IceCube Search for Galactic Neutrino Sources based on HAWC Observations of the Milky Way

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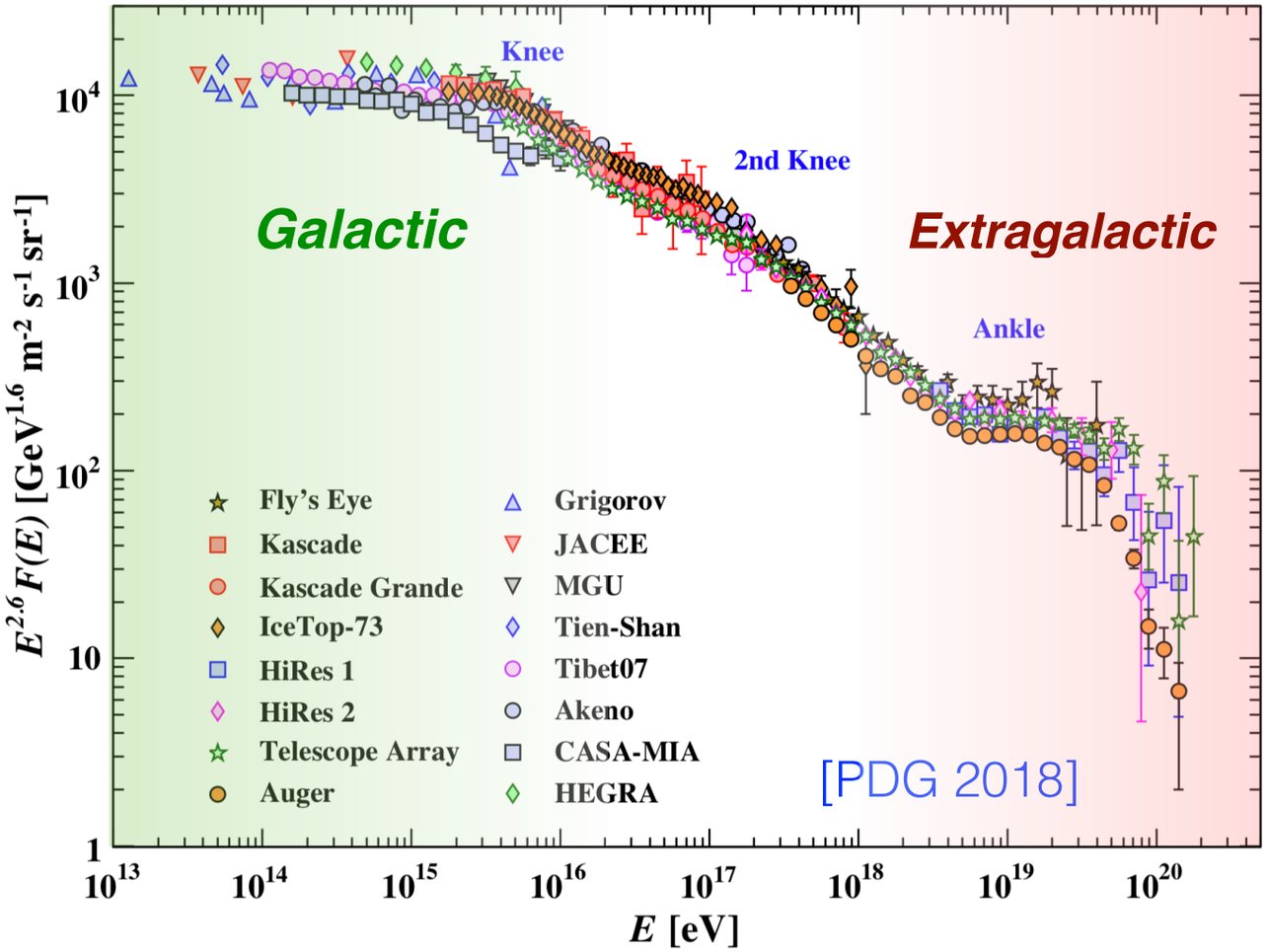
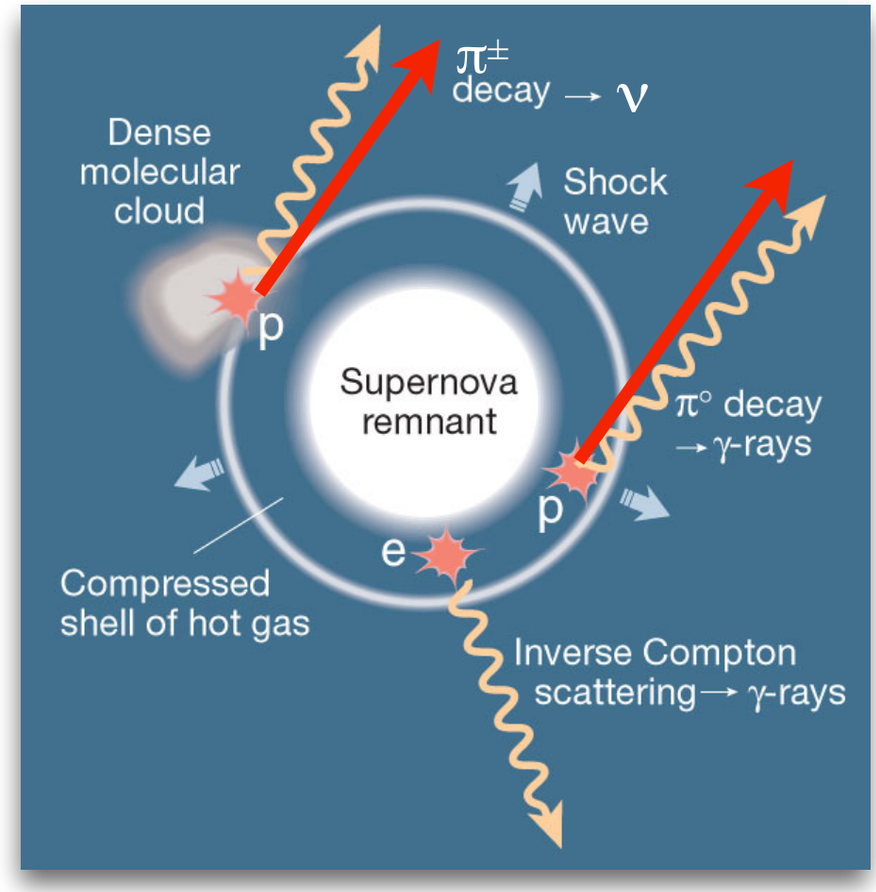
ICECUBE

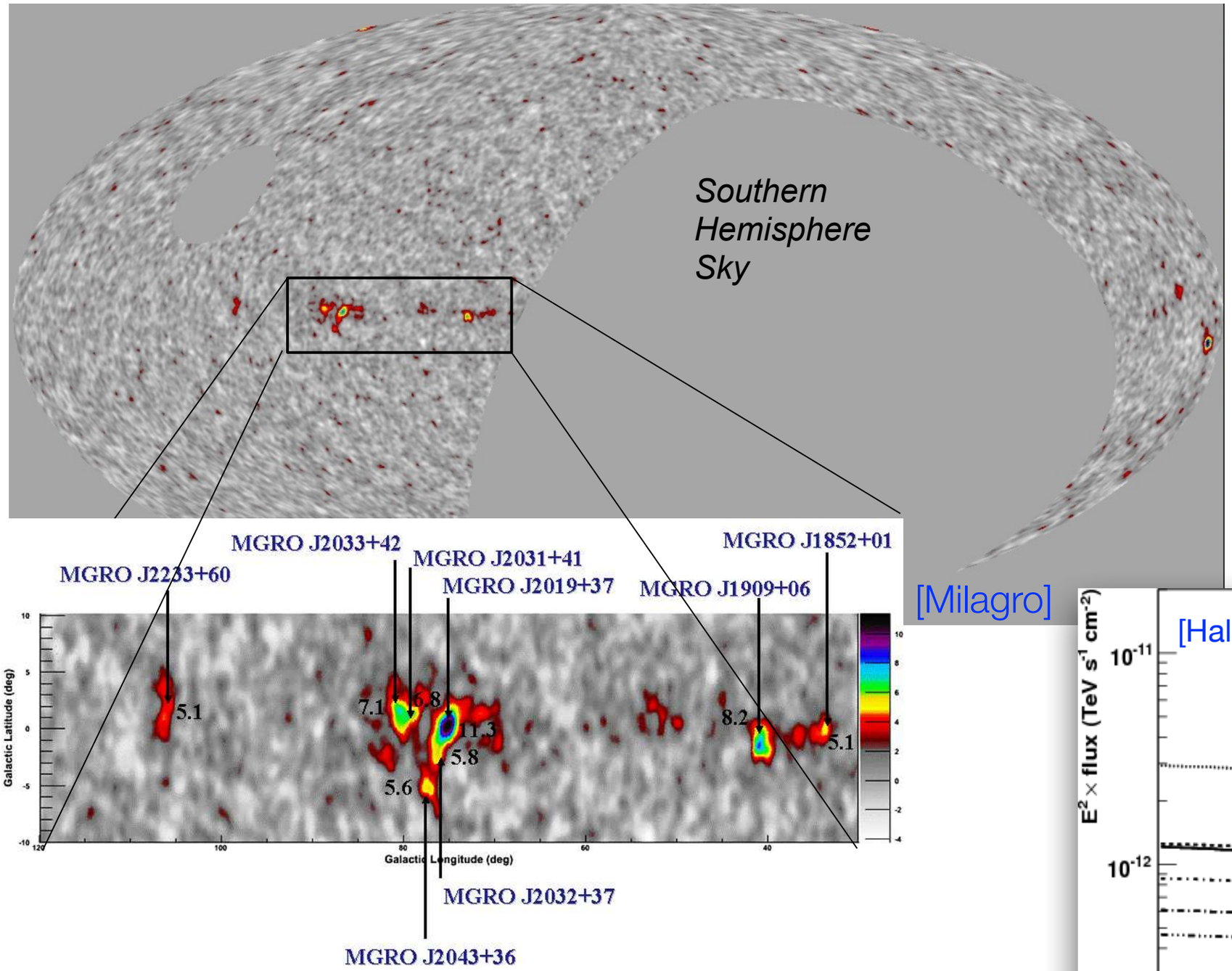
Galactic Cosmic Ray Accelerators

- The search for Galactic cosmic neutrino sources concentrates on the search for "**Pevatrons**" which have the required energetics to produce cosmic rays up to the knee in the spectrum.
- "Pevatrons" will produce pionic γ-rays whose spectrum extends to several hundred TeV without cut-off.
- Supernova remnant meet these condition.
- TeV γ-rays should be accompanied by TeV neutrinos, observable by IceCube.



