New results from the IceCube Neutrino Observatory

Thursday, November 3, 1:00 PM CDT

Master of Ceremony
Albrecht Karle, University of Wisconsin–Madison

Opening Remarks
Denise Caldwell, National Science Foundation
Steve Ackerman, University of Wisconsin–Madison

Presentations
Justin Vandenbroucke, University of Wisconsin–Madison
Elisa Resconi, Technical University of Munich
Hans Niederhausen, Michigan State University and Technical University of Munich
Ignacio Taboada, Georgia Institute of Technology

Question & Answer Session

Credit: Martin Wolf, IceCube/NSF

ICECUBE

Science — Nov. 4, 2022

ICECUBE

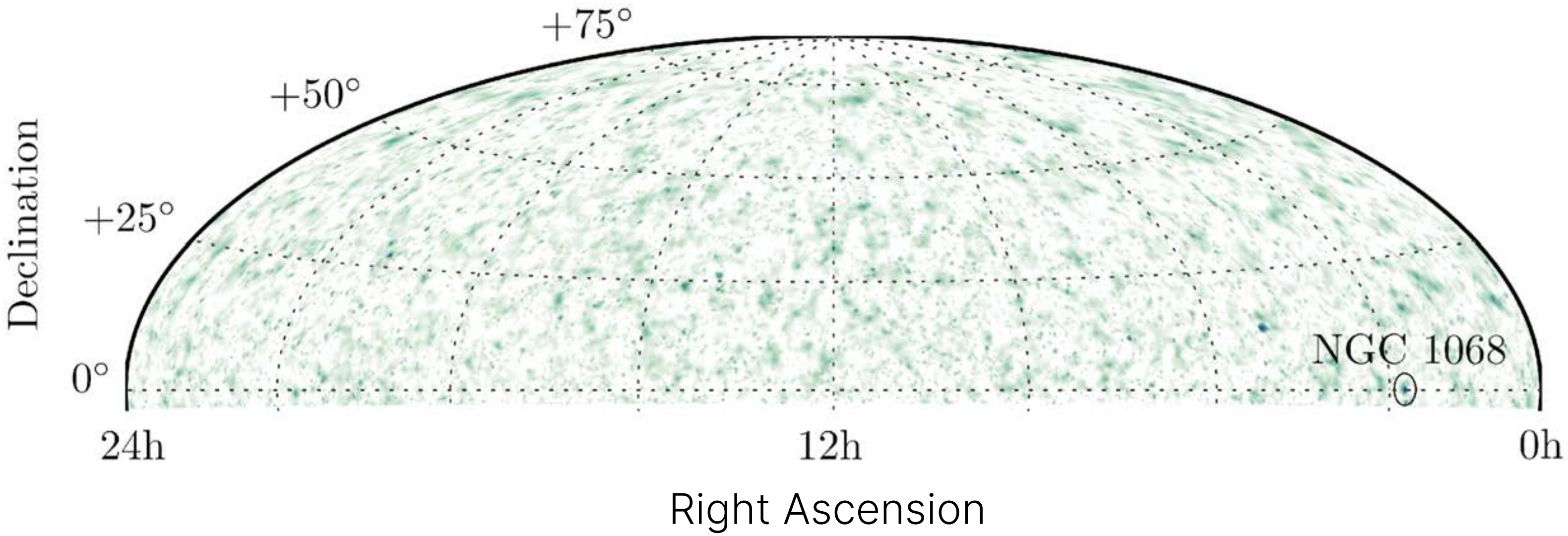
RESEARCH

RESEARCH ARTICLE

NEUTRINO ASTROPHYSICS

Evidence for neutrino emission from the nearby active galaxy NGC 1068

IceCube Collaboration*†



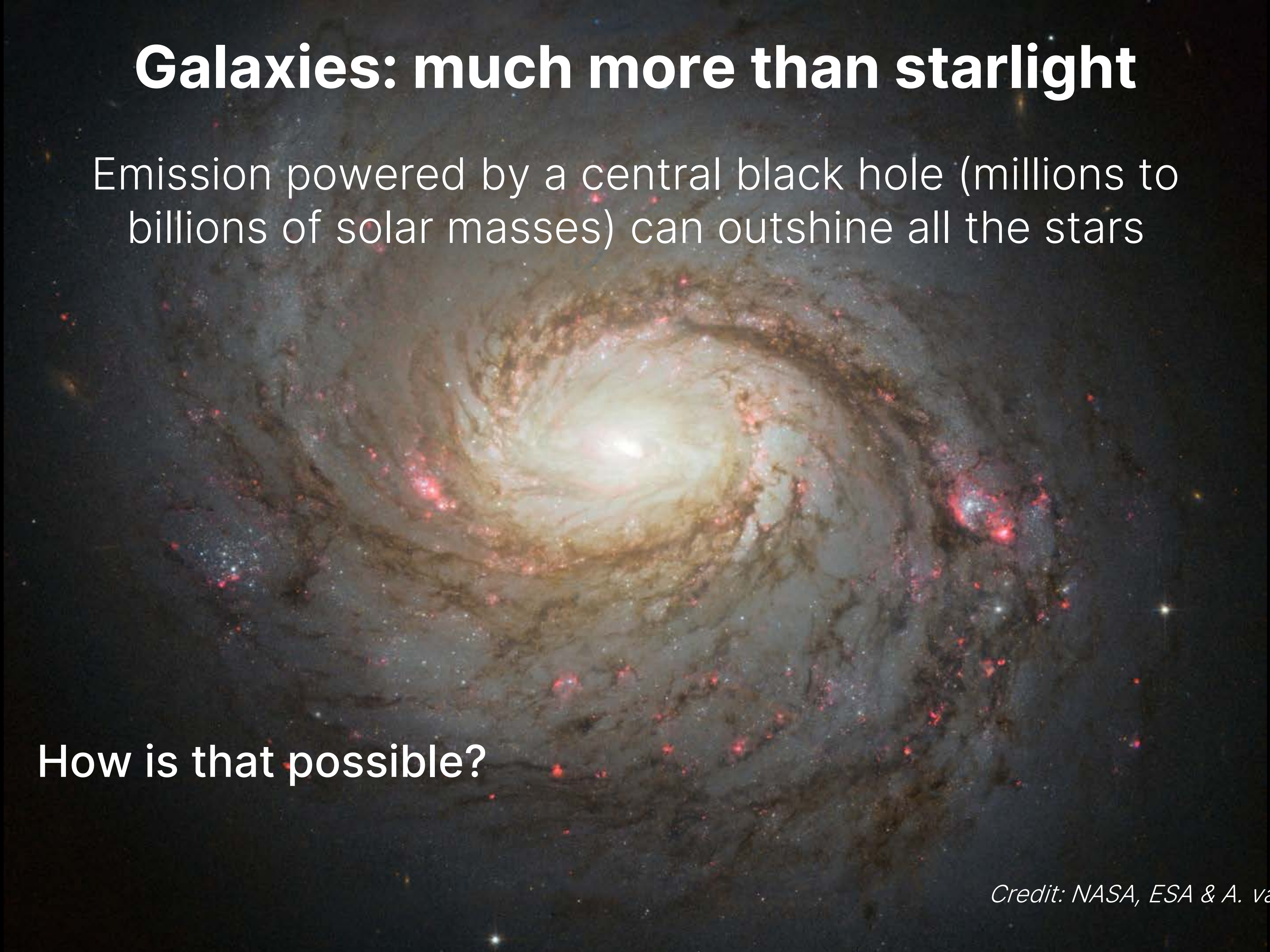
Introduction to IceCube

Justin Vandenbroucke, University of Wisconsin–Madison

Credit: Martin Wolf, IceCube/NSF

Galaxies: much more than starlight

Emission powered by a central black hole (millions to billions of solar masses) can outshine all the stars

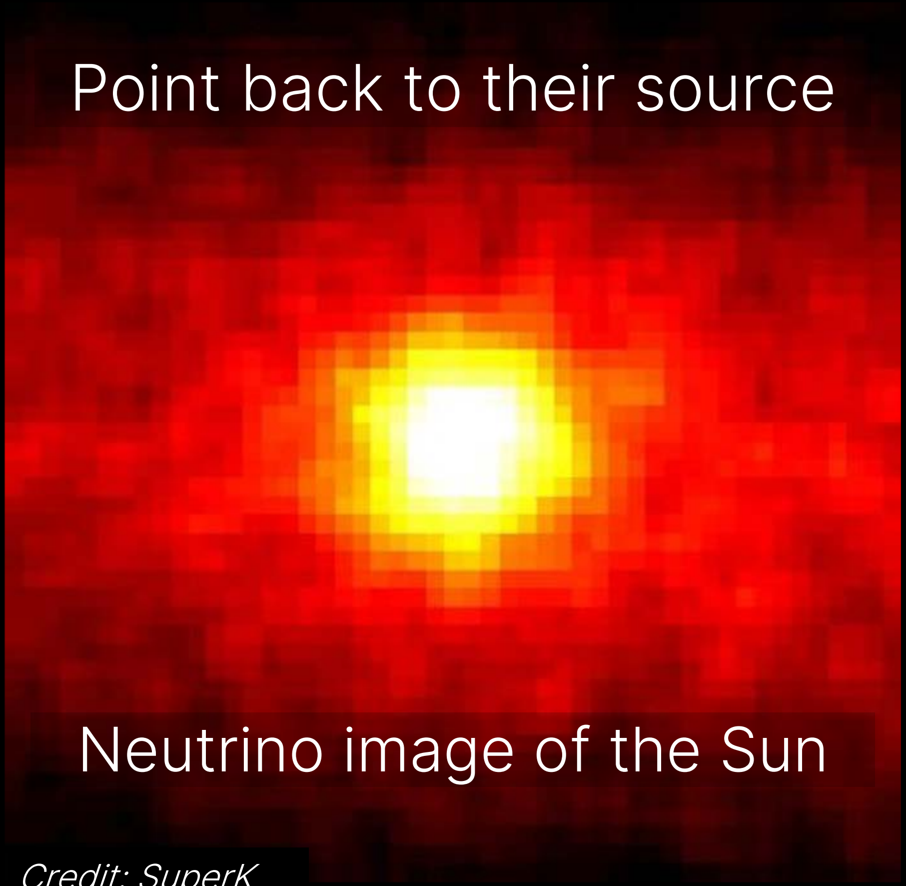


How is that possible?

Credit: NASA, ESA & A. van der Hoeven

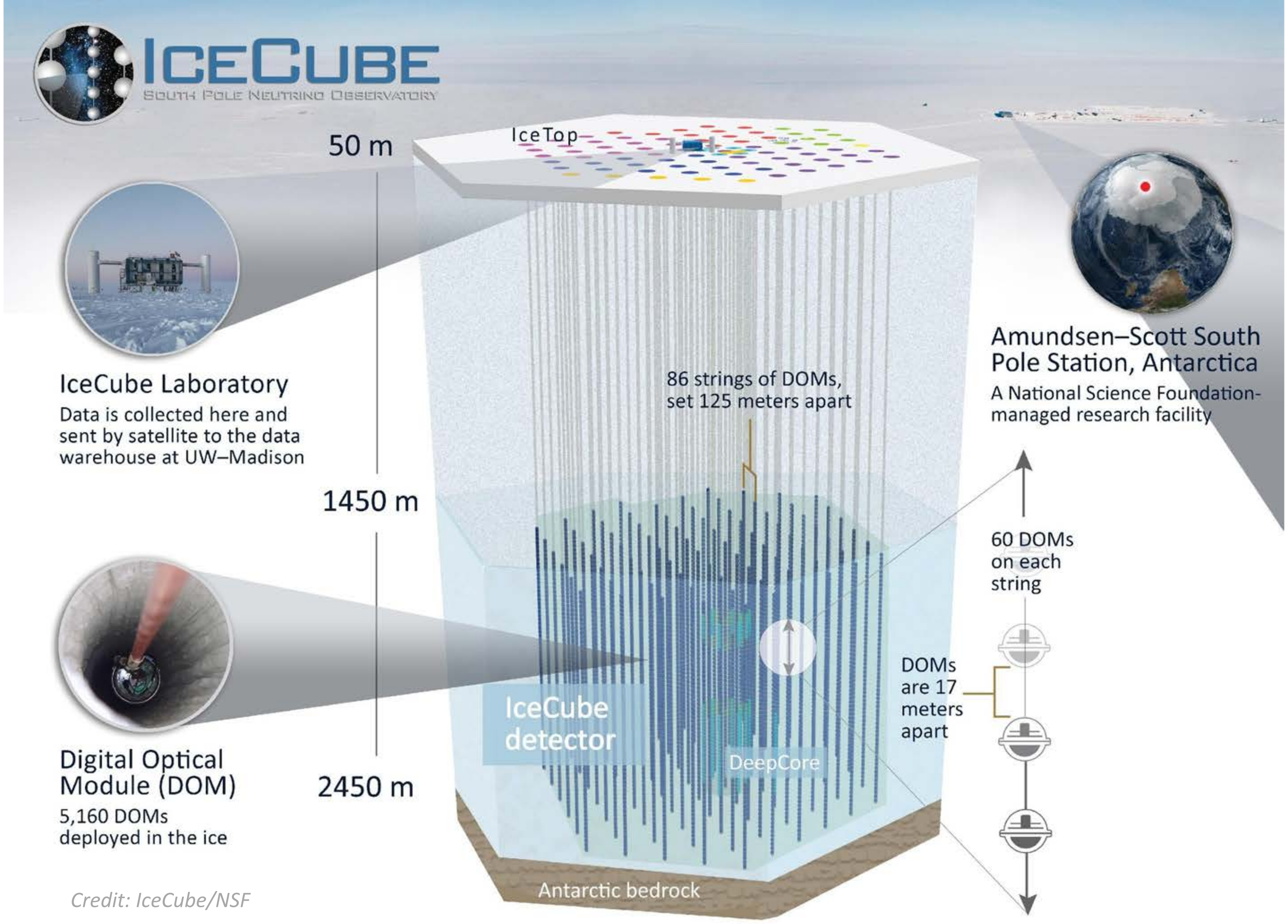
What can neutrinos tell us?

New information, complementary to all forms of light

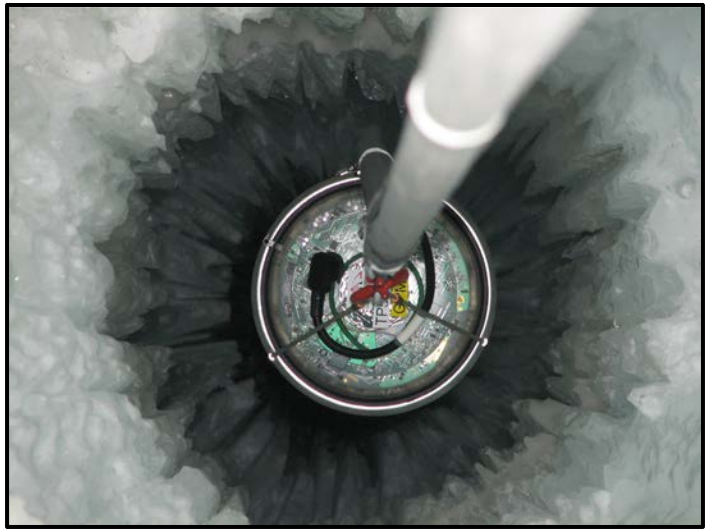


Credit: SuperK

Credit: NASA Hubble


ICECUBE
SOUTH POLE NEUTRINO OBSERVATORY
IceTop
50 m
1450 m
2450 m
IceCube Laboratory
Data is collected here and sent by satellite to the data warehouse at UW–Madison
86 strings of DOMs, set 125 meters apart
Amundsen–Scott South Pole Station, Antarctica
A National Science Foundation-managed research facility
60 DOMs on each string
DOMs are 17 meters apart
IceCube detector
DeepCore
Digital Optical Module (DOM)
5,160 DOMs deployed in the ice
Antarctic bedrock
Credit: IceCube/NSF

IceCube Neutrino Observatory at NSF's Amundsen-Scott South Pole Station



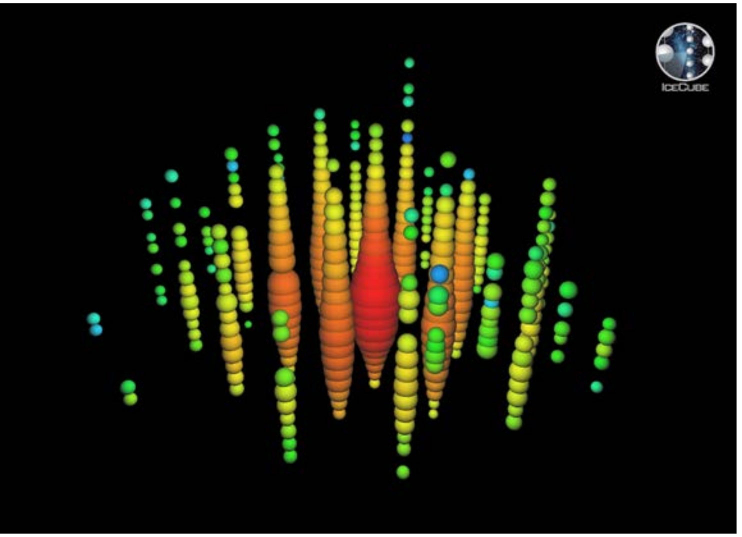
Seven seasons of construction at South Pole (2003 to 2011)

