Search for Neutrino Emission from Compton Thick AGN with IceCube

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UNLV NCfA IceCube Neutrino Observatory

Neutrinos: Cosmic Messengers

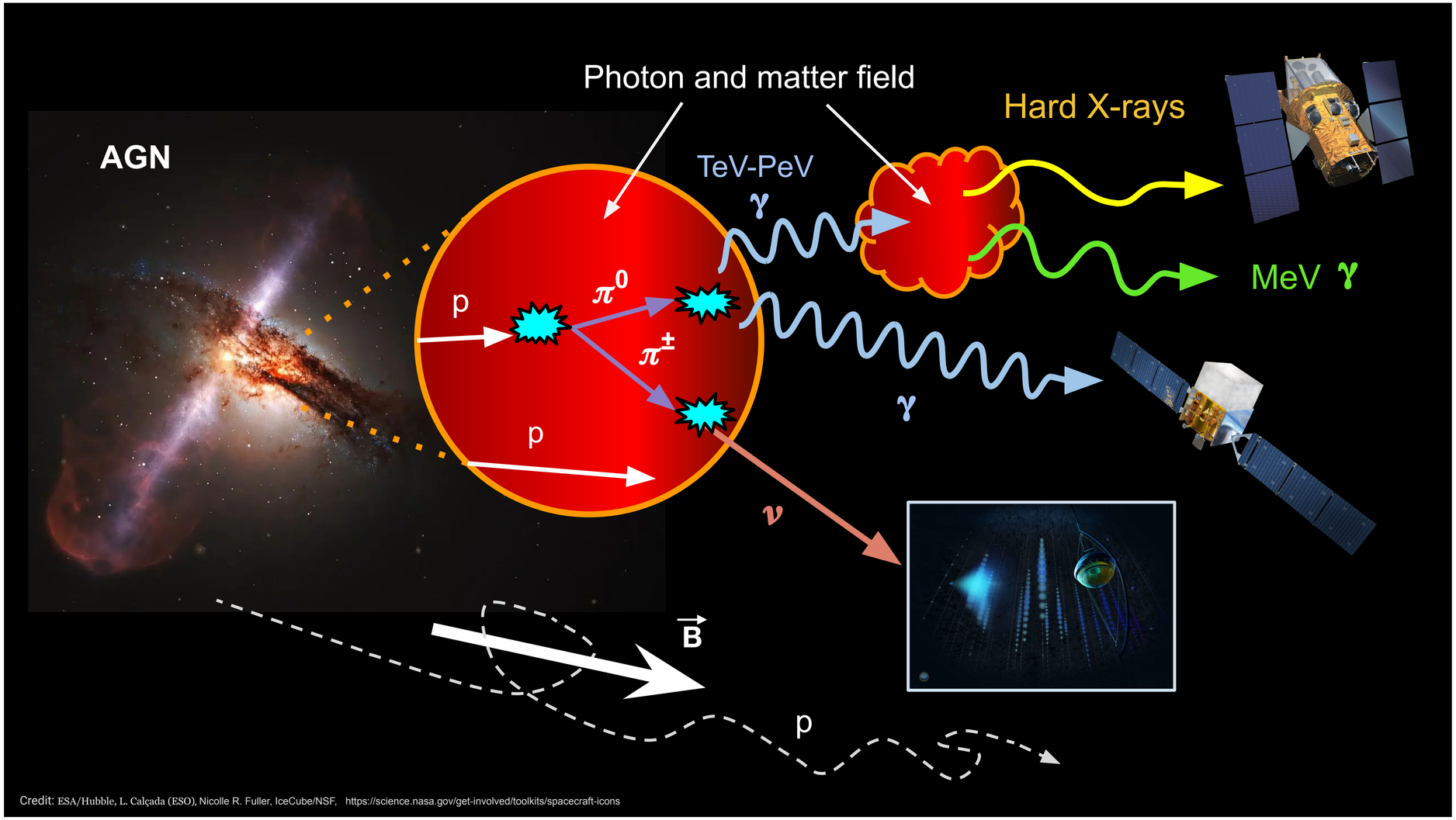
Cosmic accelerators

↓

VHECRs

↓

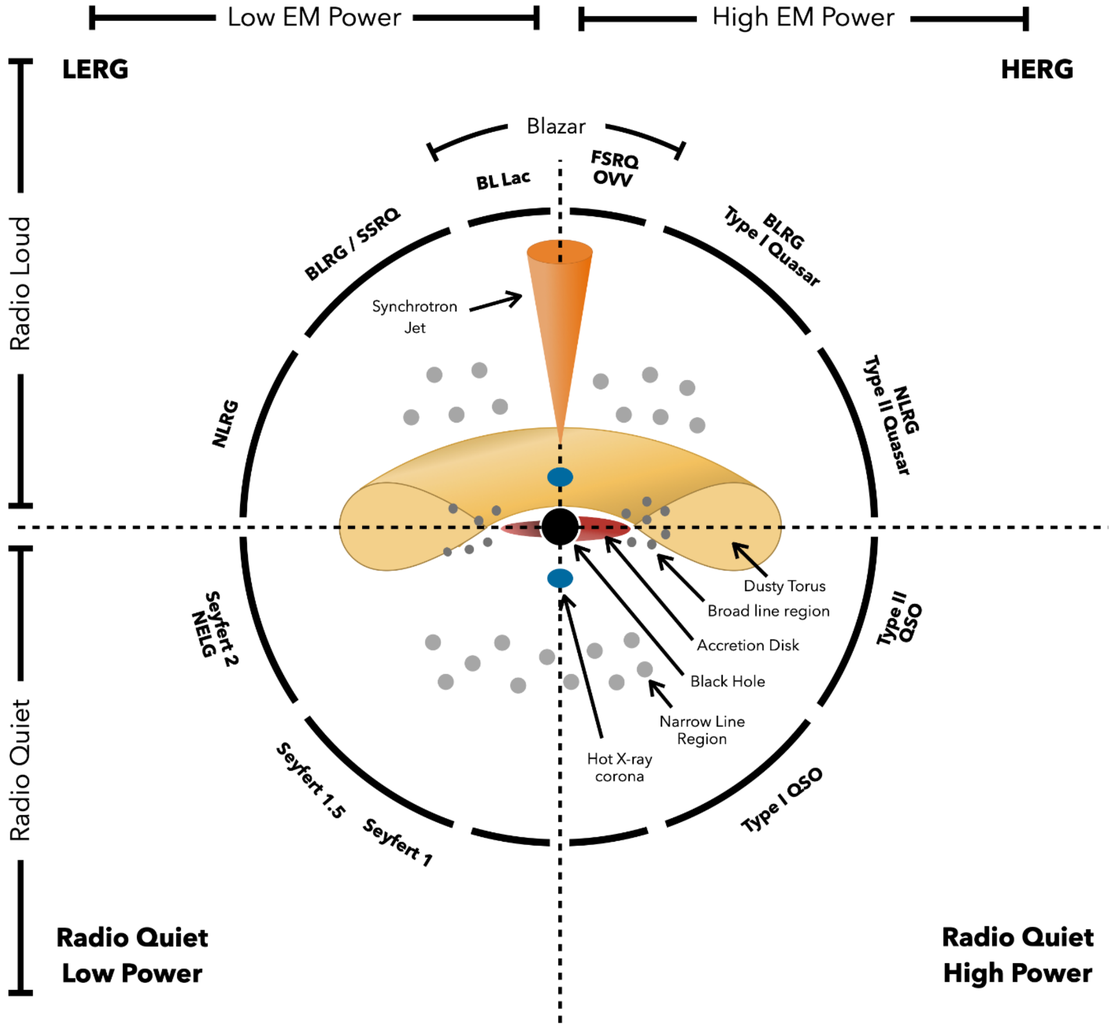
Escape environment	hadronic interactions
↓	↓
Propagation through **B**	Produce γ-rays and ν
↓	↓
Deflection	γ-rays + EBL /photons / matter



Credit: ESA/Hubble, L. Calçada (ESO), Nicolle R. Fuller, IceCube/NSF, https://science.nasa.gov/get-involved/toolkits/spacecraft-icons

Active Galactic Nucleus : Primary Candidate

- High luminosity radiation over the entire EM spectrum.
- Jet orientation or obscuration → different classes of AGN.
- Seyfert galaxies: Large class of non-jetted AGN
- Obscured AGN: core shrouded in an optically thick torus of gas and dust.



