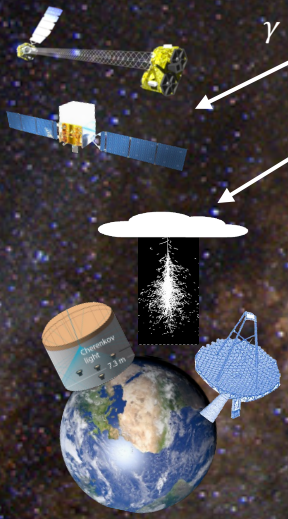
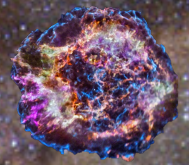
(Design inspired by Yoann Génolini)

Hunting for Galactic PeVatrons with X-rays & gamma-rays





γ

γ

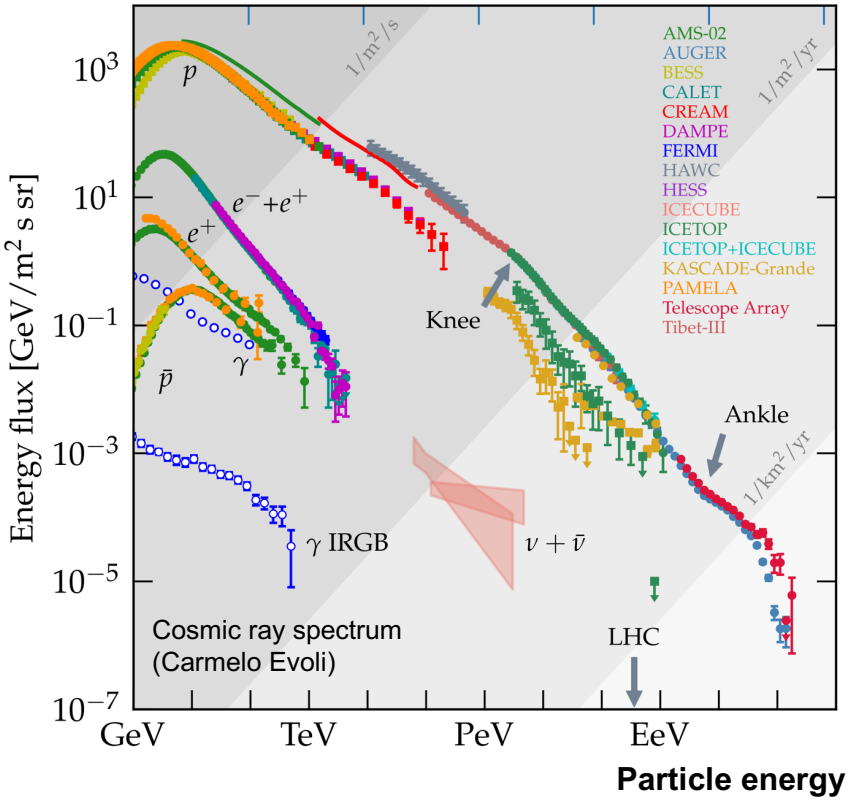
p, $e^{\pm}$

Jooyun Woo

(Columbia University)

11/19/2024 @ 1st NASA PhysCOS early-career workshop

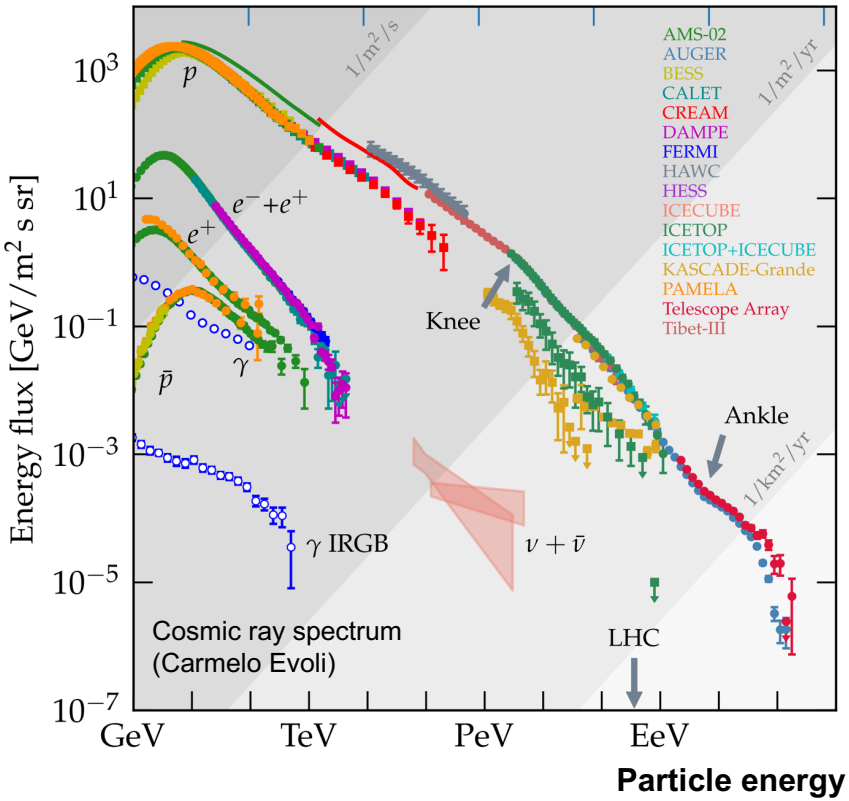
Origin of cosmic rays (CRs)? A century-old mystery behind high-precision CR spectral measurement

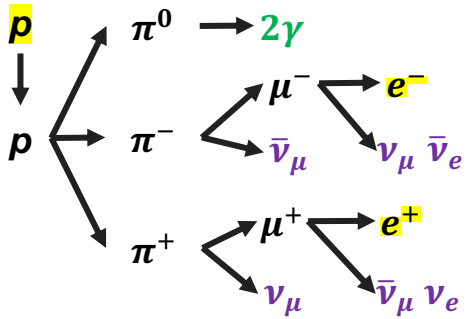


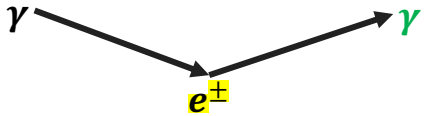
- **CRs: relativistic charged particles** with (almost) isotropic and constant flux
- **< "knee" ~ PeV: Galactic origin**
- > "ankle" ~ EeV: Extragalactic origin
- **<u>What is the origin of Galactic CRs?</u>**

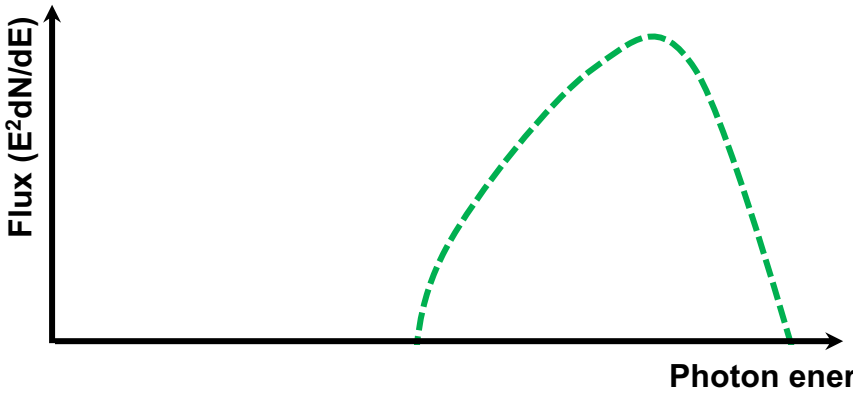
		CR process	Physical property
CR flux	=	**Injection**	Shock speed, magnetic field, ambient matter density
	+	**Diffusion**	Diffusion coefficient, magnetic field
	–	**Energy loss**	Magnetic field, ambient photon and matter density
	–	Drift, advection	(Large scale)

Cosmic ray (= charged particle) reveals its origin through its neutral products (= photon and neutrino).