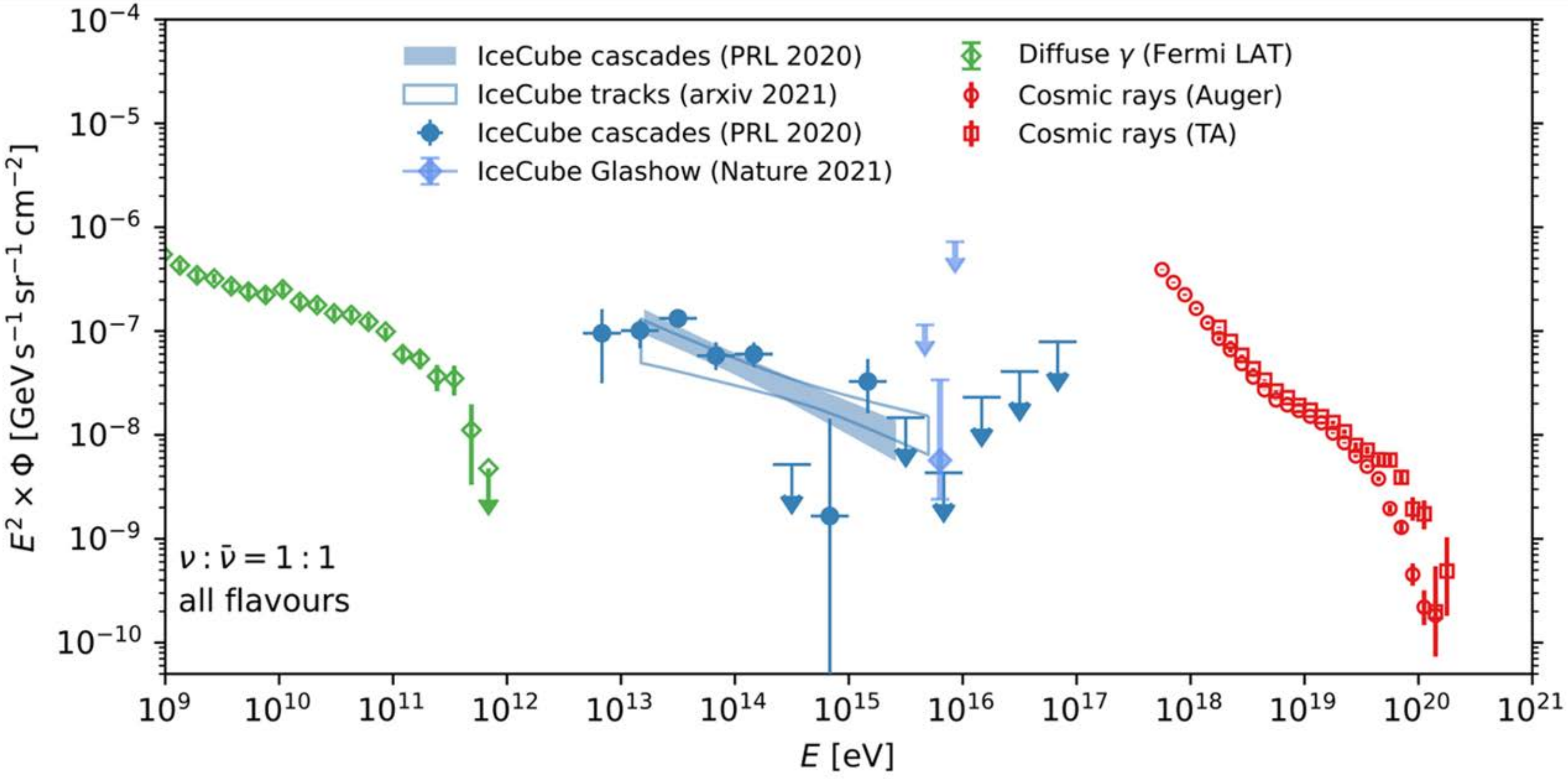
Dedicated team and collaboration-wide effort critical to success

IceCube Collaboration:
more than 350 scientists from 58 institutions in 14 countries

Credit: Benjamin Eberhardt

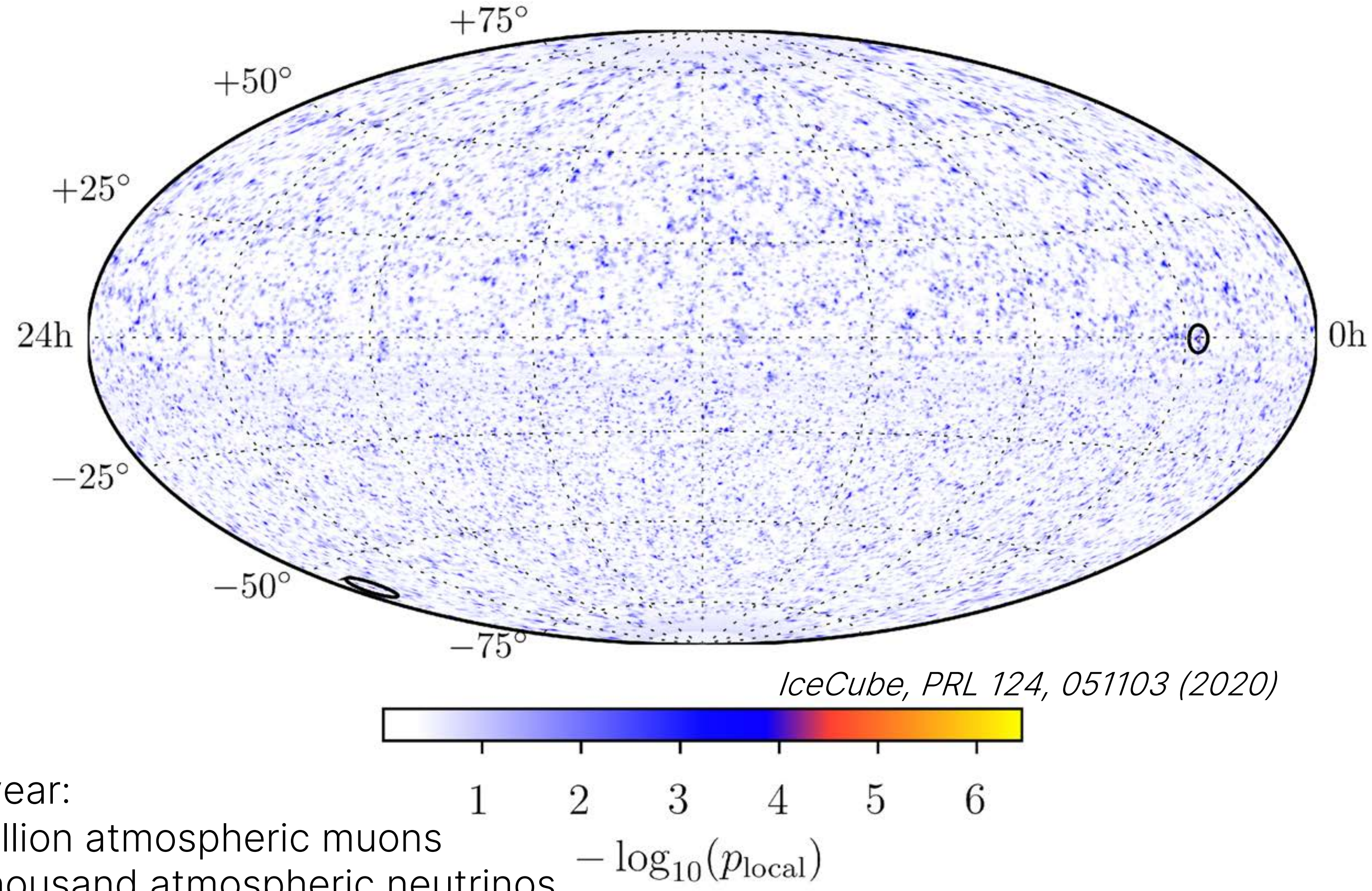
What have we learned from IceCube?
The Universe glows brightly in high-energy neutrinos





Neutrino energy density matches gamma rays and cosmic rays.
Neutrinos in all directions (isotropic). What is producing them?

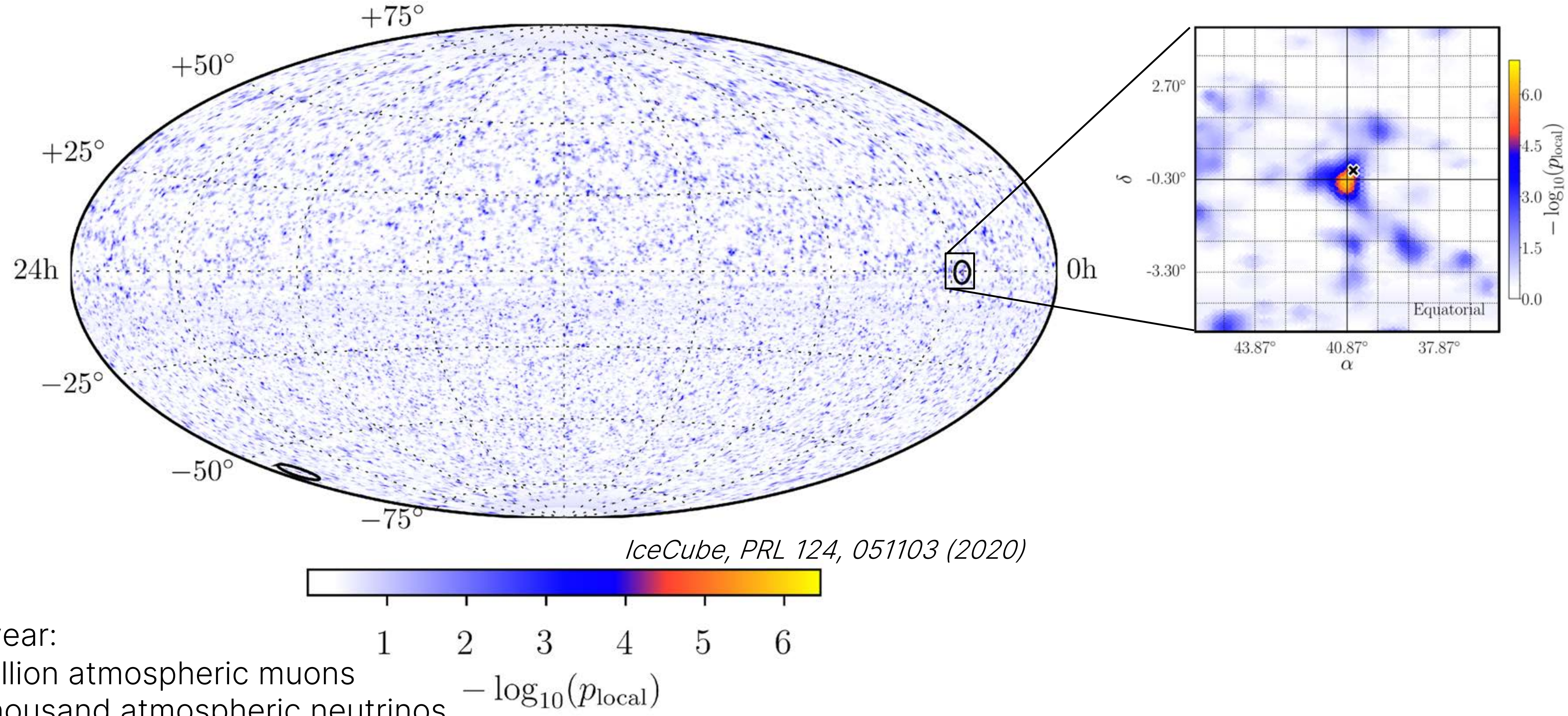
Prior IceCube results: time-integrated neutrino source search



IceCube, PRL 124, 051103 (2020)

Per year:
90 billion atmospheric muons
80 thousand atmospheric neutrinos

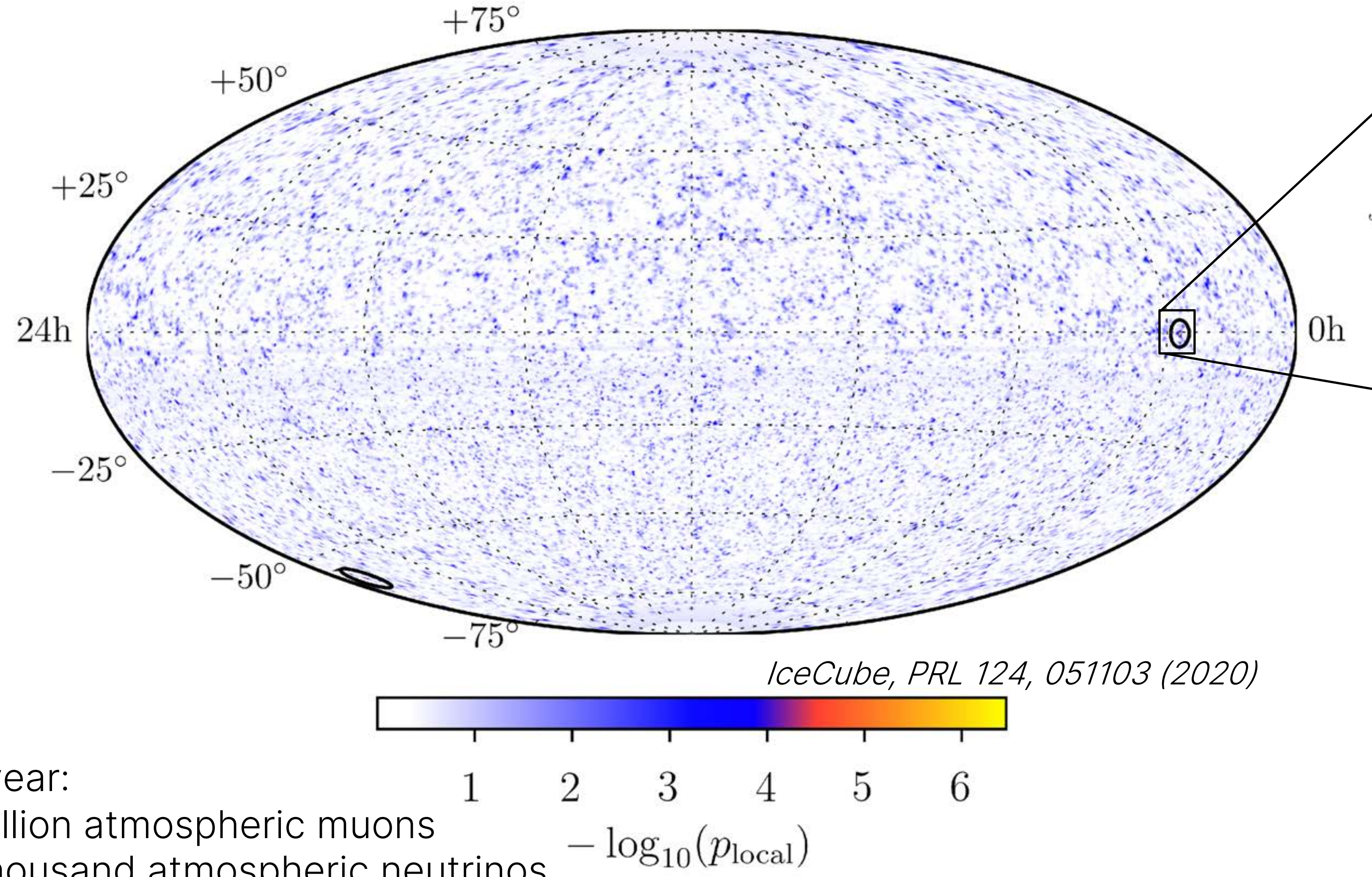
Prior IceCube results: searching for statistical evidence of clustering



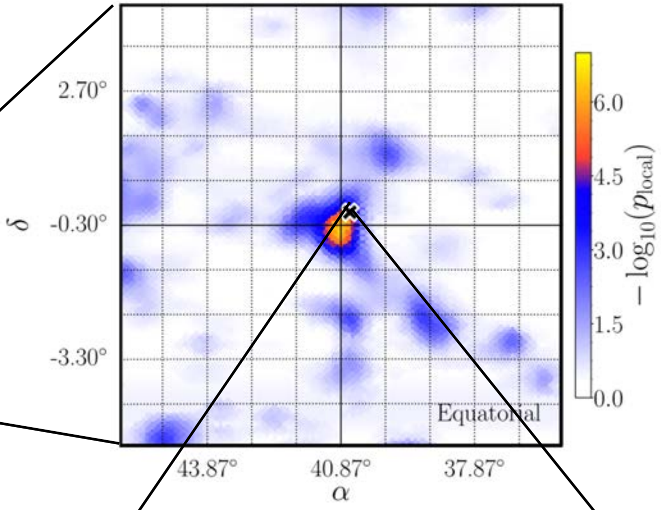
IceCube, PRL 124, 051103 (2020)

Per year:
90 billion atmospheric muons
80 thousand atmospheric neutrinos

Most significant position on sky: consistent with NGC 1068 (Messier 77), a Seyfert II galaxy (2.9 σ)



IceCube, PRL 124, 051103 (2020)



