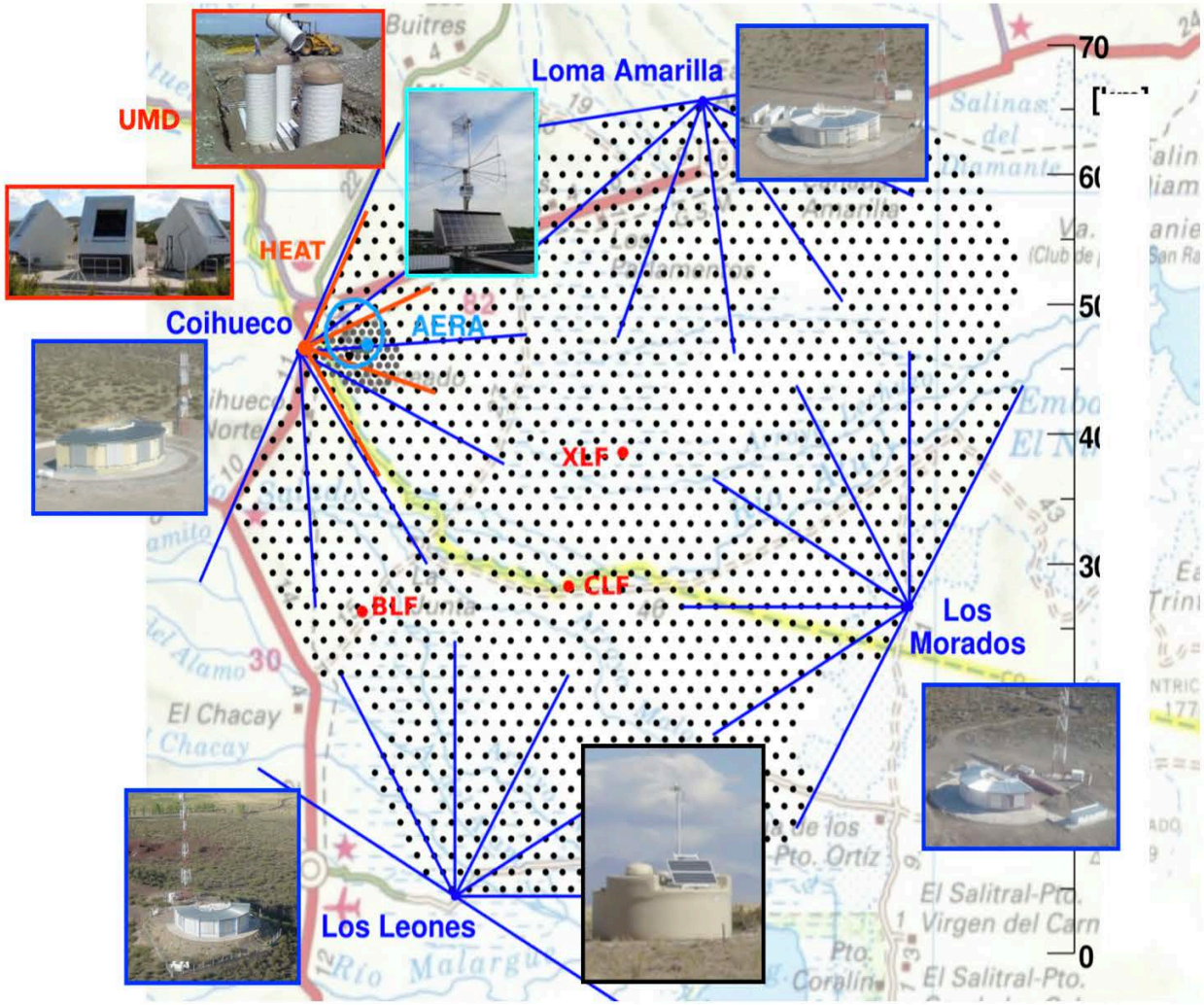
Our landscapes(s)







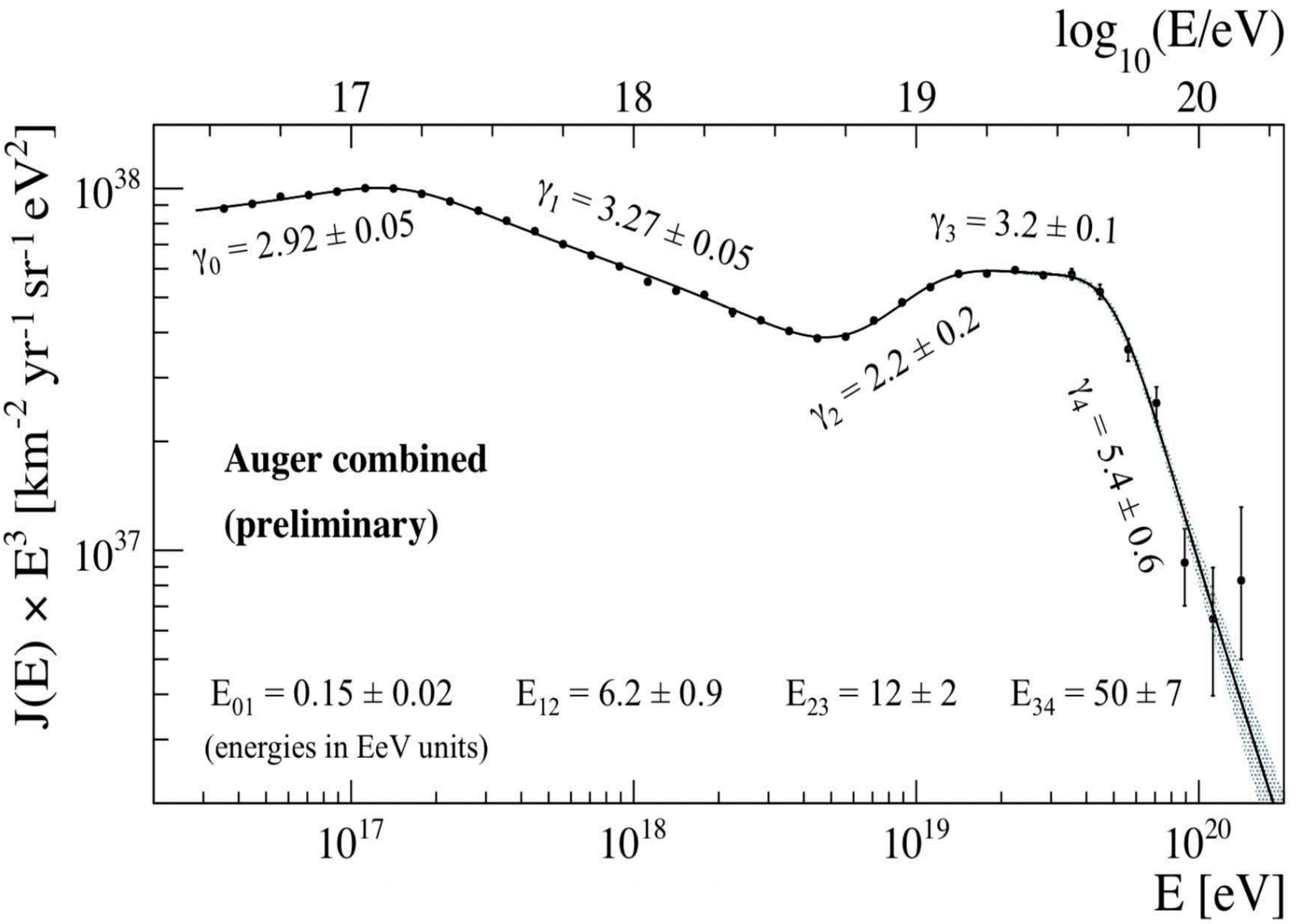
The Pierre AUGER Observatory



- Water-Cherenkov stations
  - ➡SD1500 : 1600, 1.5 km grid, 3000 km^2
  - ➡SD750 : 61, 0.75 km grid, 25 km^2
- 4 Fluorescence Sites
  - ➡24 telescopes, 1-30^0 FoV
- Underground Muon Detectors
  - ➡7 in engineering array phase - 61 aside the Infill stations
- HEAT
  - ➡3 high elevation FD, 30-60^0 FoV
- AERA radio antennas
  - ➡153 graded 17 km^2