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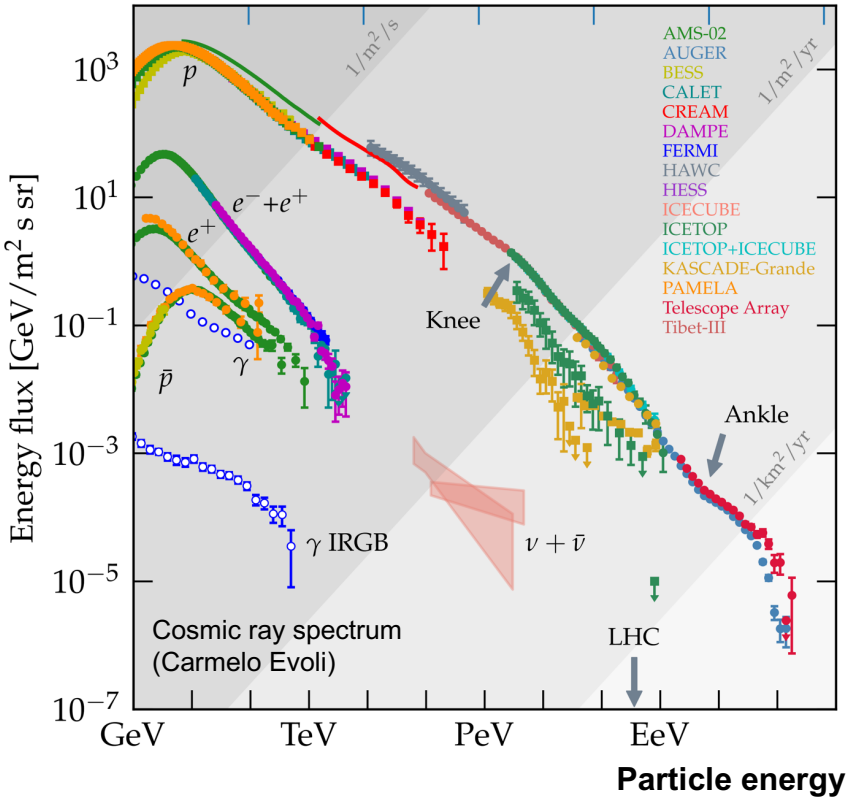
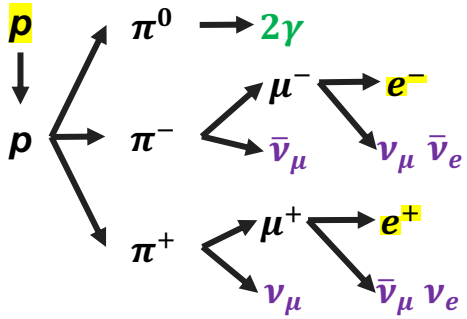
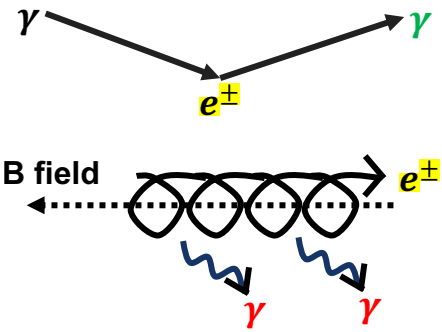
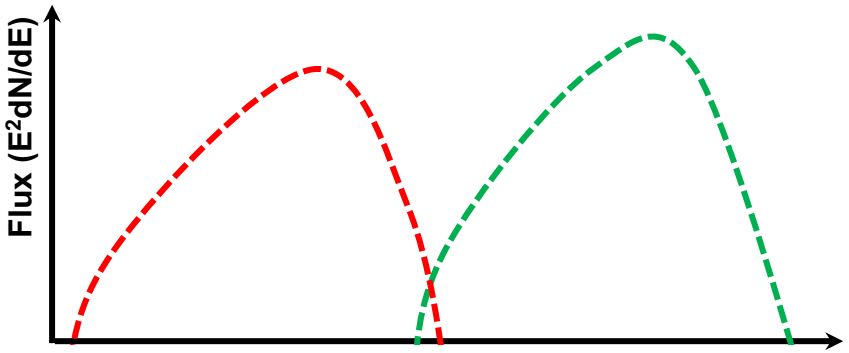
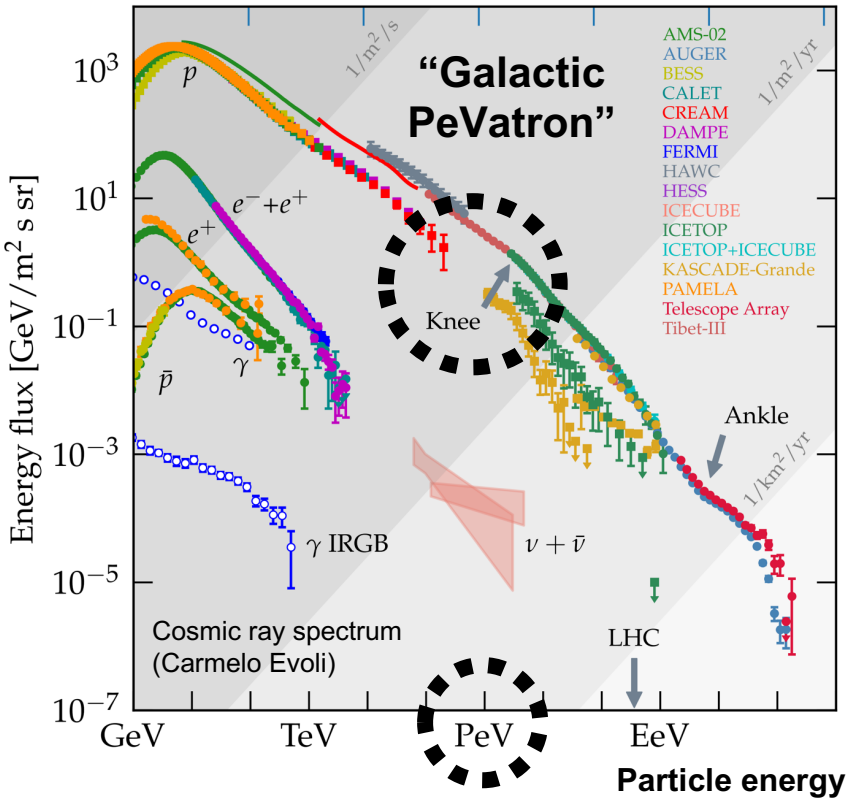


