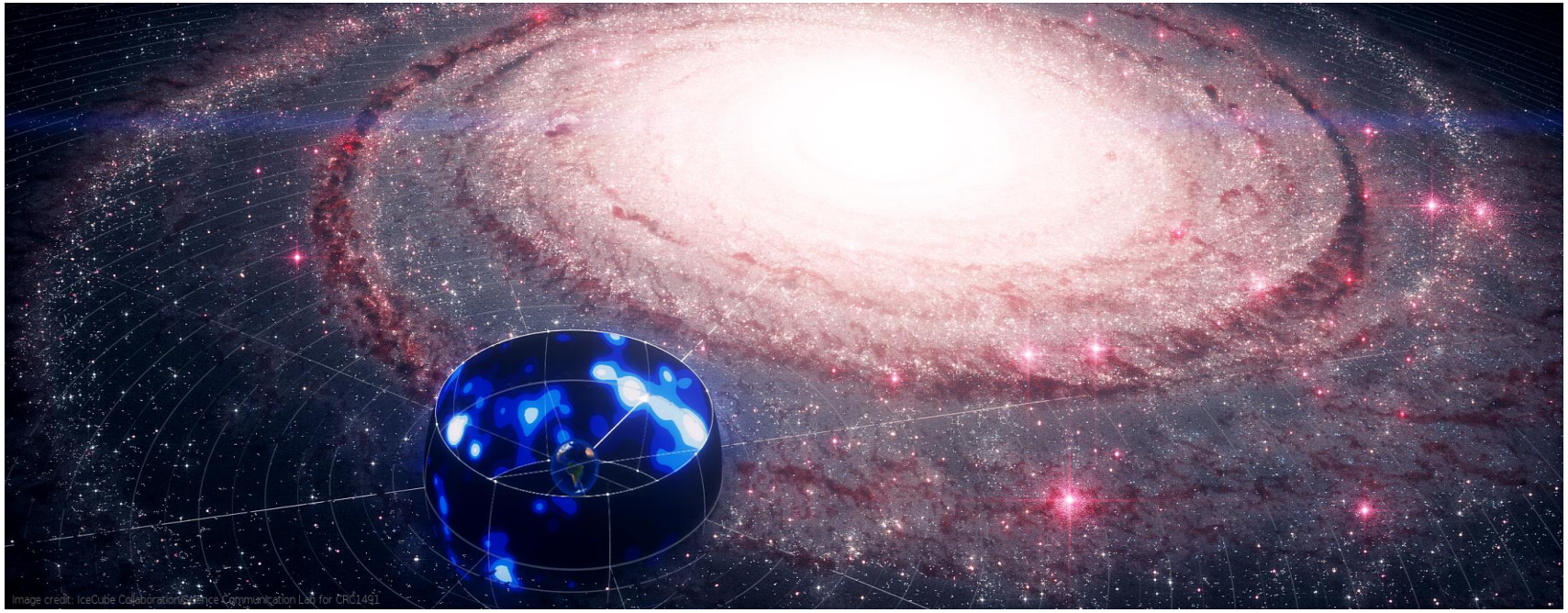
technische universität dortmund

IceCube Neutrino Observatory

SFB 876 Providing Information by Resource-Constrained Data Analysis

SFB1491



Observation of High-Energy Neutrinos from the Galactic Plane

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NeuTel 2023, Venice
October 24th, 2023

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RESEARCH

RESEARCH ARTICLES

NEUTRINO ASTROPHYSICS

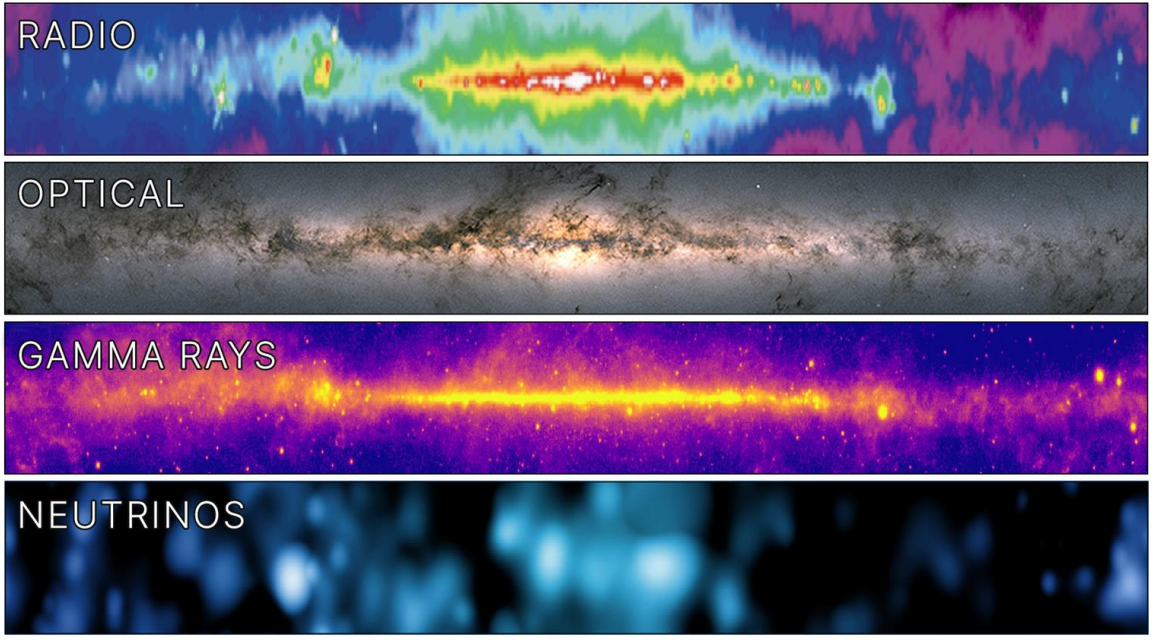
Observation of high-energy neutrinos from the Galactic plane