50 neutrinos

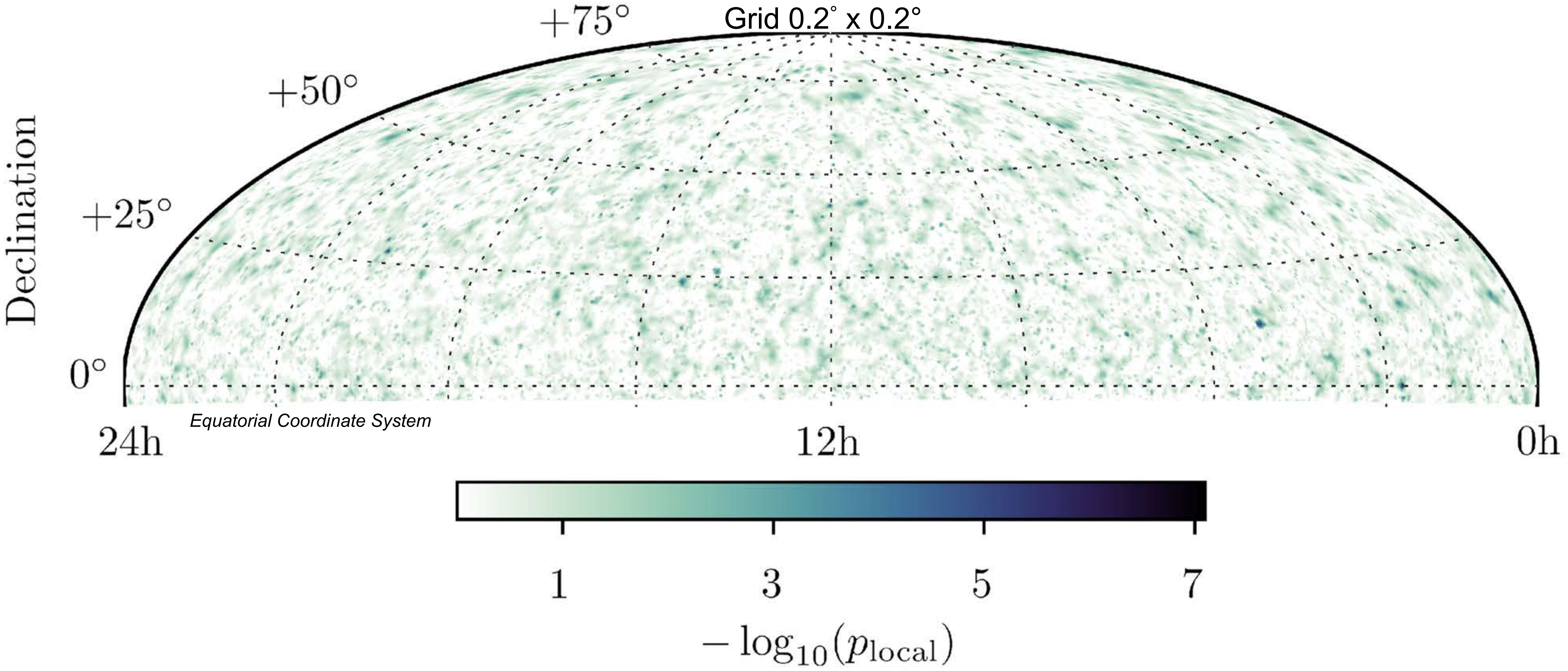
Per year:
90 billion atmospheric muons
80 thousand atmospheric neutrinos

IceCube enhanced sensitivity to neutrino sources

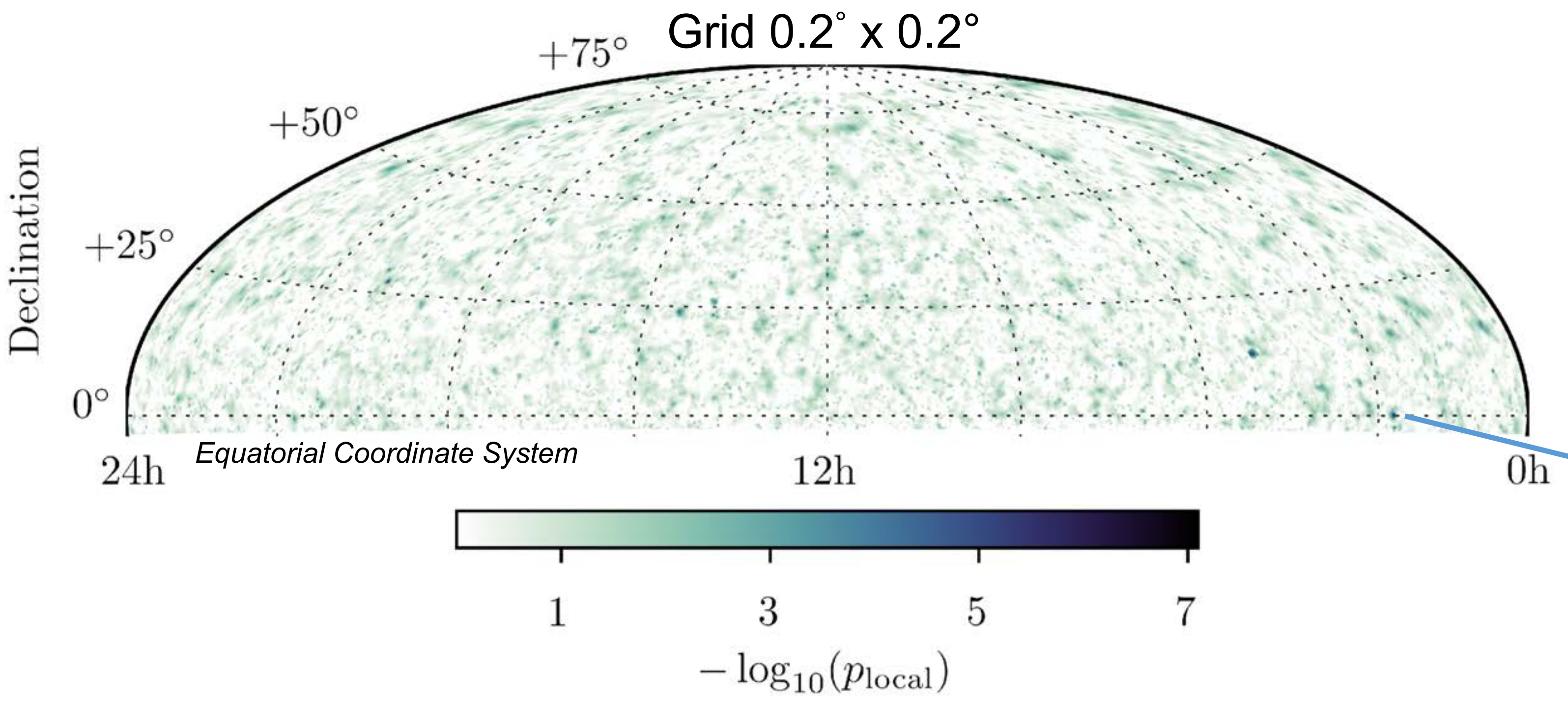
Elisa Resconi, Technical University of Munich

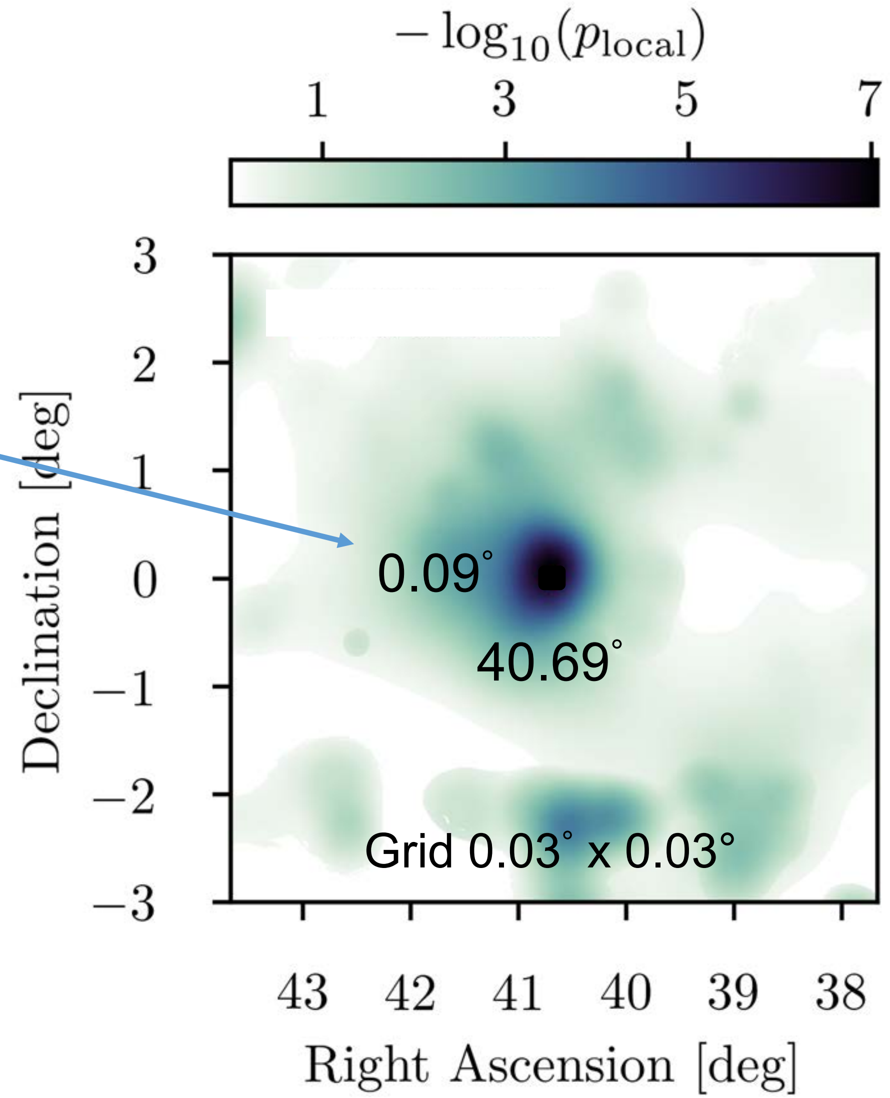
Credit: Martin Wolf, IceCube/NSF

The new IceCube neutrino map



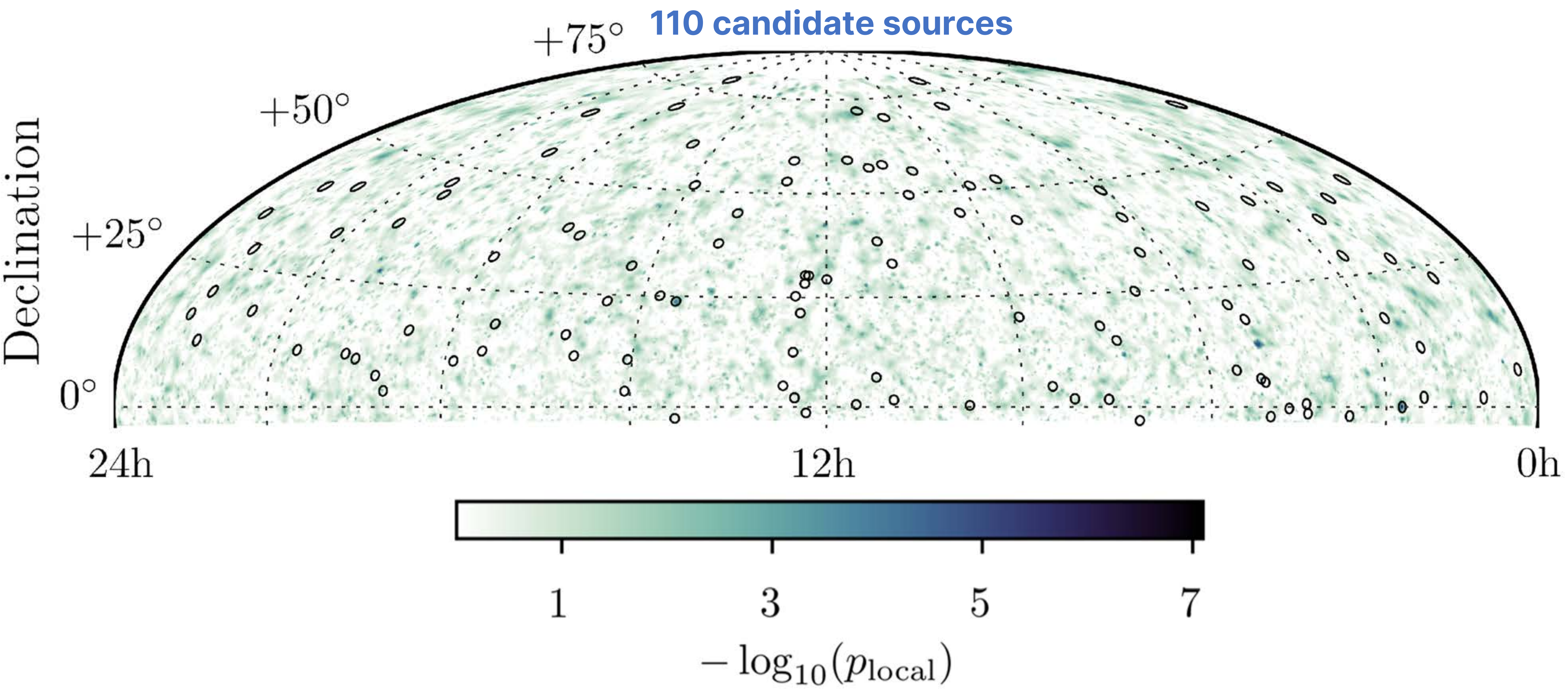
Identified ‘hot’ spot



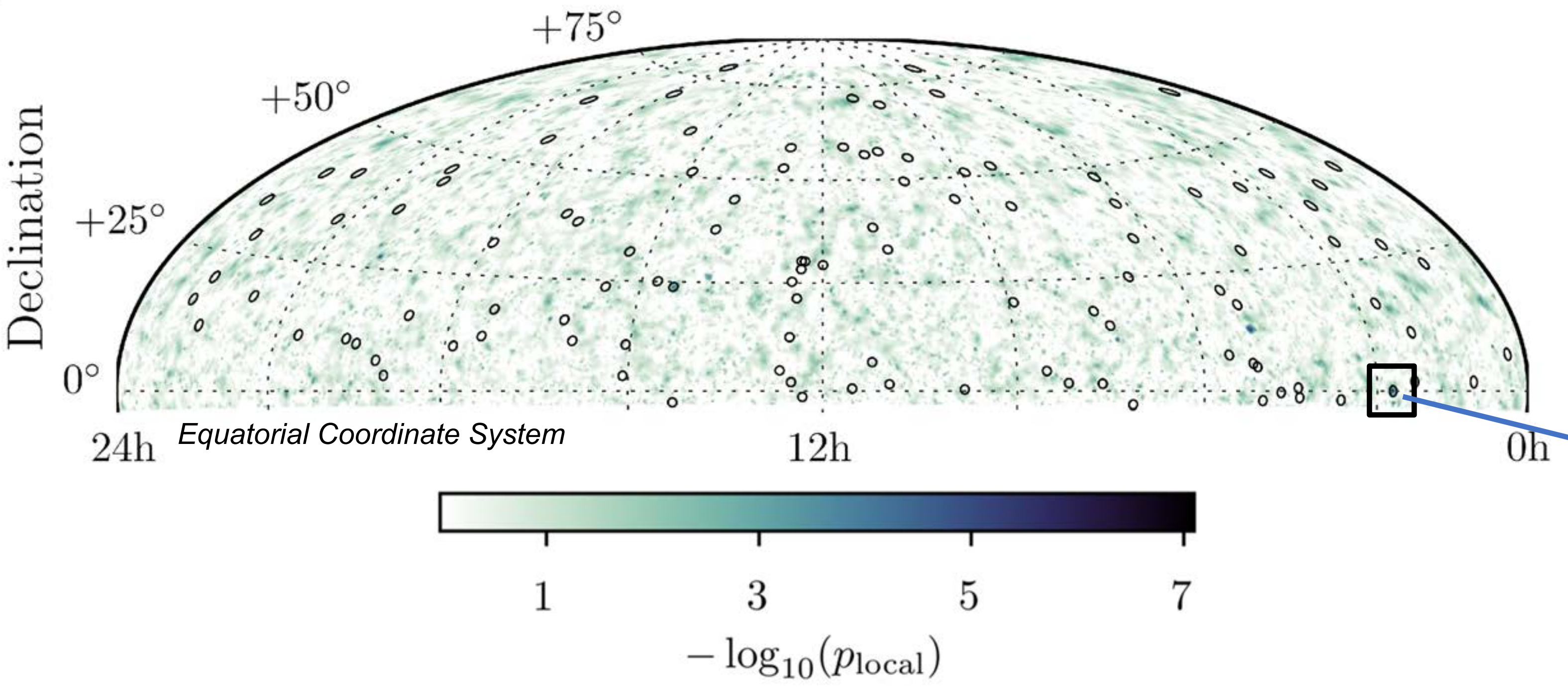


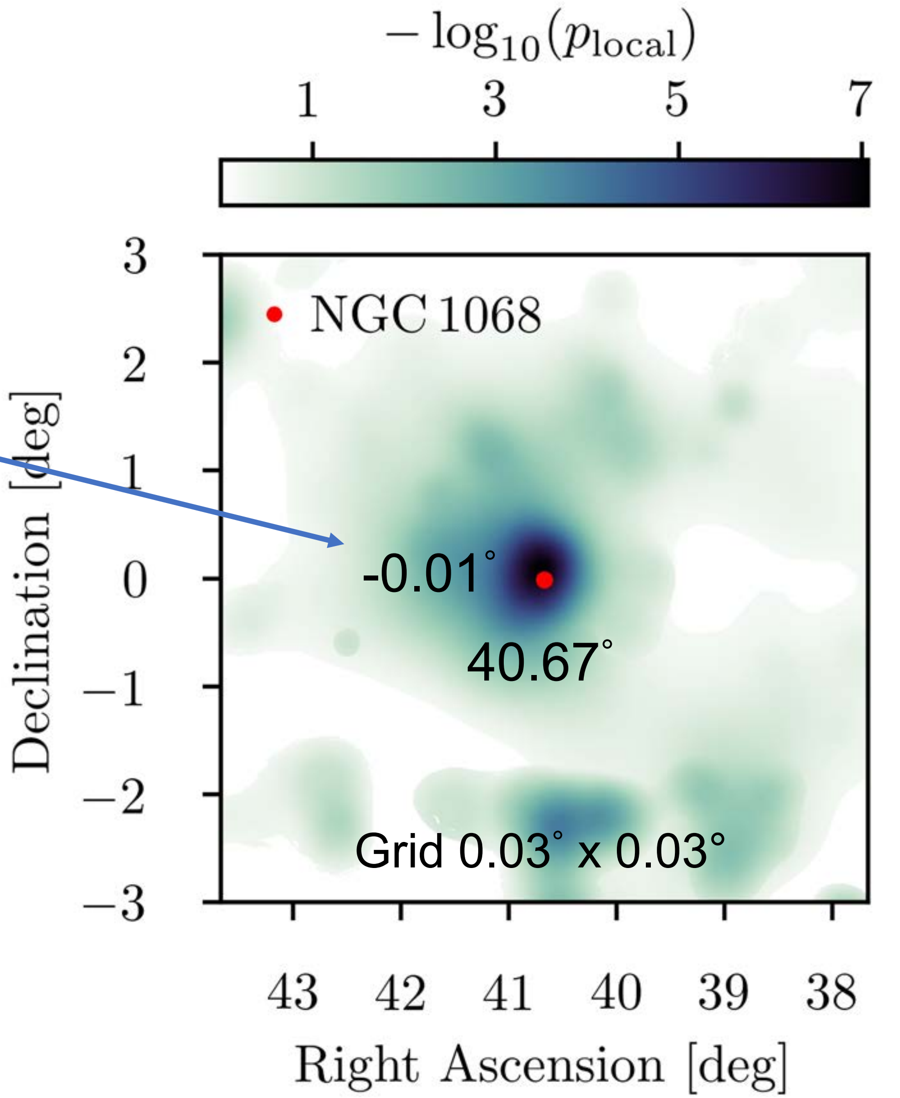
At the brightest location in full sky scan:
Mean astrophysical neutrino events = 81
Mean spectral index = 3.2

Is the ‘hot’ spot in coincidence with an object?