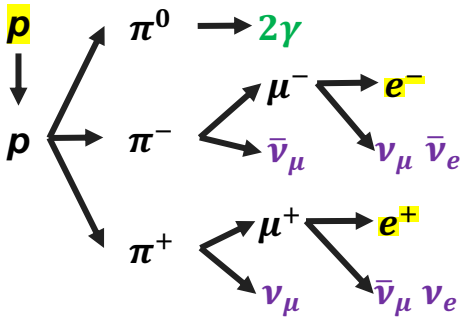


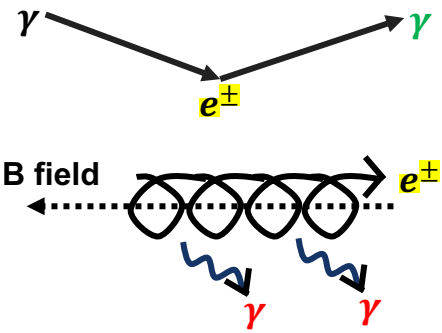


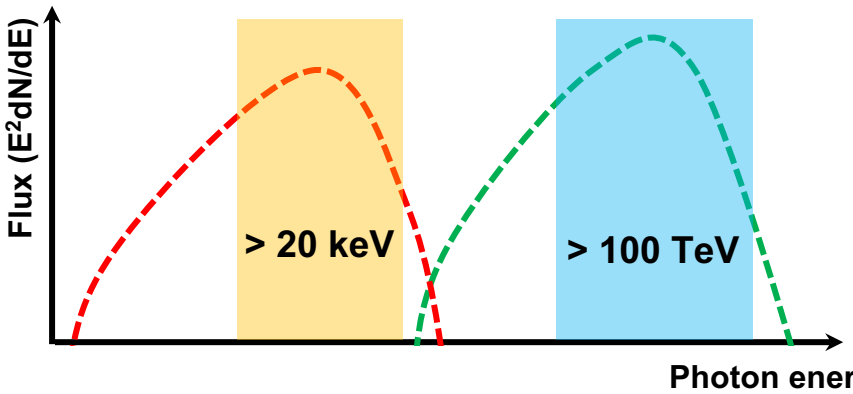


Hard X-ray, UHE γ-ray, and TeV neutrino: 3 keys to the most energetic secrets of our galaxy

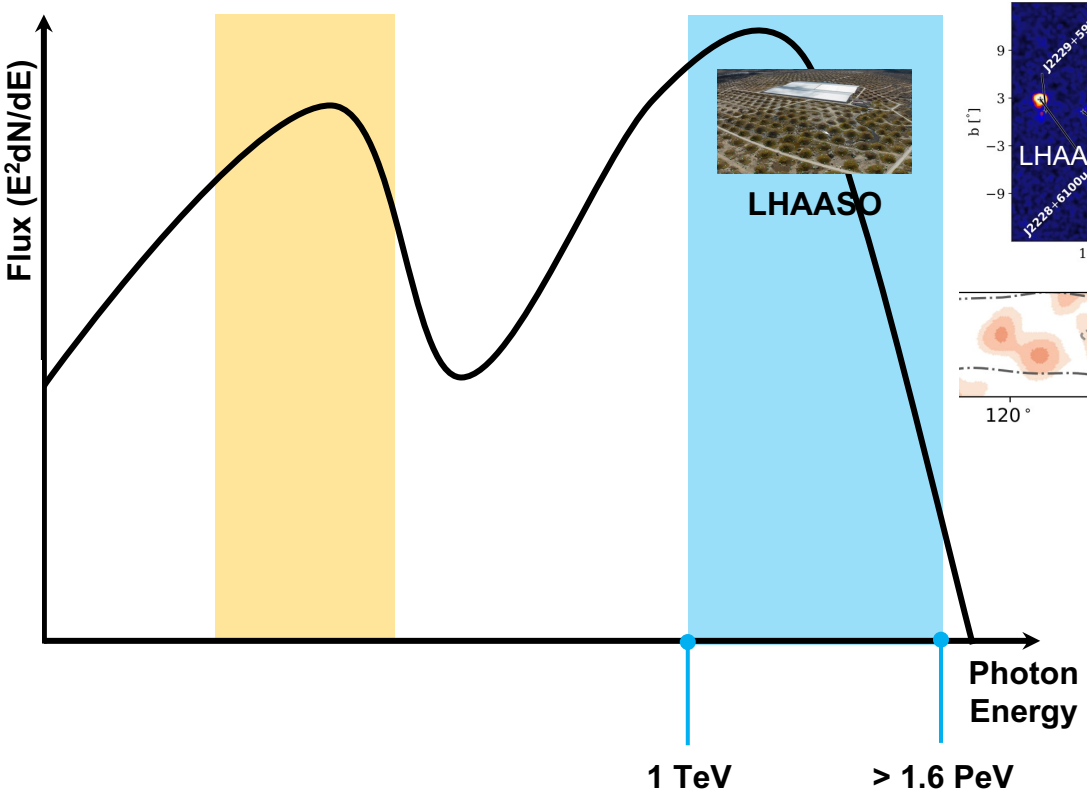


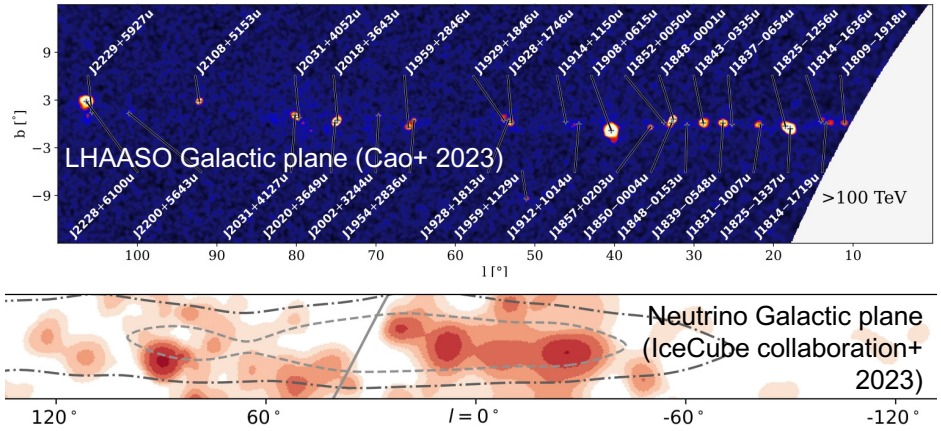




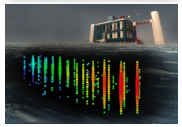


Galactic PeVatrons exist! First detection of UHE γ-rays and TeV neutrinos along the Galactic plane





