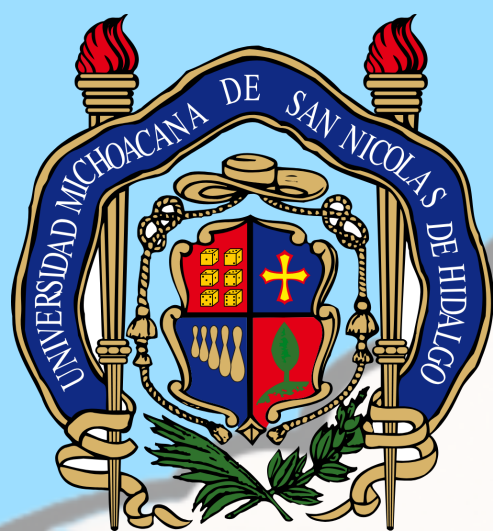




HAWC & PARTICLE PHYSICS FROM THE SMALLEST TO THE BIGGEST

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2026 Annual Meeting of the Division of Particles
and Fields of the Mexican Physical Society

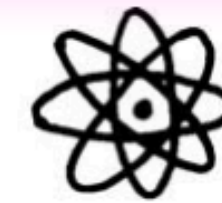
June 18, 2026



ASTROPARTICLE PHYSICS

Particle Physics

Nuclear Physics



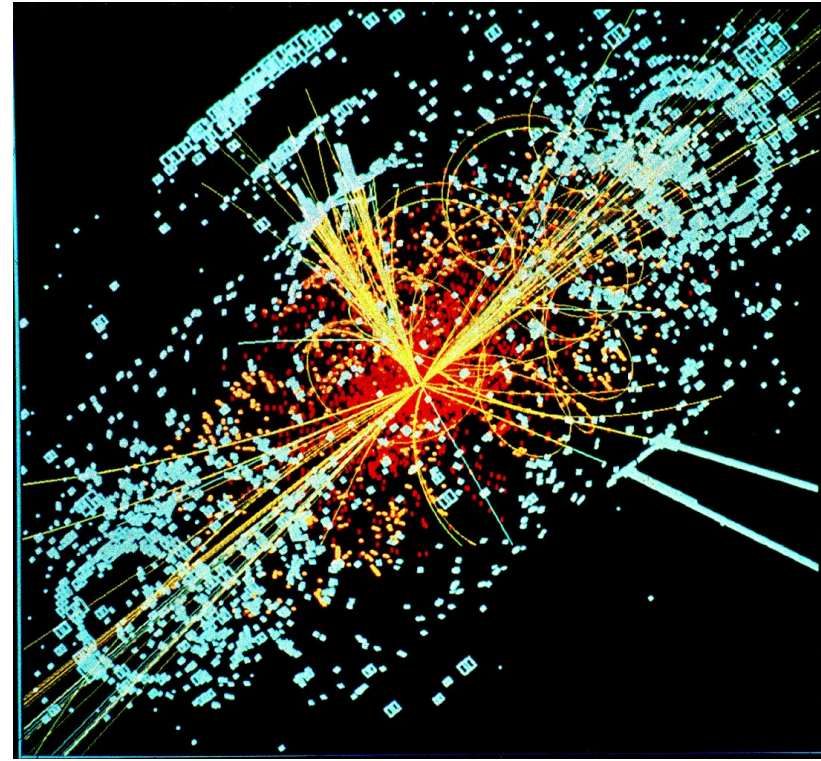
Astrophysics

Cosmology



Gruppen, C. (2005). *Astroparticle physics*. Berlin, Heidelberg: Springer Berlin Heidelberg.

Fundamental physics



<https://cds.cern.ch/record/2646378>

Astroparticle physics

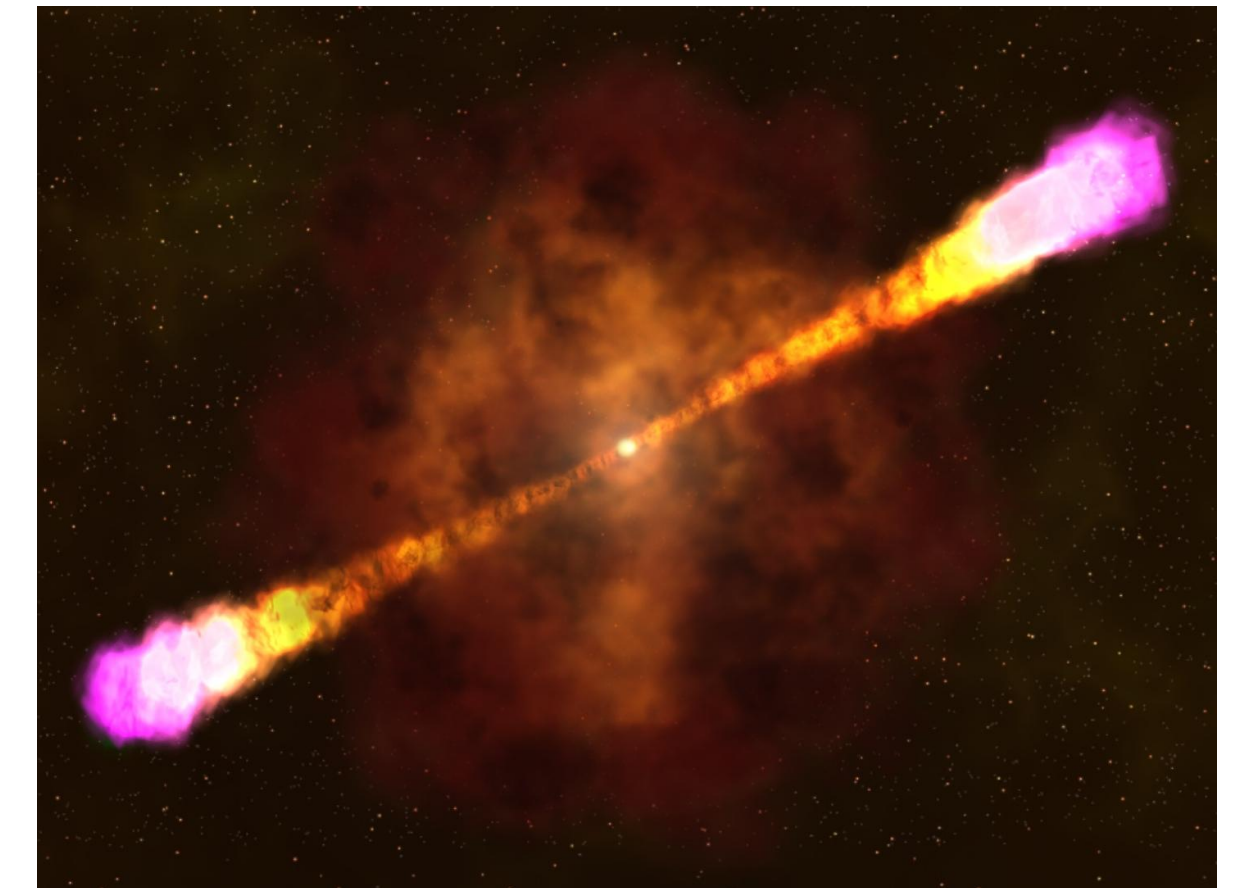


Cosmic rays



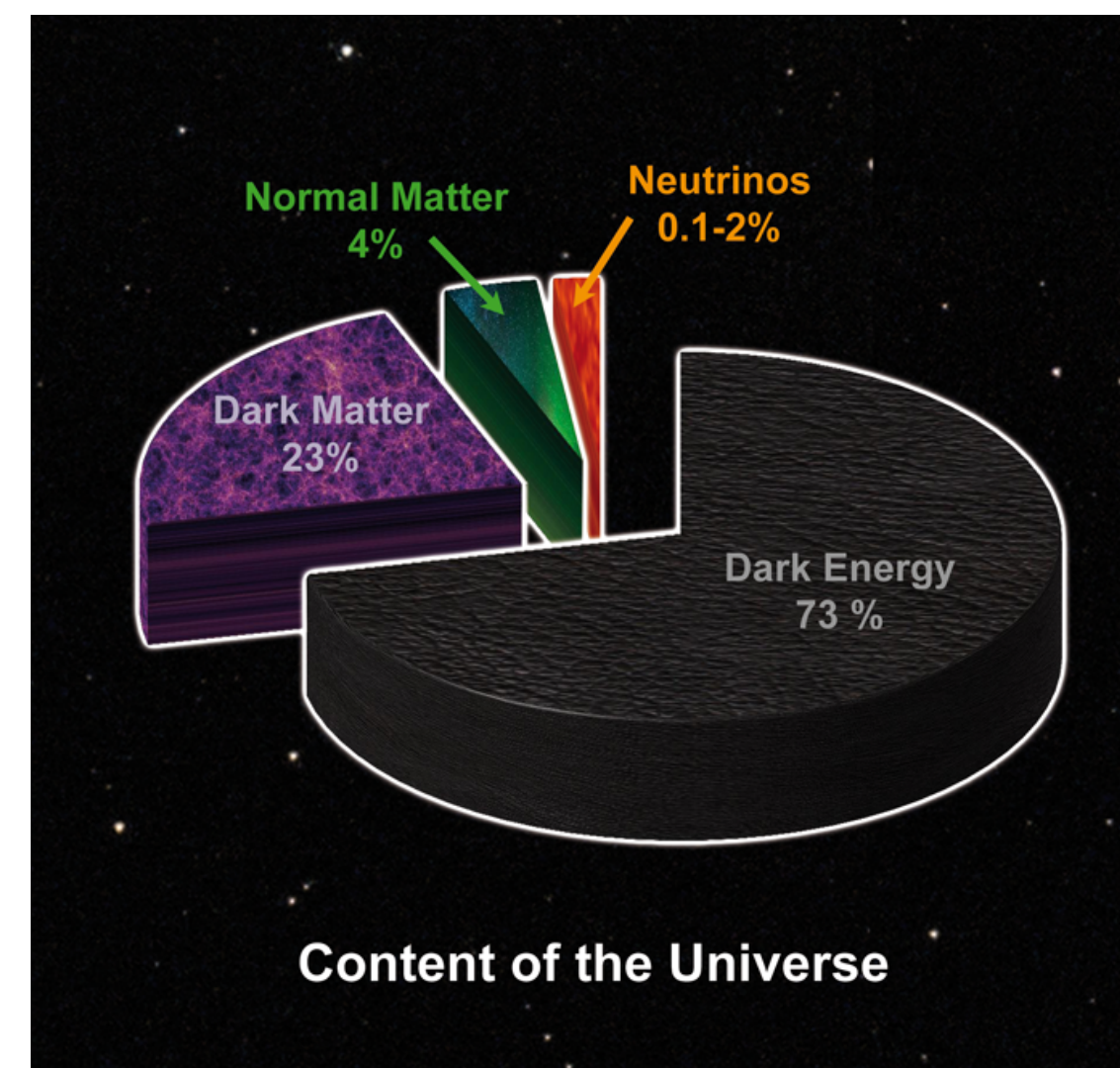
<https://www.innovationnewsnetwork.com/furthering-understanding-origins-cosmic-rays/12019/>

