Evidence of Neutrino Emission from X-ray Bright Seyfert Galaxies with IceCube

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(for the IceCube collaboration)

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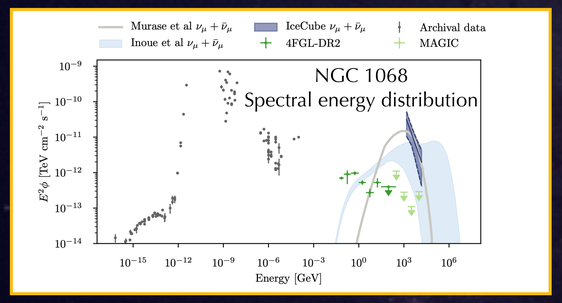
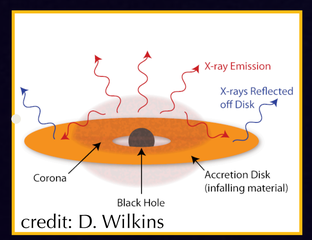
Introduction

- A nearby Seyfert Galaxy, NGC 1068 has been identified as the most significant high-energy neutrino source (4.2σ) by IceCube [1].
- It sits in a Compton-thick environment with a high level of star formation. It is dim in gamma-rays, but is bright in X-rays.
- Neutrino emission at 1.5 - 15 TeV, medium energies for IceCube neutrino detection. Soft best-fit spectrum $E^{-3.2}$.
- Can we find more similar sources and examine models with current data?

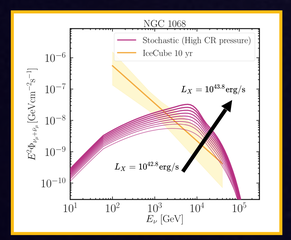


Disk-corona Models

- AGN cores optically thick for GeV-TeV gamma rays are one of the best neutrino source candidates [2,3].
- Acceleration of ions can happen via stochastic &/or magnetic reconnection processes.
- In Seyfert galaxies, a magnetized corona above the disk can be formed due to accretion and magnetic dissipation, providing sufficient targets for neutrino production and gamma-ray absorption.
- Disk-corona models can accommodate the total neutrino flux at medium energies $\mathcal{O}(\text{TeV}) - \mathcal{O}(10\ \text{TeV})$.
- Intrinsic X-ray luminosity is a proxy for neutrino luminosity.

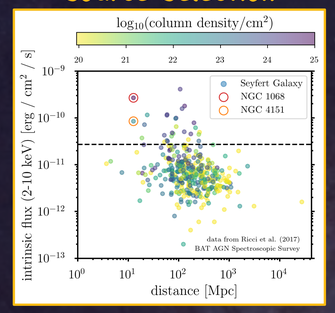


credit: D. Wilkins



Method

Source Selection



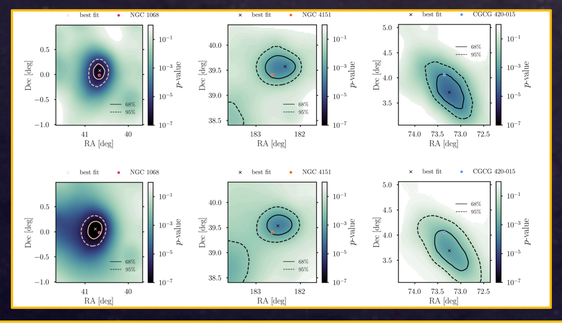
- Seyfert Galaxies in the BAT AGN Spectroscopic Survey (BASS), which are bright in the intrinsic 2-10 keV X-ray flux.
- Northern Sky: 27 (+NGC 1068) sources.
- Southern Sky: 14 sources