TeV – PeV neutrinos



IceCube

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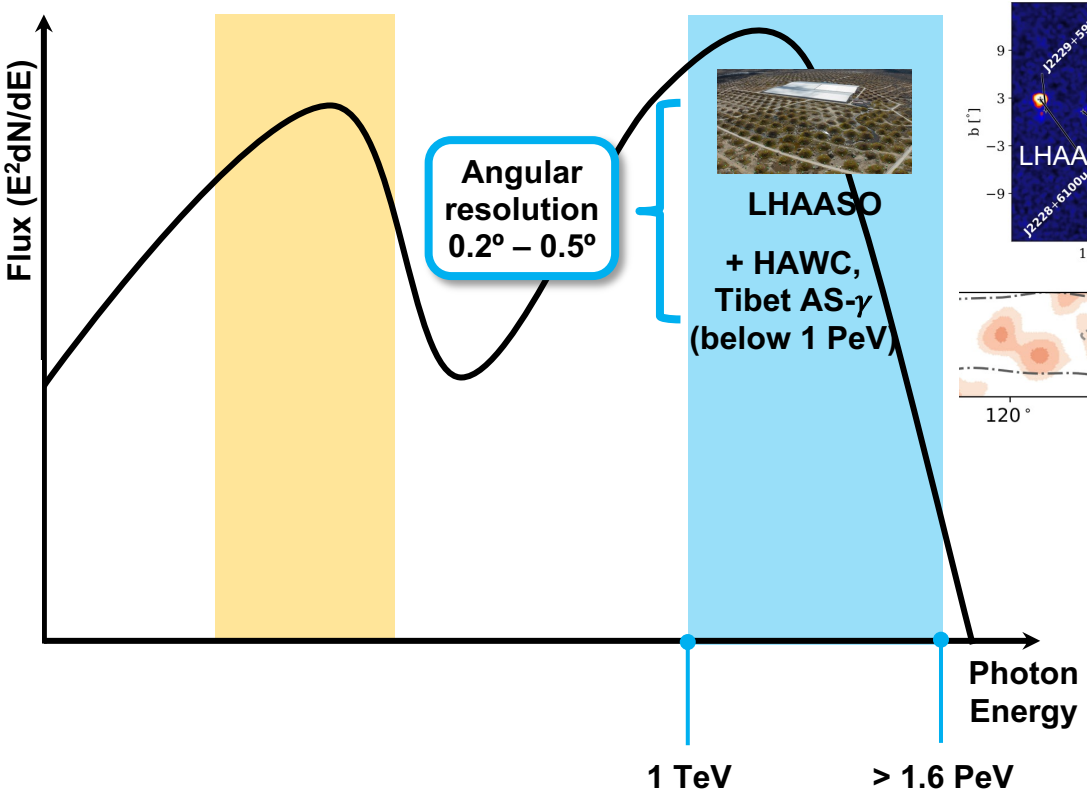

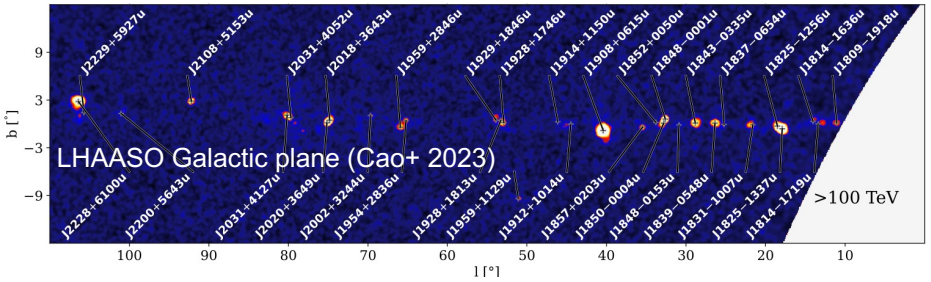

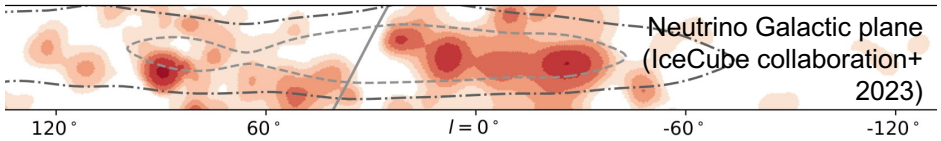

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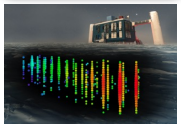