+Atmospheric monitoring devices
CLF, XLF, Lidars, …

AUGER: the UHECR energy spectrum



AUGER: the arrival directions

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

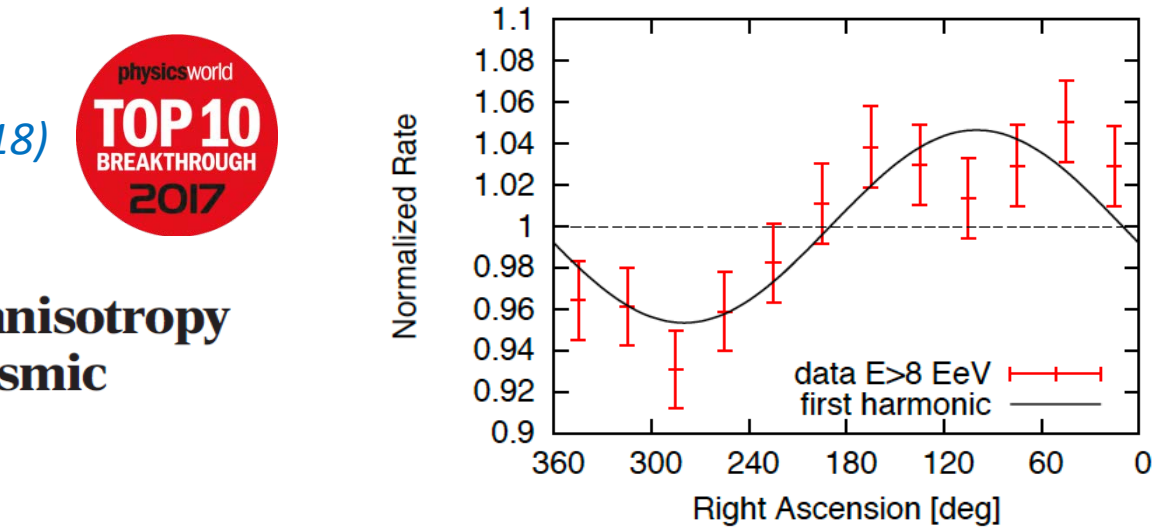
physicsworld TOP 10 BREAKTHROUGH 2017

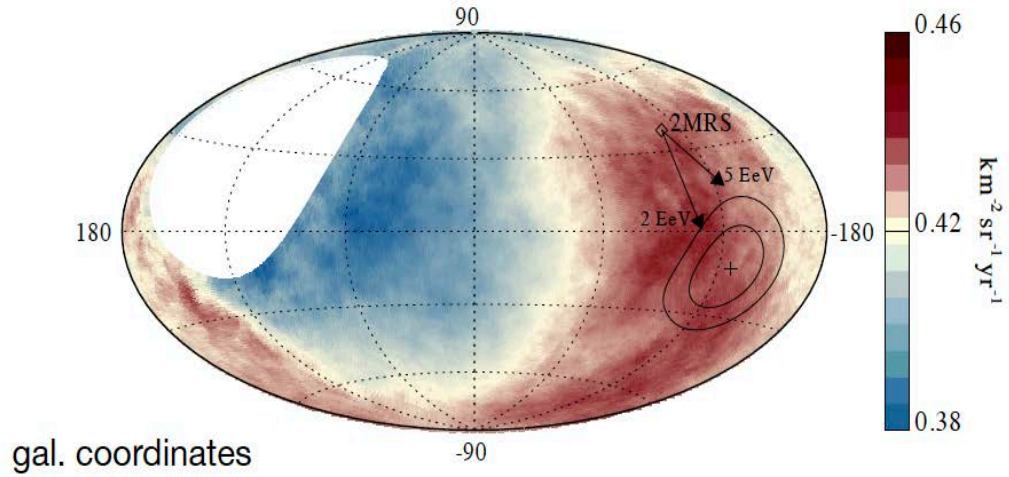
COSMIC RAYS

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

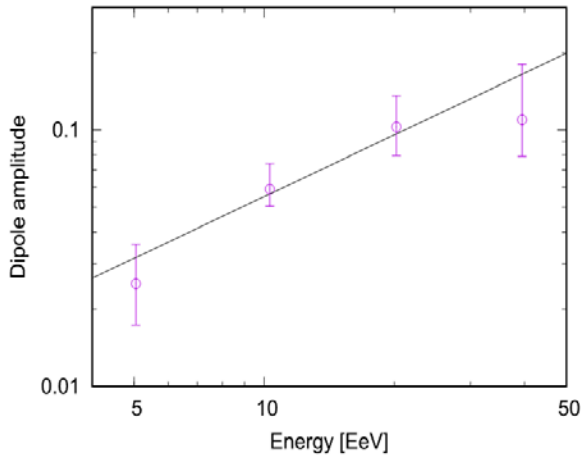
The Pierre Auger Collaboration*†

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

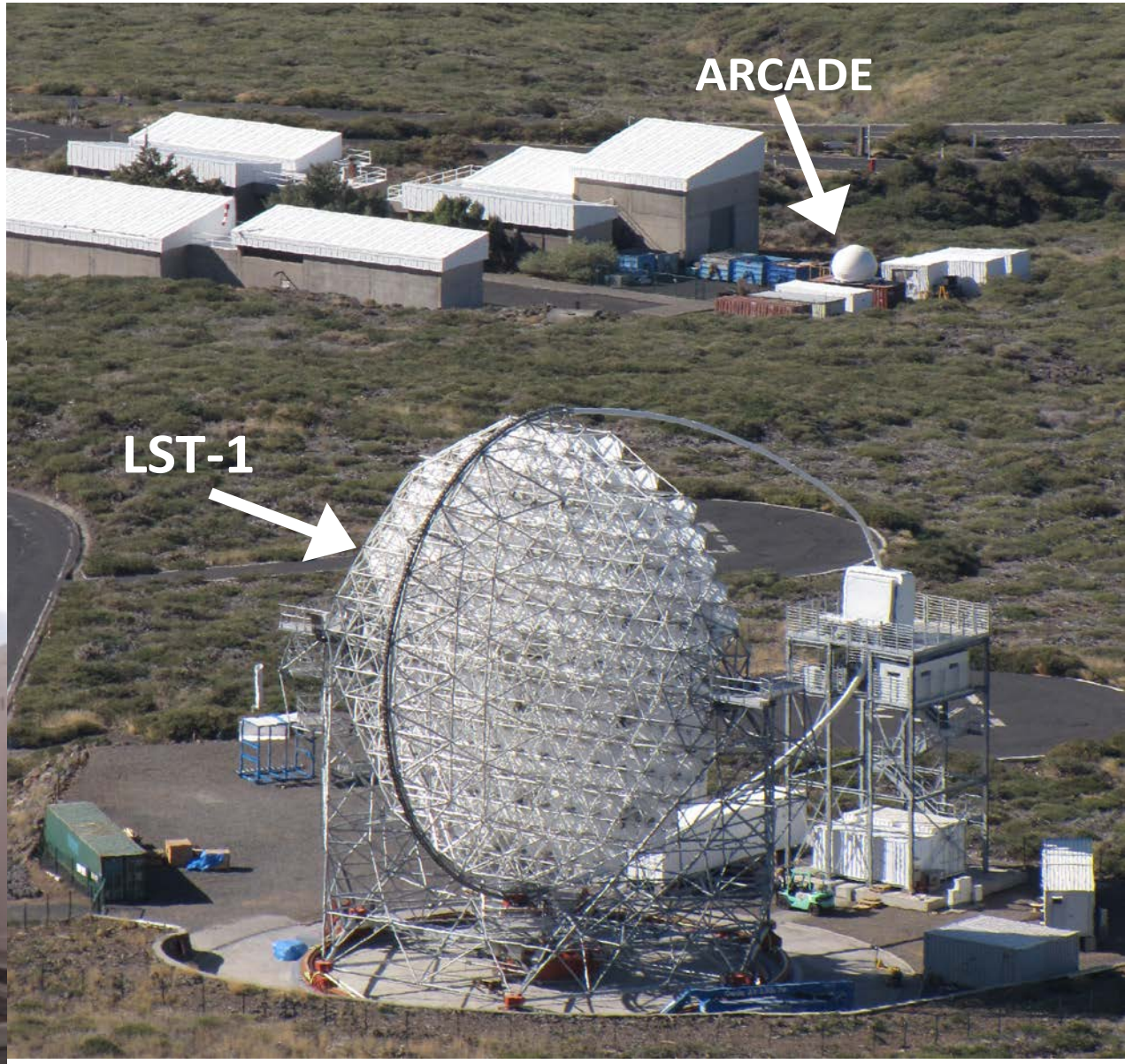
cta cherenkov telescope array

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

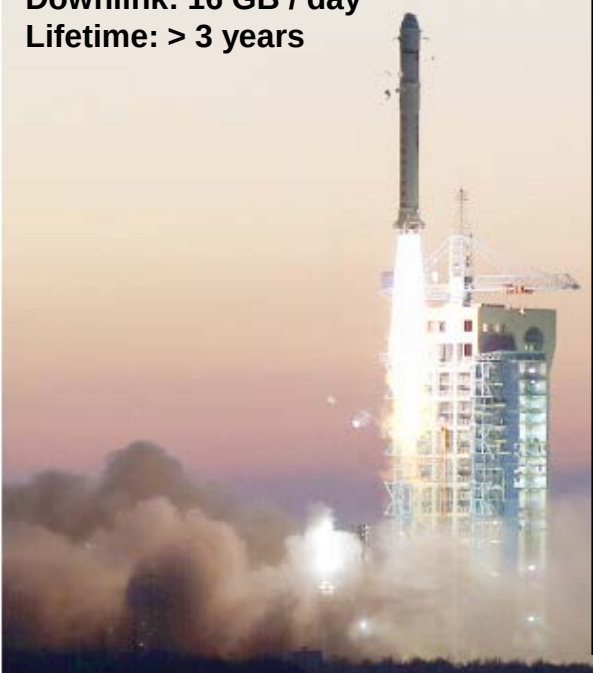
Università degli Studi di Napoli Federico II
Dipartimento di Fisica «Ettore Pancini»

