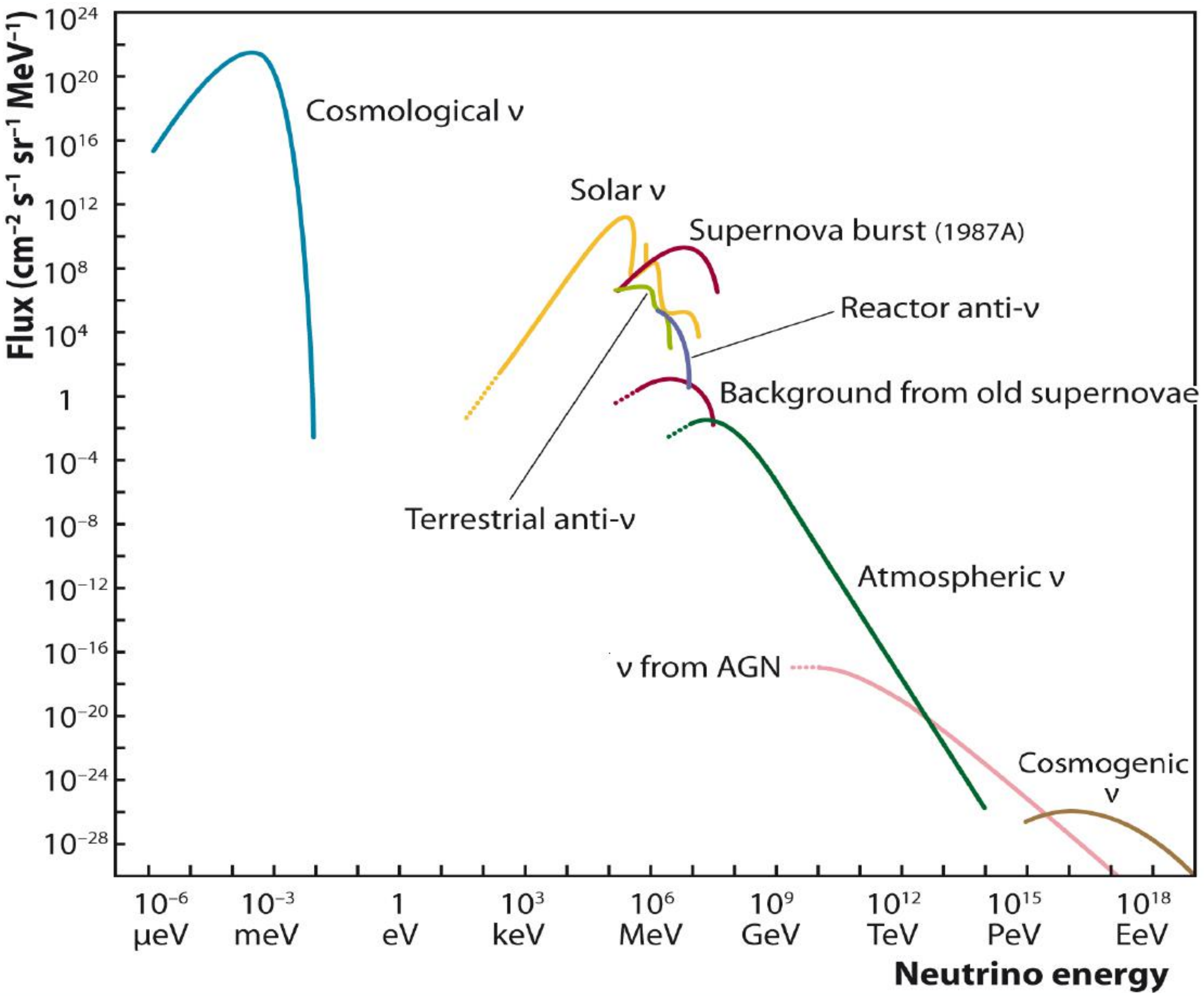
Results from KM3NeT and IceCube

Review on neutrino astronomy at high-energy (and beyond)

Valentin Decoene — Journées ATPEM 2025

Which neutrinos?

“Global” neutrino spectrum:



C. Spiering 2020

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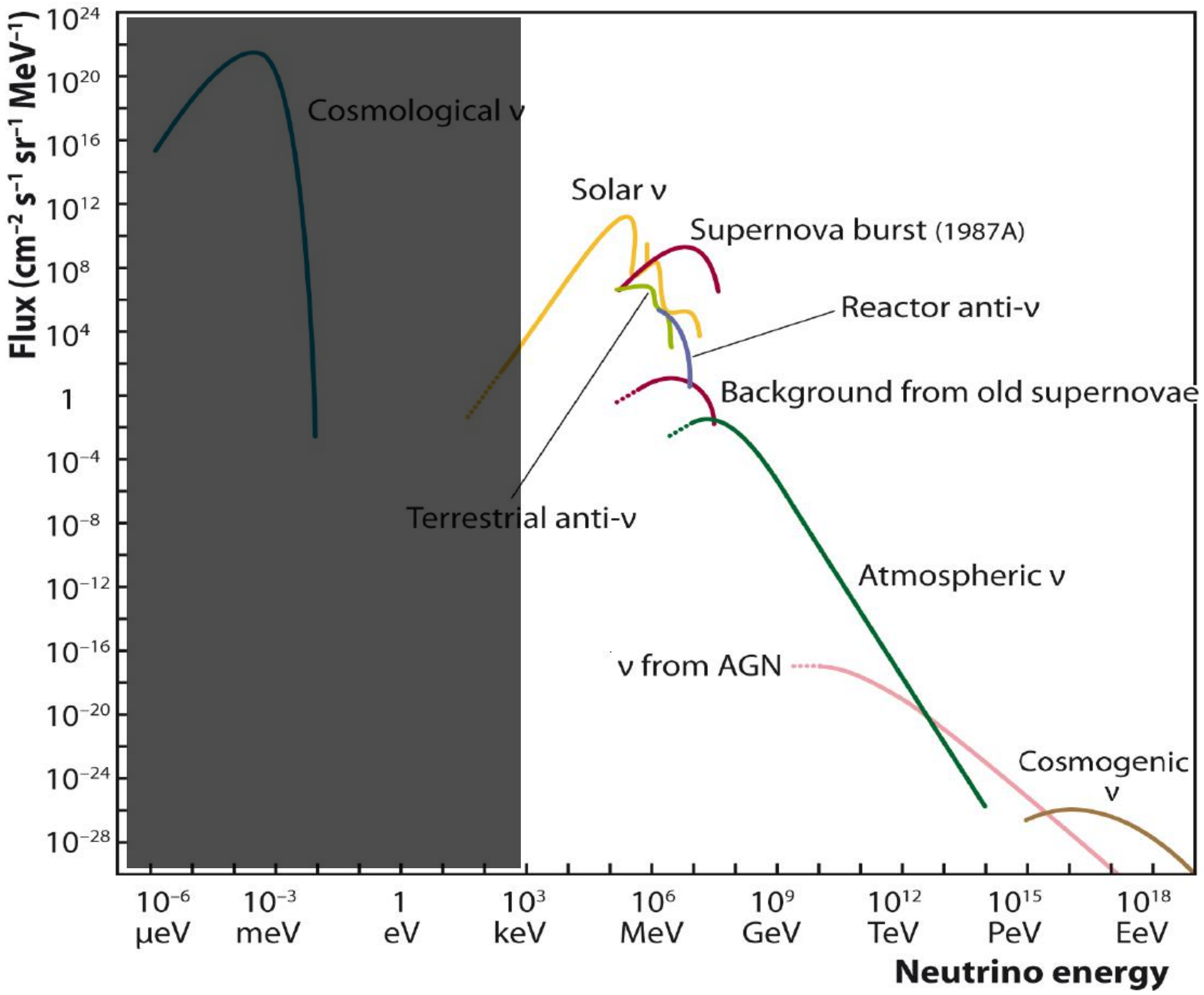

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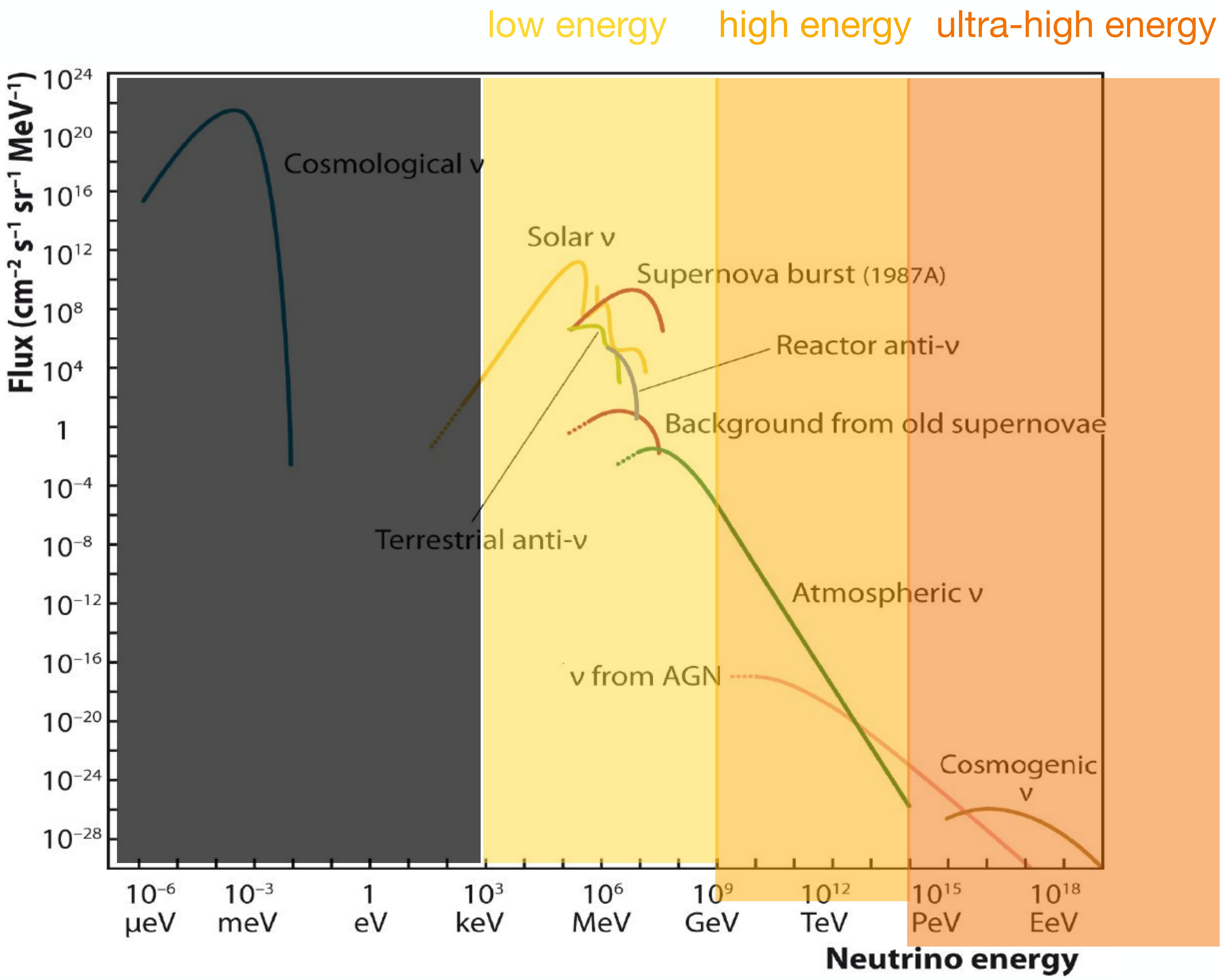

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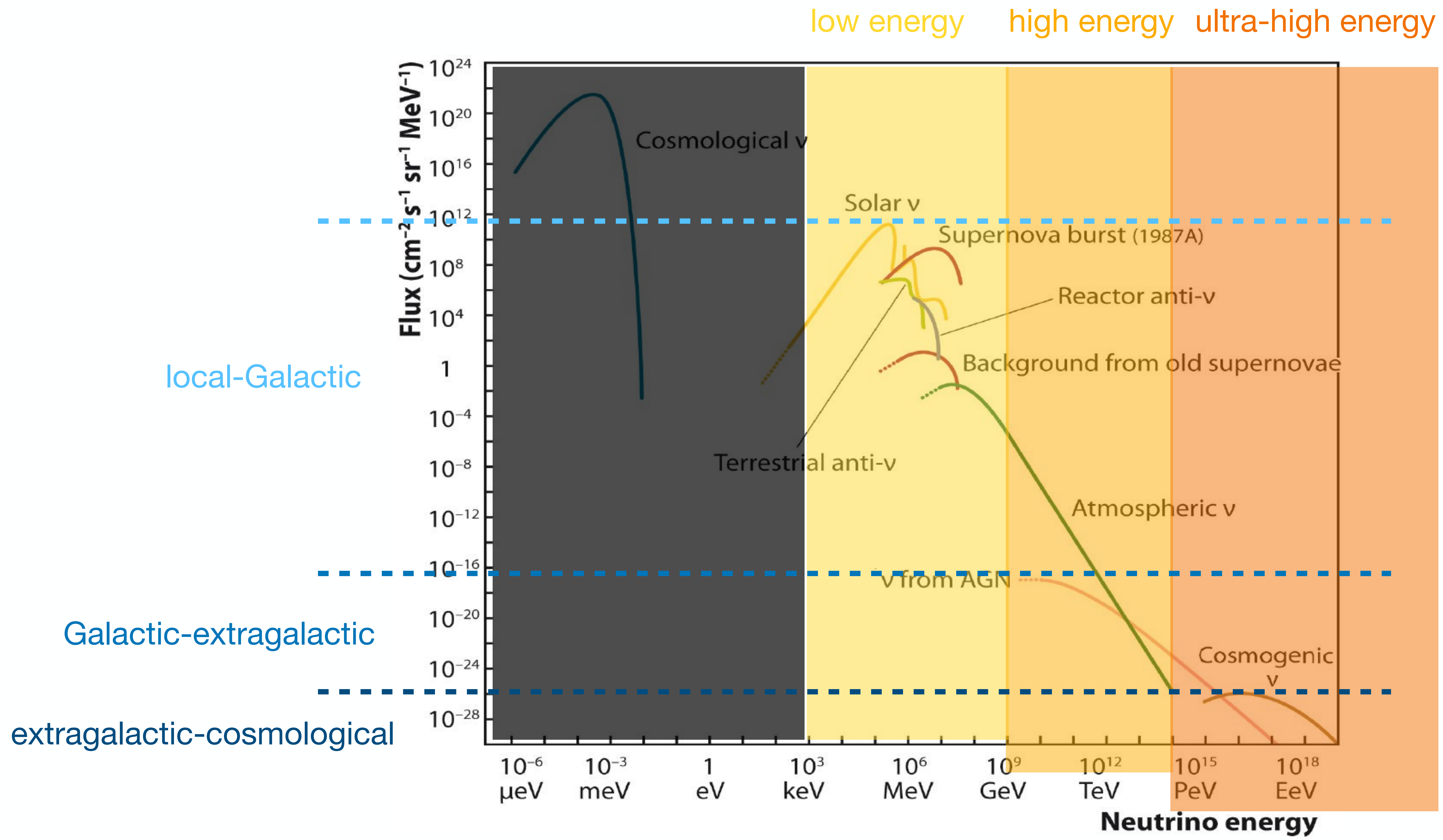

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“Global” neutrino spectrum:

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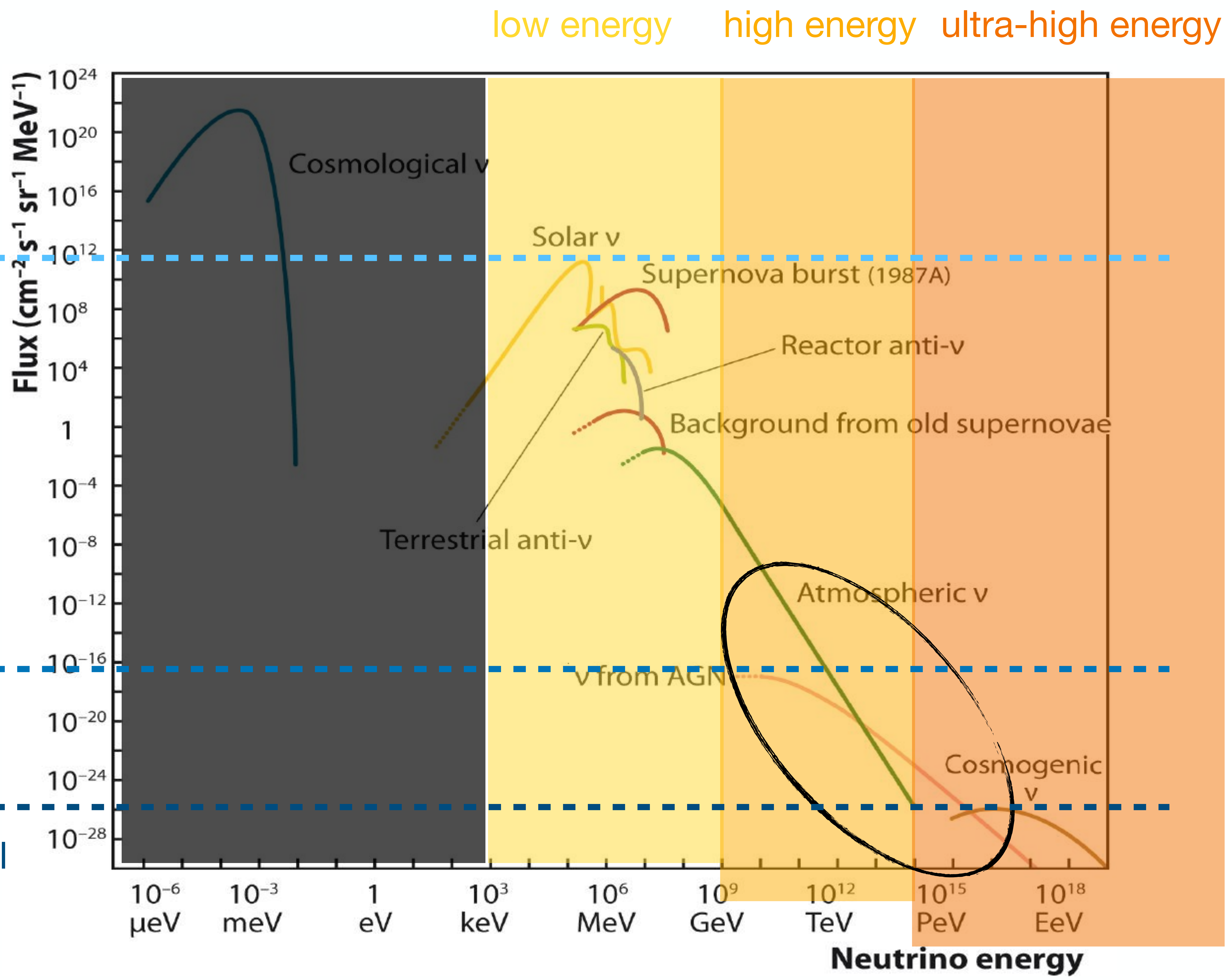
local-Galactic

Galactic-extragalactic

extragalactic-cosmological



Focus on high energy neutrinos → local to extragalactic sources

Which sources?

Guépin, Kotera and Oikonomou Nat. Rev. Phys. 2022, Halzen 2023

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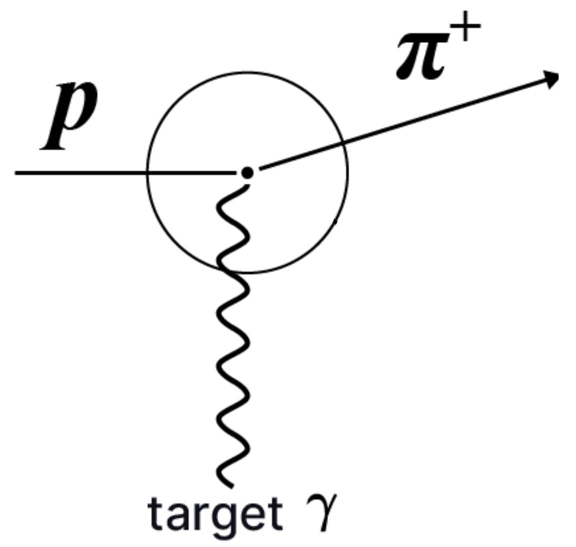

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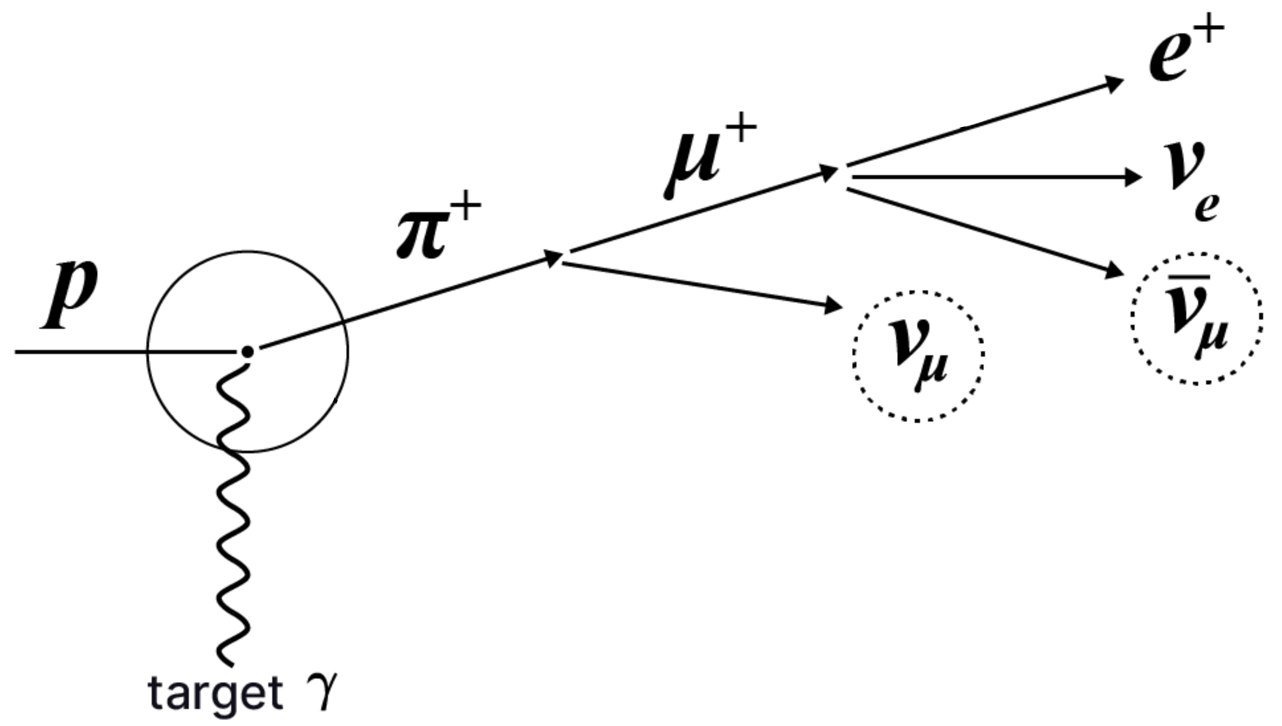

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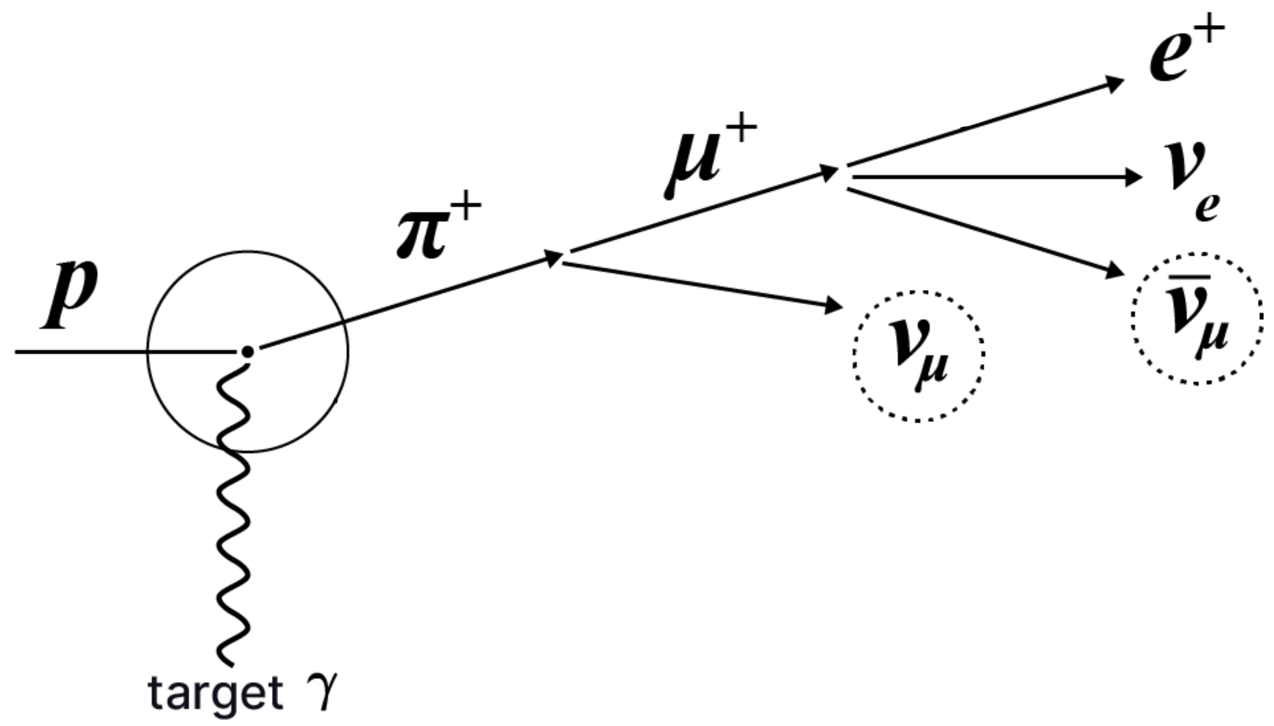

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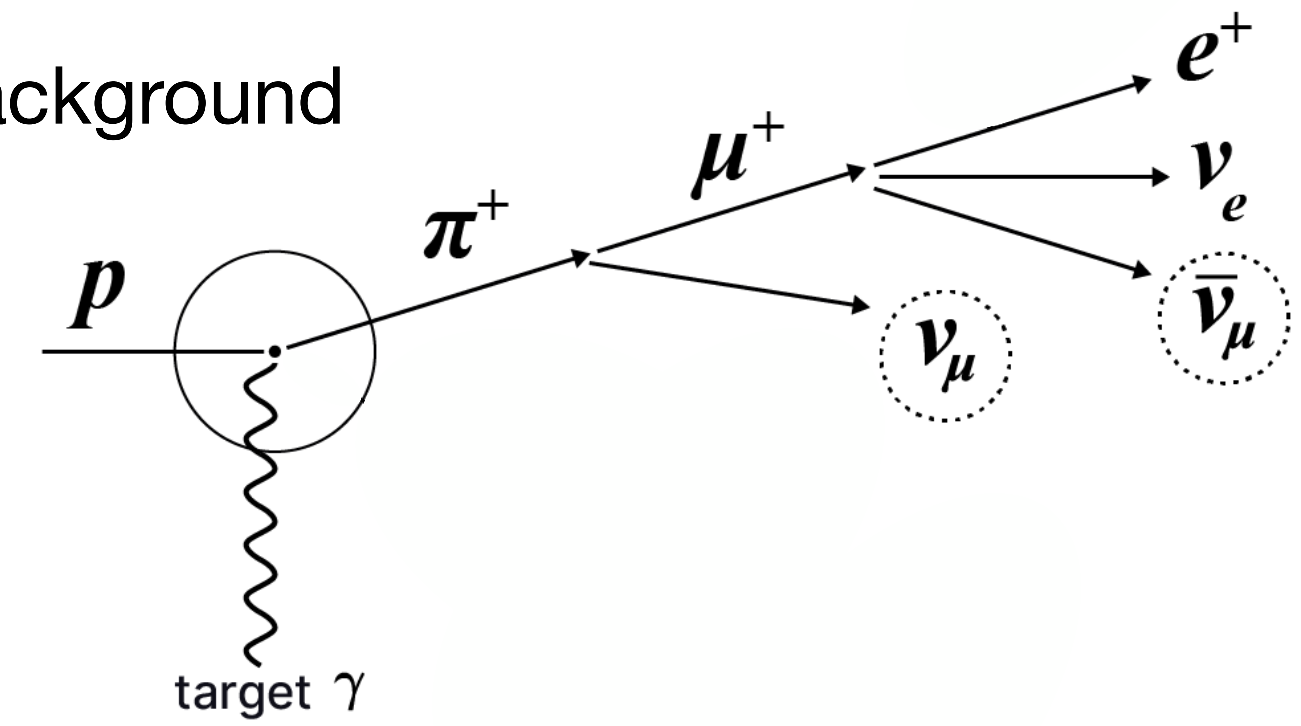

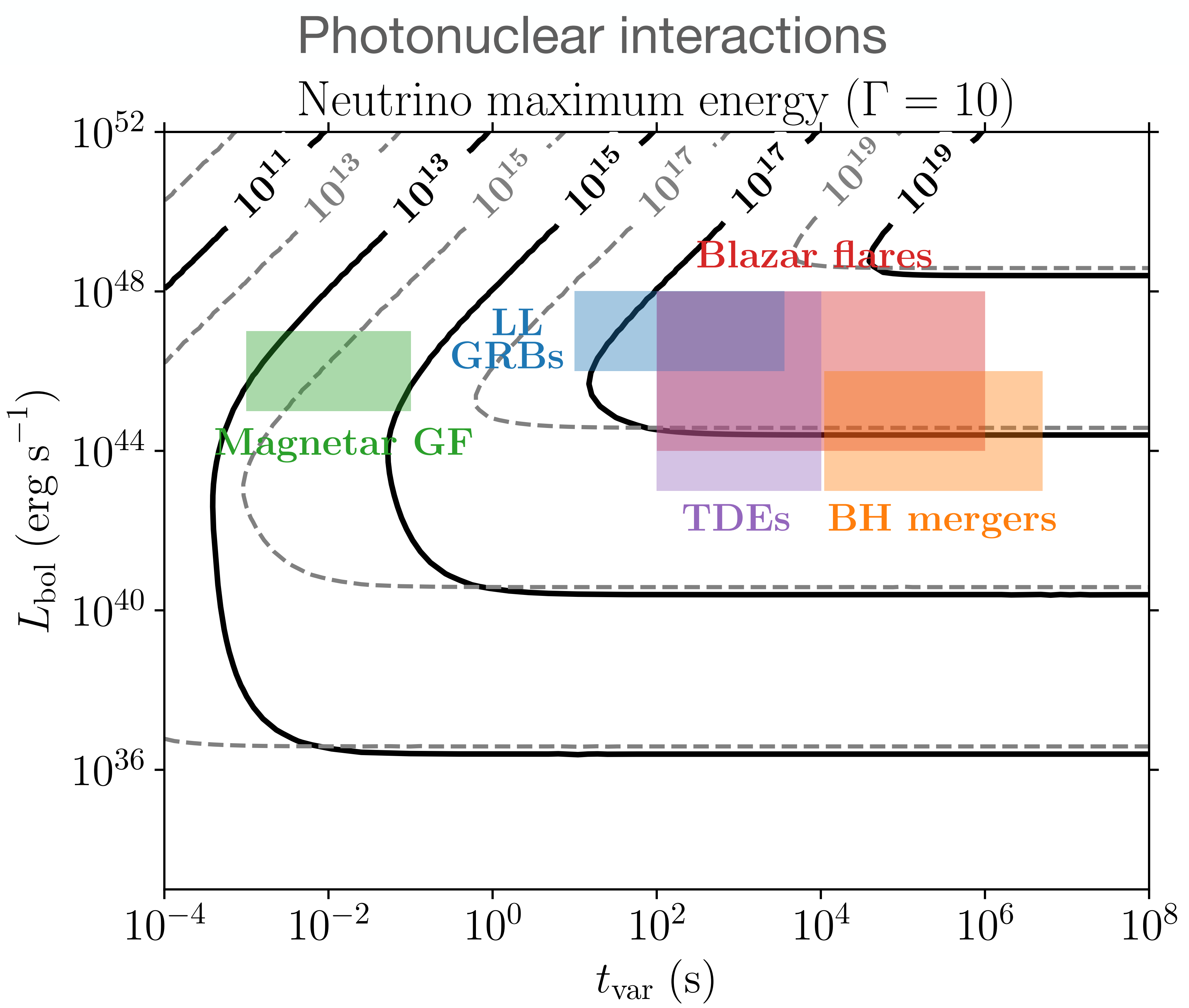

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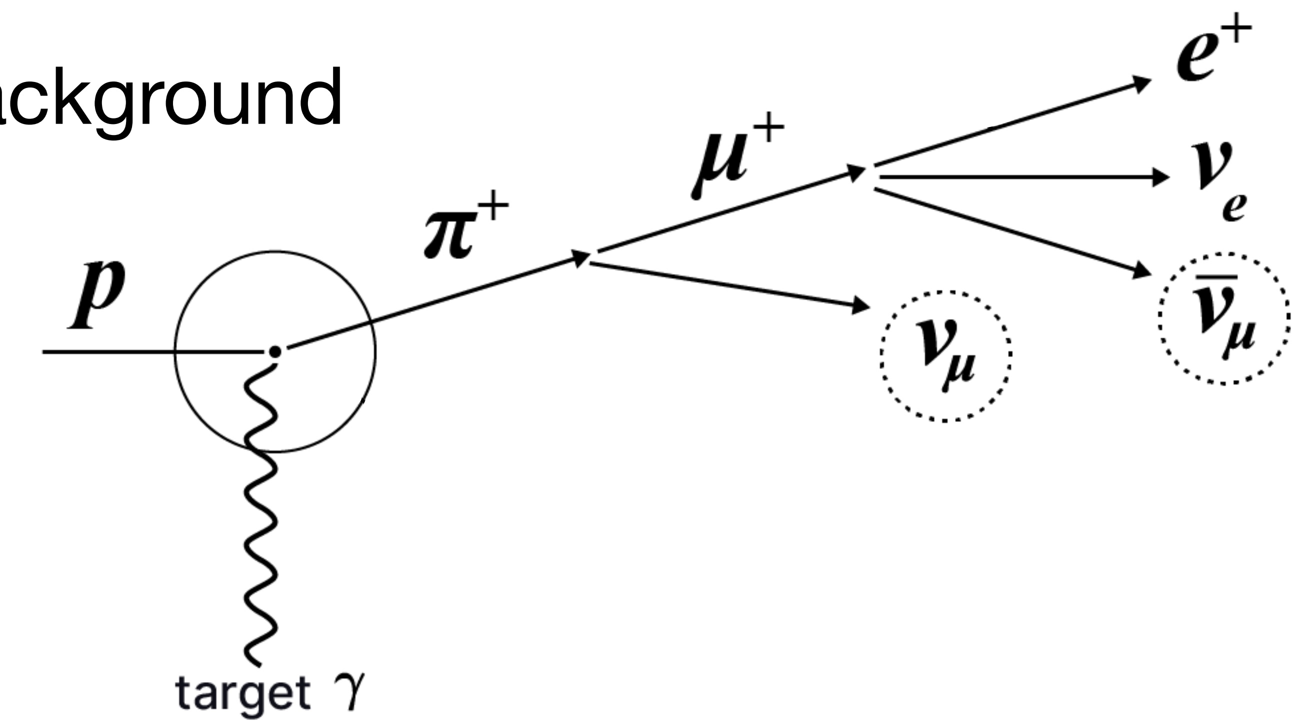

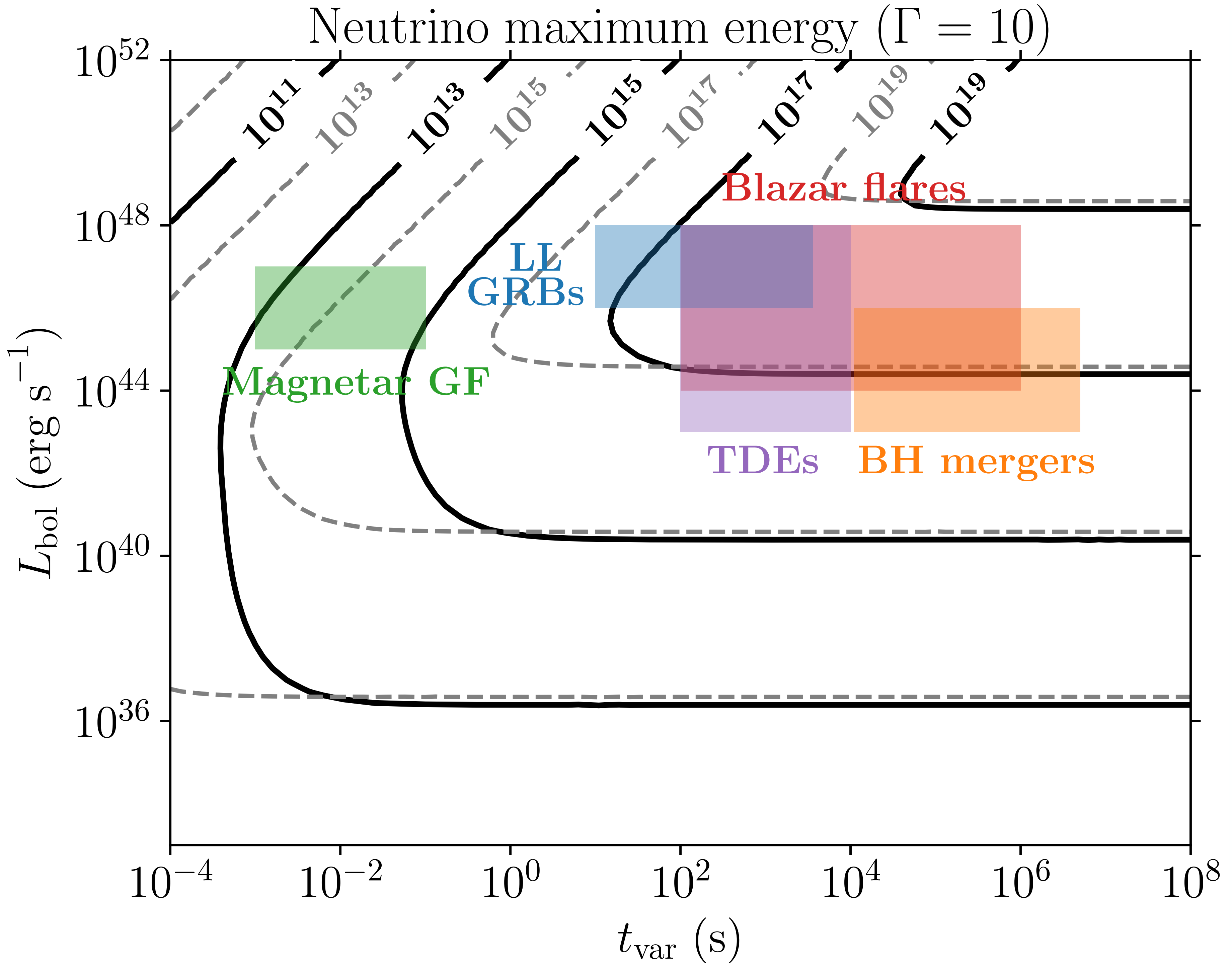

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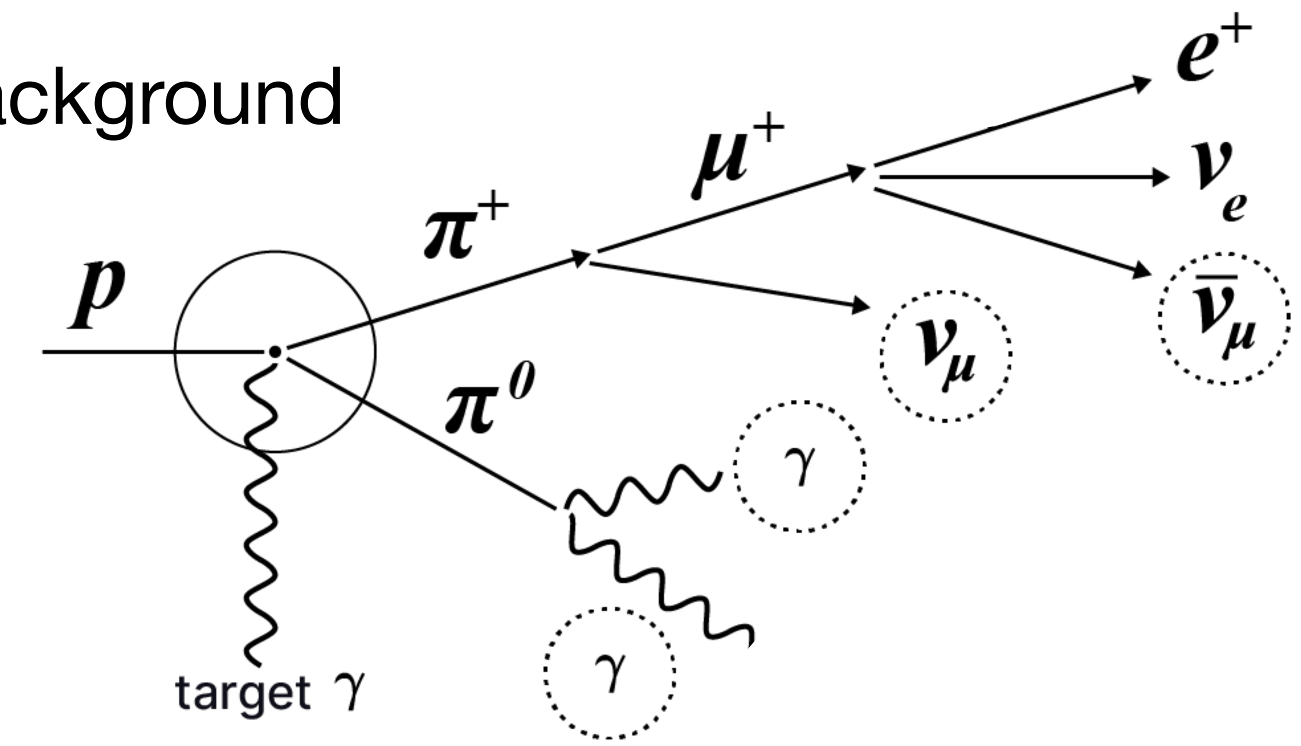

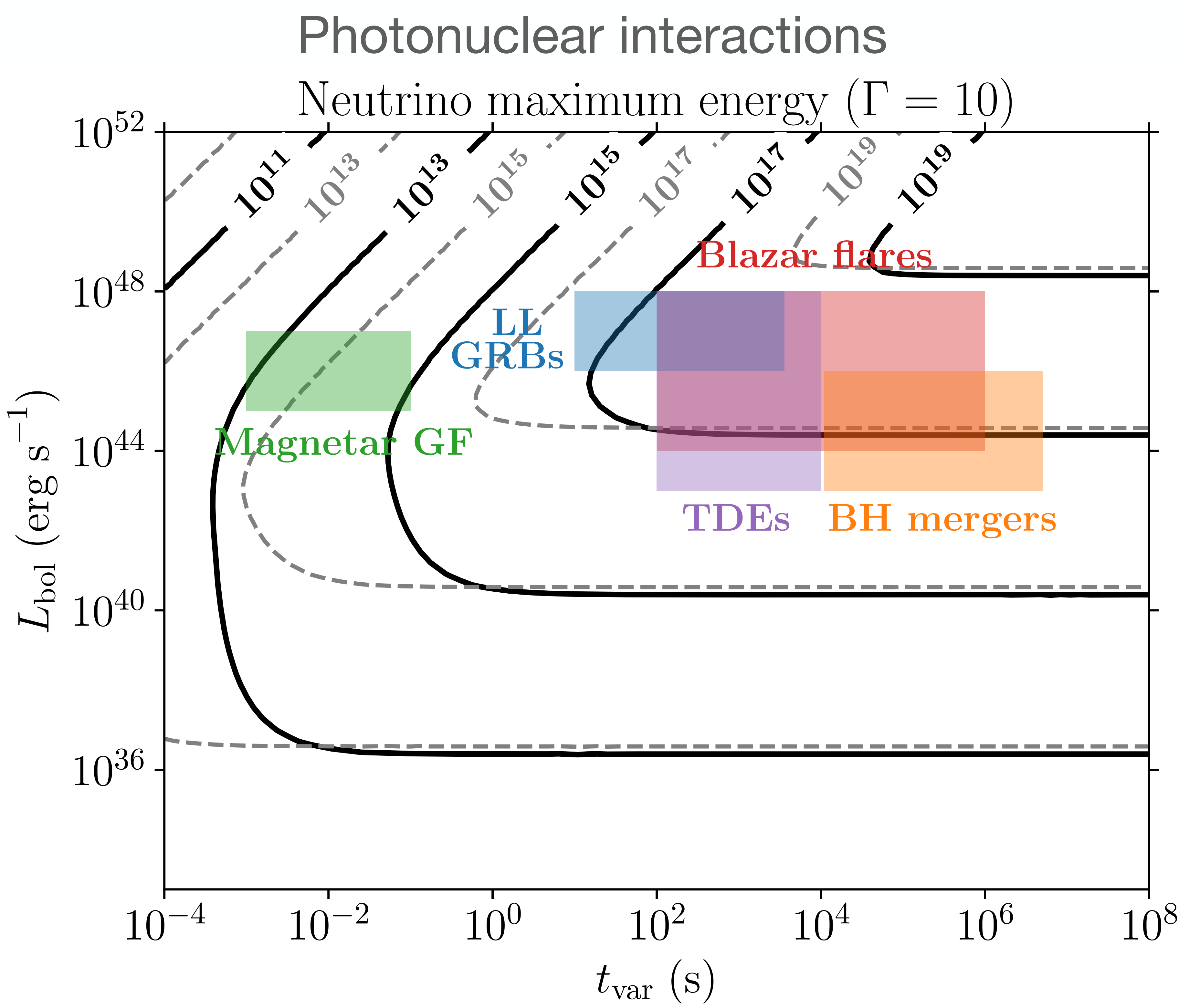

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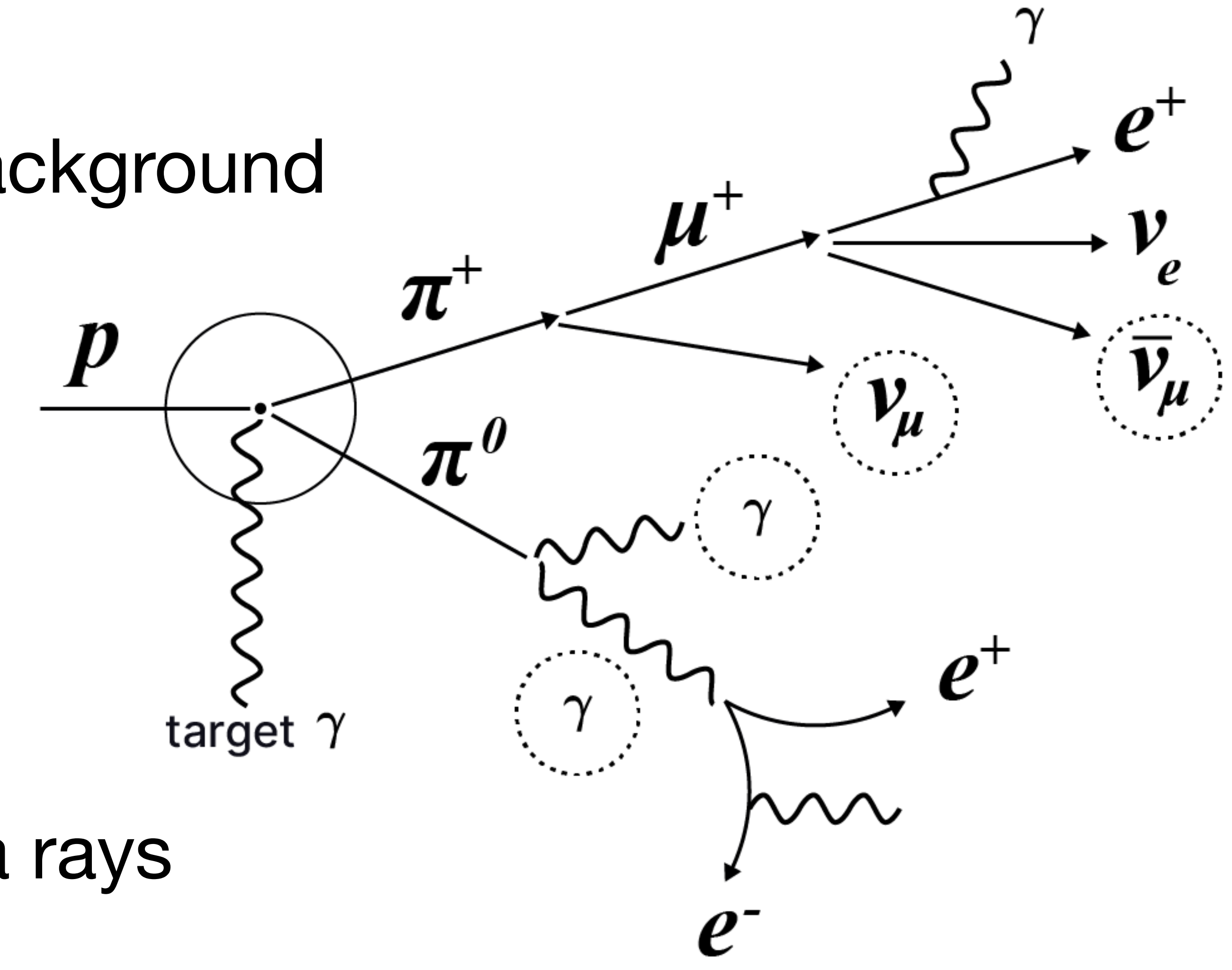