Gamma rays

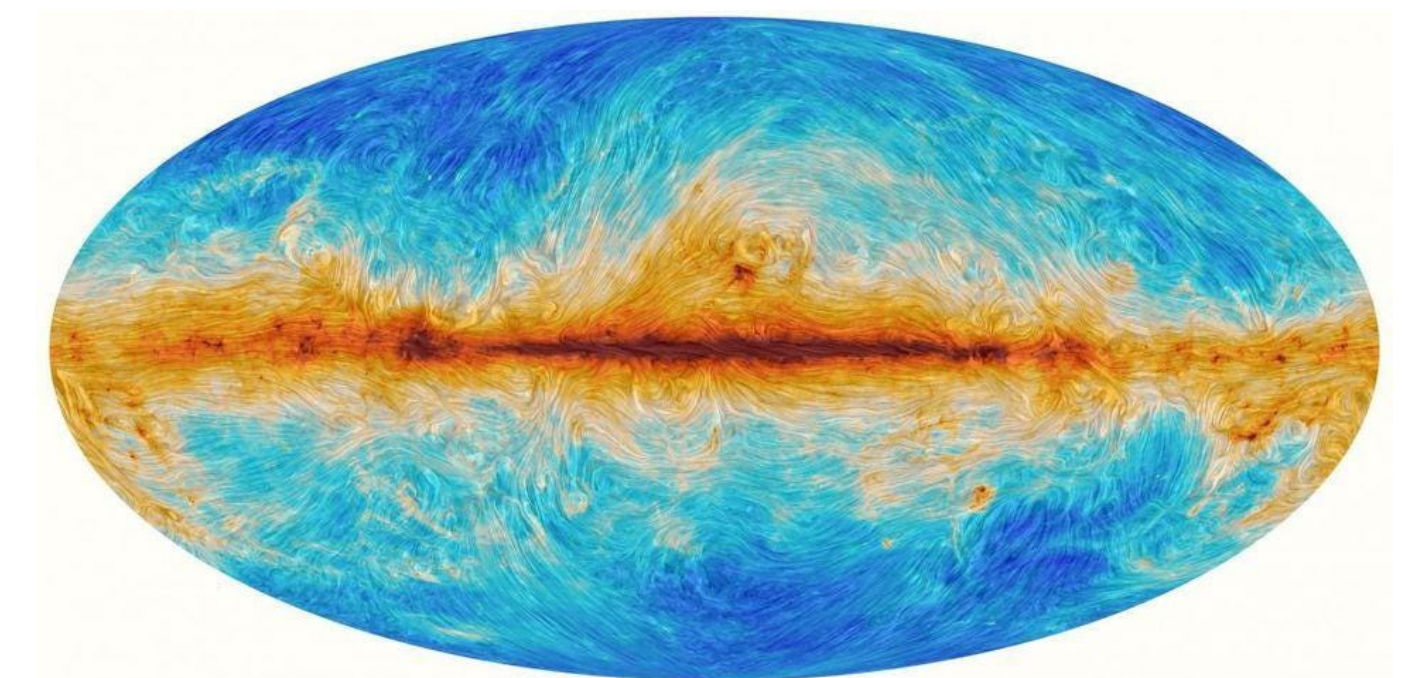


<https://www.psu.edu/news/research/story/ultra-bright-gamma-ray-burst-shakes-theories-light-production>

Dark matter searches

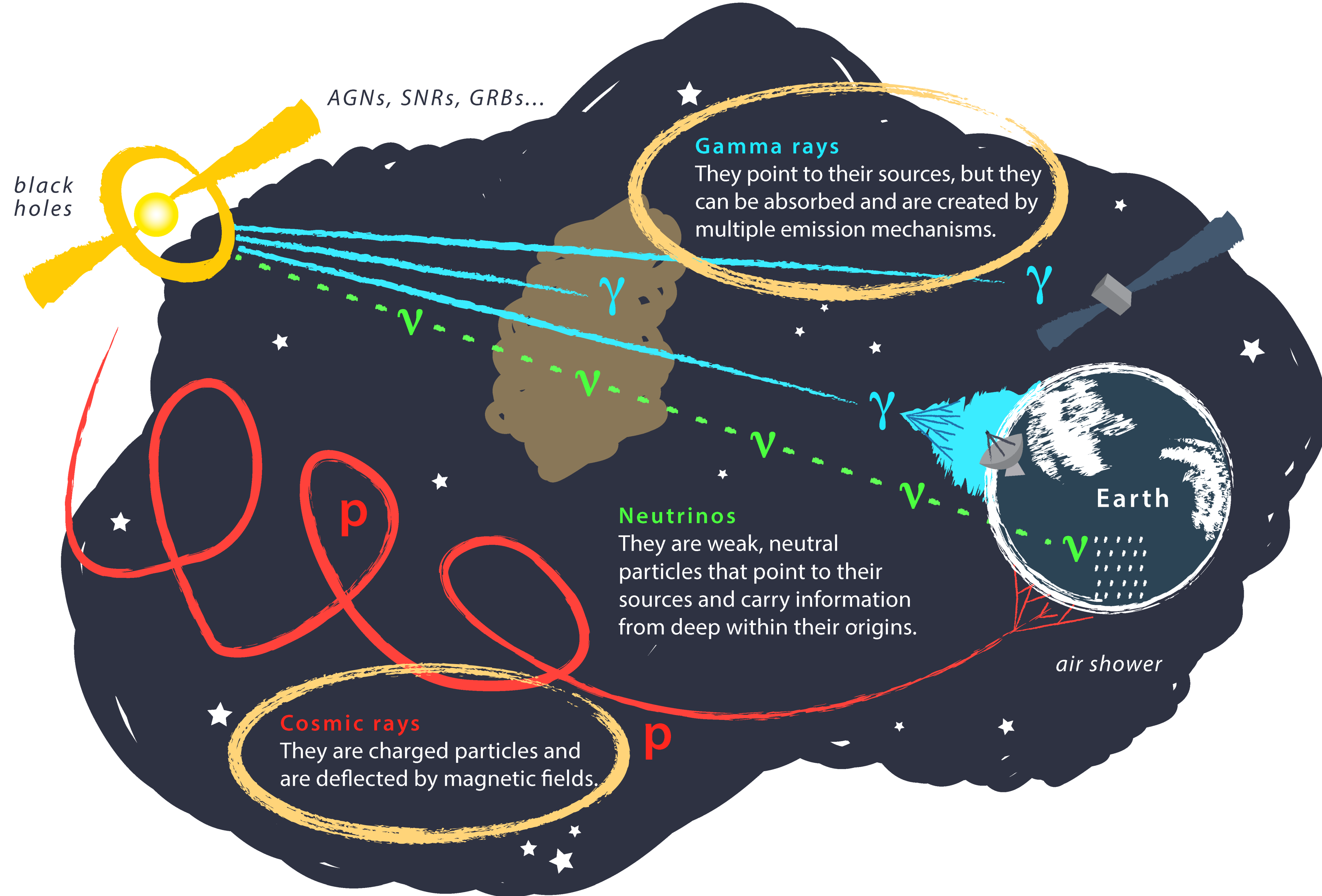


Galactic and extragalactic magnetic fields



<https://medium.com/starts-with-a-bang/this-is-what-the-milky-ways-magnetic-field-looks-like-a805e8a6edf2>

THE HIGH ENERGY UNIVERSE



Source: IceCube

Cosmic Rays: the most energetic particles in the universe

- ◆ Relativistic particle population, mostly charged, that hit Earth from outer space.

- ◆ **Composition:**

- ◆ Atomic nuclei (99%): H (85%), He (12%), $Z > 2$ (3%)

- ◆ Electrons (1%)

- ◆ Antiparticles (<1%)

