Probing the Statistical Correlation of Optical Tidal Disruption Events with High Energy Neutrinos

Presenter: Dimitrios Alkinoos Langis

Supervisor: Dr. Ioannis Liodakis

Affiliations: Institute of Astrophysics FORTH, Physics Department University of Crete

BO TES

Black hOle Optical polarization TimE domain Survey

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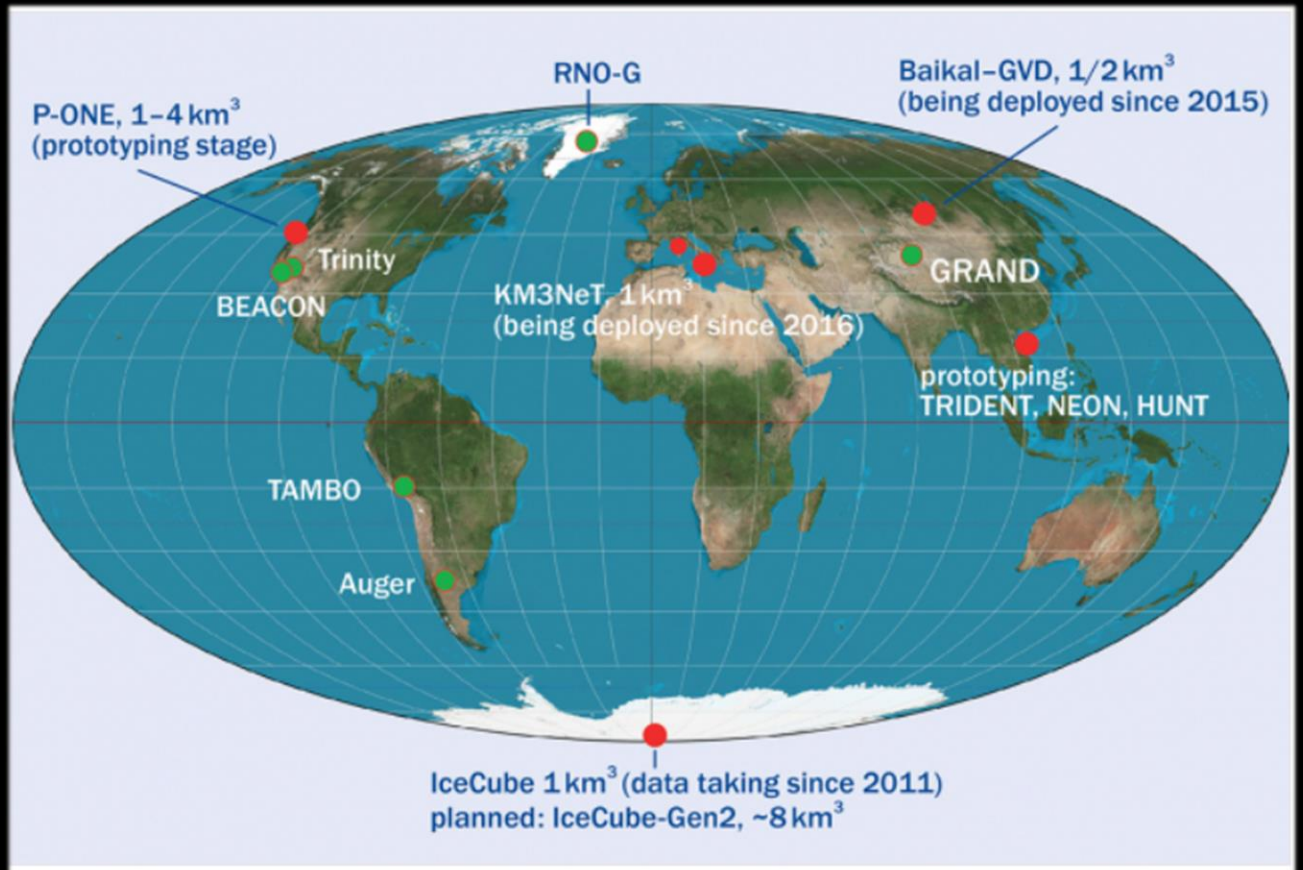
Neutrino observatories

- Extragalactic neutrinos are now routinely observed (around 10 high-confidence astrophysical events per year)

- Most events come from IceCube. Recently from Baikal-GVD and KM3NeT.

