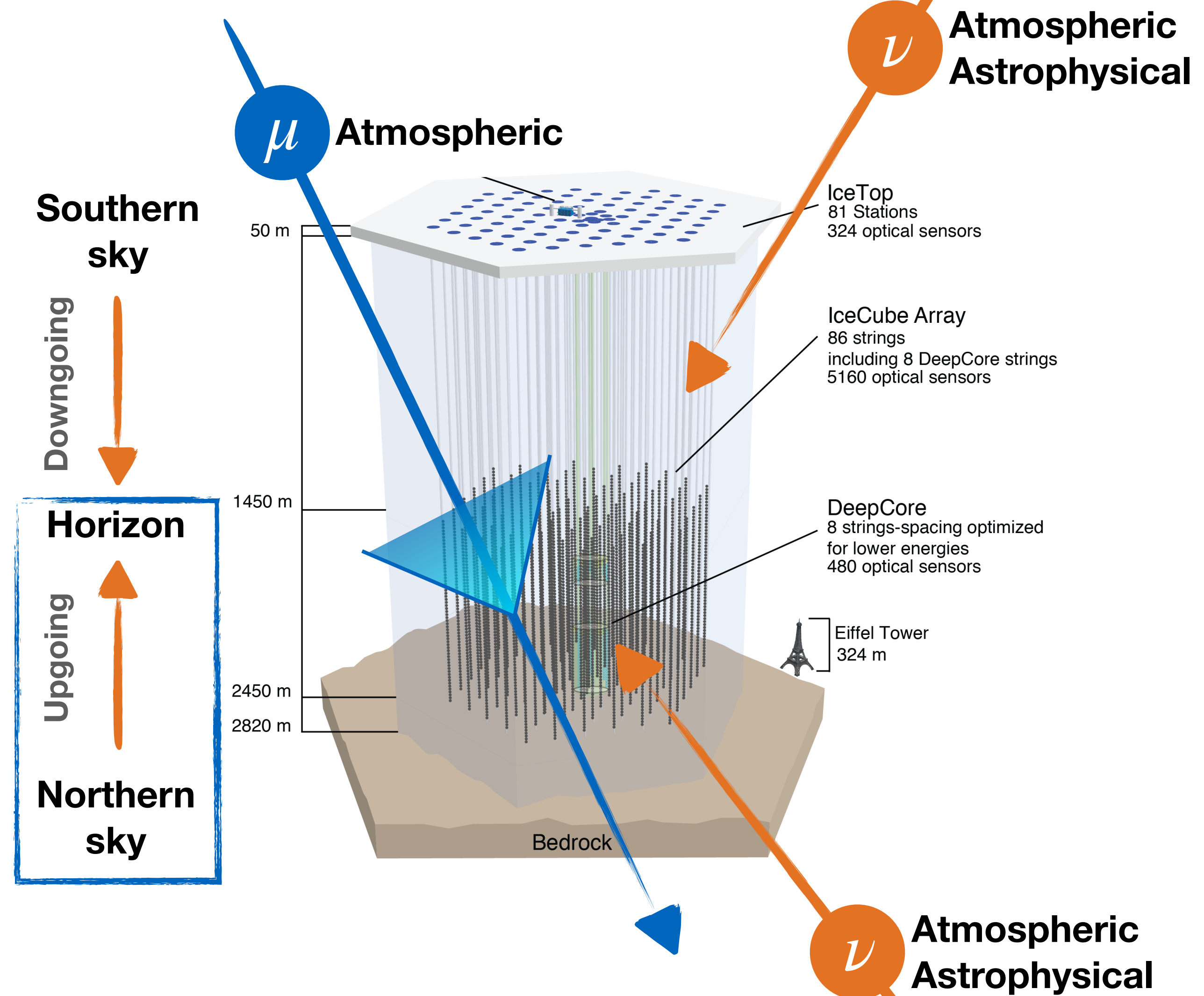


Evidence of Neutrino Excess from a Population of X-ray Bright non-Blazar AGNs in the Northern Sky with 13 Years of IceCube Data

Tomas Kontrimas, Chiara Bellenghi, Elena Manao, Martin Ha Minh
for the IceCube Collaboration

Introduction to IceCube

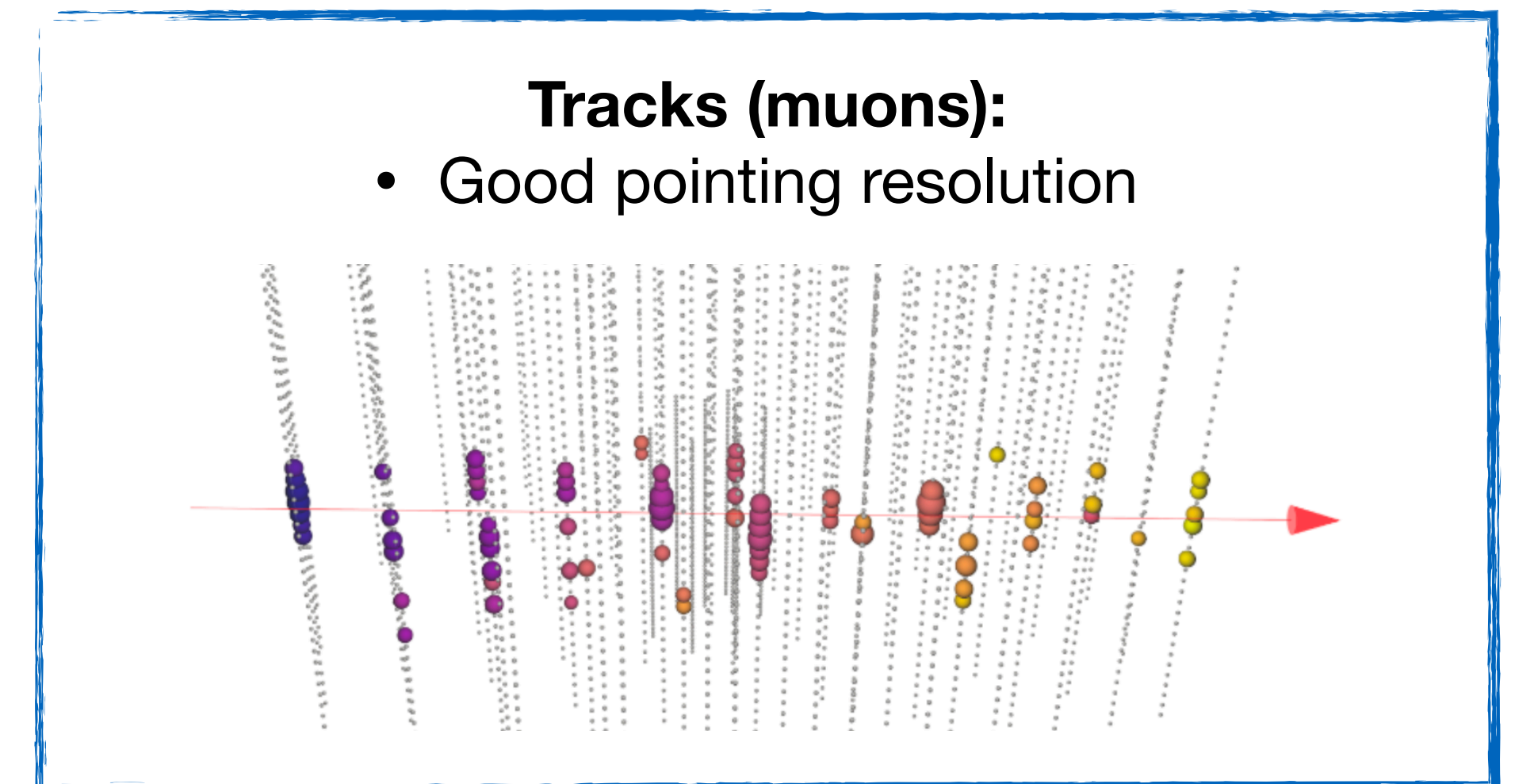
- 5160 optical modules attached to 86 strings in 1km³ Antarctic ice
- The ice is the target for atmospheric and astrophysical neutrinos
- Reconstruct the original neutrino properties (direction and energy) from deposited **Cherenkov light** in the optical modules
- Earth absorbs atmospheric muon background from the northern sky!



