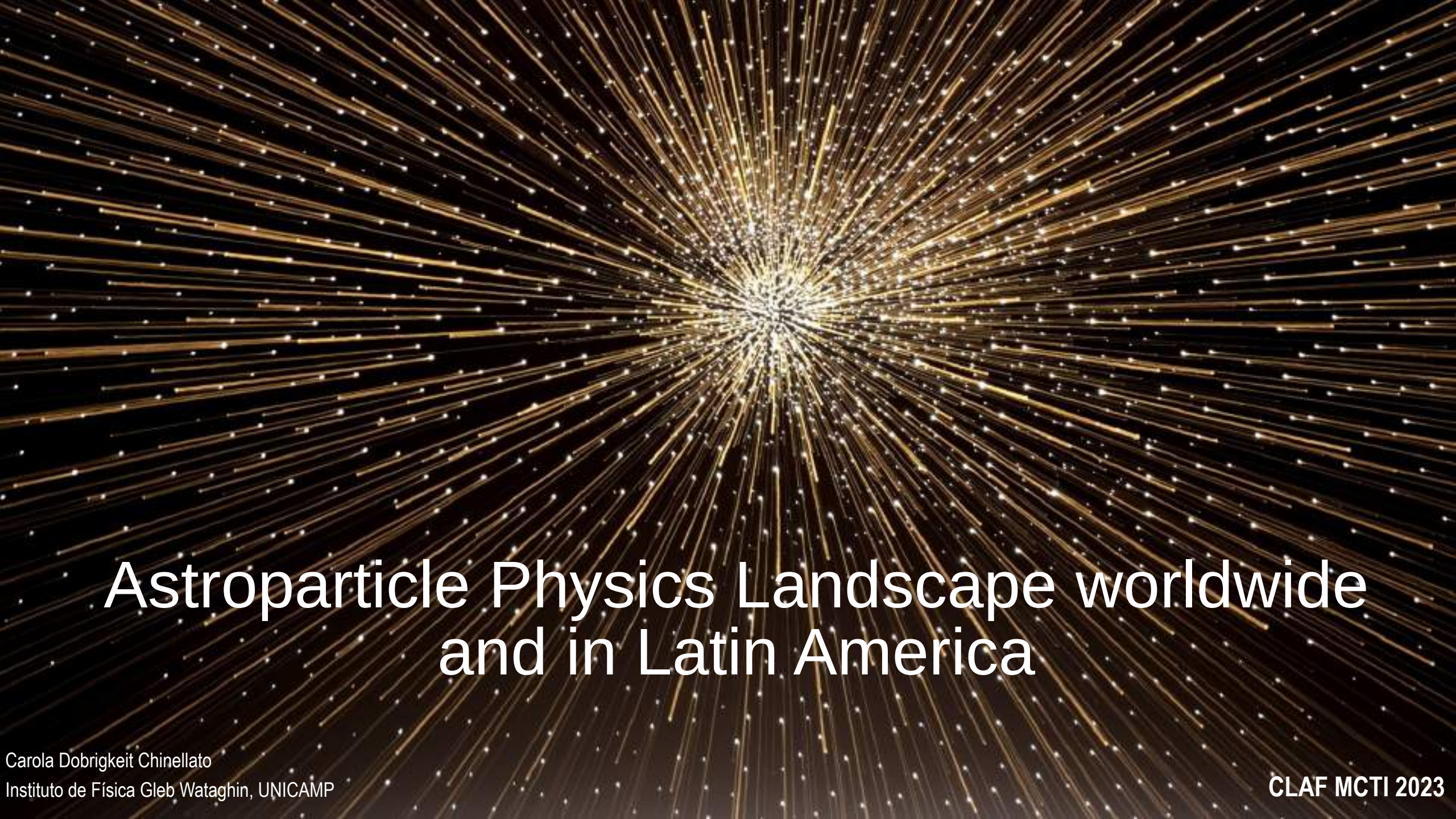
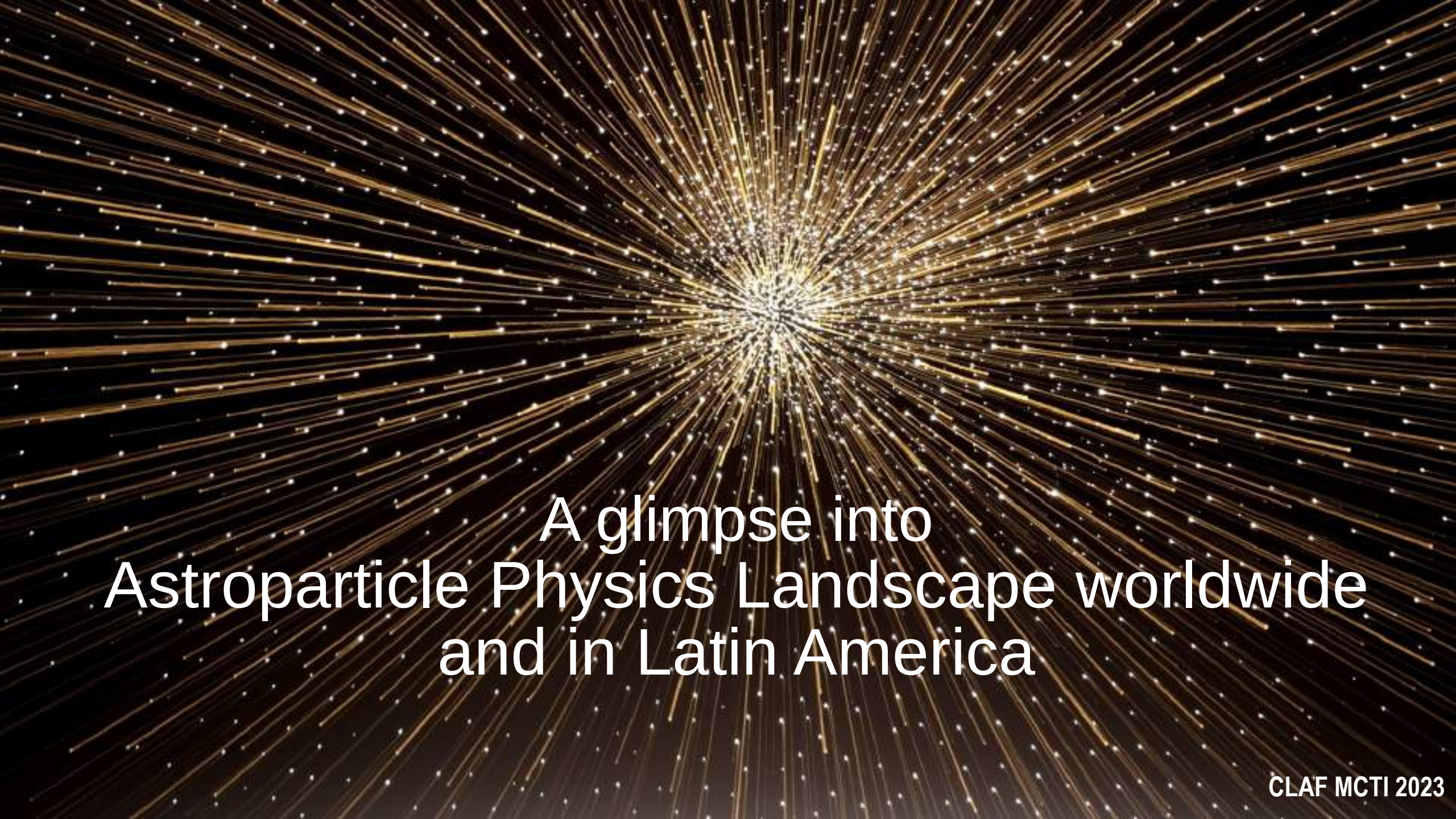


Astroparticle Physics Landscape worldwide and in Latin America

Carola Dobrigkeit Chinellato
Instituto de Física Gleb Wataghin, UNICAMP

CLAF MCTI 2023



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

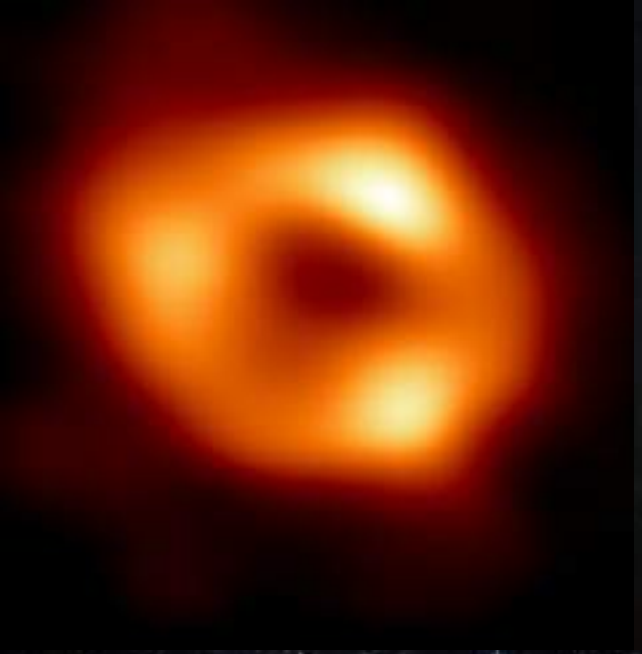
- Close to neutron stars and black holes
- Relativistic jets, winds and explosions
- Cosmic voids

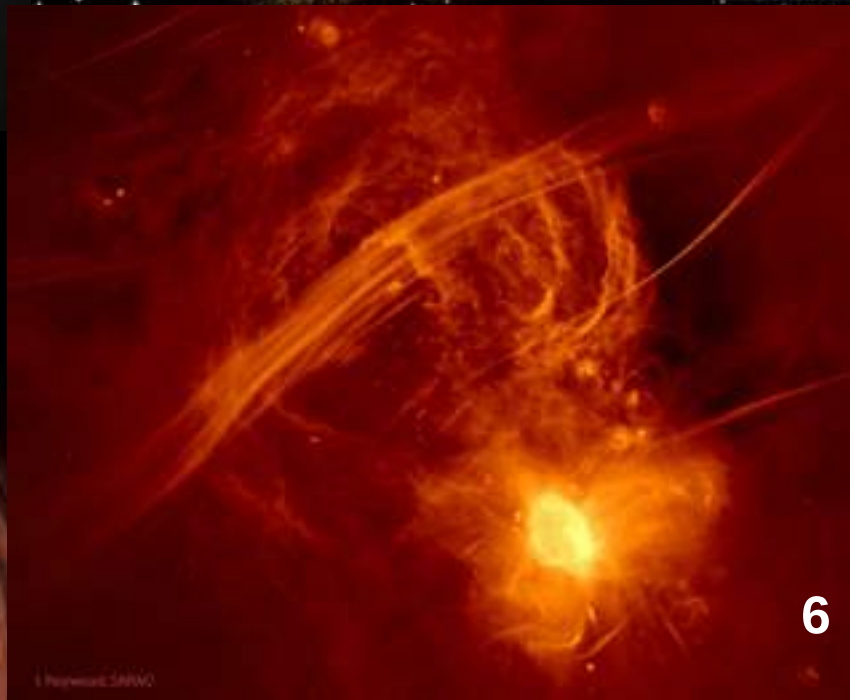
PHYSICS FRONTIERS

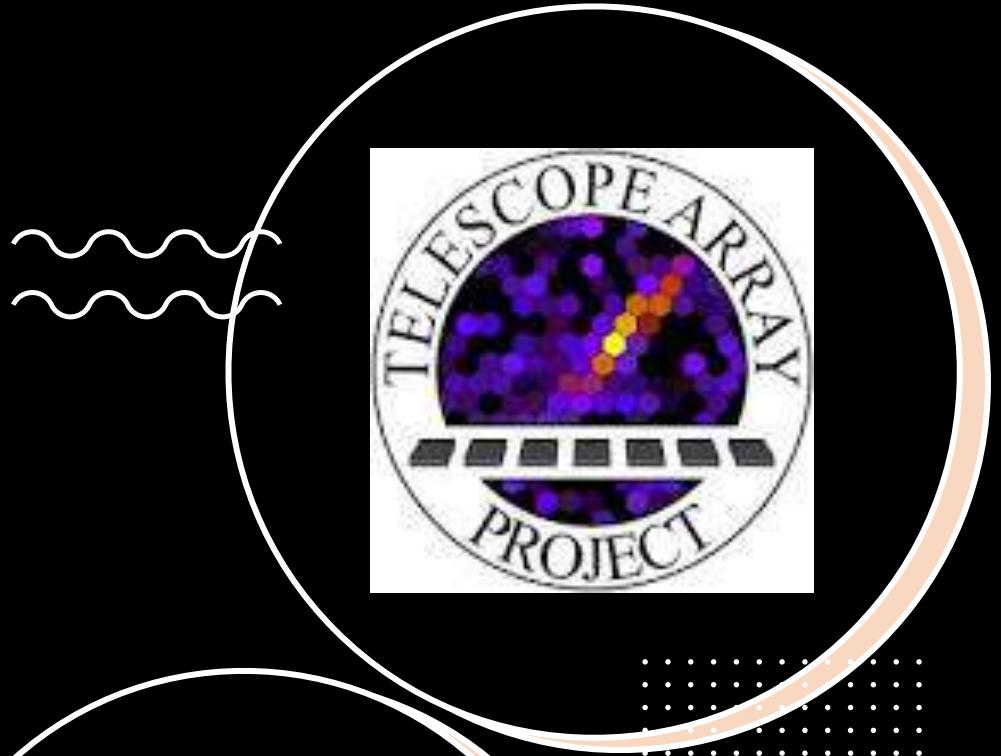
- What is the nature of Dark Matter?
- Is the speed of light a constant?
- Do axion-like particles exist?

