GRAN SASSO
SCIENCE INSTITUTE

SCHOOL OF ADVANCED STUDIES

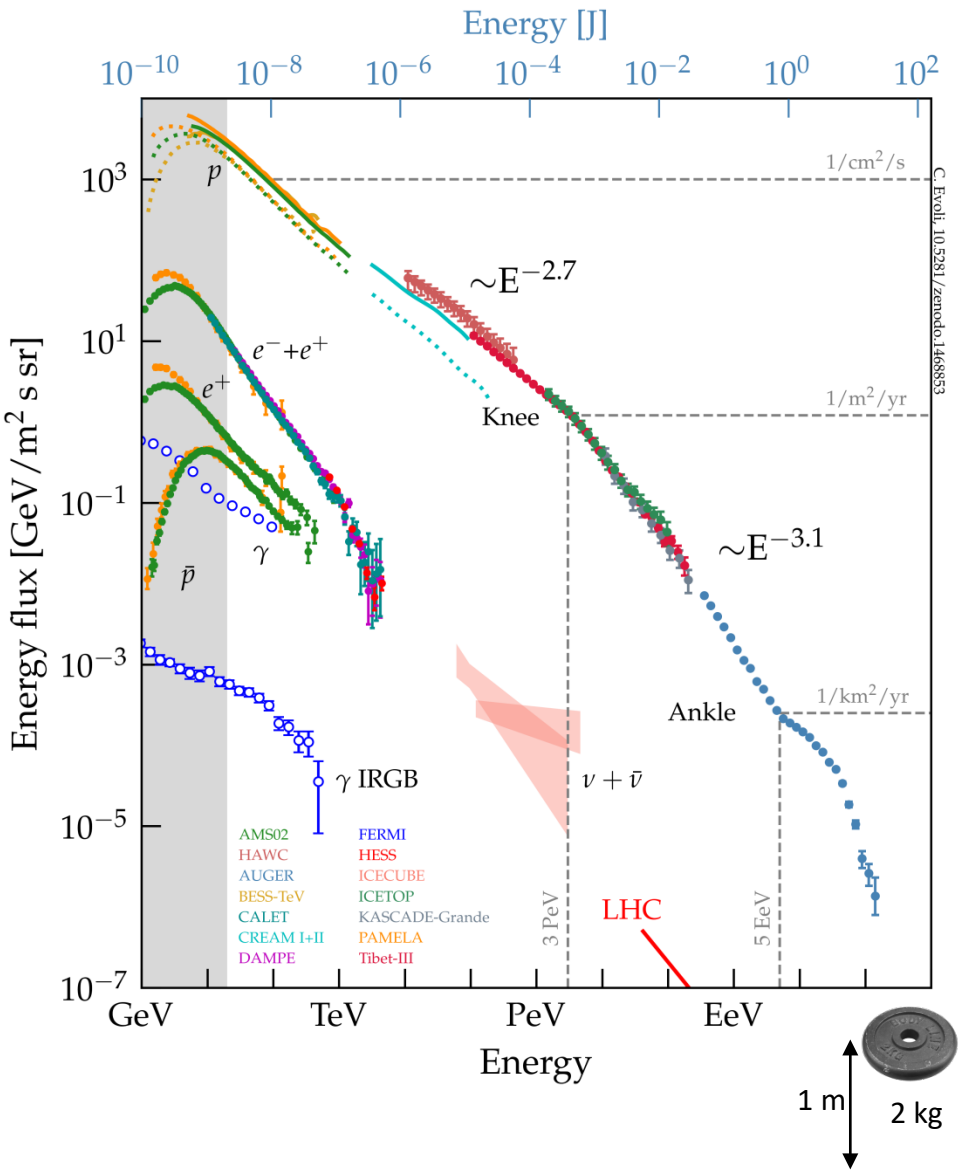
Radiations from the Universe: experiments

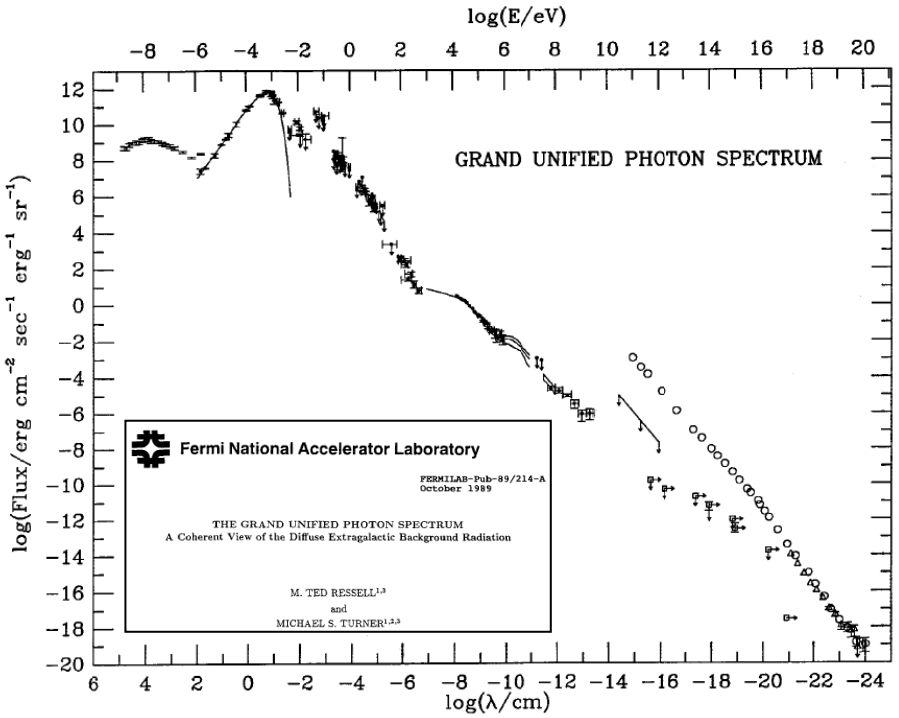
Ivan De Mitri

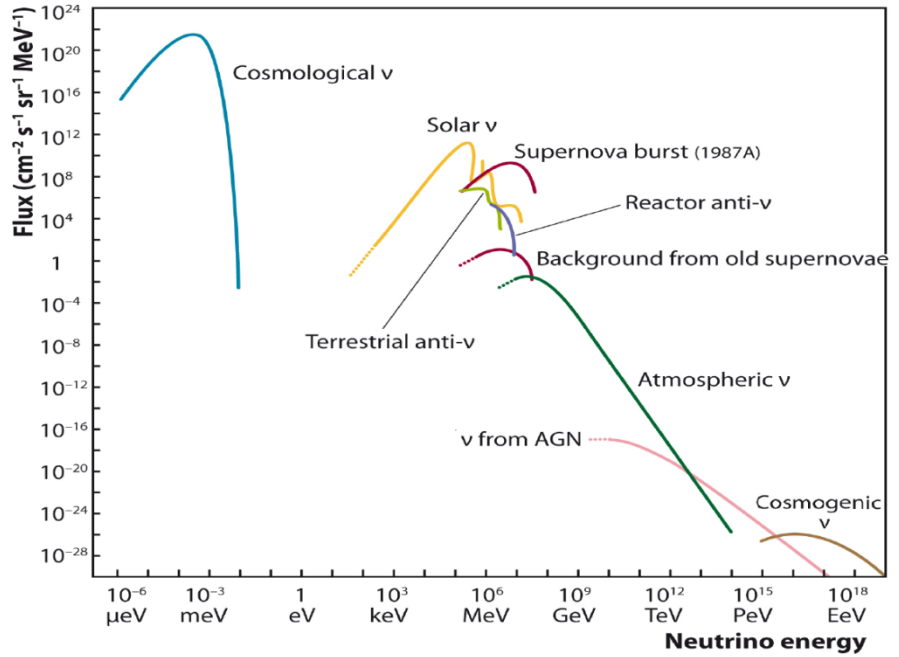
8th GSSI Science Fair
L'Aquila, February 15, 2022

www.gssi.it

Our landscapes(s)







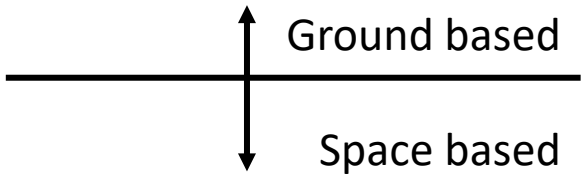
Ongoing activities at GSSI-LNGS-UNIVAQ

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 2027.

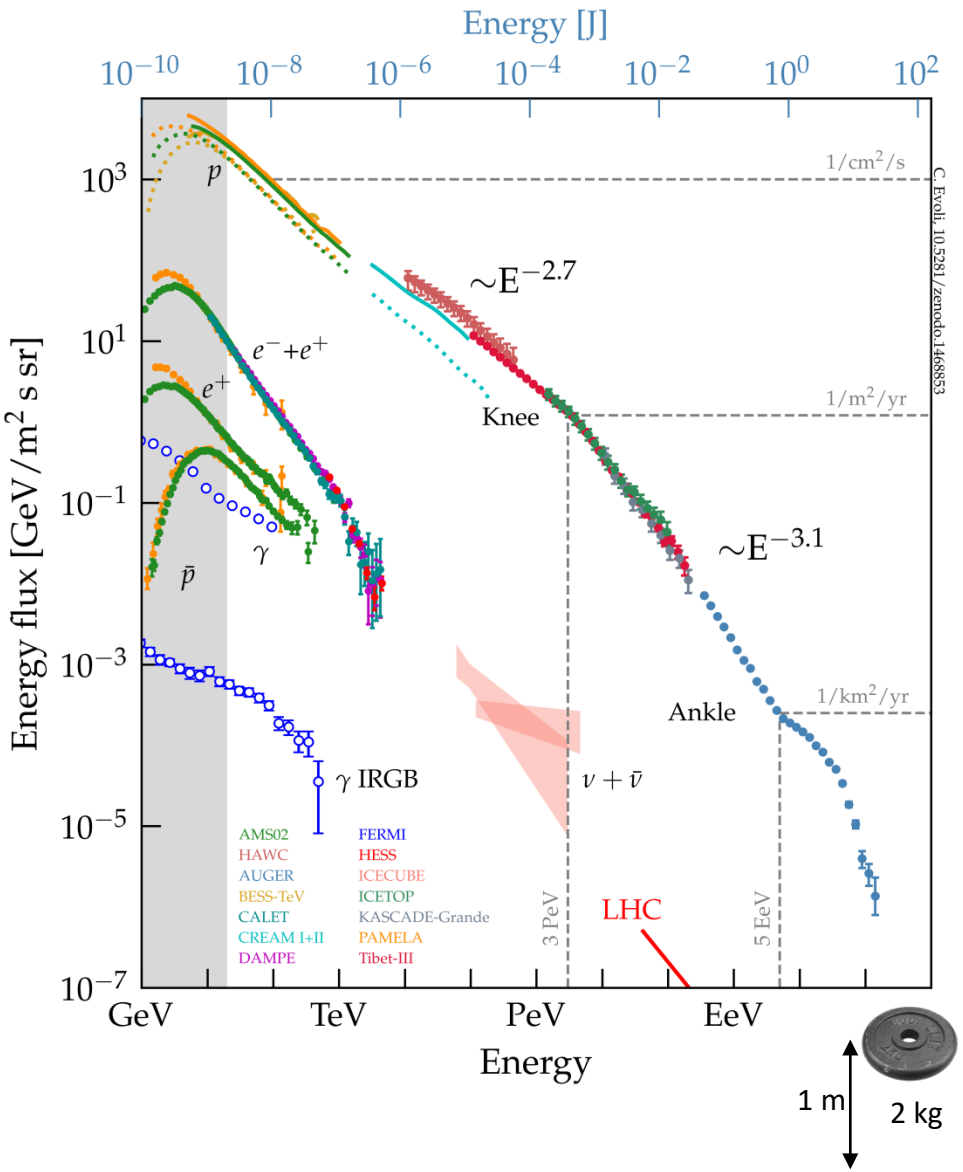
CRYSTAL EYE + GRAAL + ….