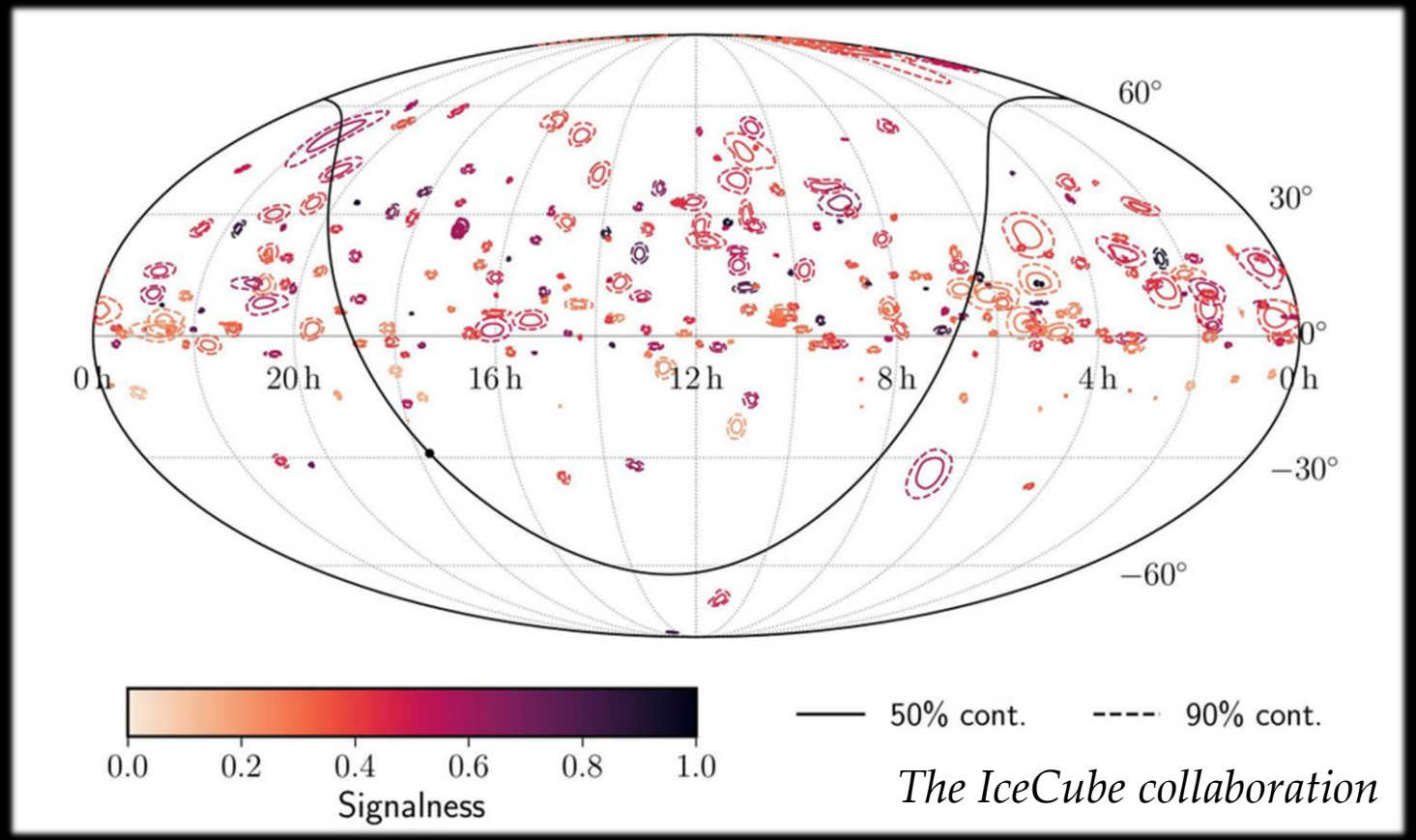


Full-sky coverage The global distribution of operating and proposed optical Cherenkov detectors (red) and ultra-high-energy detectors using alternative detection methods (green). Credit: L Lu based on work by A Karle