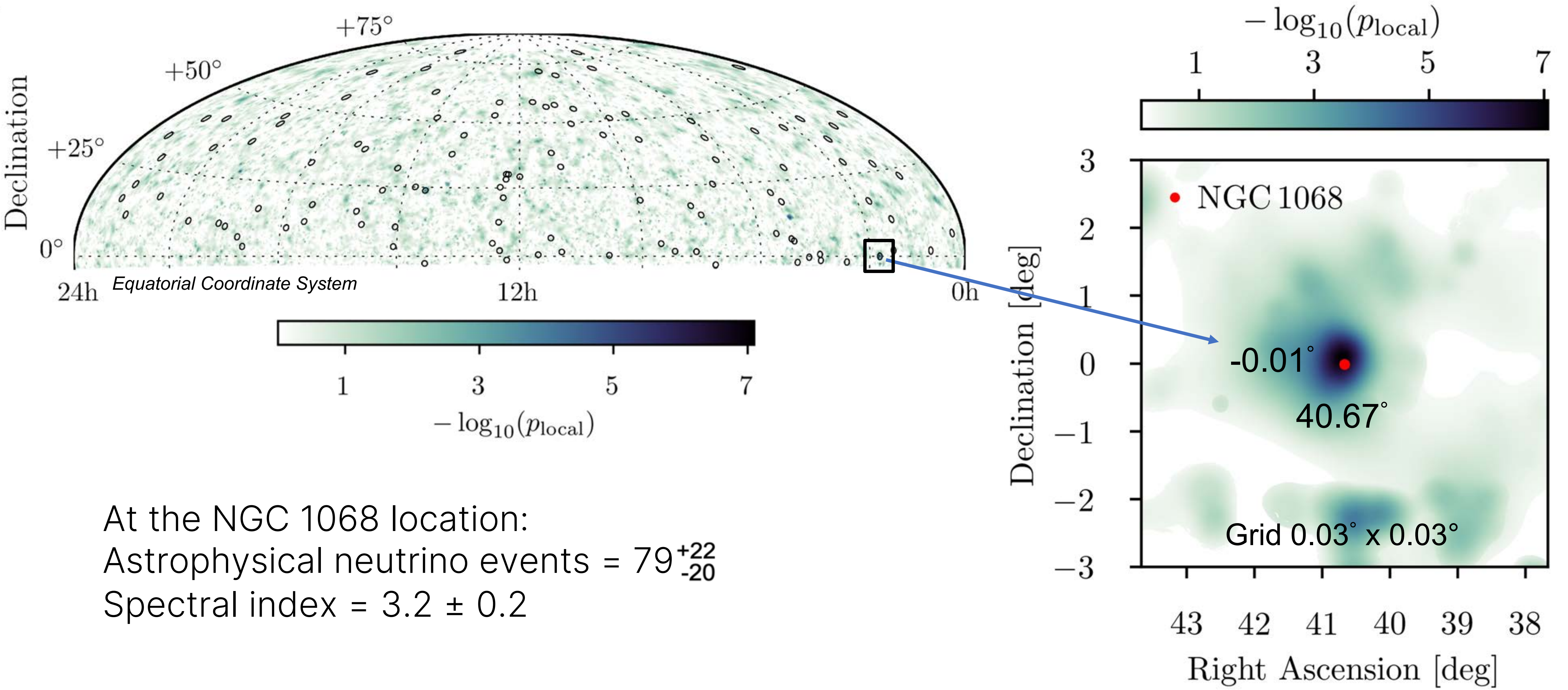


Hottest spot coincides with NGC 1068



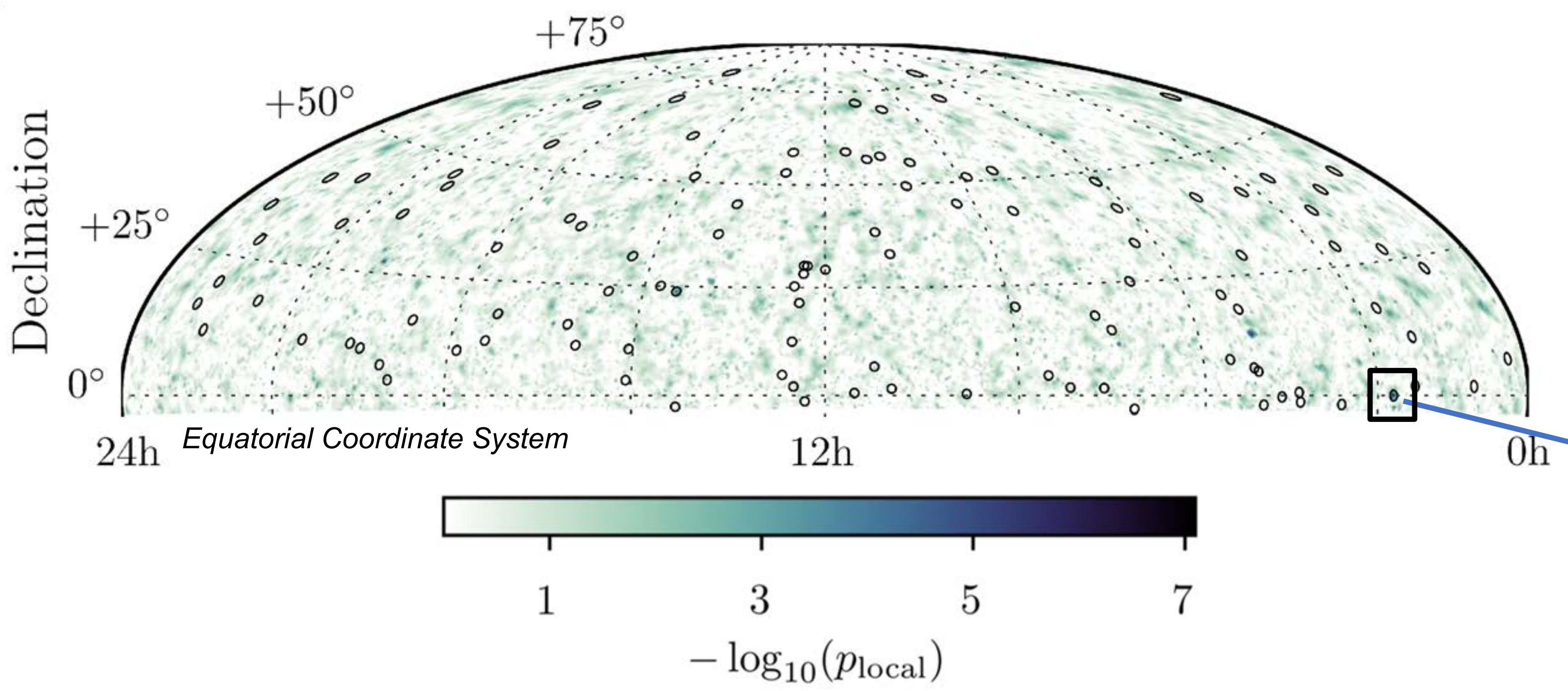


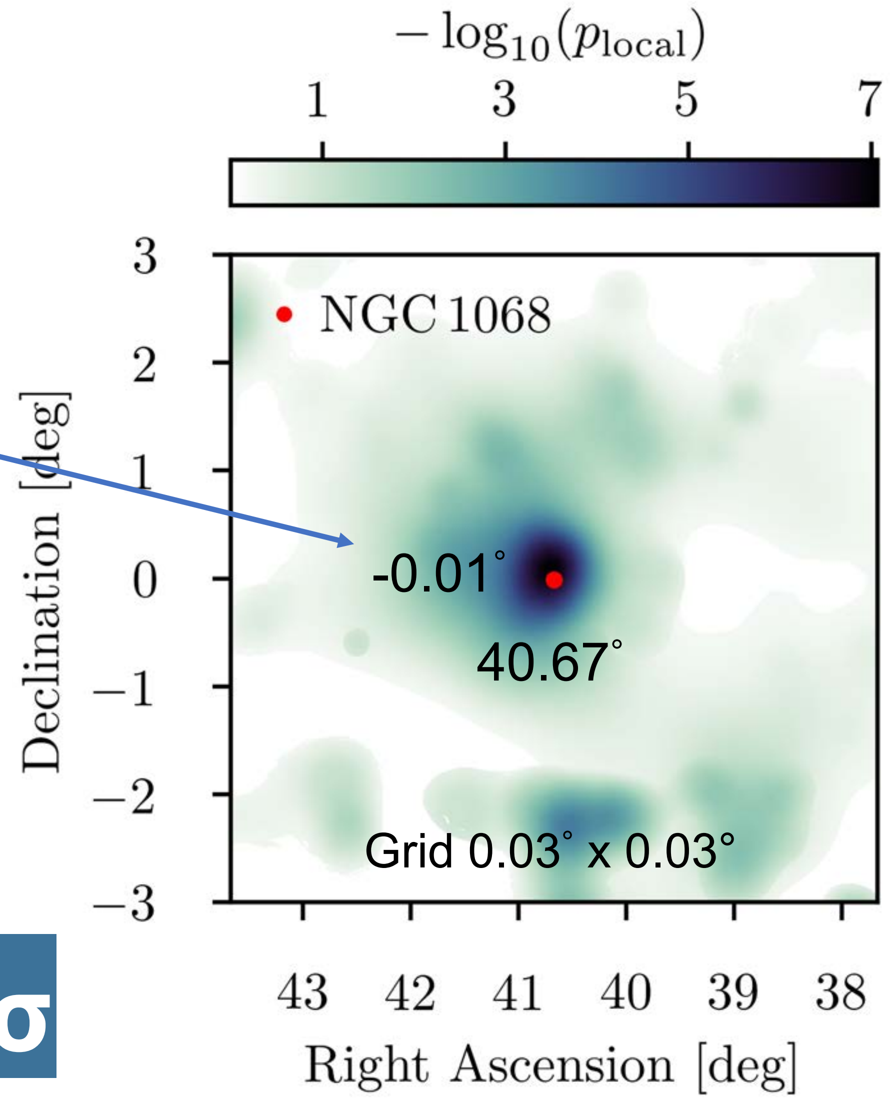
Hottest spot coincides with NGC 1068



At the NGC 1068 location:
Astrophysical neutrino events = 79^{+22}_{-20}
Spectral index = 3.2 ± 0.2

Evidence for neutrino emission from NGC 1068





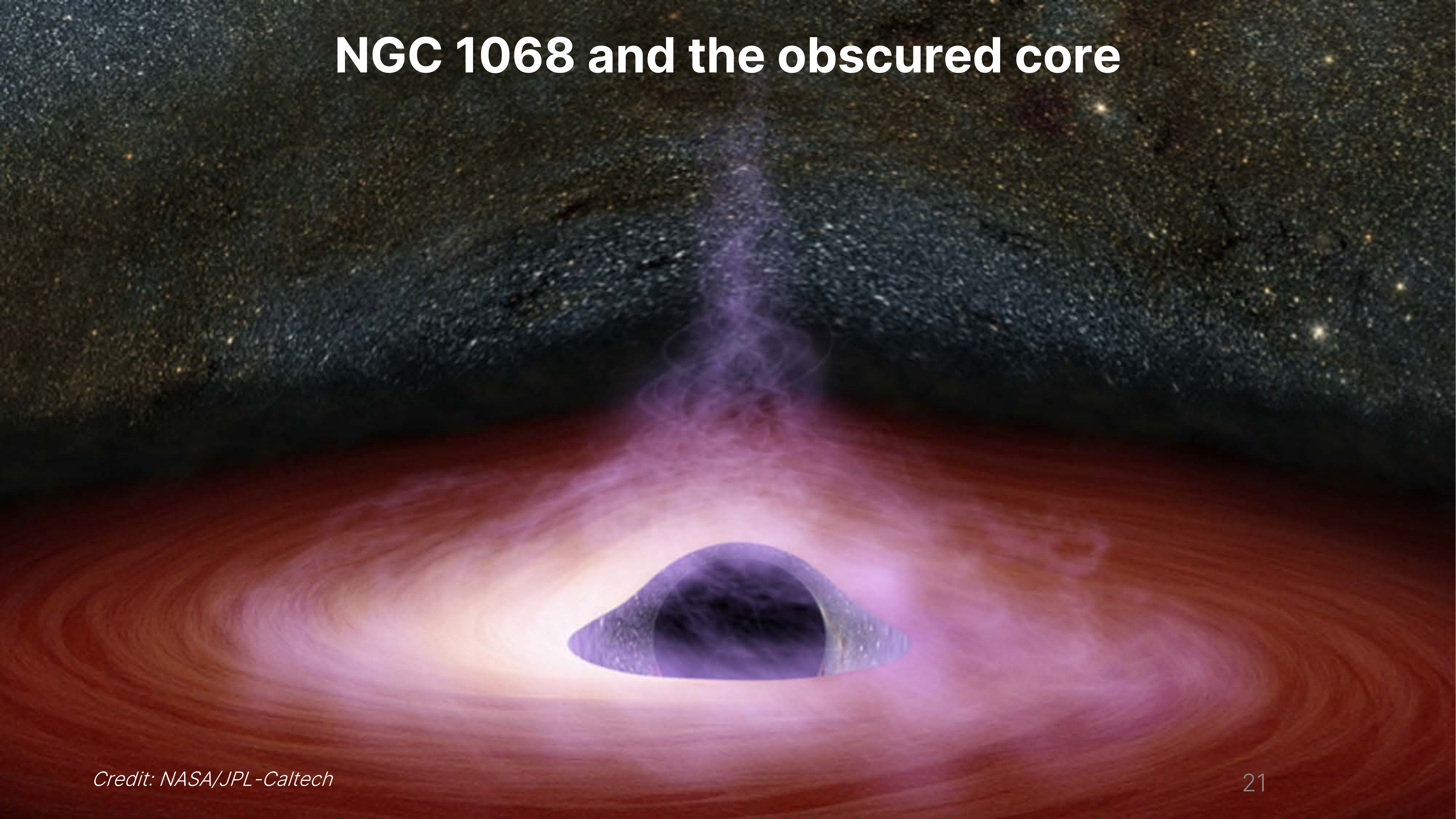
At the NGC 1068 location:
Astrophysical neutrino events = 79^{+22}_{-20}
Spectral index = 3.2 ± 0.2

Global significance 4.2σ

NGC 1068: a non-jetted AGN with an obscured black hole

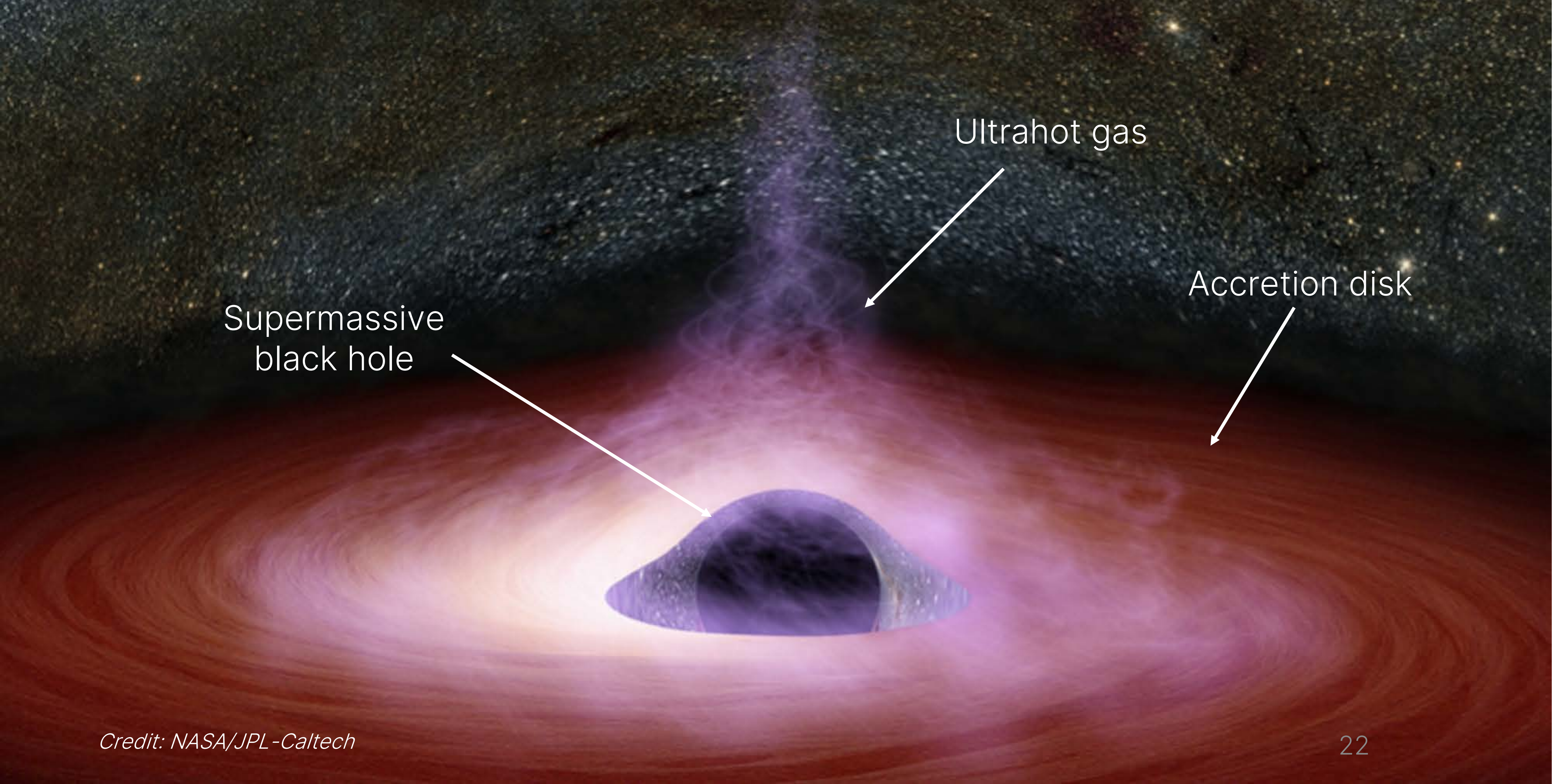
Credit: NASA/JPL-Caltech

NGC 1068 and the obscured core



Credit: NASA/JPL-Caltech

NGC 1068 and the obscured core



Credit: NASA/JPL-Caltech

How are neutrinos produced in non-jetted AGNs?

