The First Neutrino Observation of the Galactic Plane

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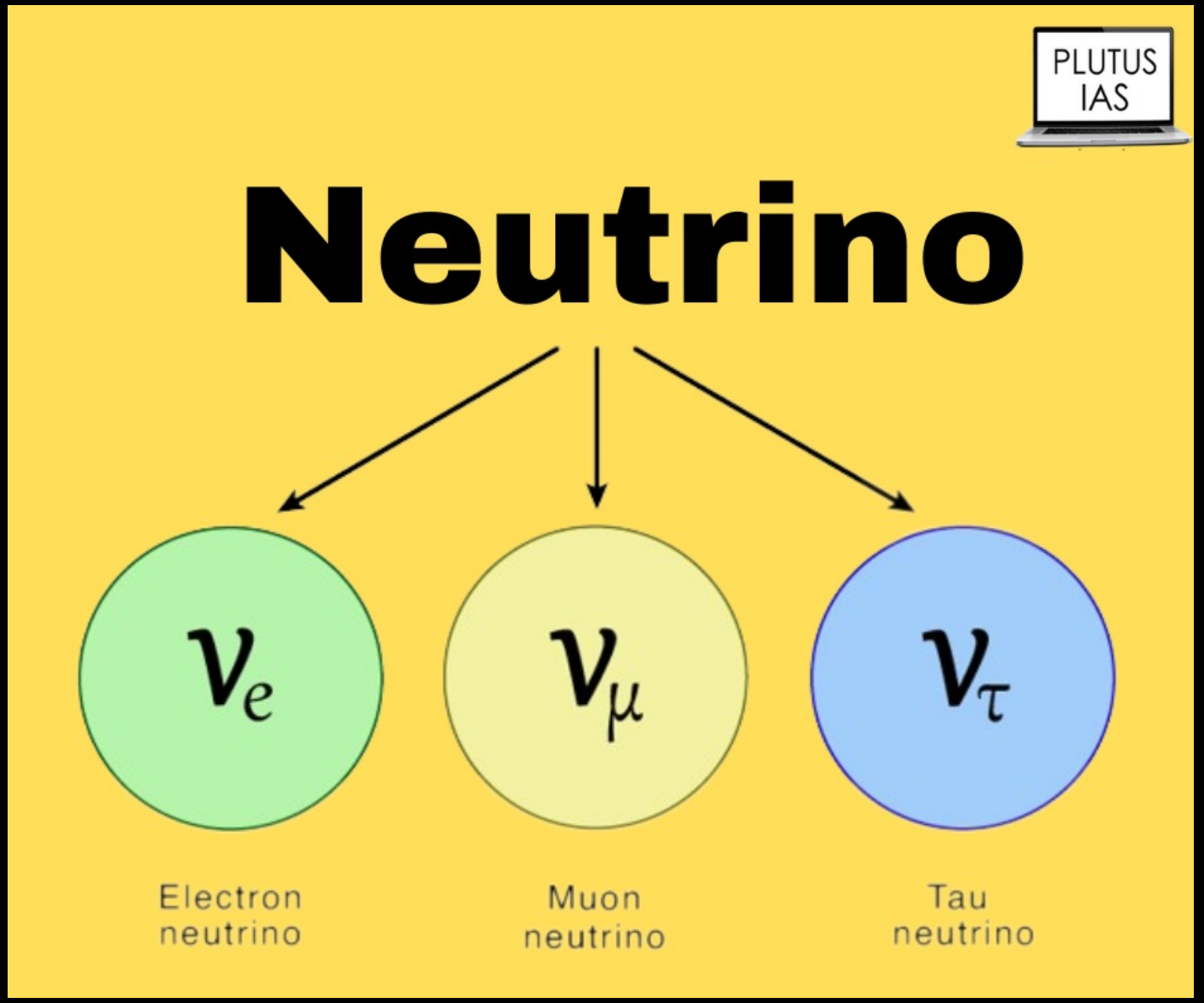
Observation of high-energy neutrinos from the Galactic plane, IceCube collaboration, 2023

