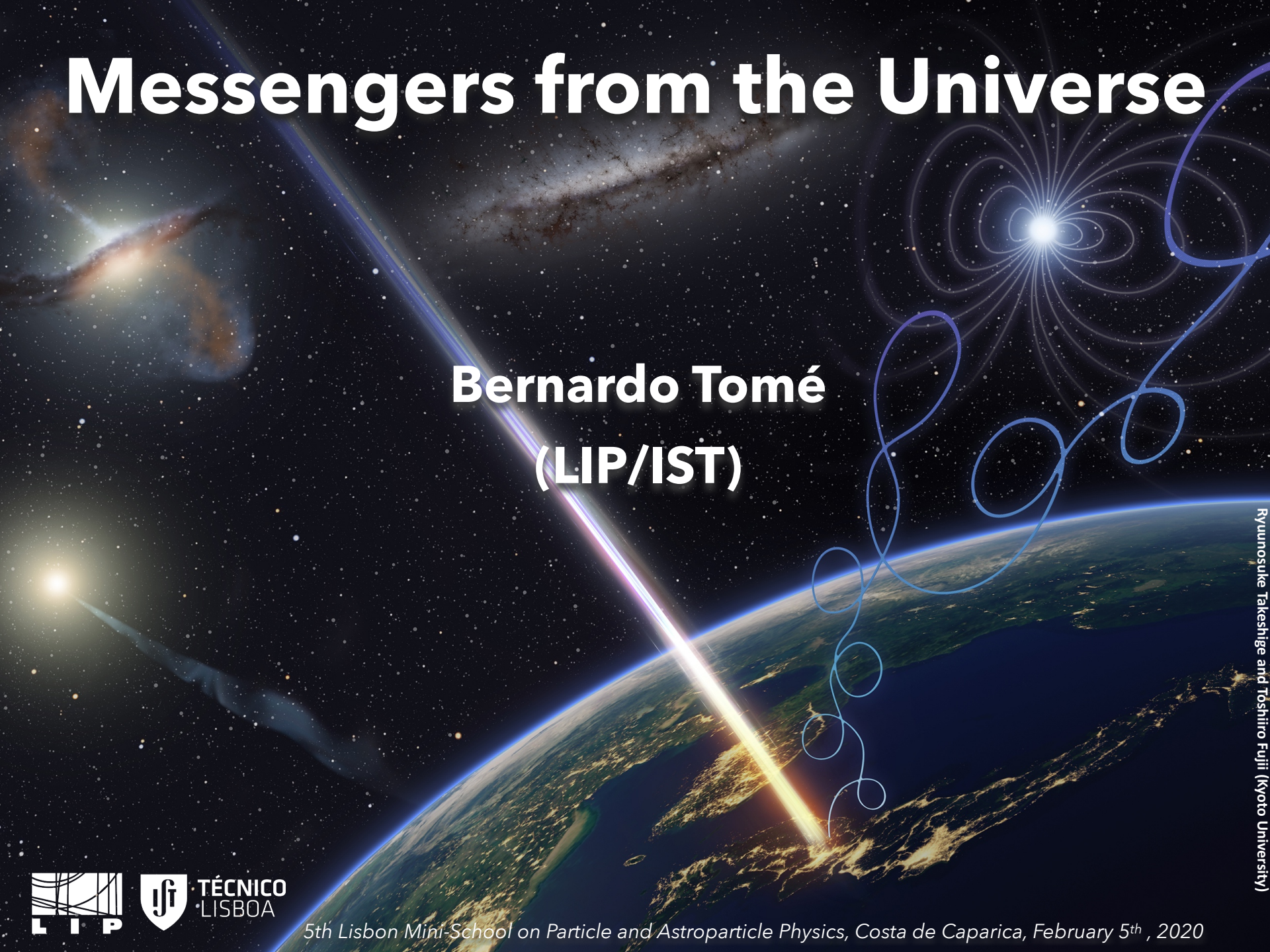
Messengers from the Universe

Bernardo Tomé

(LIP/IST)



Ryuunosuke Takeshige and Tōshiiro Fujii (Kyoto University)

LIP

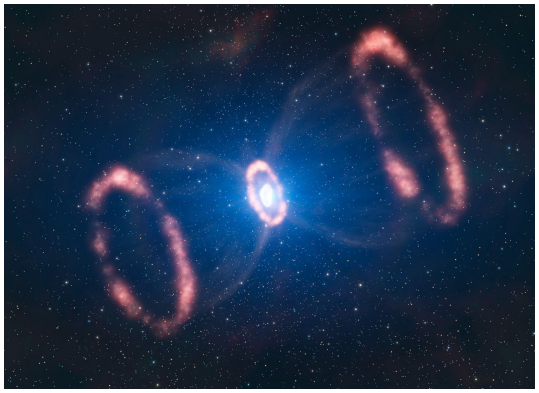
TÉCNICO LISBOA

5th Lisbon Mini-School on Particle and Astroparticle Physics, Costa de Caparica, February 5th , 2020

Topics to be covered

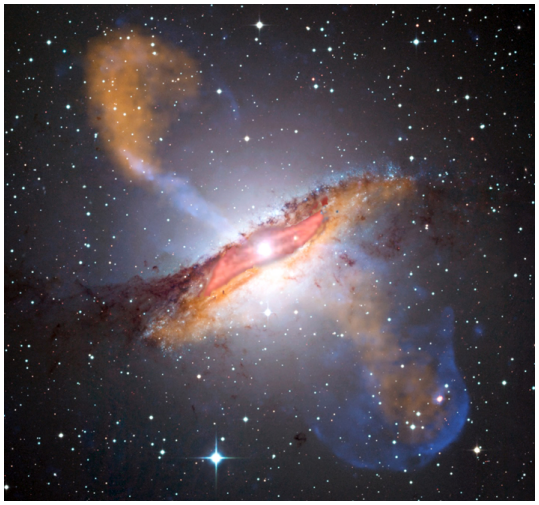
- Ultra high-energy cosmic rays
  - Universe **greatest accelerators**
    - Nature and origin still a mystery…
  - Opportunity to do particle physics above the human-made accelerator energies

SN1987a

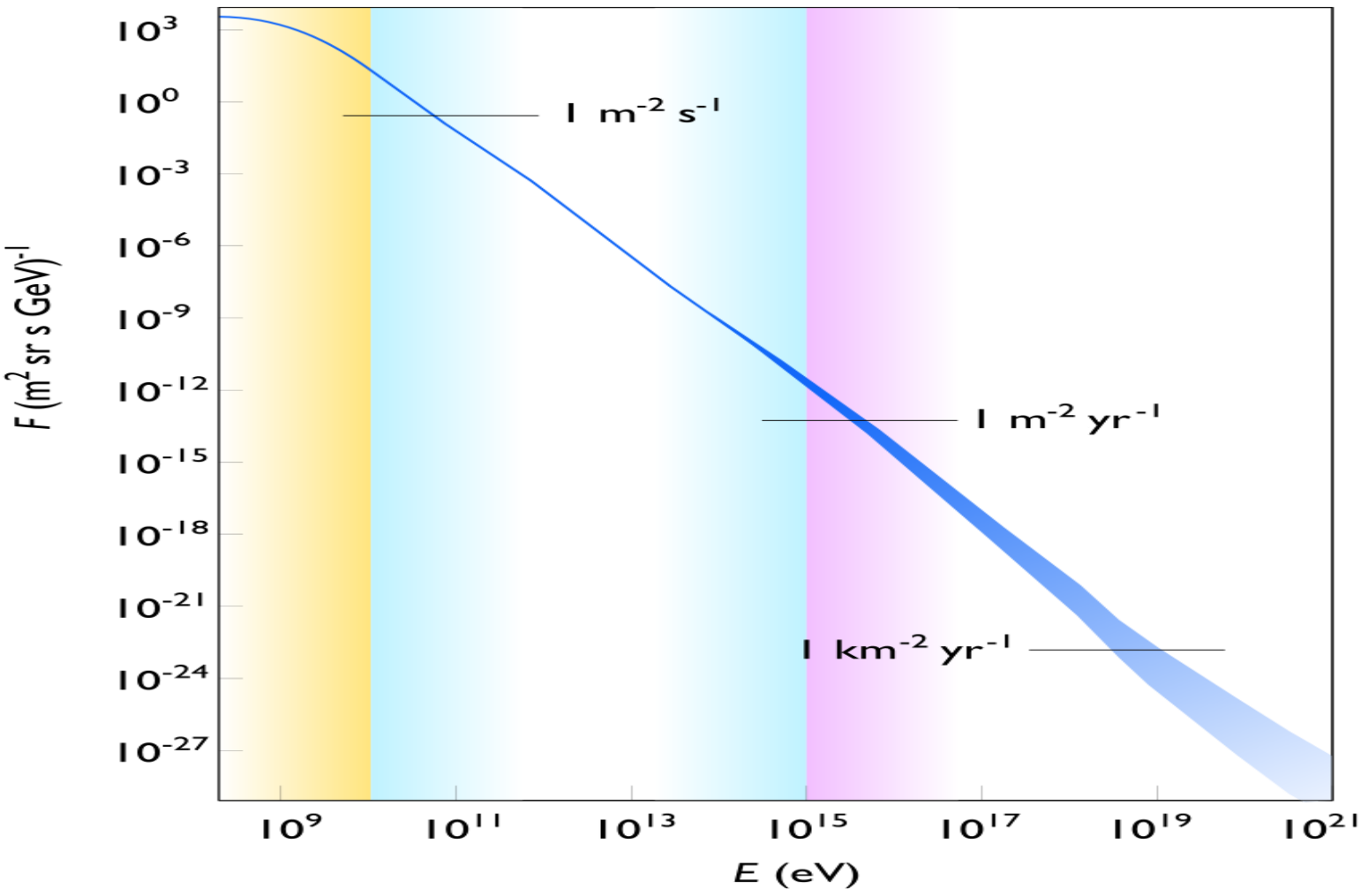


- (Very) high-energy gamma-rays
  - Probe some of the **most violent astrophysical phenomena**
    - SuperNovae (SN) & SuperNovae Remnants (SNR)
    - Gamma-ray bursts (GRB)

Centaurus A

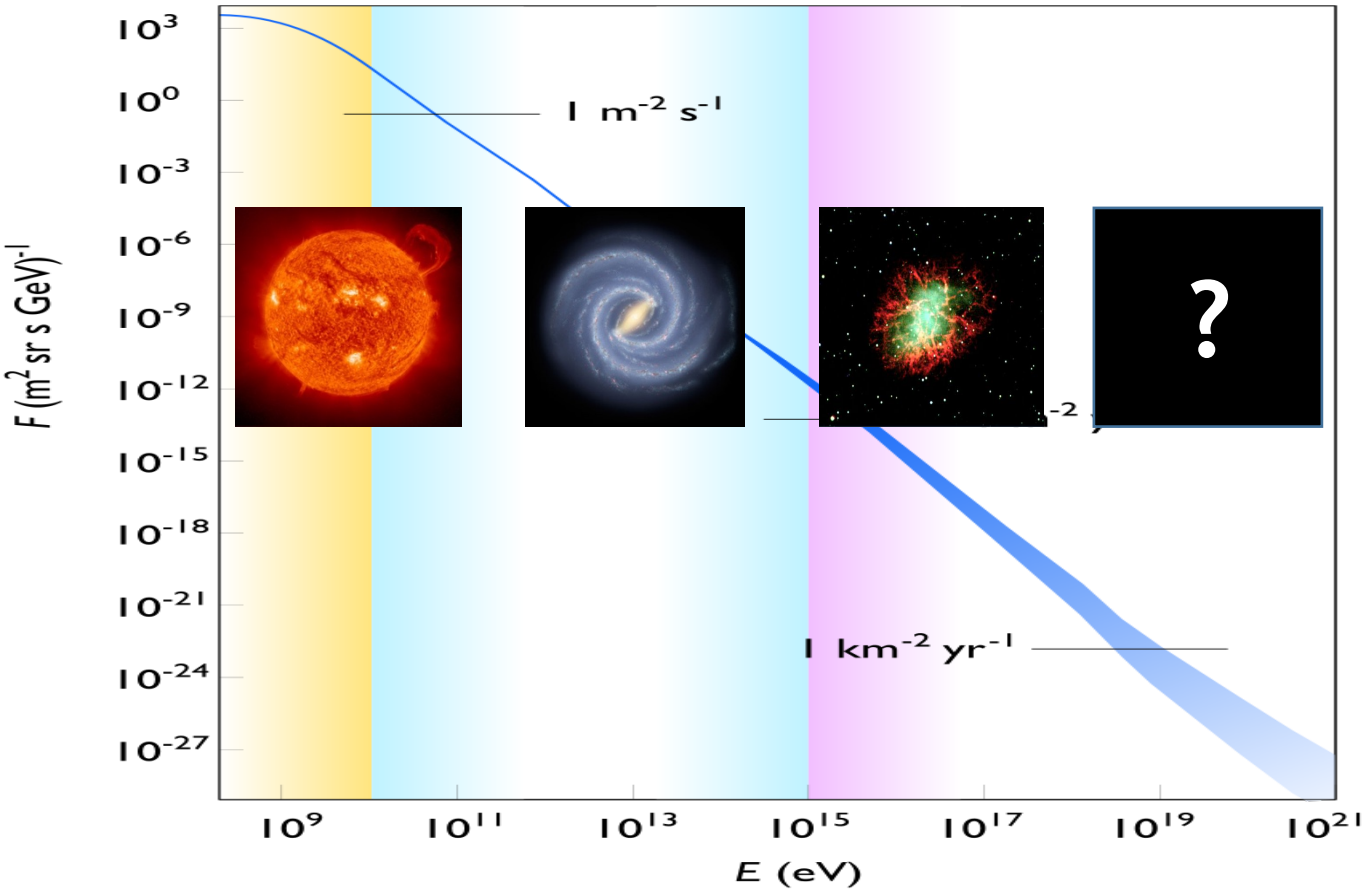


Cosmic ray energy spectrum



(Charged particles continuously bombarding Earth)

