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# Investigating the neutrino emission of candidate neutrino-emitter blazars with the IceCubePy likelihood framework

— **Massimiliano Lincetto** —

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Julius-Maximilians-  
**UNIVERSITÄT  
WÜRZBURG**

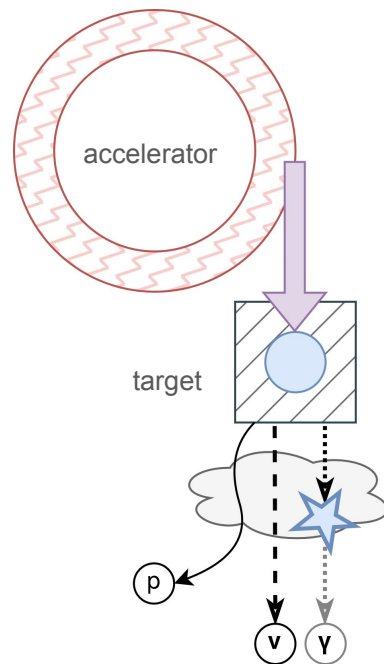
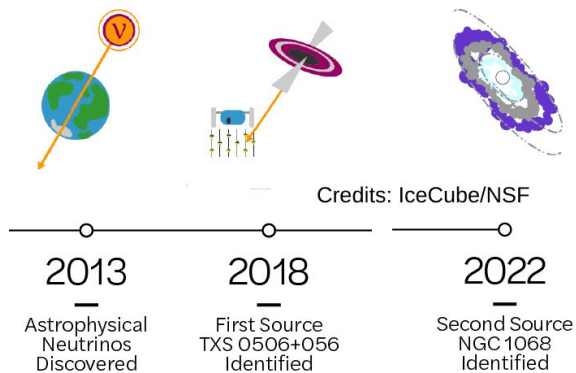


# Context and motivation

**Neutrinos** are a key messenger to probe **hadronic processes** in astrophysical sources.

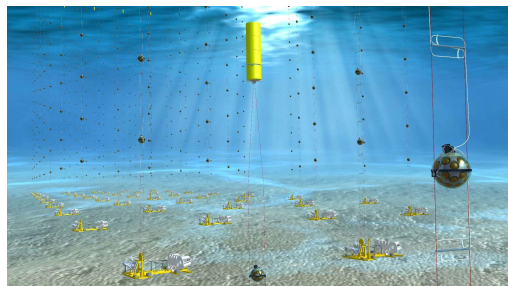
The origin of the **astrophysical diffuse flux** observed by the IceCube Neutrino Observatory is still mostly unknown.

Candidate **point-sources** are AGN or blazar (TXS 0506+056) or Seyfert (NGC 1068) type.



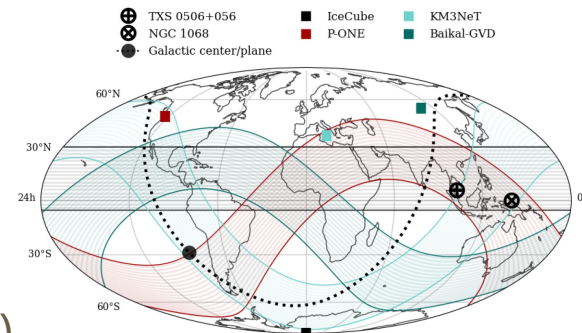
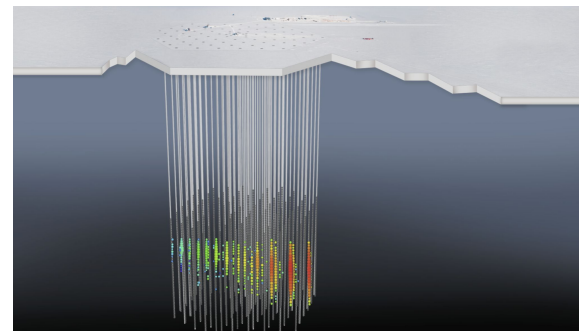
# The era of neutrino telescopes

**IceCube** has a large instrumented volume and has surpassed 15 year of data taking, teaching us a lot about astrophysical neutrinos.



