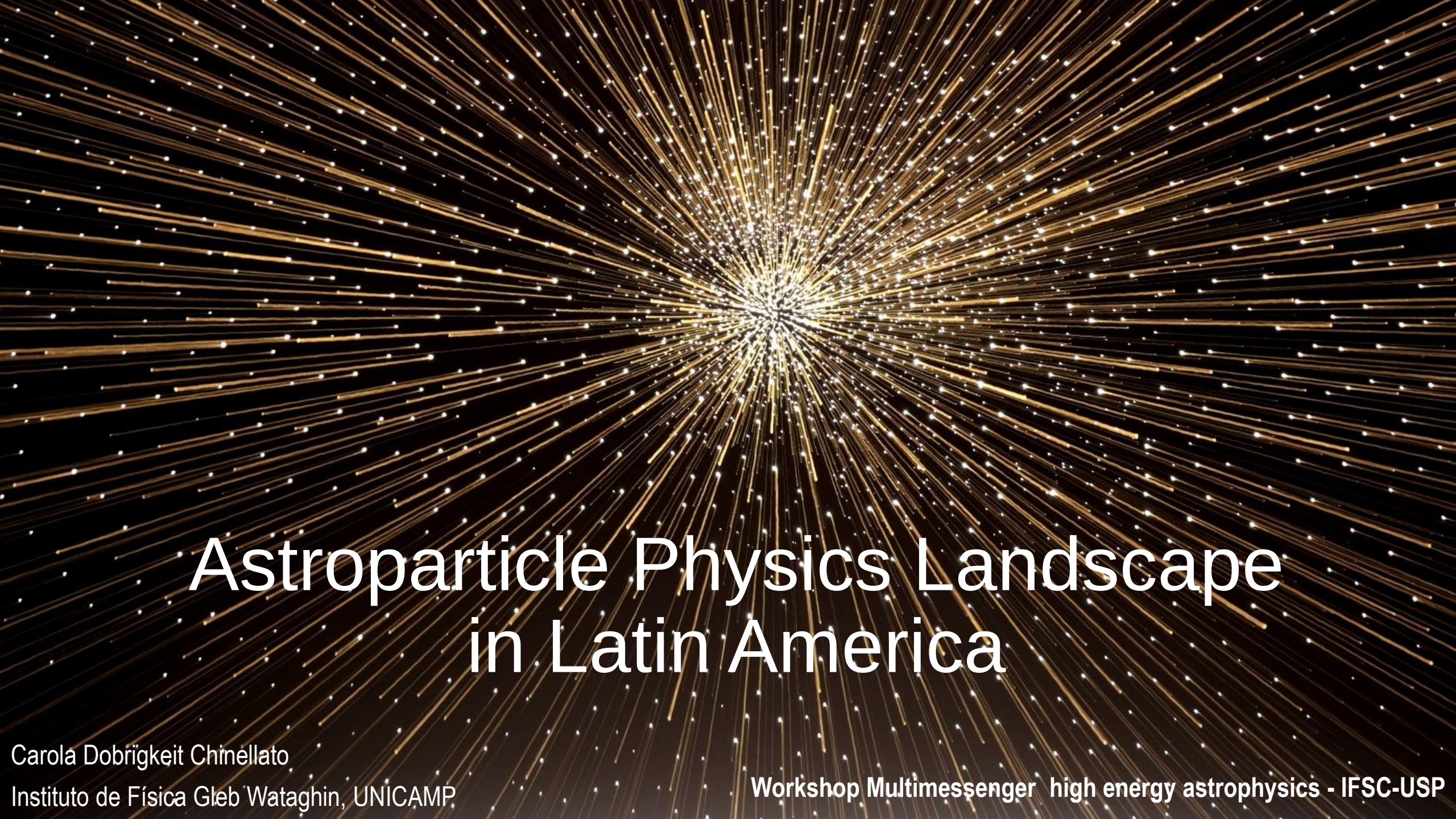


Astroparticle Physics Landscape in Latin America

Carola Dobrigkeit Chinellato
Instituto de Física Gleb Wataghin, UNICAMP

Workshop Multimessenger high energy astrophysics - IFSC-USP

Introduction

Before discussing Cosmic-Ray Physics in the XXI century, please allow me to give you a glimpse of the role that cosmic-ray physics played and still plays in our contemporary research activities in South America, particularly in Brazil.

Compton about South America and Cosmic Rays

In 1942, the Nobel Prize-winning physicist Arthur Compton pointed out that

> "Because in this field of cosmic ray studies certain unique advantages are given by their **geographical position**, this field of physics has been especially emphasized in South America."

To which advantages Compton was referring?

- High-altitude mountains (up to 6,000 m, extending over 8,000 km in length)
- Good climatic conditions (mild weather, clear and unpolluted skies)
- The center of our Galaxy comes within the field of view of the experiments
- Various regions in Brazil, Peru, and Bolivia near to the geomagnetic equator

Early research in cosmic-ray physics in South America

- There is a long tradition in cosmic-ray research in South America, particularly in Brazil, starting in the 1930s with Bernhard Gross in Rio and Gleb Wataghin in São Paulo.
- In the 1930s, Wataghin and his co-workers measured coincidences of penetrating particles (at the same time as Pierre Auger et al.) in a gold mine in the State of Minas Gerais, in a tunnel under construction in São Paulo and on flights with Brazilian Air Force (FAB) planes.
- They published their results in Phys. Rev. in 1940 as Letters to the Editor ("*Simultaneous Penetrating Particles in the Cosmic Radiation I and II*", P. A. Pompeia, M. Damy de Souza Santos, G. Wataghin, both in Phys. Rev. 57). These are the first international publications of cosmic-ray experiments done in Brazil.

Simultaneous Penetrating Particles in the Cosmic Radiation II*

An excerpt of the conclusion:

- Further studies on the number of penetrating particles in a shower and on the extension of those showers are in course, and **results already obtained lead us to think that the observed particles are associated with the penetrating cores of the extensive air showers discovered by Auger and his co-workers.**

*** "Simultaneous Penetrating Particles in the Cosmic Radiation II", P. A. Pompeia, M. Damy de Souza Santos, G. Wataghin, The Physical Review, v.57, n.1, p.61, 1940**

Compton in São Paulo

- Arthur Compton visited São Paulo in 1941 and participated in the International Symposium of Cosmic Rays organized by Wataghin and held in Rio de Janeiro.
- He also launched balloon flights not far from São Carlos.

Arthur Compton

Oscar Sala

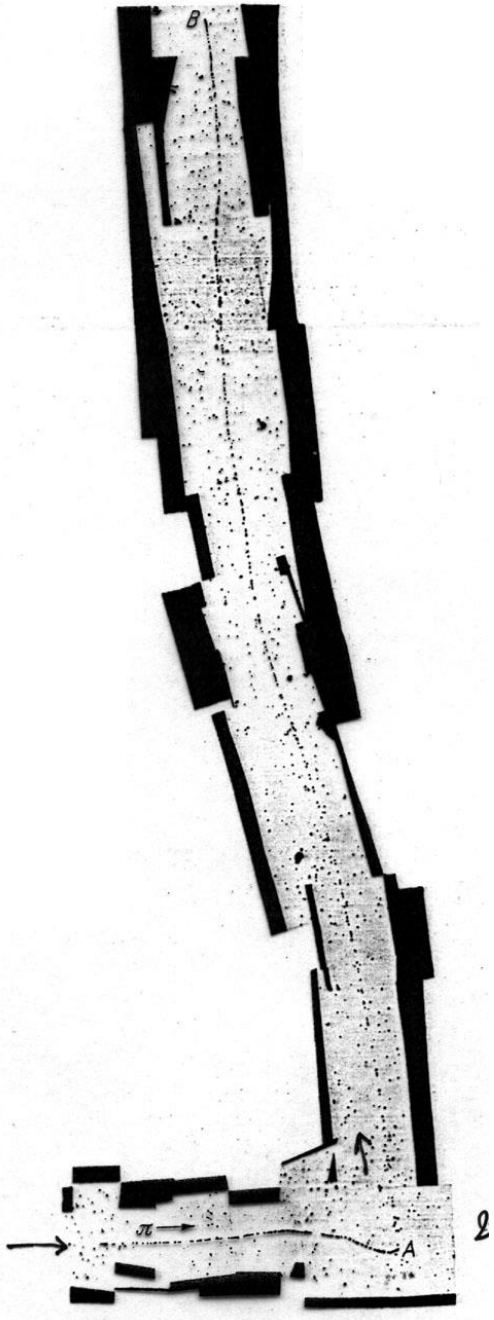
Compton expedition in 1941: launching balloons to the stratosphere to catch cosmic rays.

Cesar Lattes

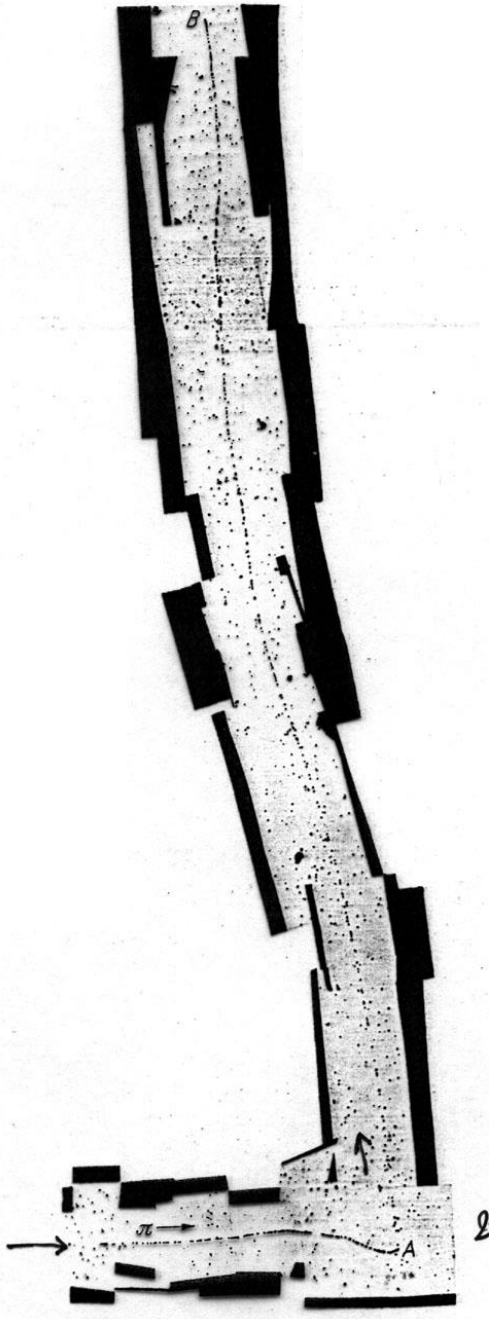
- A former student of Wataghin at the University of São Paulo, Lattes received a scholarship to work in Cecil Powell's group at Bristol (UK).

- He participated in the measurements that led to the discovery of the pion in 1947 using nuclear emulsion plates exposed to cosmic rays (*"Observation on the Tracks of Slow Mesons in Photographic Emulsions Part 1 and 2",* C. M. G. Lattes, G. P. S. Occhialini and C. F. Powell, Nature 160). Powell received the Nobel Prize in 1950.

- We are celebrating Lattes' centenary this year.



Pic du Midi
French Pyrenees
(2,877 m)



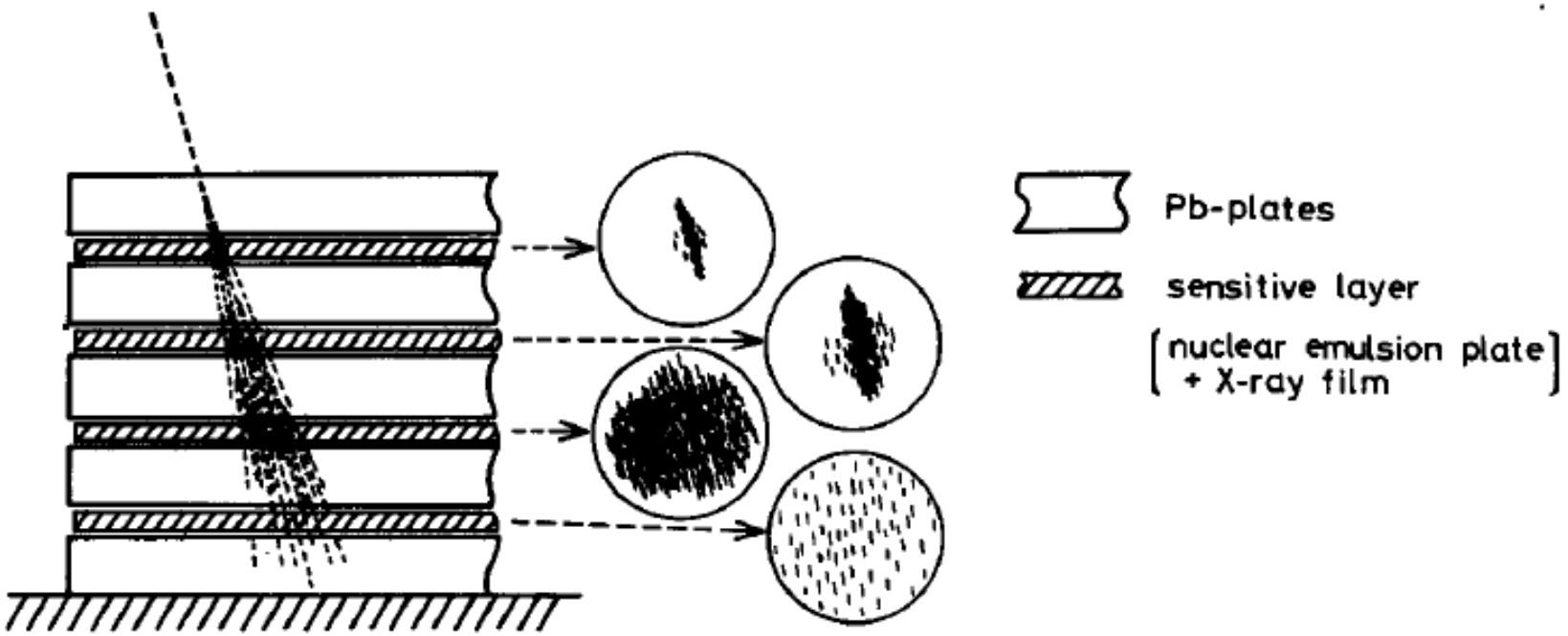
Pic du Midi
French Pyrenees
(2,877 m)

Mount Chacaltaya
Bolivia
(5,200 m)

The next experiments at Mt. Chacaltaya

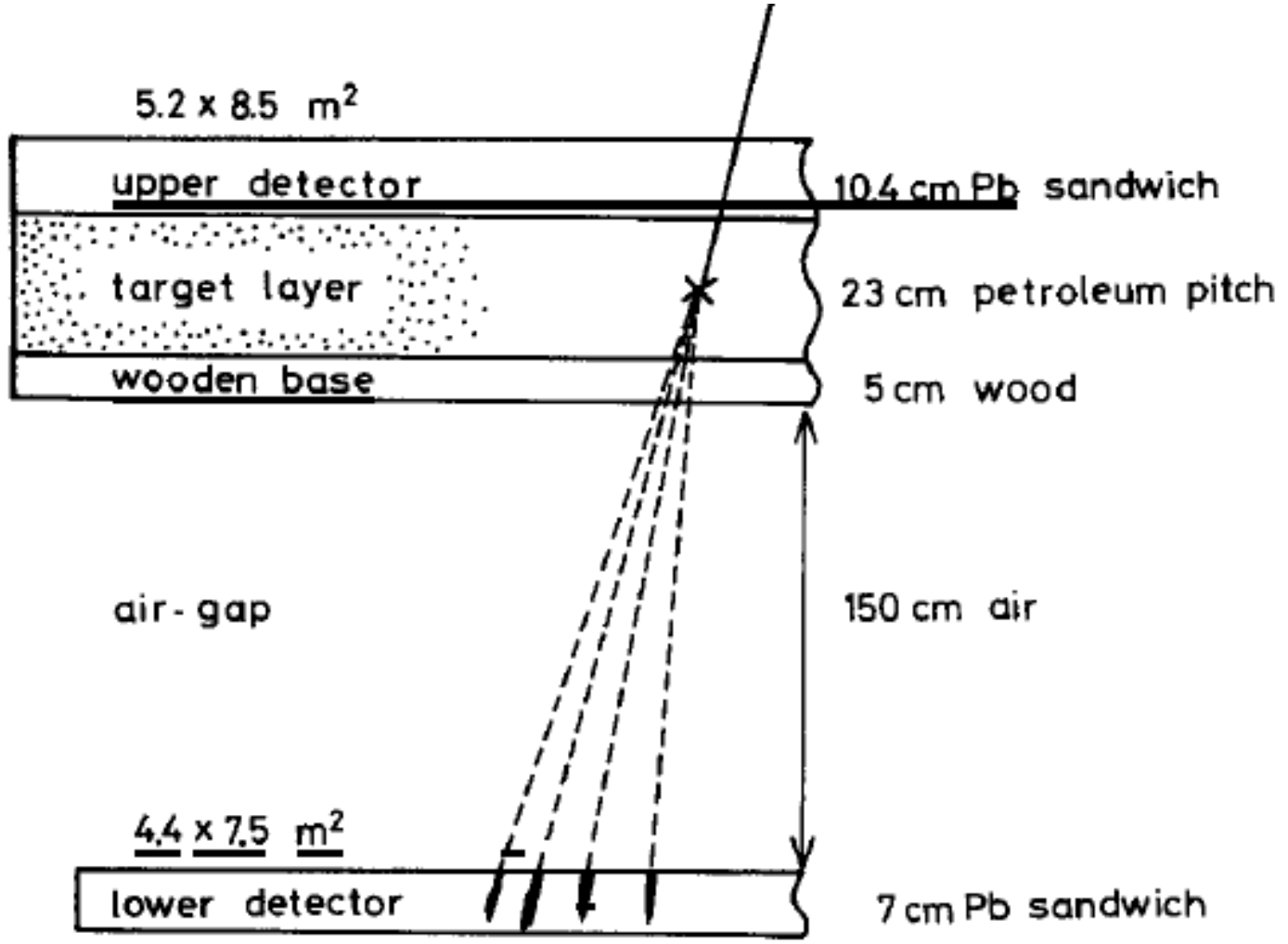
- From the 1960s until today, the Mt. Chacaltaya Observatory hosted many cosmic-ray experiments, such as the Brazil-Japan Collaboration, the Bolivian Air Shower Joint Experiment BASJE experiment (Bolivia, Japan and USA) and today ALPACA (Andes Large area PArticle detector for Cosmic ray physics and Astronomy).

Emulsion chambers of the Brazil-Japan Collaboration



Basic structure of an emulsion chamber working as an electron shower detector.

A two-storey emulsion chamber..



Also theoretical work was done

Manuel Sandoval Vallarta (Mexico)

With Georges Lemaître, Vallarta discovered that the intensity of cosmic rays varied with latitude because these charged particles are interacting with the Earth's magnetic field.

They also worked on a theory of primary cosmic radiation and applied it to their investigations of the Sun's magnetic field and the effects of the galaxy's rotation.

While at Universidad Nacional Autónoma de México, Vallarta worked with Nobel Prize laureates Luis Alvarez and Arthur Compton on experiments to show that cosmic rays were composed of protons.

