

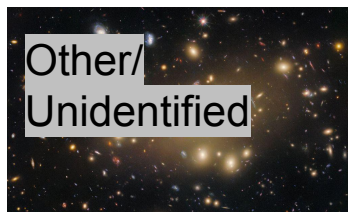
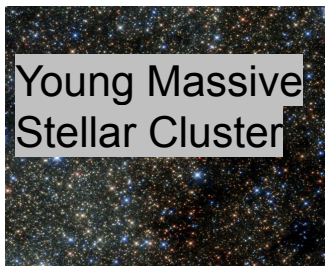
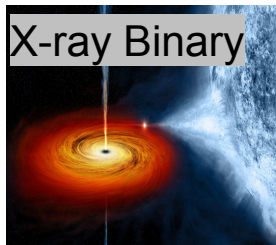
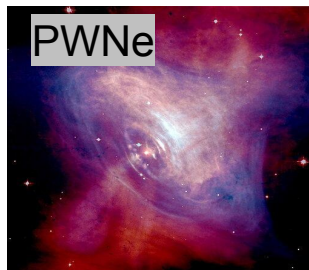
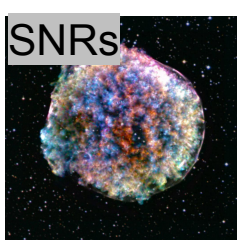
Searching multi-flavor neutrinos for Galactic PeVatrons with IceCube

Leo Seen, **Yuhua Yao**, Matthias Thiesmeyer, Tianlu Yuan, Lu Lu, and Albrecht Karle
University of Wisconsin-Madison

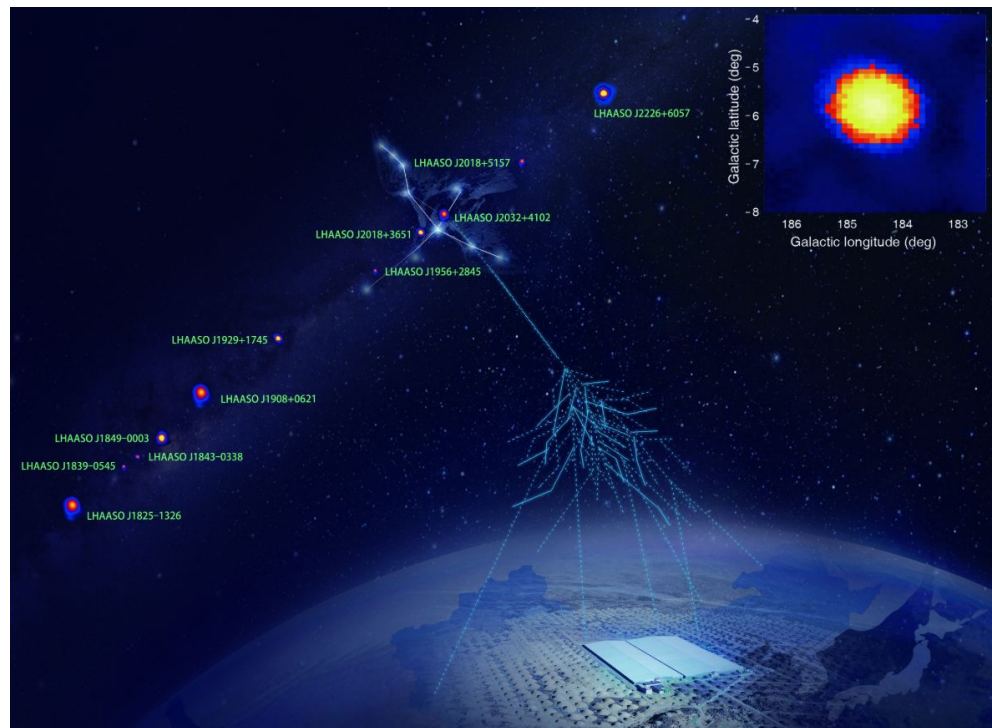
IPA 2026, Madison
Oct 14, 2026

Galactic PeVatrons

Possible Galactic PeVatron Sources

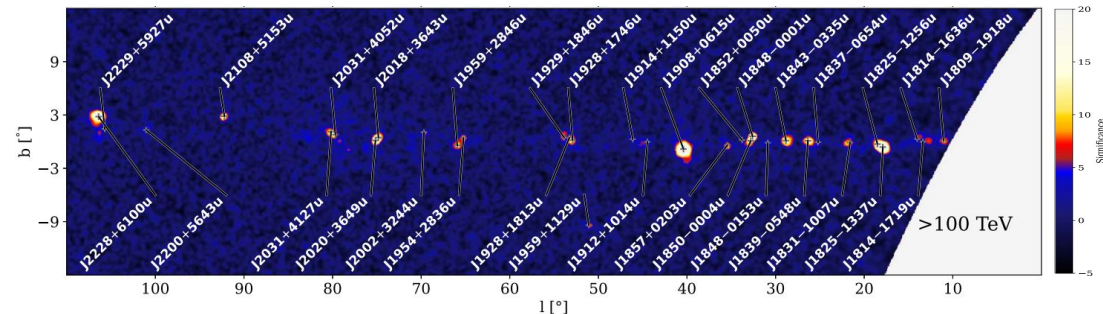


- May tell us where GCR accelerated up to PeV
- Key targets in high-energy γ -ray astronomy