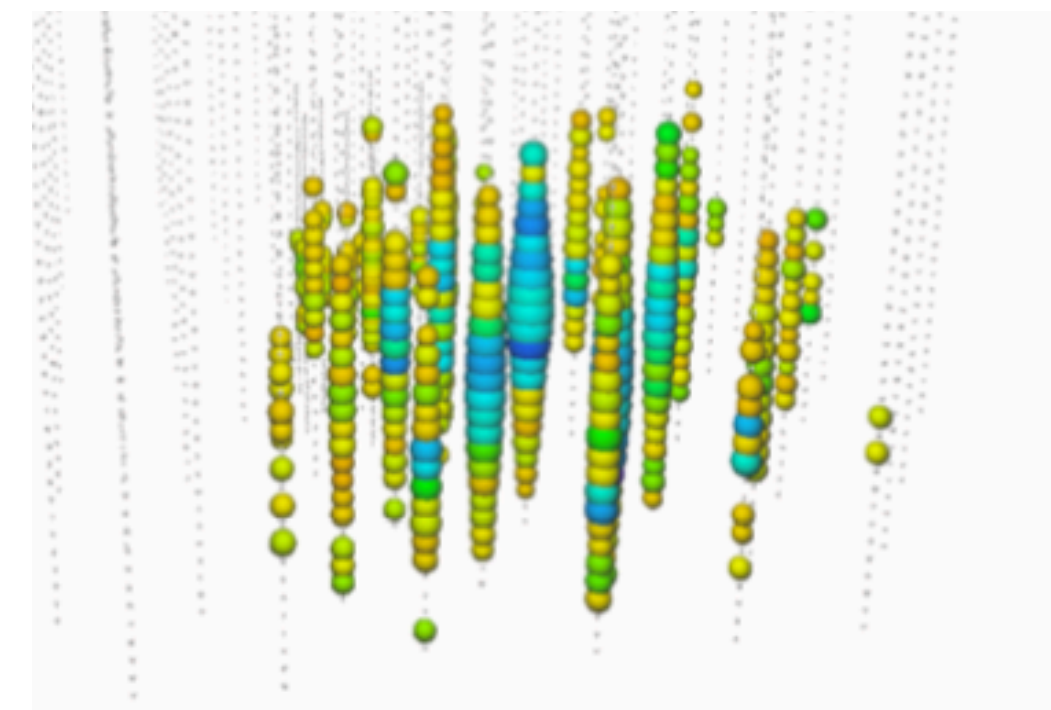
Point source analysis dataset

Upgoing muon data sample:

- Event selection is optimised for upgoing muons ($-5^\circ < \delta < 90^\circ$)
- Has good agreement between data and Monte-Carlo simulations, crucial for improved analysis methods
- Muons energy range from 100 GeV to ~ 6 PeV
- **99.8%** of the sample made of up-going neutrino-induced muon tracks

