Recent IceCube results on the origin of cosmic neutrinos

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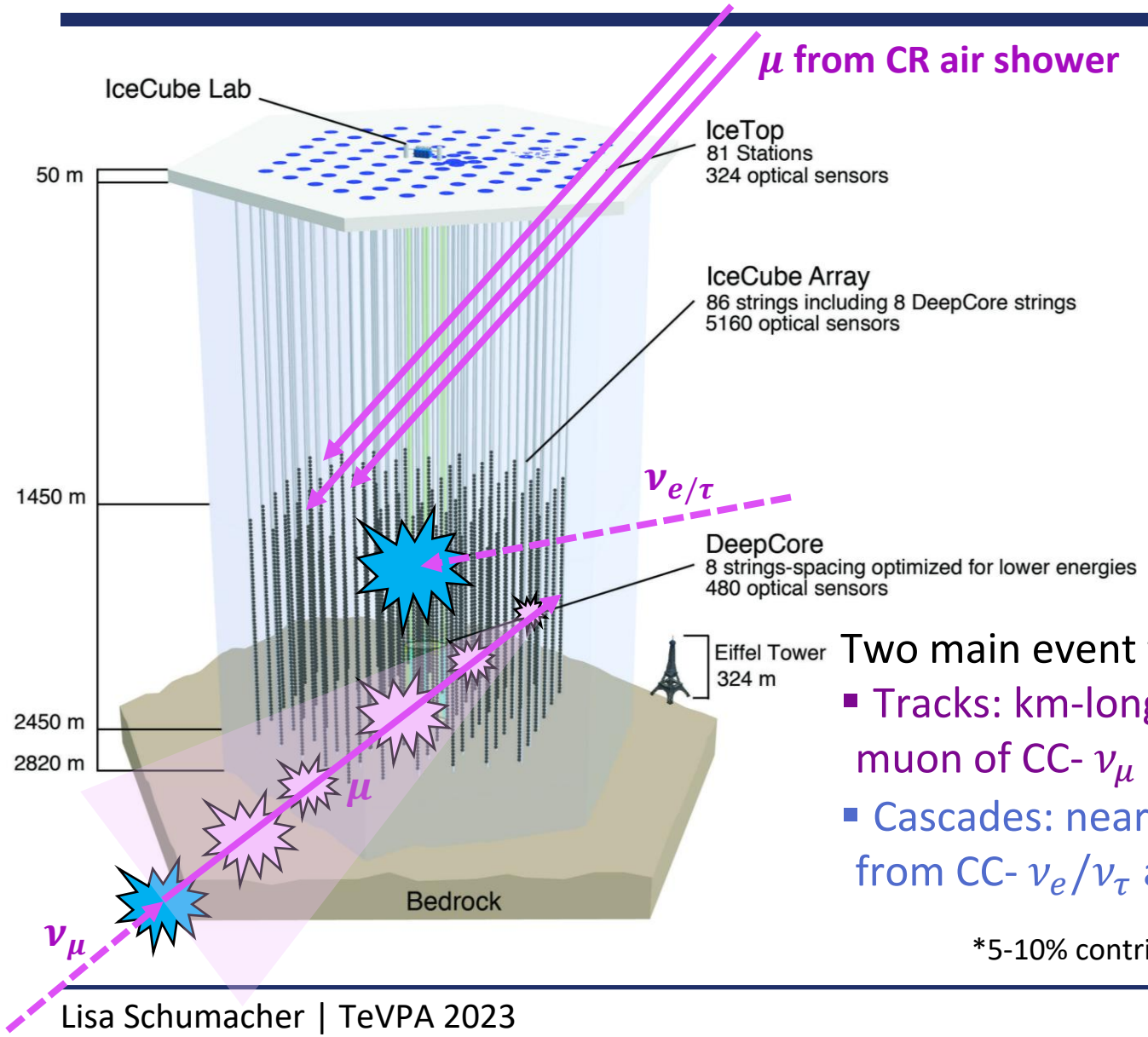
for the IceCube Collaboration

TeVPA, Napoli 2023

The IceCube Neutrino Observatory



- Located at the geographic south pole 1.45-2.45 km deep in the ice with an instrumented volume of 1 km³
- 86 Strings with 60 Digital Optical Modules (DOMs) = 5160 DOMs in total
- Full configuration running with > 99% uptime since 2011
- Main Background: 3 kHz atmospheric μ

Two main event topologies:

- Tracks: km-long light emission along the muon of CC- ν_μ interactions*
- Cascades: near-spherical light emission from CC- ν_e/ν_τ and NC neutrino interactions