**KM3NeT** is growing fast. Successfully detected a **UHE neutrino** ( $\sim 220$  PeV). 51 lines now deployed in KM3NeT/ARCA.

Interesting results on **diffuse flux** by Baikal-GVD. More potential underway (**P-ONE, TRIDENT, Trinity...**)



Credits: PLEnuM

# IceCube 10-year public data sample

IceCube has released **10 year muon track** event sample in 2020 [IceCube, PRL 124, 051103]

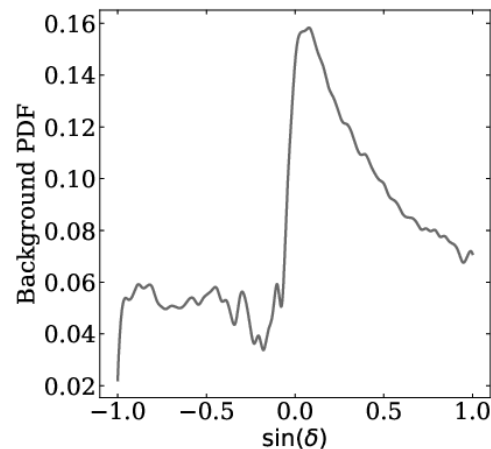
**Most sensitive** point-source neutrino dataset publicly available.

**Same data** of IceCube publication.  
**Instrument model** is provided with **limited accuracy** (no Monte Carlo)

Limited availability of guidelines and tools for the analysis (e. g.. SkyLLH, Bellenghi+, PoS ICRC2023 1061)

$O(10^6)$  events dominated by atmospheric backgrounds

Rate heavily dependent on declination.



# IceCubePy: framework for analysing public IceCube data

**Aim:** facilitate the study of candidate astrophysical neutrino sources, enabling reproducibility of findings (FAIR principles)



**Method:** develop and release an **open source software** for the analysis of the 10 year IceCube public neutrino data.

**Focus:** point-source studies, constrain neutrino spectrum, investigate neutrino skymap.

# Unbinned likelihood

Standard method adopted in IceCube analyses [Braun+, Astropart.Phys. 29 (2008) 299-305]

$$\mathcal{L}(n_s, \gamma) = \prod_{i=0}^N \left[ \frac{n_s}{N} \mathcal{S}(\vec{x}_i, \sigma_i, E_i; \gamma) + \left(1 - \frac{n_s}{N}\right) \mathcal{B}(\vec{x}_i, E_i) \right]$$

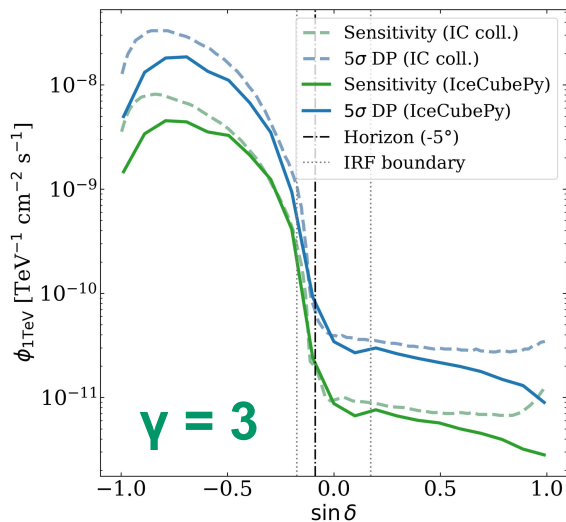
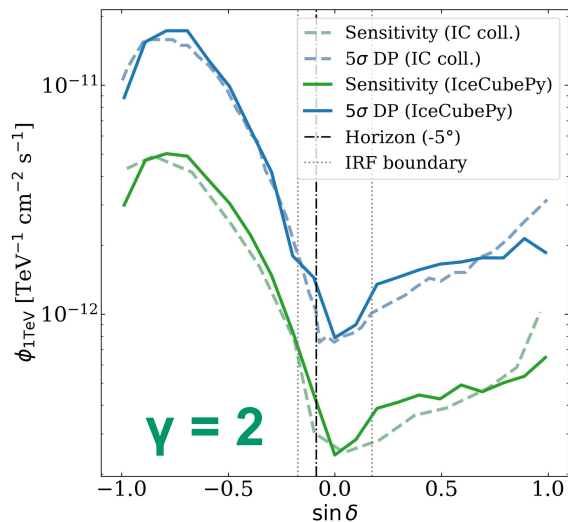
$$\text{TS} = 2 \log \frac{\mathcal{L}(\hat{n}_s, \hat{\gamma})}{\mathcal{L}(n_s = 0)}$$