IceCube Collaboration*†

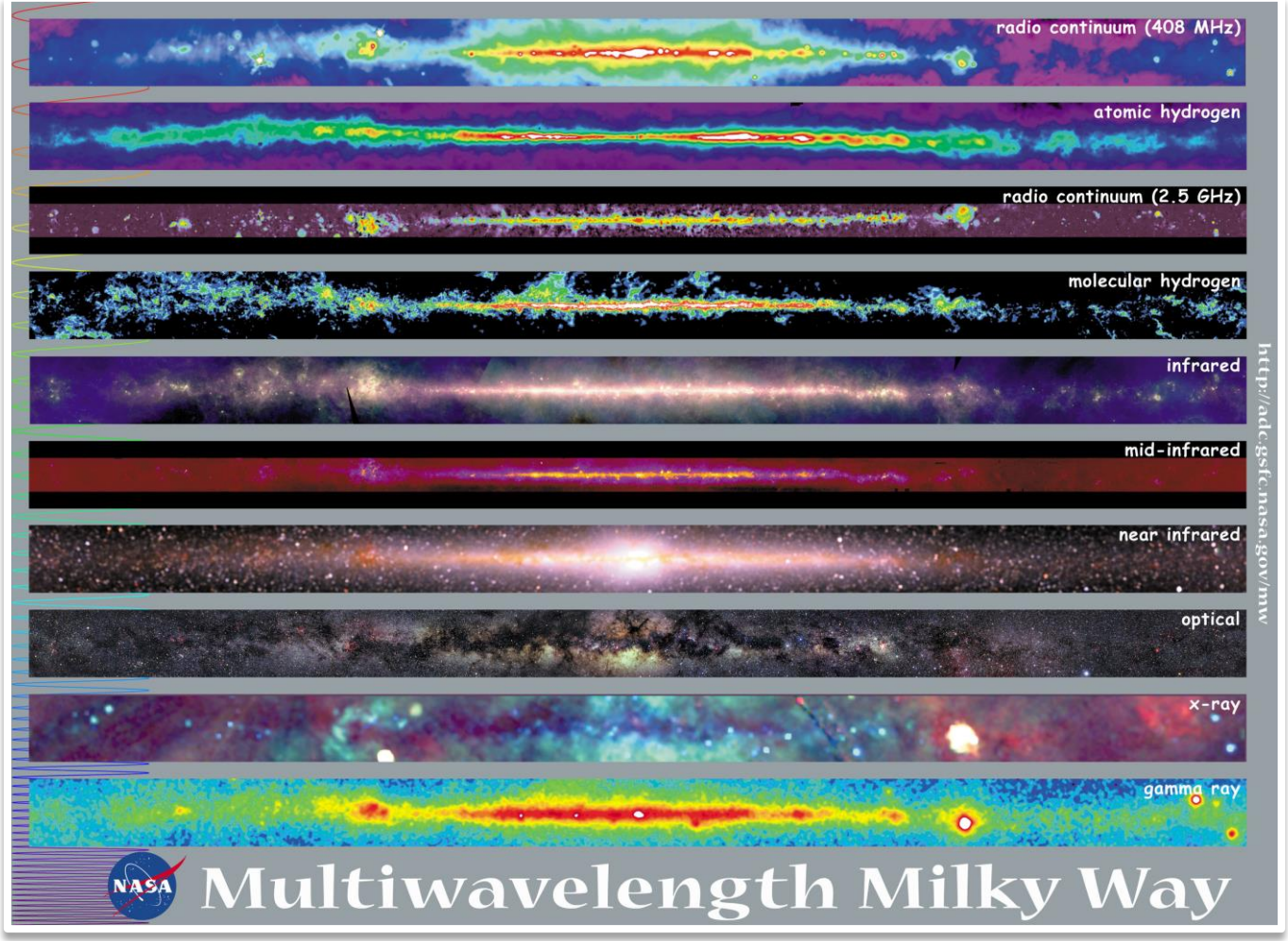
DOI: 10.1126/science.adc9818

Stephen Sclafani

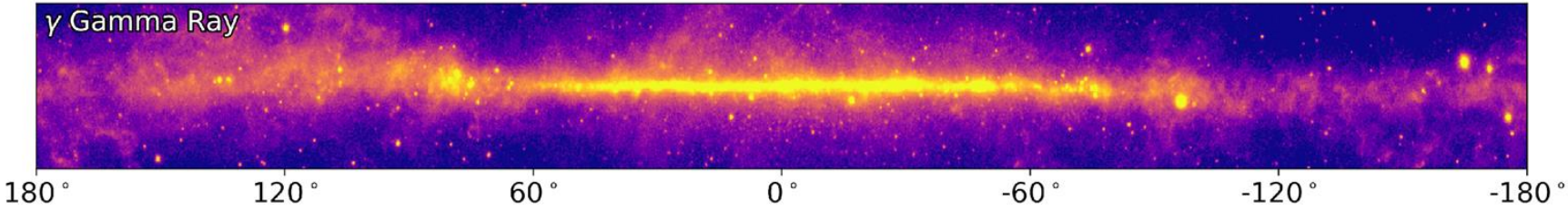
Mirco Hünnefeld



The Multiwavelength Milky Way

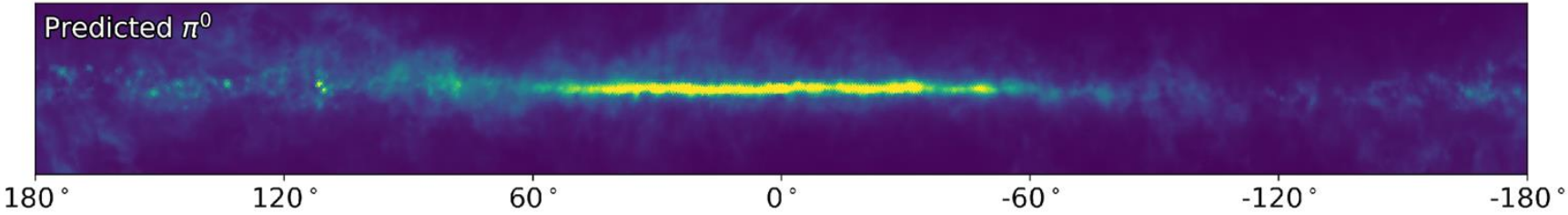


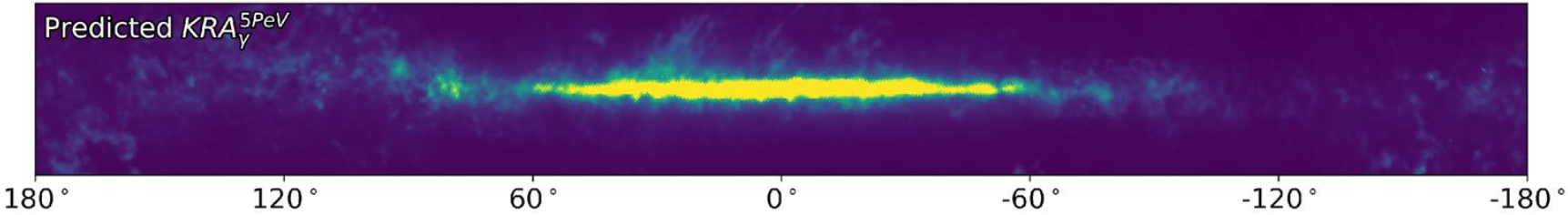
Models of Diffuse Neutrino Emission in the Galactic Plane



$$\pi^0 \rightarrow \gamma + \gamma$$

$$\pi^+ \rightarrow \mu^+ \nu_\mu \rightarrow e^+ \nu_e \bar{\nu}_\mu \nu_\mu$$
$$\pi^- \rightarrow \mu^- \bar{\nu}_\mu \rightarrow e^- \bar{\nu}_e \nu_\mu \bar{\nu}_\mu$$