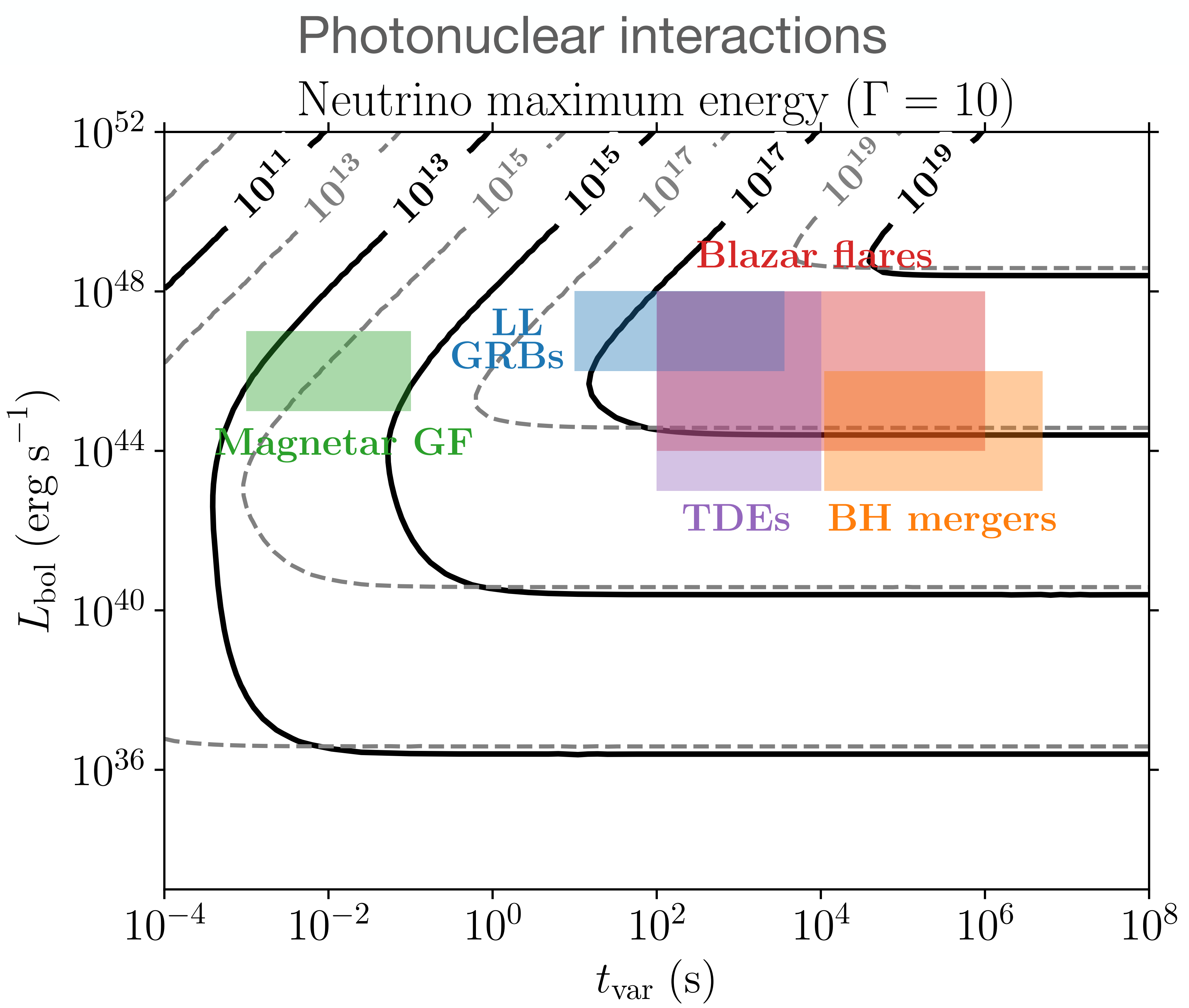

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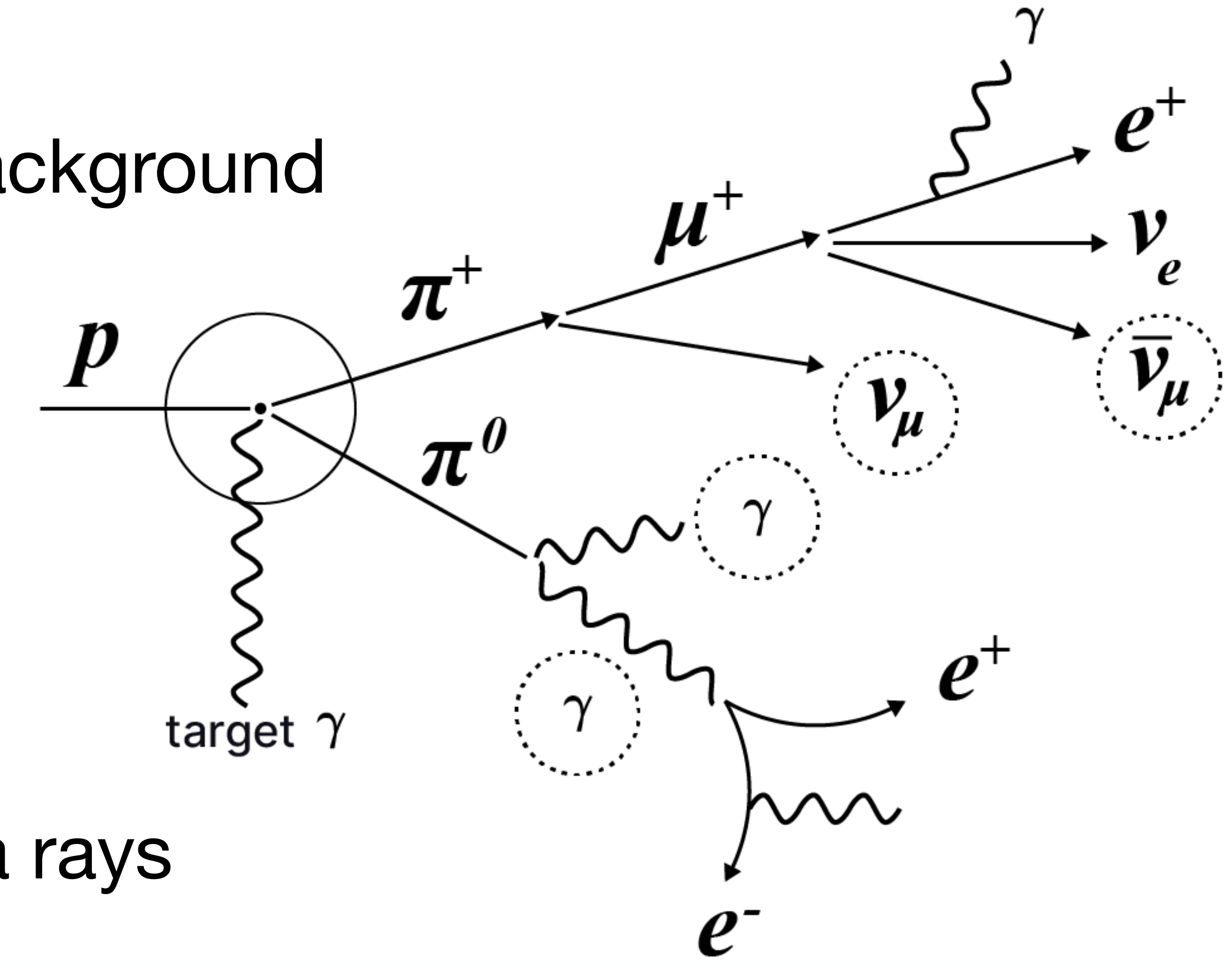

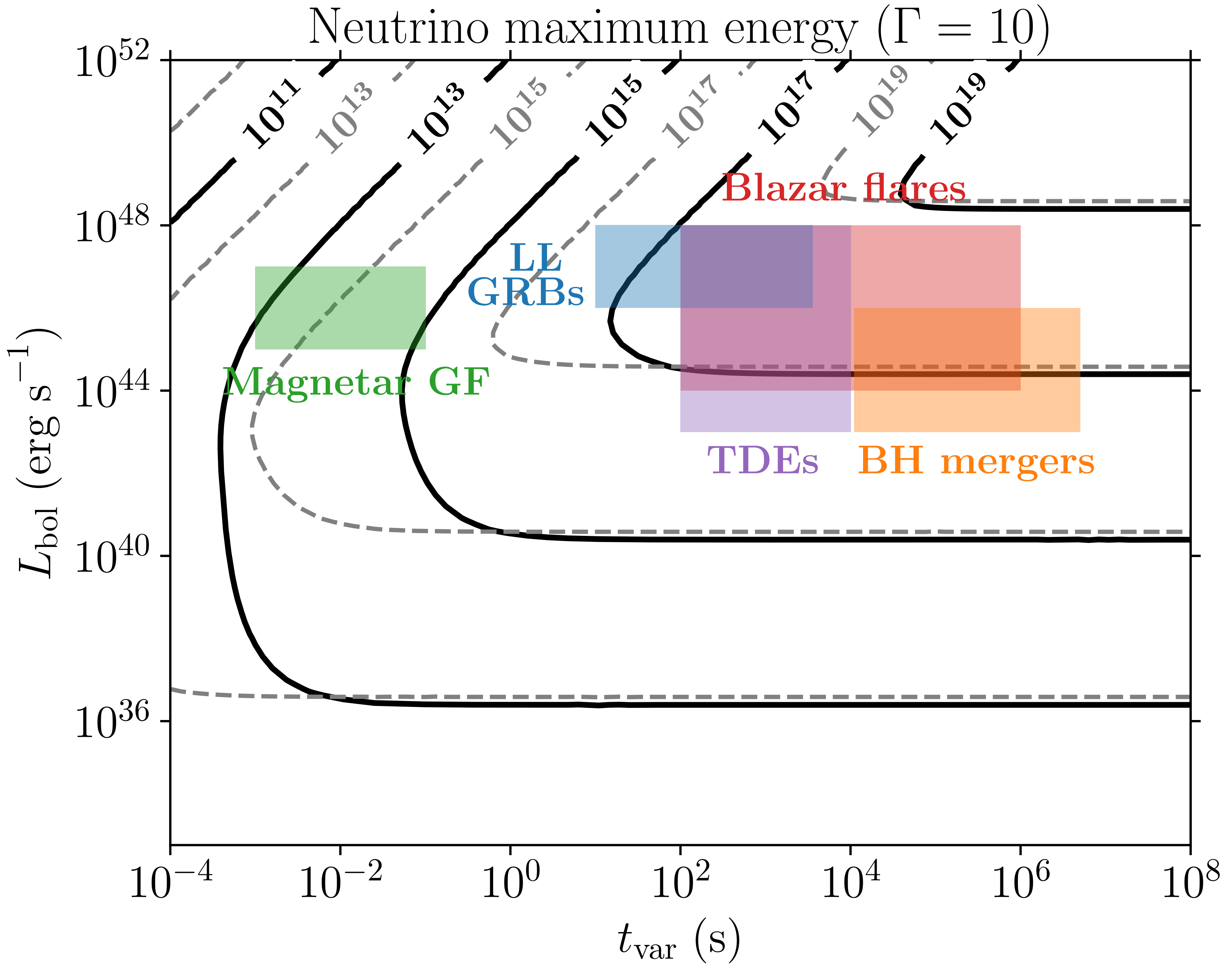

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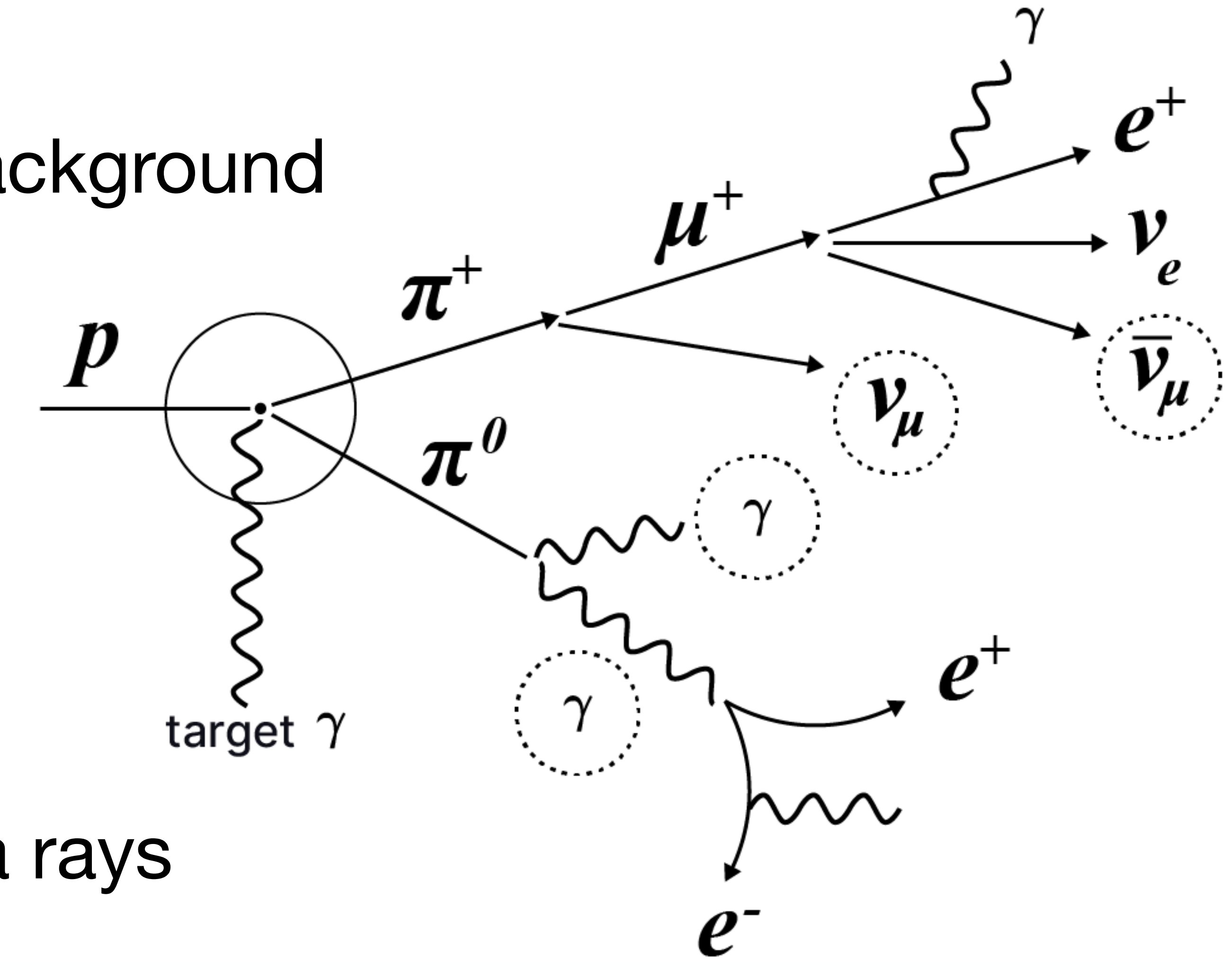

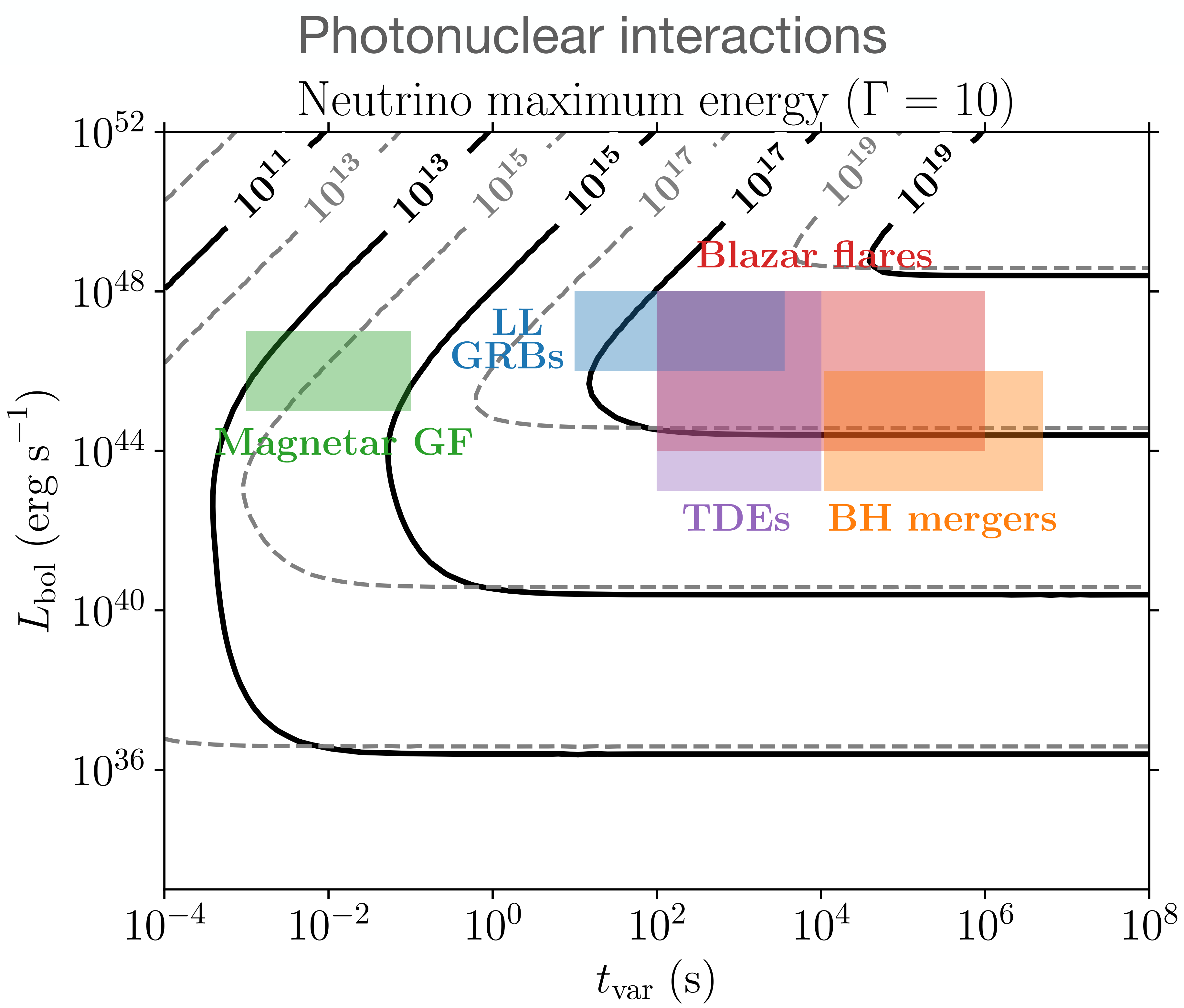

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High-energy neutrinos can probe internal hadronic mechanisms of cosmic-ray and high-energy sources

Guépin, Kotera and Oikonomou Nat. Rev. Phys. 2022, Halzen 2023

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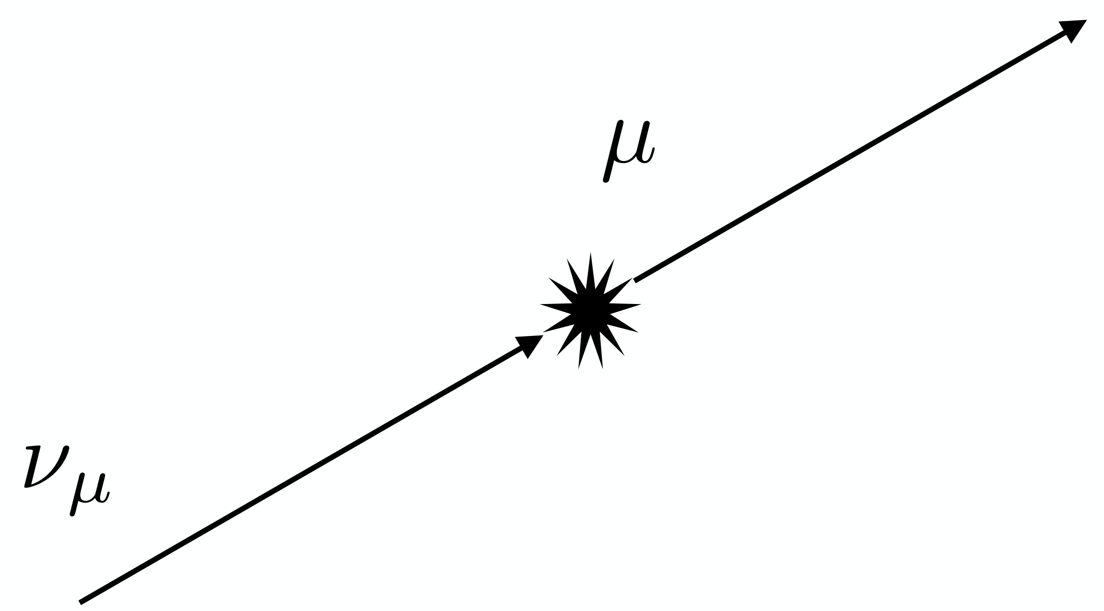

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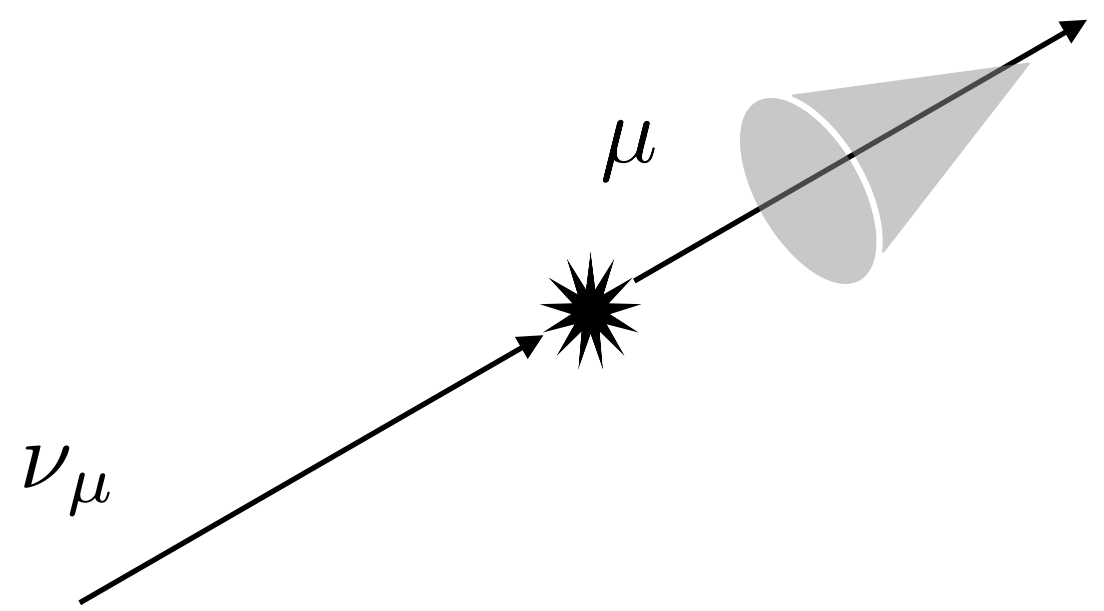

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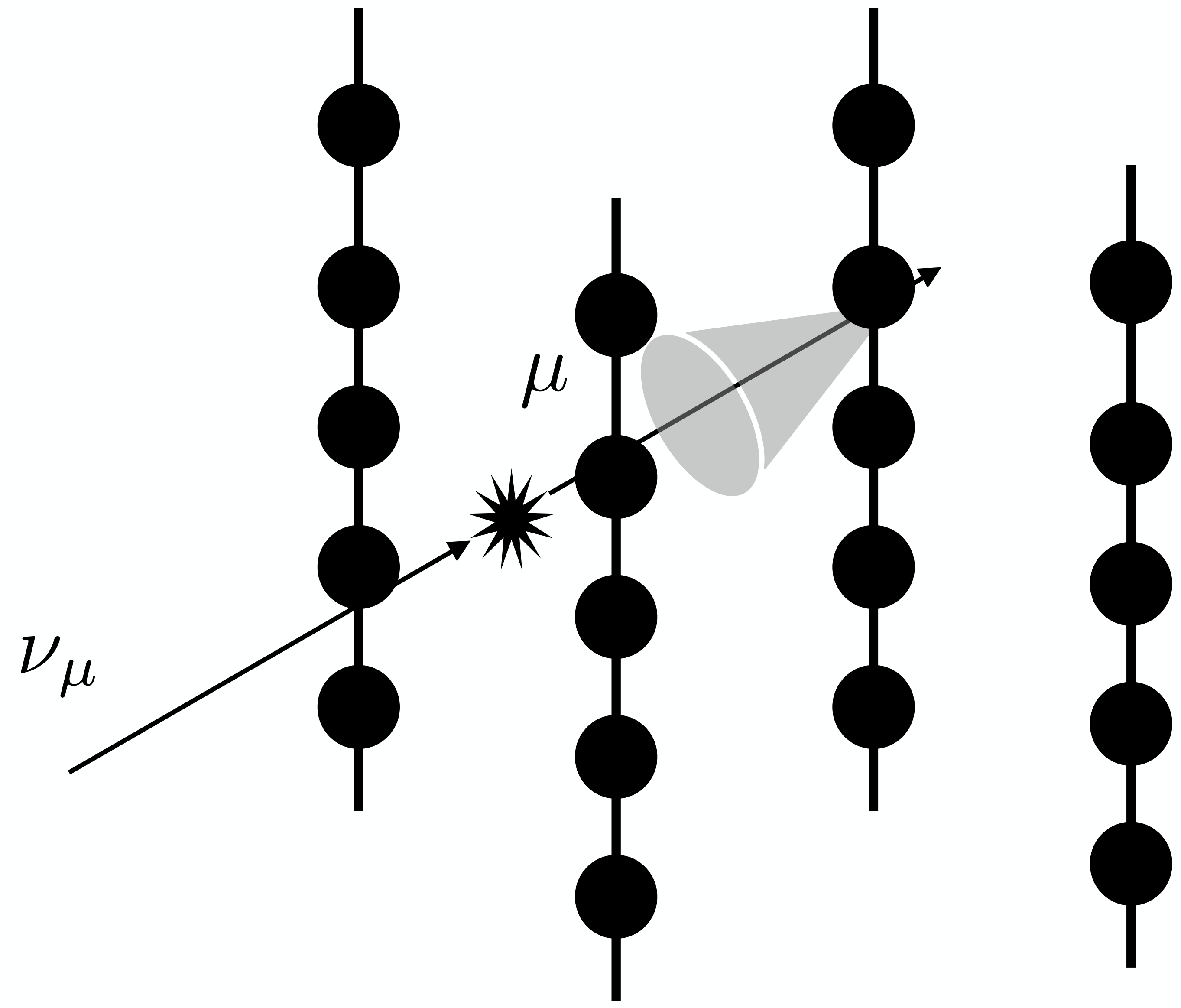

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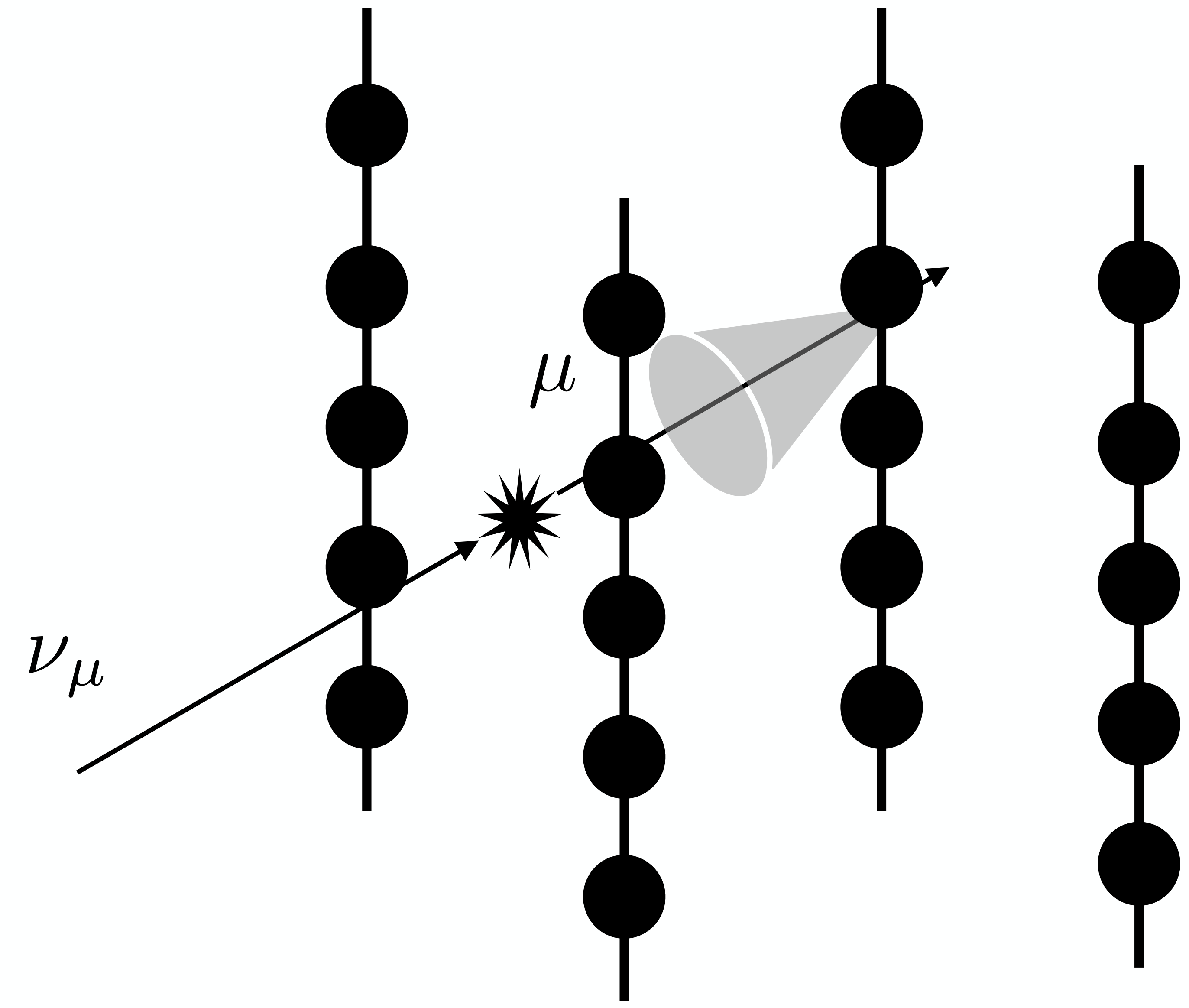

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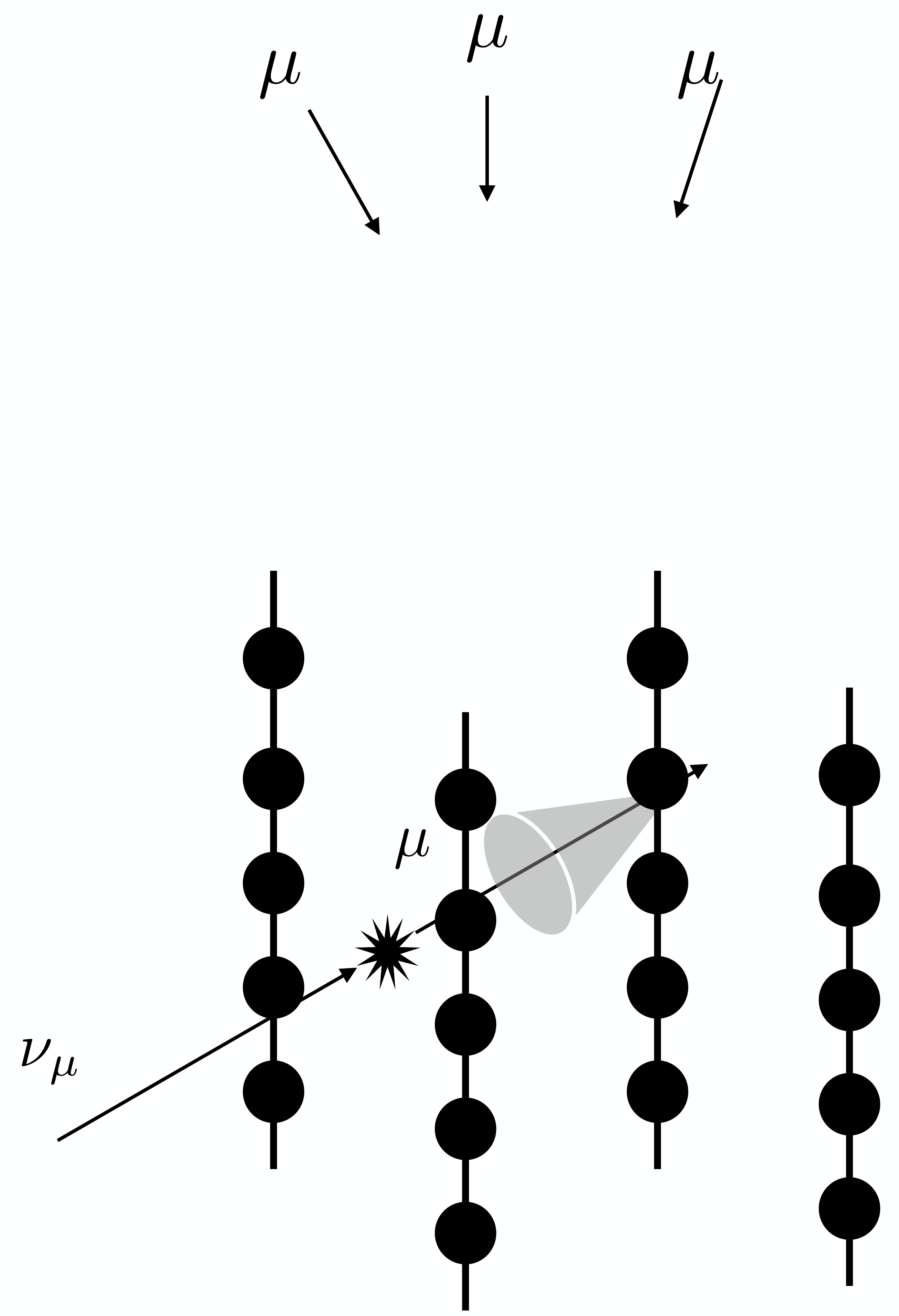

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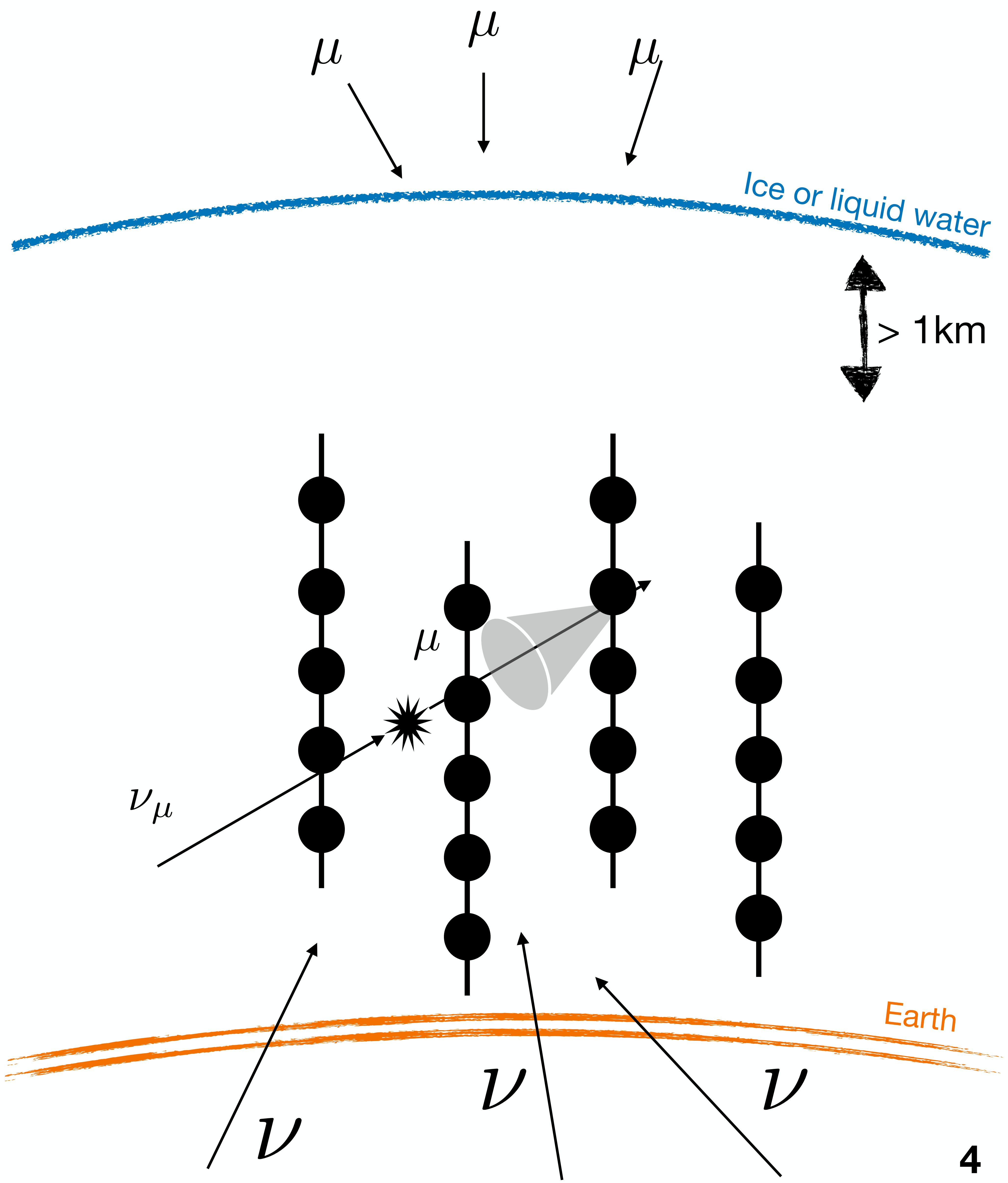

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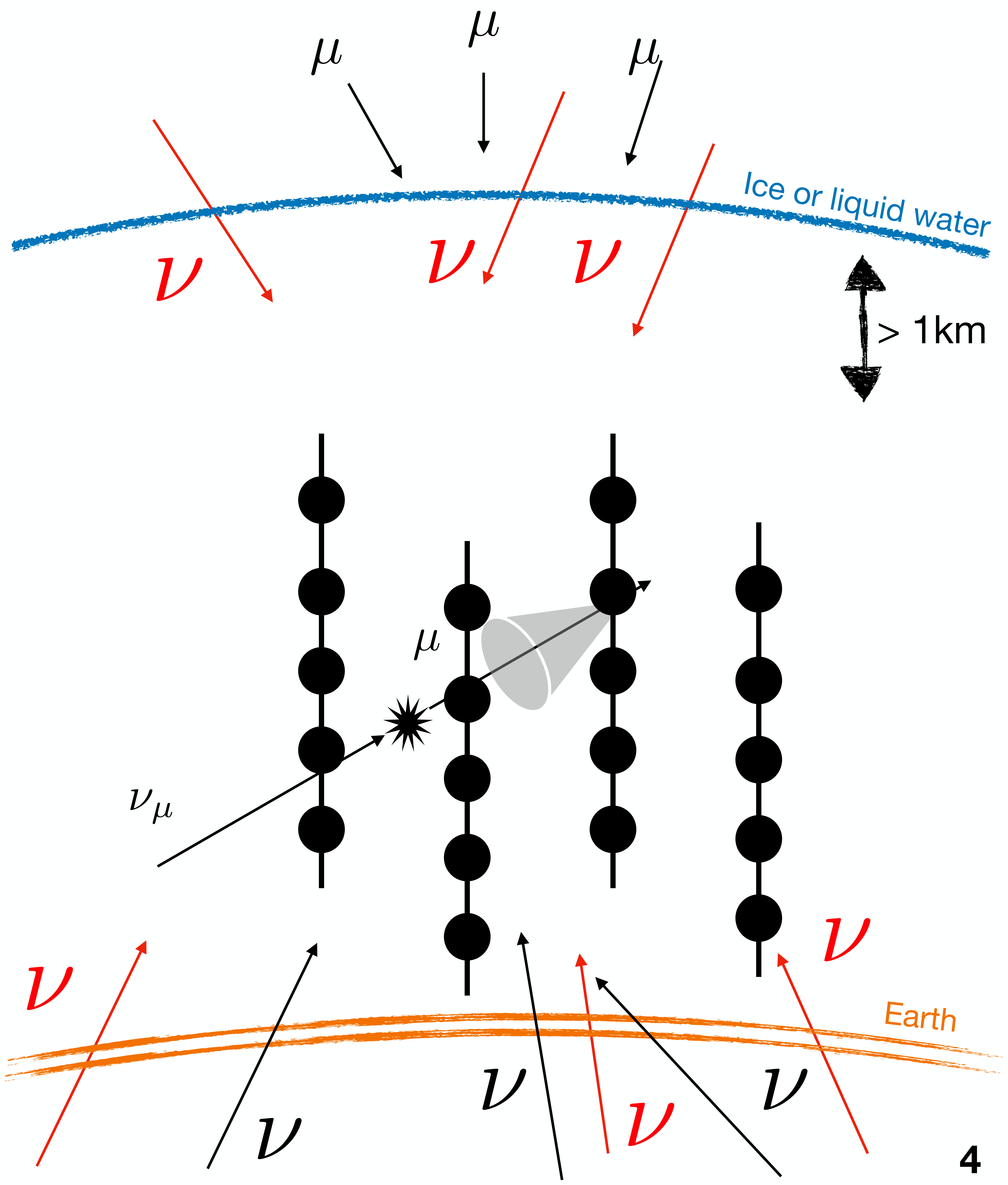

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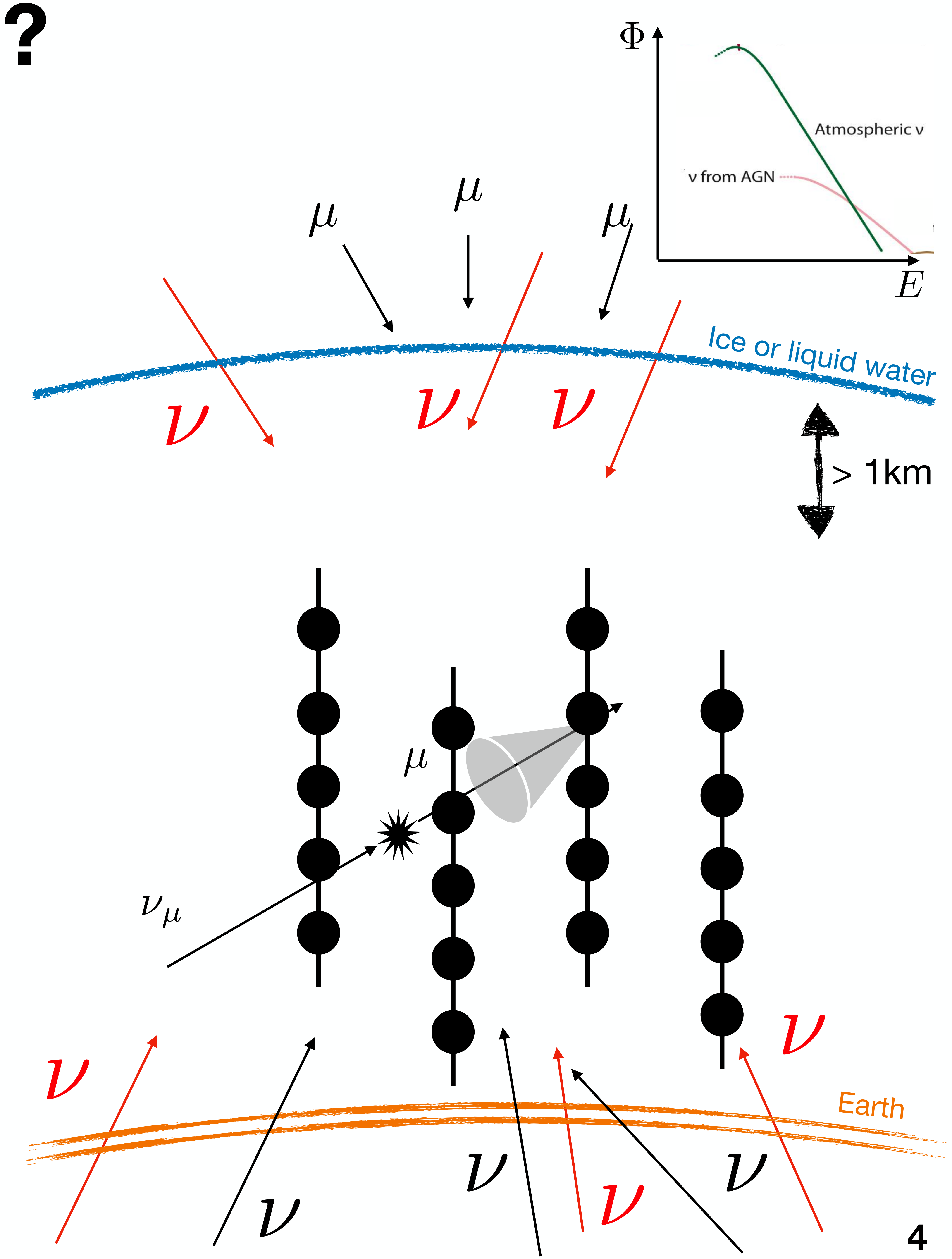

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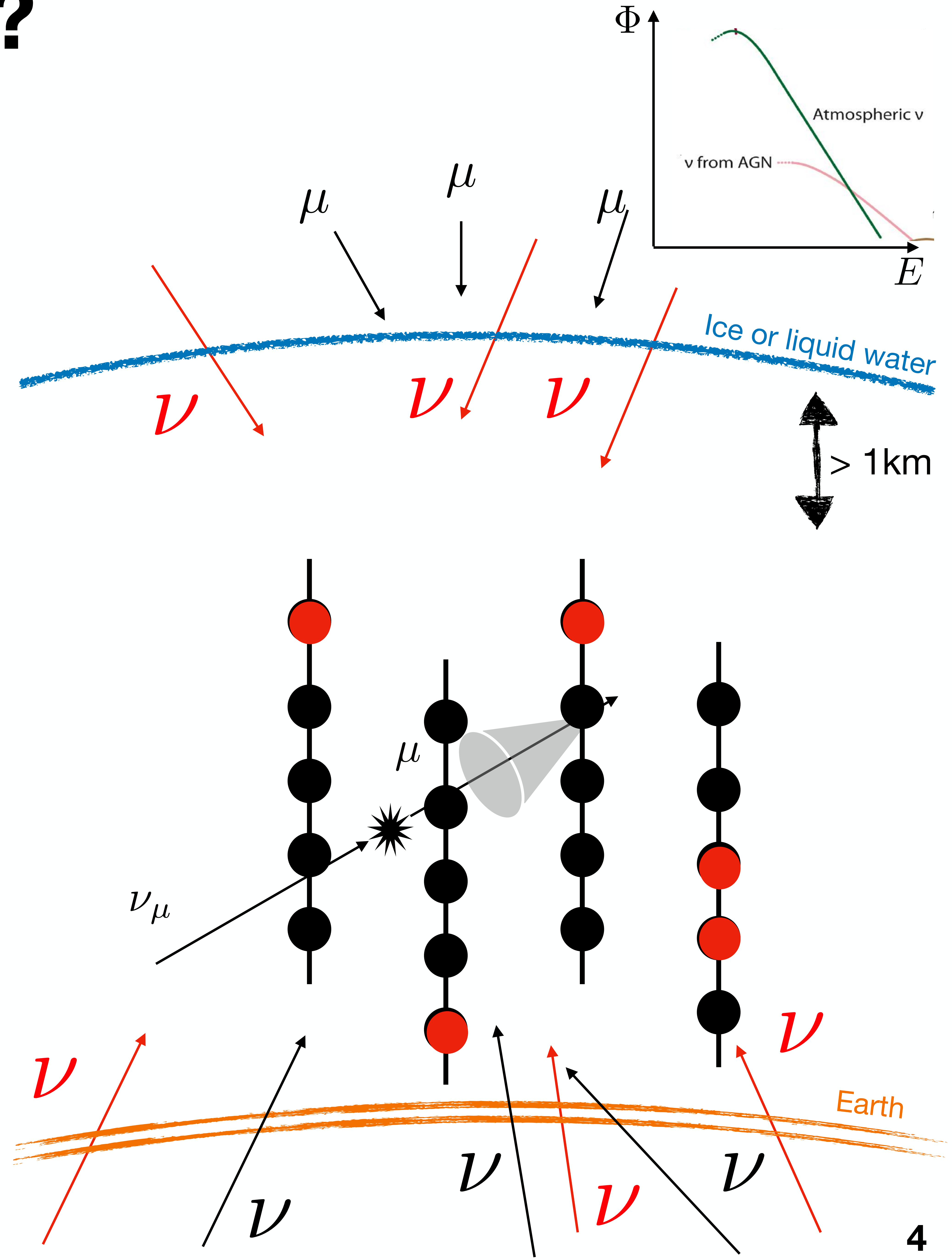