Cosmic ray energy spectrum

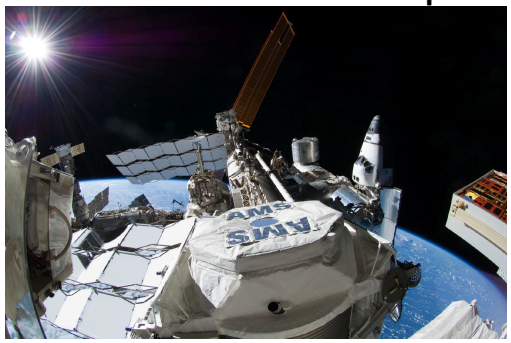


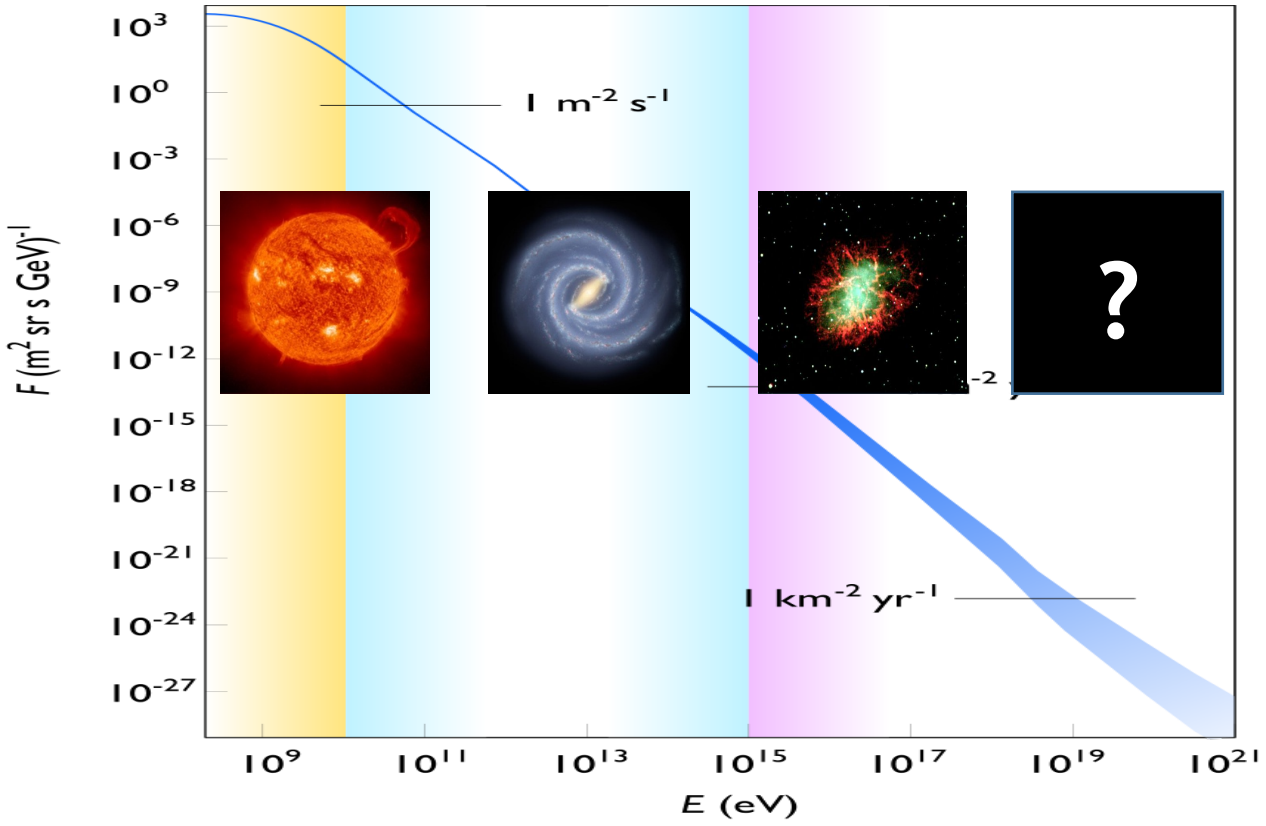
Rapidly falling energy spectrum

Different sources according to the energy

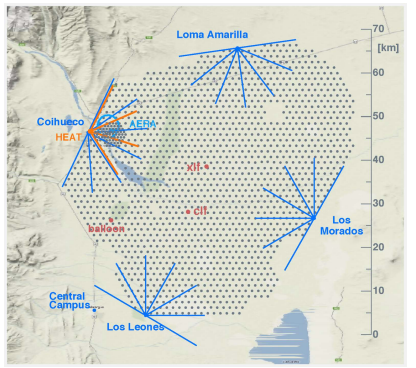
Different experimental techniques vs energy

Detectors above Earth atmosphere





Large ground detector arrays

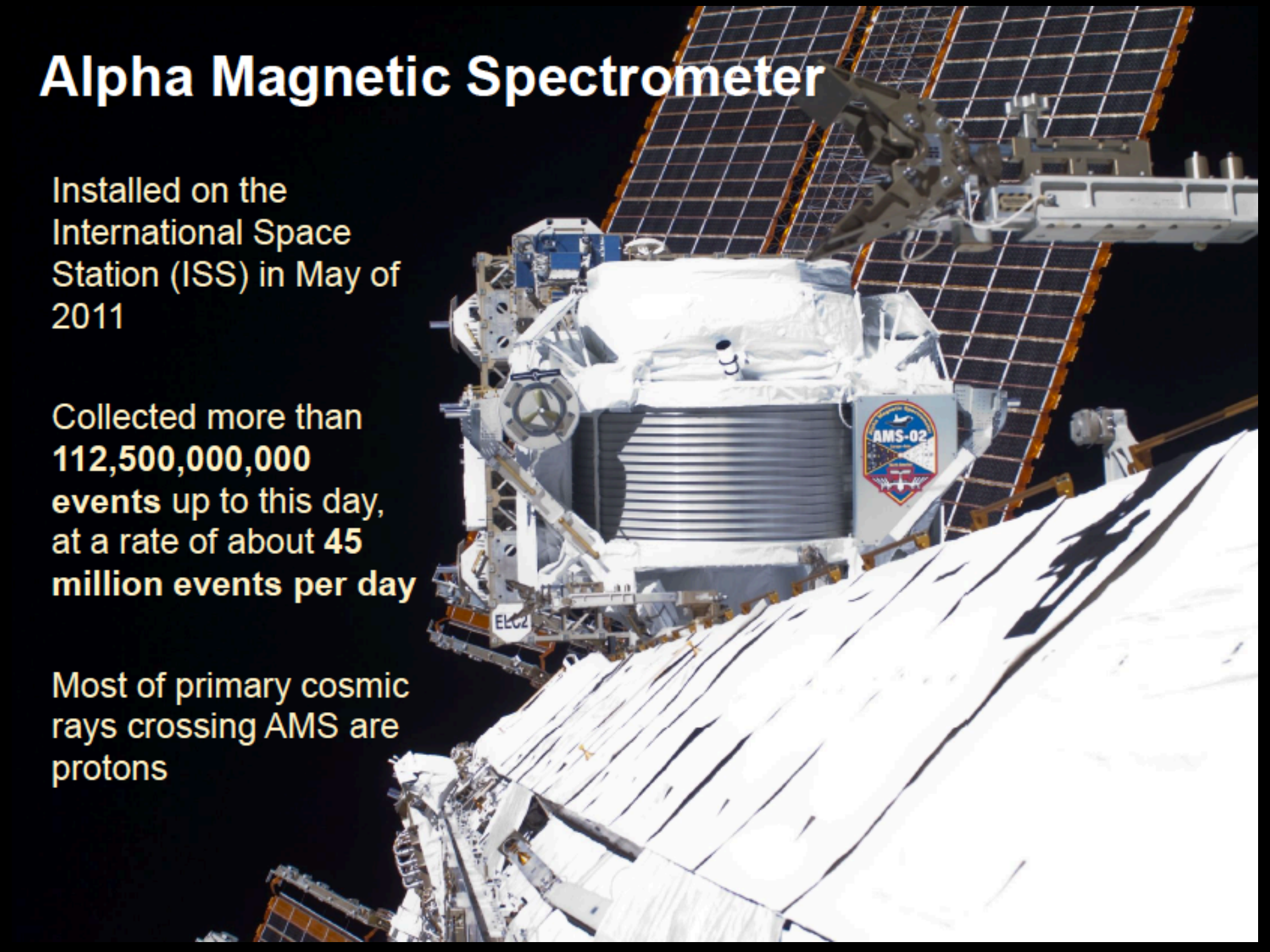


Alpha Magnetic Spectrometer

Installed on the International Space Station (ISS) in May of 2011

Collected more than **112,500,000,000 events** up to this day, at a rate of about **45 million events per day**