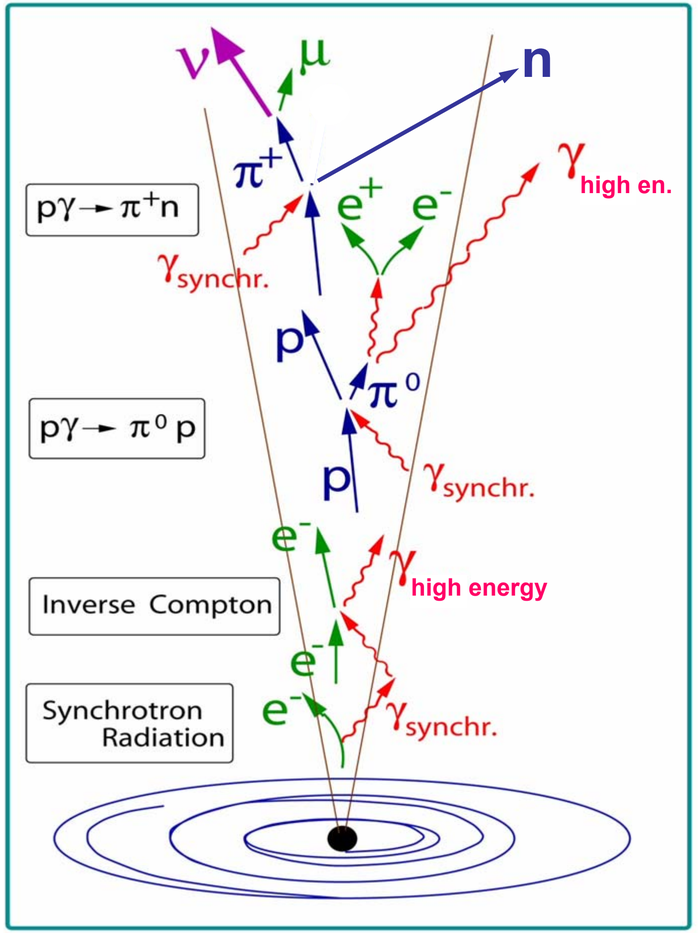
Thorne, Jessica, Robotham, Aaron, Davies, Luke, & Bellstedt, Sabine. (2022).

AGN : Promising Source Class ?

- Meets conditions for neutrino production.

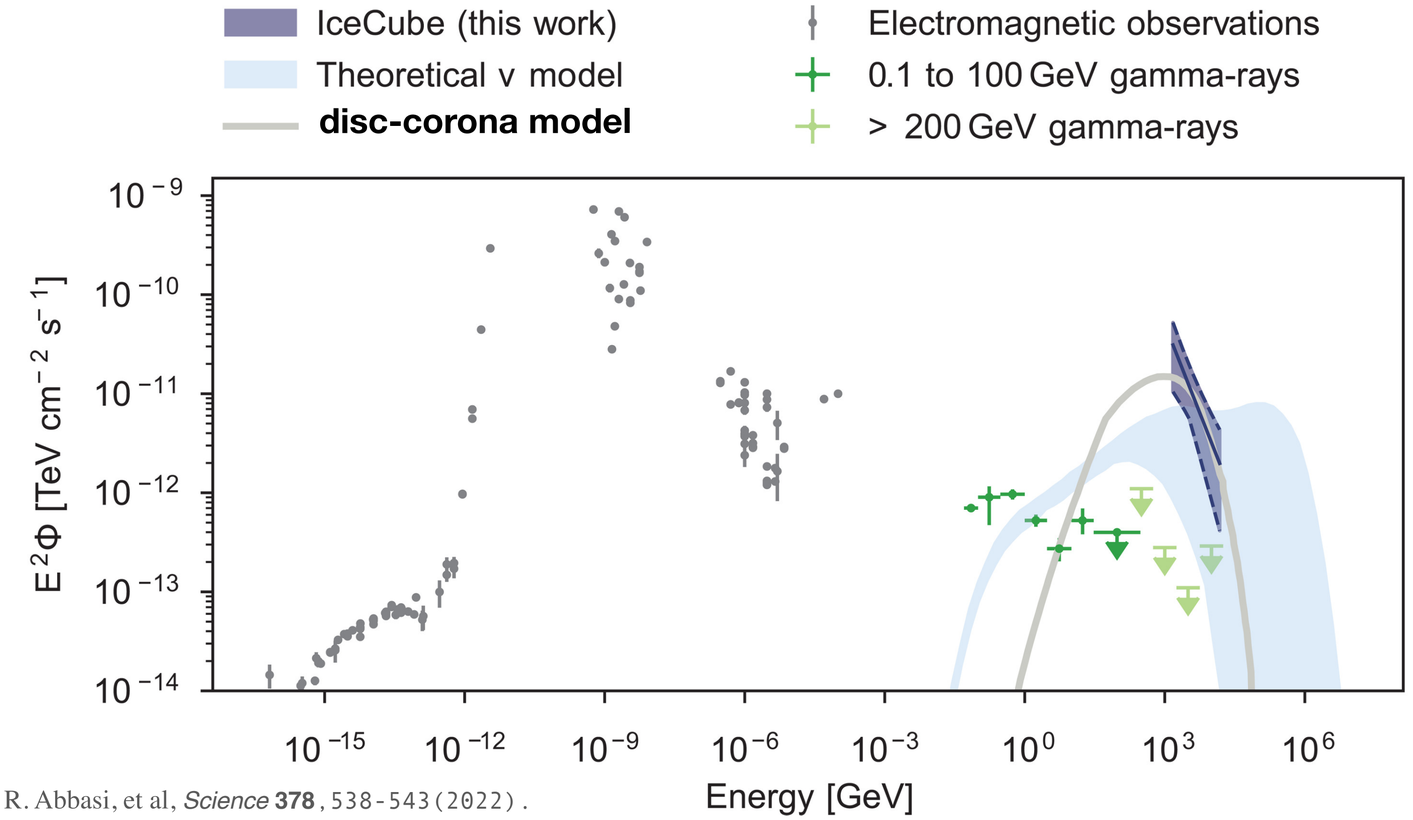
  1. Acceleration sites: shocks in jets, magnetically arrested accretion disks
  2. Regions with high matter and/or photon density: accretion disk, corona, dusty torus

- No significant correlation with gamma ray sources
  - Neutrino sources **opaque to high-energy gamma rays.**
  - **Added Condition:** possibly hidden sources.
  - X-rays can penetrate through gas and dust.



Katz & Spiering (2012)