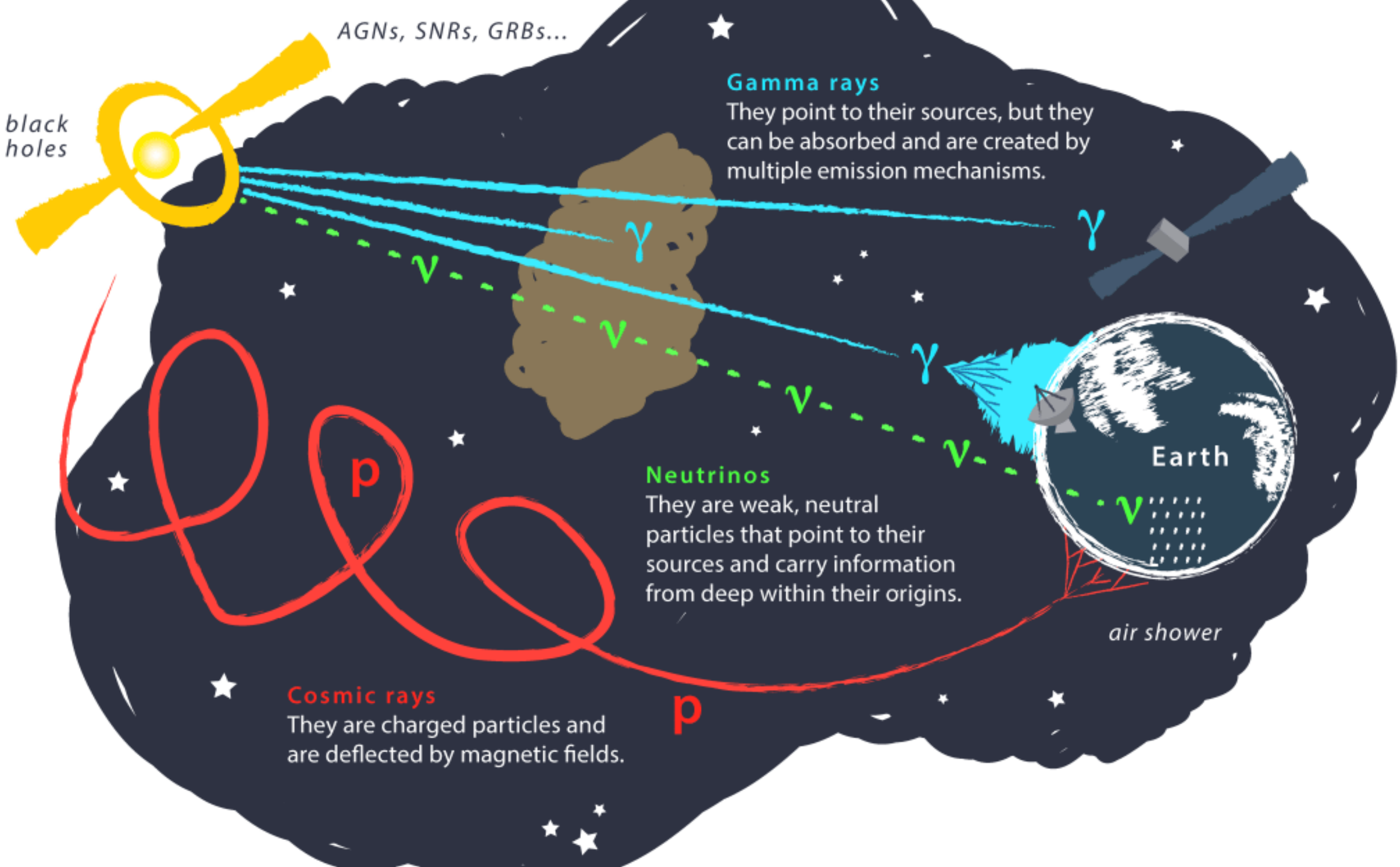
Overview

- What are neutrinos
- What is the IceCube Observatory
- Detecting neutrinos from the galactic plane using IceCube Observatory
- Implications of results