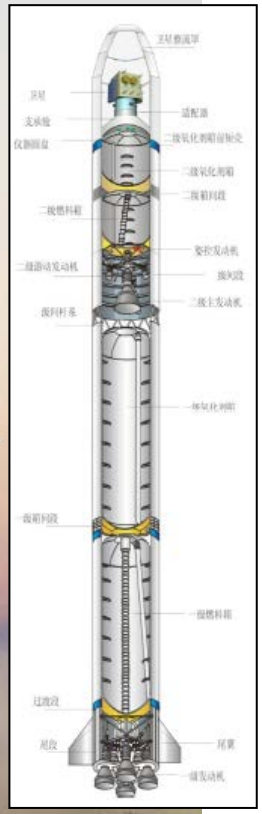


DAMPE: the mission

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

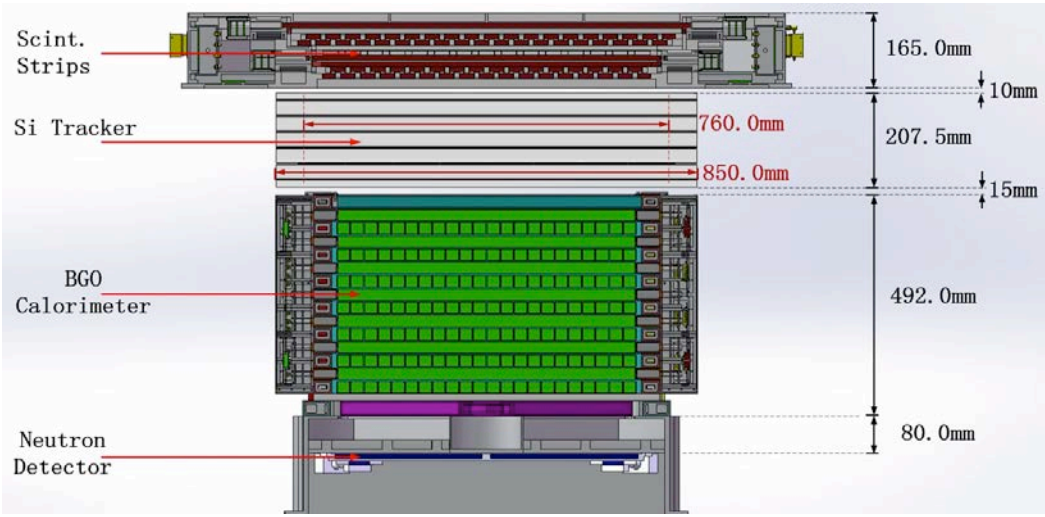
Cosmic ray physics

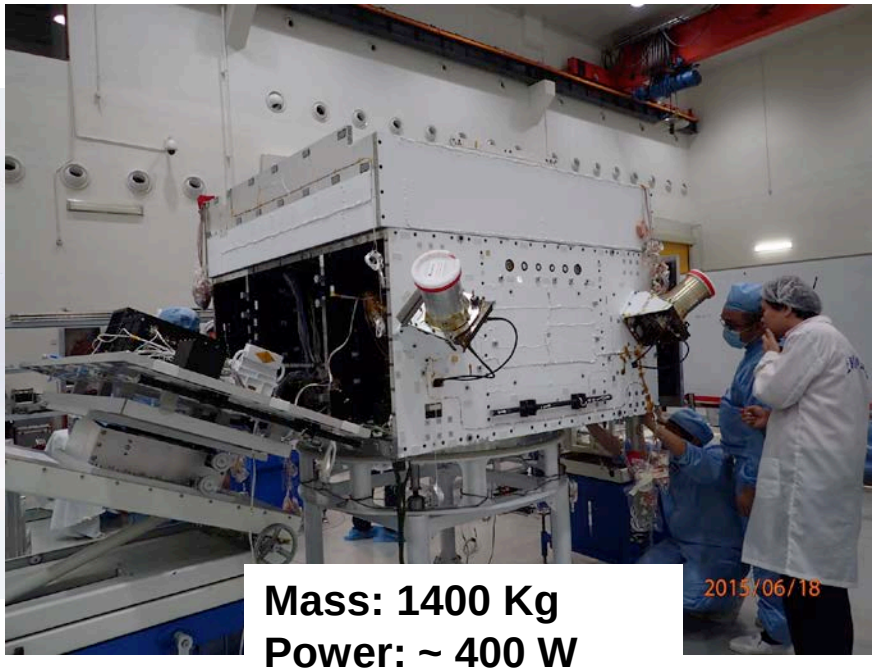
γ-ray astronomy

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





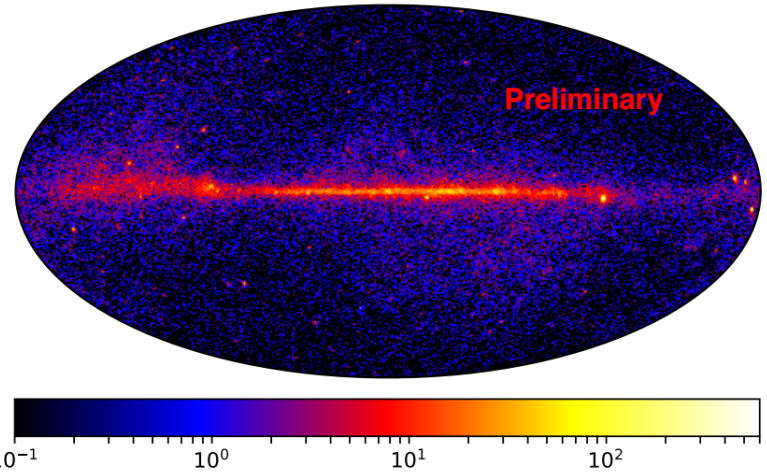
Mass: 1400 Kg
Power: ~ 400 W
Livetime: > 3 years

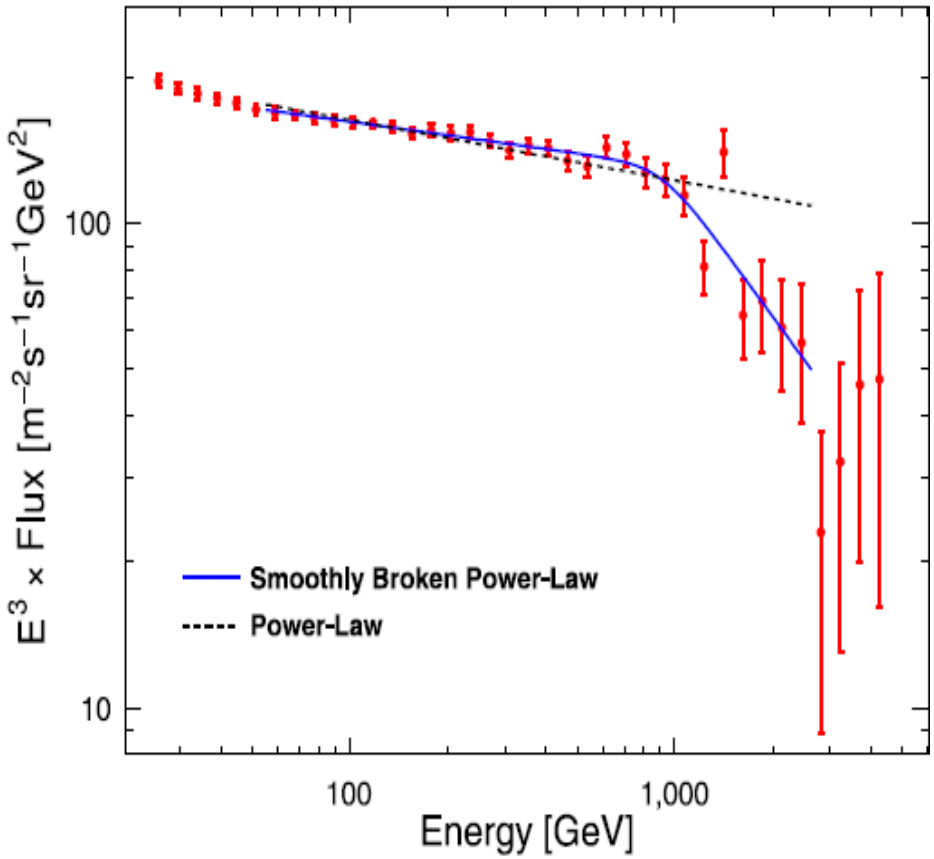
DAMPE: some science results

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*

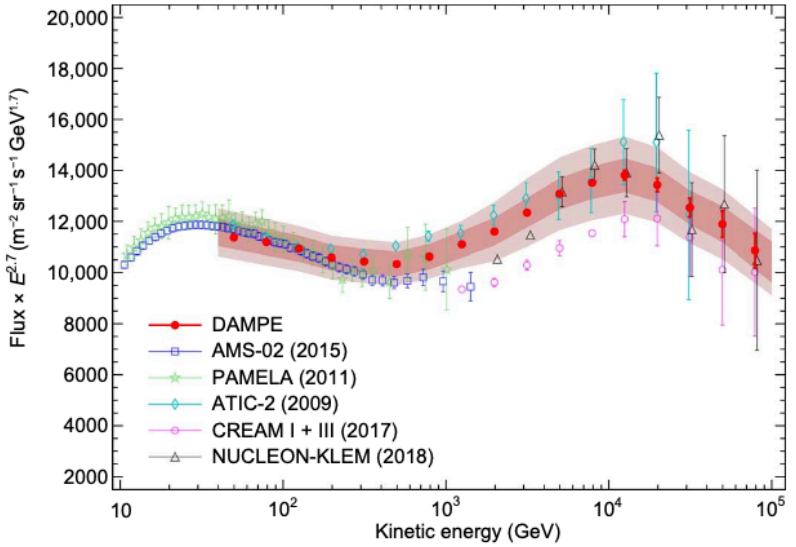




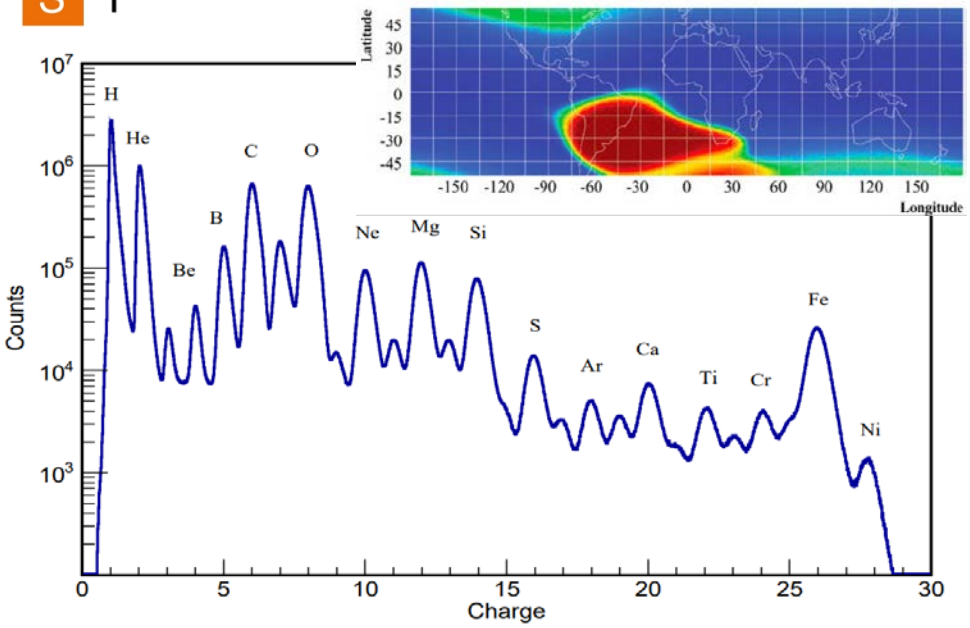
SCIENCE ADVANCES | RESEARCH ARTICLE

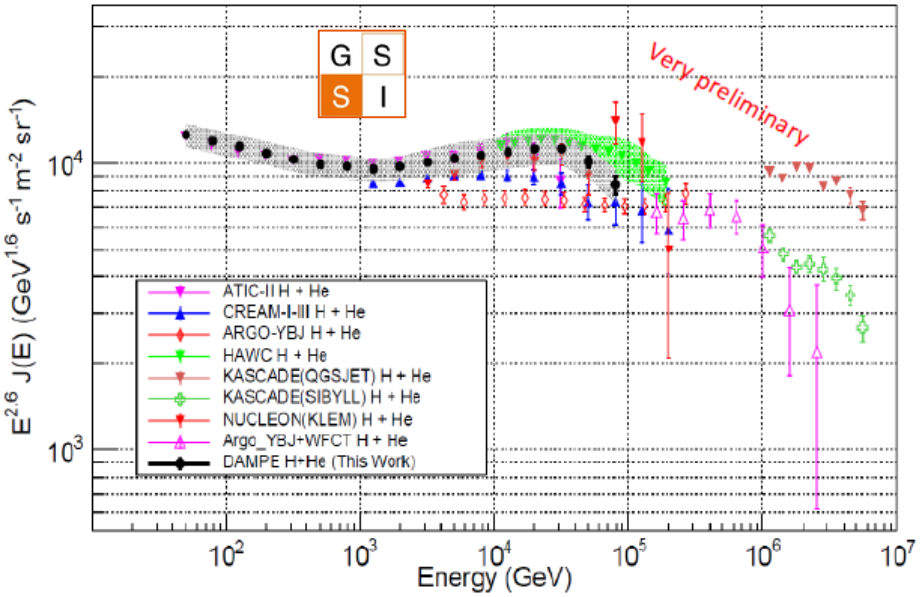
PHYSICS

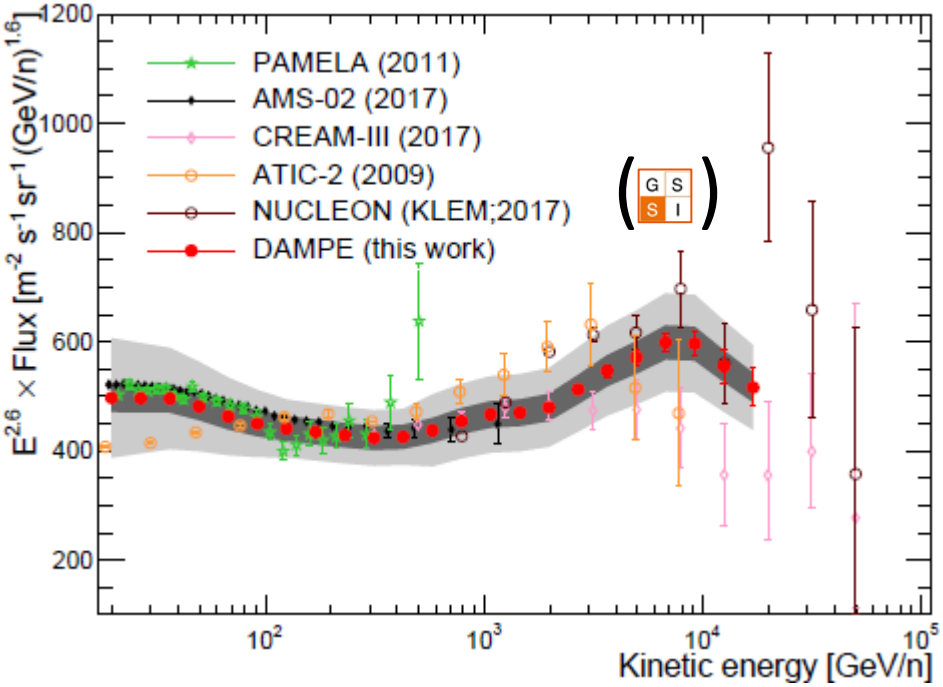
Measurement of the cosmic ray proton spectrum from 40 GeV to 100 TeV with the DAMPE satellite