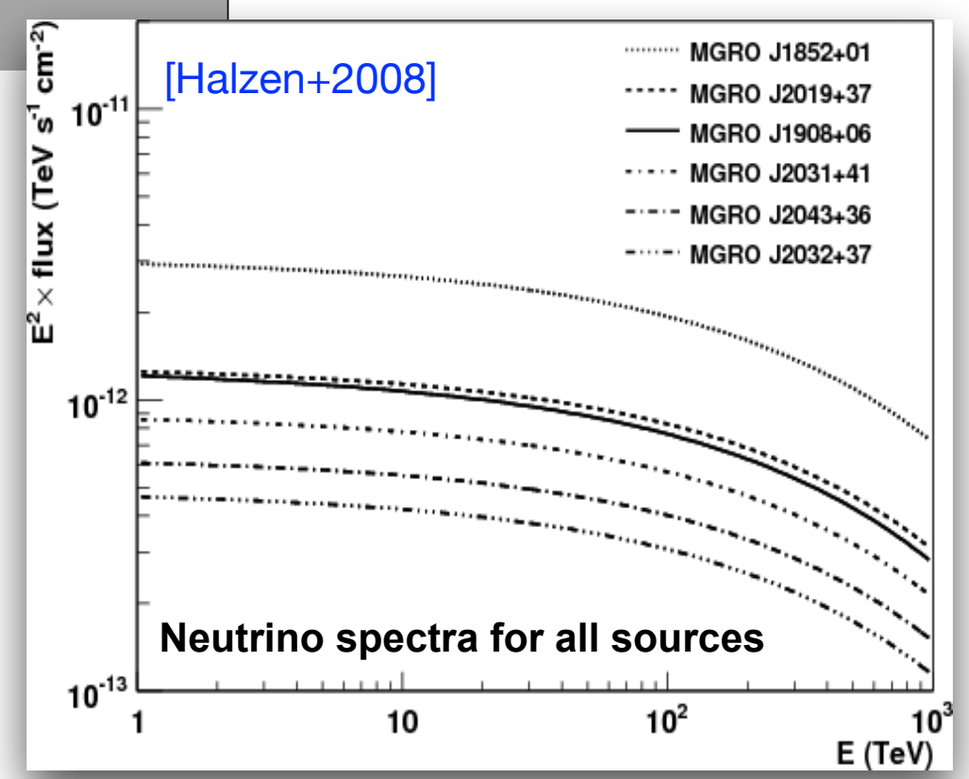


Galactic Plane at High Energies



[Milagro]

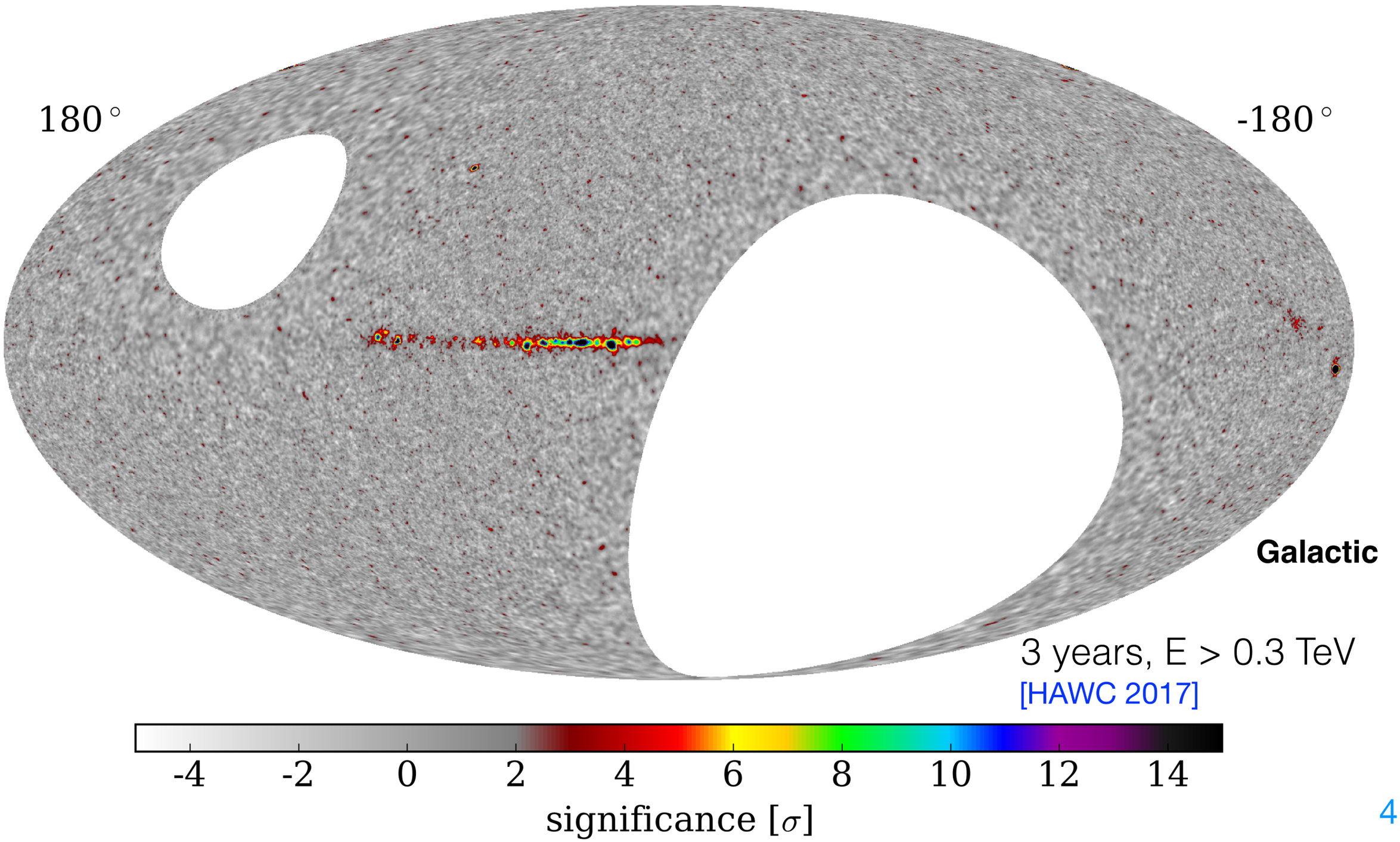
Sources were identified in the initial map of Milagro that were the most significant sources after Crab. The idea was to look for supernova remnants in star forming regions.



- Early predictions: IceCube should observe sources after 5 years.

[Beacom+2007, Halzen+2008, Gonzalez-Garcia+2009]

HAWC VHE Survey of the Galaxy



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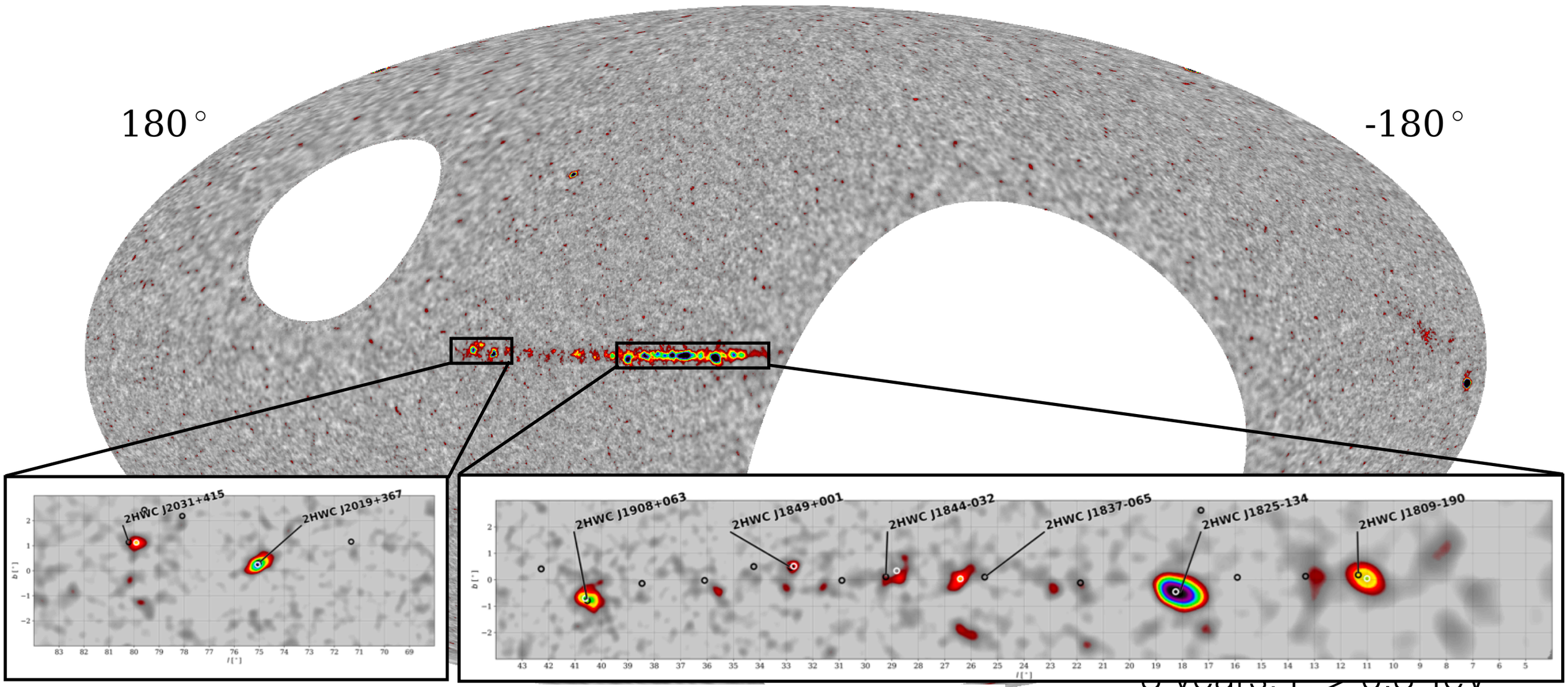
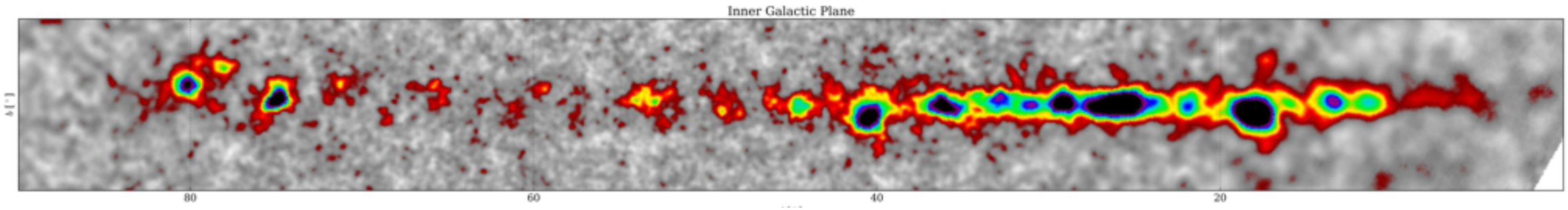


Galactic plane at E>56 TeV

[HAWC 2017]

significance [σ]