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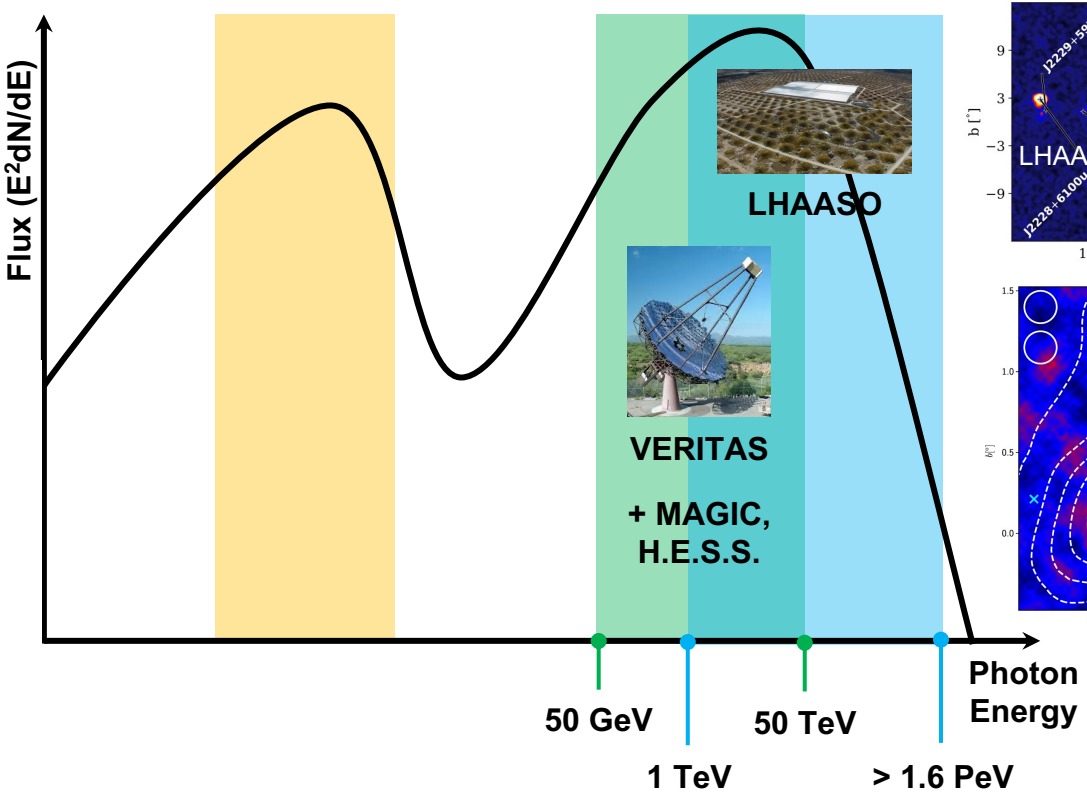
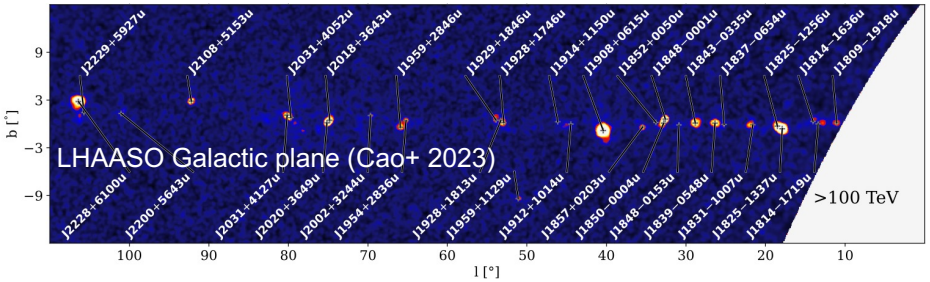
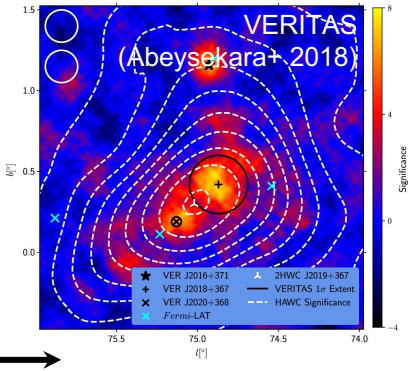
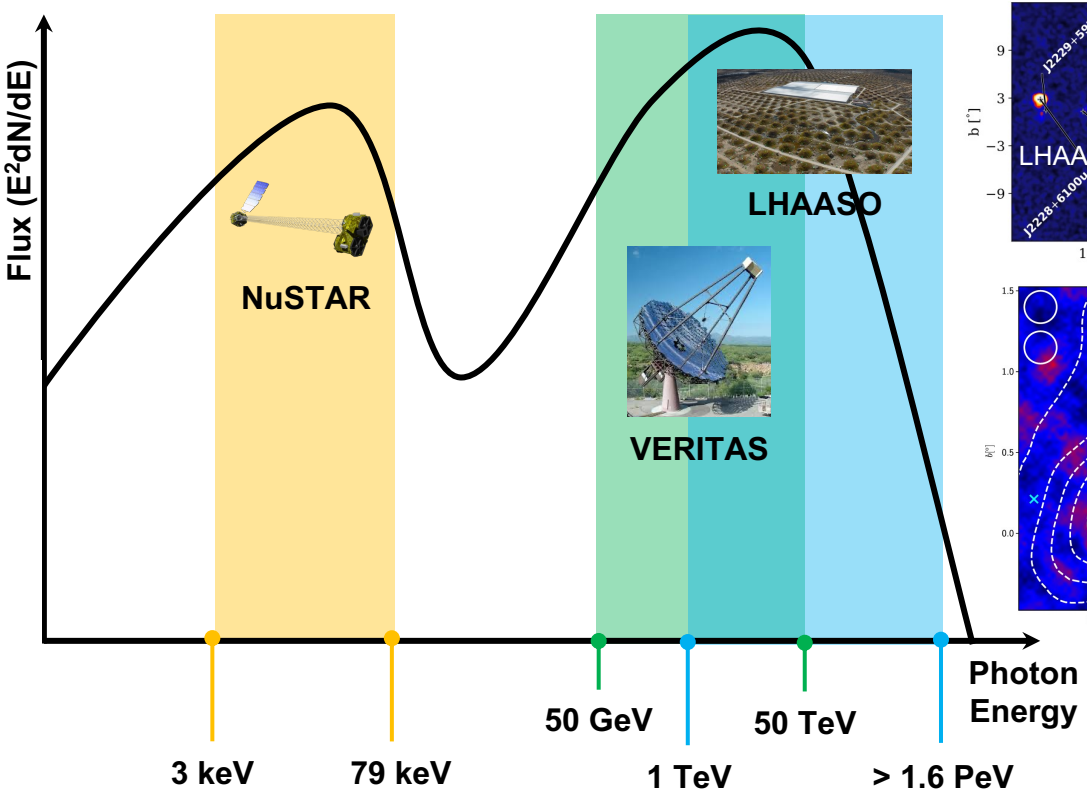
VHE γ-ray observation can resolve source confusion and locate PeVatrons with angular resolution < 0.1º.

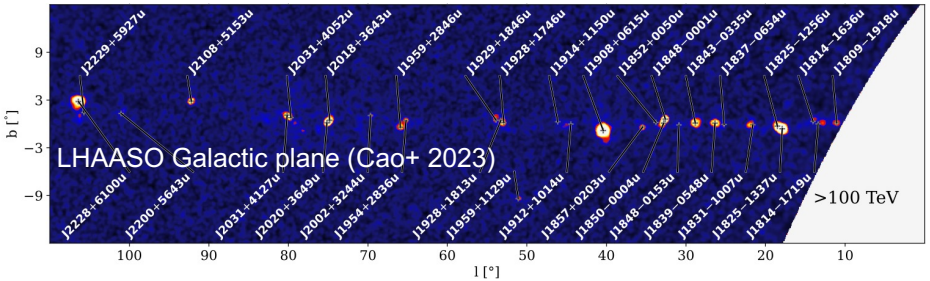


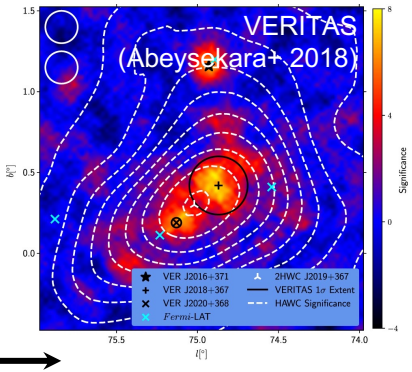


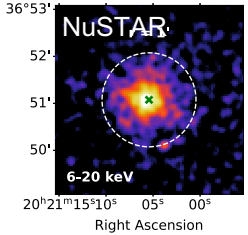


(Hard) X-ray observation probes central engines and help identify PeVatrons with angular resolution < 1’.