What are neutrinos

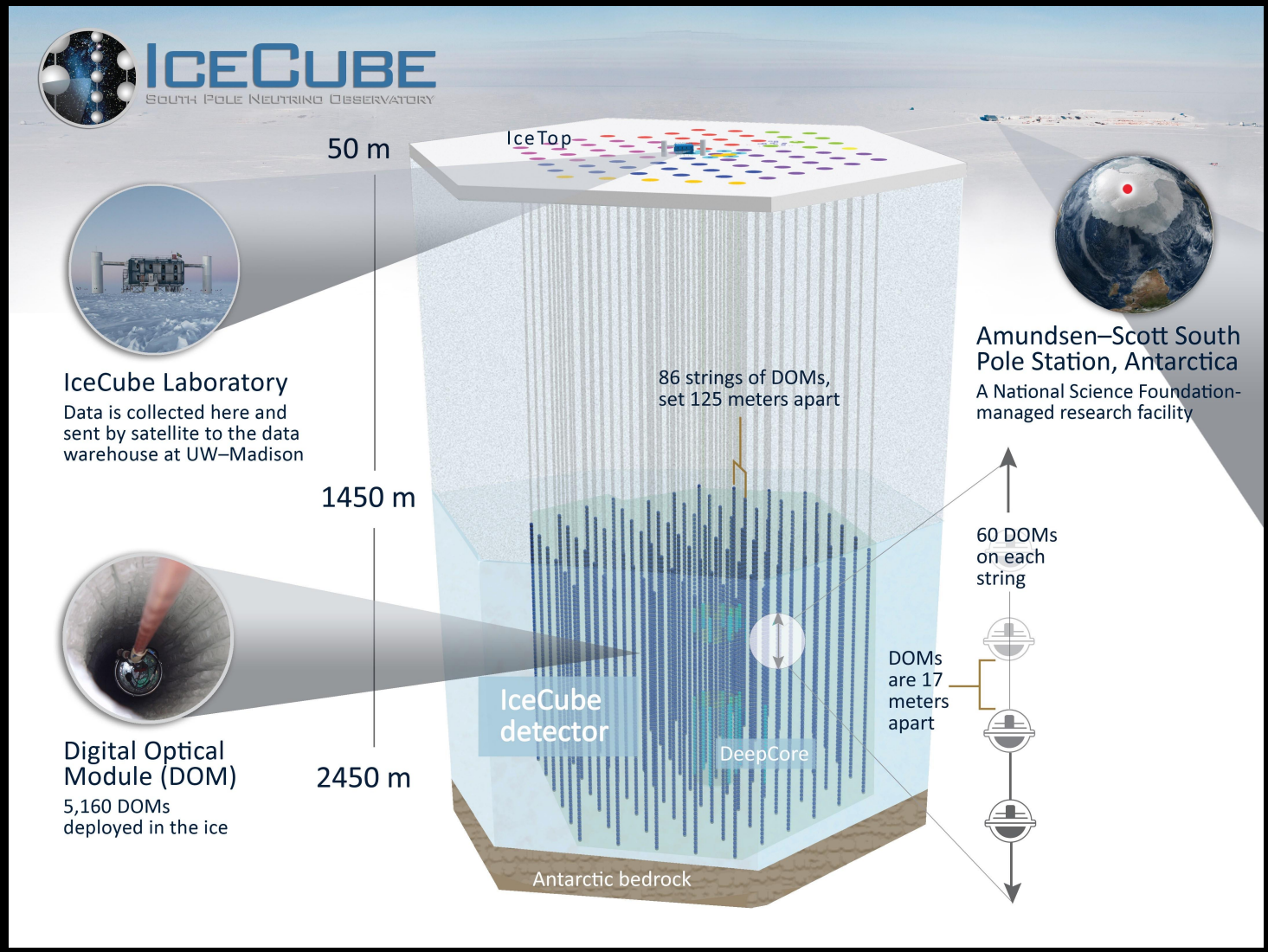
- Predicted to be the most abundant particle with mass in the universe
- Charge: neutral
- Rarely interact
- Three flavors
  - Muon (anti-muon)
  - Tau (anti-tau)
  - Electron (anti-electron)




AGNs, SNRs, GRBs...
black holes
Gamma rays
They point to their sources, but they can be absorbed and are created by multiple emission mechanisms.
γ
γ
γ
ν
ν
ν
ν
p
p
Neutrinos
They are weak, neutral particles that point to their sources and carry information from deep within their origins.
Earth
air shower
Cosmic rays
They are charged particles and are deflected by magnetic fields.

