Search for neutrinos from optically-identified AGNs with IceCube

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DESY Zeuthen / Humboldt Universität zu Berlin

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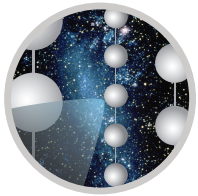
HELMHOLTZ

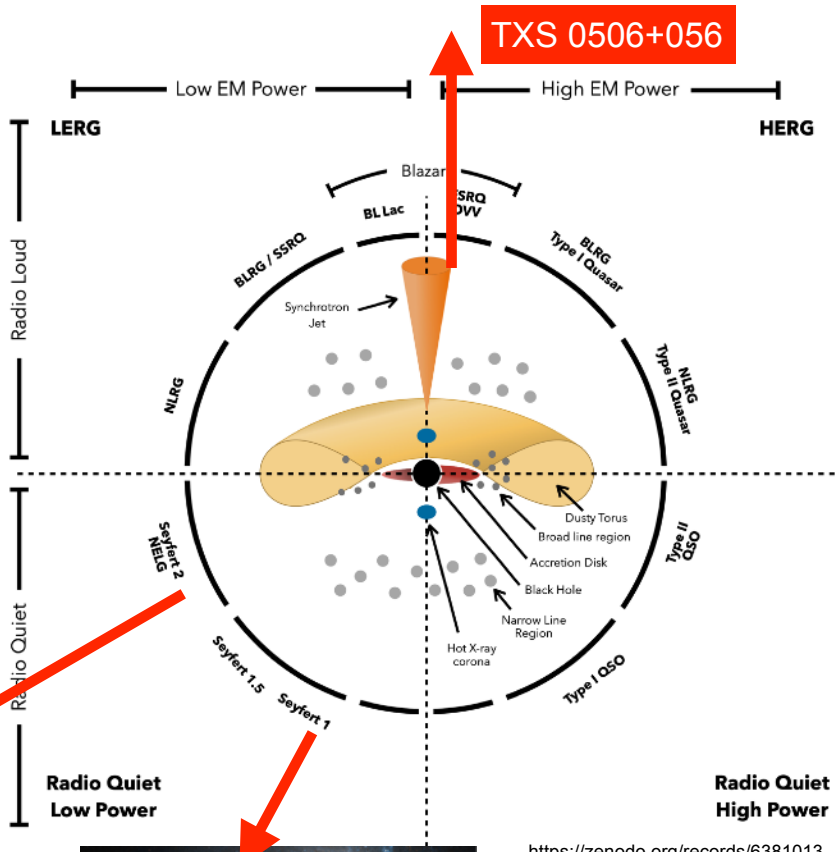


ICECUBE

TeV Neutrinos from AGNs

IceCube observations

- Evidence of TeV neutrinos from AGNs:
  - 3 σ from TXS 0506+056 (blazar flare)
    Science **361** eaat1378
  - 4.2 σ from NGC 1068 (Seyfert galaxy)
    Science **378** 538
  - 3.3 σ from 11 X-ray bright Northern Seyfert galaxies (with NGC 4151 most significant, excl. NGC 1068)
    ApJL **1000** L26
  - 3 σ from 14 X-ray bright Southern Seyfert galaxies
    ApJL **1000** L37
  - ...
- This study focuses on Seyfert galaxies (+QSOs)