**Background** PDFs: derived from data

**Signal:** Gaussian **spatial PDF**. Simulation-based **energy PDF**.

Instrument response function interface and simulation toolkit based on public (GPL) code from M. Larson ([I3PublicDataSampler](#))

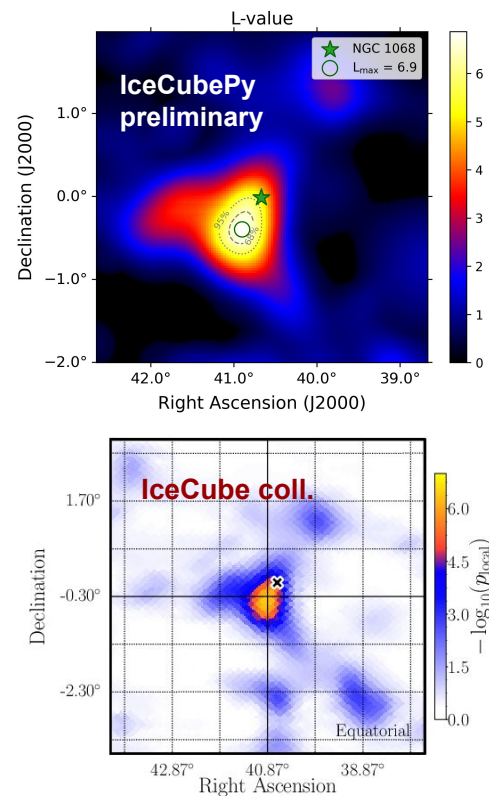
# Performance evaluation



**Sensitivity** compatible with IceCube coll. results.

Deviations can be attributed to the limited accuracy of the released instrument response.