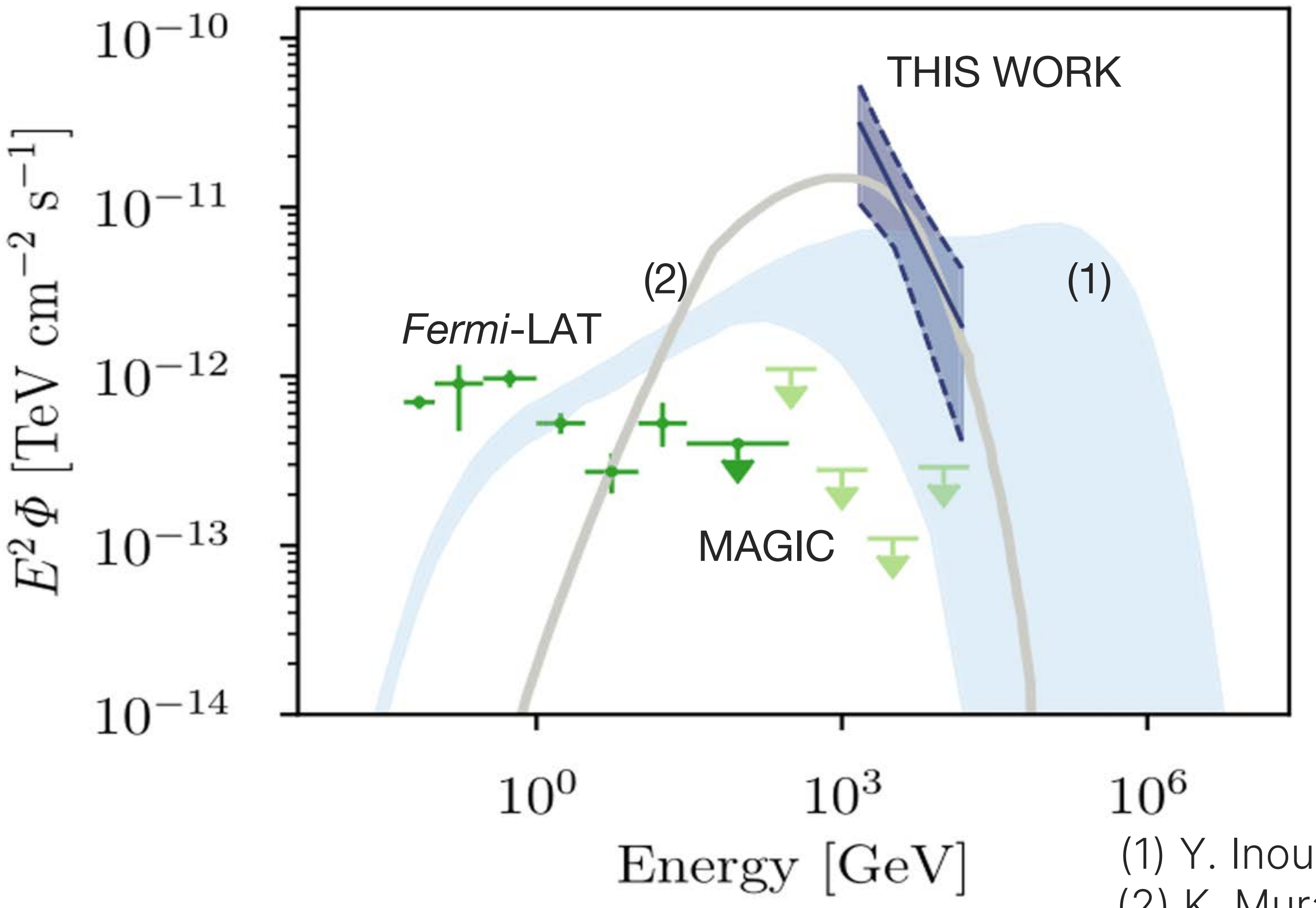
We conclude that active galactic nuclei are powerful sources for accelerating particles to cosmic ray energies. The bulk of meta-
galactic cosmic rays is likely to ori
particular, in the Virgo supercluster
NGC 4151 and NGC 1068 are likely to b
"local" metagalactic cosmic rays, inc
the ultra-high energy ($E \gtrsim 10^{19}$ eV) a
density of photons in the immediate v
be too high (Blumenthal, 1970) to permit the acceleration of protons beyond $\sim 10^{14}$ eV, (except by beaming processes). The highest energy protons hence are accelerated somewhat farther out, or else by beaming (Lovelace, 1976). Gamma rays from the ergosphere of a black hole are degraded at energies above ~ 1 MeV, and from a spinar, above ~ 1 GeV. Neutrinos are not thus affected and would provide information on very high energy particles in active galactic nuclei.

R. Silberberg and M. M. Shapiro

Laboratory for Cosmic Ray Physics
Naval Research Laboratory
Washington, D.C. 20375

1982

NGC 1068: a cosmic obscured accelerator



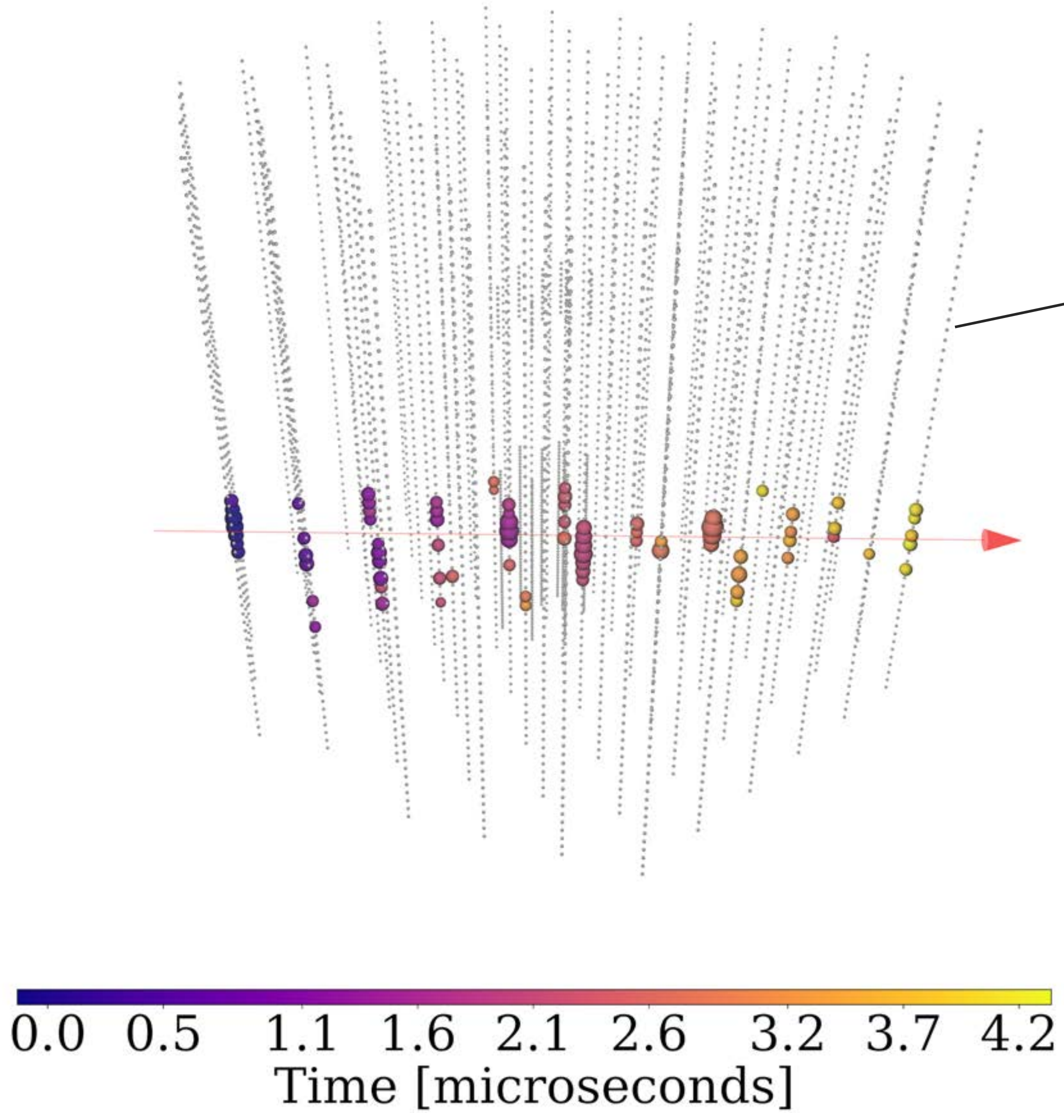
(1) Y. Inoue et al., ApJL'20
(2) K. Murase et al., PRL'20

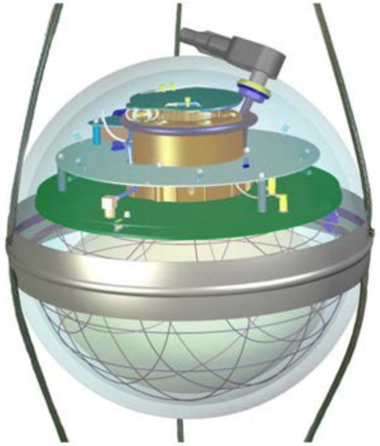
Improving searches for astrophysical neutrino sources

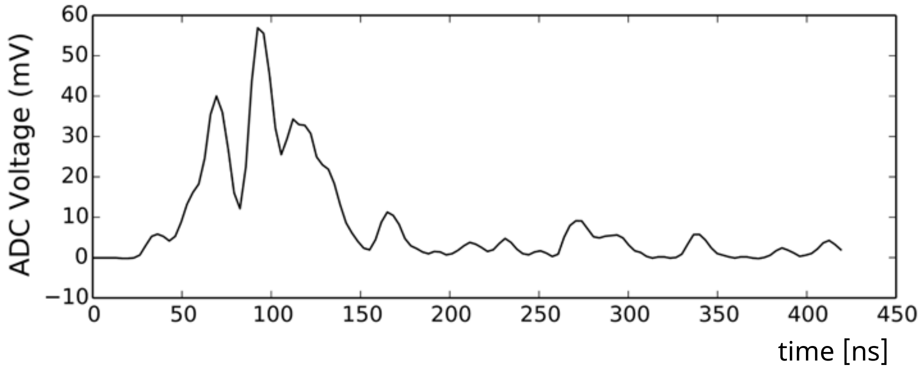
Hans Niederhausen, Michigan State University & Technical University of Munich

Credit: Martin Wolf, IceCube/NSF

Detecting neutrinos with IceCube







neutrino events are characterized by reconstructed quantities **direction**, **energy**, **angular uncertainty**