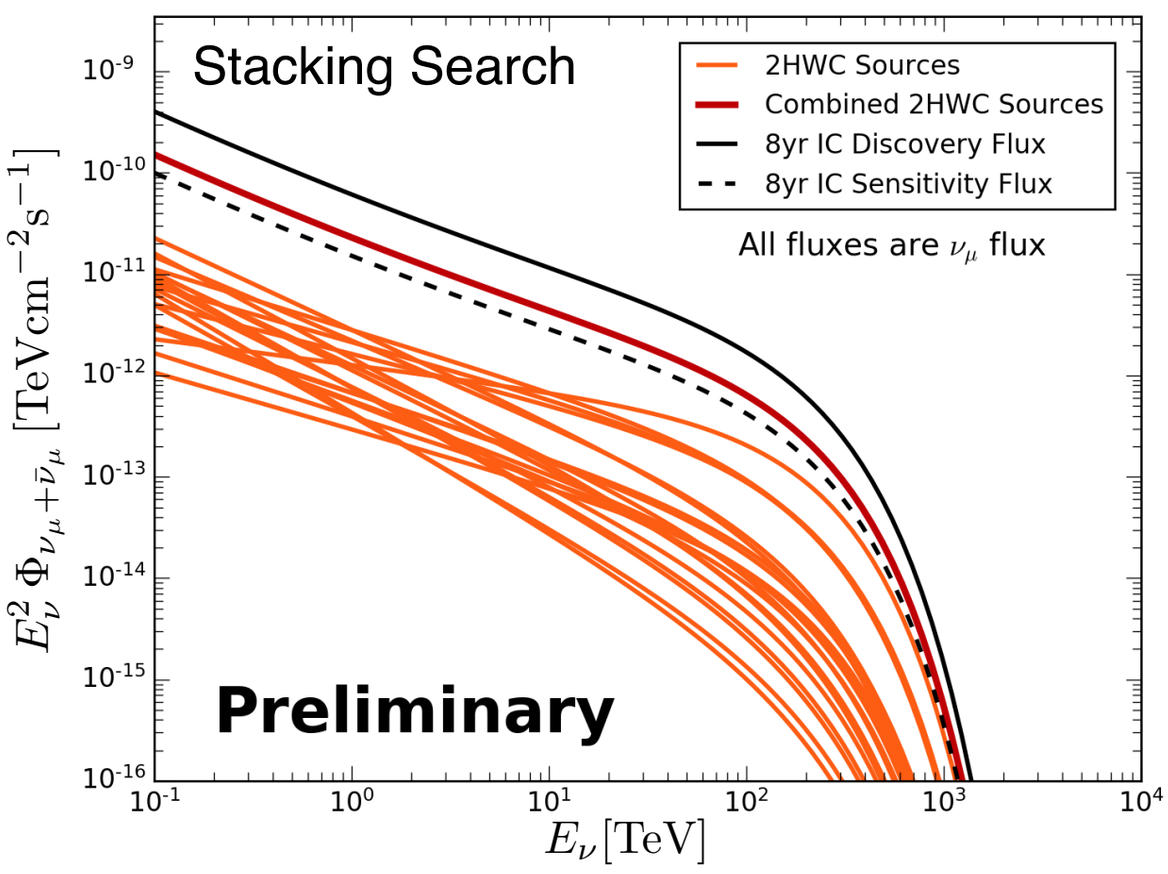
Joint IceCube-HAWC Search

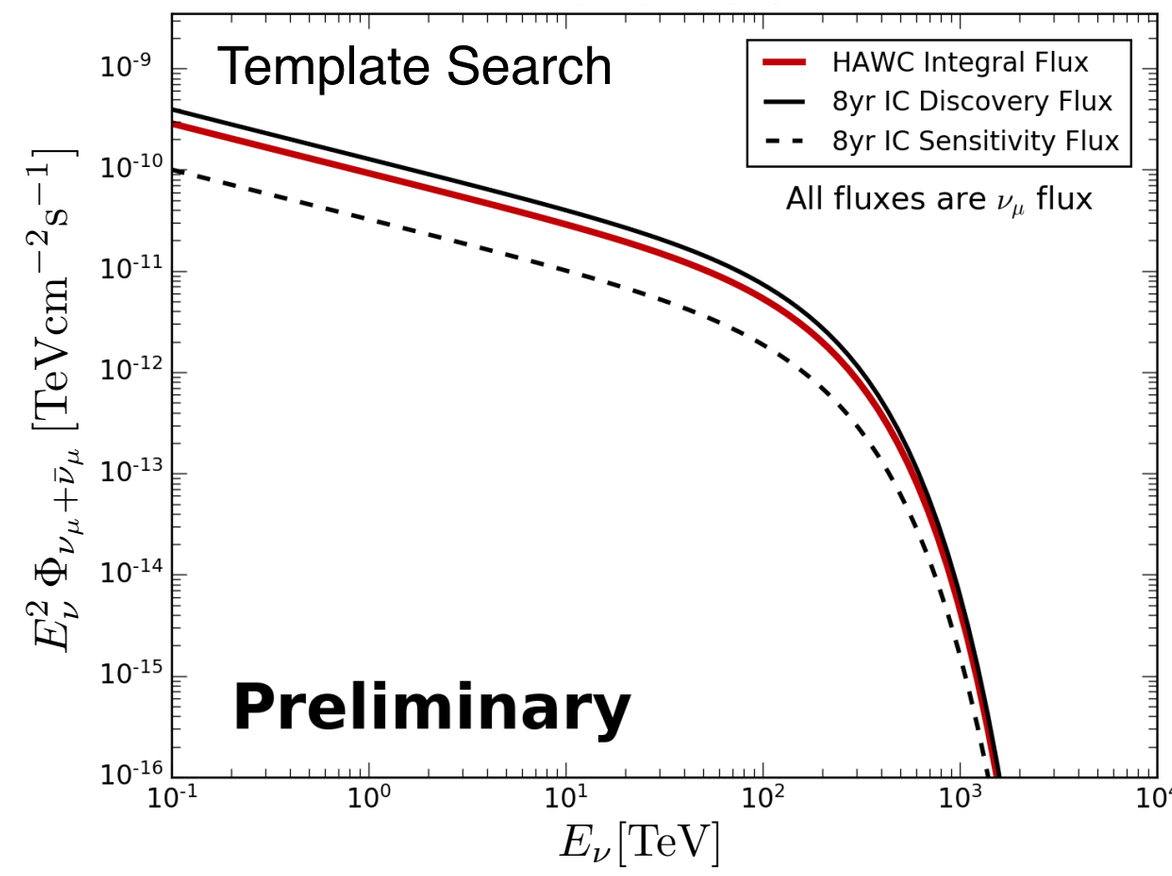


HAWC-IceCube Synergy

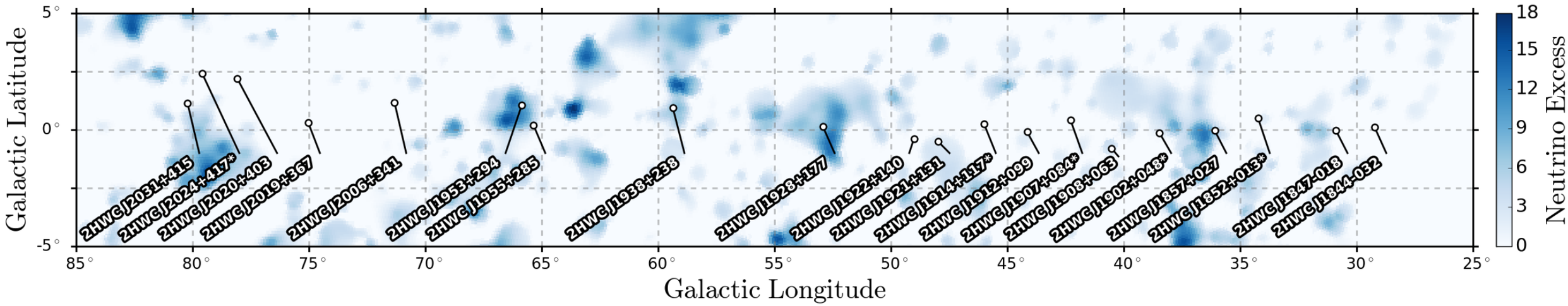
✓HAWC targets the portion of sky IceCube is the most sensitive.
✓HAWC operates at very high energies related to IceCube.
✓HAWC can study sources with any extension.

- Using 2HWC Catalog, we perform
  - **Stacked Search** for neutrino emission from identified sources
  - **Template** analysis for neutrino emission from Galactic plane and special regions

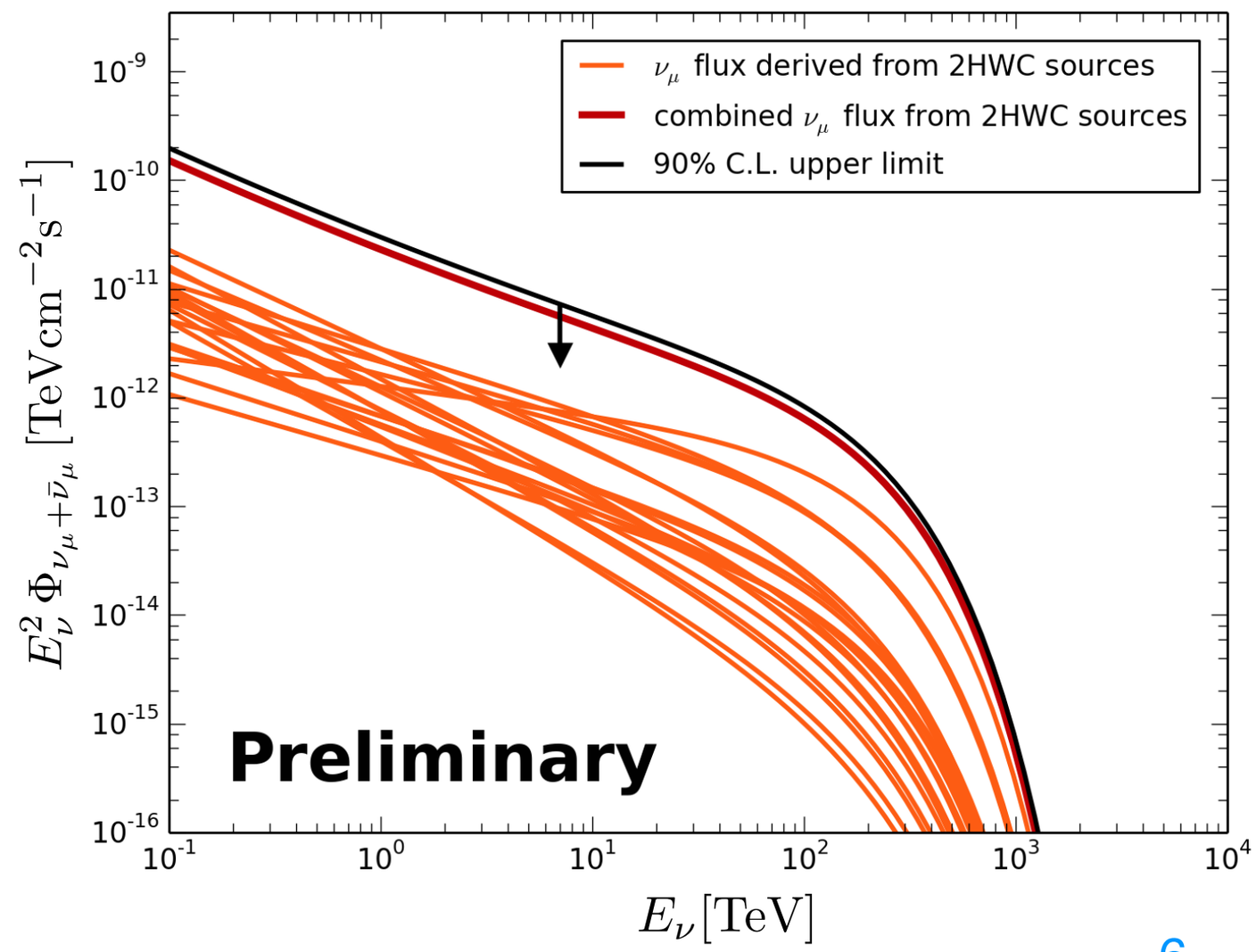




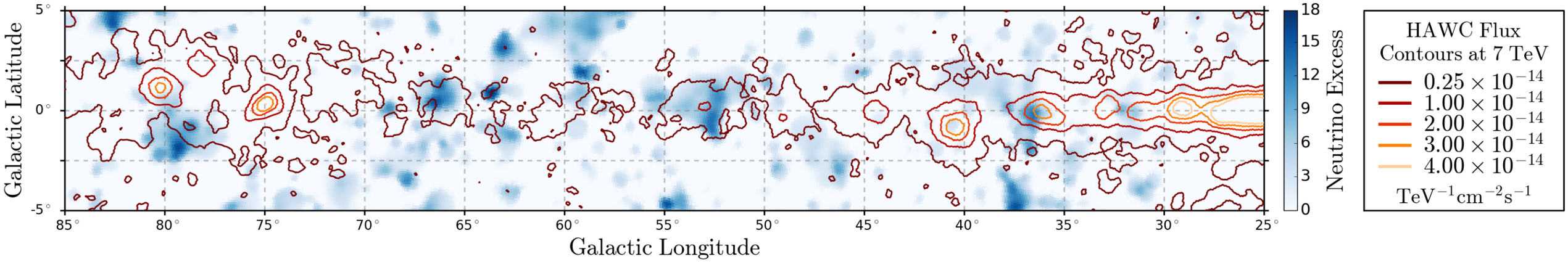
Stacking Search



- Stacked 20 sources from 2HWC Catalog (excluding PWNe)
- Best fitted signal events: 15
  → *pre-trial p-value: 0.09*
- 90% UL on neutrino flux: 1.5×10^{-13} TeV/cm² s at 7 TeV
- *Not constraining the hadronic component!*