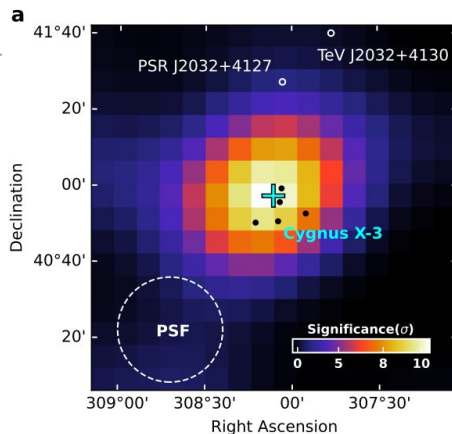


Galactic PeVatron Candidates

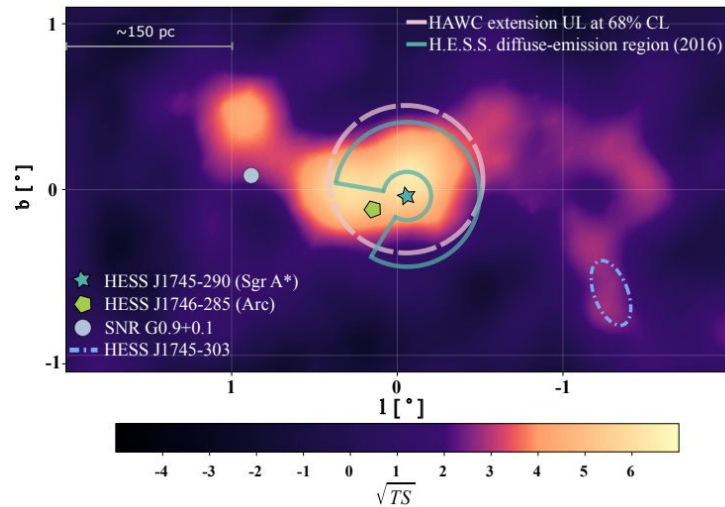
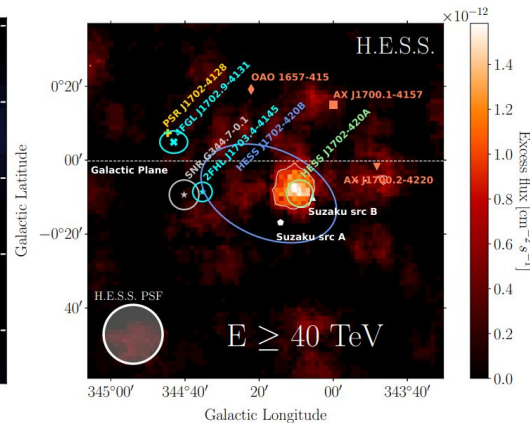
- 1st LHAASO catalog reported 43 gamma-ray sources with >100 TeV emission
- HAWC, H.E.S.S. observed multiple PeVatron candidates
- Notable candidates
 - Cygnus X-3
 - HESS J1702-420A
 - Galactic center



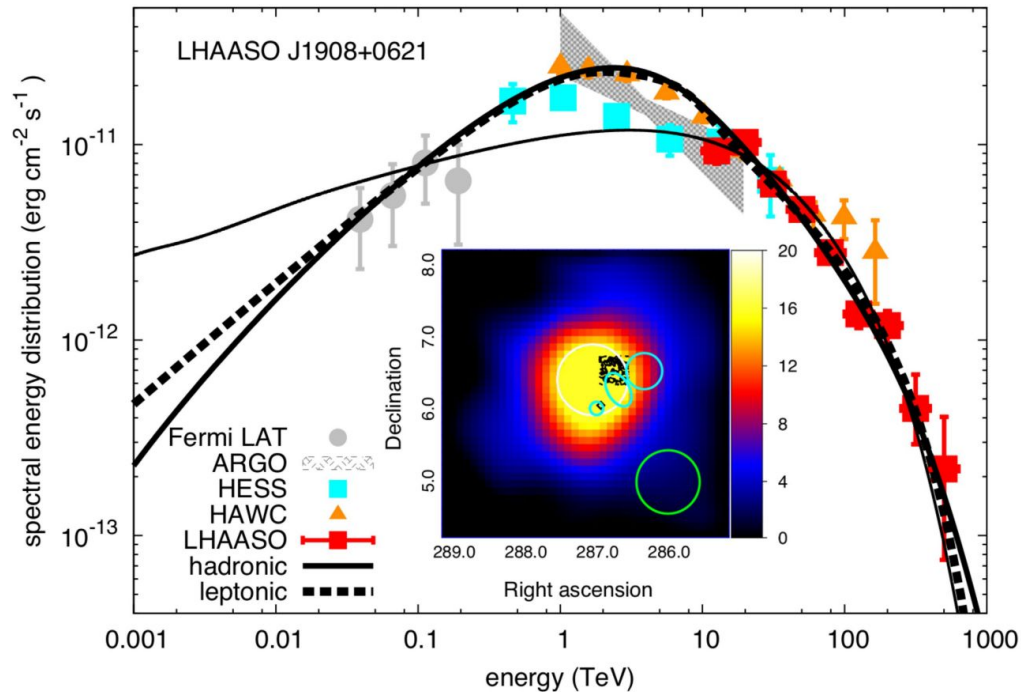
LHAASO Collaboration. 2026



H.E.S.S. Collaboration. A&A. 2021

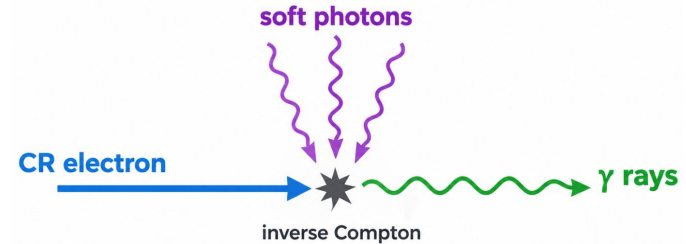


γ rays: extreme acceleration, but ambiguous origin

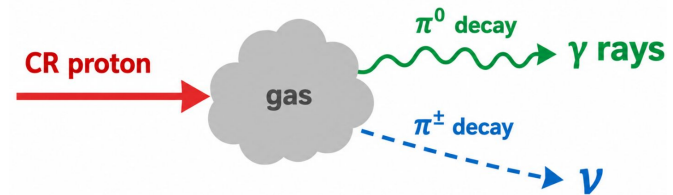


[LHAASO, Nature 594, 33–36 \(2021\)](#)