Courtesy Prof. Vitor de Souza

Where are their sources?

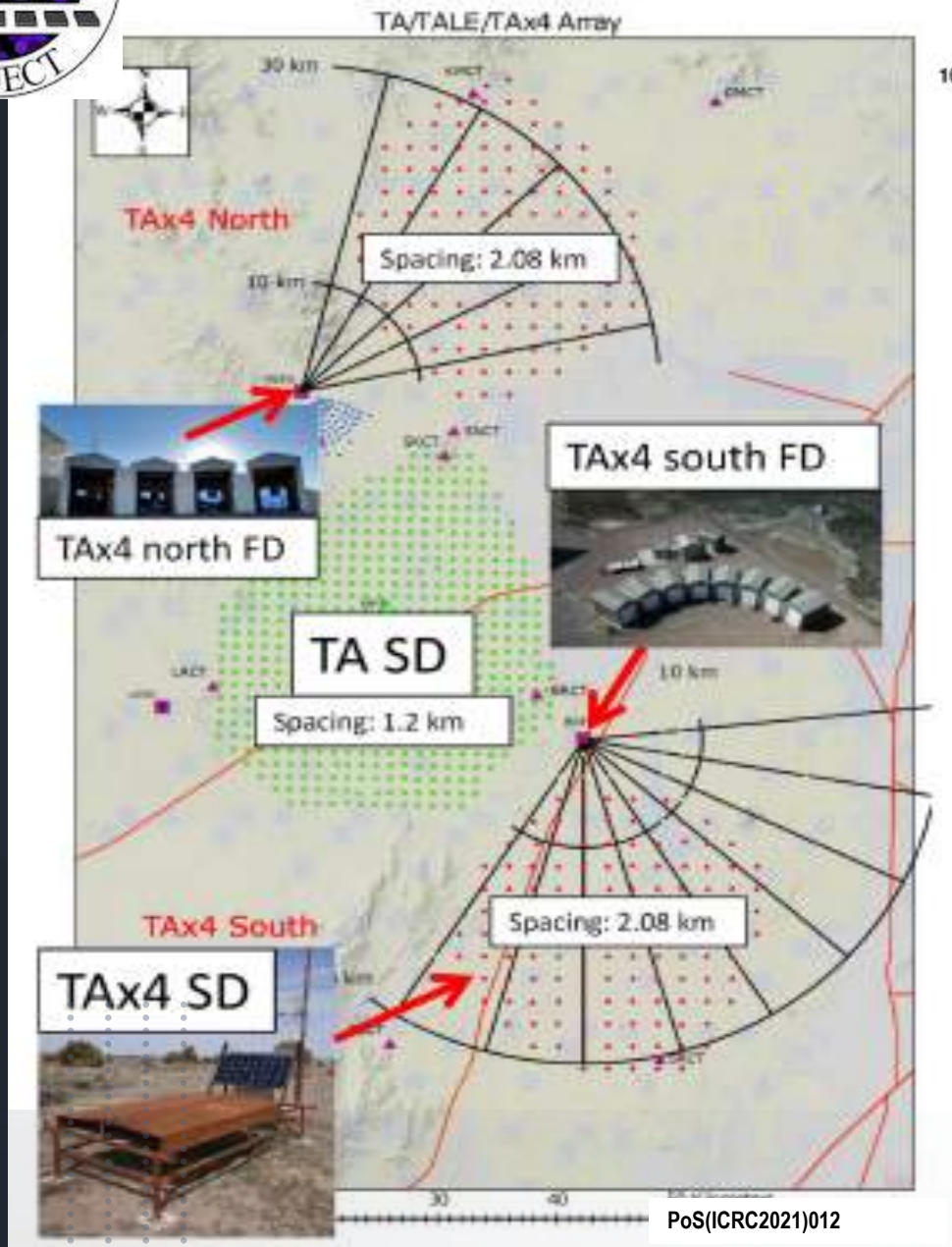




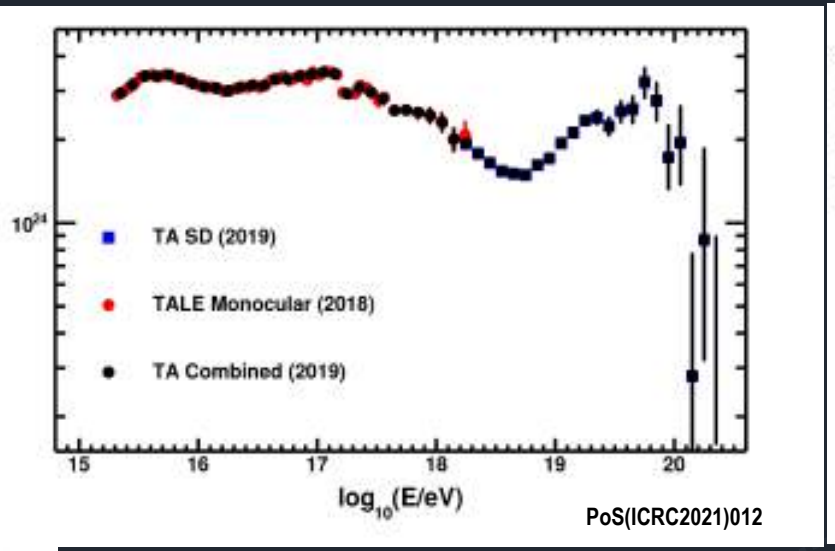


- Ultrahigh- energy cosmic rays above 10^{17} eV

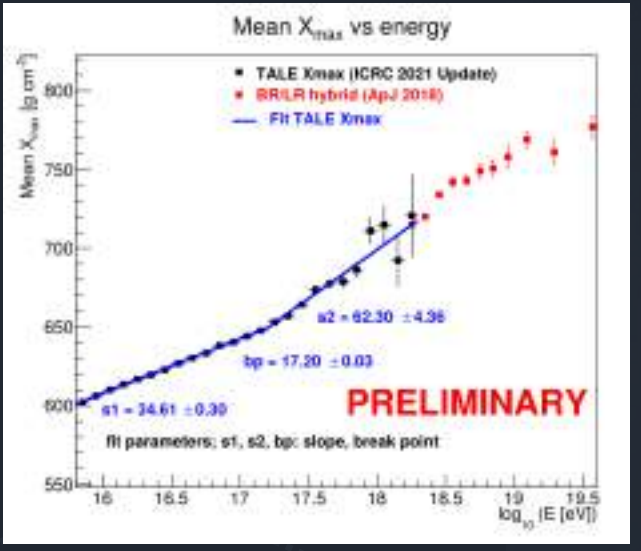
Telescope Array

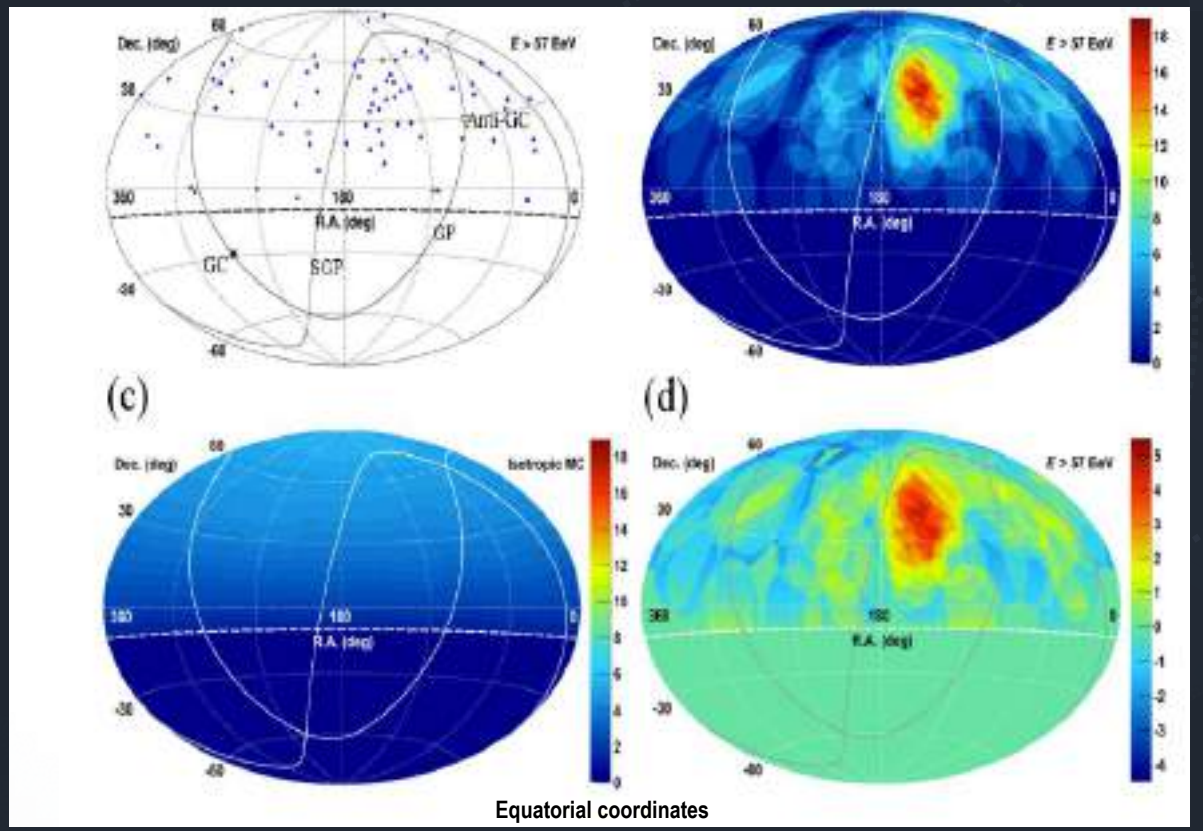


PoS(ICRC2021)012



PoS(ICRC2021)012



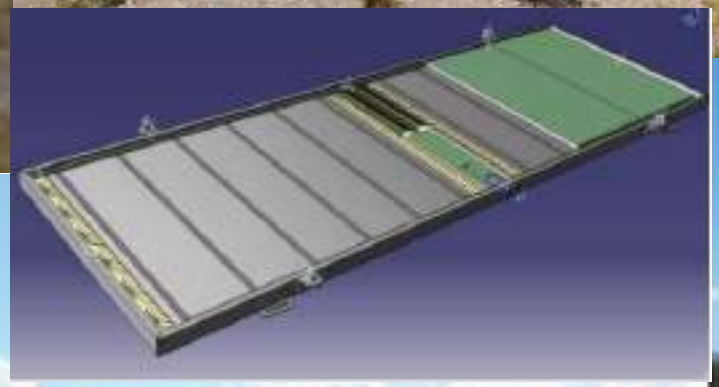


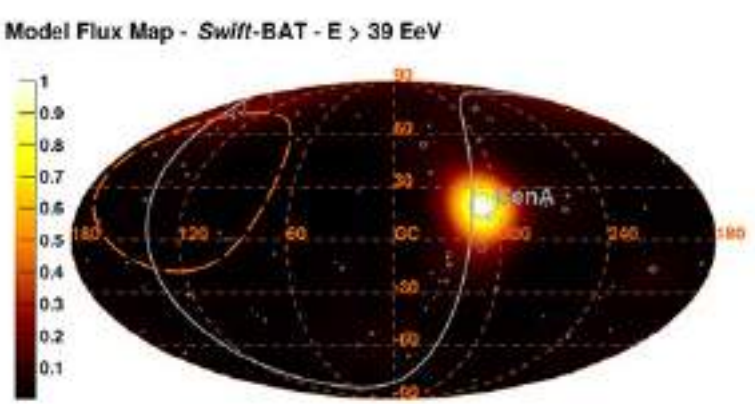
Equatorial coordinates

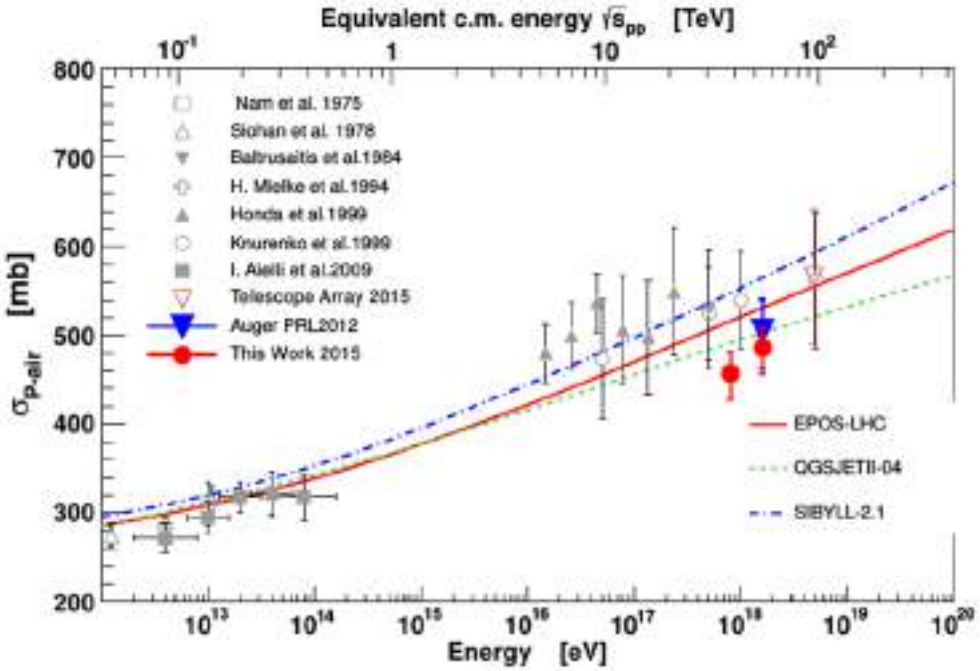
The Astrophysical Journal Letters, 790:L21 2014