Template Search-Northern Plane



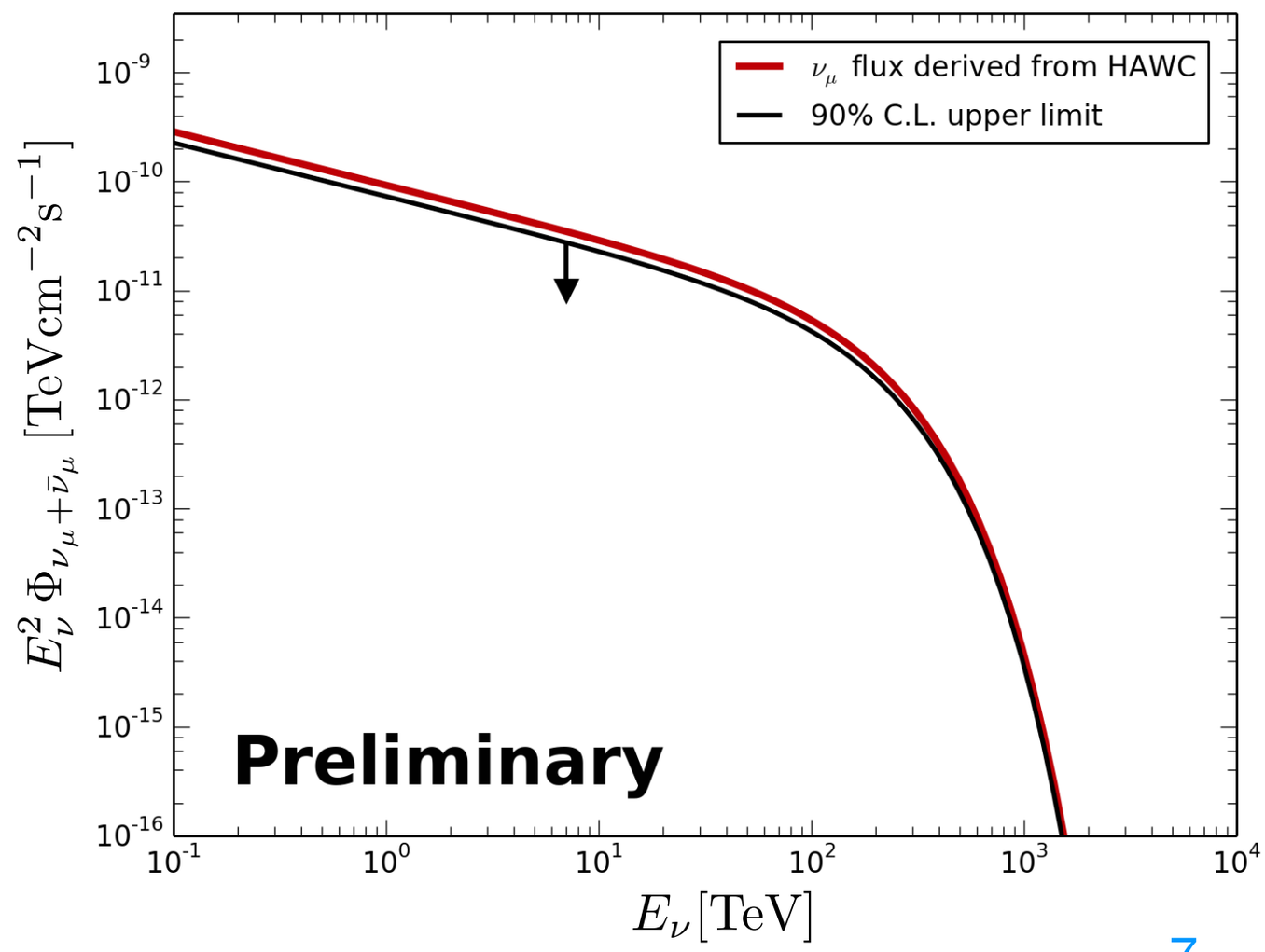
- Incorporating full **morphology** of emission from HAWC

- Neutrinos weighted according to their energy and γ-ray flux with cut-off at 300 TeV

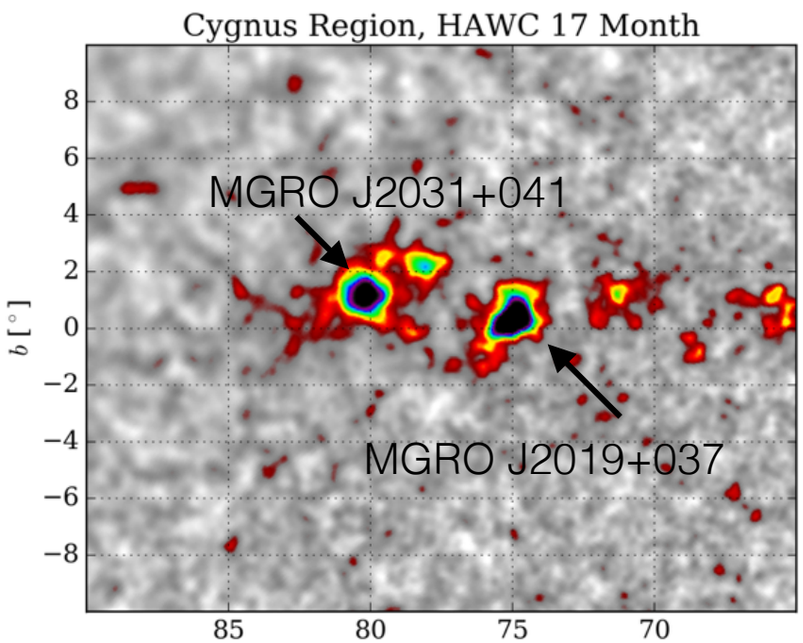
- Best fit signal events: 77

→ *pre-trial p-value: 0.06*

- Constraining hadronic component to < 80% of the total flux.



Cygnus Region



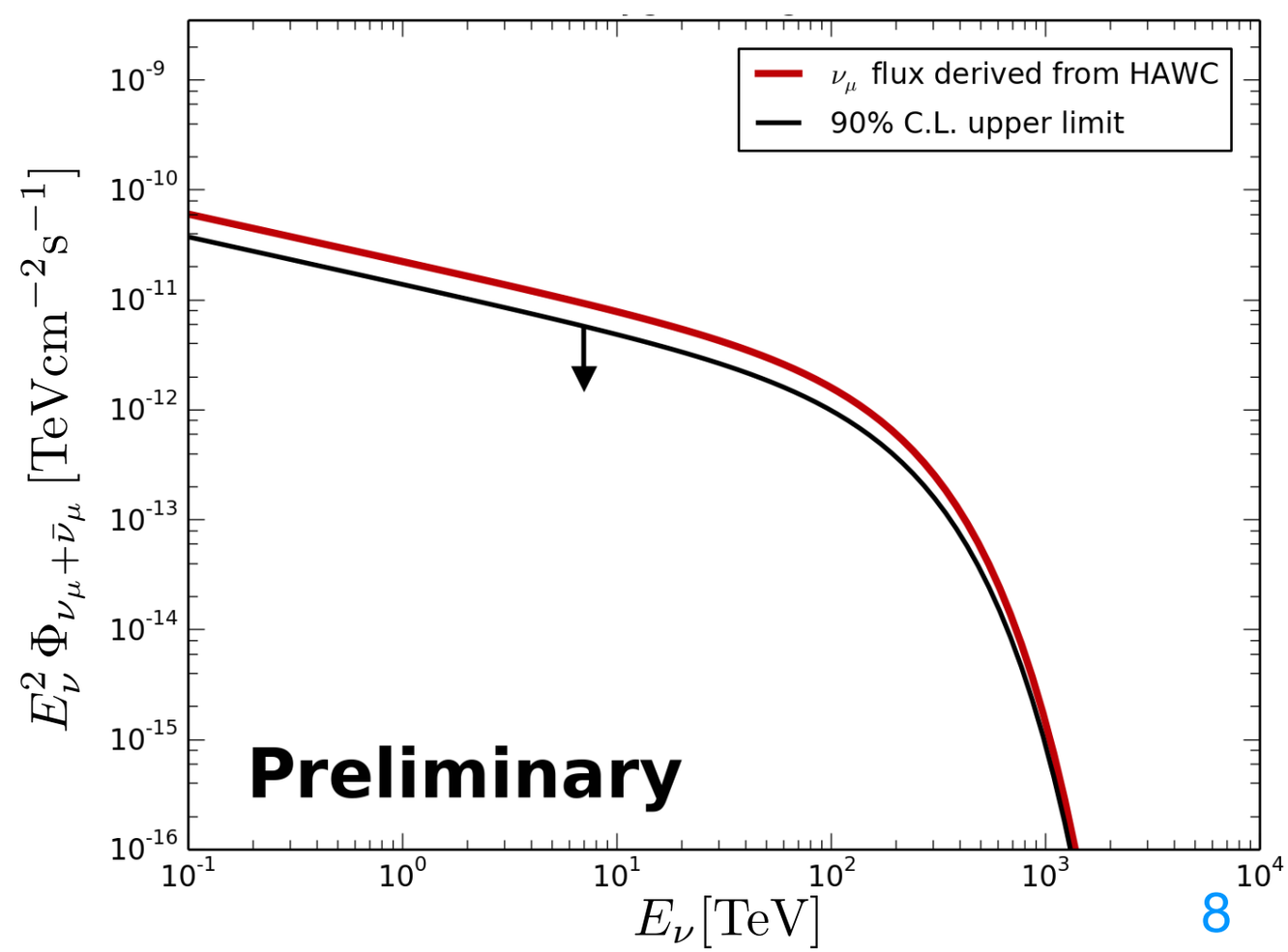
- Star forming region with a **high level of γ-ray activity** and young stars
- Very high energy **diffuse γ-ray emission**
- γ-ray emission from the **cocoon**
- Uncertainties on **resolved sources** & their **extensions**

- No Signal events!

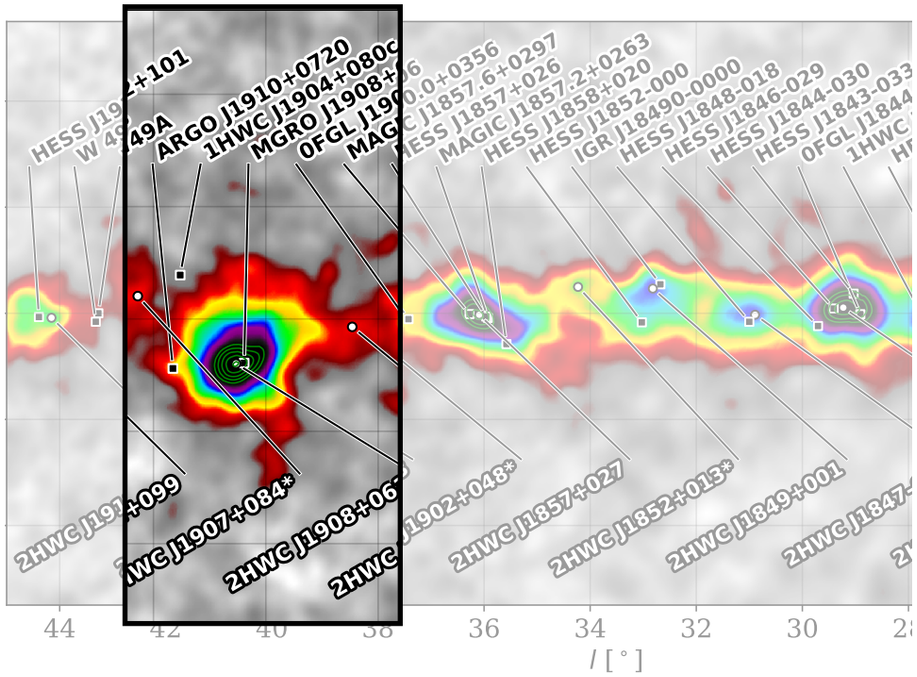
→ *under-fluctuation.*

- Compatible with other observations and theoretical studies of the γ-ray emission.

