High-Energy Emission Analysis from the Galactic Center Region with HAWC and IceCube

Sohyoun Yun Cárcamo (speaker) & Rishi Babu

For the HAWC and IceCube collaborations

TeVPA 2026

Introduction

✳ Origin of PeV Galactic cosmic rays: unresolved

✳ Gamma rays trace particle interactions, but can't separate hadronic vs. leptonic origin

✳ Neutrinos = unambiguous hadronic tracer ($\pi^{\pm} \rightarrow \nu$)

✳ Galactic Center (GC) *proposed* as PeVatron by H.E.S.S. (Abramowski et al. Nature 531, 476–479, 2016)

Sohyoun Yun-Cárcamo (postdoc), sy645@drexel.edu

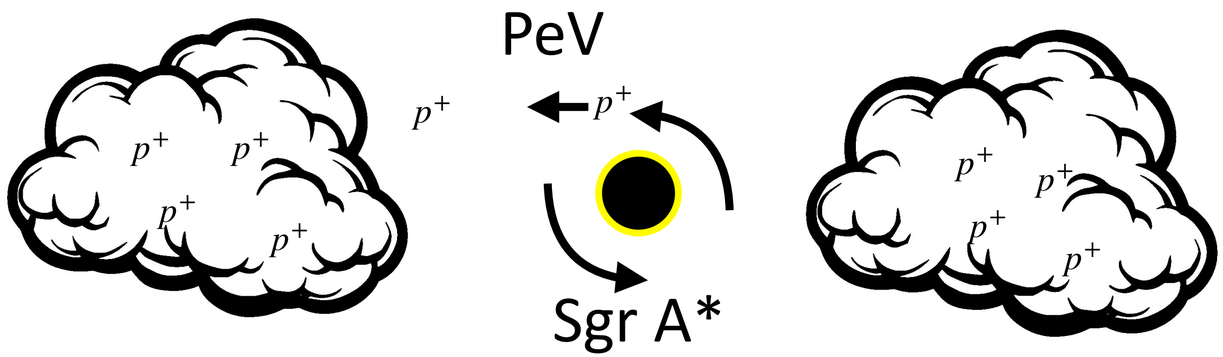
Introduction

✳ Origin of PeV Galactic cosmic rays: unresolved

✳ Gamma rays trace particle interactions, but can't separate hadronic vs. leptonic origin

✳ Neutrinos = unambiguous hadronic tracer ($\pi^{\pm} \rightarrow \nu$)

✳ Galactic Center (GC) *proposed* as PeVatron by H.E.S.S. (Abramowski et al. Nature 531, 476–479, 2016)



Molecular clouds
(Target gas)

Motivation

✳ HAWC: GC gamma-ray emission extends beyond 100 TeV, no cutoff
→ PeVatron observation (Albert et al. ApJL 973, L34, 2024)

✳ IceCube's diffuse Galactic-plane ν flux (Abbasi et al., Science 380, 6652, 1338–1343) motivates a direct GC search

Motivation

✳ HAWC: GC gamma-ray emission extends beyond 100 TeV, no cutoff
→ PeVatron *observation* (Albert et al. ApJL 973, L34, 2024)

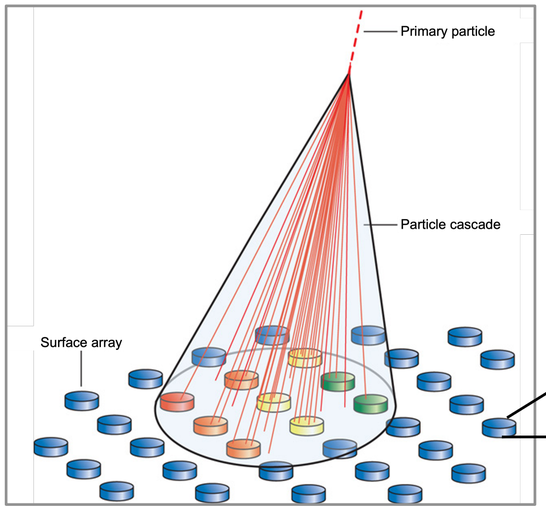
✳ IceCube's diffuse Galactic-plane ν flux (Abbasi et al., Science 380, 6652, 1338–1343) motivates a direct GC search

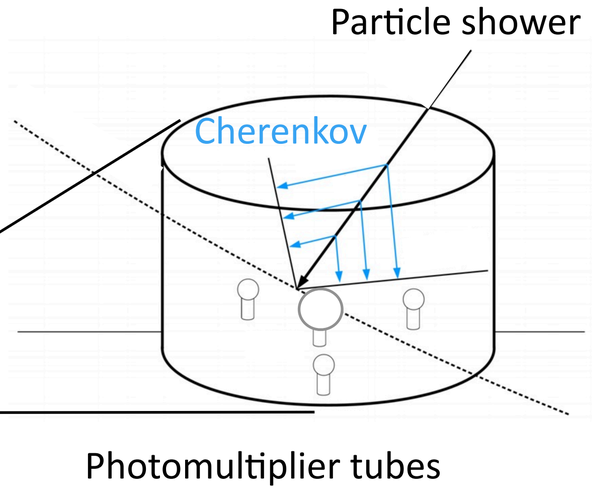
This analysis: use HAWC's best-fit gamma-ray model to predict and search for a neutrino counterpart with IceCube

Sohyoun Yun-Cárcamo (postdoc), sy645@drexel.edu

HAWC: instrument and data

- High-Altitude Water Cherenkov (HAWC) Gamma-Ray Observatory
- Sierra Negra, Mexico (4100 m)
- Wide field of view: continuous overhead monitoring





Source: *Nature* (Vol. 458, pp. 847–851).

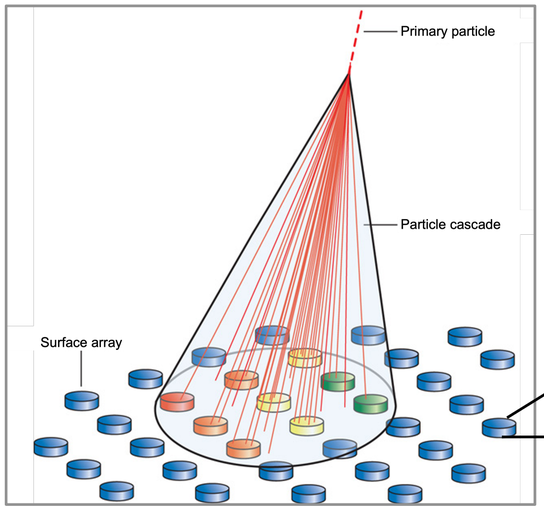
Source: Kristi Engel.