+ angular resolution
-- energy resolution

-- angular resolution
+ energy resolution

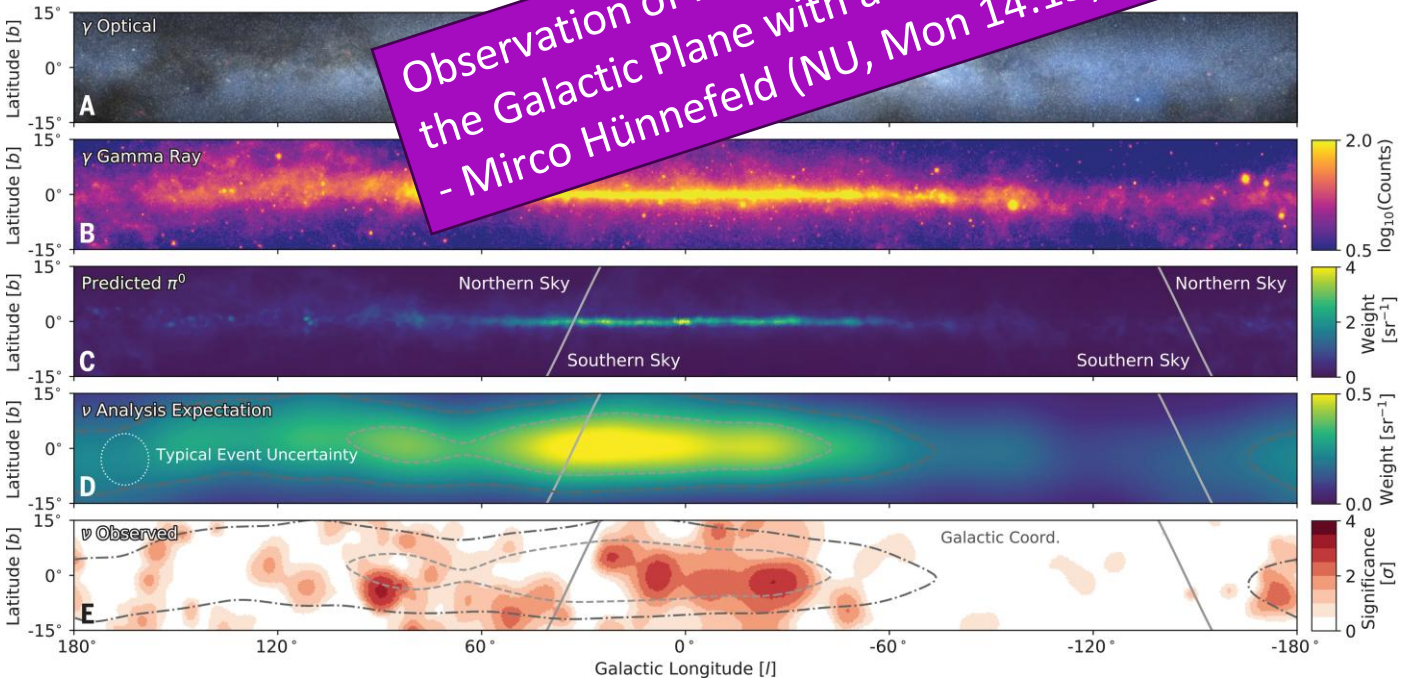
*5-10% contribution from CC- ν_τ

Overview – our recent highlights

Roughly 2 broad categories:

- Galactic neutrinos
- Extragalactic neutrinos

Observation of High-Energy Neutrinos from the Galactic Plane with a significance of 4.5σ - Mirco Hünnefeld (NU, Mon 14:15)



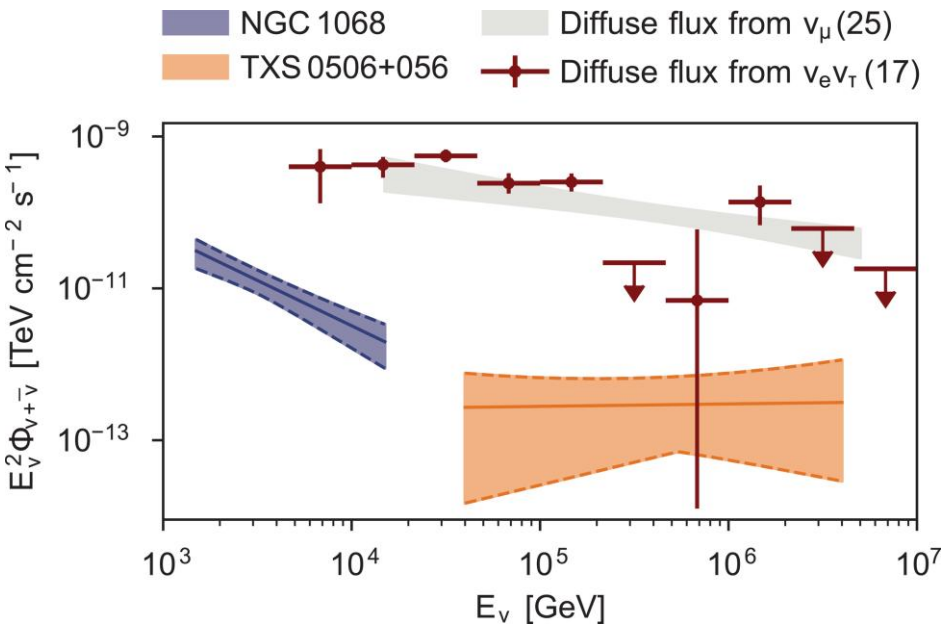
https://doi.org/10.1126/science.adc9818

Major contributions by Mirco Hünnefeld and Steve Sclafani

Disclaimer: There are a lot of (ongoing) source searches! I cannot cover all of them in this talk

https://doi.org/10.1126/science.abg3395

Evidence for neutrino emission from the nearby active galaxy NGC 1068 with a significance of 4.2σ