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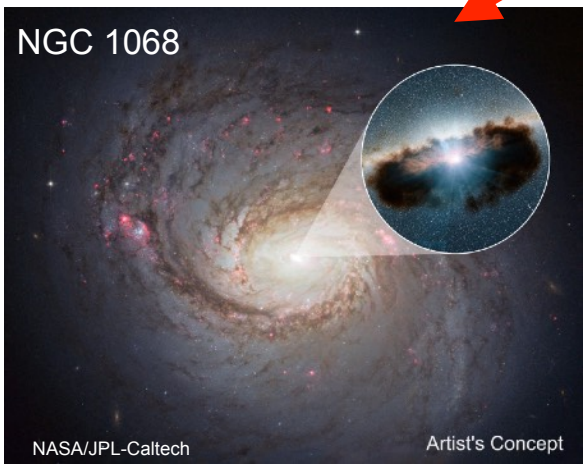
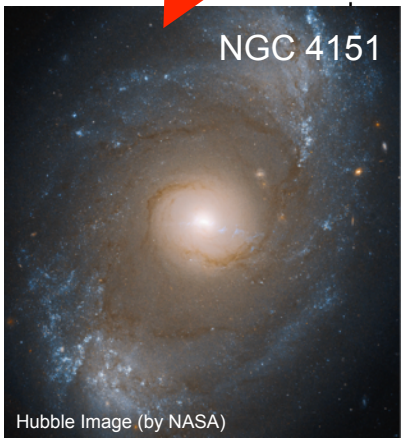
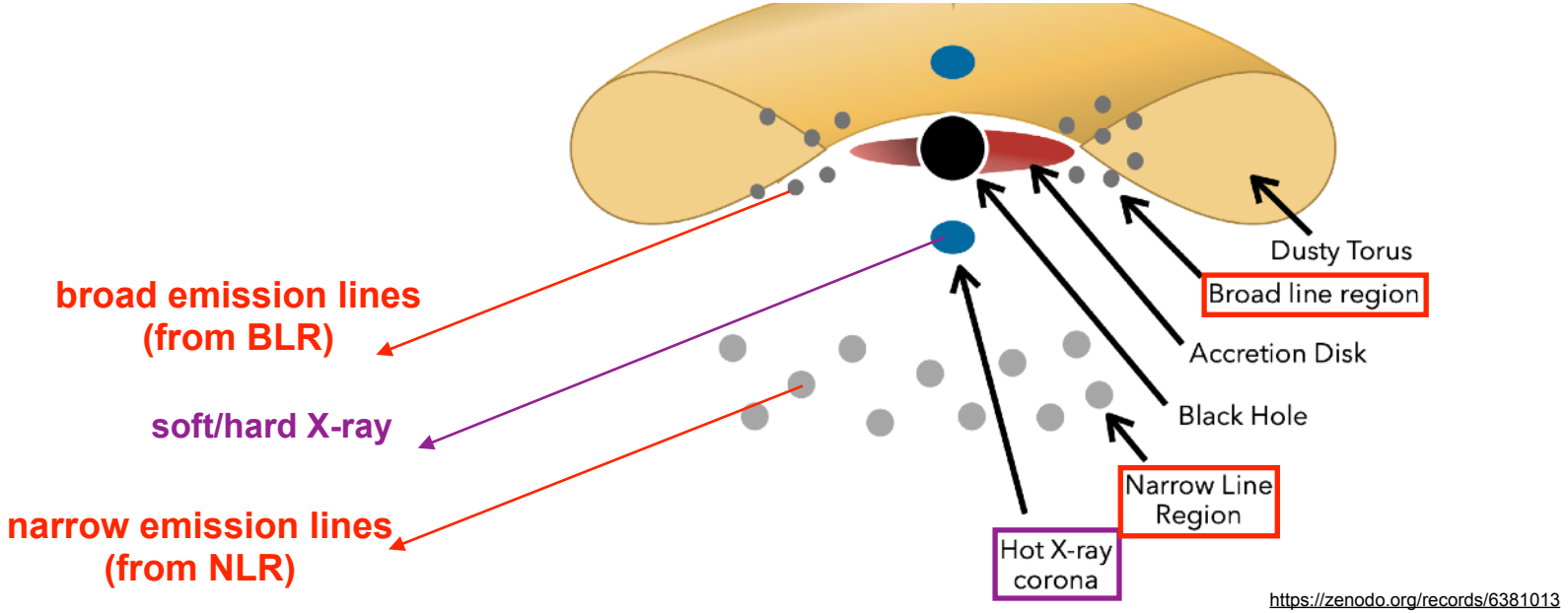




Target AGN selection

Alternative to X-ray based method

- **"stacking analysis"** is necessary to improve detection significance from 3-4 σ
- Most IceCube stacking analyses on Seyfert galaxies use *Swift* BAT hard X-ray AGN catalog (BASS), but with some caveats
  - *Swift* BAT has relatively large PSF (~20 arcmin) → contamination from AGN jet / host galaxy
  - X-ray flux is highly variable (~days) → average flux uncertain during IceCube observations
- Alternatively, optical emission lines from BLR/NLR are another good tracer