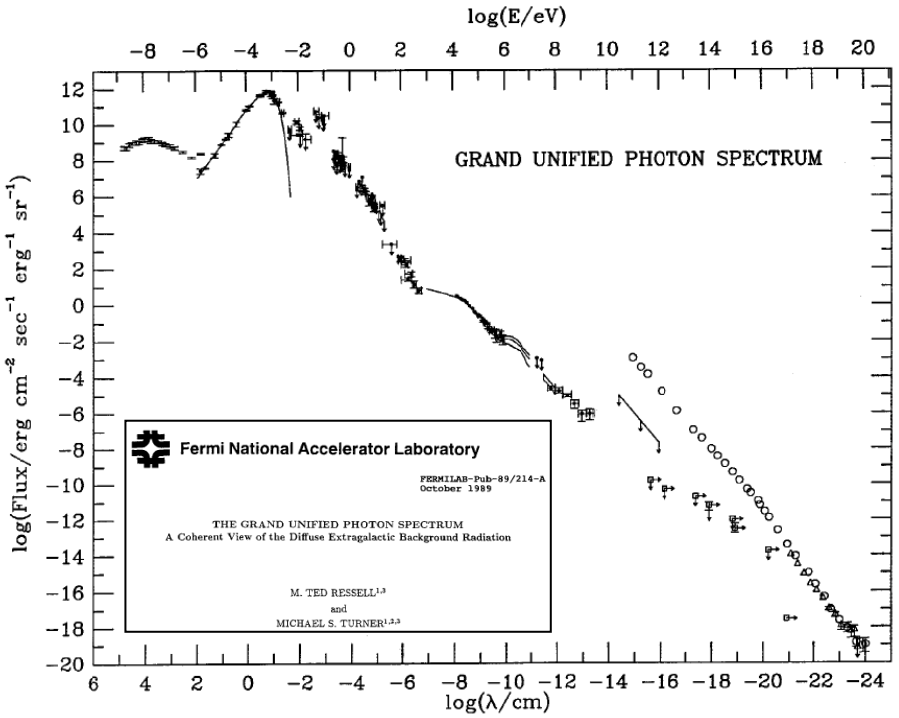
Prototype construction. To fly onboard Space Rider in 2023.
ESA call: Gamma Ray Astronomy and Astrophysics on the Lunar surface.
ESA call: fast and medium size mission opportunities

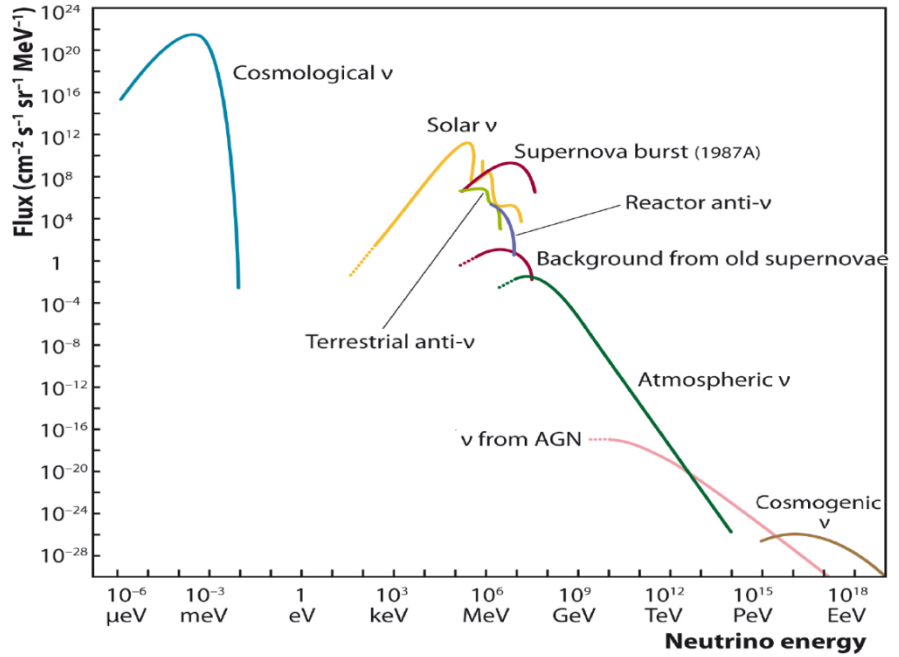
NUSES

R&D activity to start. Pathfinder for new technologies and new observational techniques in space (UHE neutrinos, Space weather, interdisciplinary applications,…)

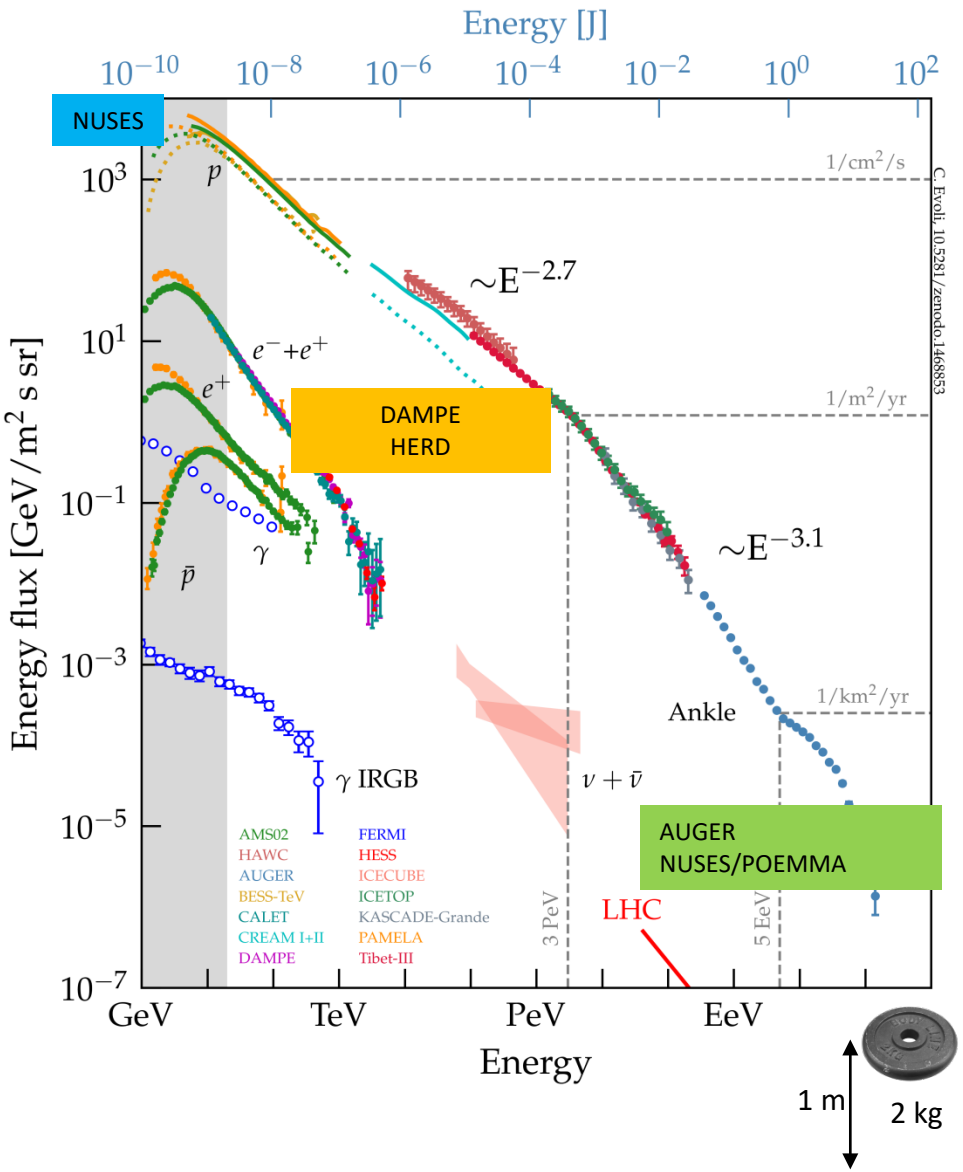
Our landscapes(s)