Most of primary cosmic rays crossing AMS are protons

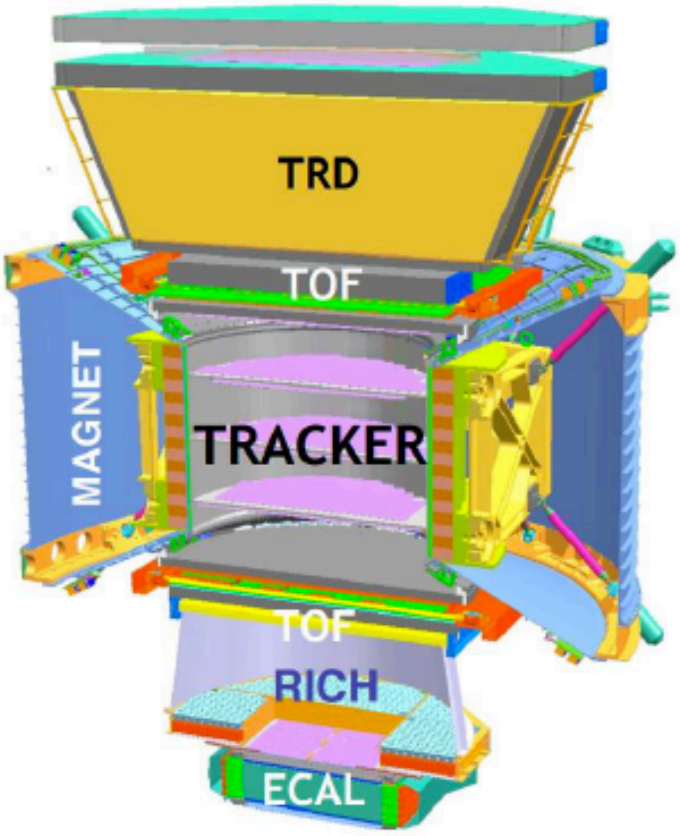


AMS detector

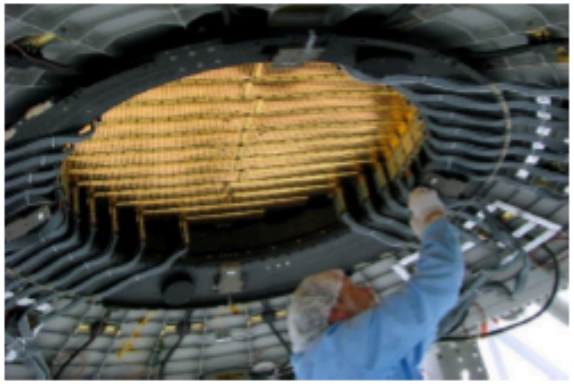
Upper TOF

Lower TOF

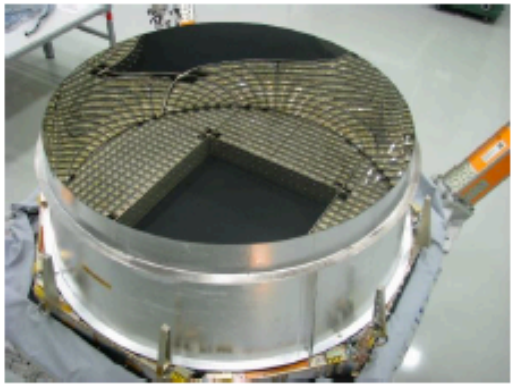
Transition Radiation Detector



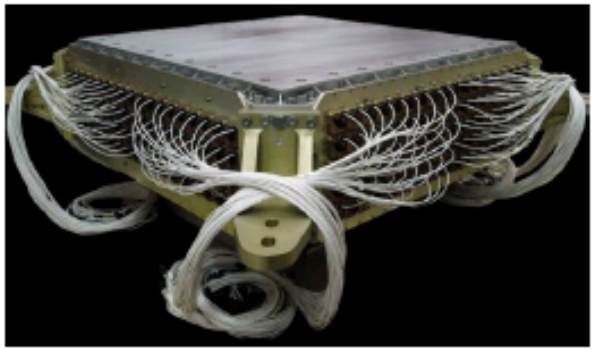
Sillicon Tracker



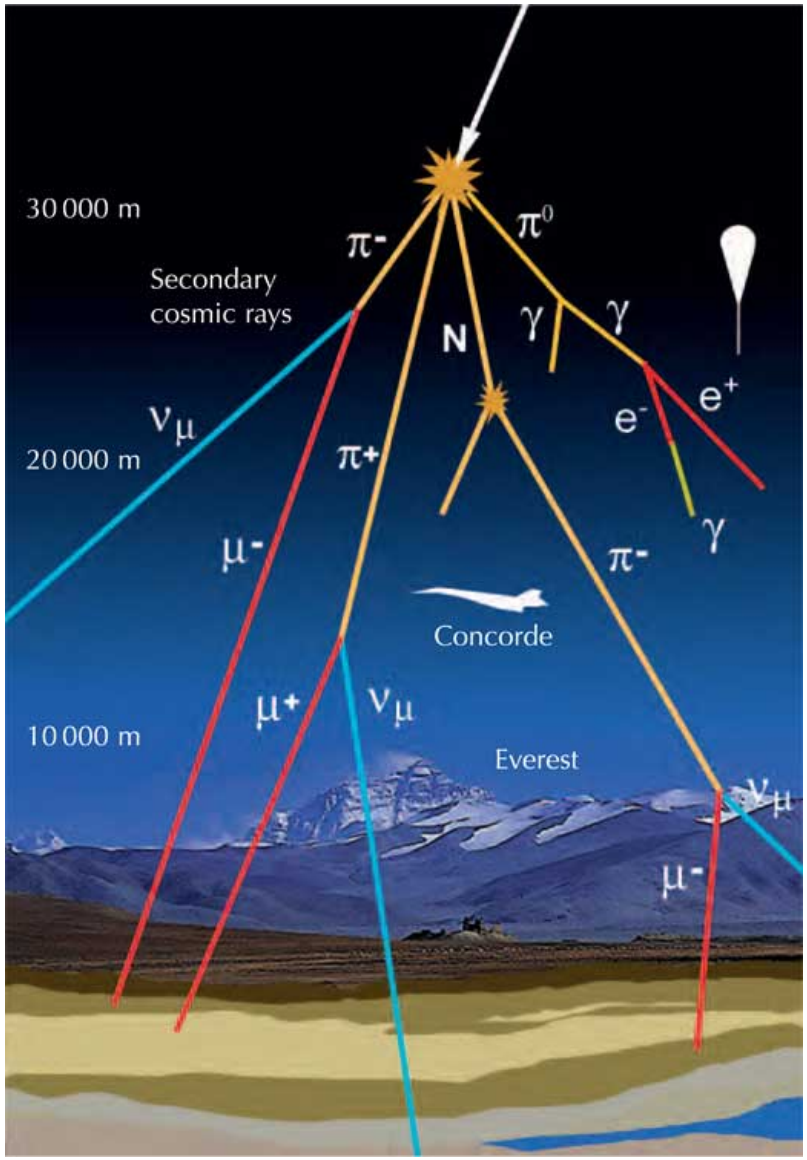
Ring-Imaging Cherenkov Detector



Electromagnetic Calorimeter



Extensive Air showers



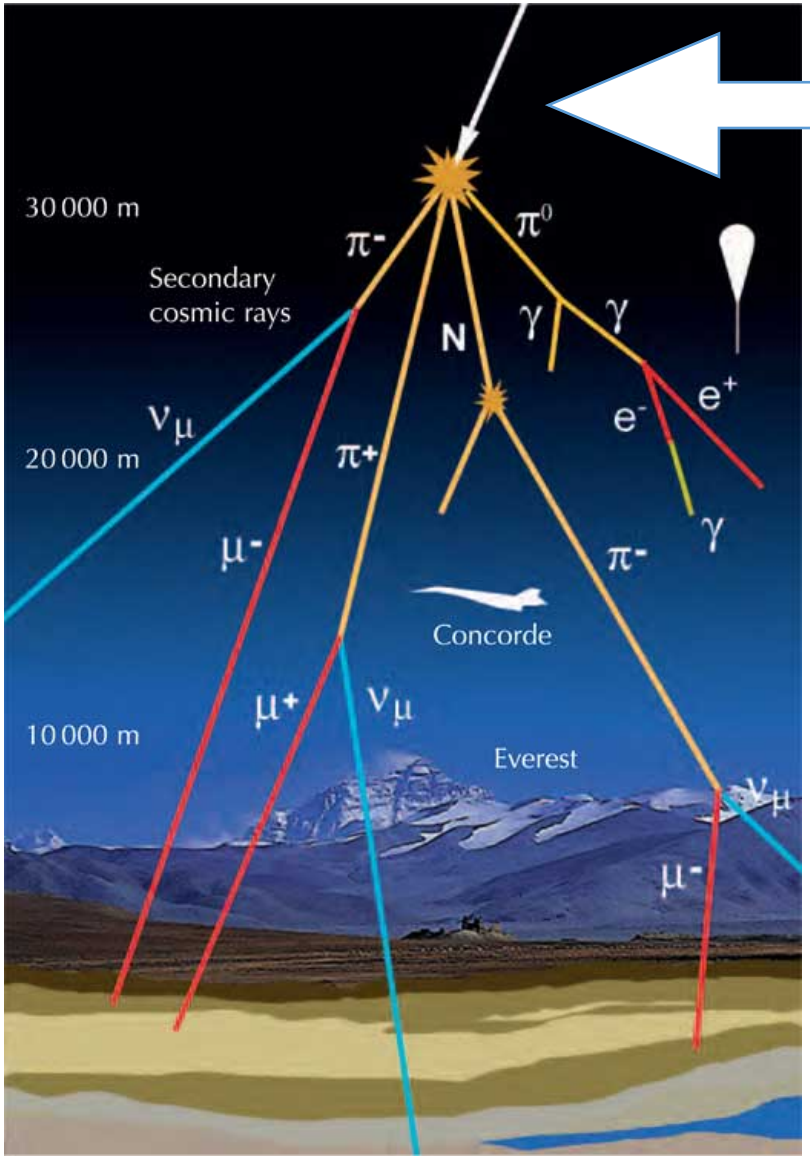
Cosmic Ray Interactions in a Cloud Chamber

We can see the cosmic rays !

Spark chamber @ LIP

Photos by R. Conceição

Ultra High Energy Cosmic Rays



High-energy interactions

$E \sim 10^{19} - 10^{20}$ eV

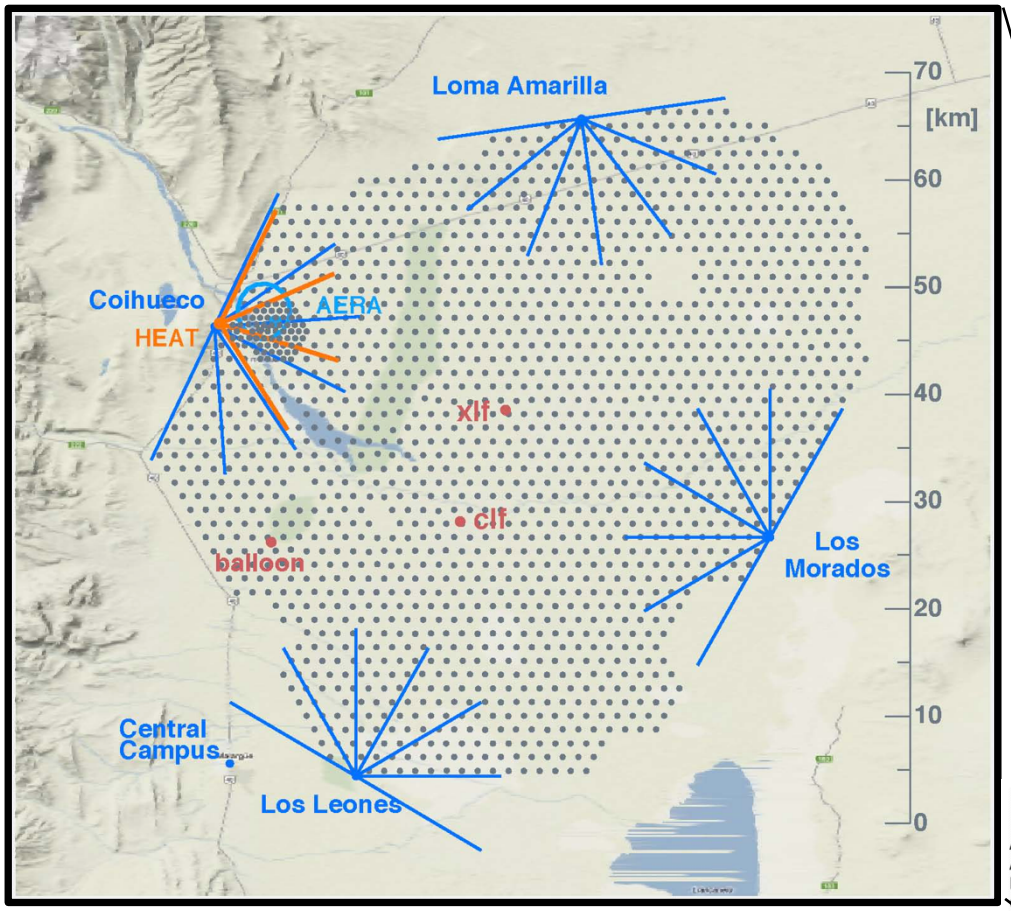
$E_{CM} \sim 100$ TeV

Understand high-energy Universe

Production (sources; acceleration mechanisms…)