What is Ice Cube

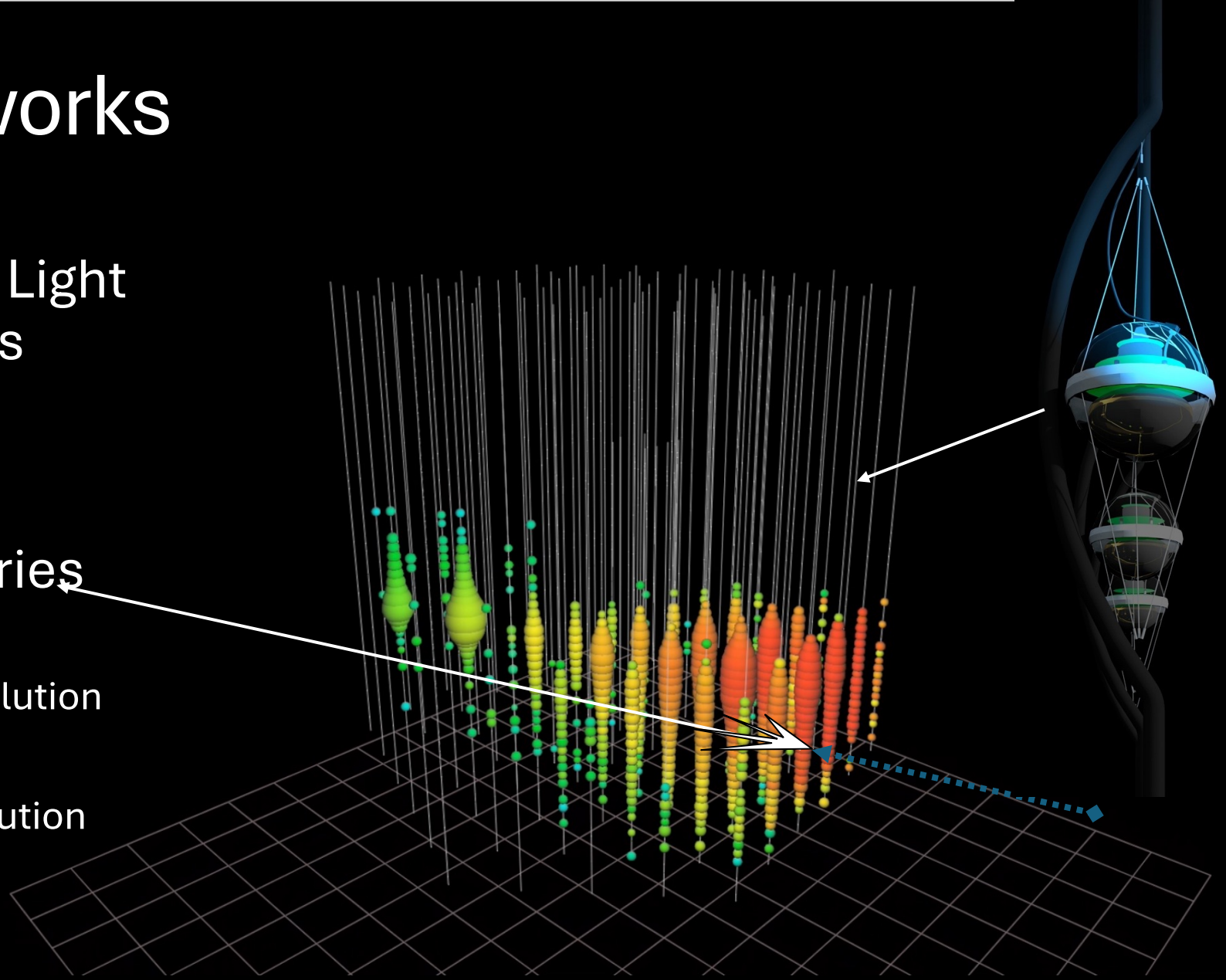
- Dimensions: 1 cubic kilometer
- Detects: Cherenkov radiation
- Composed of 5160 DOMs
- Full detector was completed in 2011
- Location: South Pole
- Energy sensitivity range: 300 TeV – 1 EeV