An improved track dataset

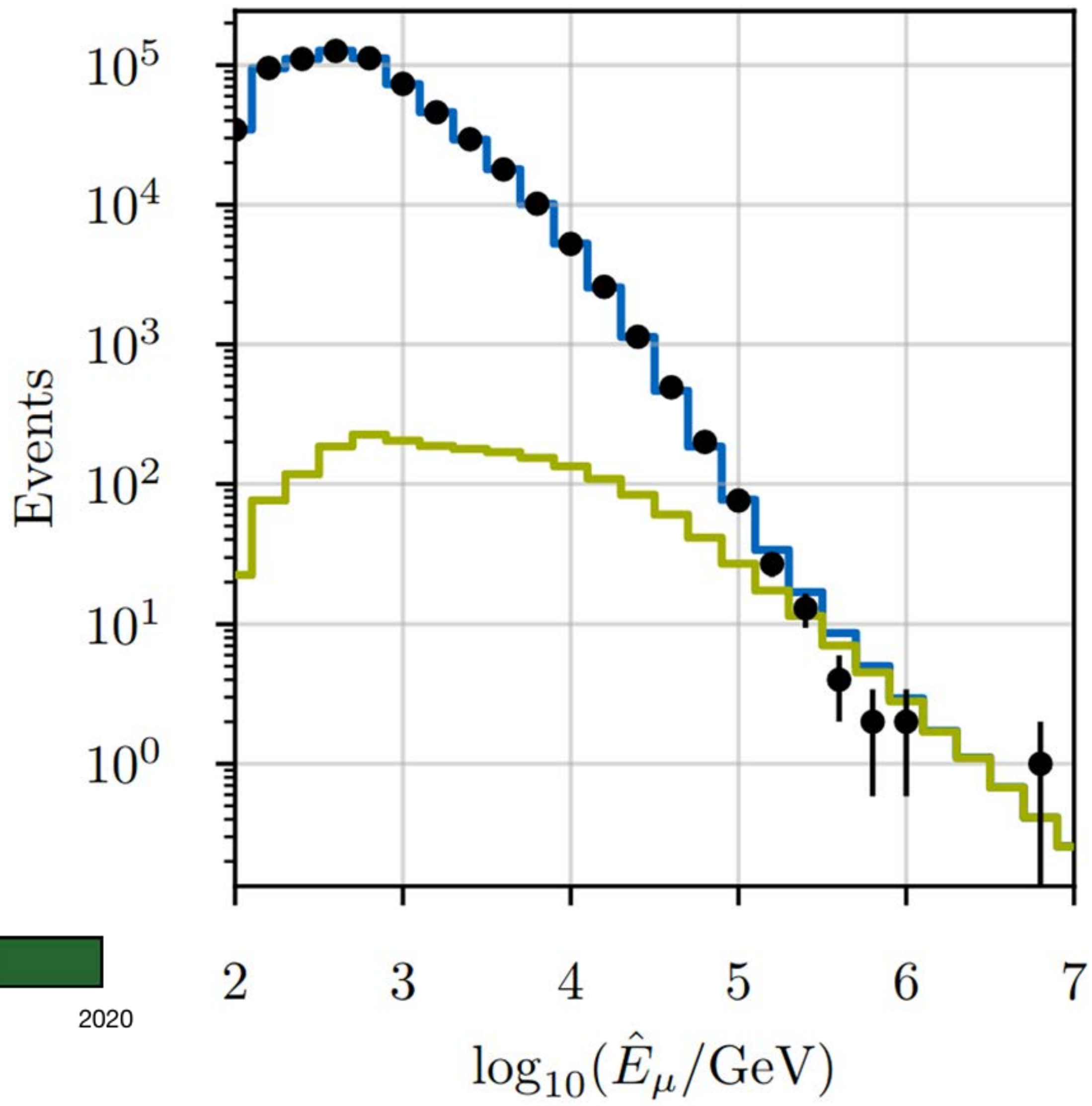
data: May 2011 to May 2020

~99% detector uptime

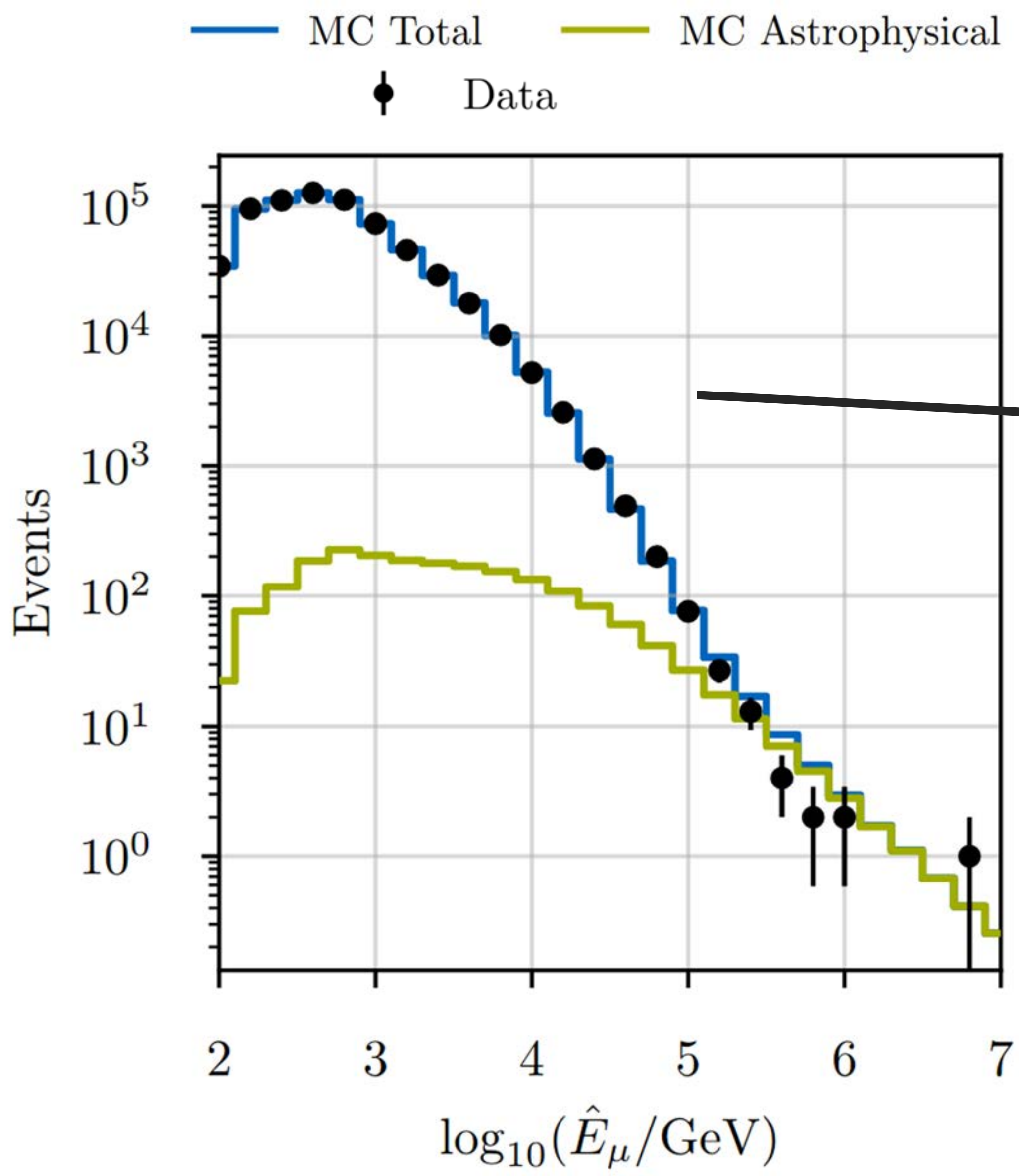
~670,000 neutrinos selected (99.7% purity)
out of ~1 trillion events recorded

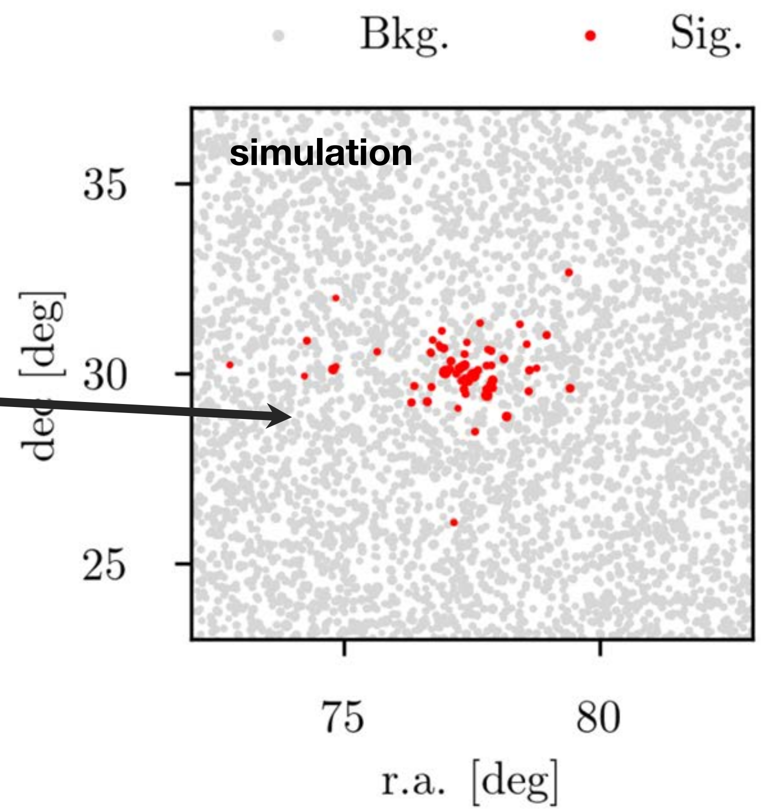
multiple improvements
detector calibration, data filtering and processing
applied to entire dataset (all ~1 trillion events)

=> IceCube Pass 2 data



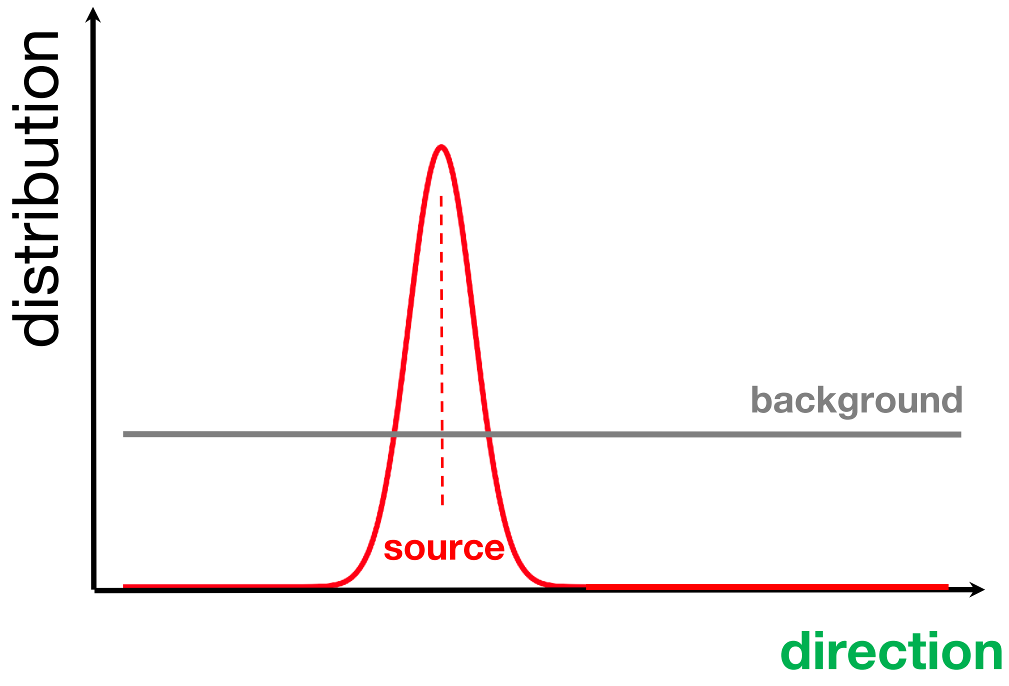
Searching for neutrino sources

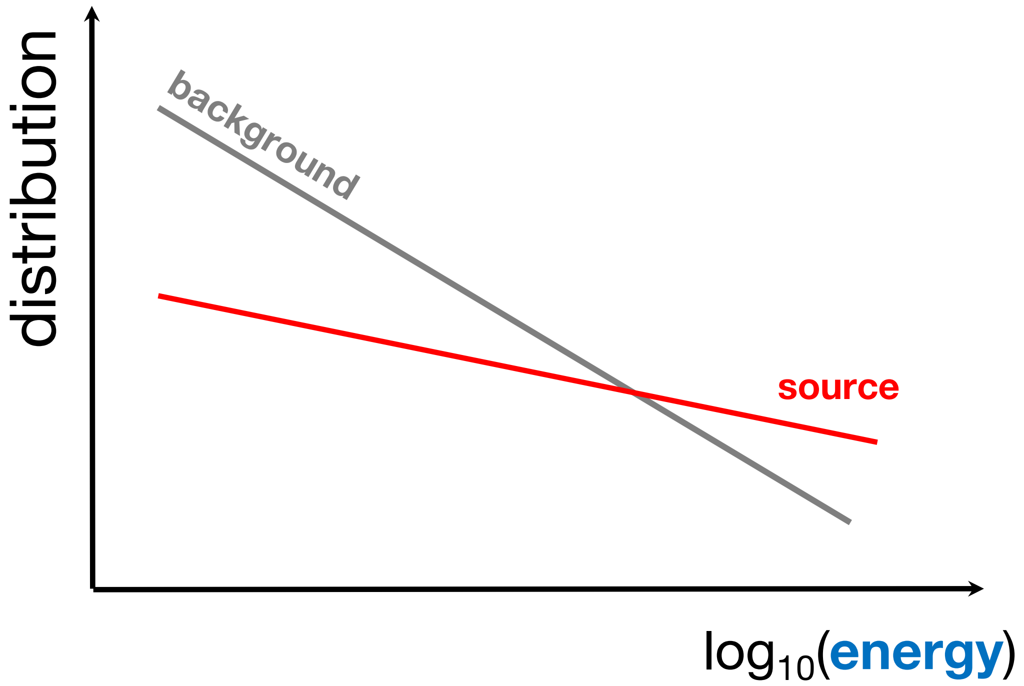




vast majority of the neutrinos are background in searches for extragalactic neutrino sources

Searching for neutrino sources

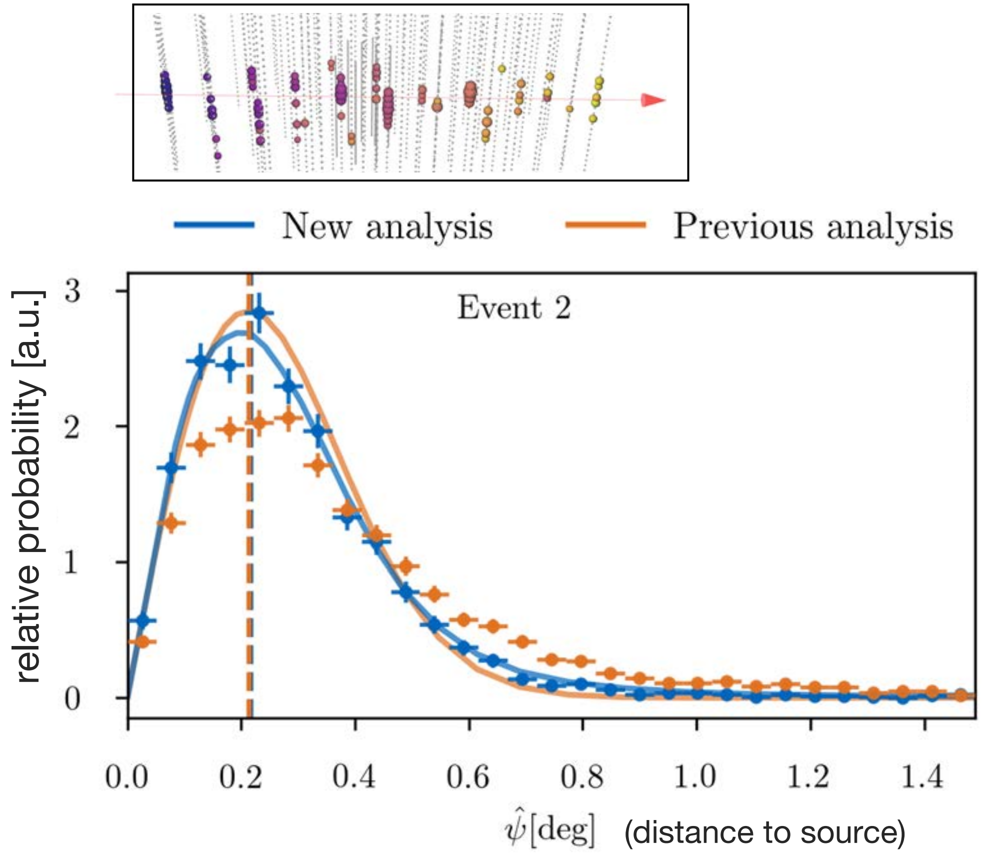


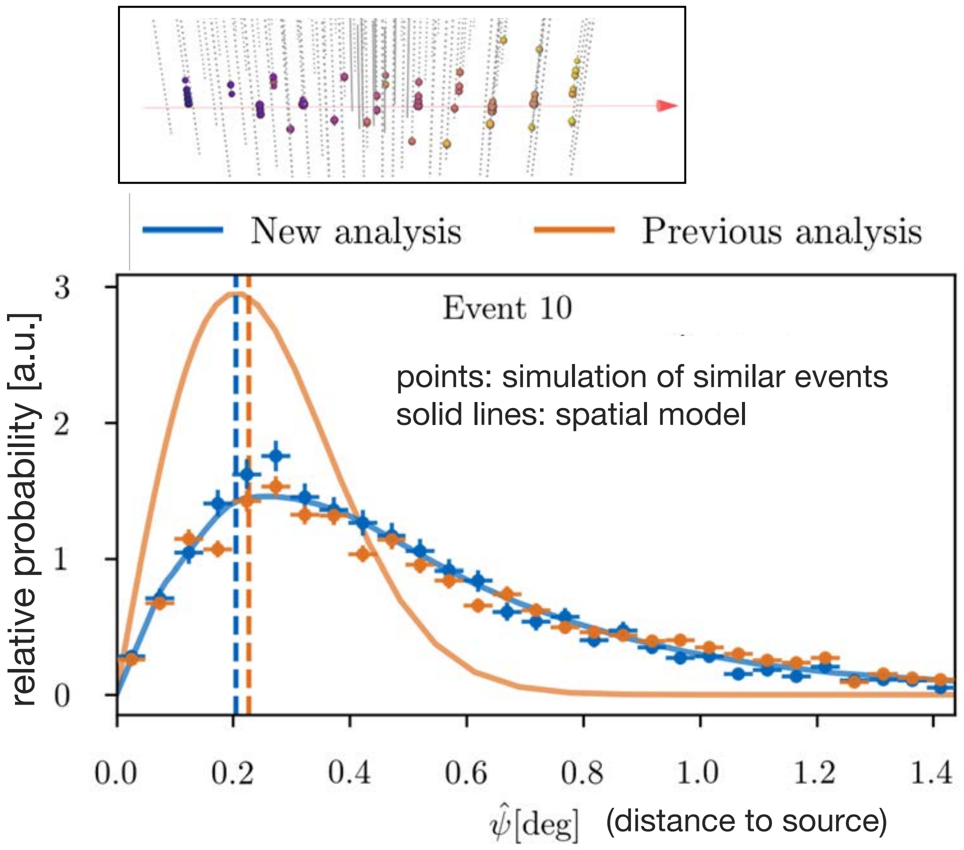


need good reconstruction of directions and energies
and model of how they differ between signal and background

We improved in both areas!