Test particle physics at energies above the LHC

Pierre Auger Observatory

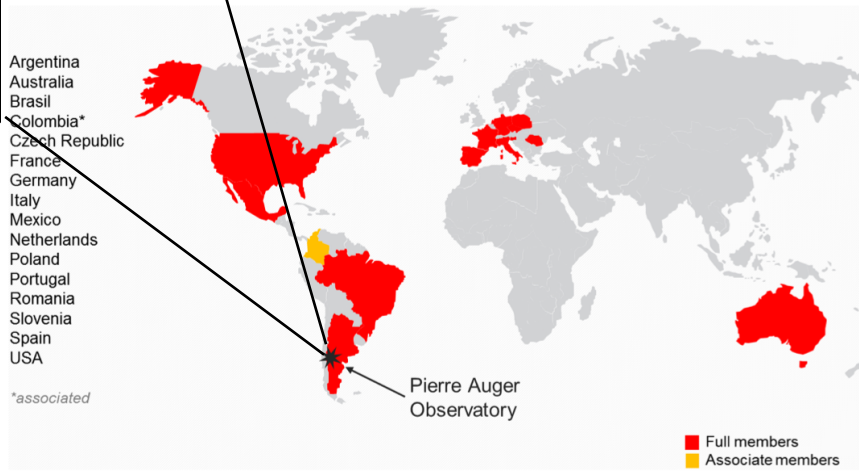


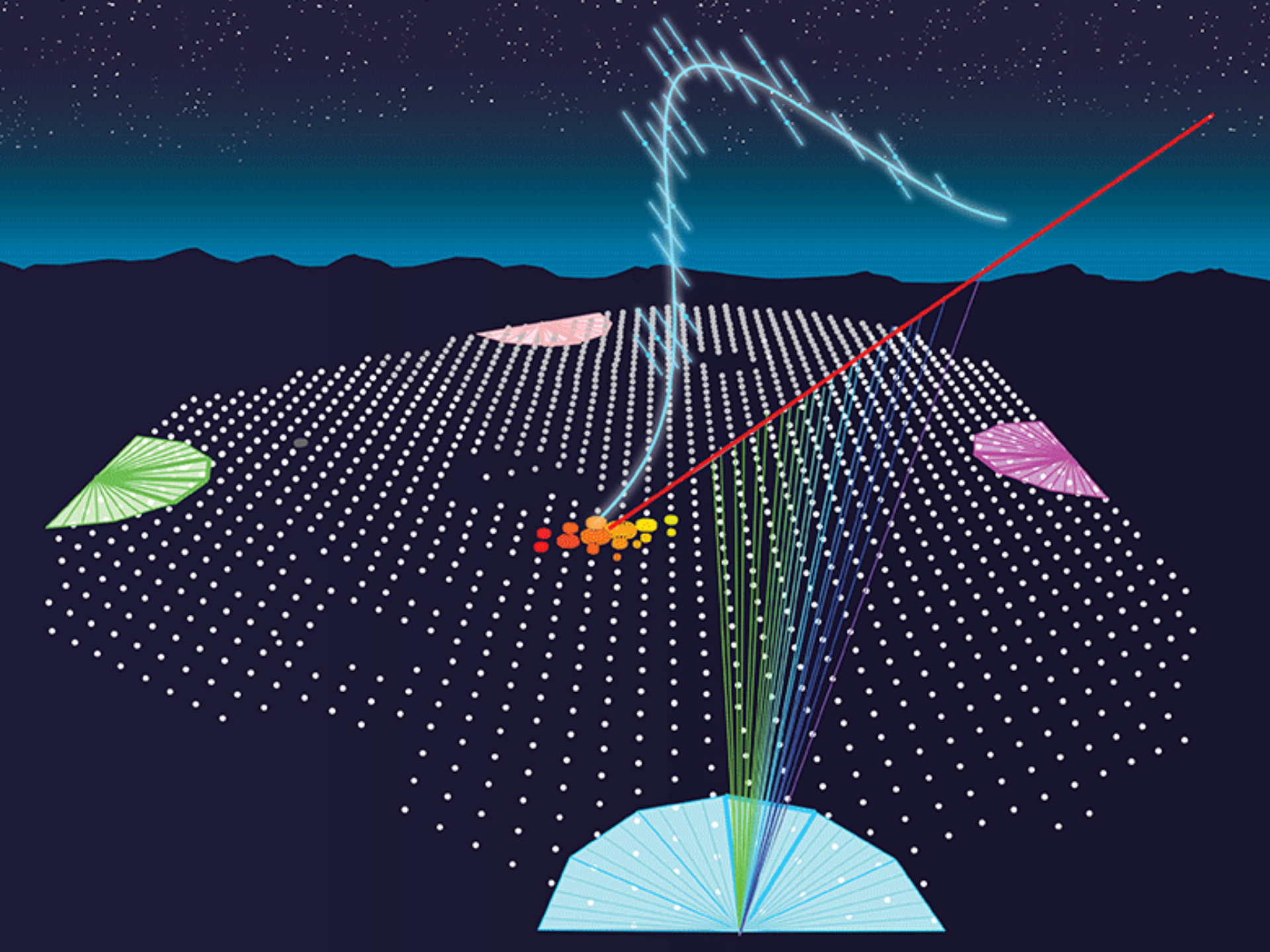
~ 60 km

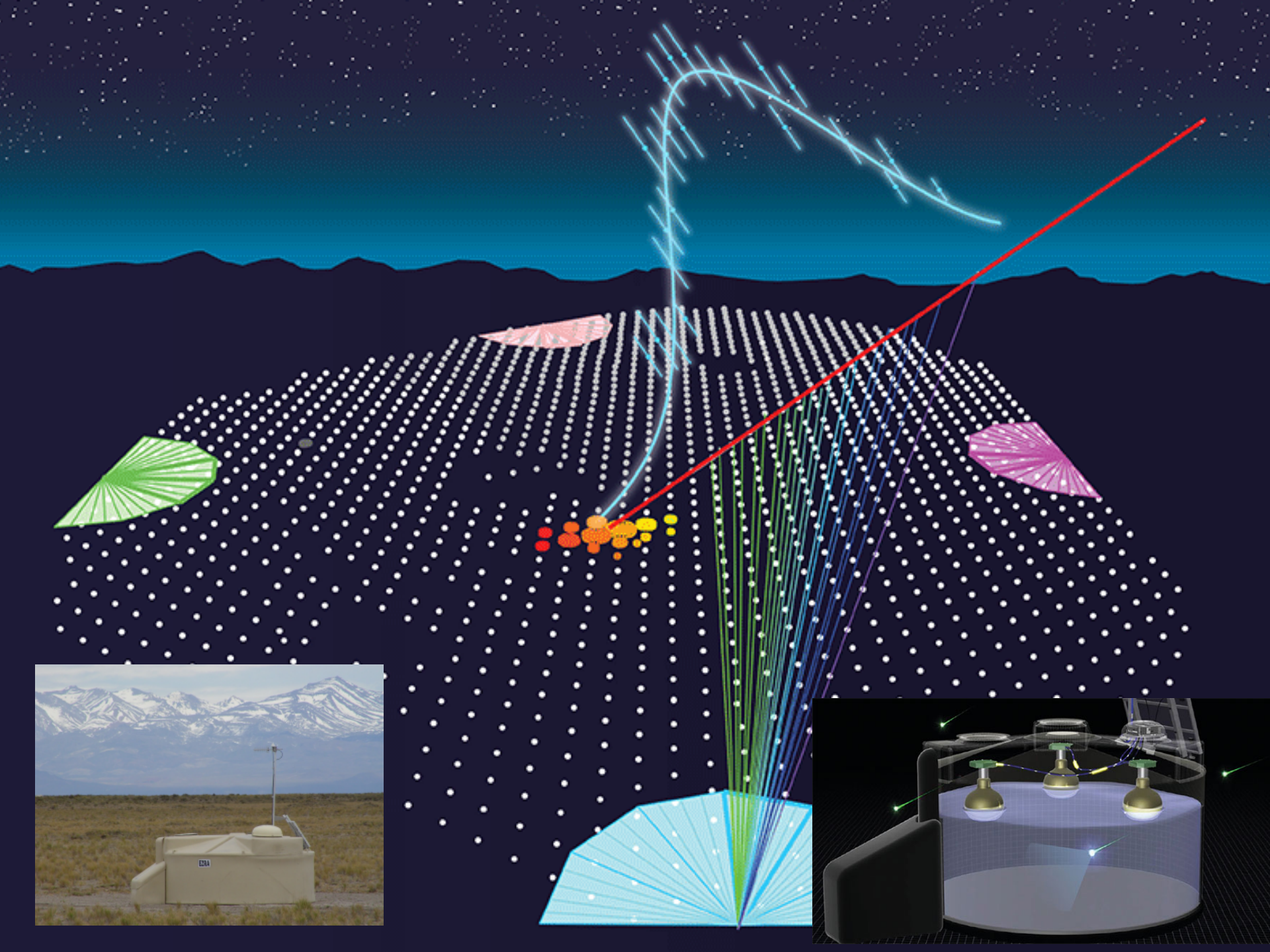
Area: 3000 km^2

Located in the Pampa Amarilla, Mendoza, Argentina

Altitude: 1400 m a.s.l.








two types of mirrors (f
glass
aluminum
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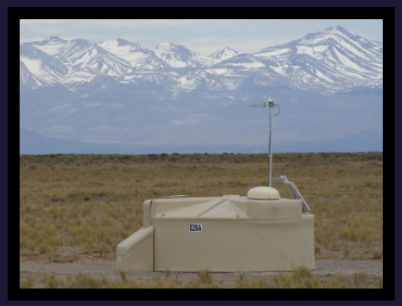
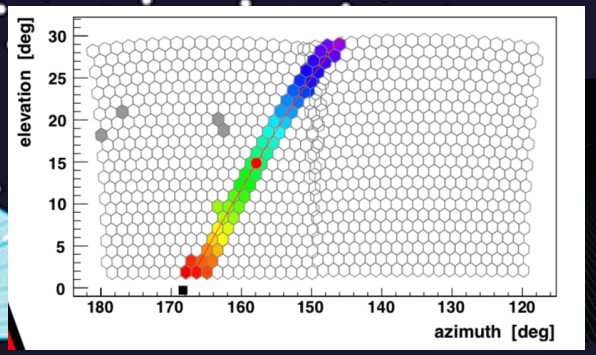
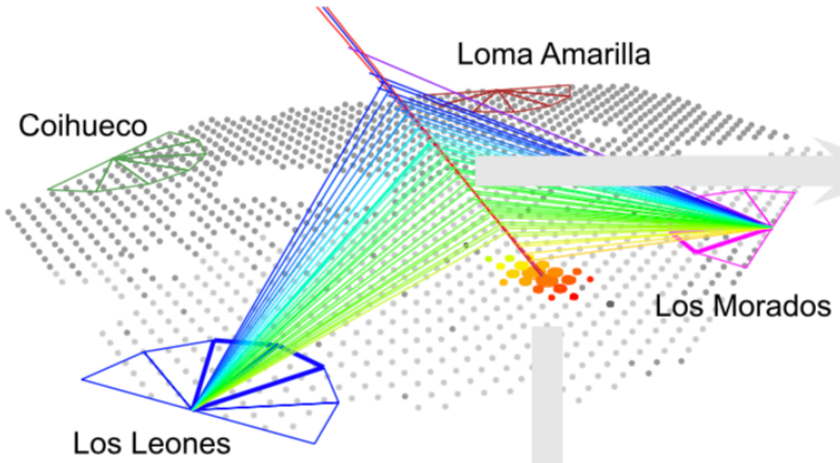
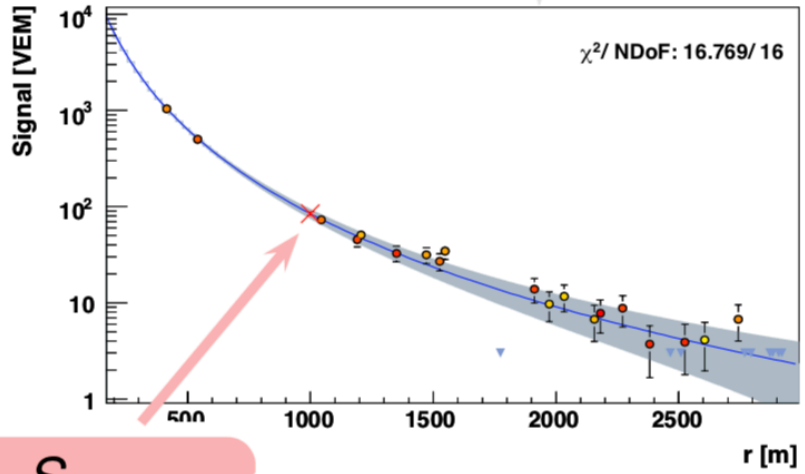
rrector lenses




elevation [deg]
30
25
20
15
10
5
0
180
170
160
150
140
130
120
azimuth [deg]

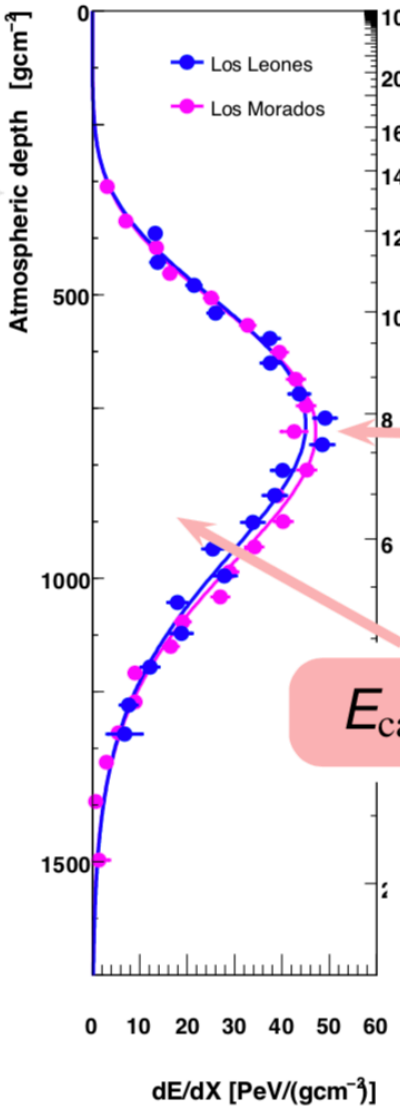
Hybrid Technique





S_{1000}

$E_{\text{surface}} = f(S_{1000}, \theta)$



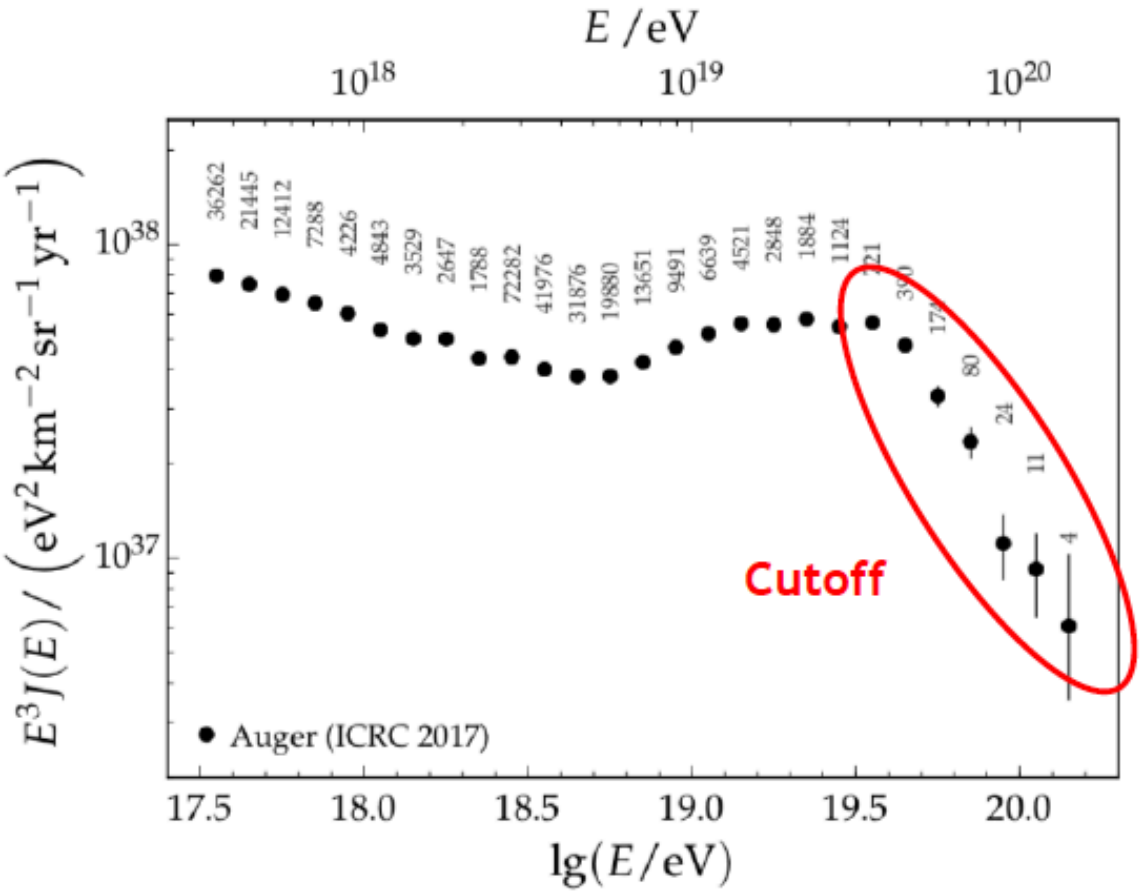
$\sigma X_{\text{max}} \leq 20\ \text{g/cm}^2$
$\Delta_{\text{sys}} \leq 10\ \text{g/cm}^2$

X_{max}

$E_{\text{cal}} = \int \frac{dE}{dX}\, dX$

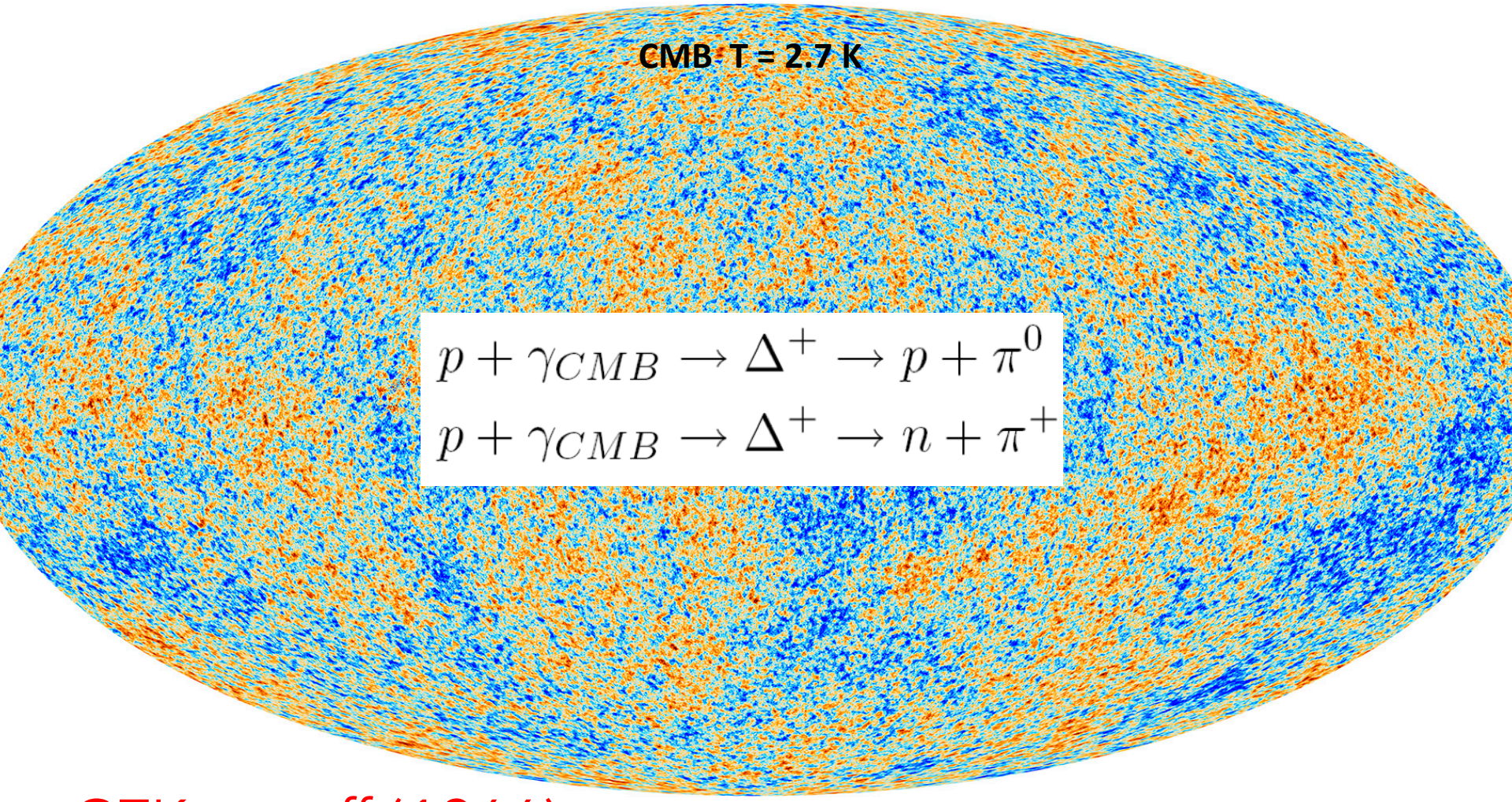
$\sigma_E/E \sim 8\,\%$
$\Delta_{\text{sys}} \approx 15\,\%$