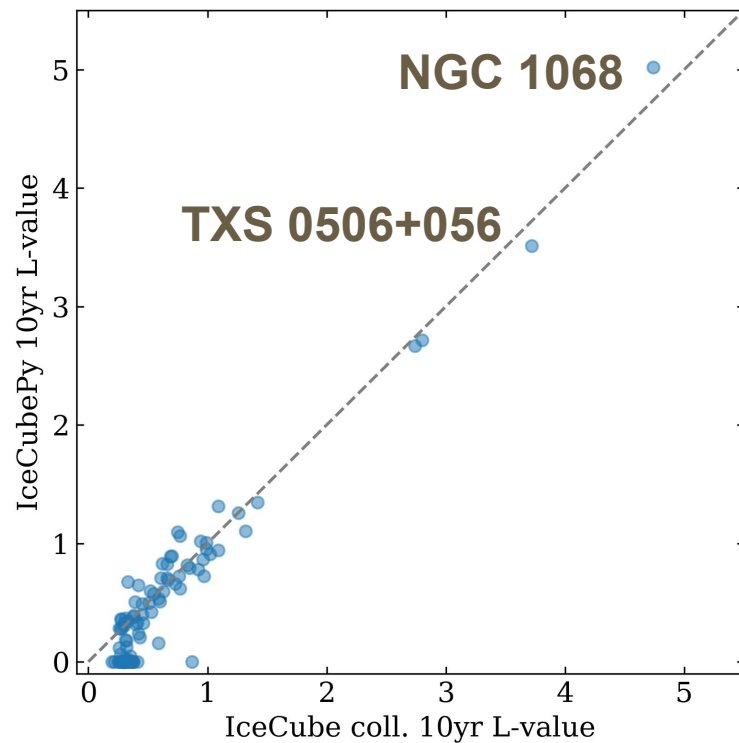
## NGC 1068 hotspot



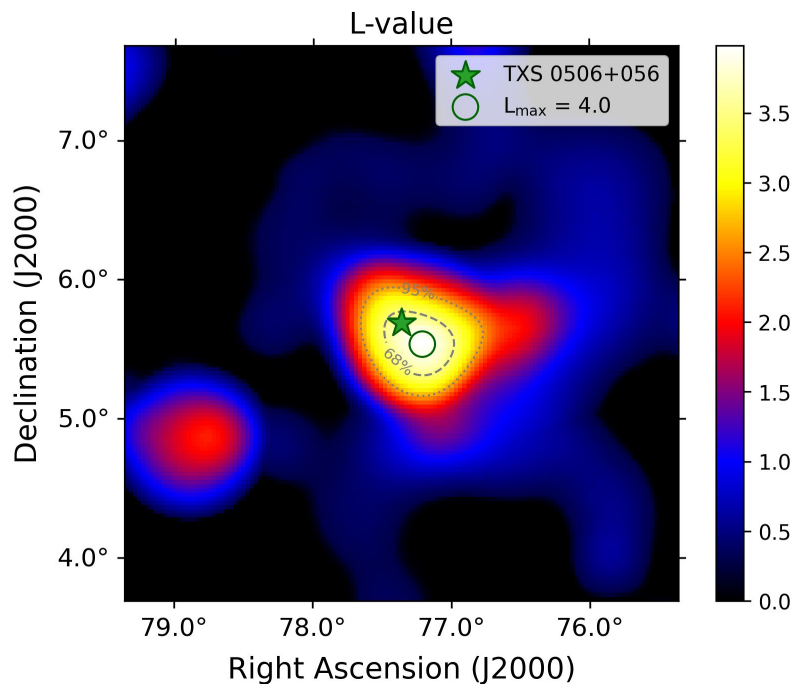
# Comparison with IceCube 10-year catalogue search

Local significance values estimated for a catalogue of 110 sources analysed in IceCube point-source studies.

Consistent with IceCube 10-year analysis. Note: **same data, some differences in detector model.**



# TXS 0506+056 p-value map



## Map of local significance

$L\text{-value} = -\log_{10}(\text{p-value})$

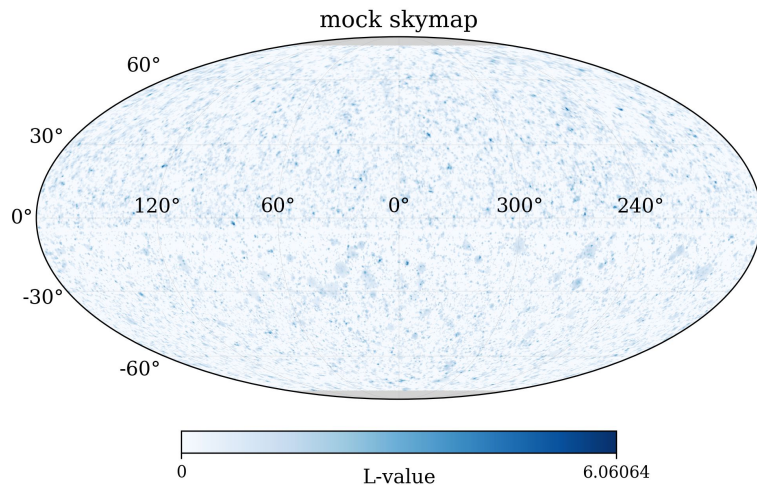
At TXS 0506+056 coords (77.36, +5.69):