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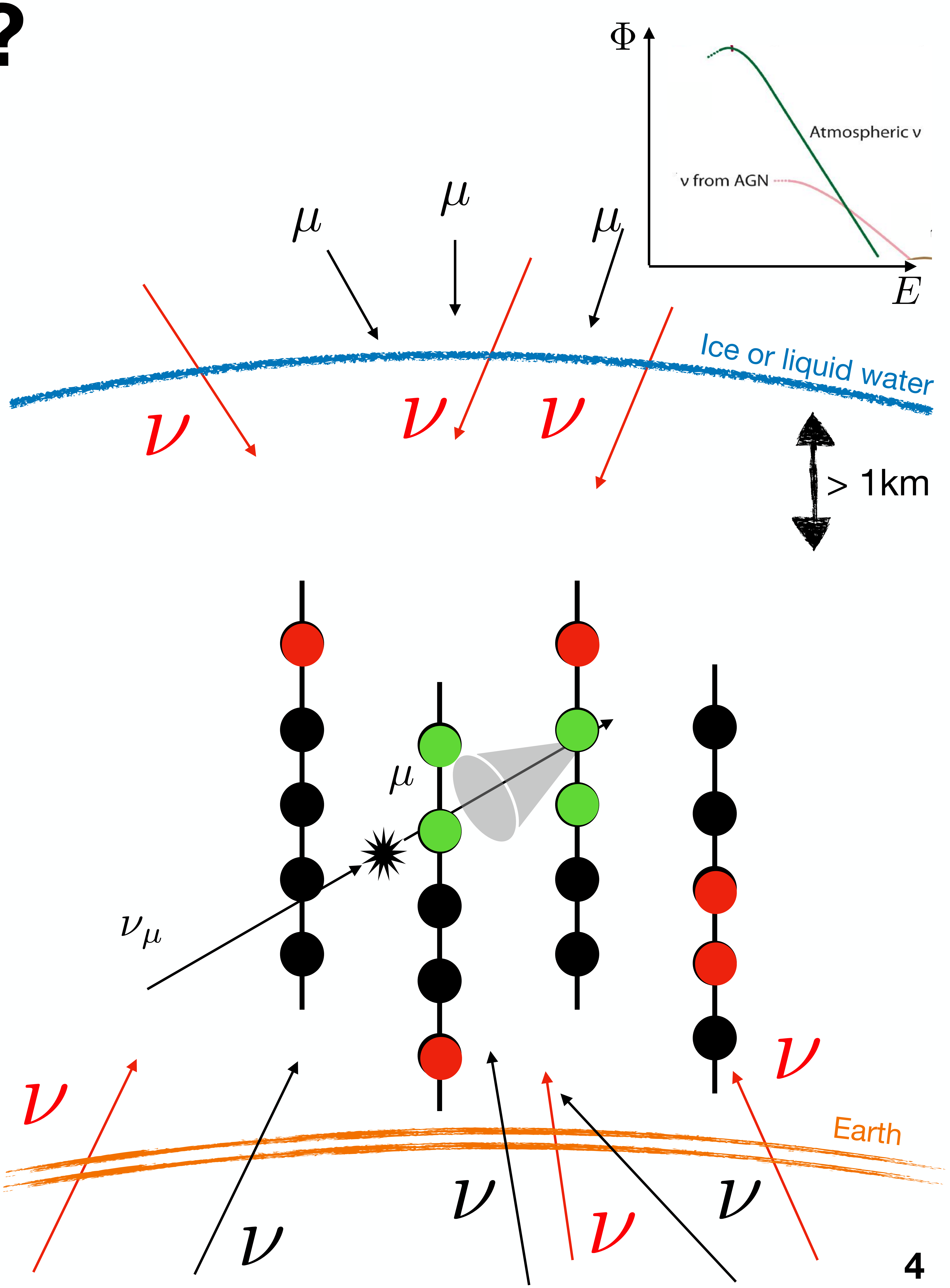

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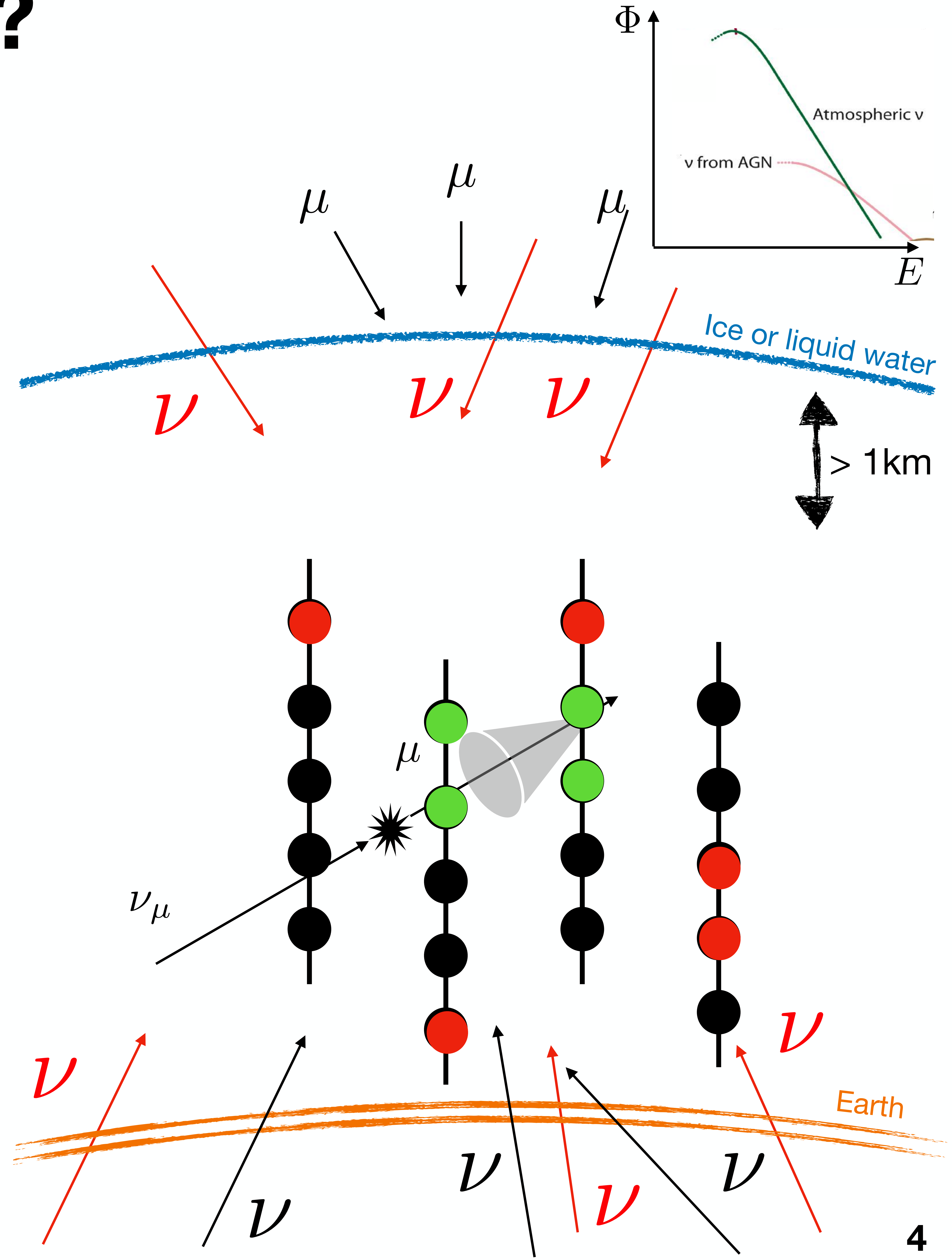

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Main challenge: low fluxes + weakly interacting particle
→ large effective volume → large scale detectors

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KM3NeT and IceCube

Guépin, Kotera, Oikonomou, Nature Review Physics 2022

KM3NeT and IceCube

~1Gton of instrumented water target (Ice or liquid)

- minimum energy: 100-300GeV
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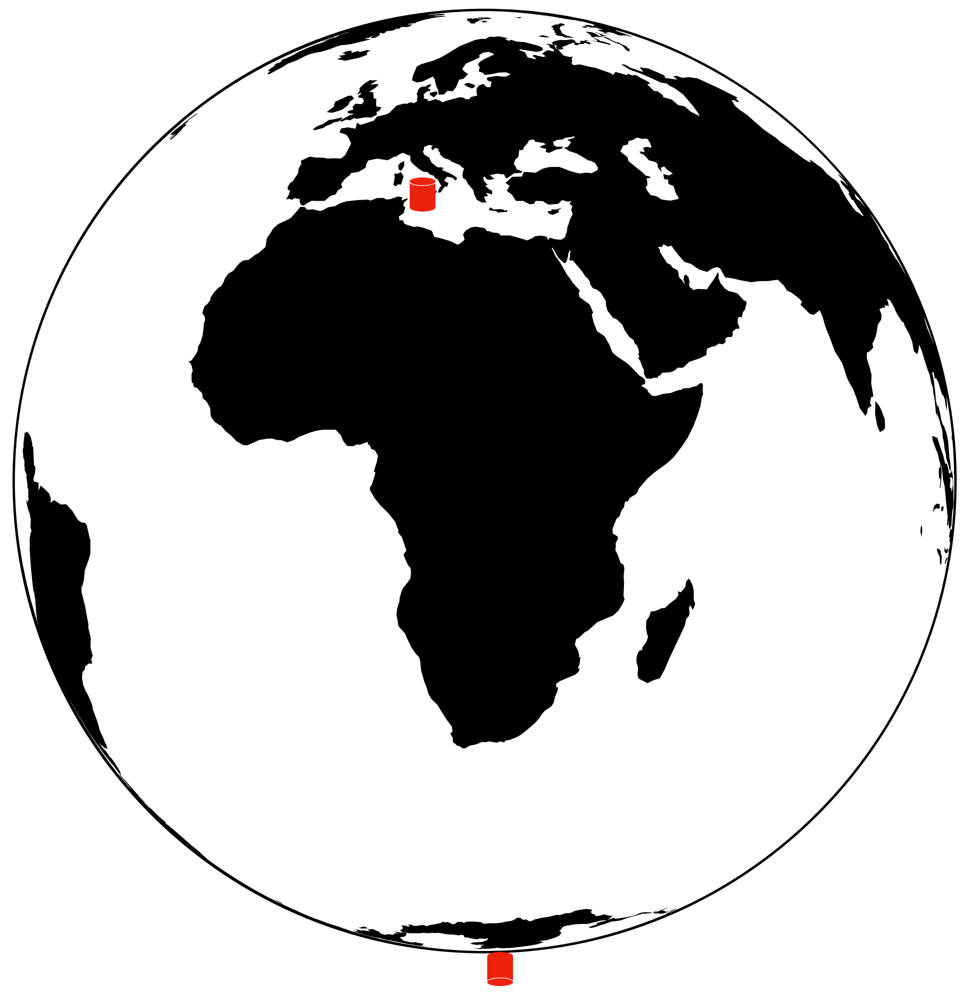
- sensitivity: 10^{-8}-10^{-9} GeV cm^{-2}s^{-1} sr^{-1}



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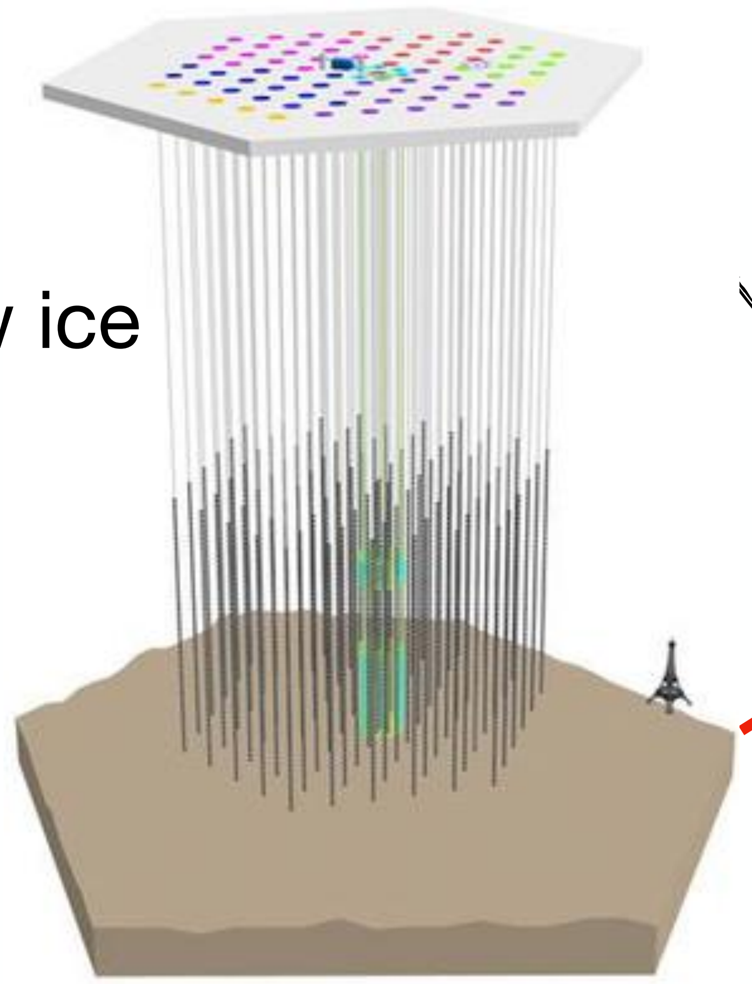
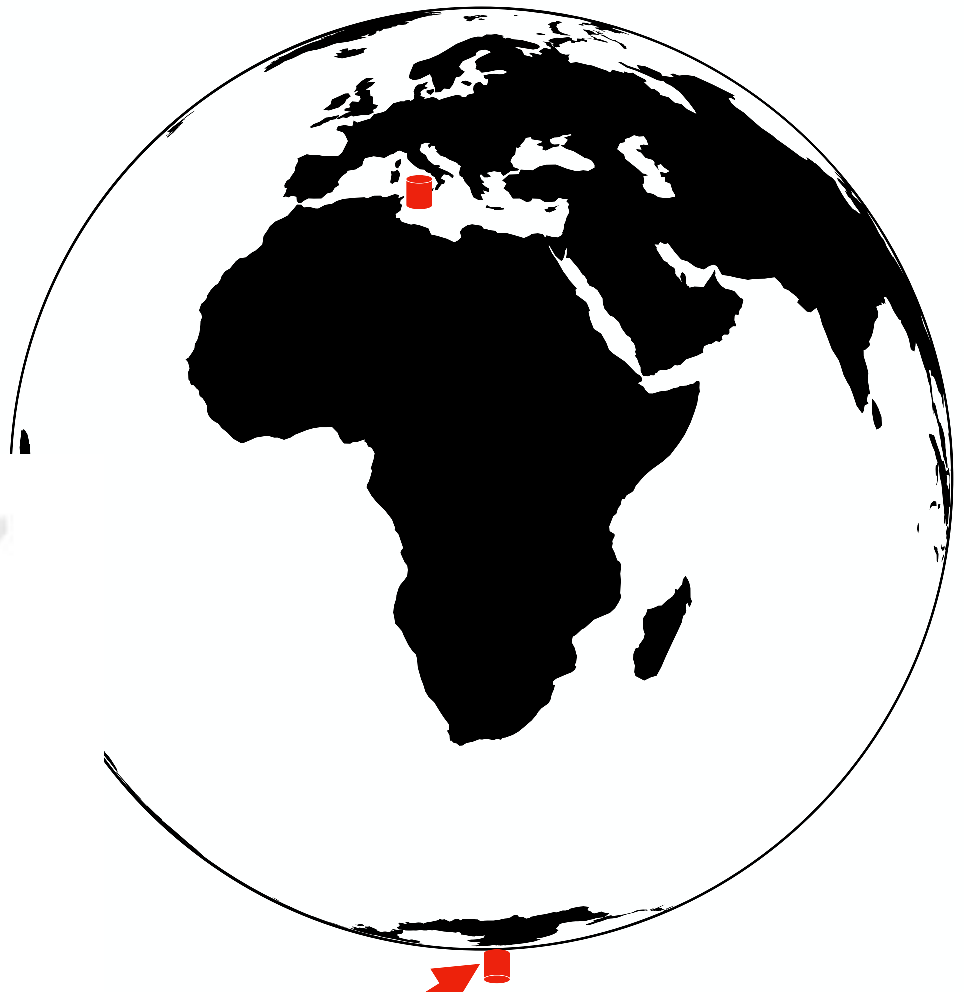
- angular resolutions: 0.4° (10°)
- completion date: 2010

- ~2500m below ice
- 86 strings
- 5160 DOMs





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KM3NeT-ARCA (Mediterranean sea):

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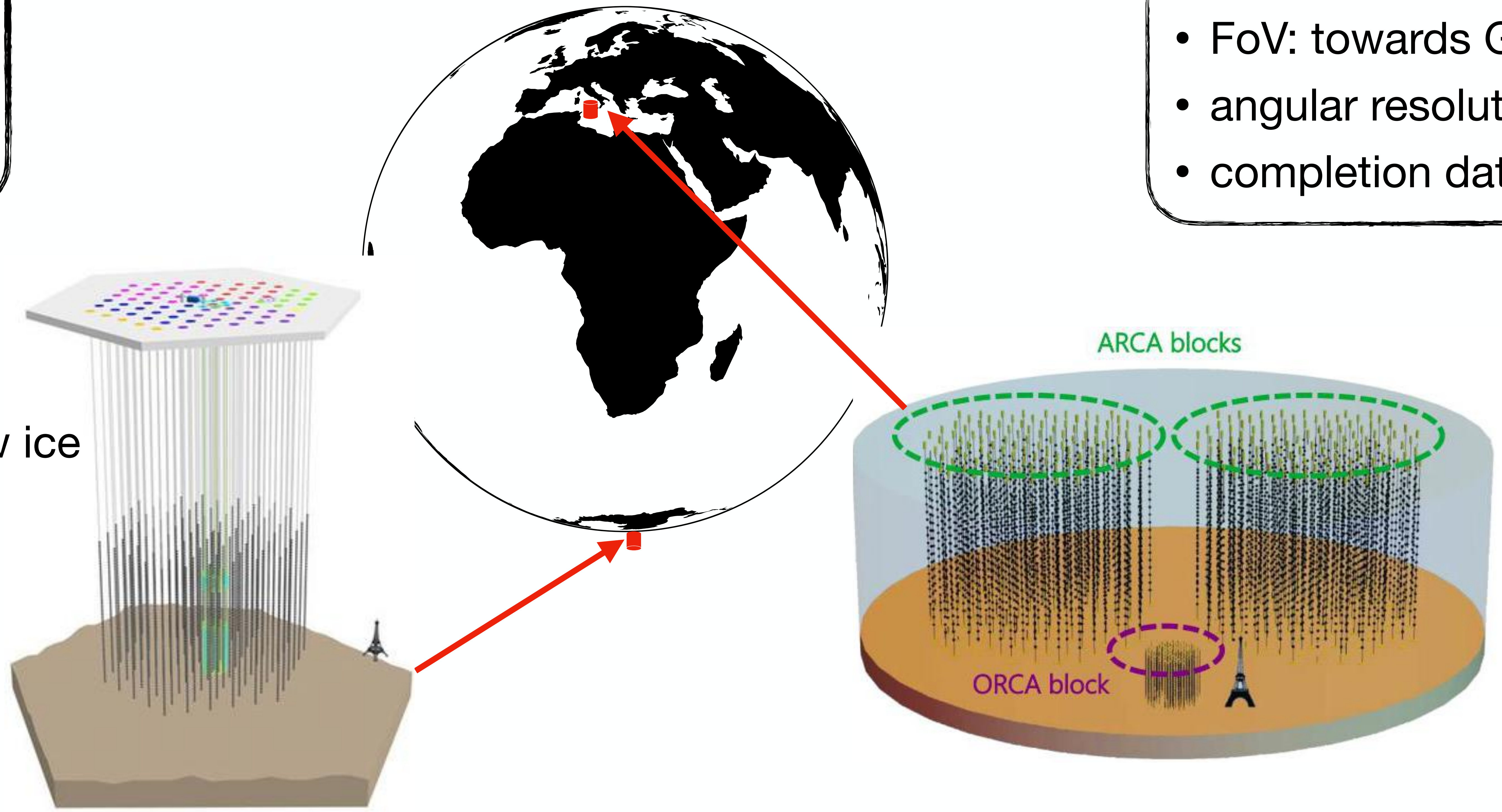

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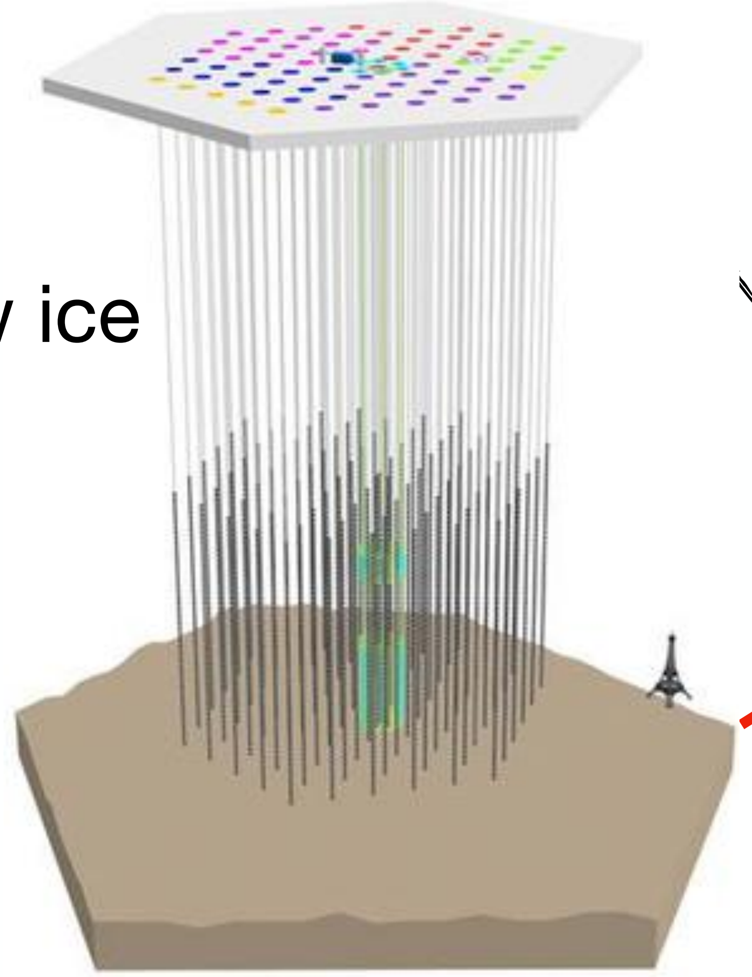

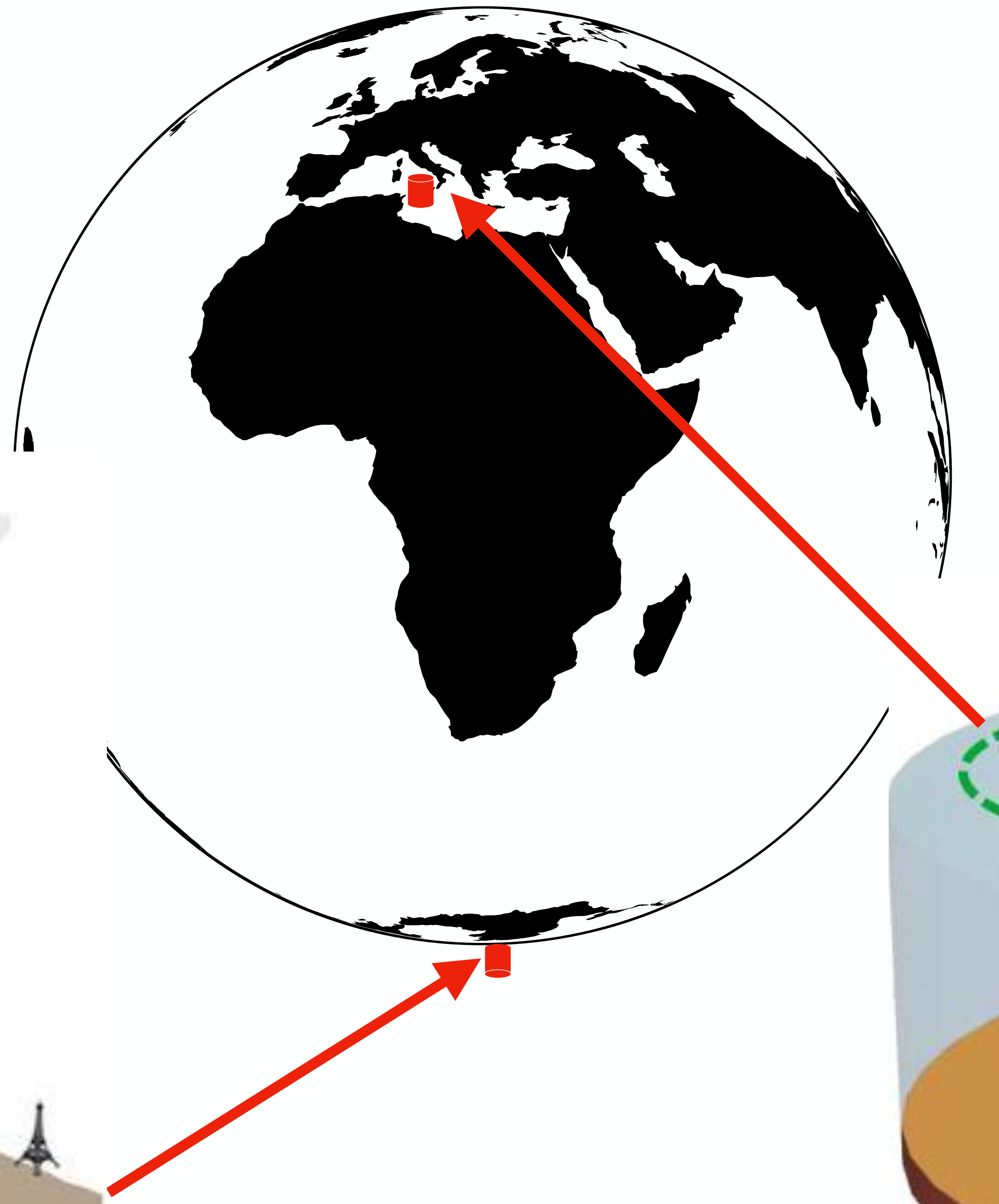

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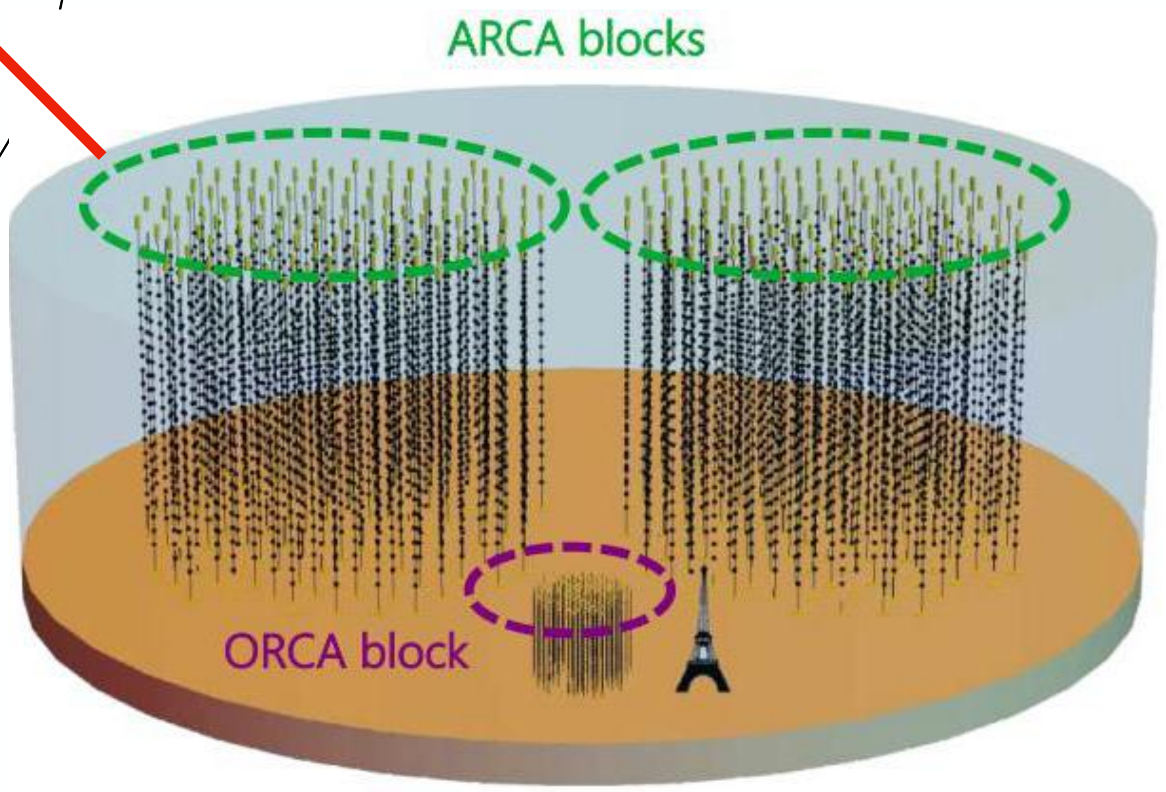

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What did we see?!

Guépin, Kotera, Oikonomou, Nature Review Physics 2022

A diffuse flux from TeV to PeV

IceCube coll. 2025, IceCube coll. Phys. Rev. D 110 (2024)

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- Detection of a diffuse astrophysical flux of high-energy neutrinos
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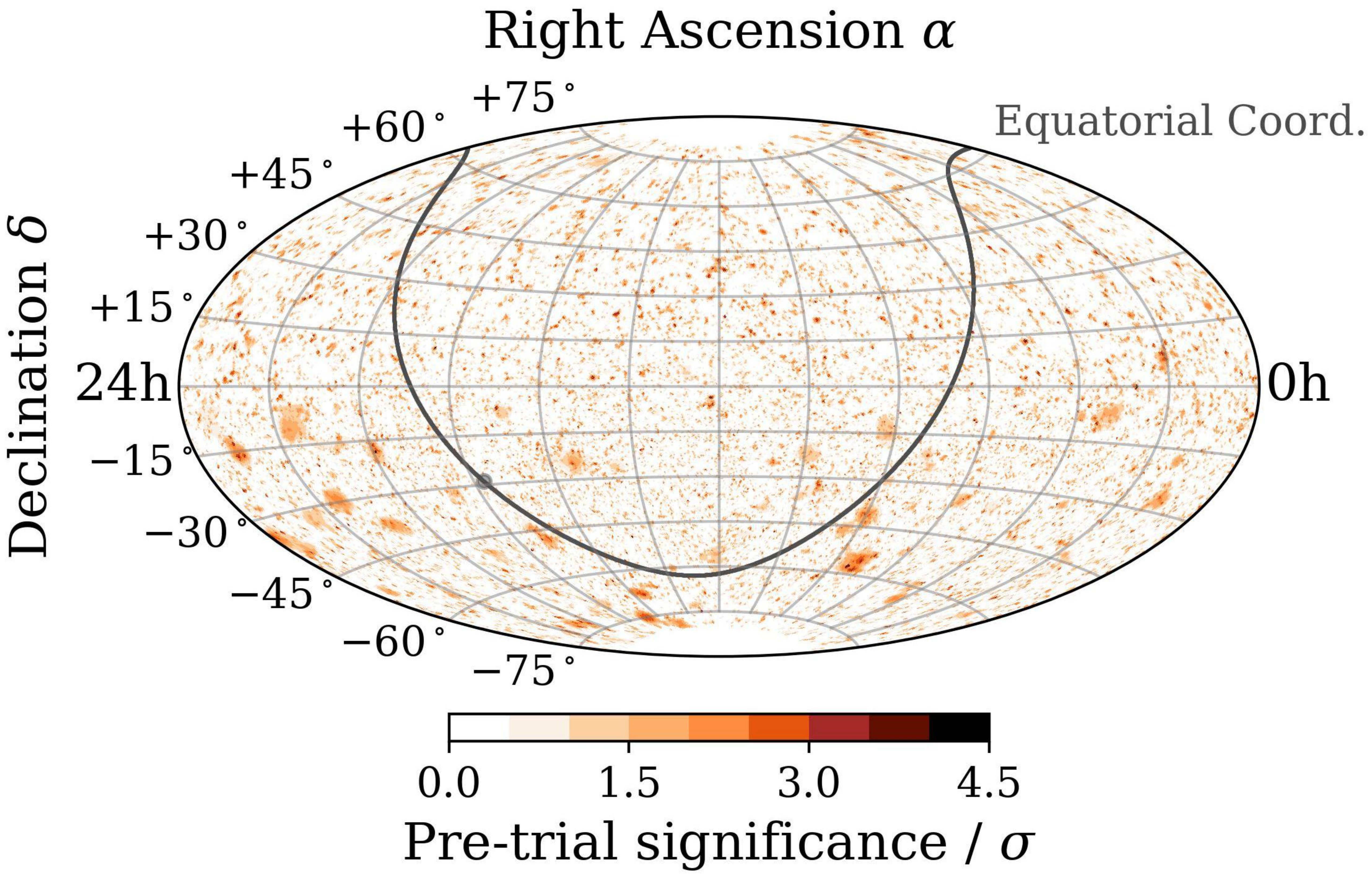

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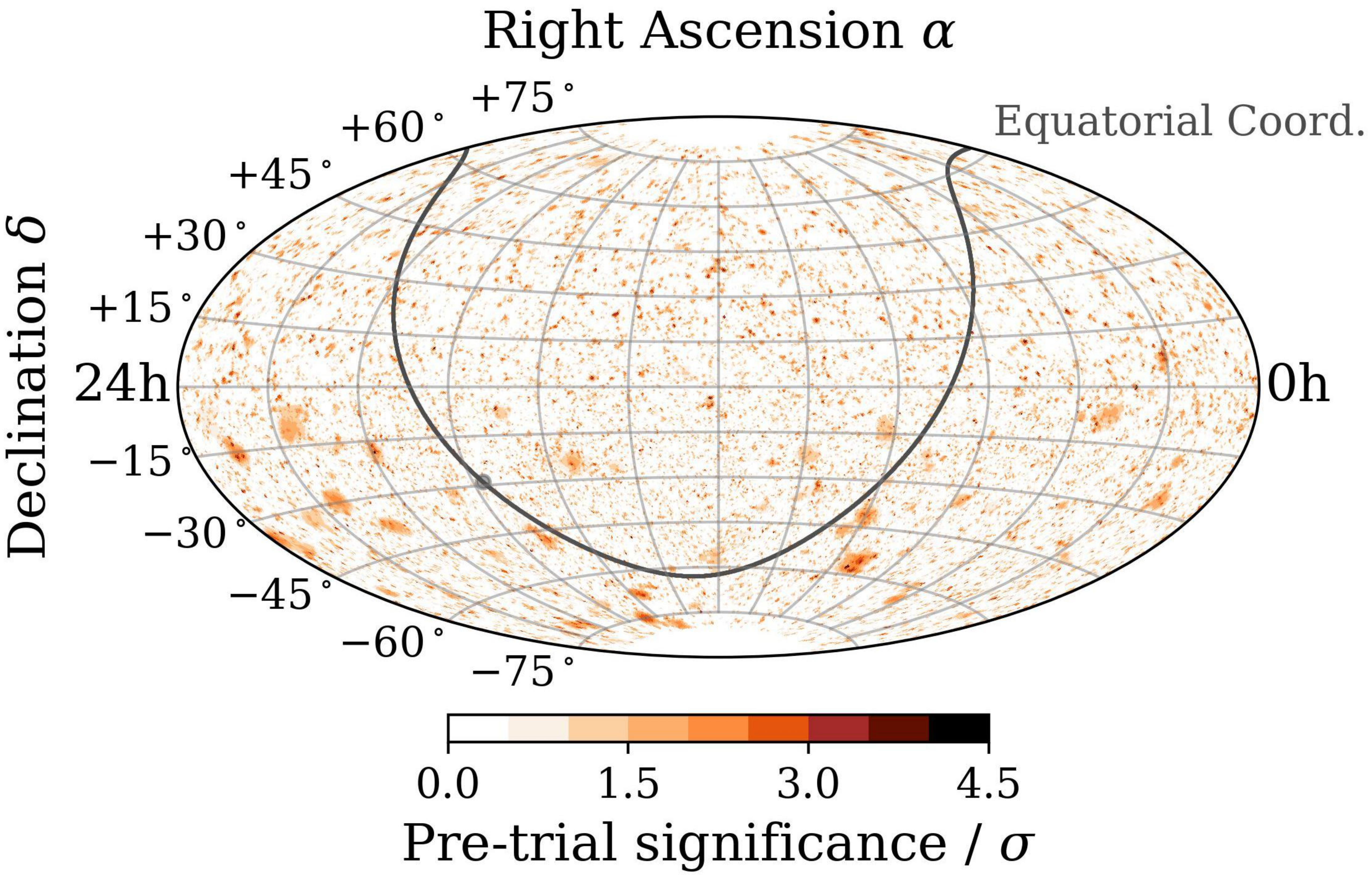

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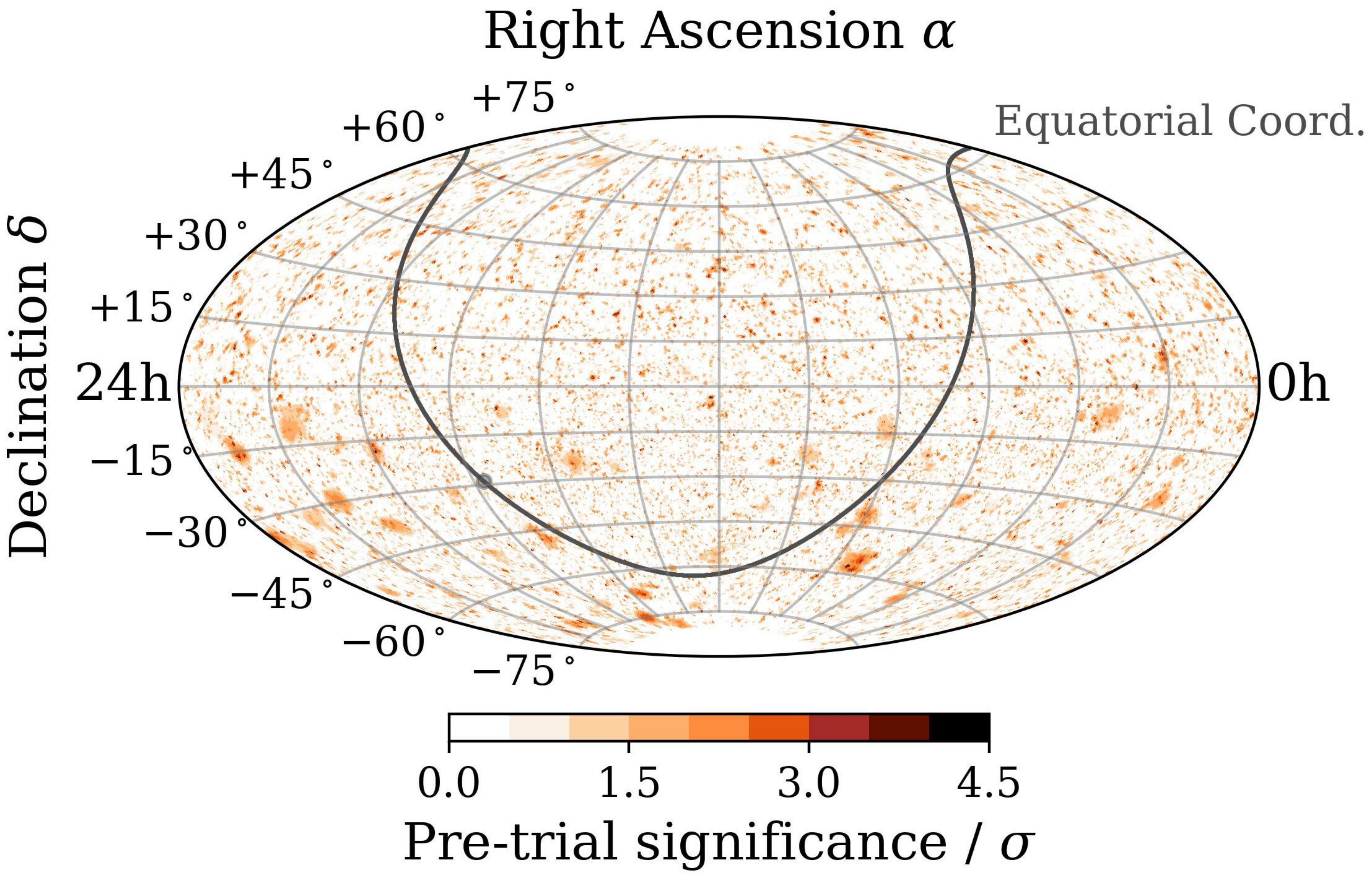

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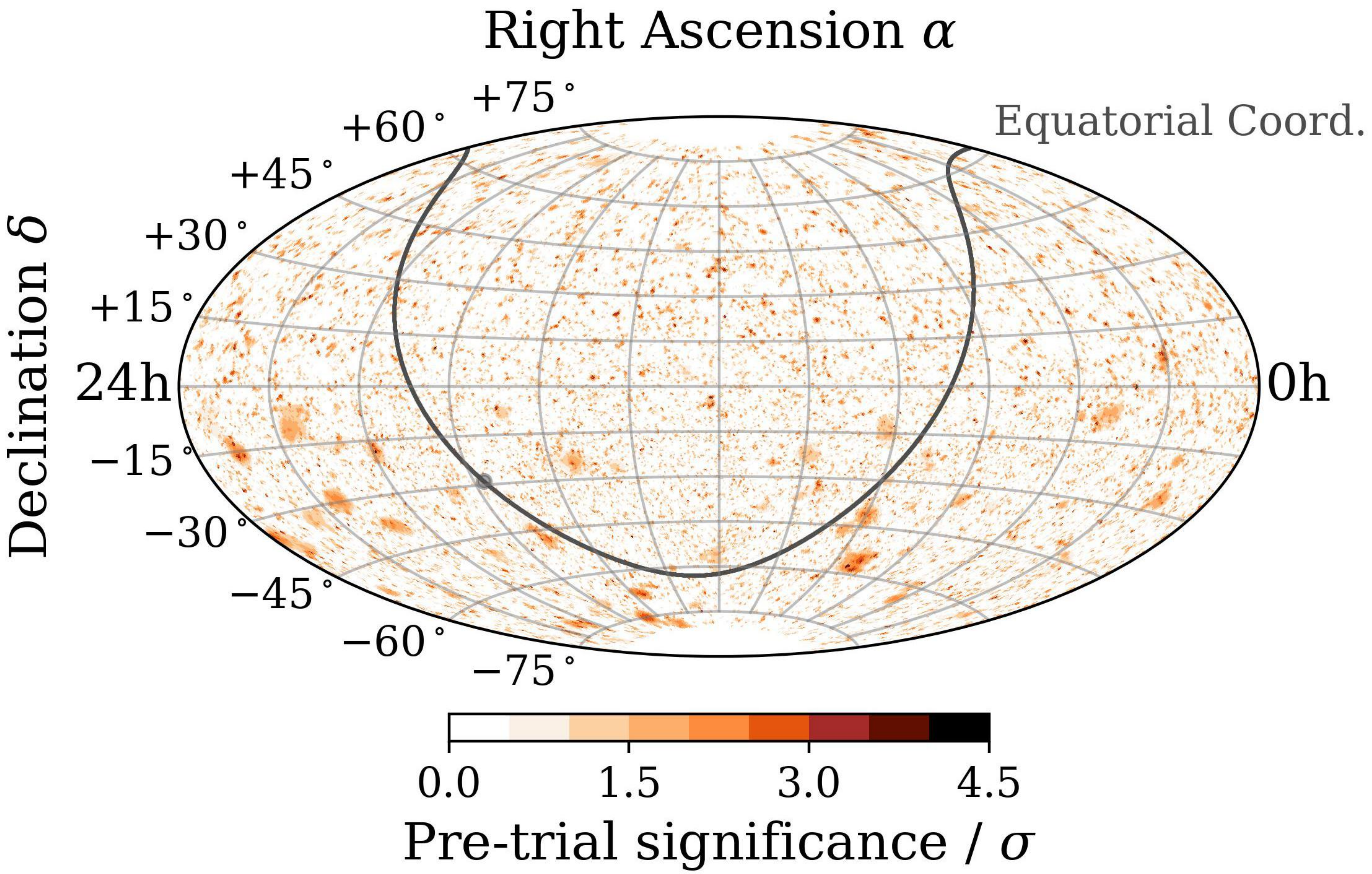

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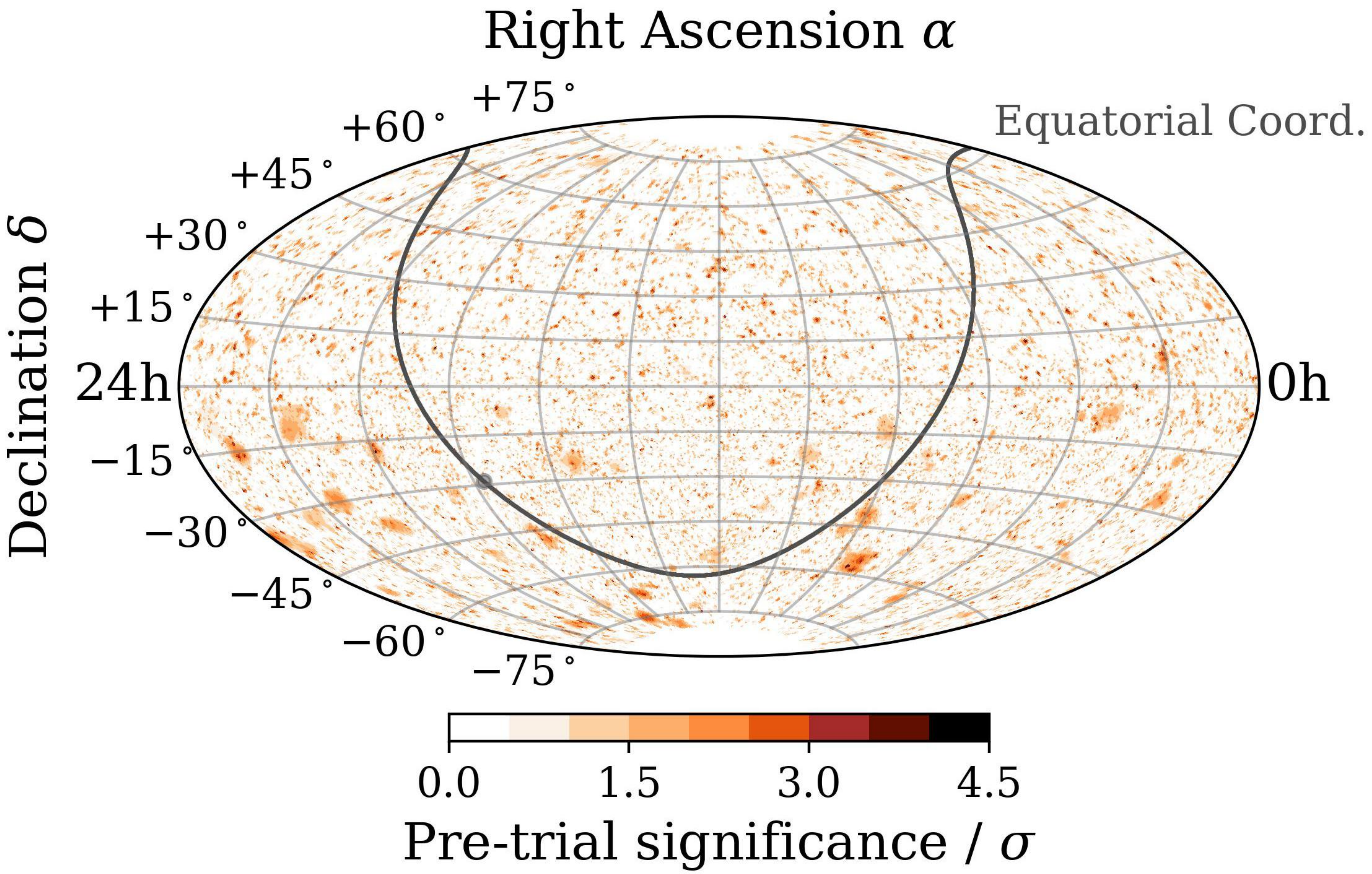
- Isotropic → extragalactic origin (mostly)
- Produced by a population of un-resolved sources
- Blazars and GRBs excluded as the main sources



Some directions are slightly more significant → nearly resolved sources?