Very-high-energy cosmic-ray flux



(Suppression could still be due to the source exhaustion)

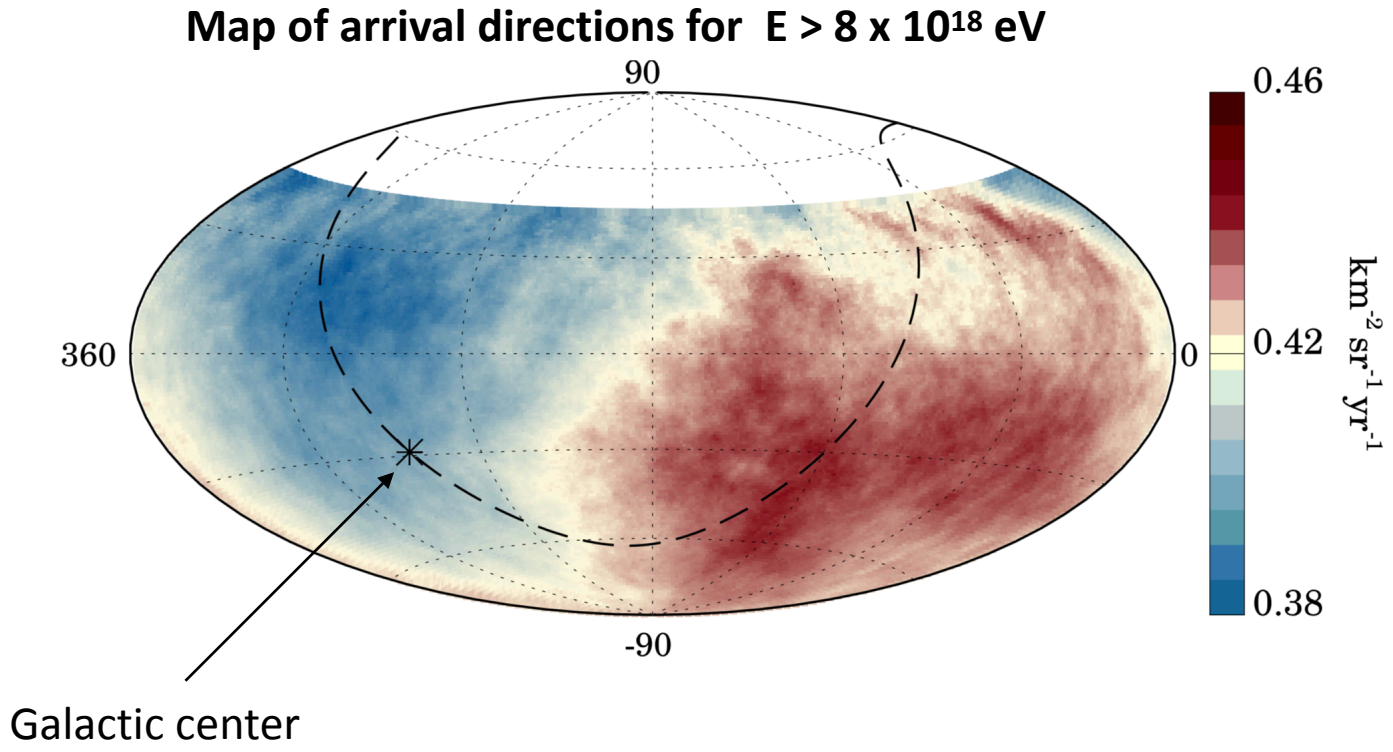
Greisen, Zatsepin, Kuz'min effect



- GZK cuttoff (1966):
  - E ~ 10^{20} eV : $E_{CM} > m_{\Delta} = 1.23$ GeV

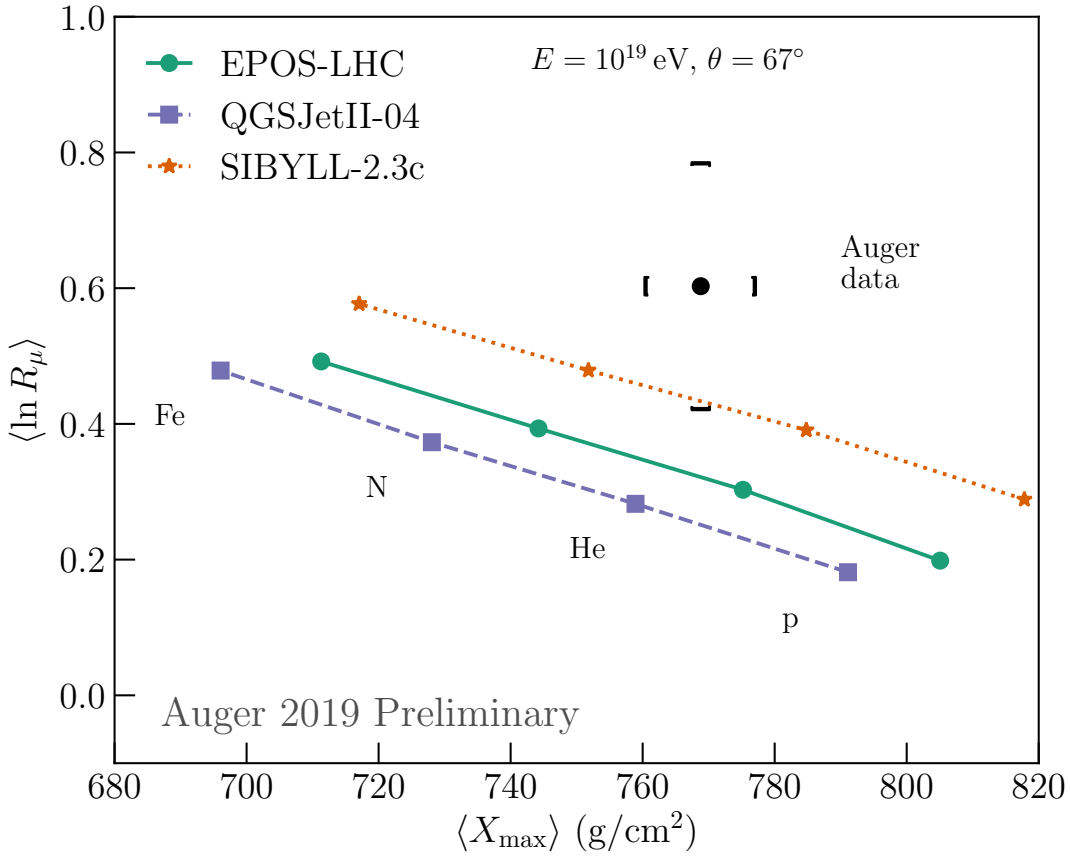
Dipolar anisotropy

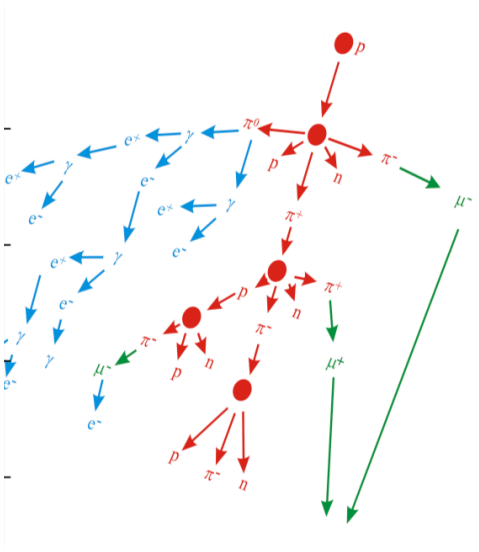
Science 357 (2017) no.6537, 1266-1270



UHECRs coming from outside our galaxy !

Composition vs Hadronic interactions



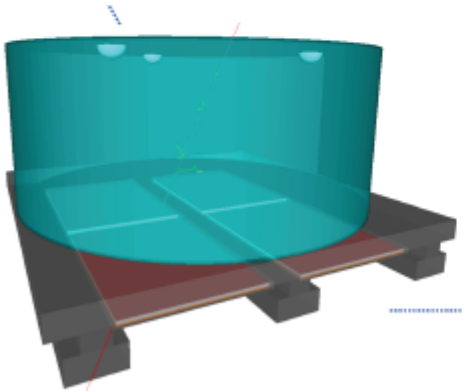


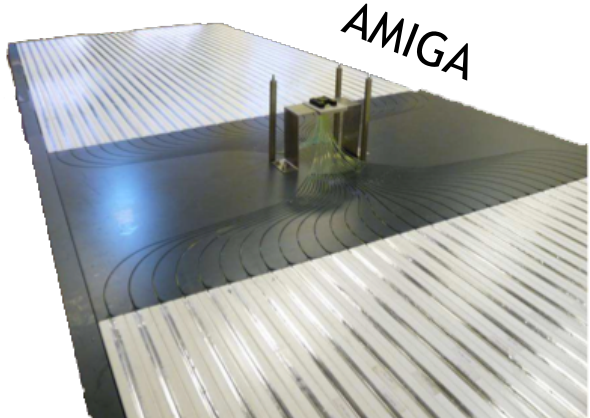
Tension between data and all hadronic interaction models

–> calls for an independent direct measurement of the number of muons

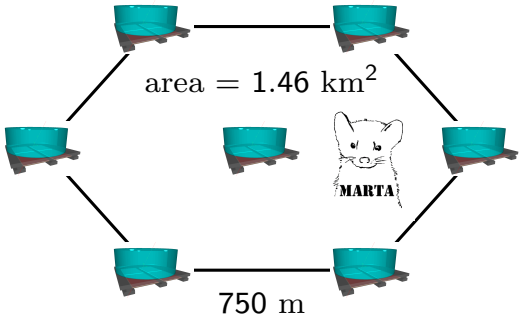
The future in Auger

- **Auger upgrade**
  - Auger PRIME (operates until 2025)
  - Put a scintillator on top of the SD
  - Complementary information to separate the muon from the e.m. shower component
- **Several R&D projects**
  - EAS radio detection
  - MARTA engineering array
    - RPCs below the tank
  - AMIGA
    - Scintillators below the ground

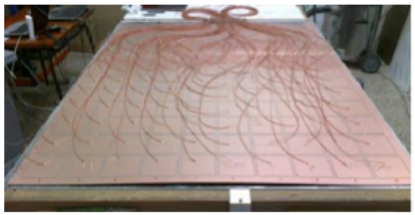




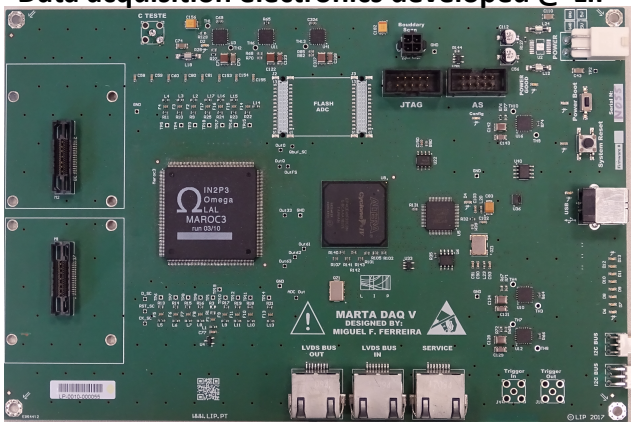
The MARTA project



Resistive Plate Chambers developed @ LIP



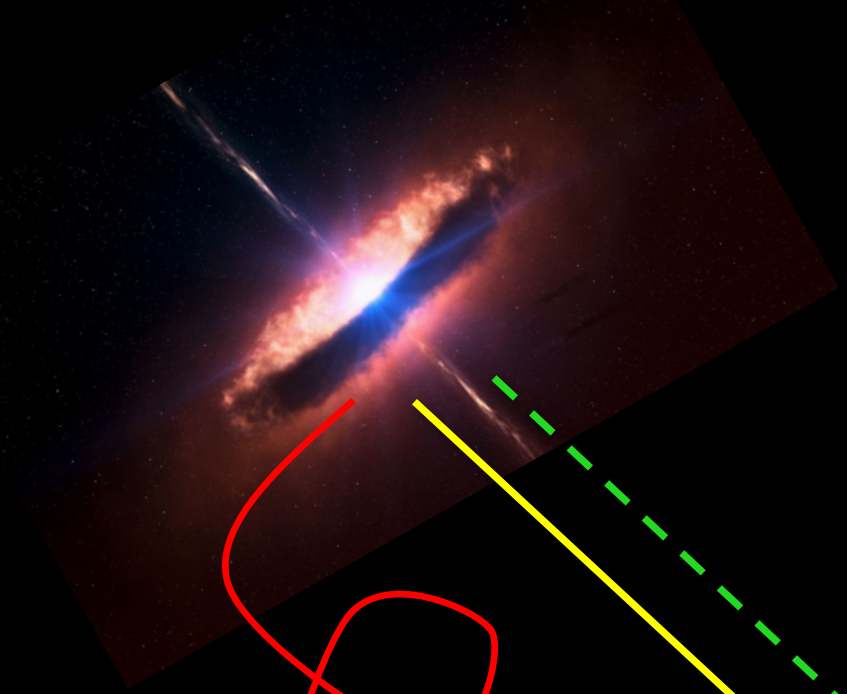
Data acquisition electronics developed @ LIP