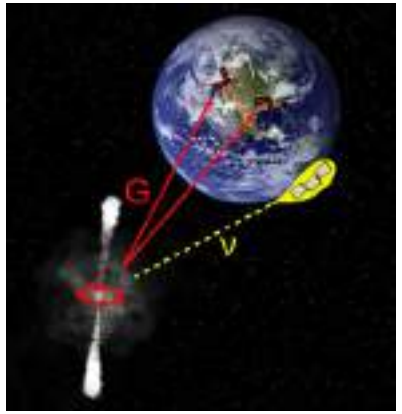
PIERRE
AUGER
OBSERVATORY

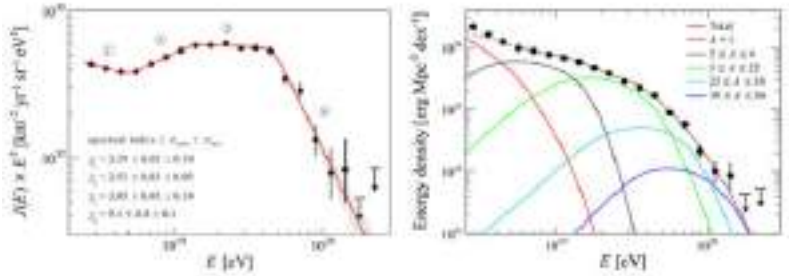
The Pierre Auger Observatory

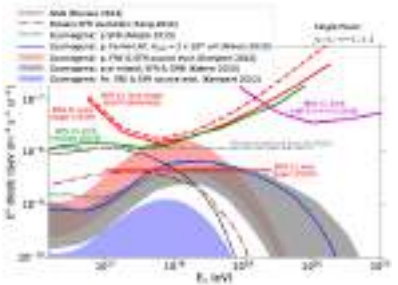


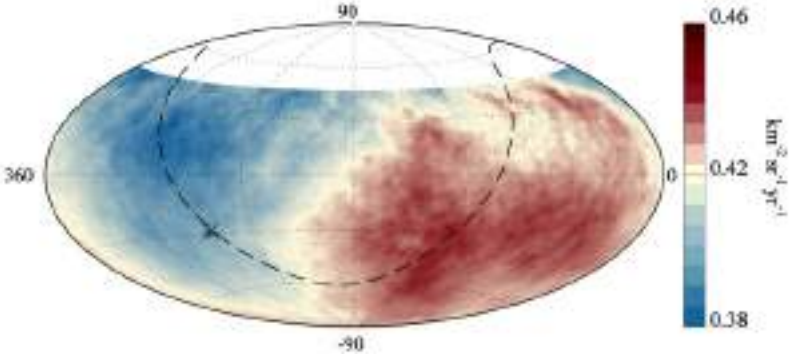

Model Flux Map - Swift-BAT - E > 39 EeV
CenA

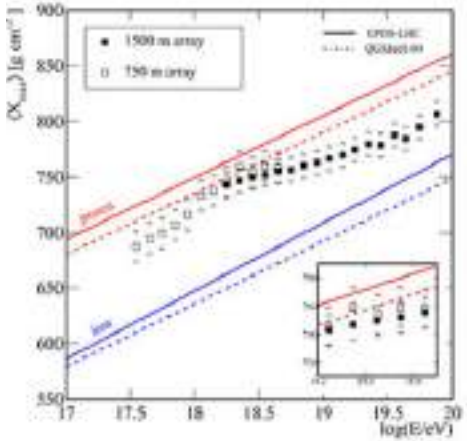

Equivalent c.m. energy √s_pp [TeV]
Nam et al. 1975
Sichan et al. 1978
Baltrusaitis et al.1984
H. Mielke et al.1994
Honda et al.1999
Knurenko et al.1999
I. Aielli et al.2009
Telescope Array 2015
Auger PRL2012
This Work 2015
EPOS-LHC
QGSJETII-04
SIBYLL-2.1
σp-air [mb]
Energy [eV]

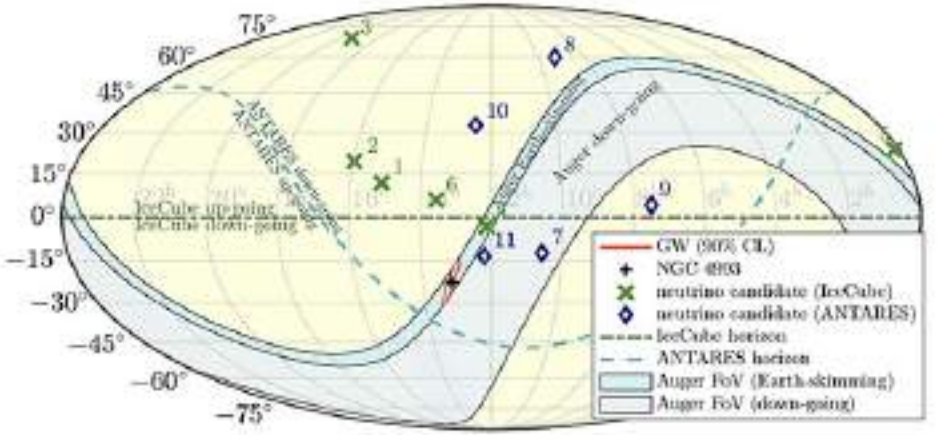

G
ν










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

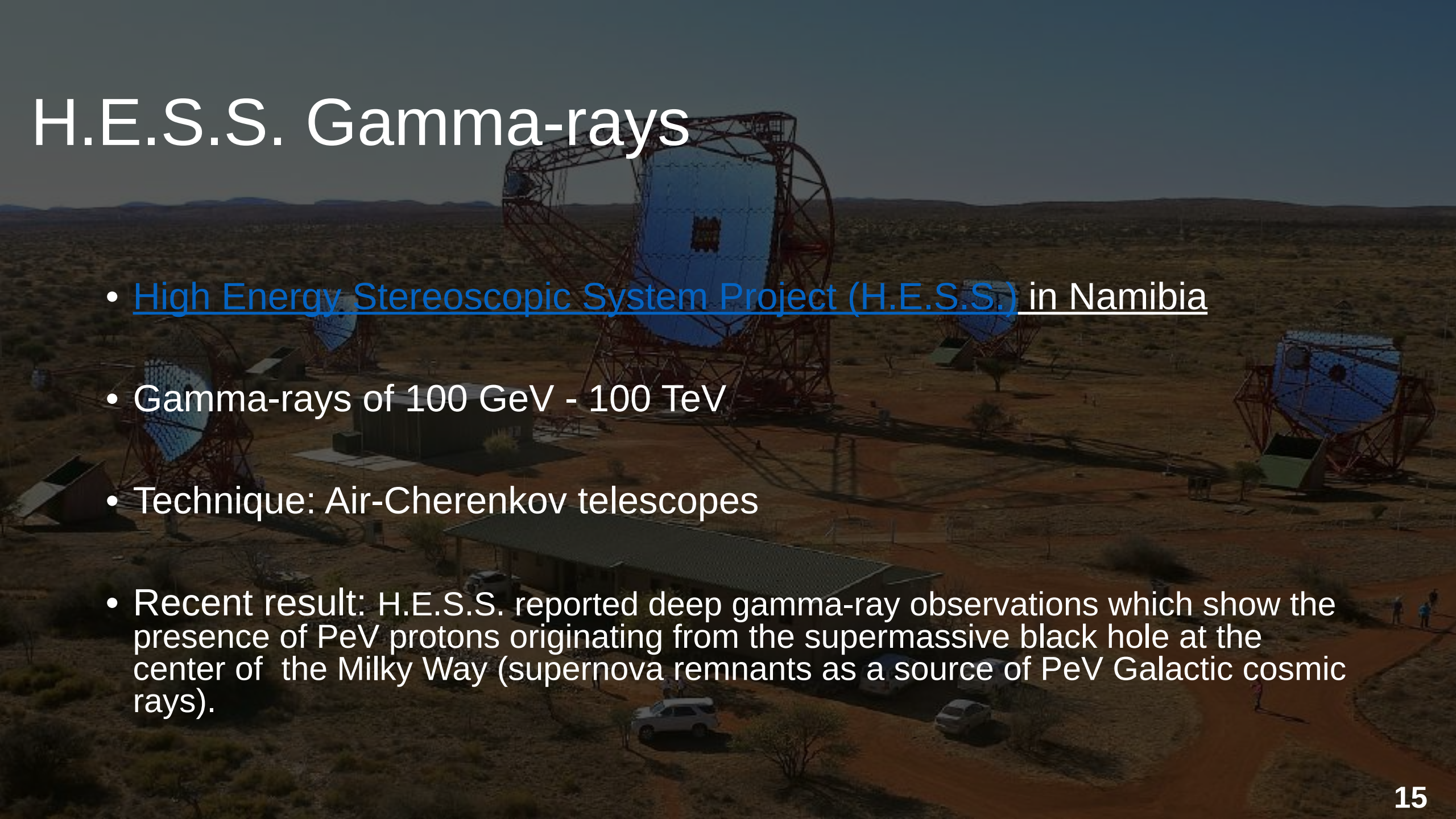
- **Energy spectrum and flux suppression at the highest energies**
- **Measuring proton-air cross section at $\sqrt{s} \approx 57$ TeV**
- **Tests of hadronic-interaction models**
- **Investigating air showers with an excess of muons**
- **Challenging level of isotropy with a dipole**
- **Targeted search 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