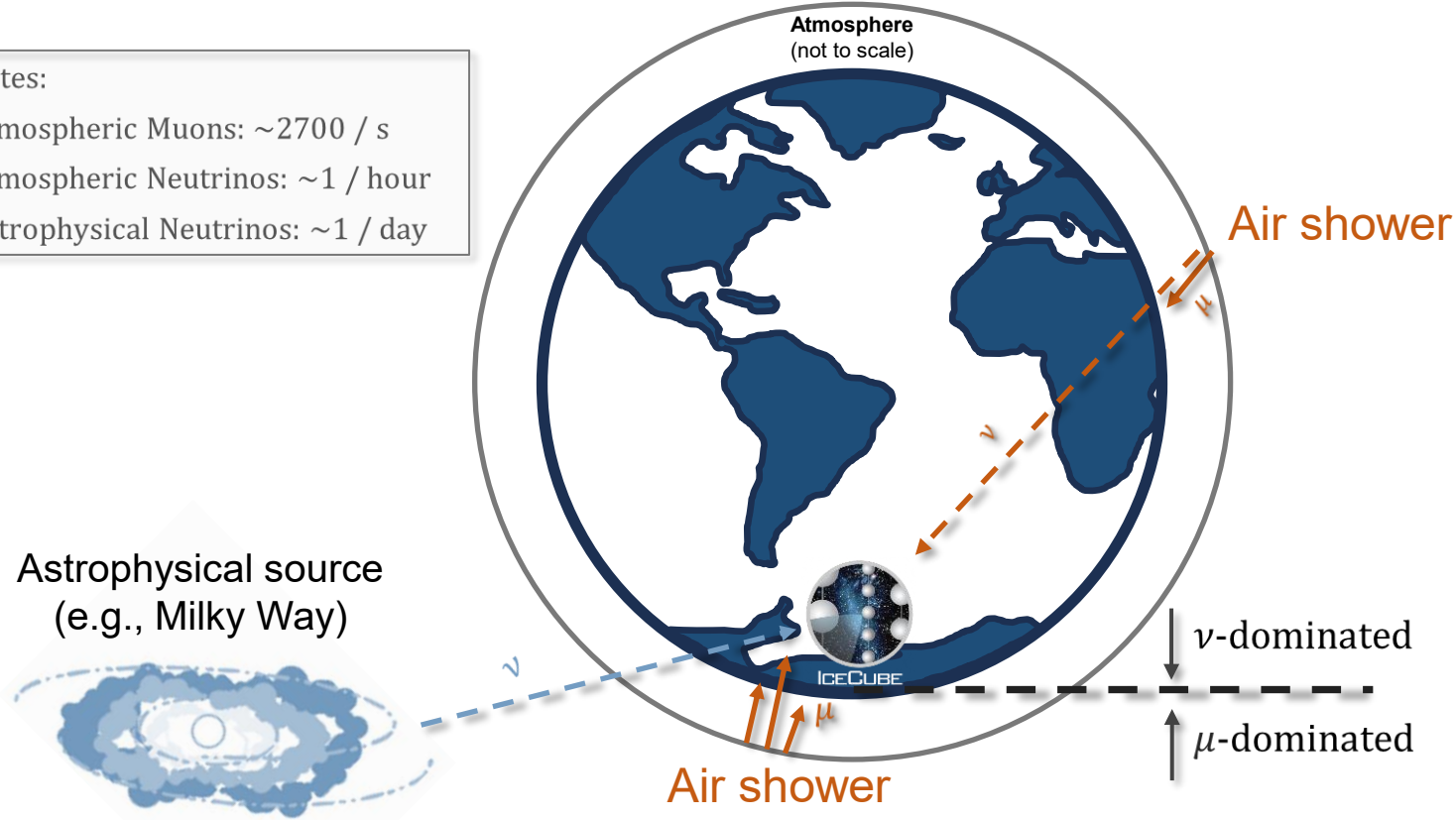




1. Ackermann et al. *The Astrophysical Journal* 750, no. 1 (April 2012): 3.
2. Gaggero et al *The Astrophysical Journal* 815, no. 2 (December 2015): L25.

Challenges of Neutrino Source Searches

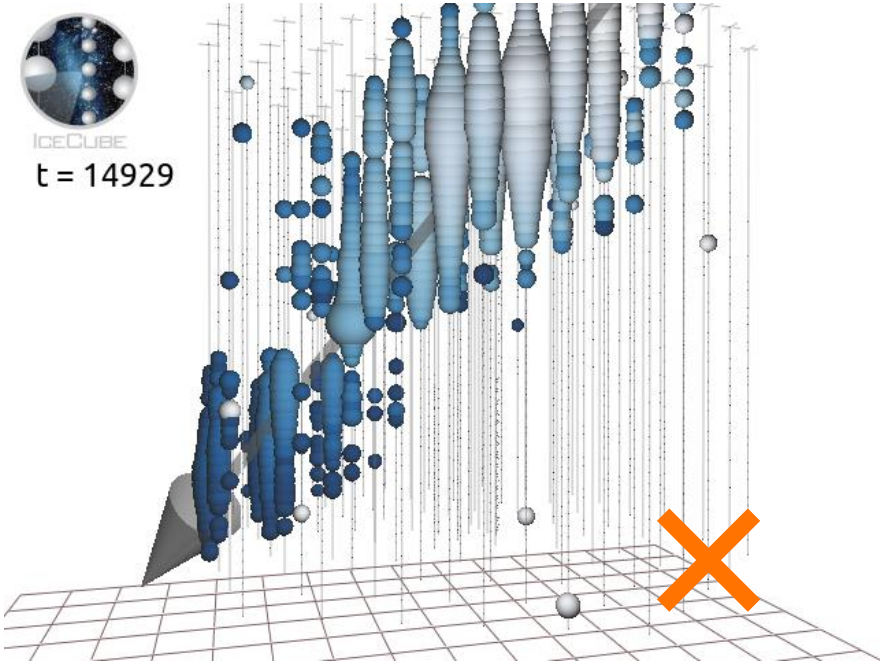
Rates:
Atmospheric Muons: ~2700 / s
Atmospheric Neutrinos: ~1 / hour
Astrophysical Neutrinos: ~1 / day



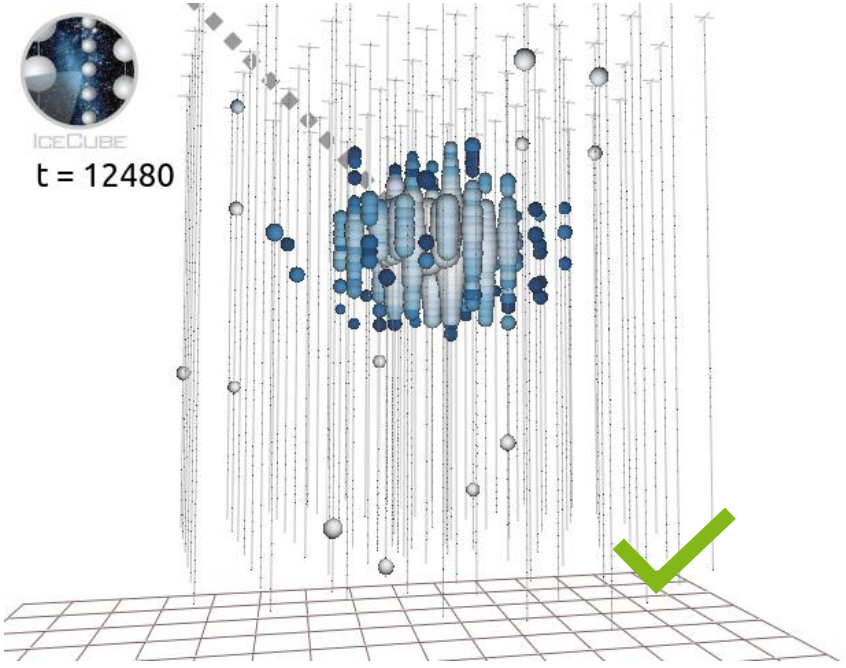
→ Solved challenges with new tools based on deep learning