Source: CERN Courier, "Discovering the neutrino sky" (Lu Lu, 19 May 2025)

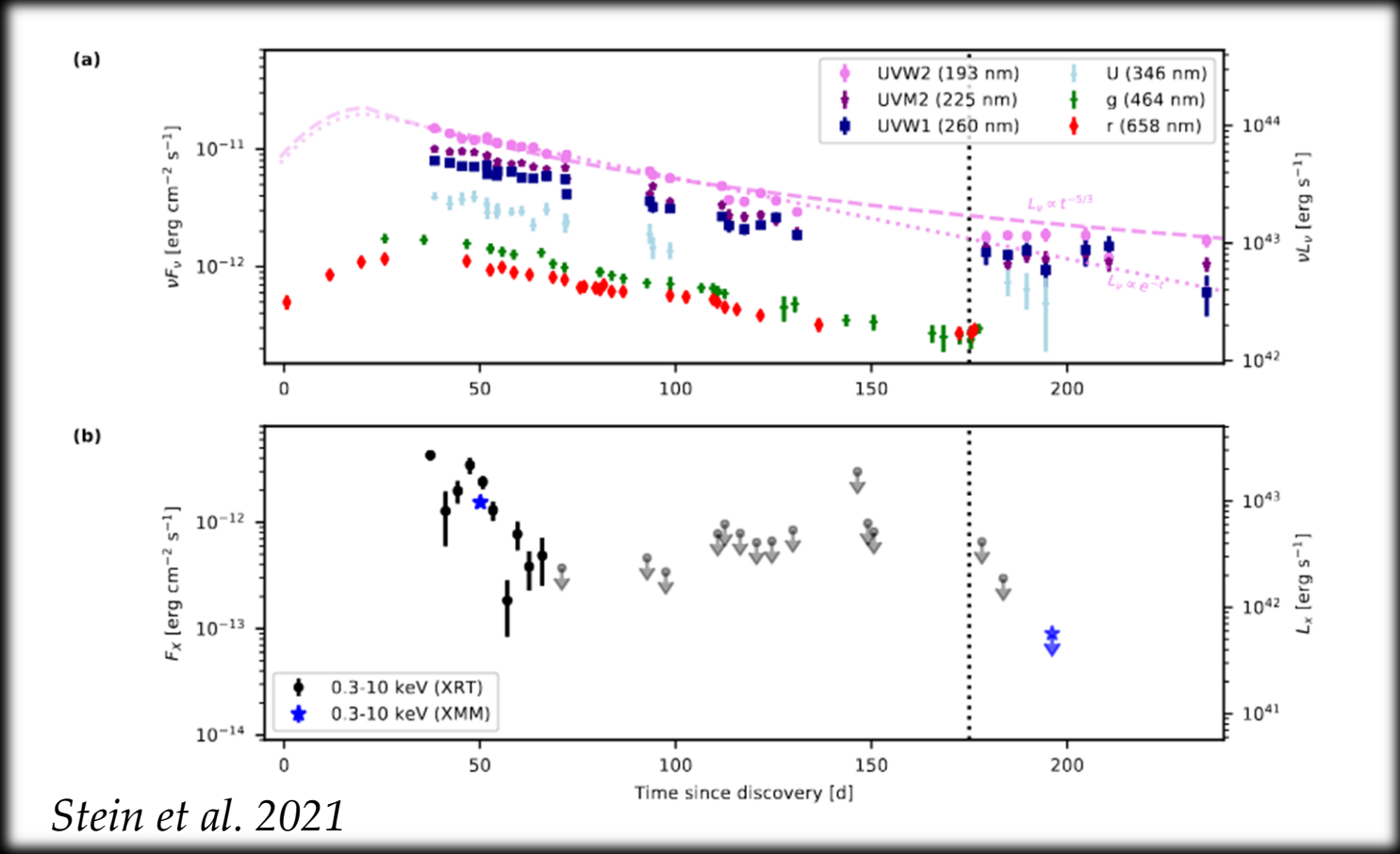
Neutrino observations

Error regions → of the order of sub to 10s of deg^2
Signalness → probability that neutrinos are astrophysical



TDEs and Neutrinos?