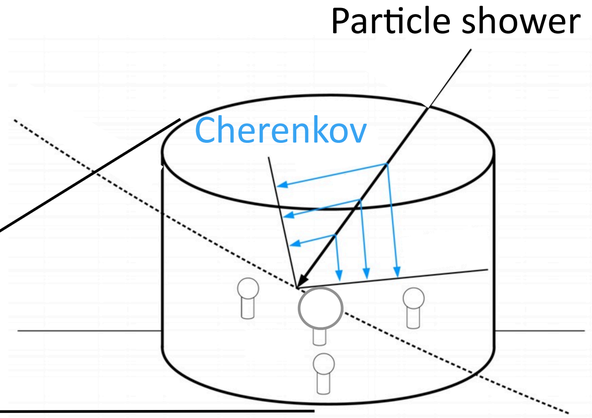
HAWC: instrument and data

- High-Altitude Water Cherenkov (HAWC) Gamma-Ray Observatory
- Sierra Negra, Mexico (4100 m)
- Wide field of view: continuous overhead monitoring

In this analysis:

- ~2860 days of data (7 + 1 year)
- Neural Network energy estimator dataset
- improved machine-learning-based background rejection





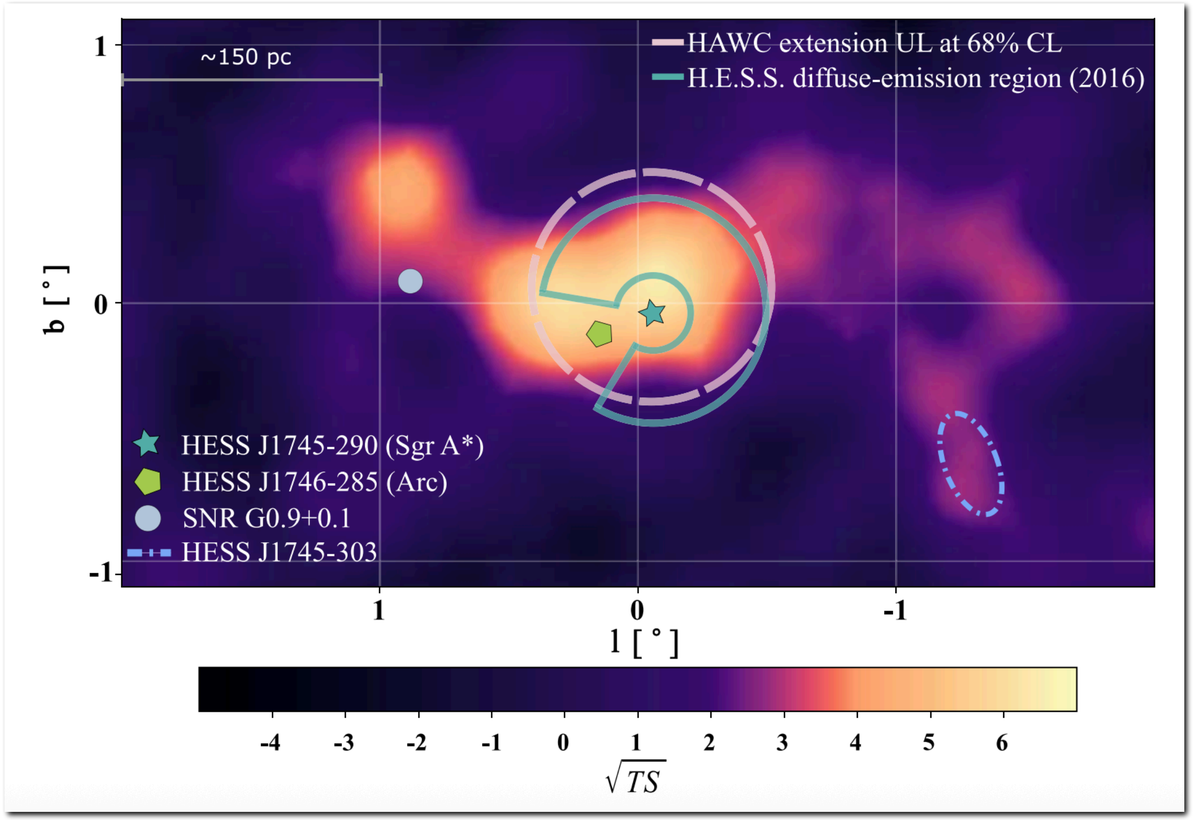
Source: *Nature* (Vol. 458, pp. 847–851).

Source: Kristi Engel.

Sohyoun Yun-Cárcamo (postdoc), sy645@drexel.edu

HAWC: Data and best-fit model

✳ In HAWC's previous publication (2024; 6.5σ), the best fit model was a single point source with a power-law spectrum