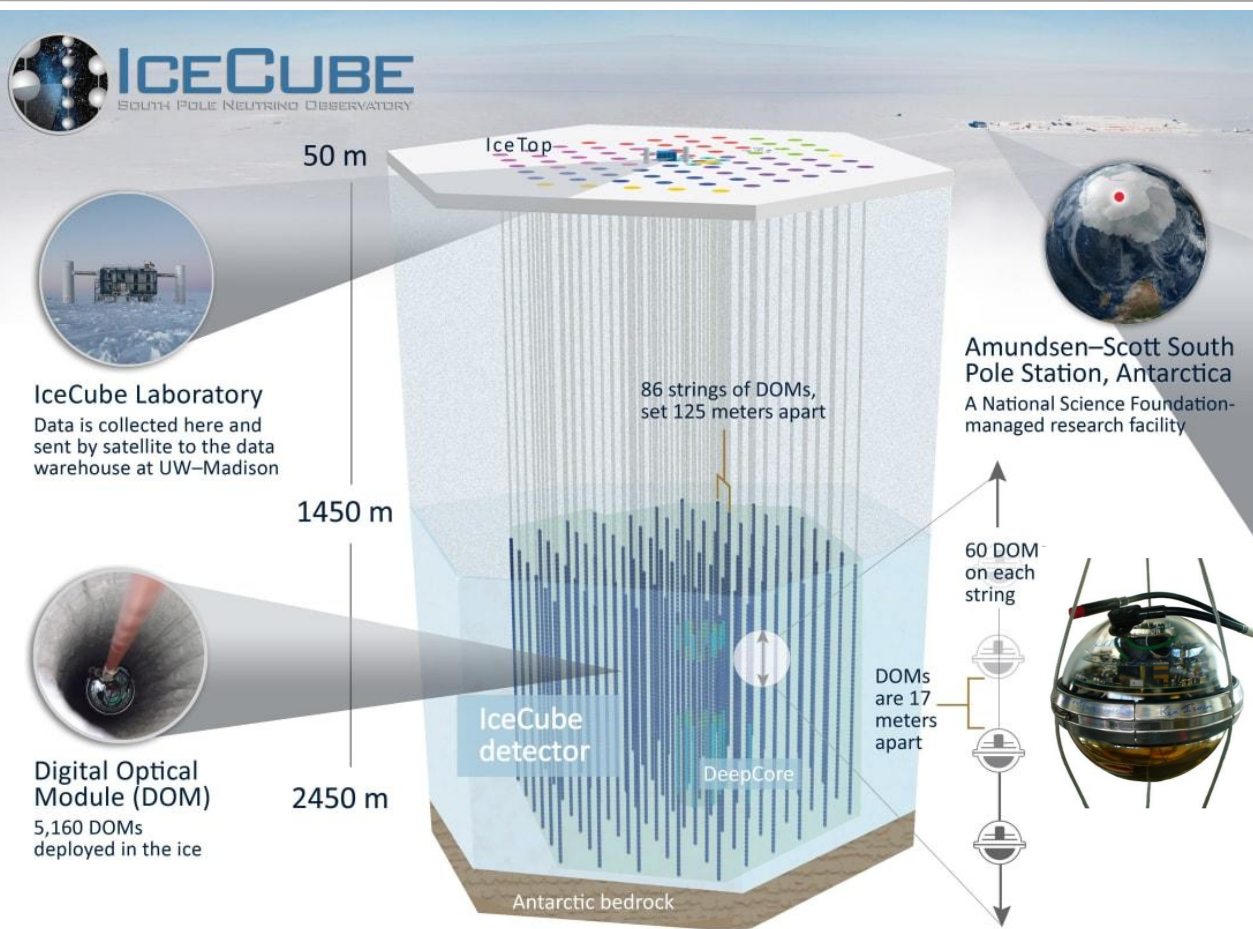
Leptonic scenario



Hadronic scenario

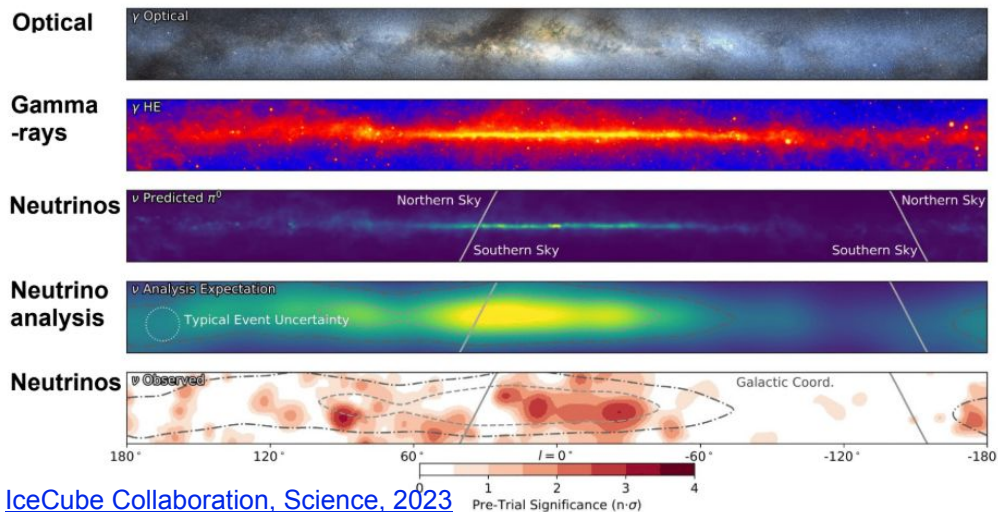


IceCube Neutrino Observatory

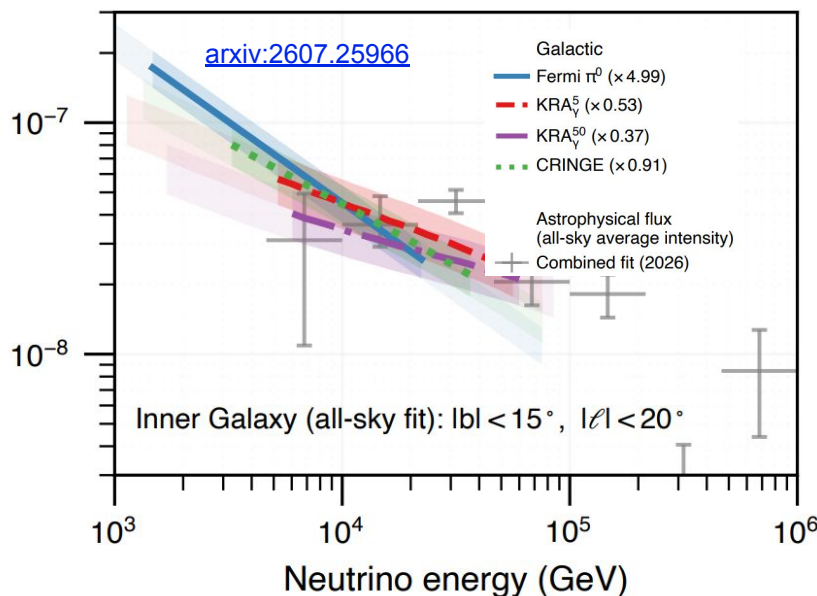


- Cubic kilometer detector instrumented in the ice at the South Pole
- 5160 DOMs on 86 strings in the Main array
- Detects Cherenkov light from charged particles produced in nu interactions
- Main array: optimized for TeV-PeV neutrinos
- DeepCore: densely instrumented infill array for GeV neutrinos
- Upgrade: complete 2026 with new dense strings