Interesting paper: *“The scattering of cosmic rays by the stars of a galaxy”*, by M. S. Vallarta, R. Feynman, published in Phys. Rev (1939). This was Feynman's first scientific publication.

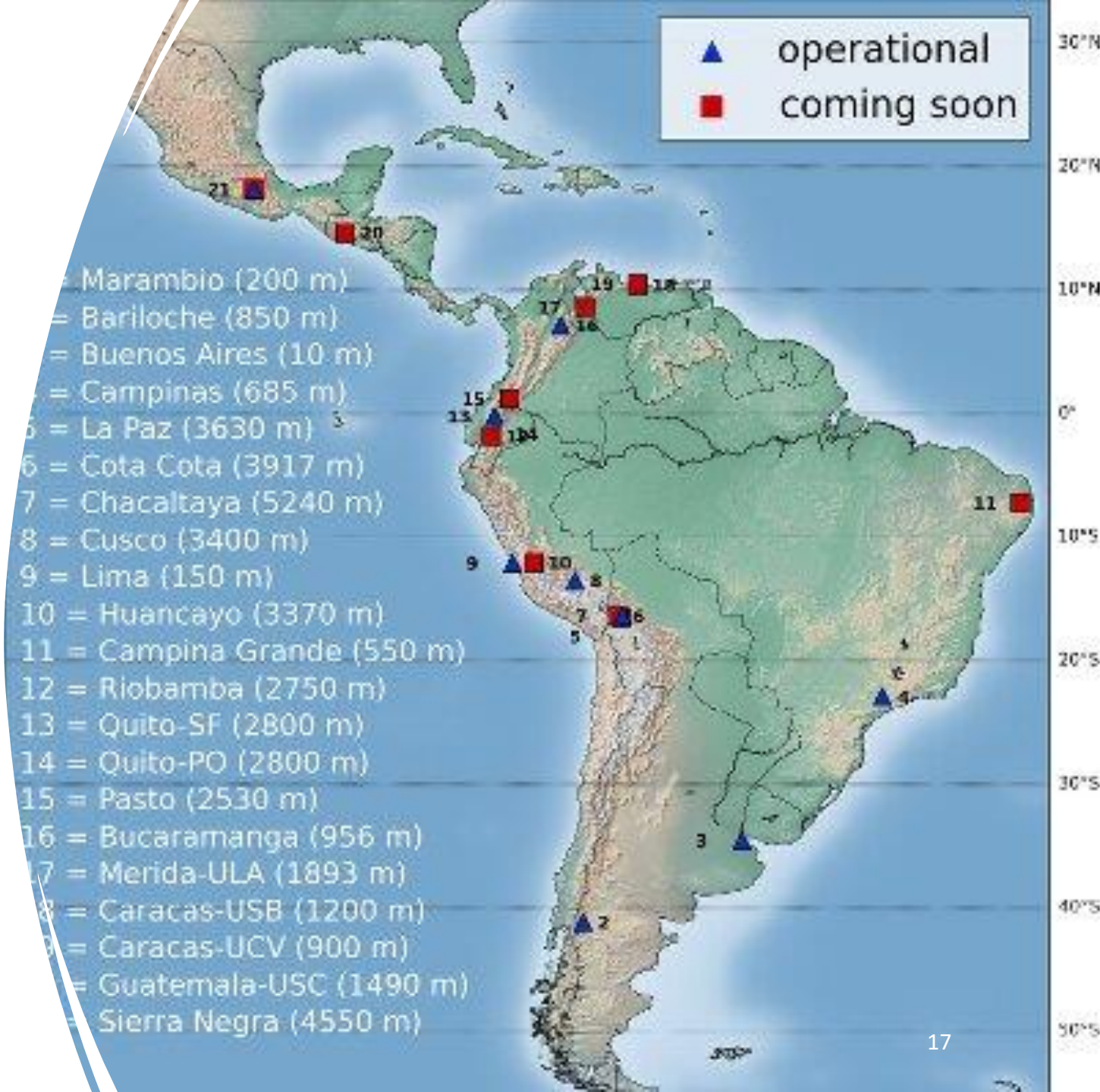
Activities ongoing also in other countries in these years

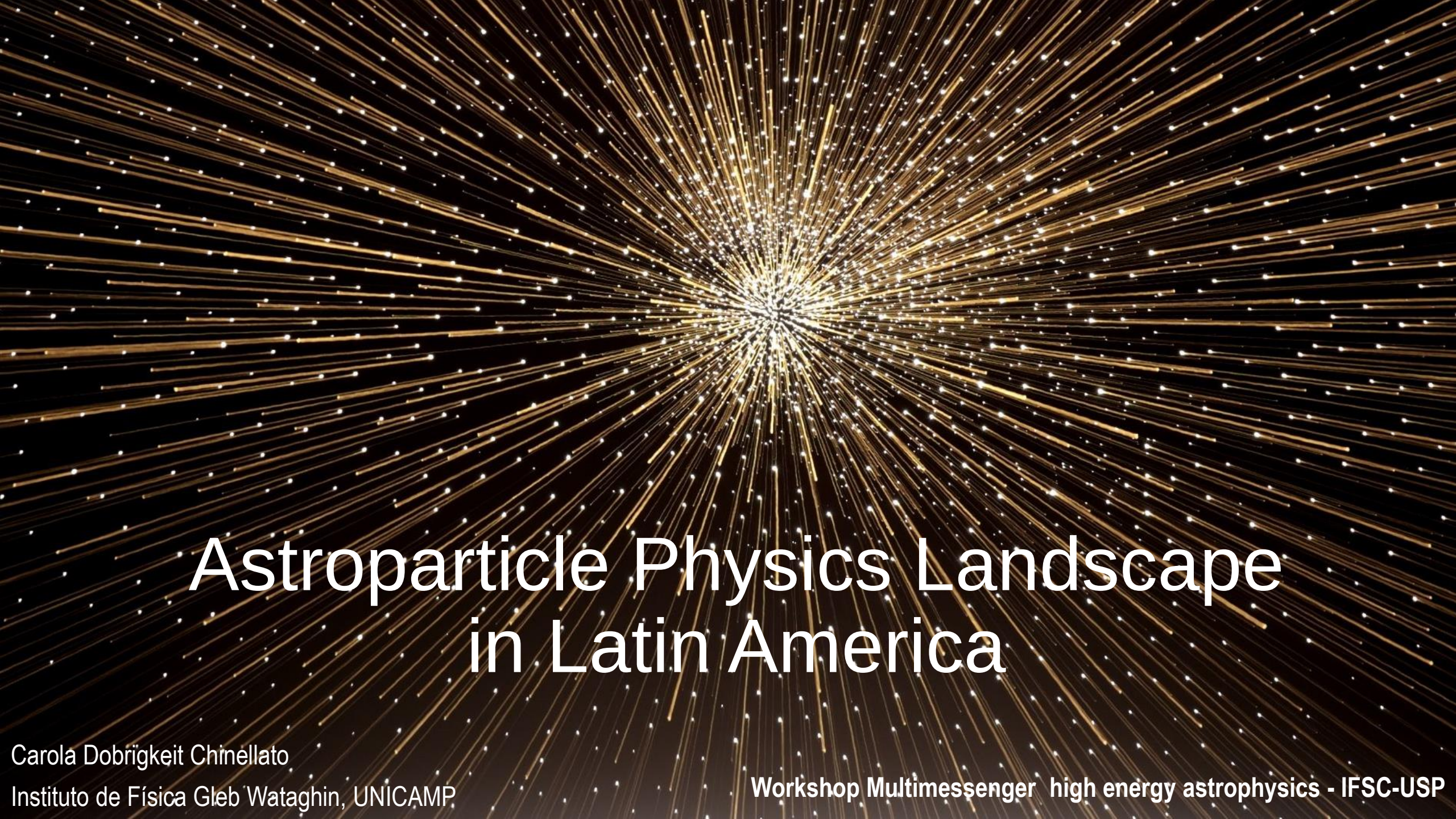
- Argentina
- Bolivia
- Peru
- Mexico

LAGO

Latin American Giant Observatory

involving scientist from nine countries: Argentina, Bolivia, Brazil, Colombia, Ecuador, Guatemala, Mexico, Peru, and Venezuela.





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A glimpse into
Astroparticle Physics Landscape
worldwide and in Latin America
CLAF MCTI 2023

Which particles are we talking about?

- Ultrahigh-energy cosmic rays, primarily atomic nuclei
- High-energy gamma-rays
- High-energy neutrinos
- Other unknown objects?

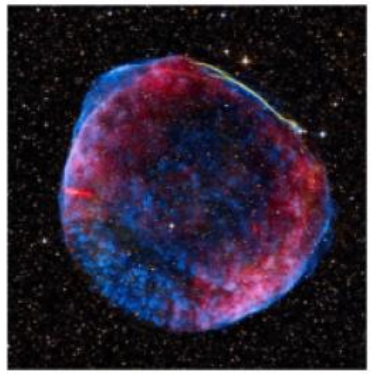
Which questions we address?

- How are these UHE particles created/ accelerated?
- How do they propagate through the Universe?
- Which are the violent phenomena and extreme environments at their sources?
- What do we learn from their HE interactions?

Which questions we address?

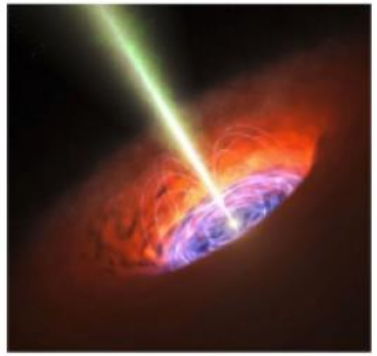
COSMIC PARTICLE ACCELERATION

- How and where are particles accelerated?
- How do they propagate?
- What is their impact on the environment?



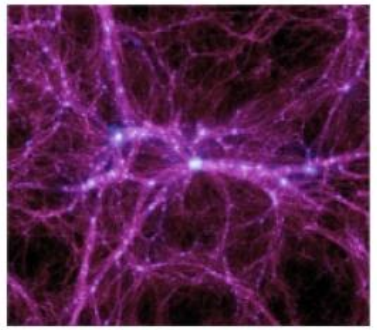
PROBING EXTREME ENVIRONMENTS

- Close to neutron stars and black holes
- Relativistic jets, winds and explosions
- Cosmic voids



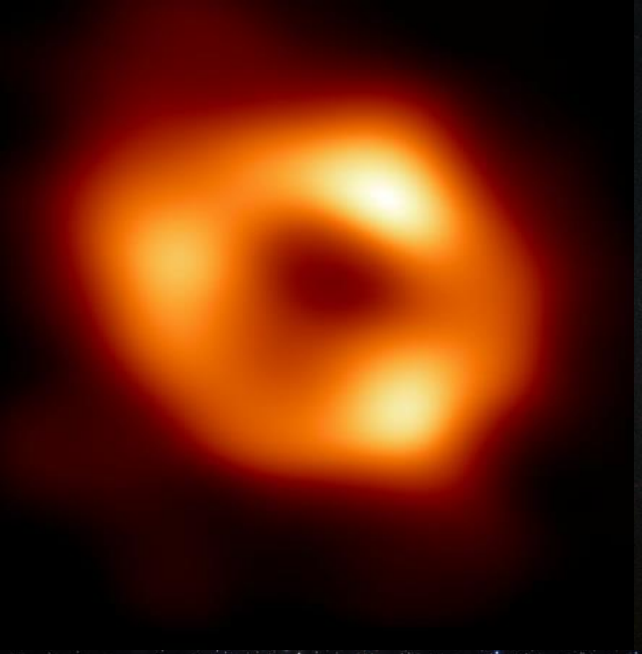
PHYSICS FRONTIERS

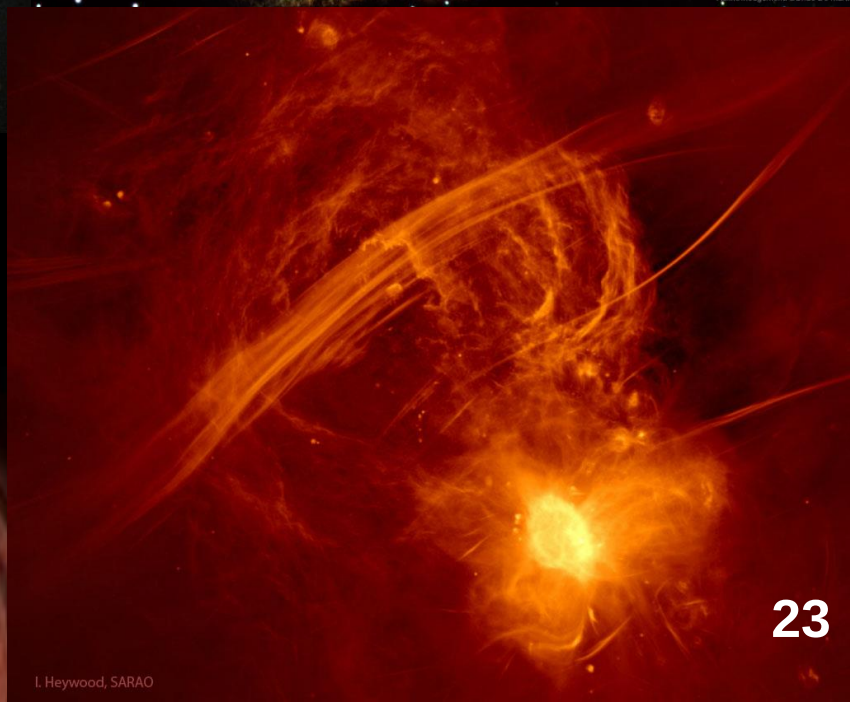
- What is the nature of Dark Matter?
- Is the speed of light a constant?
- Do axion-like particles exist?

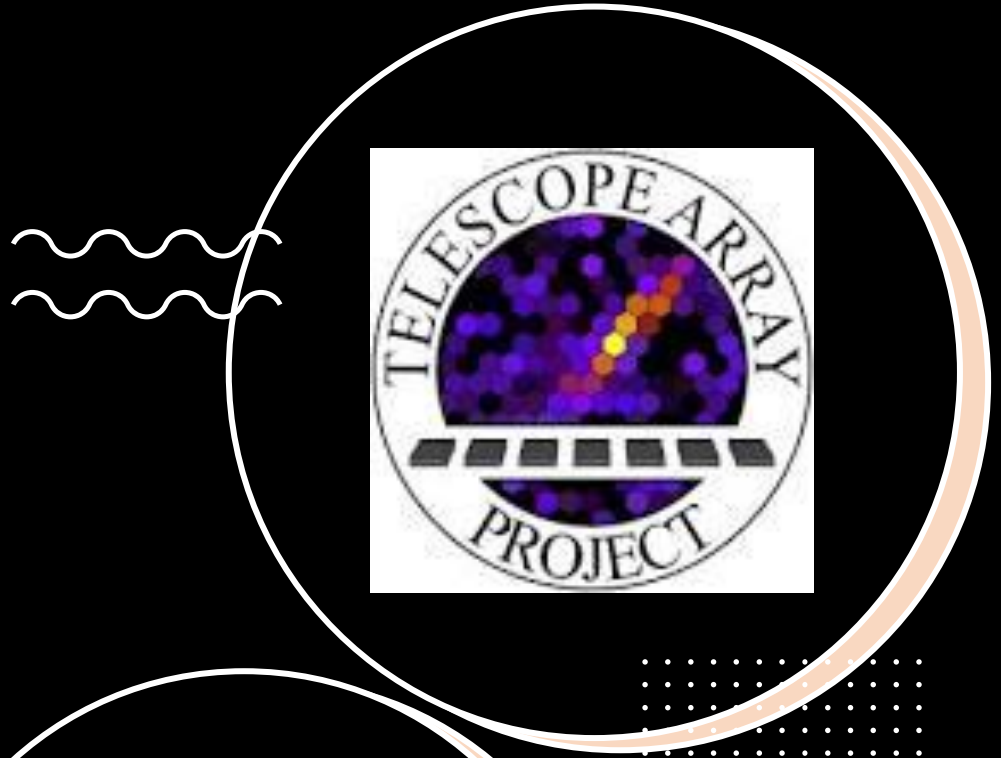


Courtesy Prof. Vitor de Souza

Where are their sources?