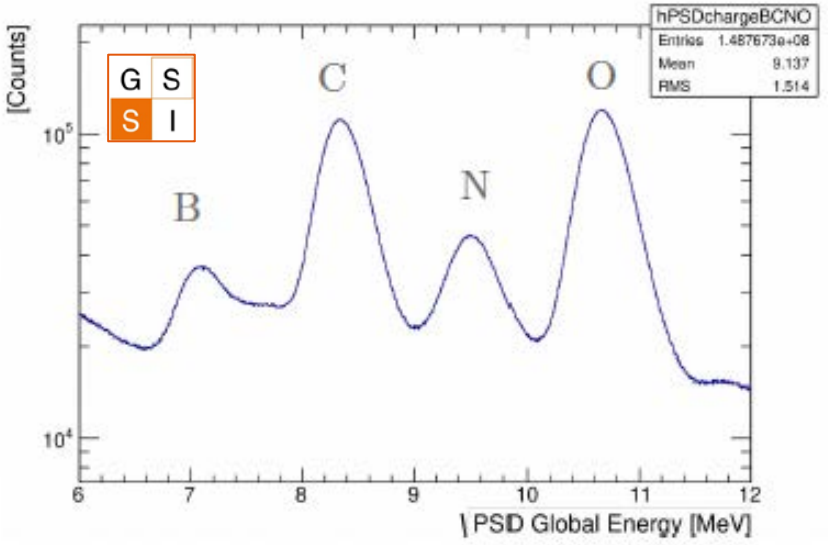


DAMPE: some science results



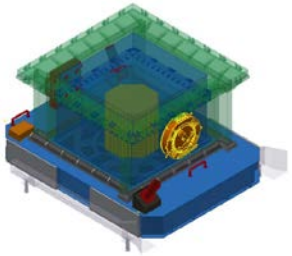




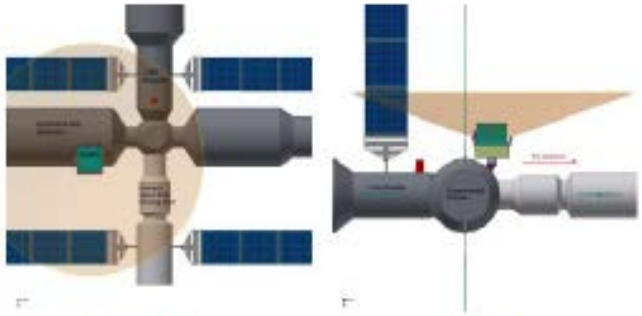


HERD: High Energy Radiation Detector

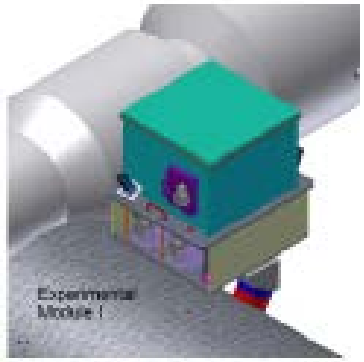
- HERD, a China-led mission with a key European contribution led by Italy, is proposed by IHEP as an astronomy and particle astrophysics experiment onboard the China's Space Station, which is planned for operation starting around 2025 for about 10 years.



- 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

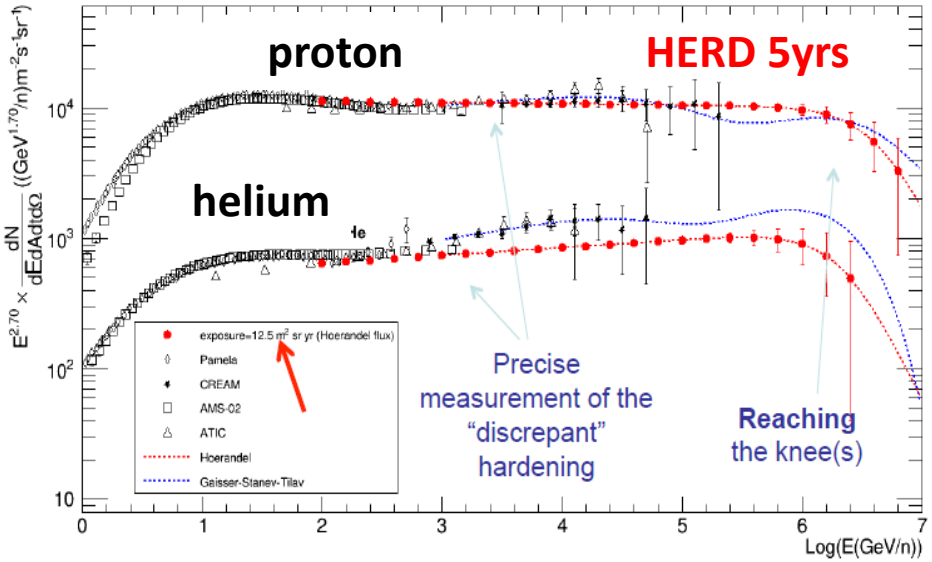


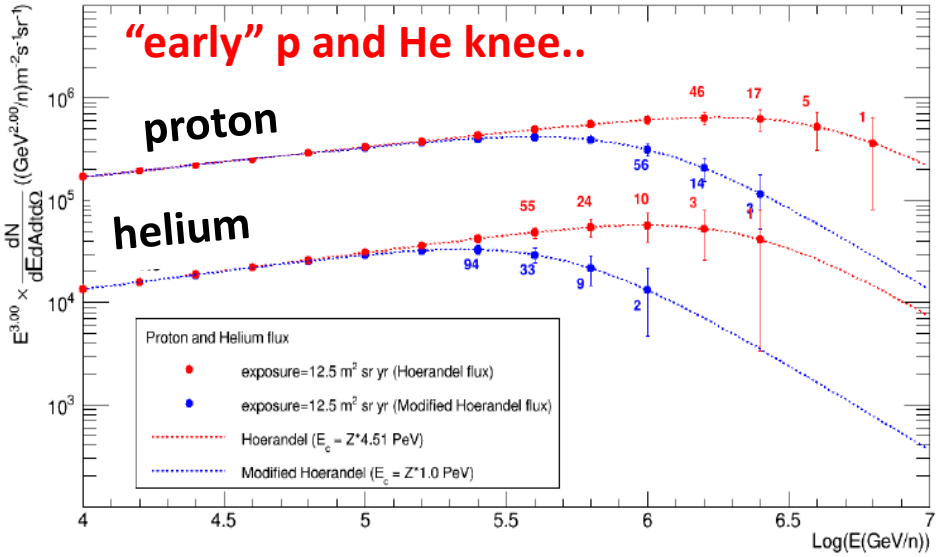
(a) Top view (b) Side view

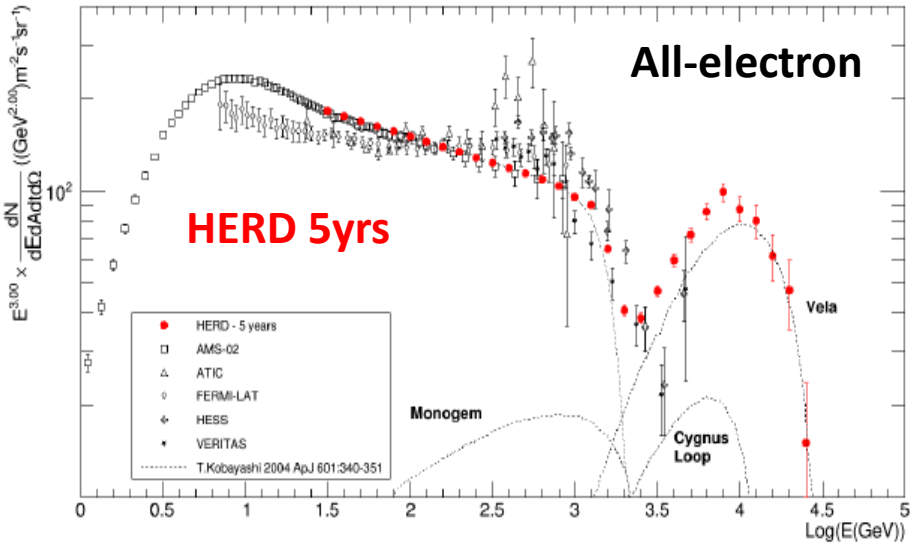


(c) Oblique view

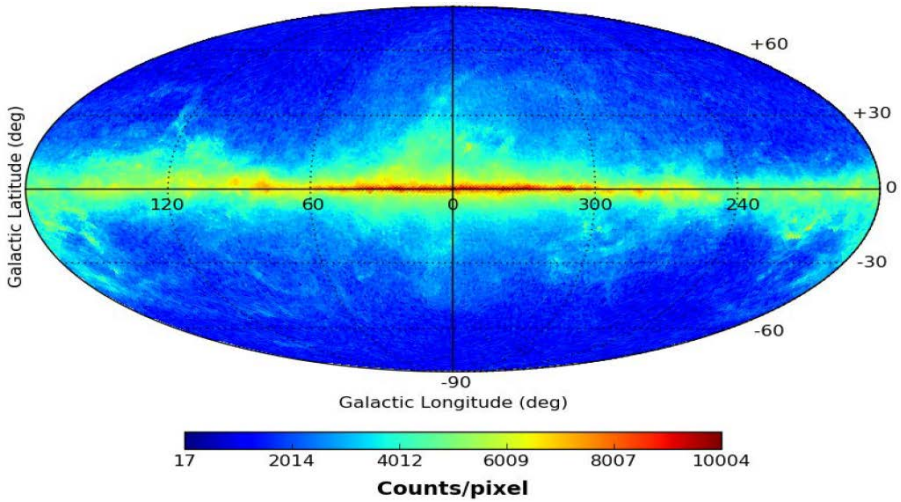
HERD: some performance plots (1)