IceCube coll. 2025, IceCube coll. Phys. Rev. D 110 (2024)

A diffuse flux from TeV to PeV

2025

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- More statistic and new selection of events (ESTE → MESE)

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  → Best fitted by BPL at 4.7 σ or log parabola at 4.2 σ
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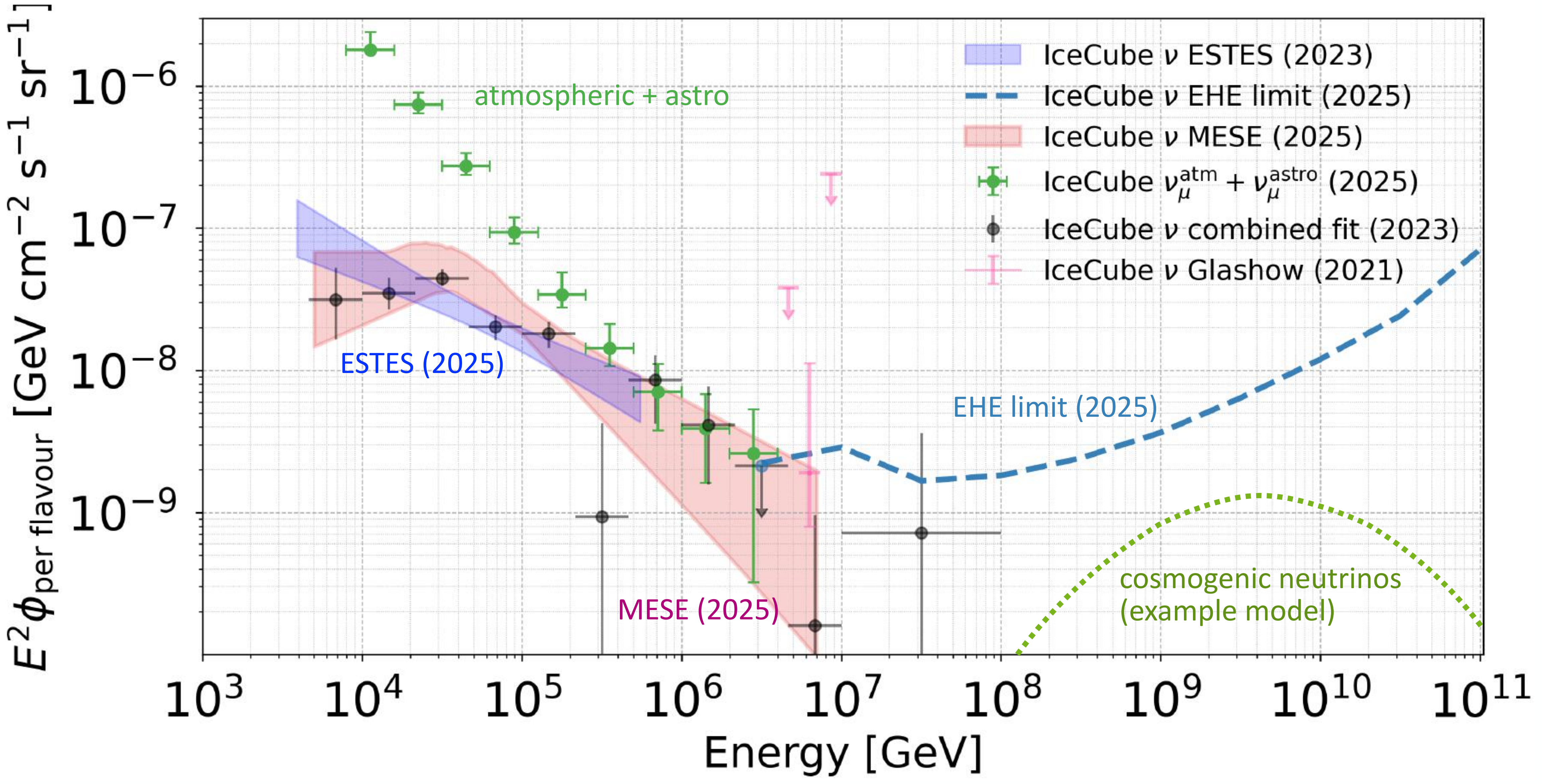

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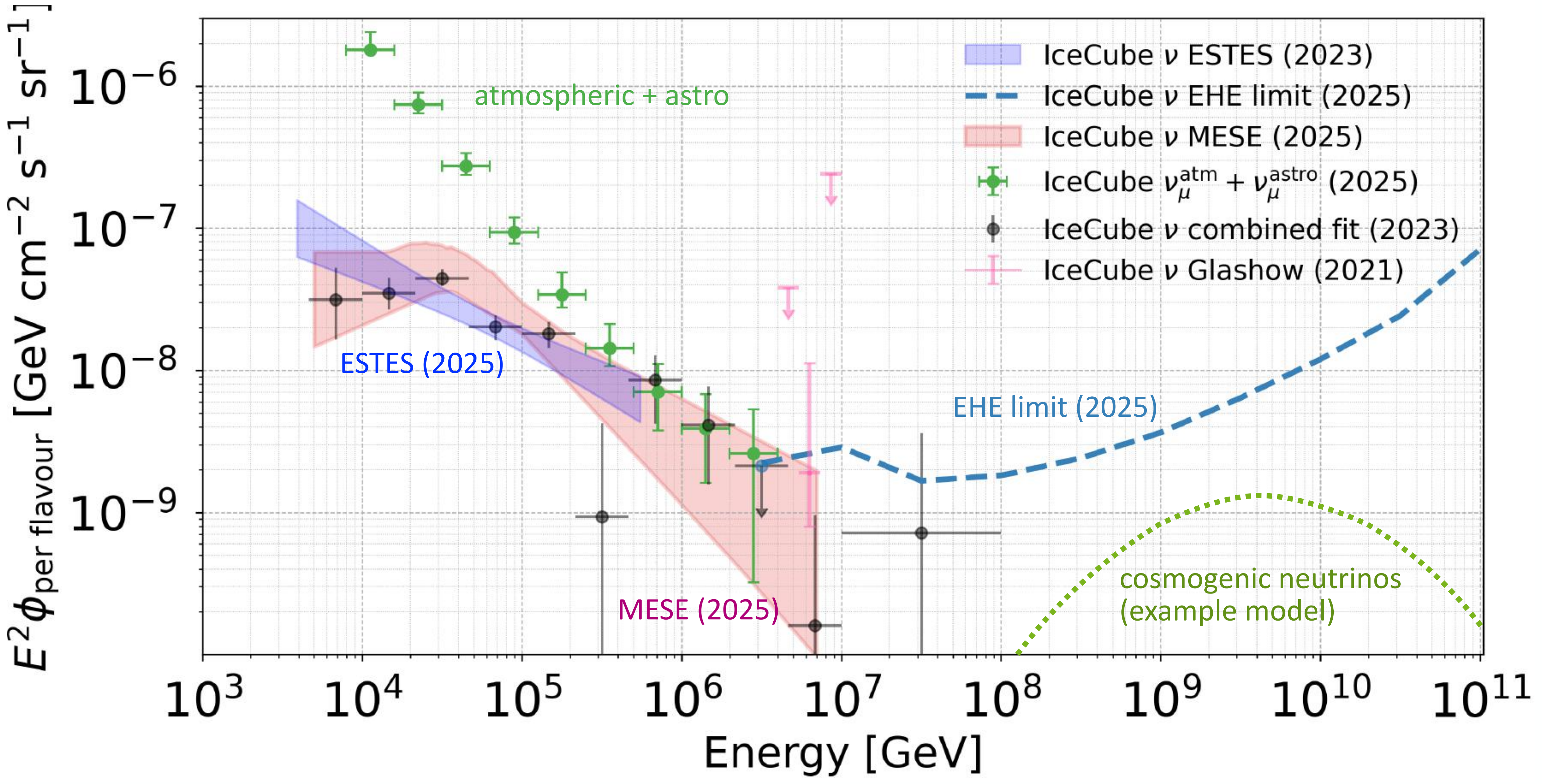

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  - Pion beam and muon damp mechanisms → compatible (68% C.L.)
  - However pion beam favoured over muon damp
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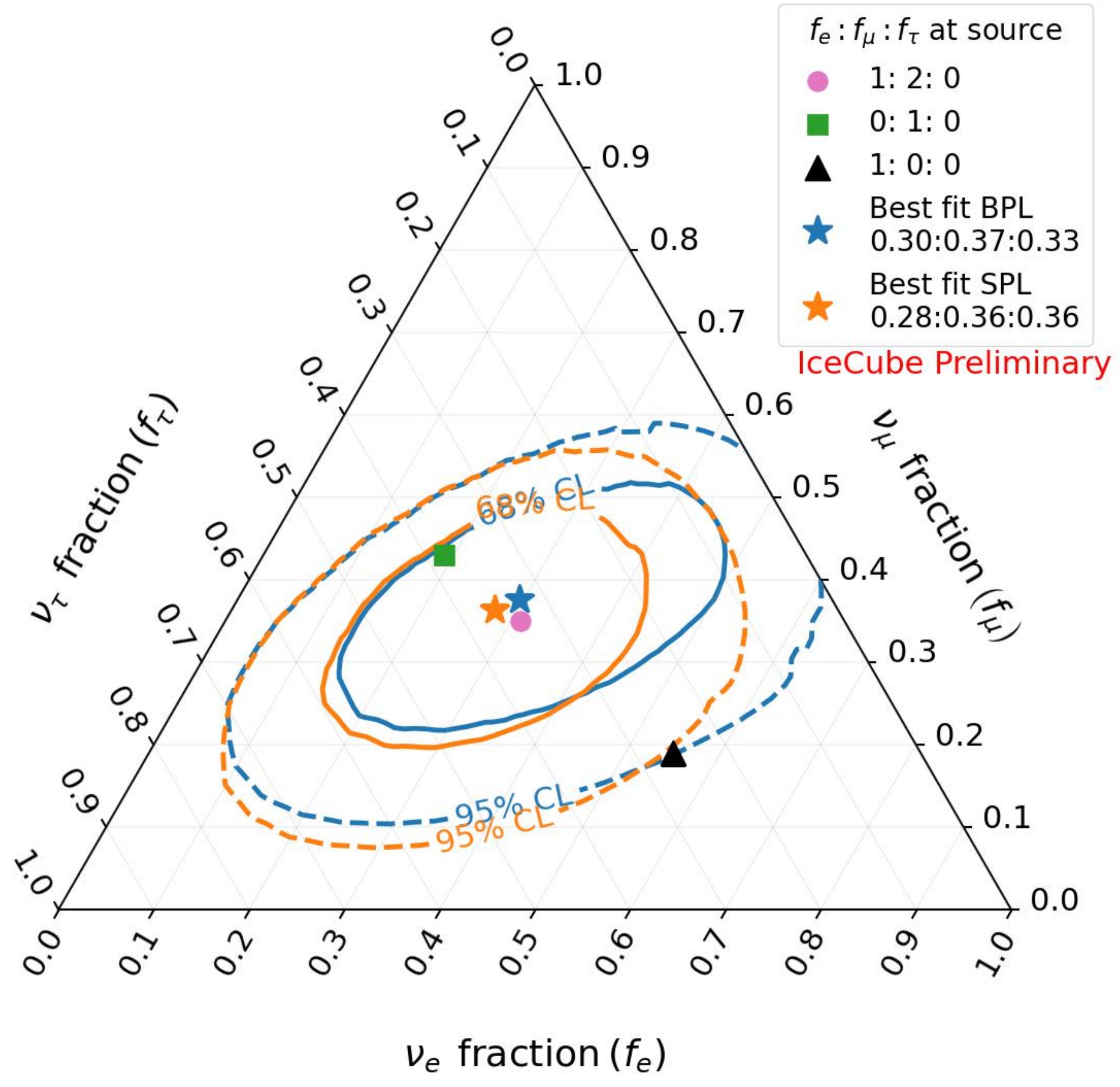

ICRC2025(983, 985, 1011, 1199 +Alexander KAPPES highlight talk)

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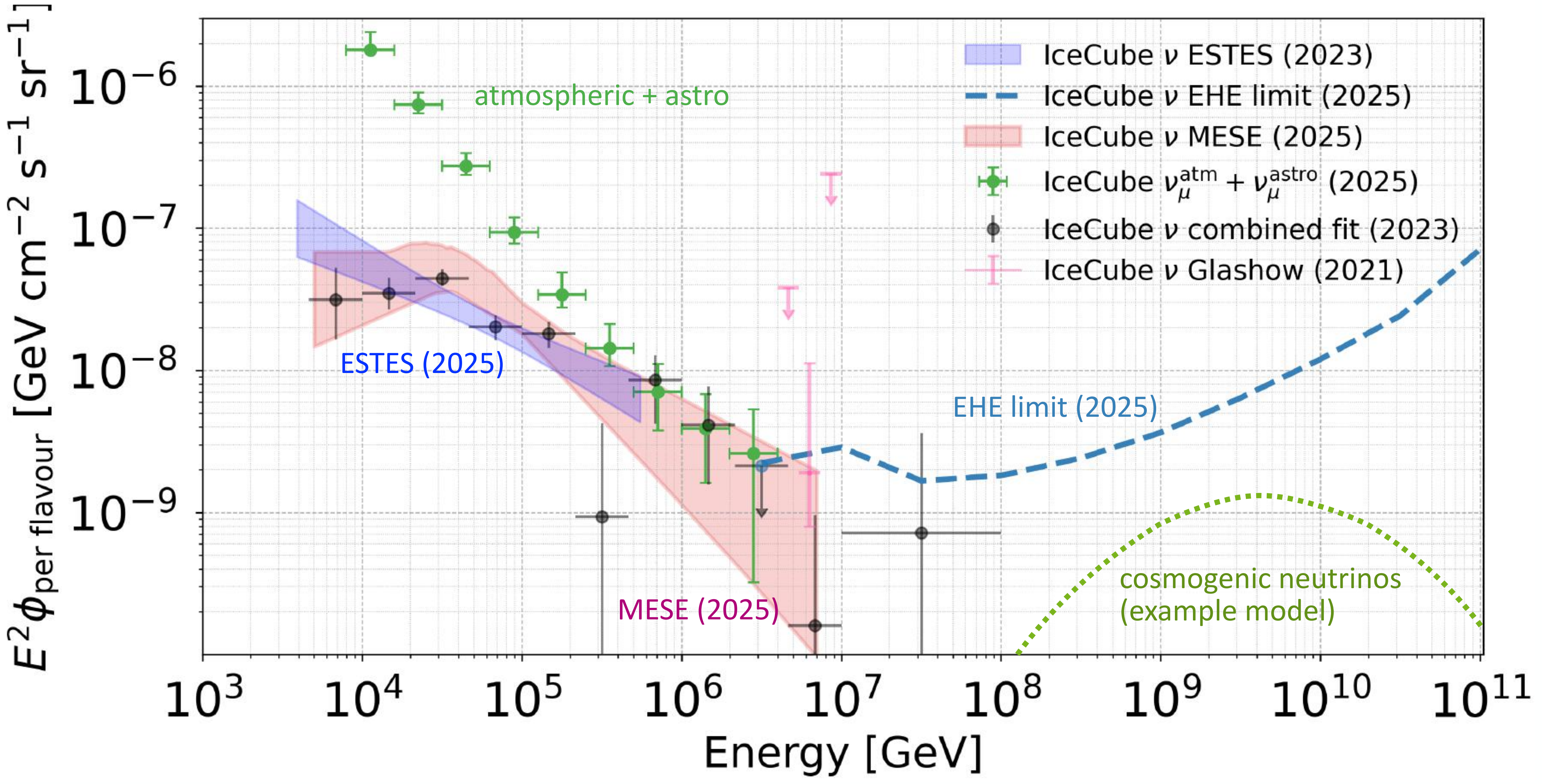

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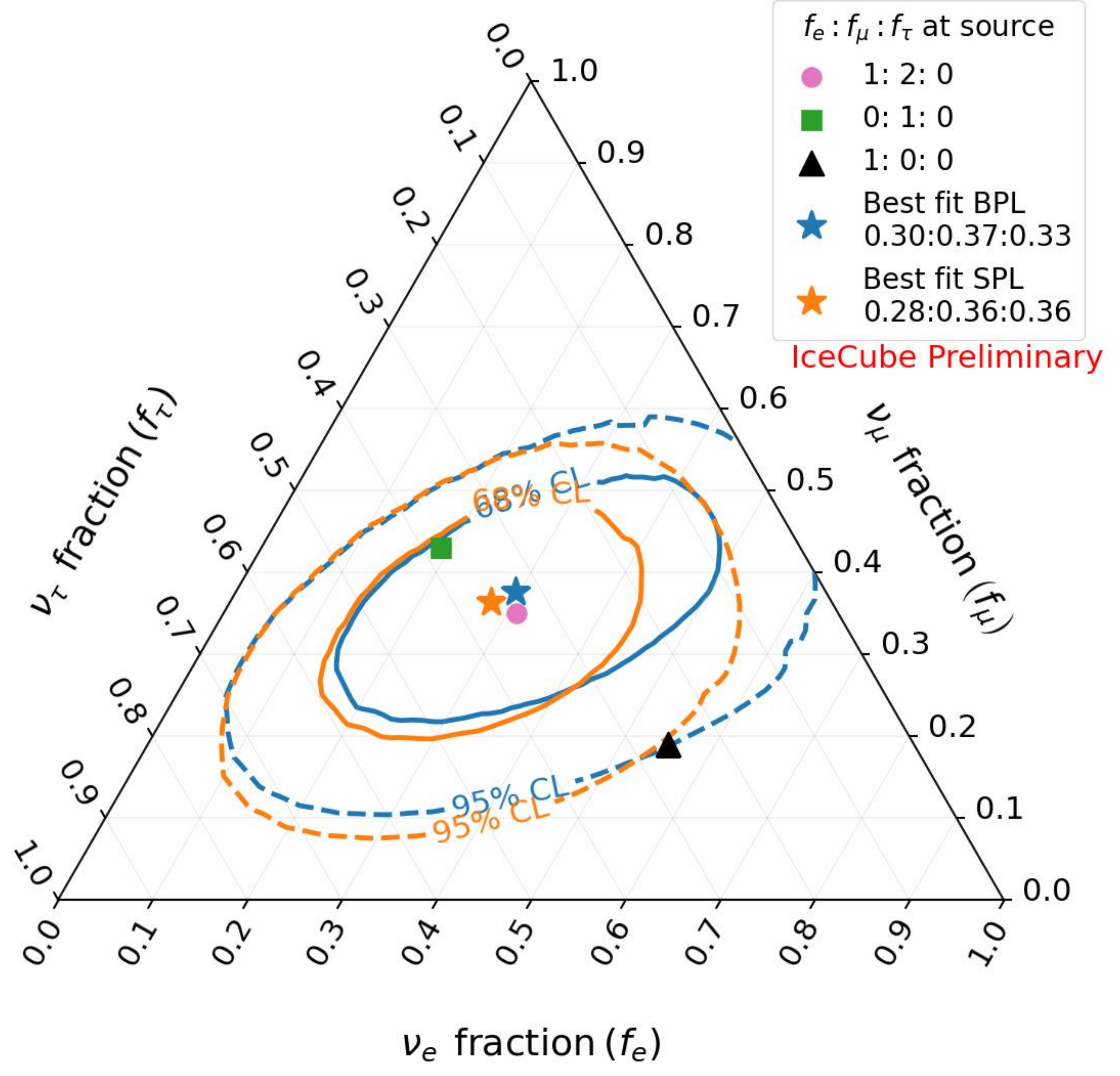

The sources of the diffuse neutrino flux remain unknown

ICRC2025(983, 985, 1011, 1199 +Alexander KAPPES highlight talk)

A transient source: TXS0506+056

IceCube coll. et al., Science 361, 146 (2018)

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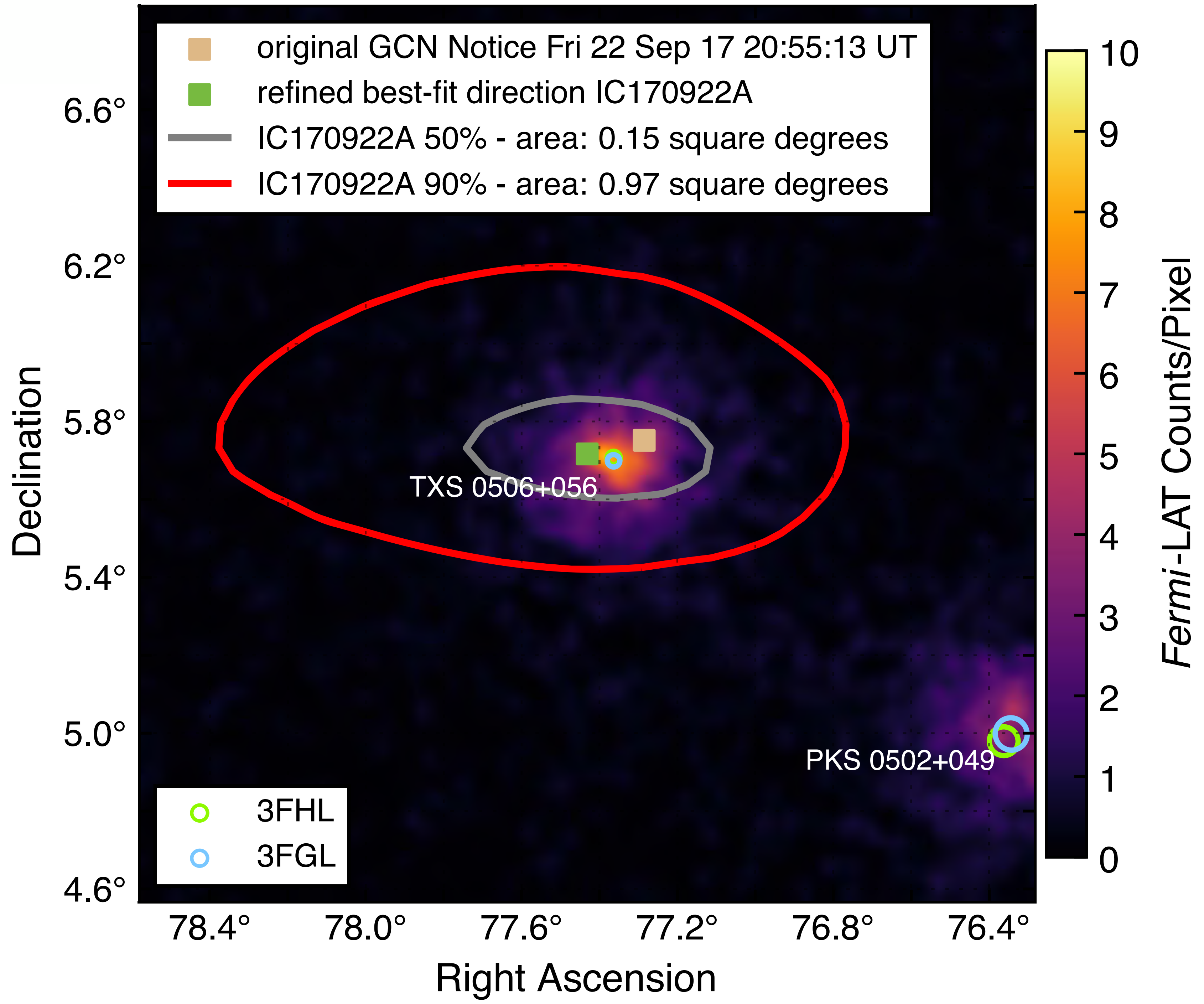
2018

- Detection of a neutrino event in coincidence with a blazar flare



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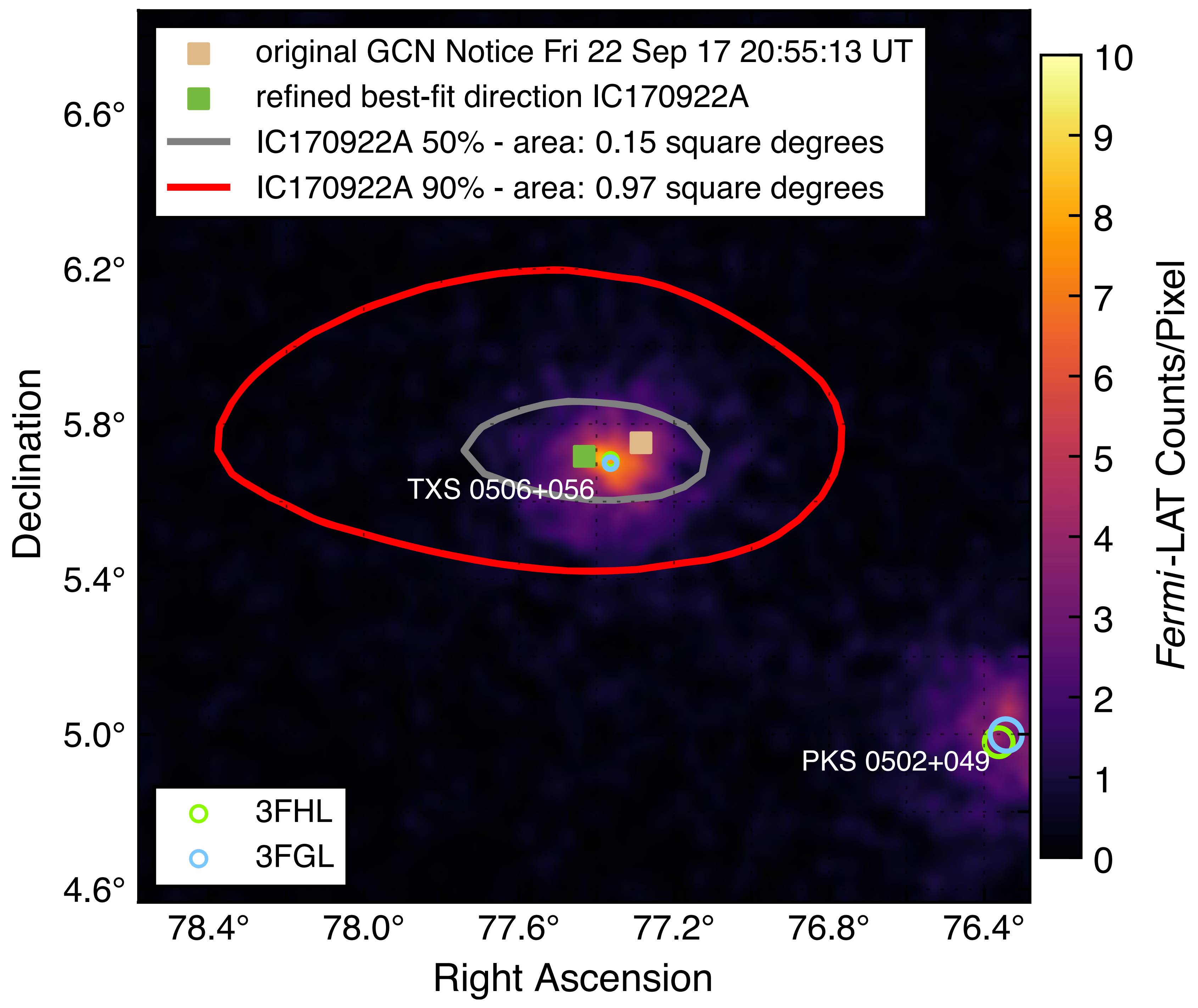

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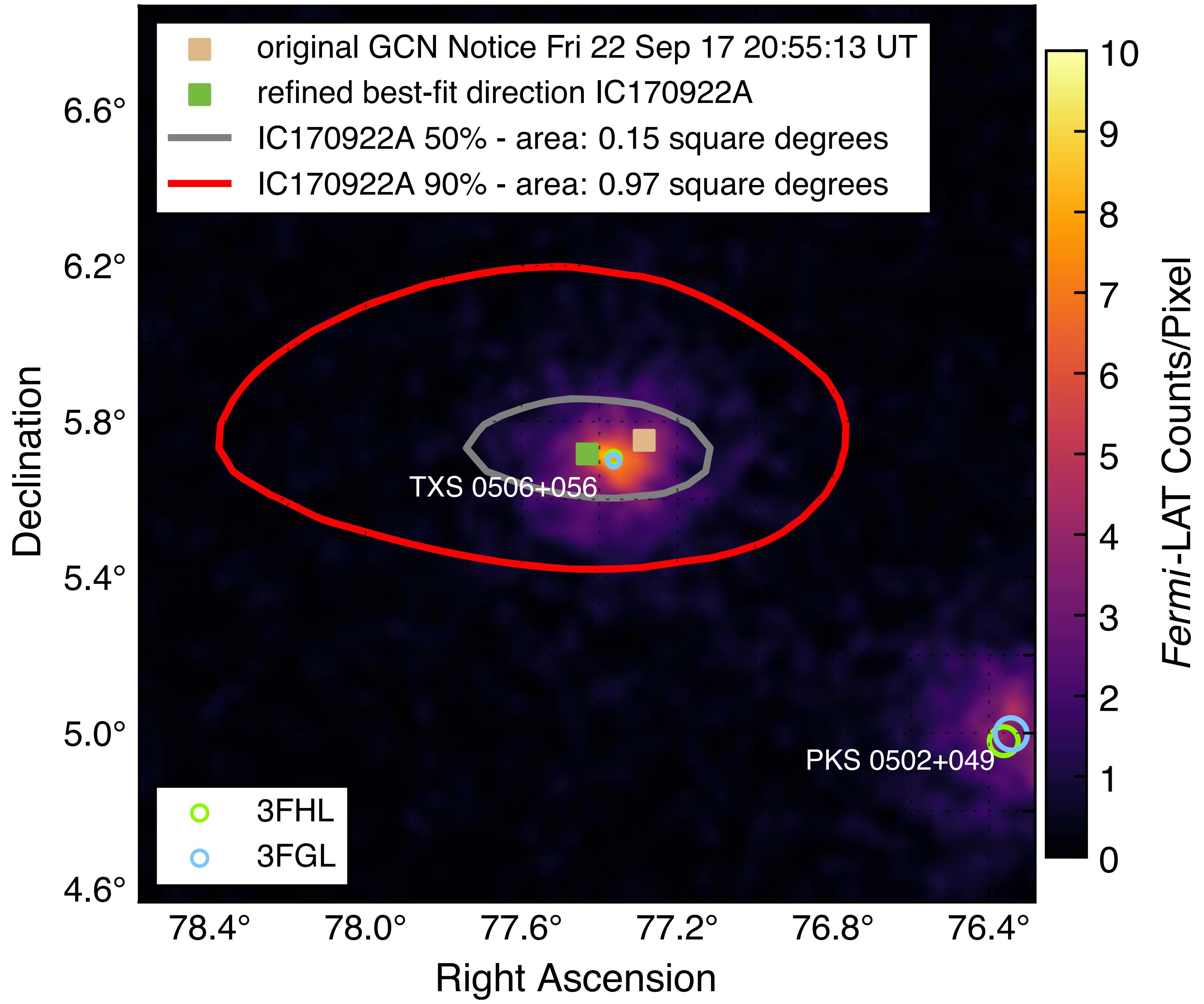

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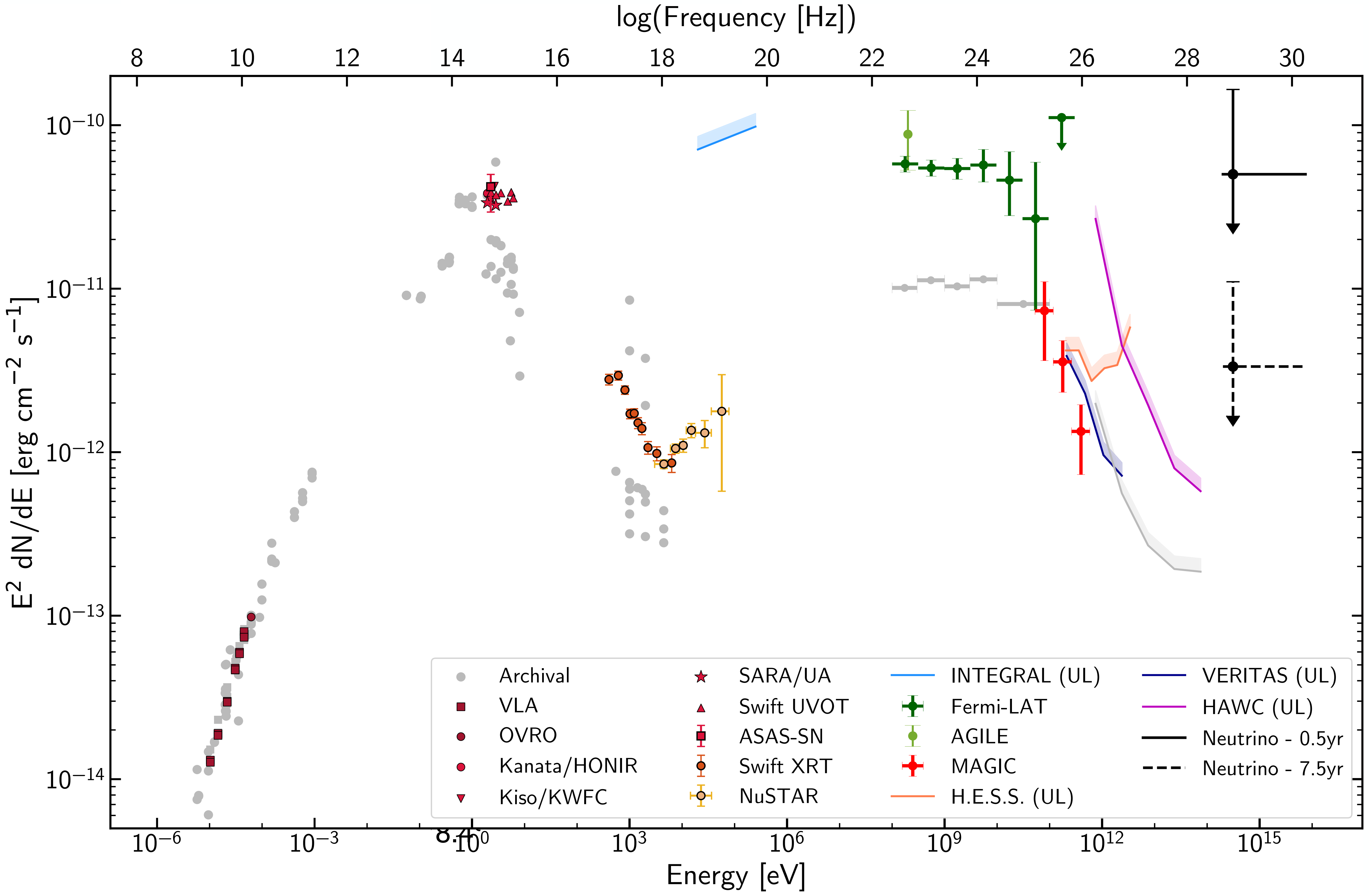

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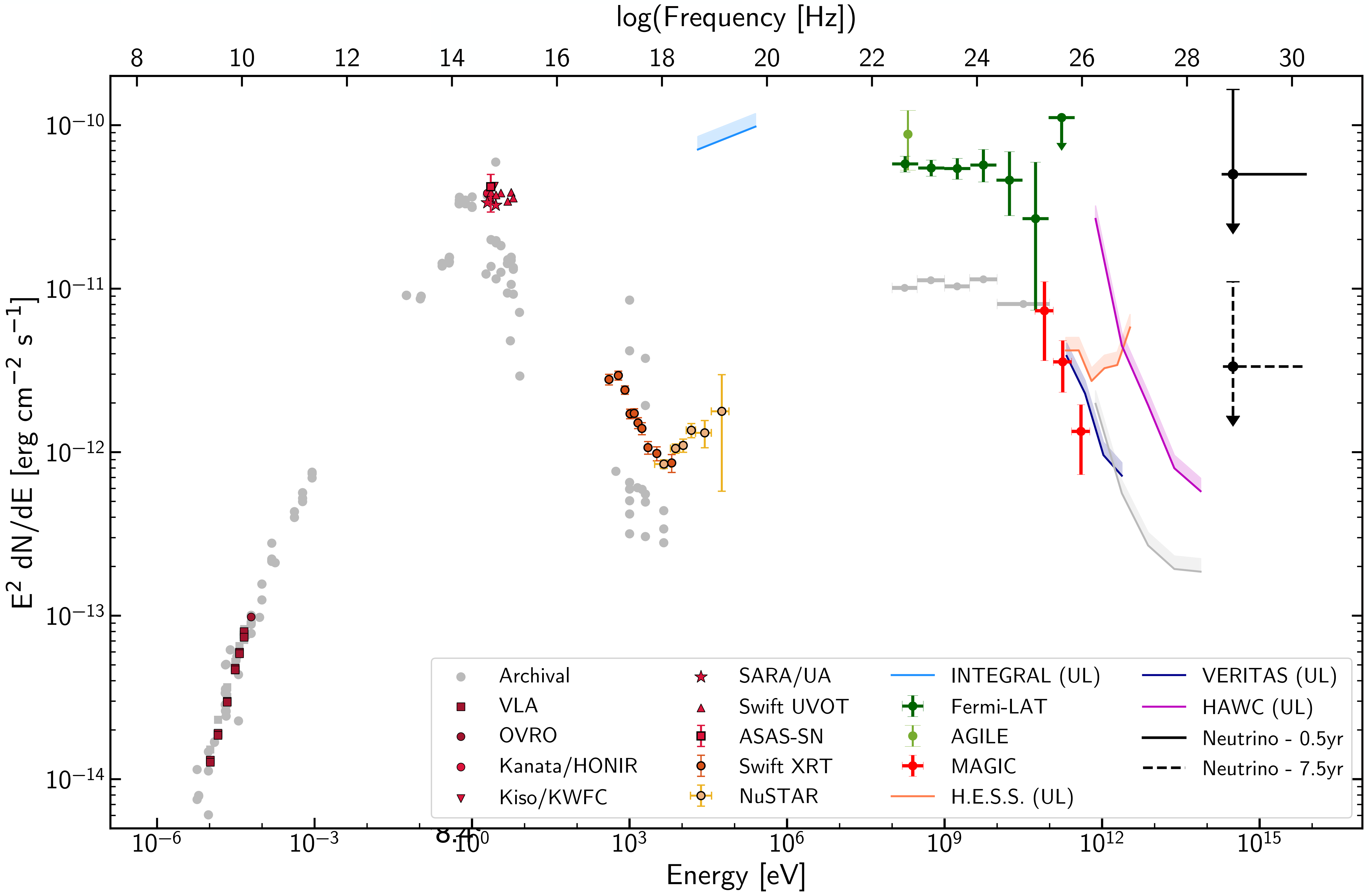

Wether or not the neutrino event is associated to the gamma-ray events
it has shown the importance of multi-messenger alerts

IceCube coll. et al., Science 361, 146 (2018)

A steady source: NGC1068

IceCube Coll., Science 378 (2022)

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- Discovery of a neutrino excess in the direction of the AGN NGC1068 (M77)

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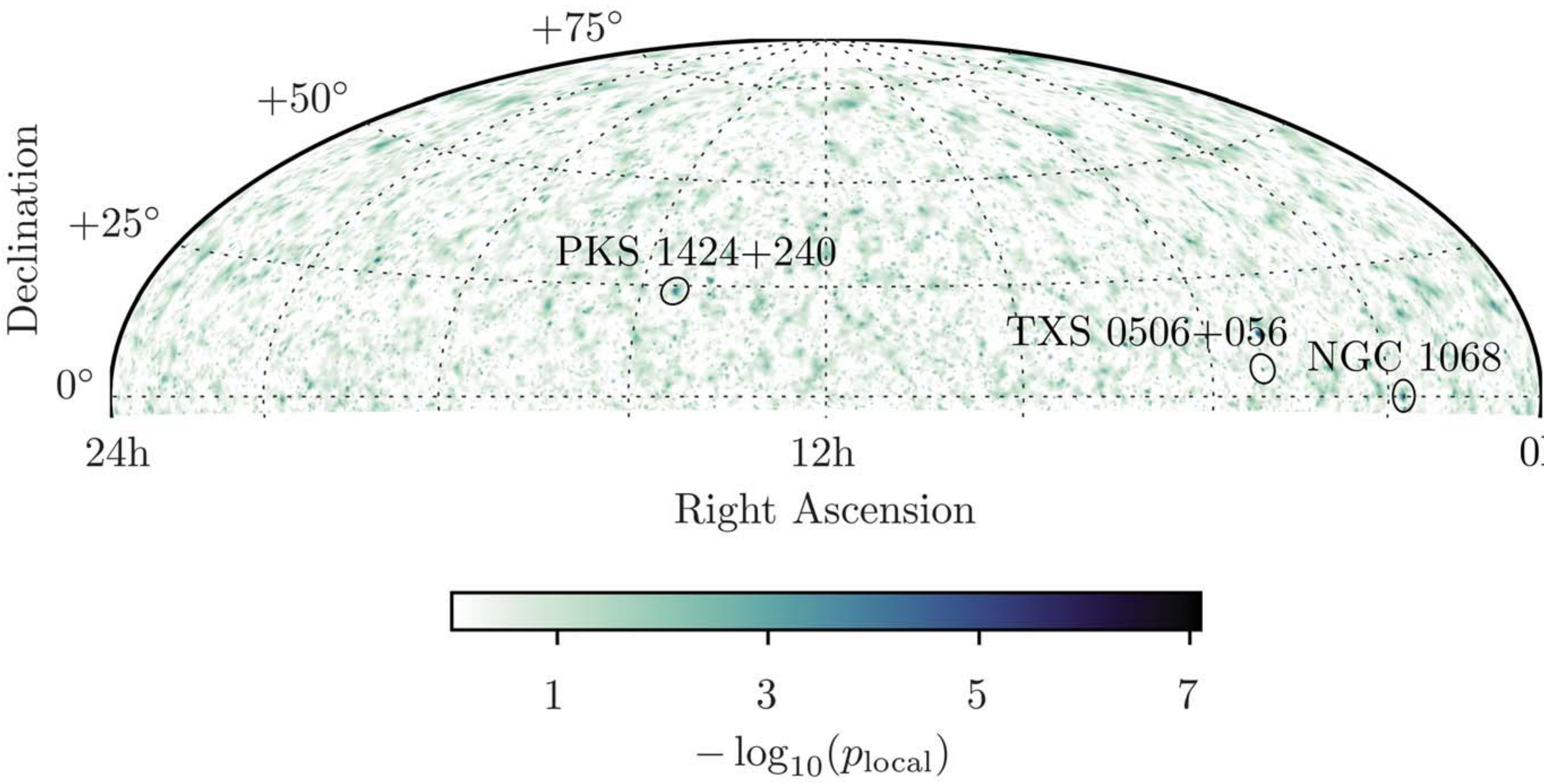

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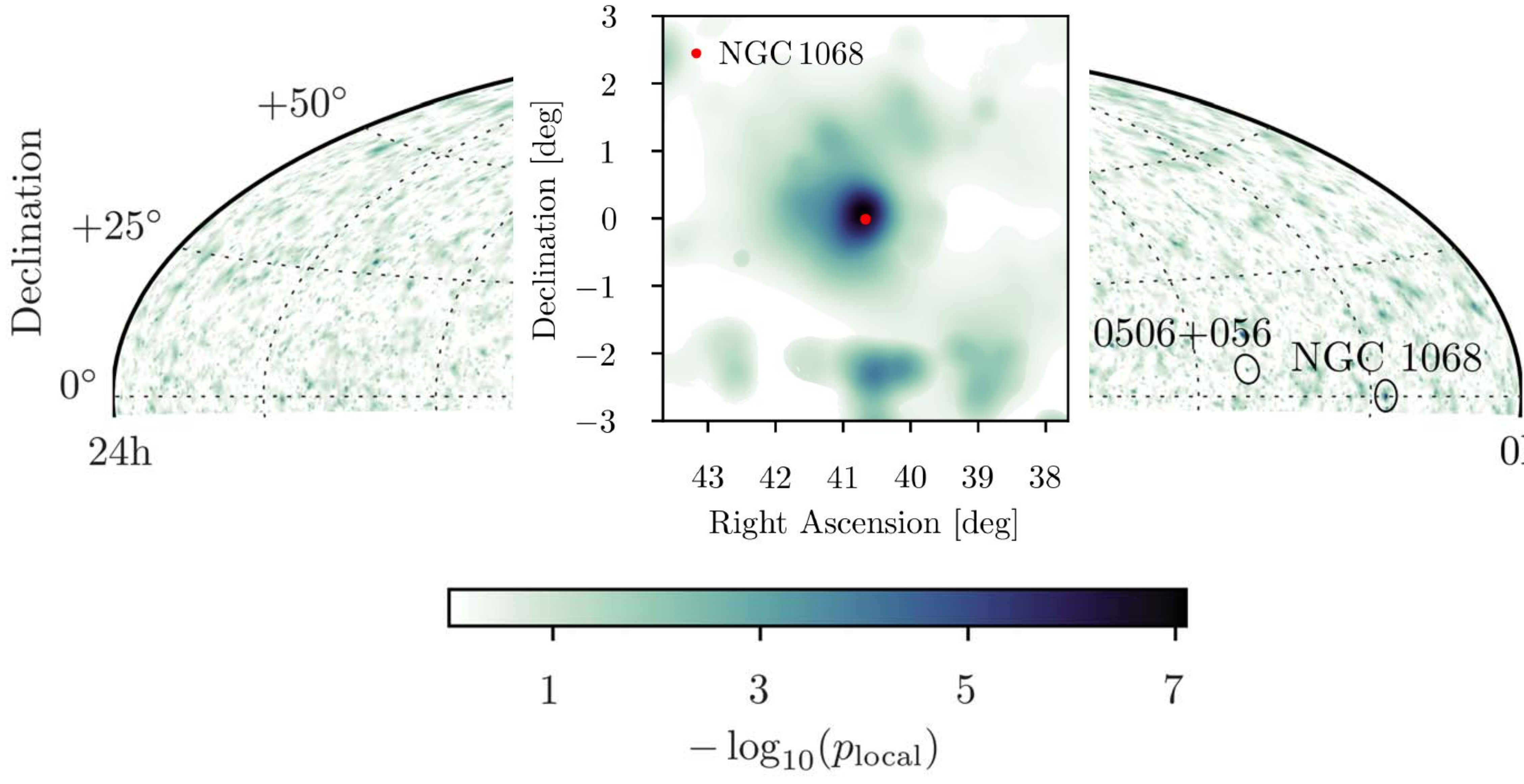

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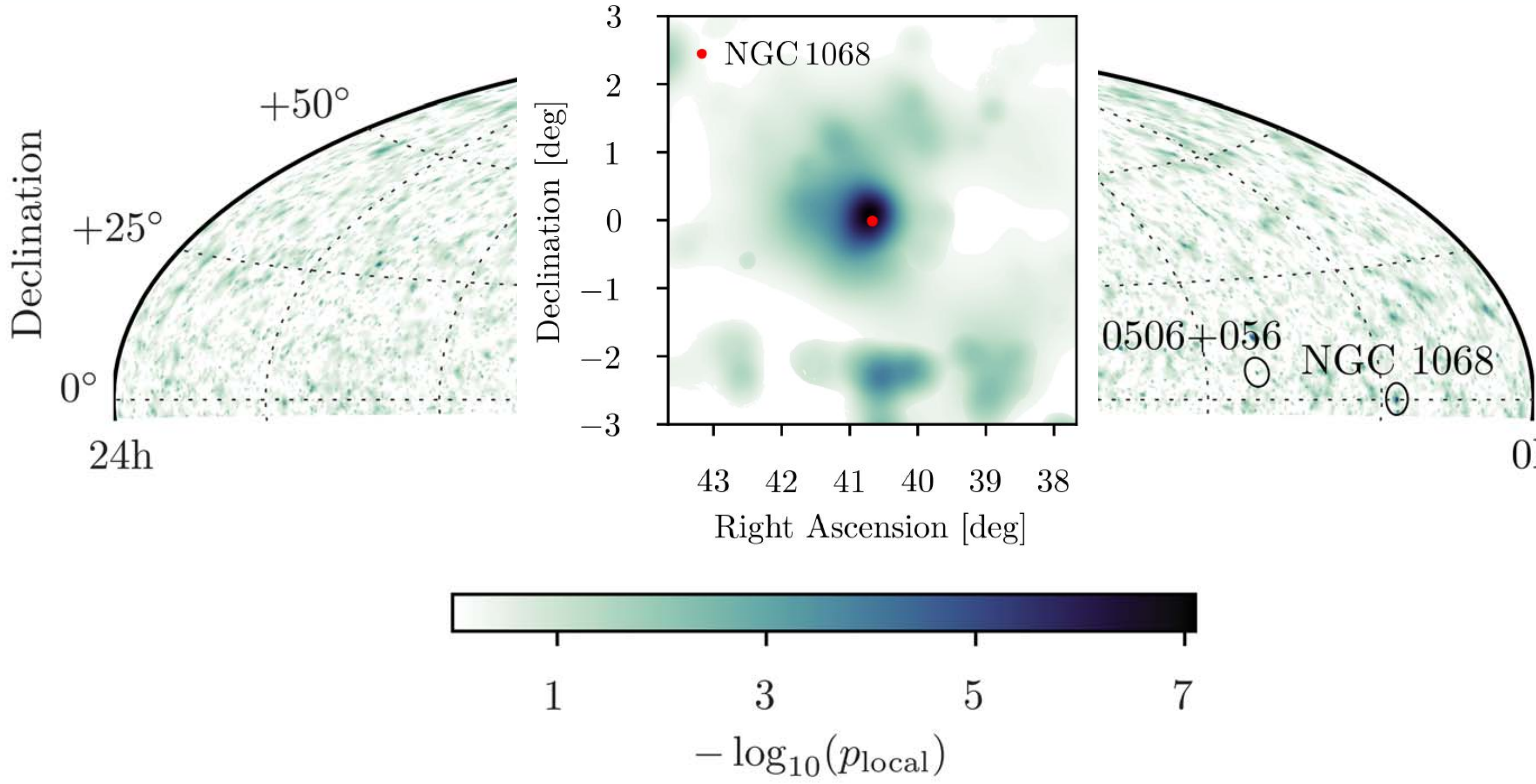
  - → Suggests an opaque environment around the source