Galactic plane – diffuse emission

1) Observation of High-Energy Neutrinos from the Galactic Plane with a novel machine-learning reconstruction of Cascades (all sky)
   Significance: 4.5σ

   Mirco Hünnefeld (NU, Mon 14:15)

2) Results from searches for astrophysical neutrino sources in the southern sky and galactic plane using IceCube starting Track events
   Significance: $< 2\sigma$

   Sarah Mancina (NU, Thu 16:30)

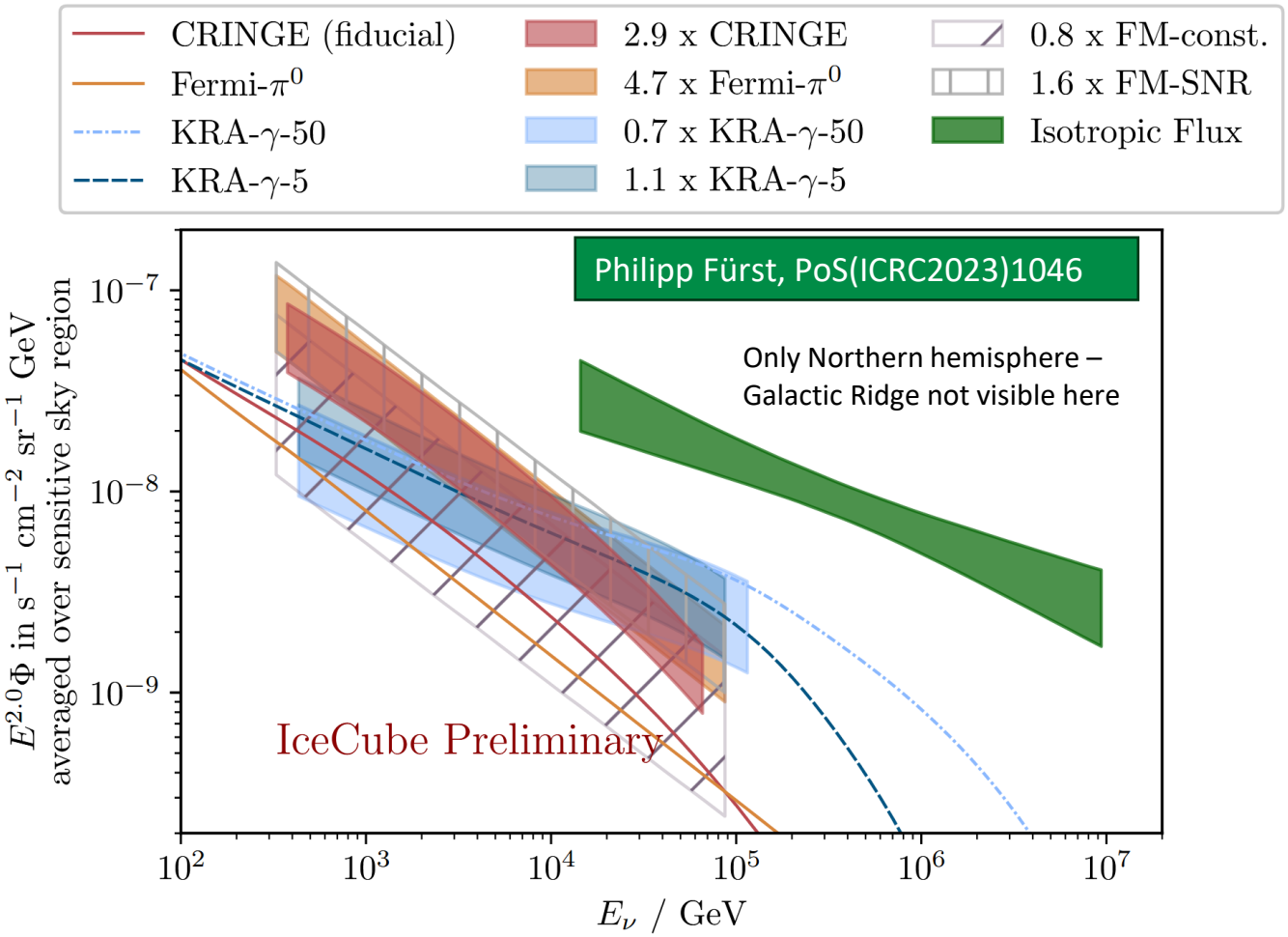
3) Galactic and Extragalactic Analysis of the Astrophysical Muon Neutrino Flux with 12.3 years of IceCube Track Data (Northern Sky)
   Significance: 2.7σ