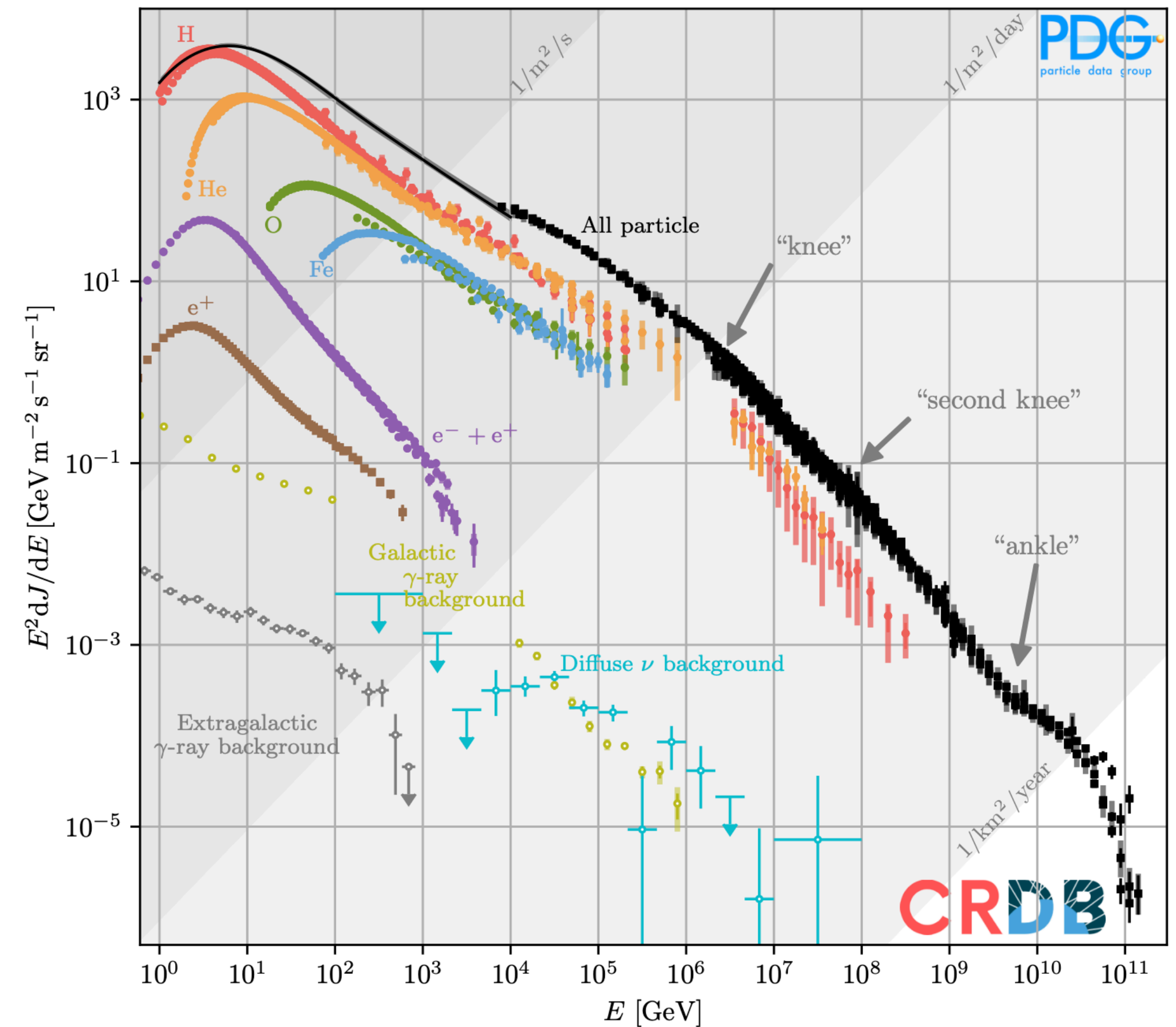
- ◆ **Spectrum:**

- ◆ 100 MeV to 1 ZeV

- ◆ Power law $\Phi(E) \propto E^{-\gamma}$

- ◆ **Origin:**

- ◆ Galactic and extragalactic

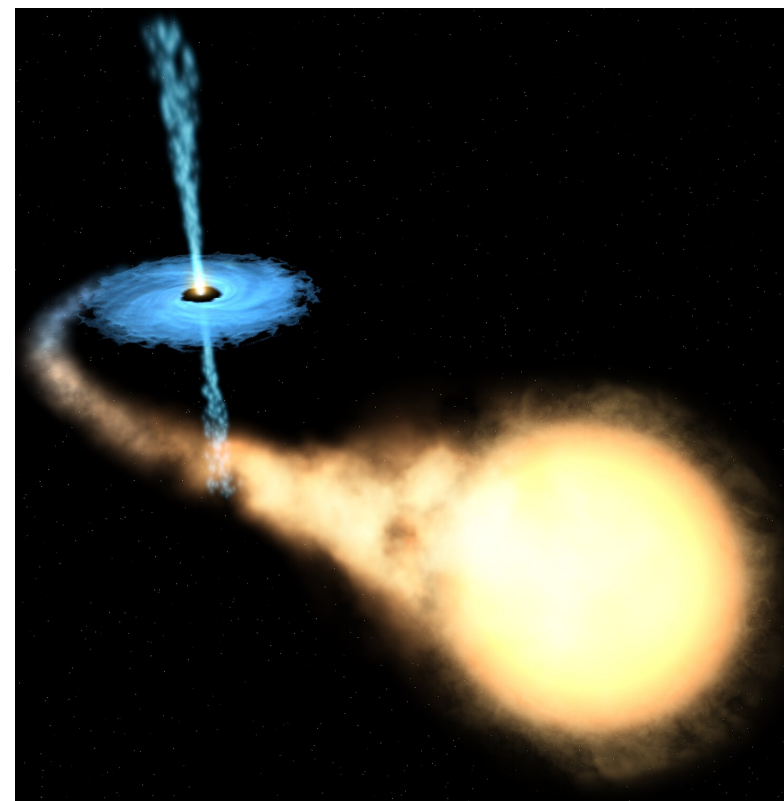


R. W. et al (Particle Data Group) 2022

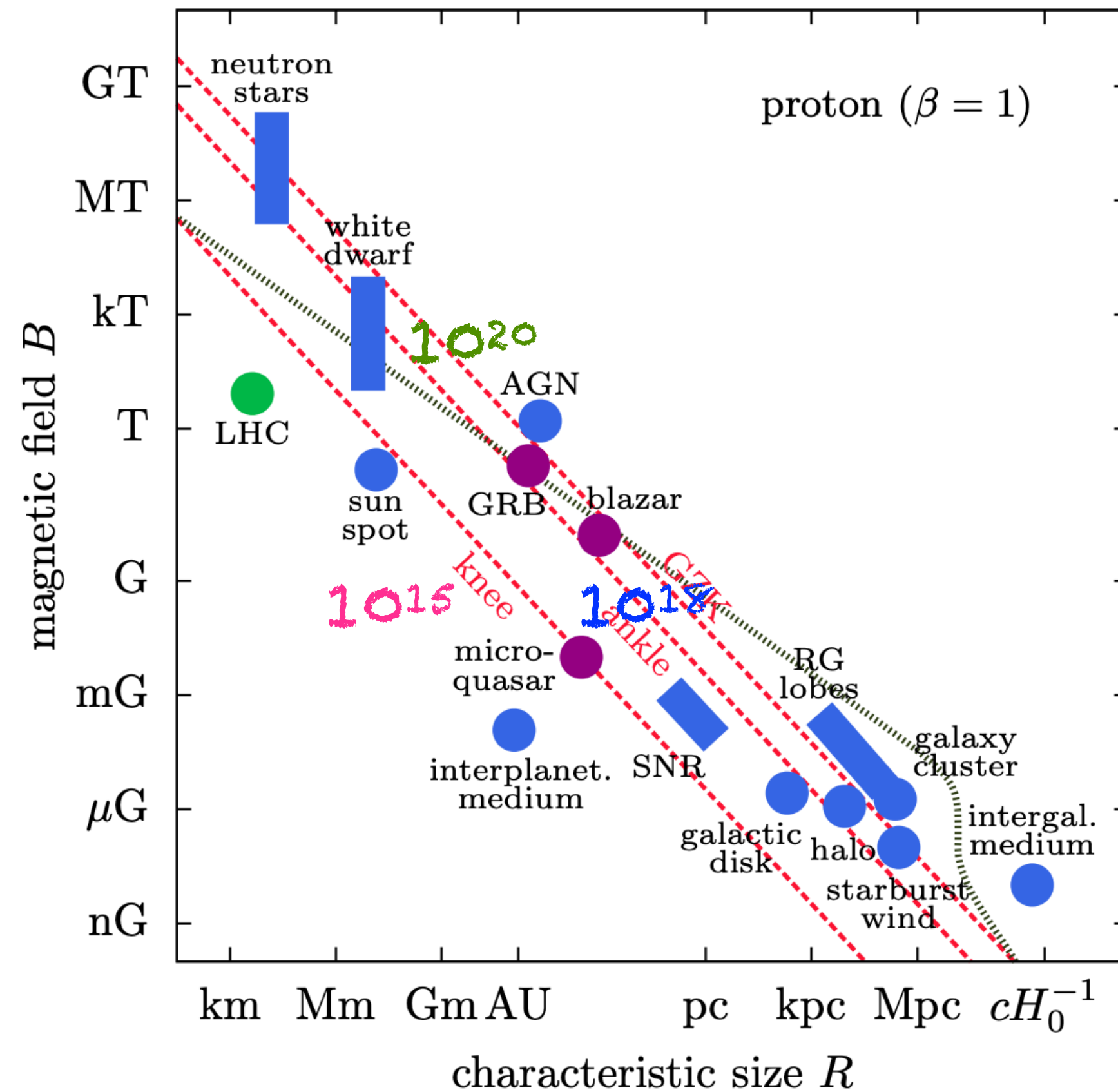
Extraterrestrial accelerators



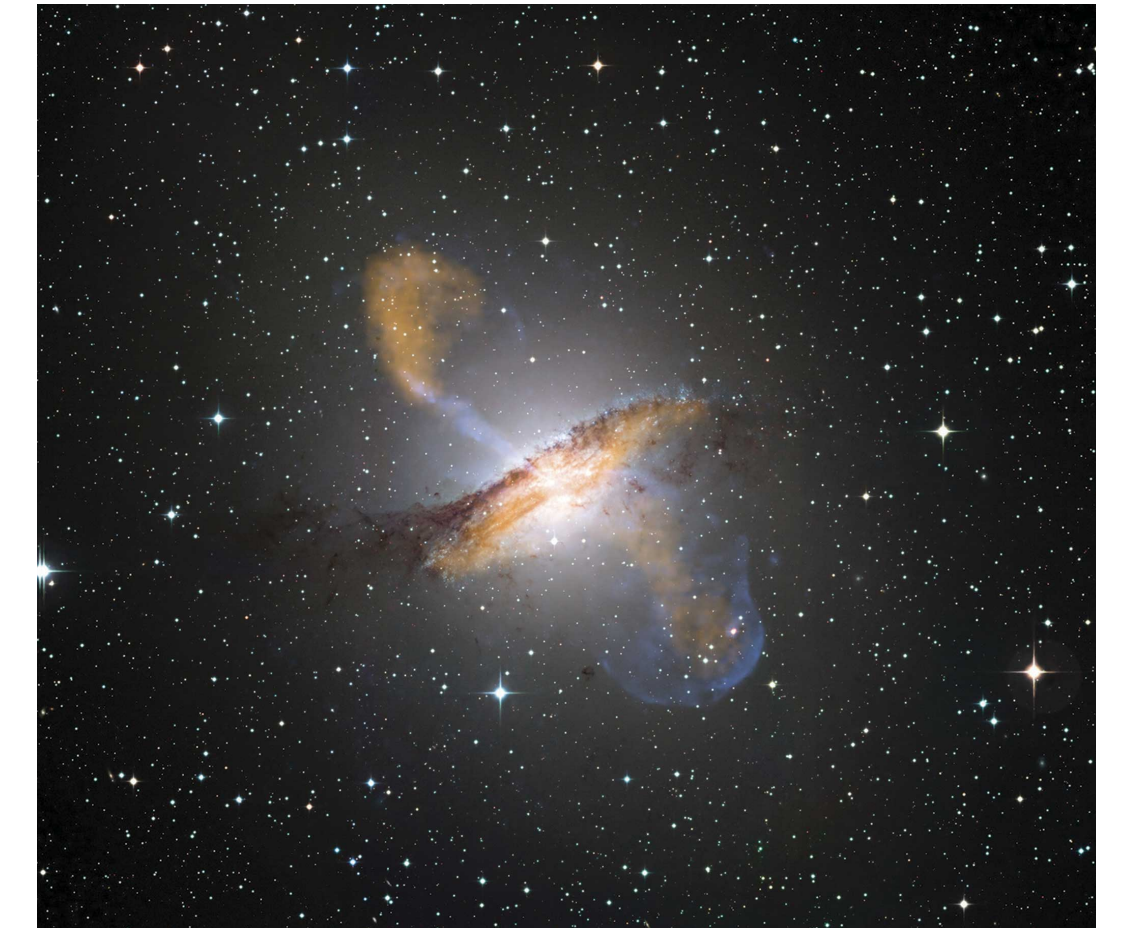
Por NASA and The Hubble Heritage Team (STScI/AURA)