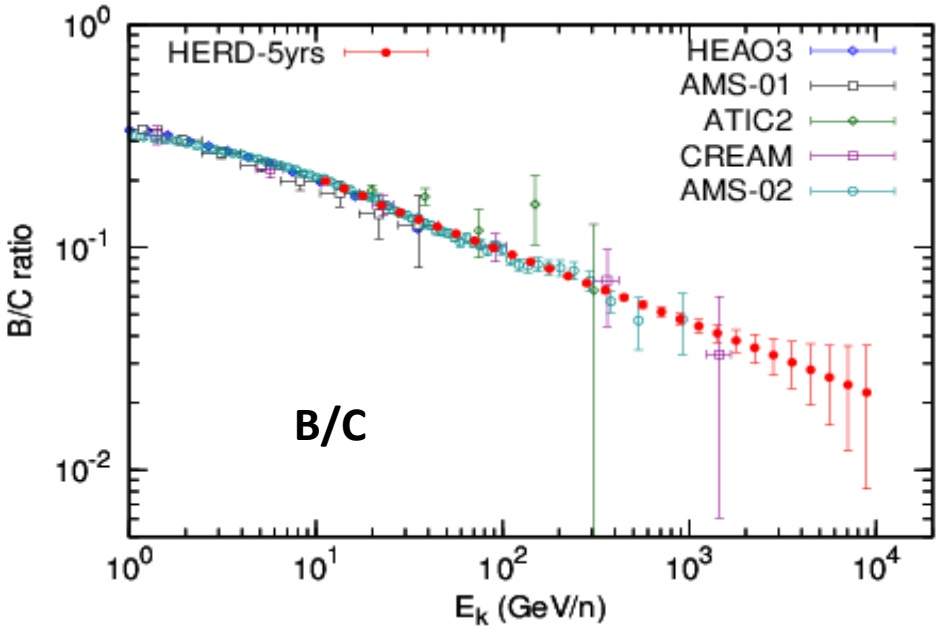


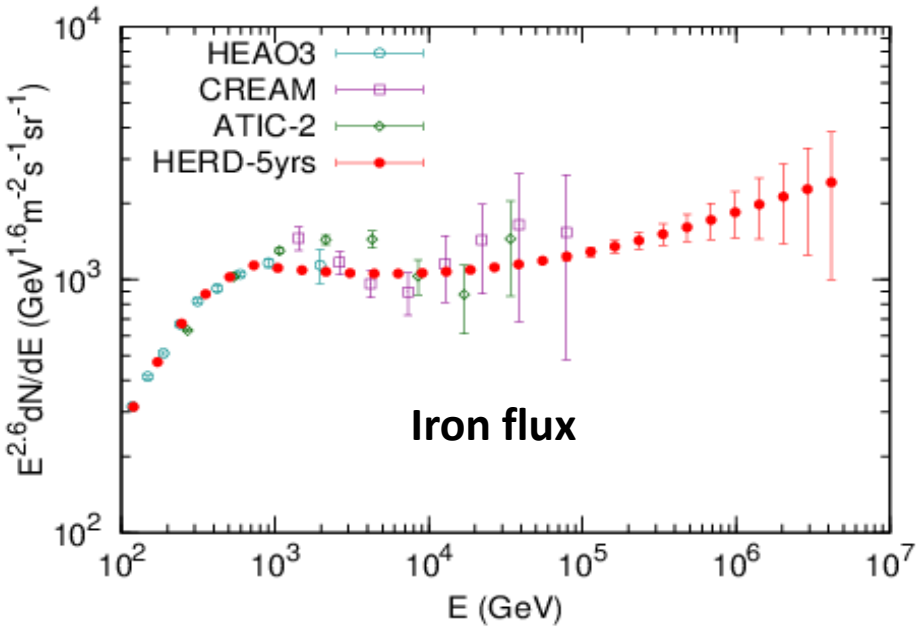


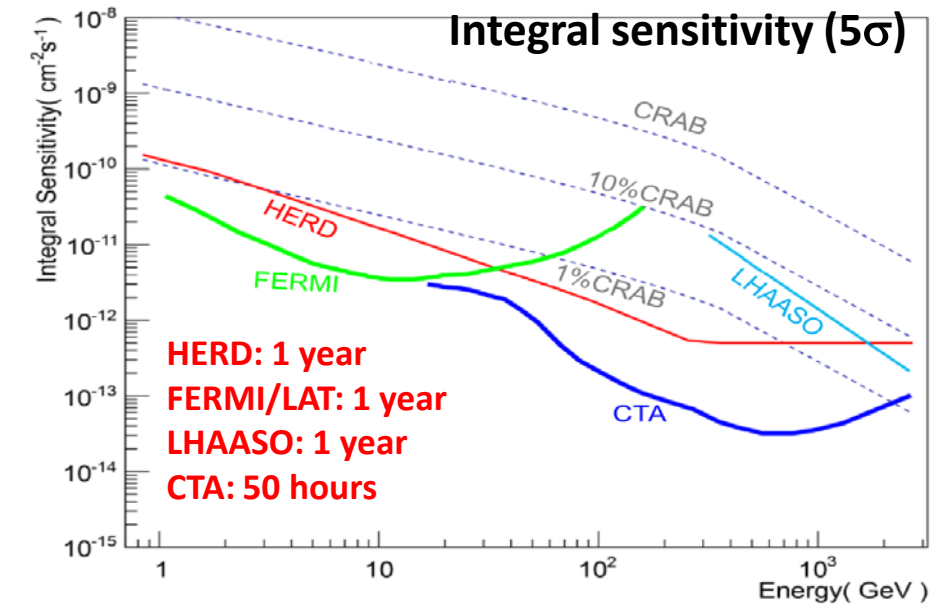
HERD 5yrs, photon map, E_γ > 1GeV

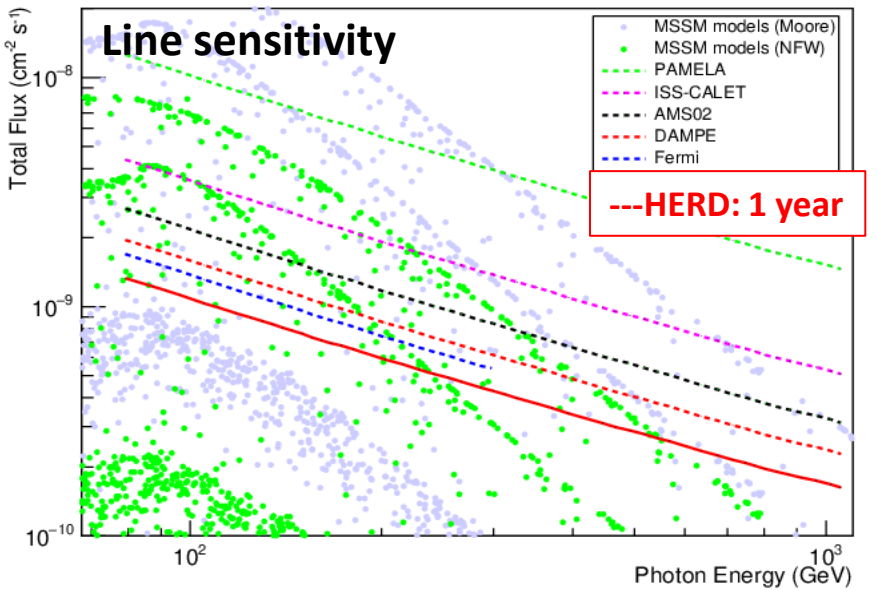


HERD: some performance plots (2)