   Philipp Fürst, PoS(ICRC2023)1046

- Three independent results by now using different detection channels
- Results using tracks are not yet significant, but are compatible with cascades
- Work ongoing on combining these independent data sets

What we (don't) know

http://dx.doi.org/10.3847/1538-4357/acc1e2 CRINGE as baseline model



- ✓ We see the galactic plane in neutrinos!
- ✓ View of our Galaxy at highest energies & complementary to Fermi and LHAASO gamma rays
- ✓ About 6-13% of total measured (diffuse) neutrino flux comes from GP

- ❑ Multiple diffuse neutrino emission models were tested, but no clear preference yet
- ❑ Normalization larger than expected could hint at sources in addition to diffuse emission, but this is still speculative

Galactic sources

- Starting tracks: no galactic sources identified

Sarah Mancina, NU, Thu 16:30

- Enhanced track selection at the Galactic Center region: no time-dependent emission found at the location of Sgr A*

Xinyue Kang PoS(ICRC2023)1051

- Through-going tracks: no significant evidence for extended sources in the Galactic Plane, but 2.6σ significance at region of unidentified TeV gamma-ray source 3HWC J1951+266

Upcoming publication arXiv:2307.07576

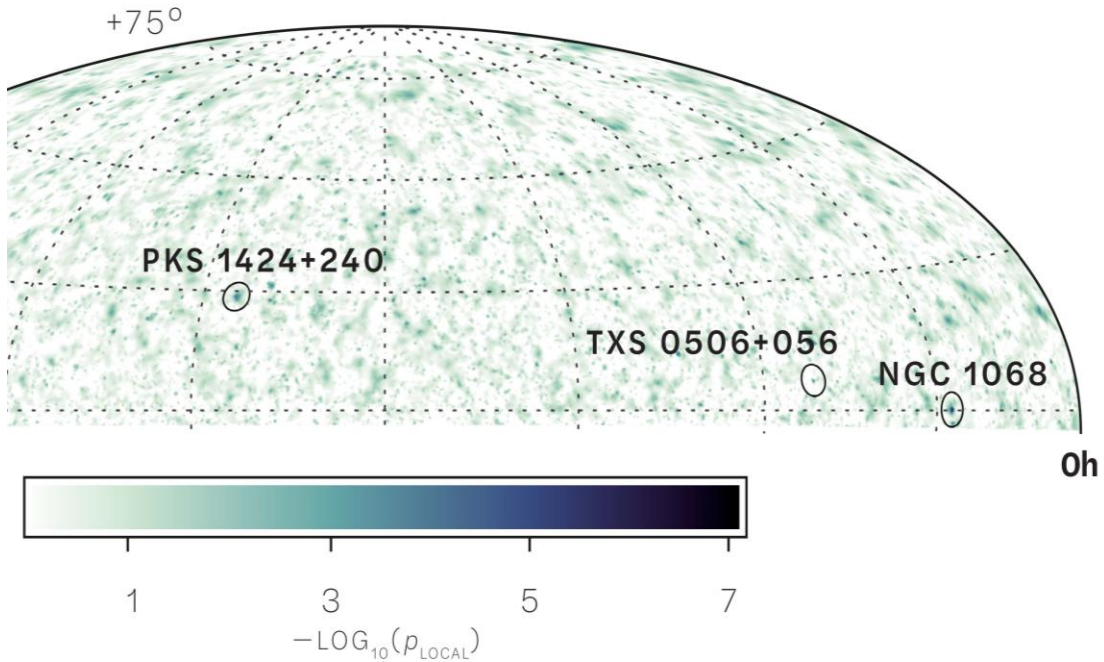
- Cascades: $> 3\sigma$ significance for correlation with TeV-gamma ray sources in GP, cannot be disentangled from the diffuse GP emission due to large angular uncertainty of cascades

Same cascade data as used for GP analysis

We start to see the (diffuse) neutrino emission of the plane, but individual sources cannot be resolved yet