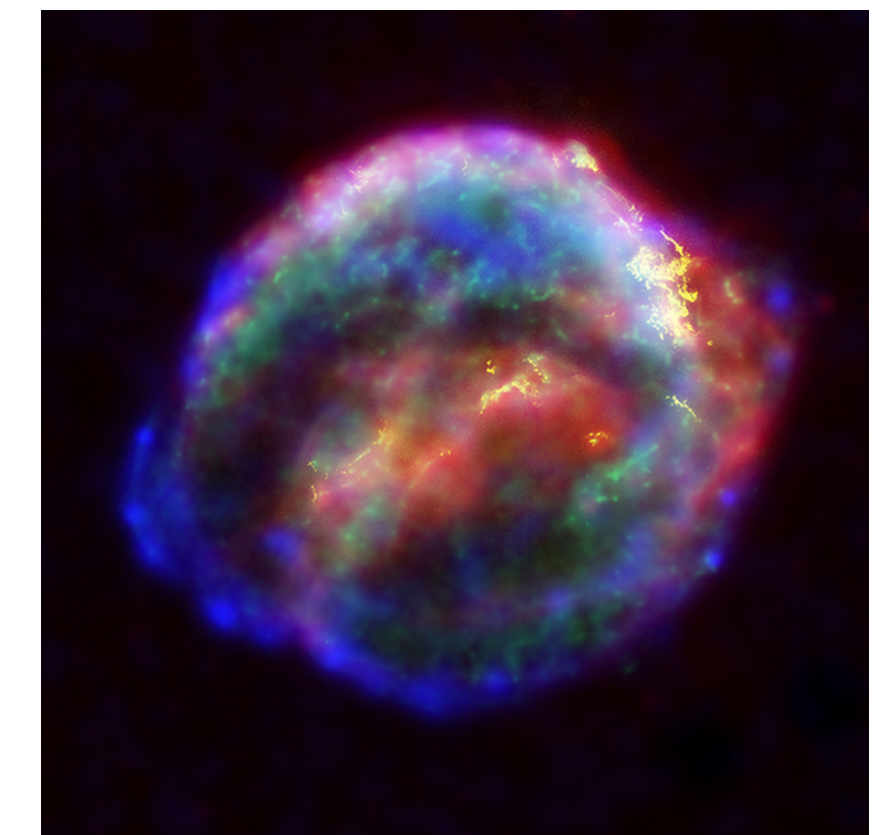
ESA, NASA, and Felix Mirabel



Collaboration, I., et al. "Neutrinos and Cosmic Rays Observed by IceCube." (2017).



Centaurus A: ESO/WFI; MPIfR/ESO/APEX/A.Weiss et al.; NASA/CXC/CfA/R.Kraft et al



SN Kepler: NASA/ESA/JHU/R.Sankrit & W.Blair

HAWC: Overview

Gamma & Cosmic rays Observatory

- ◆ **Location:** Parque Nacional Pico de Orizaba
- ◆ **Altitude:** 4100 m a.s.l. atmospheric depth of 637 g/cm²
- ◆ **Main array:** 300 water Cherenkov detectors, area of 22,000 m²
- ◆ **Detectors:** 7.3 m of diameter, 5.4 m height and contain 200,000 l of water
- ◆ **PMTs:** in each tank 3 PMTs of 8 in and 1 PMT of 10 in
- ◆ **Energy range:** 500 GeV - 100 TeV for gamma rays and TeV-PeV for cosmic rays



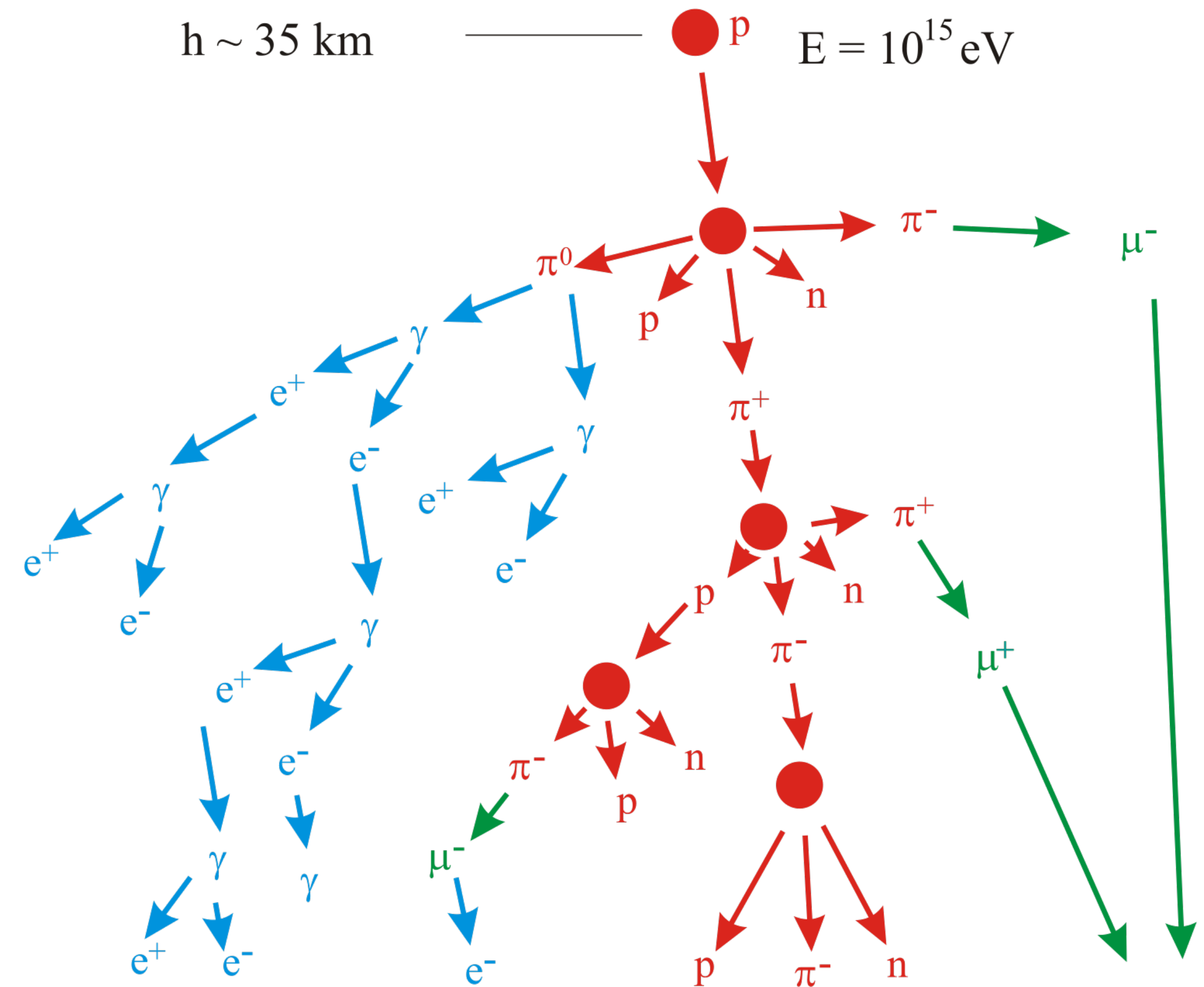
Foto: Pedro Mirón y Rafael Nieto.

https://unamglobal.unam.mx/global_revista/observatorio-hawc-rayos-gamma-unam-aniversario-10-anos/

High Altitude Water
Cherenkov Detector

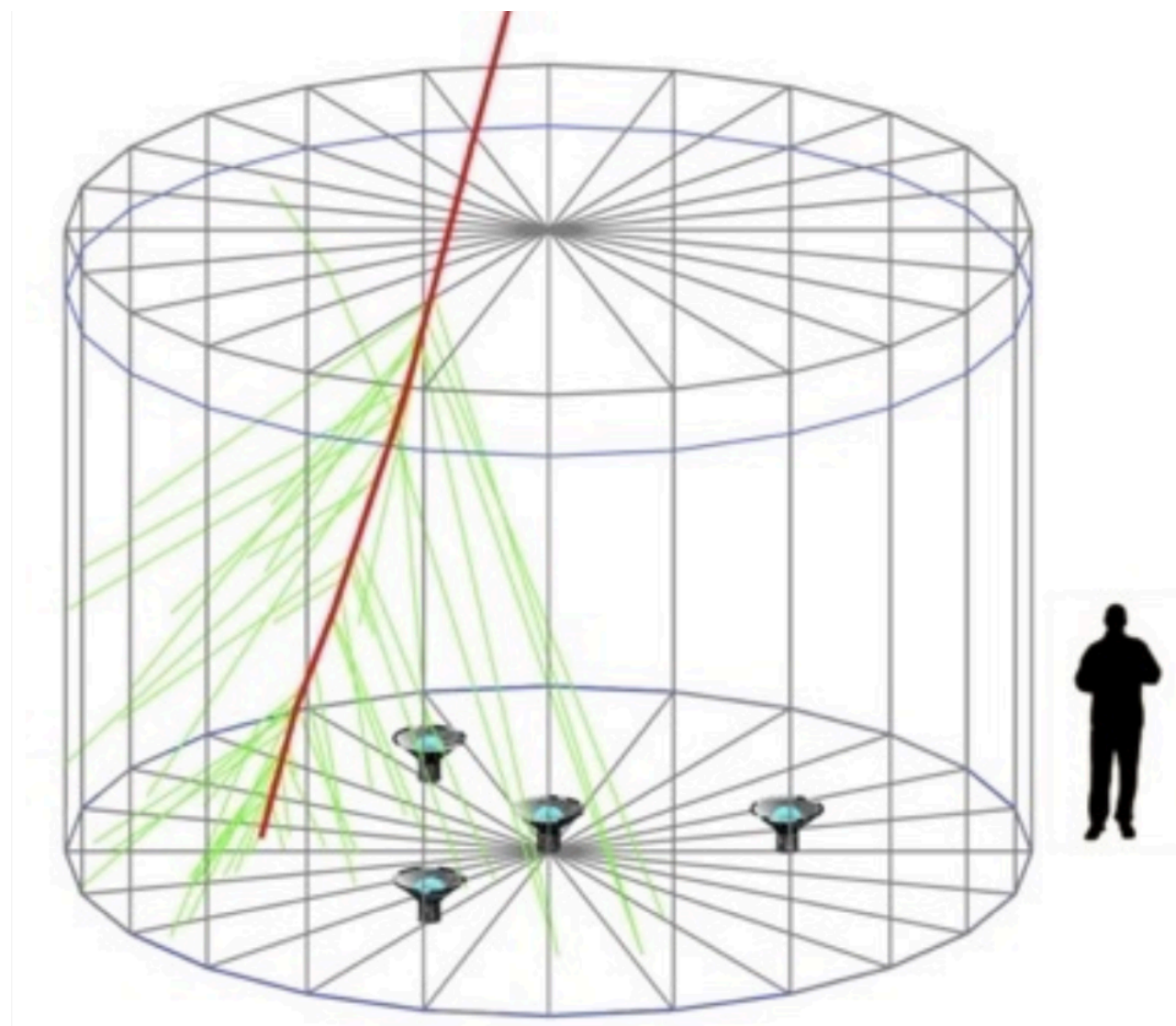
Extensive Air Showers

- ◆ A primary cosmic-ray interacts with an atmospheric nucleus, producing a myriad of secondary particles.
- ◆ Components:
 - ◆ Electromagnetic: (90%) Photons, electrons and positrons.
 - ◆ Hadronic: (<1%) Pions, kaons and nucleons.
 - ◆ Penetrating: (10%) Muons and neutrinos.