Selection of Astrophysical Neutrinos

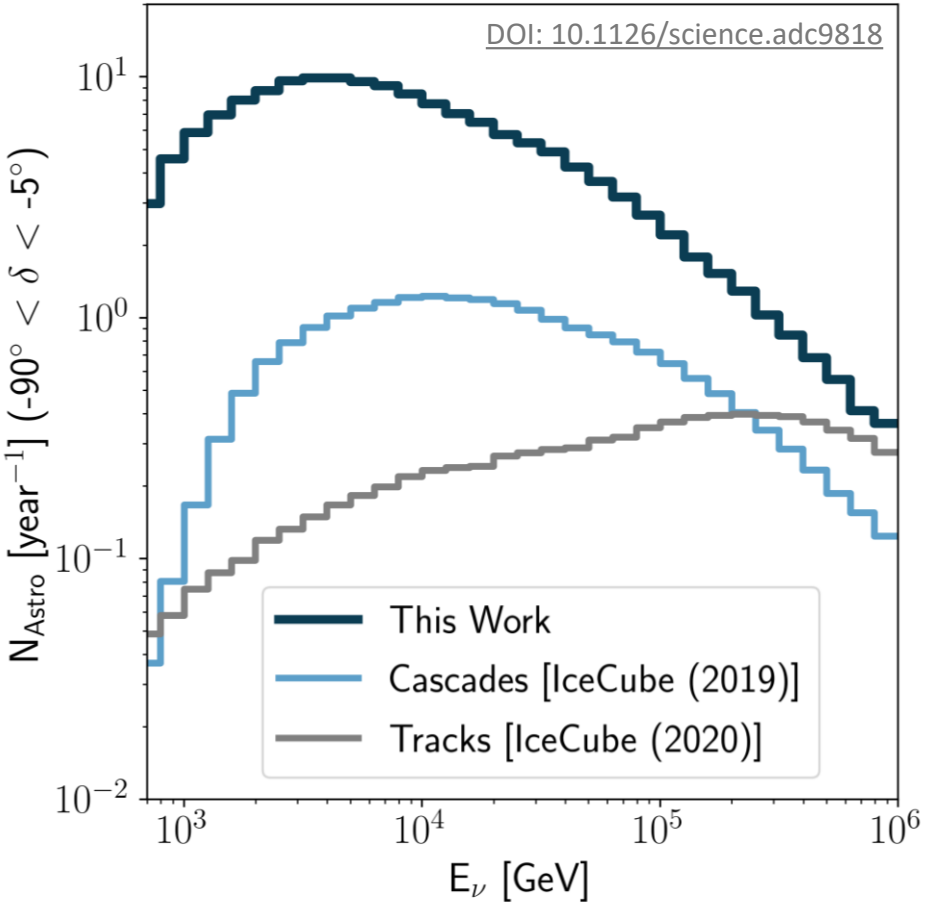
Entering μ

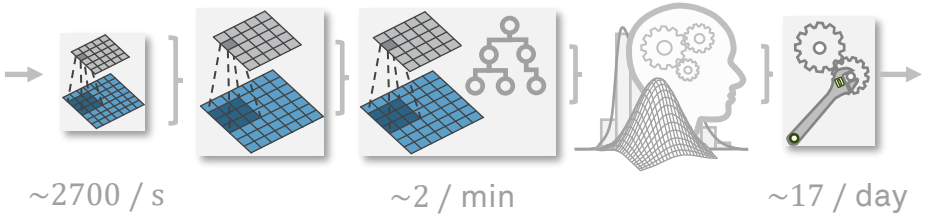


Cascade Event



Selection of Astrophysical Neutrinos

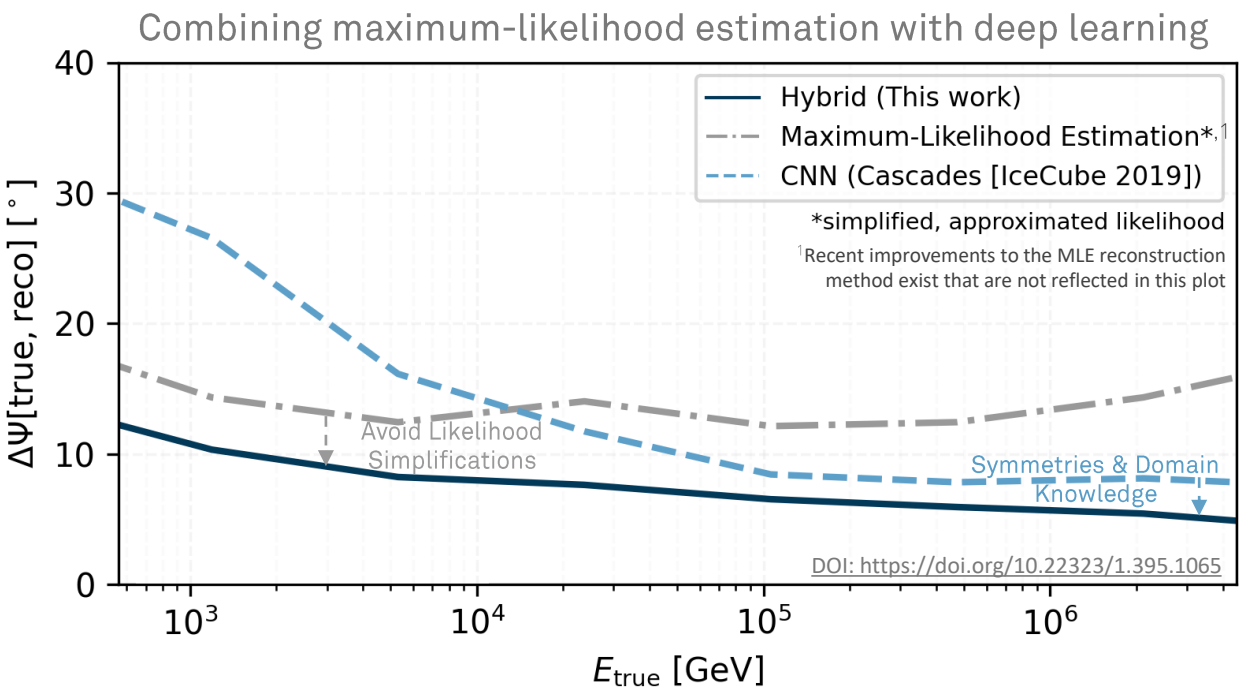


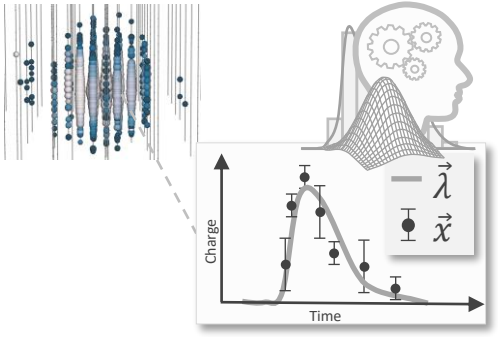


Event selection:

- Employs series of convolutional neural networks (CNNs) and boosted decision trees
- Background reduced by almost 8 orders of magnitude
- 30 times as many events as precursor analysis