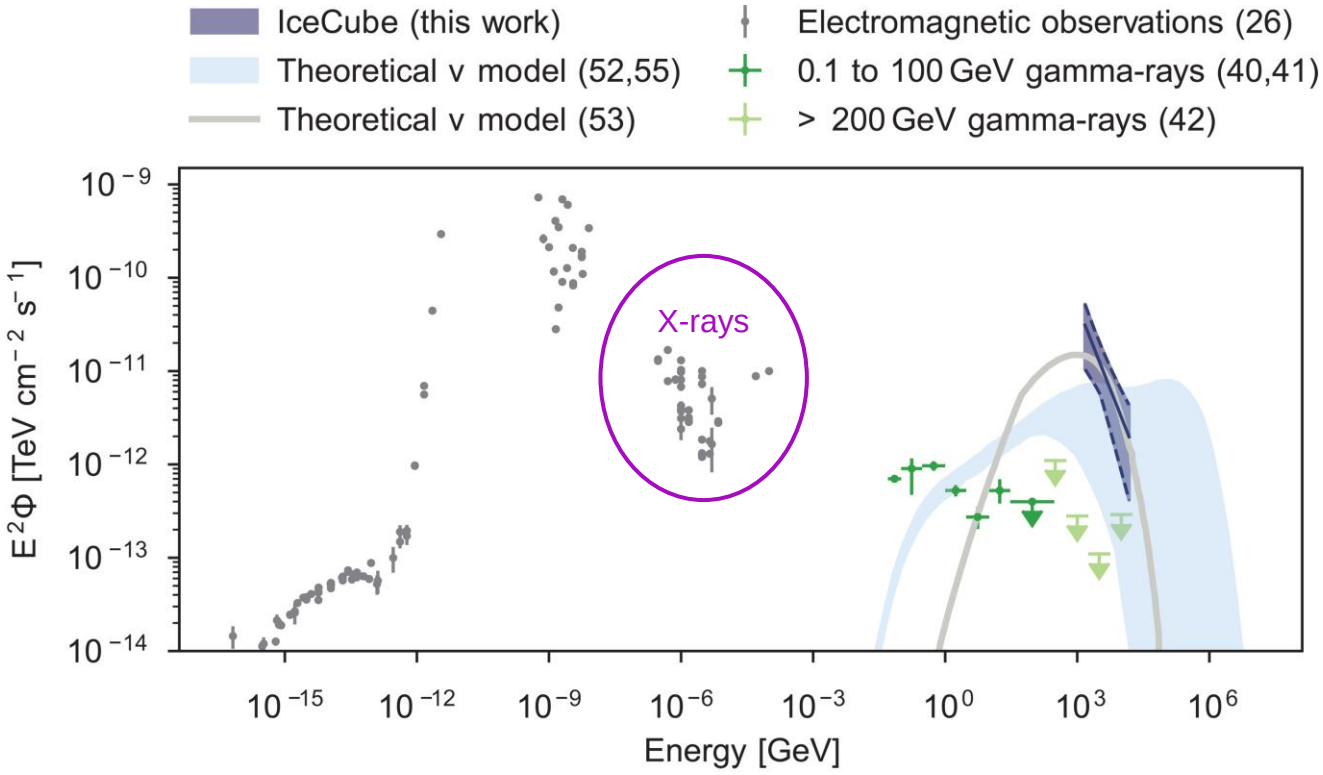
NGC 1068

- Evidence for neutrino emission from NGC 1068 with significance of 4.2σ using tracks
- Significance based on pre-defined source list
- A-posteriori analysis: NGC 4151 might be associated with another neutrino hotspot



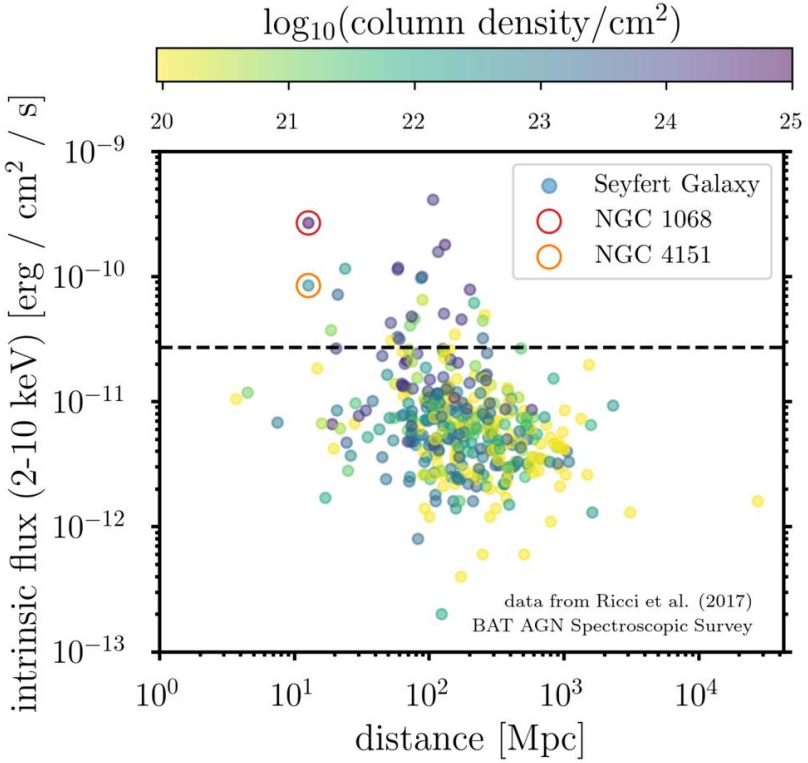
https://doi.org/10.1126/science.abg3395

- Seyfert II galaxy at a distance of 14.4 Mpc (very close by!) with Compton-thick AGN
- X-Ray corona around accretion disk may enable neutrino production & gamma-ray absorption



Seyfert Galaxies & X-ray bright AGN

- Excess of neutrinos associated with two sources, NGC 4151 and CGCG 420-015 @ 2.7σ significance
- Results constrain the collective neutrino emission from chosen source catalogue