Neutrinos from the Milky Way



$E^2 \Phi_{\nu+\bar{\nu}}$ ($\text{GeV cm}^{-2} \text{s}^{-1} \text{sr}^{-1}$)



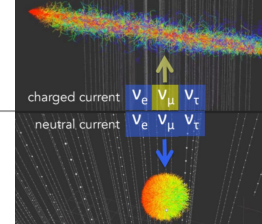
- 2023: First evidence of diffuse Galactic-plane neutrino emission at 4.5σ , using DNNC sample

- 2026: A multi-flavor analysis established Galactic plane neutrino emission at 5.7σ

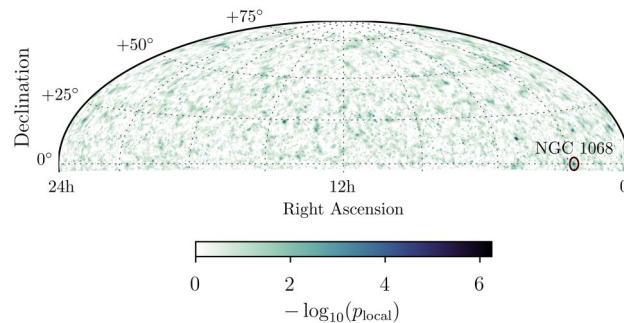
Natural question: Galactic point sources? → Motivates this work

ICEMAN Data Samples

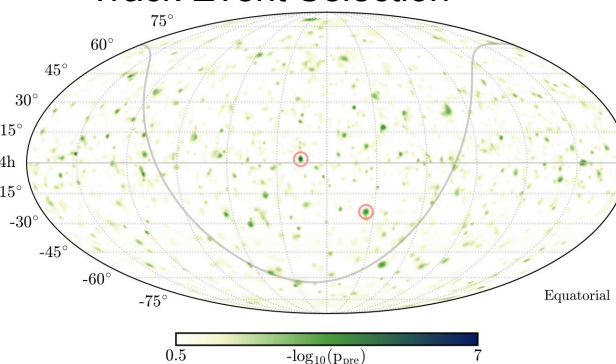
➤ IceCubE Multi-flavor Astrophysical Neutrino dataset