- $TS = 14.1$
- $n_s = 16.1$
- $\gamma = 2.3$
- $L\text{-value} = 3.5$ 
  - IceCube coll.  $L = 3.72$

# Current and planned features

## Implemented features

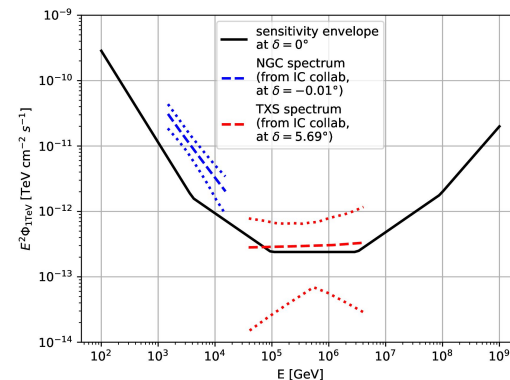
- ✓ Point source likelihood
- ✓ Sensitivity
- ✓ Region maps
- ✓ Sky maps



## Work in progress

Sensitivity energy range

Neutrino spectral energy distributions



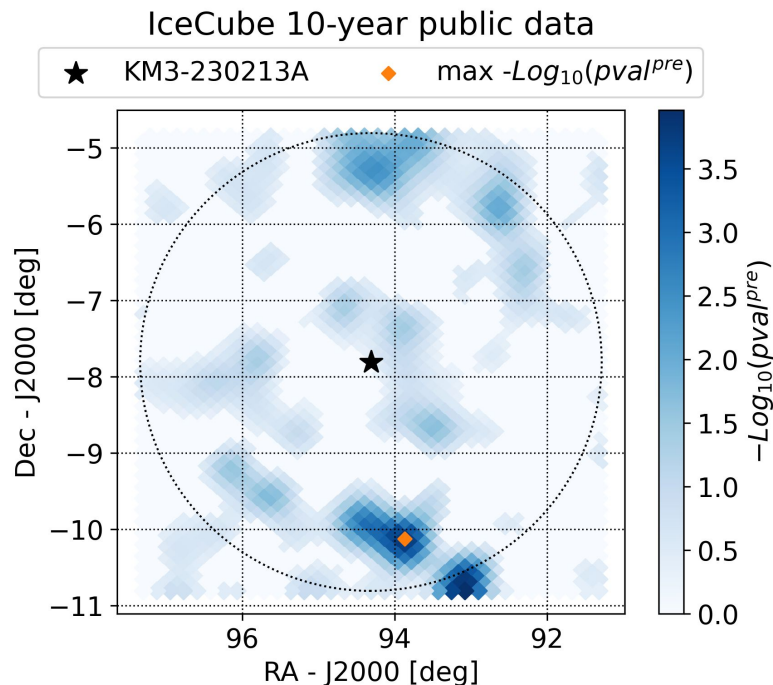
# IceCubePy analysis of the KM3NeT UHE event region

KM3-230213A 3-deg error region

Most stringent **upper limits on steady neutrino flux** from the UHE event direction (KM3NeT, Nature 2025)

Dataset	$n_{\text{sig}}$	$-\log_{10}(p\text{-value})$	Flux Upper Limit [ $\text{GeV}^{-1}\text{cm}^{-2}\text{s}^{-1}$ ]	(RA, Dec) [deg, deg]	Distance [deg]	$P$ -value
ARCA6-21	0.4	0.044	$1.8 \times 10^{-8}$	(94.3, -7.8)	0.0	-
	1.3	1.308	$1.9 \times 10^{-8}$	(96.7, -6.8)	2.6	0.44
ORCA6-18	0	-	$2.1 \times 10^{-7}$	-	-	-
ORCA18-23	0	-	$2.3 \times 10^{-6}$	-	-	-
ORCA-combined	-	-	$2.0 \times 10^{-7}$	-	-	-
ANTARES	0	-	$1.1 \times 10^{-8}$	(94.3, -7.8)	0.0	-
	1.3	1.308	$1.7 \times 10^{-8}$	(94.1, -5.8)	2.5	0.58
IceCube	1.4	0.327	$1.2 \times 10^{-9}$	(94.3, -7.8)	0.0	-
	15.1	3.782	$6.3 \times 10^{-9}$	(93.9, -10.1)	2.4	0.07

See also M. Marconi's talk (22-07-2025, 15:35)





# Conclusion and outlook

**IceCubePy**, an open-source Python framework to perform general maximum likelihood analysis of IceCube point-source data.