NGC 1068 : First Evidence from AGN



R. Abbasi, et al, *Science* **378**, 538-543(2022).

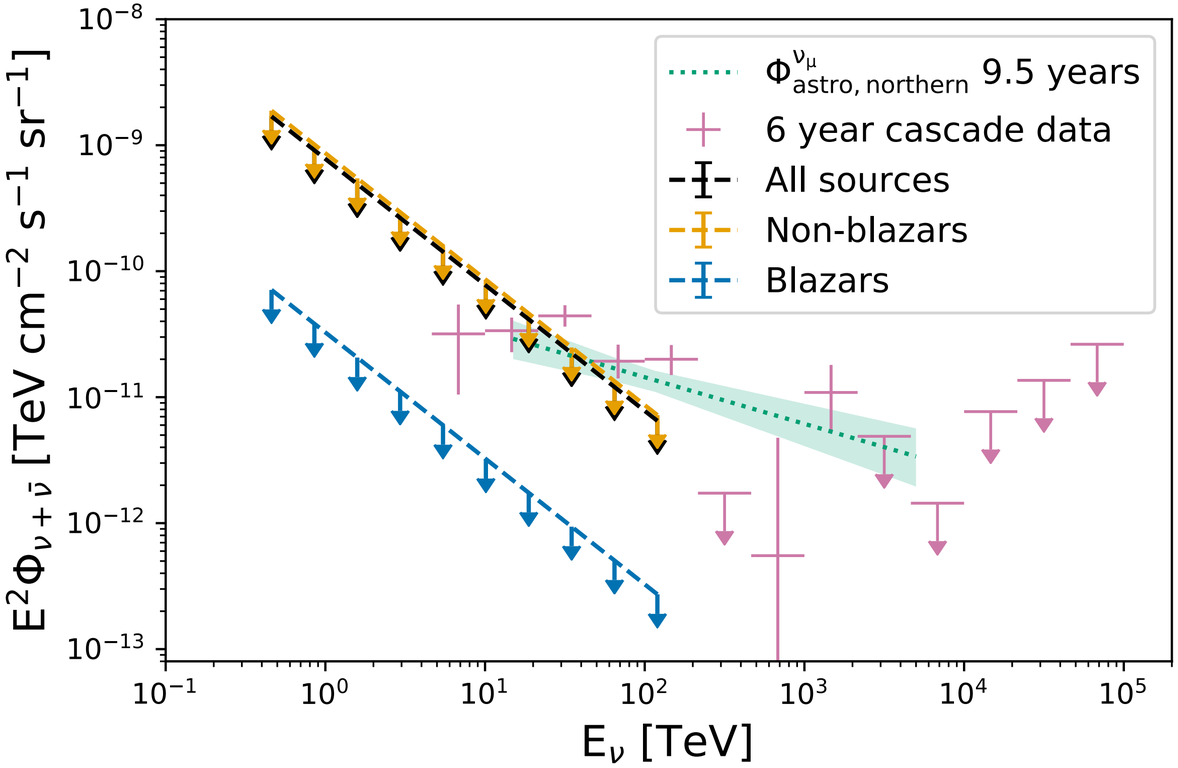
Seyfert II Galaxy NGC 1068
Source: ESO

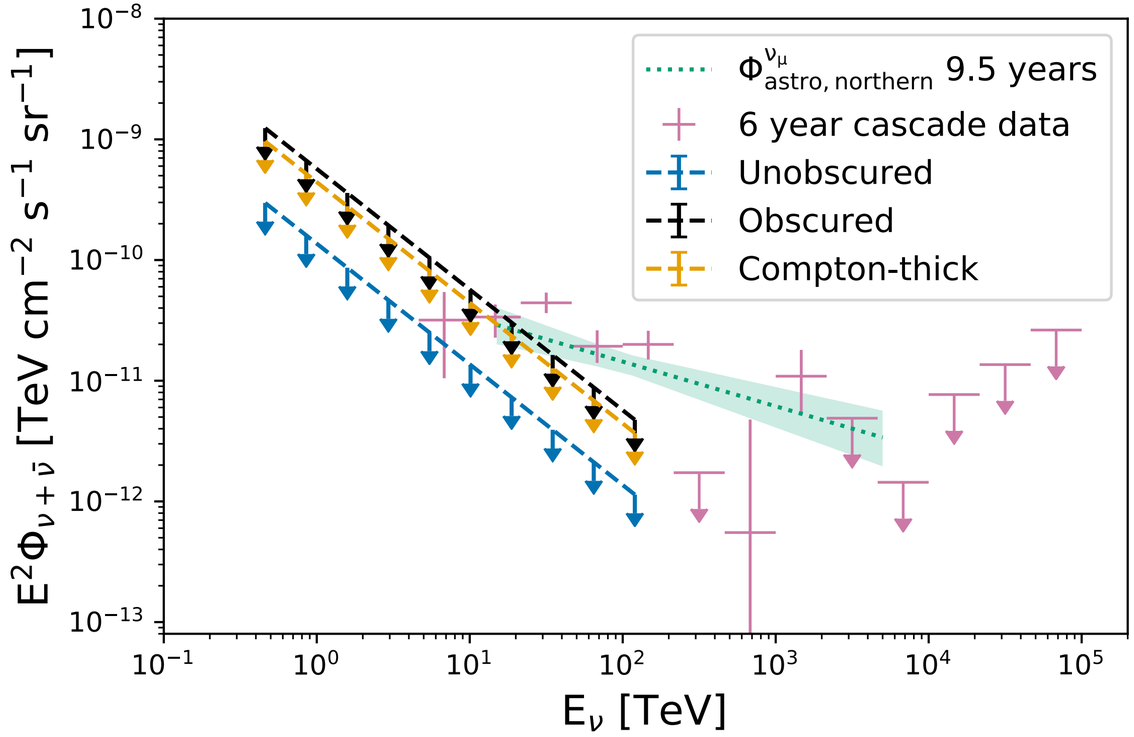
- Search for neutrino emission using IceCube muon neutrino tracks from Northern Hemisphere.
- Observation of an excess of 79 neutrinos at a global significance of **4.2σ** from direction of NGC 1068.

Search for Neutrinos from Hard X-ray AGN

Analysis I : Stacked Search

R. Abbasi et al., 2024: arXiv:2406.06684v2

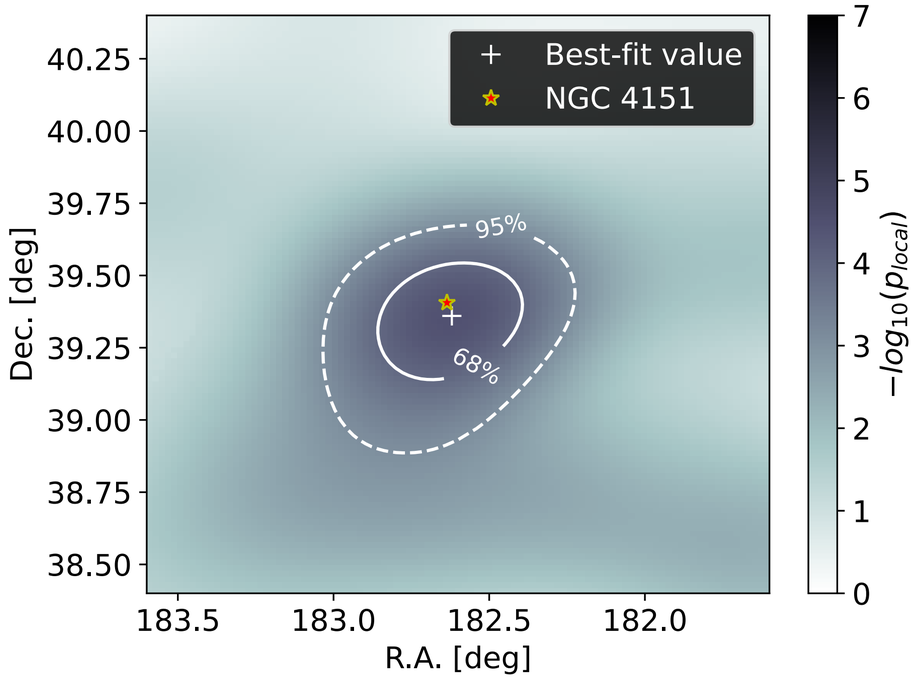


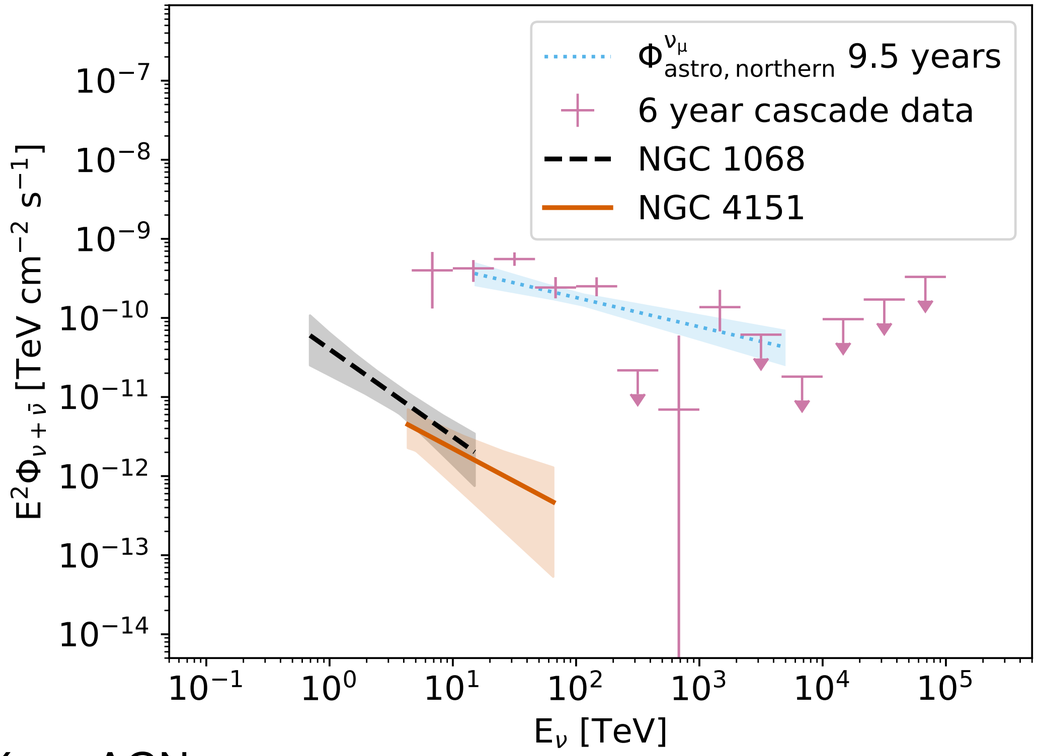


- Search for neutrino emission by stacking 836 AGN and subclasses various from BASS catalog.
- Intrinsic flux in 14-195 keV range used as weights.
- Obscured sources shows highest significance among subclasses with post-trial 2.1σ observation.