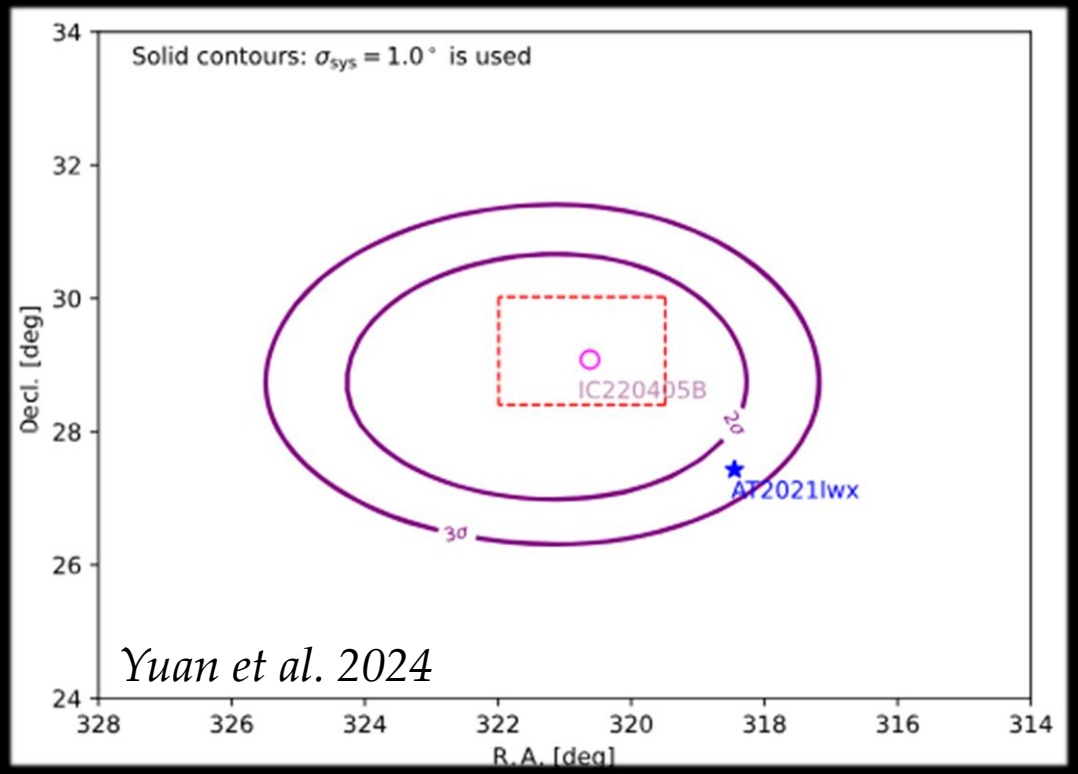
- First TDE coincident with high-energy neutrino (*Stein et al. 2021*)