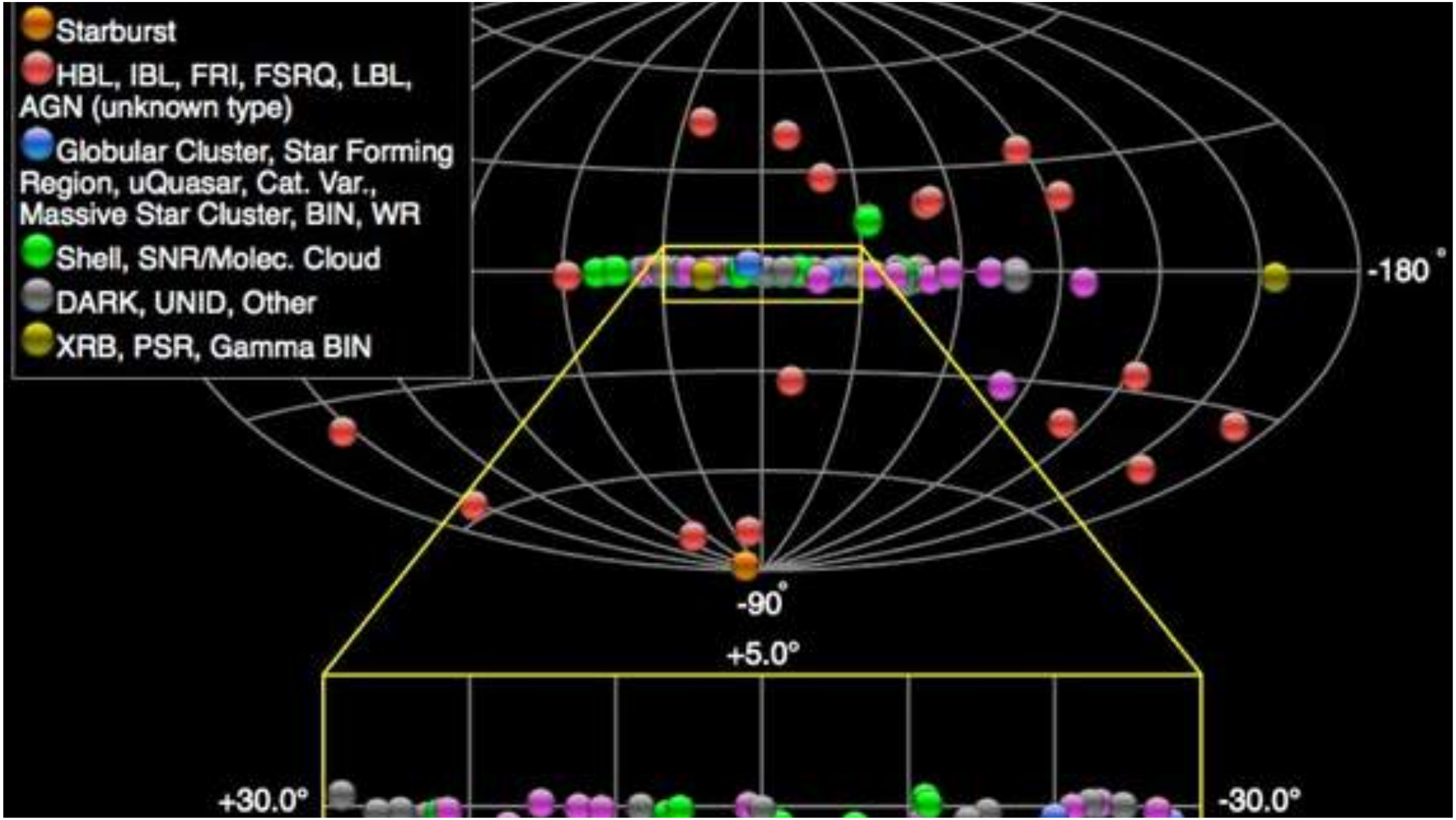
H.E.S.S. Gamma-rays

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

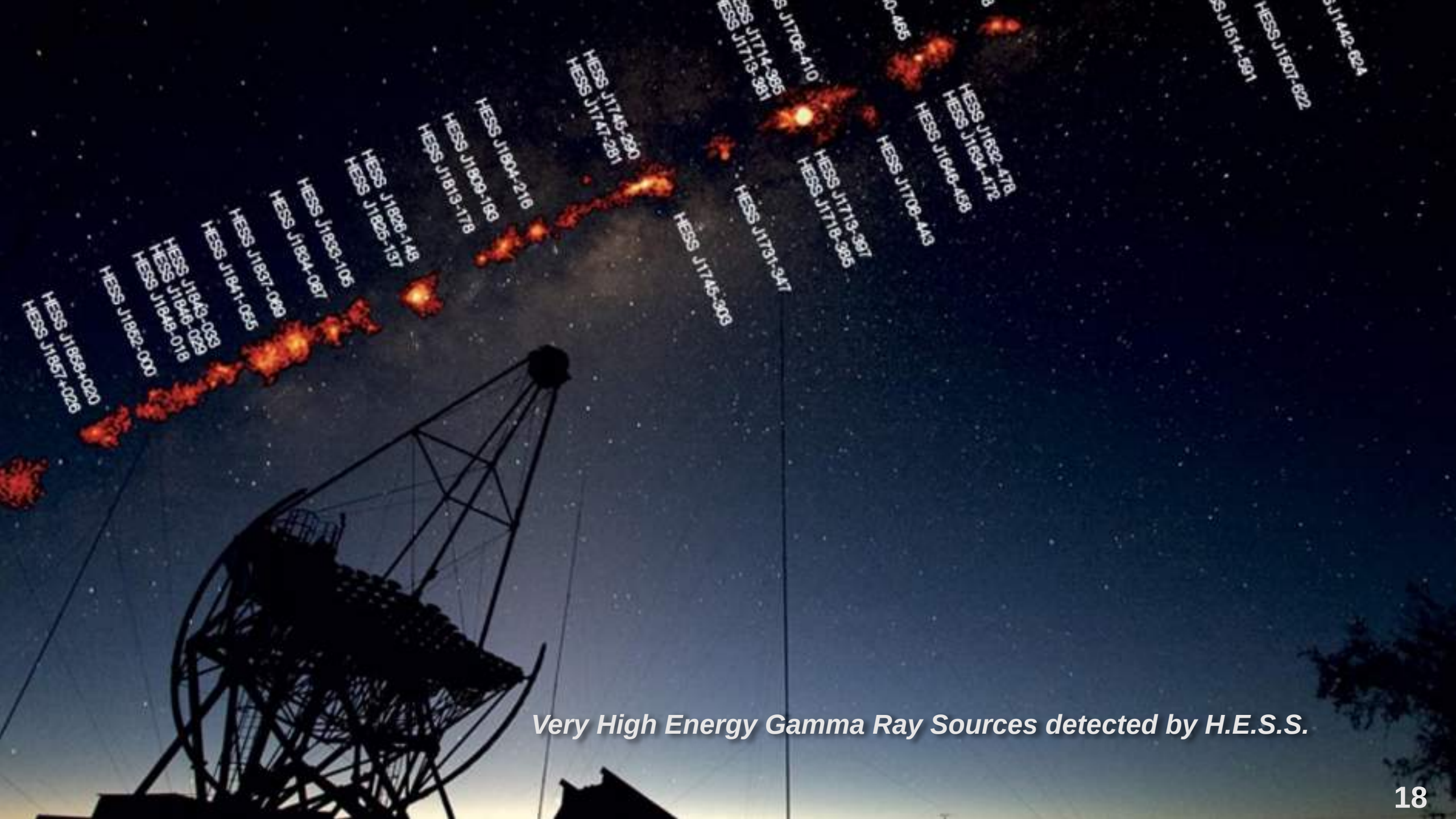
H.E.S.S. Gamma-rays



- 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).



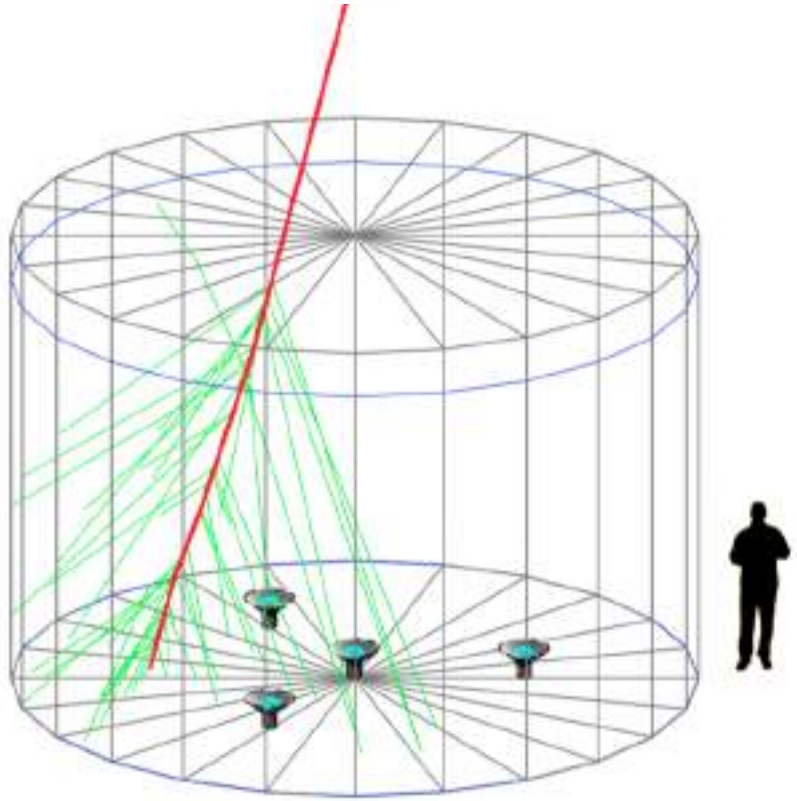
Very High Energy Gamma Ray Sources detected by H.E.S.S. (still 2012)



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

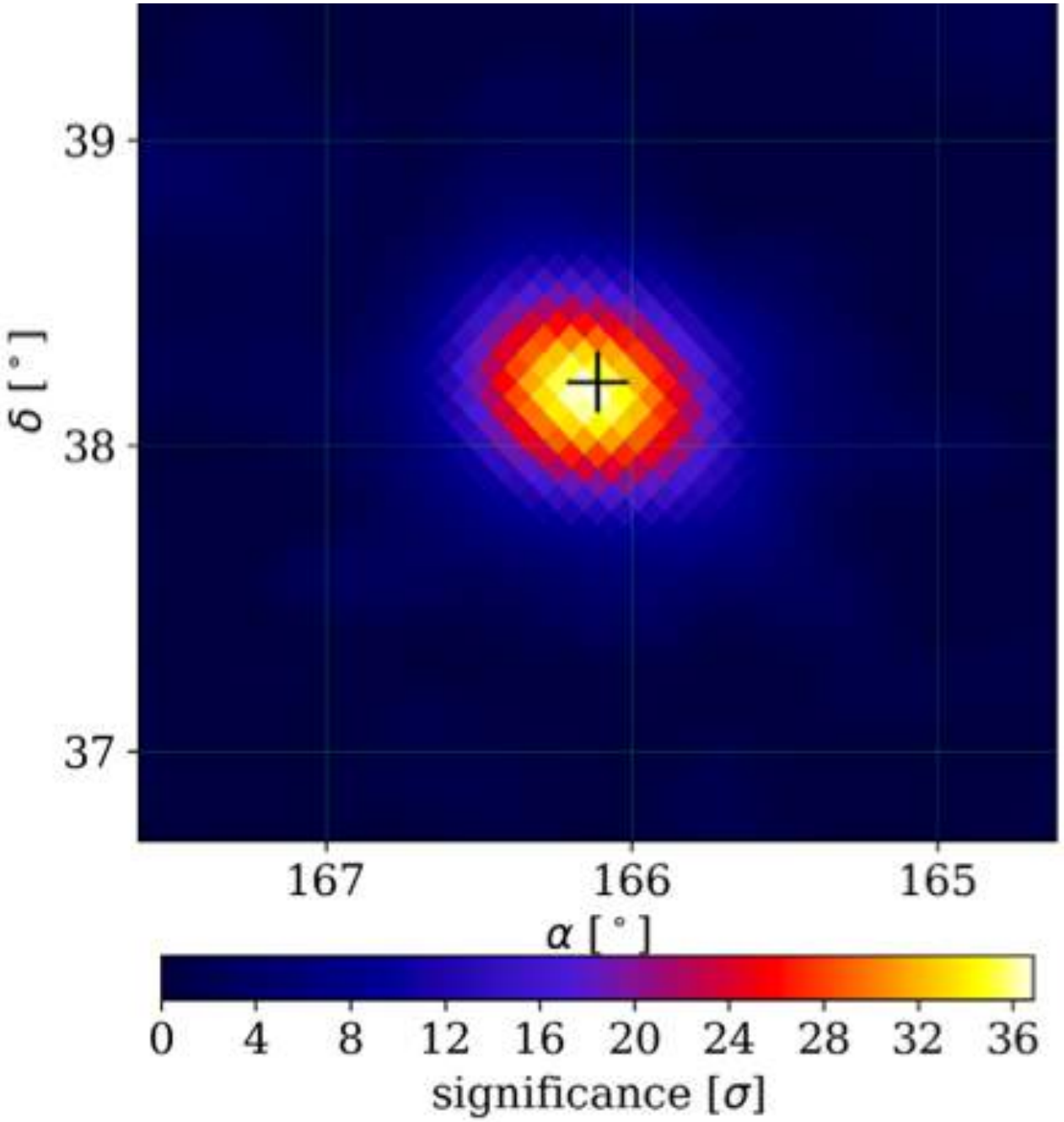


By HAWC Collaboration - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=35125676

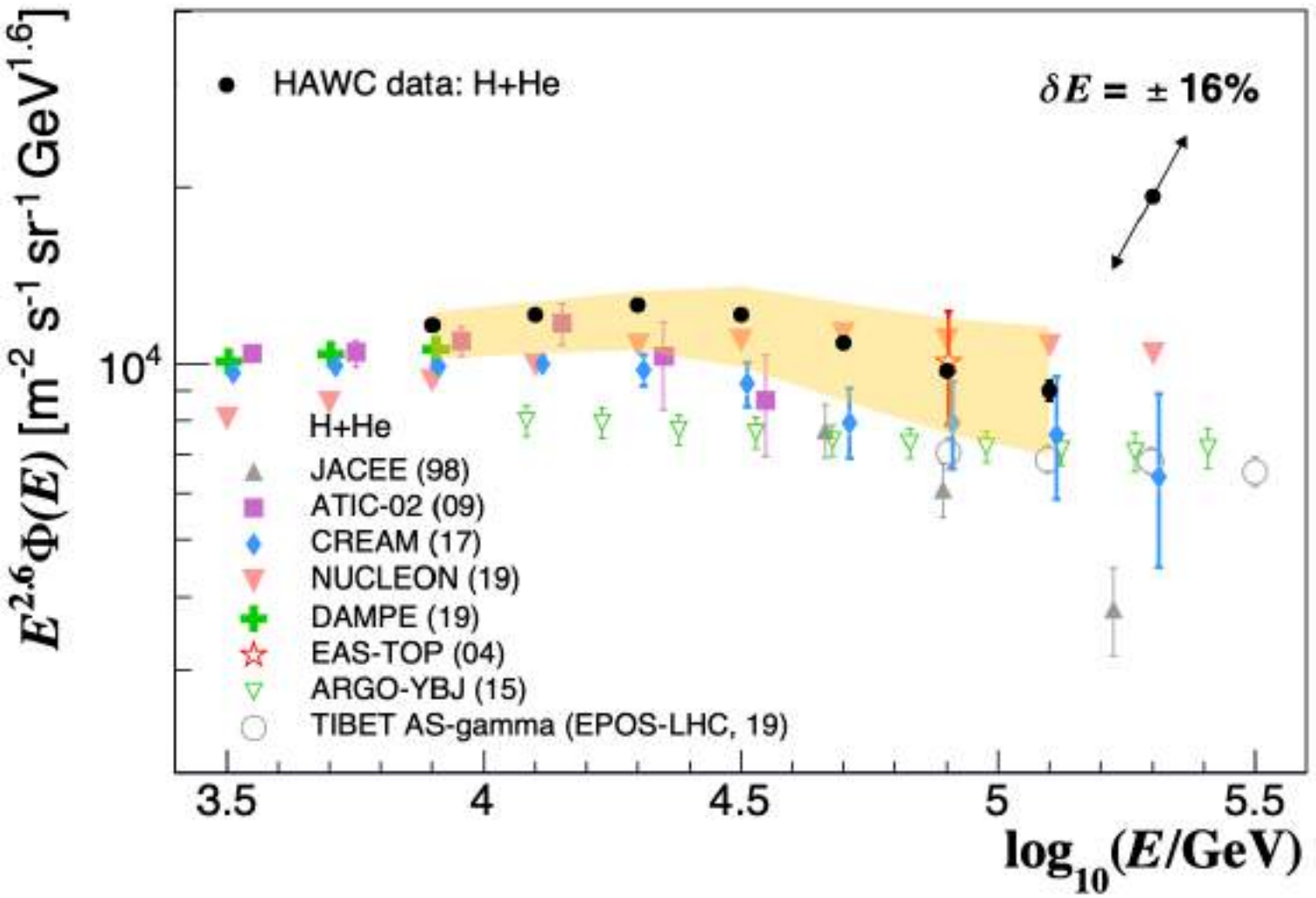
HAWC is a gamma-ray and cosmic-ray observatory in the state of Puebla, in Mexico, at an altitude of 4100 meters.