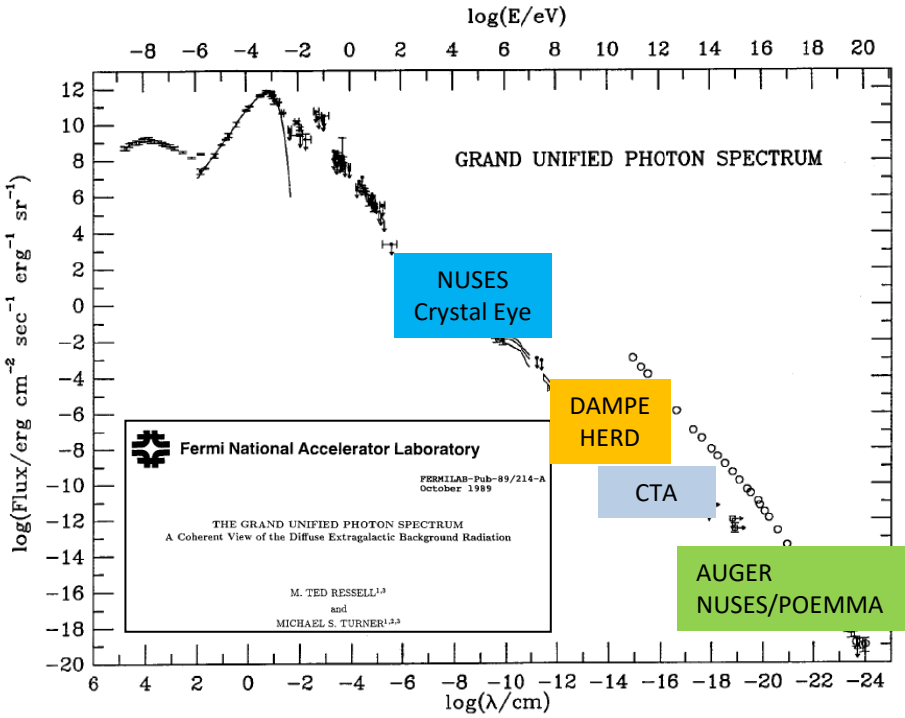


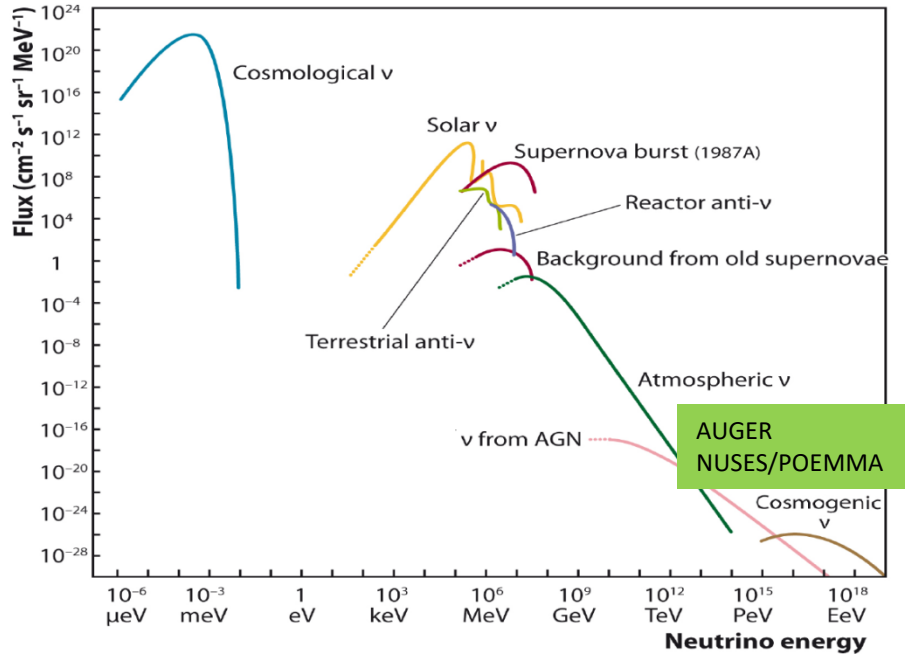




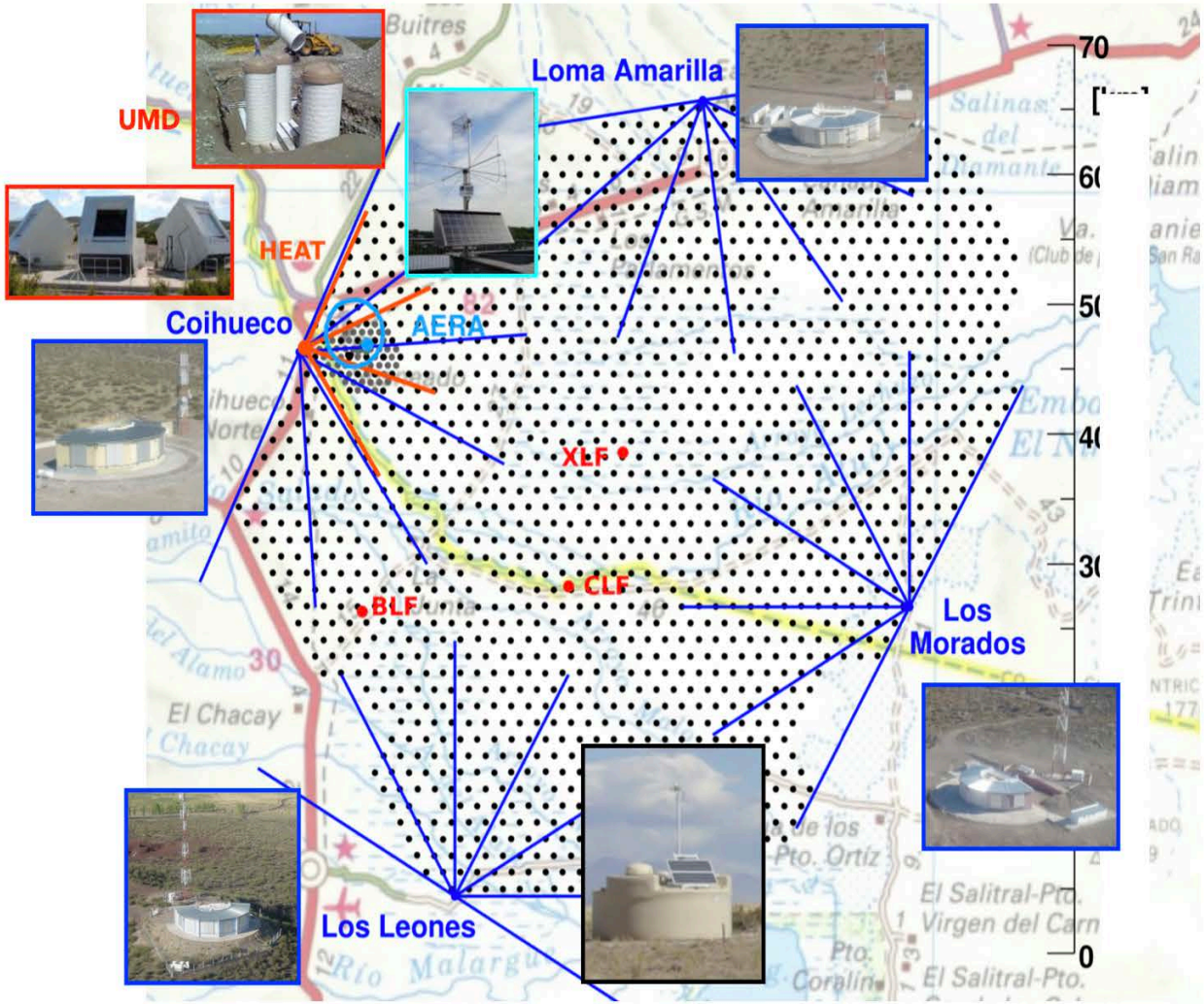
Our landscapes(s)







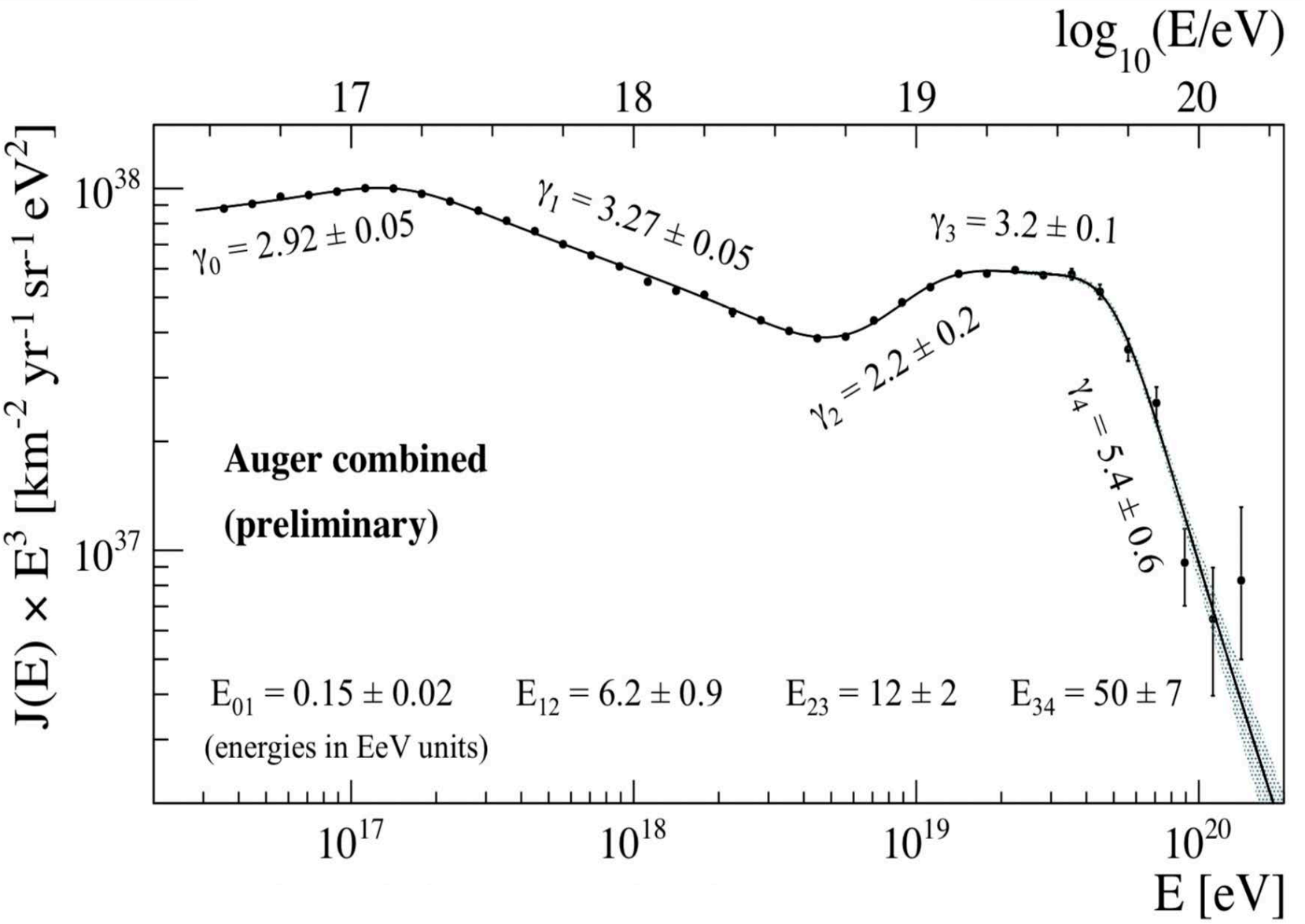
The Pierre AUGER Observatory



- 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)