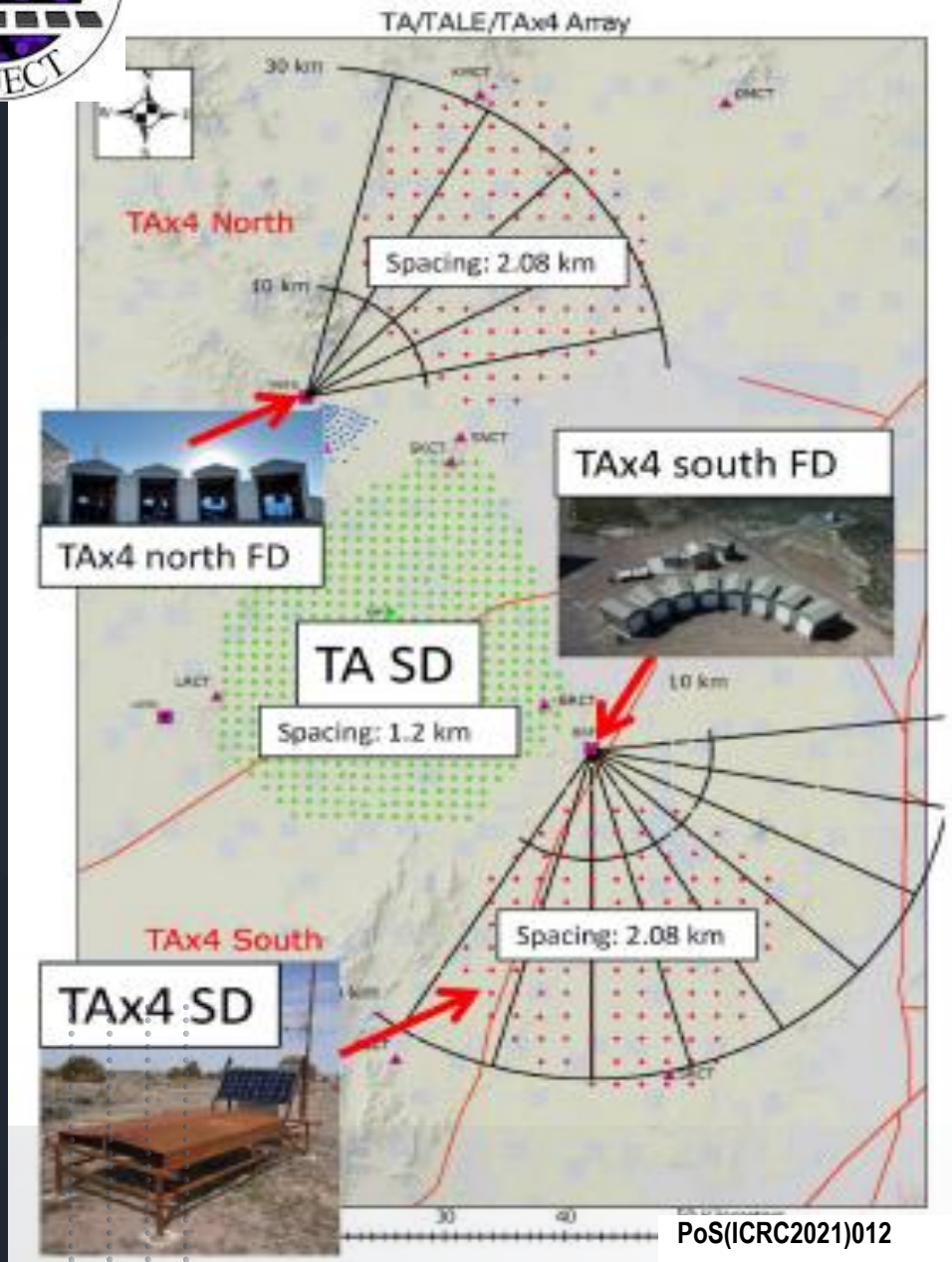




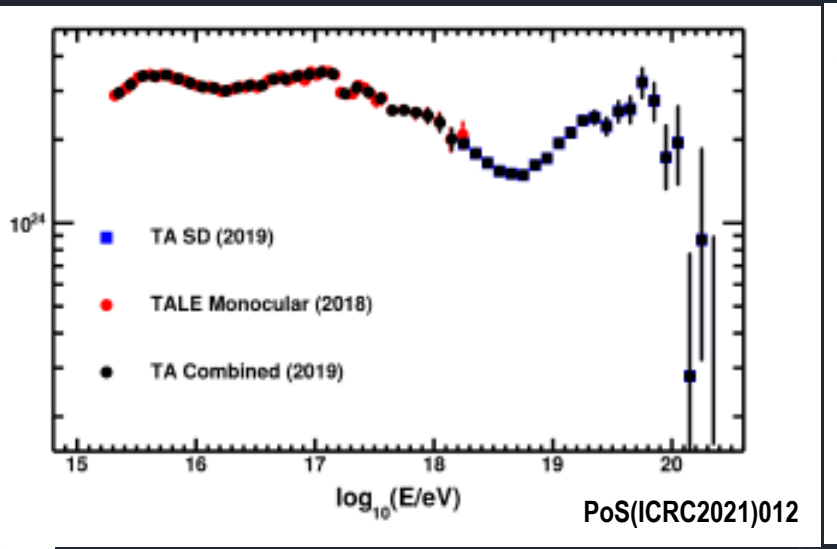


- Ultrahigh- energy cosmic rays above 10^{17} eV

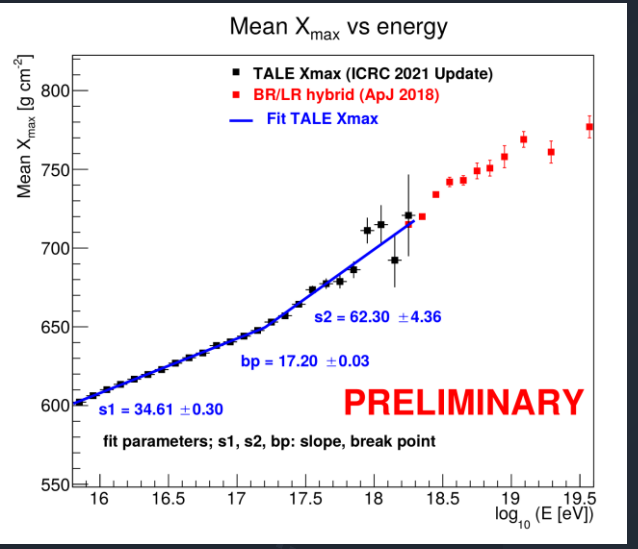
Telescope Array

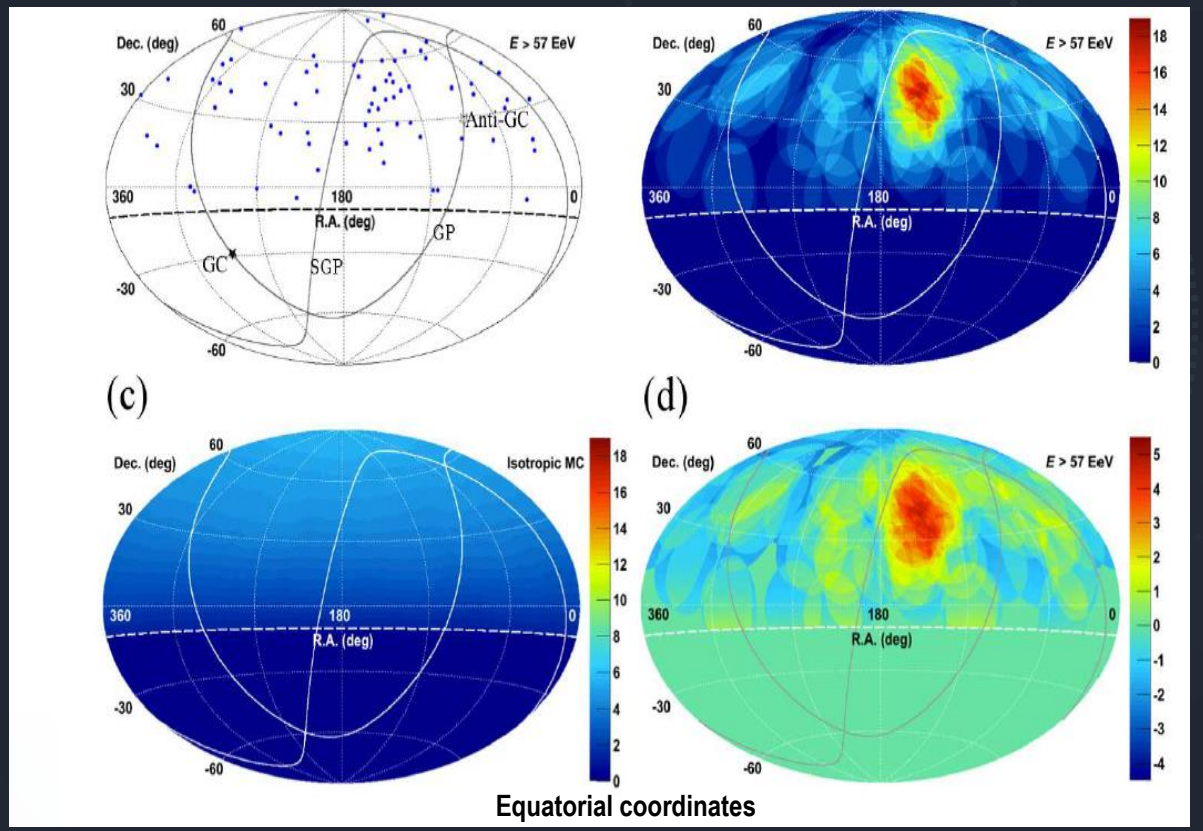


PoS(ICRC2021)012



PoS(ICRC2021)012

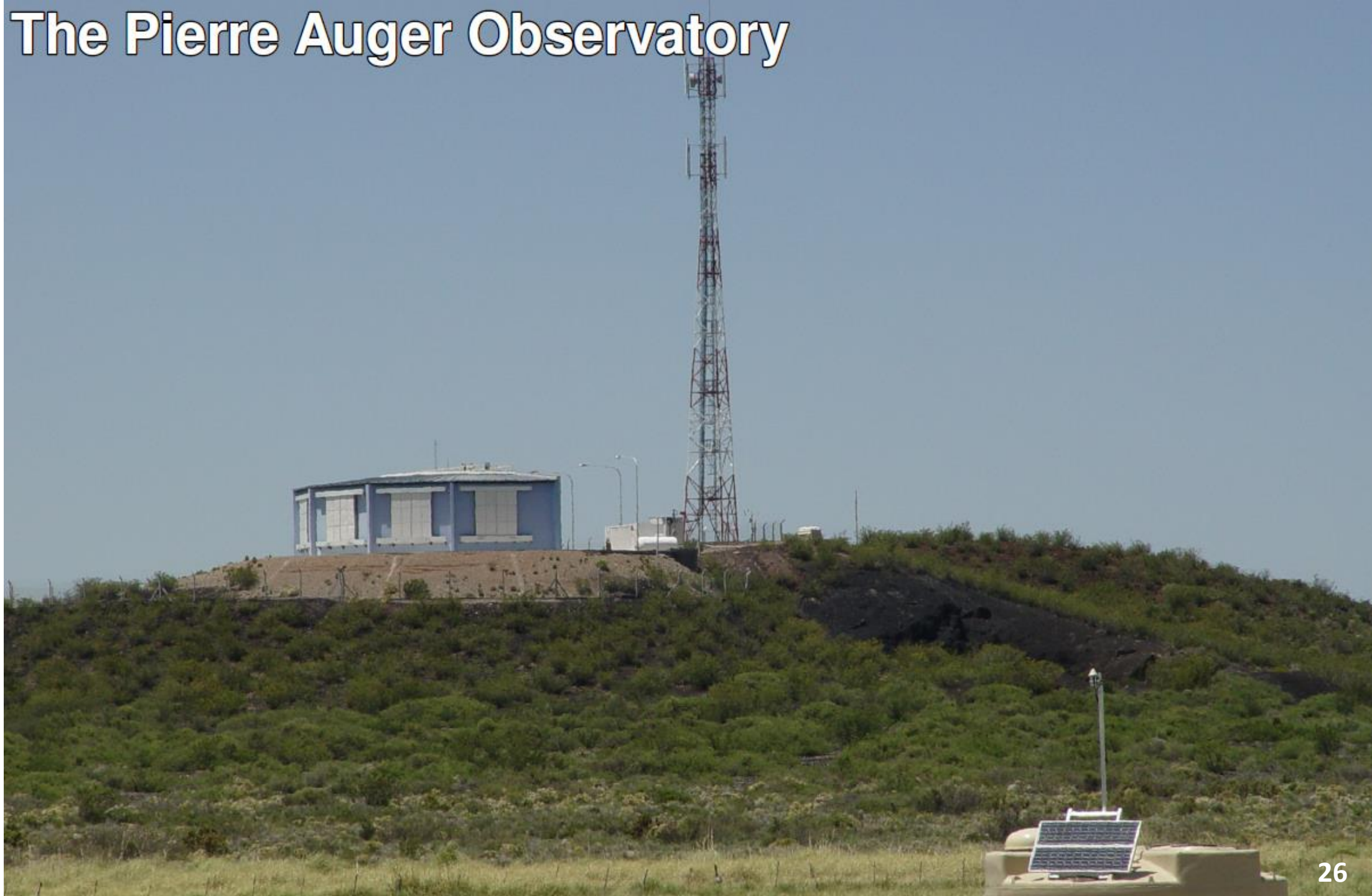


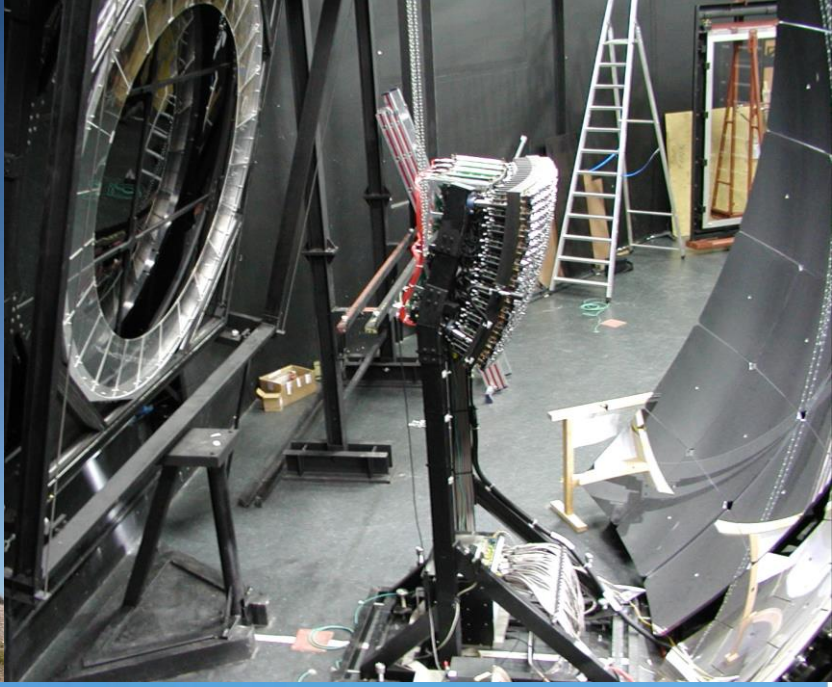


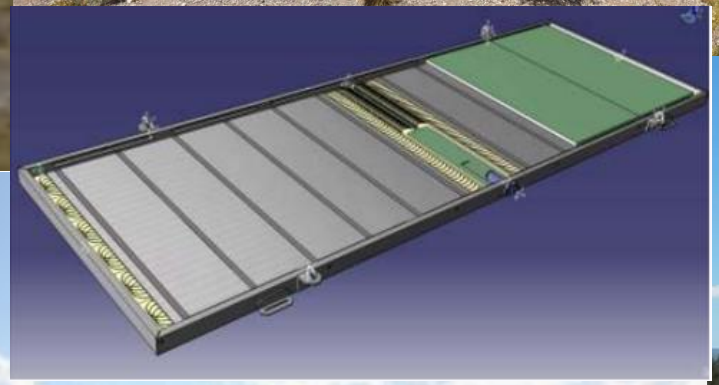
Equatorial coordinates

The Astrophysical Journal Letters, 790:L21 2014

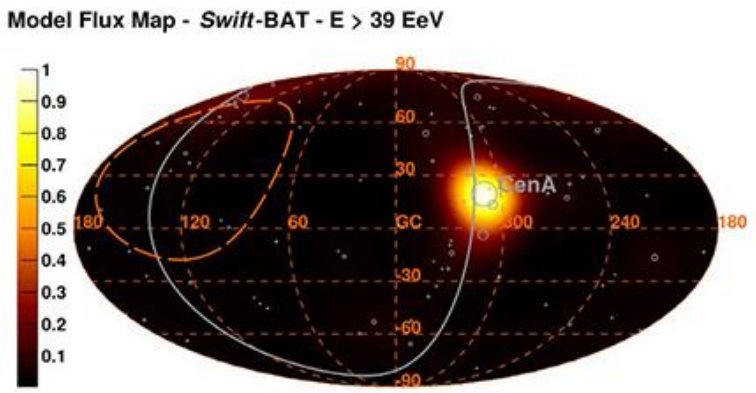
The Pierre Auger Observatory

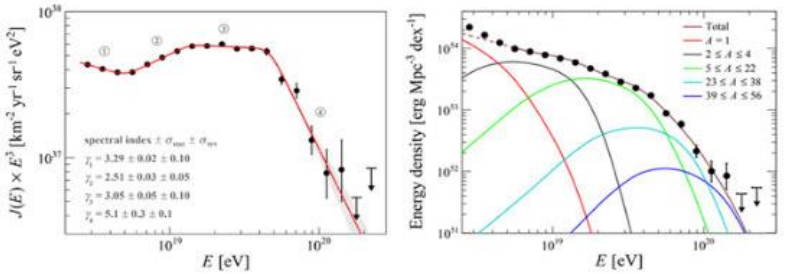


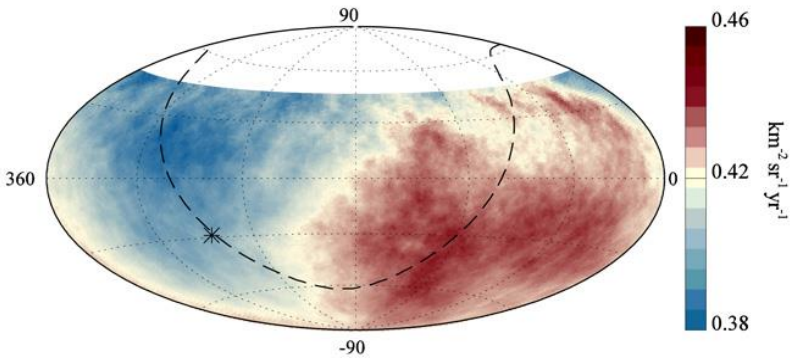


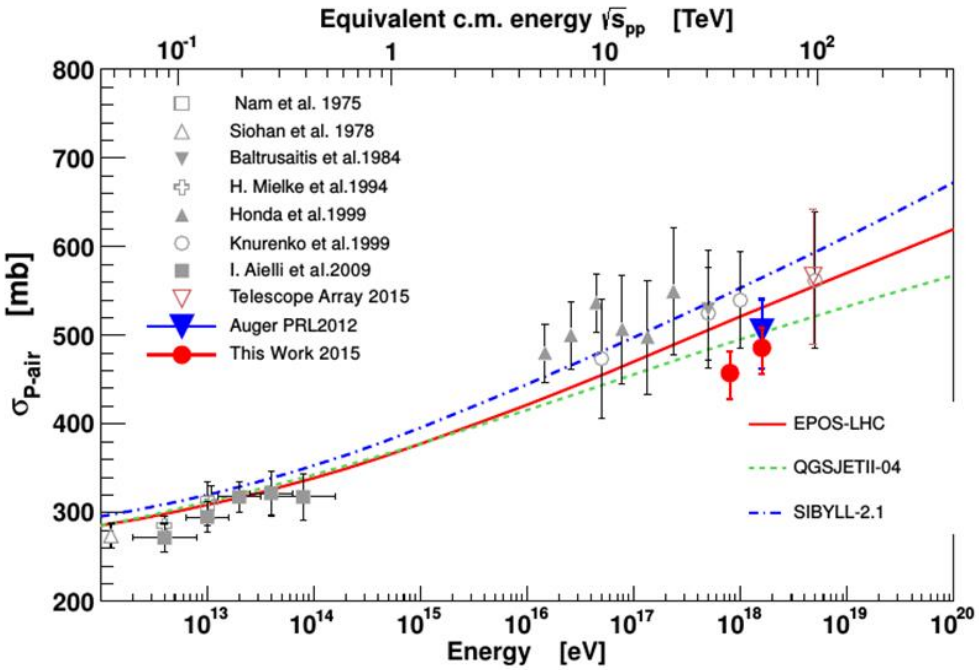


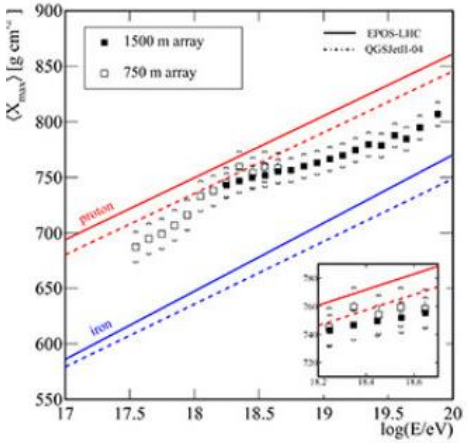

TRAK

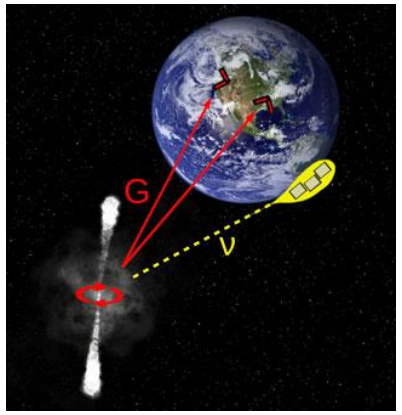

Model Flux Map - Swift-BAT - E > 39 EeV
CenA
GC

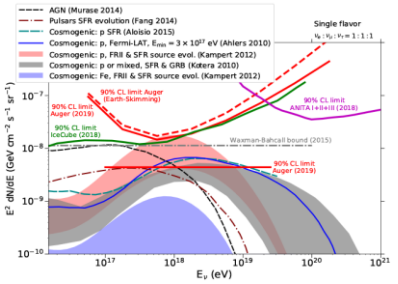

spectral index ± σstat ± σsys
E [eV]
Energy density [erg Mpc-3 dex-1]
Total

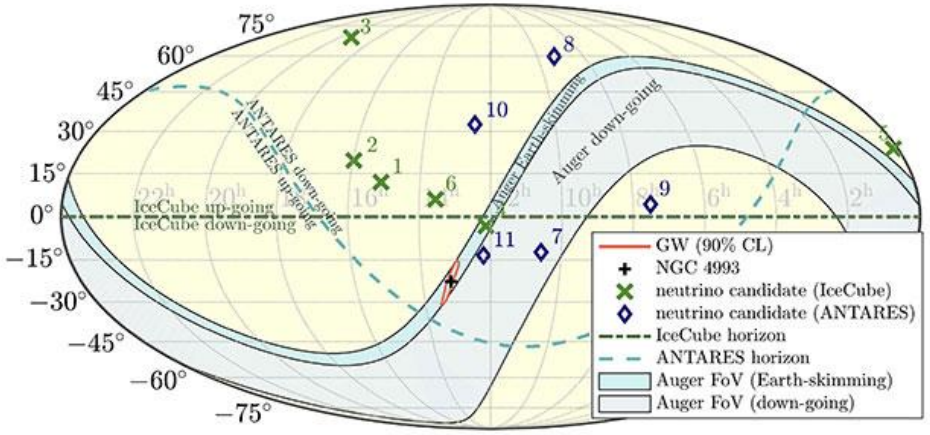

km-2 sr-1 yr-1


Equivalent c.m. energy √spp [TeV]
Nam et al. 1975
Siohan et al. 1978
Baltrusaitis et al.1984
H. Mielke et al.1994
Honda et al.1999
Knurenko et al.1999
I. Aielli et al.2009
Telescope Array 2015
Auger PRL2012
This Work 2015
EPOS-LHC
QGSJETII-04
SIBYLL-2.1
σP-air [mb]
Energy [eV]