Search for Neutrinos from Hard X-ray AGN

Analysis II : Point Source Search

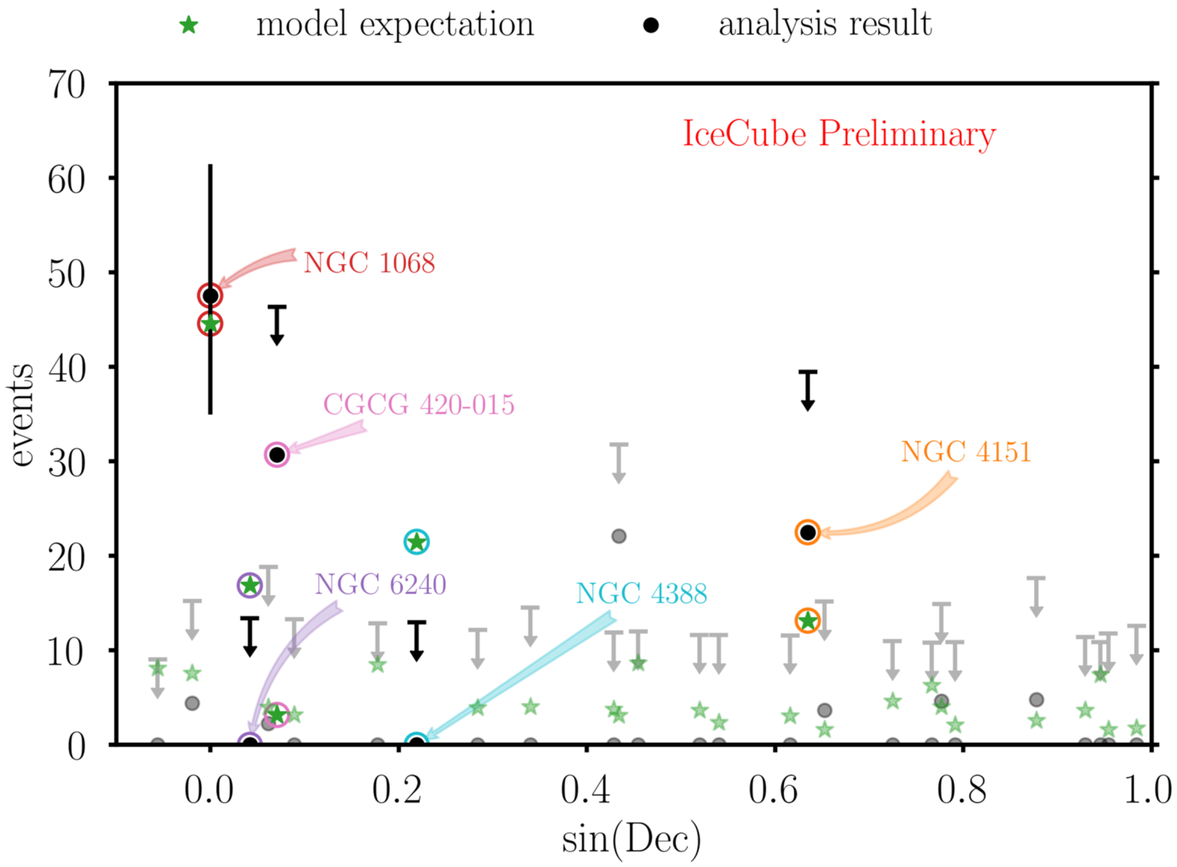




- Search for neutrinos individually from a list of 43 hard X-ray AGN.
- **NGC 4151** shows a global **2.9σ** excess. It is the second most significant source observed by IceCube.
- **NGC 1068** observed a local **4.7σ.** Since it was previously observed, the global significance is not evaluated.
- **NGC 3079** is third most significant source with a local 2.7σ observation.

Neutrinos from Bright Seyfert Galaxies

- Search from 27 Bright Seyfert galaxies from BASS catalog.
- Differences with Hard X-ray AGN analysis:
  - Dataset is restricted to Northern Sky.
  - Disc-corona model is tested.
- Results:
  - *Catalog search:* 2 promising sources apart from NGC 1068 found,
    NGC 4151 and **CGCG 420-015**.
  - *Binomial Search:* **2.7**σ without NGC 1068 and **4.0**σ with NGC 1068 posterior.
- Search for neutrinos from Seyferts in the Southern sky shows a **3.0**σ emission from a stacking analysis.



R. Abbasi et al., 2024: arXiv:2406.07601v1.

See talk by Shiqi Yu

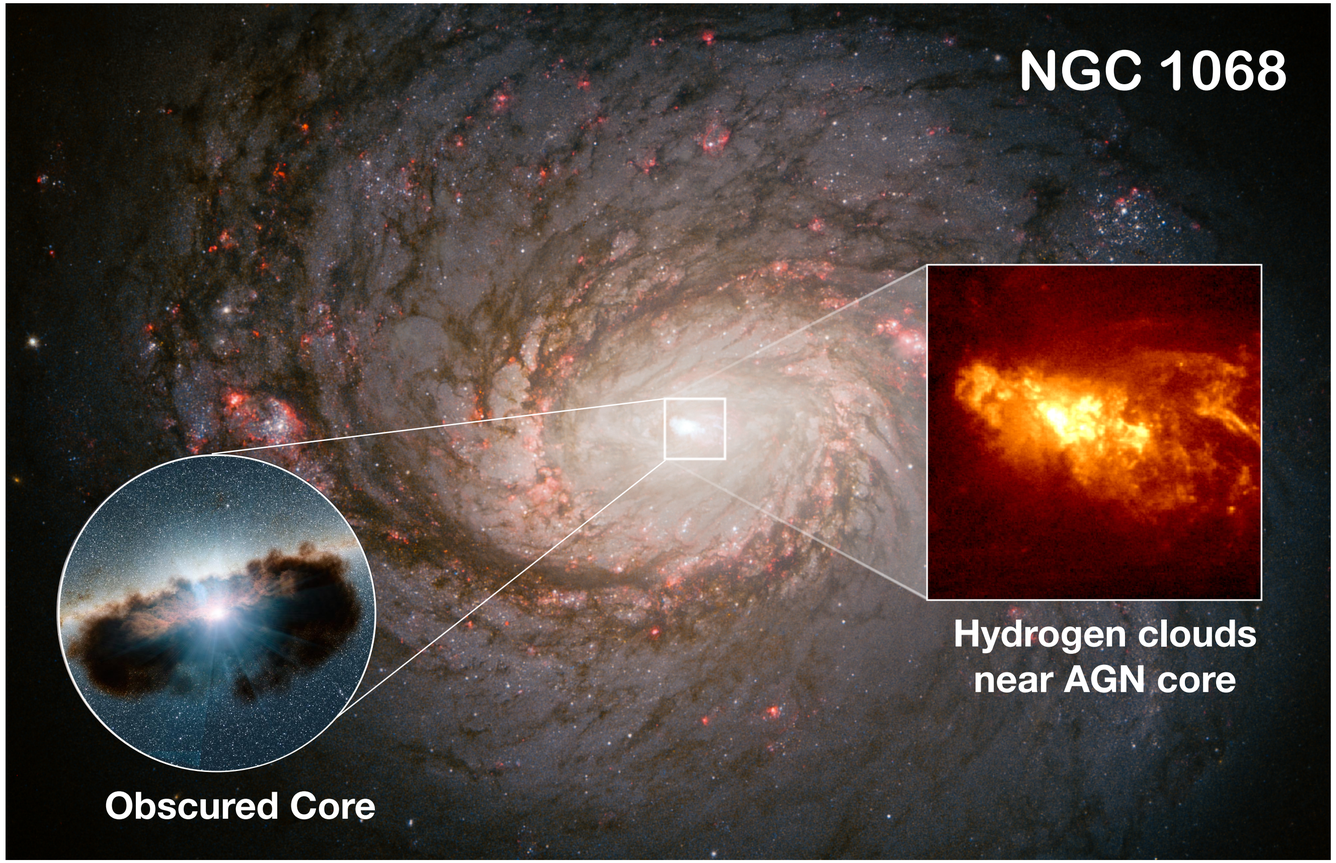
203. Search for neutrino emission from Seyfert Galaxies with IceCube

Search for Neutrinos from Compton Thick AGN

**New Analysis*

Motivation:

- Analyses using X-ray bright AGN show excess from individual sources that disappears in a stacking analysis.
- Many AGN cores are obscured by gas and dust resulting in high uncertainty of flux estimates which was a weight in stacking searches.
- Hidden sources with high levels of obscuration indicate presence of more targets for interaction.