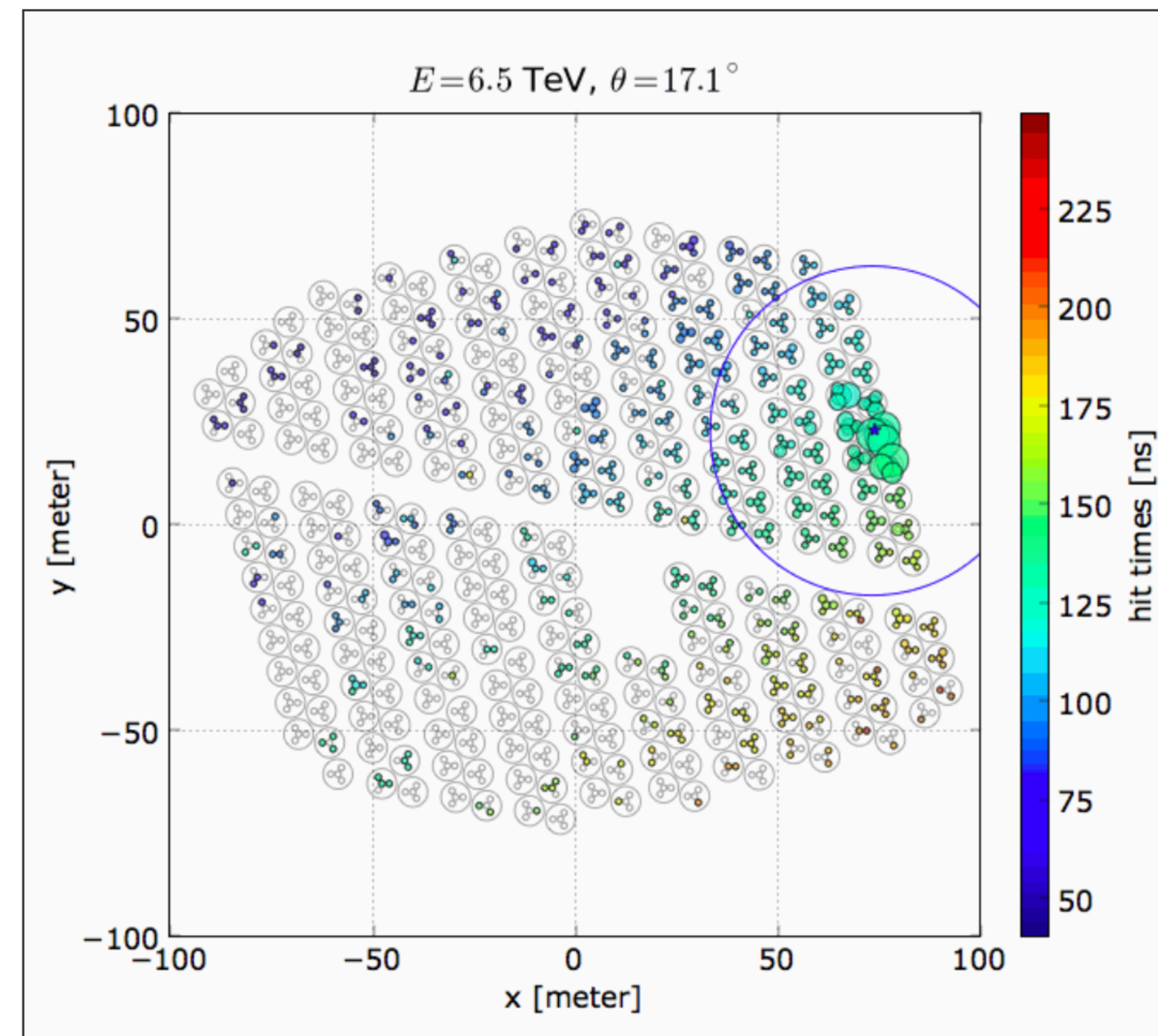


Water Cherenkov Detectors

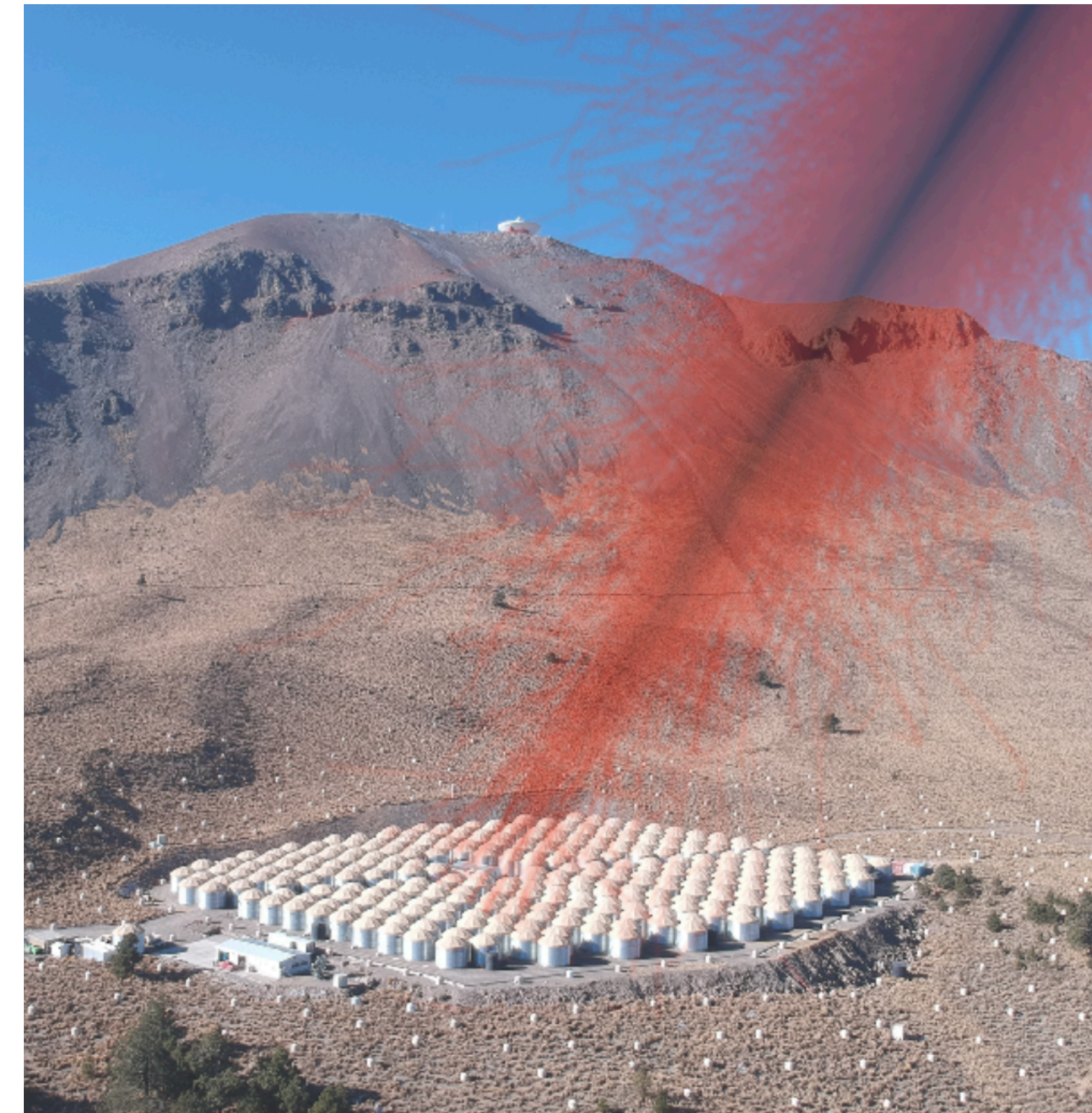
→ Emitted when a charged particle passes through a medium at a speed greater than the speed of light in that medium