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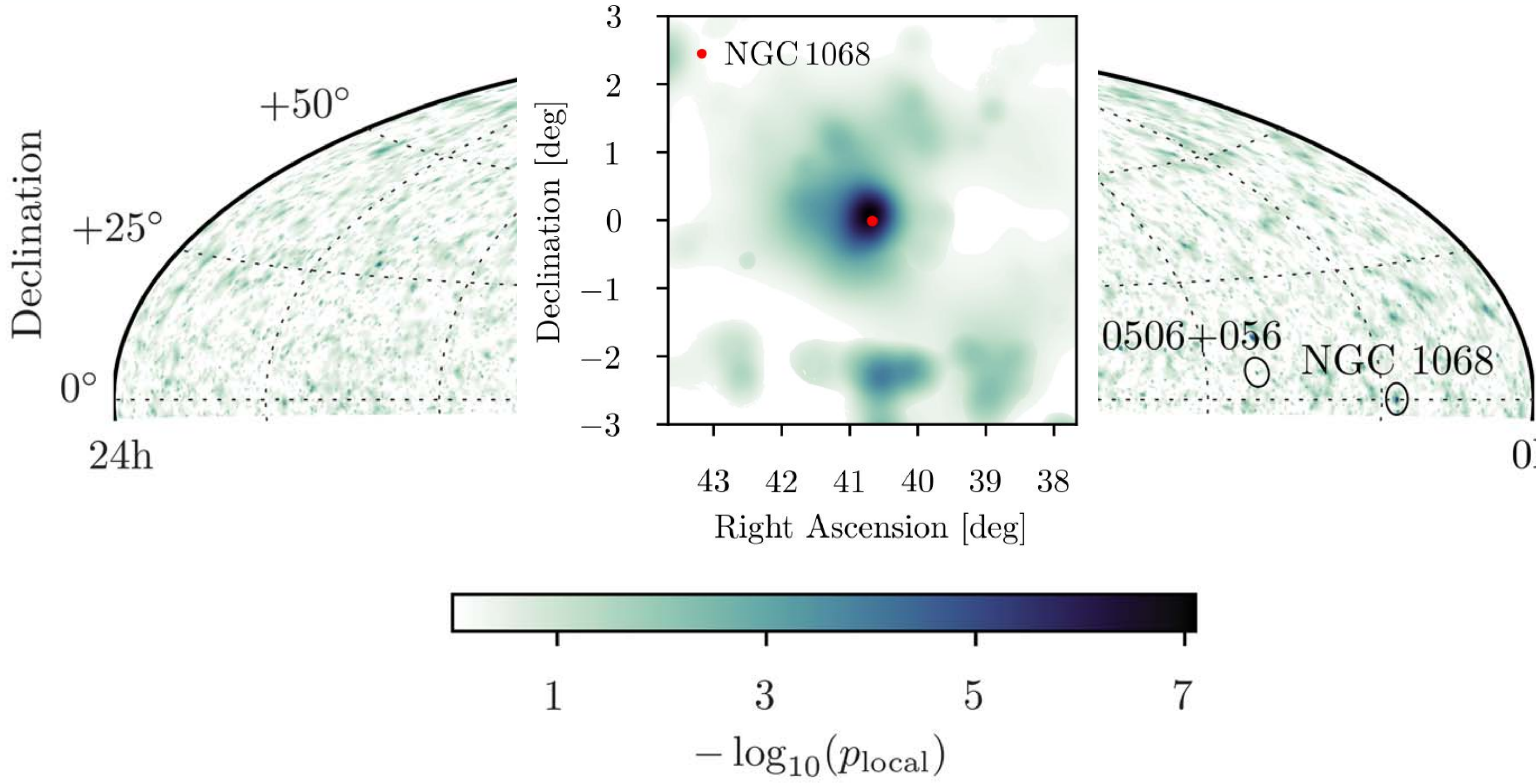
- What causes the opacity (BH, absorption, …) is still unclear



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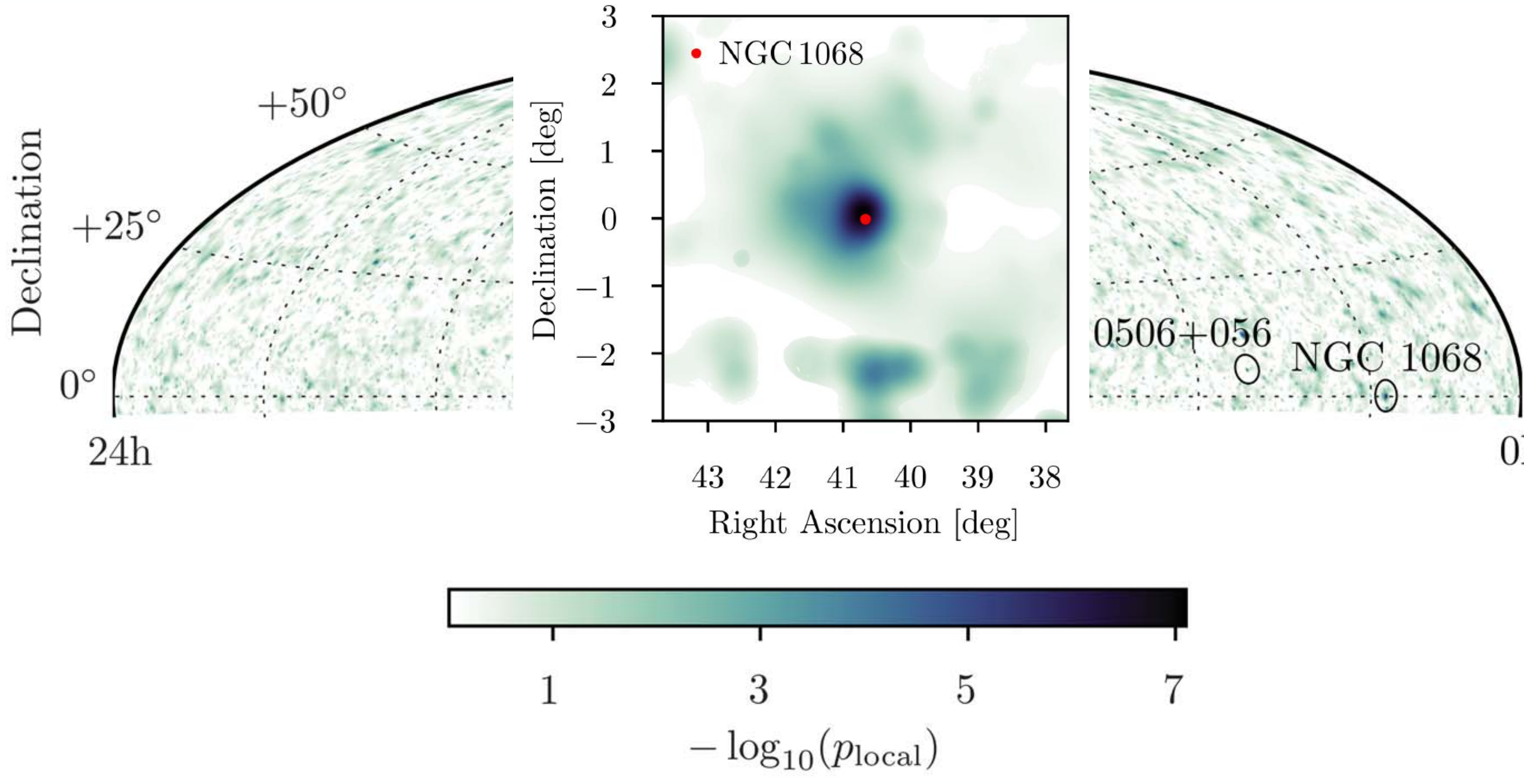

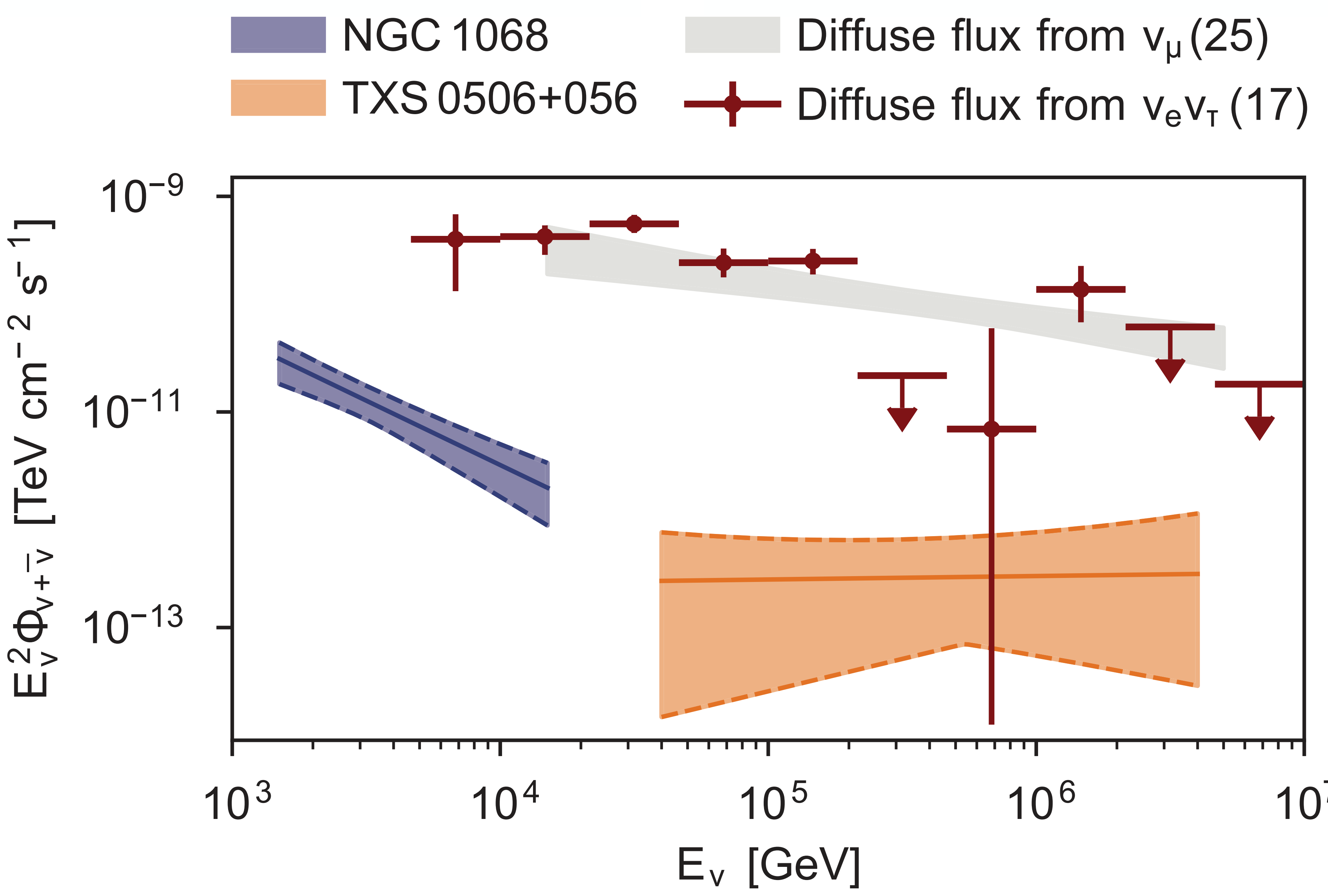

The first clearly identified source is a Seyfert II galaxy with very different properties than TXS0506+056

IceCube Coll., Science 378 (2022)

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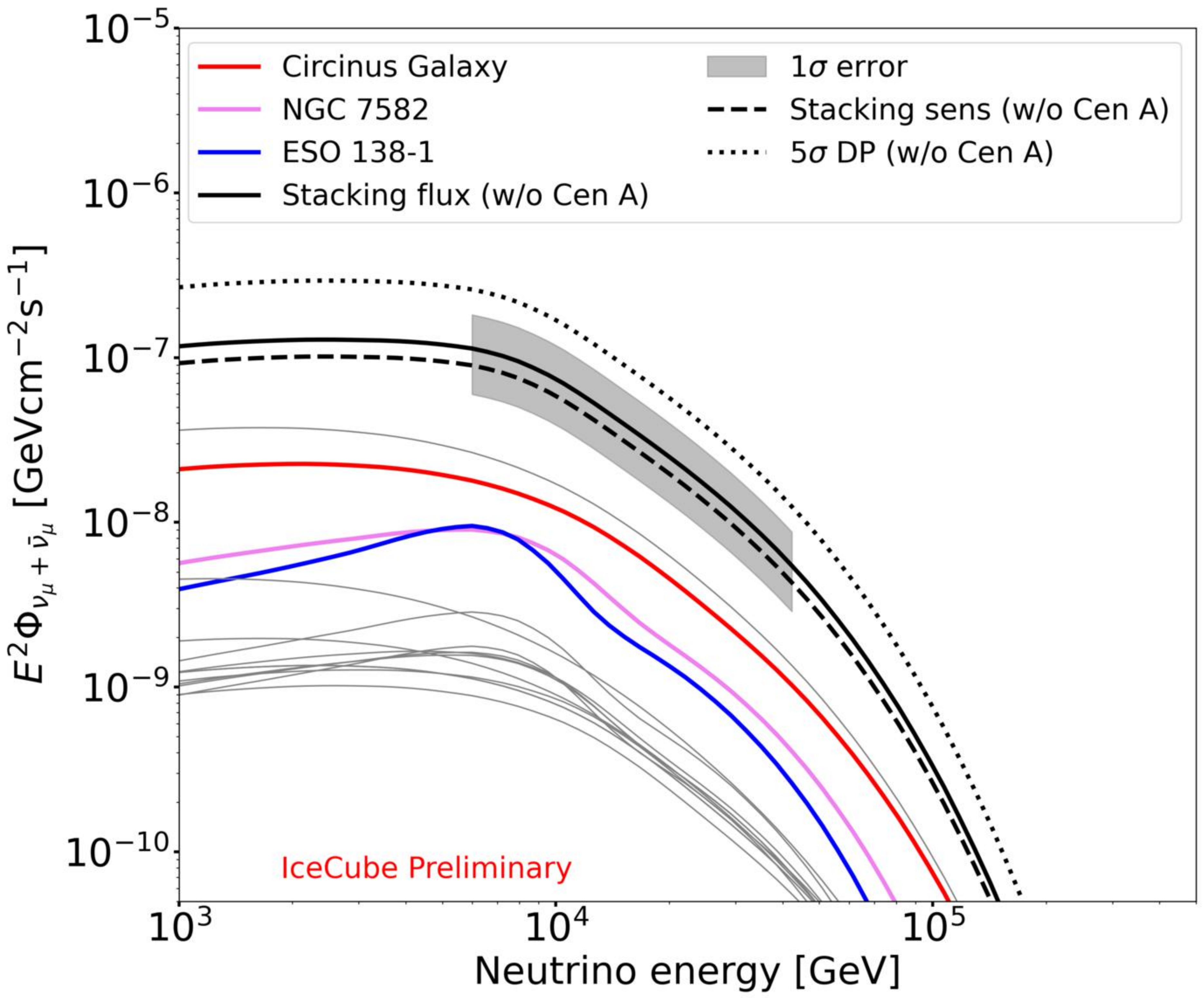
2025

- Stacking analysis on Seyfert galaxy catalogs → ~ 3 σ



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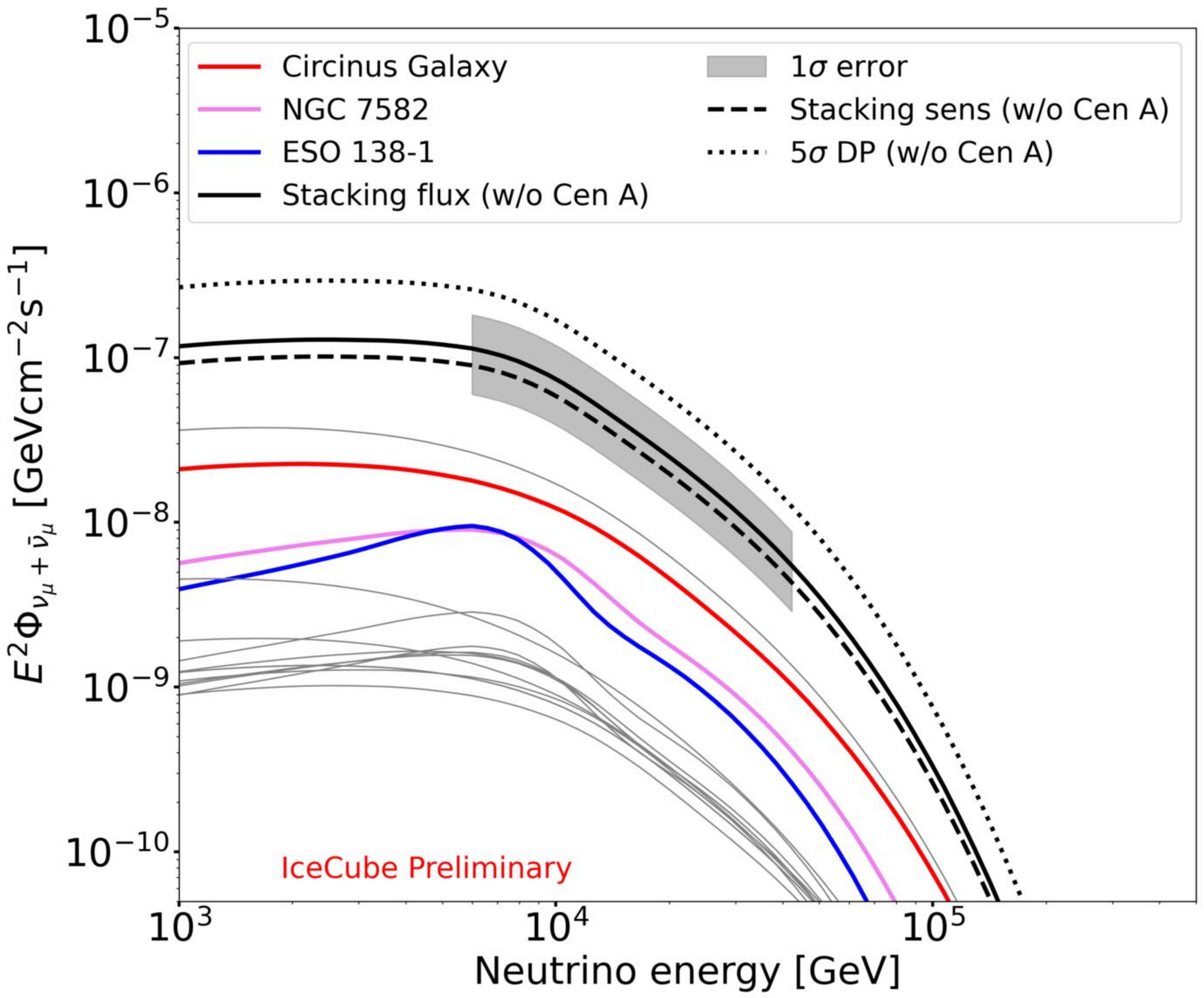

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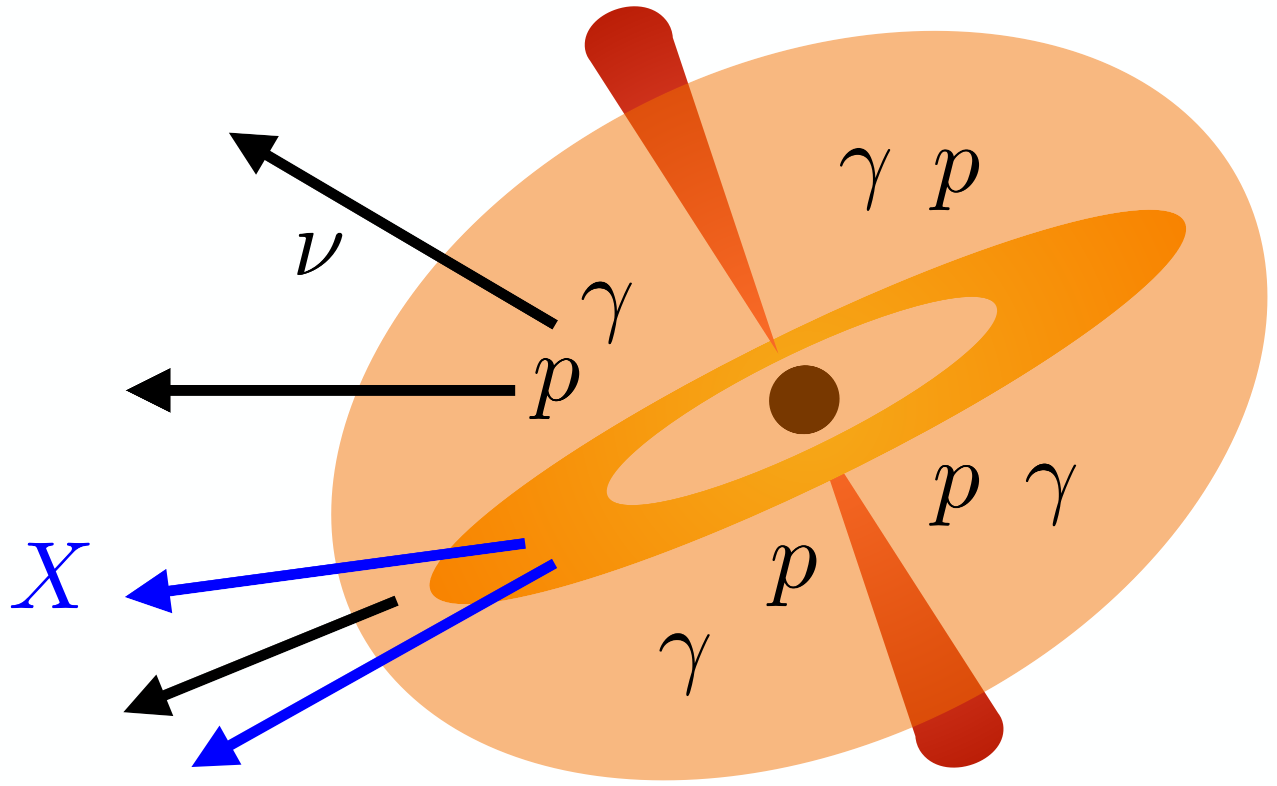

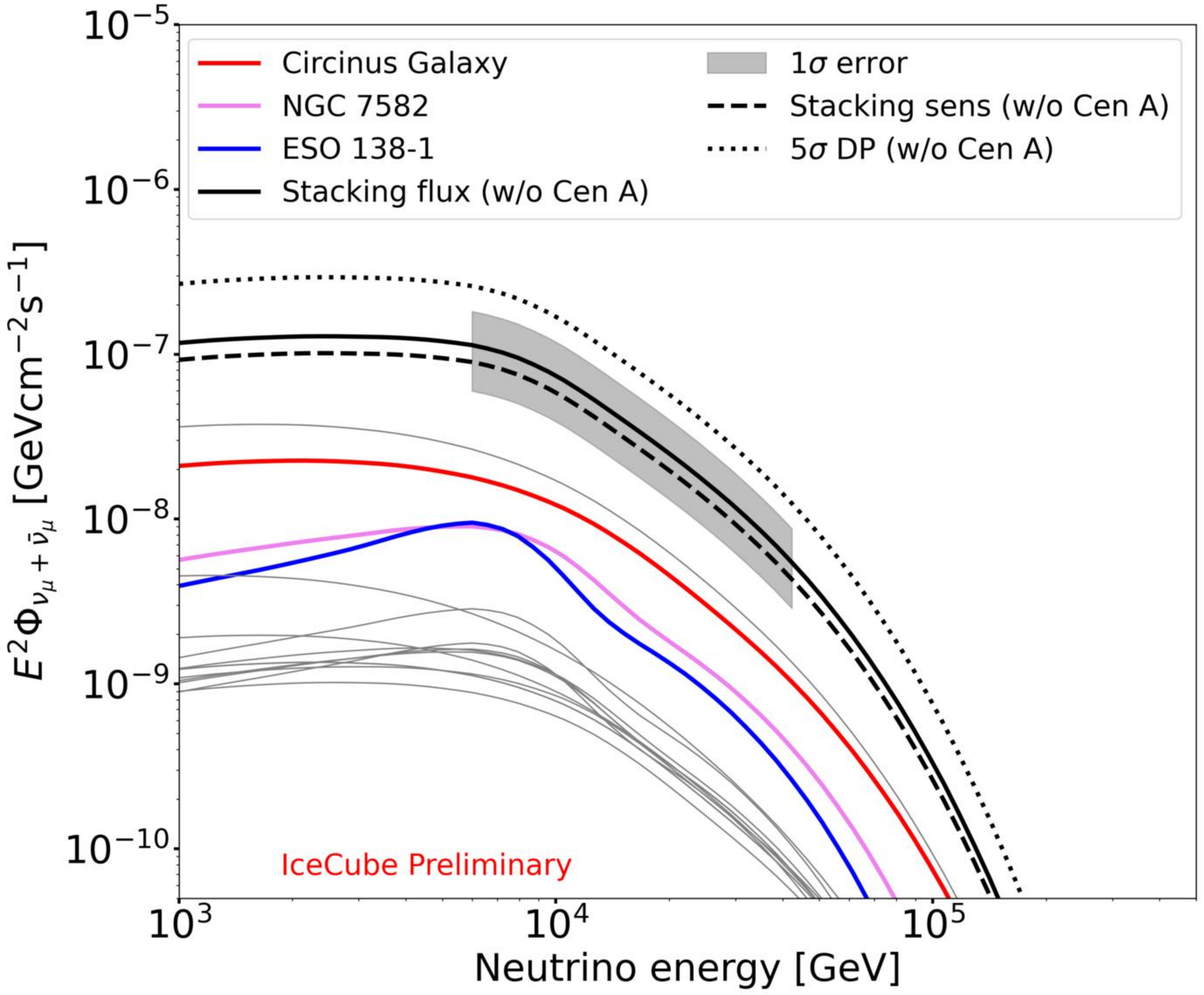

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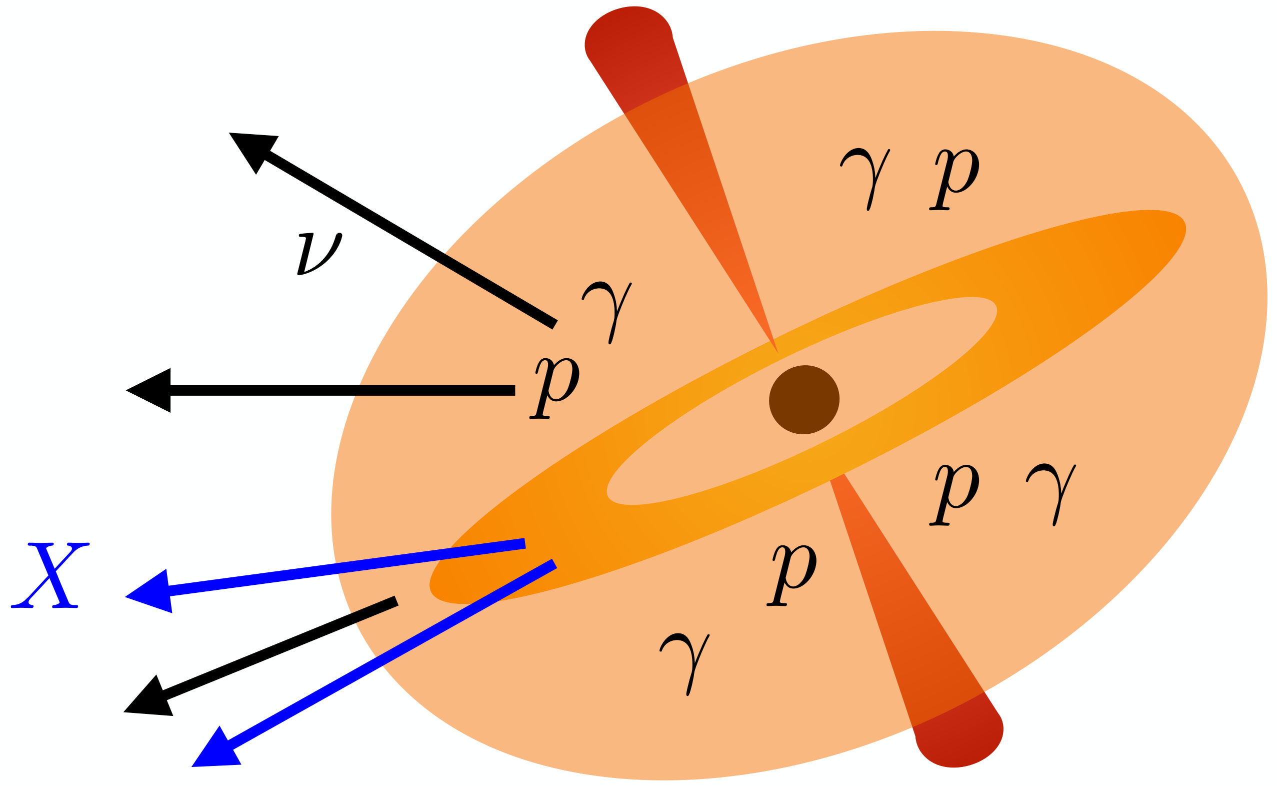

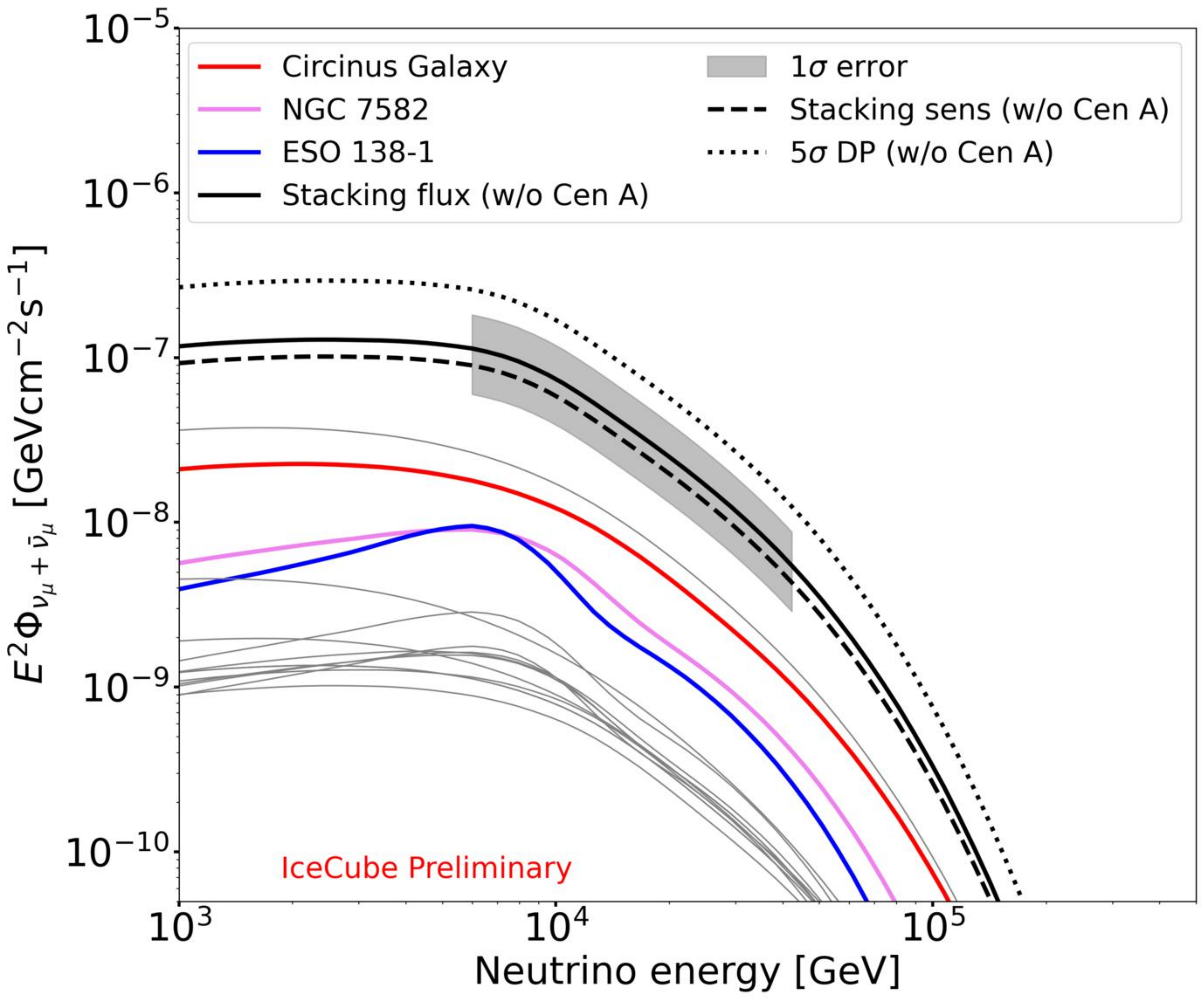

Obscured AGNs seem to play a significant role in the origin of the diffuse HE neutrino flux

A “local” source: the Galactic plane

IceCube coll. Science 2023

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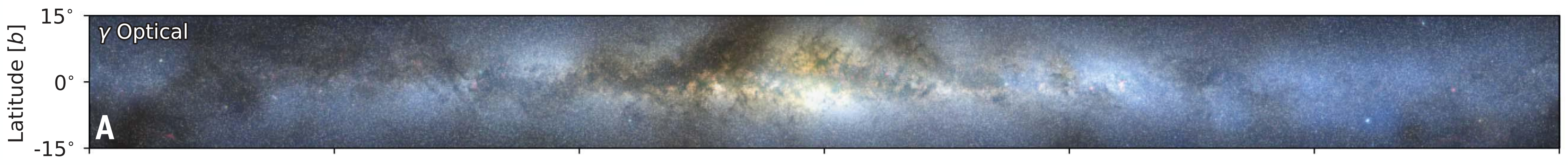
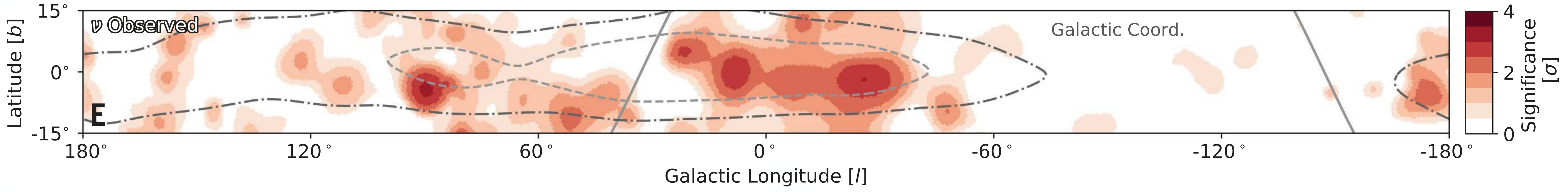
2023

- Identification of a neutrino contribution from the Galactic Plane (~ 4.5 σ)!





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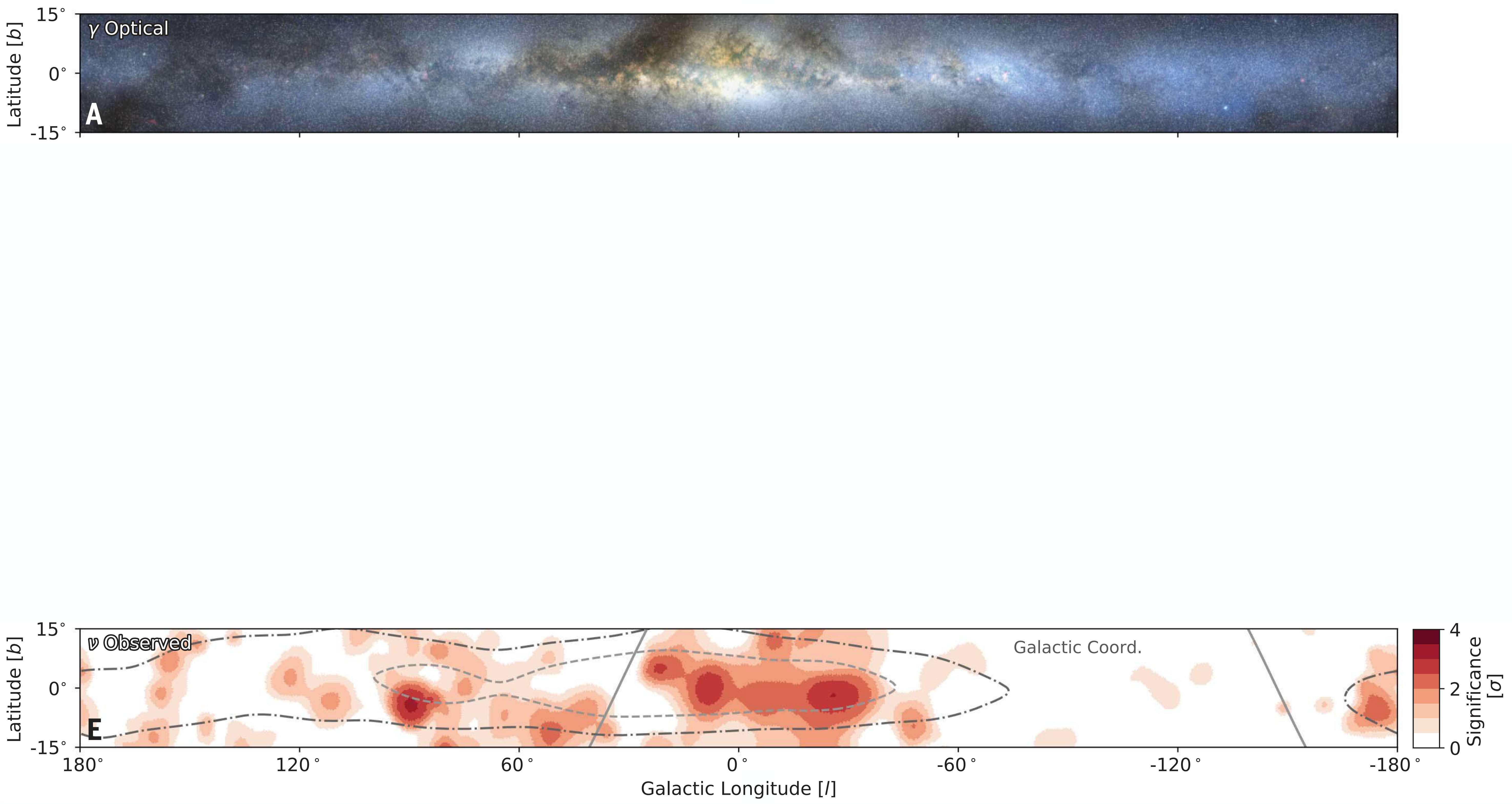

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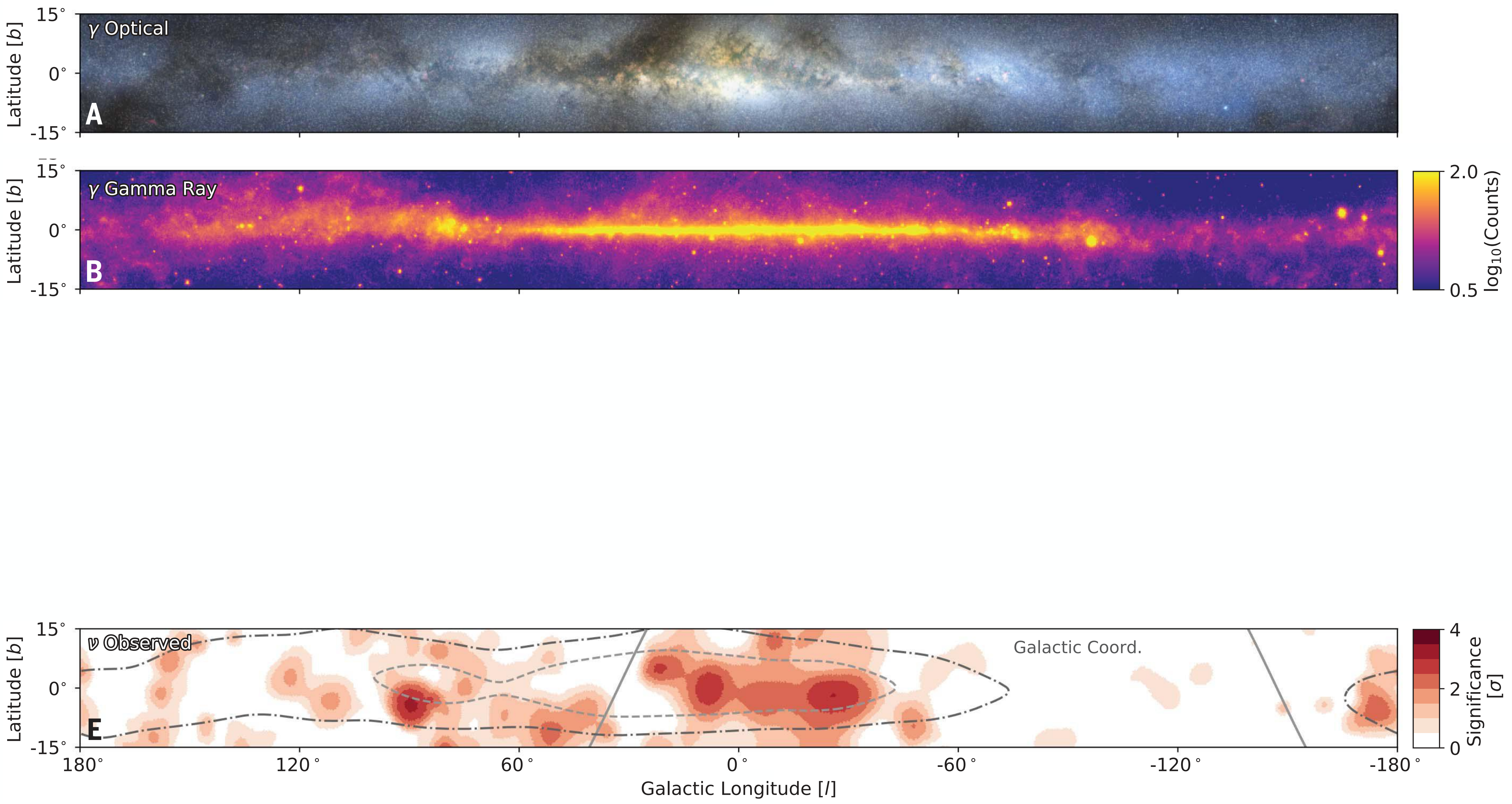

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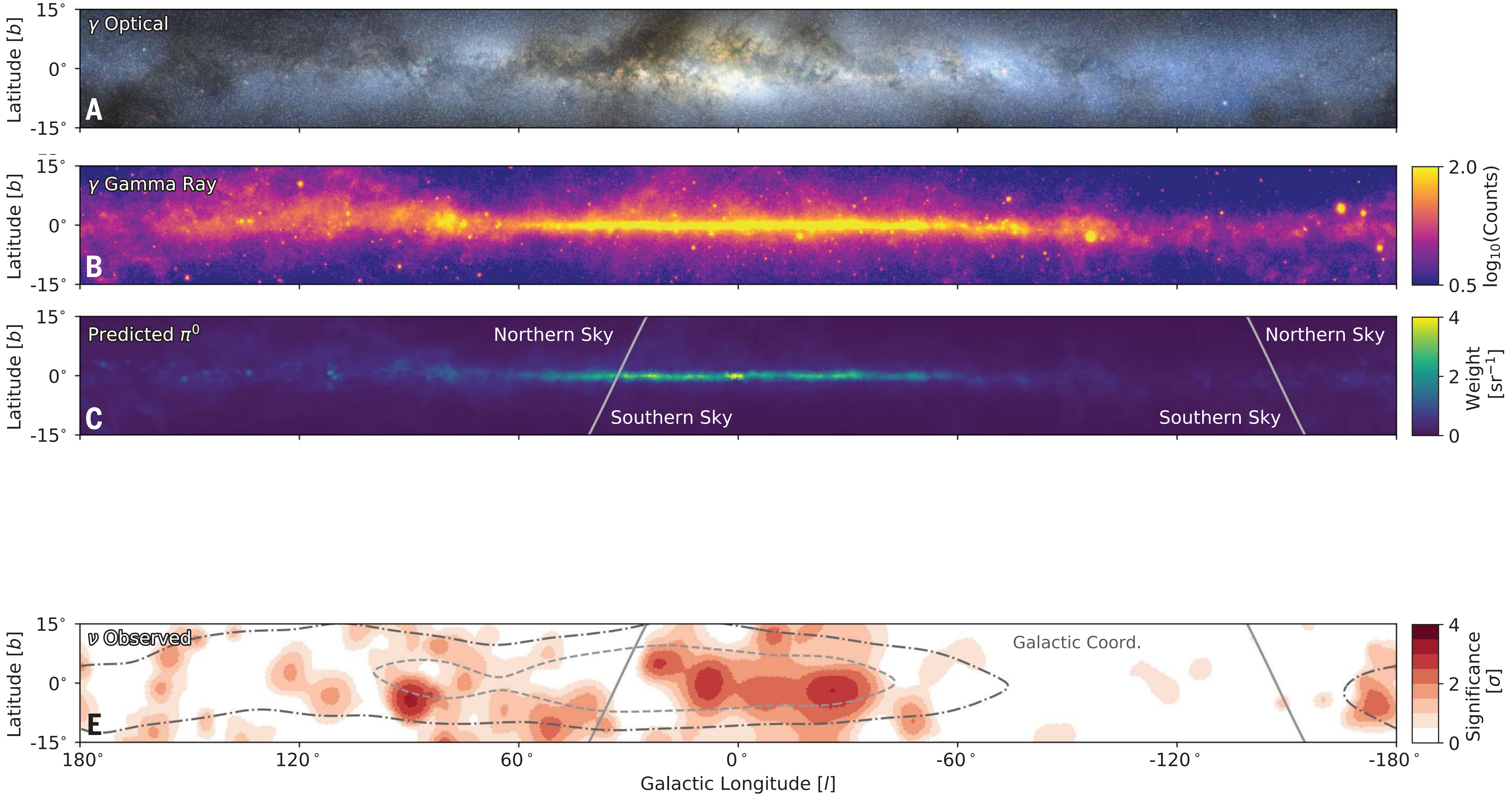

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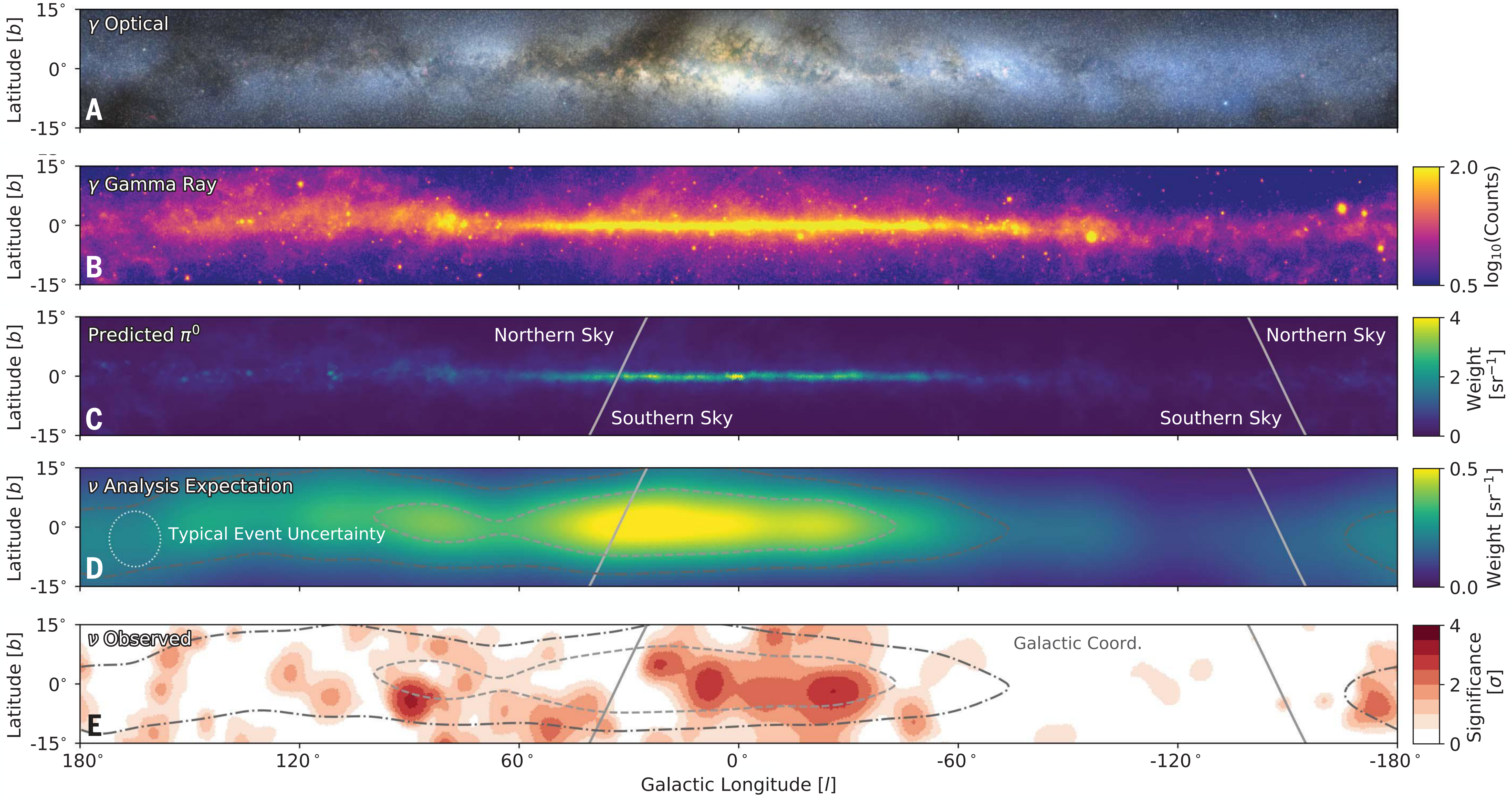