Stein et al. 2021

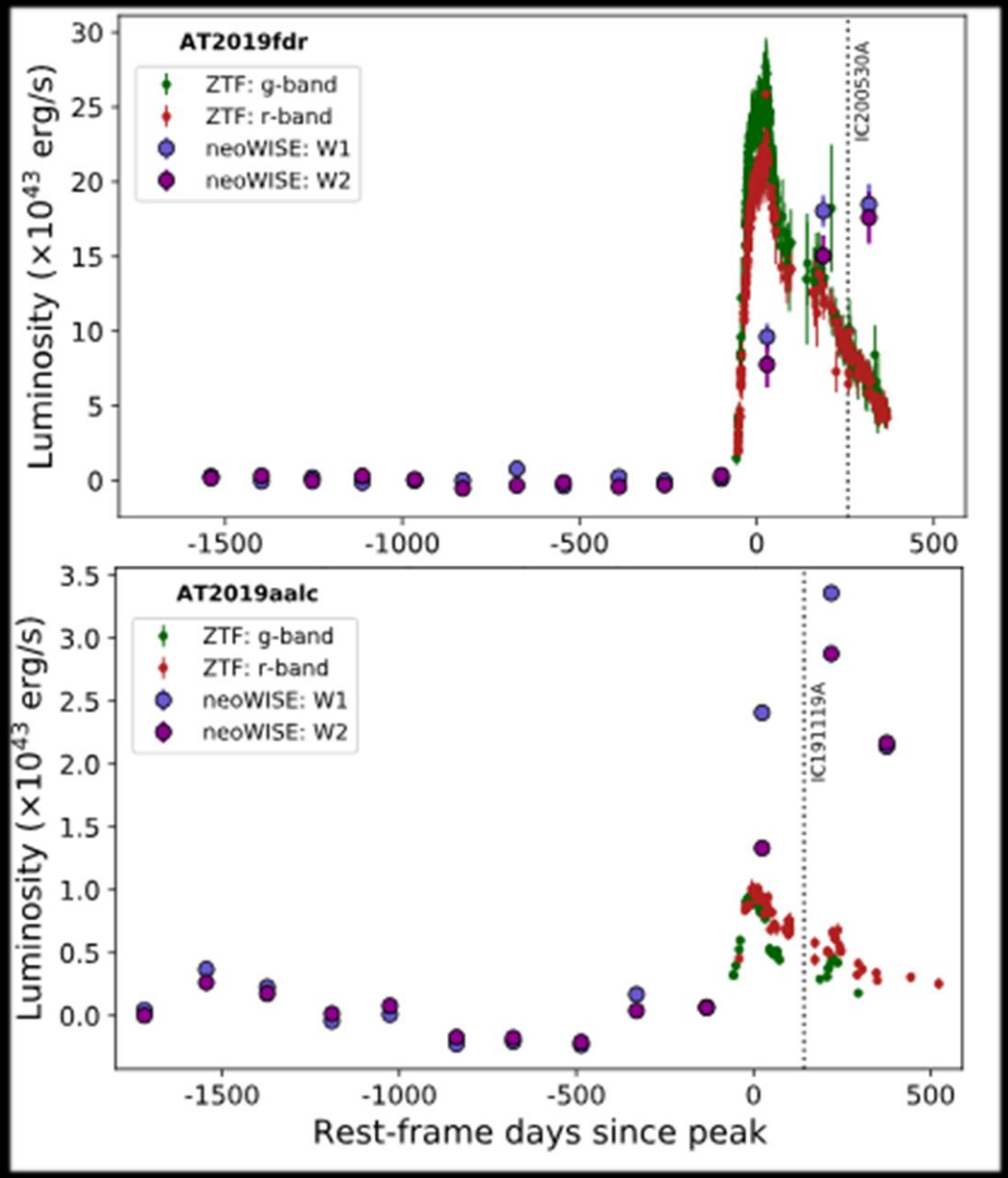
Later associations

- AT2019fdr - IC200530A (*Reusch et al. 2022*)
- AT2019aalc - IC191119A (*van Velzen et al. 2024*)
- AT2021lwx - IC220405B (*Yuan et al. 2024*)



Yuan et al. 2024

van Velzen et al. 2024



TDE Catalogue: TDECat

- Confirmed TDEs → photometry + spectra from the time of the flare

- Main sample: 134 TDEs, 131 confirmed optical TDEs and 3 jetted TDEs

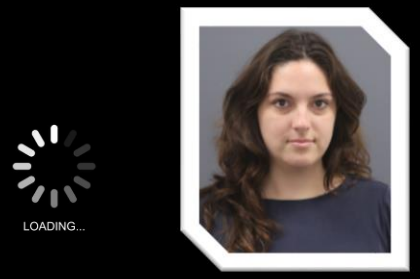
- Collected multi-wavelength (X-ray, UV, optical, IR) photometry and optical spectroscopy → TDECat GitHub repository