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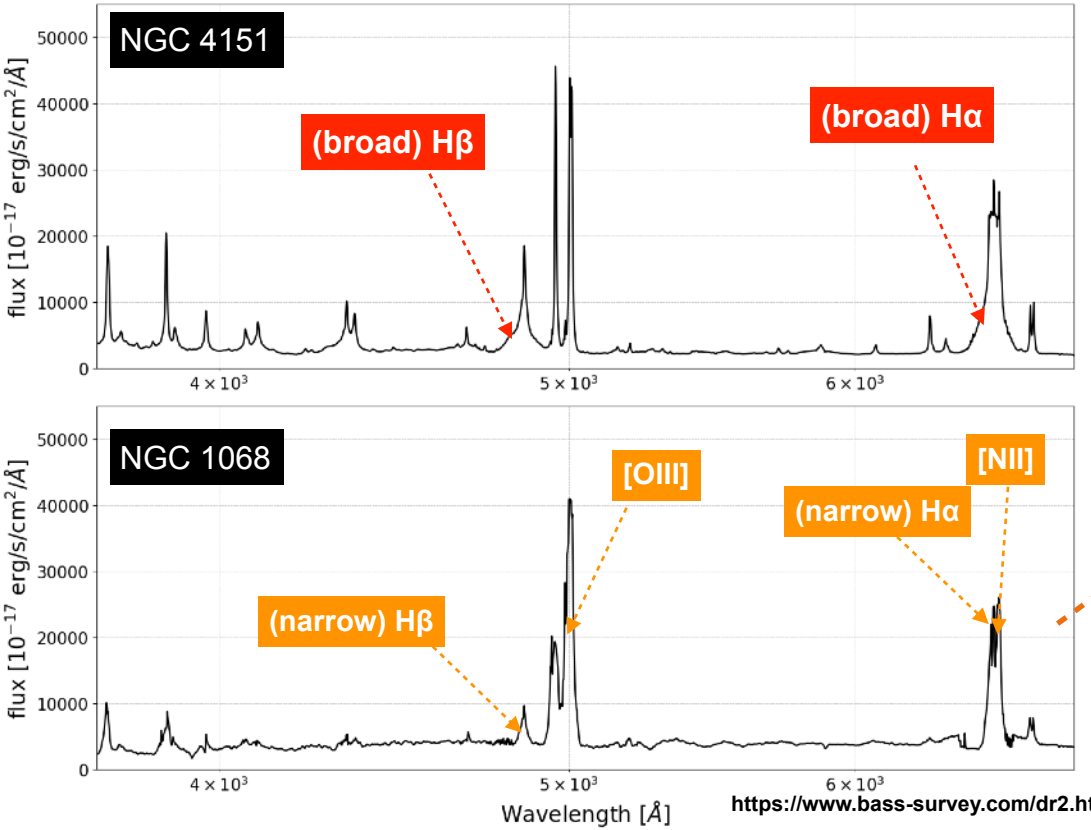
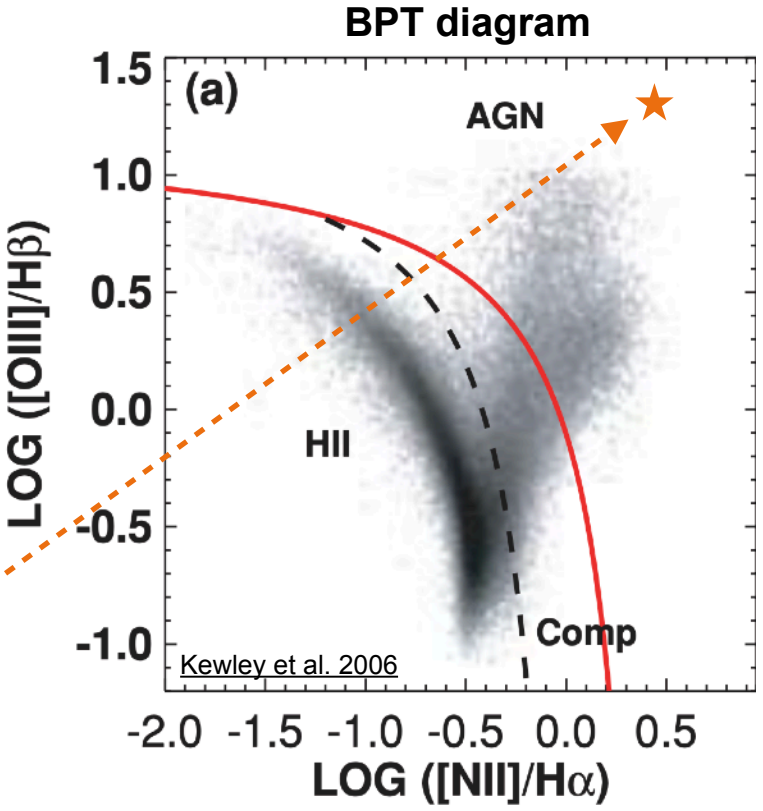
Target AGN selection

Selection using optical emission lines

- AGNs are identified either by:
  - existence of significant broad emission lines (for **type-I AGNs**)
  - mapping narrow emission line flux ratios (called **BPT diagnosis**, for **both type-I/type-II AGNs**)