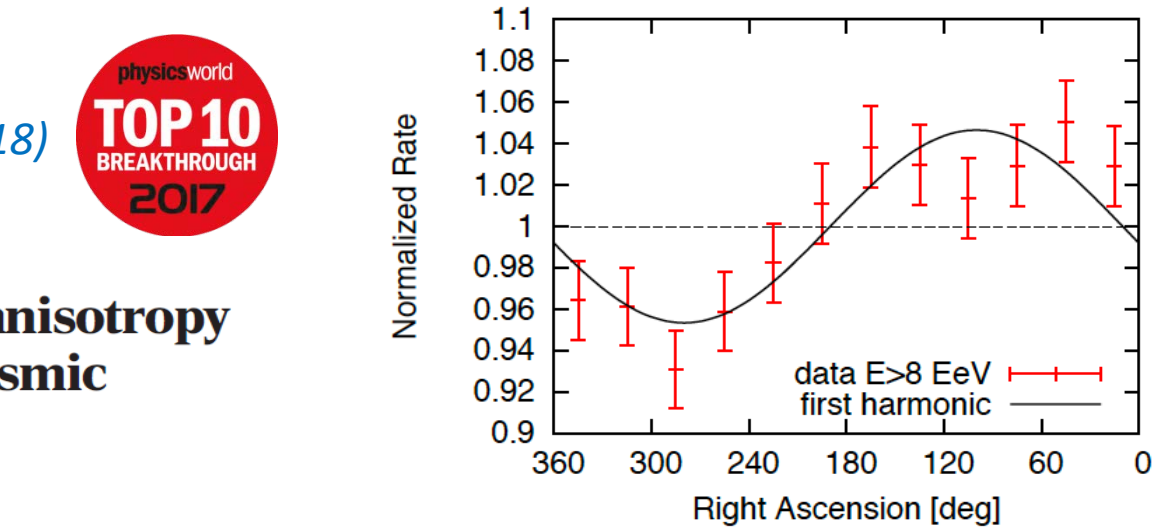
physicsworld TOP 10 BREAKTHROUGH 2017

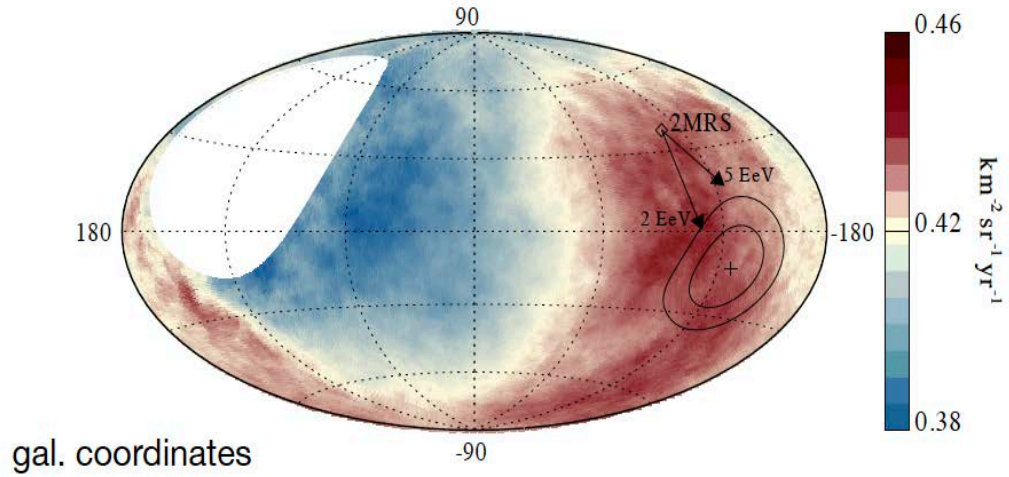
COSMIC RAYS

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

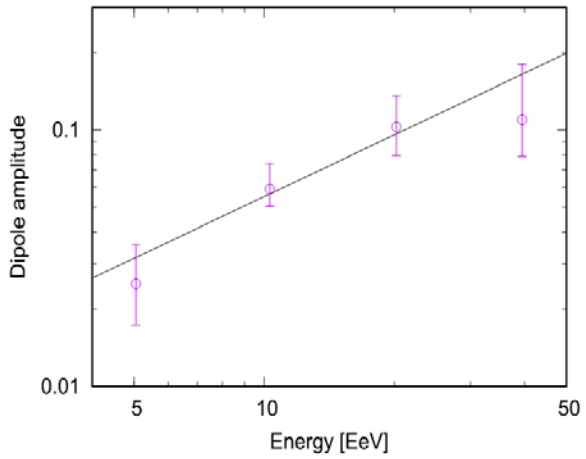
The Pierre Auger Collaboration*†

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

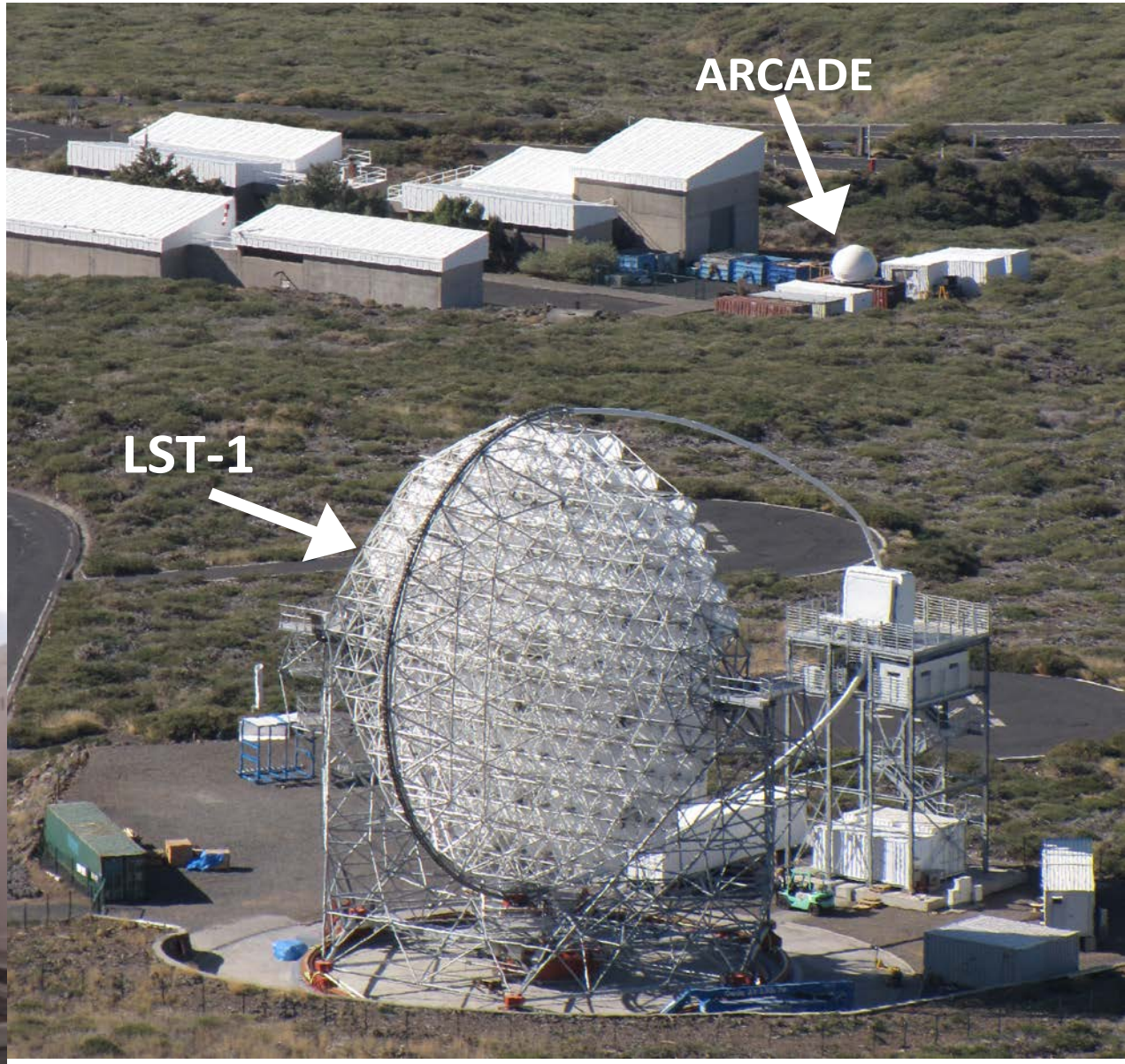
cta cherenkov telescope array

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

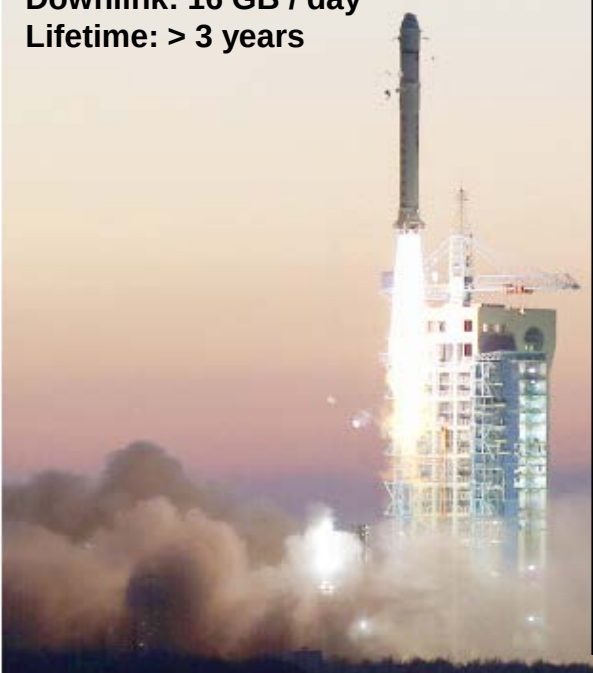
Università degli Studi di Napoli Federico II
Dipartimento di Fisica «Ettore Pancini»

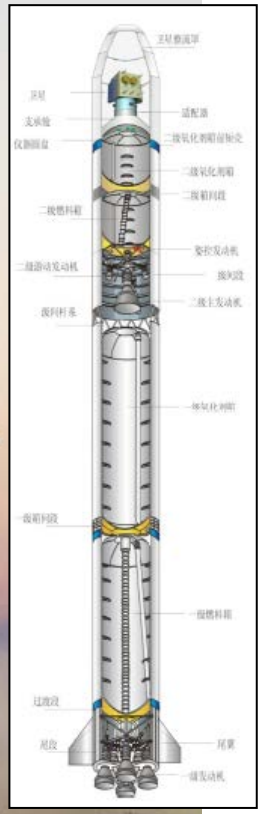


DAMPE: the mission

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

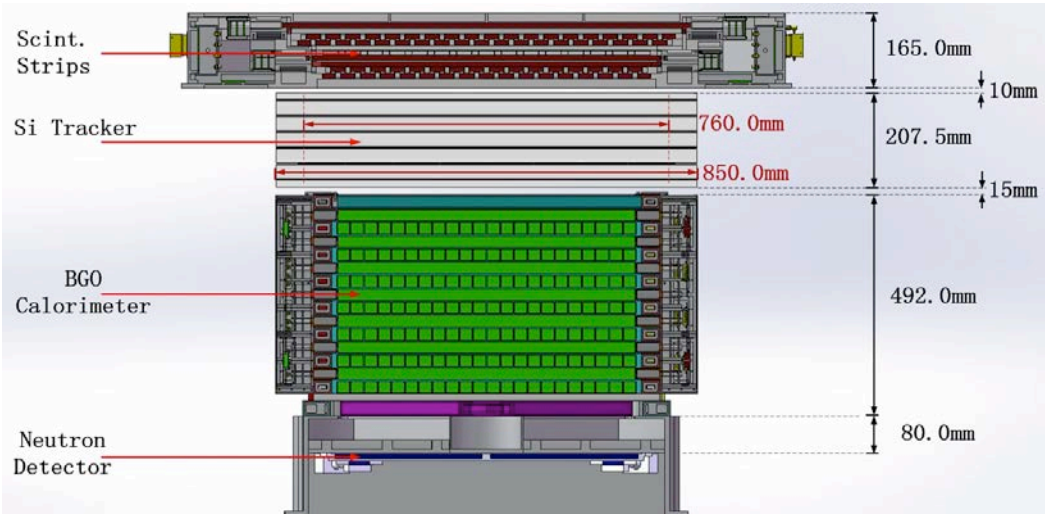
Cosmic ray physics

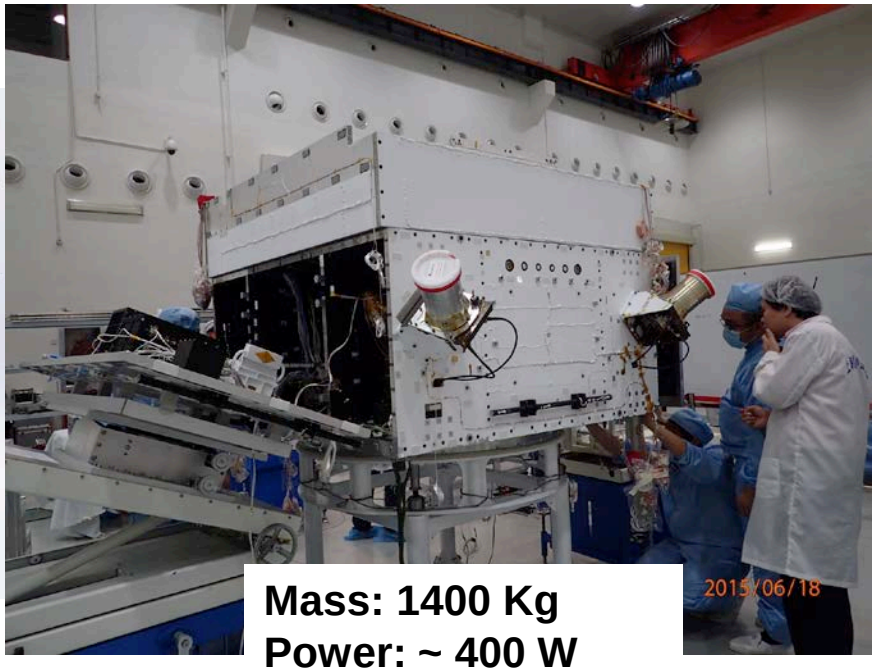
γ-ray astronomy

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





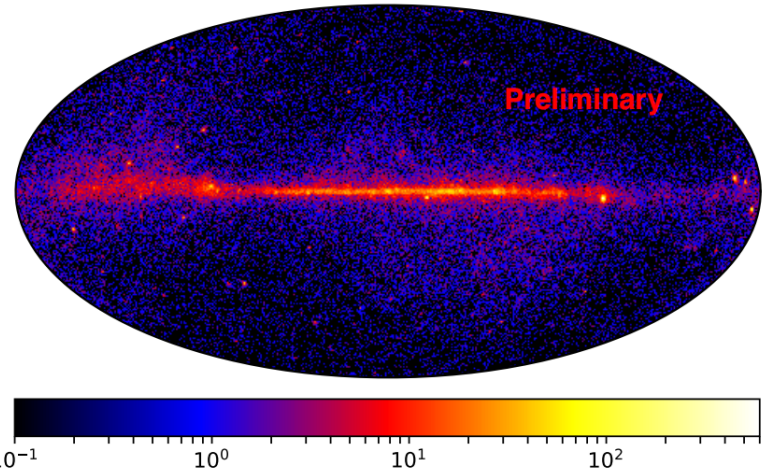
Mass: 1400 Kg
Power: ~ 400 W
Livetime: > 3 years