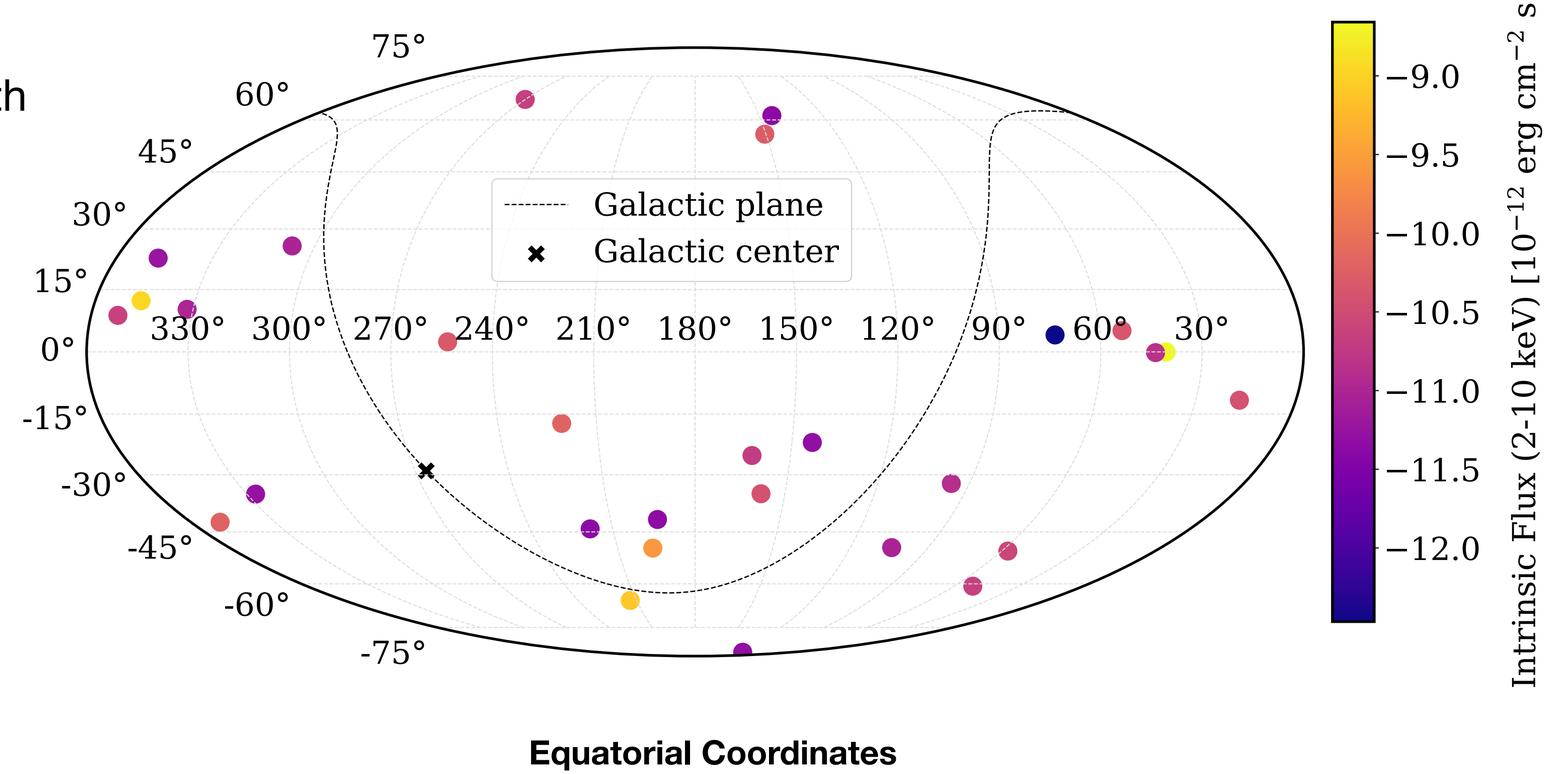


Credits: Science NASA, ESA, Alex Filippenko (UC Berkeley), William Sparks (STScI), Luis C. Ho (KIAA-PKU), Matthew A Malkan (UCLA), Alessandro Capetti (STScI), Circular inset: NASA/JPL-Caltech.

See talk by Jose Carpio
156. Characterizing High-Energy Neutrino Emission Parameters in Bright Seyfert Galaxies and Quasars

Sources for the Analysis

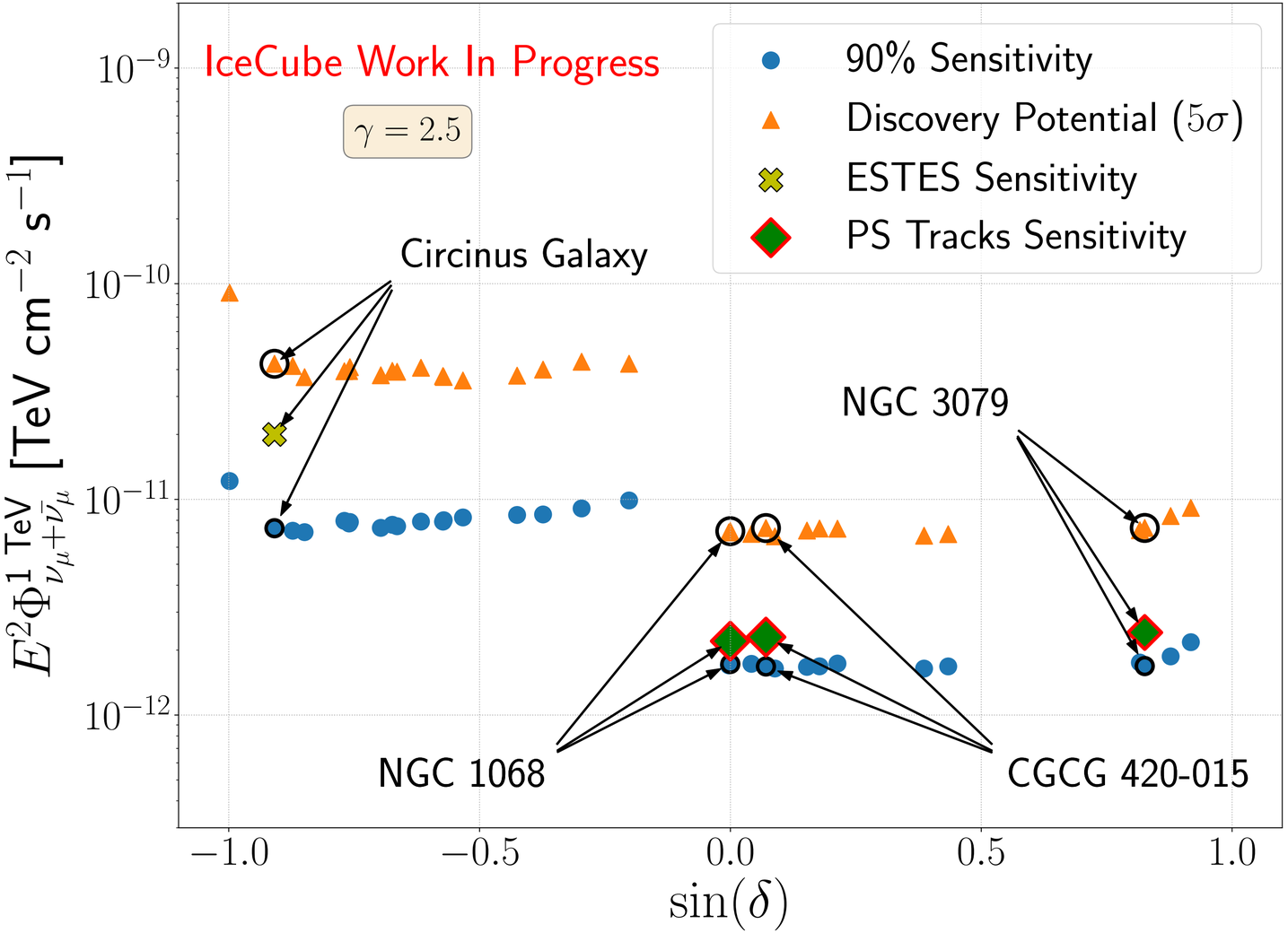
- A catalog of **Compton Thick AGN:** *Clemson-INAF Compton thick AGN project*
- Compton Thick AGN: highly obscured AGN with column density, $N_H > 1.5 \times 10^{24}$ cm^{-2}
- Sources selected from the BASS catalog.
- **Improvements over previous source selections:**
  - **NuSTAR** observations → **better estimates of intrinsic flux with lower uncertainty**
  - Importance of X-ray flux → Hypothesis tested: Intrinsic flux ∝ neutrino flux
  - **Better estimates of the intrinsic luminosity** and the **obscuration levels** around the core



Skymap in Equatorial coordinates showing the position of the sources in the catalog and the color bar shows the intrinsic flux in the 2 - 10 keV.