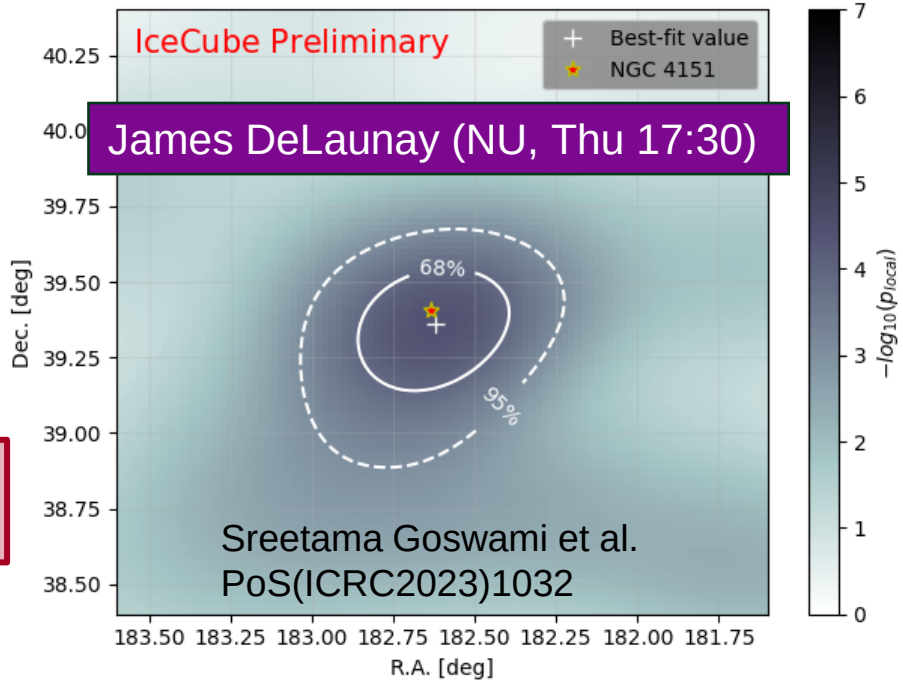


Shiqi Yu, (MM, Thu 14:40)

- Overlapping data sets and source catalogues → not independent results
- Further studies on-going
- Open questions remain about neutrino production mechanism in source candidates

Intriguing results, but no rejection of isotropic neutrino flux yet!

- Search for high-energy neutrino emission from hard X-ray AGN
- Confirmed emission of NGC 1068 and found NGC 4151 @ 2.9 σ significance



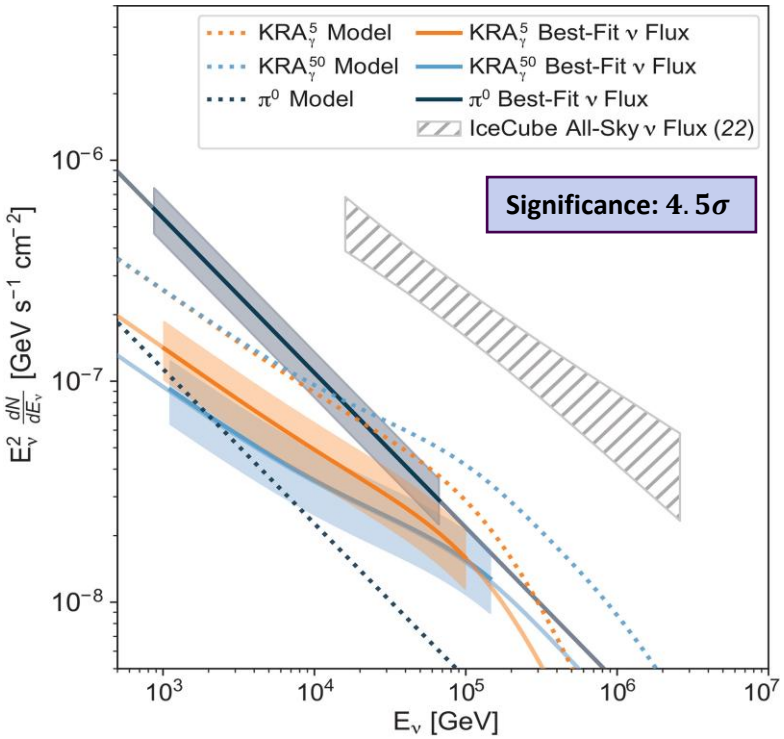
James DeLaunay (NU, Thu 17:30)