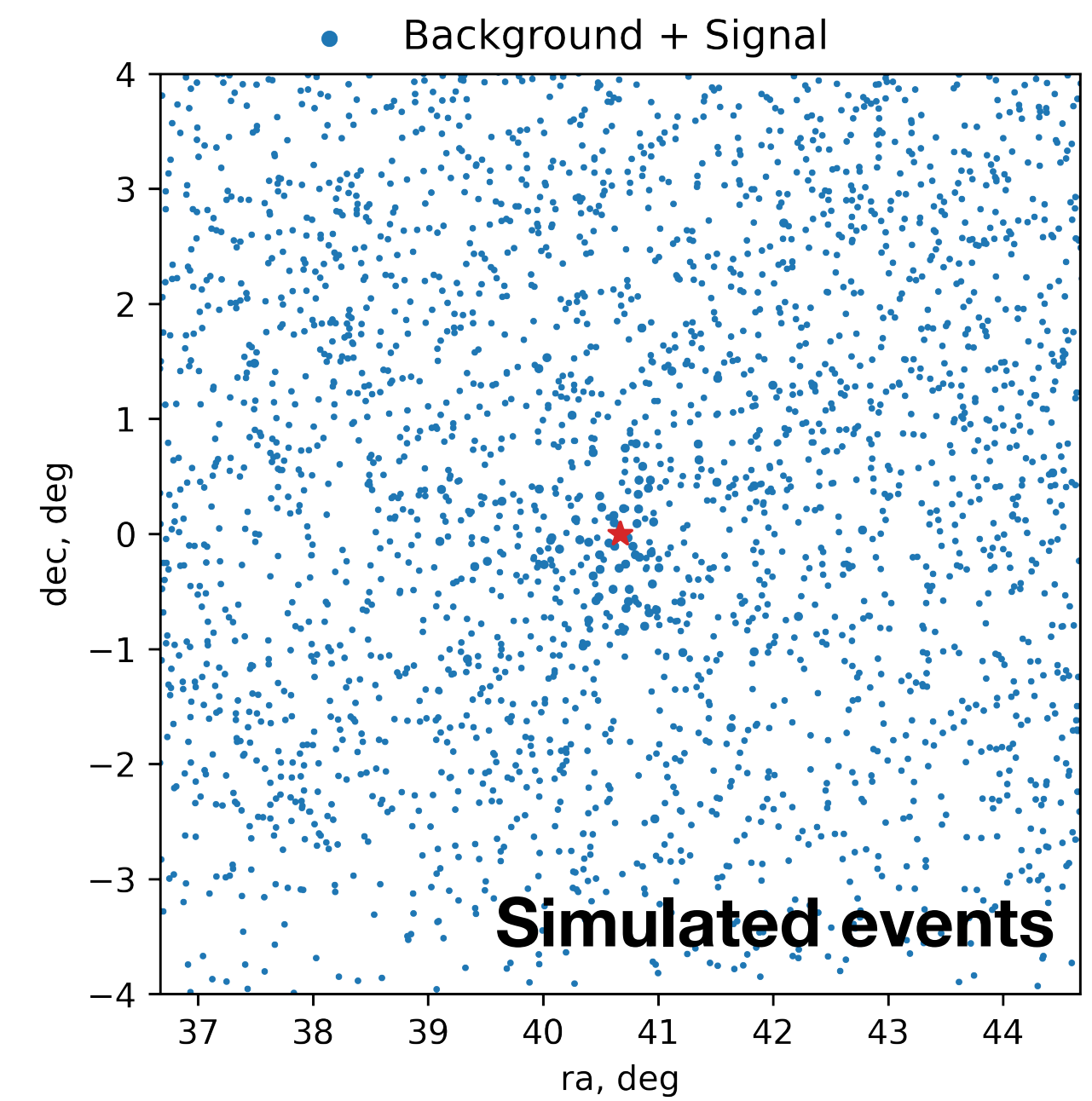


- Cascades:**
- Good energy resolution
 - Worse pointing



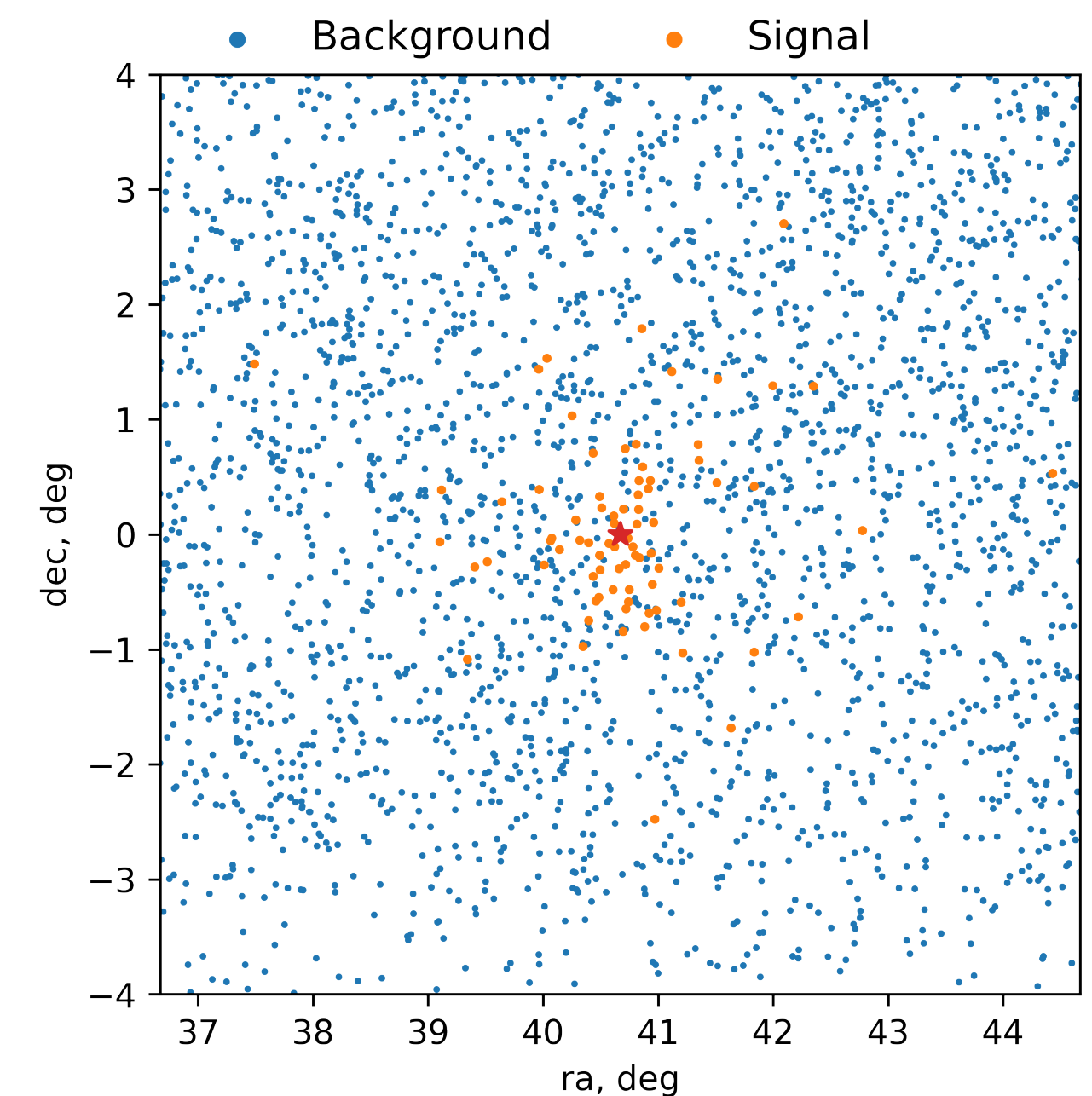
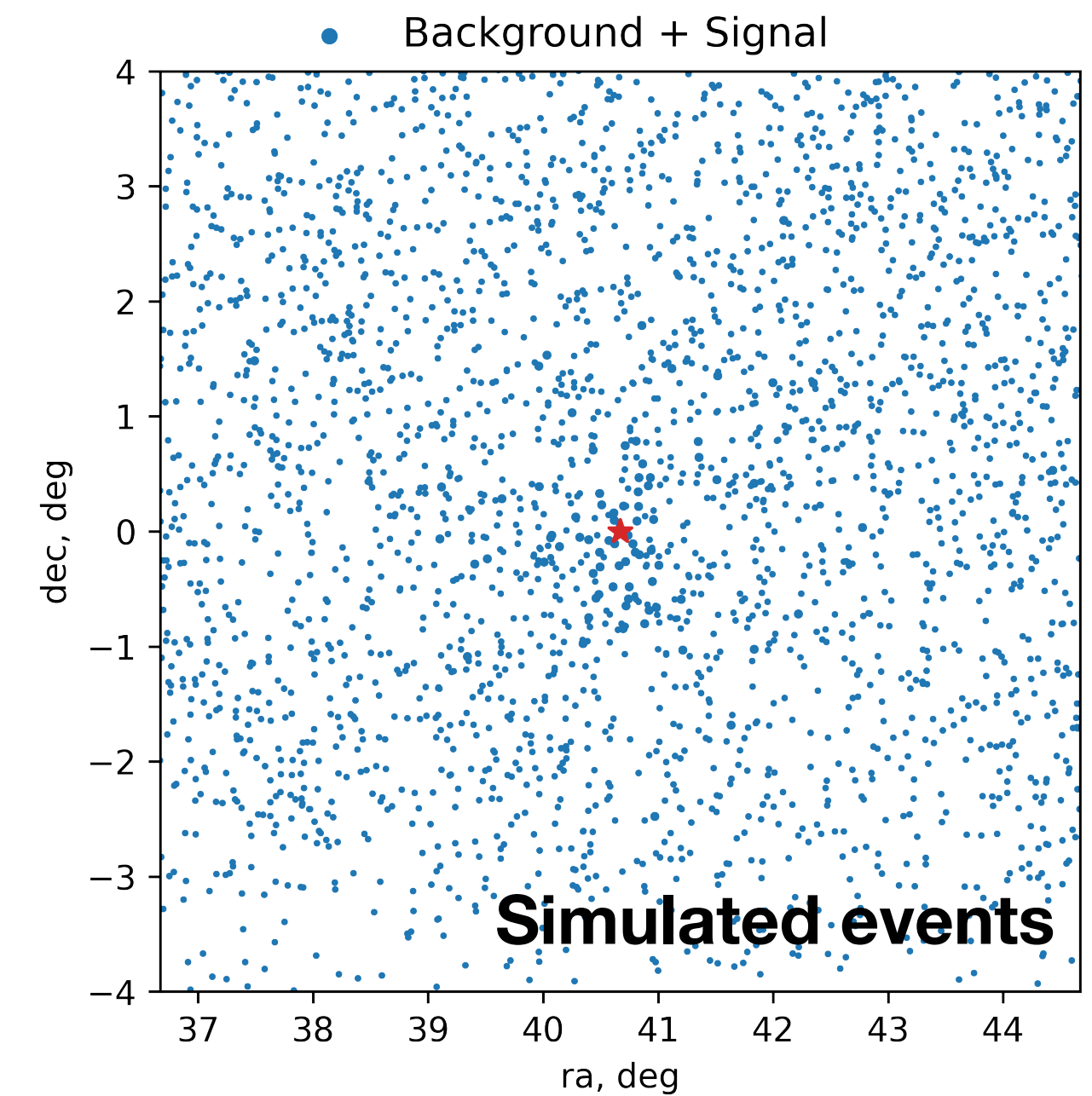
How events look like

- We drown in **background** events!



How events look like

- We drown in **background** events!
- The atmospheric and diffuse astrophysical neutrino fluxes are isotropic
 - ▶ **Point source** — search for **signal clustering**
- The atmospheric flux is orders of magnitude higher than the astrophysical one
 - ▶ Astrophysical diffuse flux of high-energy neutrinos measured by IceCube has a **different spectral shape** than the atmospheric flux

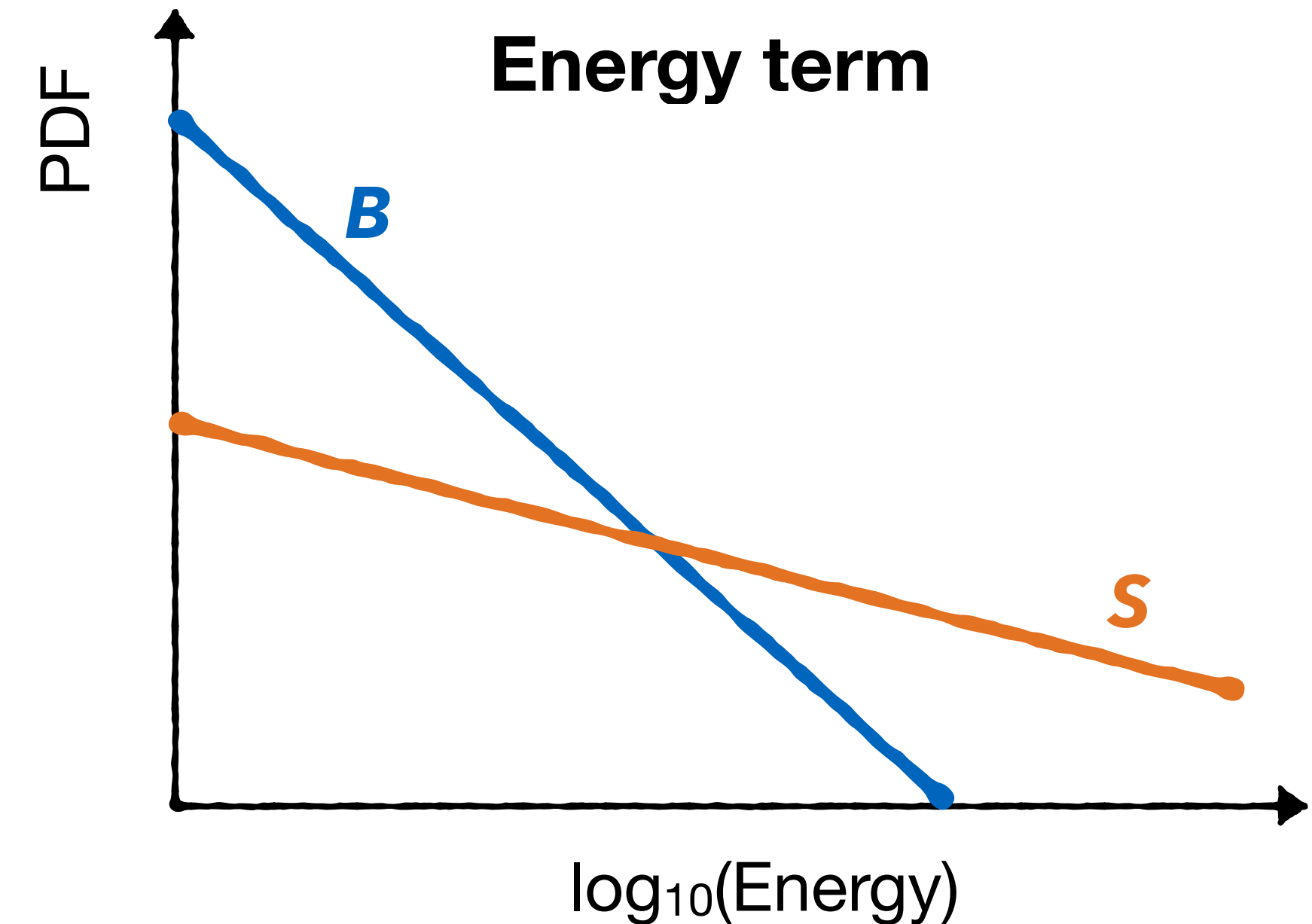
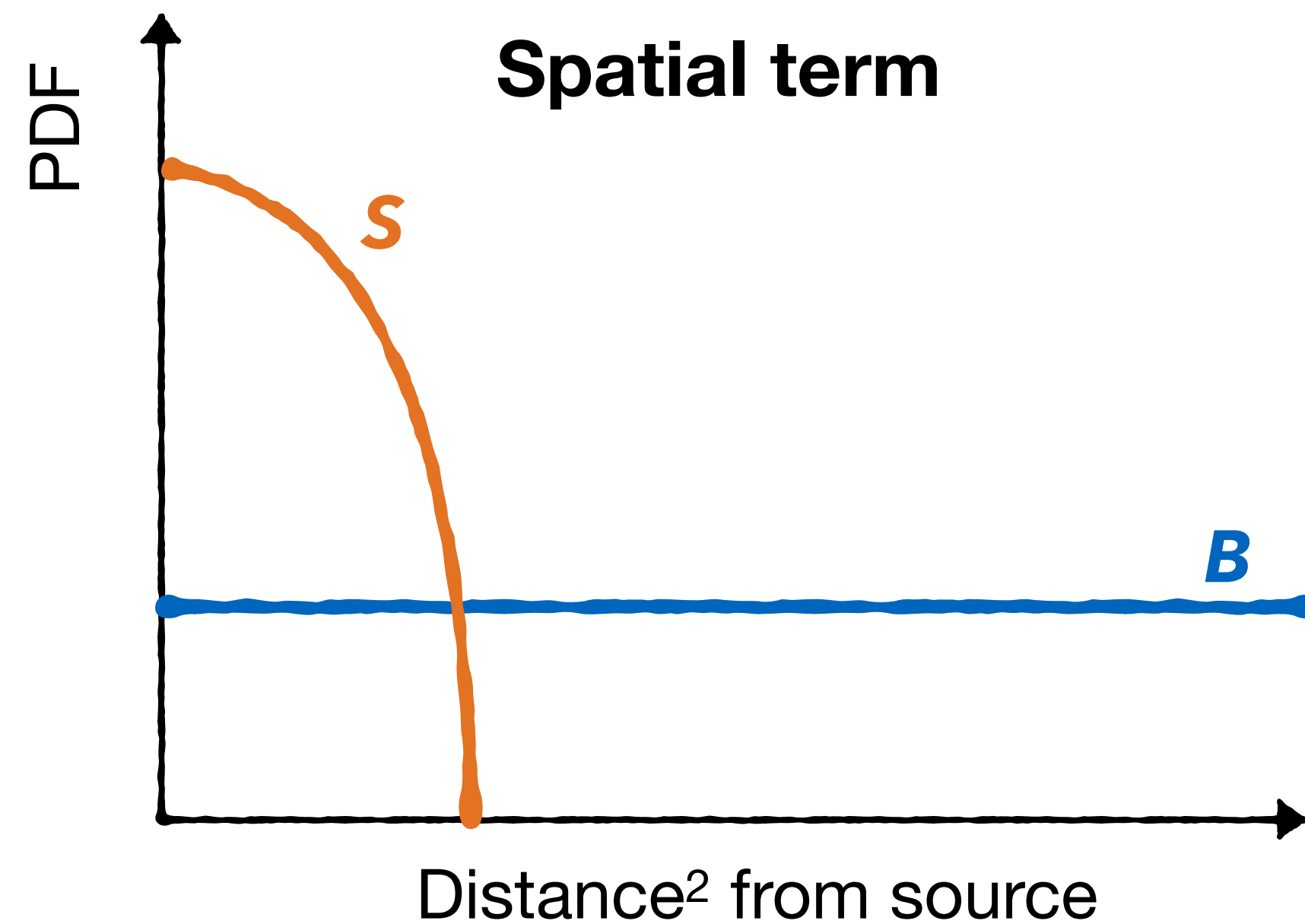