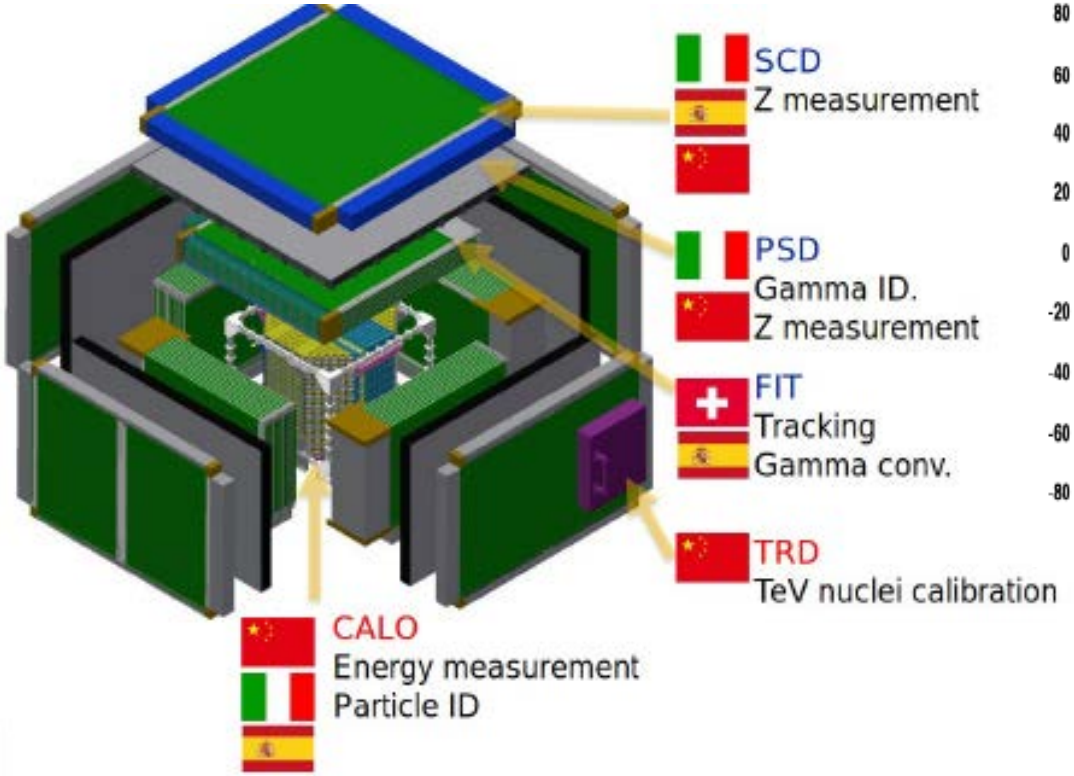


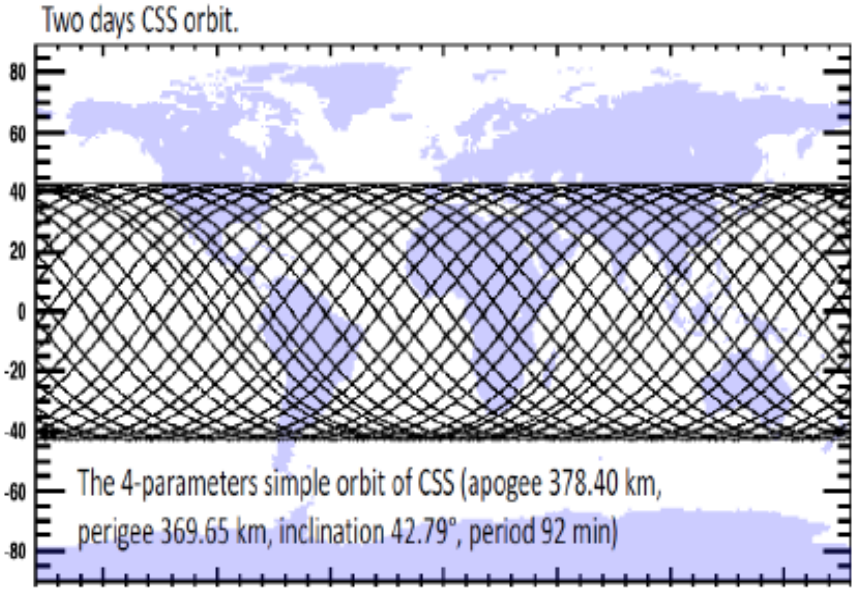






HERD: the detector and CSS the orbit

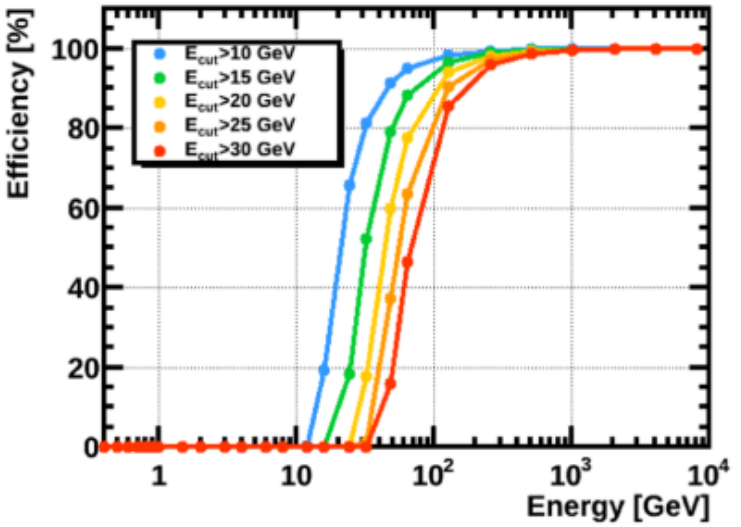




~7500 LYSO crystals (55 R.L, 3 N.I.L.)
Dual readout with IsCMOS & PD

Envelope (L*W*H)	~ 2300*2300*2000 mm^3
Weight	~ 4000 kg
Power Consumption	~ 1400 W

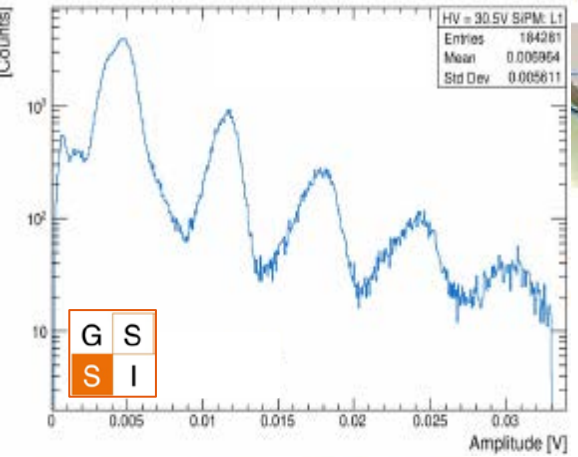
Threshold at tens of GeV

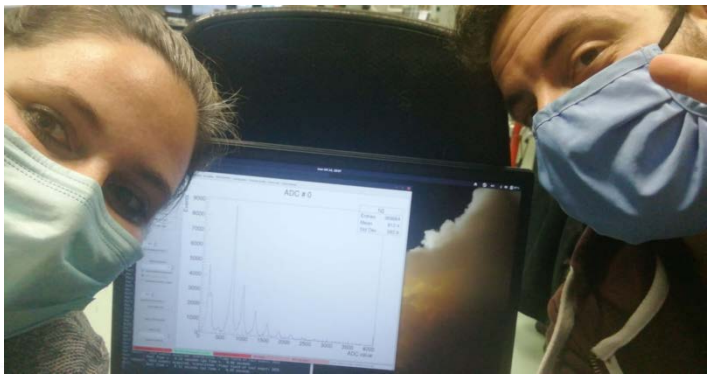


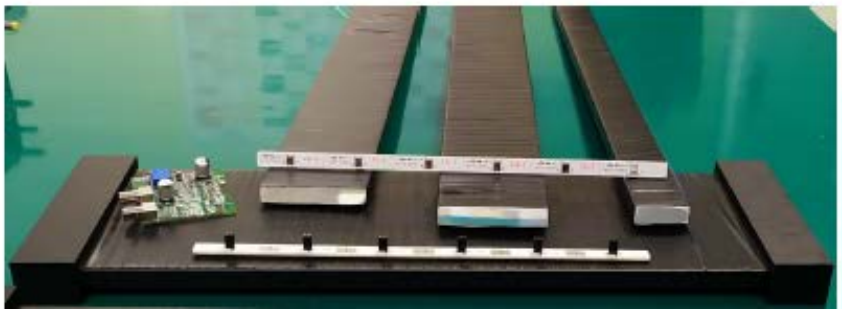
HERD: PSD R&D activity at GSSI

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.







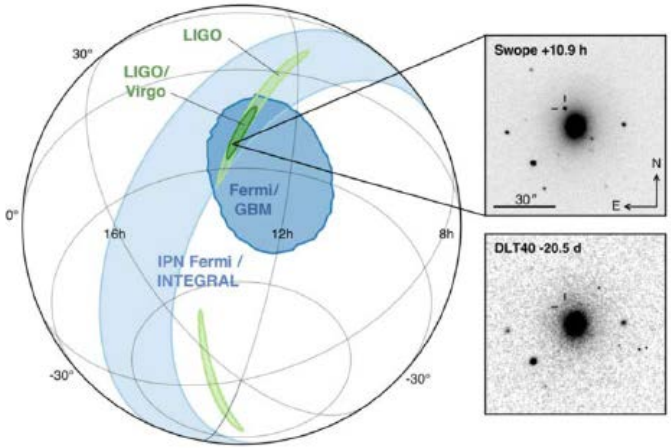
HERD: perspectives / performances

- The HERD consortium includes 150+ scientists from China and Europe
  - Most of the members have been collaborating on previous high energy experiments in science and hardware development.
- 8 HERD international workshops have been organized in China and Europe since 2012.
- 3 CERN beam tests on HERD prototypes have been successfully implemented by Chinese and European colleagues.
- Institution Leader Board established on 2019 (I. De Mitri representing GSSI)
- Joint working groups active on Mission Design and Optimization

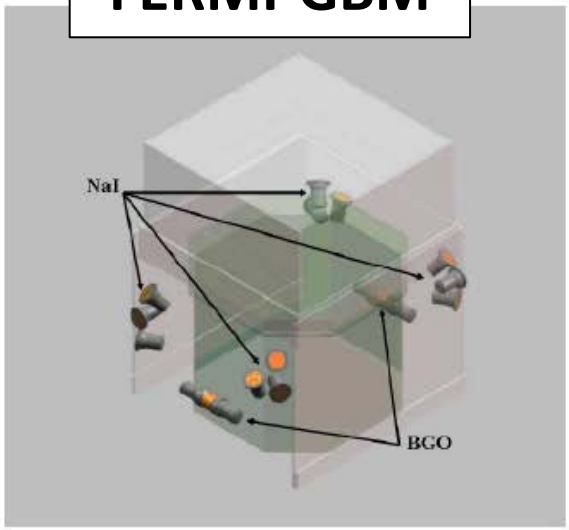
Crystal Eye: a sky monitor for X-rays and low energy γ-rays

University of Naples , ASI ,
Gran Sasso Science Institute

Multimessenger observation of **GRB170817** **EM counterpart of GW event**

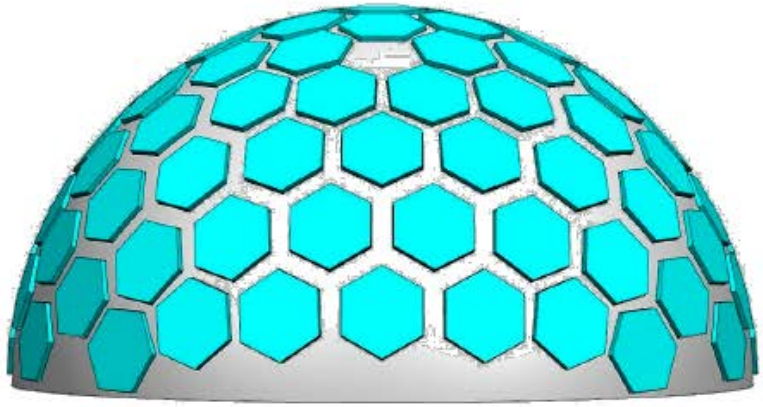


FERMI-GBM



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

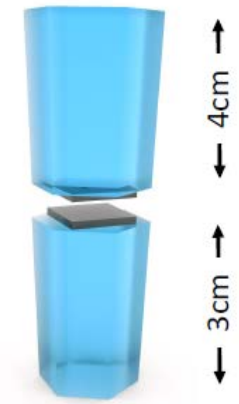
CRYSTAL EYE

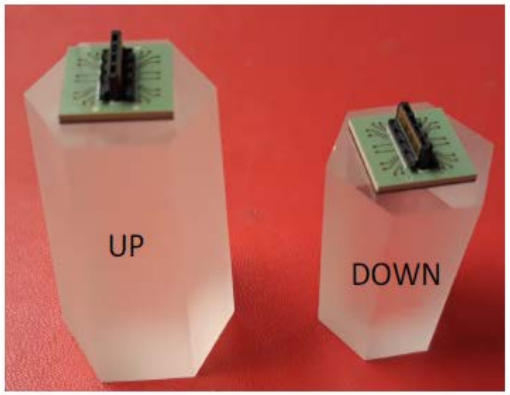


- All sky monitor
- **High** resolution
- Triangulation on **110 pixels**
- Pixel diameter **3.3 cm**

Crystal Eye: detector and pathfinder

Double layer of LYSO pixels covered by a veto dome.
The device will have 110 pixels per layer.
Pixel readout with a 12 x12mm^2 **SiPM array**