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)

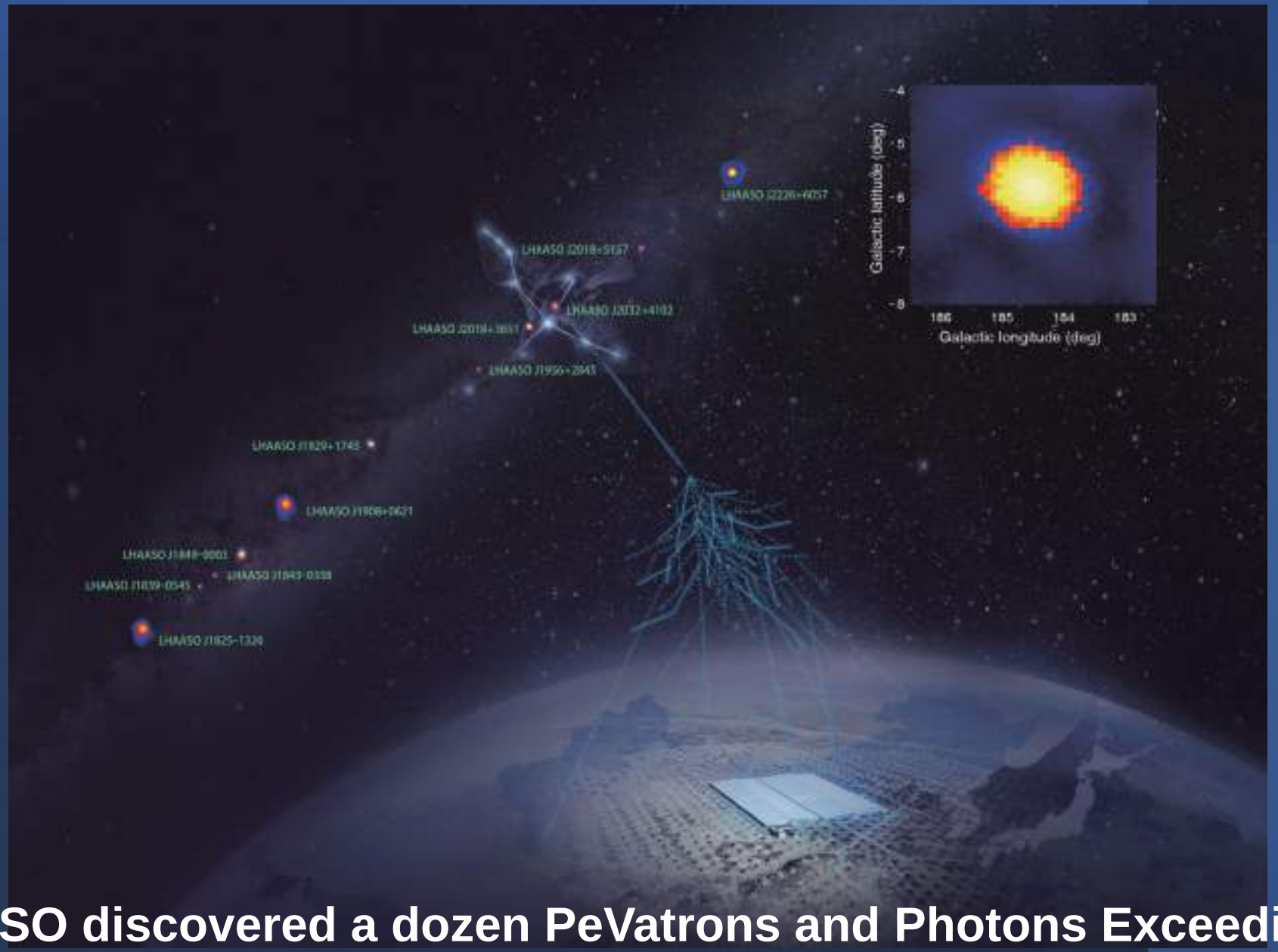


Recent HAWC results (2022): detection of gamma rays coming from the central zone of the galaxies Mrk 421 and Mrk 501



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.

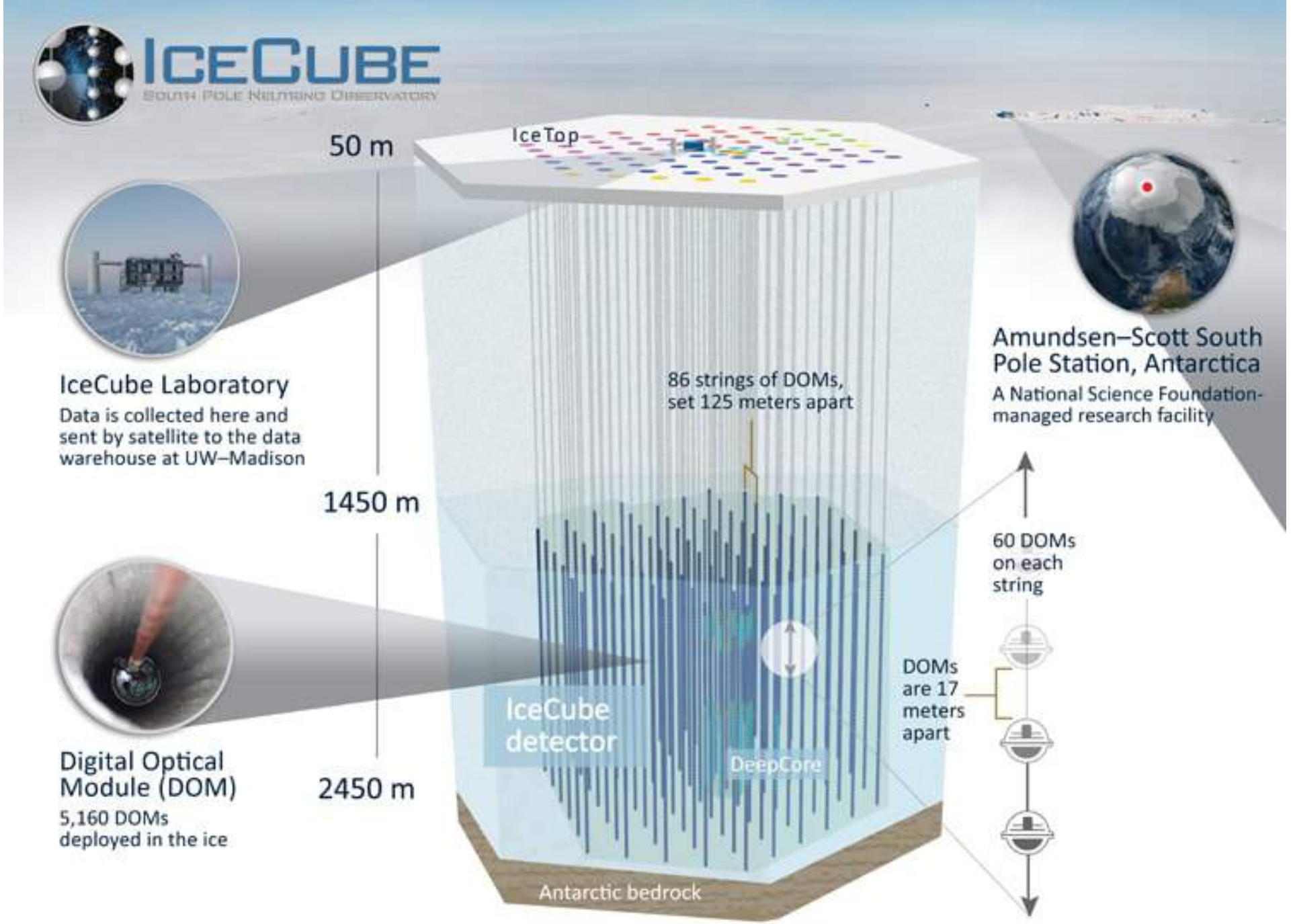


LHAASO discovered a dozen PeVatrons and Photons Exceeding 1 PeV and launches UHE Gamma Astronomy Era

- Ultrahigh- energy neutrinos

Facing a few difficulties in the ice…

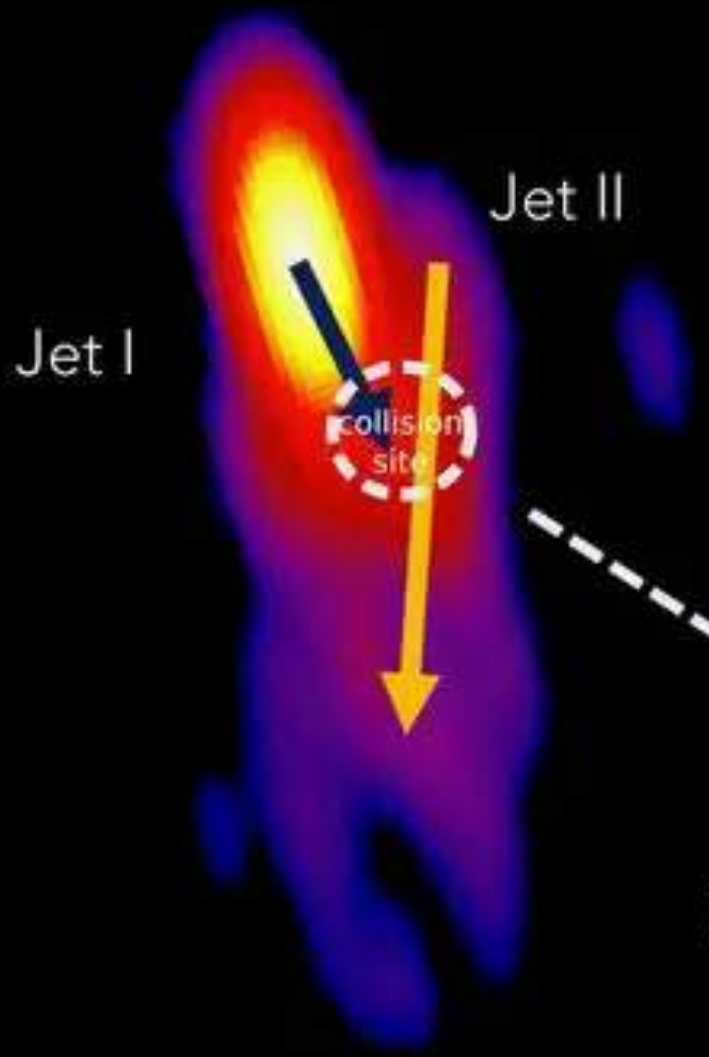
Facing a few difficulties in the ice...


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
86 strings of DOMs, set 125 meters apart
Amundsen–Scott South Pole Station, Antarctica
A National Science Foundation-managed research facility
1450 m
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

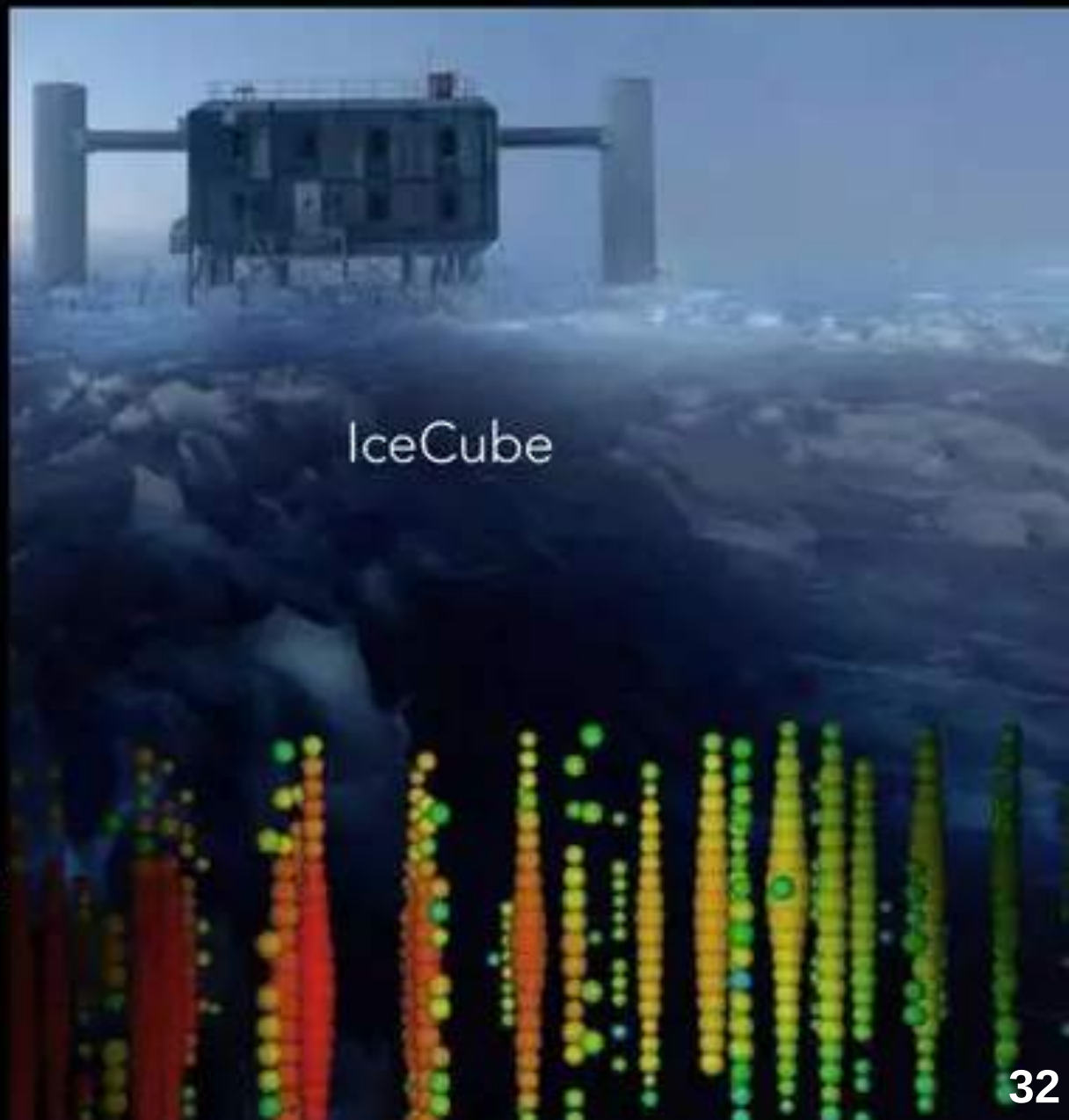
The dawn of the astroparticle multimessenger era

- 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.