1500 m array
750 m array
EPOS-LHC
QGSJetII-04
proton
iron
log(E/eV)

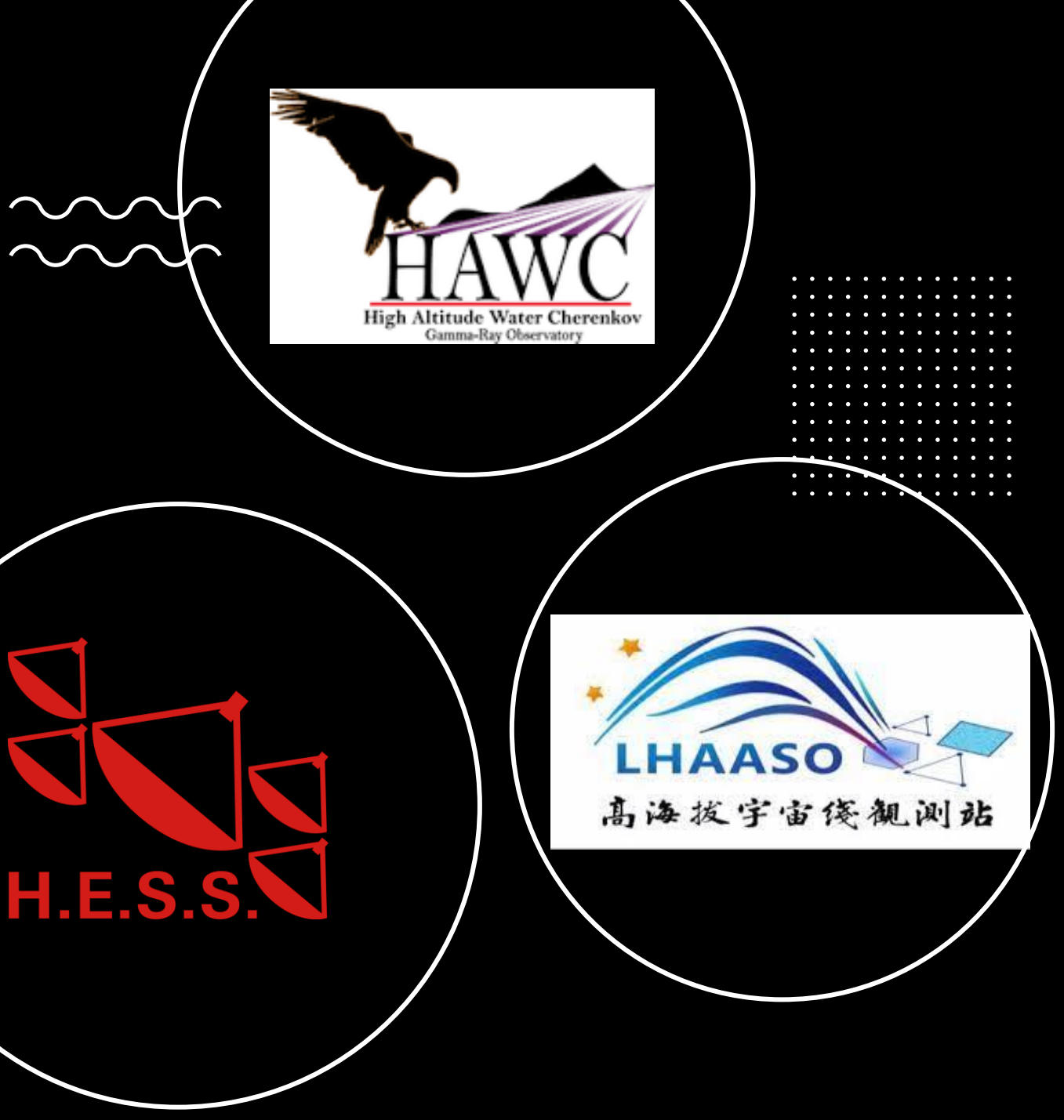

G
ν


Single flavor
Eν (eV)


IceCube up-going
IceCube down-going
ANTARES up-going
ANTARES down-going
Auger down-going
GW (90% CL)
NGC 4993
neutrino candidate (IceCube)
neutrino candidate (ANTARES)
IceCube horizon
ANTARES horizon
Auger FoV (Earth-skimming)
Auger FoV (down-going)

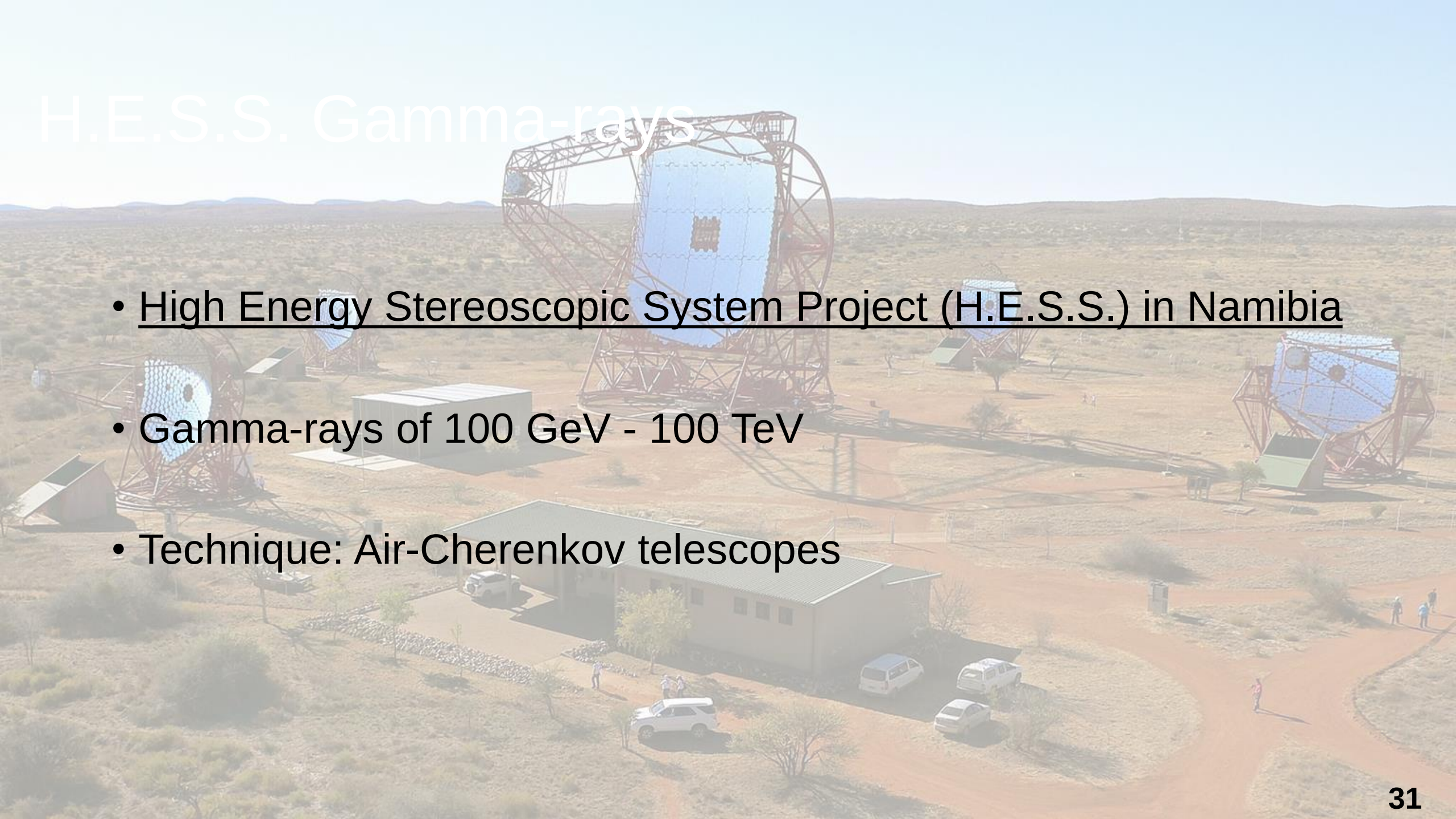
Highlights of UHE Cosmic-Ray Physics

- **Energy spectrum and flux suppression at the highest energies**
- **Measuring proton-air cross section at $\sqrt{s} \cong 57\ \mathrm{TeV}$**
- **Tests of hadronic-interaction models**
- **Investigating air showers with an excess of muons**
- **Challenging level of isotropy with a dipole**
- **Targeted search for neutron and gamma-ray sources**
- **Upper limits on neutrino flux**
- **Neutrinos/photons in coincidence with gravitational waves**
- **Radio signal from air-showers**
- **Atmospheric Science**
- **Upper limits for magnetic monopoles**
- **Tests of exotic scenarios**
- **Unexpected mass composition**



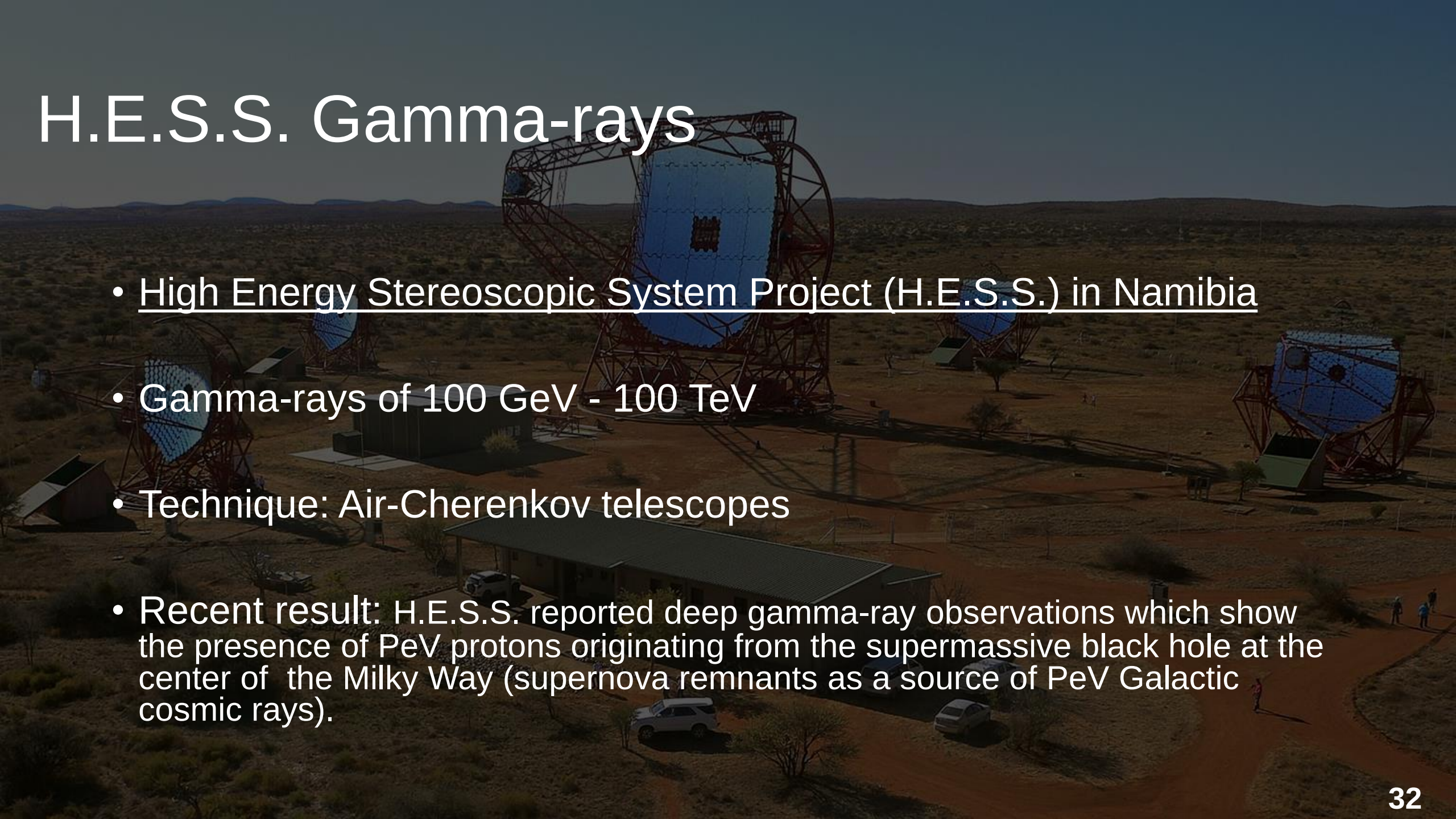
- Ultrahigh- energy gamma-rays of GeV → TeV → PeV