Simulated
Cherenkov light in
a HAWC WCD



gamma induced air-shower



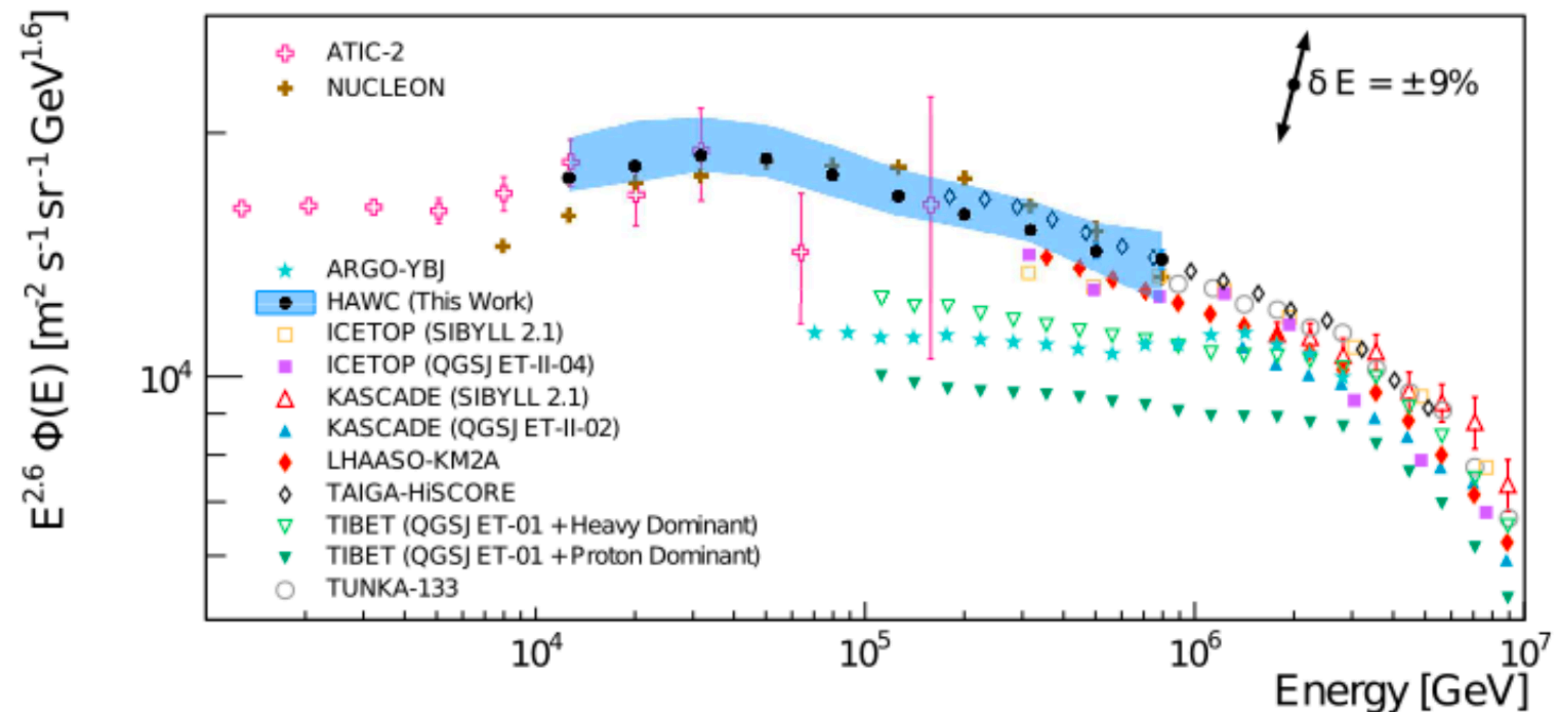
Images: HAWC website



SOME (SELECTED) RESULTS FROM HAWC

The all-particle cosmic ray

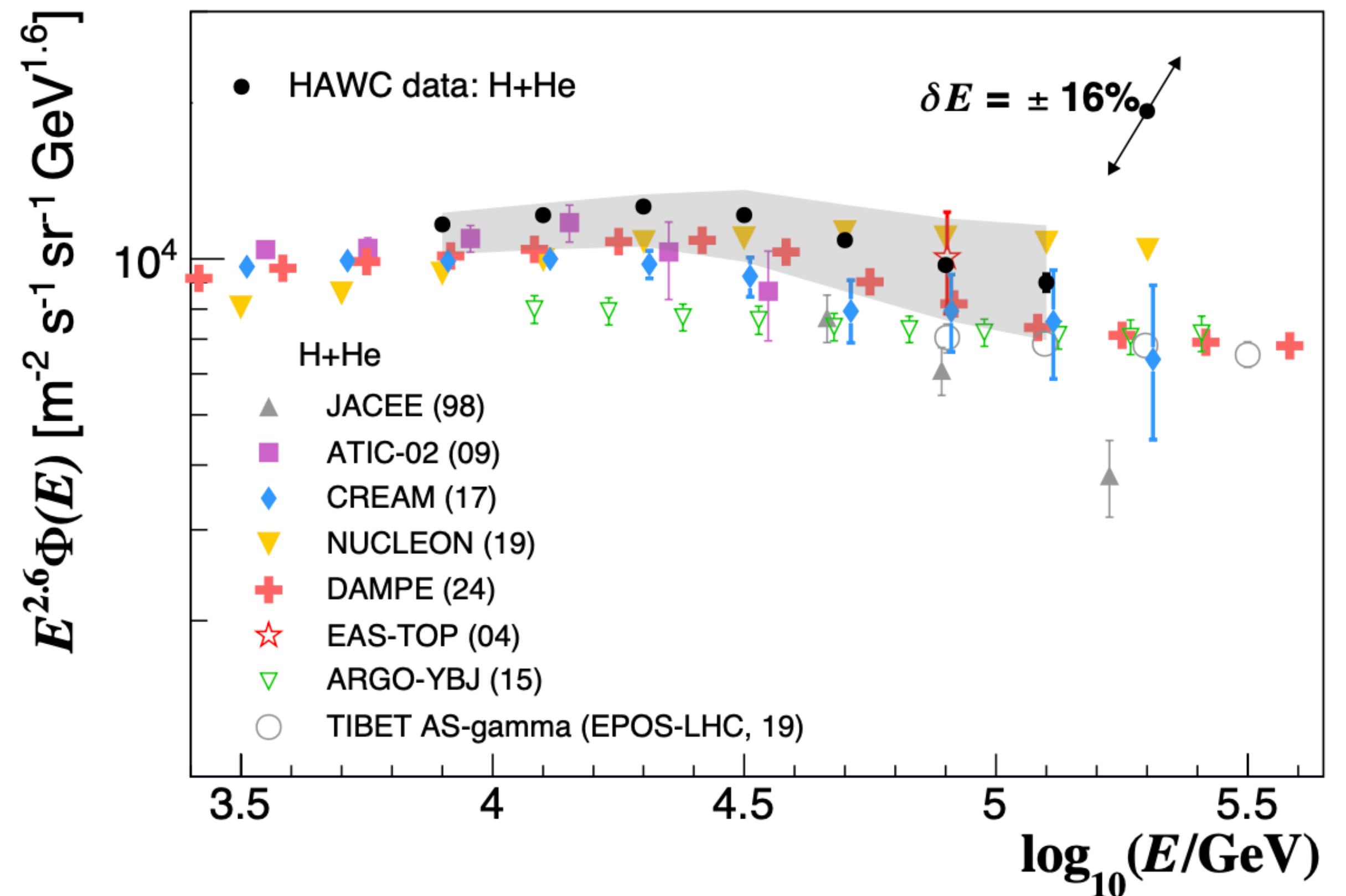
- ◆ Provided precise measurements of the cosmic ray spectrum in the TeV regime.
- ◆ Softening observed at $40.2 \pm 0.1(\text{stat.})_{-6.4}^{+6.2}(\text{syst.})$ TeV
- ◆ **HAWC found a deviation from a simple power-law behavior.**
 - ◆ Sources in cosmic rays
 - ◆ Acceleration mechanisms
 - ◆ Propagation through interstellar medium



Longinotti, A. L., & HAWC Collaboration. (2025). The first 10years of the HAWC Gamma-Ray Observatory: science results. *arXiv preprint arXiv:2512.03938*.

The cosmic-ray light spectrum

- ◆ HAWC measured the light cosmic-ray energy spectrum (H + He) from 6 to 158 TeV.
- ◆ Observed a spectral break at 24 TeV
 - ◆ Nonconventional models of:
 - Production
 - Acceleration
 - Propagation



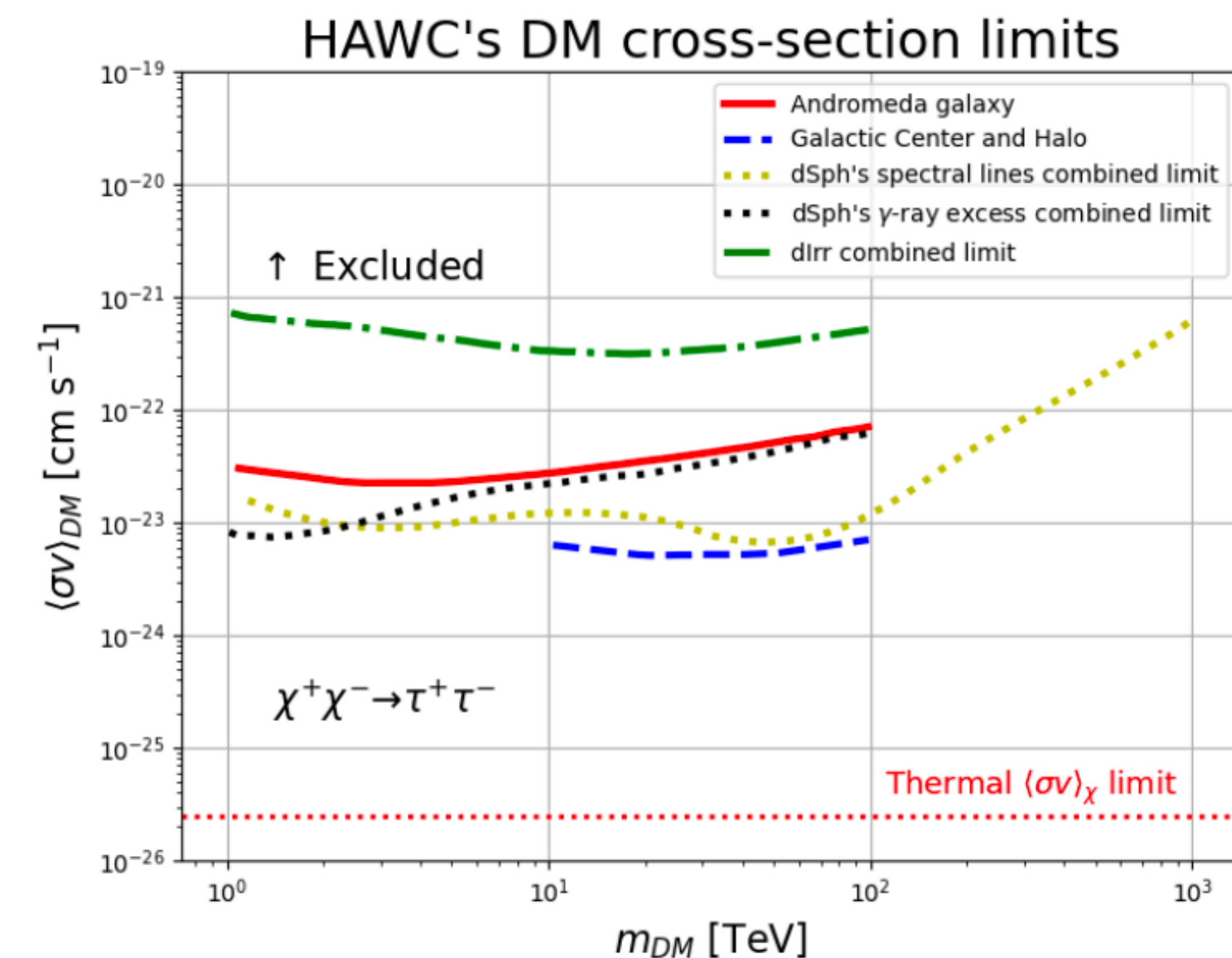
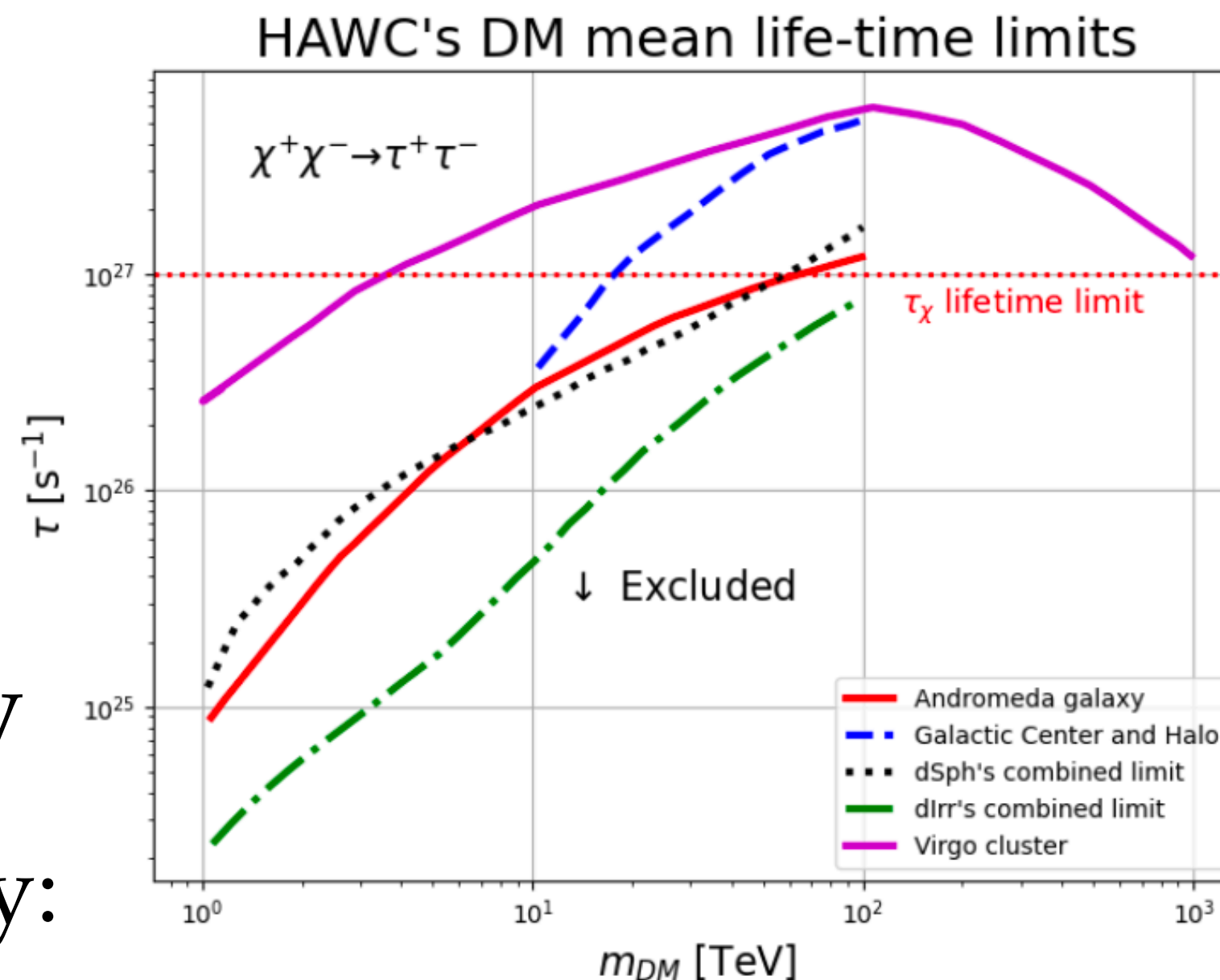
Longinotti, A. L., & HAWC Collaboration. (2025). The first 10 years of the HAWC Gamma-Ray Observatory: science results. *arXiv preprint arXiv:2512.03938*.