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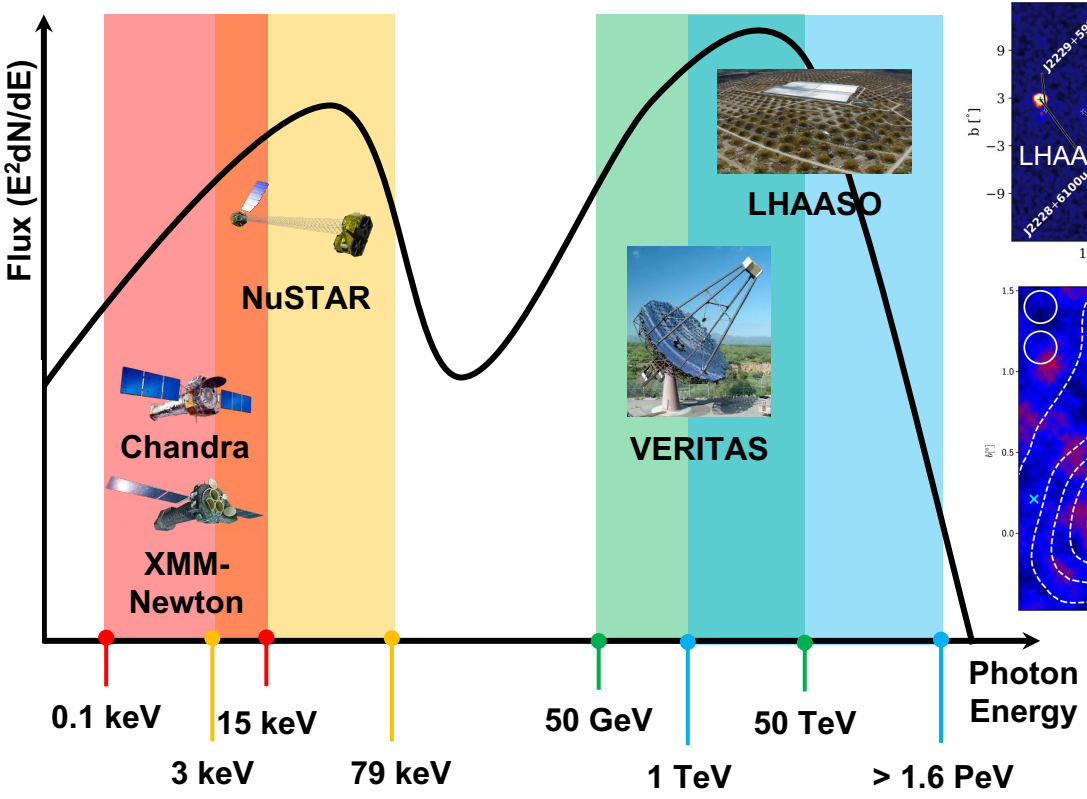
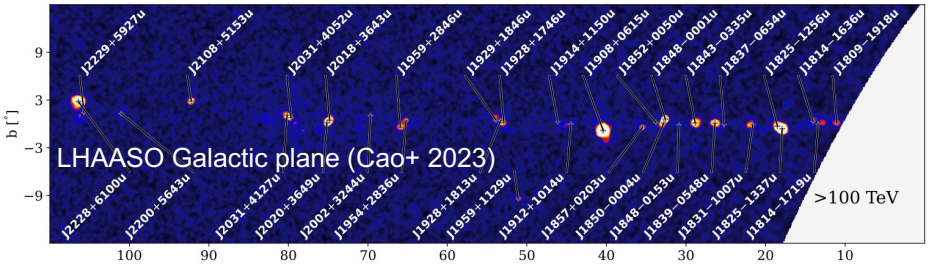
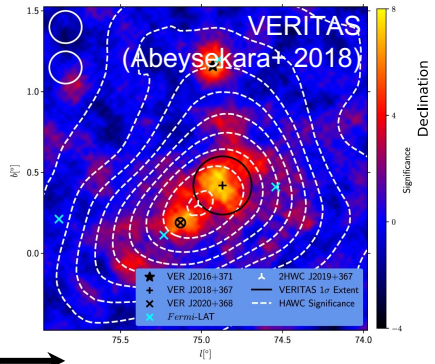
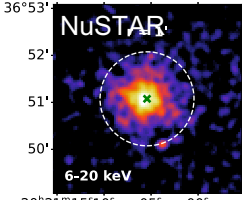
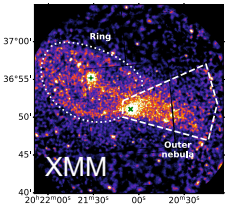


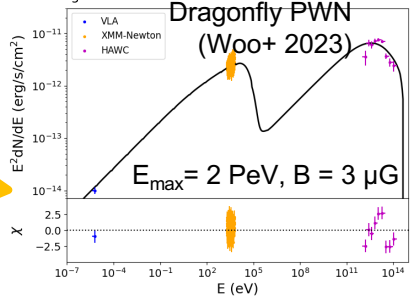




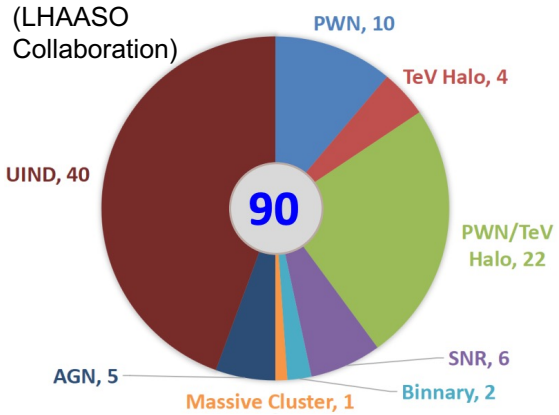




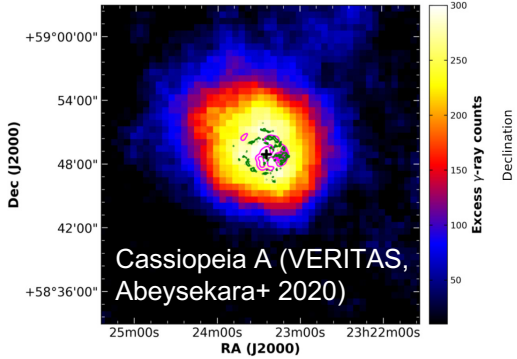
Matter&photon density, E_{SN}, $M_\star$, pulsar $\dot{E}$, η…
→ **Magnetic field, CR $e^\pm$ spectrum (E_{max}, Γ)…**

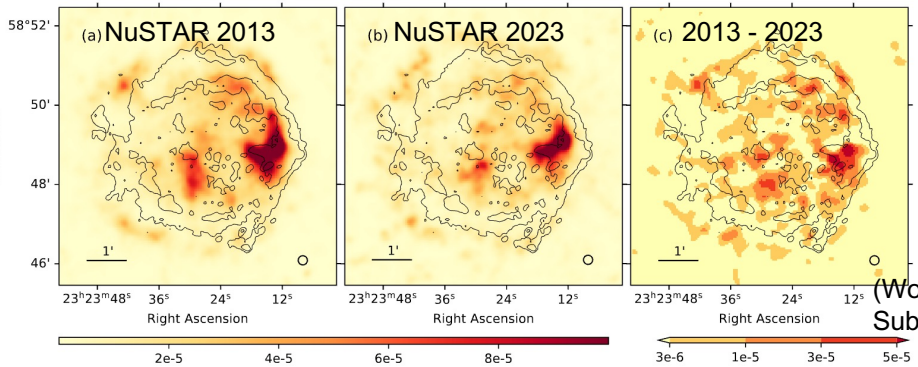


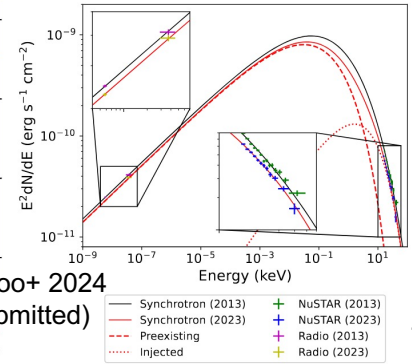
Among 90 LHAASO sources, 50 are associated with known CR accelerators. Are they PeVatrons?