H.E.S.S. Gamma-rays

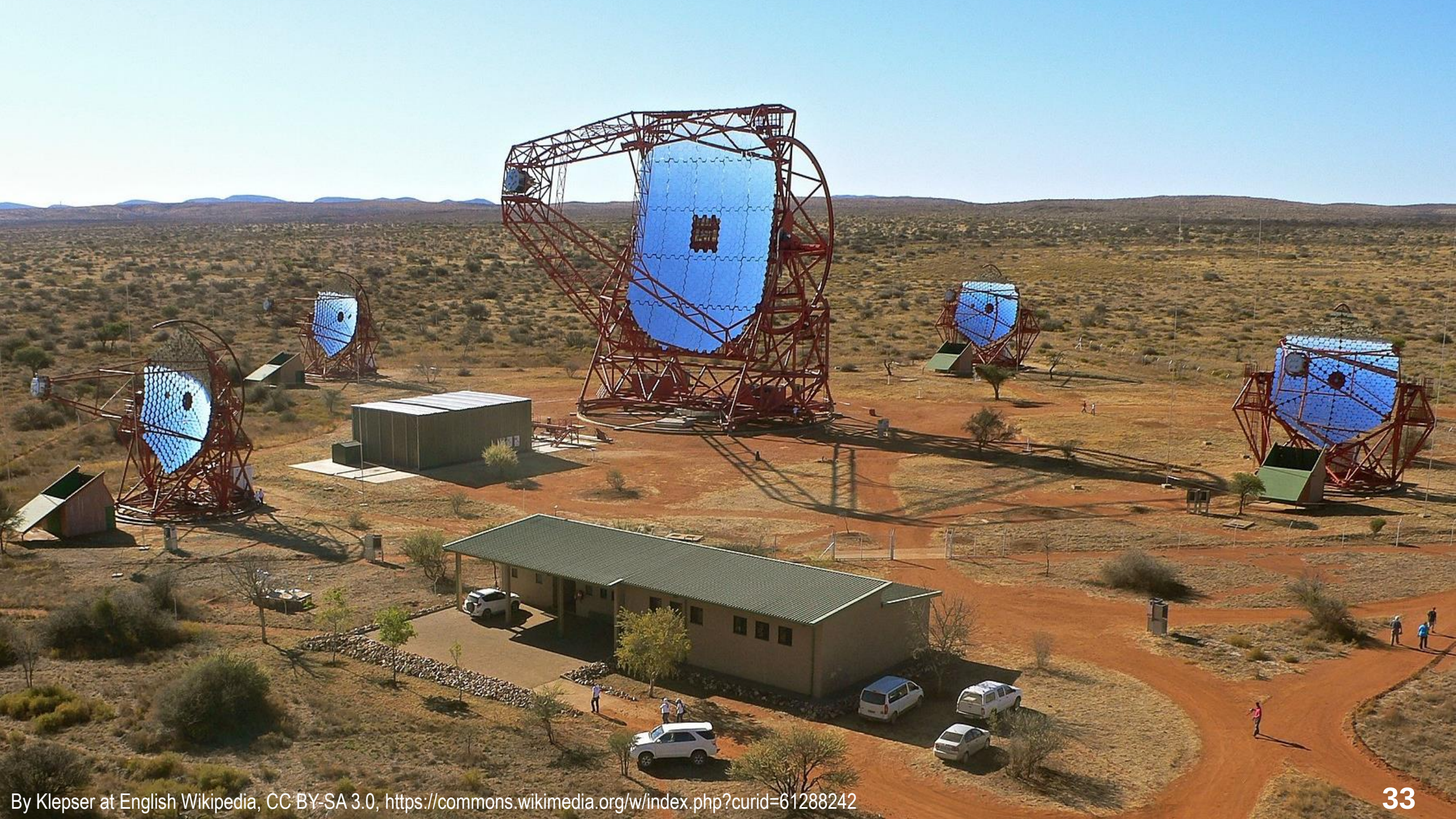


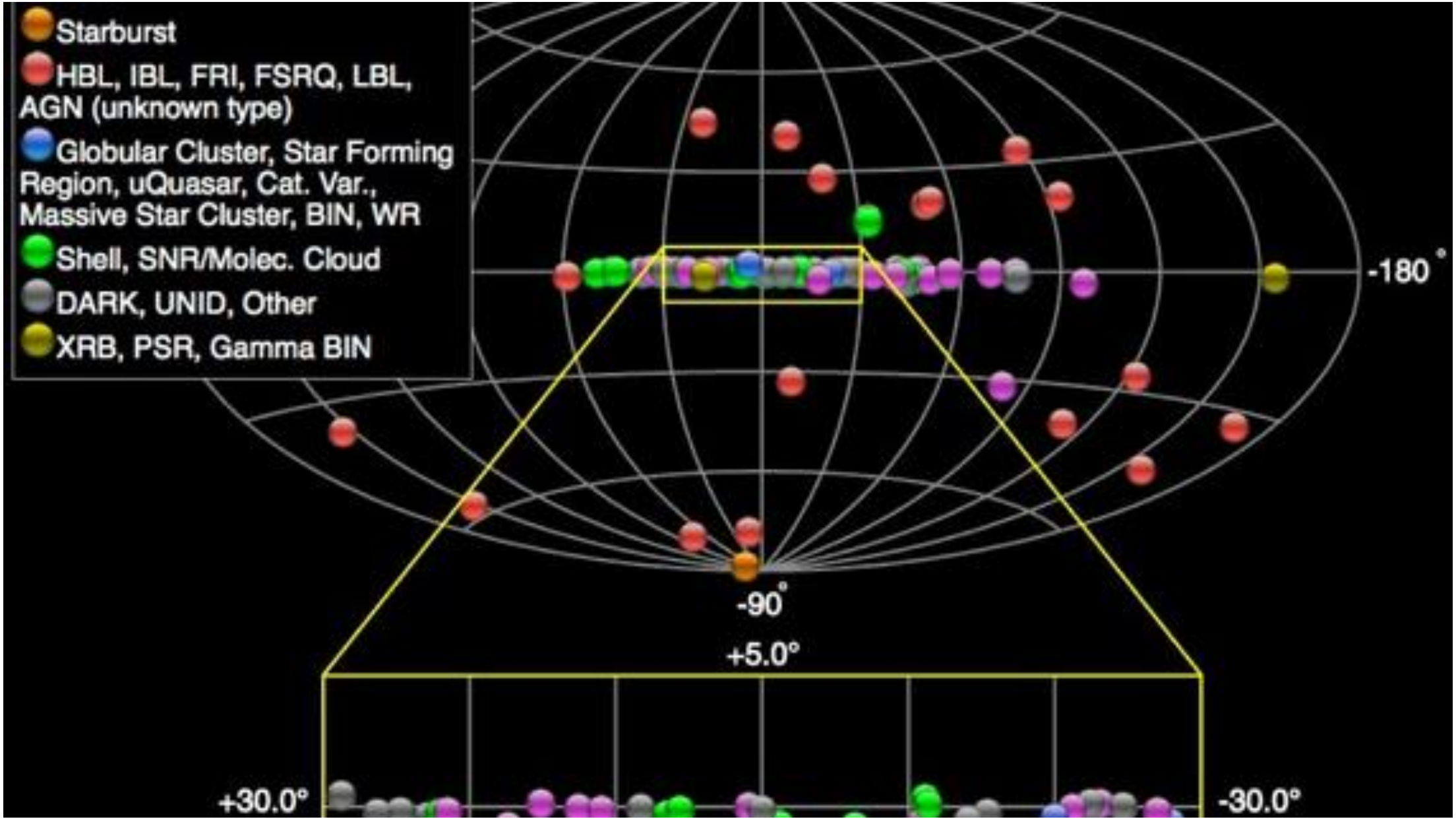
- High Energy Stereoscopic System Project (H.E.S.S.) in Namibia
- Gamma-rays of 100 GeV - 100 TeV
- Technique: Air-Cherenkov telescopes

H.E.S.S. Gamma-rays



- High Energy Stereoscopic System Project (H.E.S.S.) in Namibia
- Gamma-rays of 100 GeV - 100 TeV
- Technique: Air-Cherenkov telescopes
- Recent result: H.E.S.S. reported deep gamma-ray observations which show the presence of PeV protons originating from the supermassive black hole at the center of the Milky Way (supernova remnants as a source of PeV Galactic cosmic rays).



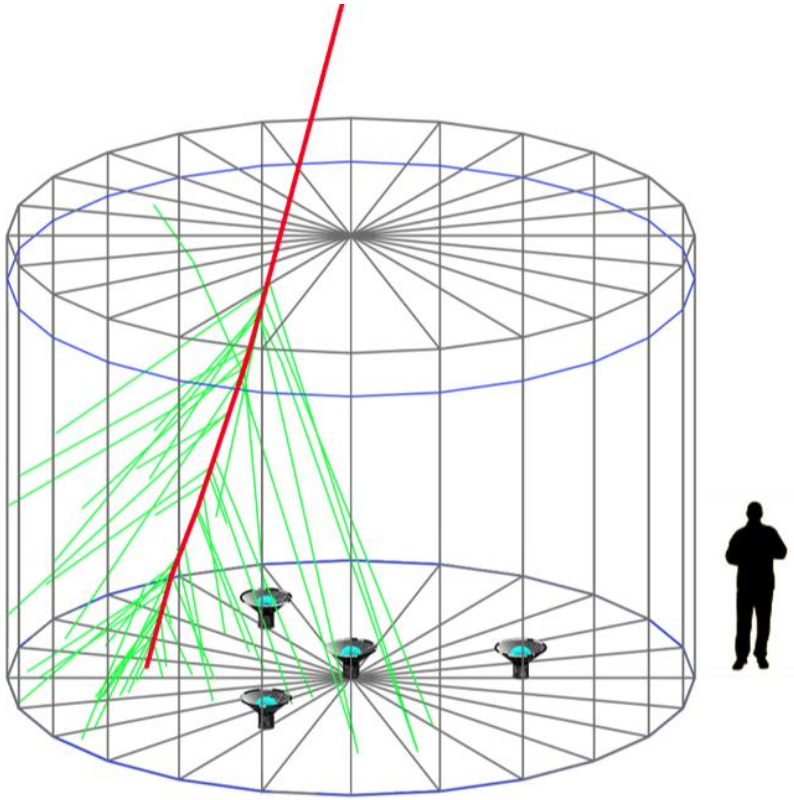


Very High Energy Gamma Ray Sources detected by H.E.S.S. (still 2012)

Very High Energy Gamma Ray Sources detected by H.E.S.S.

HAWC - The High-Altitude Water Cherenkov Experiment

The High-Altitude Water Cherenkov Experiment

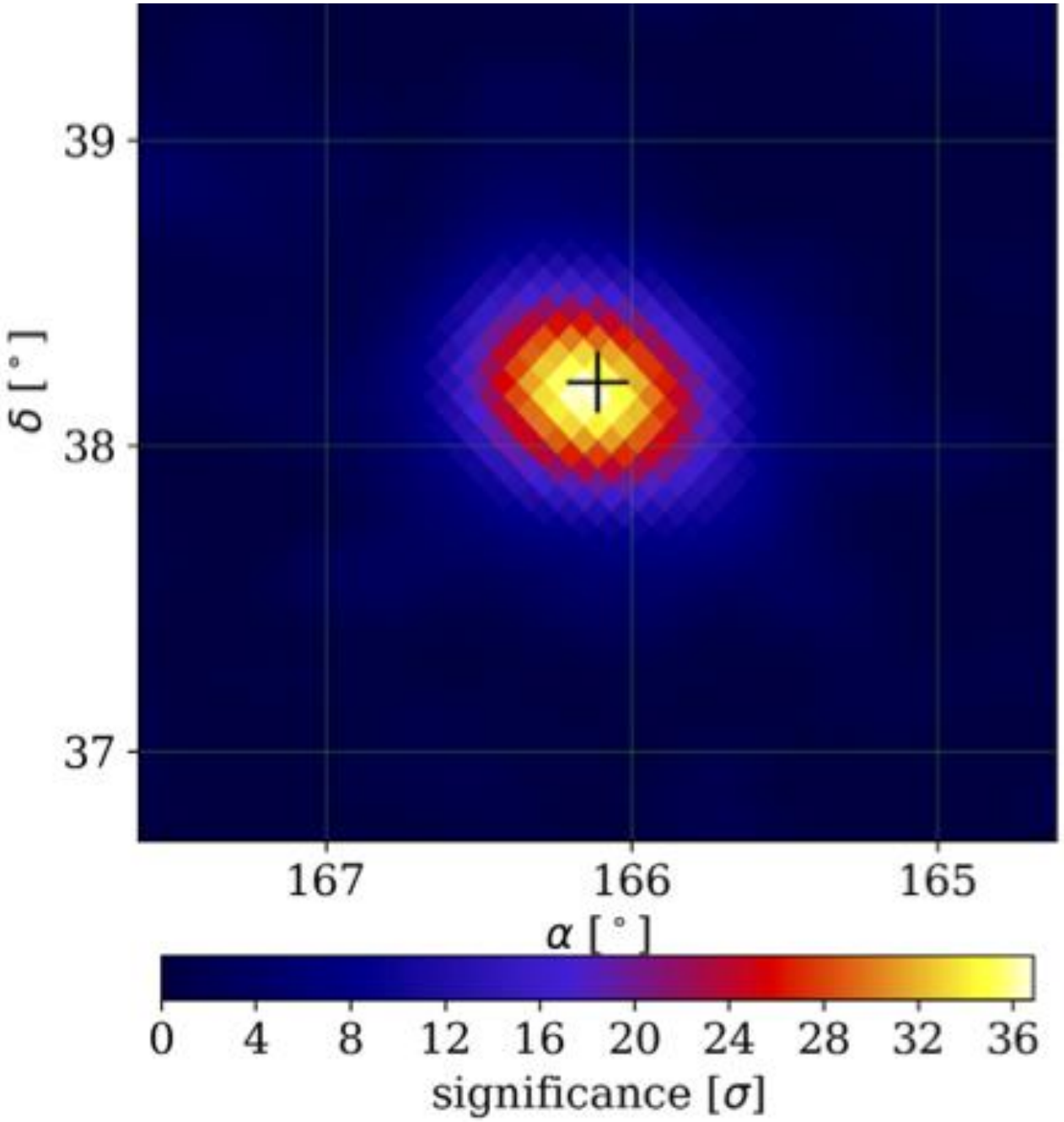


By HAWC Collaboration - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=35125676

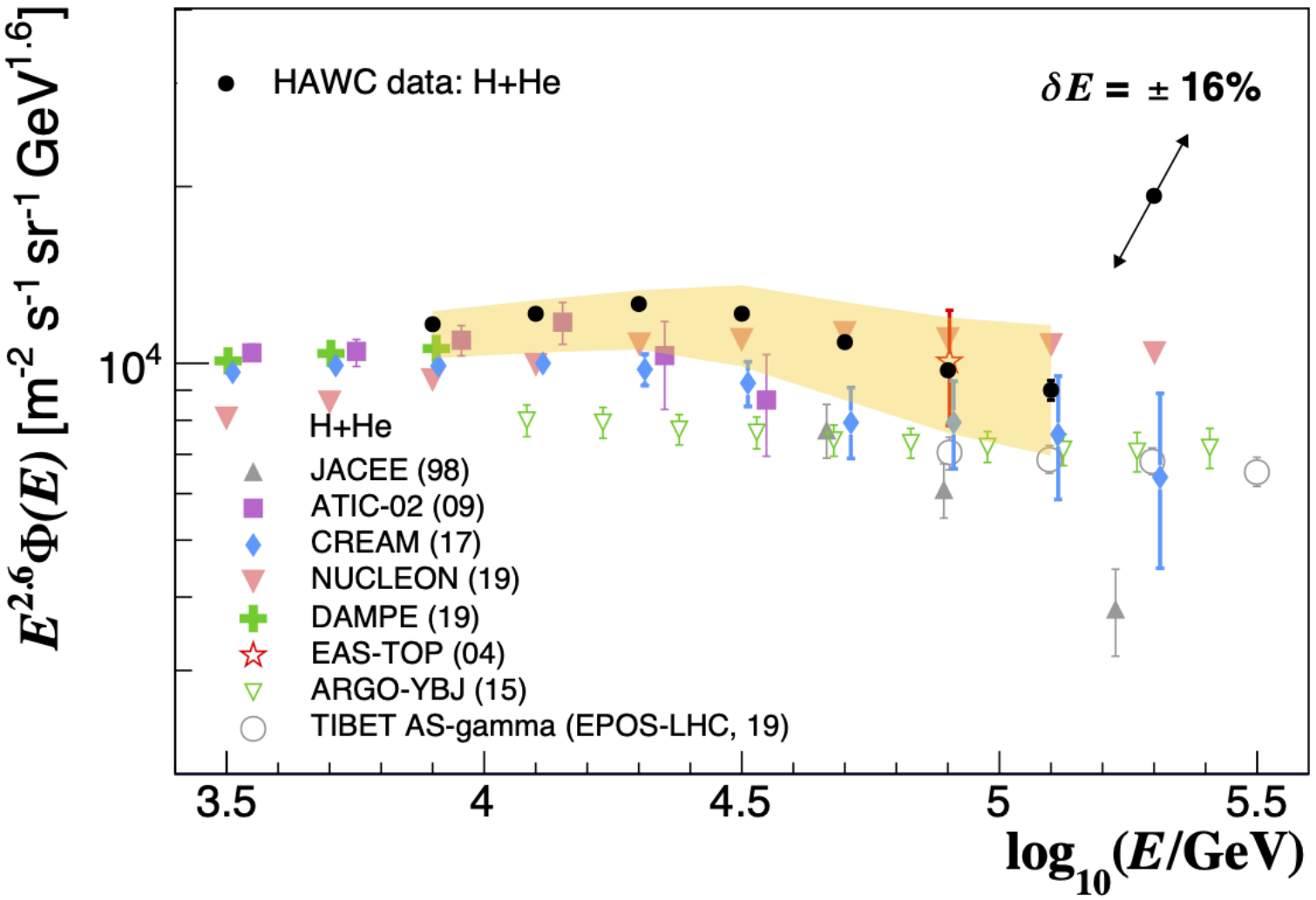
HAWC is a gamma-ray and cosmic-ray observatory in the state of Puebla, in Mexico, at an altitude of 4100 meters.

Technique: Altitude particle arrays detecting gamma-rays indirectly using the water-Cherenkov method.

Science goals: HE Galactic sources, Galactic diffuse emission, Transient emission from AGN and the Crab, Gamma-ray bursts, Cosmic rays at TeV energies, fundamental physics (LIV, dark matter)

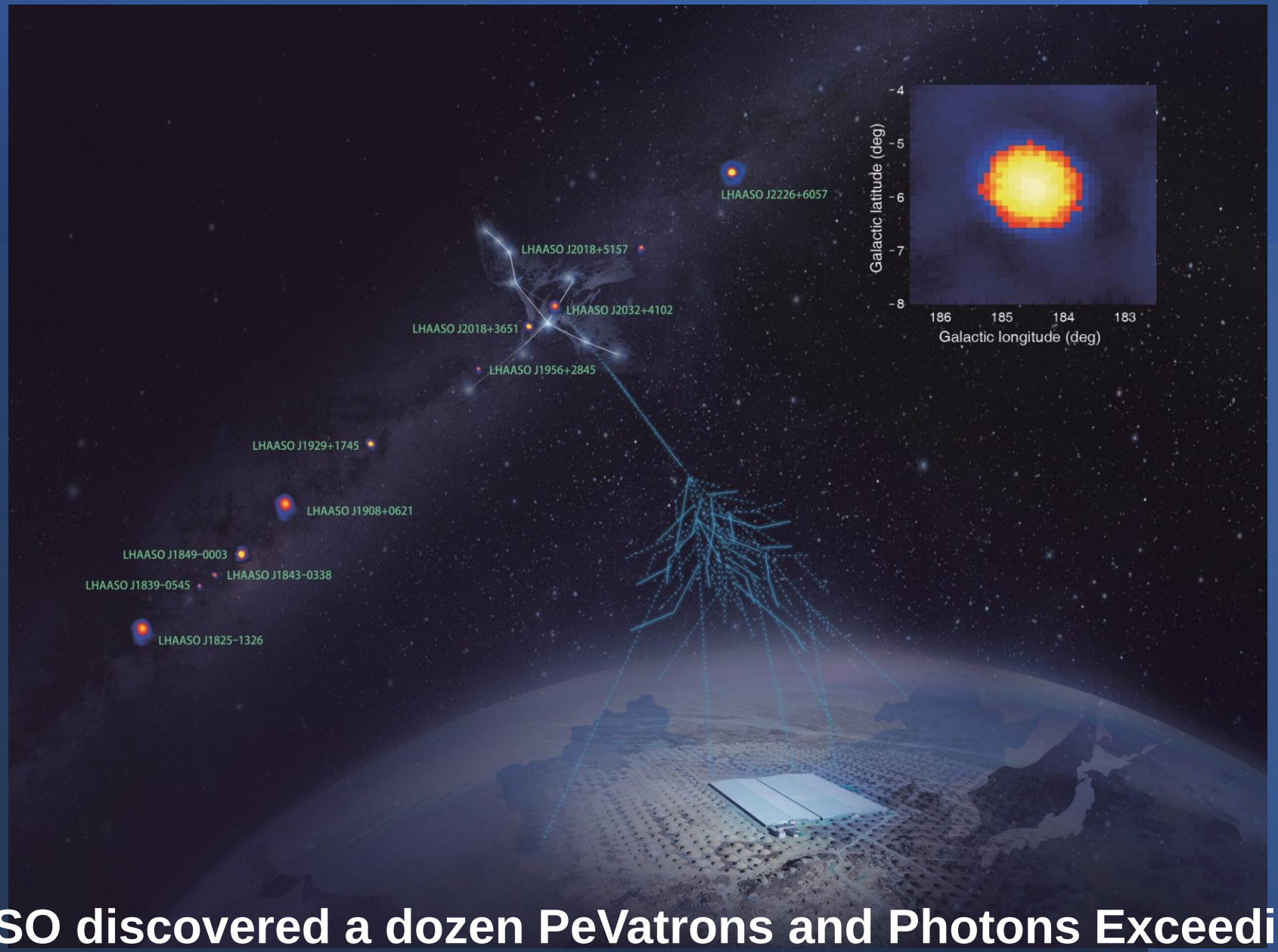


Recent HAWC results (2022): detection of gamma rays coming from the central zone of the galaxies Mrk 421 and Mrk 501

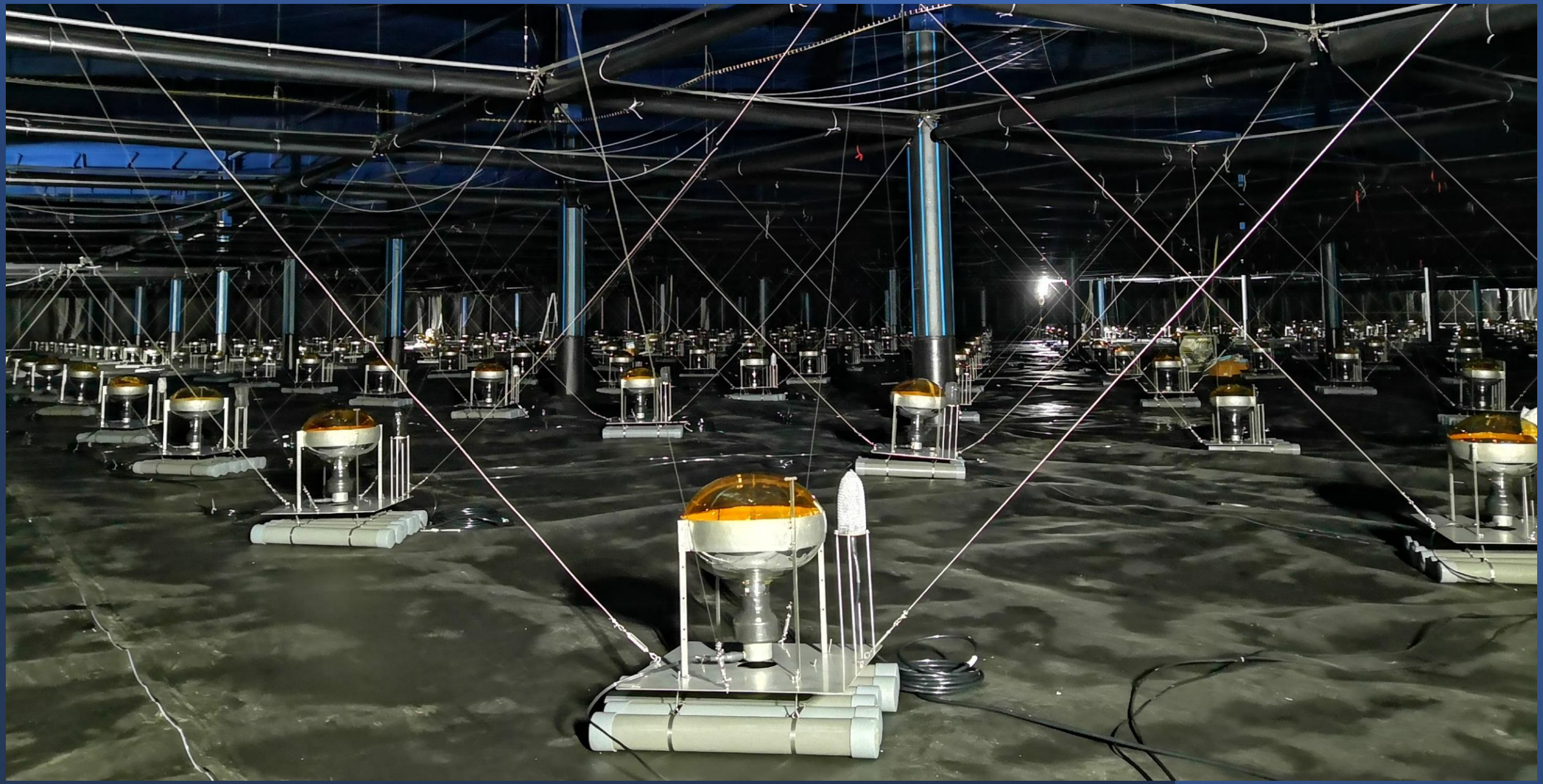


Recent HAWC results (2022): the cosmic ray energy spectrum of protons plus helium at high energies

Large High Altitude Air Shower Observatory
Sichuan, China, 4410 m a.s.l.