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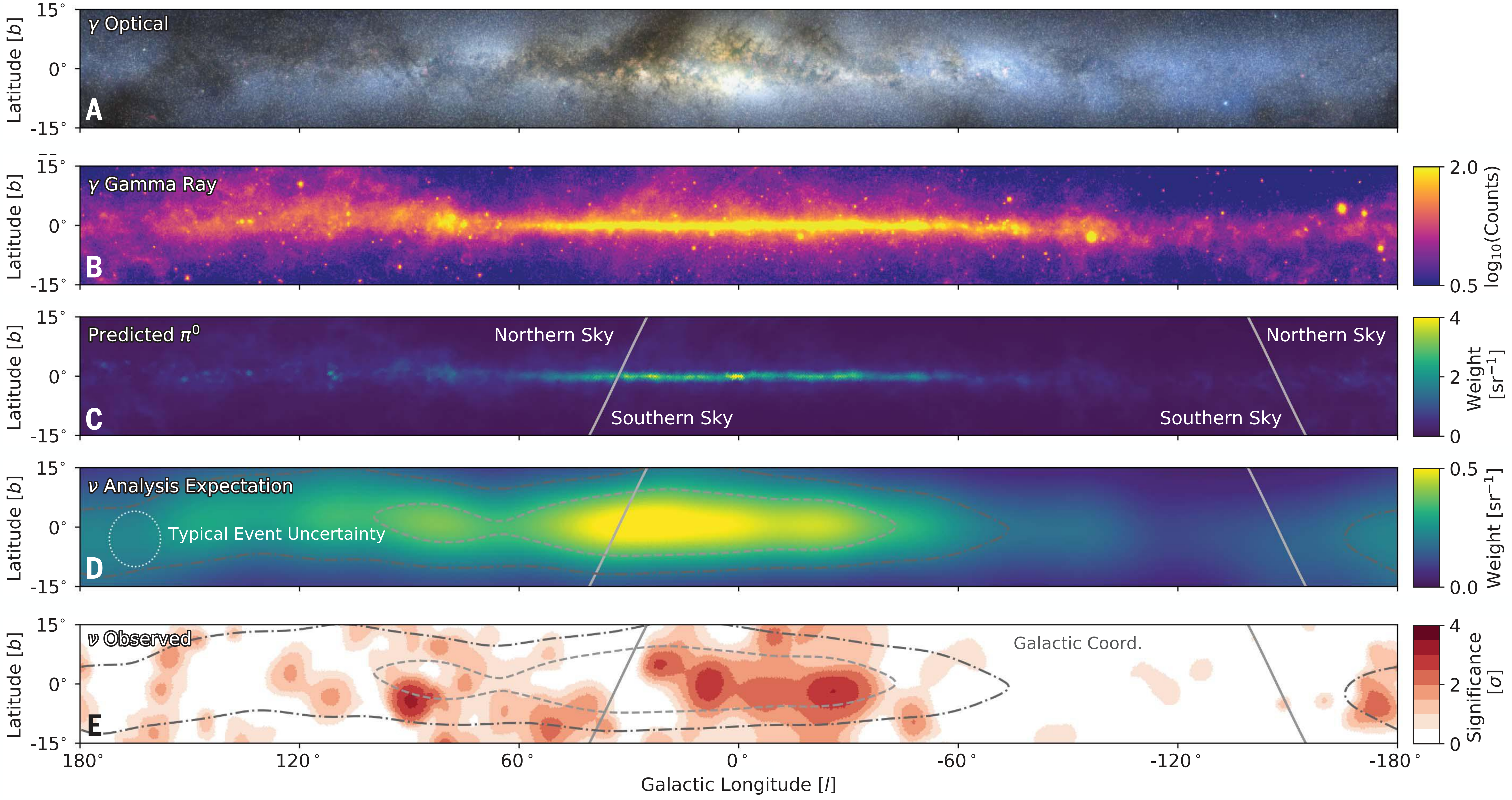

Galactic TeV neutrinos → 6-13% of all diffuse flux above 30 TeV

IceCube coll. Science 2023

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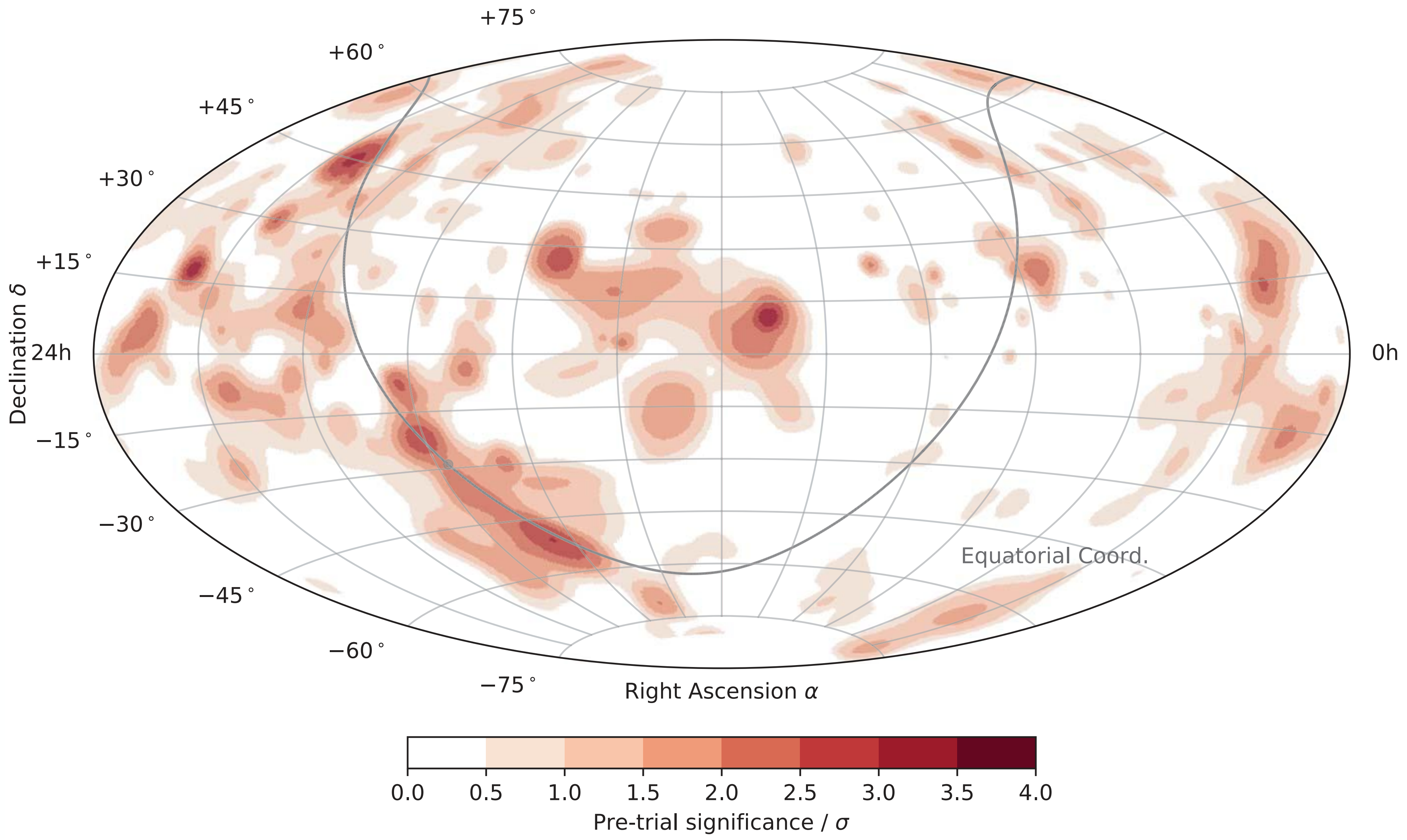

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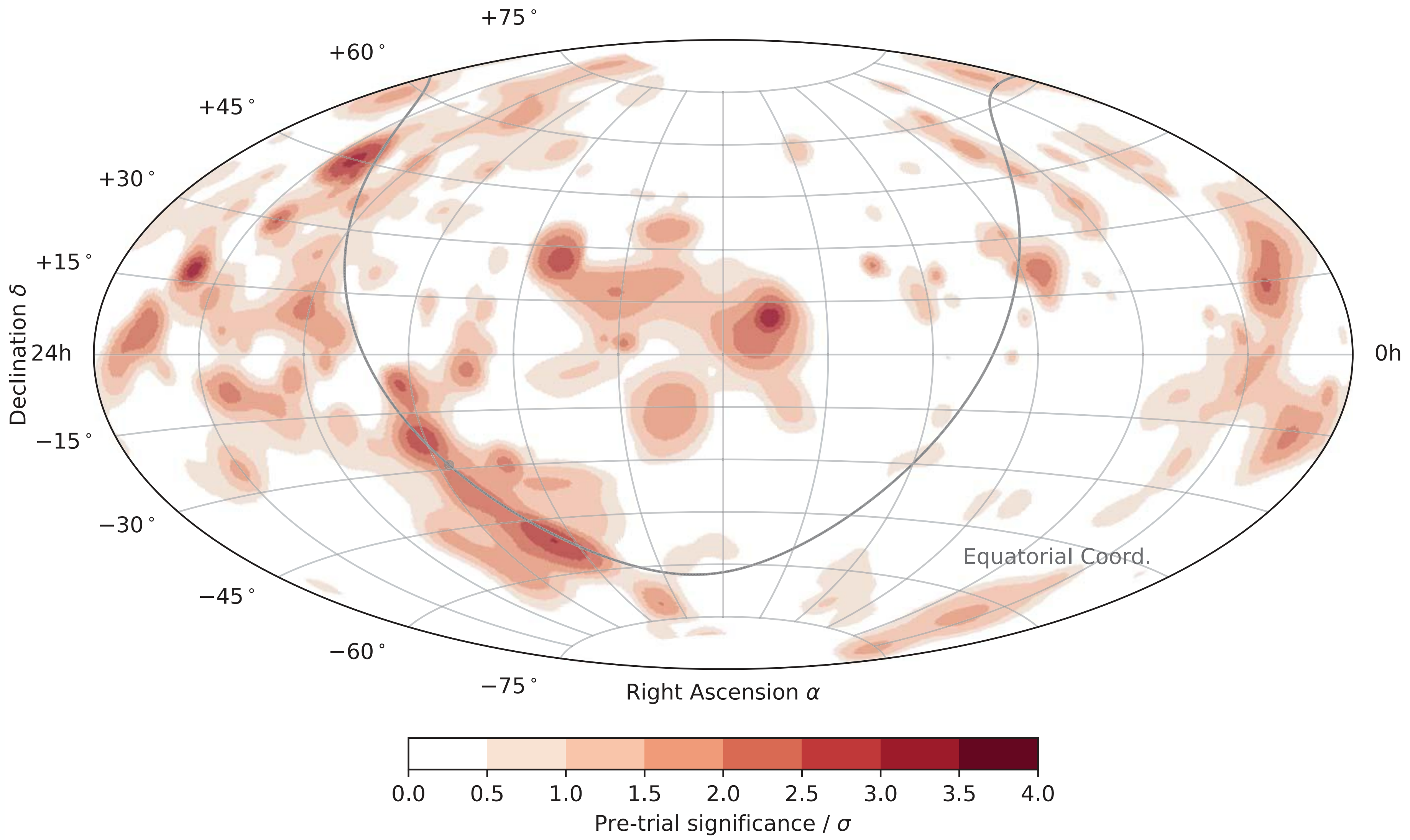
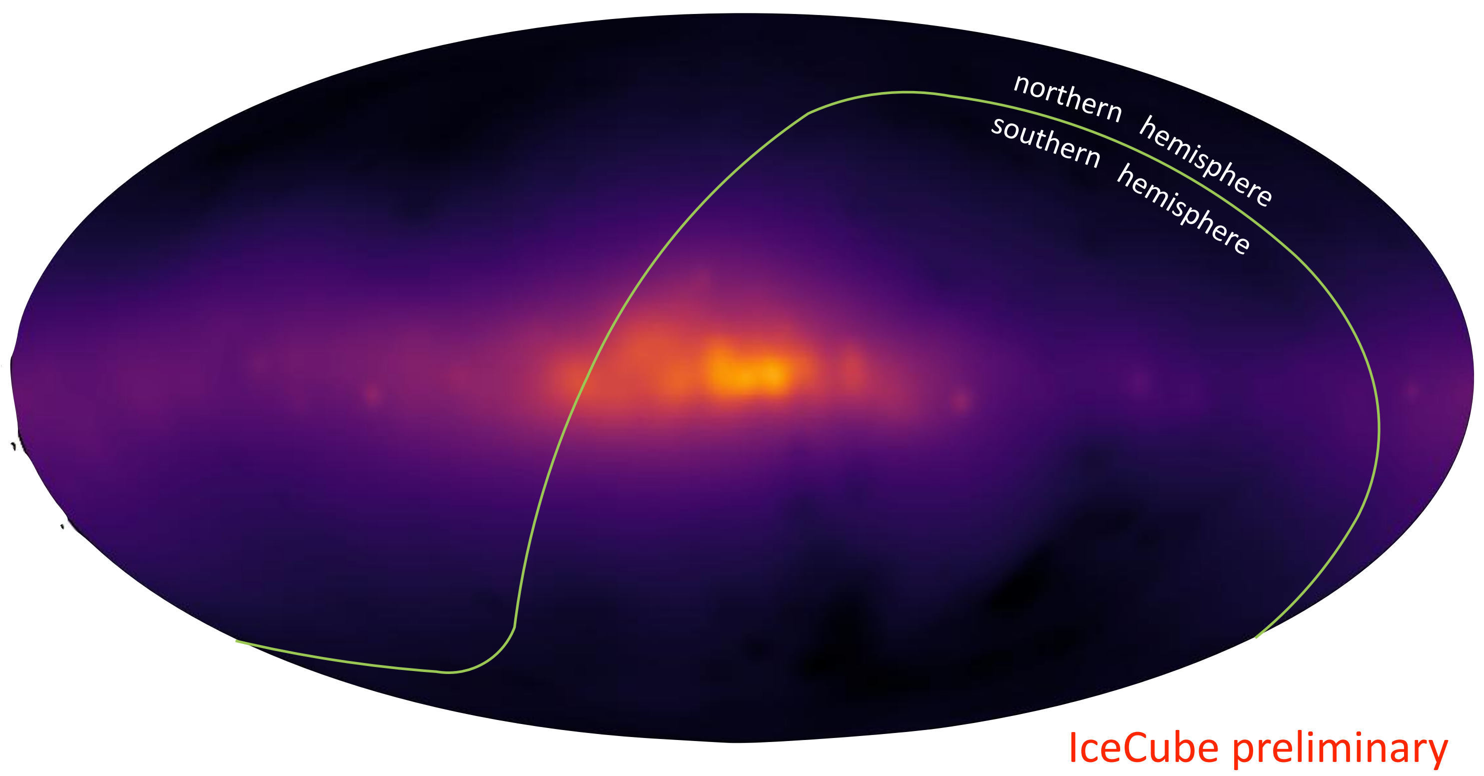
2025

- 2.5 yr more data
- Addition of muon tracks (starting events + up-going)

  → detection > 5 σ



TS cascades (π^0)



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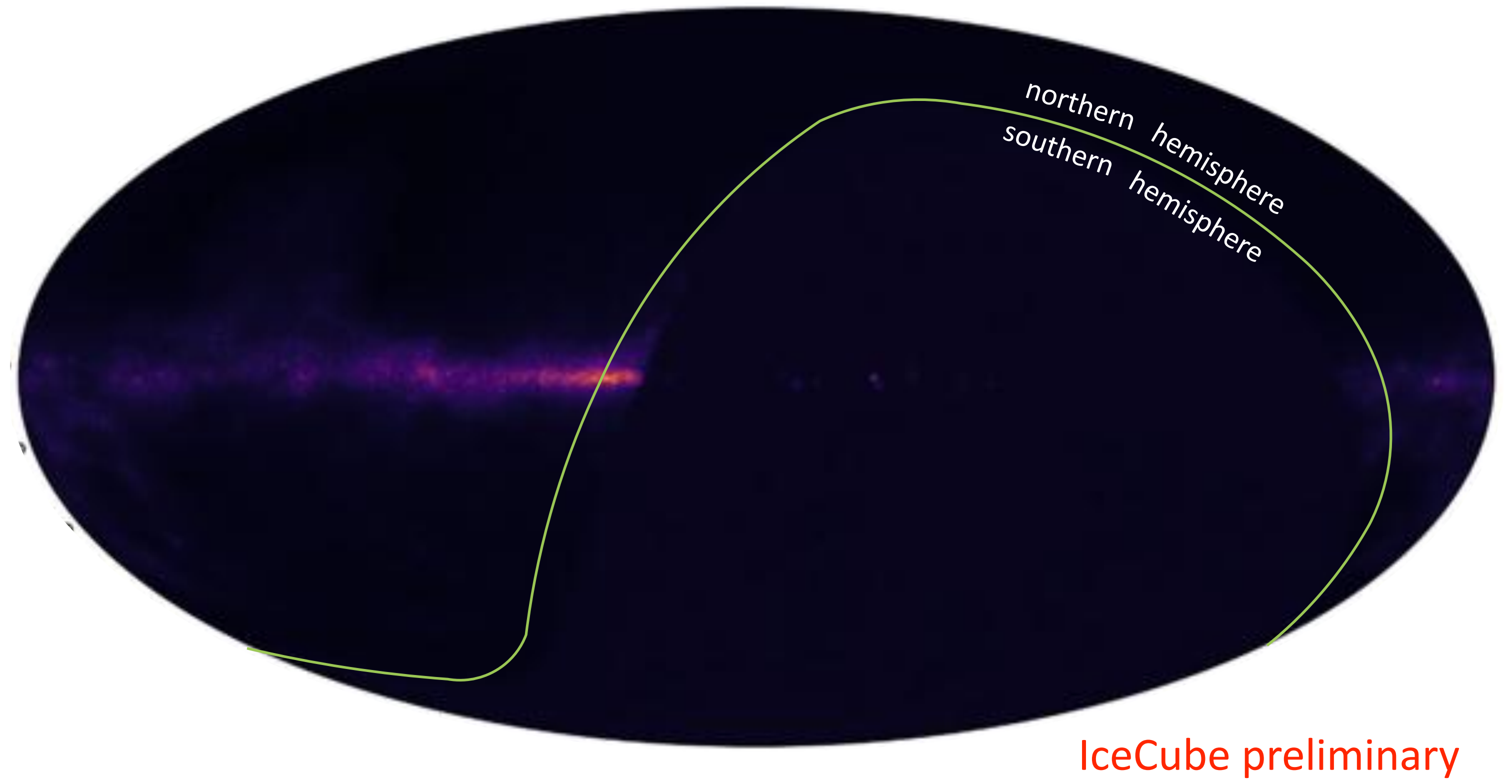

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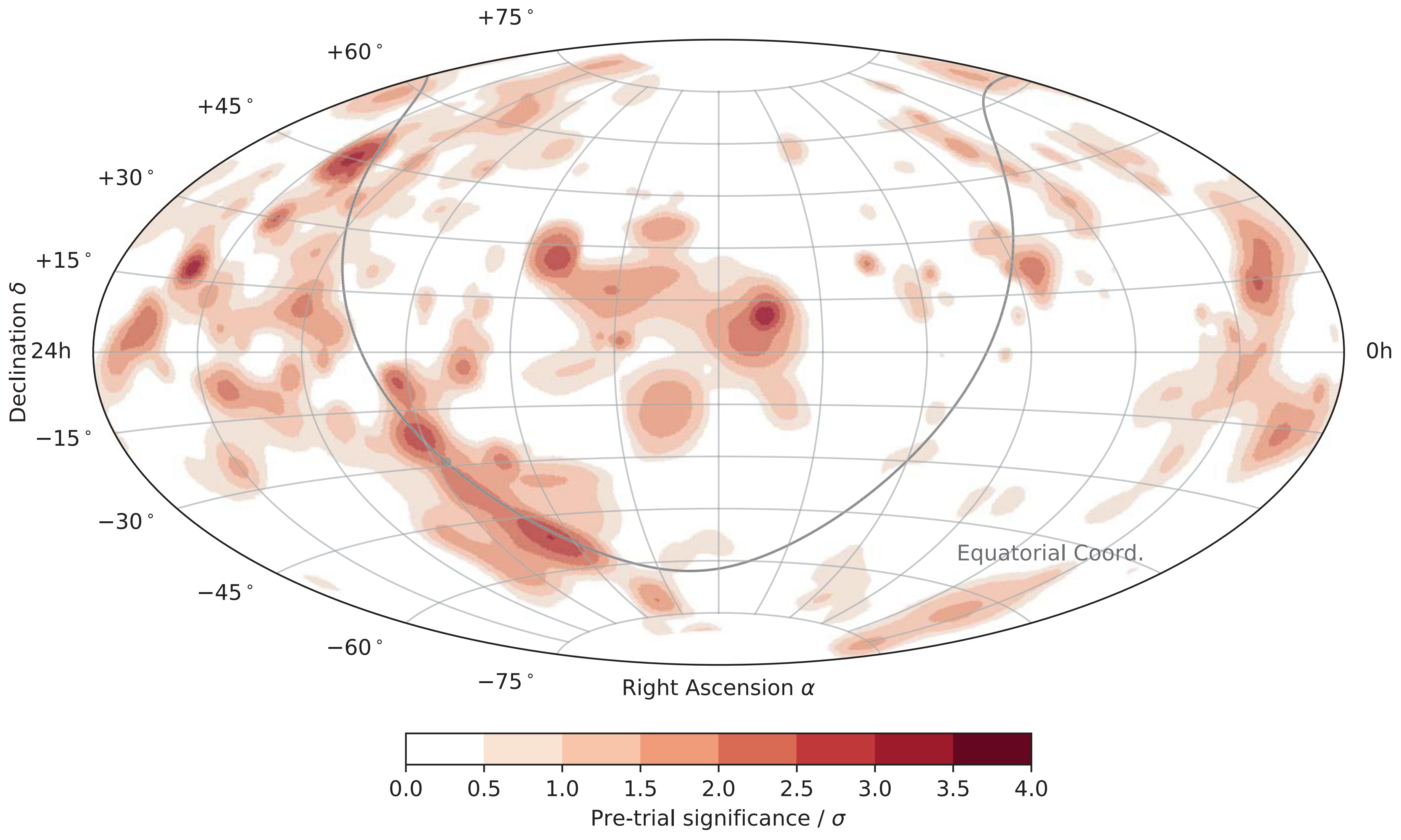

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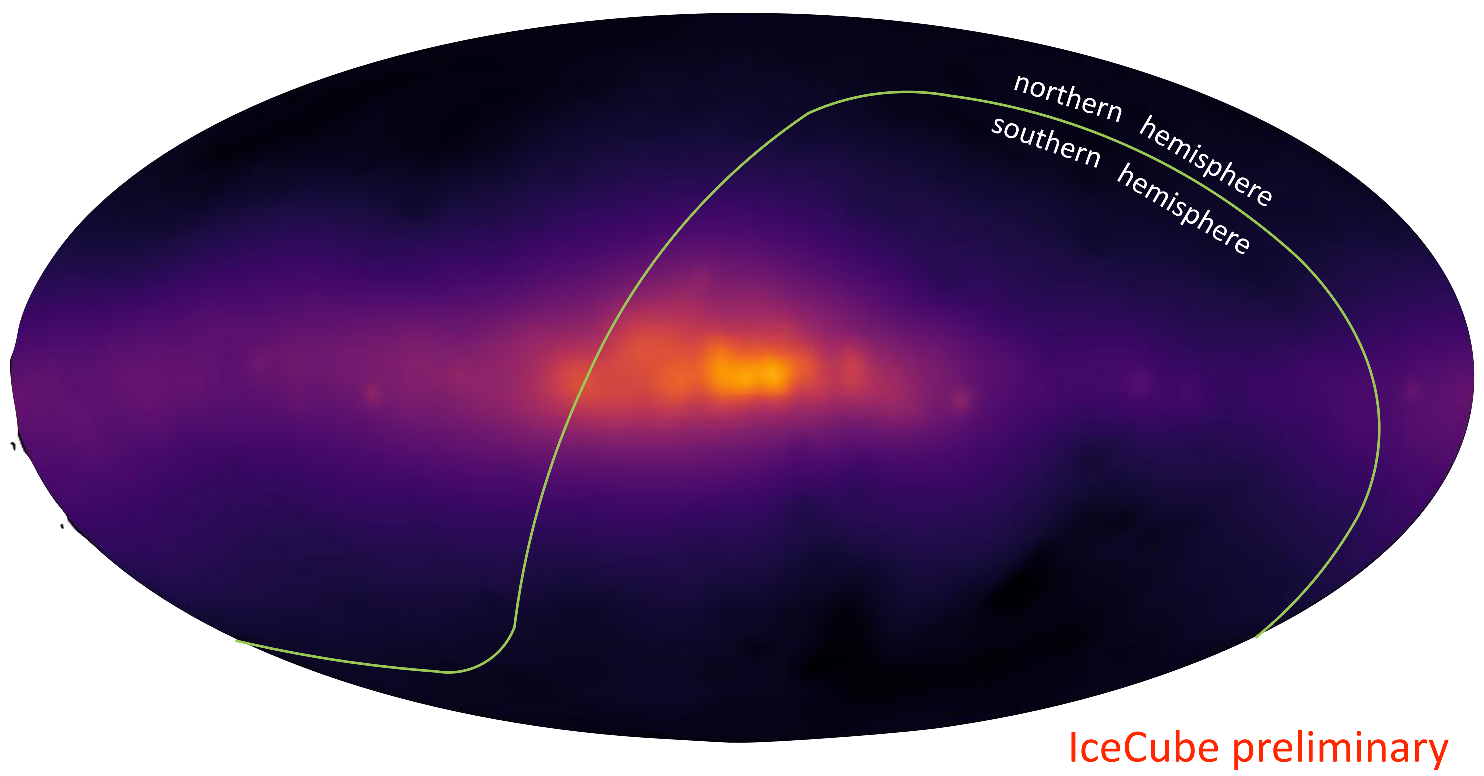

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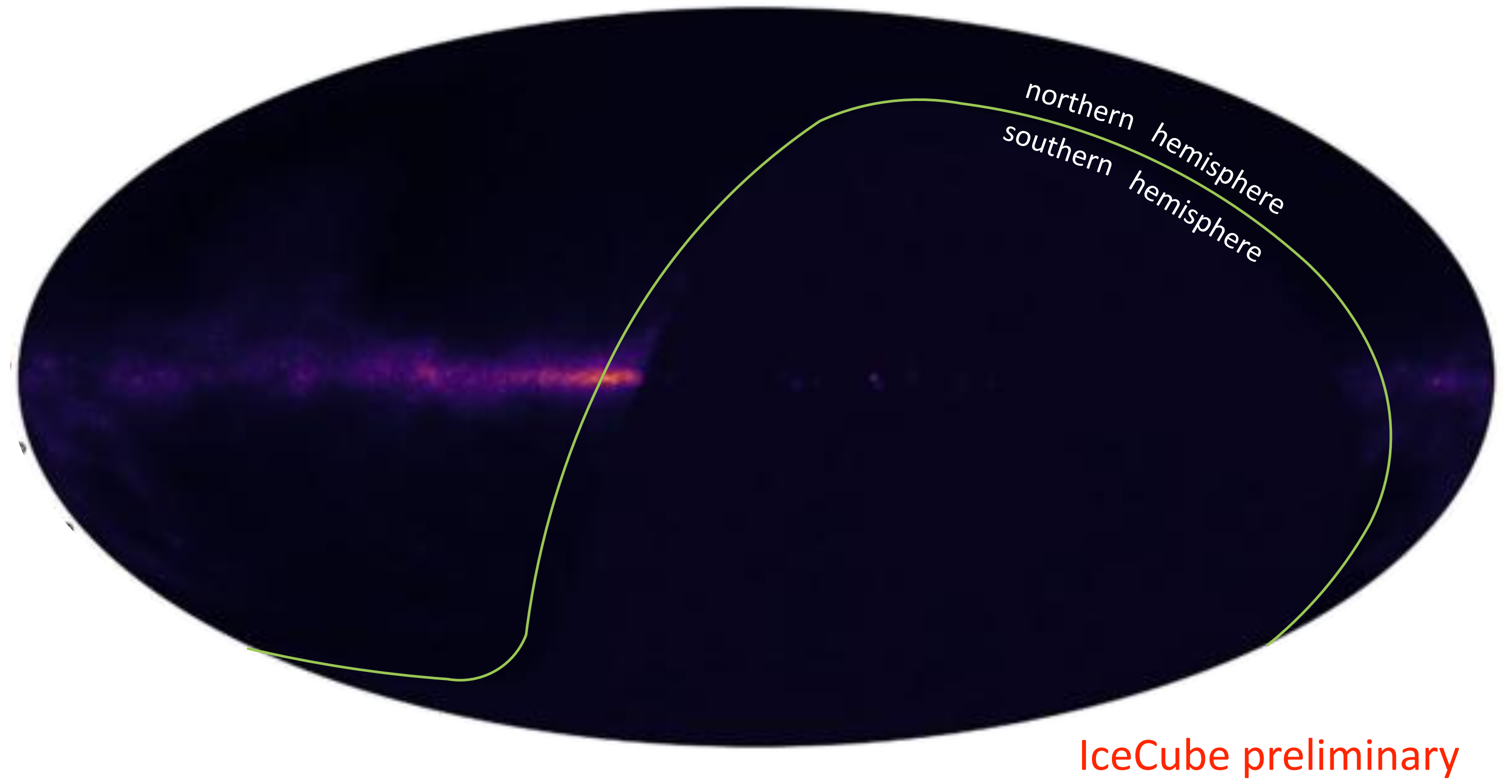

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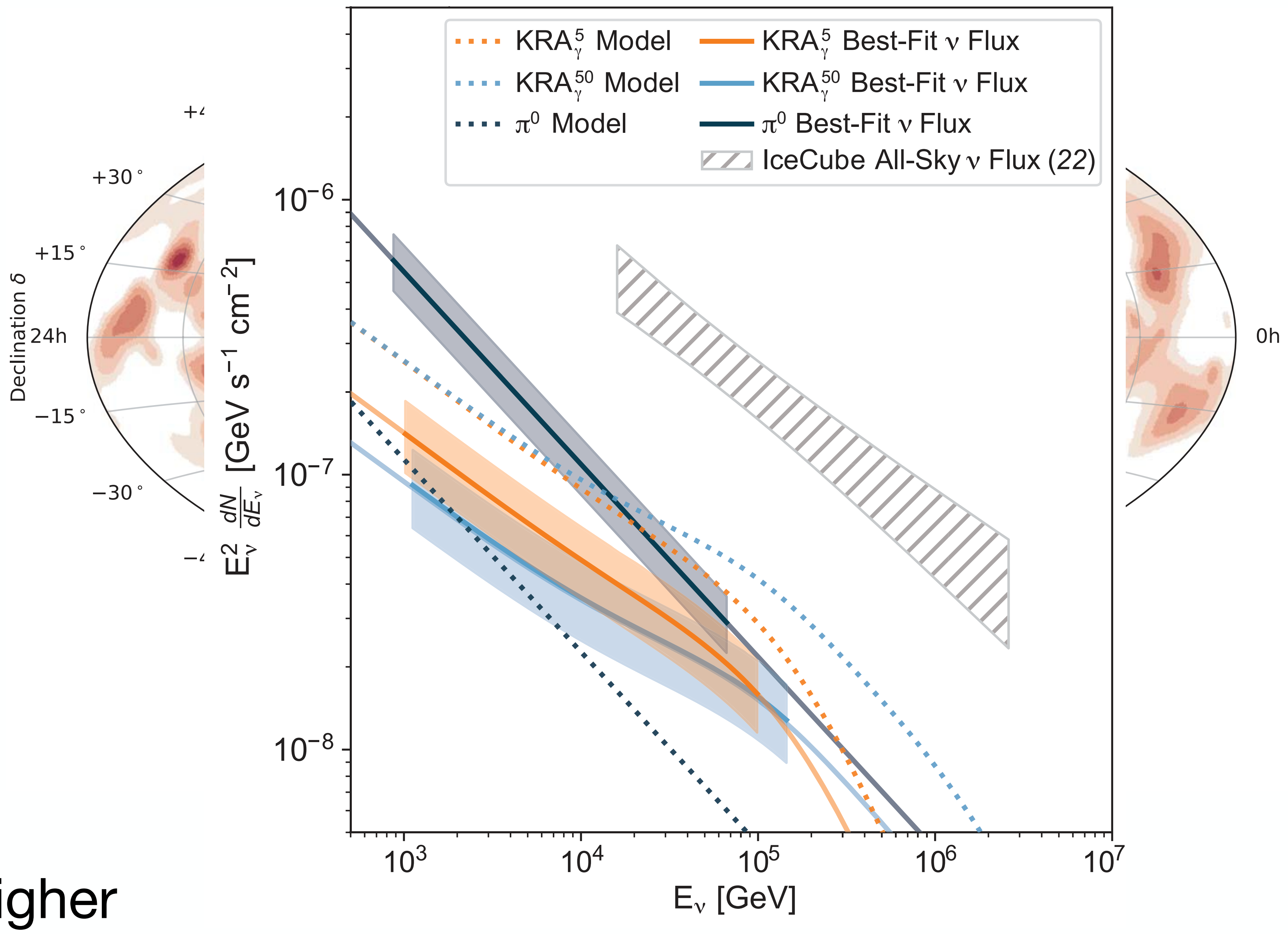
- The best model remains Fermi π^0 but the observed flux is still x5 higher than predicted by the model



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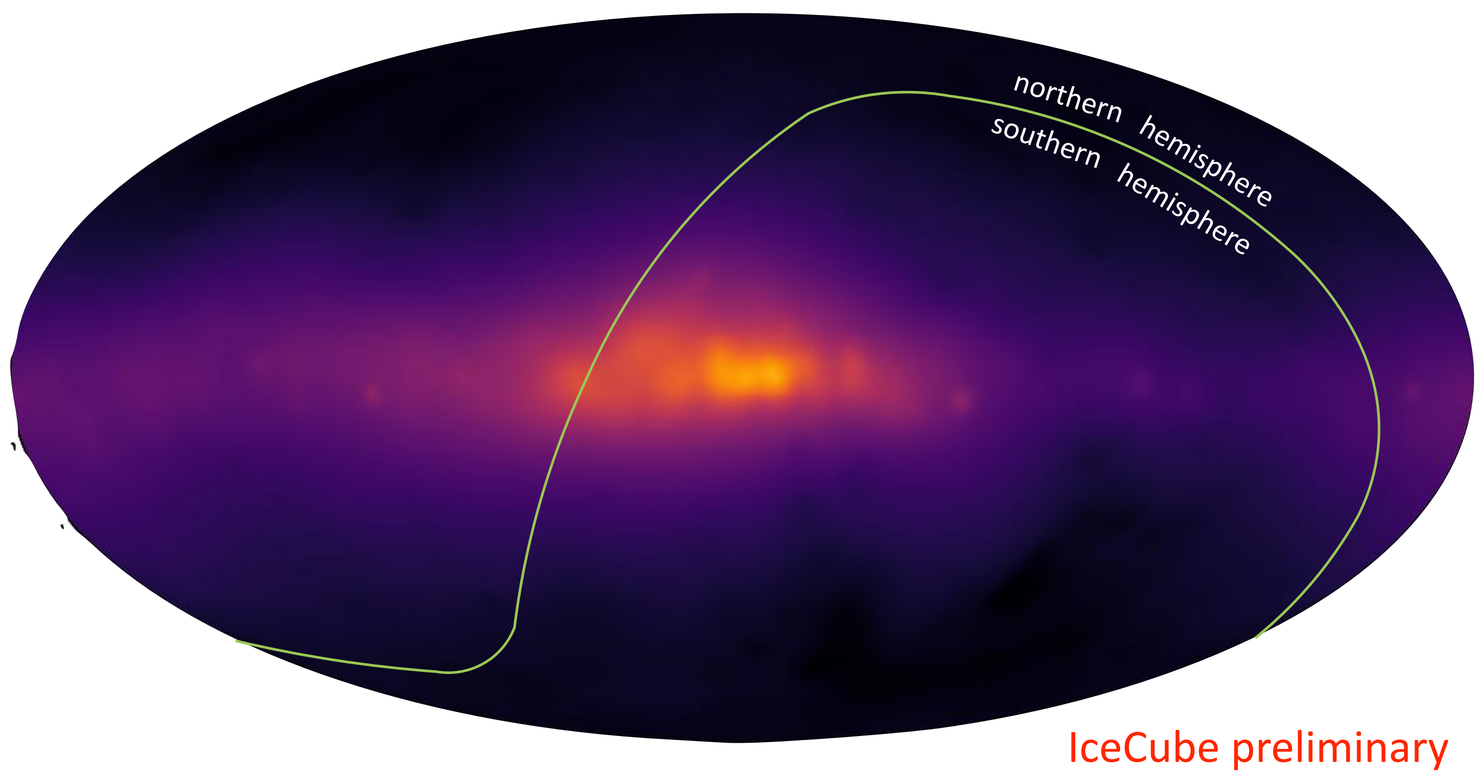

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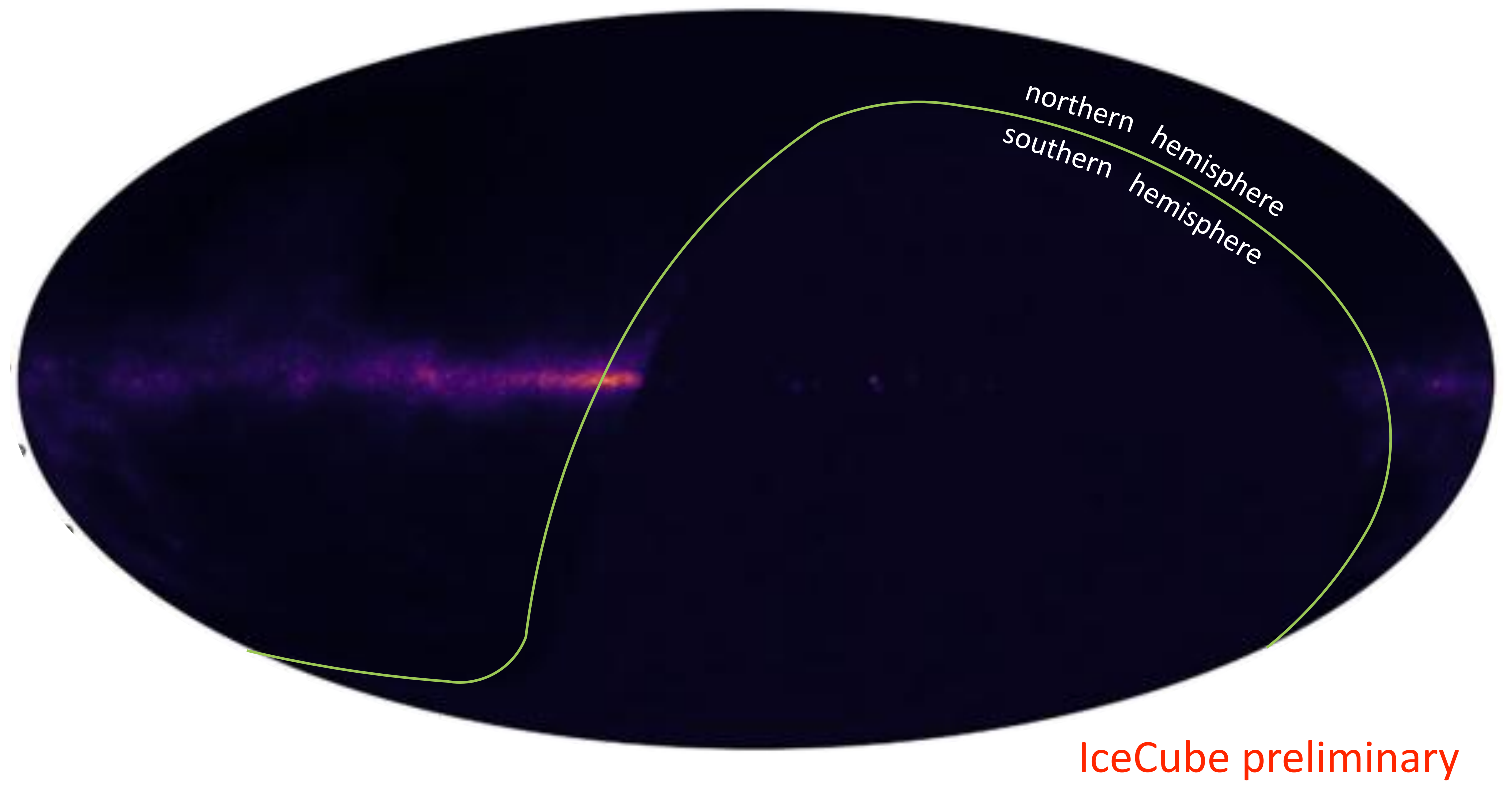

ICRC2025(1130, 1219)

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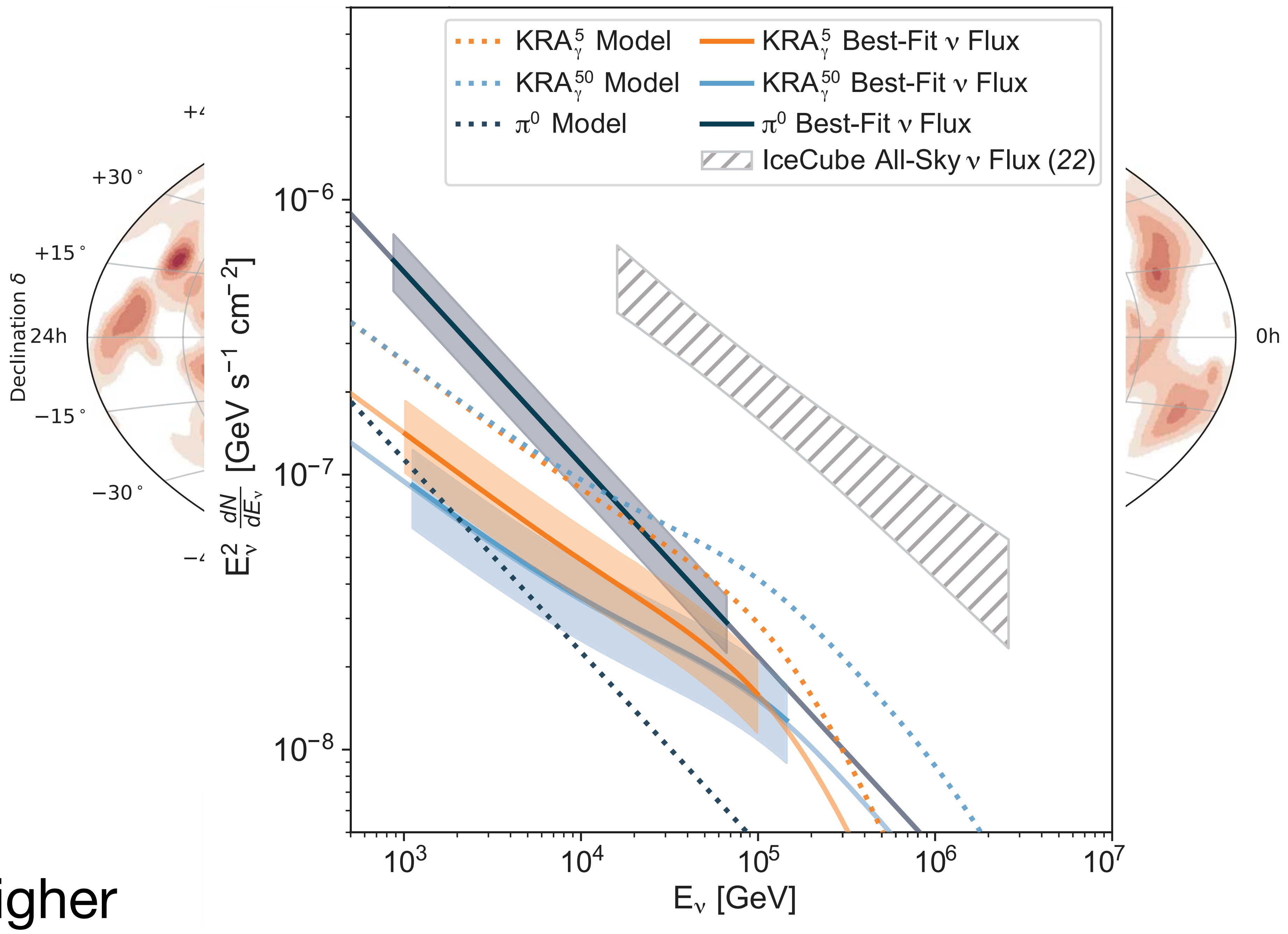

No individual source identified (yet?)