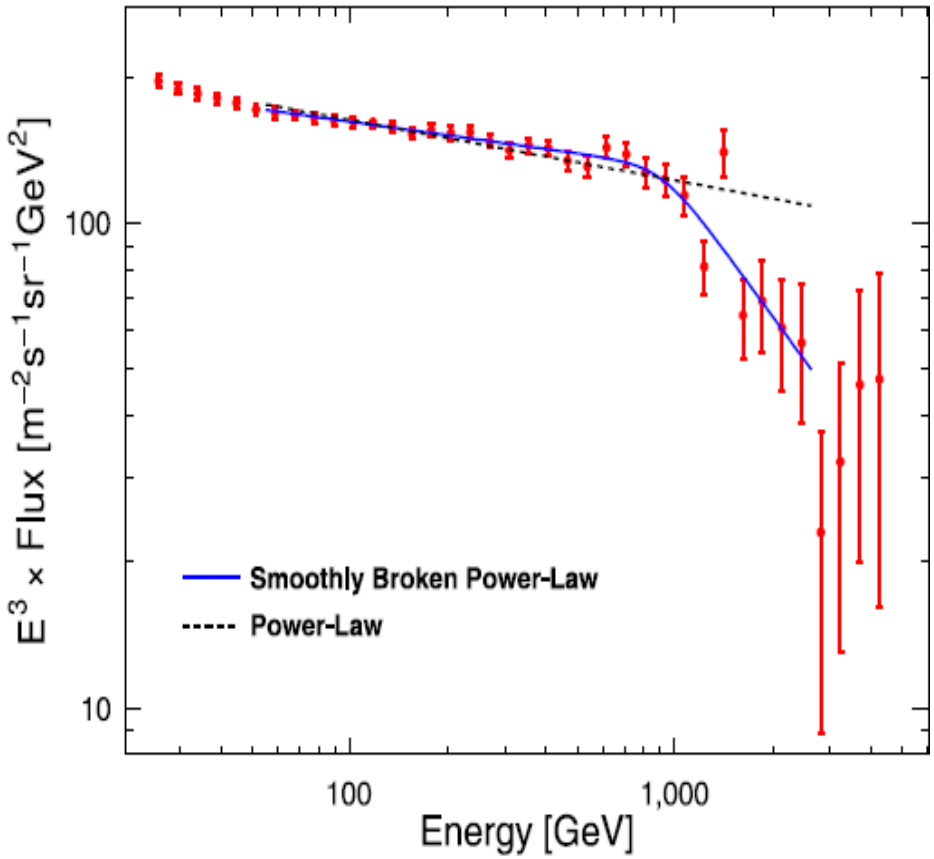
DAMPE: some science results

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*

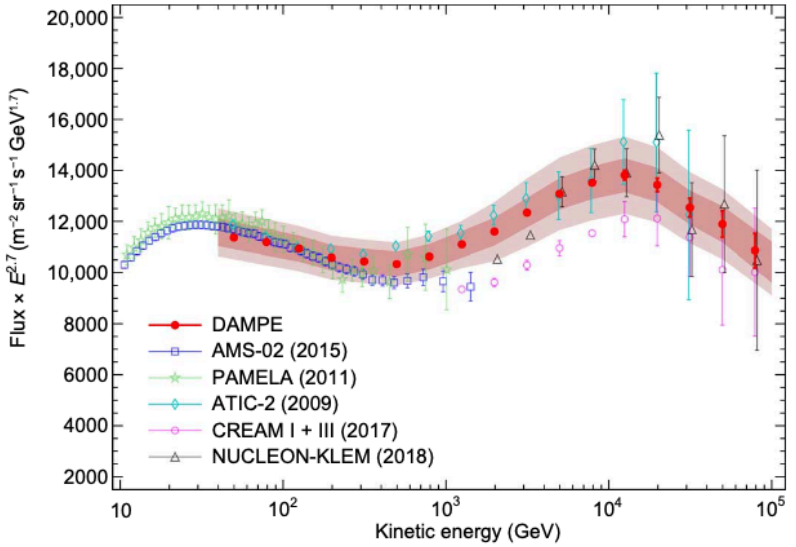




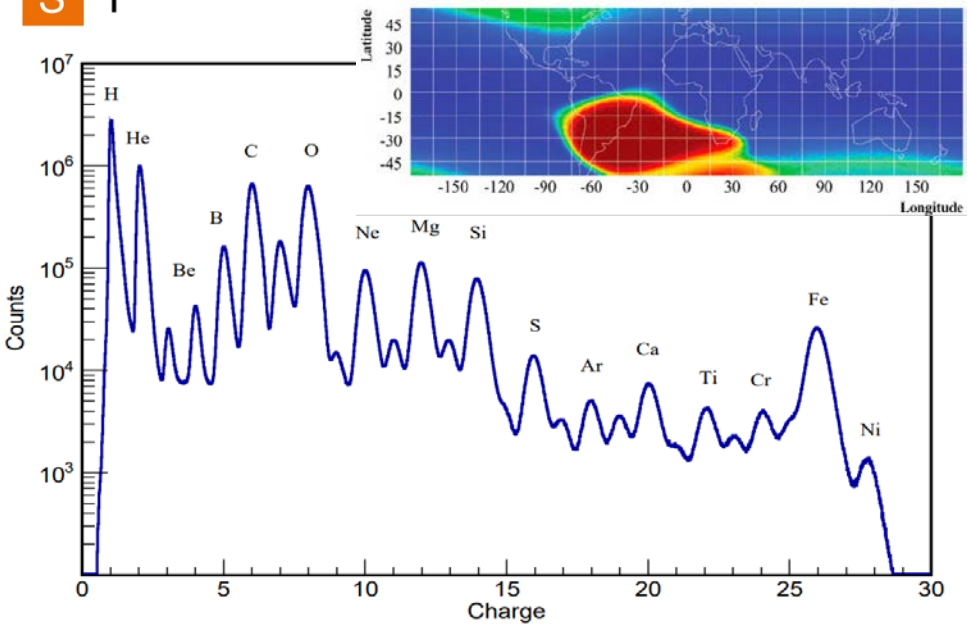
SCIENCE ADVANCES | RESEARCH ARTICLE

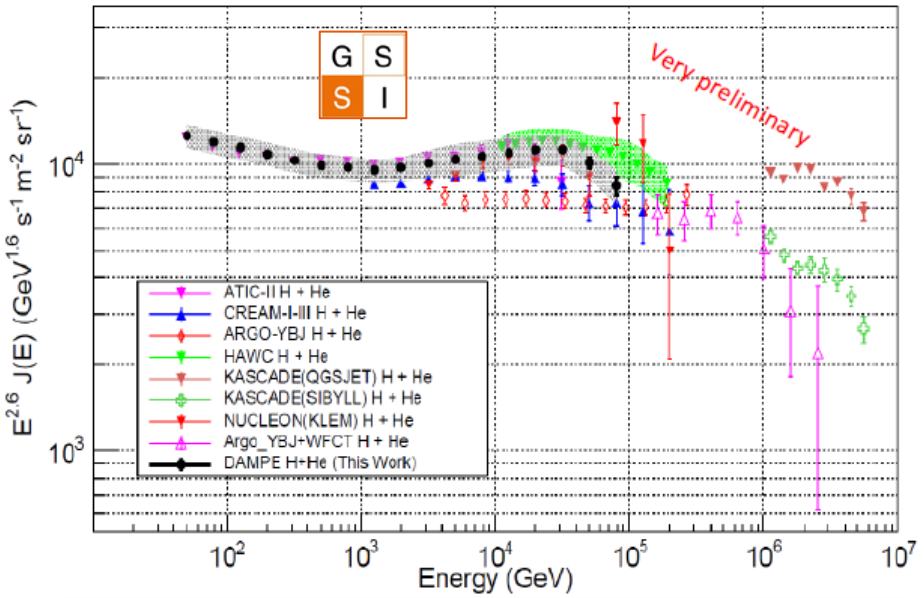
PHYSICS

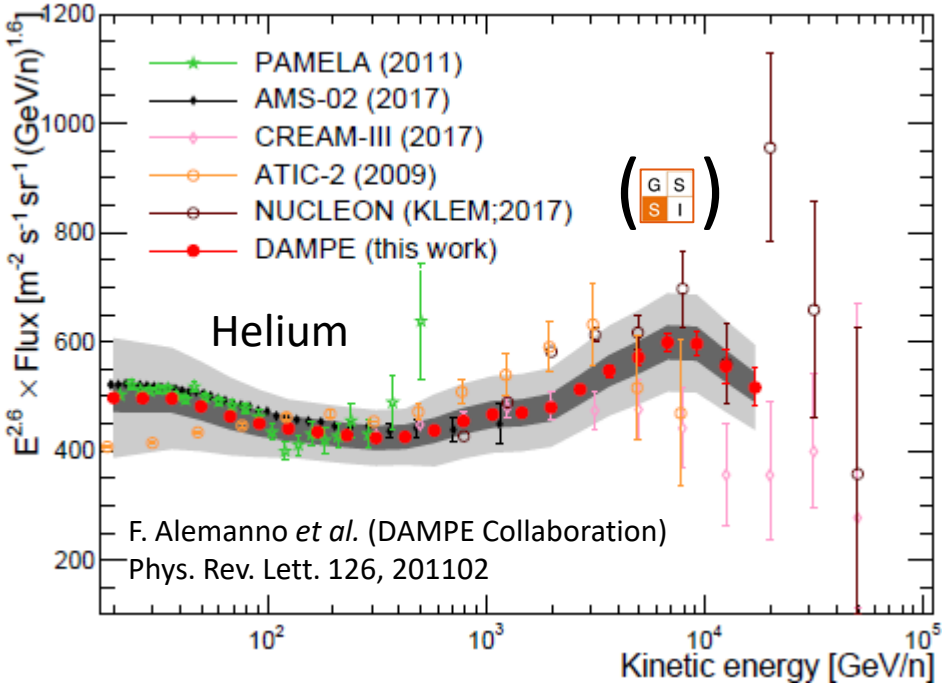
Measurement of the cosmic ray proton spectrum from 40 GeV to 100 TeV with the DAMPE satellite



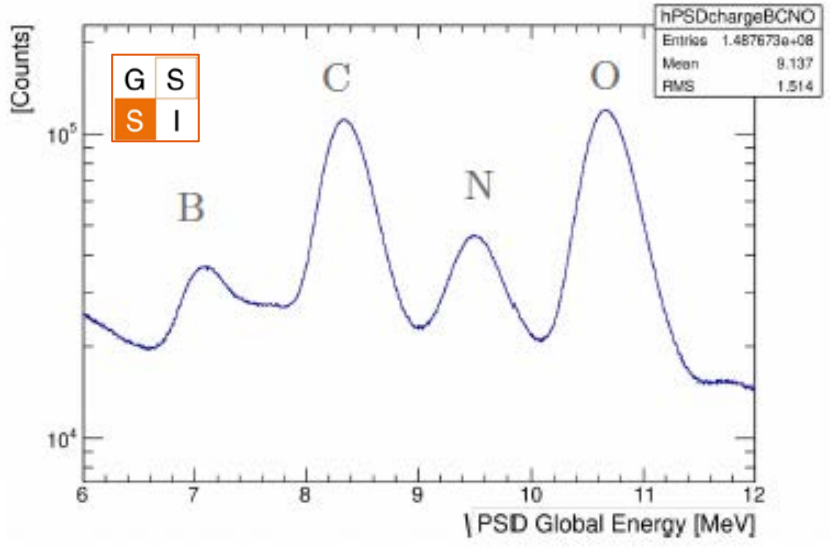
DAMPE: some science results





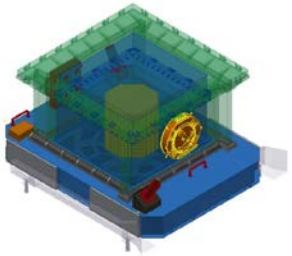


F. Alemanno *et al.* (DAMPE Collaboration)
Phys. Rev. Lett. 126, 201102

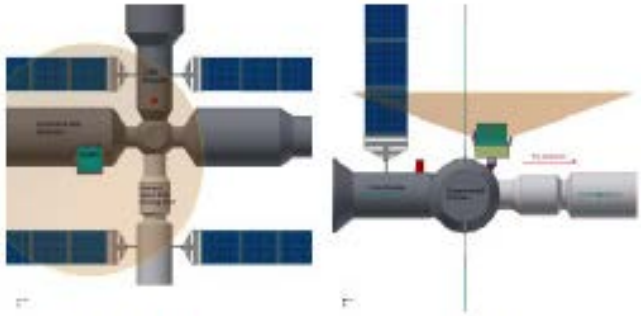


HERD: High Energy Radiation Detector

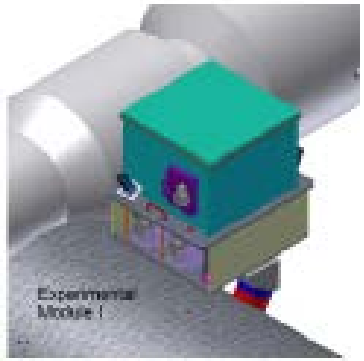
- HERD, a China-led mission with a key European contribution led by Italy, is proposed by IHEP as an astronomy and particle astrophysics experiment onboard the China's Space Station, which is planned for operation starting around 2027 for about 10 years.