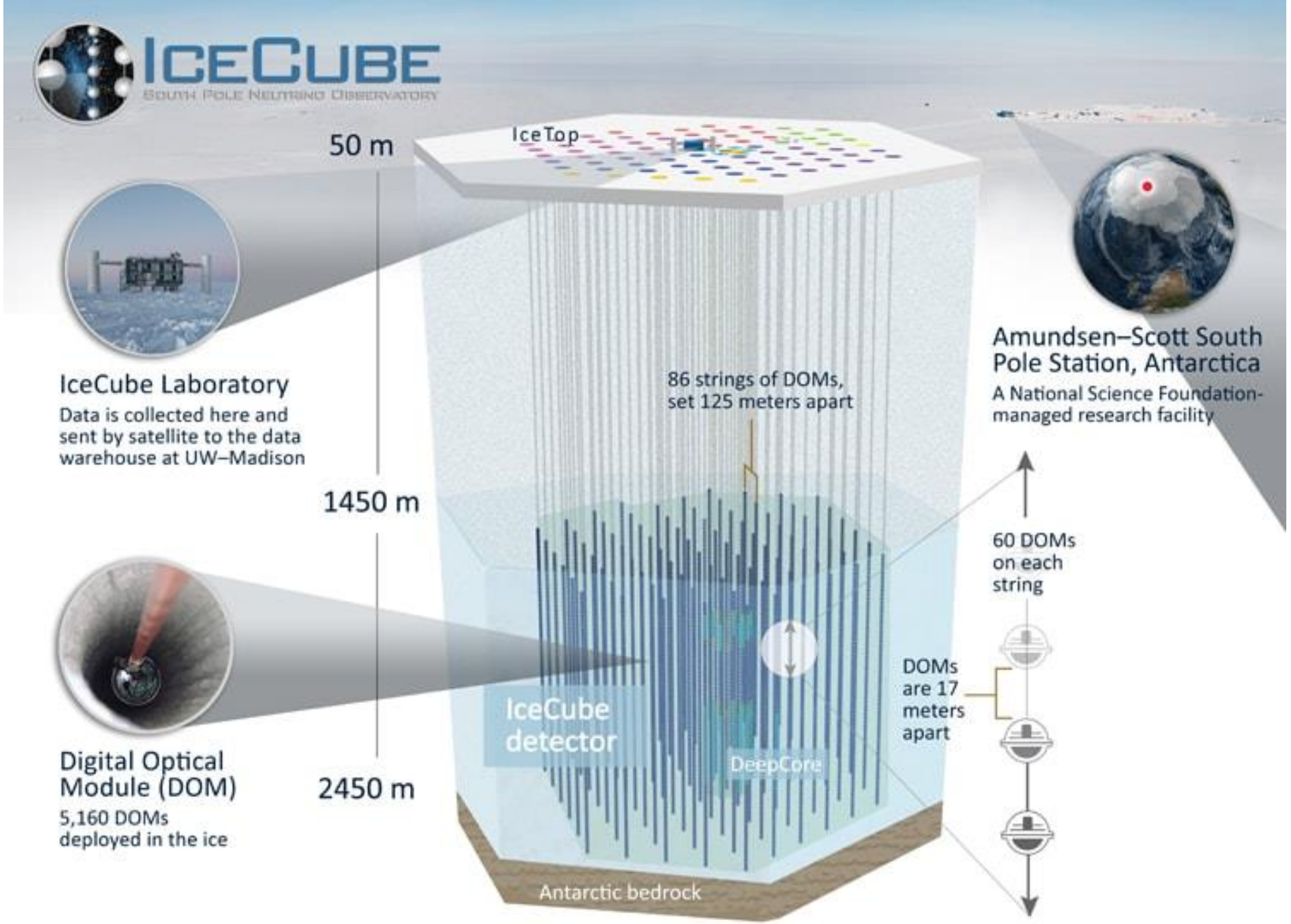
LHAASO discovered a dozen PeVatrons and Photons Exceeding 1 PeV and launches UHE Gamma Astronomy Era



- Ultrahigh- energy neutrinos

Facing a few difficulties in the ice…

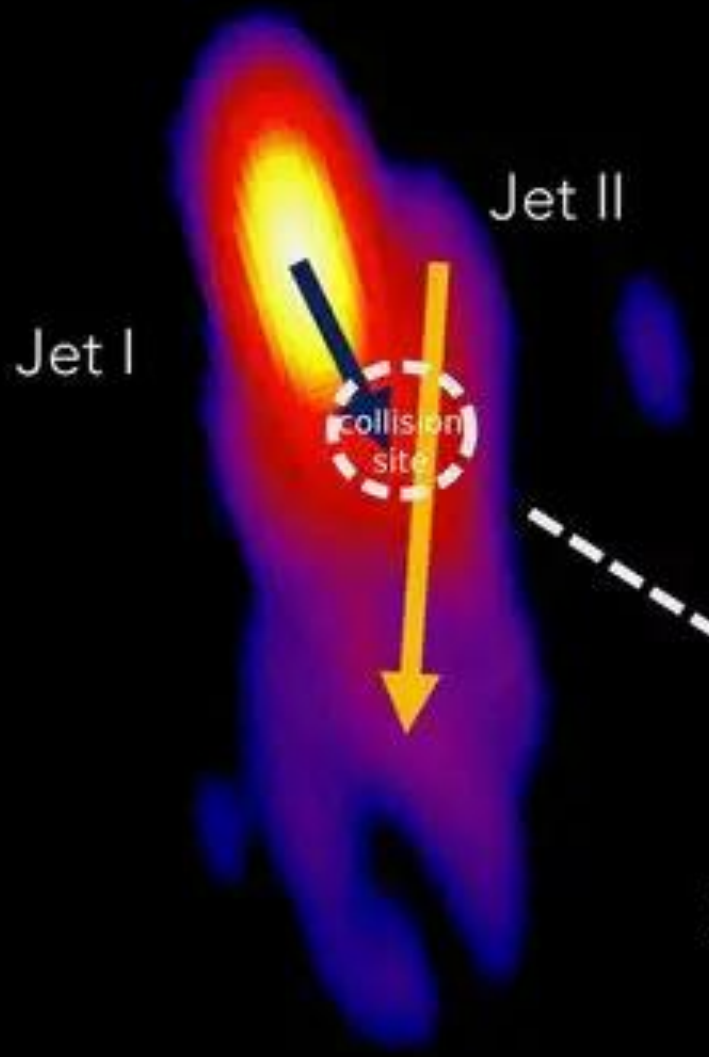
Facing a few difficulties in the ice...


IceCube
South Pole Neutrino Observatory
50 m
IceTop
IceCube Laboratory
Data is collected here and sent by satellite to the data warehouse at UW–Madison
1450 m
86 strings of DOMs, set 125 meters apart
Amundsen–Scott South Pole Station, Antarctica
A National Science Foundation-managed research facility
60 DOMs on each string
DOMs are 17 meters apart
IceCube detector
DeepCore
Digital Optical Module (DOM)
5,160 DOMs deployed in the ice
2450 m
Antarctic bedrock

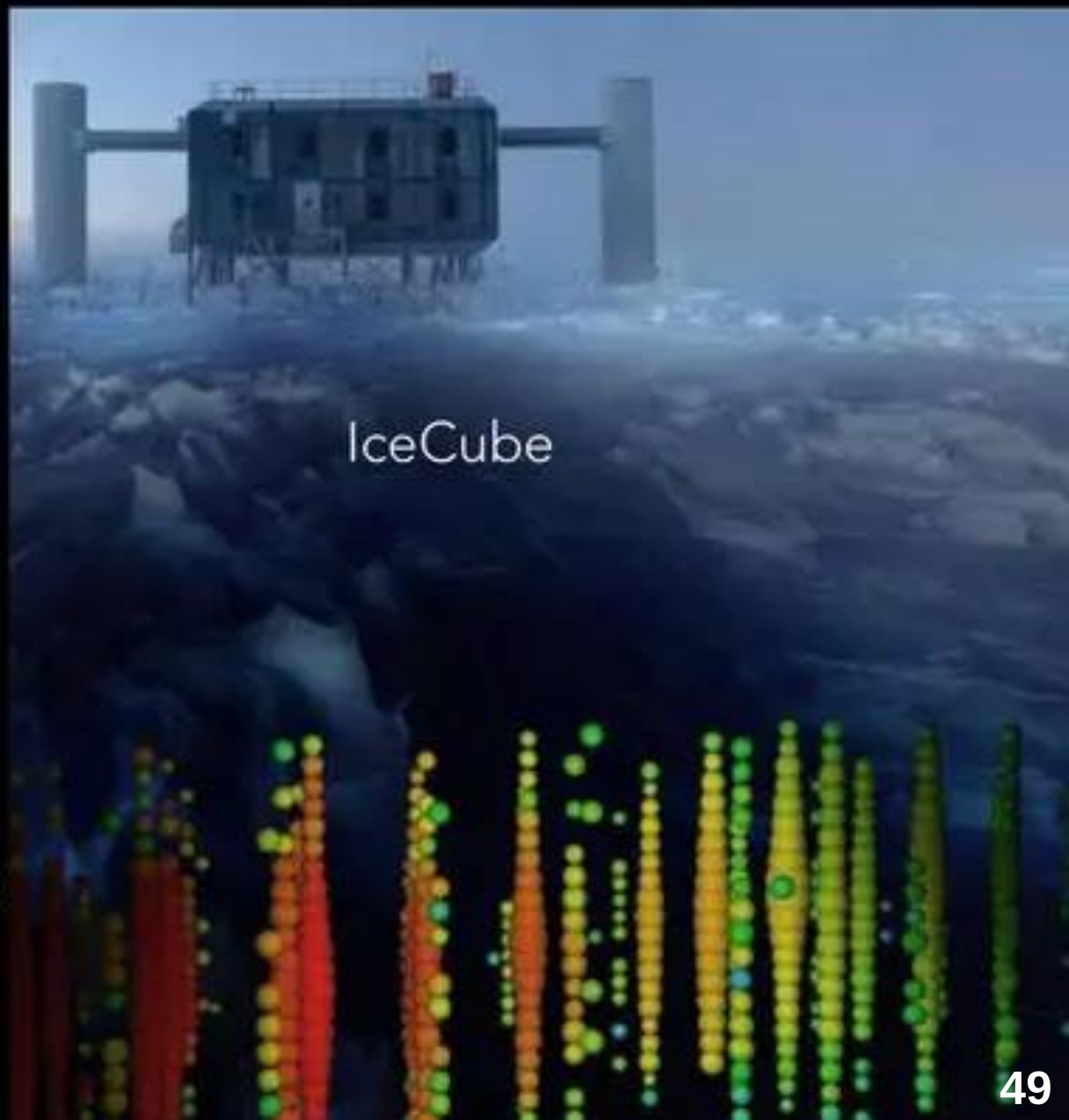
The dawn of the astroparticle multimessenger era

- Detection of cosmic neutrinos of ~10^{15} eV in 2013 by IceCube.
- In 2017, it was possible to simultaneously detect extremely energetic neutrinos by IceCube and gamma-ray flares of a blazar detected by the Fermi LAT and MAGIC telescopes to identify a potential source of UHE neutrinos and, therefore, a possible source of cosmic rays.
- This font has been associated with the blazar TXS 0506+056, 5,708 billion light years away from us. A blazar is a giant, very active elliptical galaxy. It has a supermassive black hole at its center that spins rapidly and emits two opposing jets of light and elementary particles. One of the jets points directly at Earth.