Analysis Part 1: Catalog search

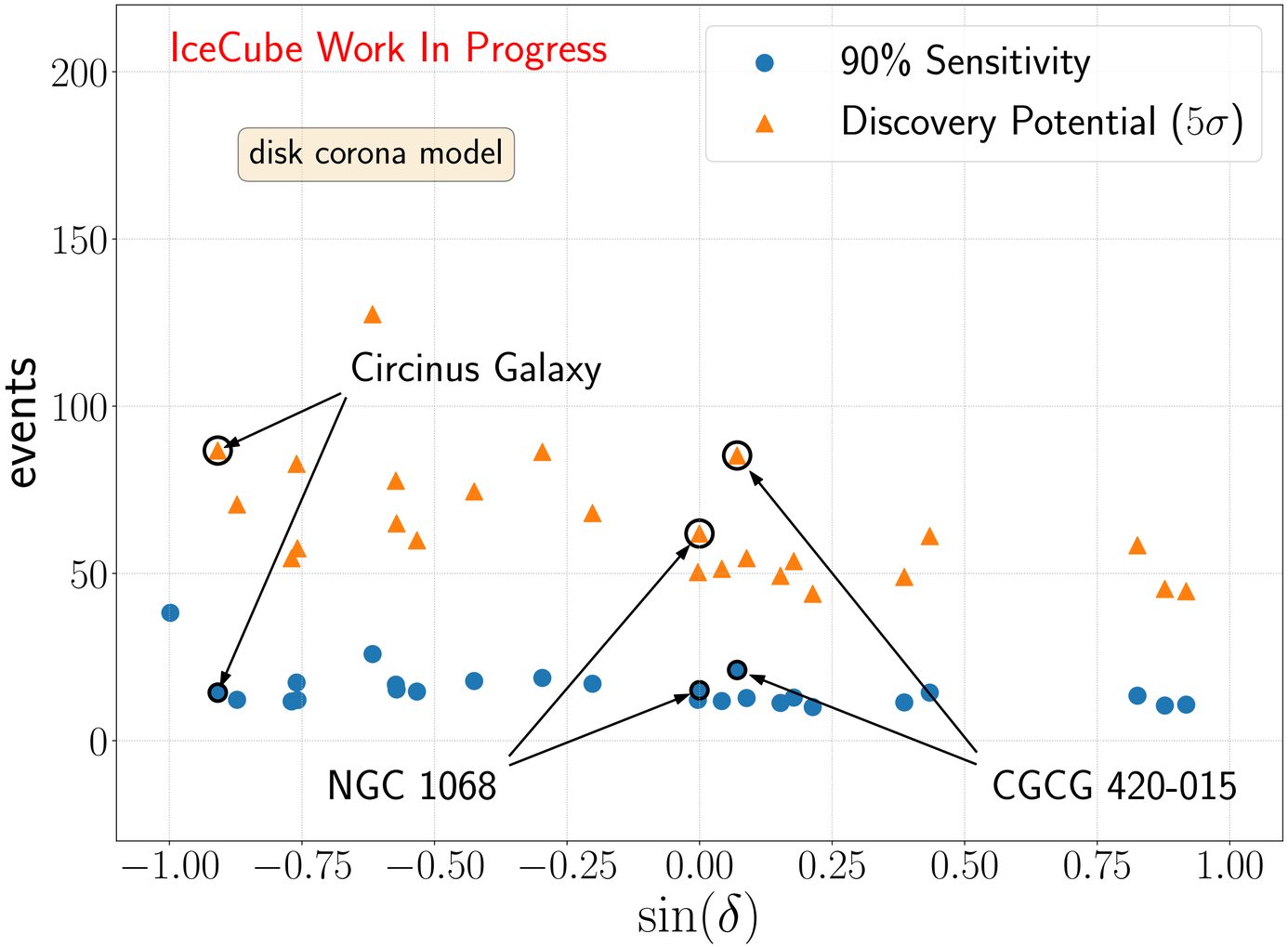
I. Hypothesis: power law flux



- A combined neutrino dataset of:
  - DNN cascades 9.6 years of shower data
  - ESTES 9.6 years of starting track data
  - NT 13 years of track data from the northern sky
- Results in the best all-sky sensitivity of all neutrino flavor data.
- Plots shows 90% sensitivity and 5σ discovery potentials for the sources in the catalog.
- Promising source candidates from previous analyses are indicated with arrows.

Analysis Part 1: Catalog search (continued)

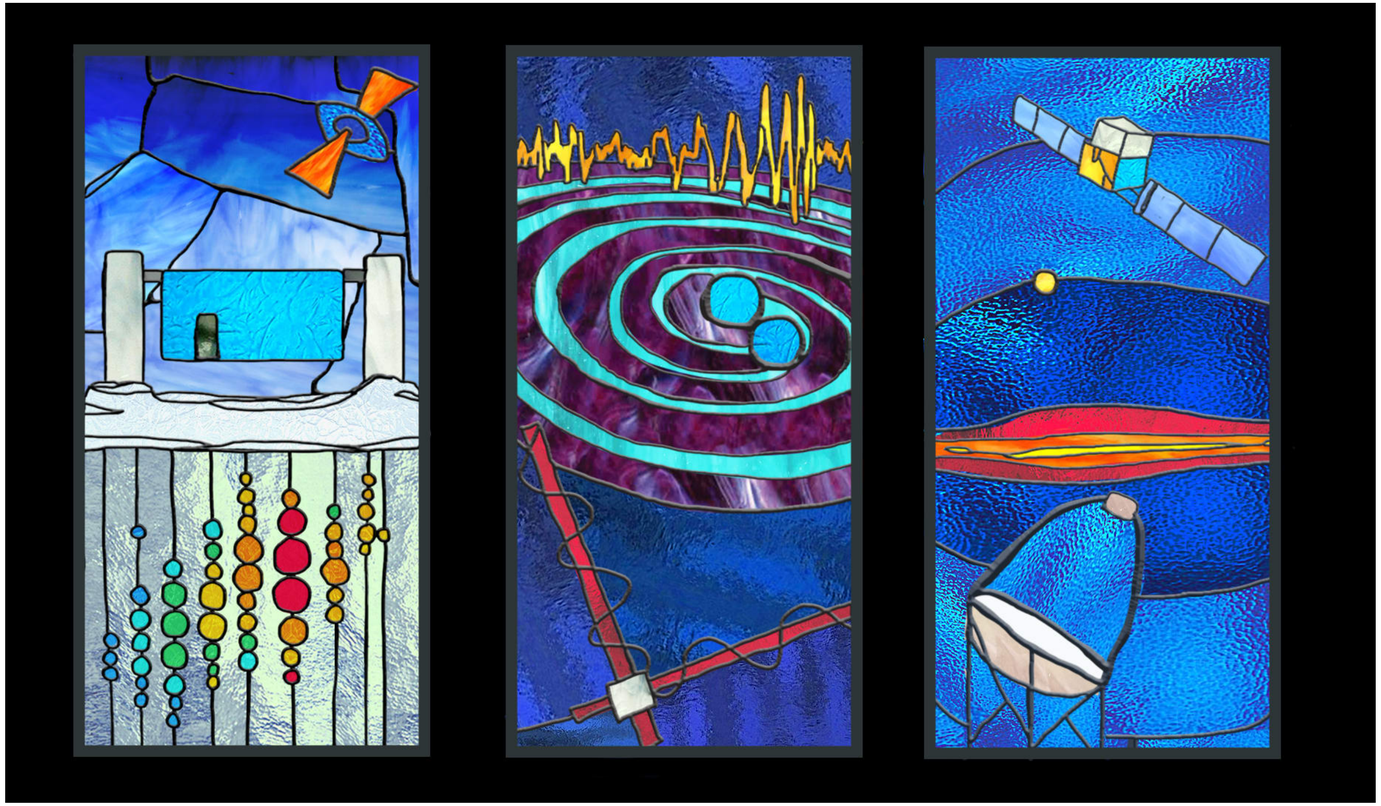
II. Hypothesis: Disk-corona model



- Plots shows 90% sensitivity and 5σ discovery potentials for the sources in the catalog.
- They are obtained using the combined dataset (all-flavor) and updated disk corona model fluxes.
- Promising source candidates are indicated with arrows.

Summary & Outlook

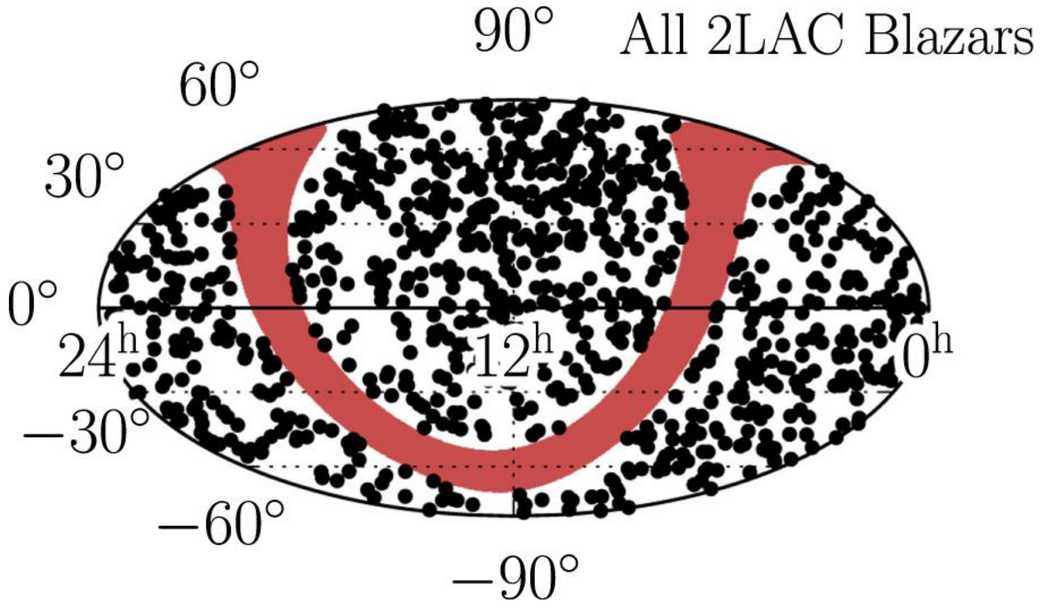
- Growing evidence points to gamma-ray obscured AGN as primary source of high-energy cosmic neutrinos.
- This is compatible with the multimessenger picture of high-energy neutrinos.
- The search for neutrinos from Compton Thick AGN:
  - Uses a comprehensive estimate for intrinsic X-ray emission available for X-ray bright AGN.
  - Using all flavor neutrino data to achieve best all-sky sensitivity.