- Encouraging results from testing and performance evaluation.
- Reached a mature stage for scientific analysis (Lincetto *et al. in prep*)
- Upcoming applications: multimessenger characterisation of blazars.

Ultimately, a release it with an **open source license** is planned (adhering to FAIR principles)

- Currently, source code access may be granted upon request
- Open to contributions and testing from the community,

Stay tuned on [GitHub.com/messmapp/IceCubePy-public](https://github.com/messmapp/IceCubePy-public)



Star  
IceCubePy!

# Backup

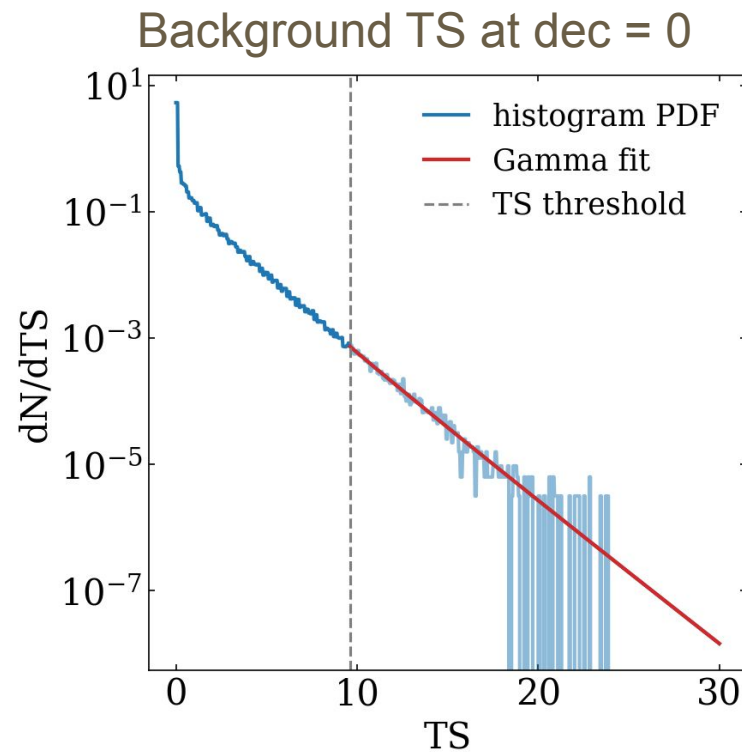
# Background TS distributions

Create background dataset by shuffling data events.

Evaluate TS as a function of  $\sin(\text{dec})$ .