Likelihood ratio test construction

The unbinned likelihood approach:

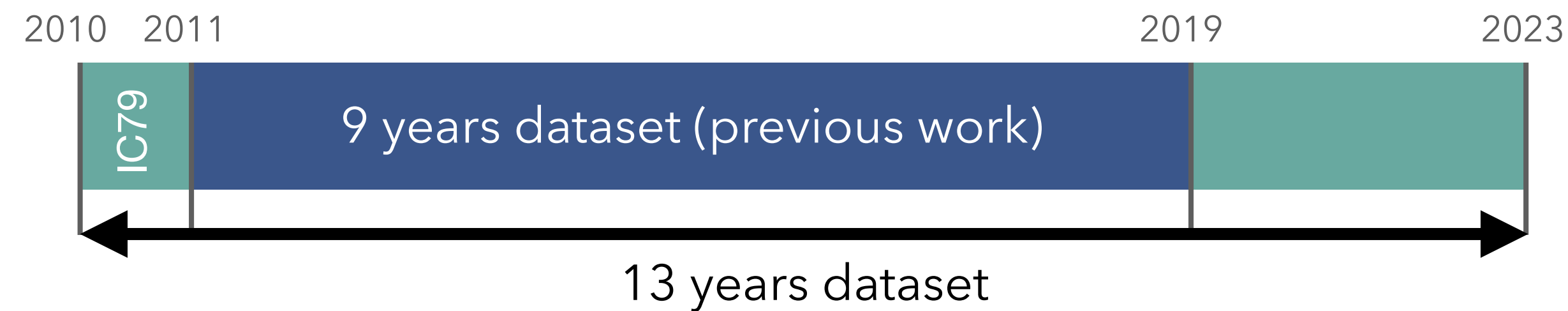
$$\mathcal{L} = \prod_i^N \left[\frac{n_s}{N} \boxed{S_i} + \left(1 - \frac{n_s}{N} \right) \cdot \boxed{B_i} \right]$$

Signal (orange) Background (blue)



Main analysis plan

1. Re-test emission from NGC 1068 with 4 years of additional data (~50% increase in statistics) without changes in calibration and reconstruction



2. Look for other neutrino sources (new list of Seyfert sources)



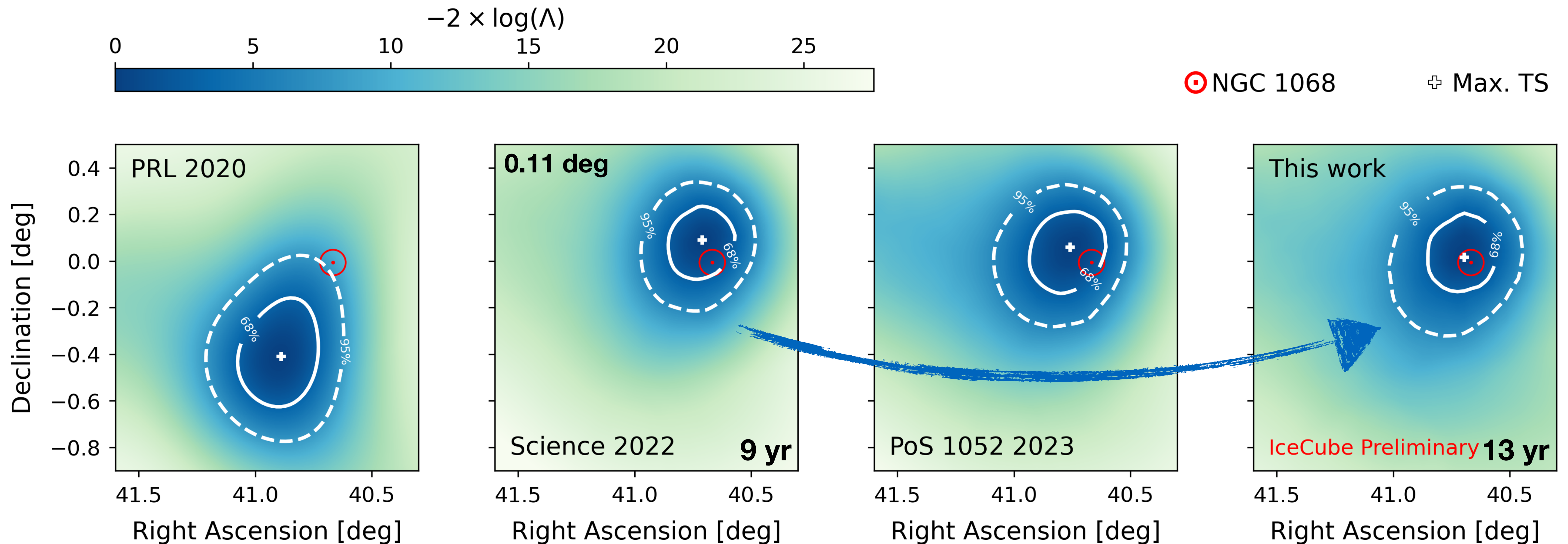
48 - This work

28 - X-ray Bright Seyfert Galaxies (Northern sky)