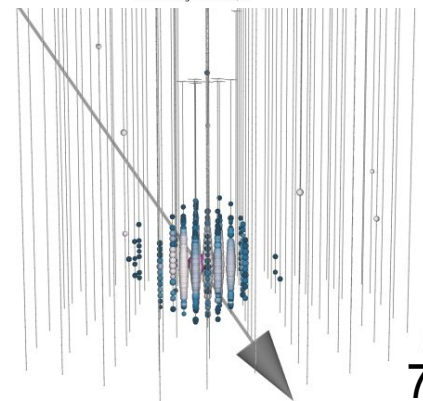
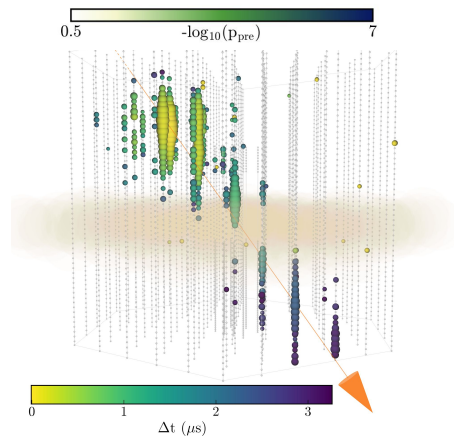
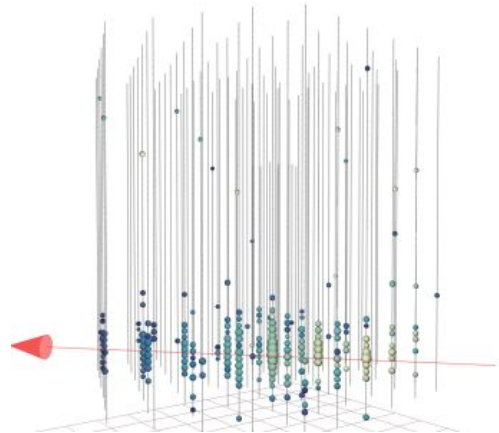
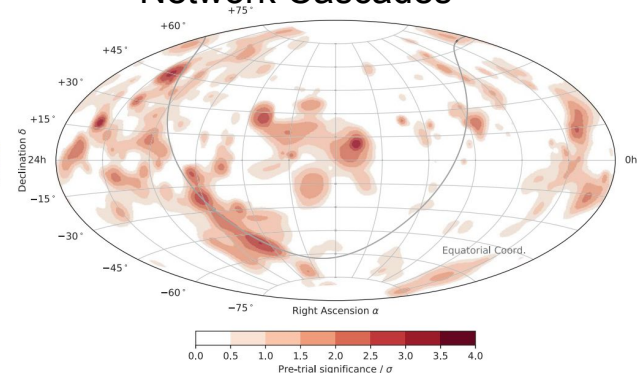
NT: Northern Tracks



ESTES: Enhanced Starting Track Event Selection



DNNC: Deep Neural Network Cascades

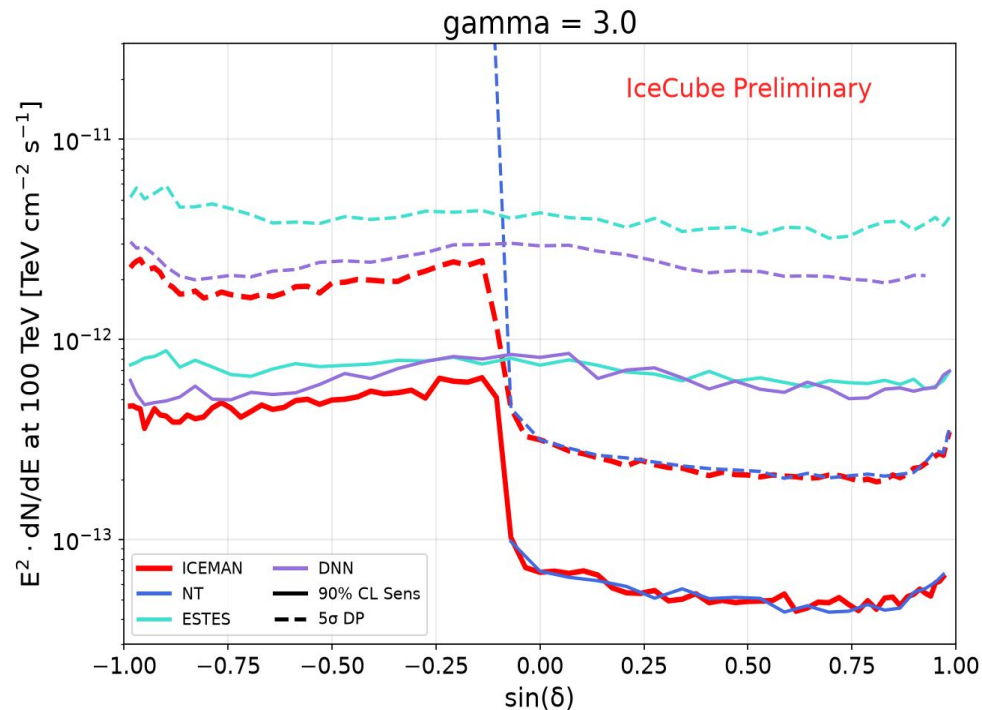


ICEMAN Data Samples

➤ ICEMAN: dataset combination

- NT: 13 years
- ESTES: 12 years
- DNNC: 12 years
 - Improved reconstruction
 - Improved ice modeling
 - Improved point spread function estimator

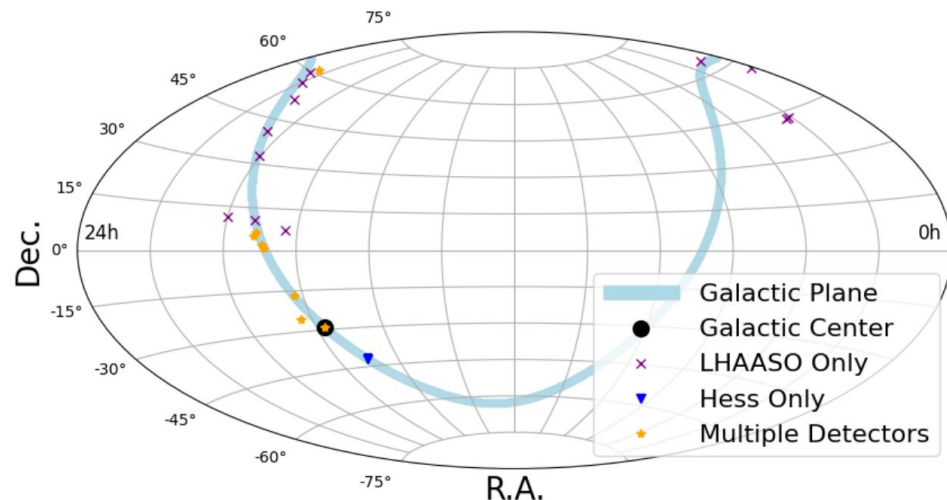
➤ Point-source sensitivity improves after combining samples