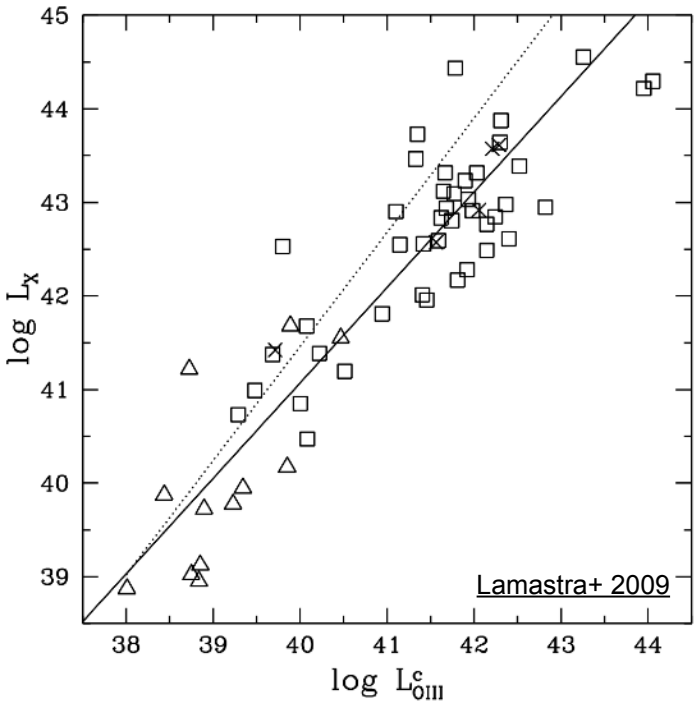




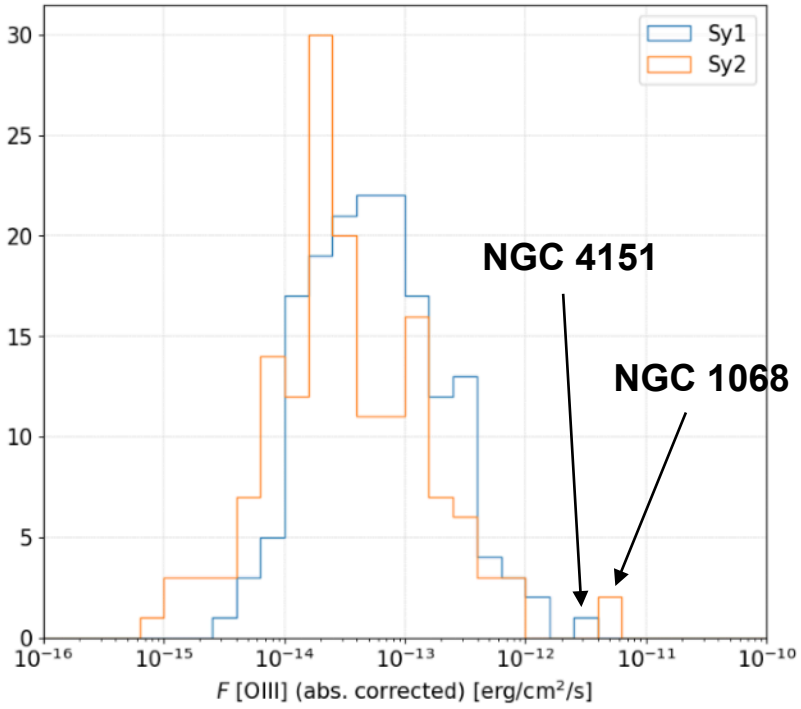
Target AGN selection

Select “Bright” AGNs

- Neutrinos are expected to come from **AGN corona** (Y. Inoue+ 2019, K. Murase+ 2021)
- [OIII] narrow line flux has a good correlation with **bolometric flux** (which correlates with **AGN corona** flux) (Lamastra+ 2009, Pennell+ 2017)
  - NGC 1068 and NGC 4151 are strong [OIII] emitters
  - NLR size is large -> stable emission over years



[OIII] flux (BASS AGNs, E-gal & northern sky)