43 - Hard X-ray AGN

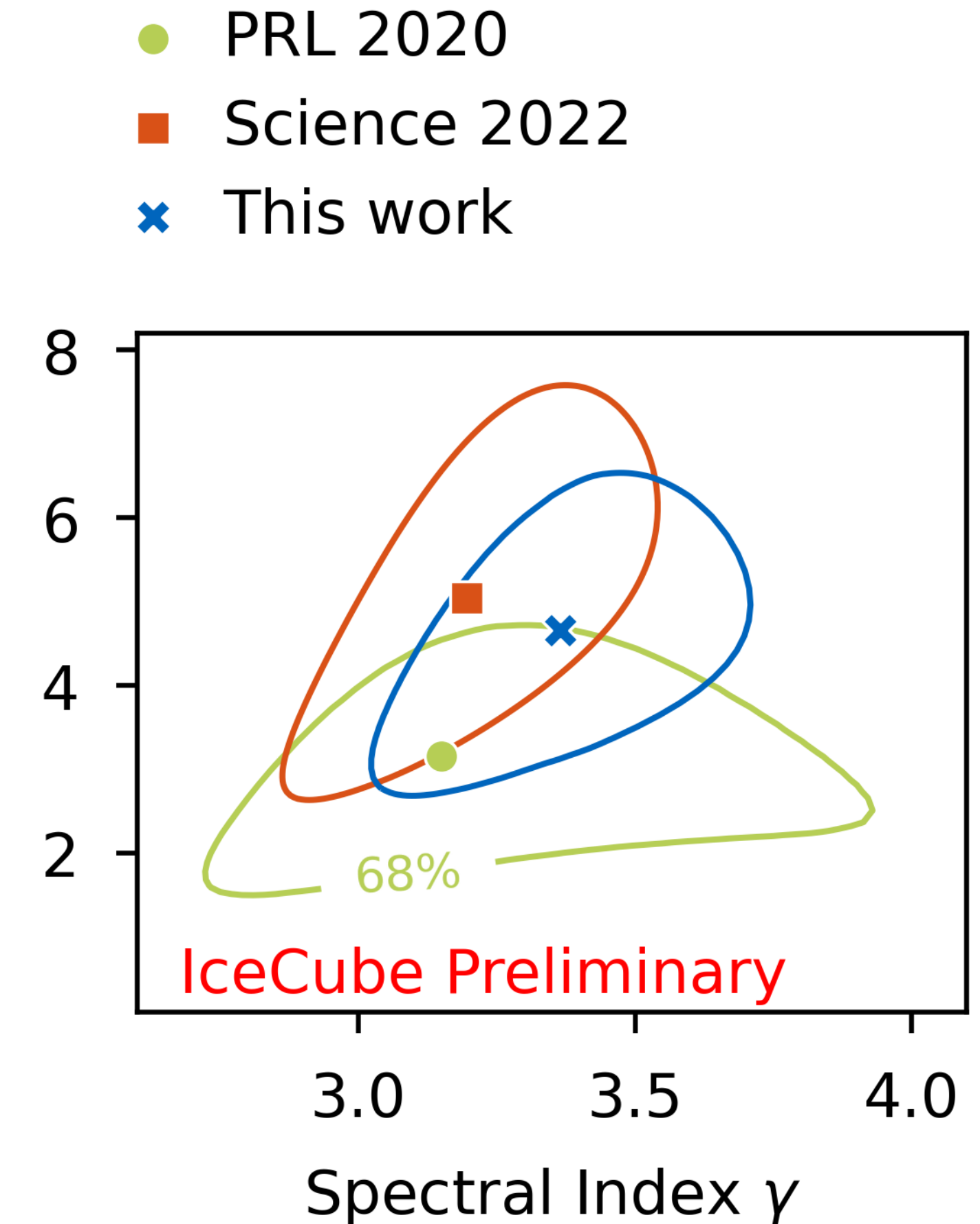
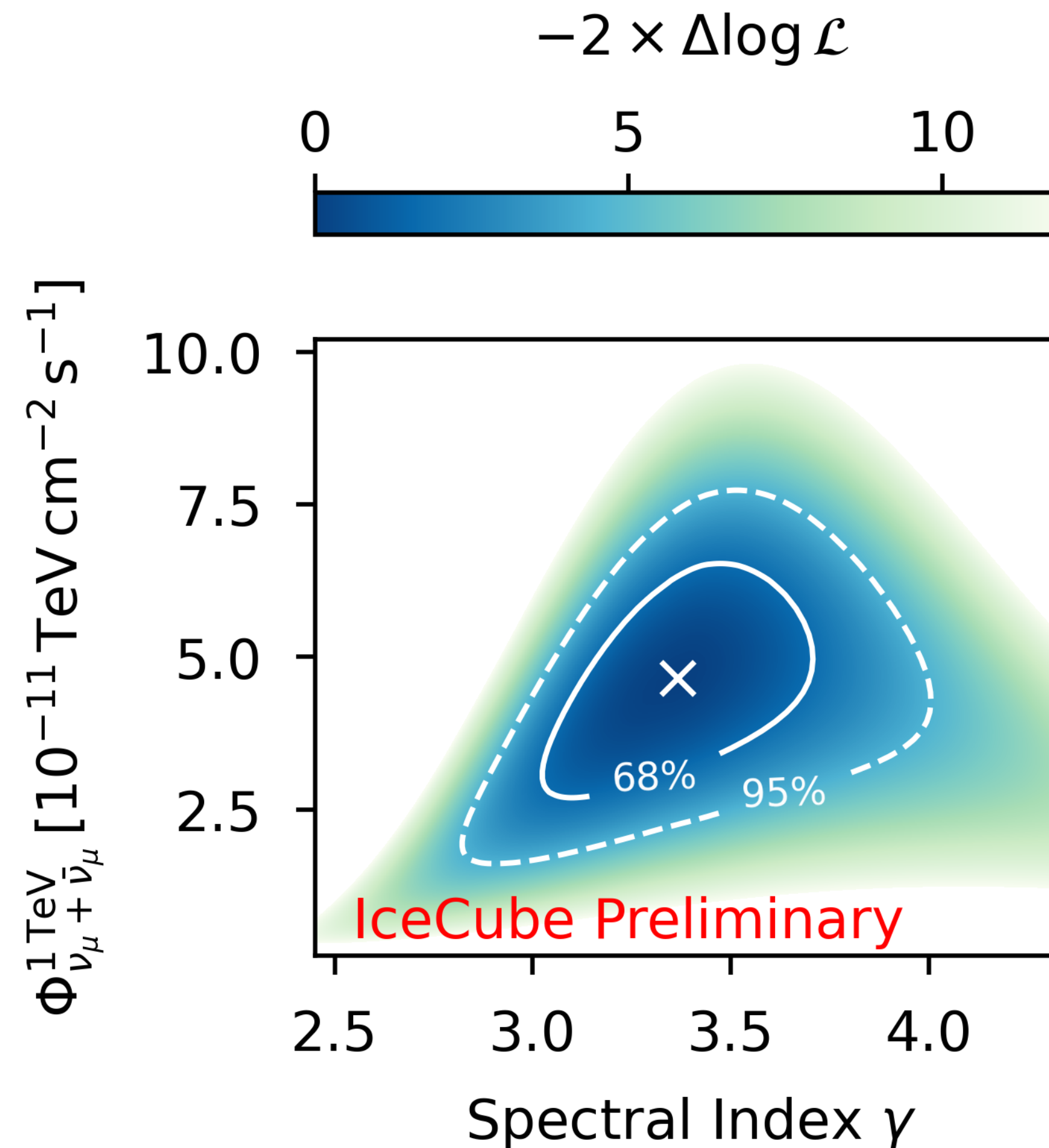
1. NGC 1068, the hottest spot in the Northern Sky

- Hotspot position is now only 0.04 degrees away, within the optical size of the galaxy!



Updated NGC 1068 flux and significance

- Updated post-trial significance of NGC 1068 is 4.0σ
- Best-fit has softer spectral index $\gamma = 3.4$
- Best-fit results are compatible within the 68% contours