Individual Point Source list

- Starting sample: 49 gamma-ray sources with emission > 100 TeV
 - detected by LHAASO, HAWC, and H.E.S.S.
- First-step selection: prioritize sources more likely to be hadronic
 - associated with molecular clouds
 - supernova remnants
 - microquasars
 - dark or unidentified sources
- Exclude sources likely dominated by leptonic emission
 - PWNe / pulsars
 - sources classified as leptonic in literature,
 - keep exceptions with plausible hadronic scenarios

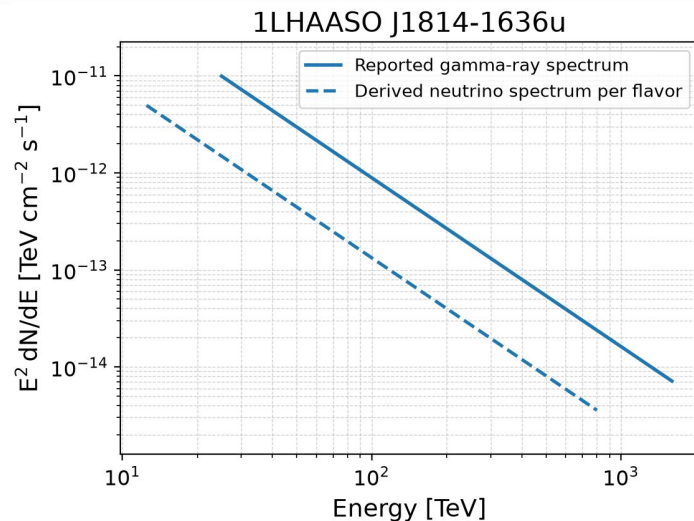
→ 21 candidates remain



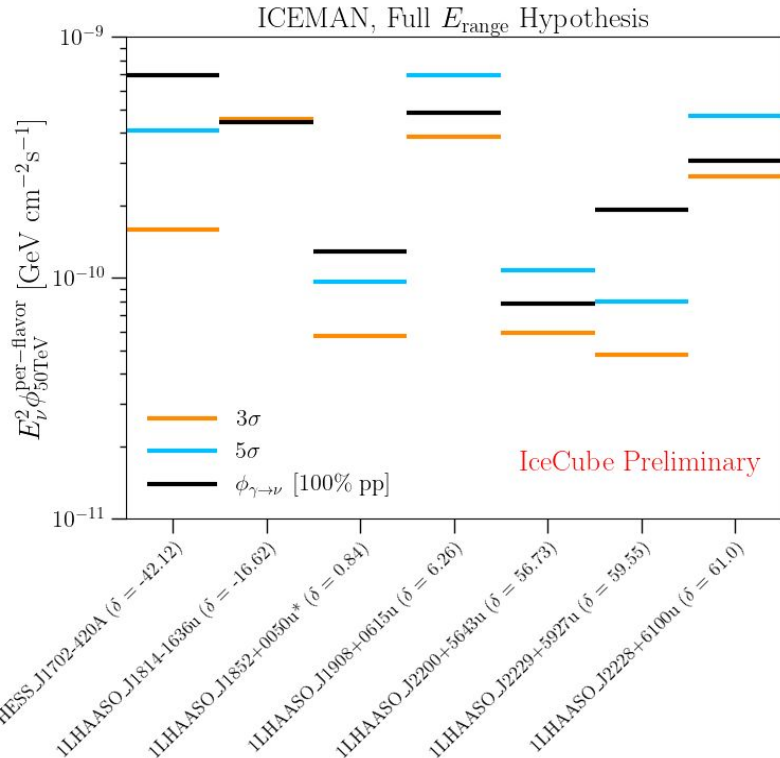
Individual Point Sources

- Estimate neutrino flux from gamma-ray flux assuming 100% pp interaction

$$E_\nu^2 \Phi_{\nu_\alpha}(E_\nu) \simeq \frac{2}{3} E_\gamma^2 \Phi_\gamma(E_\gamma), \quad E_\gamma \simeq 2E_\nu$$



- Compare predicted flux with ICEMAN sensitivity and discovery potential



→ 7 sources have expected neutrino emission above 3 σ threshold

- No significant excess observed
- Detailed results are in progress

HESS J1702-420A

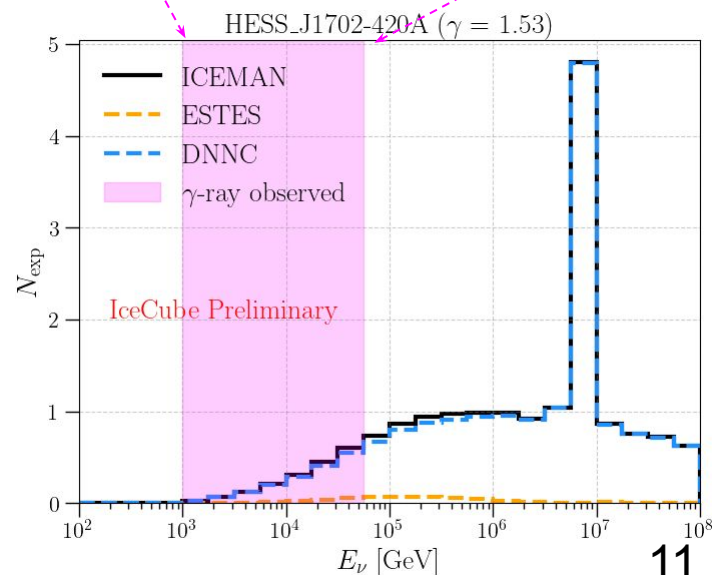
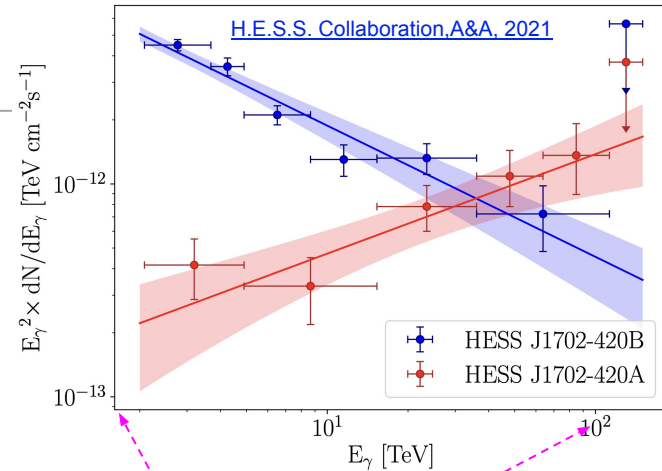
➤ Southern sky PeVatron candidate observed by H.E.S.S.