Sreetama Goswami et al.
PoS(ICRC2023)1032

The bigger picture

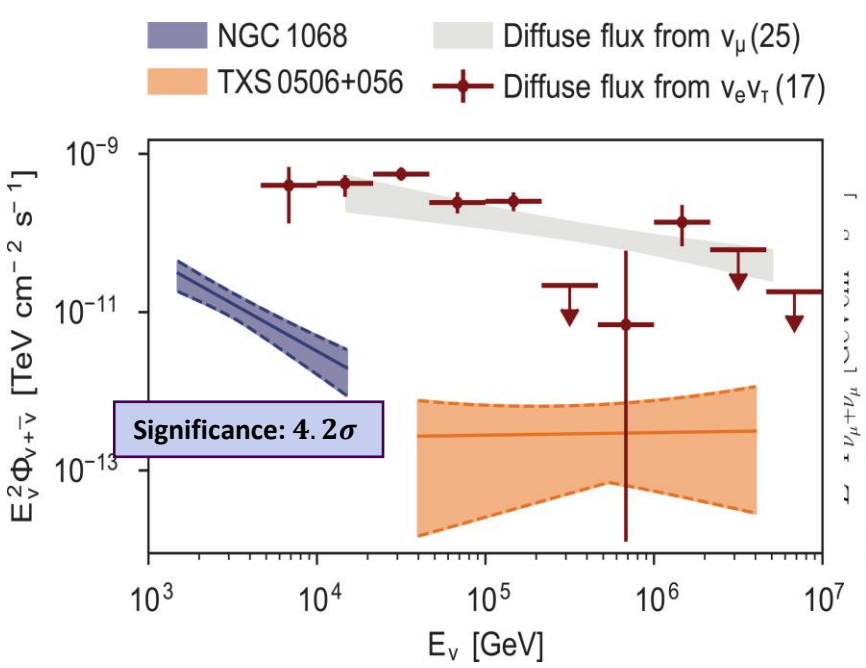
1) Galactic & extragalactic neutrino associations (start to) appear
2) Significant proportion of overall neutrino flux is still not accounted for

Galactic Plane

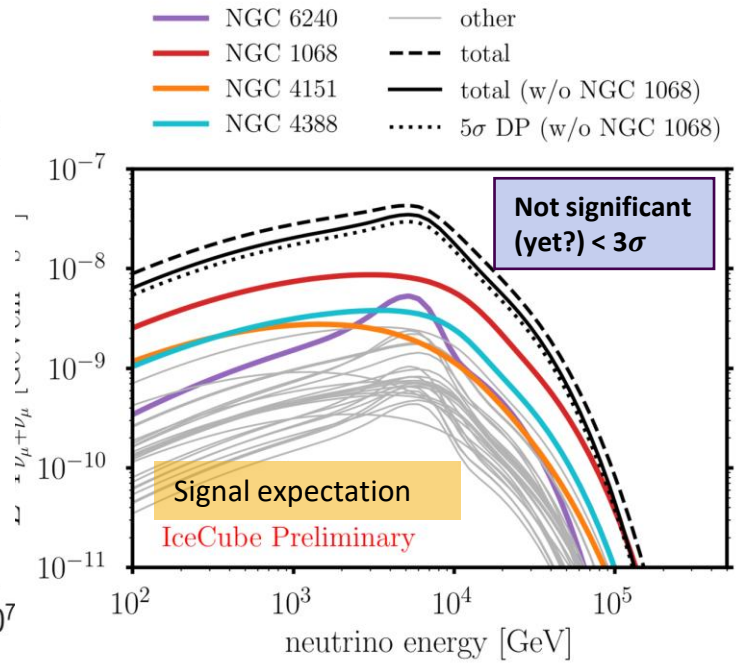


Mirco Hünnefeld (NU, Mon 14:15)

NGC 1068 & TXS 0506+056



Seyfert/X-Ray AGN



Shiqi Yu, (MM, Thu 14:40)

Overview – IceCube at this conference

Contributions regarding the origin of astrophysical neutrinos:

- Observation of High-Energy Neutrinos from the Galactic Plane - Mirco Hünnefeld (NU, Mon 14:15)
- Investigating Millimeter-Bright AGN as IceCube's Astrophysical Neutrino Sources - Alina Kochocki (NU, Tue 15:00)
- The IceCube Realtime Program - Giacomo Sommani (MM, Wed 17:10)
- Development of a new IceCube realtime alert using multiplet signal for optical follow-up - Nobuhiro Shimizu (MM, Wed 17:25)
- IceCube Search for High Energy Neutrino Emission from X-ray Bright Seyfert Galaxies - Shiqi Yu (MM, Thu 14:40)
- Results from searches for astrophysical neutrino sources in the southern sky and galactic plane using IceCube starting track events - Sarah Mancina (NU, Thu 16:30)
- A search for neutrinos from dark matter in the Galactic Centre with IceCube - Nhan Chau (IDM, Thu 17:00)
- Searching for high-energy neutrino emission from hard X-ray AGN with IceCube - James DeLaunay (NU, Thu 17:30)

Other contributions:

- A combined Flavour composition measurement of astrophysical neutrinos using multi-sample IceCube data - Neha Lad (NU, Thu 16:45)
- Inelasticity studies using TeV-scale starting track neutrino events in IceCube - Marjon Moulai (NU, Thu 17:00)
- IceCube Starting Events For Diffuse Astrophysical Neutrino Measurements - Aswathi Balagopal V. (NU, Thu 17:45)
- New Results for eV-scale Sterile Neutrino Searches with IceCube - Alfonso Andres Garcia Soto (PL, Thu 9:00)
- Reconstruction and identification methods of sub-PeV gamma rays at the IceCube Neutrino Observatory - Federico Bontempo (GRA, Thu 17:15)