HAWC contributions to Particle Physics

- ◆ Indirect searches for dark matter by studying VHE gamma-rays
 - ◆ Constrains on dark matter signatures
 - ◆ Investigated the possible existence of dark matter candidates (WIMPs and ALPs)
- ◆ Testing fundamental physics by placing limits on Lorentz Invariance Violation.
- ◆ **Complements collider and underground experiments.**

Weakly Interacting Massive Particles

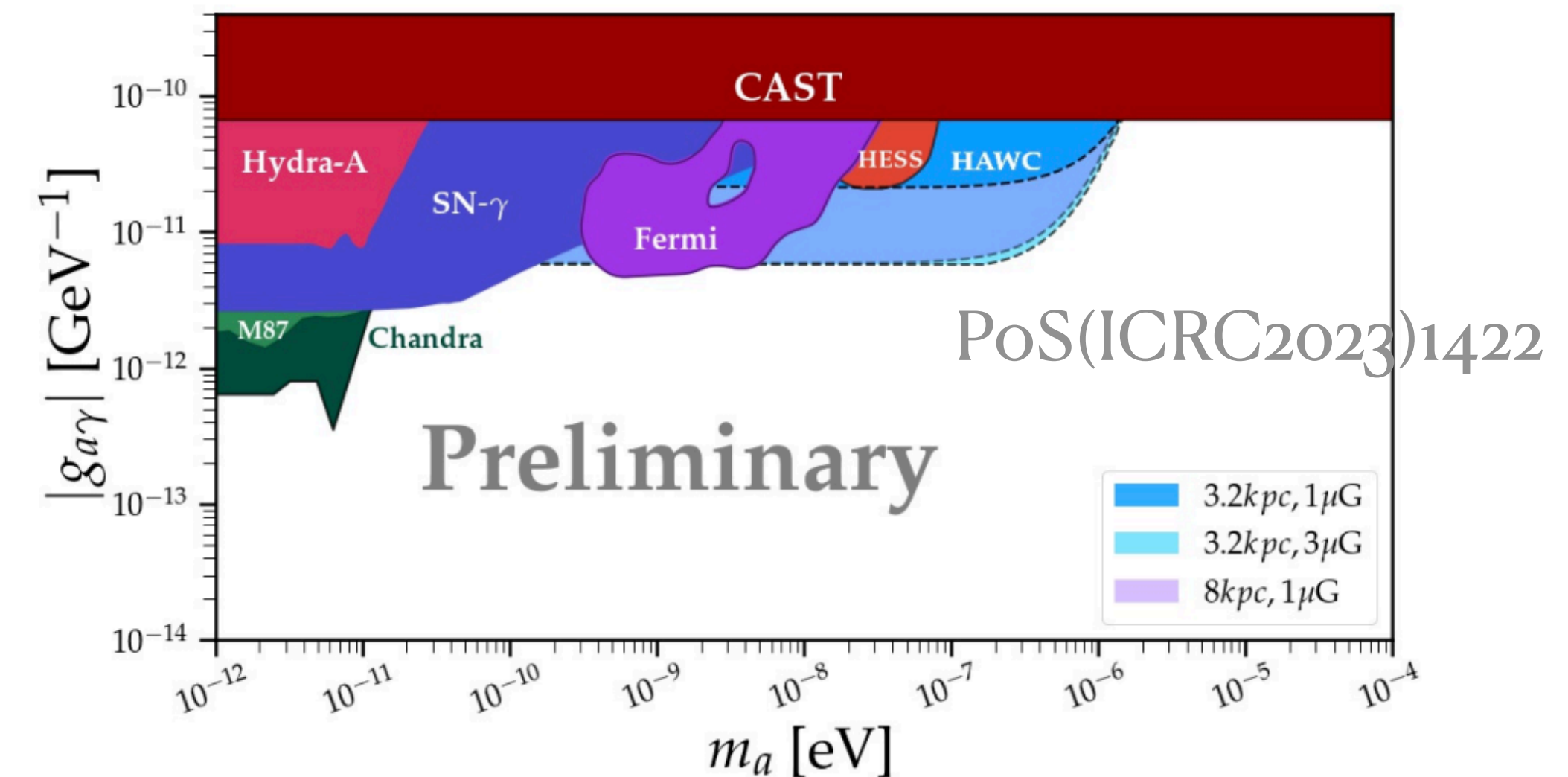
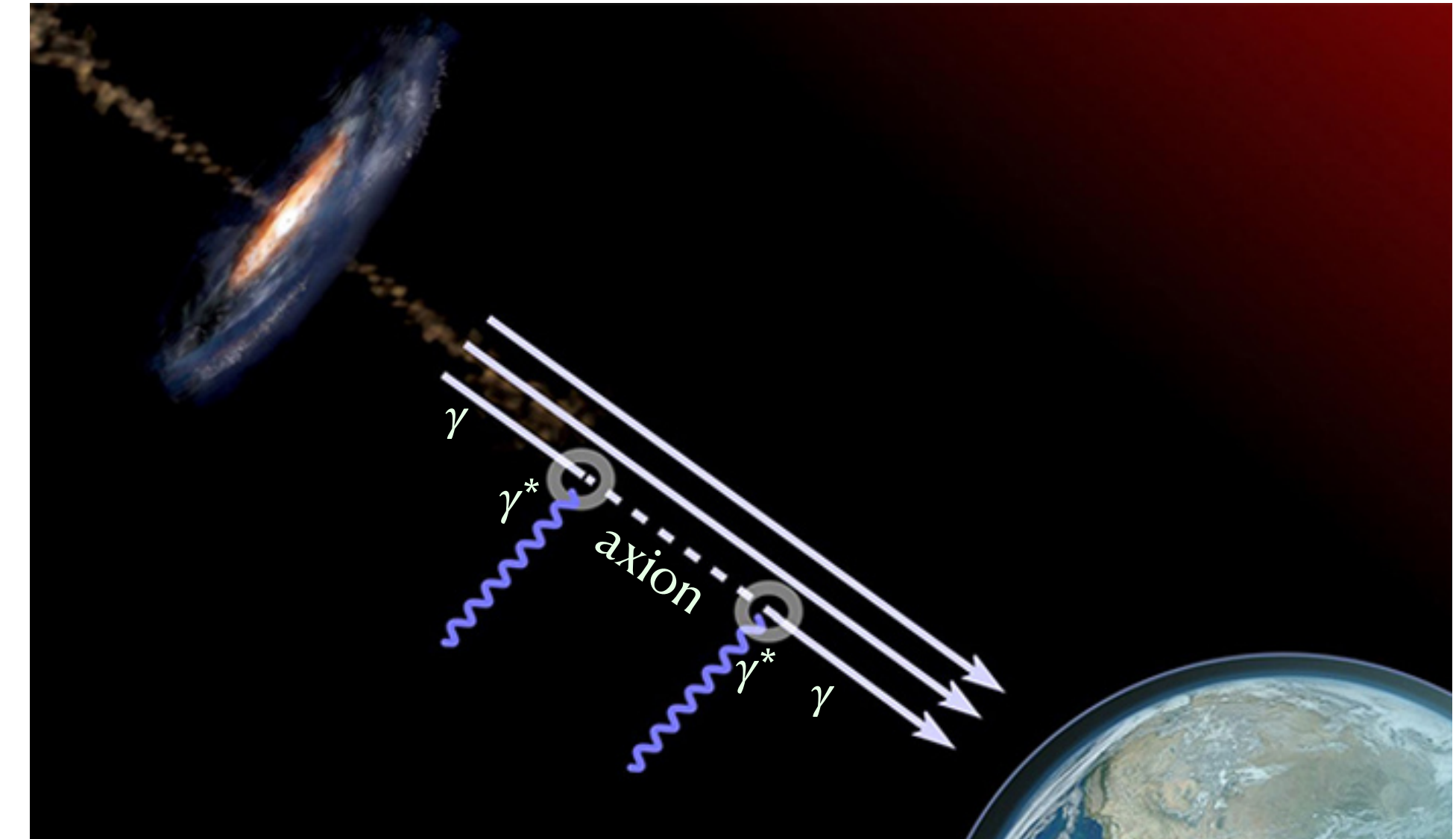
- WIMPs annihilation or decay can produce very-high-energy gamma rays.
- HAWC targets:** Dwarfs spheroidal and irregular galaxies, galactic center and halo, Andromeda Galaxy and the Virgo Cluster.
- No significant gamma-ray excess detected.**
- Constraints on annihilation cross-section:
 - $\langle \sigma v \rangle \lesssim 10^{-23} \text{ cm}^3 \text{ s}^{-1}$
 for WIMP masses of $\sim 10 - 100 \text{ TeV}$
- Constraints on dark matter decay:
 - $\tau \gtrsim 10^{27} \text{ s}$
 for masses above tens of TeV



Longinotti, A. L., & HAWC Collaboration. (2025). The first 10 years of the HAWC Gamma-Ray Observatory: science results. *arXiv preprint arXiv:2512.03938*.