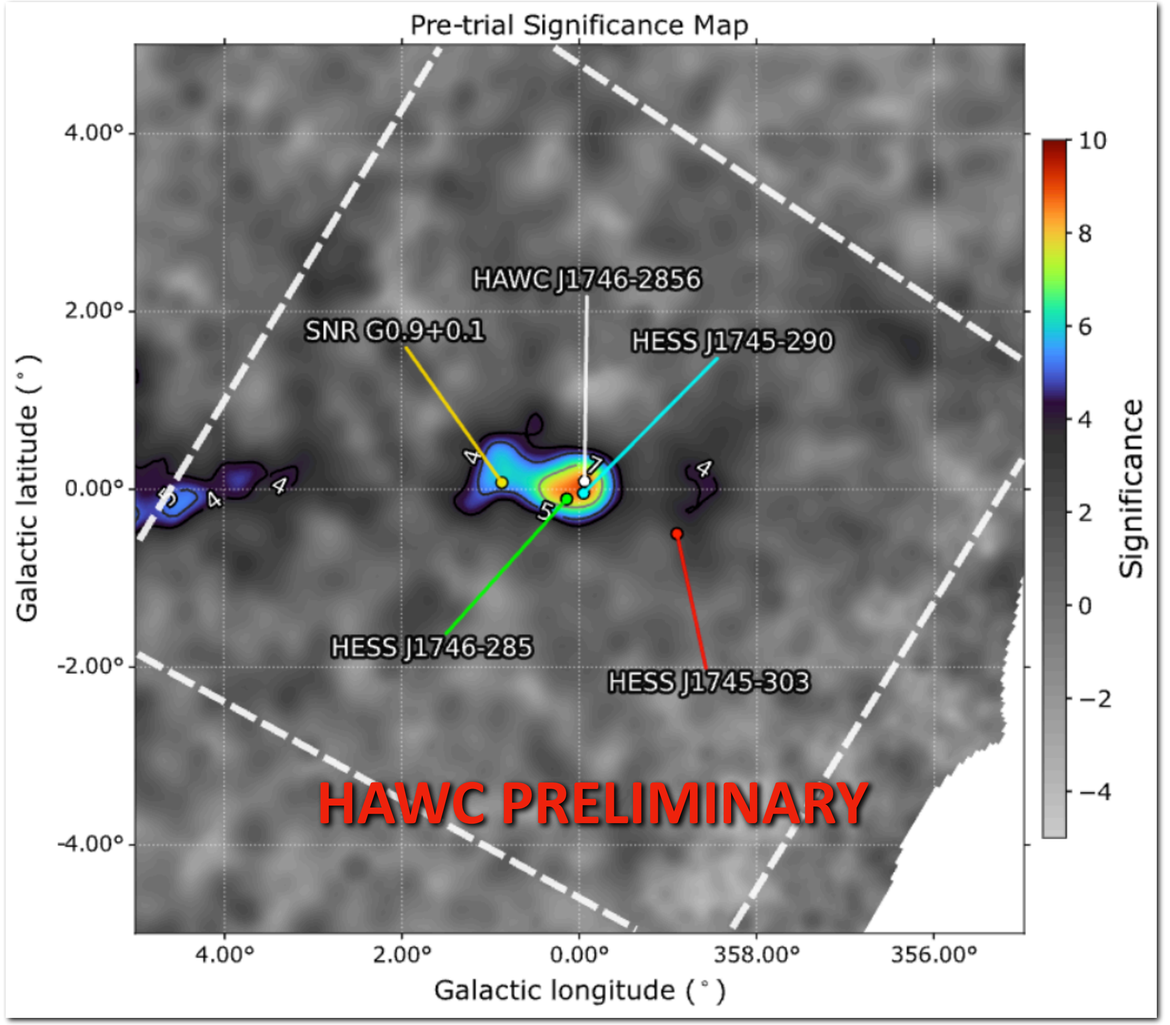


Albert et al. ApJL 973, L34, 2024

HAWC: Data and best-fit model

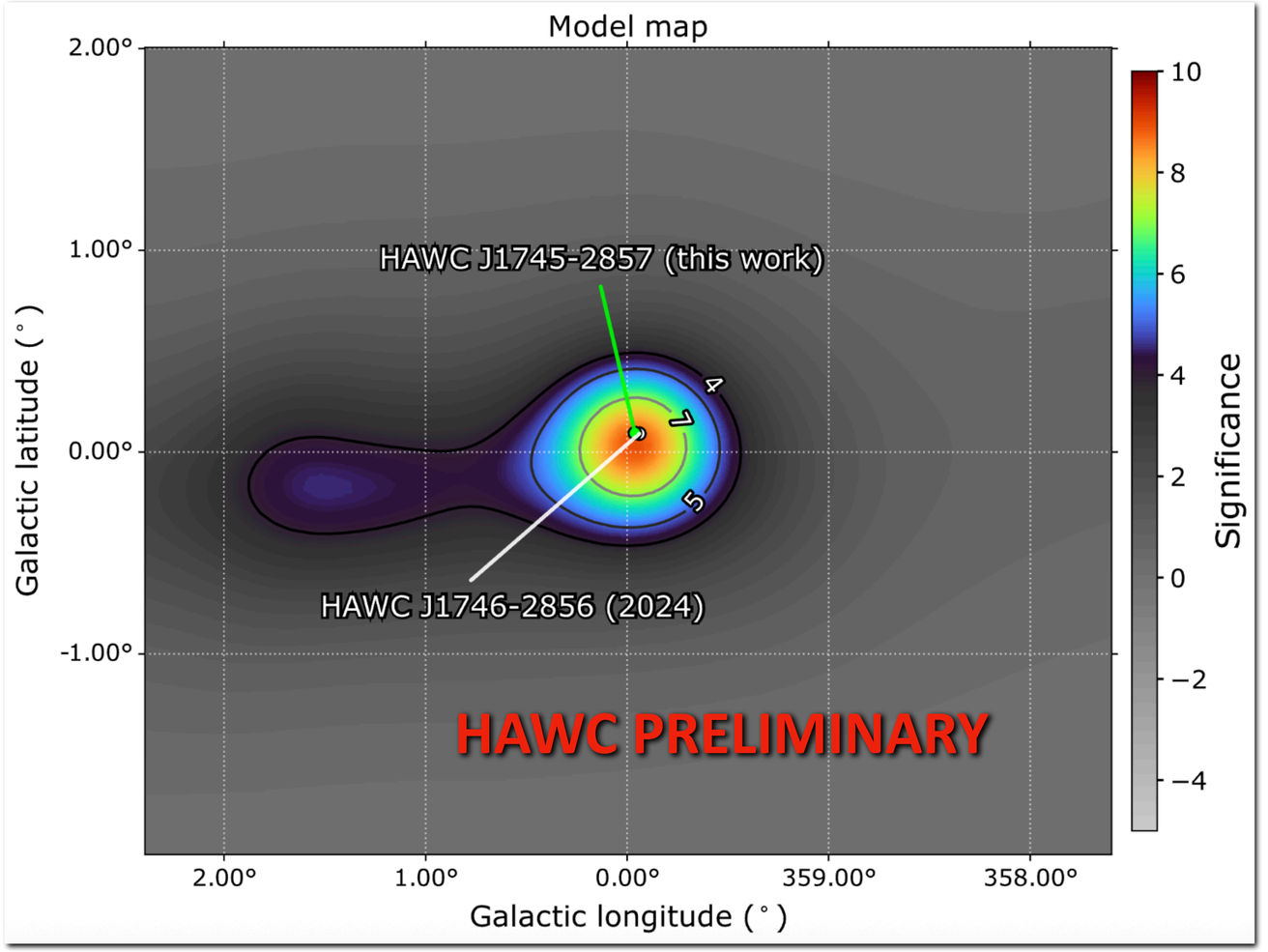
✳ In HAWC's previous publication (2024; 6.5σ), the best fit model was a single point source with a power-law spectrum

✳ **Now we detect the Galactic Center at 9σ (pre-trial)**



HAWC: Data and best-fit model

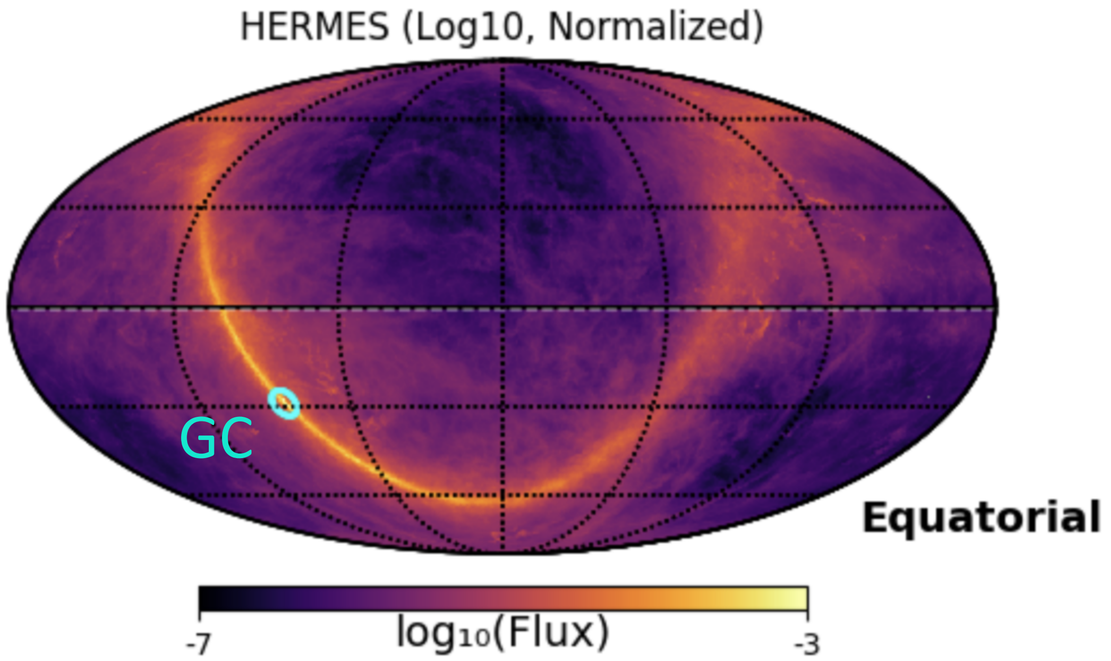
- In HAWC's previous publication (2024; 6.5σ), the best fit model was a single point source with a power-law spectrum
- Now we detect the Galactic Center at 9σ (pre-trial)
- **The best-fit model is a Galactic diffuse emission (GDE) component + point source with a power-law spectrum**