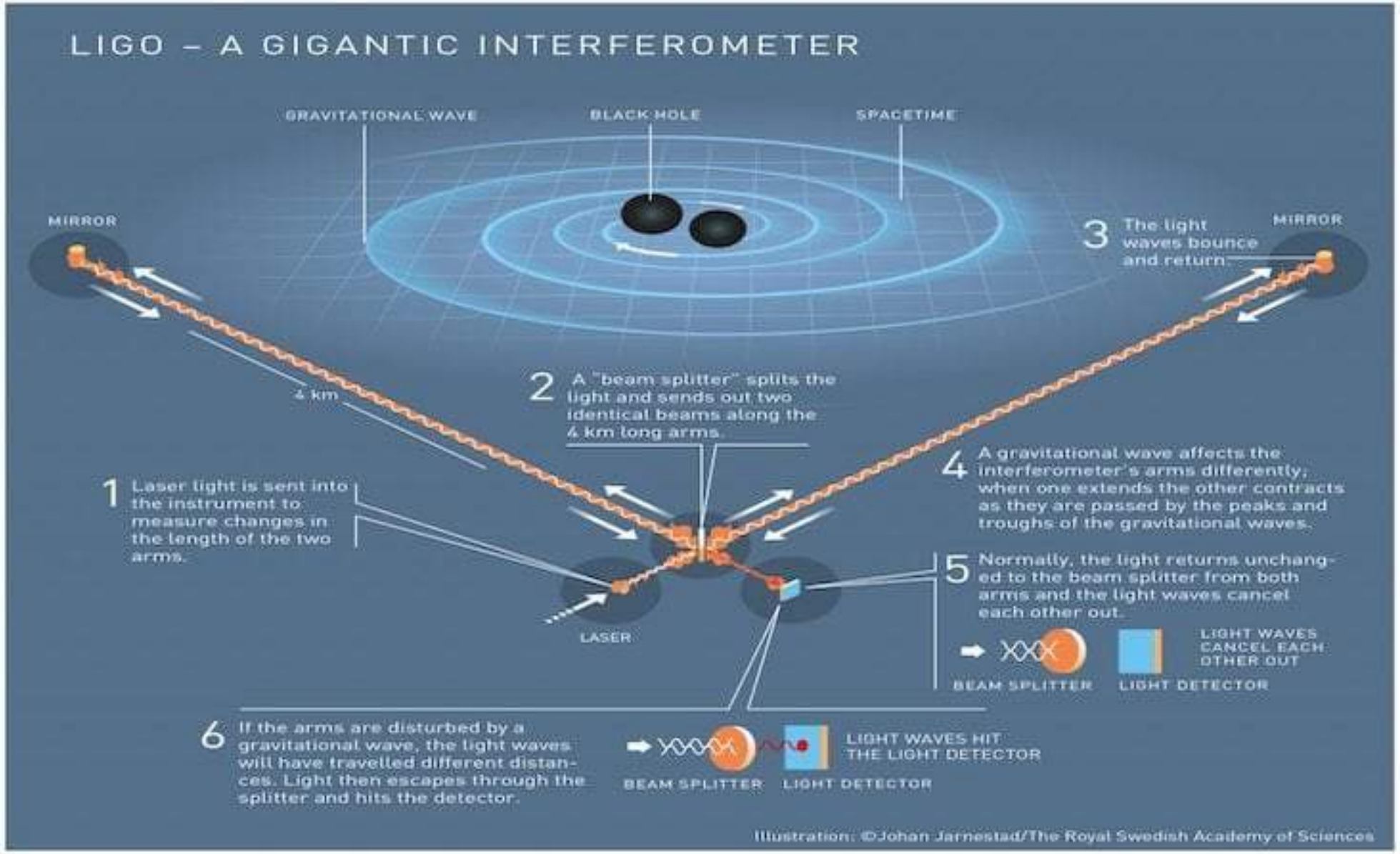
TXS 0506+056



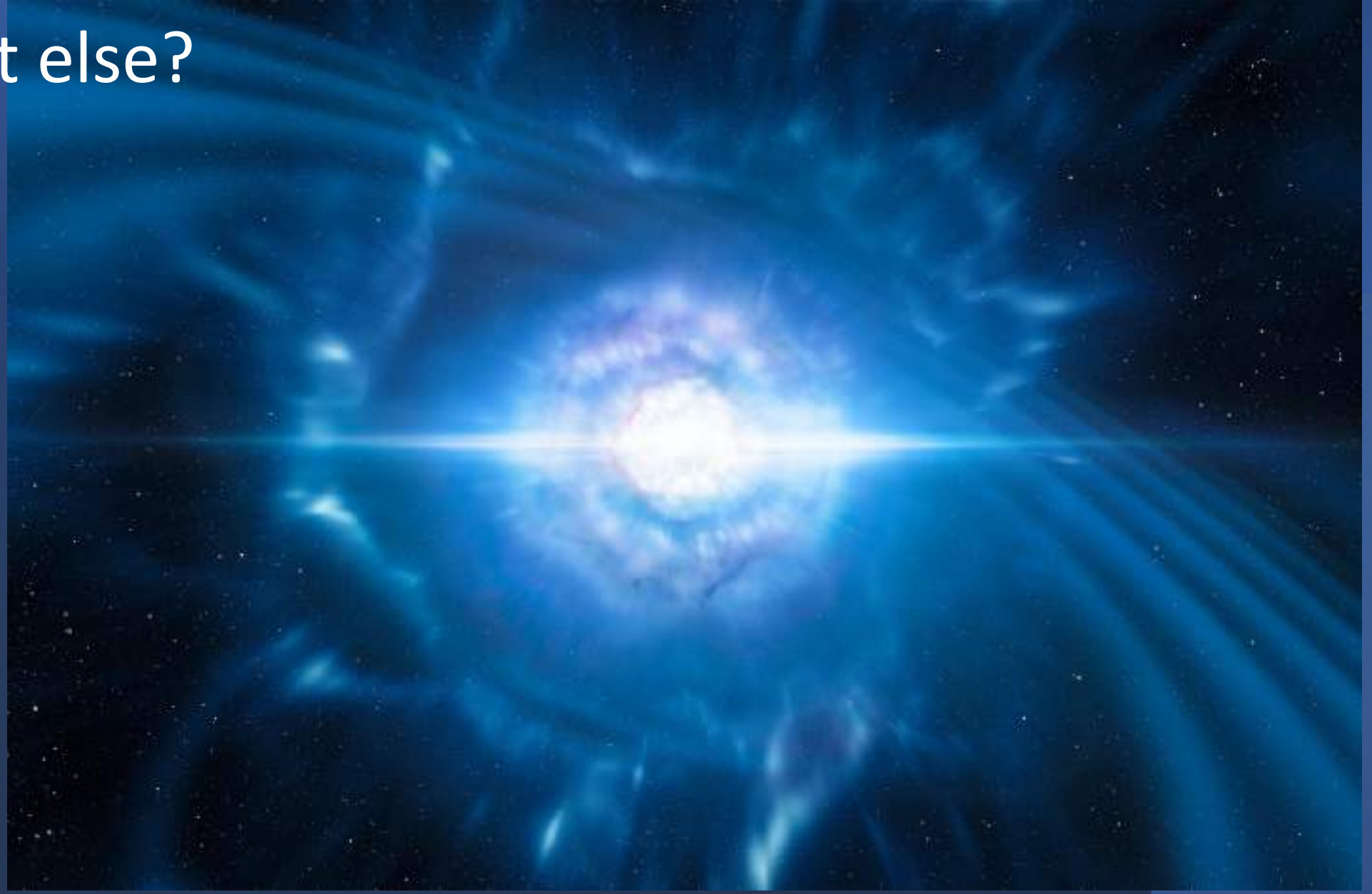
Neutrino



What else?


LIGO – A GIGANTIC INTERFEROMETER
GRAVITATIONAL WAVE
BLACK HOLE
SPACETIME
MIRROR
MIRROR
3 The light waves bounce and return
4 km
2 A "beam splitter" splits the light and sends out two identical beams along the 4 km long arms.
1 Laser light is sent into the instrument to measure changes in the length of the two arms.
4 A gravitational wave affects the interferometer's arms differently; when one extends the other contracts as they are passed by the peaks and troughs of the gravitational waves.
5 Normally, the light returns unchanged to the beam splitter from both arms and the light waves cancel each other out.
LASER
LIGHT WAVES CANCEL EACH OTHER OUT
BEAM SPLITTER
LIGHT DETECTOR
6 If the arms are disturbed by a gravitational wave, the light waves will have travelled different distances. Light then escapes through the splitter and hits the detector.
LIGHT WAVES HIT THE LIGHT DETECTOR
BEAM SPLITTER
LIGHT DETECTOR
Illustration: ©Johan Jarnestad/The Royal Swedish Academy of Sciences

What else?