- Hadronic component constrained to < 60% of the total flux

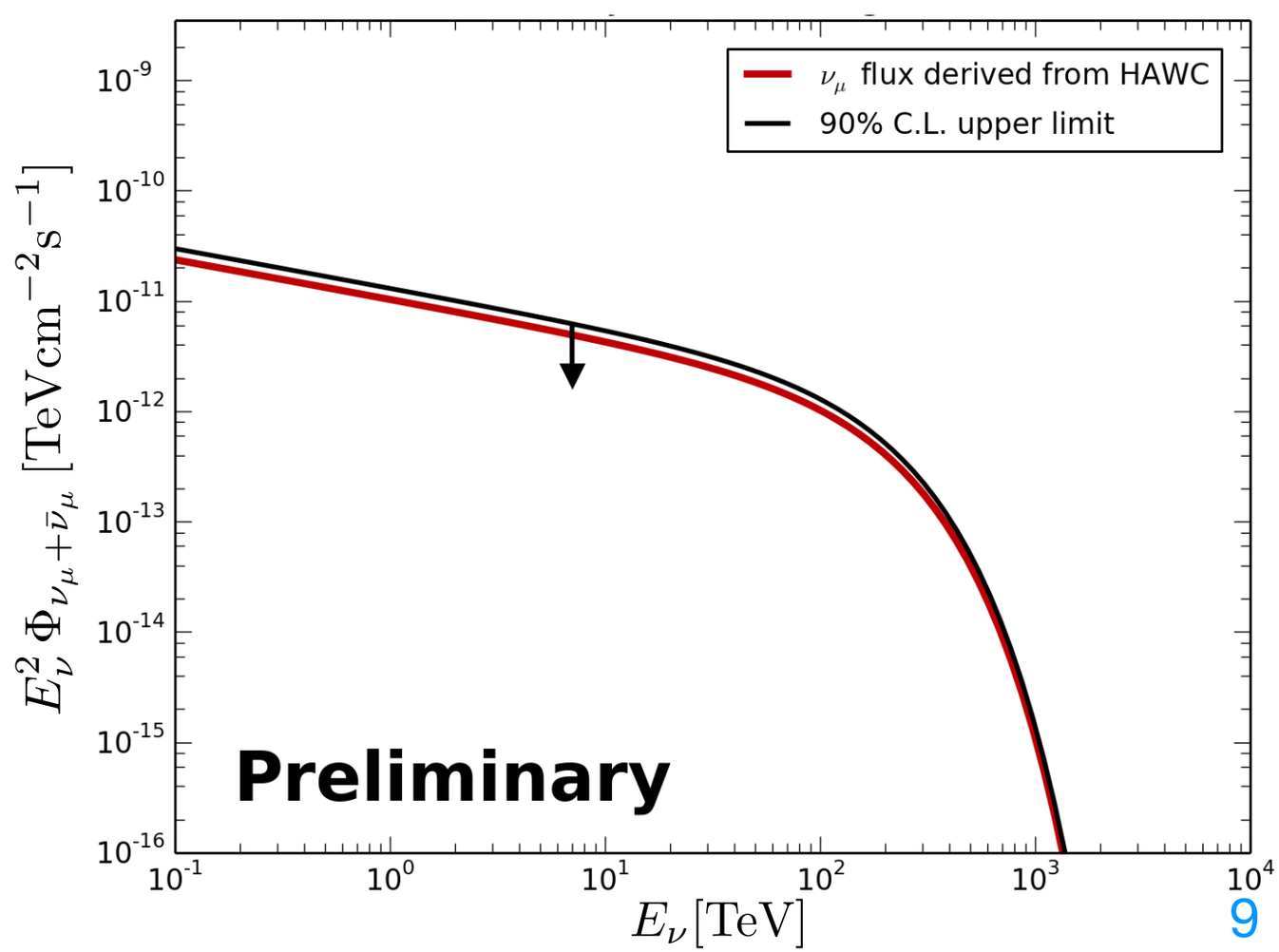


MGRO J1908+06

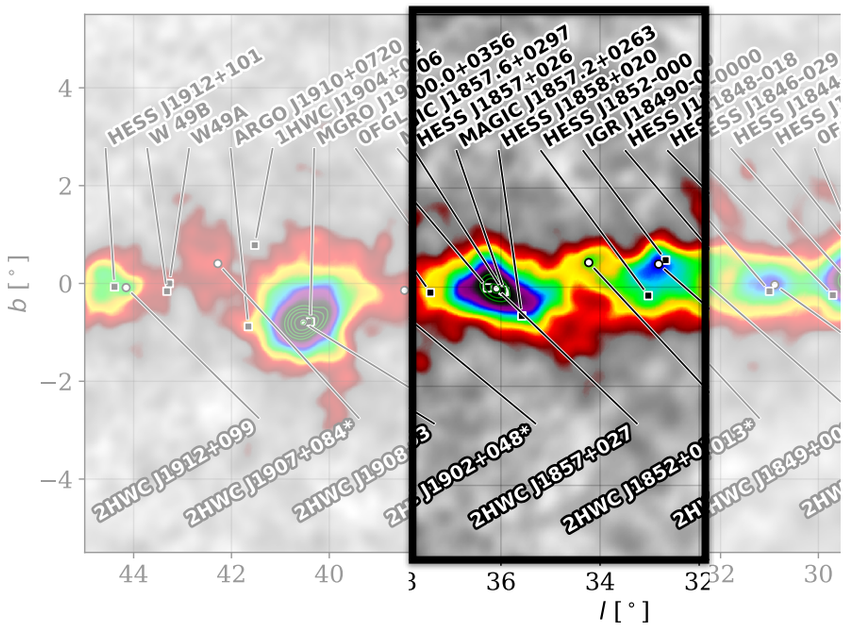


- Region containing previously identified sources with spectra consistent with PeVatron scenarios
- Located at the best place (near horizon) for IceCube
- Nature of γ-ray emission not well understood

- Best fit signal events: 12
→ *pre-trial p-value=0.14*
- Upper limit is 1.3 times the total flux, assuming all γ-rays are hadronic! Not constraining!



2HWC J1857+027

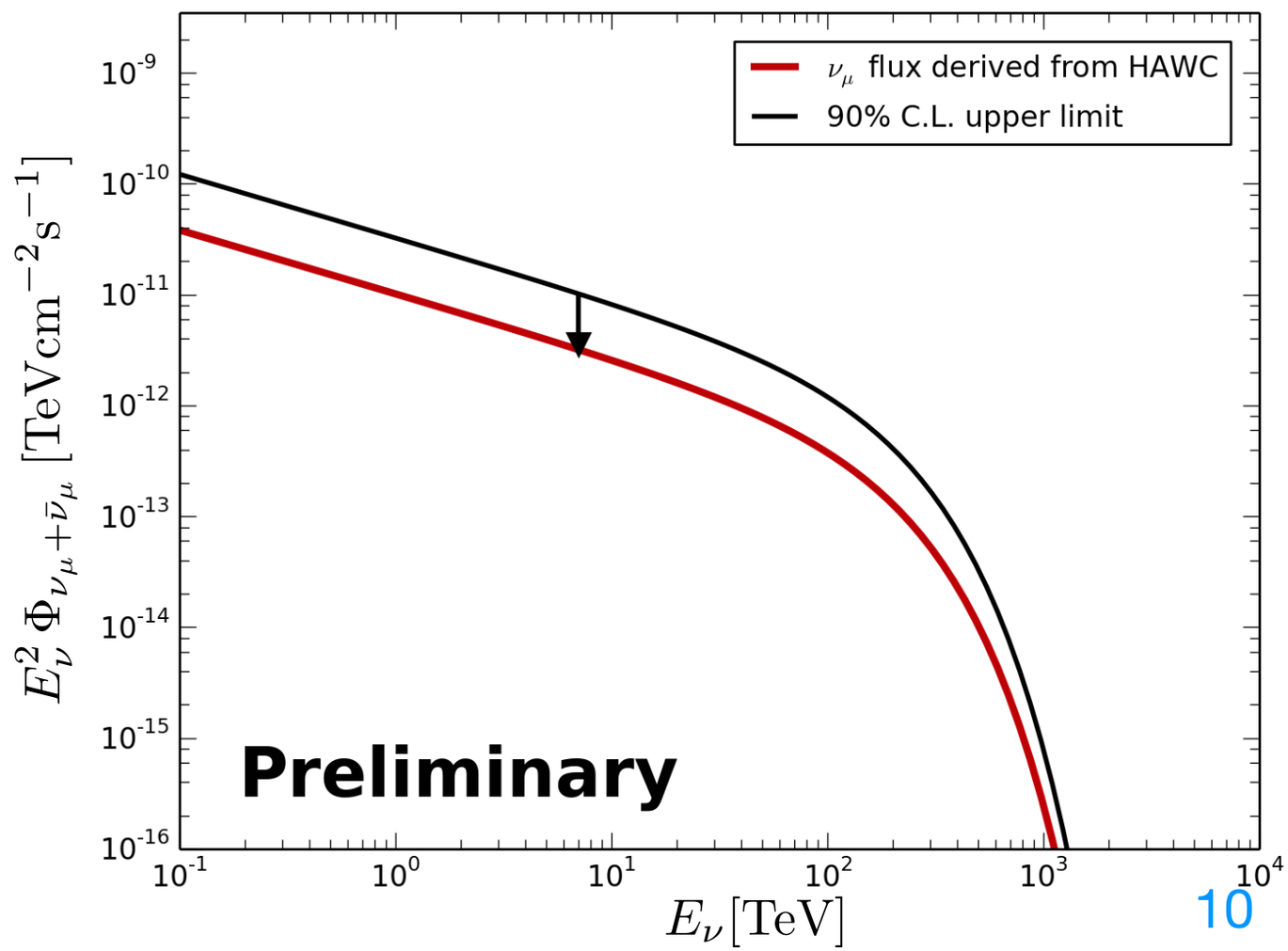


- Region containing previously identified sources with spectra consistent with PeVatron scenarios
- Located at the best place for IceCube
- γ-ray emission nature not well understood

- The most significant result!
- Best fit signal events: 36

→ *pre-trial p-value=0.02*

- Upper limit is 3 times the total flux, assuming all γ-rays are hadronic! Not constraining!



Summary

- Galactic cosmic ray accelerators are guaranteed to contribute to the total observed high-energy cosmic neutrino flux.
- The contribution of Galactic sources to the IceCube neutrino flux is limited to less than 15%.
- The upper limits from searching for high-energy neutrinos from major γ-ray emitters in the Milky Way constrain but do not exclude hadronic components.
- Continuous observation of IceCube and new techniques for identification of neutrinos with high purity will help finding Galactic neutrino sources.
- Advancements in ground base γ-ray telescopes and future instruments will improve our understanding of the spectra and morphologies and will help identifying potential sources of high-energy neutrinos in the Milky Way.

Thanks!

Back up Slides

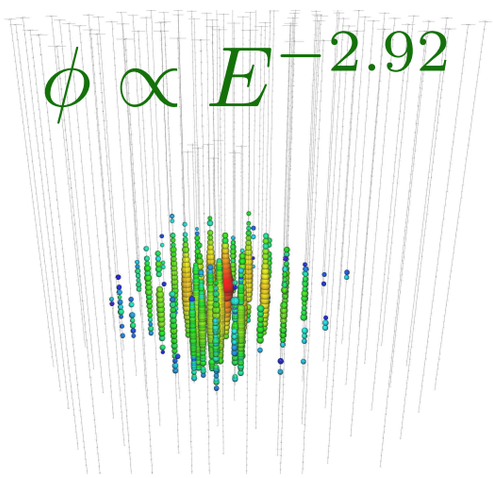
High-Energy Cosmic Neutrino Flux

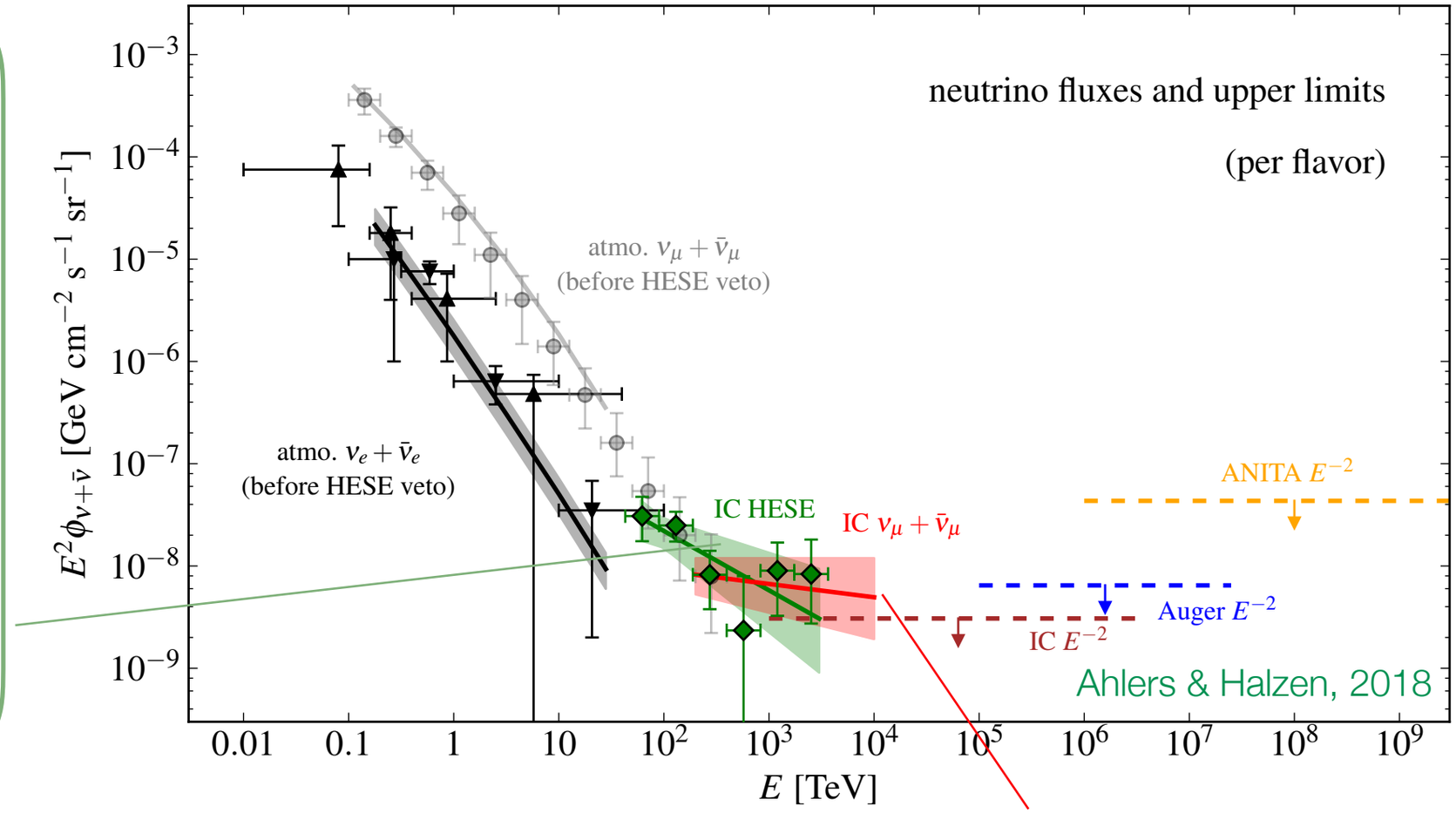
High-Energy Starting Events

7 years Observation ➛ 8σ

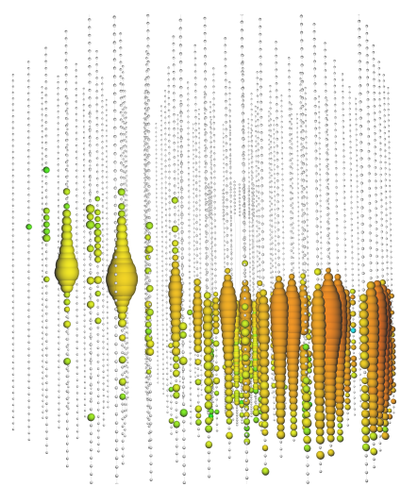
80 events (all flavor)