New hybrid reconstruction method utilized





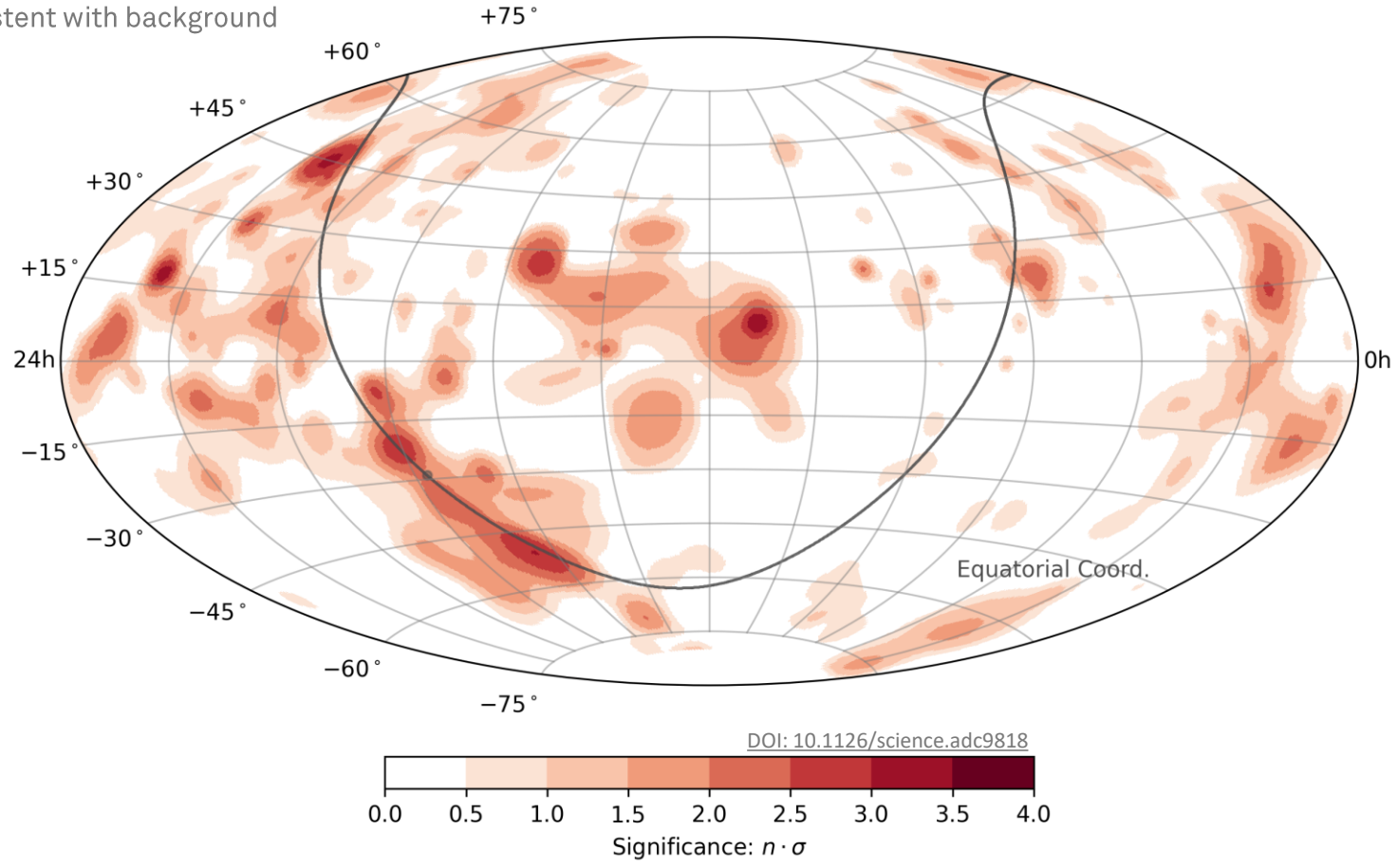
Improvements due to novel methods:

- Improved reconstruction resolution over entire energy range
- 30 times as many events
- Analysis sensitivity improved by a factor of 3

Equivalent to savings of 75 years of detector livetime and > $500 million

Results from All-Sky Search

Individual warm spots
consistent with background



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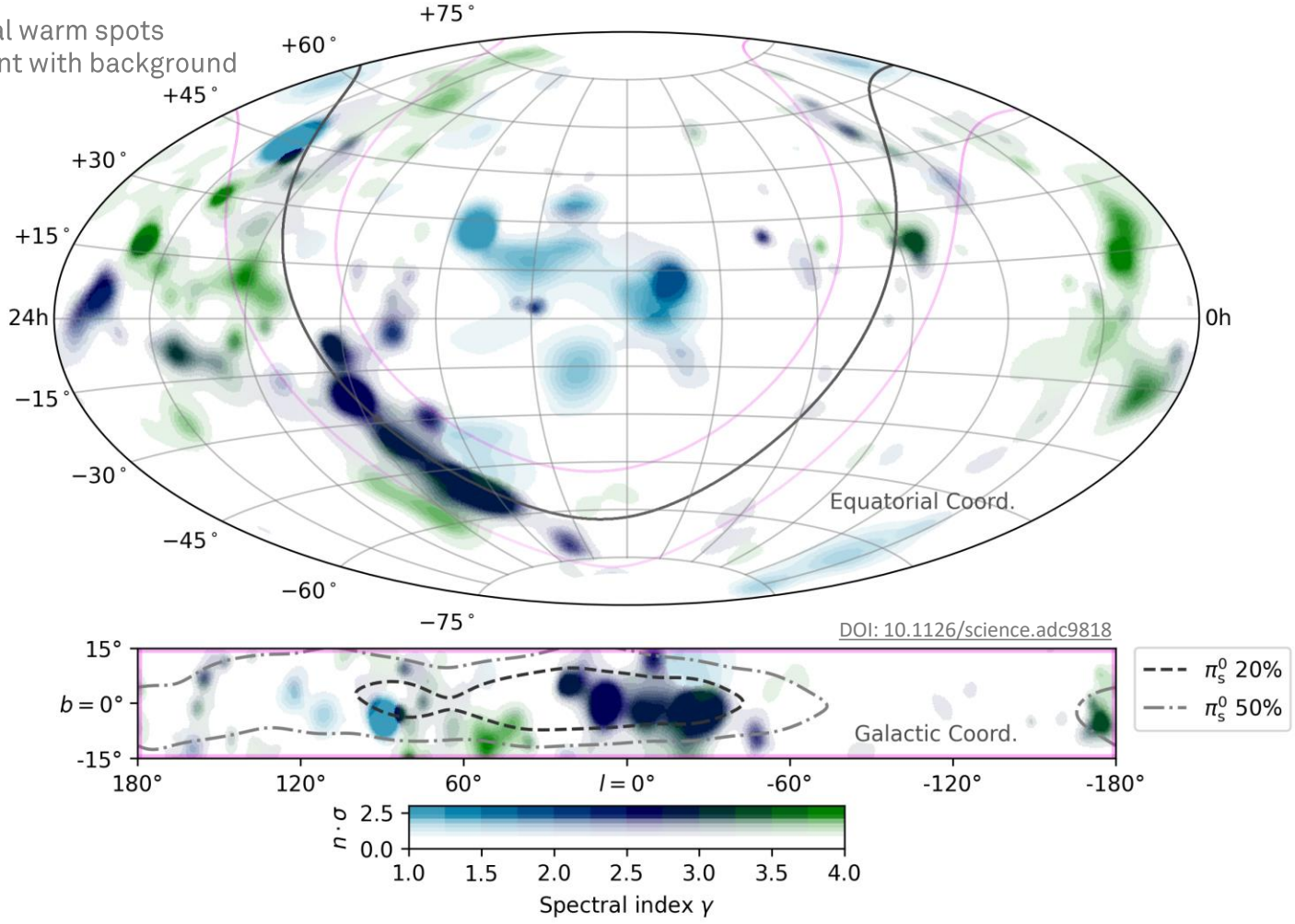
Results from All-Sky Search