- 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

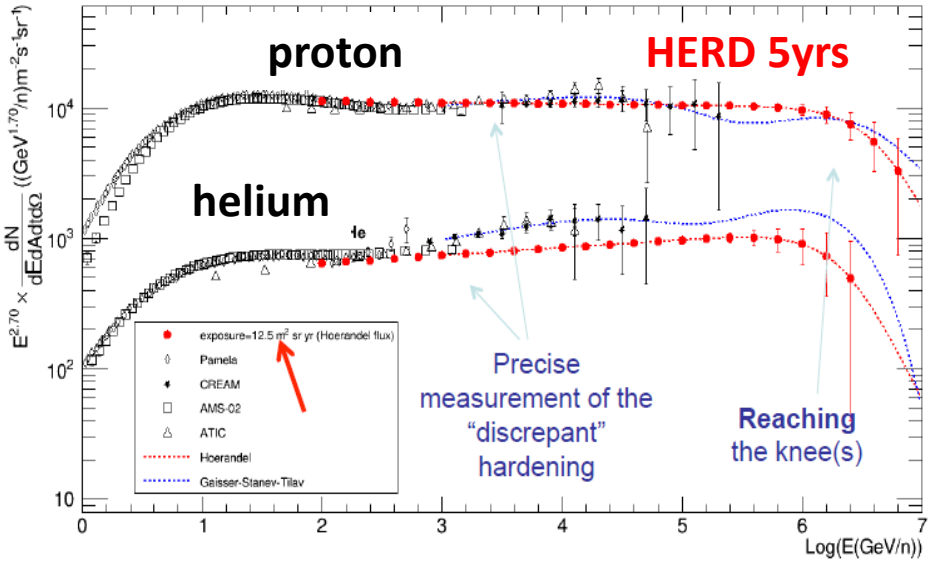


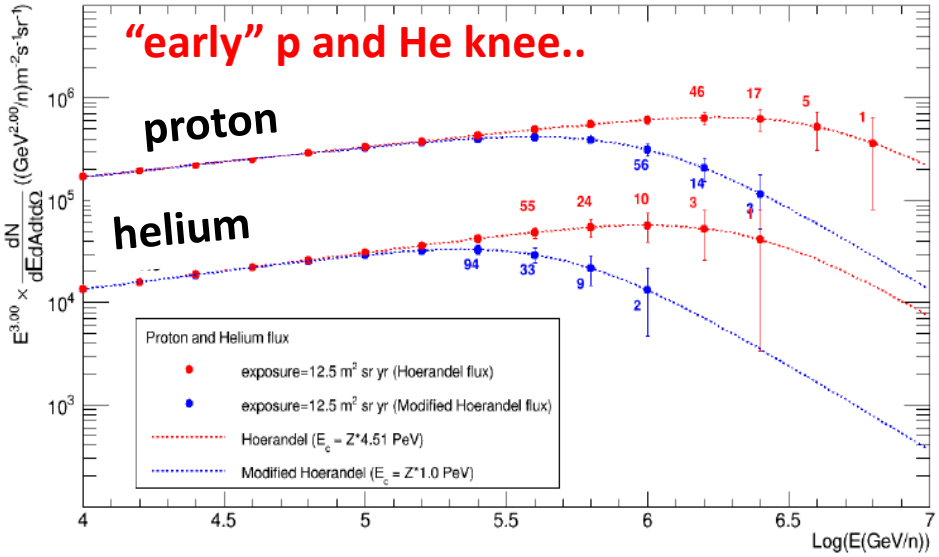
(a) Top view (b) Side view

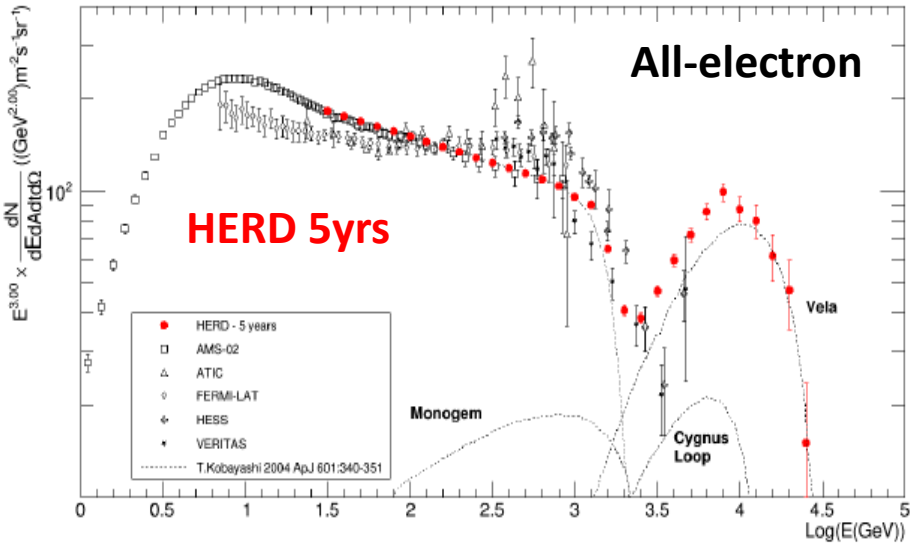


(c) Oblique view

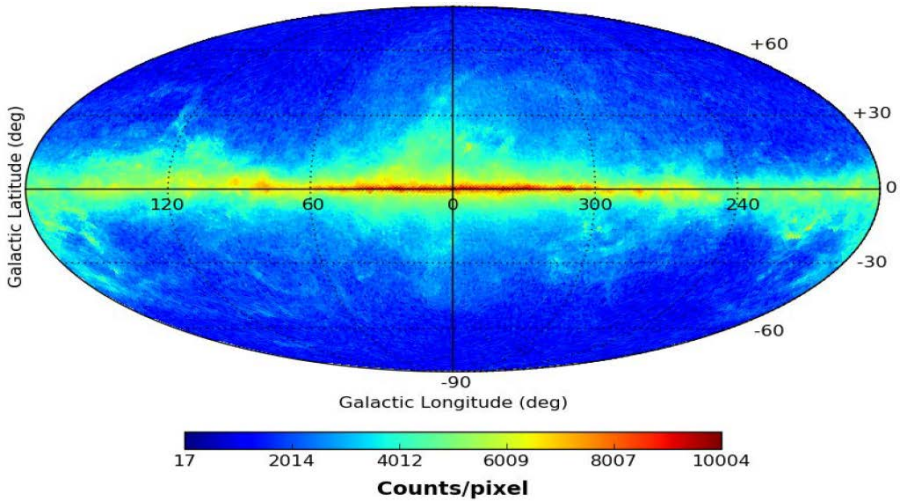
HERD: some performance plots (1)



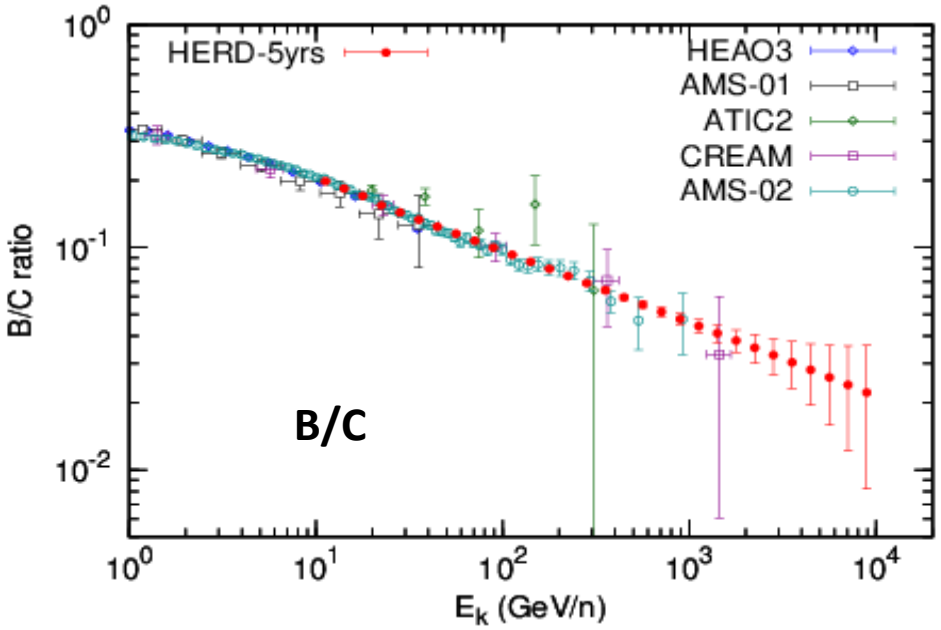


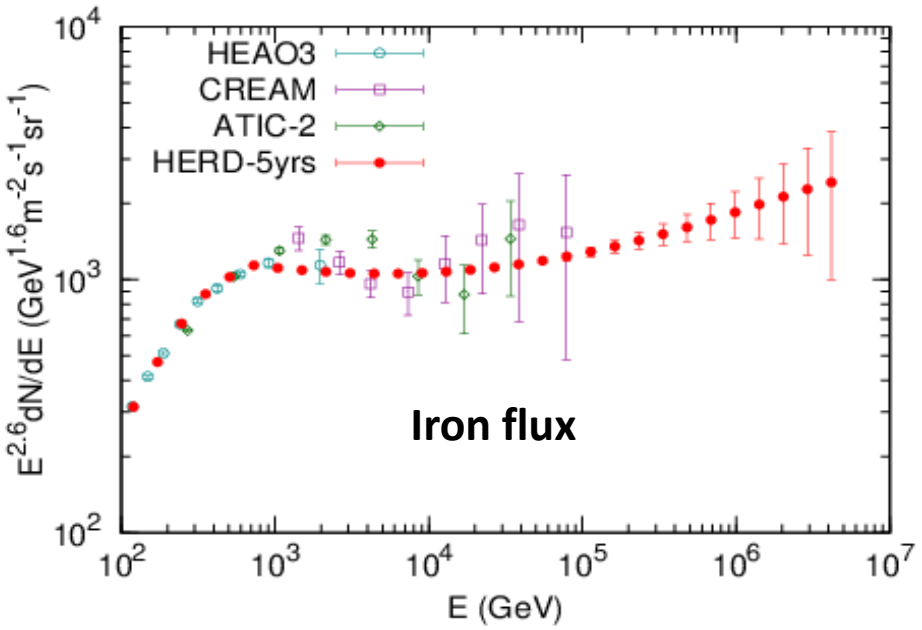


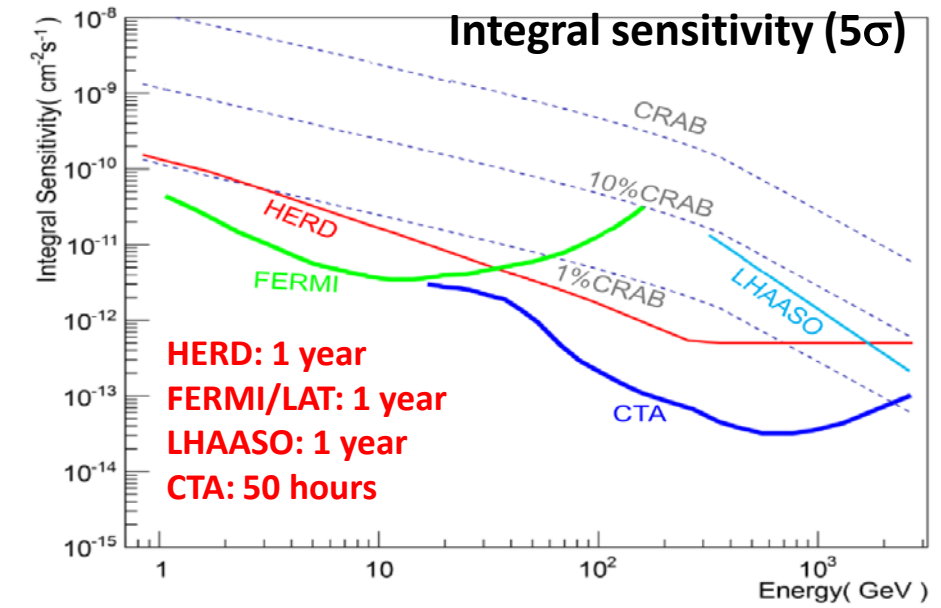
HERD 5yrs, photon map, E_γ > 1GeV

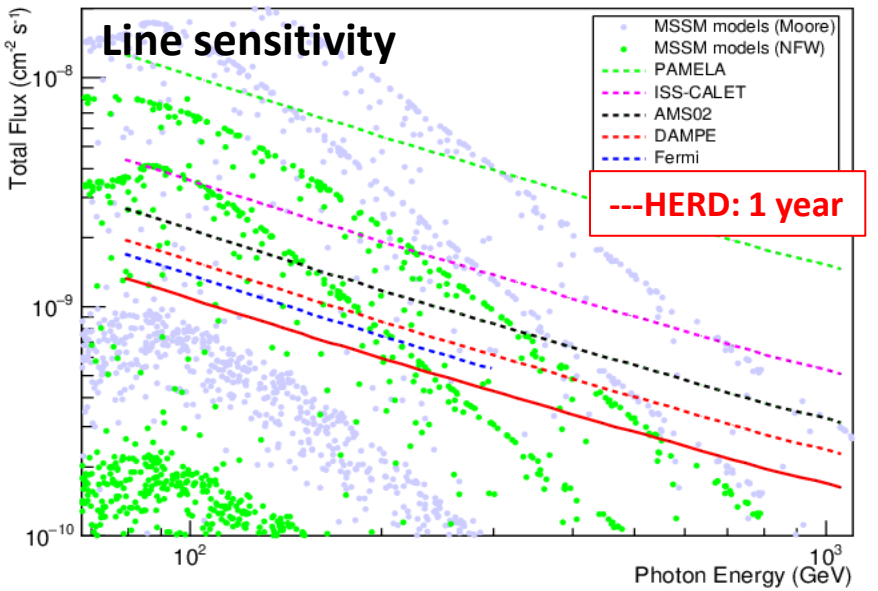


HERD: some performance plots (2)