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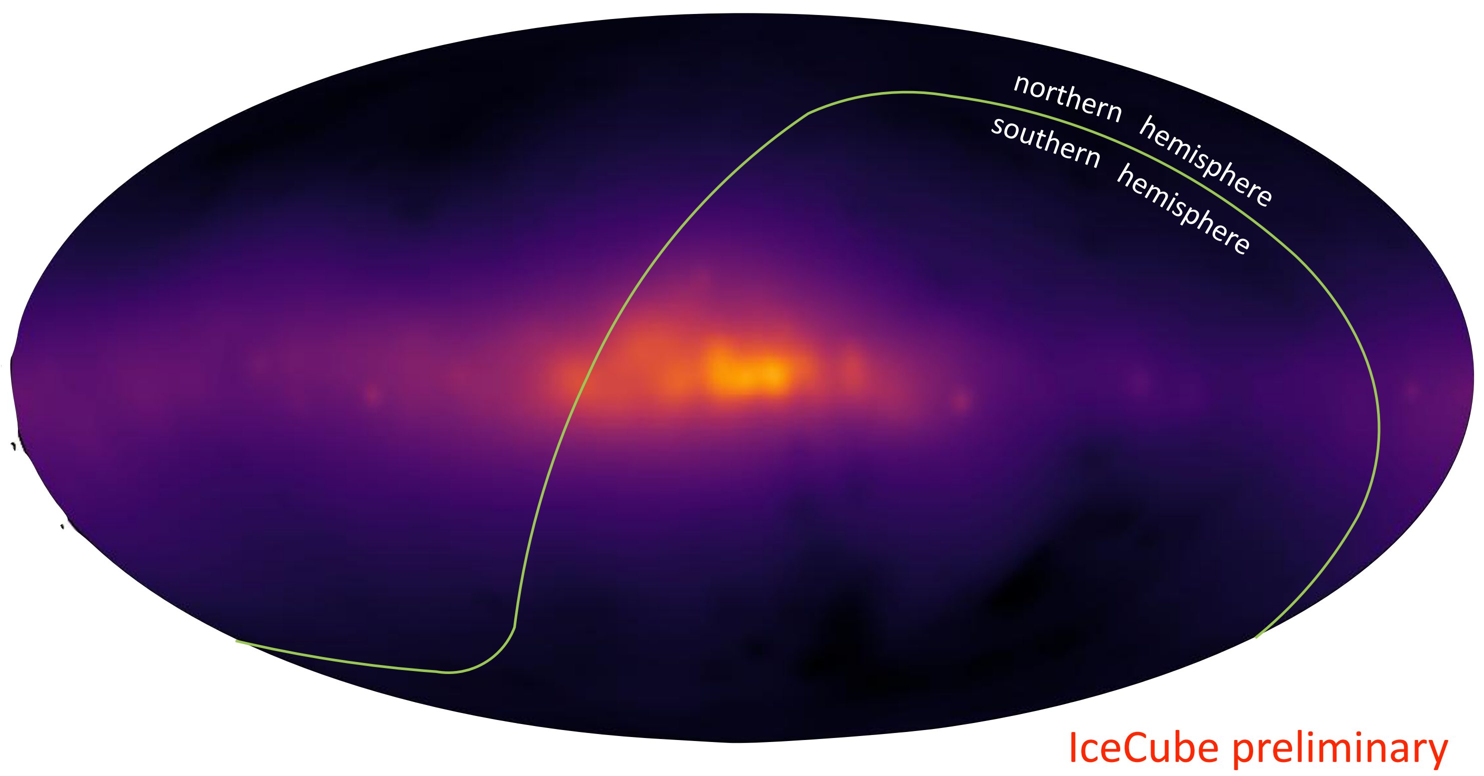

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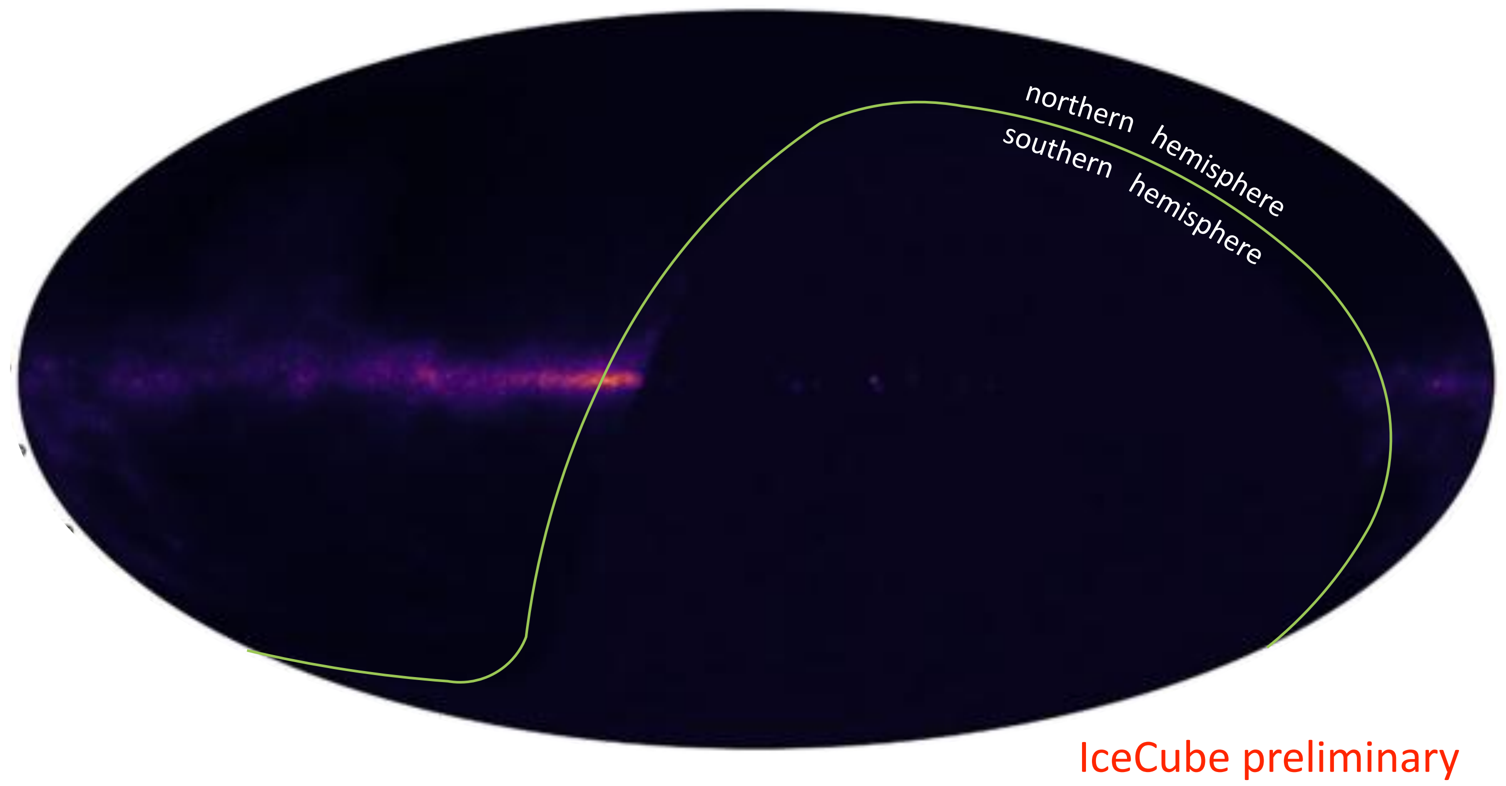

ICRC2025(1130, 1219)

An unexpected discovery: KM3-230213A

KM3NeT Coll. Nature 638, 376 (2025)

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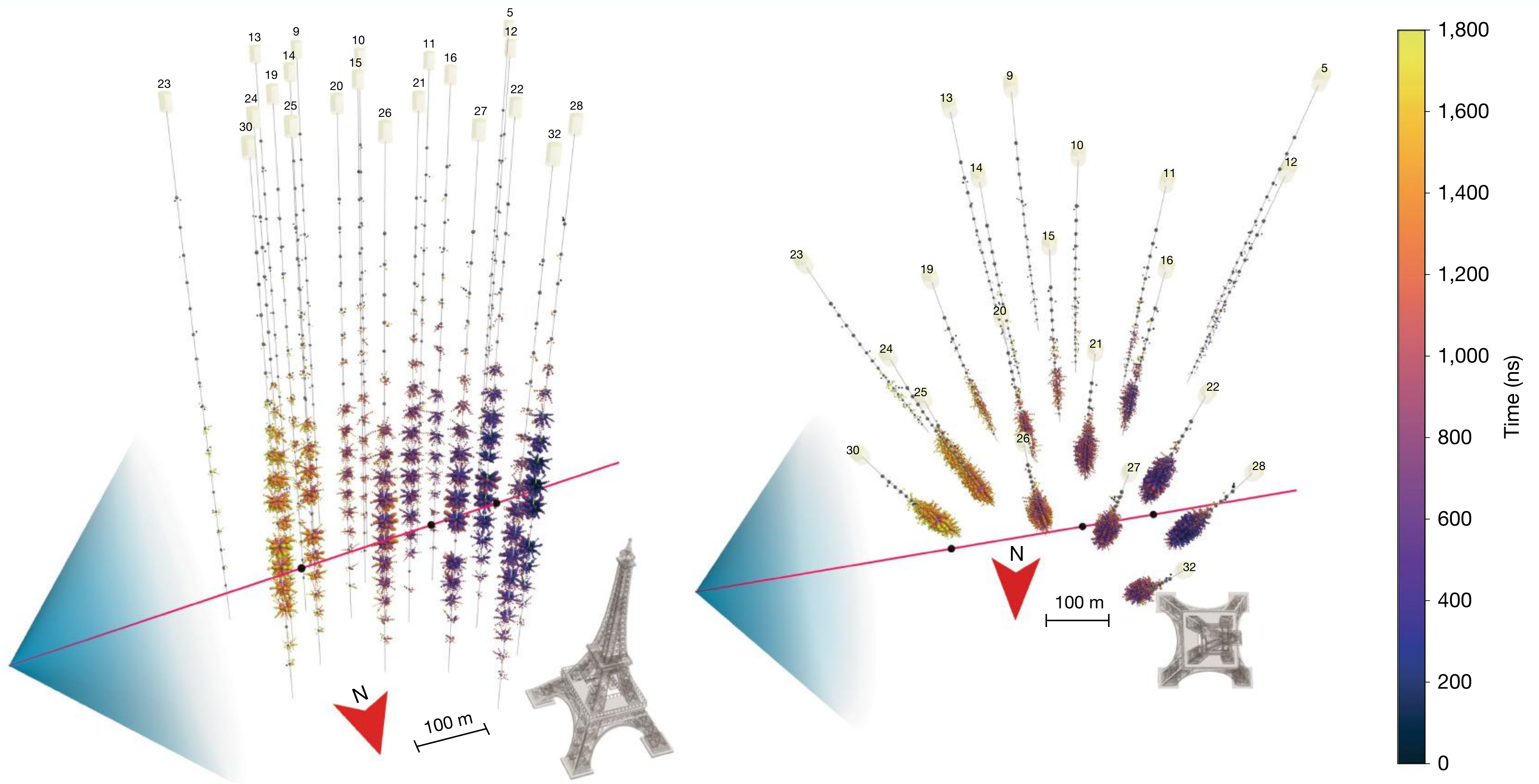
- Outstanding event : 28,086 PMT hits → clearest track ever



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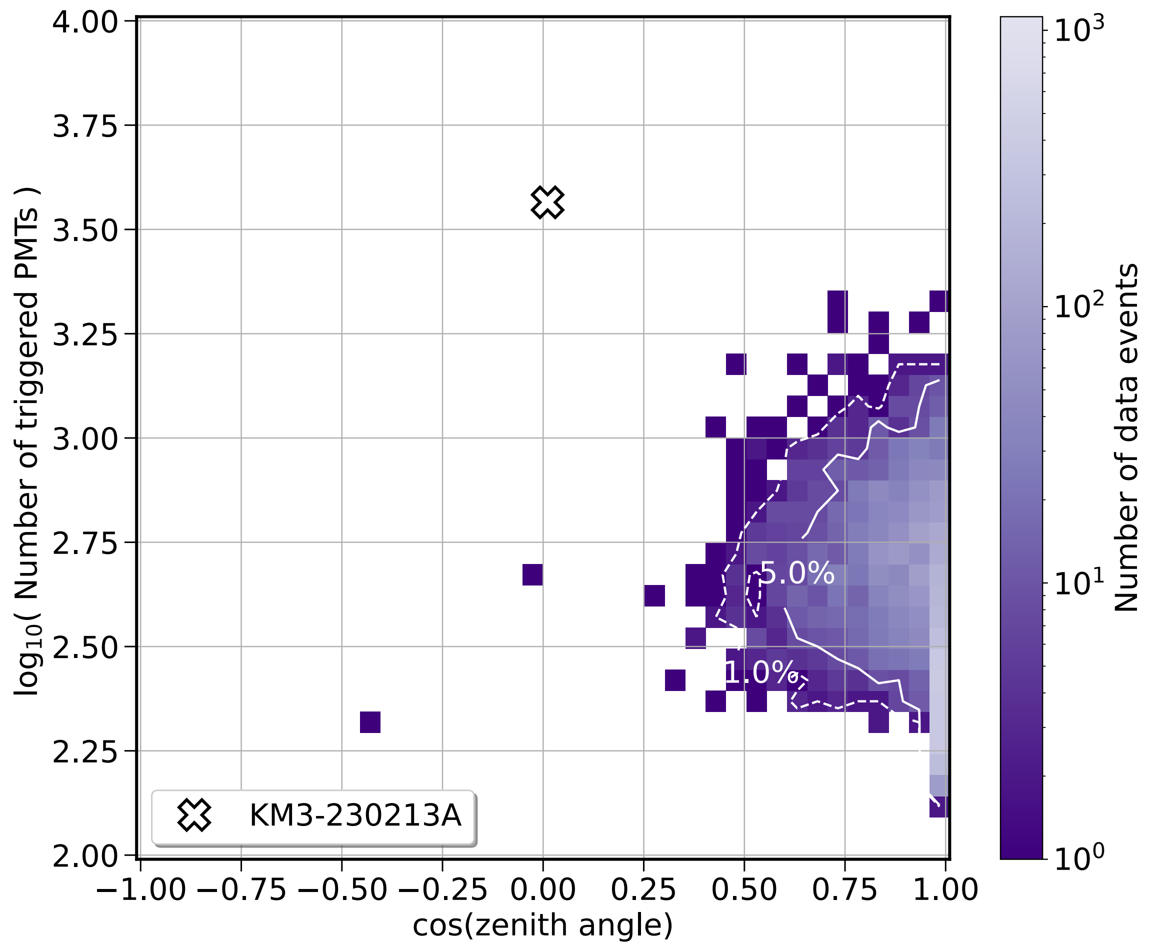

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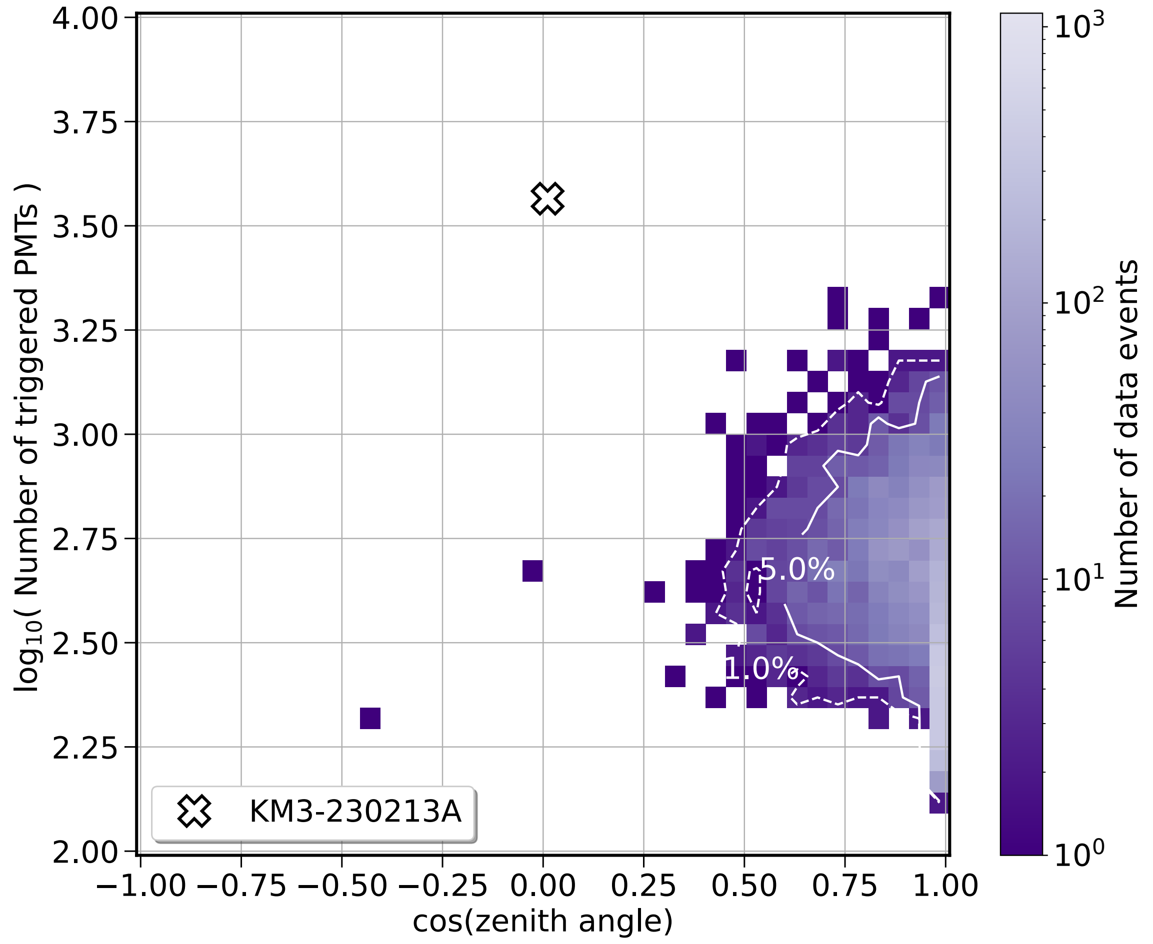

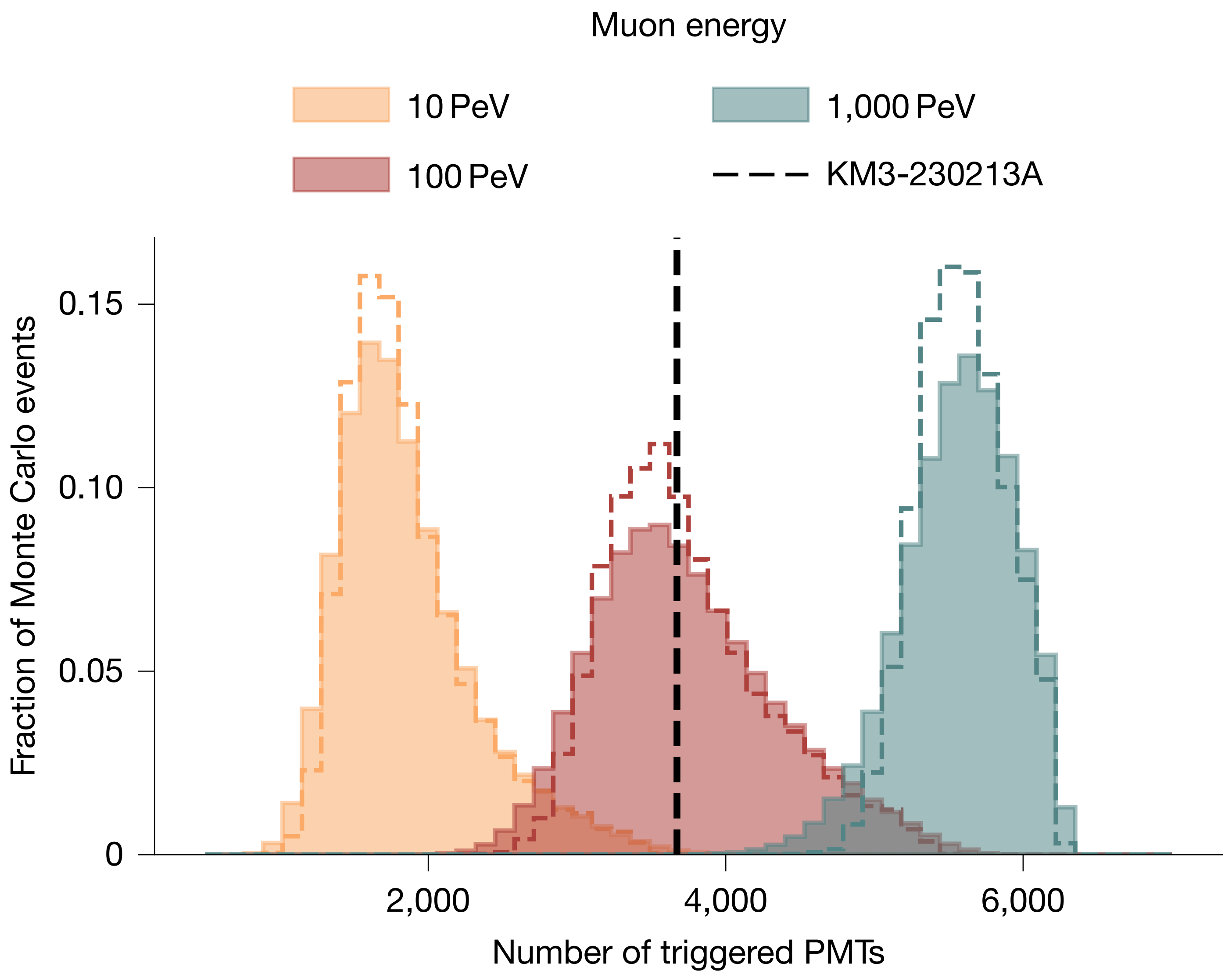

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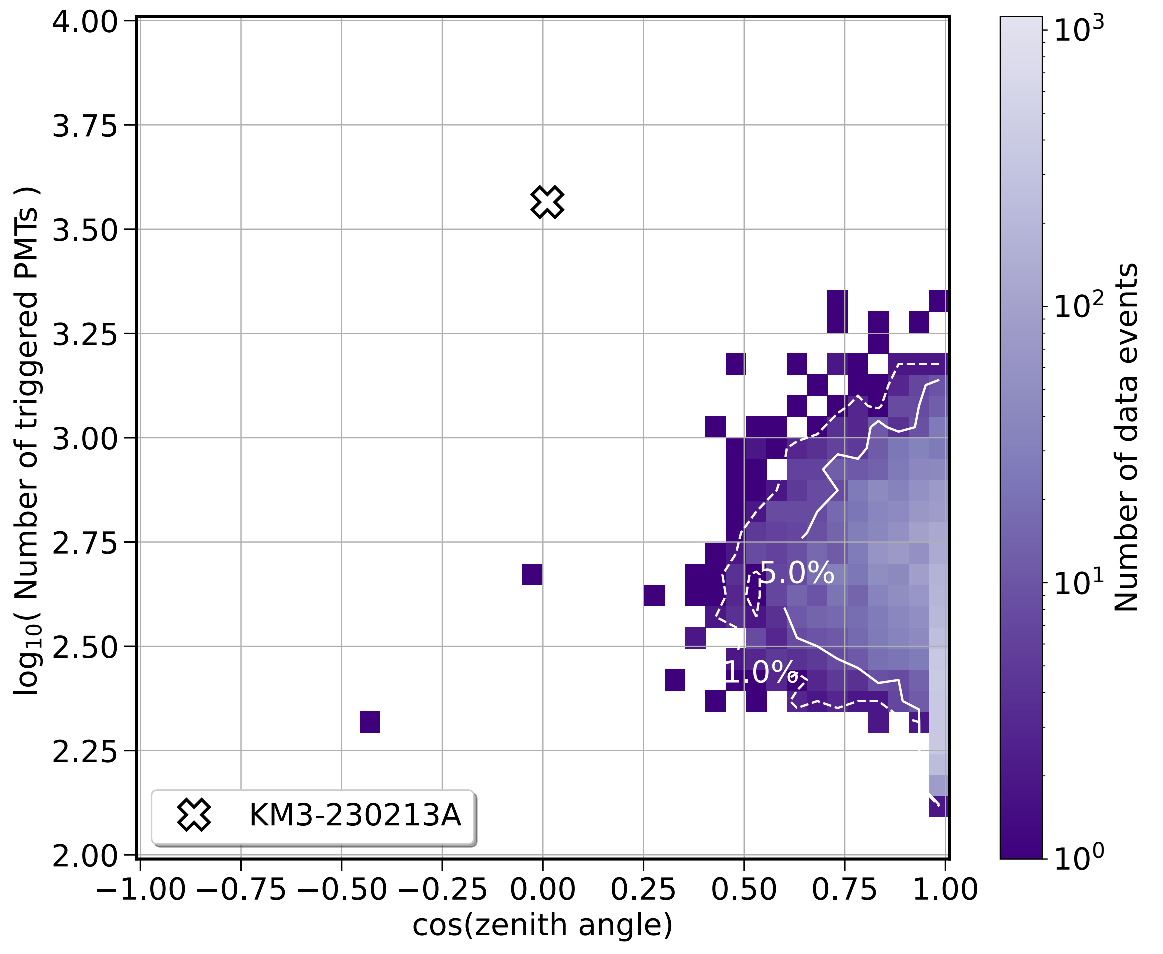
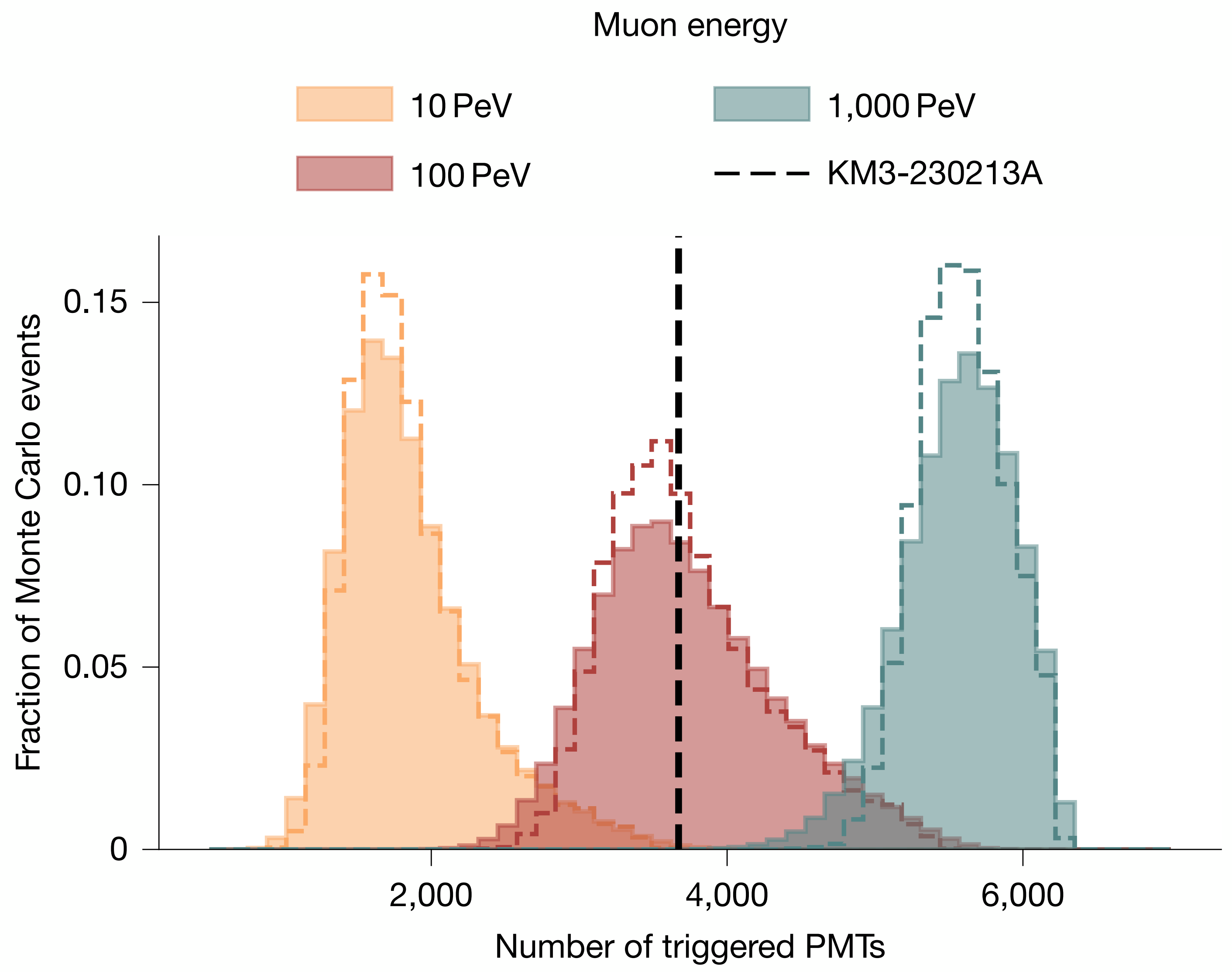
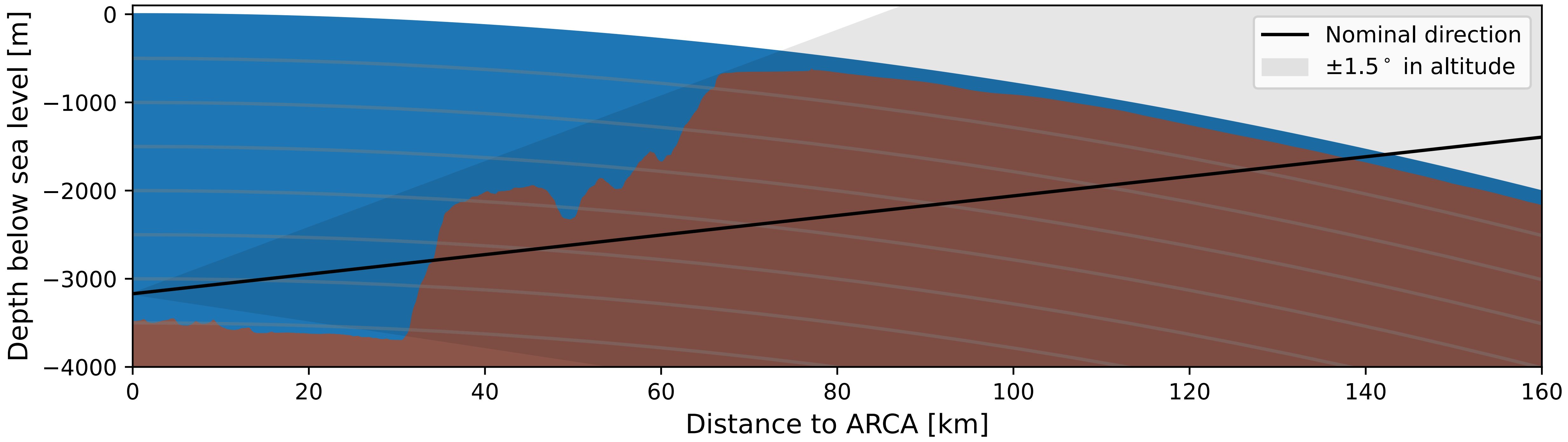
  → UHE event

- Direction near horizon → through the continental plateau

  → Neutrino event







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An unexpected discovery: KM3-230213A

2023

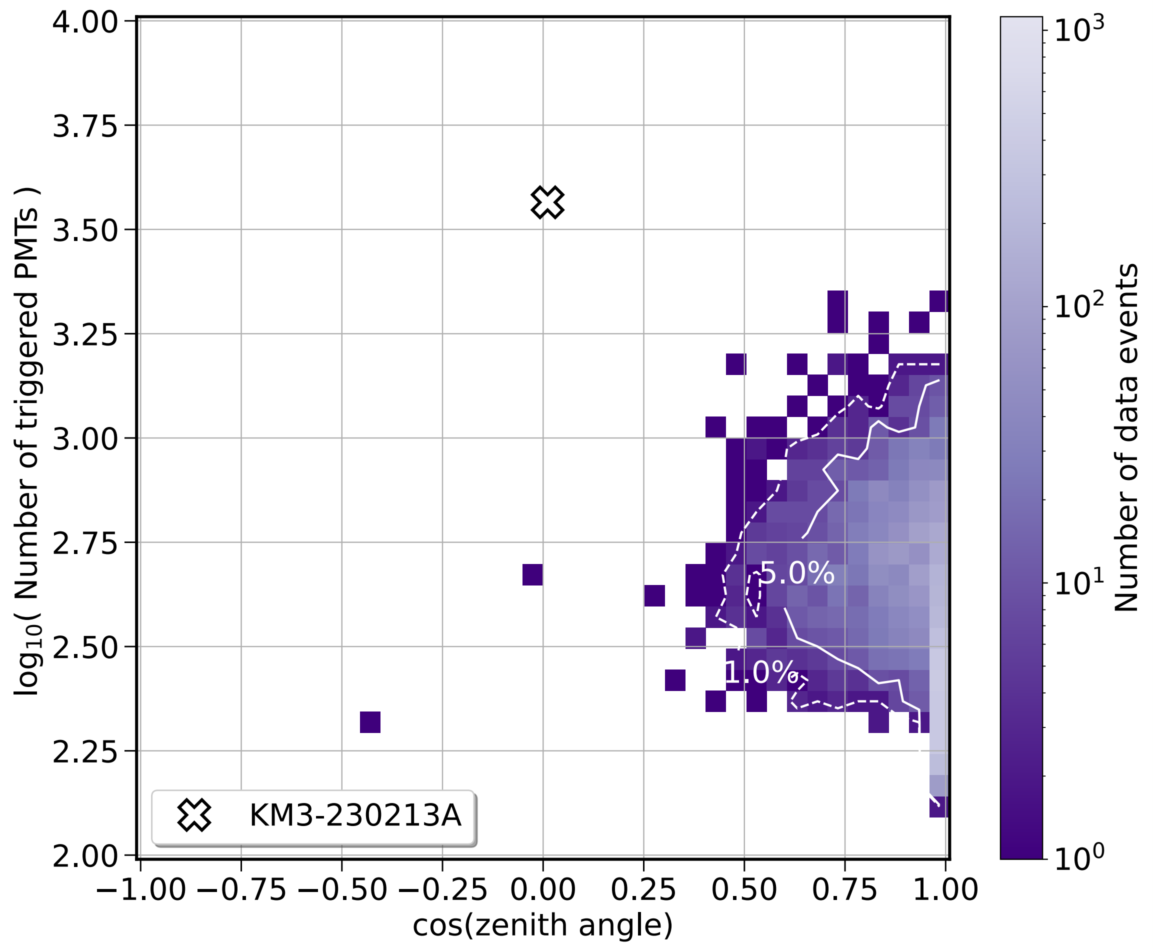
- Outstanding event : 28,086 PMT hits → clearest track ever
- Detected muon with E = 120 (+110/-60) PeV

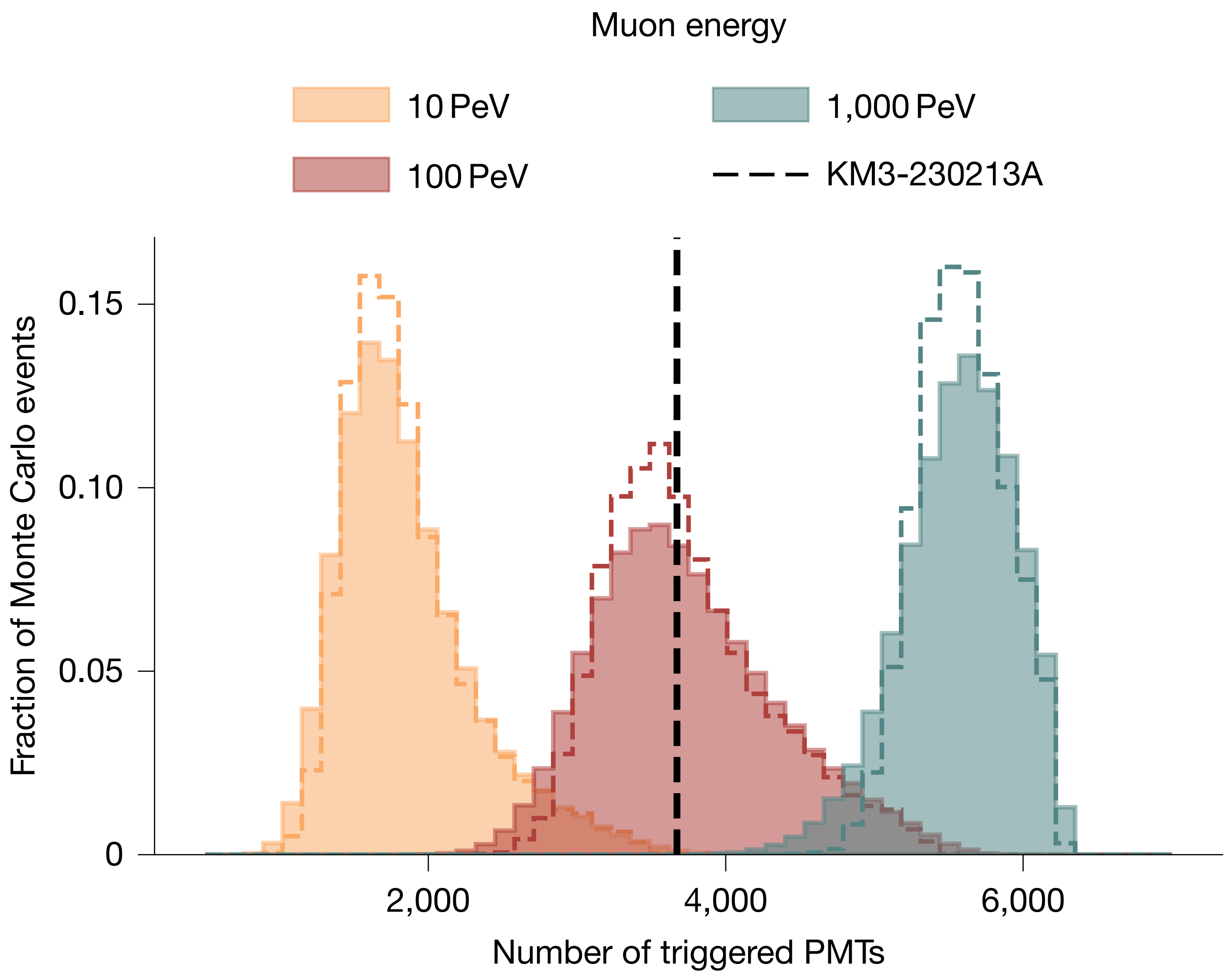
  → UHE event

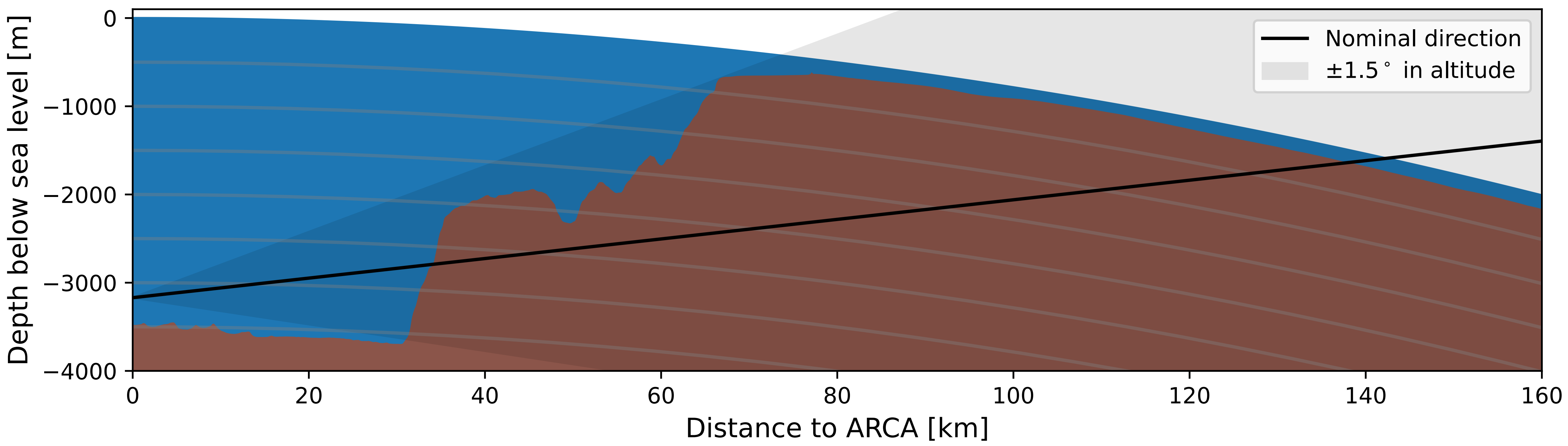
- Direction near horizon → through the continental plateau

  → Neutrino event

→ UHE neutrino with E = 220 (+570/-110) PeV







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2024-2025

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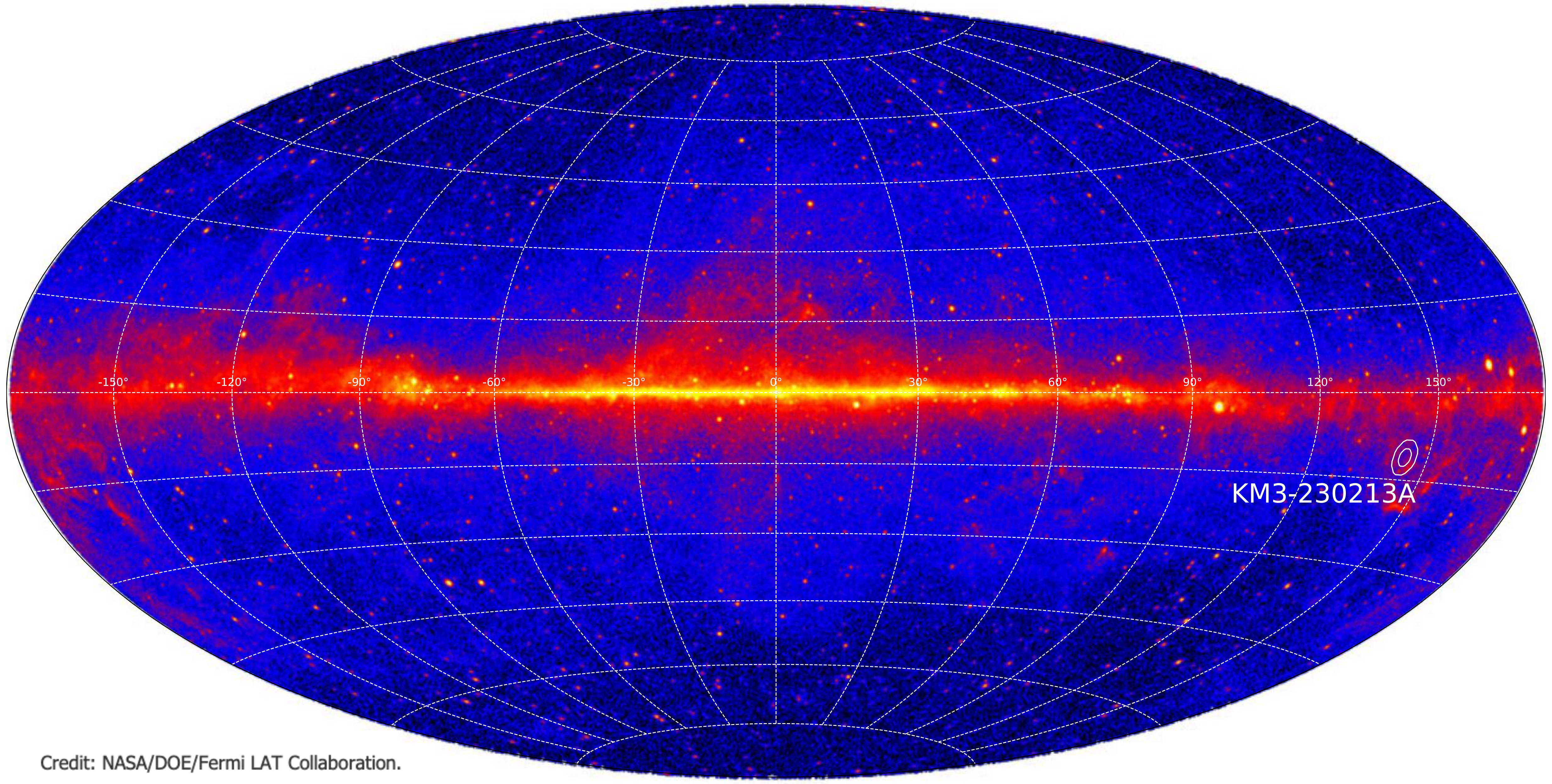

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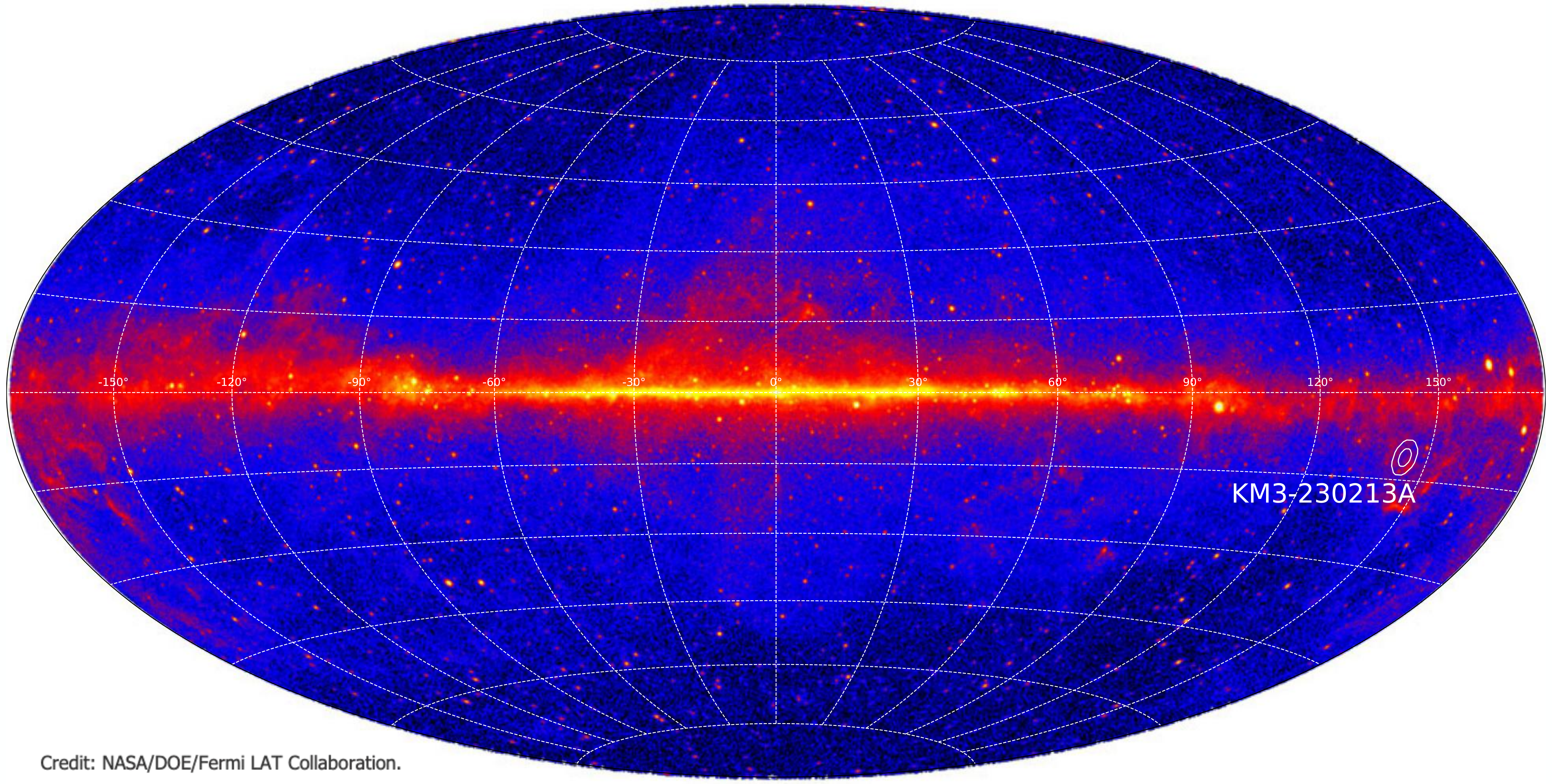

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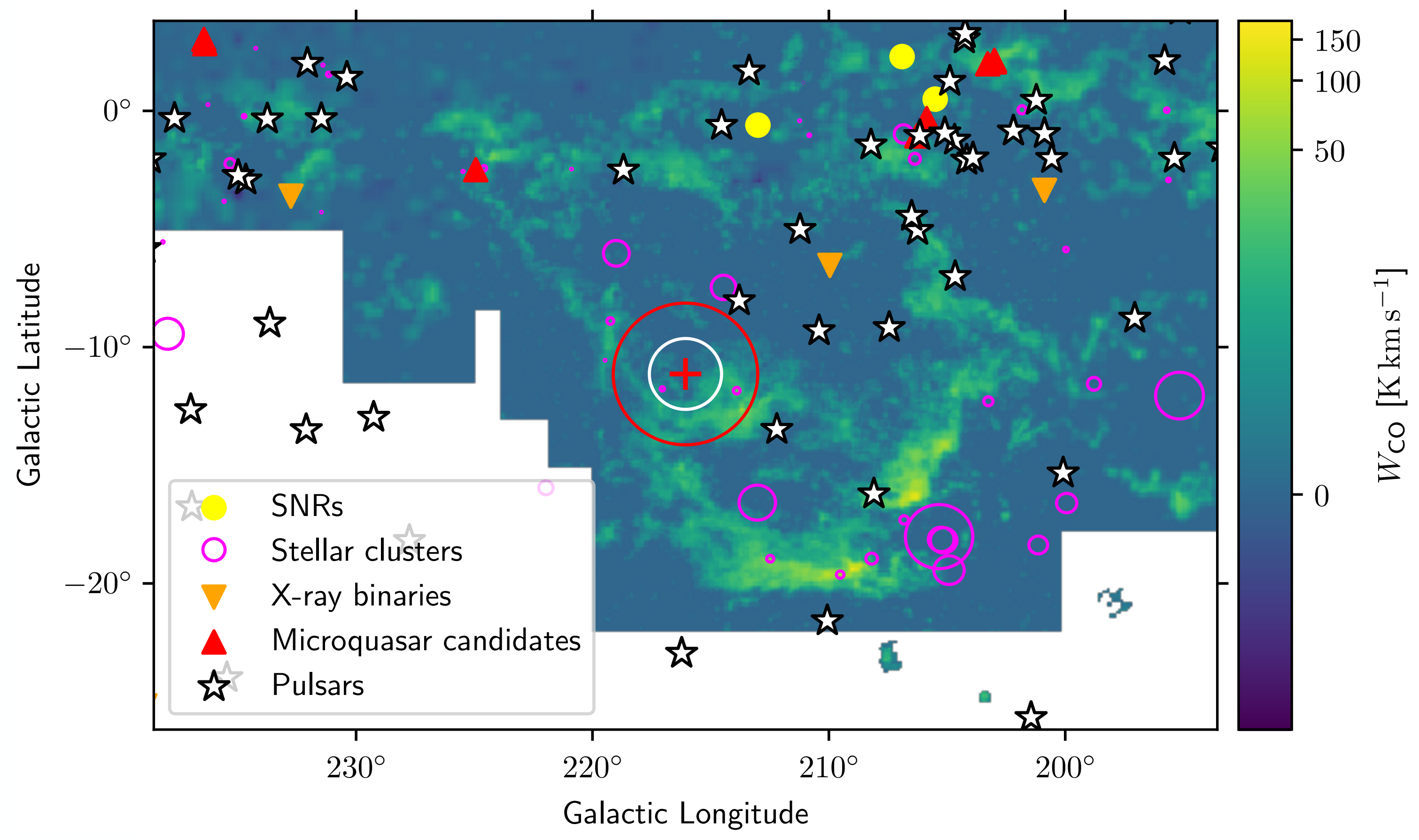

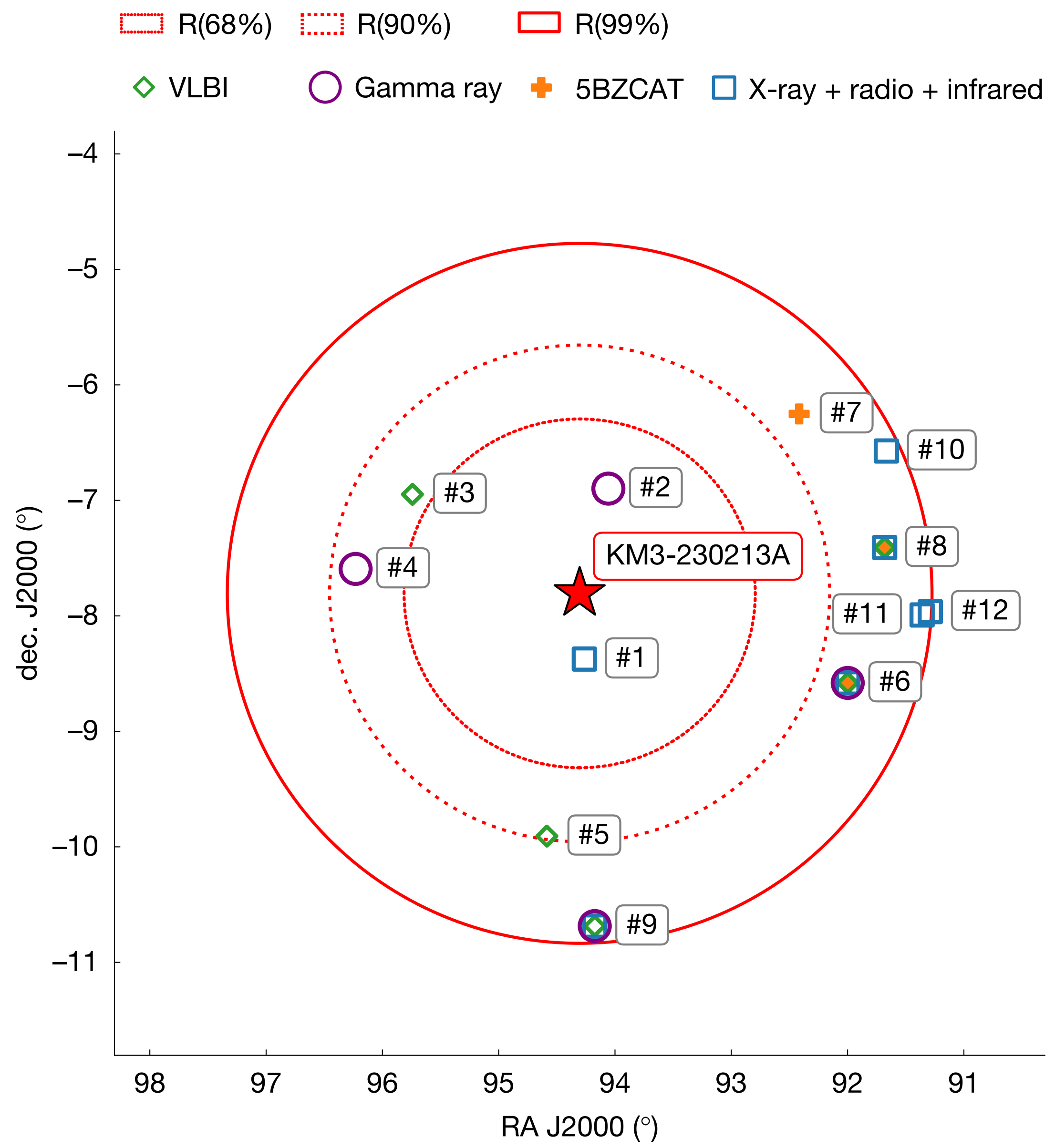

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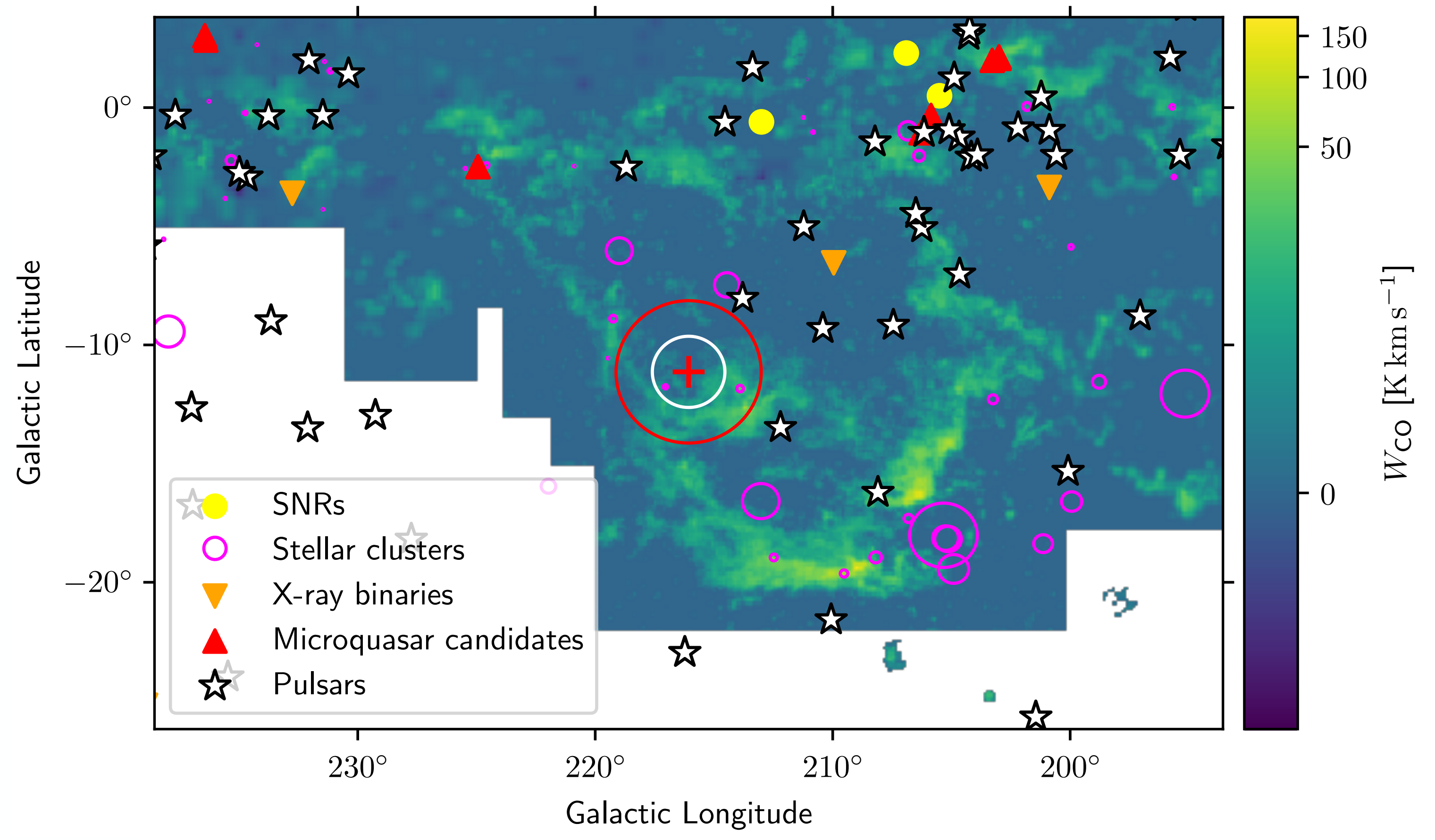