A neutrino's travels and detection by IceCube Neutrino Observatory

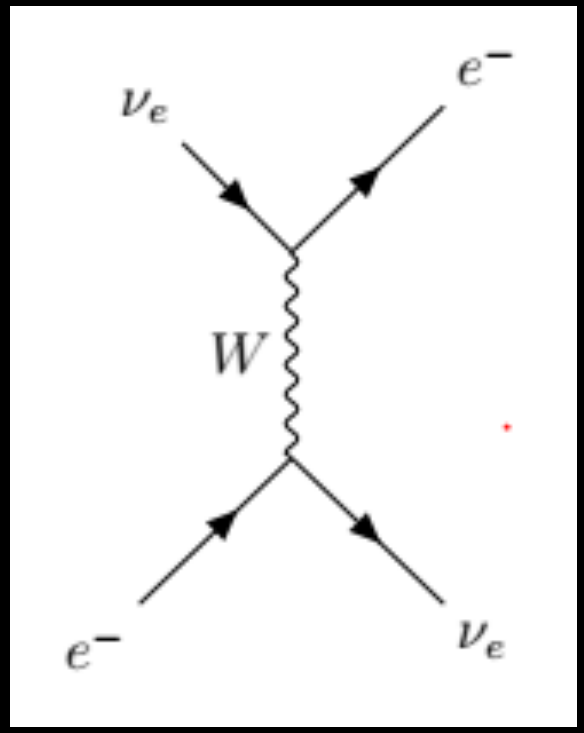
How IceCube works

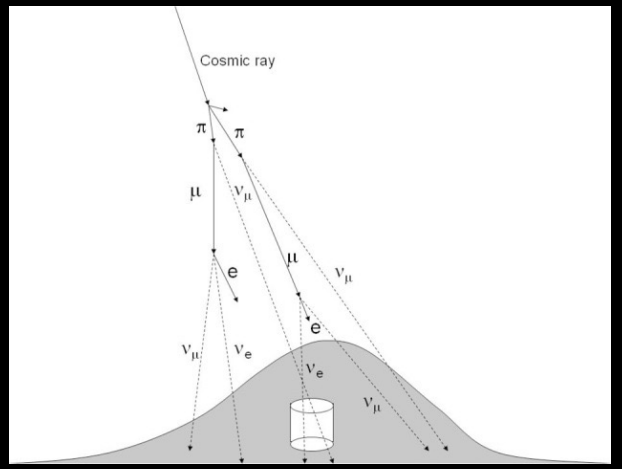
- Measures Cherenkov Light of secondary particles
- Energy and direction reconstruction
- Light patterns categories
  - Track
    - Superior angular resolution
  - Cascade events
    - Superior energy resolution



Challenges of IceCube

- Astrophysical neutrino detection
  - Background domination
    - Atmospheric Neutrinos
    - Cosmic ray Muons
  - Background to signal ratio:
    - $10^8 : 1$