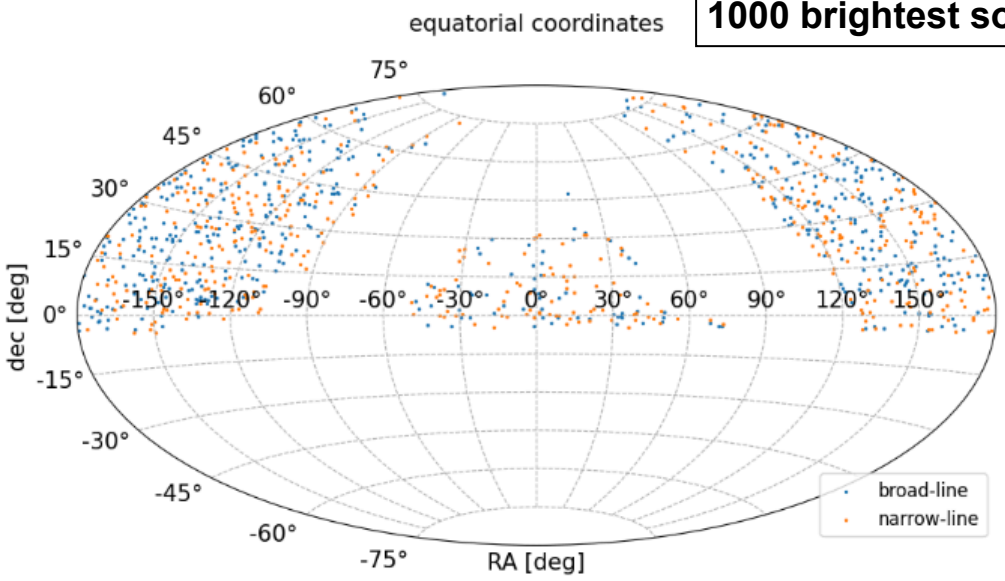


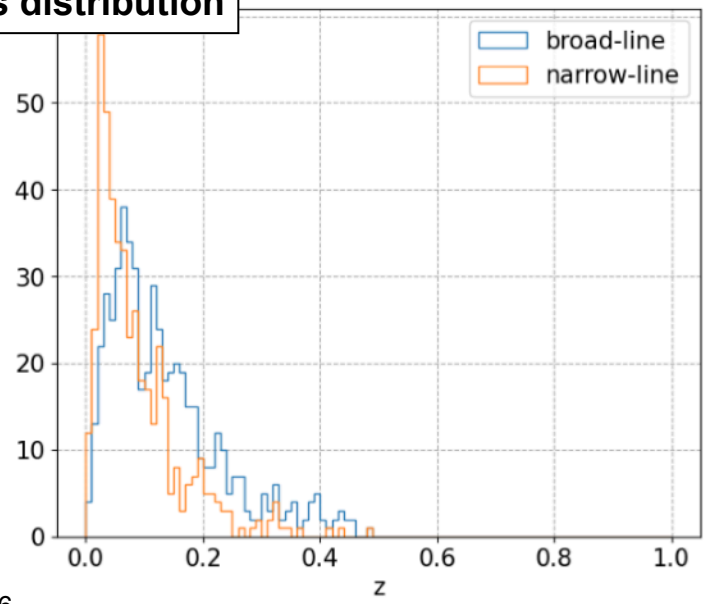
New AGN Catalog

catalog creation / properties

- Start from two large optical spectroscopic catalogs (mostly northern hemisphere)
  - **SDSS DR17** spec catalog : https://www.sdss4.org/dr17/spectro/spectro_access/
  - **DESI DR1** AGN classification catalog: https://data.desi.lbl.gov/doc/releases/dr1/vac/agngal/
- Select galaxies/quasars with either :
  - significant broad lines (Hα/Hβ, 10 sigma + >200 km/h)
  - significant narrow lines (Hα/Hβ/NII/OIII, 10 sigma) and AGN diagnosis in the BPT diagram
- Keep bright sources in the extragalactic northern sky (|b| > 15° & DEC > -5°)

1000 brightest sources distribution





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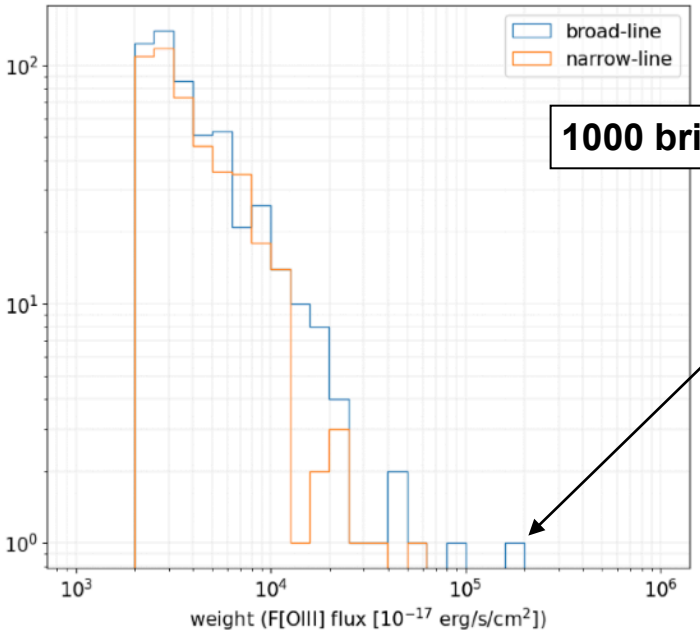