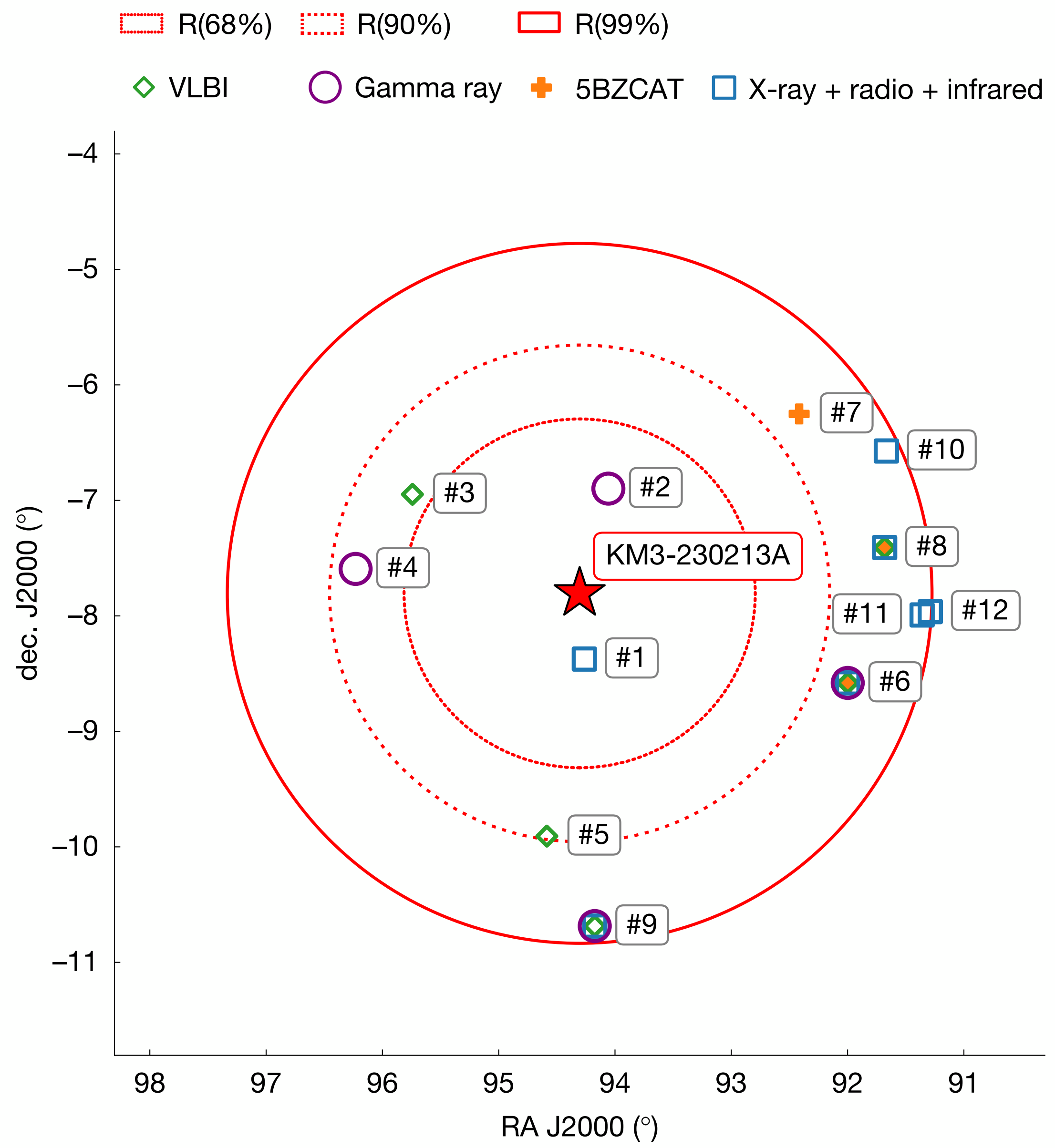

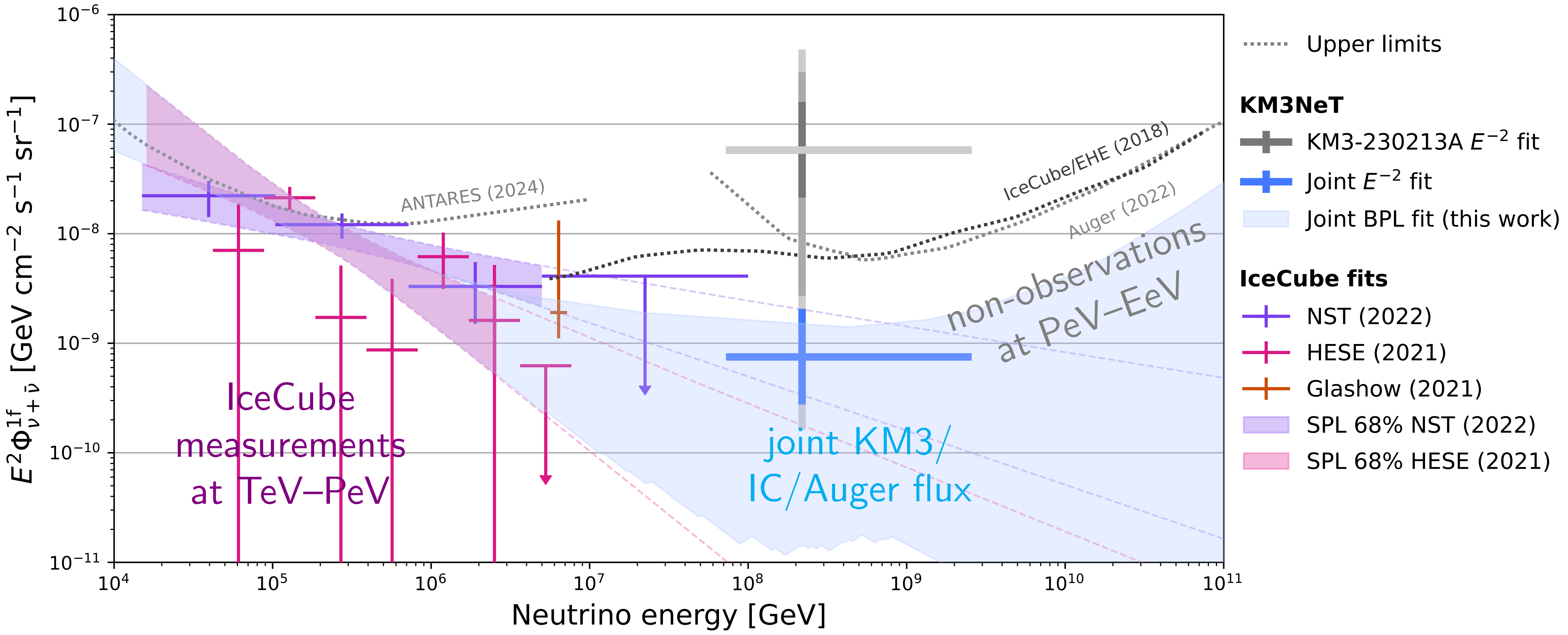

KM3NeT coll. 2025, ICRC2025(1018 +Damien Dornic highlight ta

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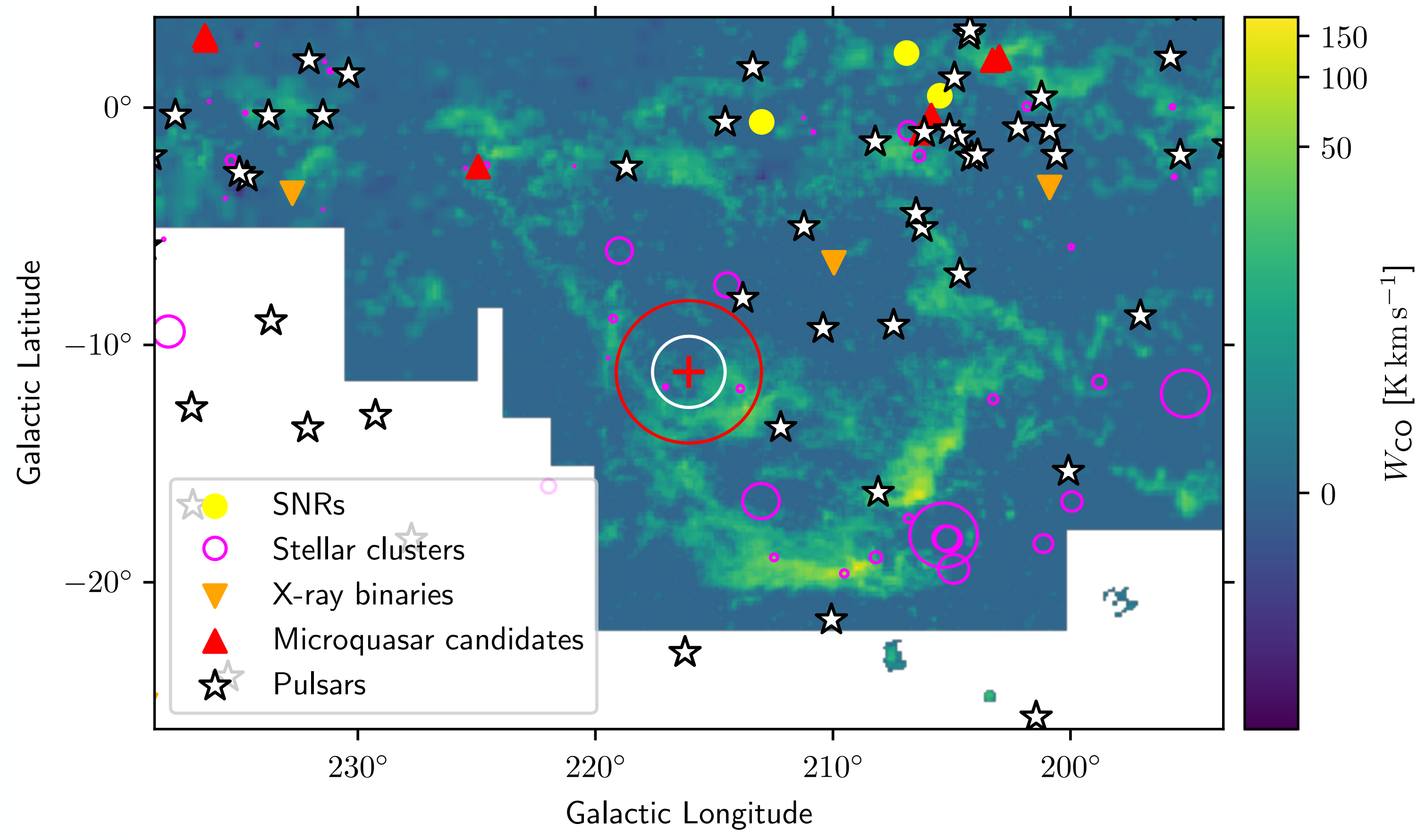
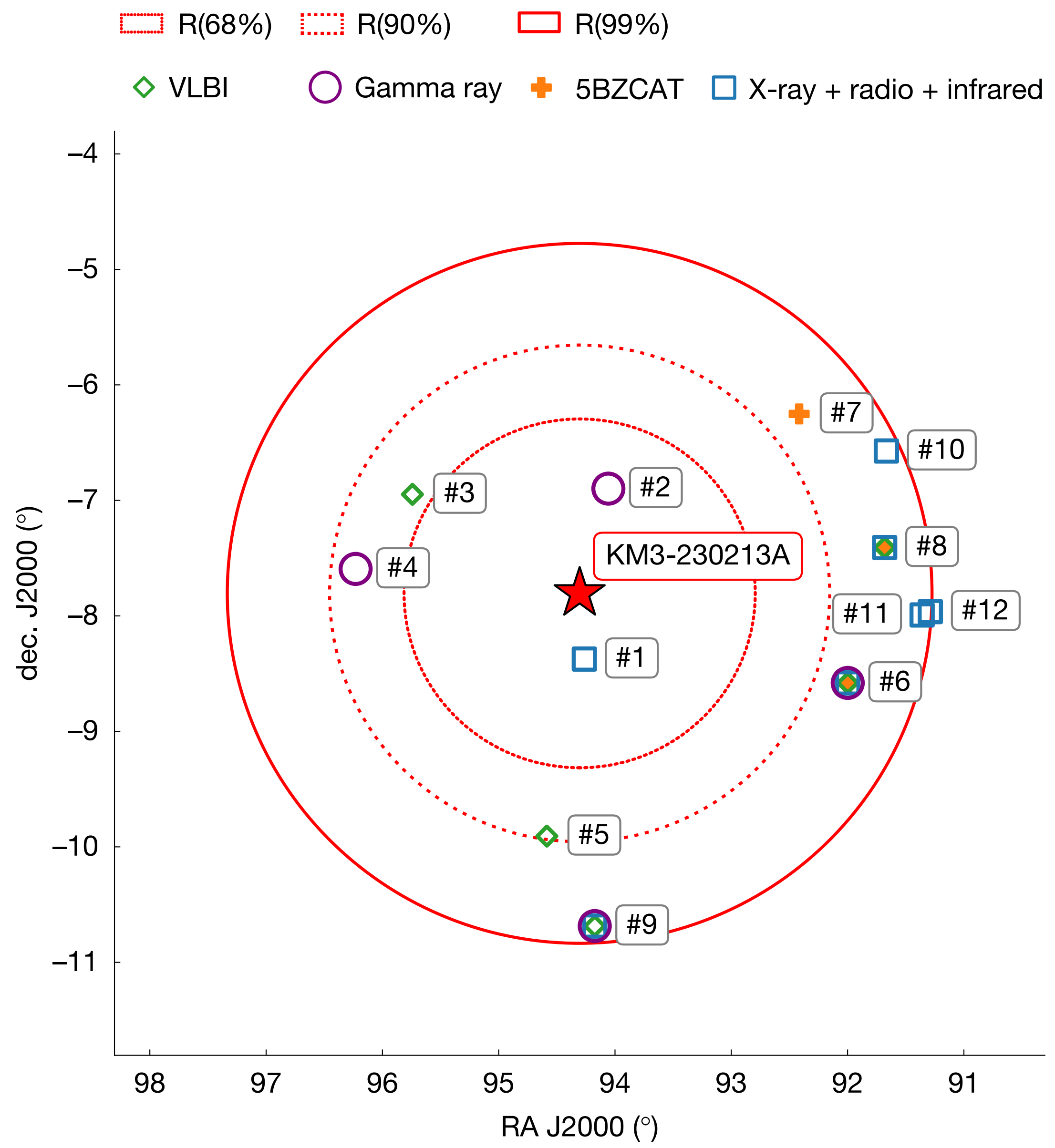
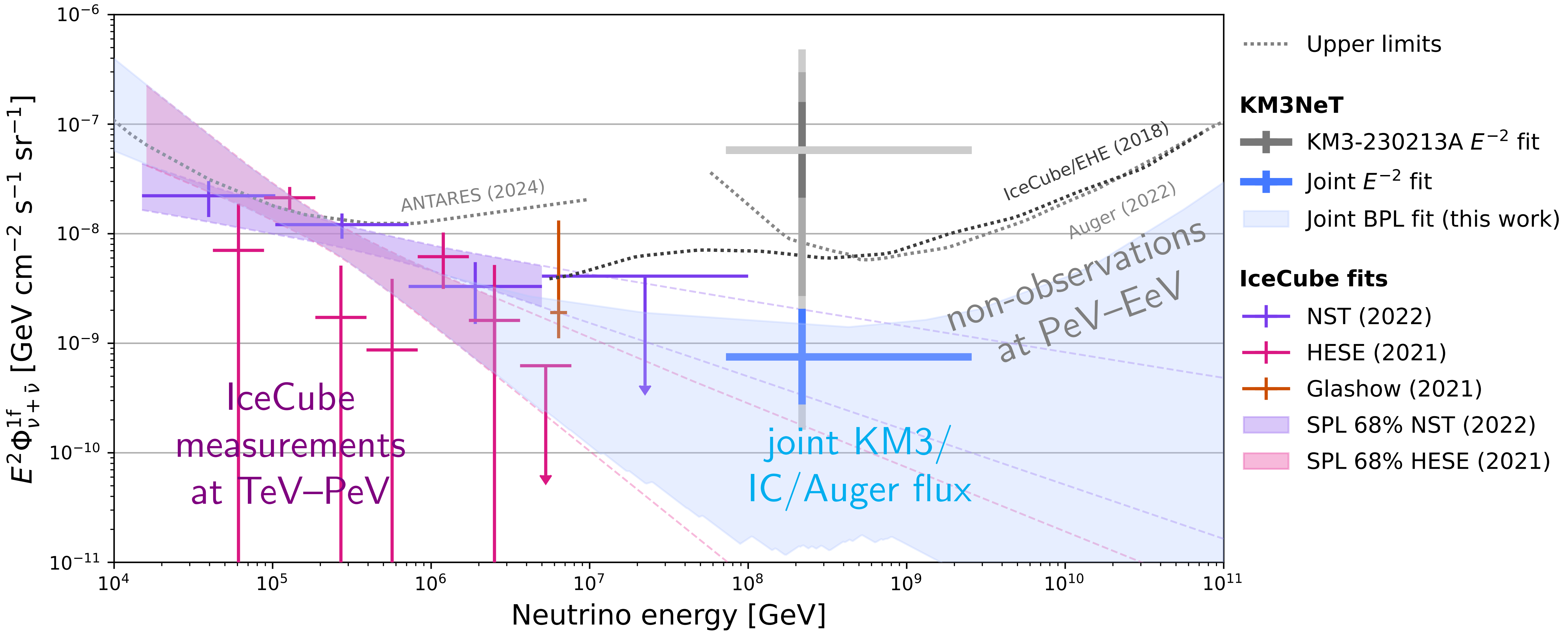




Tension ~2.5 σ with IceCube which makes this event even more interesting!



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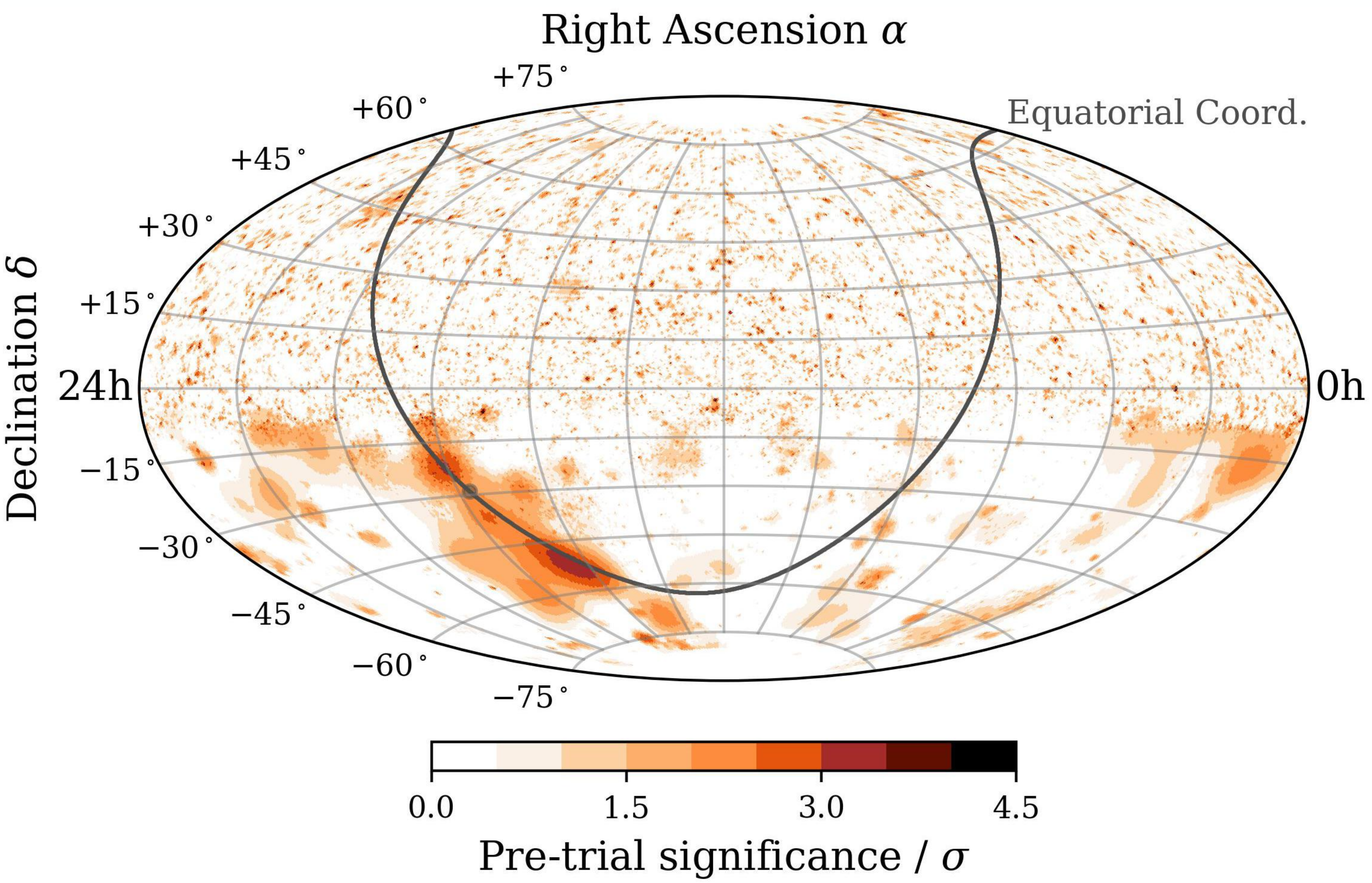

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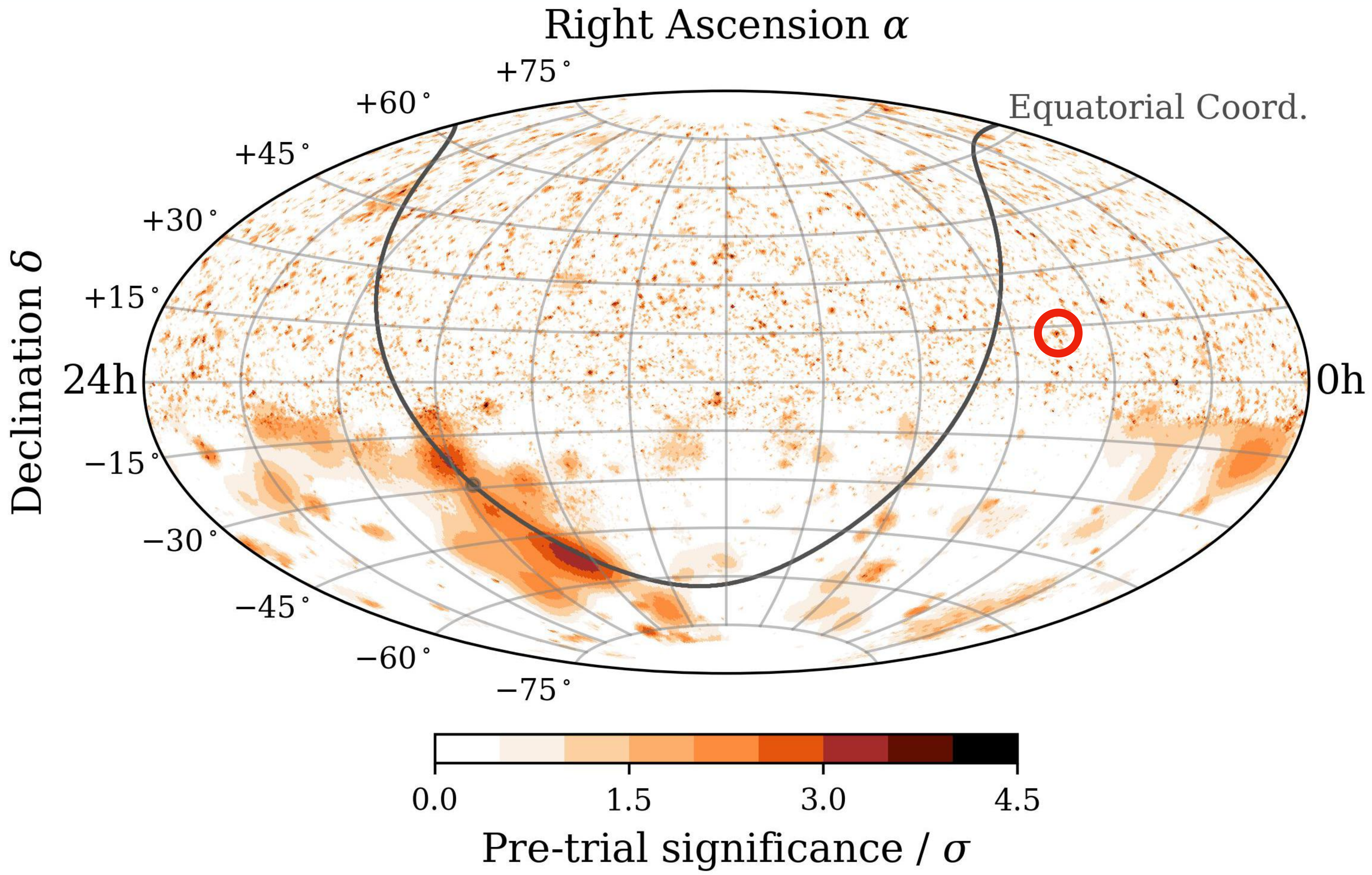

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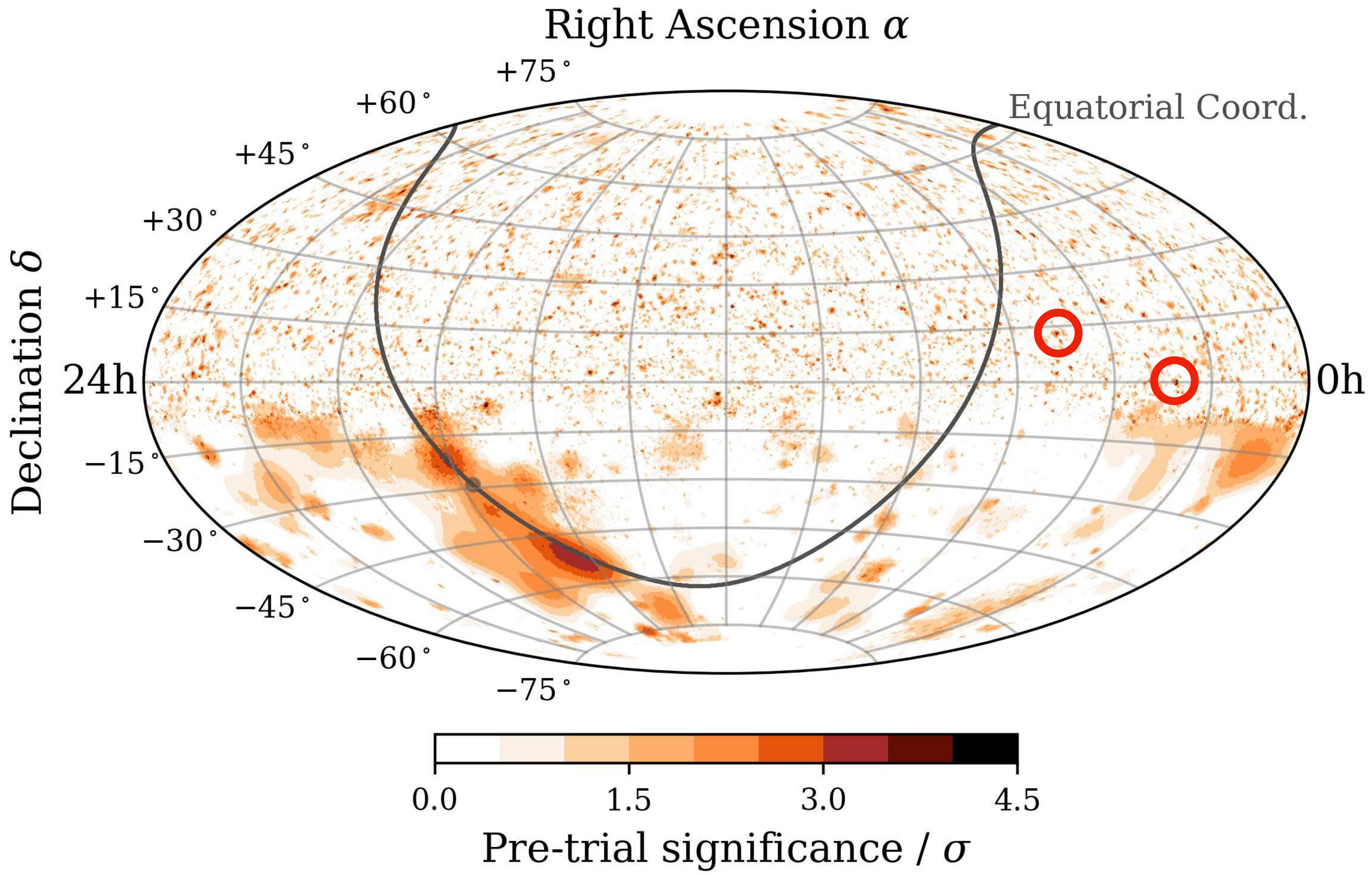

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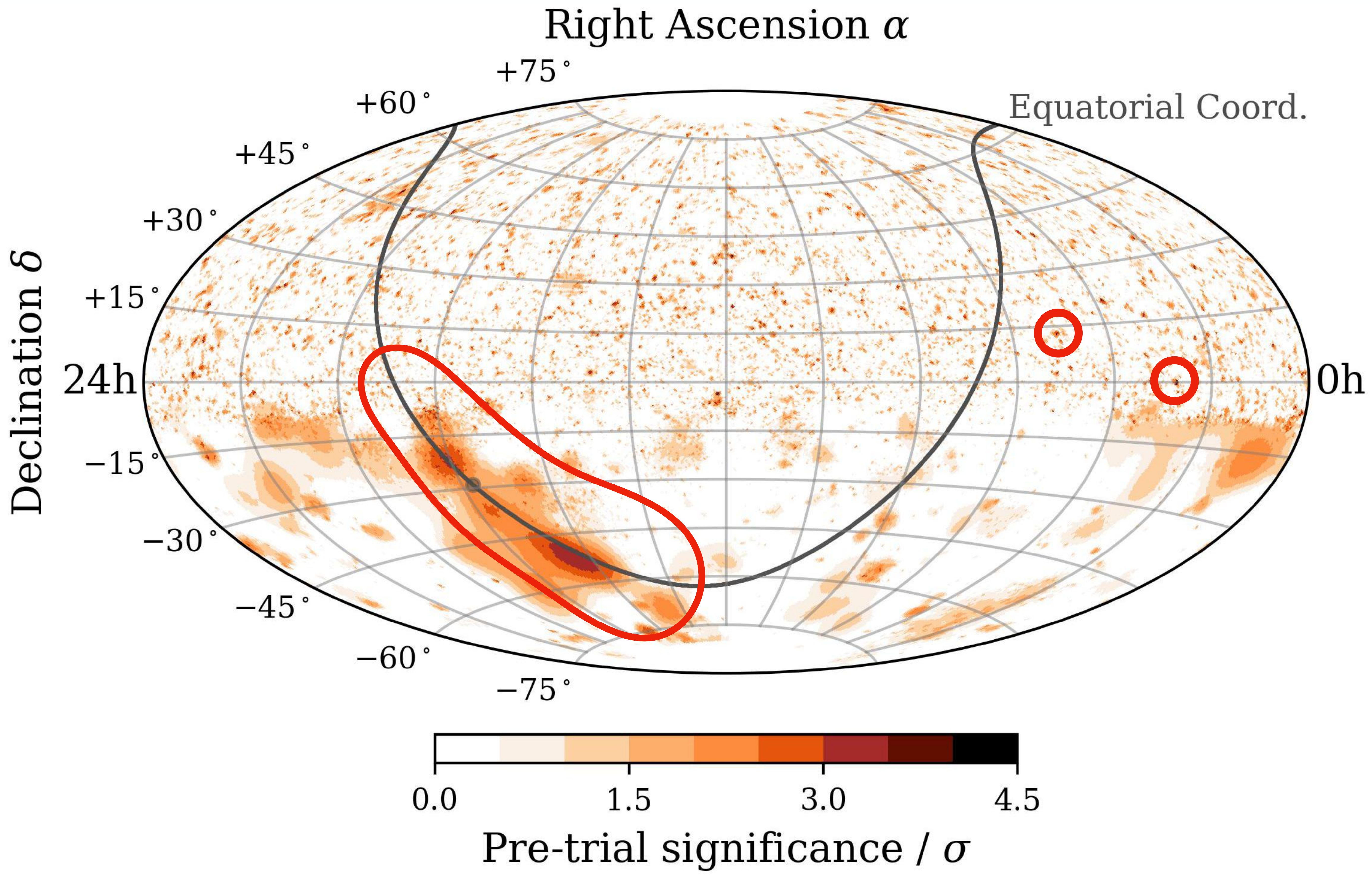

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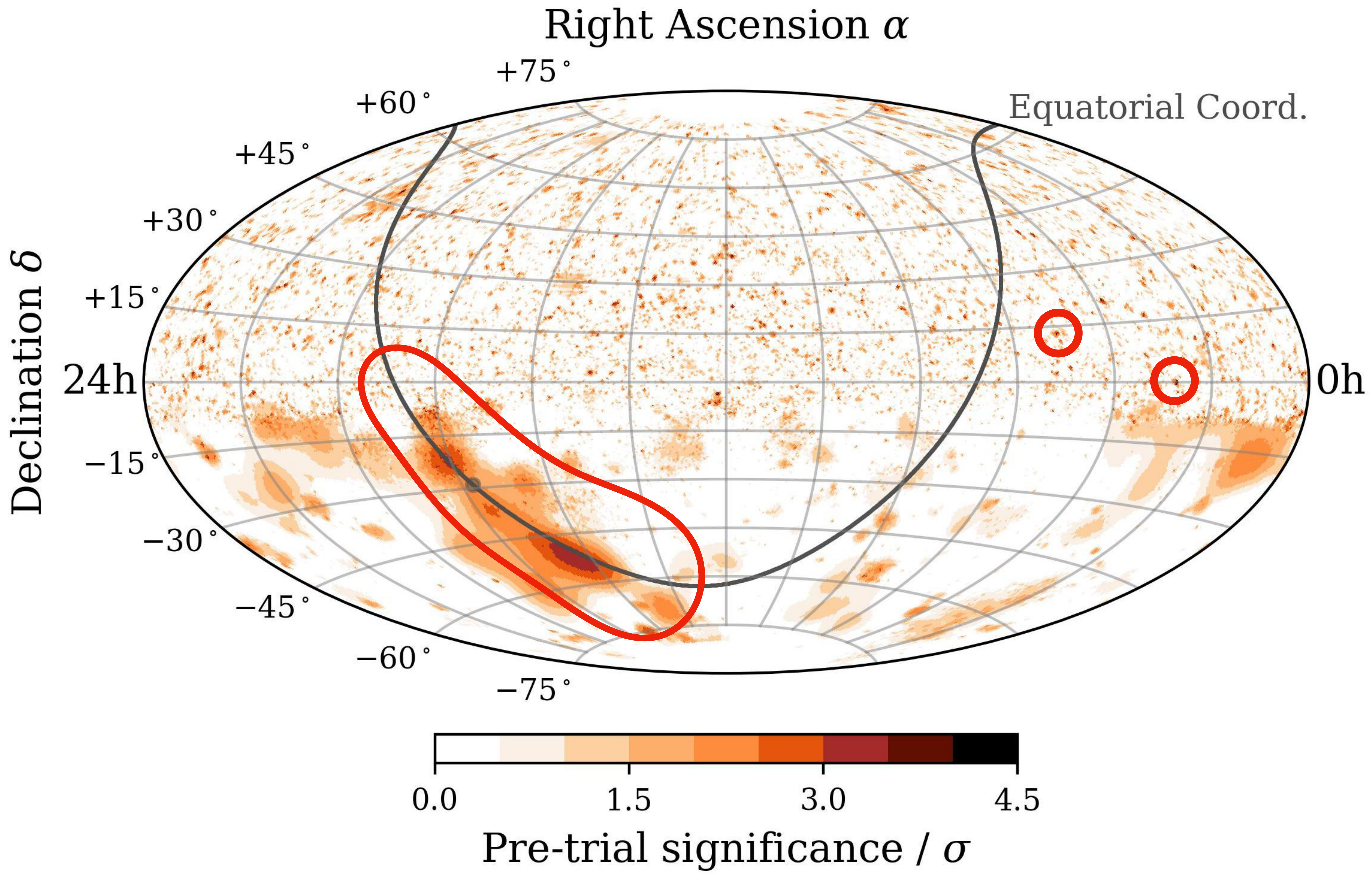

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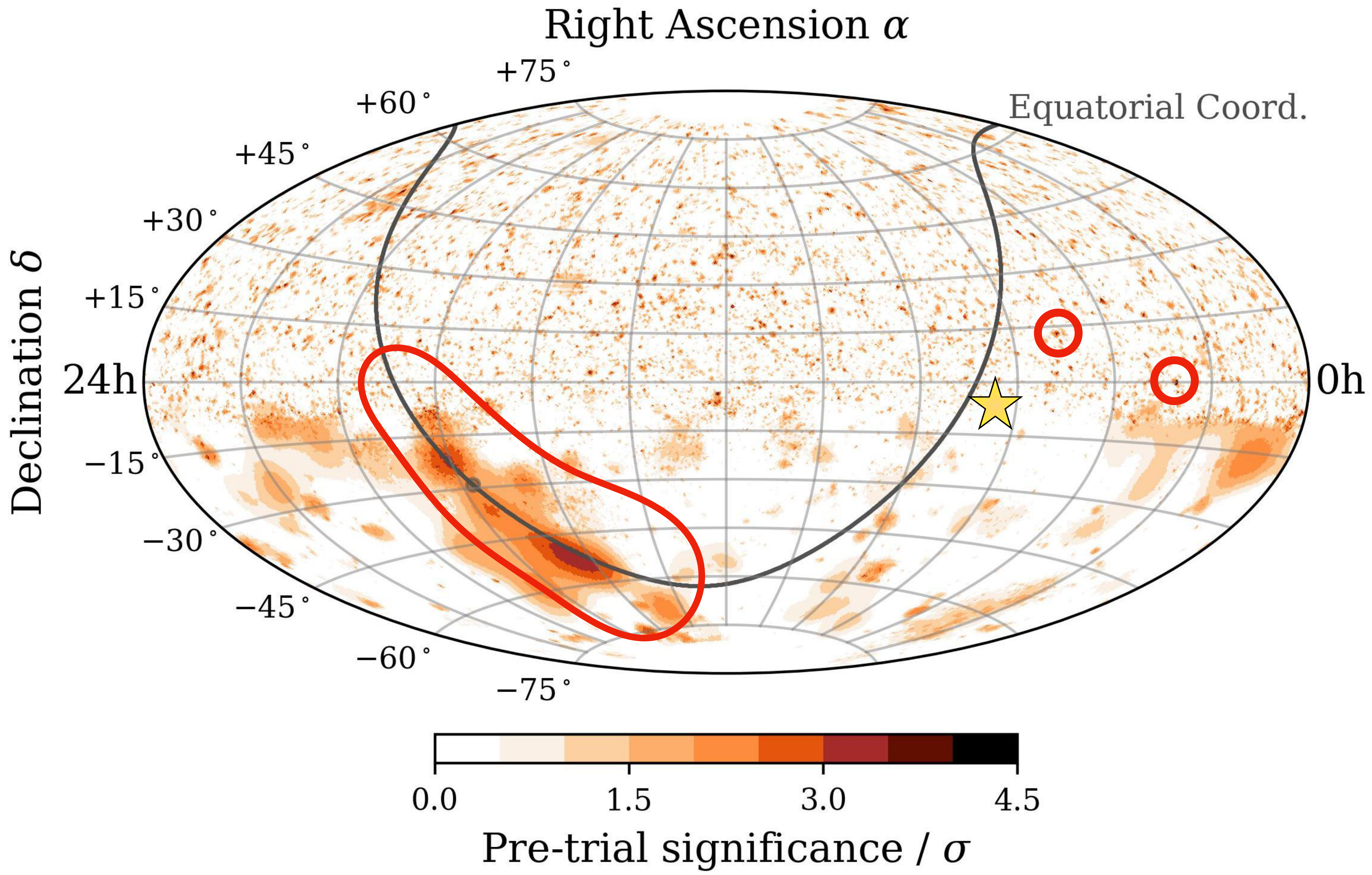

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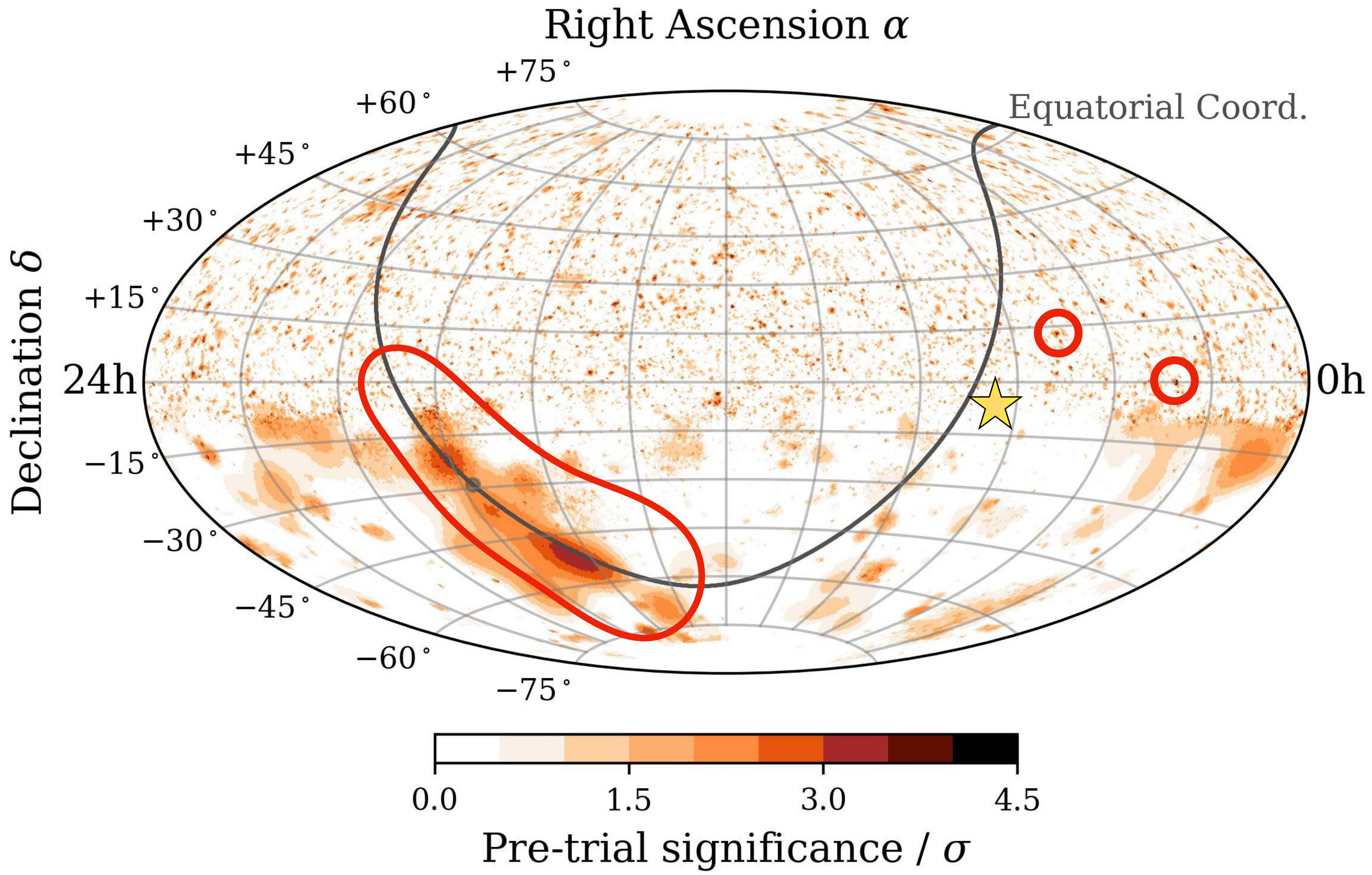
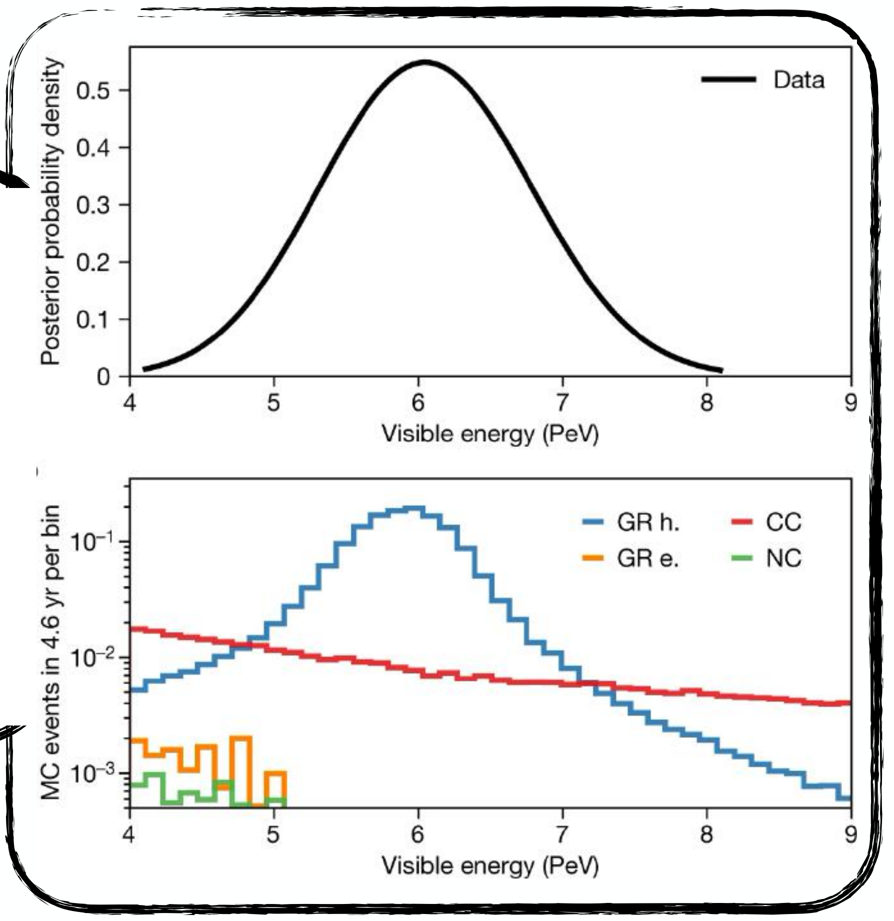


\+ Many significant contributions to neutrino physics:

- Glashow resonance IC coll. Nature 591, (2021)
- Tau neutrinos
- Oscillations, …



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