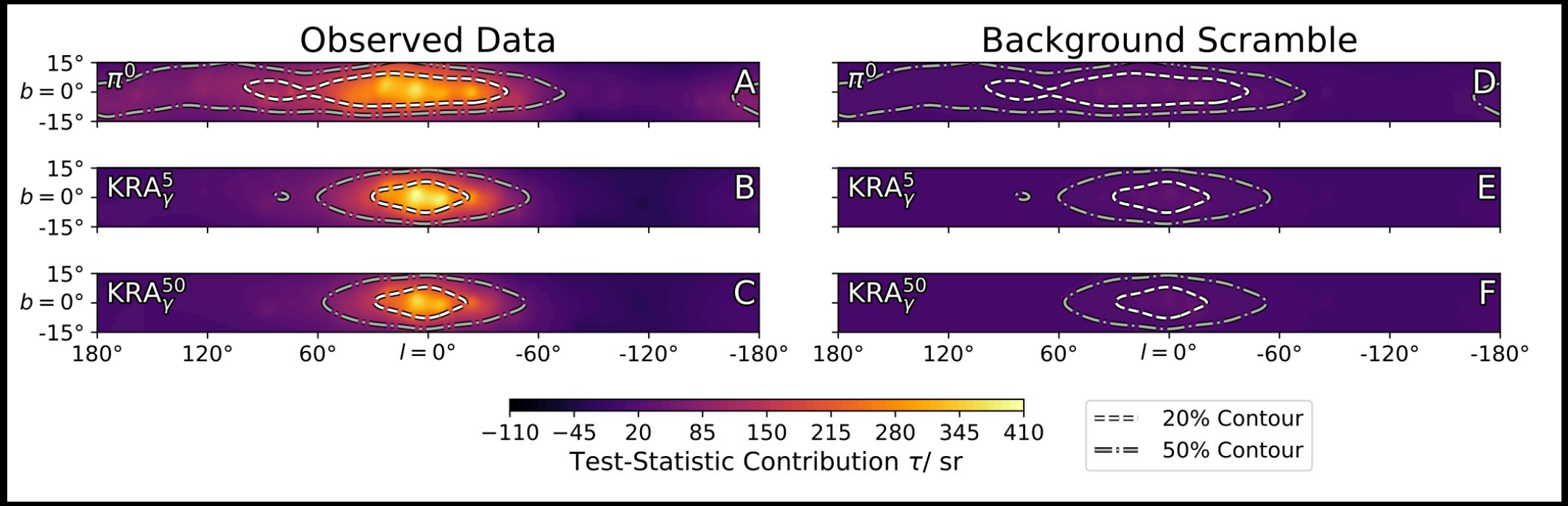
Deep Learning Techniques

- Used Deep Learning Convolutional Neural Network to perform event selection early in the event selection pipeline process.
- Utilized a Hybrid reconstruction method
  - Results
    - This method retains 20x as many events as previous selection methods of IceCube data for cascade-based Galactic plane analyses
      - 10^8: 1 ratio
    - Improved angular resolution by a factor of 2 at TeV energies

Galactic Plane Neutrino Search

- Three models of the Galactic diffuse neutrino emission were tested
  - π^0
  - KRA_γ^5
  - KRA_γ^{50}

Galactic Plane Test-statistic Contributions



The contribution to the test-statistic τ is shown in galactic coordinates (longitude and latitude indicated by l and b, respectively) for each of the three tested Galactic plane models. The overall test-statistic value was obtained by integration over the sky. The contribution for the observed data (A-C) is compared to the con- tribution for a single randomly selected mock experiment using scrambled data (D-F)..

Summarized results of the neutrino emission searches

searched for correlated neutrino emission from three distinct catalogs of Galactic sources

Diffuse Galactic plane analyses	p-value
π^0	1.26×10^{-6} (4.71σ)
KRA_γ^5	6.13×10^{-6} (4.37σ)
KRA_γ^{50}	3.72×10^{-5} (3.96σ)