1000 brightest sources distribution

NGC 4151

* NGC 1068 is not observed spectroscopically by SDSS/DESI

IceCube stacking analysis

Configuration

- Target sources : N_{src} brightest AGNs in this catalog
- Neutrino dataset : 12 years of northern sky track-like events (muon neutrinos)
- Analysis method : Unbinned likelihood method
  - fixed w_j (relative signal counts for N_{src} sources) $\propto$ [OIII] line flux
  - common γ (spectral index among all the N_{src} sources)

free parameters

$$L = e^{-N_\nu} \prod_i^{N_\nu} \left(n_s \sum_j^{N_{\mathrm{src}}} w_j S_j(\vec{x}_i, E_i | \vec{x}_j, \gamma) + (N_\nu - n_s) B(\vec{x}_i, E_i) \right)$$

fixed

$$\mathrm{TS} = 2 \times \log \frac{L_{\max}(\hat{n}_s, \hat{\gamma})}{L(n_s = 0)}$$

Total signal counts

Signal PDF
(ν from target sources)

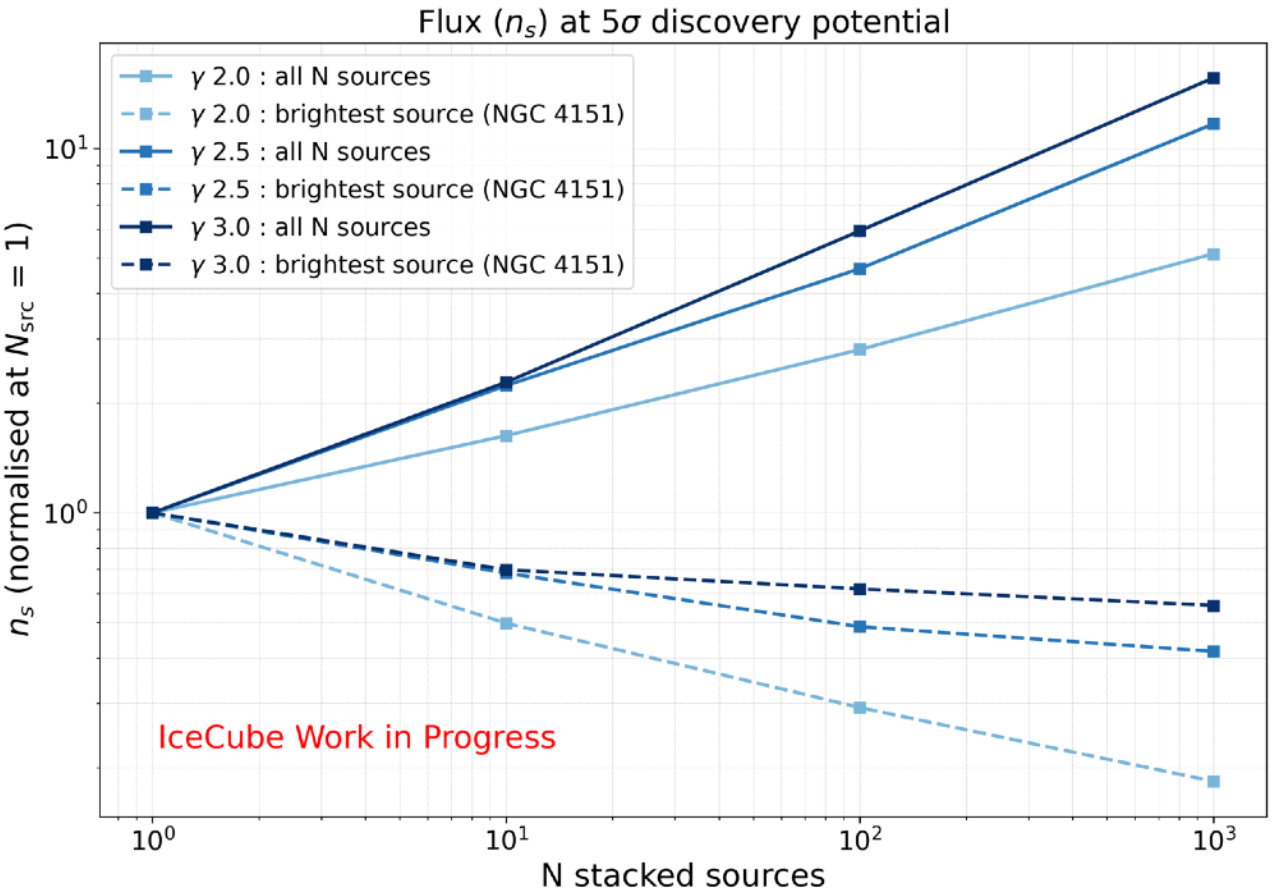
Background PDF
(atmospheric/diffuse ν)

* Only sensitivity and analysis performance shown in this talk using synthesised datasets