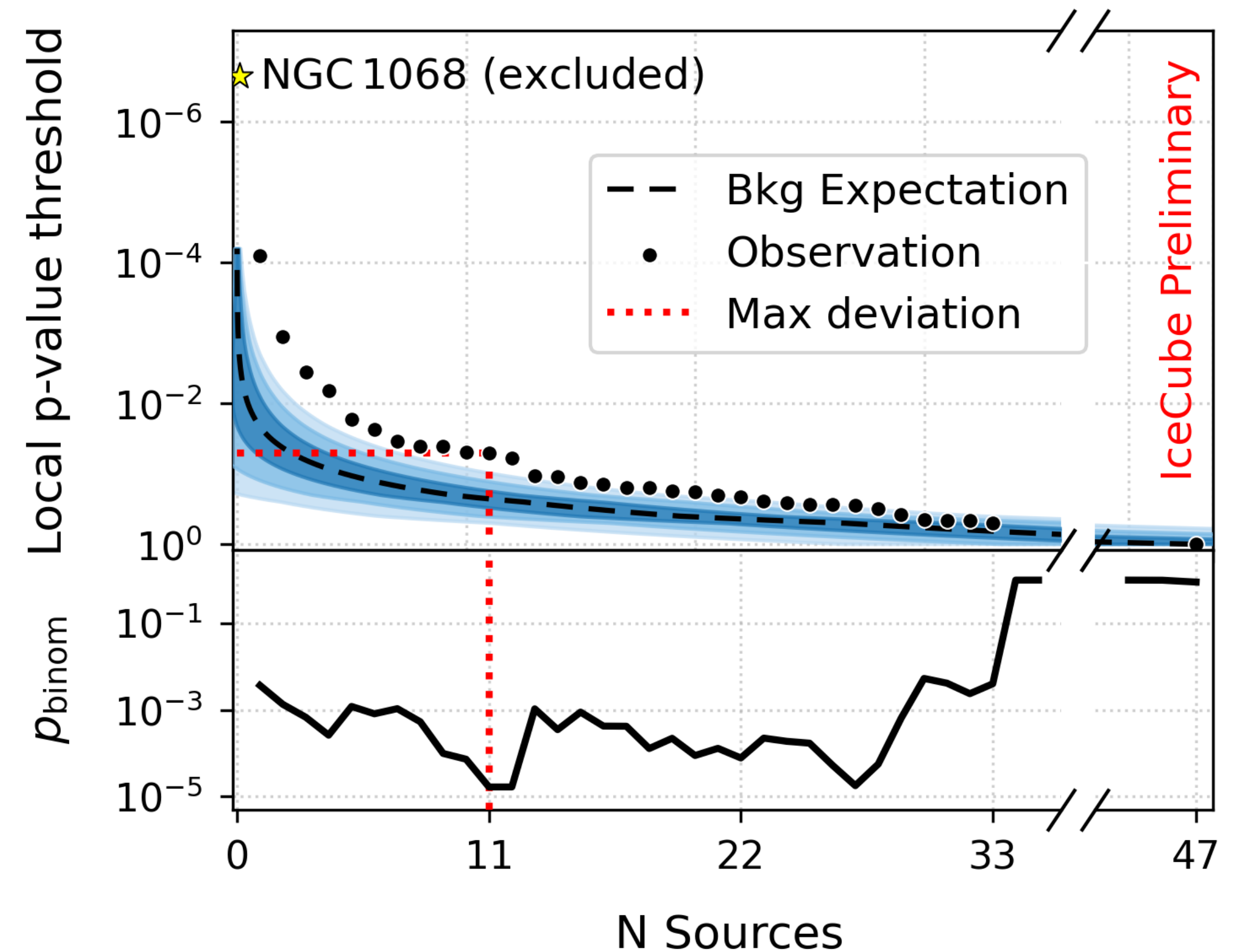


2. Looking for other sources

- Evidence of neutrino emission from NGC 1068 ([Science](#))
 - Motivates searches from similar sources
 - Challenges long-standing assumption that gamma-rays and neutrinos are correlated
 - Seyfert Galaxy especially bright in X-rays
- X-rays have a high penetration power — they don't get absorbed as easily as gamma-rays!
- **Assumption:** neutrino and X-ray luminosities are correlated
 - New list of 47 X-ray bright Seyfert Galaxies (excluding NGC 1068) selected on their X-ray flux: $F_{20-50\text{ keV}}^{\text{intr}} > 20\%$ of NGC 1068 intrinsic X-ray flux

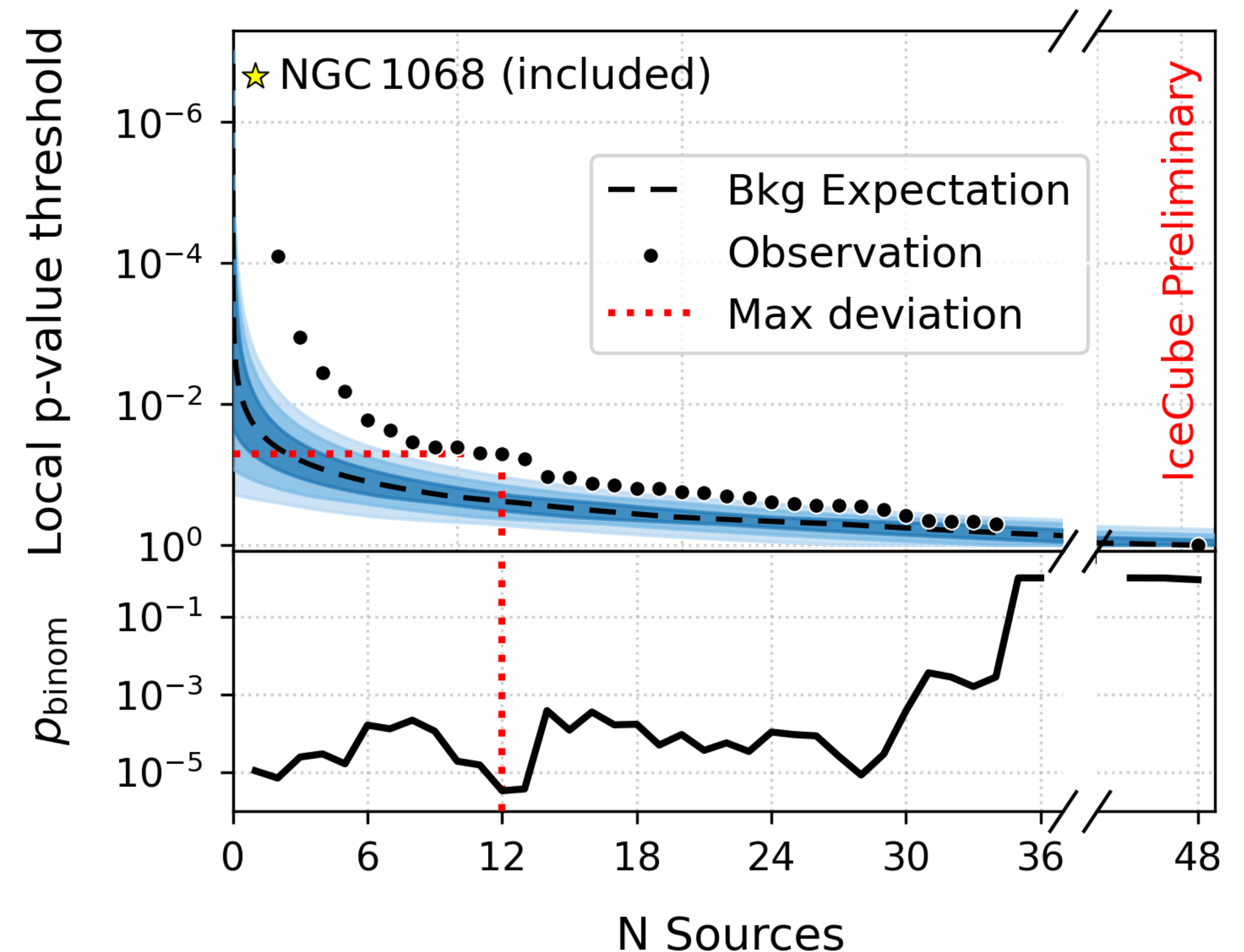
Binomial test of X-ray bright AGNs

- Binomial test: Probability of finding a signal from a group of objects that are too weak to be interesting on their own but possibly significant as an ensemble
- Most significant excess found from **11 sources** with a global **significance of 3.3σ**
- Provides indication of a possible population of neutrino emitters



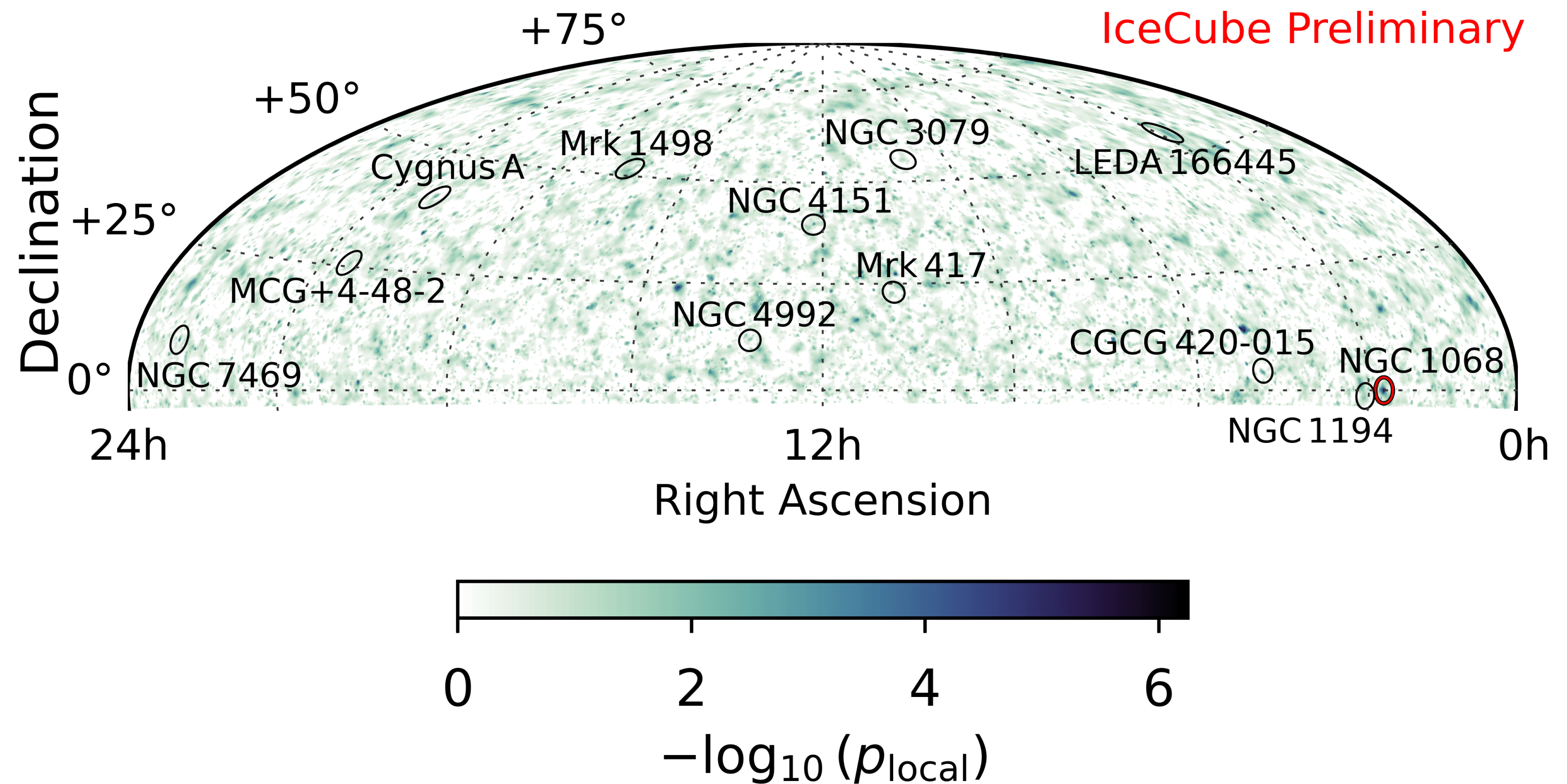
Binomial test of X-ray bright AGNs

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- Most significant excess found from **11 sources** with a global **significance of 3.3σ**
- Provides indication of a possible population of neutrino emitters
- When including NGC 1068, the excess is found for **12 sources with a significance of 3.7σ**



The new neutrino Northern Sky

- Recent IceCube results raised interest in probing neutrino emission from X-ray AGNs
- New analyses' results are pointing towards the possibility of these sources being a population of neutrino emitters



Marked 11 sources from Seyfert catalog binomial test

The emergence of a population of sources?