- hard spectral index: 1.53
- no evidence of a cutoff up to $E_\gamma \sim 100$ TeV

➤ Goal: constrain the maximum hadronic energy

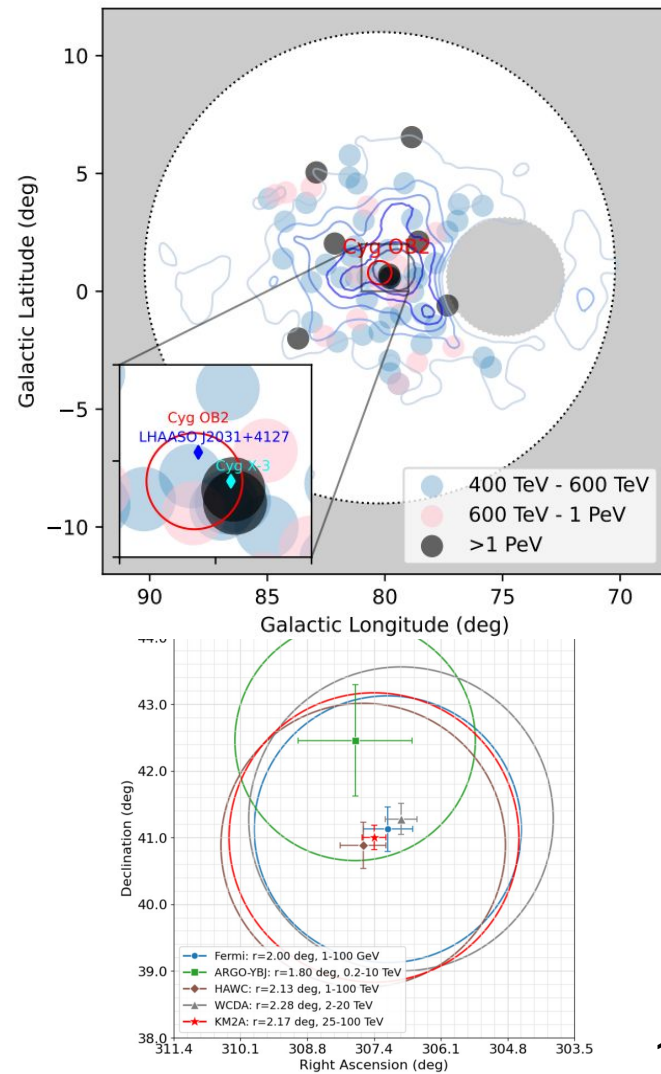
- fix spectral index to 1.53
- fit ns and exponential cutoff energy E_{cut}
- null hypothesis: hadronic spectrum continues with no cutoff
- alternative hypothesis: finite E_{cut}

→ A non-detection can still constrain the hadronic cutoff energy



Cygnus Cocoon Region

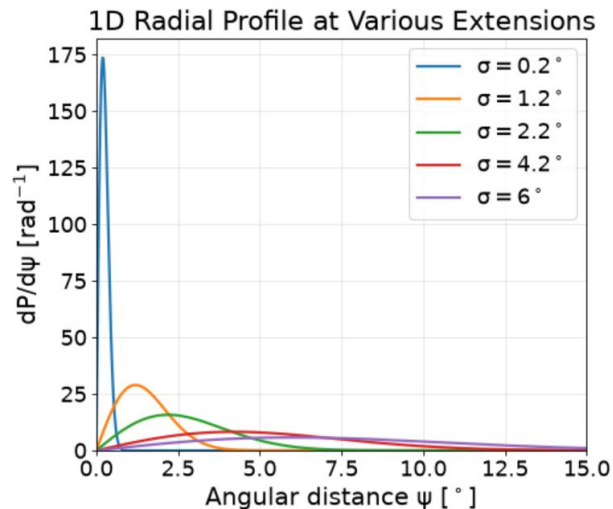
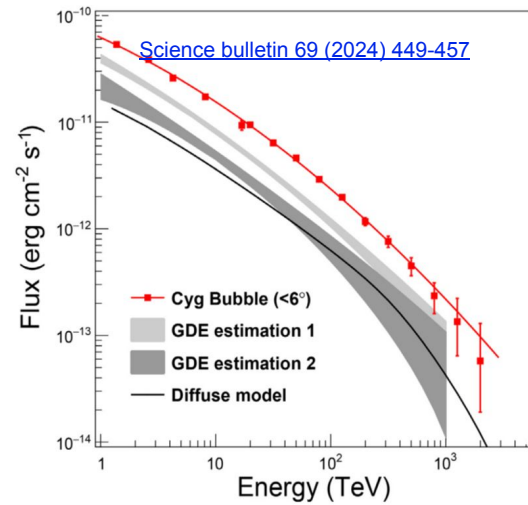
- Complex extended region in Cygnus X
 - Cygnus OB2
 - Cygnus X-3
 - and multiple TeV sources
 - LHAASO observes ultra-high-energy emission
 - Hundreds of photons > 100 TeV
 - Several photons > 1 PeV
 - Gamma-ray morphology varies with energy and instrument
- Motivates an extended-template neutrino search