Axion Like Particles

- ◆ Axion-Like Particles are another dark matter candidate.
 - ◆ HAWC study bright Galactic gamma-ray sources (eHWC J1908+063), searching for distortions in the observed gamma-ray spectrum caused by photon-ALP conversion
 - ◆ **No evidence of photon-ALP conversion**
 - ◆ Constraints on the ALP-photon coupling
 - $g_{a\gamma} < 10^{-12} \text{ GeV}^{-1}$
- for ALP masses from fractions of new up to tens of μeV



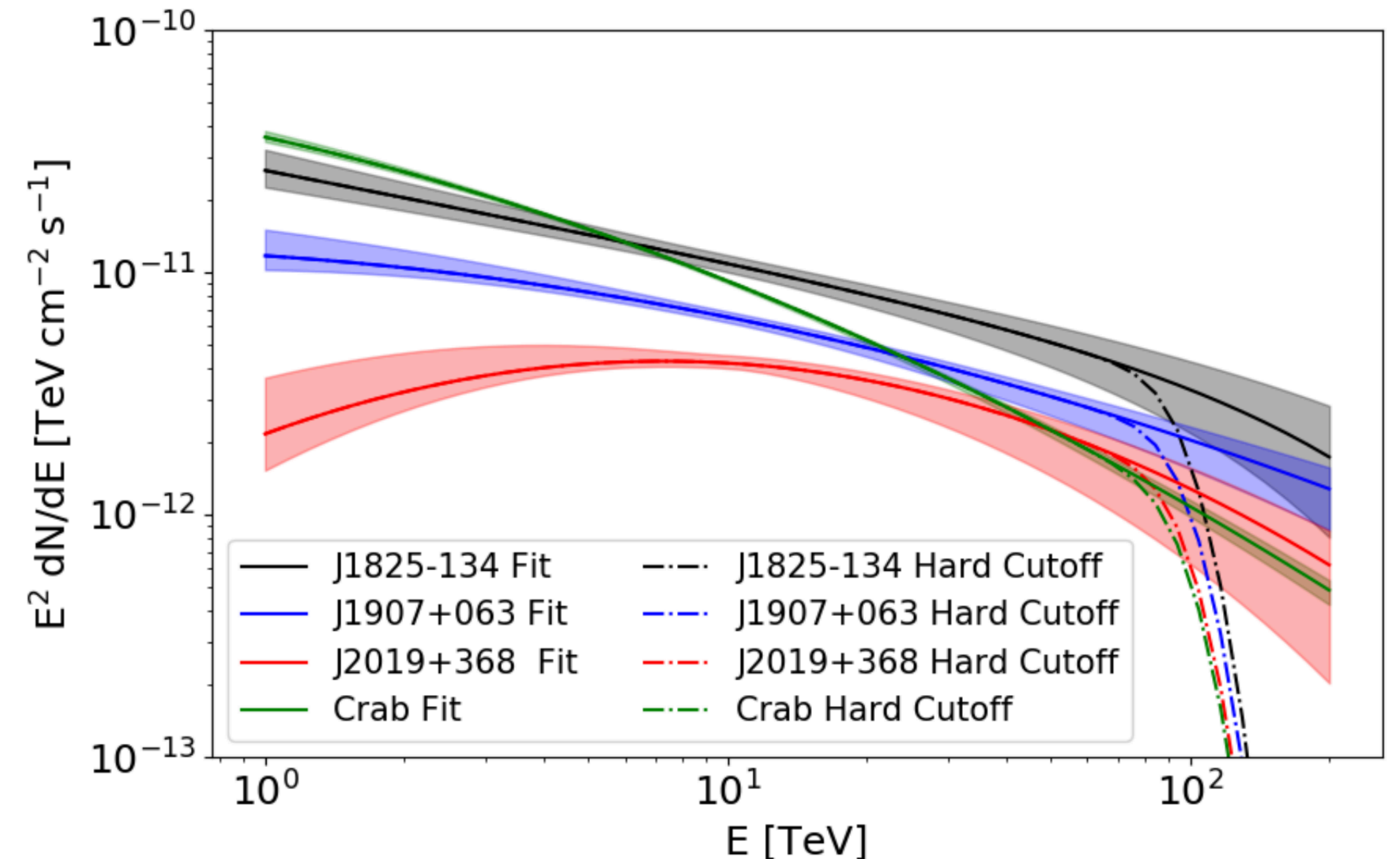
Testing Lorentz Invariance

- Many quantum gravity theories suggest that at extremely high energies, Lorentz symmetry may be violated.
- Modify the photon dispersion relation, where photons can become unstable and decay:

$$\gamma \rightarrow e^+e^-$$

producing a cutoff in the gamma-ray spectra.

- HAWC observed four galactic sources, where no hard cutoff was observed.**



Albert, A., et al. "Constraints on Lorentz invariance violation from HAWC observations of gamma rays above 100 TeV." *Physical Review Letters* 124.13 (2020): 131101.

Conclusions

- ✦ HAWC has measured the all-particle (and light component) cosmic-ray spectrum from tens of TeV to the PeV range, revealing spectral structures that provide clues about the origin of galactic cosmic rays.
- ✦ Beyond, HAWC has placed competitive constraints on dark matter candidates such as WIMPs and axion-like particles (ALPs), demonstrating that very-high energy gamma-ray observations can be used to search physics beyond the Standard Model.
- ✦ By detecting photons above 100 TeV, HAWC has also provided some of the strongest constraints on Lorentz invariance violation.

Take away

From gamma and cosmic rays, to dark matter and physics beyond the Standard Model, HAWC demonstrates how the universe can be used as a laboratory for fundamental physics!!





37omkar on DeviantArt

Gracias!

Extraterrestrial accelerators

◆ How this particles can reach such high energies?

We are not sure...

◆ **Fermi's acceleration mechanism**

◆ Energy gain per cycle

◆ **Confinement:**

◆ The particle gyroradius must remain smaller than the size of the accelerator.

$$r_g = \frac{p_{\perp}}{qB}$$

gyroradius

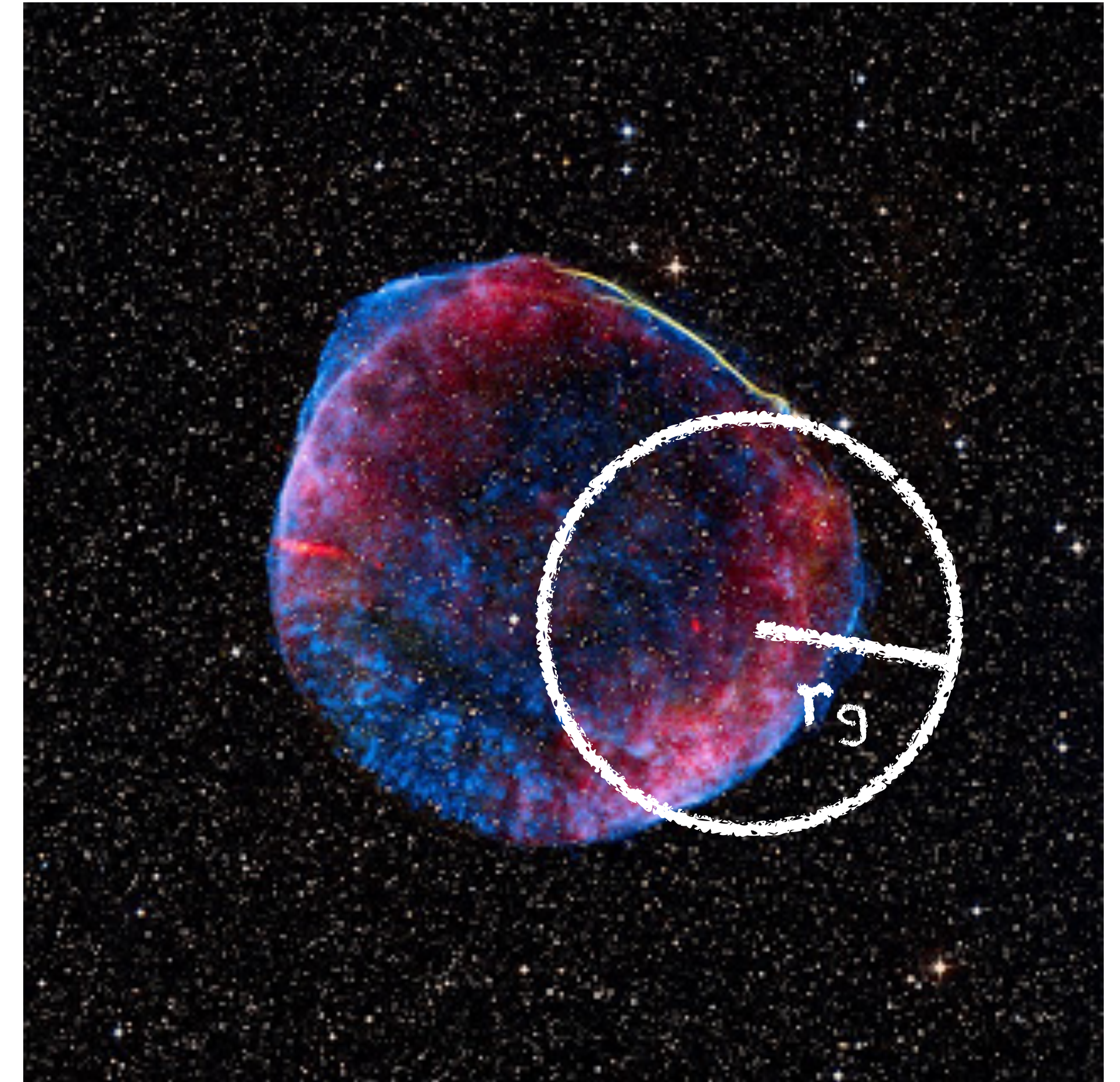
$$r_g \ll L$$

confinement
condition

$$E \gg mc^2$$

$$p = \frac{E}{c}$$

$$\Rightarrow E_{max} = qcBL$$



NASA