Sohyoun Yun-Cárcamo (postdoc), sy645@drexel.edu

HAWC best-fit model

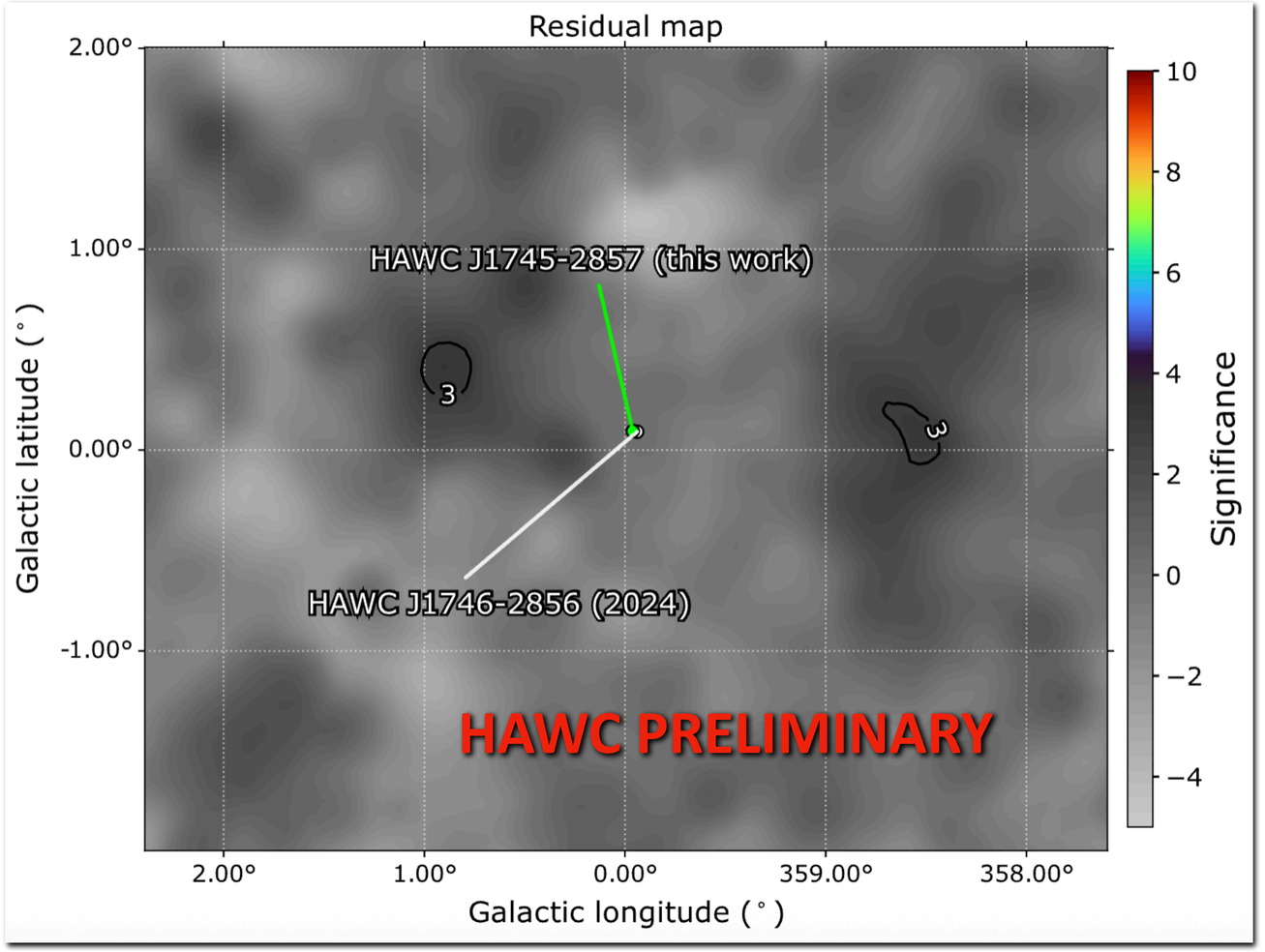
- Point source with power law spectrum
- The GDE component is modeled by a template obtained with the HERMES software
  - ➡ High-Energy Radiative MESsengers (Dundovic et al. A&A 653, A18, 2021)



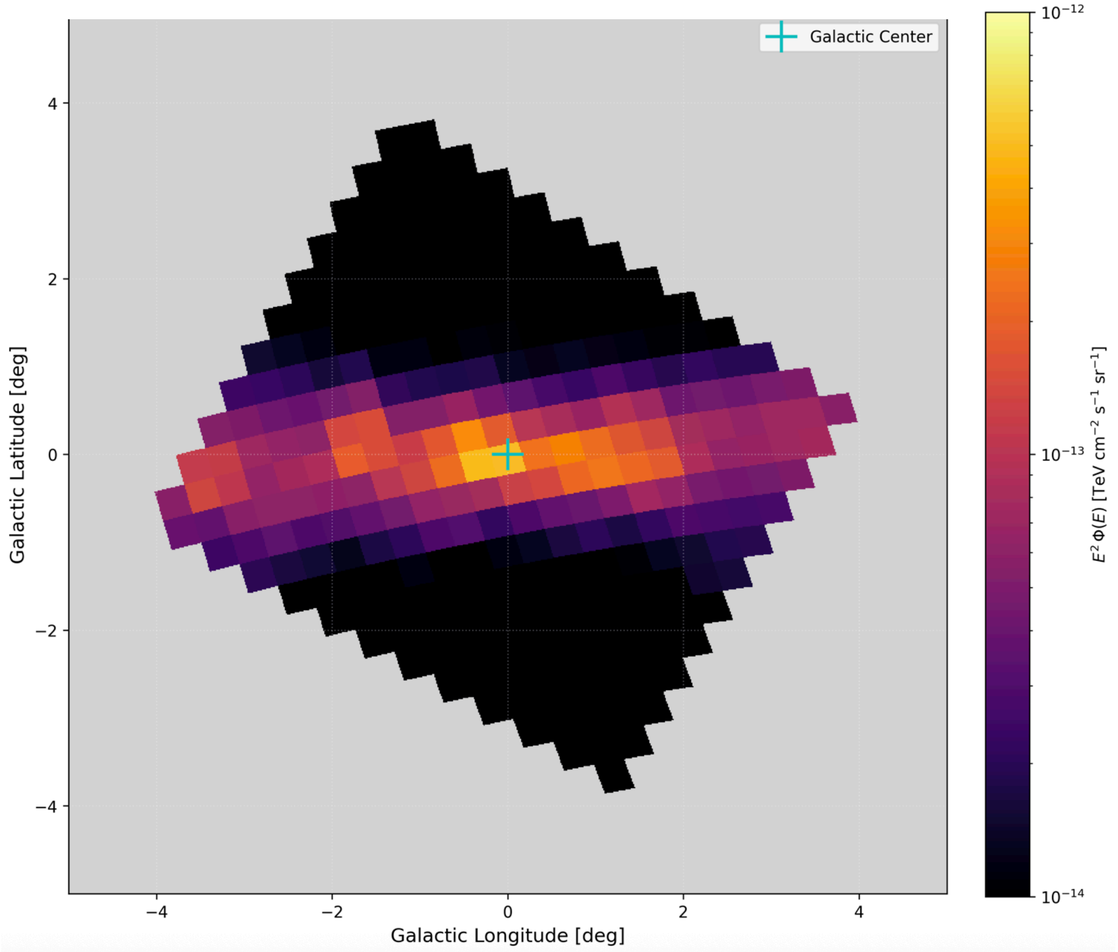
HAWC best-fit model

- Point source with power law spectrum
- The GDE component is modeled by a template obtained with the HERMES software
  - ➡ High-Energy Radiative MESsengers (Dundovic et al. A&A 653, A18, 2021)