Individual warm spots consistent with background



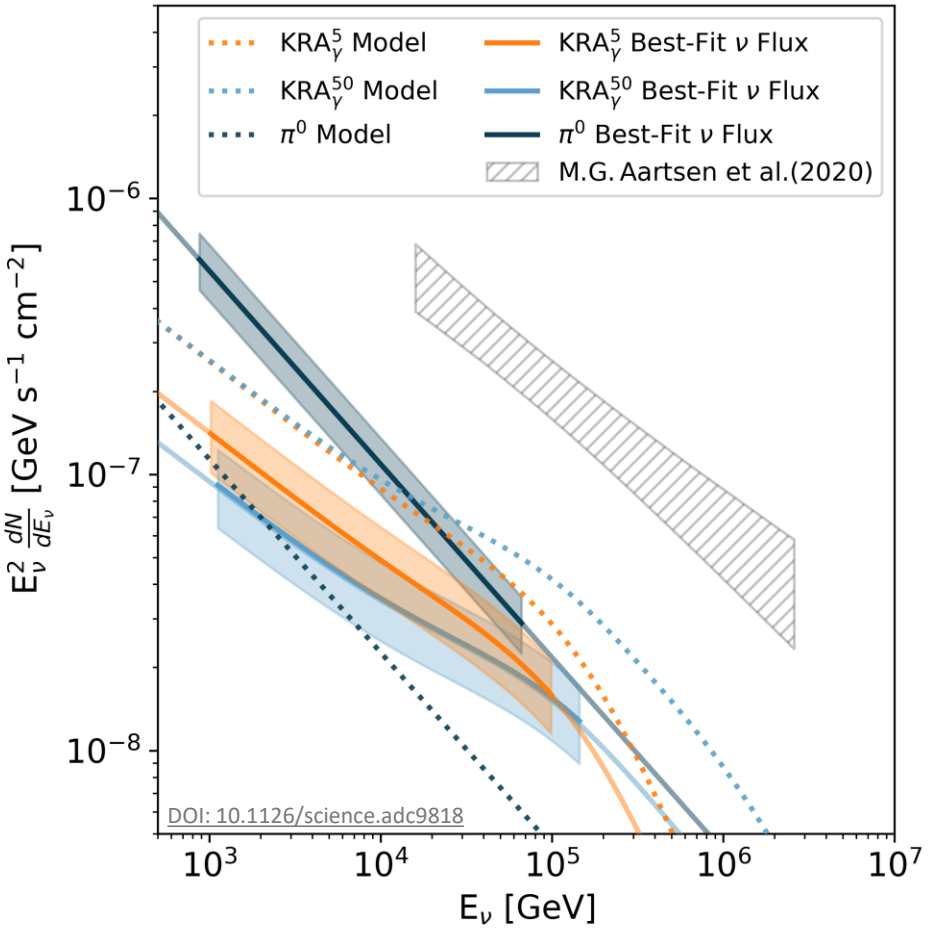
Results from Diffuse Galactic Plane Searches

After trial-correction: 4.5σ

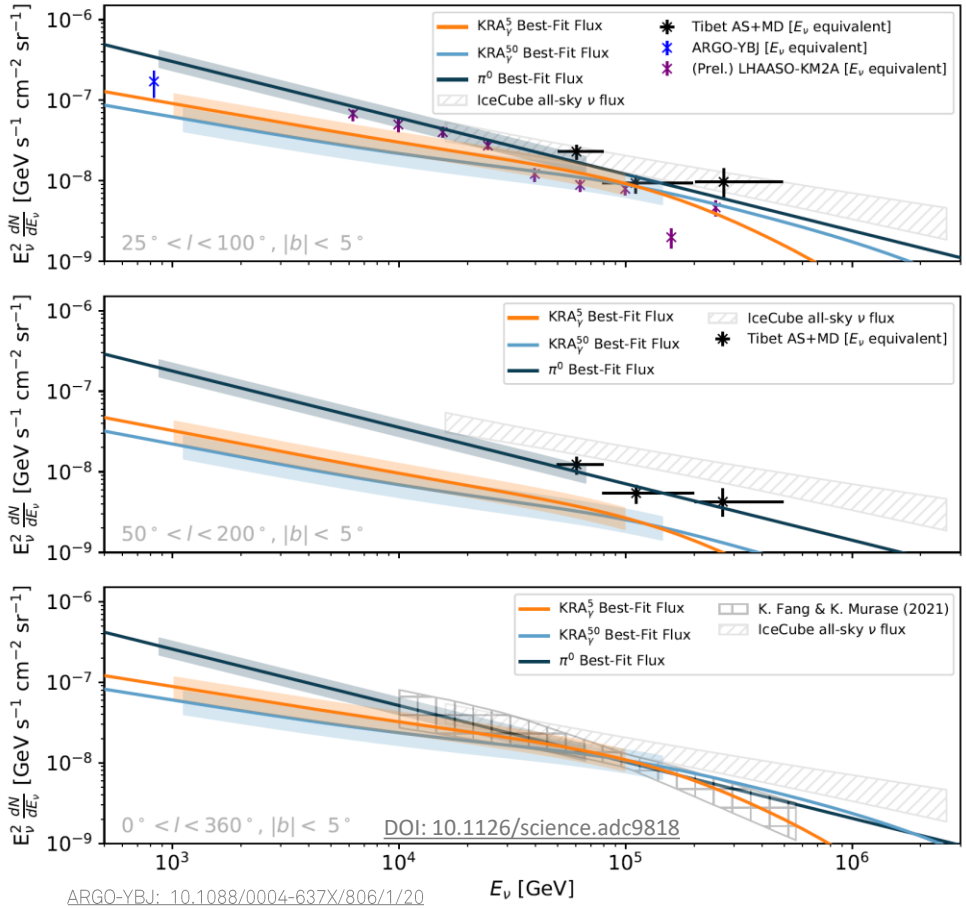
Model	Signal Events	Pre-trial p-value ($N\sigma$)
π^0	748	1.26×10^{-6} (4.71σ)
KRA_γ^5	276	6.13×10^{-6} (4.37σ)
KRA_γ^{50}	211	3.72×10^{-5} (3.96σ)

π^0: based on Fermi-LAT gamma-ray measurements (DOI: 10.1088/0004-637X/750/1/3)
$\mathrm{KRA}_\gamma^{5/50}$: based on Gaggero et. *al* (DOI 10.1088/2041-8205/815/2/L25)

- Shaded regions depict energy ranges that contribute most to the significance
- Galactic flux may explain up to ~10% of astrophysical flux
- Relative model contributions depend on location on the sky
- Note that the analysis only fits the model normalization; spectrum is kept fixed to model prediction