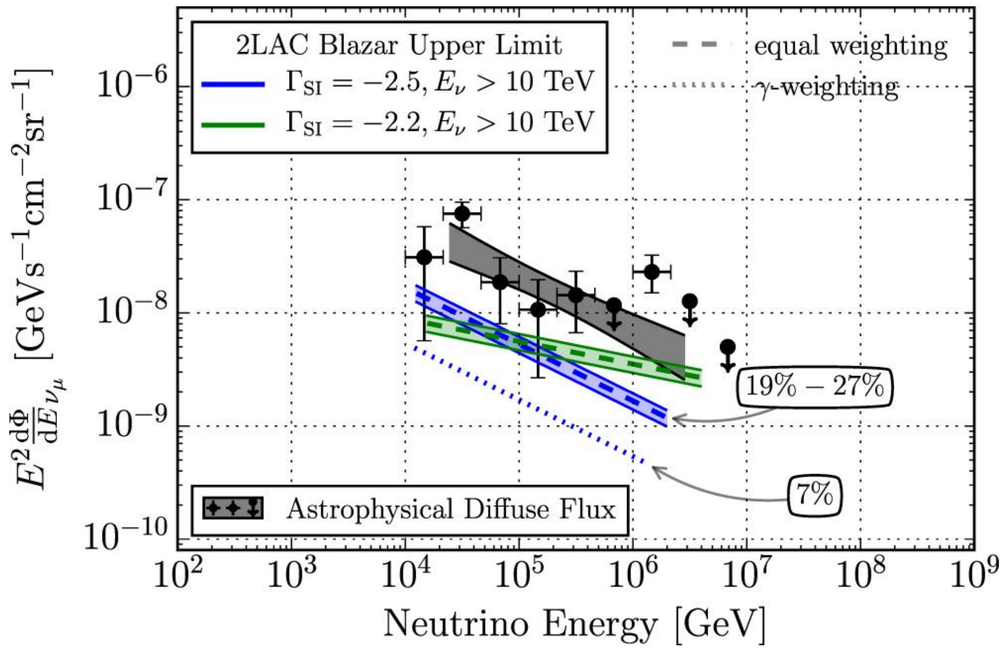


Thank you!