Analysis improvement - “Pointing with neutrinos”

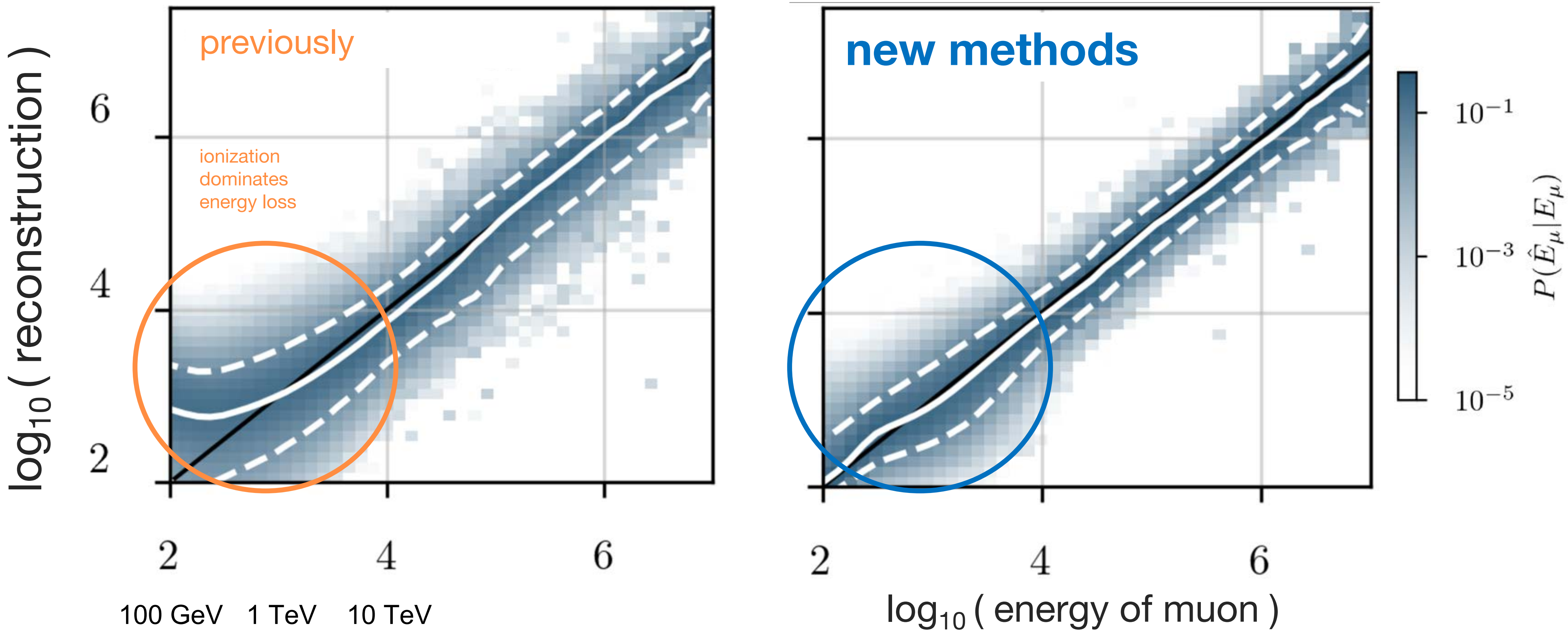




directional distributions

better modeling of directional distributions of individual neutrinos (at TeV energies)

Analysis improvement - “Energy measurement”

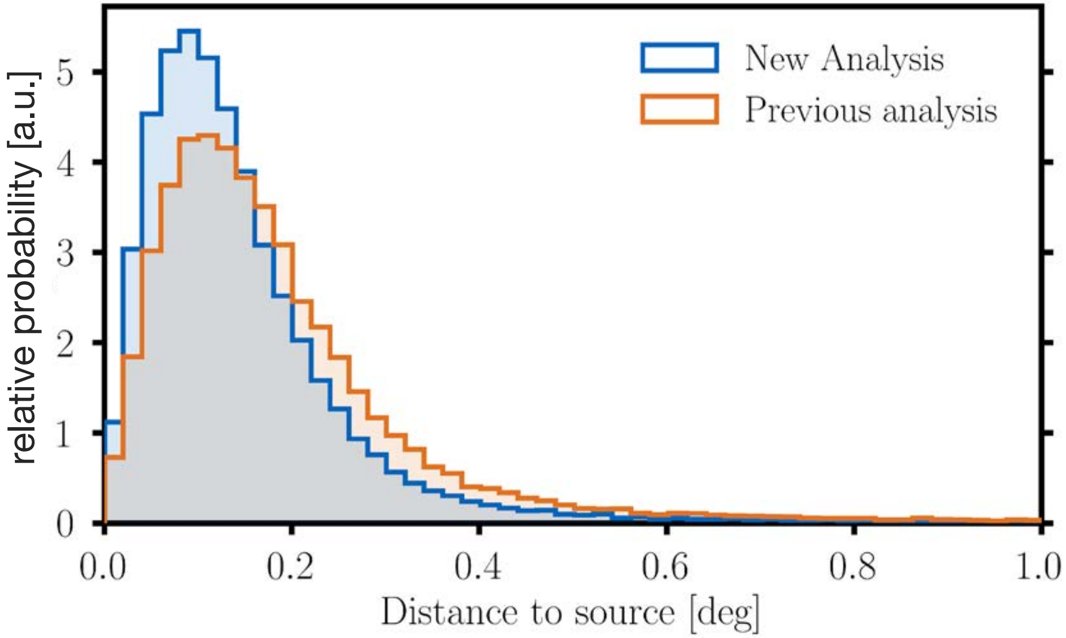


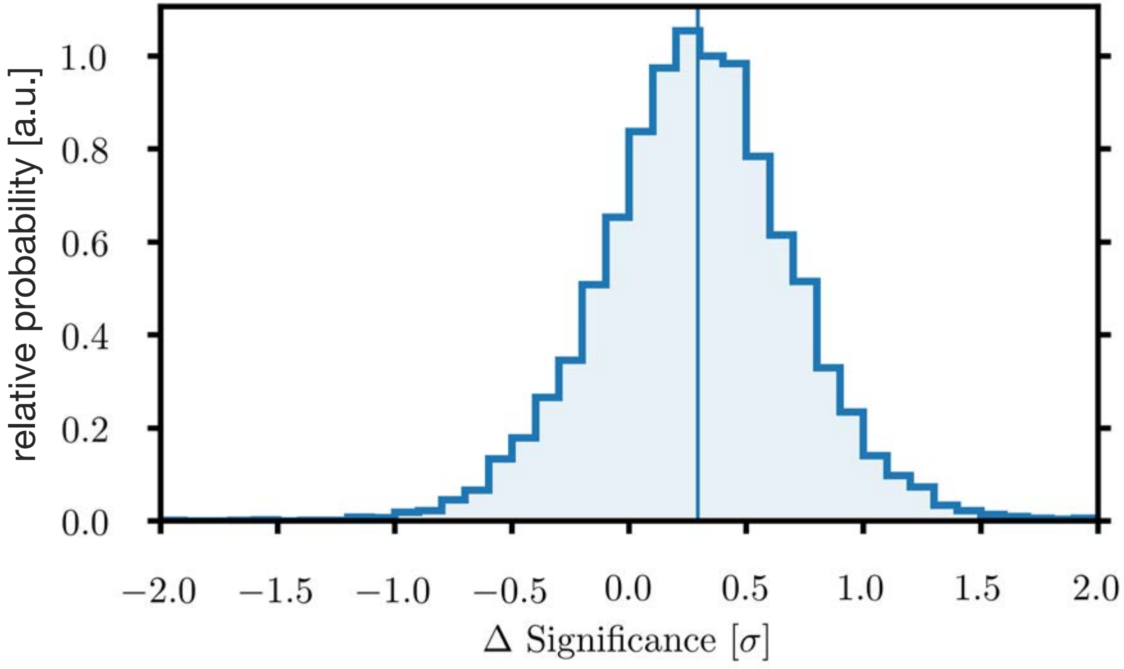
energy reconstruction

machine learning provides more accurate and more precise energy estimates especially at TeV-energies

Analysis improvements - Performance

simulated 80 neutrinos from NGC 1068 many times



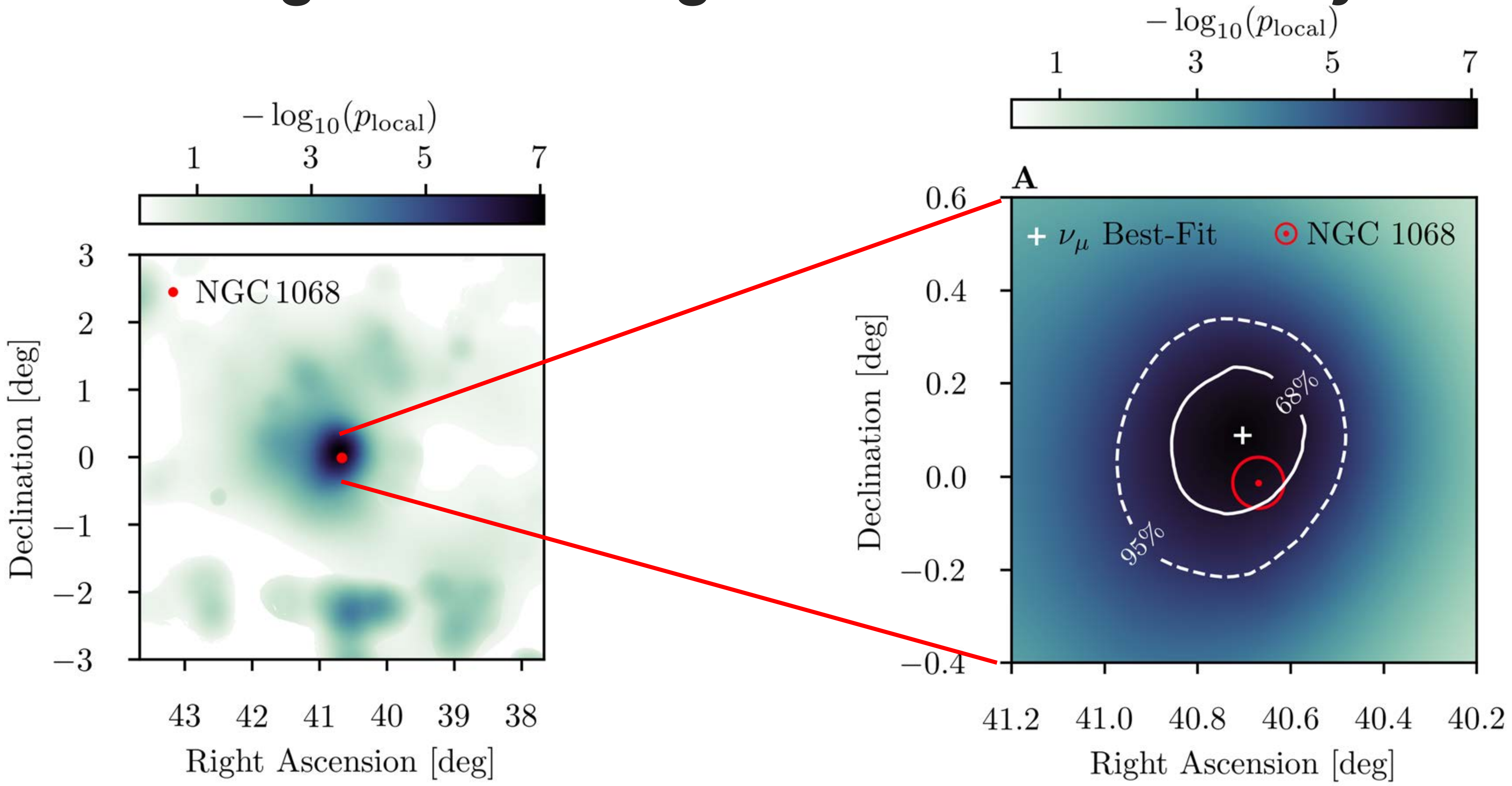


on average:

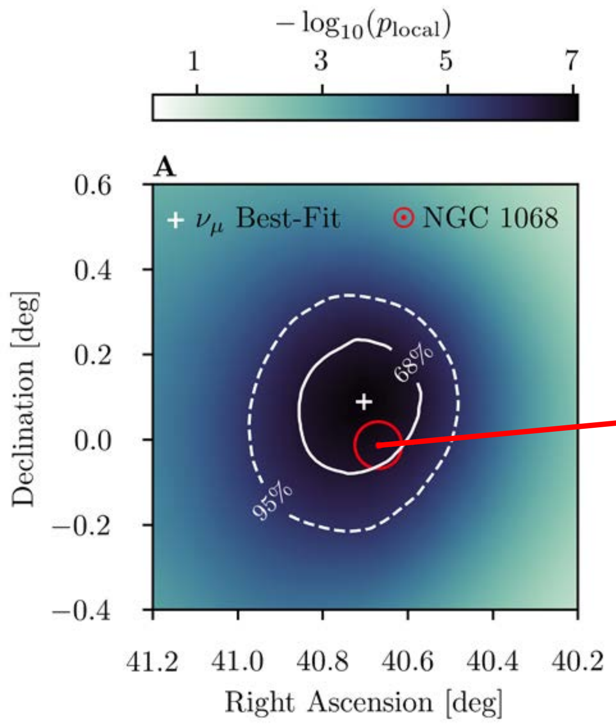
new methods provide better source localization

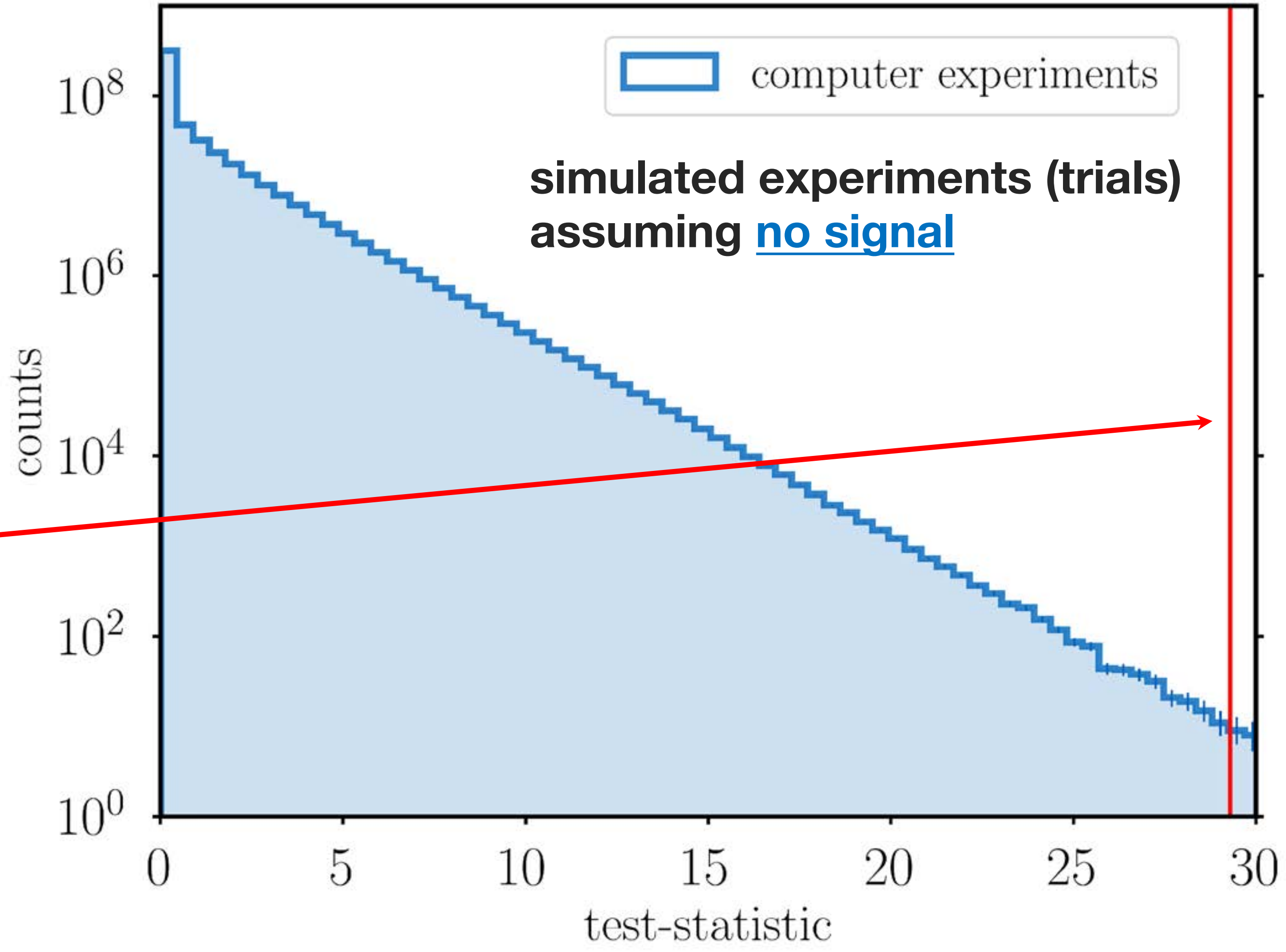
new methods give higher significance

NGC 1068 is consistent with location of strongest clustering of neutrinos in the sky



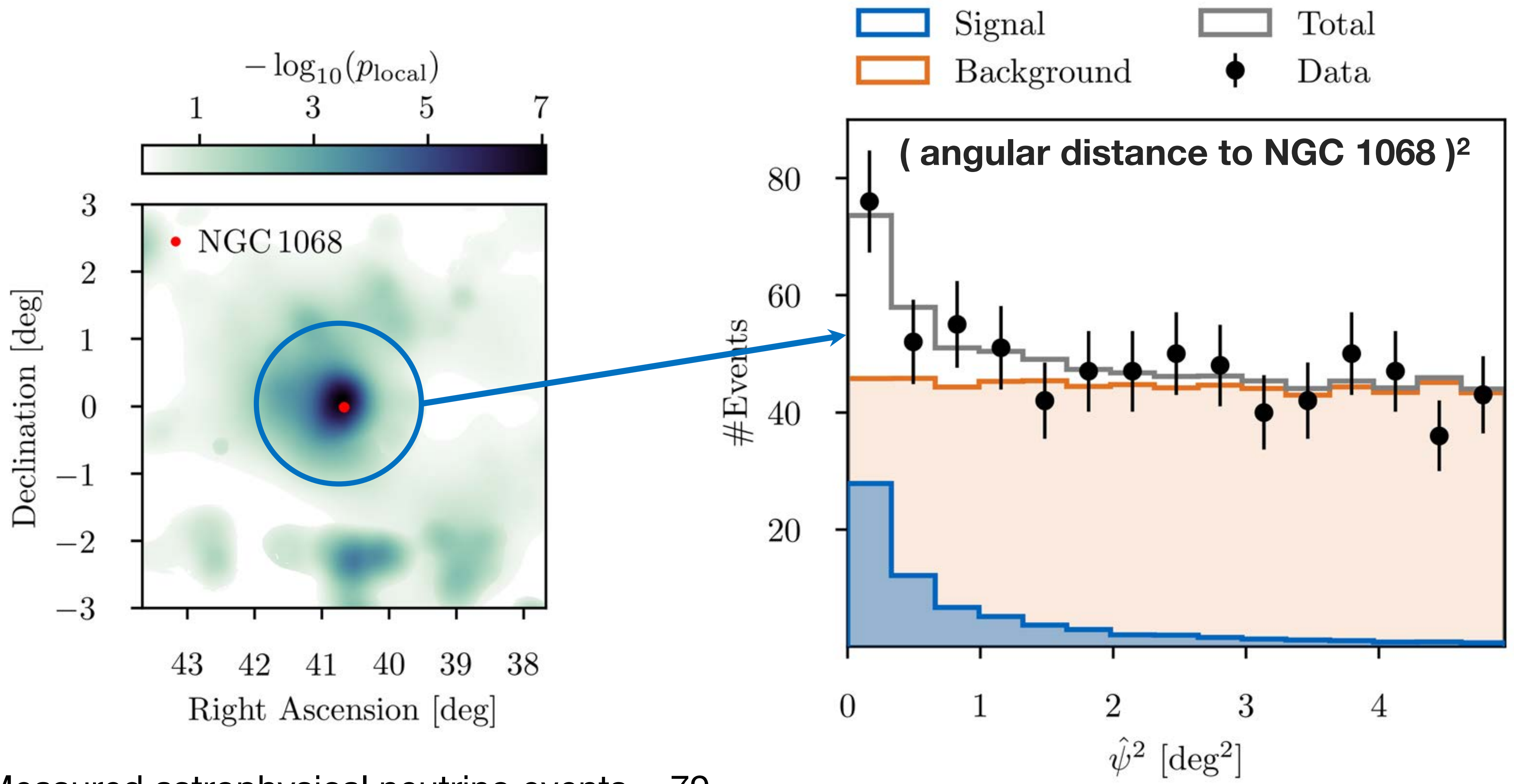
... global significance **4.2σ**





using 500x10^6 computer experiments assuming no signal
and accounting for catalog size (110 candidate sources) yields p~1.1x10^{-5}