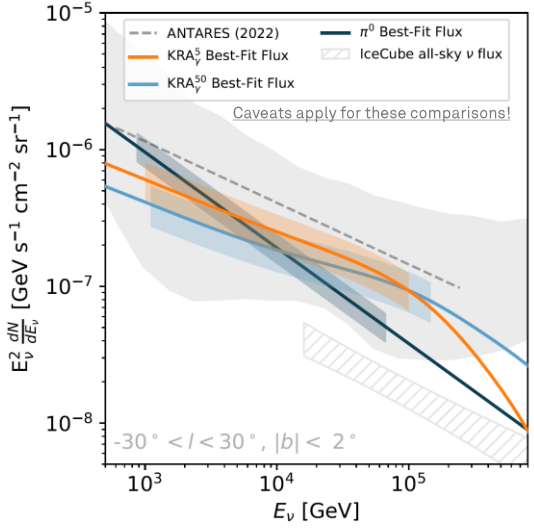


Comparisons to other measurements are challenging



ARGO-YBJ: 10.1088/0004-637X/806/1/20
(Prel.) LHAASO-KM2A: 10.22323/1.395.0859
Tibet AS+MD: 10.1103/PhysRevLett.126.141101

- Conversion of gamma ray measurements assumes pp scenario without attenuation
- Caveats apply for these comparisons!
  - IceCube measurement is over entire sky: separate measurements for individual sky regions are required for comparisons
  - Only normalization is fit for, not spectrum



ANTARES (2022): 10.1016/j.physletb.2023.137951

Follow-up Measurements of the GP Neutrino Signal

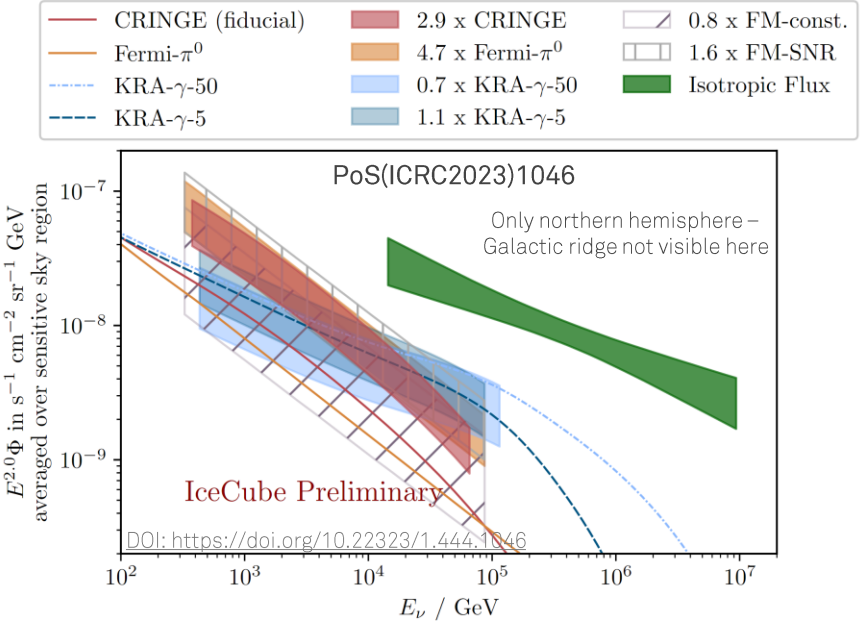
Performed Analyses

- Search for neutrino emission in southern sky and GP with IceCube starting tracks ($< 2\sigma$ for GP)[1]
  - Consistent with expectations from cascade result
- Analysis of 12.3 years of IceCube track data in northern sky (2.7σ significance for GP signal)[2]
  - Independent detection channel to cascades
  - Flux consistent with cascade measurement
  - No clear preference yet for any of the tested models

Future Analyses

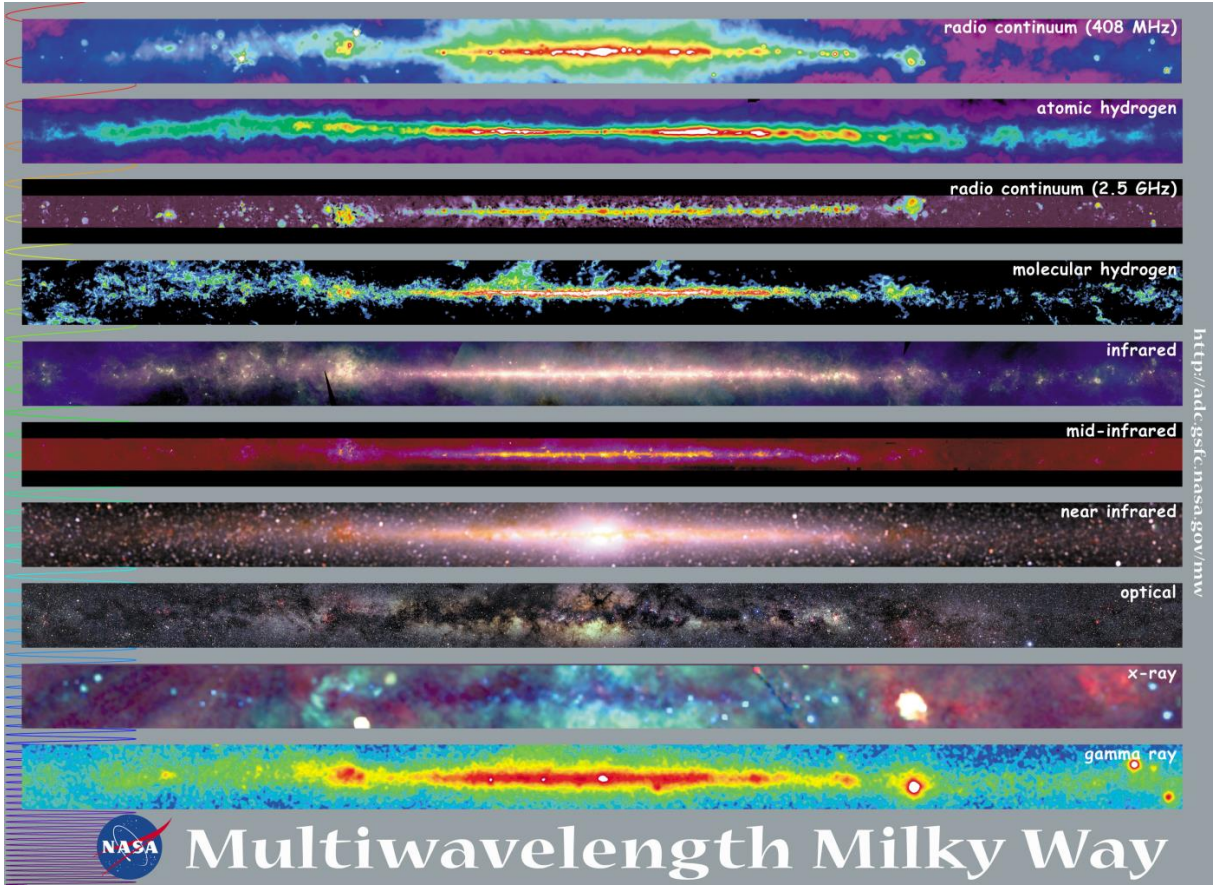
- Combined analyses utilizing track + cascade datasets
- Segmentation of observed flux along GP
  - Model independent approach
  - Measurement of individual regions along GP to enable better comparisons to gamma-ray measurements
  - If possible: extract information on energy spectrum
- Joint analyses with other neutrino telescopes