$$\phi \propto E^{-2.92}$$





- Observation confirmed in independent channels.
- Hardening of the spectrum at high energies.
- Low-energy excess hinting at spectral features.
- fluxes are compatible in the common energy range



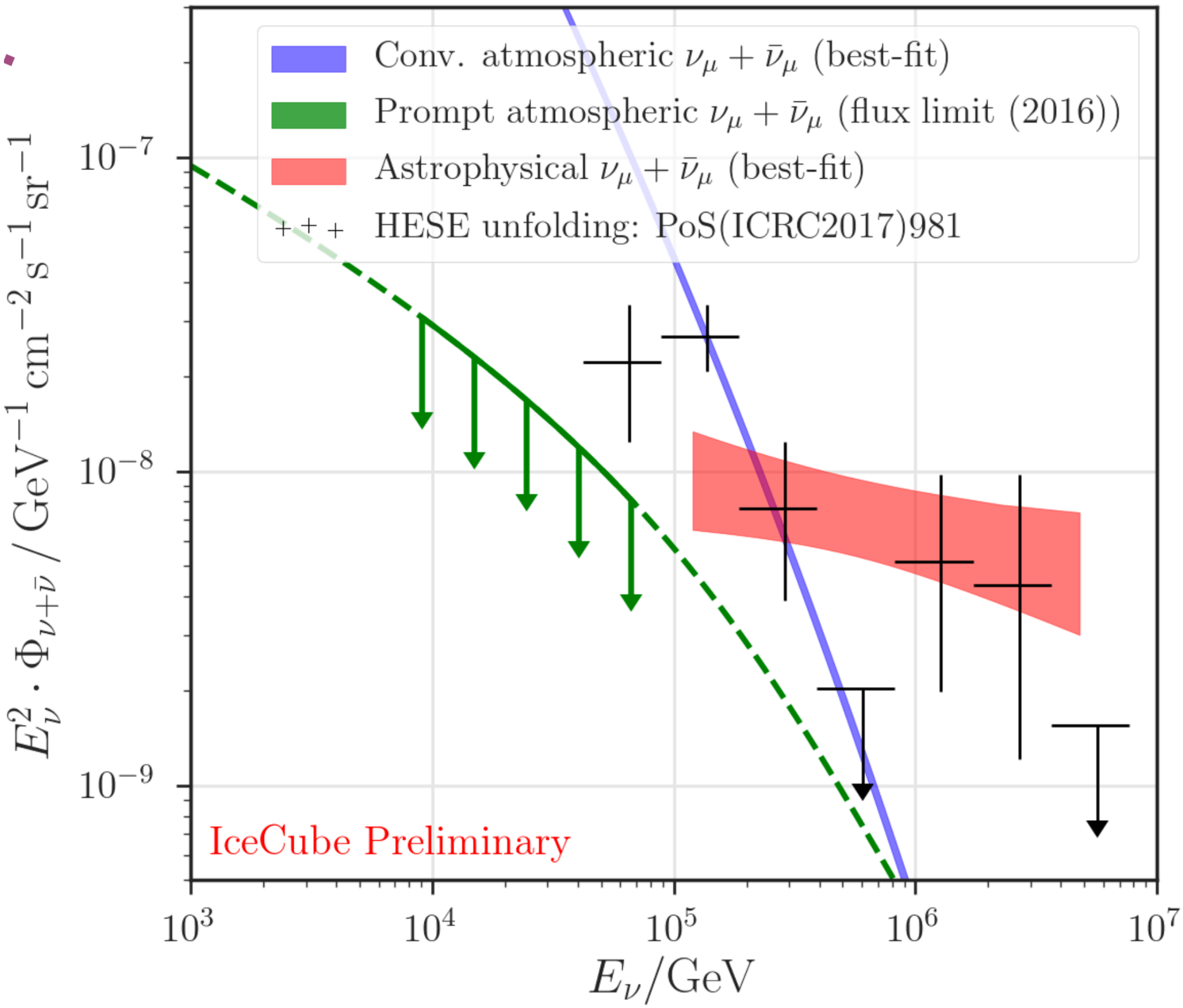
Up-going Muon Tracks

8 years Observation ➛ 6.7σ

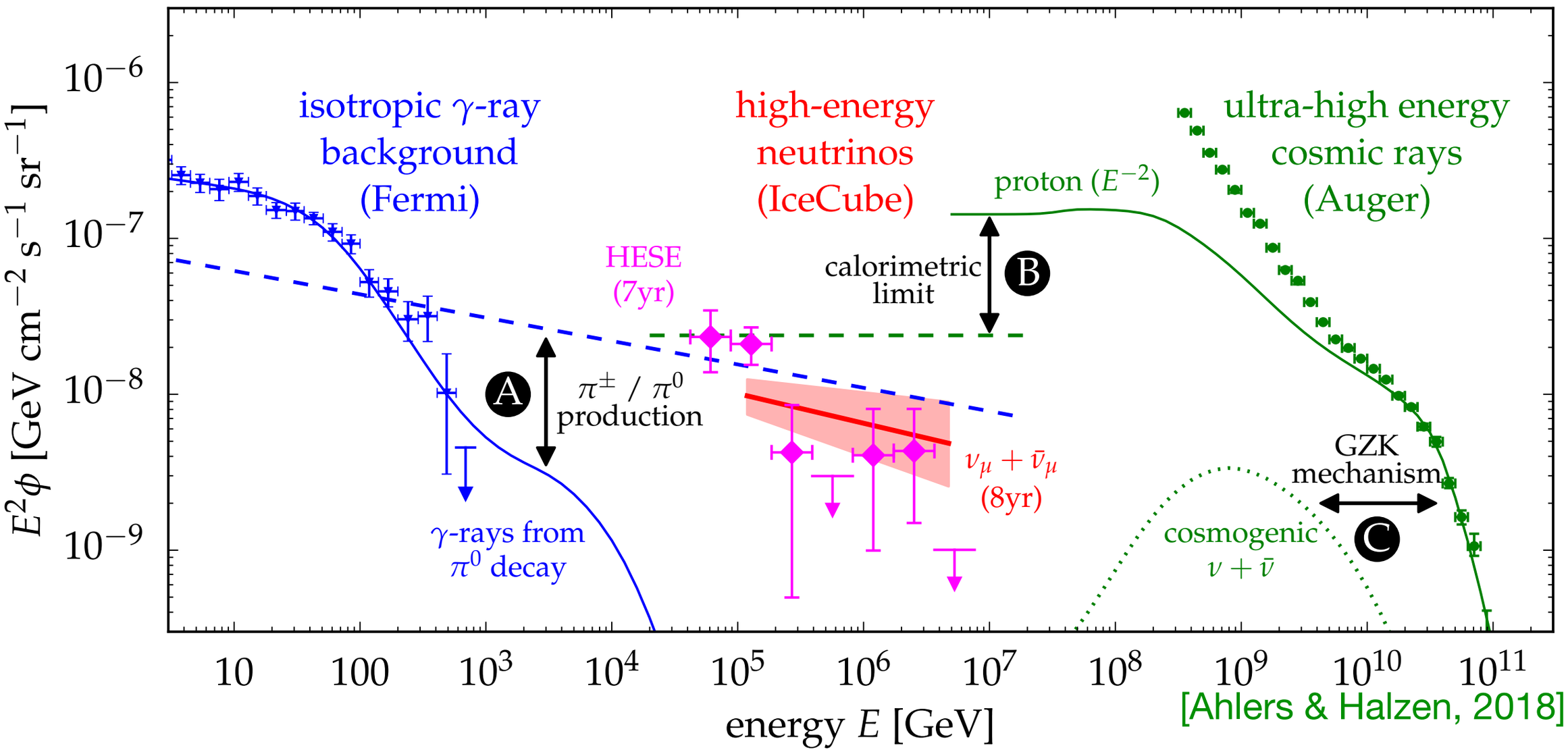
~ 500 astrophysical neutrinos

$$\phi \propto E^{-2.19}$$

8 years (ICRC 2017)



HE Cosmic Neutrinos & Multimessenger Interface

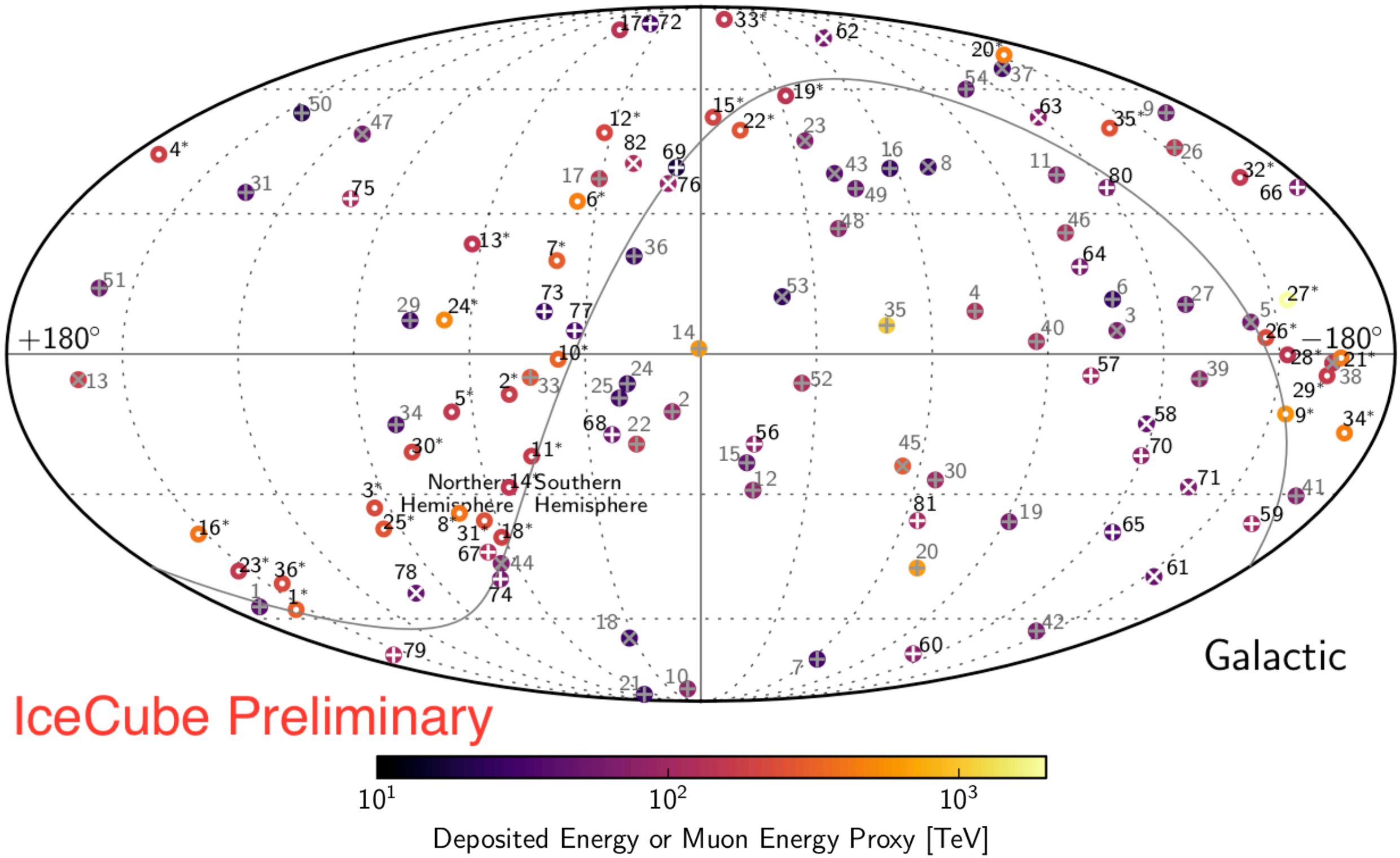


[Ahlers & Halzen, 2018]