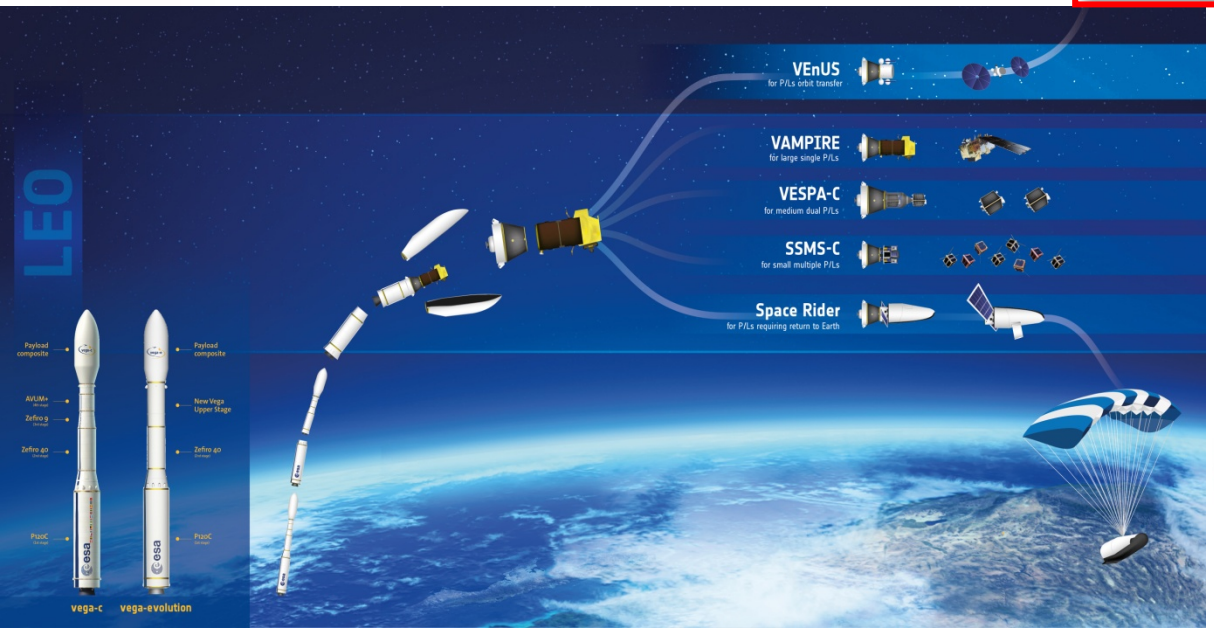




A single module is expected to improve at least by a factor 3 the localization capability of Fermi–GBM

A constellation of 3 Crystal Eyes would guarantee a continuous observation of the whole sky with enhanced localization capabilities and would give the possibility to scan both in space and in time the structure of GRBs

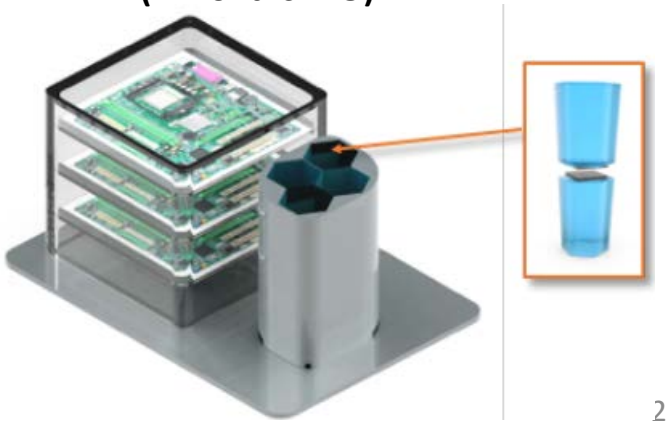
Technological pathfinder selected by ESA for the first SpaceRIDER launch in 2022



2020: Radiation hardness + mechanics

2021: Space qualification

2022: Flight onboard ESA Space Rider (2 months LEO)



Call for ideas for missions on the Moon

GAMMA RAY ASTRONOMY AND ASTROPHYSICS ON THE LUNAR SURFACE

I. De Mitri
F.C.T. Barbato
Gran Sasso Science Institute, L'Aquila (Italy) and INFN

G. Barbarino
M.N. Mazziotta
Istituto Nazionale Di Fisica Nucleare (Italy), Naples and Bari Units

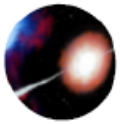
R. Battiston
R. Iuppa
University of Trento, Trento (Italy), INFN and TIFPA

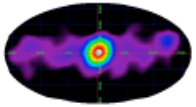
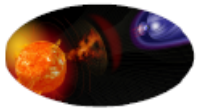
Call for ideas for missions on the Moon

SCIENCE WITH GRAAL

To perform world class science and enable new technologies

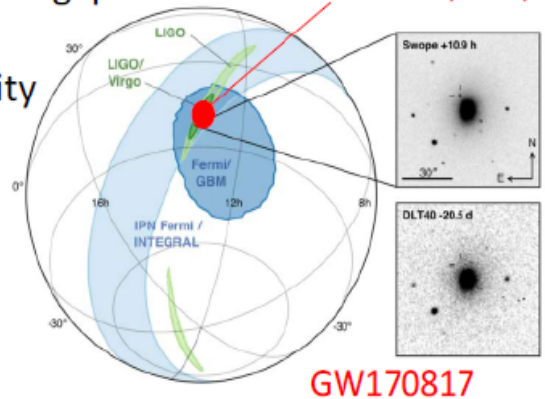
- Fundamental (continuous and transient) astrophysical observations by filling the gap in current instrument sensitivity in the 10keV-50MeV energy range
- Lunar site characterization in terms of soil and cosmic rays induced radioactivity
- Space weather monitoring
- Study X and gamma emissions form the Earth



Mission Science goals include:

GRAAL localization capability

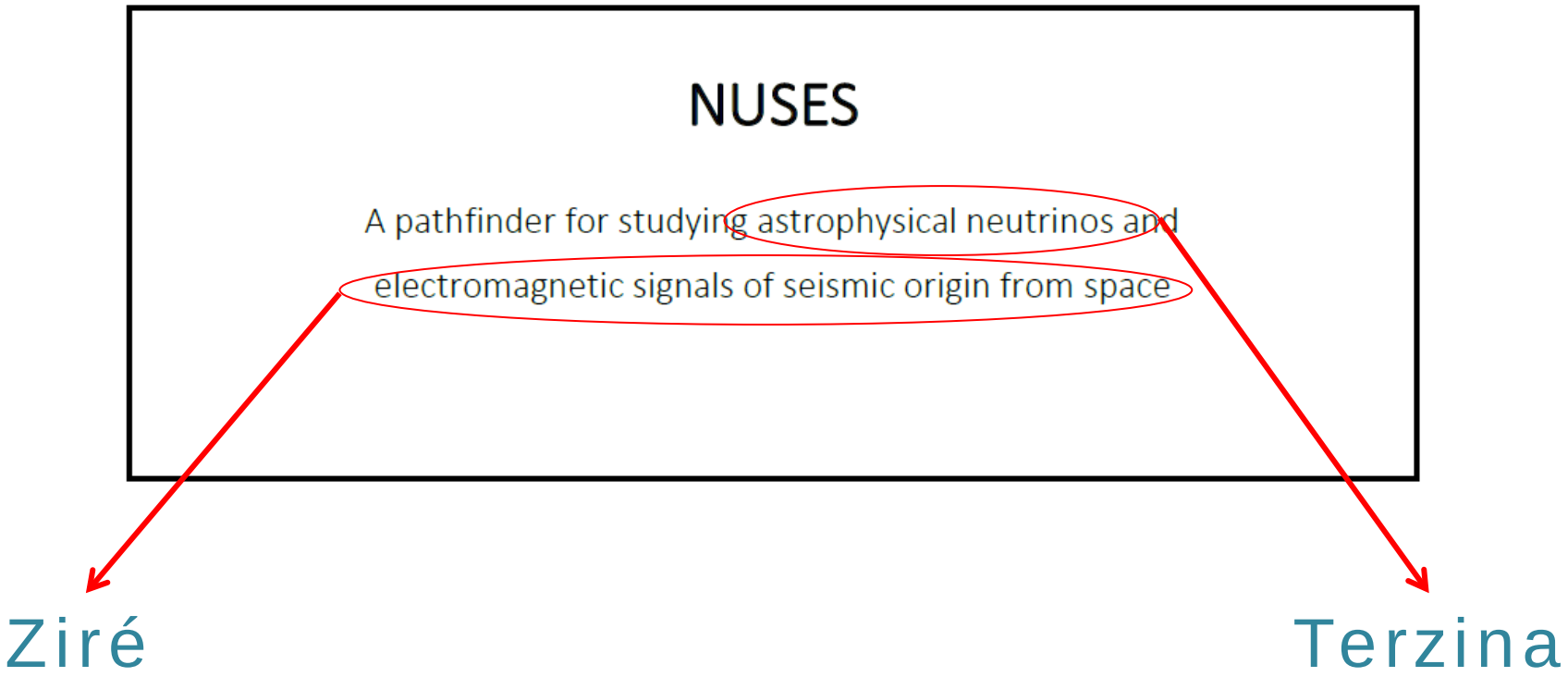


GW170817
Gravitational
wave event

- Observation of X and gamma rays production in gravitational wave events and supernovae explosions
- Gamma-ray emissions from the Galaxy
- Map of 511 keV galactic emission
- Supernova remnants, compact object binary systems, active galactic nuclei, gamma-ray bursts, ...
- Study of galactic cosmic ray sources through gamma-ray observations
- Study of the near Earth cosmic environment
- Analysis of radioactive properties of the lunar soil
- Study of the interaction between the solar wind and the lunar surface
- X and gamma-ray imaging of the Earth magnetosphere from the Moon