(Very) High Energy Gamma Rays

- Astrophysical gamma rays
  - Energy region of interest from GeVs to hundreds TeVs
- Scientific interest:
  - Key to understand the **acceleration mechanism** of cosmic rays in our galaxy
  - Violent astrophysical phenomena: pulsars and black holes
  - Galactic magnetic fields
  - Photon radiation fields in the Universe
  - Indirect search of **dark matter** (WIMP interactions)
  - Test fundamental properties of quantum gravity
  - …

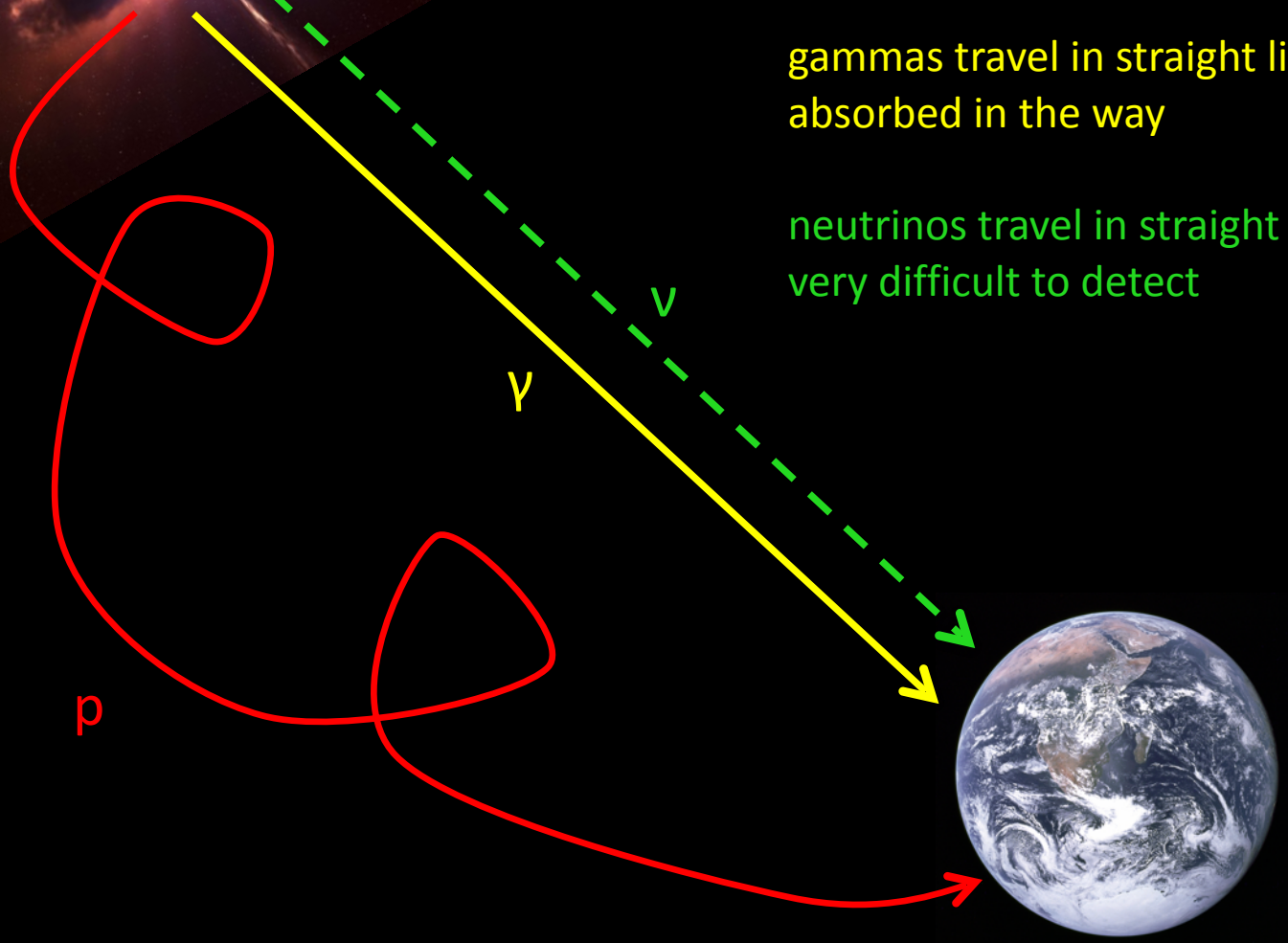
Complementarity



protons are deflected by the galactic magnetic fields

gammas travel in straight lines but can be absorbed in the way

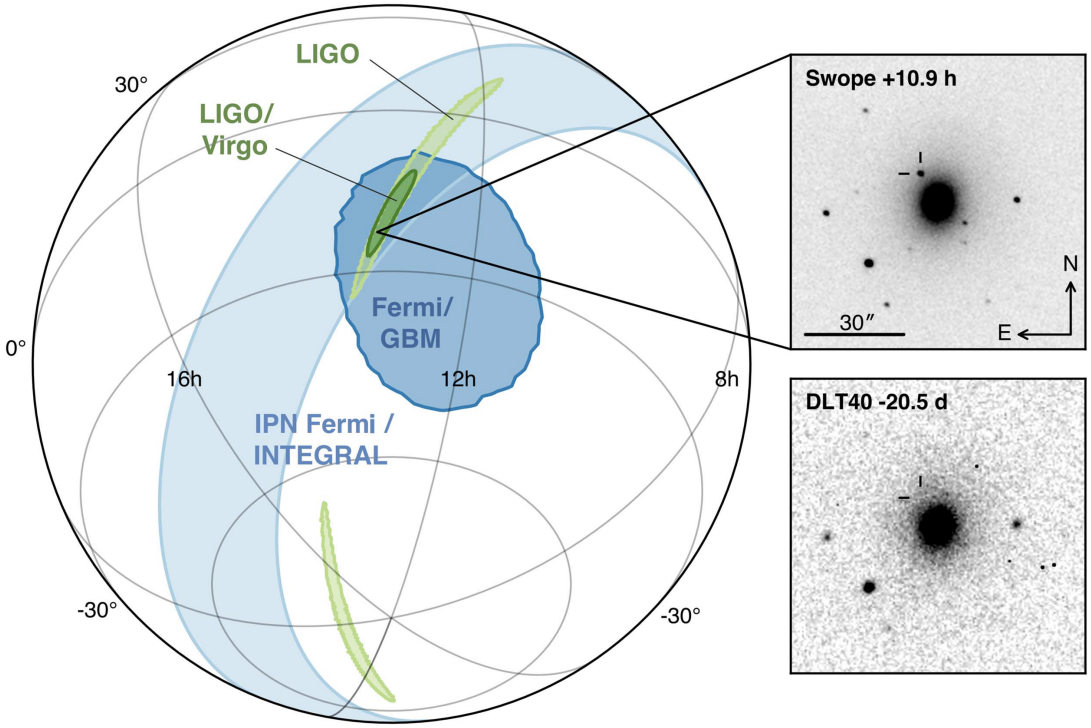
neutrinos travel in straight lines but are very difficult to detect



Multi-messenger observation of a Binary Neutron Star Merger

physicsworld BREAKTHROUGH OF THE YEAR 2017

Joint publication of LIGO, VIRGO, INTEGRAL, Fermi, IceCube, Pierre Auger …

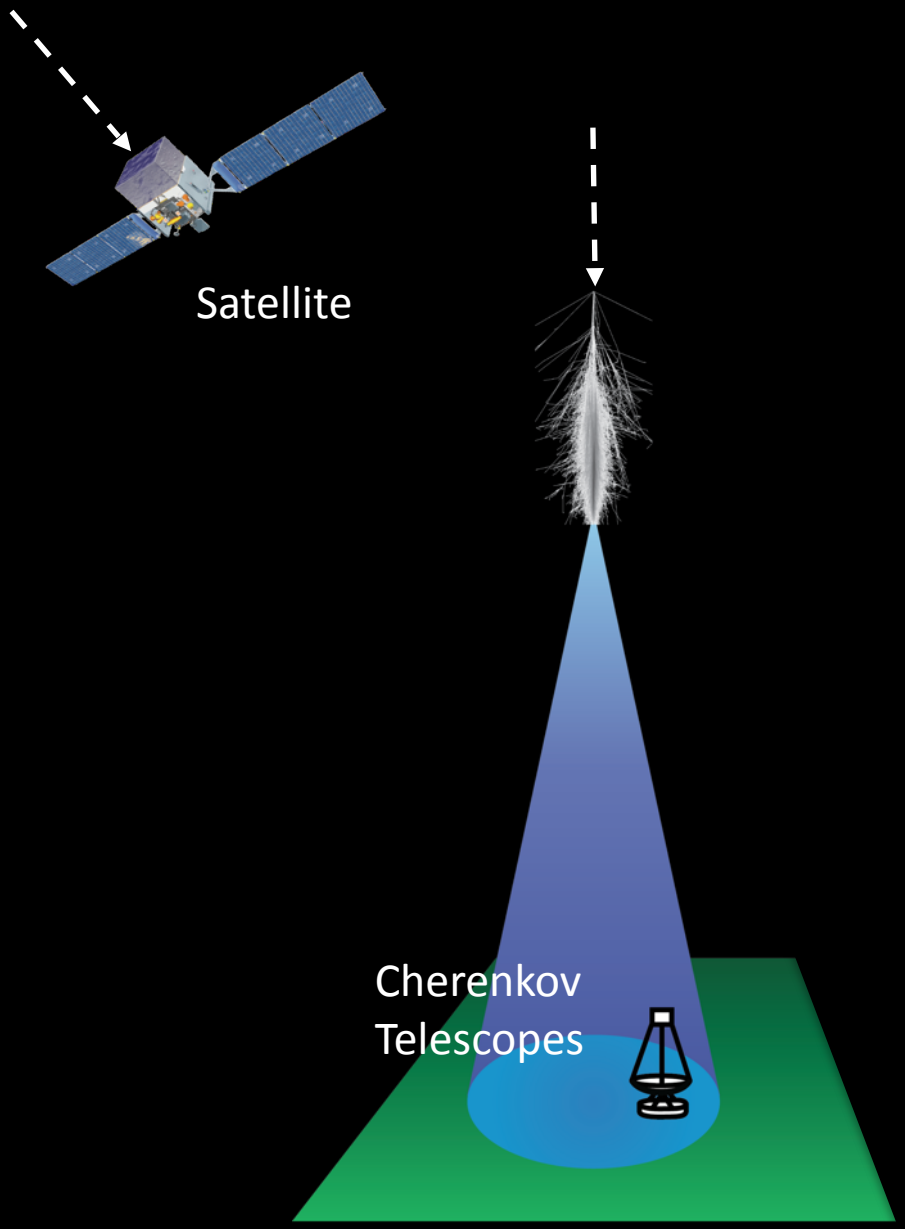


- Simultaneous observation of a Gravitational Wave + electromagnetic counter parts
- Allows to test the dynamics of our surrounding Universe
- Study of transient phenomena in all energy regions is one of the main ingredients

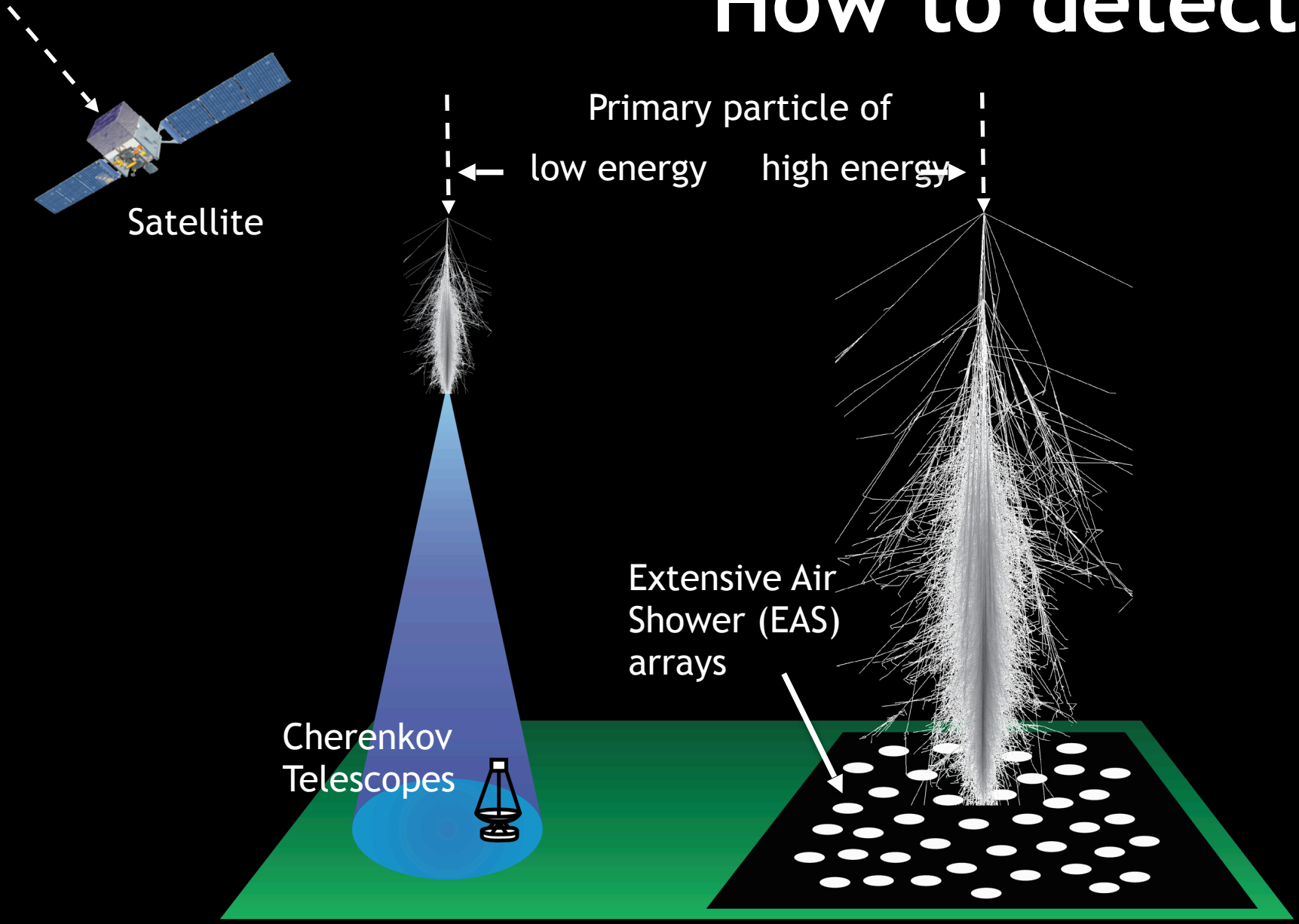
How to detect?