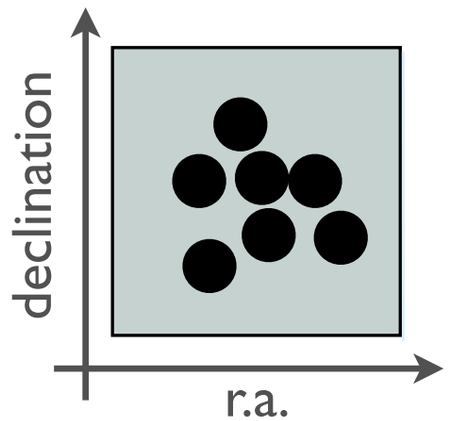
Similar energy in the Universe in γ-rays, neutrinos and cosmic rays

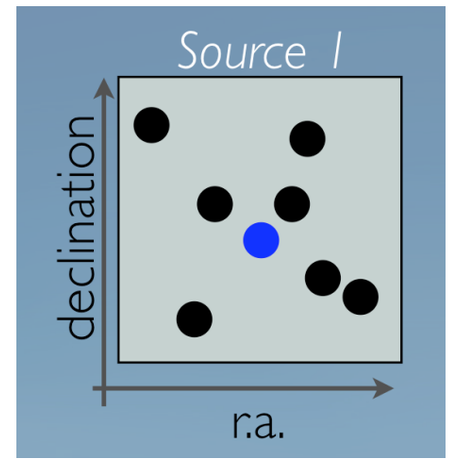
[Ahlers 2015, Murase+ 2014, Kowalski 2014]

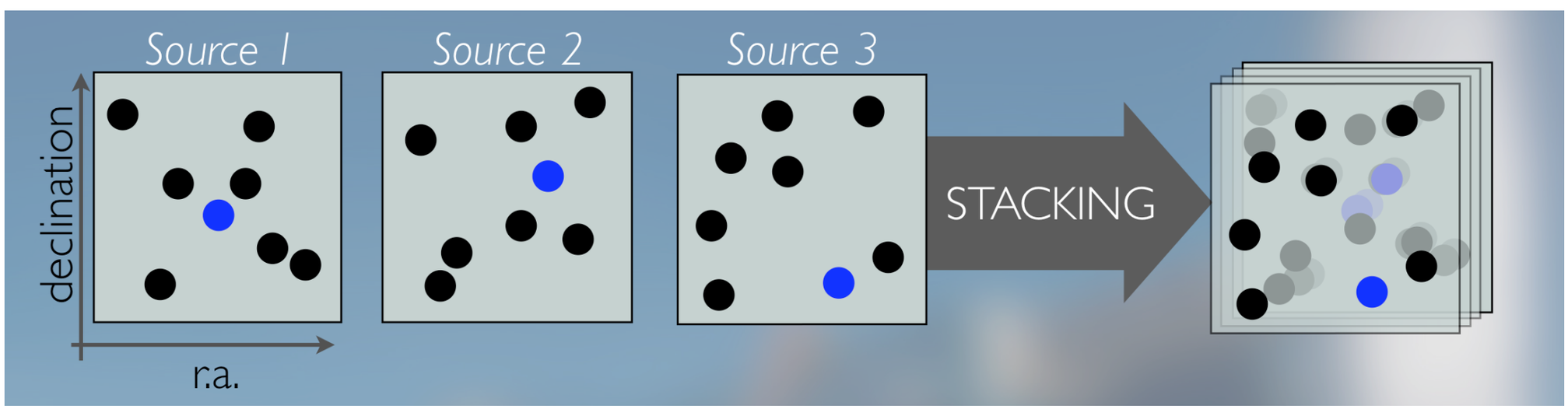
Arrival Direction of Highest Energy Neutrinos