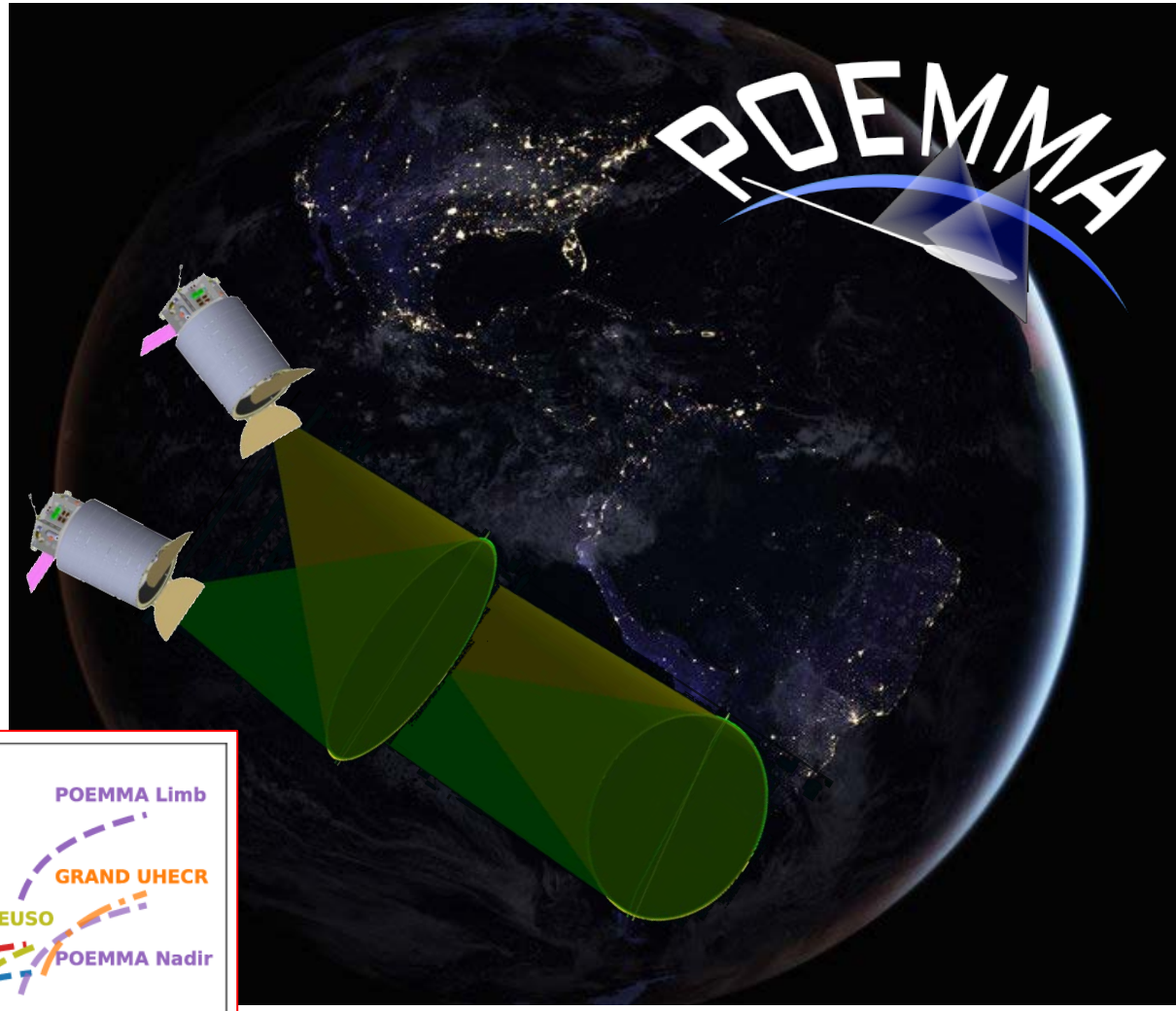
Enabling new technologies

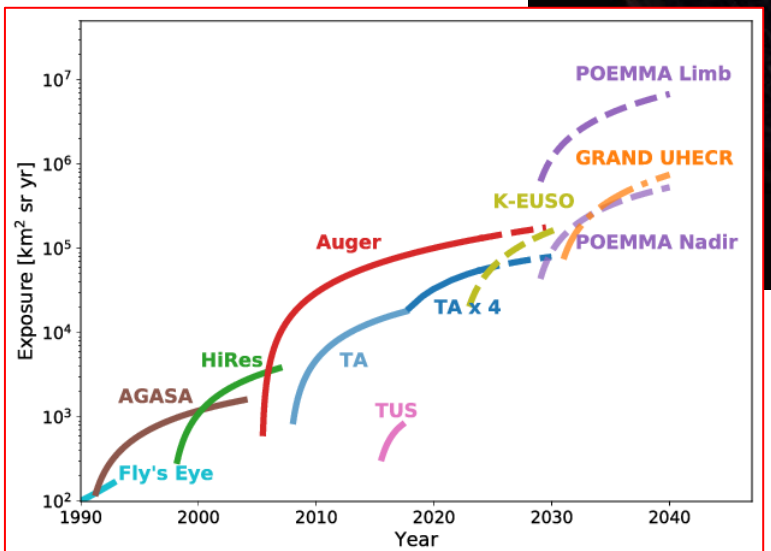
Extensive use of Silicon PhotoMultiplier (SiPM) sensors/arrays for scintillation light readout and high resolution tracking system (50-100µm)


NUSES
A pathfinder for studying astrophysical neutrinos and
electromagnetic signals of seismic origin from space
Ziré
Terzina

Probe of Extreme Multi Messenger Astrophysics

- ✓ Ultra High Energy Cosmic Rays.
- ✓ Astrophysical Neutrinos.
- ✓ International collaboration (lead by U. Chicago) main participants: USA, Italy, Germany, France, Denmark, Japan.
- ✓ Selected by NASA as probe study for the next decade class B missions.





Tavolo Tematico su Strumentazione Scientifica

Silicon based technologies for scientific space missions and interdisciplinary applications

Felicia Barbato(1,2), Stefania Beolé (3,4), Ettore Del Monte (5), Ivan De Mitri (1,2,*), Fabio Gargano (6), Francesco Giordano (7,6), Luca Latronico (4), Mario Nicola Mazziotta (6)

(1) GSSI - Gran Sasso Science Institute - L'Aquila, Italy
(2) INFN - Laboratori Nazionali del Gran Sasso, Assergi, L'Aquila, Italy
(3) Università di Torino , Torino , Italy
(4) INFN – Sezione di Torino, Italy
(5) INAF – IAPS, Roma, Italy
(6) INFN – Sezione di Bari, Italy
(7) Università degli Studi di Bari "A. Moro", Bari, Italy

(*) Speaker: ivan.demitri@gssi.it

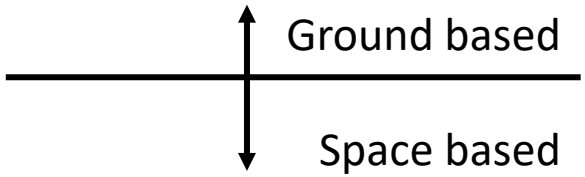
Ongoing activities at GSSI-LNGS-UNIVAQ

AUGER

Currently upgrading the detector. Atmosphere monitoring . Data analysis. Science results.

CTA

Construction of the first telescopes. Atmospheric monitoring



DAMPE

On orbit since December 2015. Data analysis. Science results.

HERD

Design optimization ongoing. To be installed on the Chinese Space Station in 2026.

CRYSTAL EYE + GRAAL

Prototype construction. To fly onboard Space Rider in 2022.
ESA call: Gamma Ray Astronomy and Astrophysics on the Lunar surface.

NUSES

R&D activity to start. Pathfinder for new technologies in space.

(POEMMA)

Design optimization ongoing. It is one of the selected projects by the NASA call for medium size missions. Final selection for phase A next year.

High Energy Astroparticle Physics: HE

EXP

PH

Tools

HE-1: Non thermal processes

Roberto Aloisio (GSSI and INFN)

Basic processes of non-thermal emission in high energy astrophysics and astroparticle physics. Synchrotron emission, inverse Compton scattering, hadronic processes. Proton-proton interaction and interactions with astrophysical photons backgrounds. Impact on observations and theoretical models.

HE-2: Data analysis techniques in HE Astroparticle Physics

Sergio Petrera (GSSI and INFN)

Review of the main techniques for Extensive Air Shower reconstruction. The following example will be discussed in detail: Inference of UHECR source scenarios from energy spectrum and composition data.

HE-3: Tracking and calorimetric systems in space-based experiments

Giovanni Ambrosi (INFN Perugia), Oscar Adriani (Università di Firenze and INFN)

Silicon based tracking system, calorimetric detectors, and their applications to existing and future missions devoted to direct cosmic ray measurements. Use of SiPMs as light sensor in space-based detectors.

HE-4: Very High Energy Gamma Ray Astronomy (VHE-GRA)

Alessandro De Angelis (Università di Padova and INFN)

Objectives and the Status of the Field. Phenomenology of VHE GRA in the context of multi-wavelength and multi-messenger approach for the study of the non thermal Universe. GRA and Origin of Galactic Cosmic Rays. GRA and Origin of Extragalactic Cosmic Rays. Cosmology with VHE gamma-rays.

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

Valter Bonvicini (INFN Trieste), Felicia Barbato (GSSI and INFN)

Introduction to front-end electronics and pulse processing. Basic noise concepts. Processing the signal from a radiation detector. Identification of noise sources. General consideration about signal shaping. Preamplifiers and Amplifiers. Radiation hardness. Specific examples on space-based detectors.

HE-6: High Energy Neutrino Astronomy

Paolo Lipari (INFN Roma)

State and perspectives of High Energy Neutrino Astronomy, and the relations with the study of the other cosmic messengers (in particular Cosmic Rays and Gamma Rays). The flux of atmospheric neutrinos (generated by cosmic rays in the Earth's atmosphere) will be also discussed.

HE-7: UHECR theory

Roberto Aloisio (GSSI and INFN)

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

HE-8: Numerical methods in Astroparticle Physics

Carmelo Evoli (GSSI and INFN)

Introduction on most common numerical methods used in astroparticle physics. Designing a numerical algorithm. Basics of computation, differentiation/integration, ODE and PDE solvers, code optimization.

Low Energy Astroparticle Physics: LE

EXP

PH

Tools

LE-1: Low radioactive background techniques for rare event searches

Ezio Previtali (INFN Milano Bicocca), Lorenzo Pagnanini (GSSI and INFN)

A detailed description of various screening methods and approaches will be presented and some results on specific measurements will be discussed in detail.

LE-2: Dark Matter Candidates

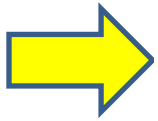
Piero Ullio (SISSA – Trieste)

General classification of particle DM candidates. Elements of thermal description of the early Universe. Boltzmann equation description of chemical and kinetic freeze-out; hot and cold thermal relics. The Higgs portal for a scalar singlet as an example of WIMP DM candidate; its direct and indirect detection. Freeze-in mechanism for non-thermal DM candidates. Dark matter as a condensate: the axion.

LE-3: Rare event searches with noble liquid TPC

Cristiano Galbiati (GSSI and INFN, Princeton University)

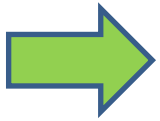
Main technical aspects of Liquid Xenon and Liquid Argon, single and double phase, Time Projection Chambers. Rare event searches with large underground TPCs.



LE-4: Satistics tools for Astroparticle Physics

N. Di Marco (GSSI and INFN), S. Petrera (GSSI and INFN), F. Salamida (University of L'Aquila and INFN)

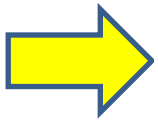
Basic and advanced statistics tools for astroparticle physics: frequentist and Bayesian approaches. Applications to: upper limit calculations, exclusion plots, spectral unfolding, etc.



LE-5: Radiation Measurements

Felicia Barbato (GSSI and INFN), Lorenzo Pagnanini (GSSI and INFN), Andrei Puiu (GSSI and INFN)

Measurement of radioactivity. Low Background and Ultra-Low Background techniques.
Measurement of secondary cosmic radiation. Setup of a cosmic ray muon detector.
This is a laboratory course with some activity at LNGS external labs.



LE-6: Monte Carlo techniques

Luciano Pandola (INFN LNS)

Sampling of random variables, numerical integration, error estimation in Monte Carlo calculations, particle tracking in homogeneous media, condensed, detailed and mixed Monte Carlo simulations, biasing techniques. Blackboard lectures will be complemented by a few practical exercises.

LE-7: Neutrino oscillation experiments

Natalia Di Marco (GSSI and INFN)

Review of neutrino oscillation experiments with both natural and artificial sources.

LE-8: Cryogenics sensors and related electronics

Andrei Puiu (GSSI and INFN), Marcello Messina (INFN LNGS)

Low temperature calorimeters and readout techniques. Detection of scintillation light in liquid Ar / Xe TPC with standard or silicon based photomultipliers and related electronics.