Satellite

How to detect?

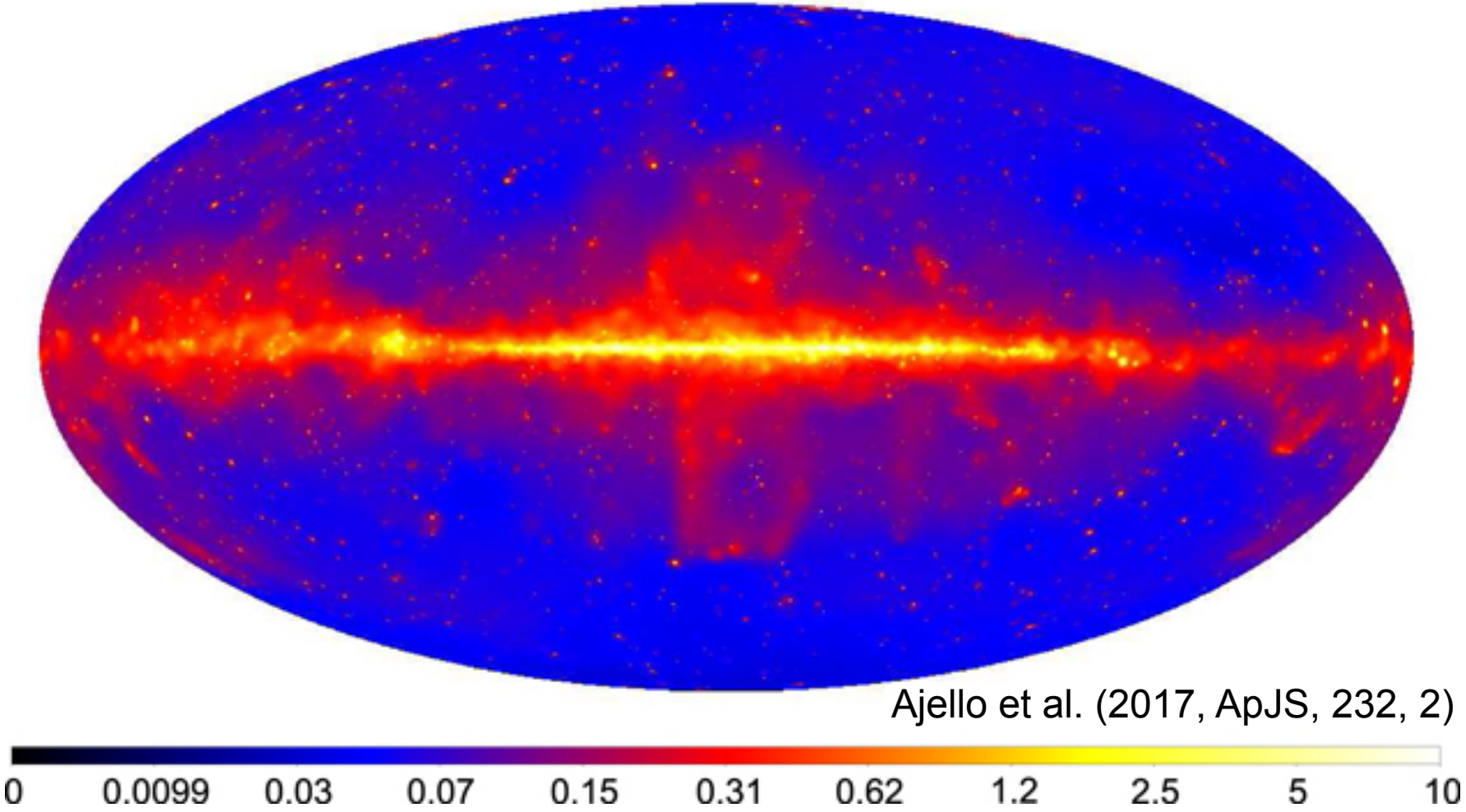


How to detect?



Arrays at high-altitude = large field of view + large duty cycle + low energy

A picture of the sky in VHE Gamma-Rays



At E > 10 GeV we can observe the most extreme processes of the Universe: relativistic particles that strike our Galaxy, jets fired by Super Massive Black Holes and cosmic explosions known as Gamma Ray Bursts

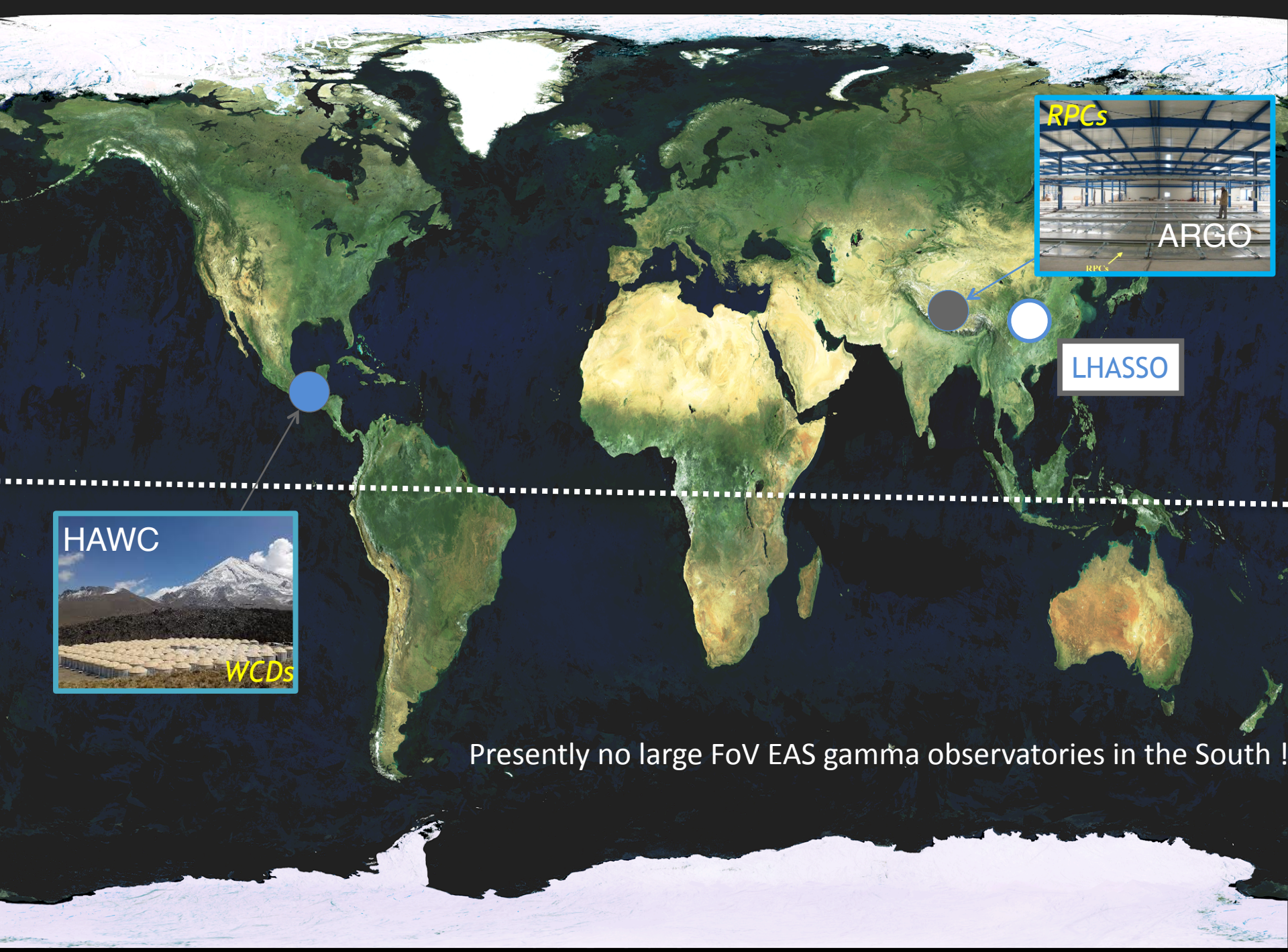
Looking at the VHE gamma sky

CTA

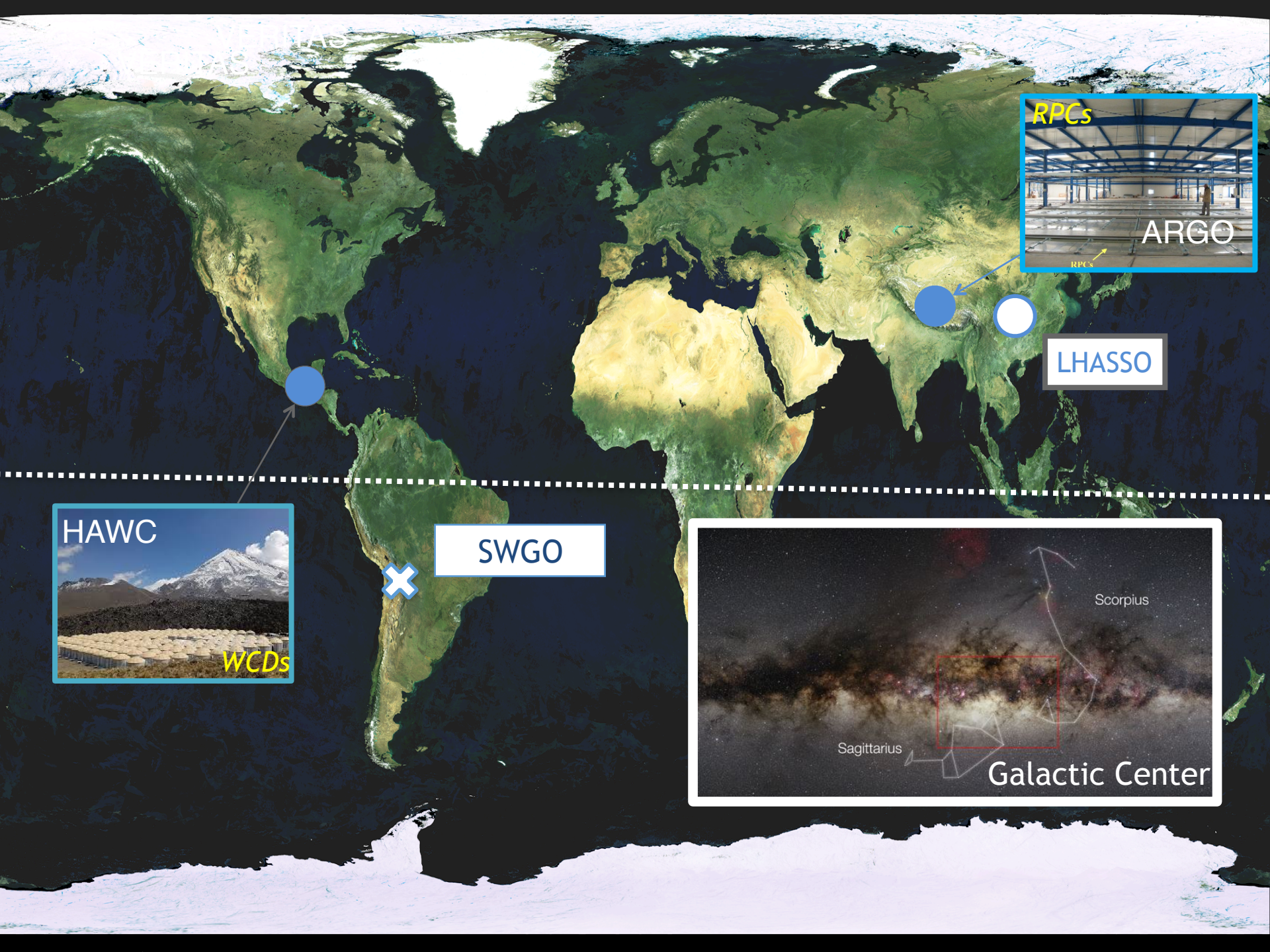
LHASSO

CTA

Built IACT
Built Array
Planned IACT
Planned Array


RPCs
ARGO
RPCs
LHASSO
HAWC
WCDs
Presently no large FoV EAS gamma observatories in the South !