- No significant unmodeled features
  - ➡ **good global fit**



Construction of neutrino model

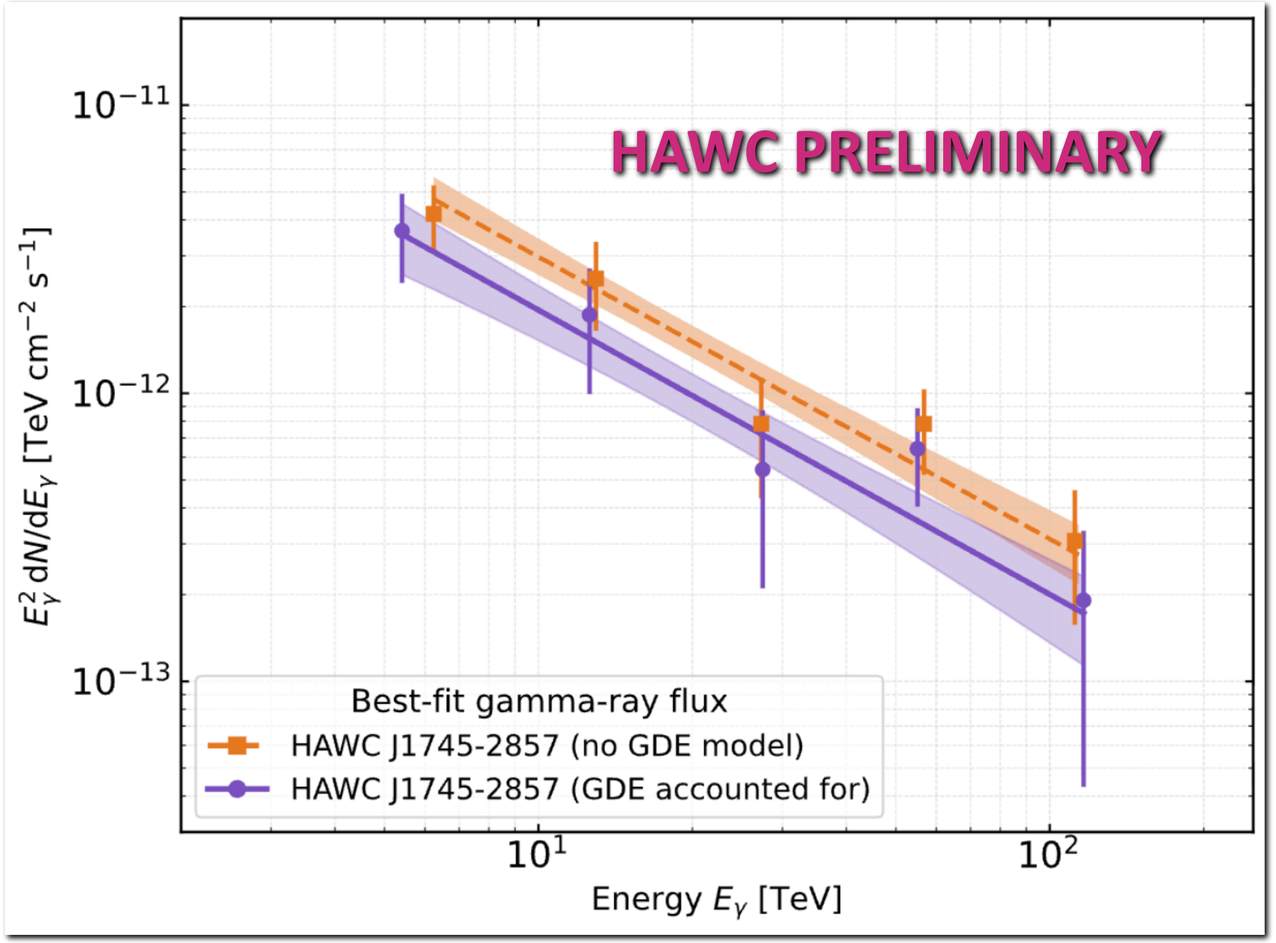


- Gamma-ray derived HERMES neutrino template
- But this is only the GDE part
- Need to add the HAWC best-fit point source
- Compare models: point source only and point source + GDE

Sohyoun Yun-Cárcamo (postdoc), sy645@drexel.edu

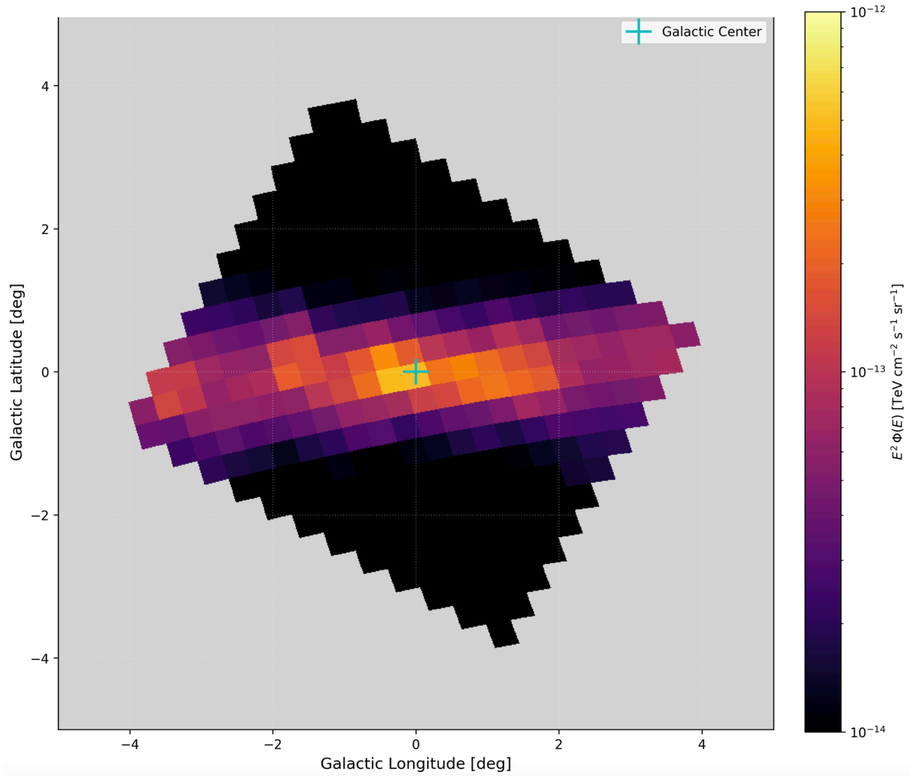
Construction of neutrino model

- The GDE-to-point-source flux ratio at the GC position is 35%
- The spectral index ($\gamma = 2.99$) remains unchanged