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

And new projects under construction and development

The future

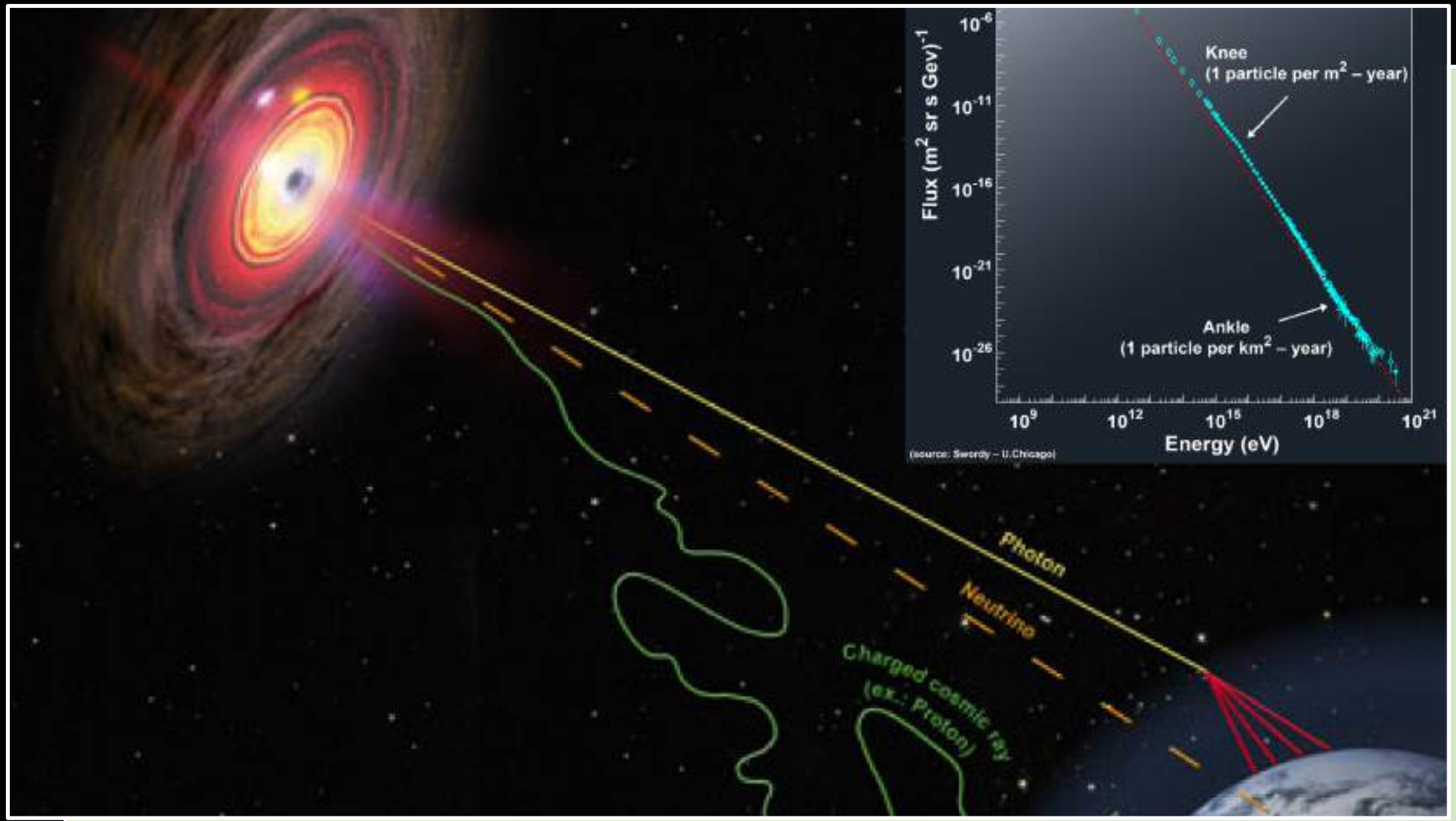
coming soon

Ground-based Gamma-ray Astronomy Network

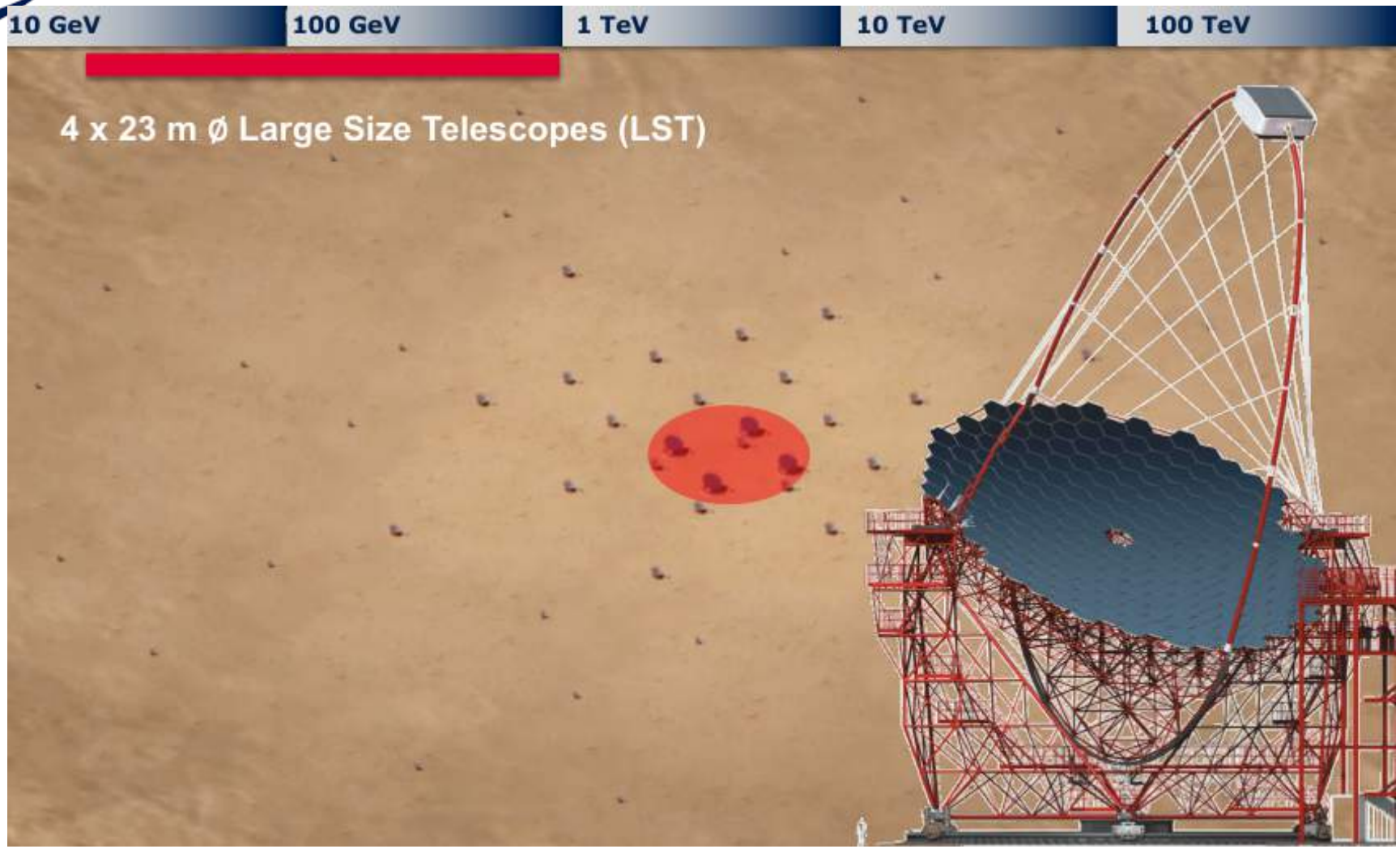
Courtesy Dr. Ulisses Barres

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.**



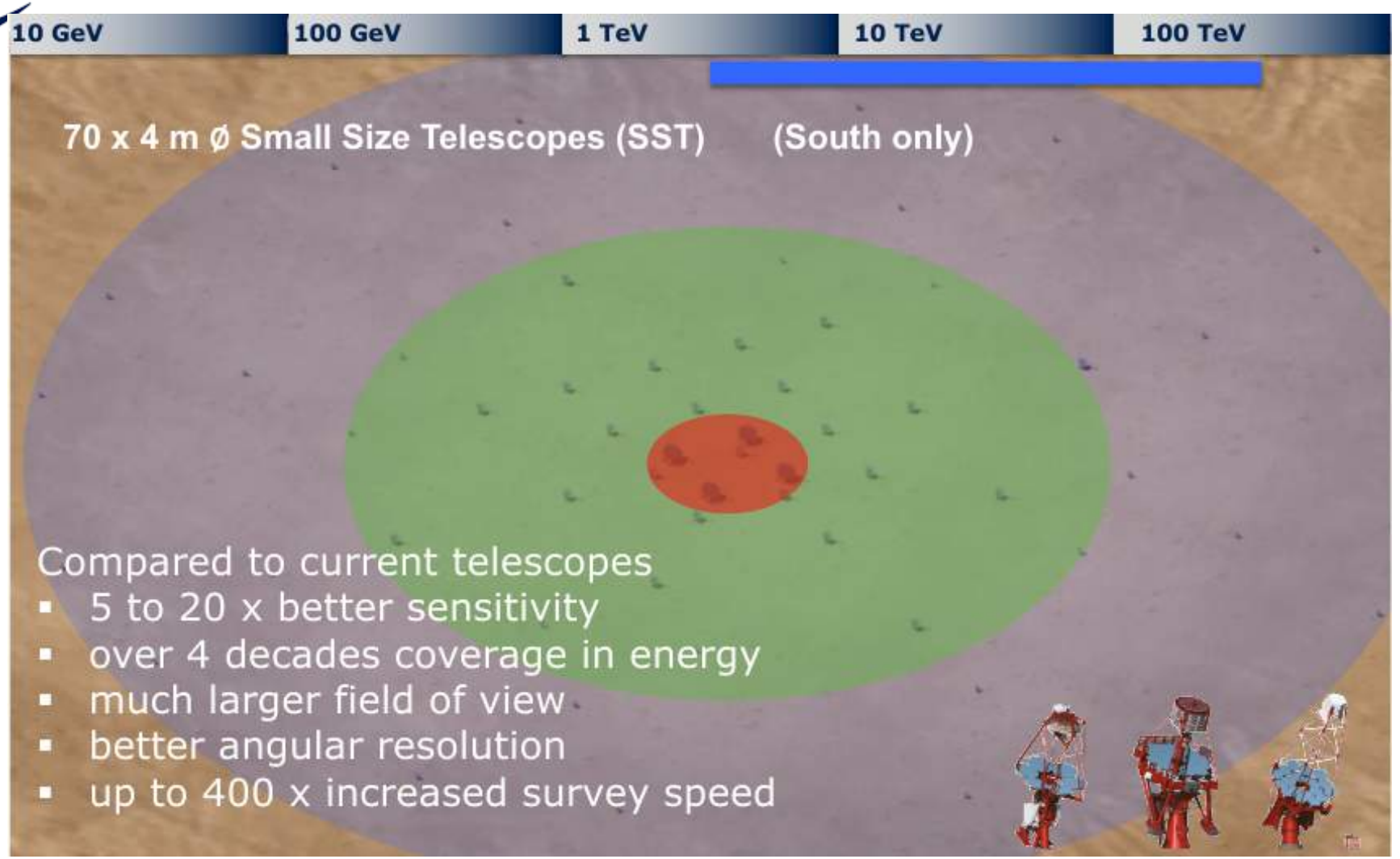
PeVatrons: The hunt for the origin of Galactic cosmic rays with CTA