Cygnus Analysis Method

- Neutrino spatial morphology is unknown
- Spatial template search:
 - spatial PDF modeled with a von Mises-Fisher distribution
 - scan source extension σ from 0.2° to 6.0° in 0.2° steps
 - fix spectral shape to the LHAASO log-parabola spectrum
- Fit ns for each extension; define final TS as the maximum TS over scanned extensions

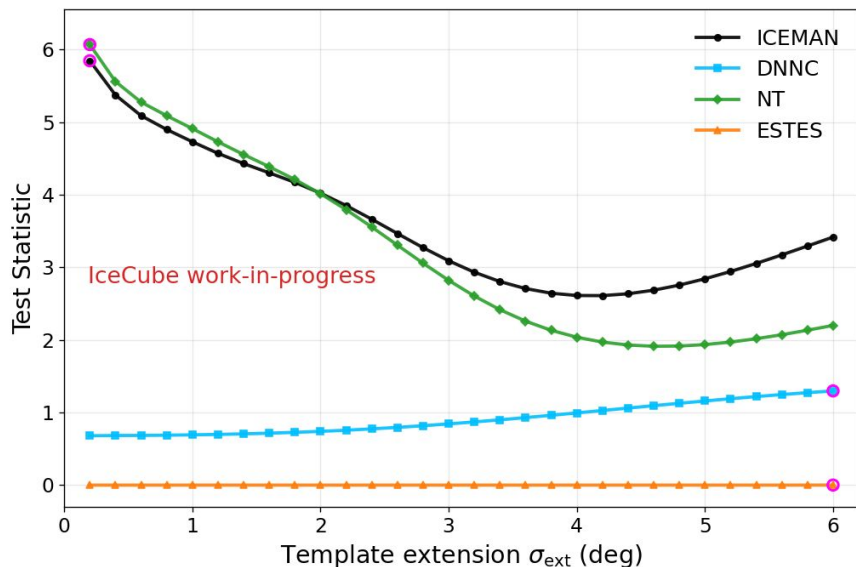
$$f(x; \sigma) = \begin{cases} \frac{\kappa}{4\pi} \cdot \frac{2 \exp[\kappa(\cos x - 1)]}{1 - \exp(-2\kappa)} & \text{if } \sigma > \sigma_{\min} \\ \frac{1}{2\pi\sigma^2} \exp\left(-\frac{x^2}{2\sigma^2}\right) & \text{if } \sigma \leq \sigma_{\min} \end{cases}$$



Cygnus Search Results

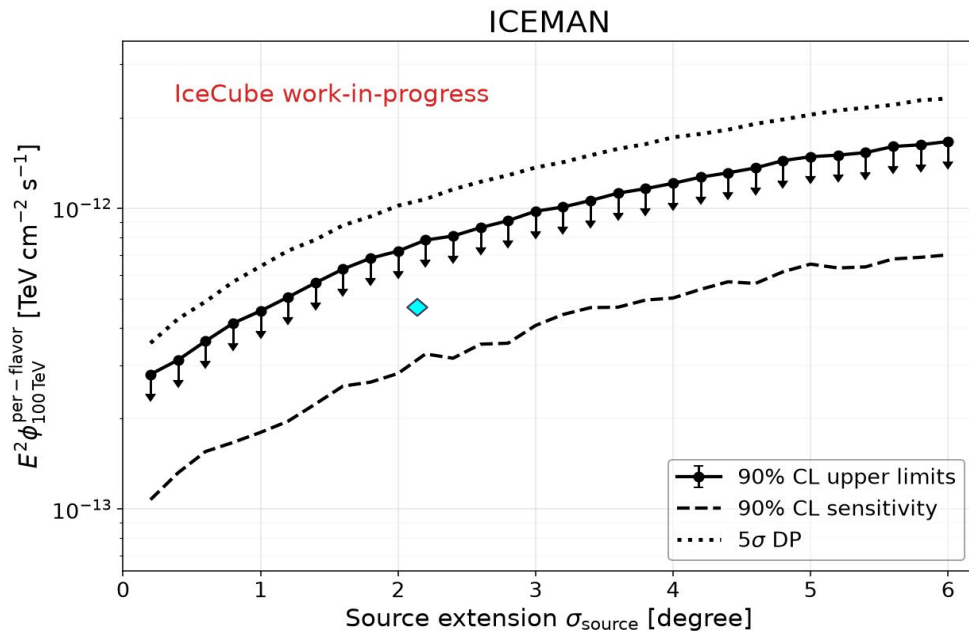
➤ Best-fit:

- Excess:pre-trial: 2.47σ
- Extension 0.2° , ns ~ 46



➤ Upper limits

➤ Detailed results are in progress



Summary

- ICEMAN provides a multi-flavor dataset for Galactic PeVatron searches
 - combines Northern Tracks, ESTES, and DNN Cascades
- We search for neutrino emission from Galactic gamma-ray sources >100 TeV
 - individual source search with hadronic-favorable candidates
 - dedicated HESS J1702-420A cutoff study
 - extended-template search for the Cygnus Cocoon region
- Cygnus Cocoon: no significant excess for extensions from 0.2° to 6.0°
- More results are coming soon

Thanks!

backup

Cygnus region from various gamma-ray observations