Results

5σ discovery potential vs N_{src}

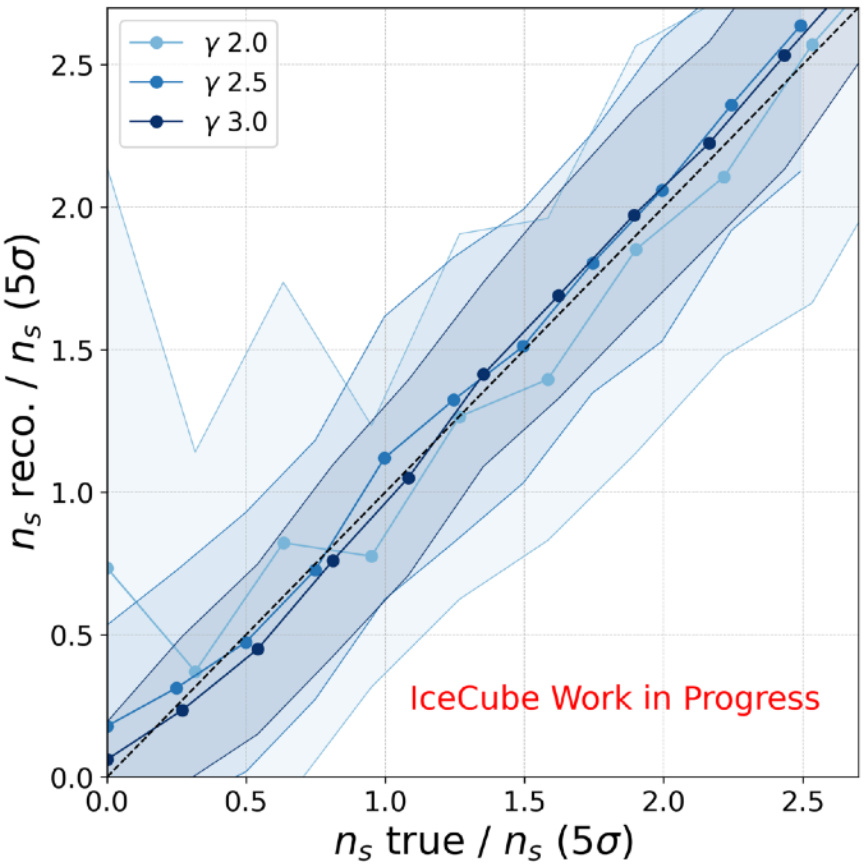
- 5σ discovery potential flux calculated for different N_{src} / simulated γ (2.0,2.5,3.0)
  - ➡ per-source flux decreases with N_{src} : more sensitive with more sources