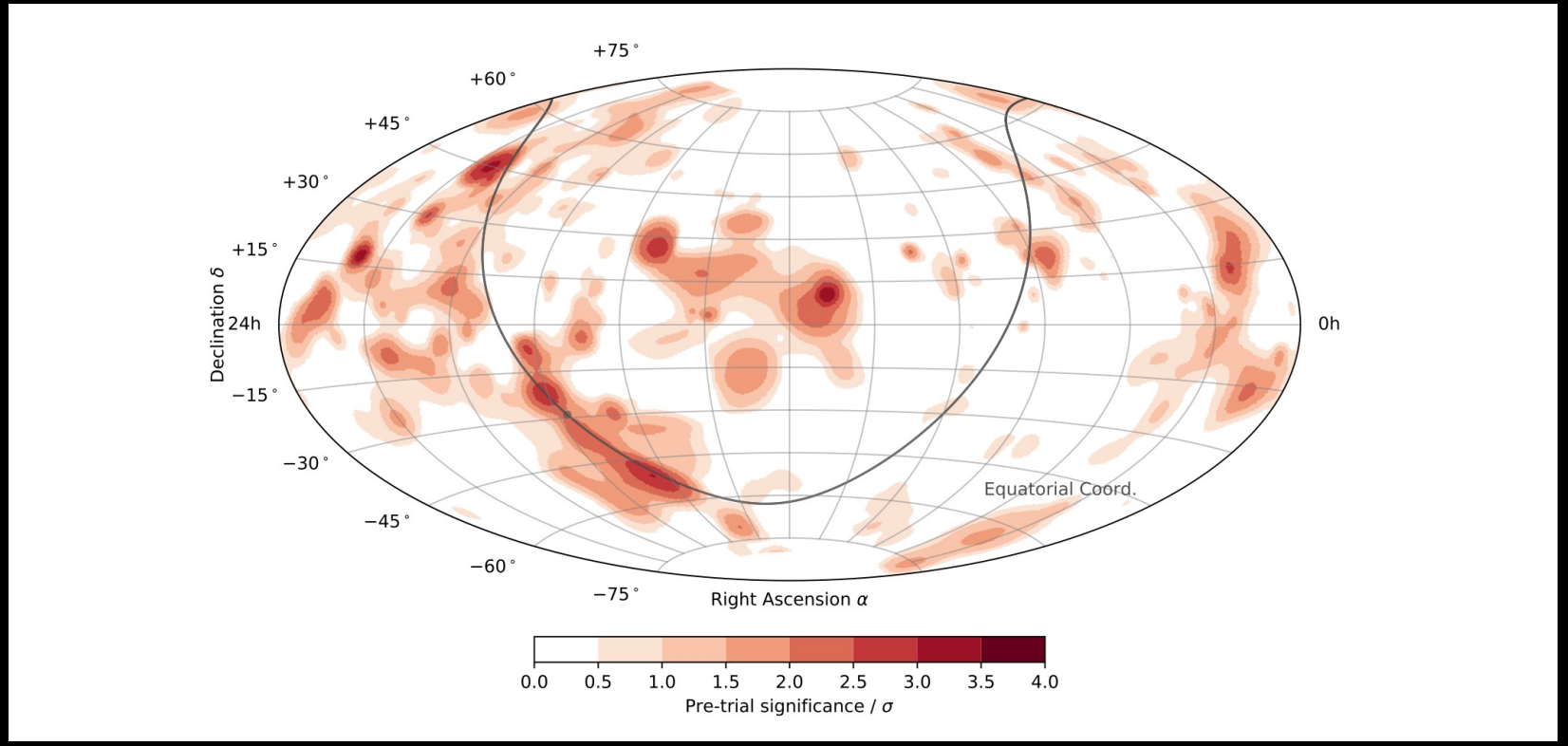
Searches using catalogs of Galactic sources

- Conclusion:
  - we can not interpret these neutrino event excesses as a detection, as the objects in these Galactic source catalogs overlap spatially with regions predicting the largest neutrino fluxes in the Galactic plane diffuse emission searches.

Catalog stacking analyses	p-value
SNR	5.90×10^{-4} $(3.24\sigma)^*$
PWN	5.93×10^{-4} $(3.24\sigma)^*$
UNID	3.39×10^{-4} $(3.40\sigma)^*$