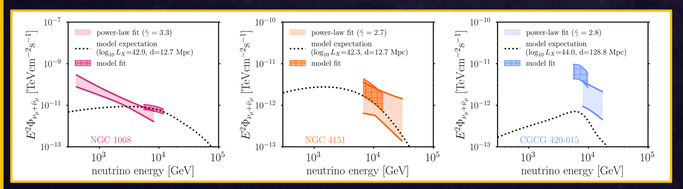
Analyses

- Catalog Search:
  - Fit the disk-corona model (optimistic scenario).
  - Fit the single-power-law spectrum.
- Stacking Search:
  - Test the accumulated emission and improve the sensitivity if the model is correct.
  - Sources are weighted based on the predicted signal event number from each source.
- Binomial Test:
  - Examine the significance of observing excesses from a subset of sources without assuming relative contributions.
- Data:
  - Northern Sky: same up-going track selection as used in the NGC 1068 identification analysis [1], with more data (9 + 1.7 yr)
  - Southern Sky: Enhanced starting track event selection (9.5 yr) [4], which effectively suppresses the down-going atmospheric background.

Results

Northern Hemisphere

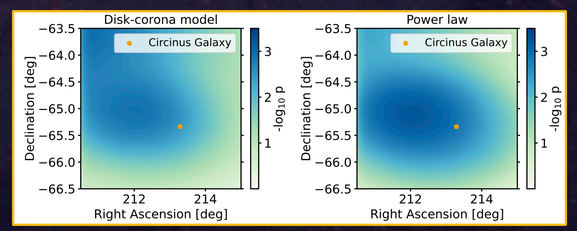


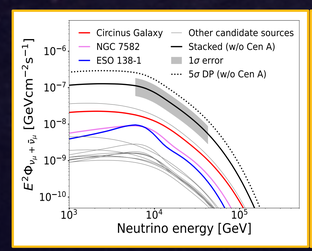


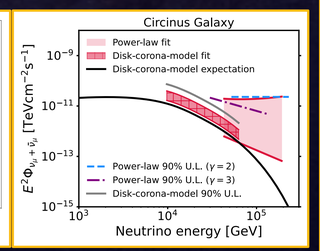
- 3 sources have local significance above 3σ.
- Excess from CGCG 420-015 and NGC 4151 (excl. NGC 1068) at 2.7σ from the bimonial test.
- No significant emission in the stacking search (excl. NGC 1068). The upper limit constrains the collective emission to 30% of the prediction.

Southern Hemisphere

- 3σ excess in the stacking search (excl. Centaurus A).
- The top source - Circinus Galaxy has 3.1σ (power-law) and 2.7σ (model) (post-trial 1.8σ)

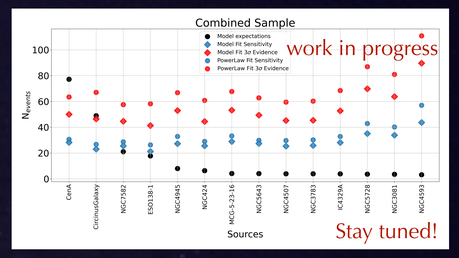






On-going Follow-up

Combining multiple data samples (tracks + cascades) for an all-flavor neutrino emission study to increase the statistics and thus enhance the sensitivity.



The stacking search in the Southern Sky is expected to reach above 3σ [5].

Takeway

- There should exist a subset of sources that can be described with an optimistic scenario of disk-corona models similar to NGC 1068.
- Moderate scenarios of disk-corona models will be testable with next-generation neutrino telescopes.
- In environments with high levels of column densities, there is a large uncertainty in the estimation of the intrinsic X-ray flux, which can significantly change neutrino emission expectations.
- Current data start to be able to test models. To find more sources and verify models, we need more precise studies on the multi-wavelength emission of the sources.
- More and more X-ray-bright, gamma-ray-suppressed AGN emerge as promising neutrino emitters. Northern Sky X-ray AGN binomial test: 11 sources 3.3σ. See refs [6, 7].

References

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3. Kheirandish, Murase & Kimura, ApJ 922 (2021) 1, 45
4. IceCube Collaboration, PRD 110 (2024) 2, 022001
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