- Ideal CR acceleration environment: strong shock / magnetic field
  - ✓ **Young supernova remnants**, middle-aged pulsar wind nebulae, young massive star clusters, TeV binaries…
- Young SNRs are **not UHE sources. Are they PeVatrons?**
  - ✓ First detection of **hard X-ray variability** in a young SNR: **ongoing CR e± acceleration up to a few 10s TeV**
  - ✓ **CR protons? No γ-ray variability (VERITAS, Fermi-LAT)**

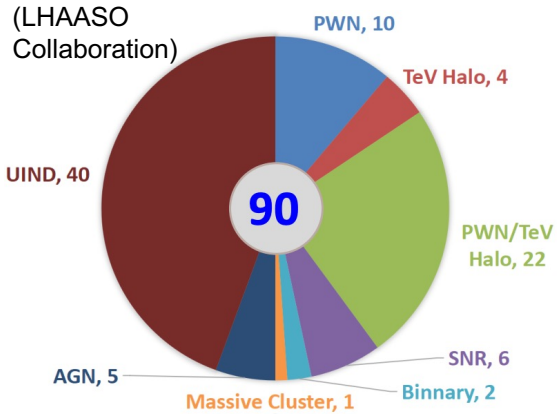






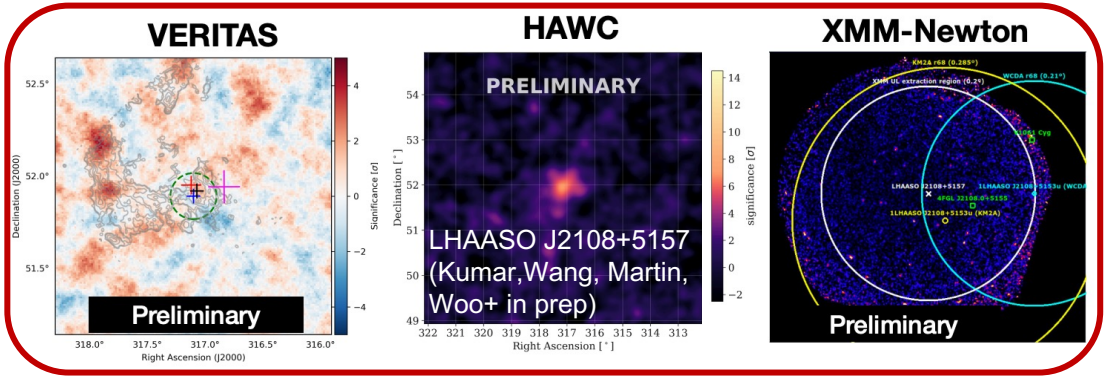
(Woo+ 2024 Submitted)

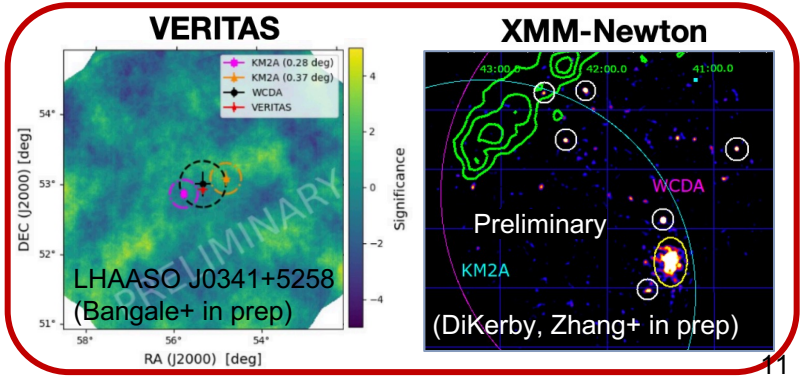
Among 90 LHAASO sources, 40 are unidentified. What are these “Dark PeVatrons”?



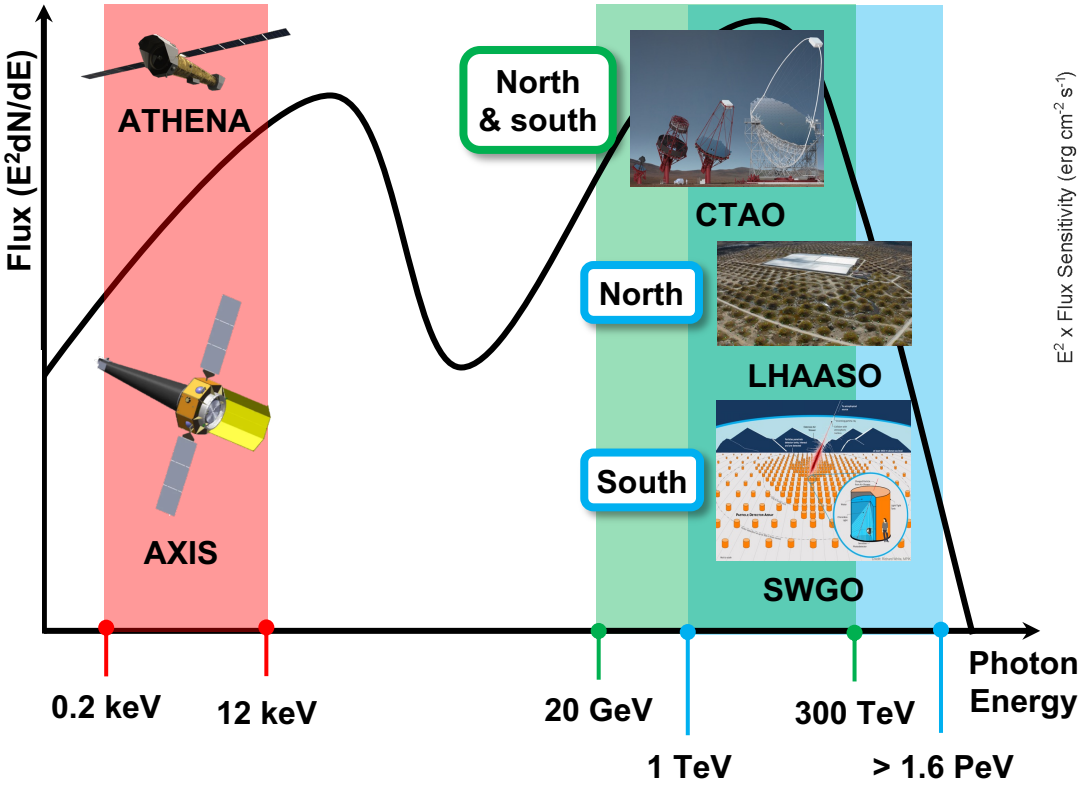
- No (or multiple) known CR accelerators associated.
  - ✓ Undiscovered known accelerator? (faint or unobserved)
  - ✓ **Molecular cloud** illuminated by CRs from nearby accelerator?
  - ✓ **New source types** of CR accelerators?
- **Multiwavelength observation** is the key!