… + external contributions using IceCube results and/or public data

… Thanks for your attention! ☺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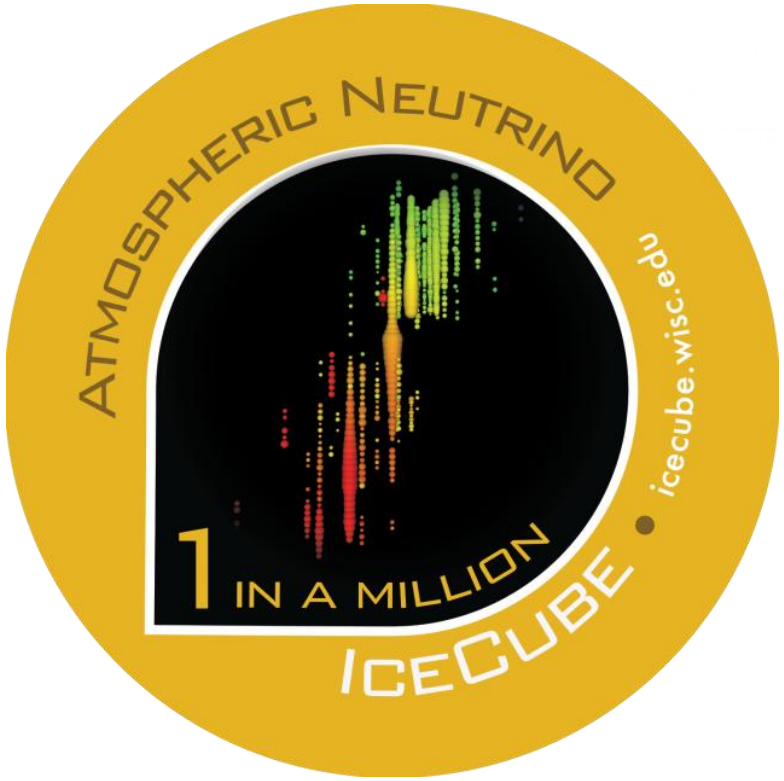
icecube.wisc.edu

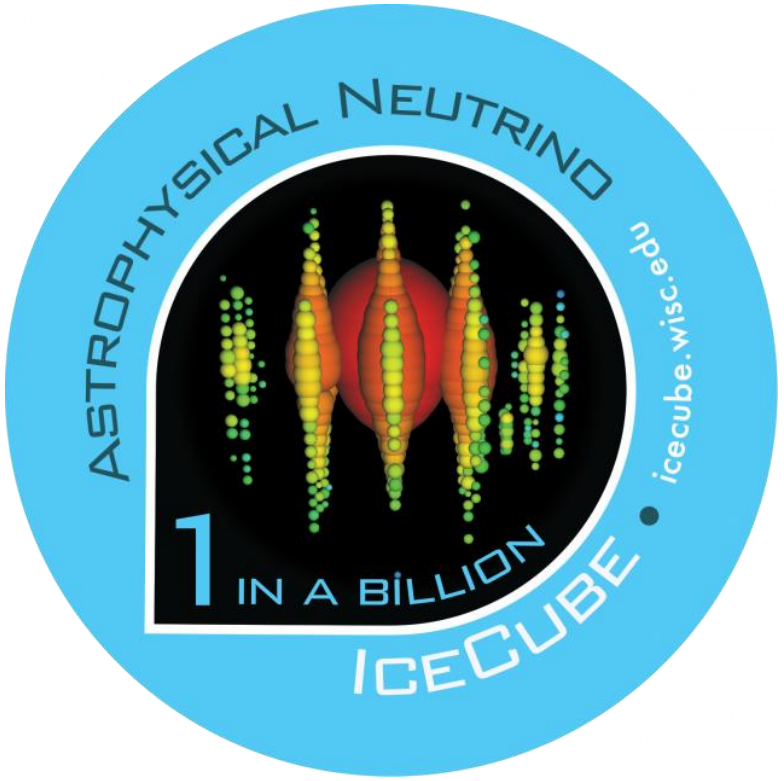
Back up

IceCube data sets – an incomplete overview

- Northern-Sky Tracks (NT), ν_μ-CC, only Northern Sky, high neutrino purity
- Point-Source Tracks (PS), ν_μ-CC, full Sky, high neutrino purity only in Northern Sky, Southern Sky is CR-muon dominated
- DNN Cascades: $\nu_{e/\tau}$ & NC all flavor, full sky, competitive with PS in Southern Sky
- ESTES: Enhanced starting track event selection, ν_μ, full sky, competitive with PS in Southern Sky
- Realtime alerts: Please see Giacomo Sommani's talk (MM, Wed 17:10) ☺
- Cascades $\nu_{e/\tau}$ & NC, currently only used for diffuse analyses
- HESE & MESE: High-energy & Medium-energy starting events, All flavors, "traditionally" used for diffuse analyses

IceCube events in numbers





= 3000 atmospheric μ per second