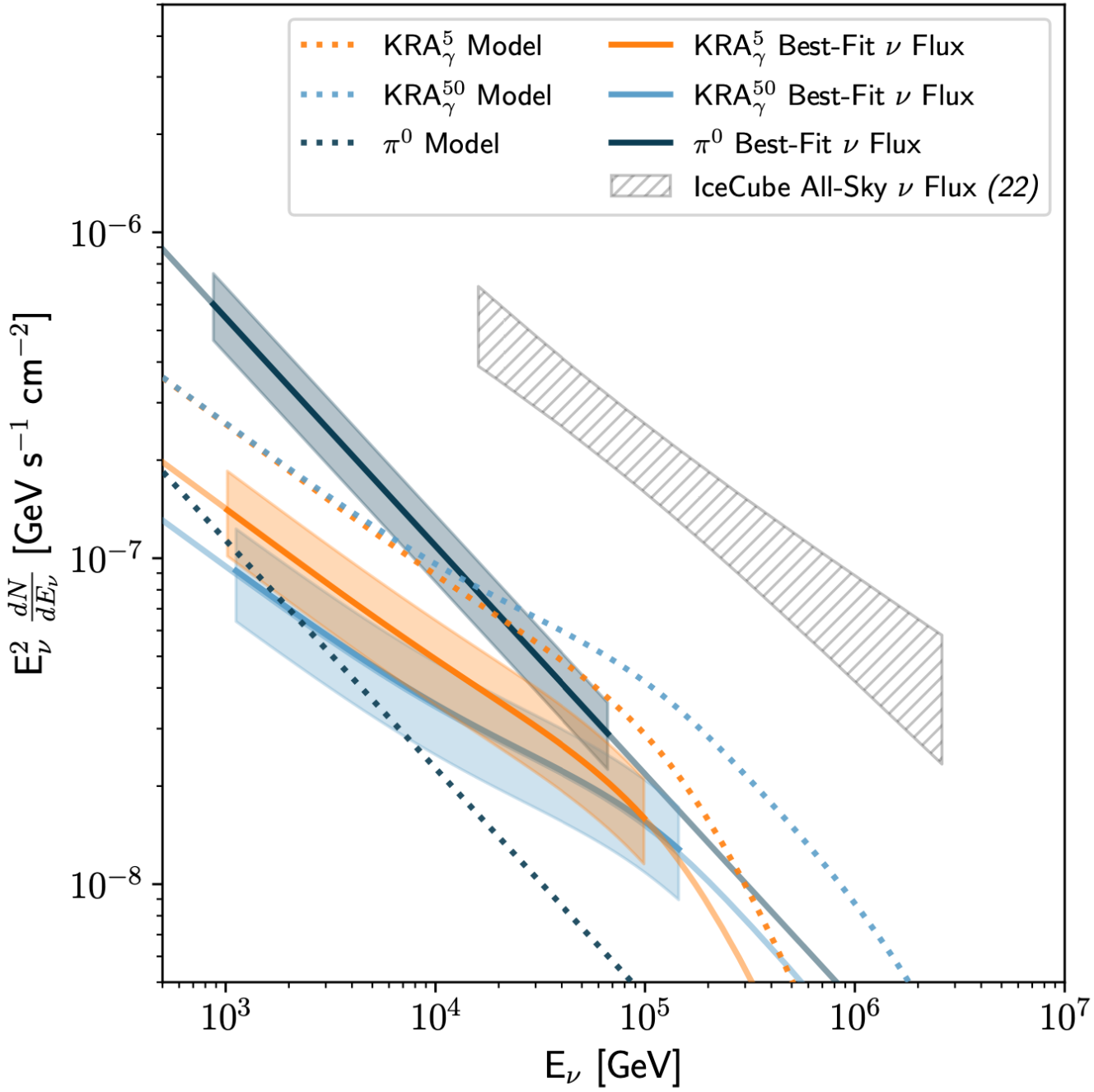
All Sky Point Source Search

- The sky is divided into a grid of equal solid angle bins, spaced 0.45° apart
  - each point is tested as a neutrino point source



Energy Spectra for each of the Galactic plane models

Energy-scaled, sky-integrated, per-flavor neutrino flux as a function of neutrino energy (Ev) for each of the Galactic plane models. Dotted lines are the predicted values for the π0 (dark blue), KRA5γ (orange) and KRA50 (light blue) models while solid lines are our best-fitting flux normalizations from the γ IceCube data. Shaded regions indicate the 1σ uncertainties, extending over the energy range that contributes to 90% of the significance.



Implications of Galactic Neutrinos

- These tests favor a neutrino signal from Galactic plane diffuse emission, but we do not have sufficient statistical power to differentiate between the tested emission models or identify embedded point sources.
- The neutrinos observed from the Galactic plane contribute to the all-sky astrophysical diffuse flux previously observed by IceCube
- The observed excess of neutrinos from the Galactic plane provides strong evidence that the Milky Way is a source of high-energy neutrinos