- 2022: Evidence of neutrino emission from NGC 1068 ([Science](#))
- 2024: IceCube Search for Neutrino Emission from X-ray Bright Seyfert Galaxies (**Northern sky**)
 - 2.7σ binomial excess from 2 sources: NGC 4151 and CGCG 420-015
- 2024: ESTES **Southern Sky** Seyfert Search
 - 3.0σ from stacking 13 Southern Seyfert galaxies.
- 2024: Search for neutrino emission from **hard X-ray** AGN with IceCube
 - 2.9σ from NGC 4151
- **This work: 3.3σ binomial excess for 11 sources** from an updated list of X-ray bright Seyfert Galaxies

arXiv:2406.07601

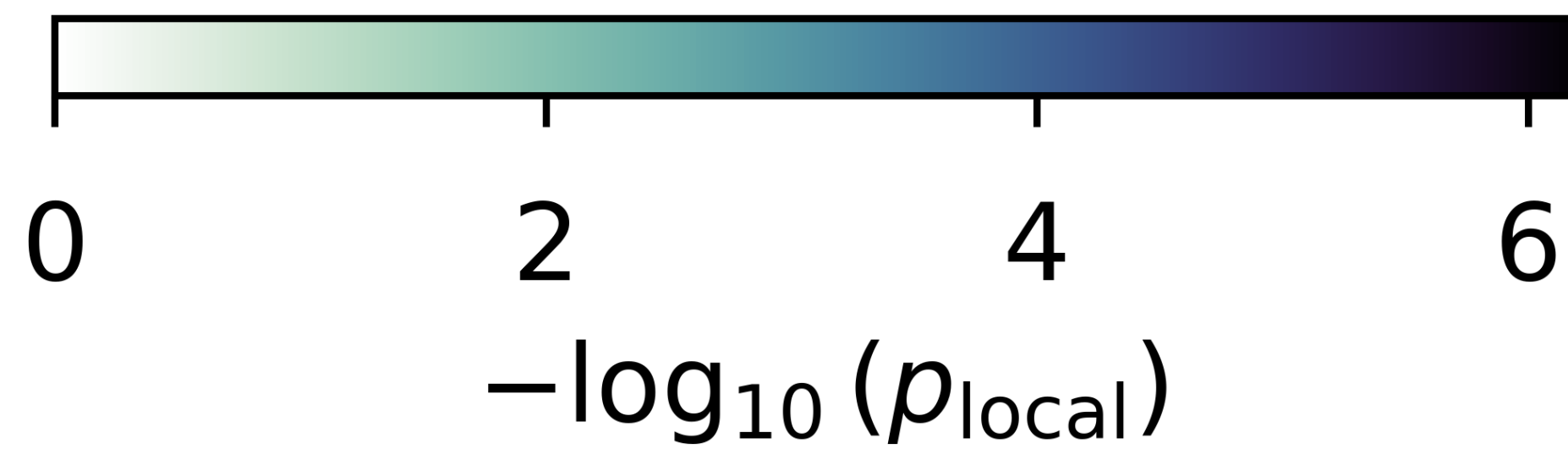
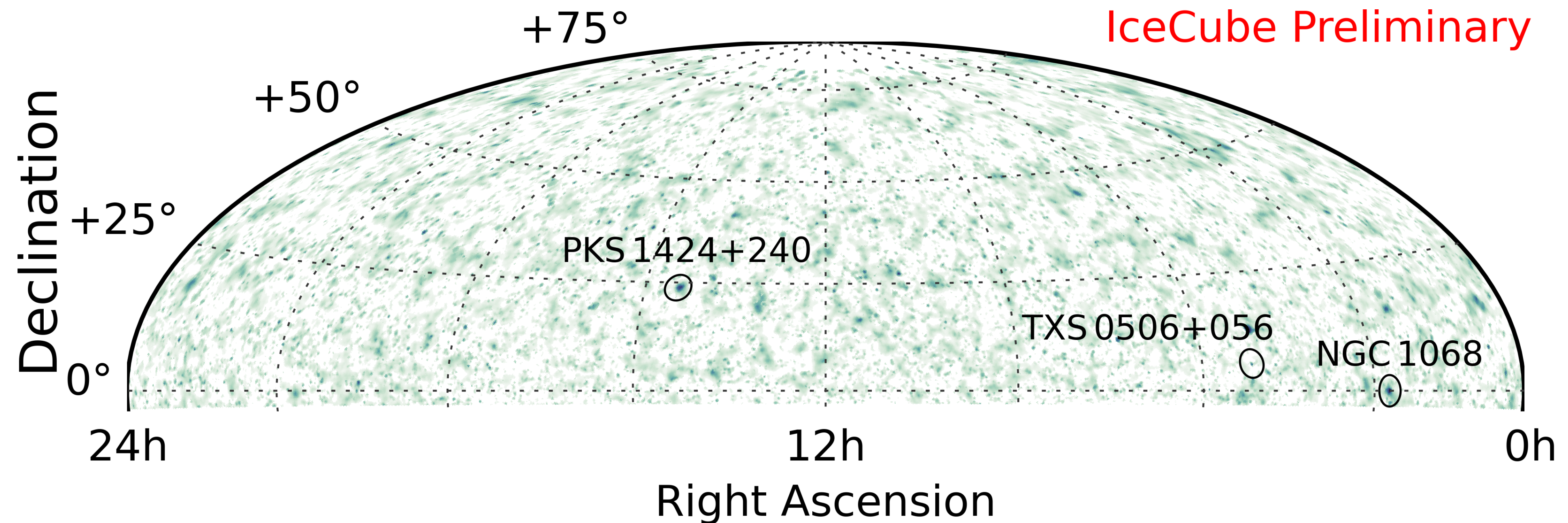
TeVPA, Tue 14:40

arXiv:2406.06684

Thank you!