Slide by Prof. Werner Hofmann

Slide by Prof. Werner Hofmann

cta
cherenkov telescope array

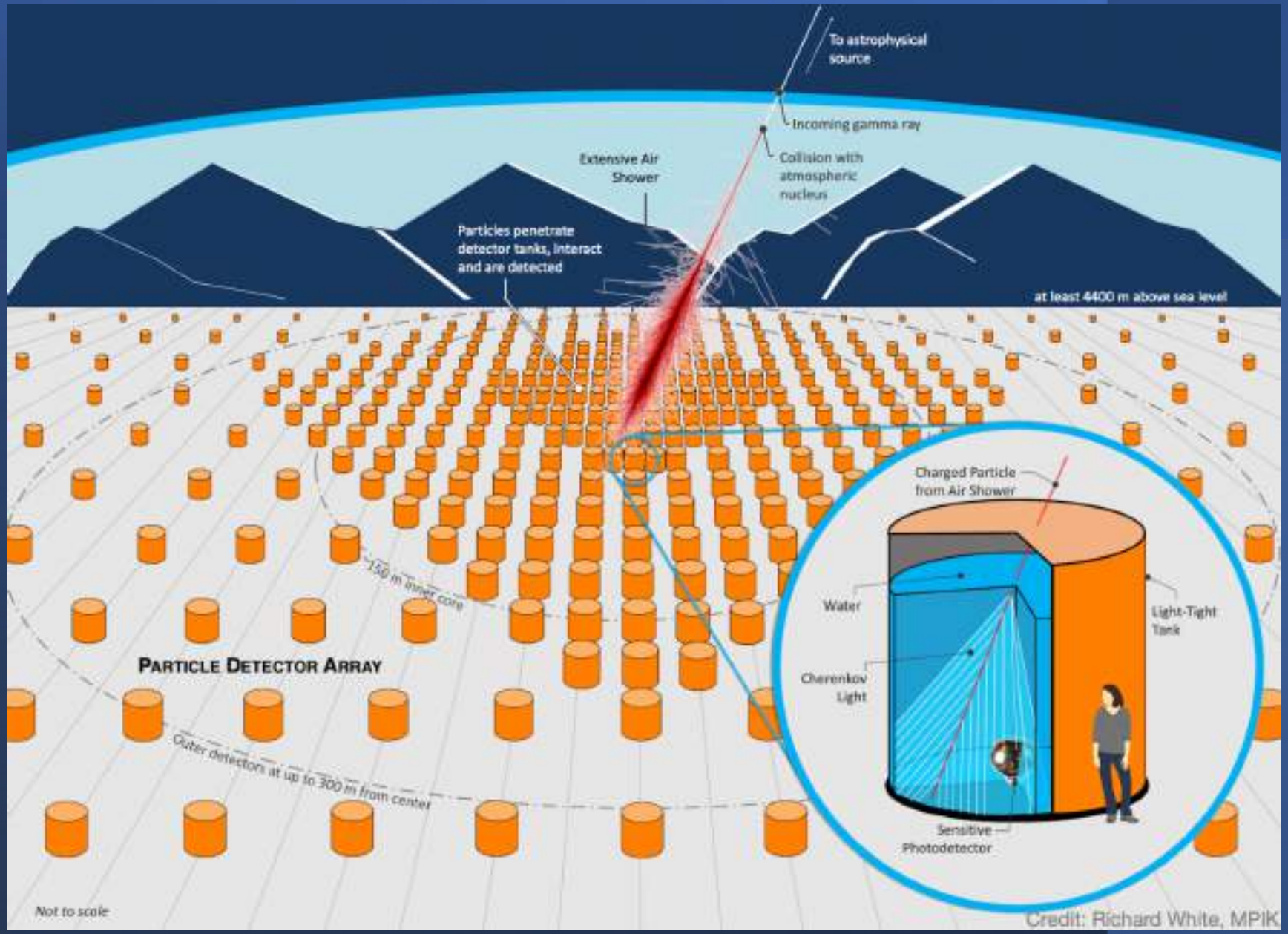


Slide by Prof. Werner Hofmann

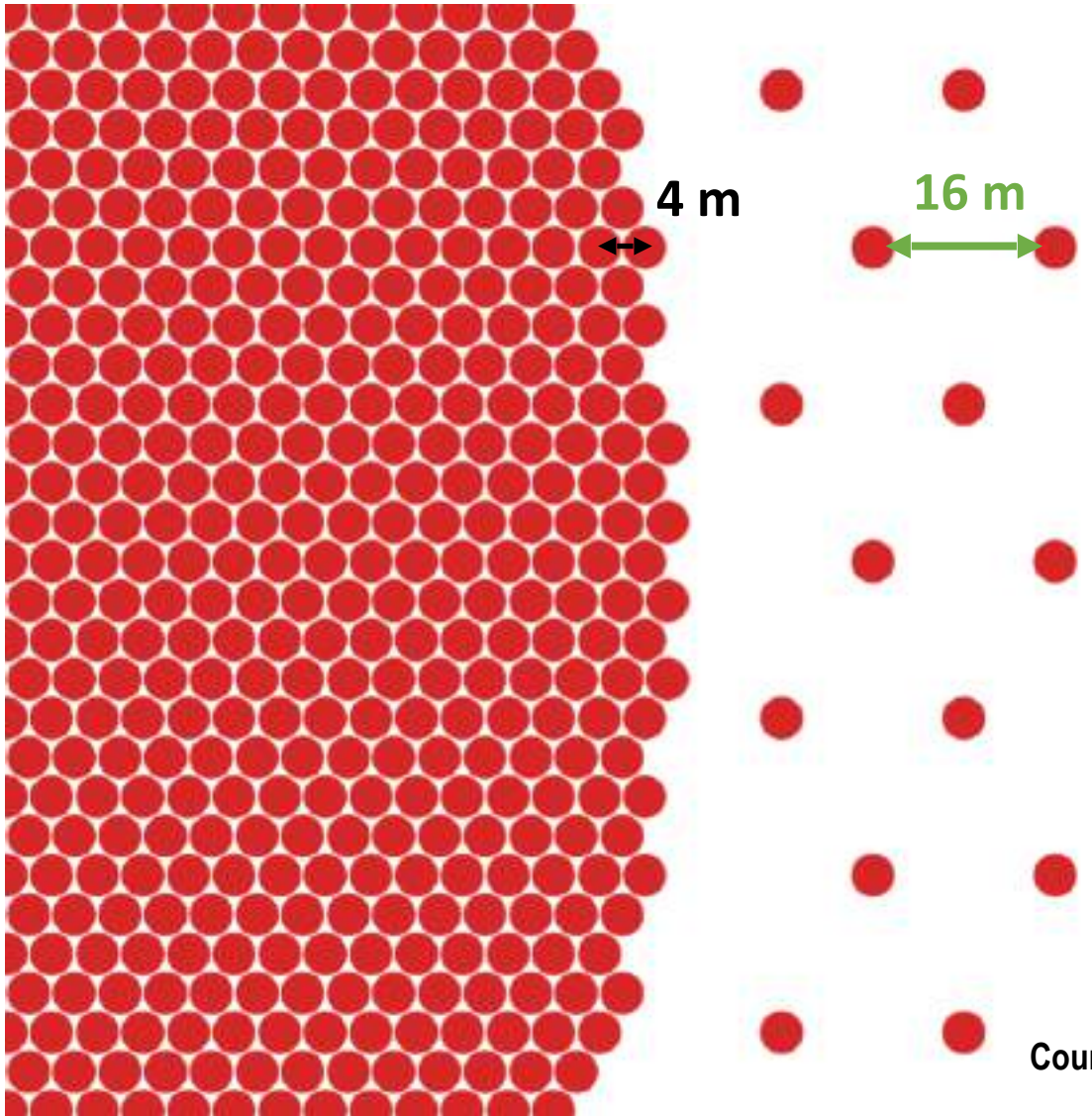
Made in Brazil

Courtesy of Prof. Vitor de Souza

SWGO
The Southern Wide-field Gamma-ray Observatory



The baseline detector concept

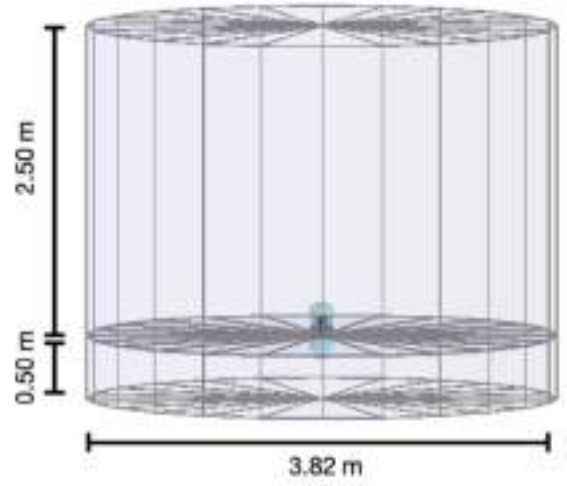


Core: Ø 320 m, FF = 80%
5,700 WCD units

Outer: Ø 600 m, FF = 5%
880 WCD units

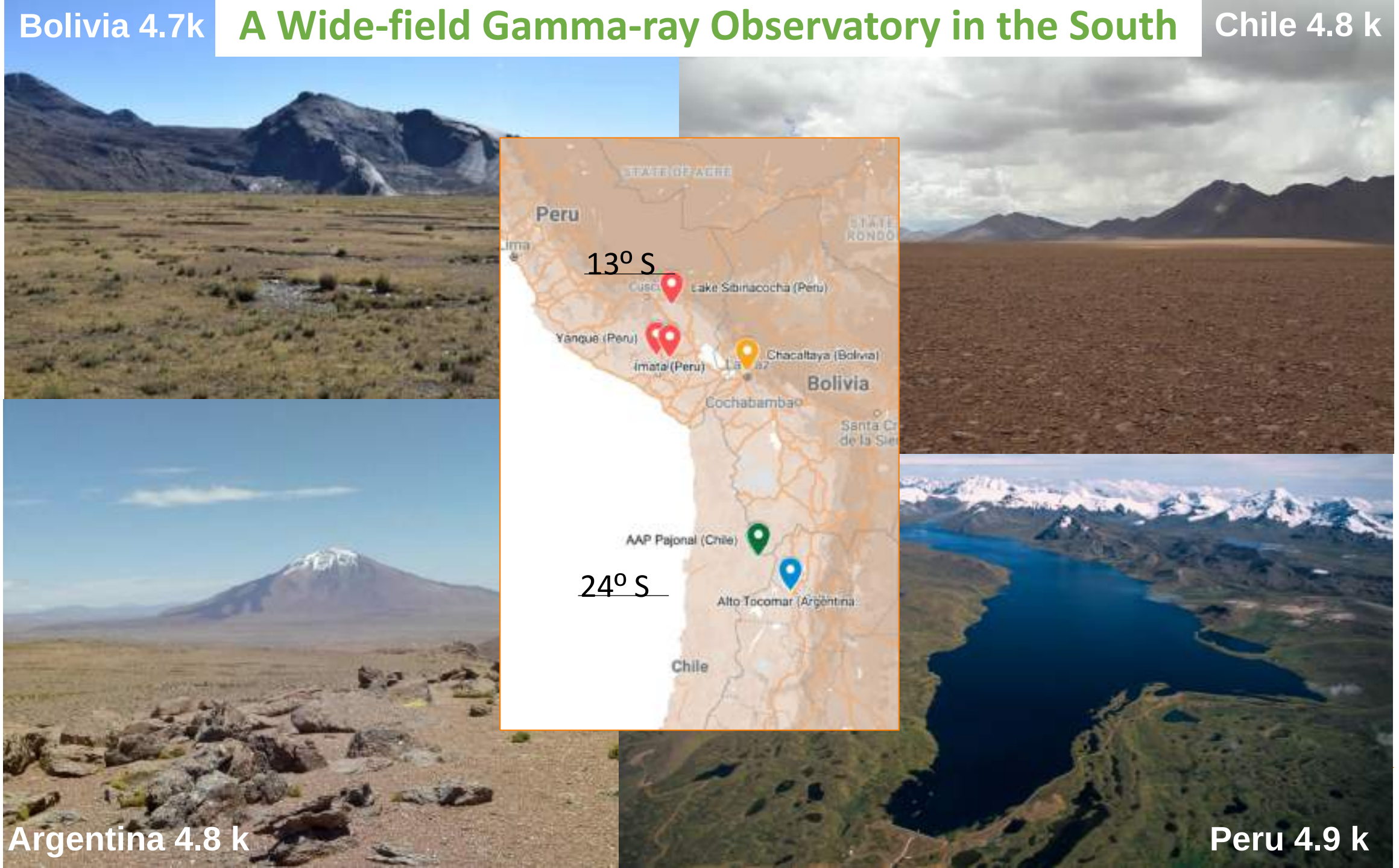
Altitude: 4,700 m a.s.l.

✧ muon counting

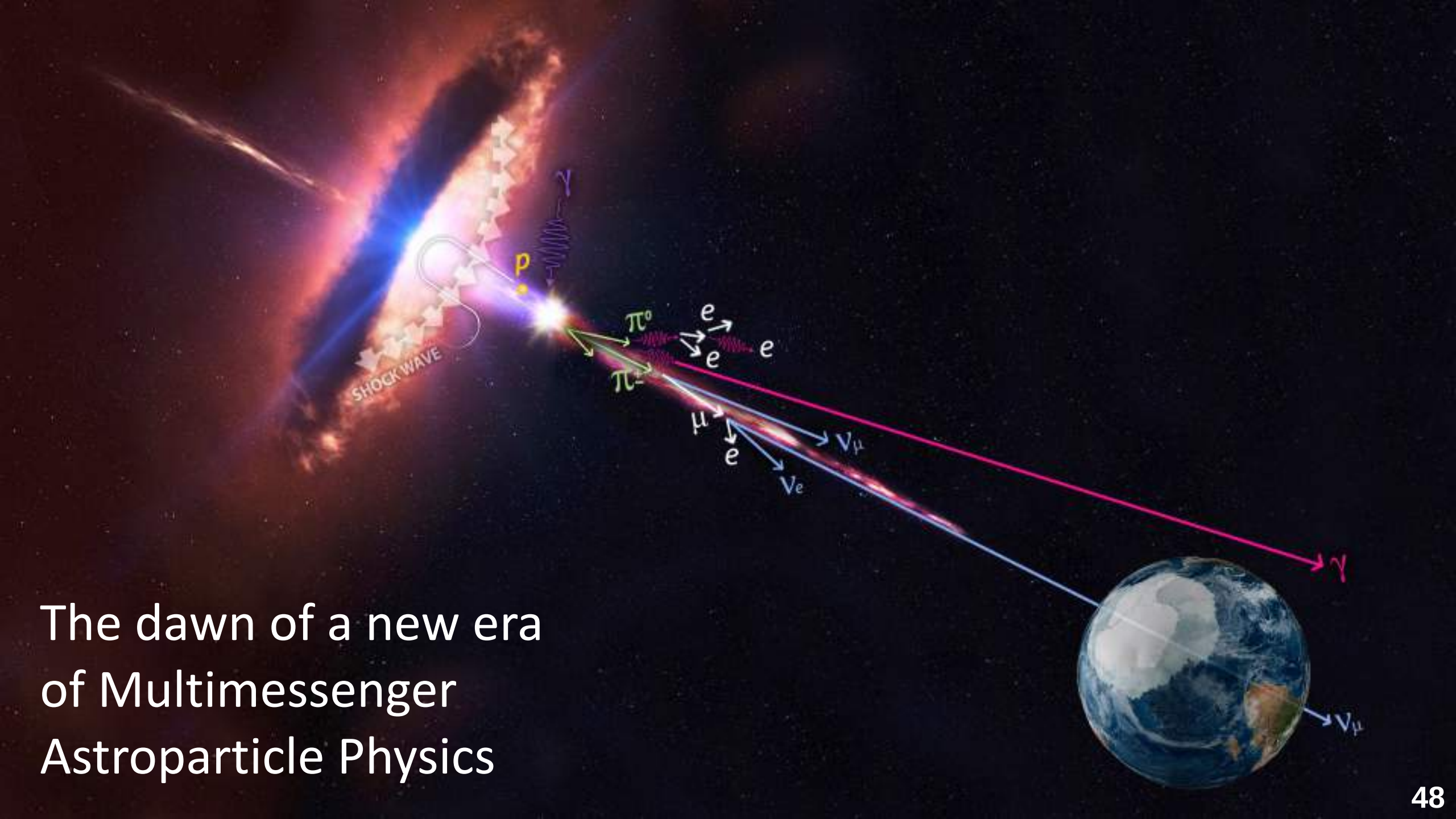


Courtesy Dr. Ulisses Barres

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 the many other
experiments aiming to detect dark matter,
dark energy and gravitational waves!

Pamela, CDMS, Xenon, DAMA, WMAP, LIGO/Virgo and many others


Thank you for your attention!

Backup

O Brasil participa com R$ 2,5 milhões, por meio de um projeto temático da FAPESP (R$ 1,8 milhão) e do Programa de Núcleos de Excelência em Pesquisa (Pronex) do Ministério da Ciência e Tecnologia (R$ 700 mil).

Compromisso Brasileiro
Construção do Observatório Sul

- **Custo total de construção do Observatório Pierre Auger: US$ 53.000.000**

- **Participação brasileira na construção: US$ 3.500.000 / (~ R$ 6.000.000)**

Contribuição Brasileira para a construção do Observatório Auger

Contribuição da ordem de R$ 6.000.000 (US$ 3.500.000 na época):

- **FAPESP: R$ 4.500.000 para importação de resina, vidro ótico, caixa de abertura, shutters, cortinas e lentes corretoras, fabricação de tanques e transporte desses itens.**
- **FINEP/Fundo Verde-Amarelo: R$ 2.100.000 para fabricação de tanques, aquisição de baterias, baterias, passagens, diárias, serviços e equipamentos.**
- **Programa de Núcleos de Excelência em Pesquisa PRONEX - MCT: R$ 700.000,00 (era US$ 700.000 na outorga)**
- **FAPERJ: R$ 72.000 para passagens e diárias;**
- **CBPF: R$ 220.000 para custos operacionais e baterias.**

Custos Operacionais

- **O custo total anual de operação e manutenção do Observatório Pierre Auger é de ~US$ 1.900.000 e tem-se mantido constante ao longo da última década.**

- **Total de contribuições das agências brasileiras desde o início de operação: ~US$ 2.000.000.**

- **Participação brasileira anual ~US$ 120.000, cerca de ~6%.**

Formação de recursos humanos

(FAPESP, CNPq, CAPES)

- Cerca de 20 bolsas de pós-doutorado
- Cerca de 40 teses de doutorado
- Cerca de 50 dissertações de mestrado
- Cerca de 100 bolsas de iniciação científica

Resultados científicos

- Cerca de 120 publicações da Colaboração em revistas internacionais de renome.
- Mais de 800 apresentações em conferências internacionais em nome da Colaboração.
- Cerca de 800 citações, excluindo autocitações (INSPIRE).