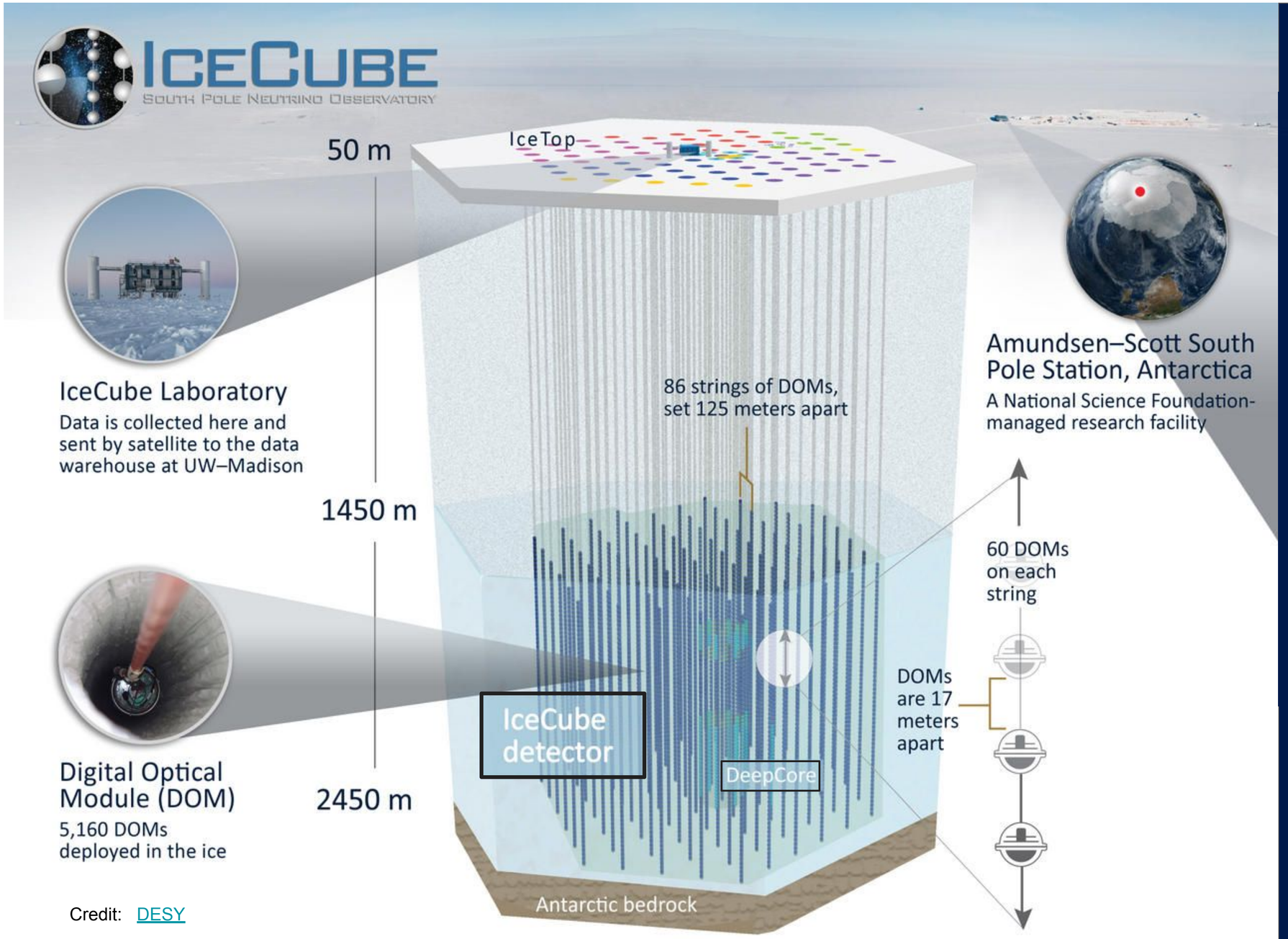
Backup Slides

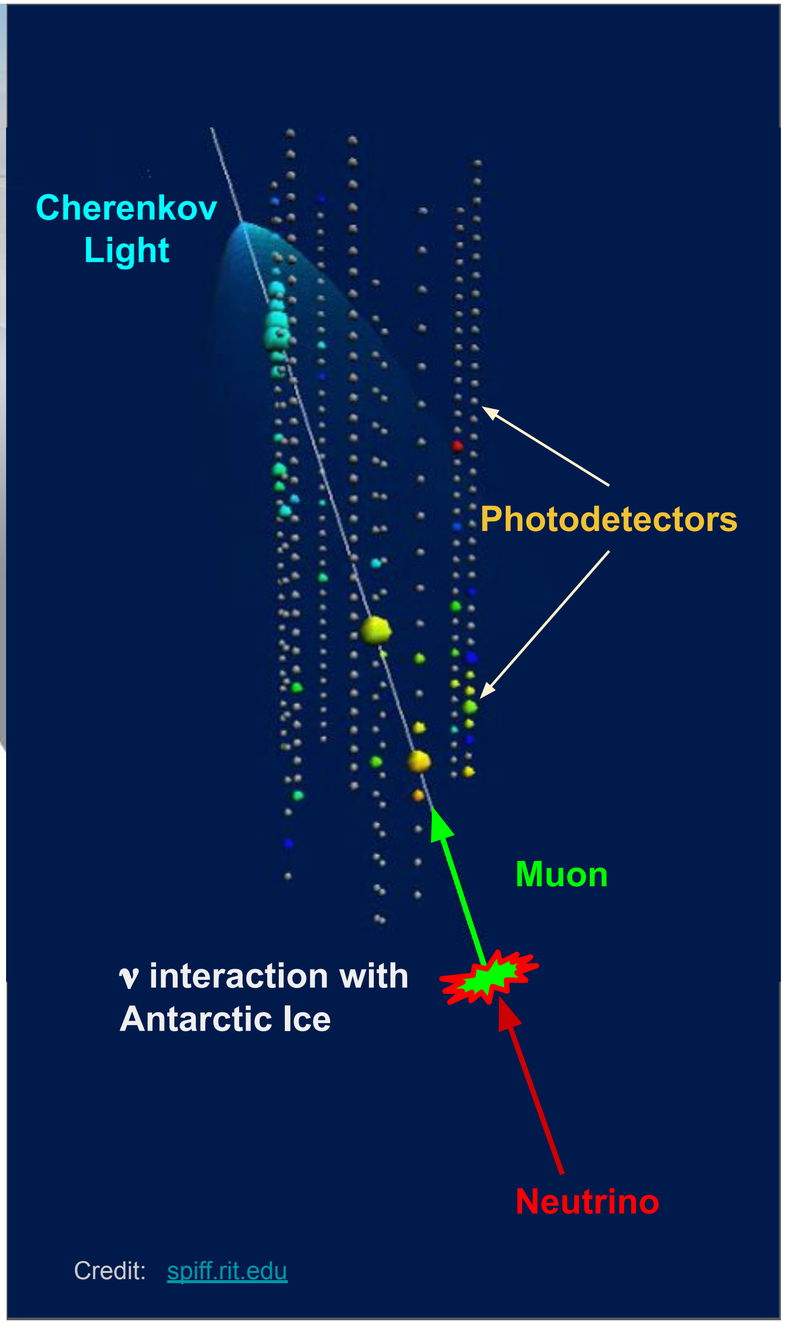
Search of neutrinos from blazars



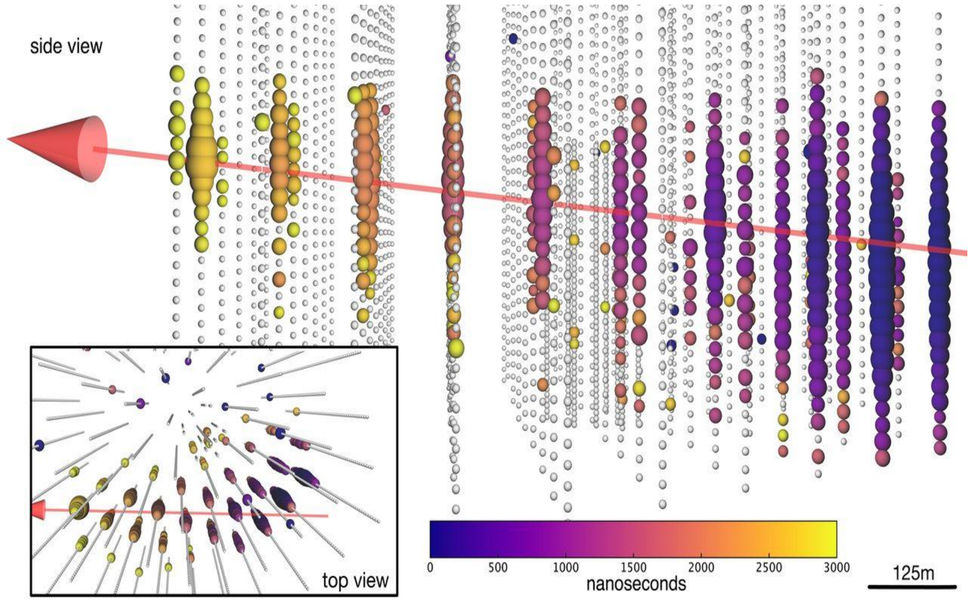


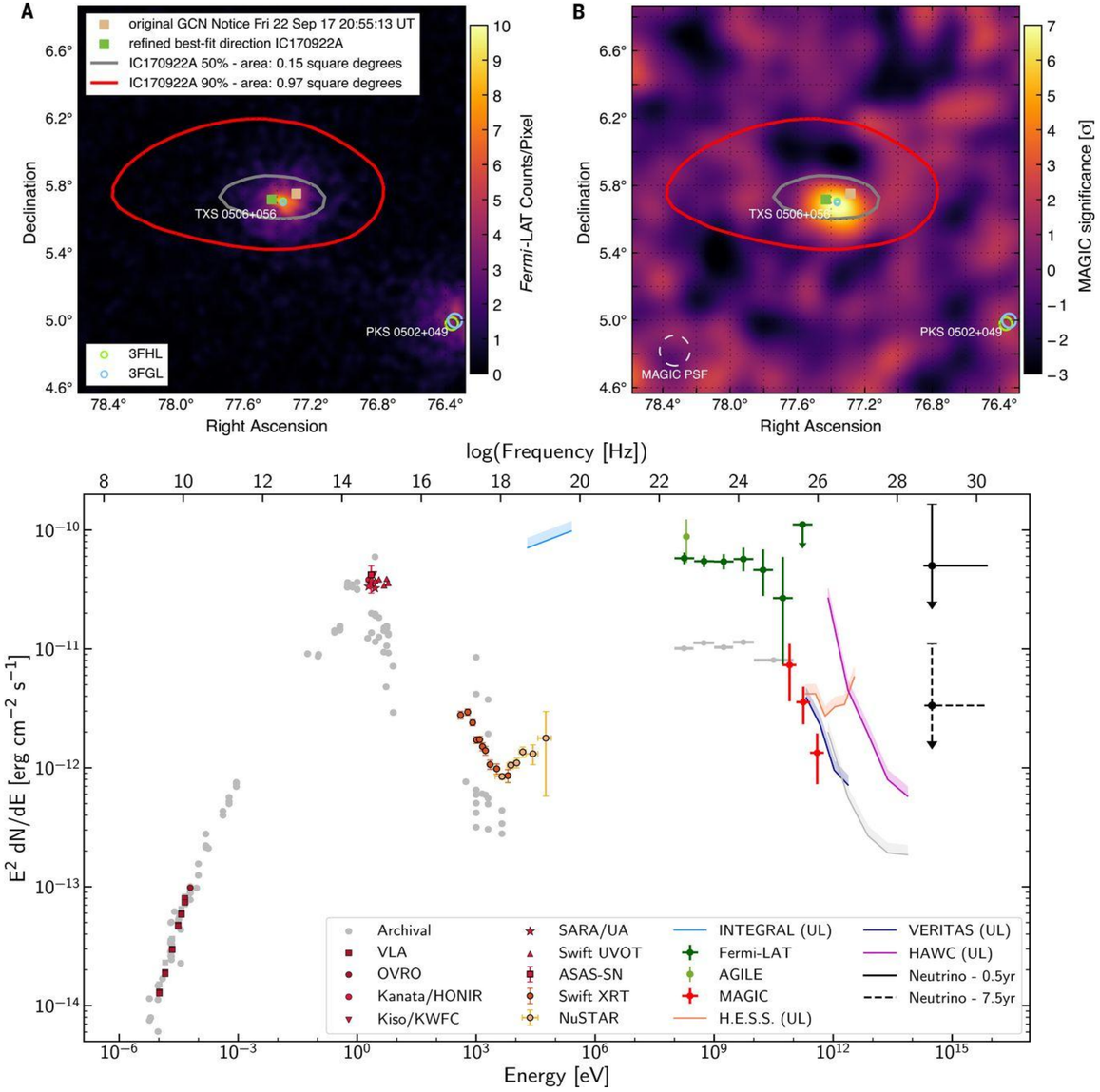
- Blazars in 2nd *Fermi*-LAT AGN catalogue (2LAC) M. G. Aartsen et al 2017 ApJ 835 45
  - **No spatial correlation** with IceCube data (2009-12)
  - **< 27%** neutrino in data from blazars (~ 10 TeV and 2 PeV)
- Blazars in *Femi* 4LAC-DR2 R. Abbasi et al. (Apr 25, 2023)
  - No significant correlation with IceCube Event Catalog of Alert Tracks


IceCube
South Pole Neutrino Observatory
50 m
IceTop
IceCube Laboratory
Data is collected here and sent by satellite to the data warehouse at UW–Madison
1450 m
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
2450 m
Antarctic bedrock
Credit: DESY


Cherenkov Light
Photodetectors
Muon
ν interaction with Antarctic Ice
Neutrino
Credit: spiff.rit.edu

Key observations: TXS 0506 + 056





The IceCube Collaboration, *Fermi*-LAT, MAGIC, *AGILE*++
Science 2018

Neutrino alert on September 22, 2017

Neutrino event IC-170922A

Evidence for a possible source of high energy neutrino $E_\nu \sim 290$ TeV

Correlation statistically significant at level $\sim 3\sigma$

Analysis details

- Improved sensitivity by combining datasets with different selection criteria.
- Point source search from a catalog of selected CT AGN.
- Time-integrated stacking analysis with:

➡ intrinsic flux in 2-10 keV regime as weights.

➡ fluxes from disc-corona model as weights.