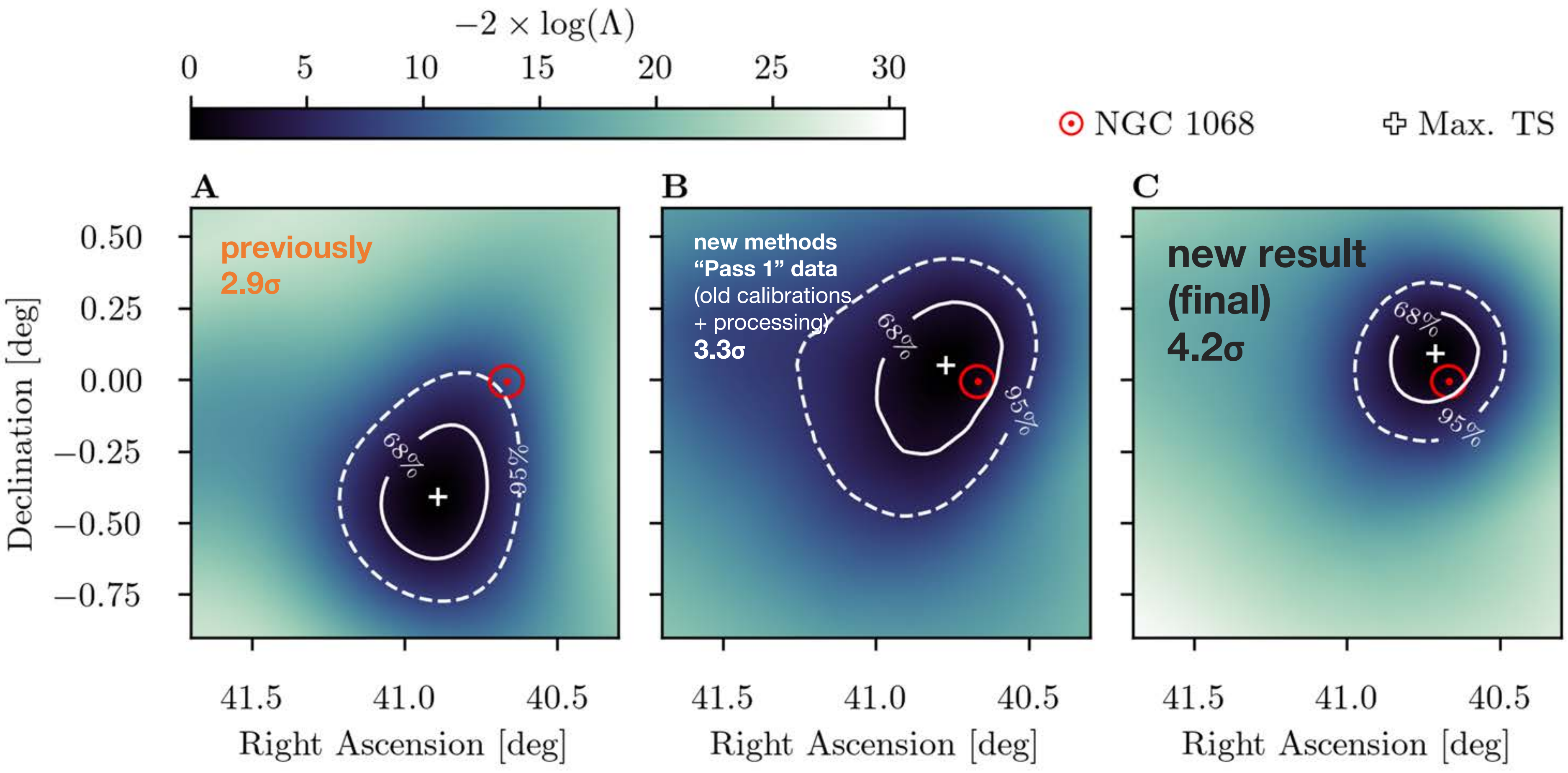
Distribution of neutrino events around NGC 1068 matches our model predictions



Measured astrophysical neutrino events = 79

Improvements made new results possible

1) Improvements in data quality (updated calibrations, uniform processing) "Pass2"
2) Improved statistical methods and reconstructions



(new processing + old methods: 3.8σ)

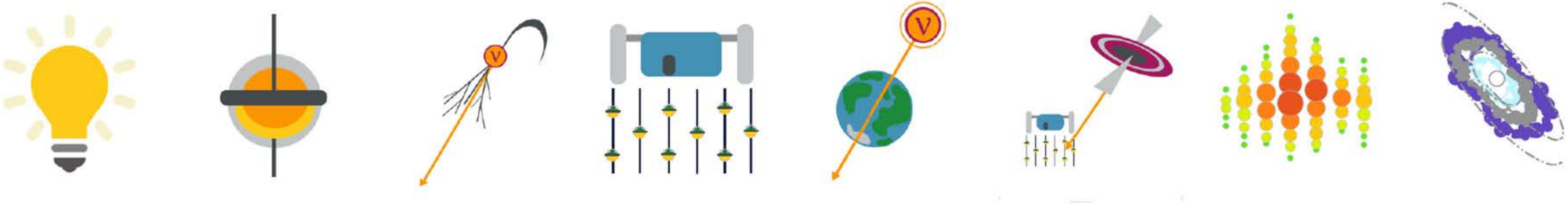
What’s next after the neutrino observation of NGC 1068

Ignacio Taboada, Georgia Institute of Technology

Credit: Martin Wolf, IceCube/NSF

IceCube

A History of Neutrino Astronomy in Antarctica



1988 — Telescope in the Ice Envisioned

2000 — AMANDA Completed

2001 — Atmospheric Neutrinos Detected

2011 — IceCube Completed

2013 — Astrophysical Neutrinos Discovered

2018 — First Source TXS 0506+056 Identified

2021 — Glashow Resonance Neutrino Identified

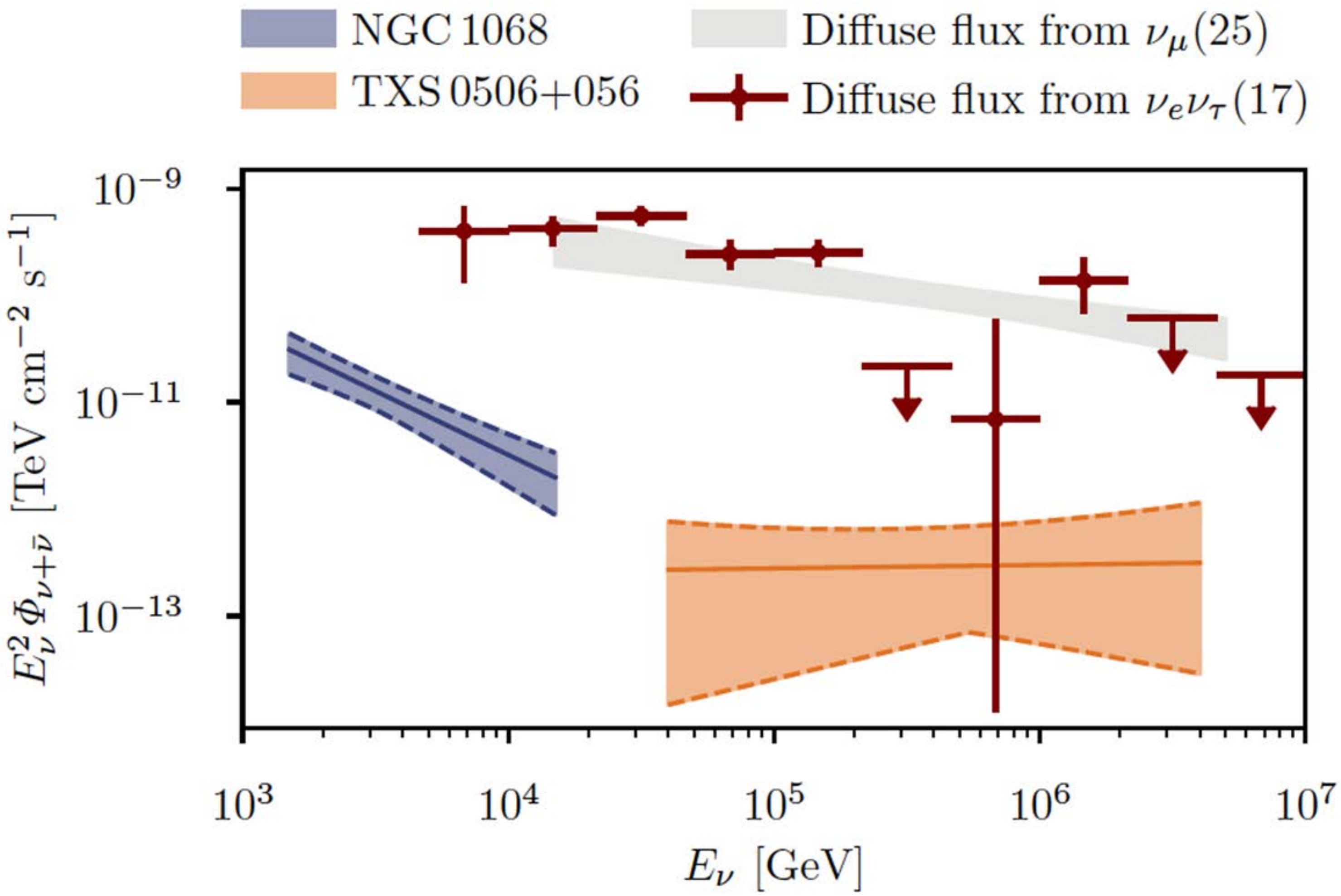
2022 — Second Source NGC 1068 Identified

Implications of the NGC 1068 neutrino observation

Active galaxies may contribute to significant fraction of extragalactic neutrino flux.

NGC 1068 is opaque to high-energy gamma-rays

NGC 1068 and TXS 0506+056 are different.



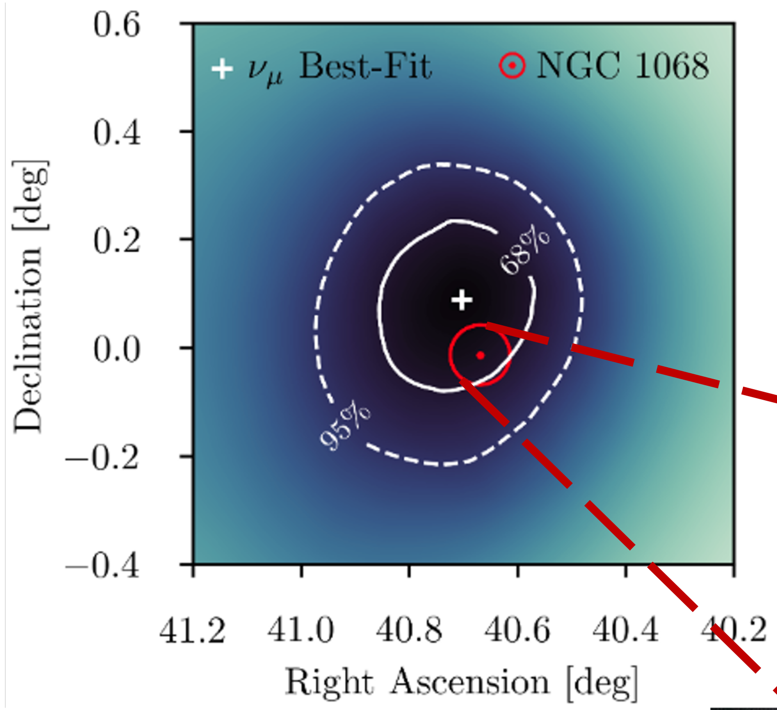
[25] IceCube. ApJ 928, 50 (2020)
[17] IceCube. PRL. 125, 121104 (2020)

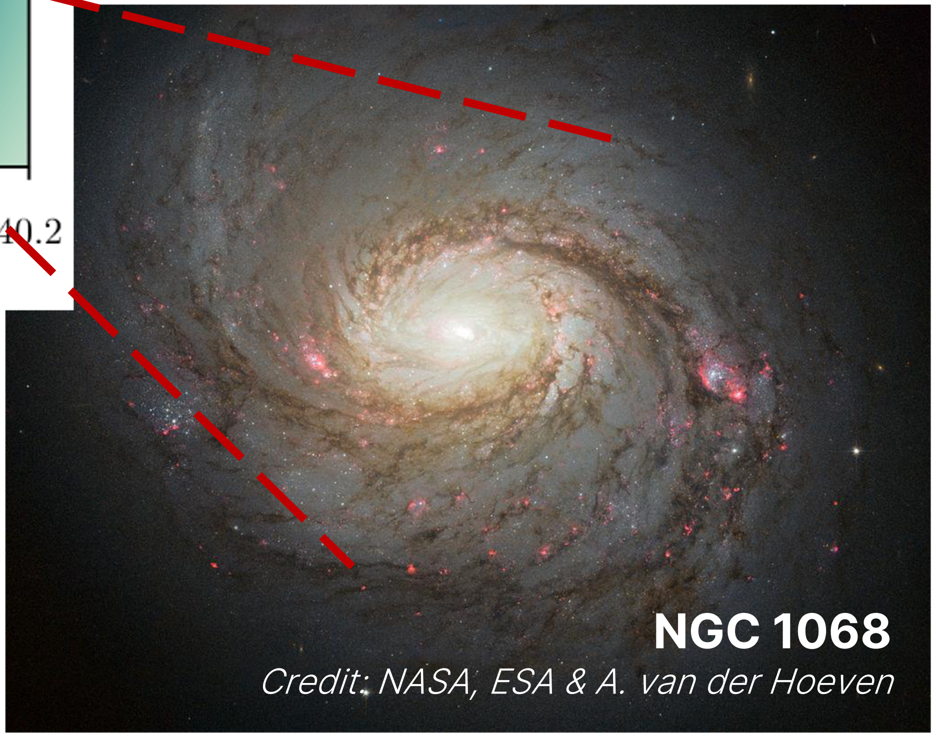
IceCube is getting better – and we are not finished

More to IceCube than "adding more years of data"

New instrumentation in 2025/2026 will improve angular resolution

The future IceCube-Gen2 will have even better sensitivity than IceCube

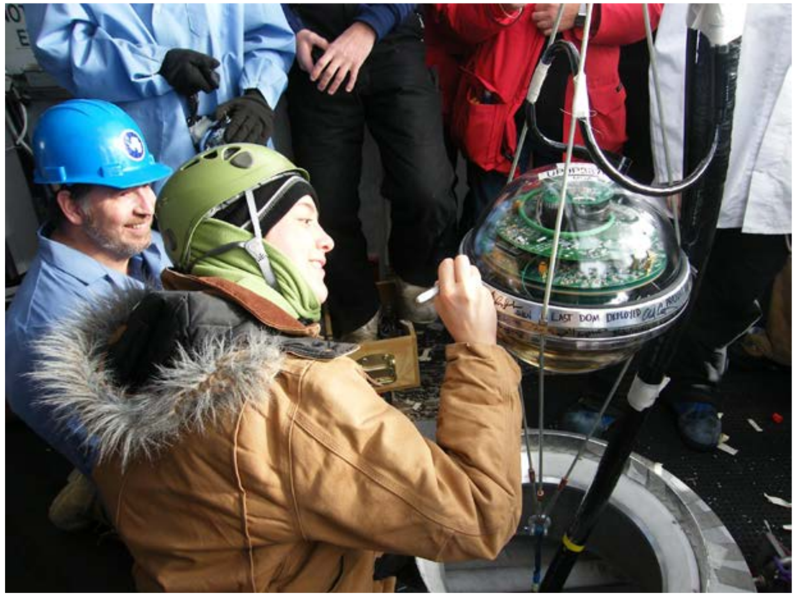




NGC 1068

Credit: NASA, ESA & A. van der Hoeven

Many contributions by the entire collaboration



Last Digital Optical Module deployed
December 2010
Credit: Gary Hill IceCube/NSF

Moreno Baricevic and Wenceslas Marie-Sainte
IceCube's 2022-23 winterovers
Credit: Ralf Auer Icecube/NSF

2019 Fall IceCube Collaboration Meeting
Chiba, Japan
Credit: IceCube Collaboration

... improved calibrations, data reprocessing, operations, and many critical activities


THE ICECUBE COLLABORATION
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University of Adelaide
BELGIUM
UCLouvain
Université libre de Bruxelles
Universiteit Gent
Vrije Universiteit Brussel
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Funding Agencies

Evidence for neutrino emission from the nearby active galaxy NGC 1068

Credit: Martin Wolf, IceCube/NSF