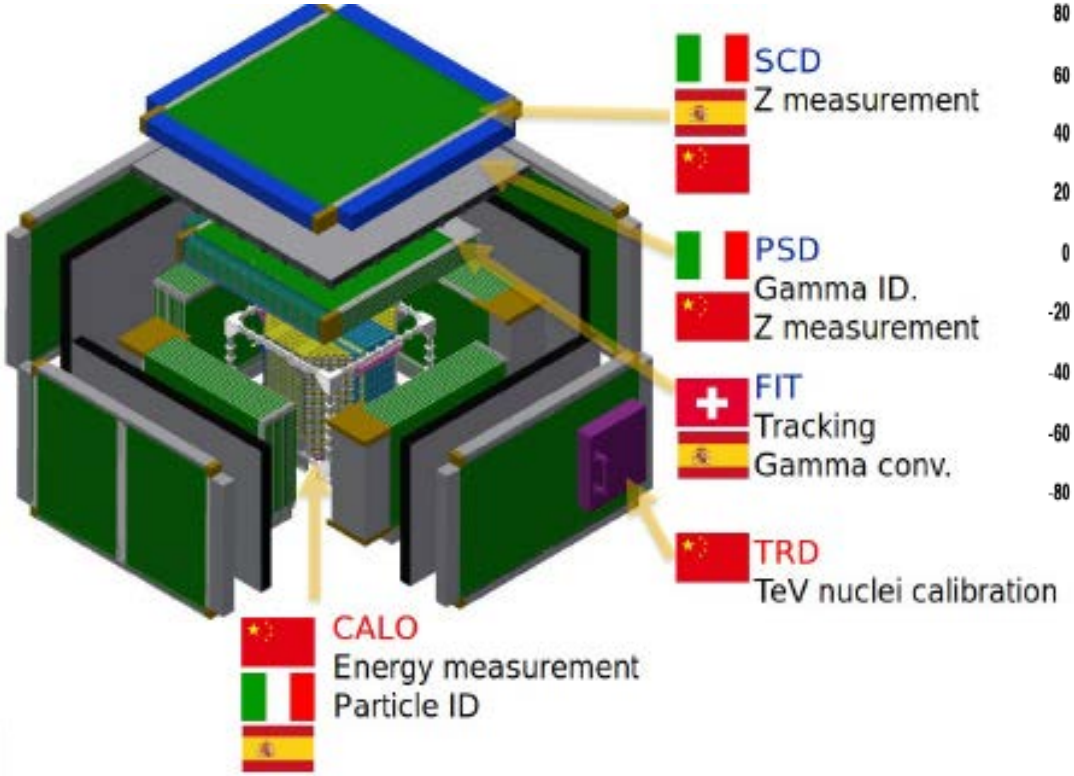


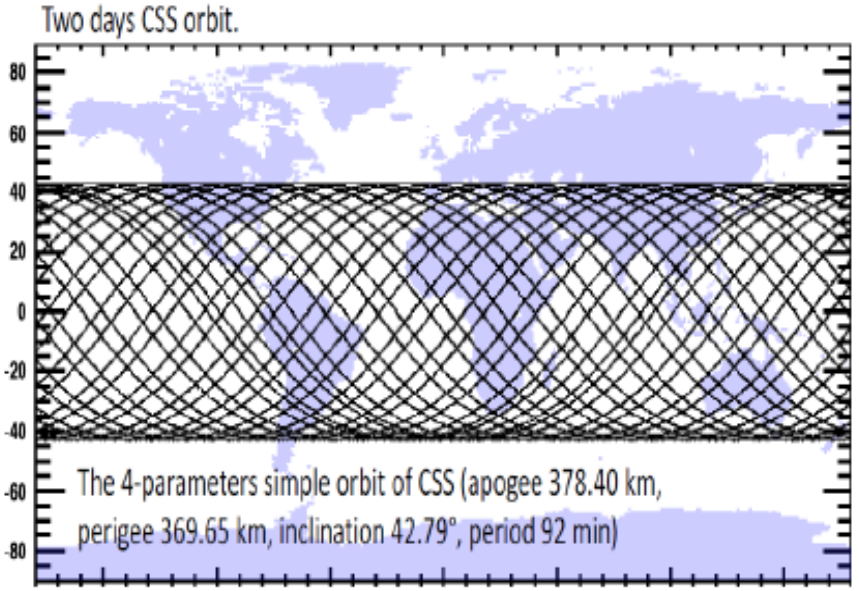






HERD: the detector and CSS the orbit

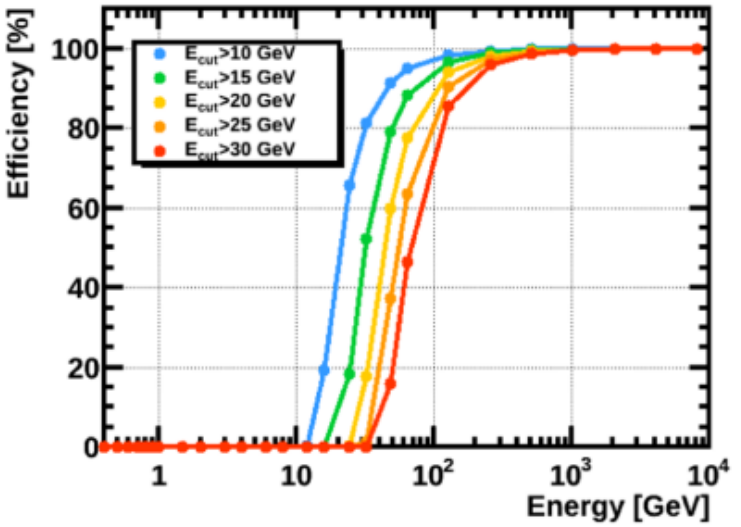




~7500 LYSO crystals (55 R.L, 3 N.I.L.)
Dual readout with IsCMOS & PD

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

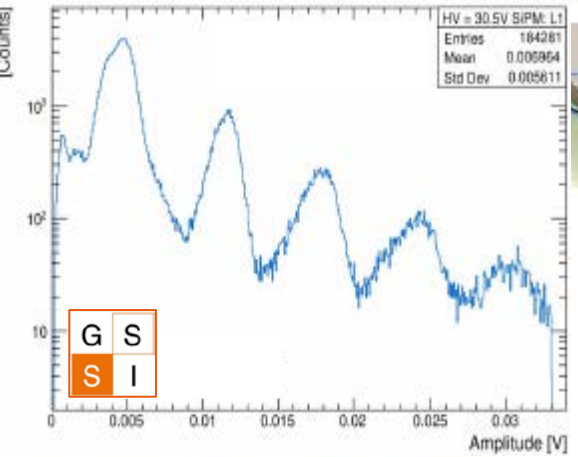
Threshold at tens of GeV

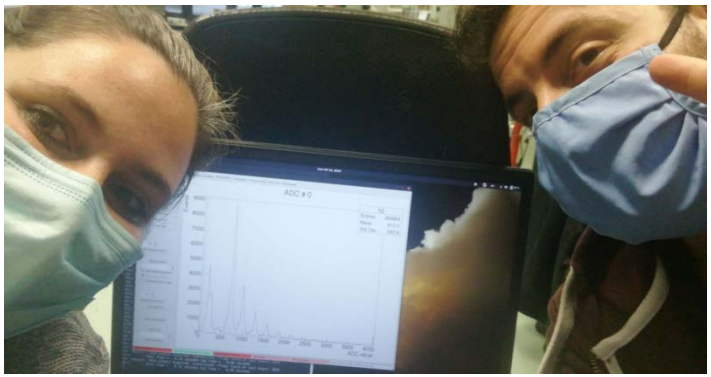


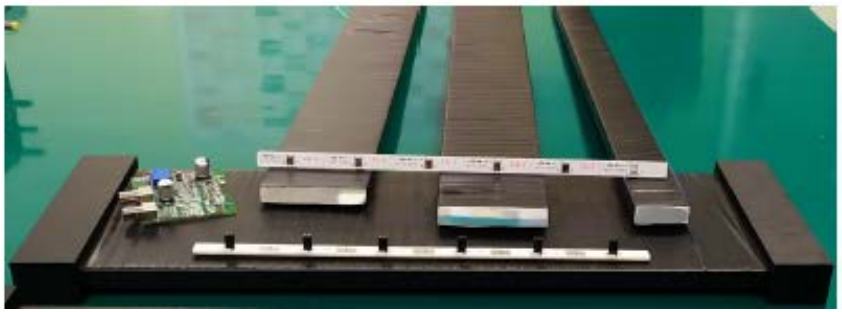
HERD: PSD R&D activity at GSSI

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.







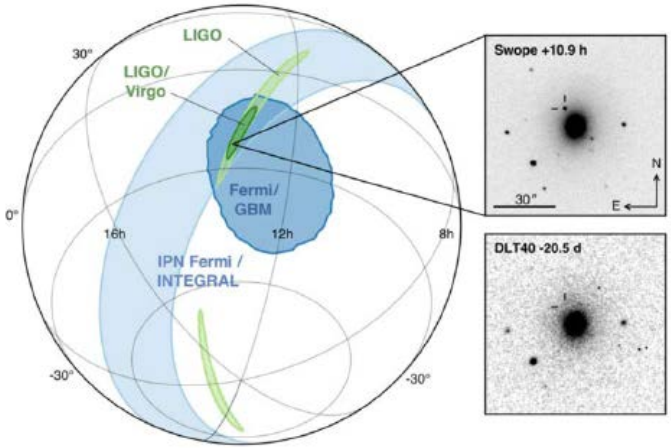
HERD: perspectives / performances

- 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

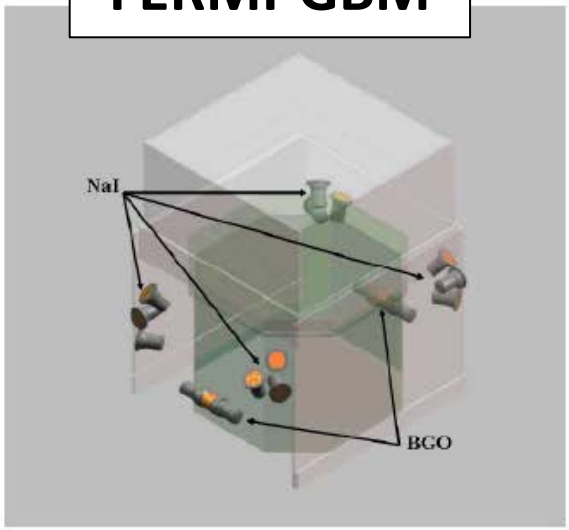
Crystal Eye: a sky monitor for X-rays and low energy γ-rays

University of Naples , ASI ,
Gran Sasso Science Institute

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

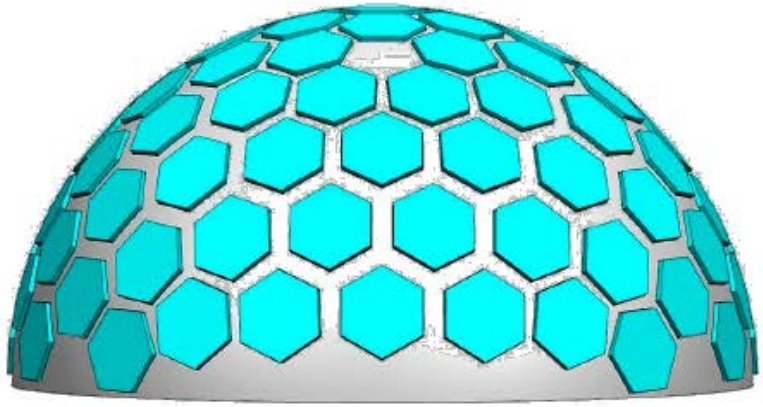


FERMI-GBM



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

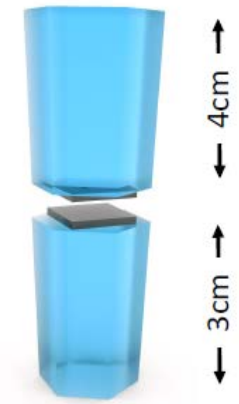
CRYSTAL EYE

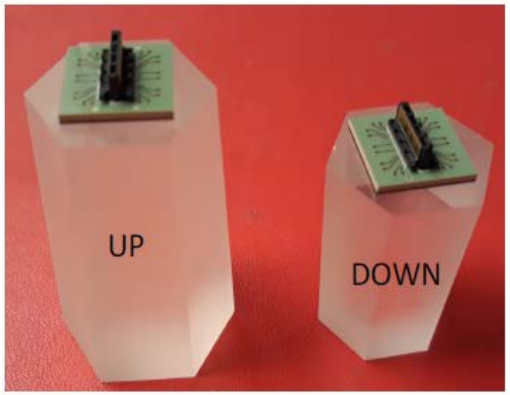


- All sky monitor
- **High** resolution
- Triangulation on **110 pixels**
- Pixel diameter **3.3 cm**