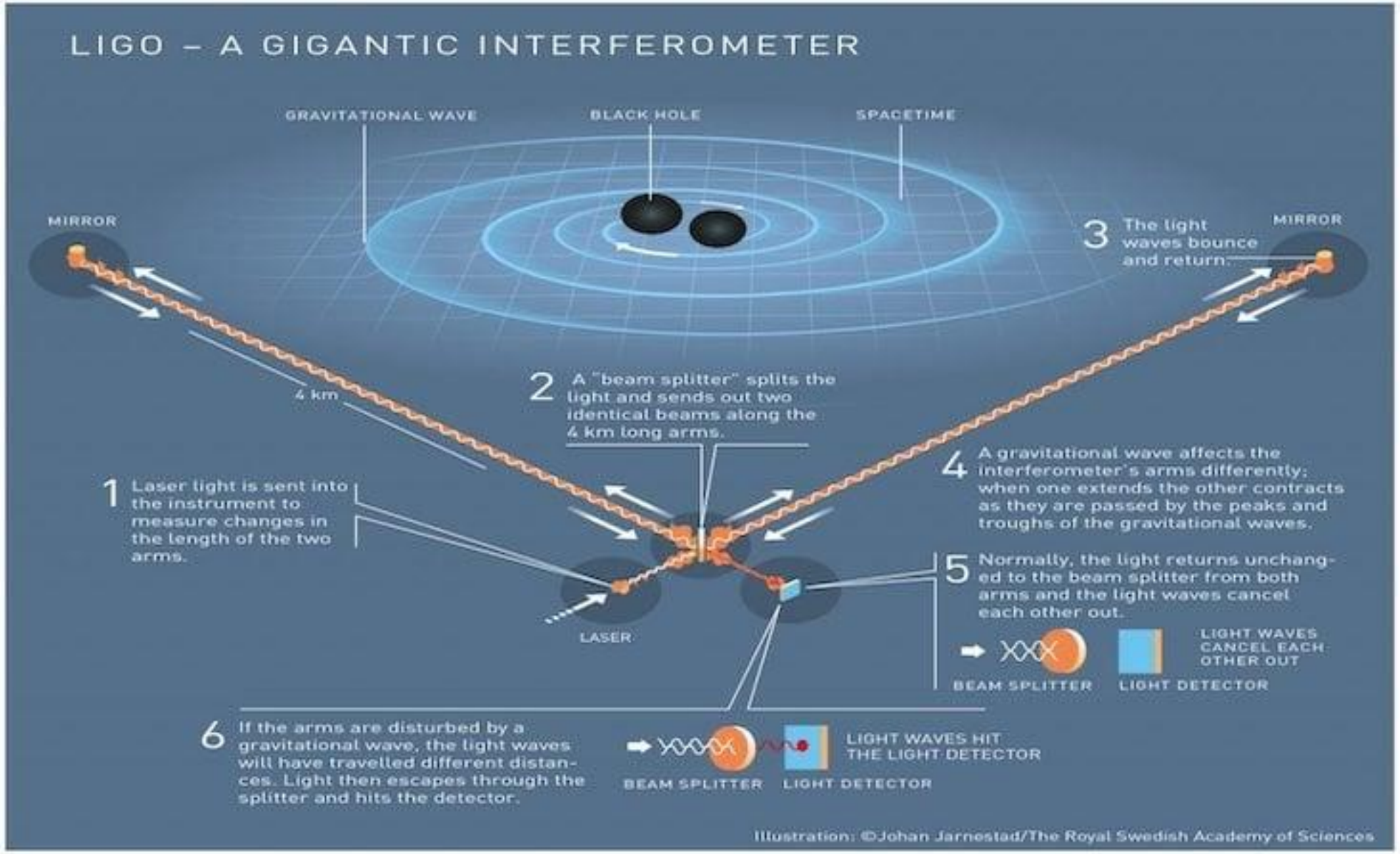
TXS 0506+056



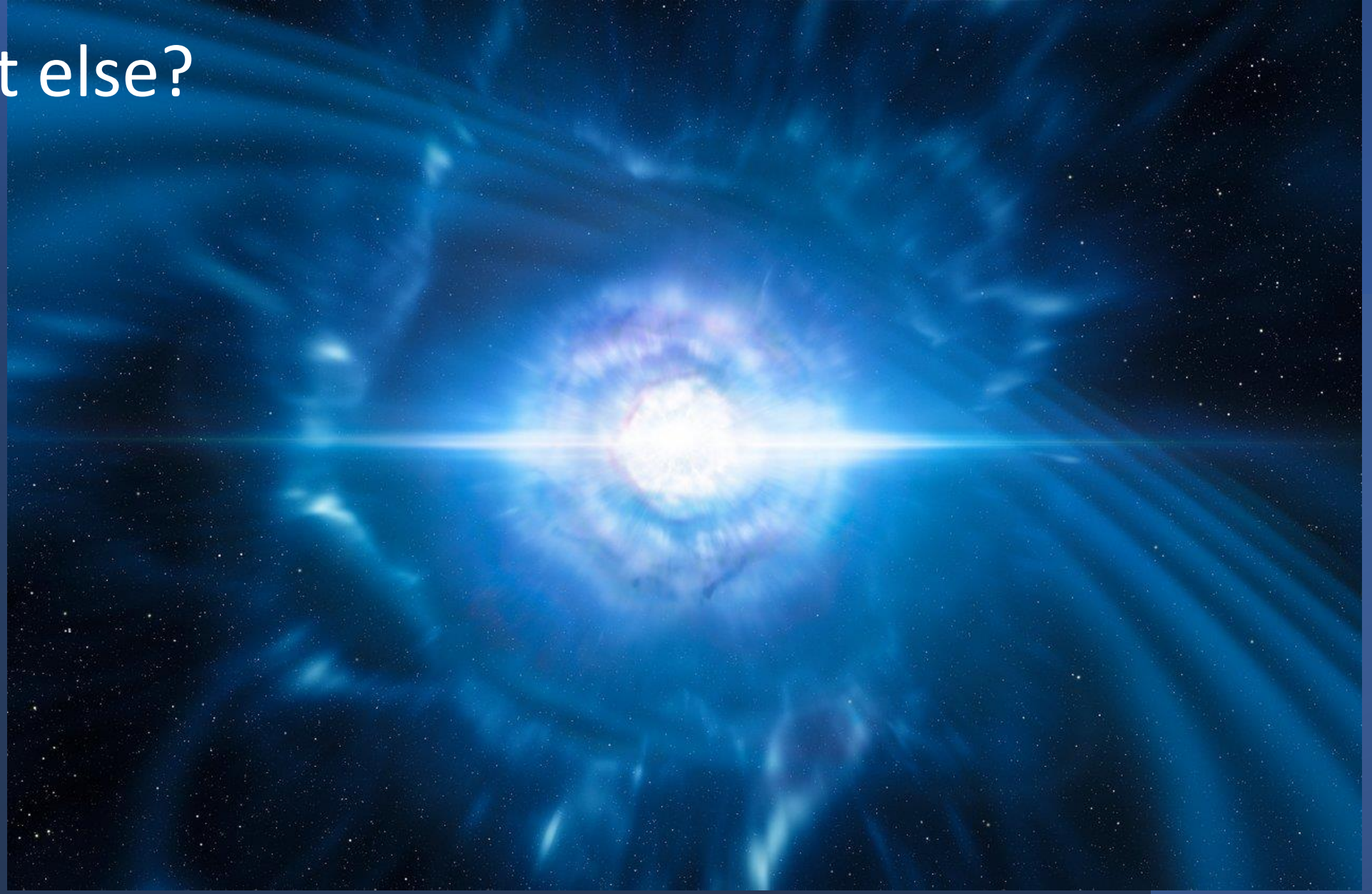
Neutrino



What else? LIGO Hanford Observatory

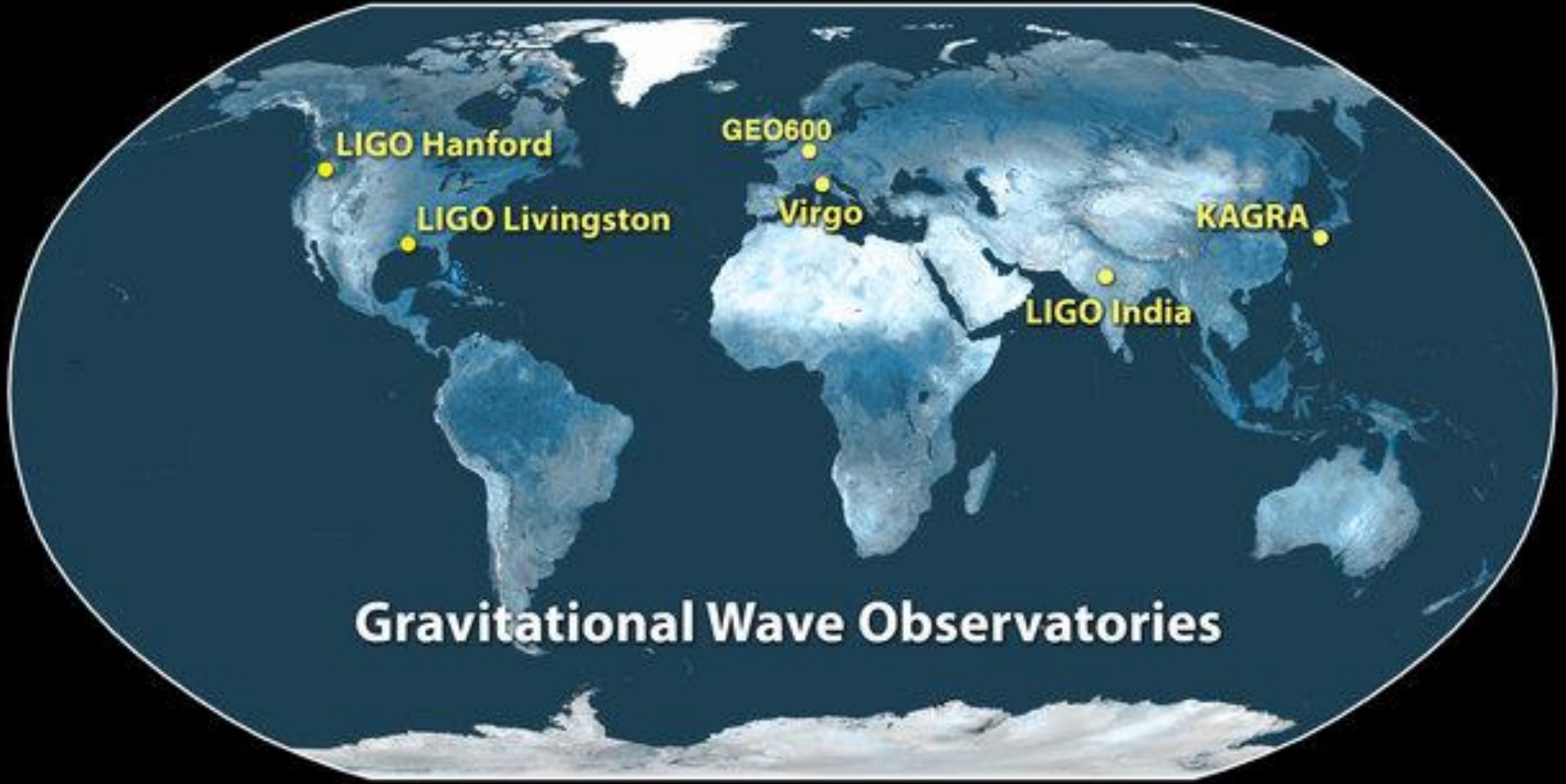


What else?



ESO Telescopes observe first light from a Gravitational Wave Source
Merging neutron stars scatter gold and platinum into space

World-Wide Gravitational Network



And new projects under construction and development

The future

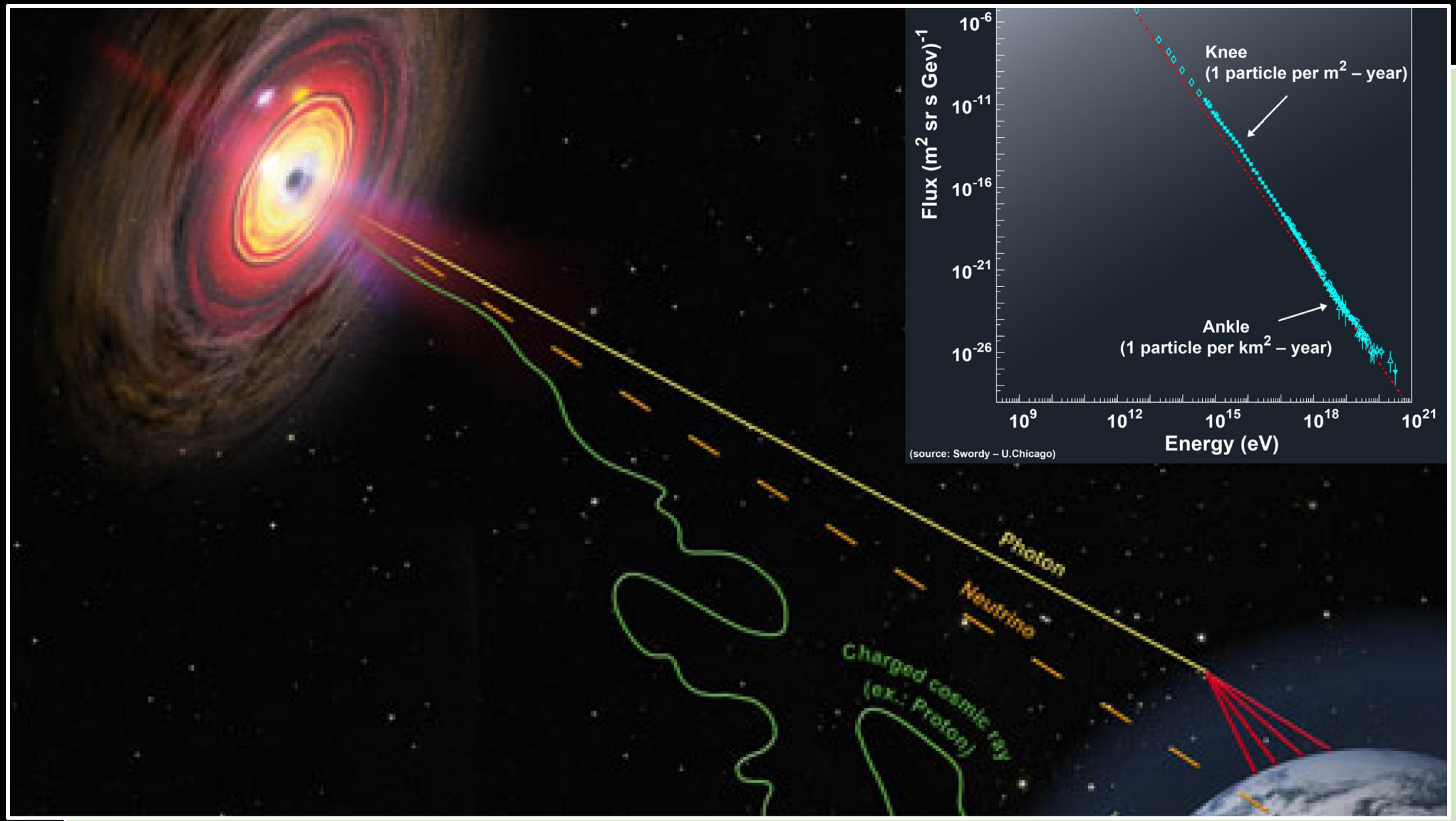
coming soon

Ground-based Gamma-ray Astronomy Network

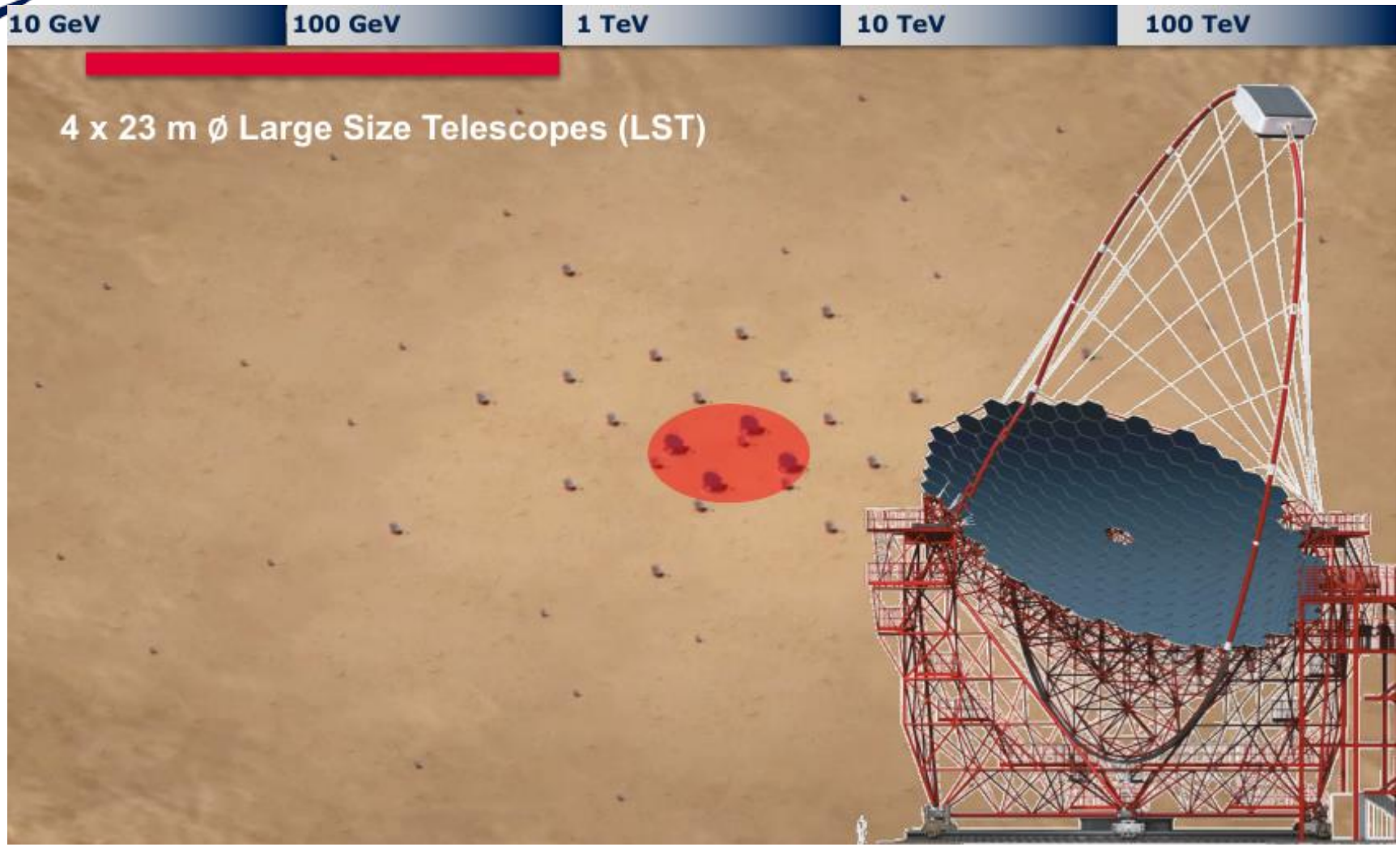
Courtesy Dr. Ulisses Barres

cta
cherenkov telescope array

- **The Cherenkov Telescope Array is a multinational, worldwide project to build a new generation of ground-based gamma-ray instruments in the energy range extending from some tens of GeV to about 300 TeV.**