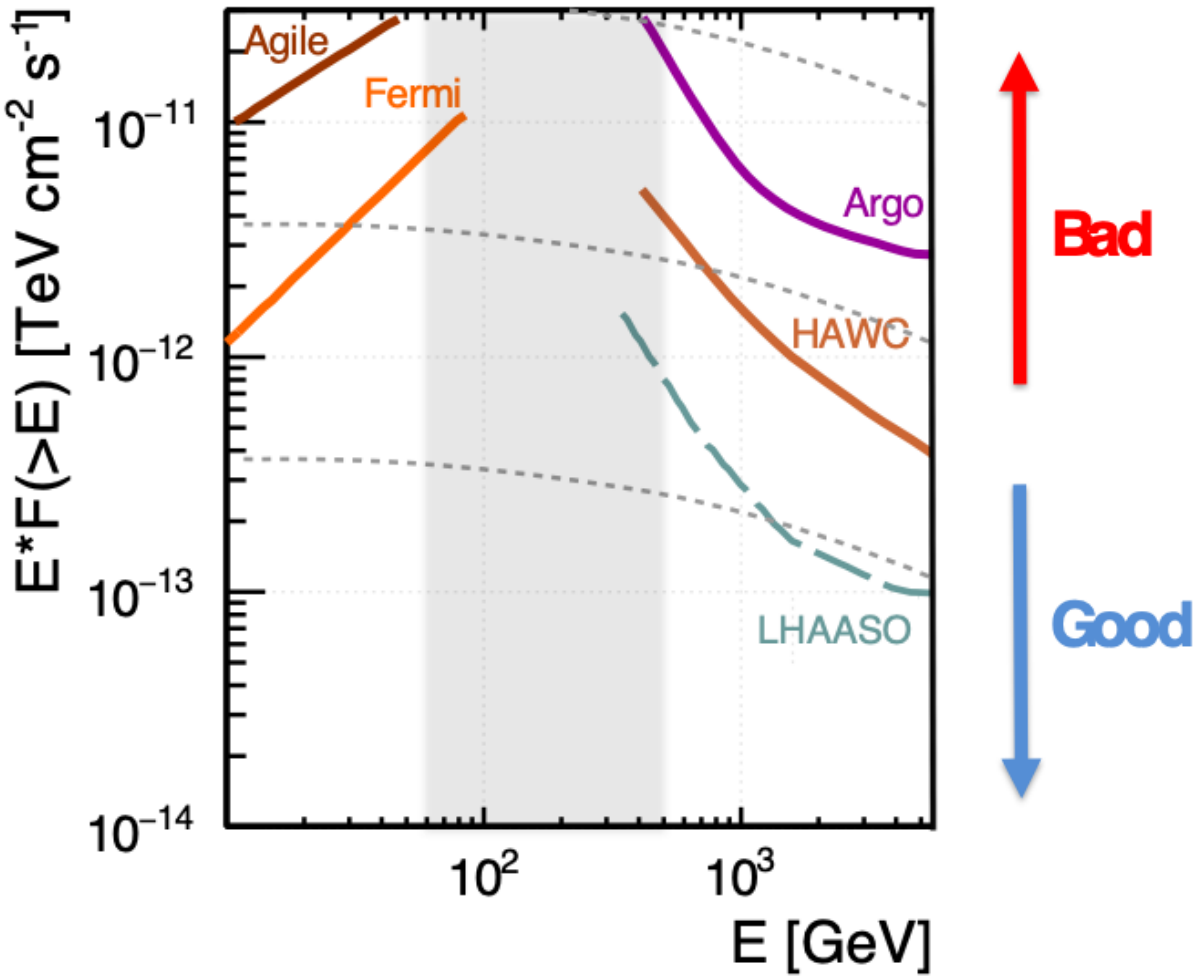

RPCs
ARGO
RPCs
LHASSO
HAWC
WCDs
SWGO


RPCs
ARGO
LHASSO
HAWC
WCDs
SWGO
Scorpius
Sagittarius
Galactic Center

SWGO

Complementary to the powerful Cherenkov Telescope Array project

Current Wide FoV Gamma-Ray Observatories



A window to be opened ! But a big challenge…

➢ Find new technological solutions;

➢ Develop novel data analysis methods;

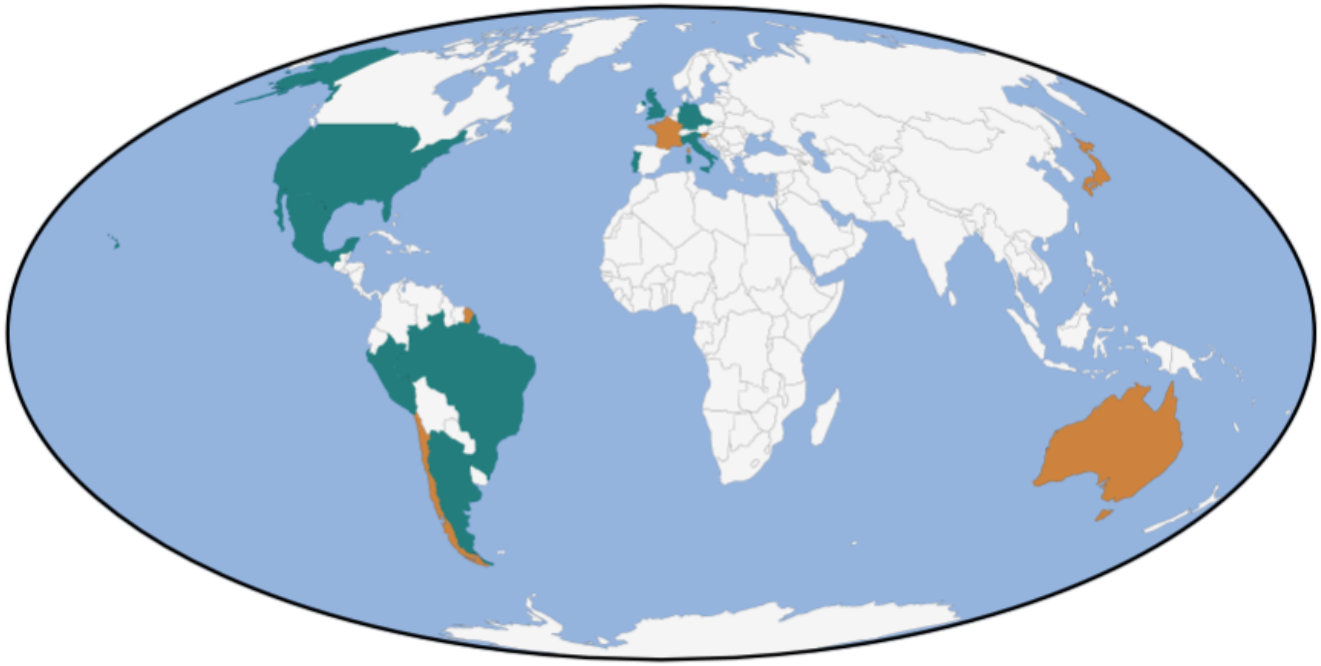
SWGO

Southern Wide-field Gamma-ray Observatory

Energy range 100 GeV – 100 TeV
High altitude in South America
Based on Water Cherenkov Detectors

SWGO Collaboration

Next 3 years R&D programme to develop the detectors design, choose site, …



Countries in SWGO

Institutes

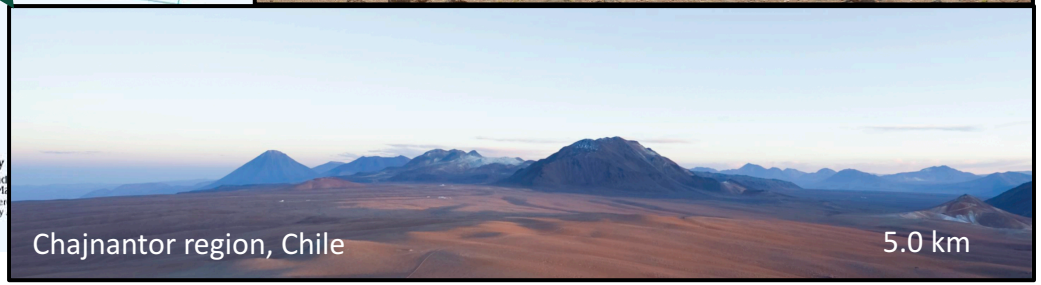
Argentina*, Brazil, Czech Republic, Germany*, Italy, Mexico, Peru, Portugal, United Kingdom, United States*

Supporting scientists

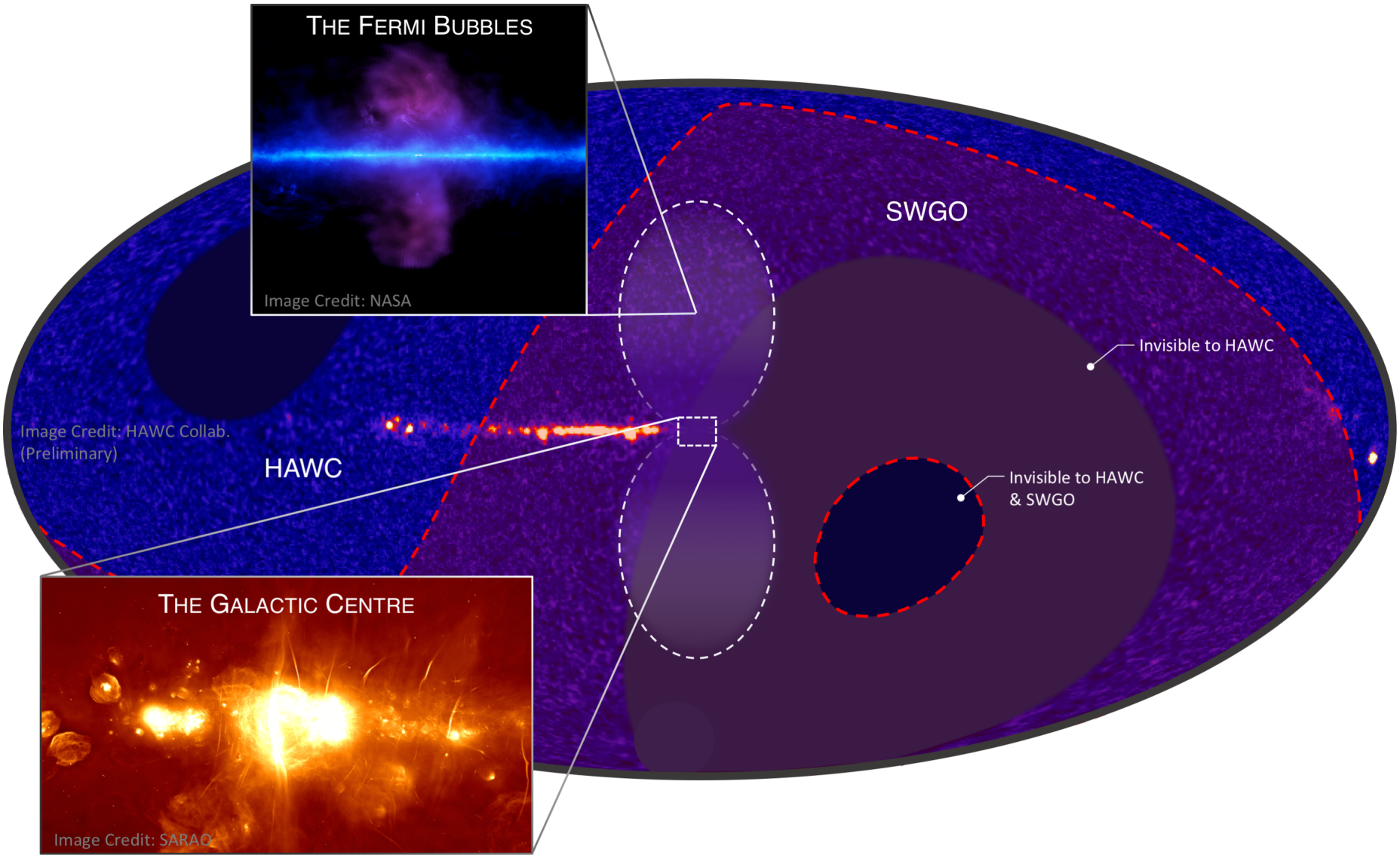
Australia, Chile, France, Japan, Slovenia

**also supporting scientists*

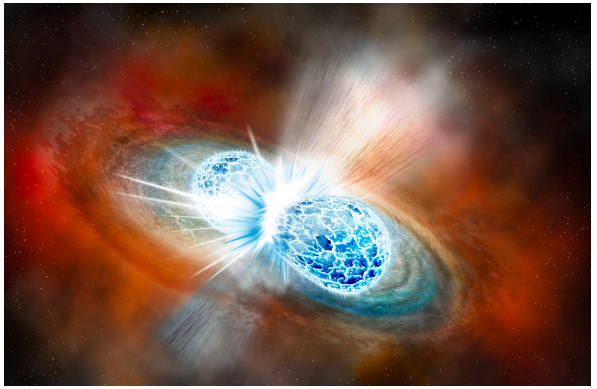
Several possible sites…



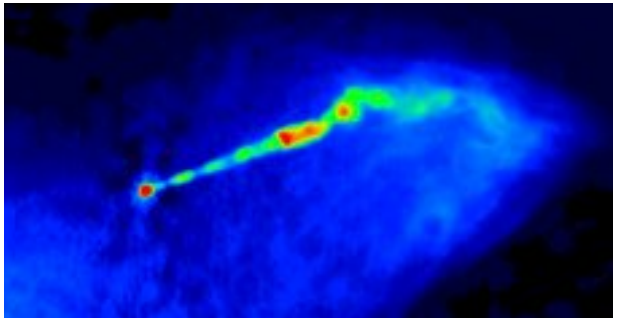
Prospective gamma-ray sky view



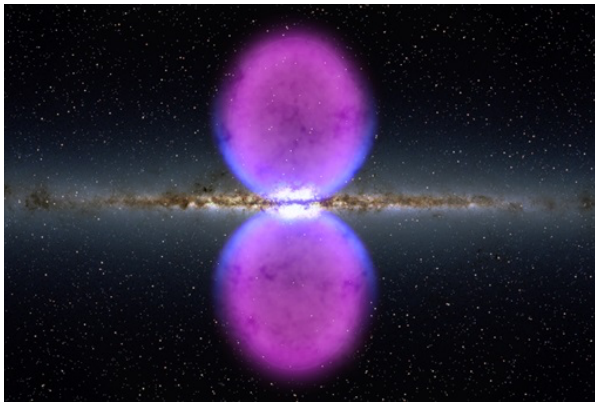
SWGO Scientific potential



- **Gamma-ray bursts**
  - SWGO as a finder for VHE bursts
  - Triggers for CTA



- **Flaring Active Galactic Nuclei (AGN)**
  - Bright AGN flares detectable on short timescales with SWGO
  - Long-term monitoring



- **Large scale Galactic emission**
  - Fermi Bubbles
  - Halos around CR accelerators

Summary

- (Multi)-Messengers from the Universe
- Gain a deeper understanding of the dynamics of our Universe
- Highest-energy particle beams available at Earth
- Several ambitious projects in which LIP participates

Backup slides