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**

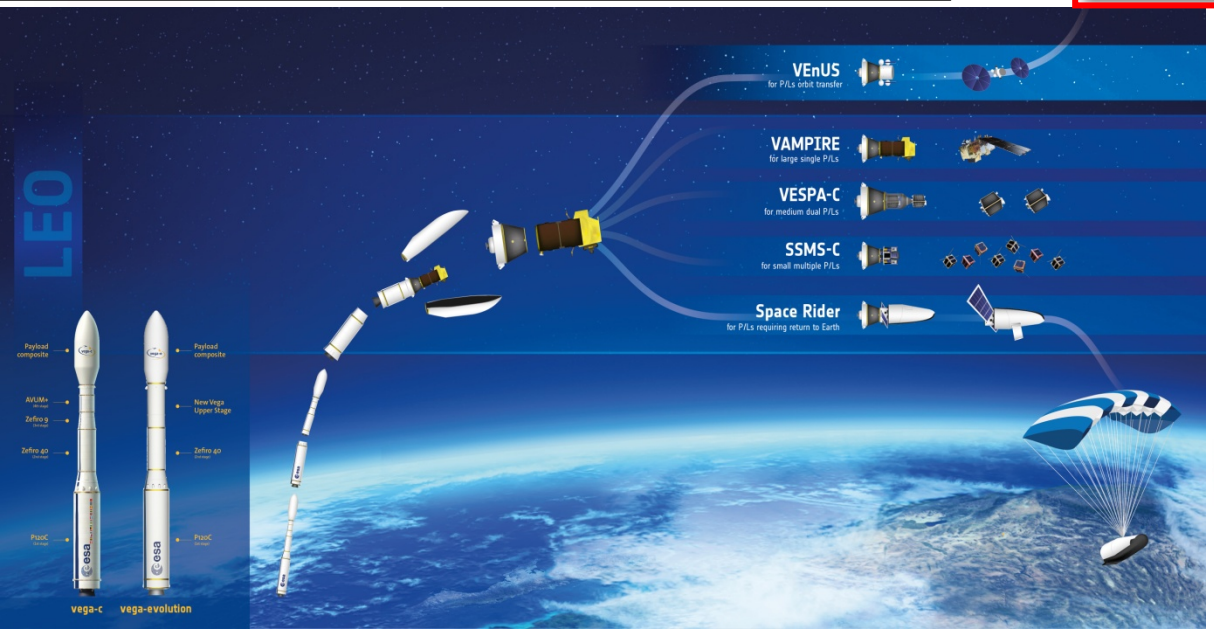




A single module is expected to improve at least by a factor 3 the localization capability of Fermi–GBM

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

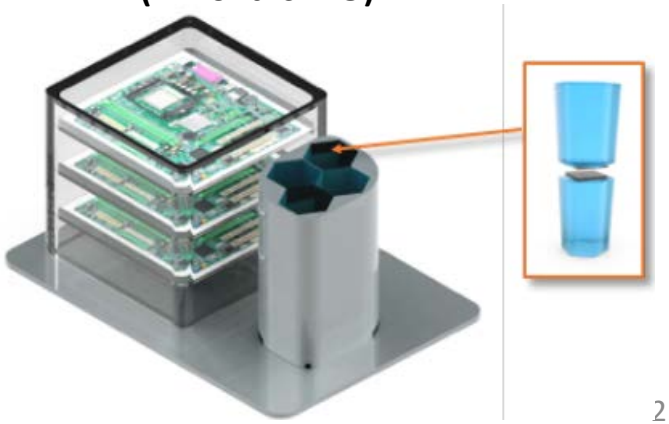
Technological pathfinder selected by ESA for the first SpaceRIDER launch in ~~2022~~ 2023



2020: Radiation hardness + mechanics

2021-2022: Space qualification

2023: 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

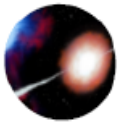
R. Battiston
R. Iuppa
University of Trento, Trento (Italy), INFN and TIFPA

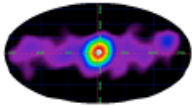
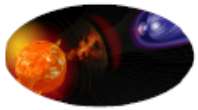
Call for ideas for missions on the Moon

SCIENCE WITH GRAAL

To perform world class science and enable new technologies

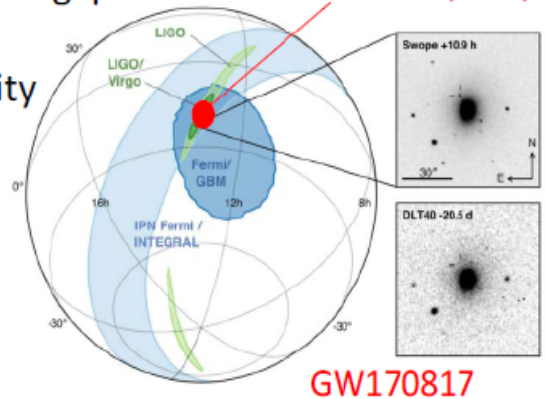
- Fundamental (continuous and transient) astrophysical observations by filling the gap in current instrument sensitivity in the 10keV-50MeV energy range
- Lunar site characterization in terms of soil and cosmic rays induced radioactivity
- Space weather monitoring
- Study X and gamma emissions form the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



Mission Science goals include:

GRAAL localization capability

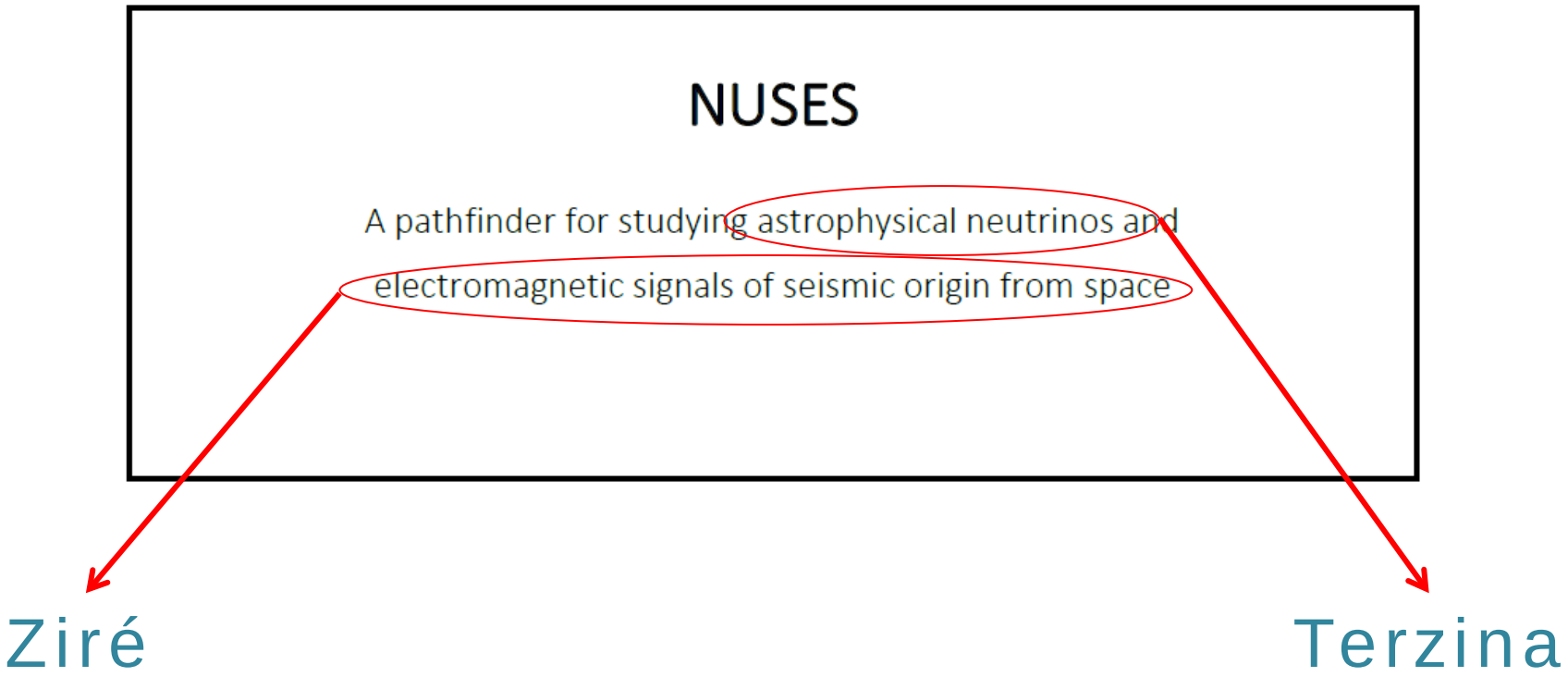


GW170817
Gravitational
wave event

- 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

The NUSES mission

Terzina

Pathfinder for future missions devoted to UHE cosmic ray and neutrino astronomy throught space-based atmospheric Cerenkov light detection.

Zirè

Monitor the fluxes of low energy (<250 MeV) CR, mainly electrons and protons, to study Van Allen belts, space weather and the lithosphere-ionosphere-magnetosphere couplings. Detect 0.1-10MeV photons for the study of transient (GRB, e.m.followup of GW events, SN emission lines,...) and steady gamma sources

New technologies

Developement of new observational techniques , sensors (e.g. SiPM) and related electronics/DAQ for space mission. New solutions for the satallite platform.

Scientific collaboration among GSSI-INFN and TAS-I

High Energy Astroparticle Physics: HE

EXP-HW

EXP-SW

EXP-Rev

TH-PH

TH

HE-1: Elementary processes for high energy Astroparticle Physics

Carmelo Evoli (GSSI and INFN)

This research-oriented course will provide a working knowledge of elementary processes related to generation and propagation of electromagnetic radiation, especially for those involving high-energy particles in the Universe. Building up a clear physical picture of the microscopic radiation mechanisms the students will develop the basic knowledge to associate observations with the underlying physical processes.

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: High Energy Radiation Measurements (LAB)

Adriano Di Giovanni (GSSI and INFN), Felicia Barbato (GSSI and INFN)

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: Very High Energy Gamma Ray Astronomy

Teresa Montaruli (Université de Genève and GSSI)

Scientific scopes of gamma-ray astronomy with selected topics on galactic and extra-galactic sources, Space and ground based experiments. Cerenkov telescopes with Davies-Cotton and Schmidt-Cassegrein optics. Cameras and new photosensors. Some example of connection to neutrino astronomy.

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

Felicia Barbato (GSSI and INFN), Adriano Di Giovanni (GSSI and INFN)

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.

HE-6: High Energy Neutrino Astronomy

Paolo Lipari (INFN Roma)

Status 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 will be also discussed. Recent observations and perspective of the field.

HE-7: UHECR theory

Roberto Aloisio (GSSI and INFN)

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

HE-8: Plasma physics around astrophysical compact objects

Elena Amato (INAF)

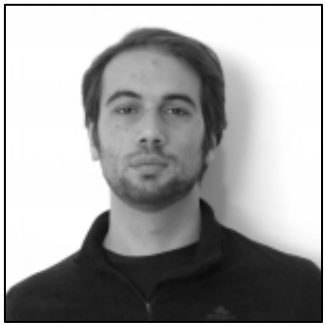
Pulsars as unipolar inductors and pair creation in its magnetosphere. Force-free solution for the outflow from an aligned rotator: the pulsar equation and the Blandford-Znajeck mechanism for energy extraction from a rotating black hole. MHD and radiation modelling of pulsar wind nebulae and particle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

The GSSI “exp-space” team

Francesca Alemanno

Dimitrios Kyratzis

Andrea Parenti



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Mateo Fernandez

Libo Wu

Post doc

Faculty

Felicia Barbato

Ivan De Mitri

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Adriano Di Giovanni

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Camilla Petrucci

Caterina Trimarelli

PhD students

Felicia Barbato

Denise Boncioli

Carmelo Evoli

Francesco Salamida

Faculty

Ivan De Mitri

Sergio Petrera

Vincenzo Rizi

The GSSI “dream” team