PeVatrons: The hunt for the origin of Galactic cosmic rays with CTA

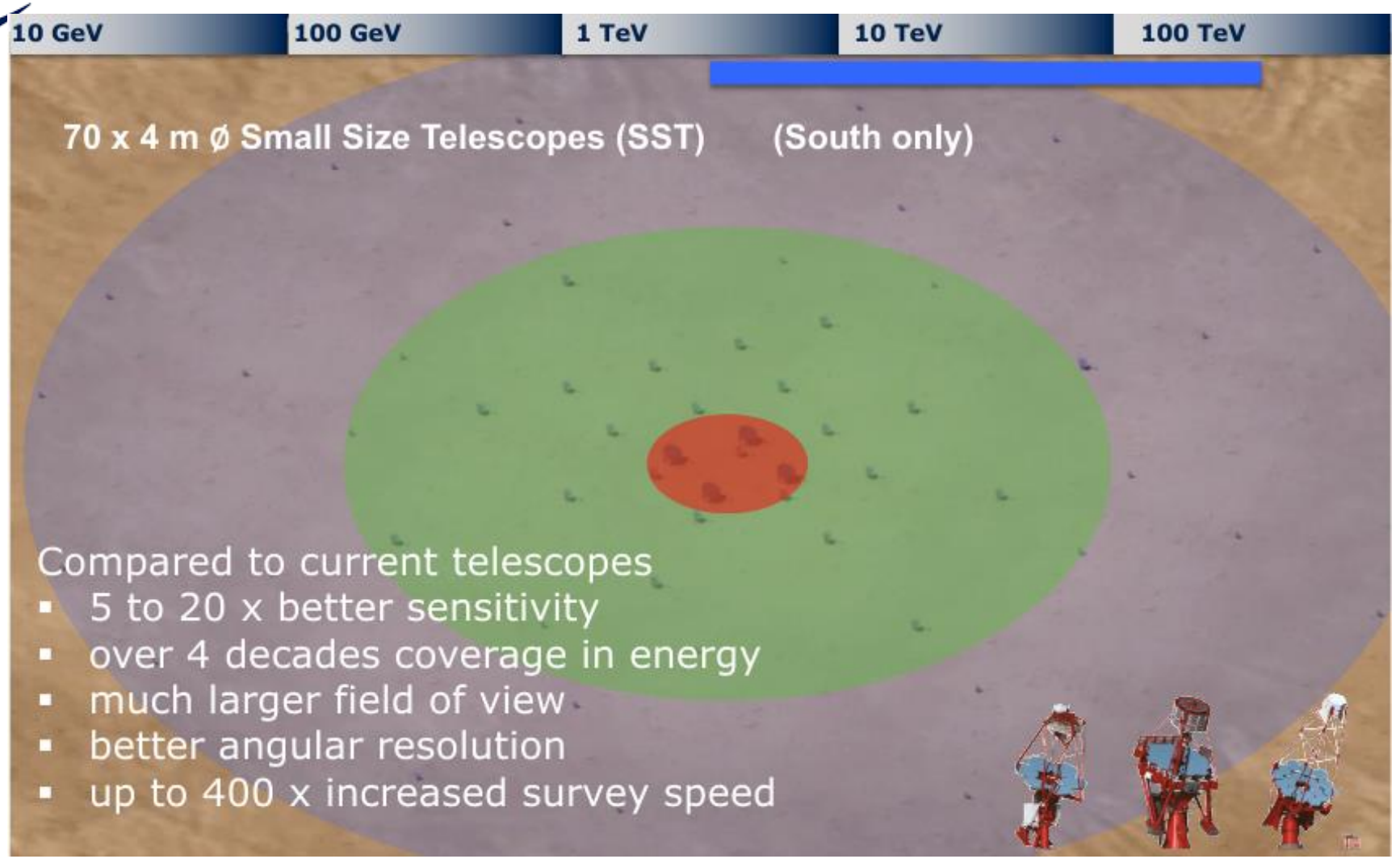


Slide by Prof. Werner Hofmann

cherenkov telescope array

Slide by Prof. Werner Hofmann

cta
cherenkov telescope array

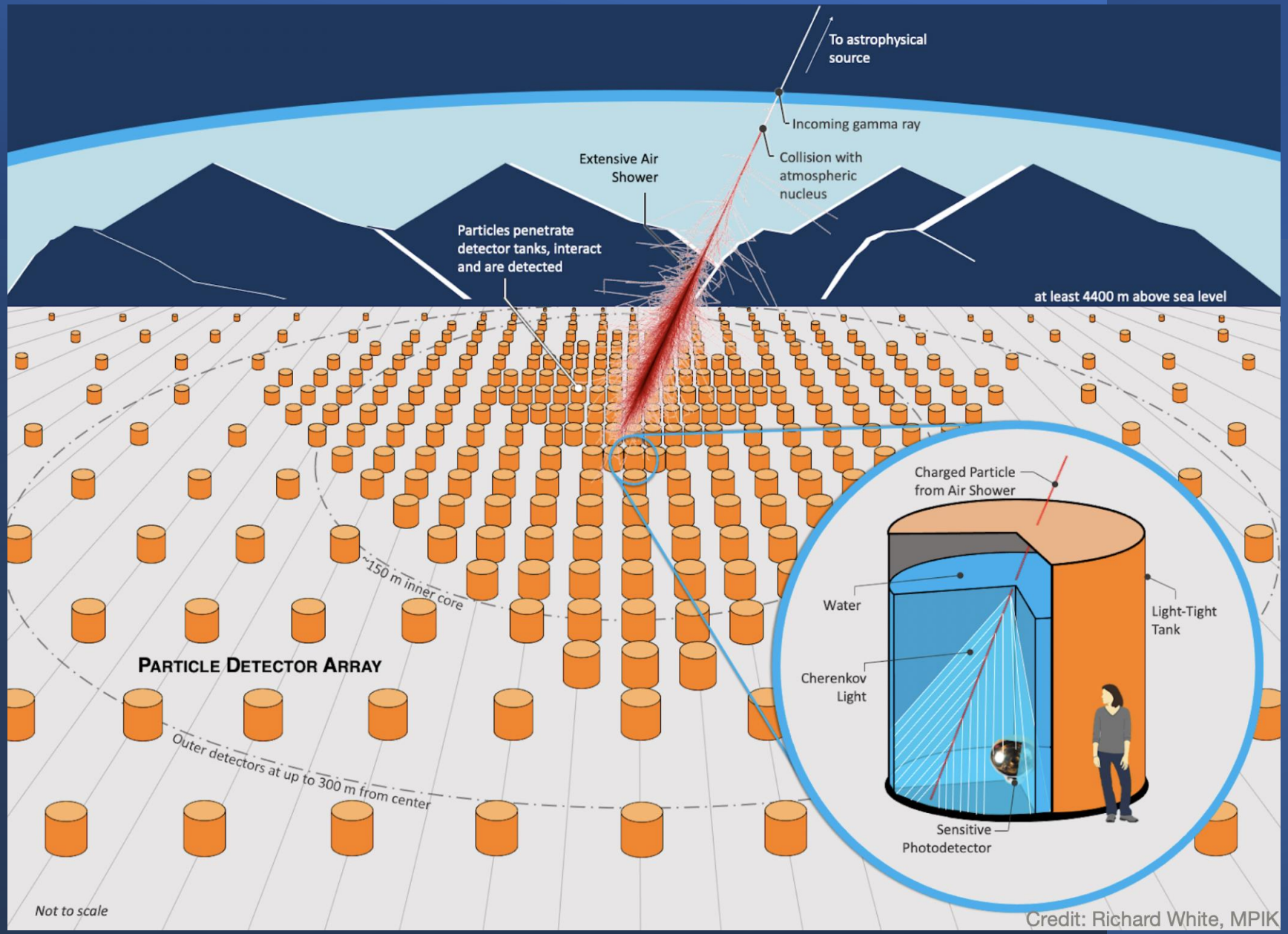


Slide by Prof. Werner Hofmann

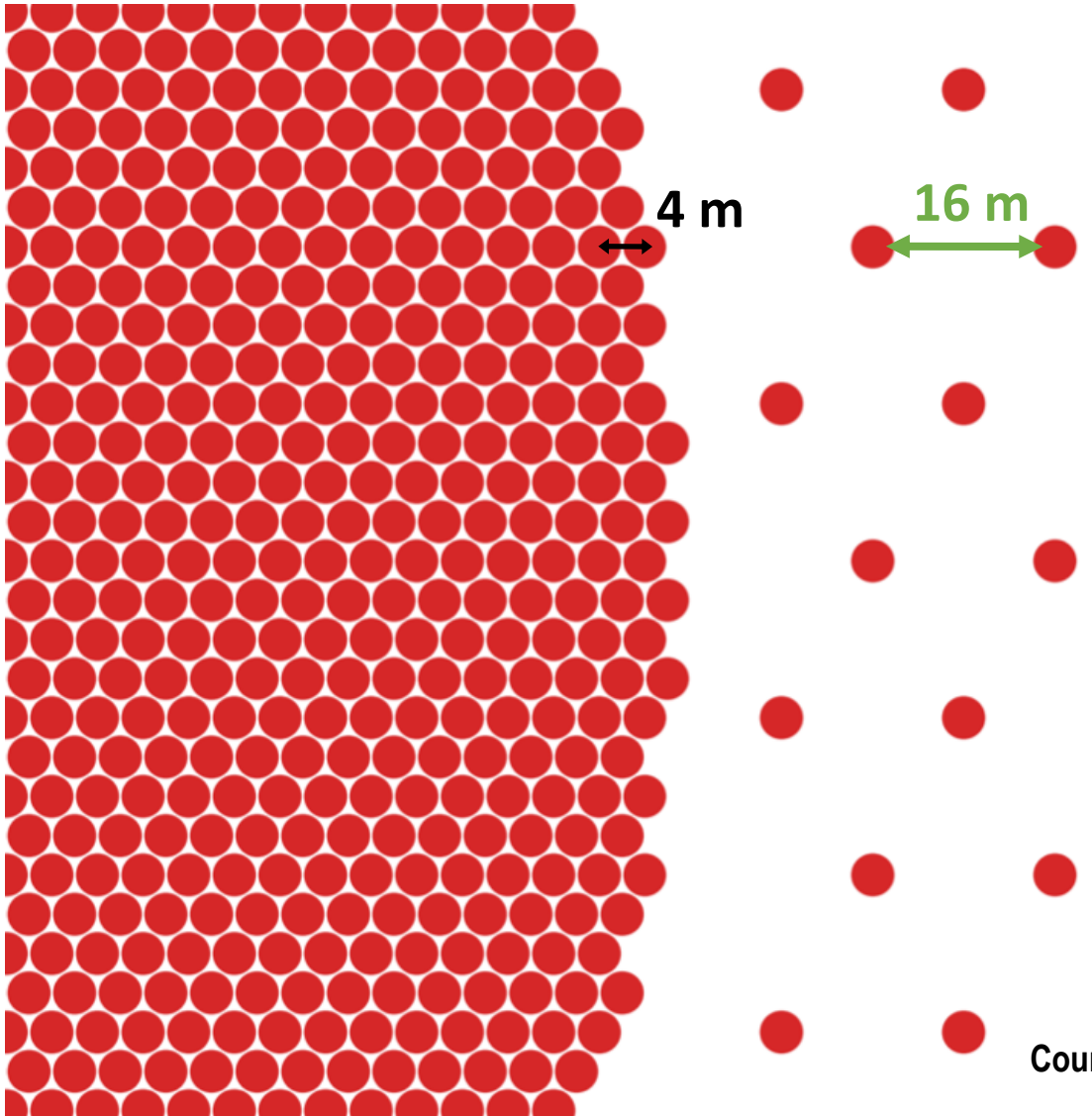
Made in Brazil

Courtesy of Prof. Vitor de Souza

SWGO
The Southern Wide-field Gamma-ray Observatory



The baseline detector concept

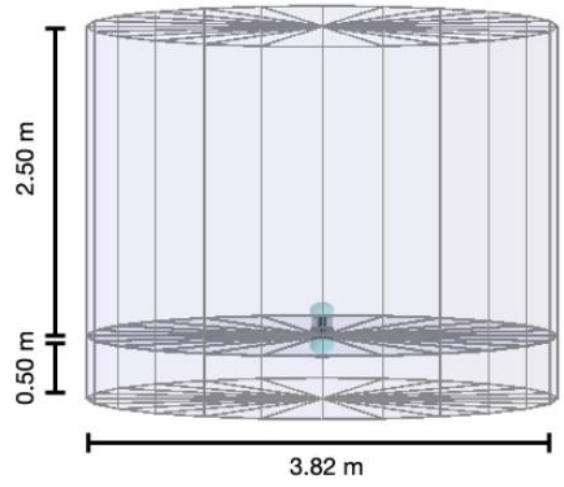


Core: Ø 320 m, FF = 80%
5,700 WCD units

Outer: Ø 600 m, FF = 5%
880 WCD units

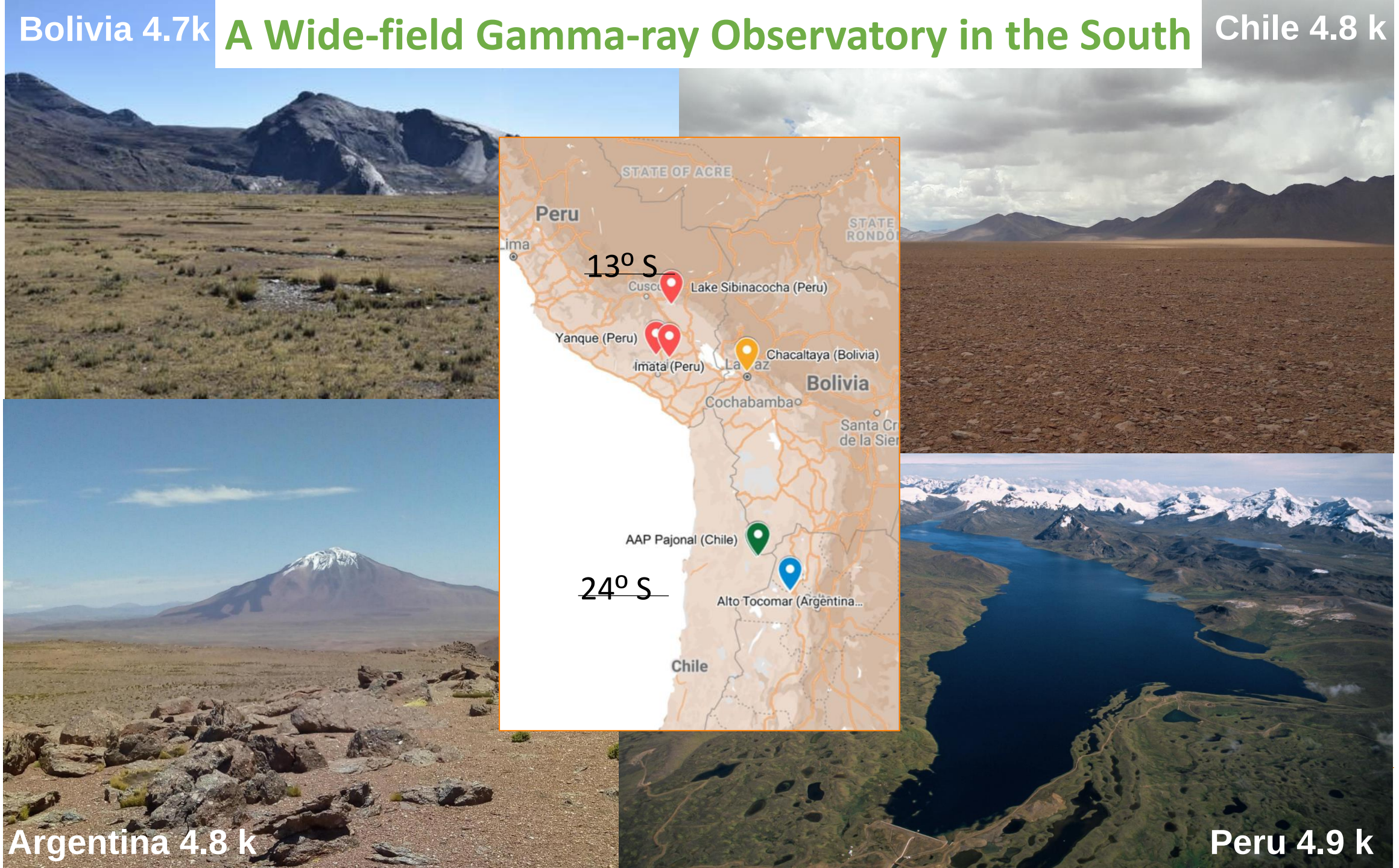
Altitude: 4,700 m a.s.l.

✧ muon counting

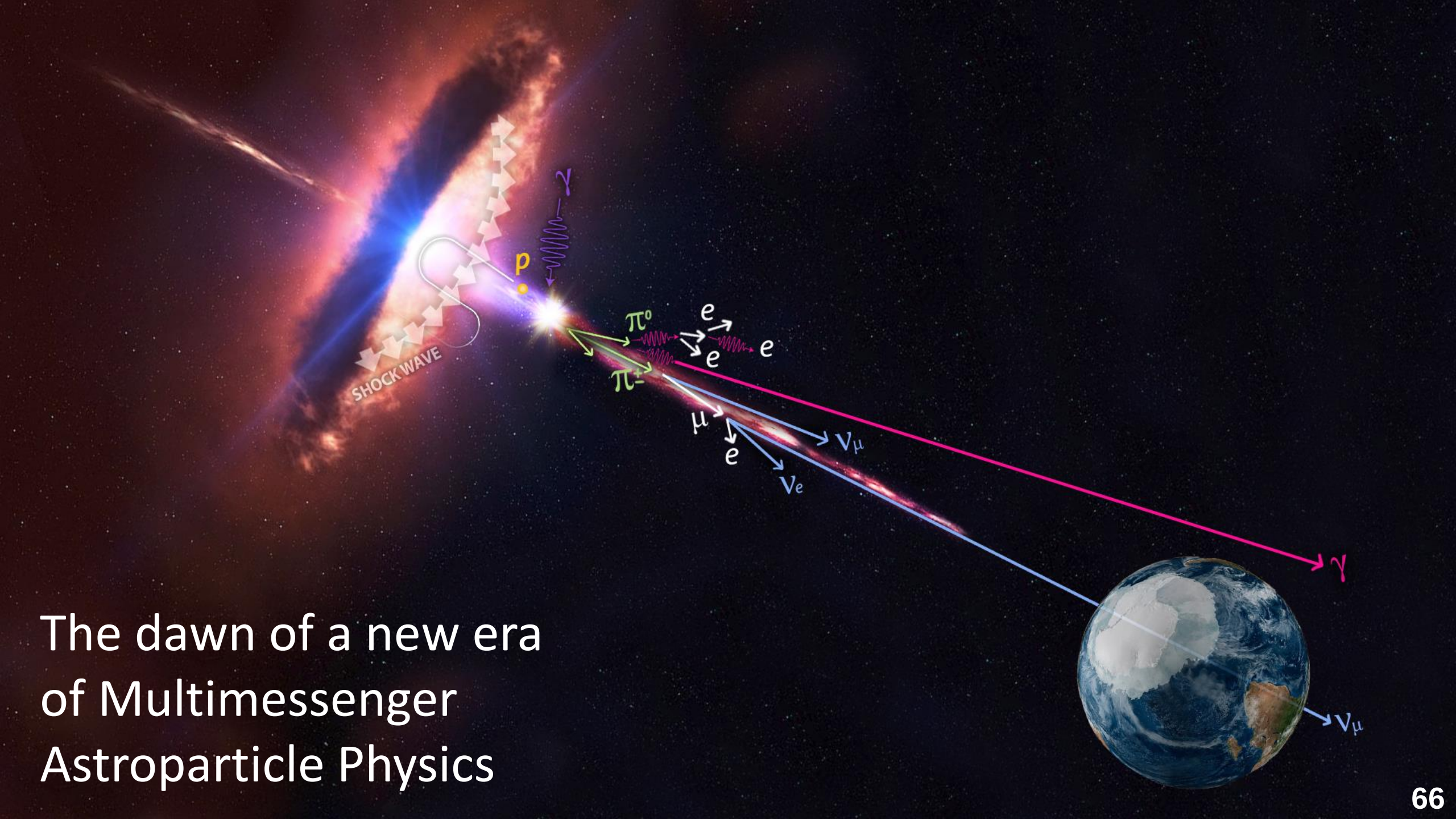


Courtesy Dr. Ulisses Barres

A Wide-field Gamma-ray Observatory in the South



Courtesy Dr. Ulisses Barres



The dawn of a new era of Multimessenger Astroparticle Physics

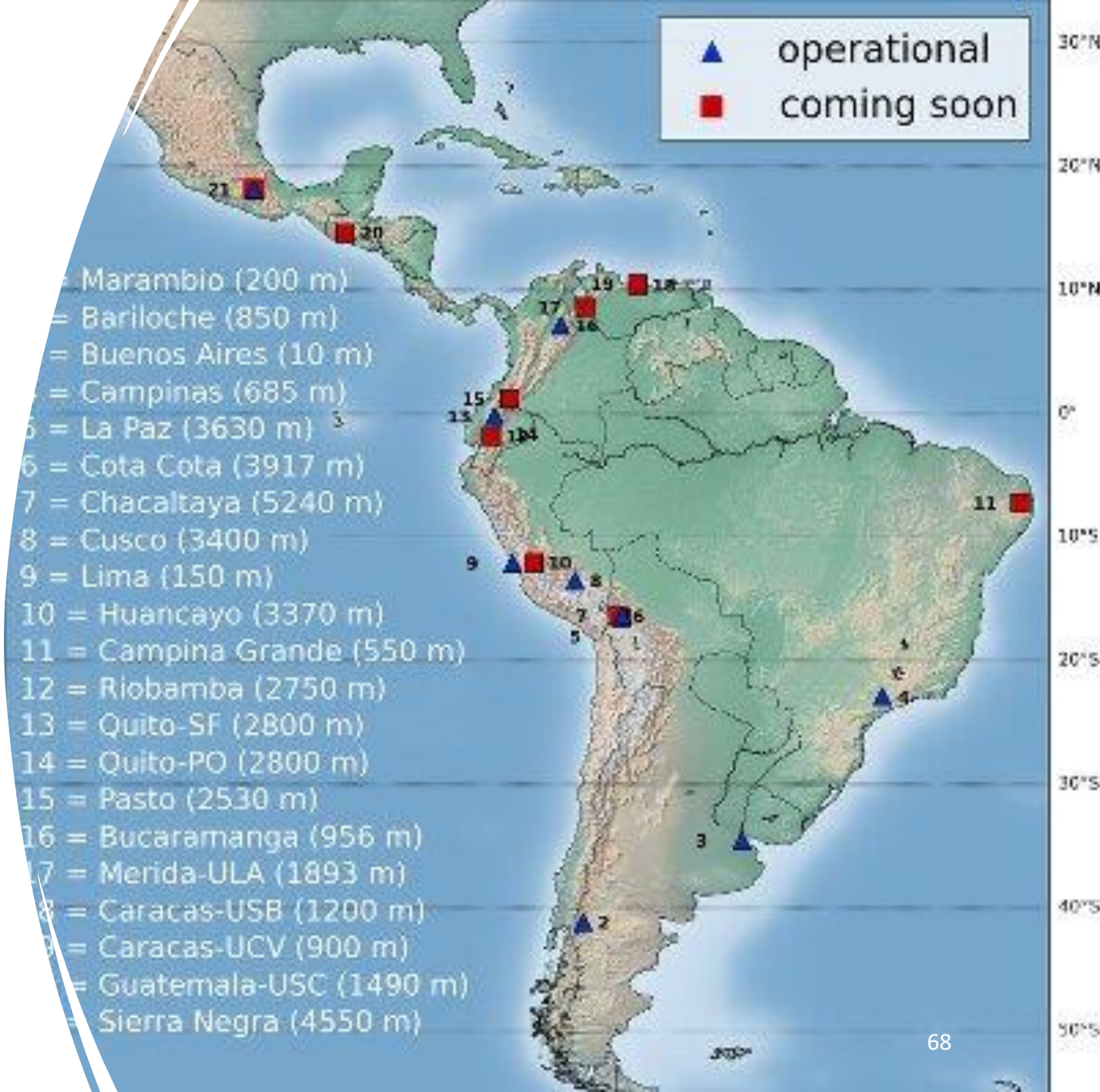
My apologies
for not addressing other experiments going on in South America
such as LAGO and ALPACA

LAGO: Latin American Giant Observatory
ALPACA: Andes Large area PArticle detector for Cosmic ray physics and Astronomy (4,740 m at Mt Chacaltaya)

LAGO

Latin American Giant Observatory

involving scientist from nine countries: Argentina, Bolivia, Brazil, Colombia, Ecuador, Guatemala, Mexico, Peru, and Venezuela.




Thank you for your attention!