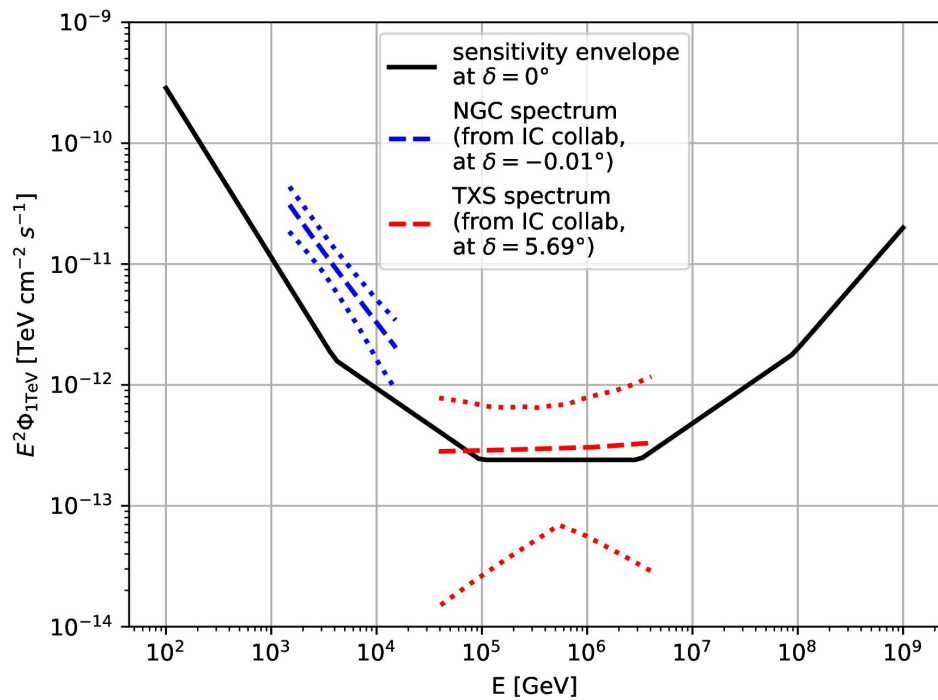
Background is **declination-dependent!**

Fit with a gamma distribution above a TS threshold equivalent to  $3.0 \sigma$





# Sensitivity envelope



Build “envelope” of sensitivities for a range of spectral indices.

“Conservative” sensitivity estimation for a source of unknown spectral index.

Comparison with IceCube flux measurements of NGC 1068 and TXS 0506+056

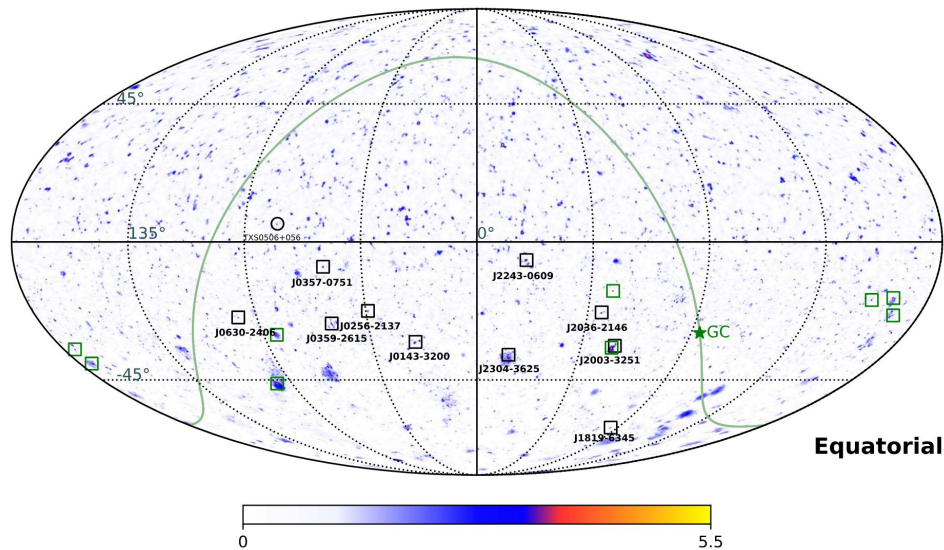
The analysis is **sensitive to IceCube signal candidates.**

# Previous results

Evidence for correlation between IceCube hotspots and 5BZcat blazars. Statistical significance at the  $5\sigma$  post-trial level (Buson+, ...)

Small subset of 52 blazars proposed as candidate neutrino emitters.

Independent studies reproduced the result, but claimed it disappears when extending the study to the 10-year data (Bellenghi+, ...)



# Caveats

IceCube coll. sensitivity is estimated for a **signal model** based on a proprietary detector data (Monte Carlo)

Public data rely on a simplified detector description (tabulated IRF)

Same model used to simulate the **hypothetical source** enters in the construction of the **likelihood PDFs!**

It is known that the PSF shape is more complex than the current simplified assumption (previously adopted also by IceCube).