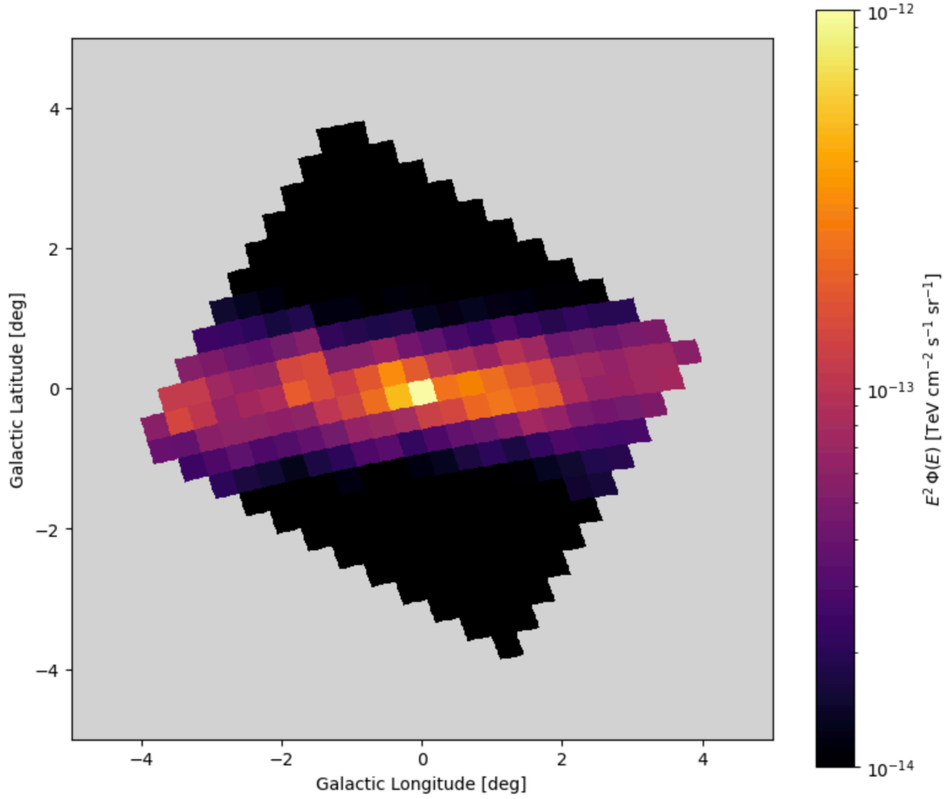


Construction of neutrino model

Gamma-ray derived HERMES neutrino template



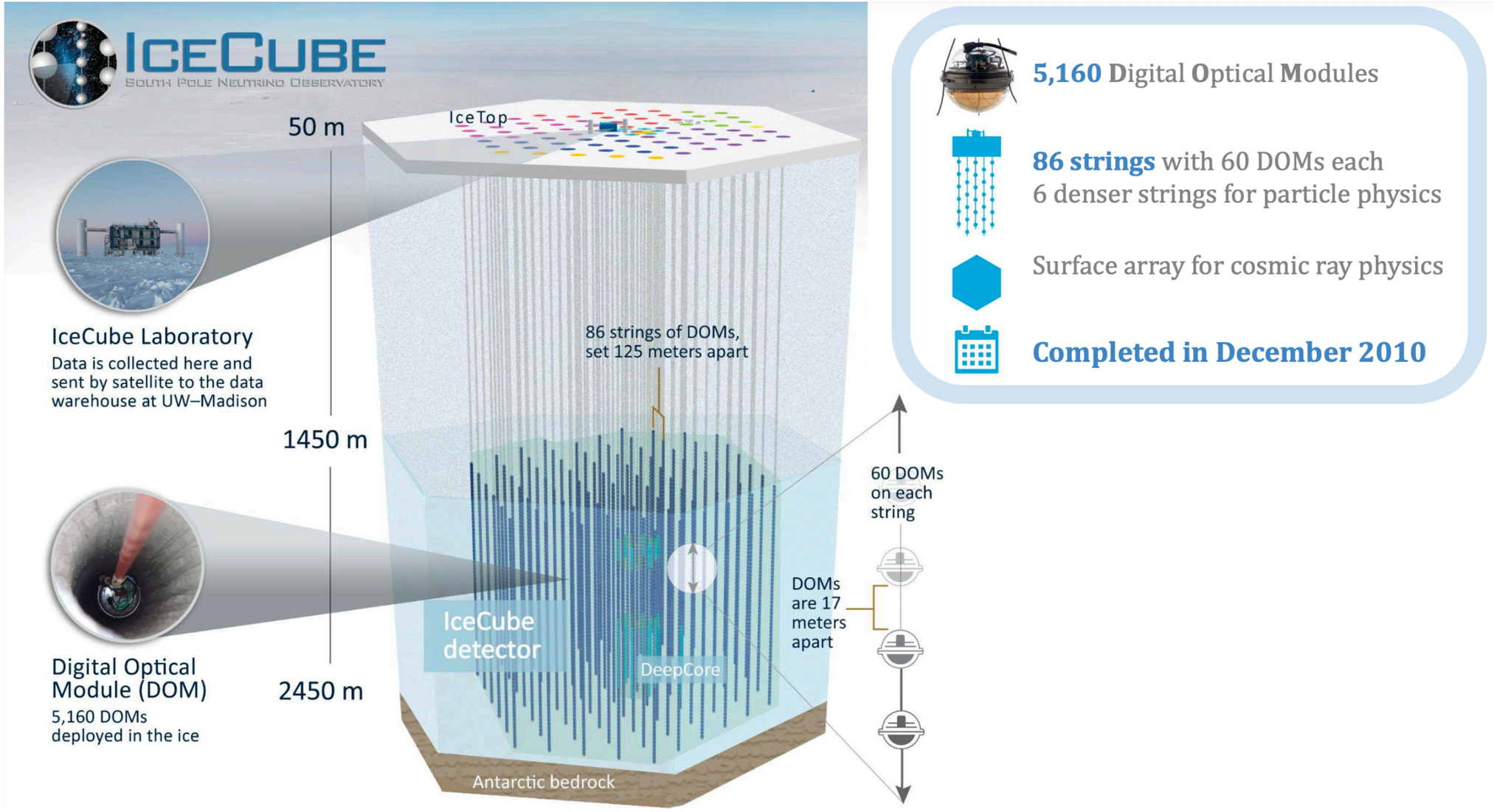
HAWC-motivated GC region emission template



- GDE-to-point-source flux ratio fixed at 35% in GC pixel
- Point source spectrum fixed to HAWC best fit

Sohyoun Yun-Cárcamo (postdoc), sy645@drexel.edu

IceCube: instrument and data



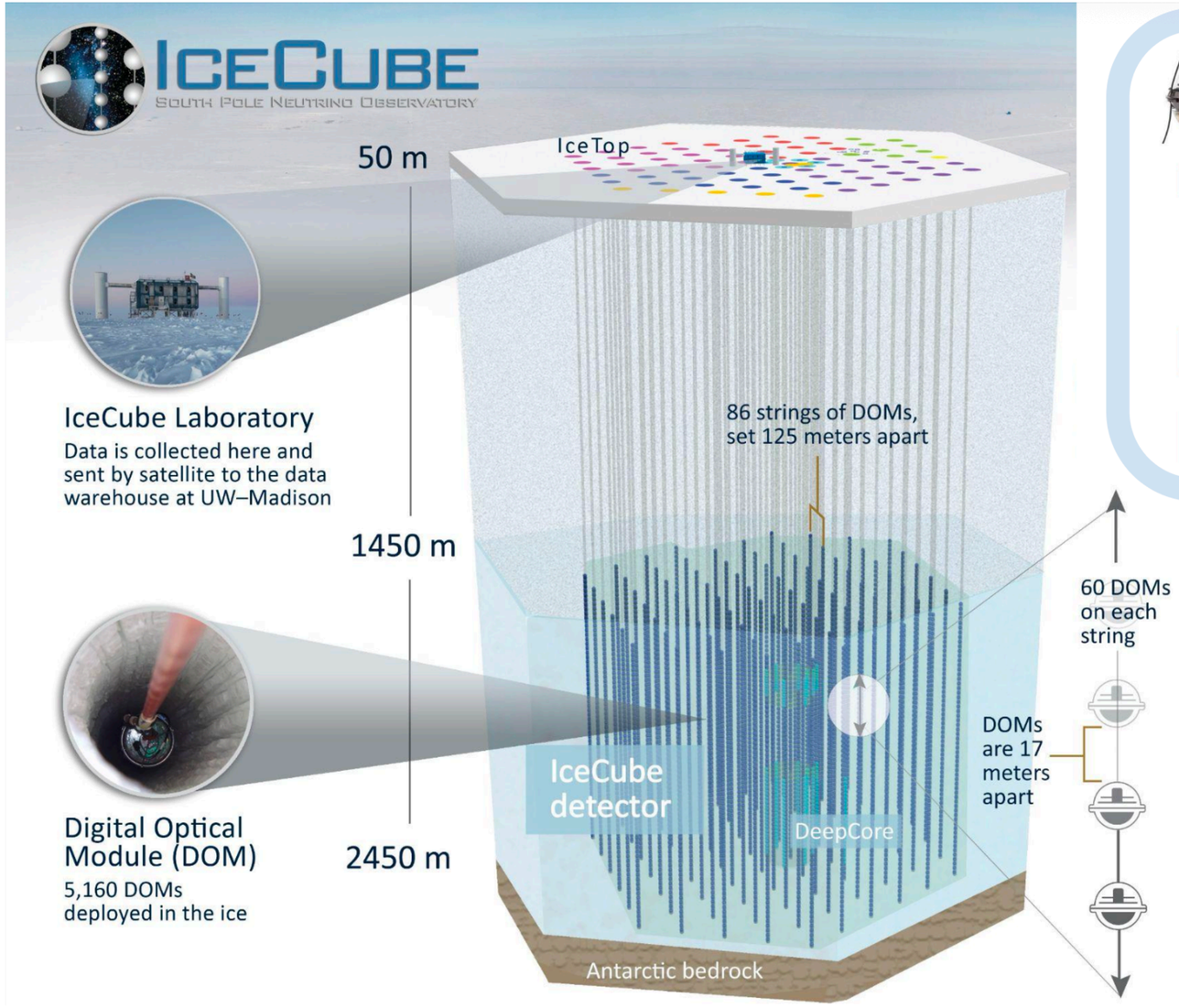
5,160 Digital Optical Modules

86 strings with 60 DOMs each
6 denser strings for particle physics

Surface array for cosmic ray physics

Completed in December 2010

IceCube: instrument and data



5,160 Digital Optical Modules

86 strings with 60 DOMs each
6 denser strings for particle physics

Surface array for cosmic ray physics

Completed in December 2010

In this analysis:

- Muon tracks (νμ CC) → excellent angular resolution
- GC in Southern sky → down-going tracks, atmospheric-muon background
- 12-year PSTracks (full-array)

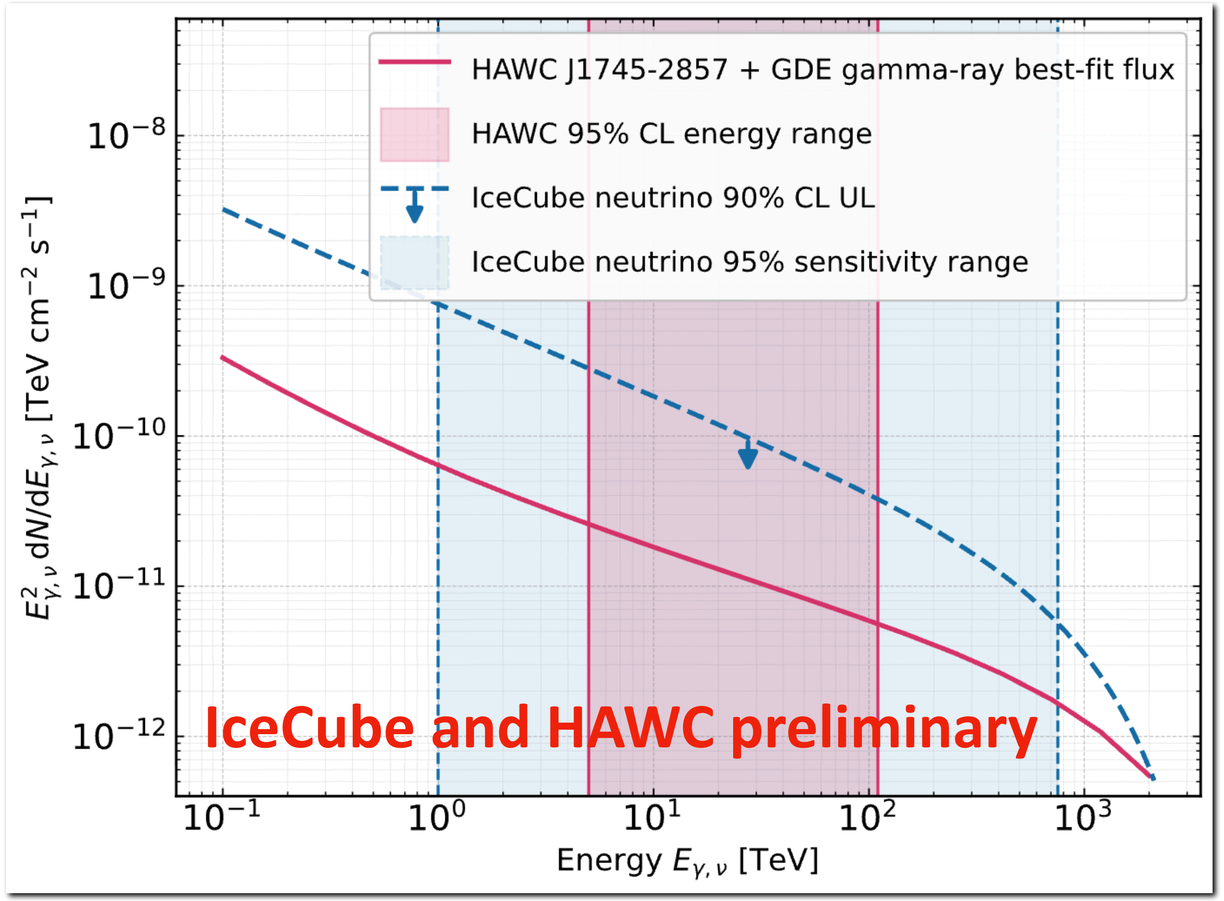
Sohyoun Yun-Cárcamo (postdoc), sy645@drexel.edu

Results

✳ Neutrino template: HAWC-derived point source + GDE (π^0-dominant), blinded search

✳ No significant excess (background-only p-value = 0.49)

✳ 90% CL UL: 12× model flux



Sohyoun Yun-Cárcamo (postdoc), sy645@drexel.edu

Conclusion

✳ Updated HAWC analysis (2860 days): point source + GDE, PeVatron interpretation reinforced (>100 TeV, no cutoff)

✳ First spatially-resolved point-source + diffuse decomposition of the GC above 40 TeV

✳ First IceCube search using a HAWC-informed multi-component neutrino template

✳ No significant excess → 90% CL UL: 12× model flux

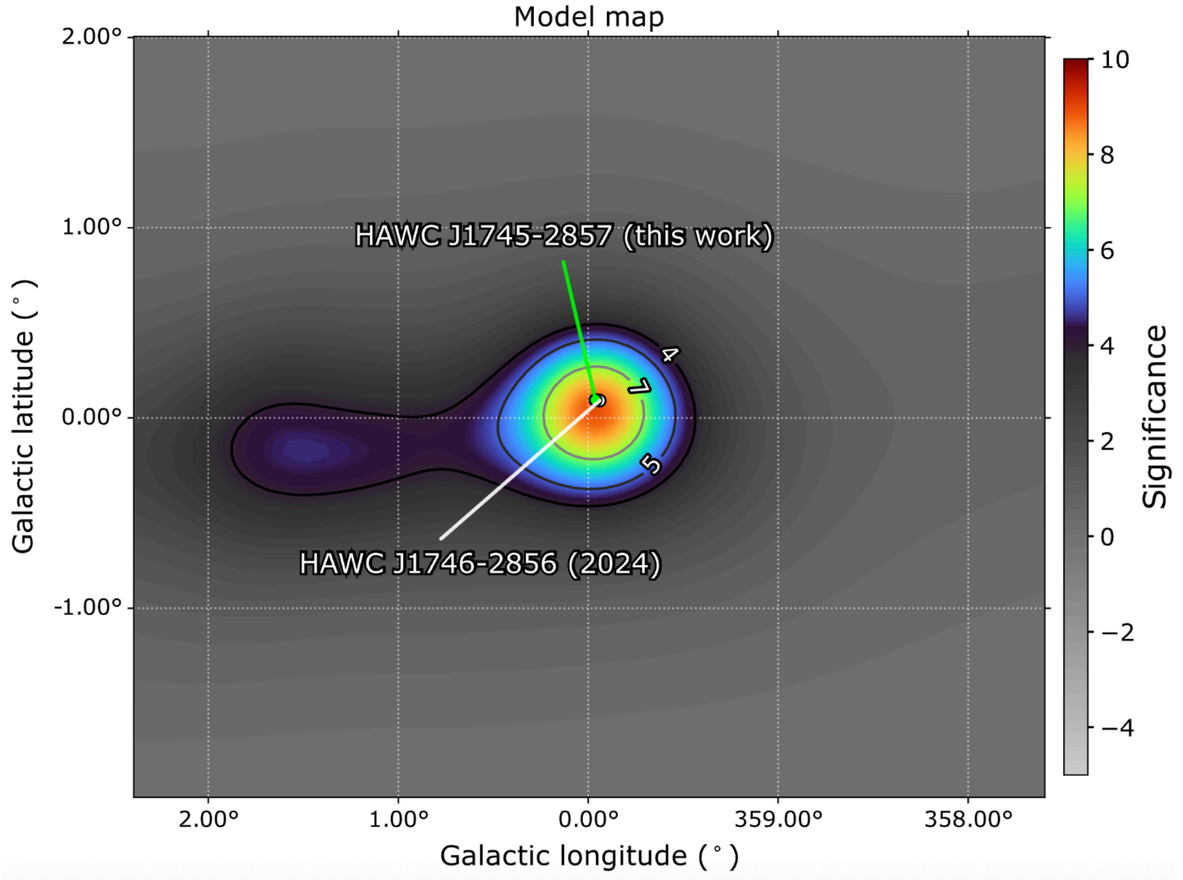
✳ Gap to hadronic prediction: ~1 order of magnitude