CRINGE Model: DOI 10.3847/1538-4357/acc1e2

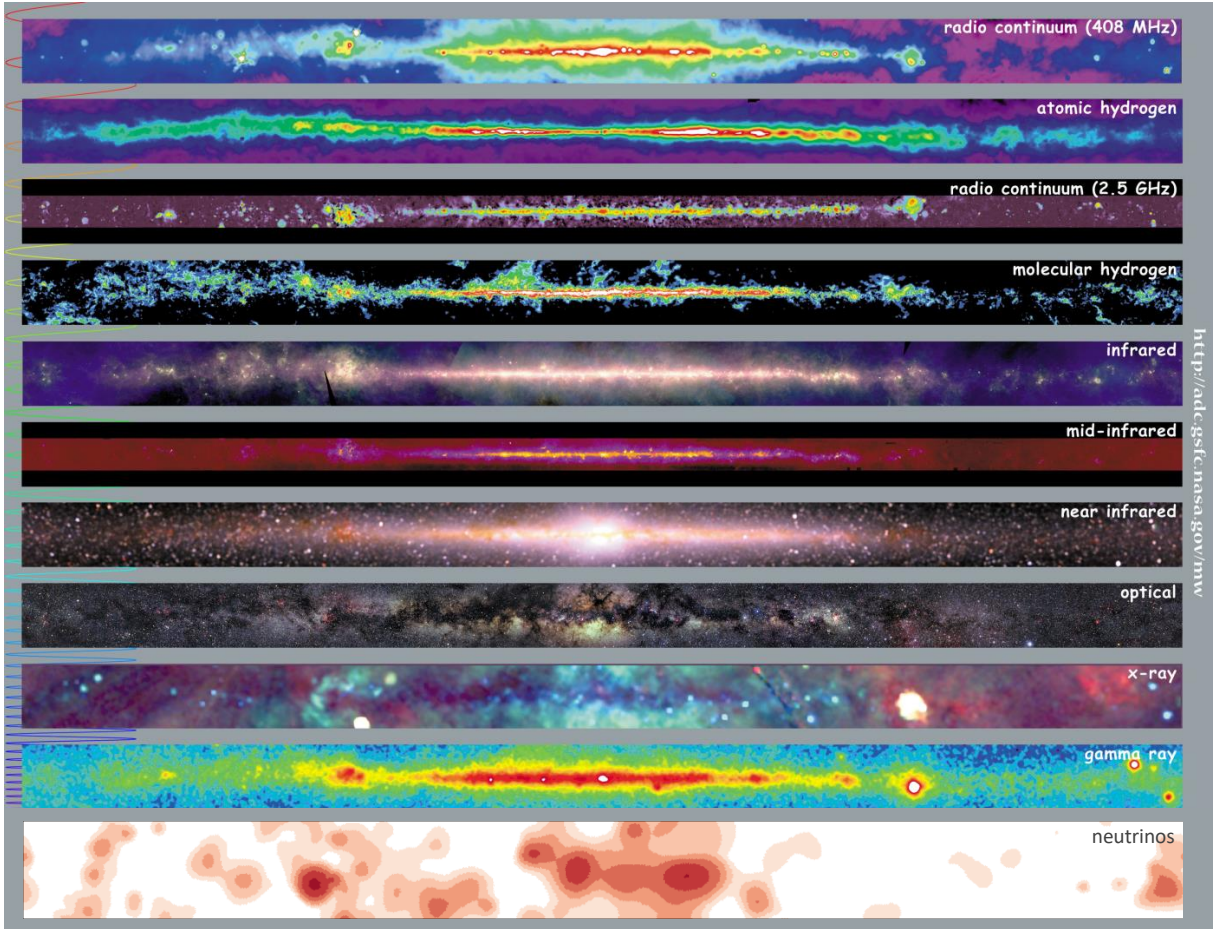


[1] DOI: 10.22323/1.444.1008
[2] DOI: 10.22323/1.444.1046

The Multiwavelength Milky Way



The ~~Multiwavelength~~ Multimessenger Milky Way



Summary & Outlook

Strong evidence for neutrino emission from the Galactic plane

- Background-only hypothesis rejected at 4.5σ
- Emission from Galactic plane may explain up to ~10% of astrophysical flux observed by IceCube
- Independent hints in IceCube track channels ($\sim 2.7\sigma$)[1] and in ANTARES[2] ($\sim 2\sigma$)

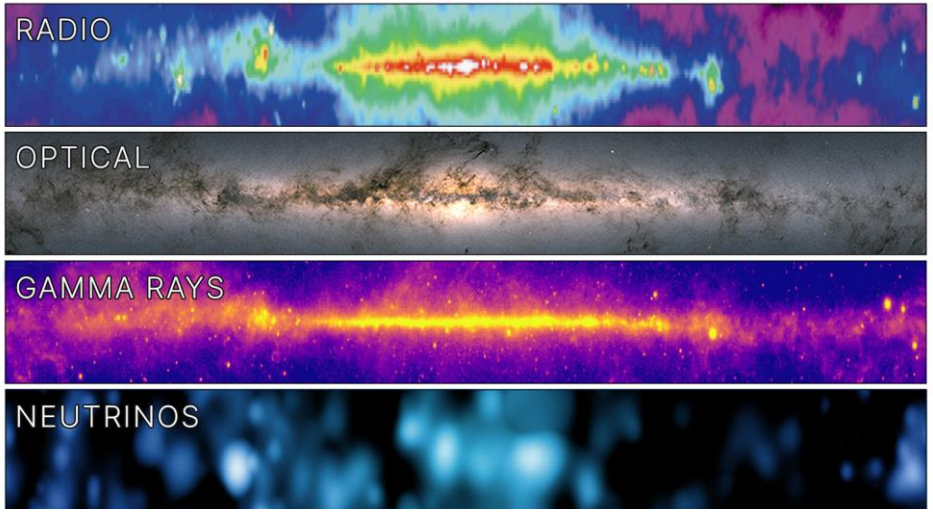
Observation enabled by new tools based on Deep Learning

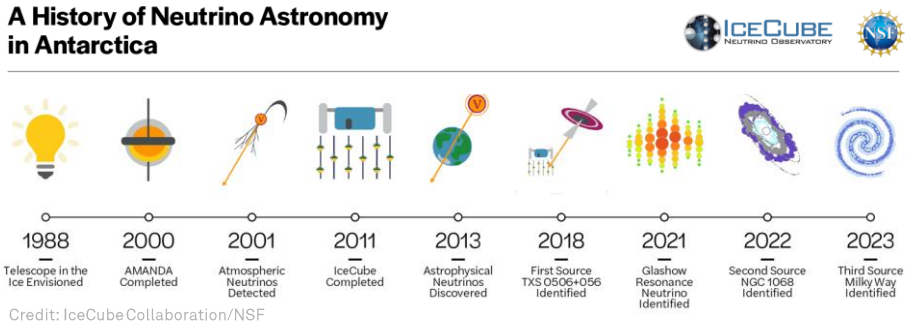
- 30 times as many events than precursor selection
- Improved reconstruction resolution by up to 50%
- Analysis sensitivity improved by a factor of 3

This result leads to many new questions:

- Diffuse or unresolved? Origin of CRs? Galactic structure? …
- Ongoing studies, future upgrades, and combination with other neutrino detectors will help to shed light on these

→ We have arrived in the era of neutrino astronomy!





Achieved milestones have picked up in pace in recent years!

[1] DOI: 10.22323/1.444.1046
[2] DOI: 10.1016/j.physletb.2023.137951