Point Source Searches

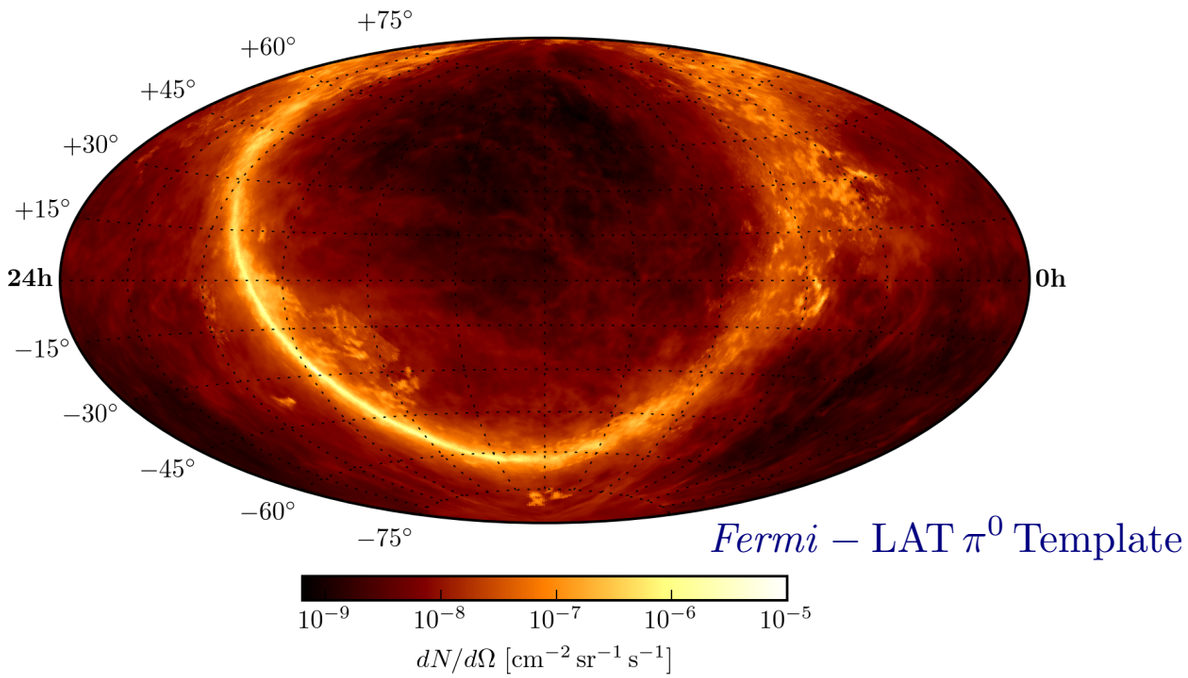




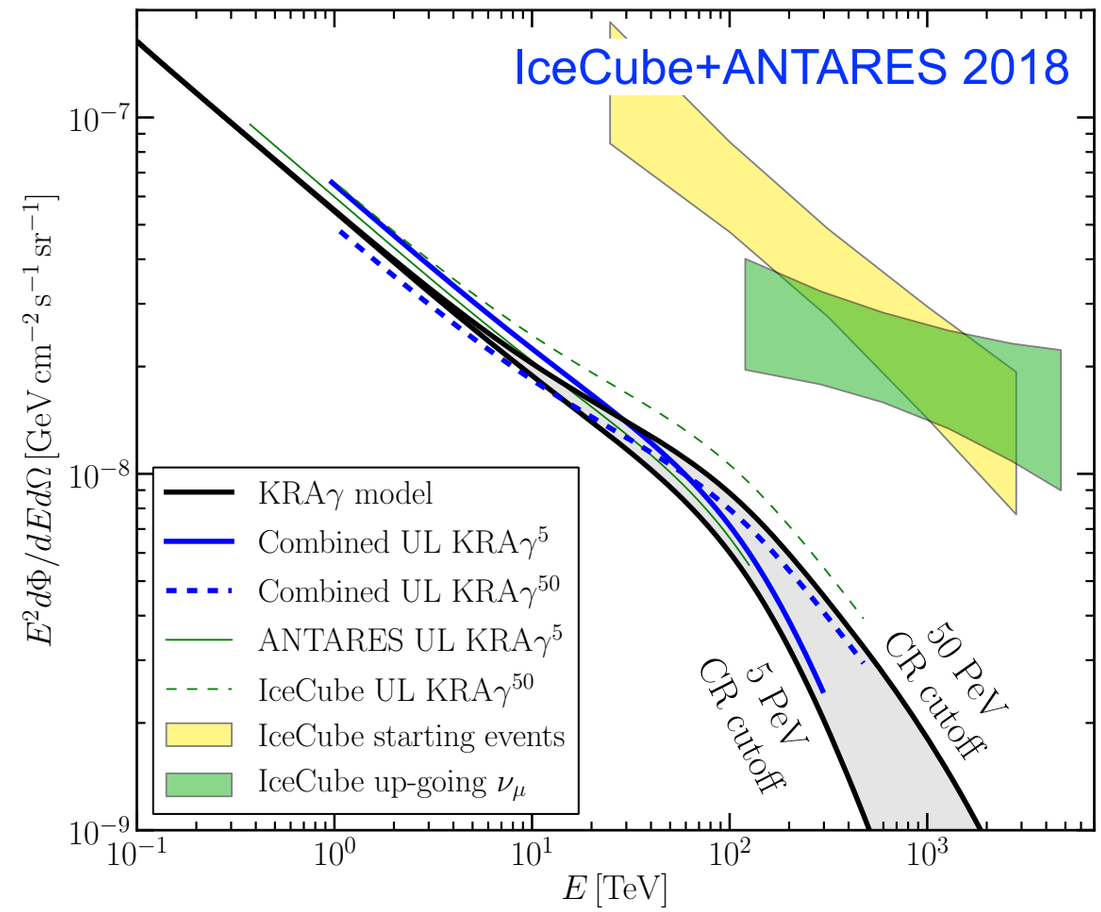


Stacking Search

Diffuse Galactic Neutrino Flux



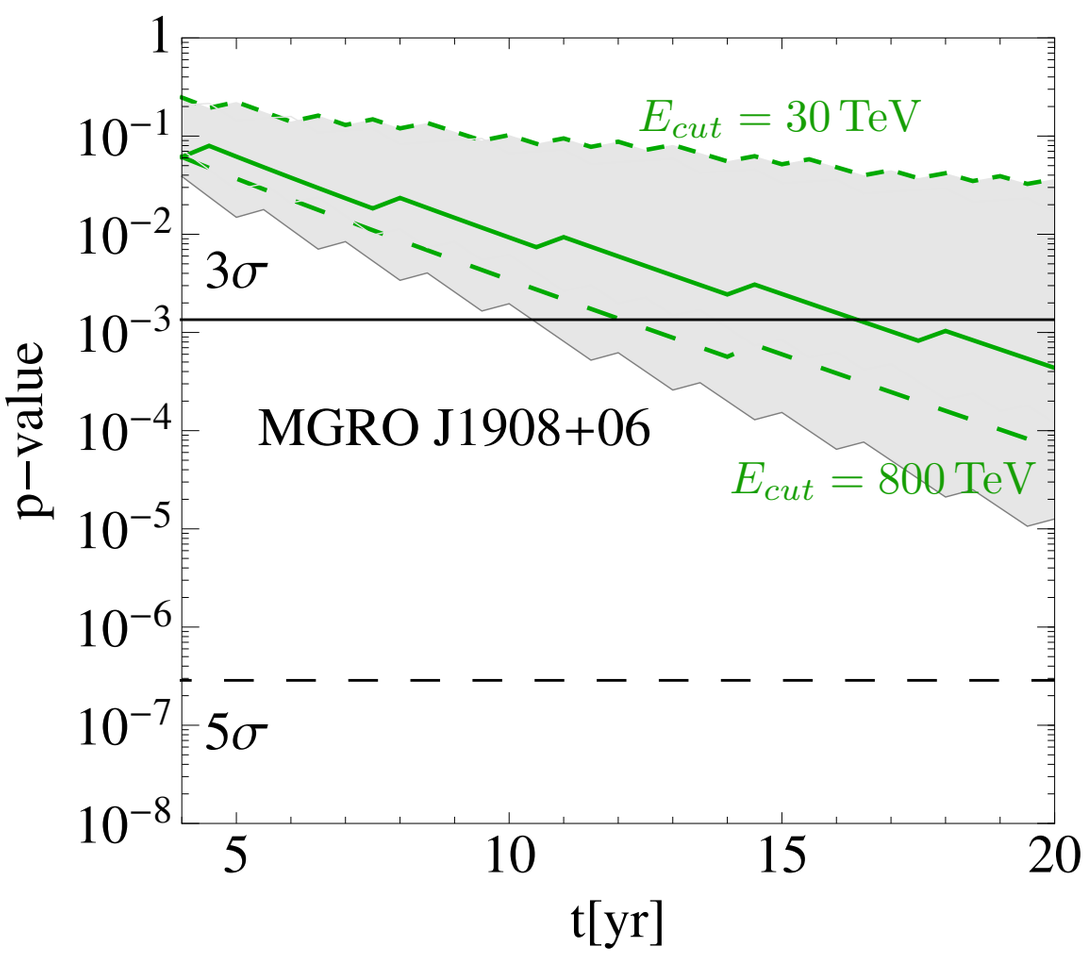
Energy cutoff	Sensitivity [$\Phi_{\mathrm{KRA}_\gamma}$]			Fitted flux	p-value	UL at 90% CL
	Combined	ANTARES	IceCube	[$\Phi_{\mathrm{KRA}_\gamma}$]	[%]	[$\Phi_{\mathrm{KRA}_\gamma}$]
5 PeV	0.81	1.21	1.14	0.47	29	1.19
50 PeV	0.57	0.94	0.82	0.37	26	0.90

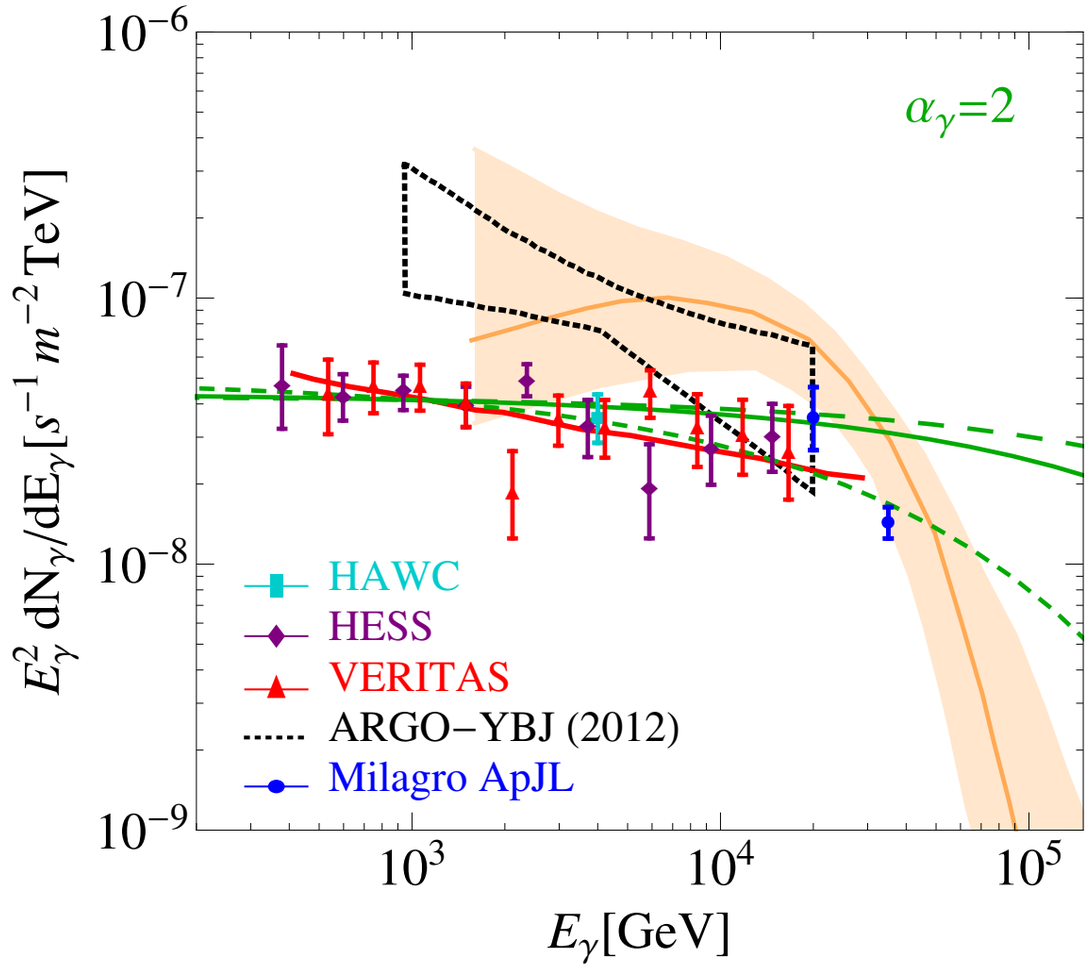


- Search for the correlation of neutrinos with the template map of emission from Galactic plane.
- Spatial distribution from gamma-ray data.
- Neutrino flux constrained at the level of ~15% of the total flux.
- Models have large uncertainty on the flux above 10 TeV

MGRO J1908+06

- One of the primary candidates identified in Milagro survey.
- Observation of the sources in IACT experiments. Tension in extension and spectrum reported.
- Classified as an *unidentified* source. Gamma ray emission nature not well understood





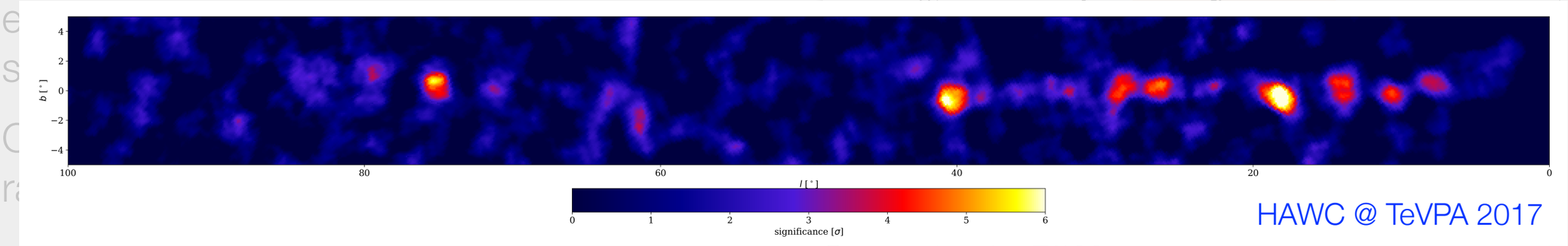
- Prospects for observation is highly entangled with the extension of the source.
- Based on HESS's observation, should be seen in ~10 years.

[Halzen, AK, Niro, 2017]

MGRO J1908+06

- One of the primary candidates identified in Milagro survey.
- Observation of the sources in IACT e s
- C ra

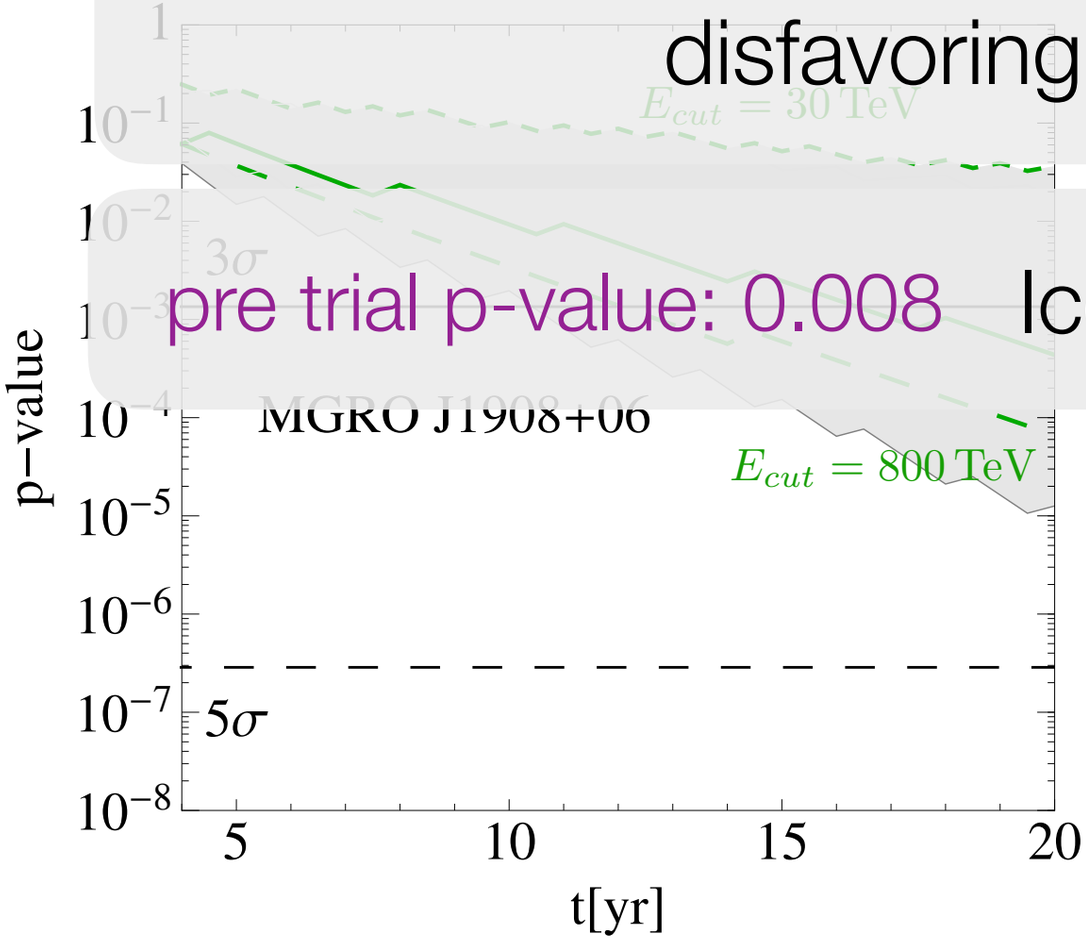
HAWC > 50 TeV



disfavoring low-energy cut-off

pre trial p-value: 0.008

IceCube 8 yr search



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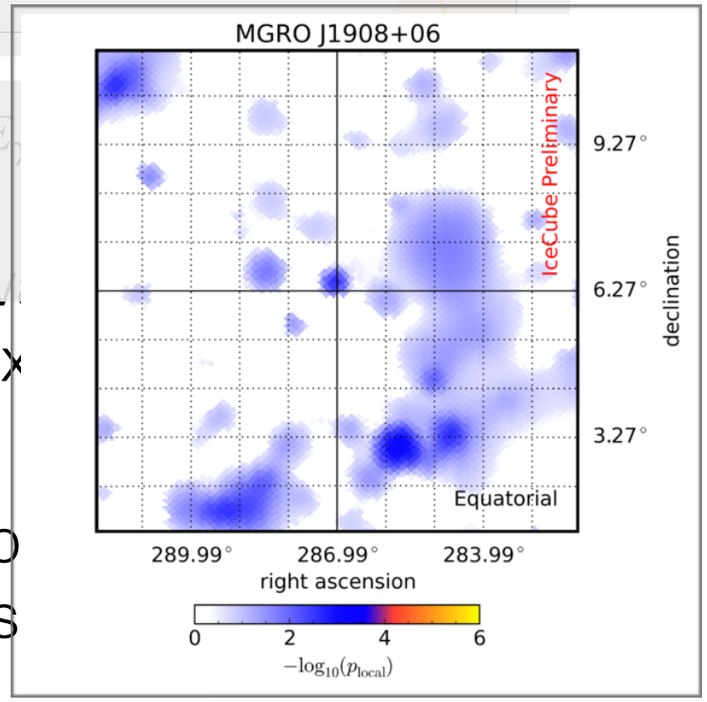

[Halzen, AK, Niro, 2017]