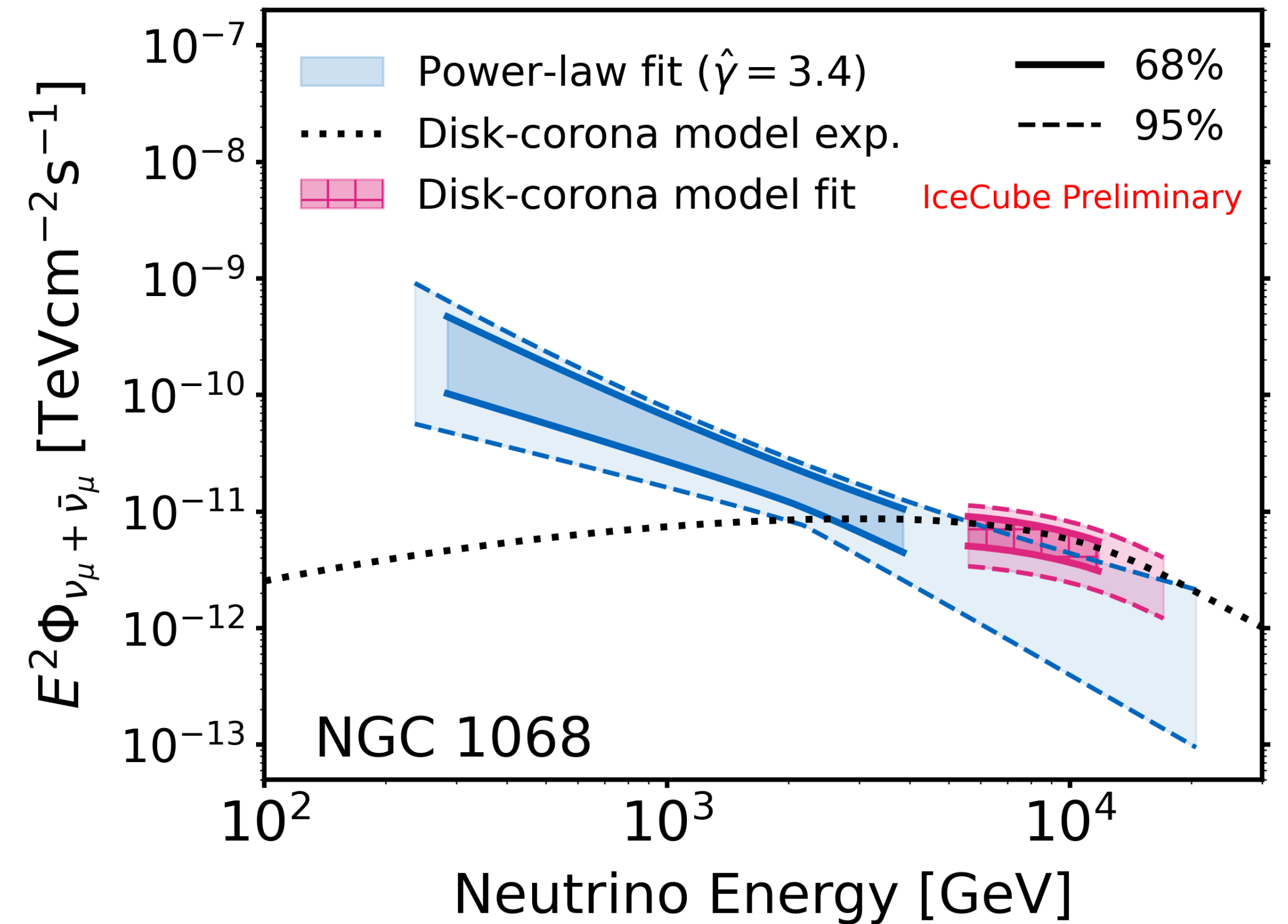
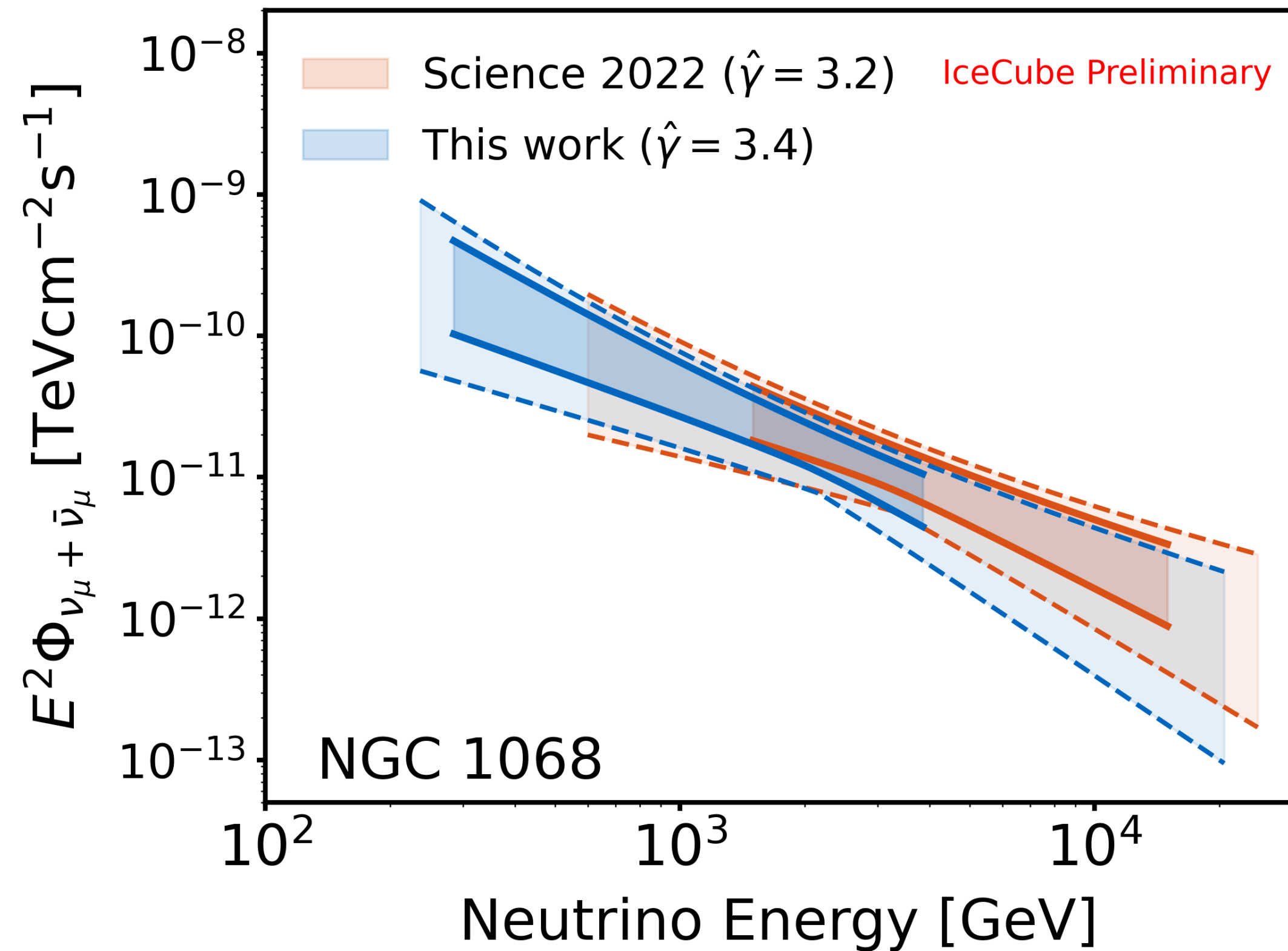
Backup

The new neutrino Northern Sky

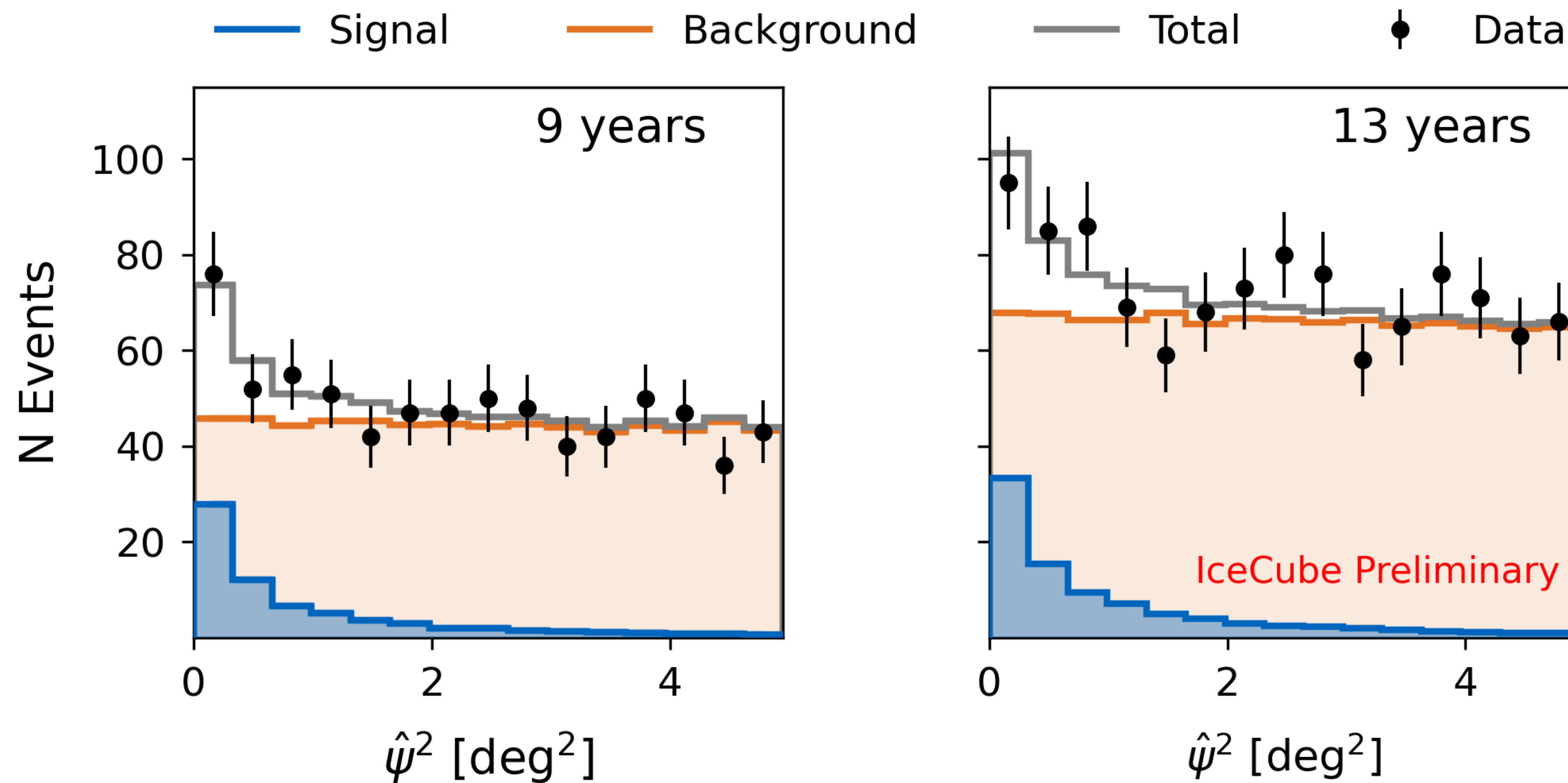


Marked 3 sources from gamma-ray catalog binomial test

Energy ranges



Events clustering around NGC 1068



Where are gamma rays?

- 4.2 σ evidence from testing the signal hypothesis on a list of 110 pre-defined gamma-ray emitters
 - Underlying hypothesis: gamma-ray and neutrino correlation

It doesn't look so trivial!

Measured neutrino flux is one order of magnitude greater than the gamma-ray flux!

Gamma-rays are easily absorbed.