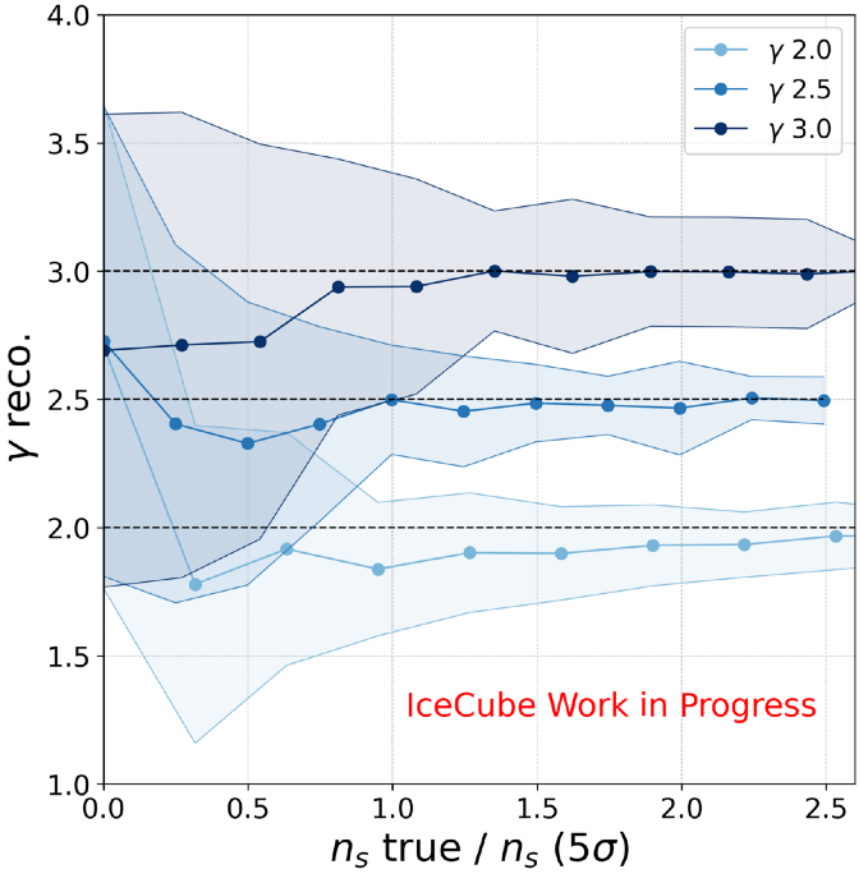


Results

Reconstruction of simulated signal with N_{src} 1000

- Injected signal parameters (n_s / γ) are well reconstructed

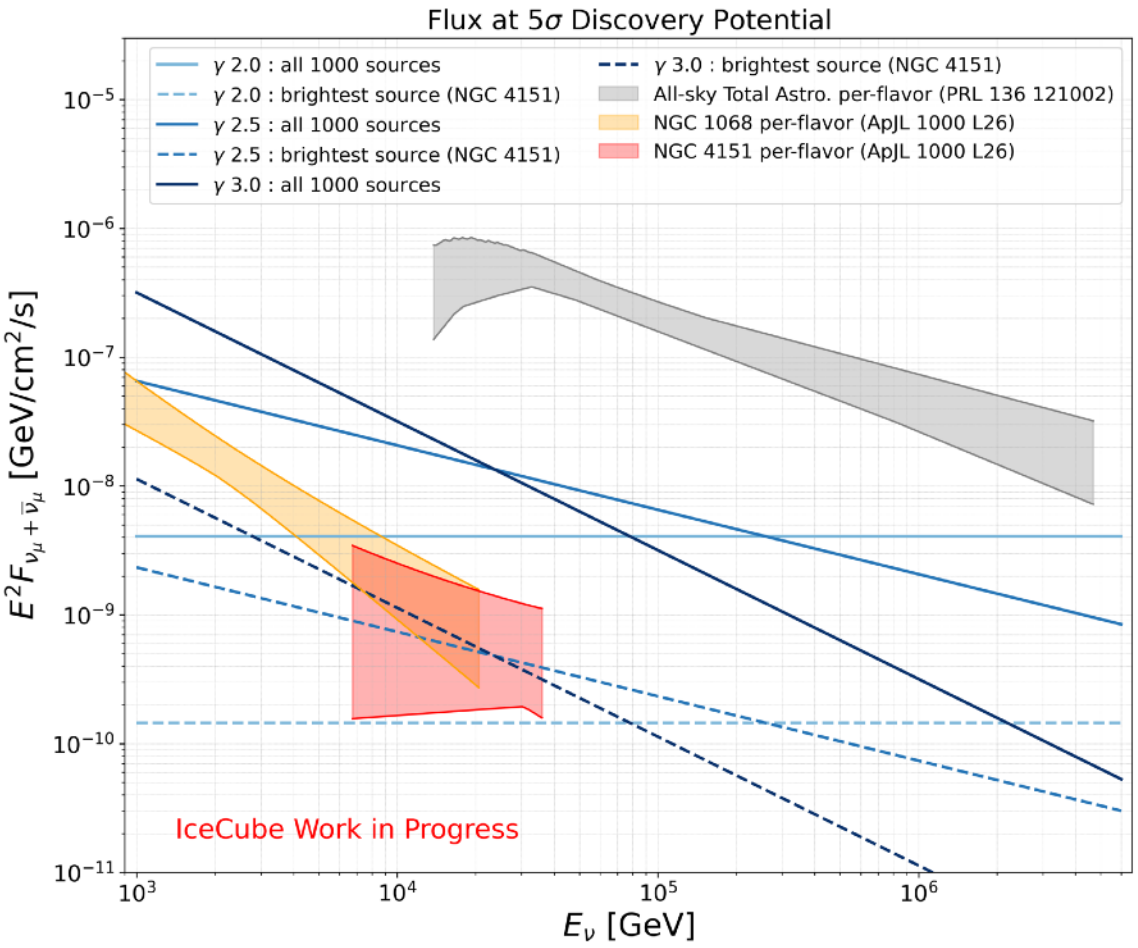




Results

5σ discovery potential with N_{src} 1000 compared to known spectra

- 5σ discovery potential flux for the brightest source (NGC 4151) reaches the real NGC 4151 spectrum
  - ➡ Neutrinos from these 1000 stacked sources could be detected at 5σ, if they are indeed emitters



Summary

- Optical spectroscopy is another powerful tool to identify/quantify an AGN sample to be used for (IceCube) stacking analysis
- Created a novel catalog of bright AGNs by utilising the recent data of two large optical spectroscopic surveys : SDSS/DESI
- Established and validated the stacking analysis method
- 5σ discovery potential flux for NGC 4151 in this analysis is comparable to the real spectrum, suggesting the detection possibility of integrated neutrino emission from this catalog's AGNs

Unblinding process ongoing. Stay tuned for the results with real data!

Backup

Catalog creation procedure