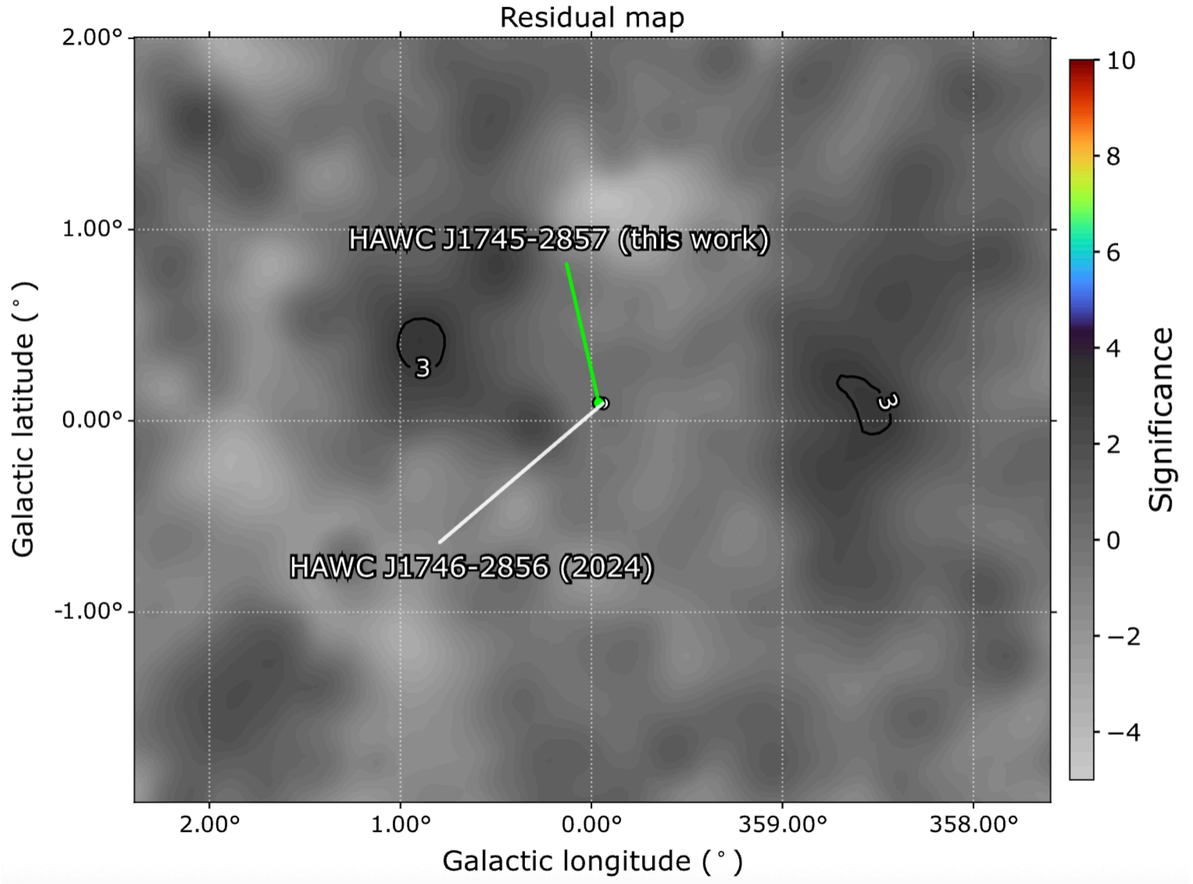
✳ Next-gen detectors (SWGO, Gen2, KM3NeT, P-ONE) will push sensitivity further, testing hadronic PeVatron scenarios in the GC

Sohyoun Yun-Cárcamo (postdoc), sy645@drexel.edu

BACK-UP slides

HAWC post-fit maps



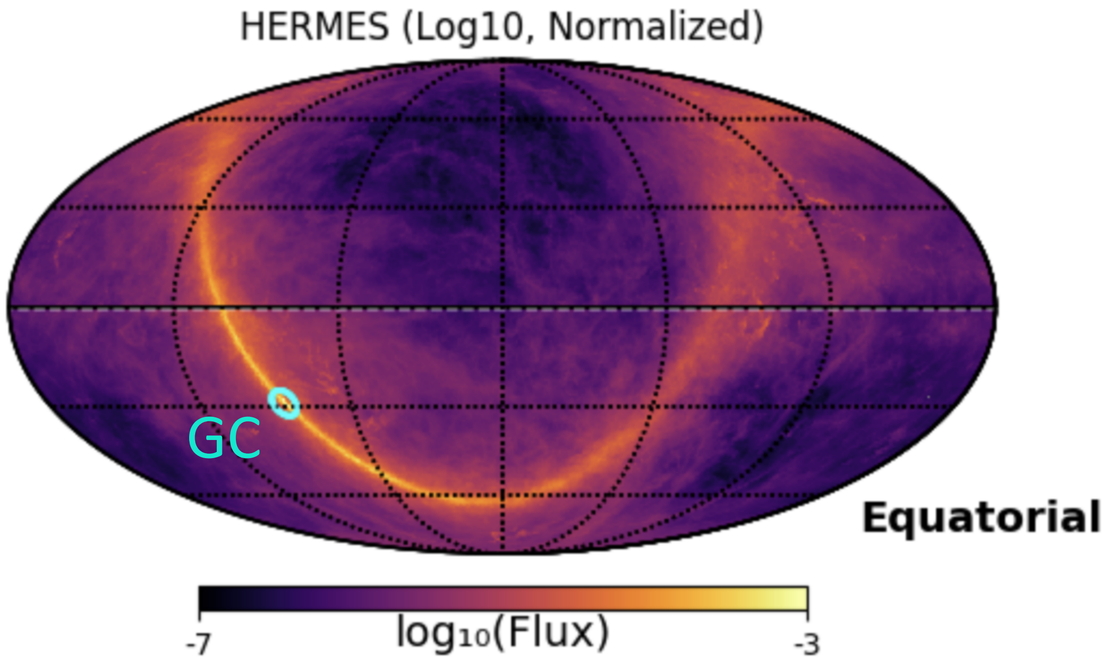


HAWC best-fit model

✳ The GDE component is modeled by a template obtained with the HERMES software

➡ High-Energy Radiative MESsengers (Dundovic et al. A&A 653, A18, 2021)

➡ Cosmic-ray models and parameters from Fornieri et al. (*JCAP* 02 (2020) 009)



Sensitivity to constructed template

	Sensitivity x [model flux]	3 sigma DP x [model flux]	5 sigma DP x [model flux]
Combined template (8°x 8° ROI)	12	26	41