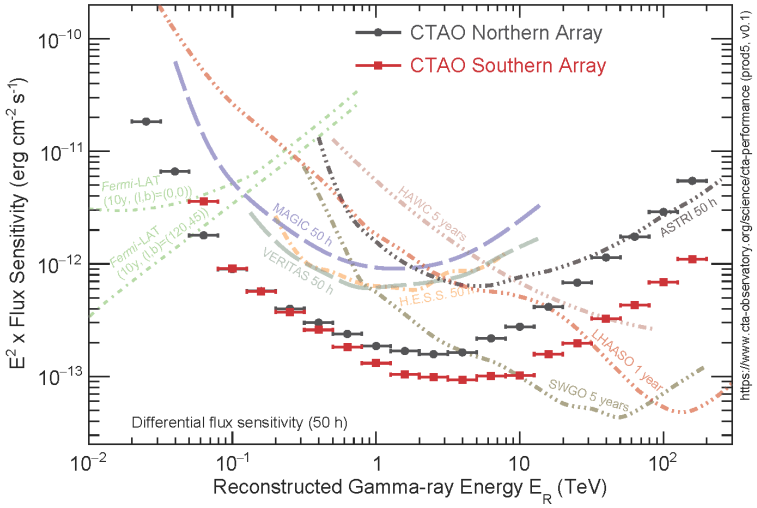
		VERITAS	XMM	HAWC
LHAASO J2108+5157	Pulsar halo?	X	X	O
LHAASO J0341+5258	PWN?	X	O	O



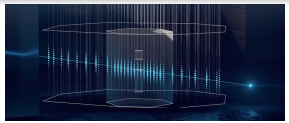


More PeVatrons to be found in the future!
Higher instrument sensitivity, new source classes



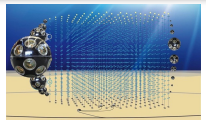


TeV – EeV neutrinos (Southern ice)



IceCube-Gen2

TeV – PeV neutrinos (Northern ocean)



KM3Net, P-One…

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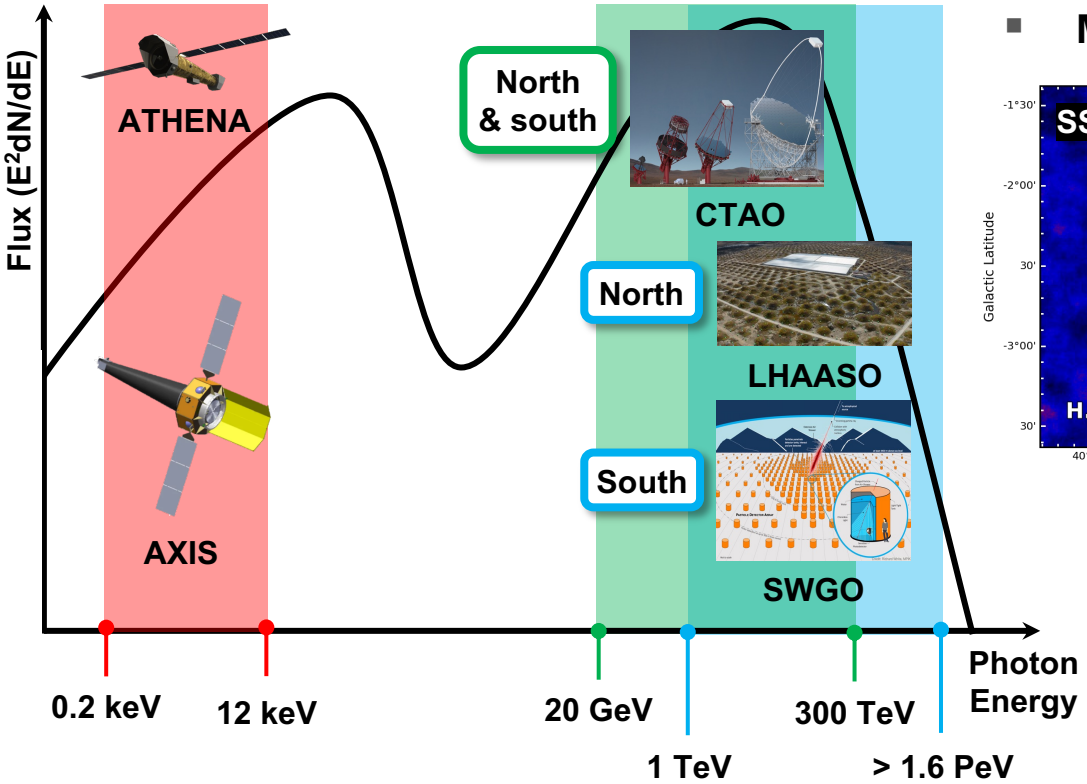
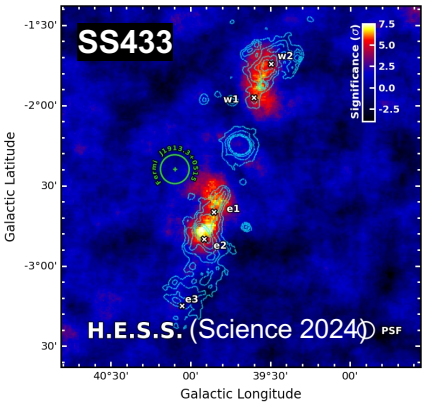
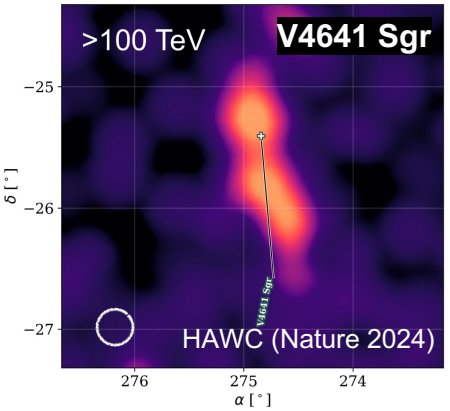


- **Microquasars** are PeVatrons?!





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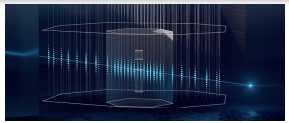

IceCube-Gen2

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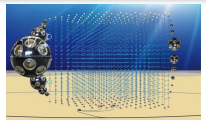

KM3Net, P-One…