GitHub

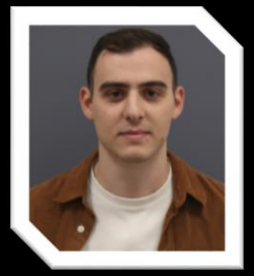
TDECat+

- **Cross correlation with high-energy neutrino events** ☑

- Black hole mass estimation



- Host galaxy morphology



- Search for γ-ray emission

Samples

TDEs

TDECat → 108 flares between 55056 and 60232 MJD

Neutrinos

356 neutrino events → IceCat-1 neutrino track events (275 in total; Abbasi et al. 2023) + 73 neutrinos from updated IceCat-1 + 16 from *Abbasi et al. 2022*

Spatio-temporal method

Spatial association → cross-correlating TDE coordinates with neutrino sky error regions (typically a few deg^2)

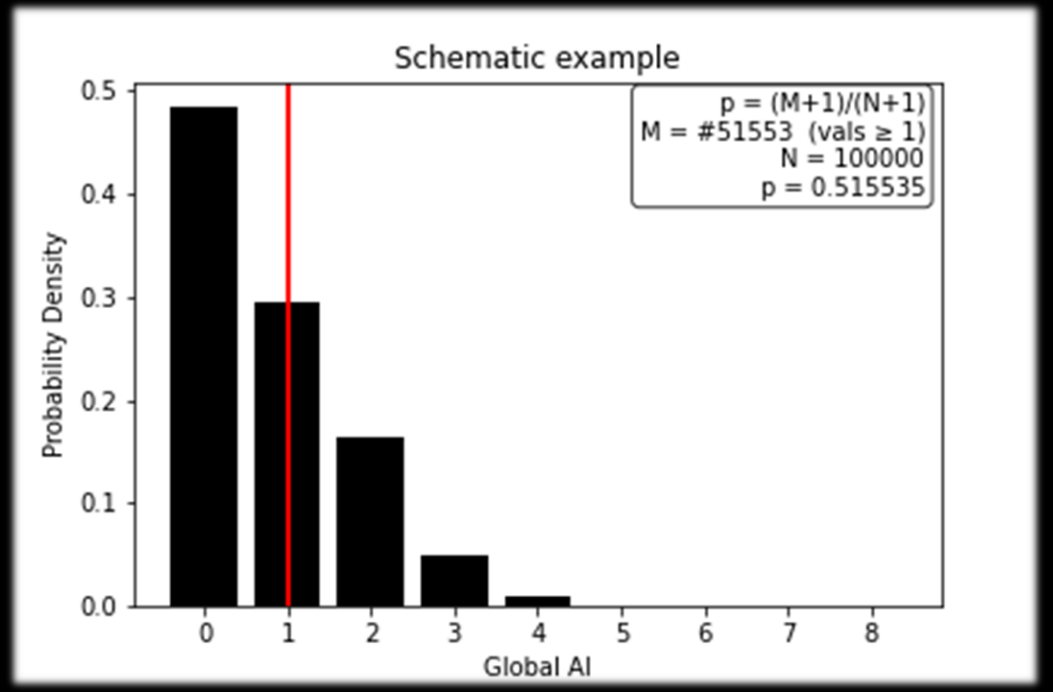
Temporal association → Activity index (AI) test statistic (TS), either 1 or 0, depending if neutrino arrives within the TDE flare duration

Weighting scheme → Raw and Weighted

Null hypothesis TS distribution

- Randomize neutrino event RA and arrival time
- All other parameters are kept the same
- 10^5 realizations through an MC experiment

$$p = \frac{M + 1}{N + 1}$$



In this work

- Simulations
  - Correlated
  - Random
  - Combined

- Observations
  - Sample
  - Individual

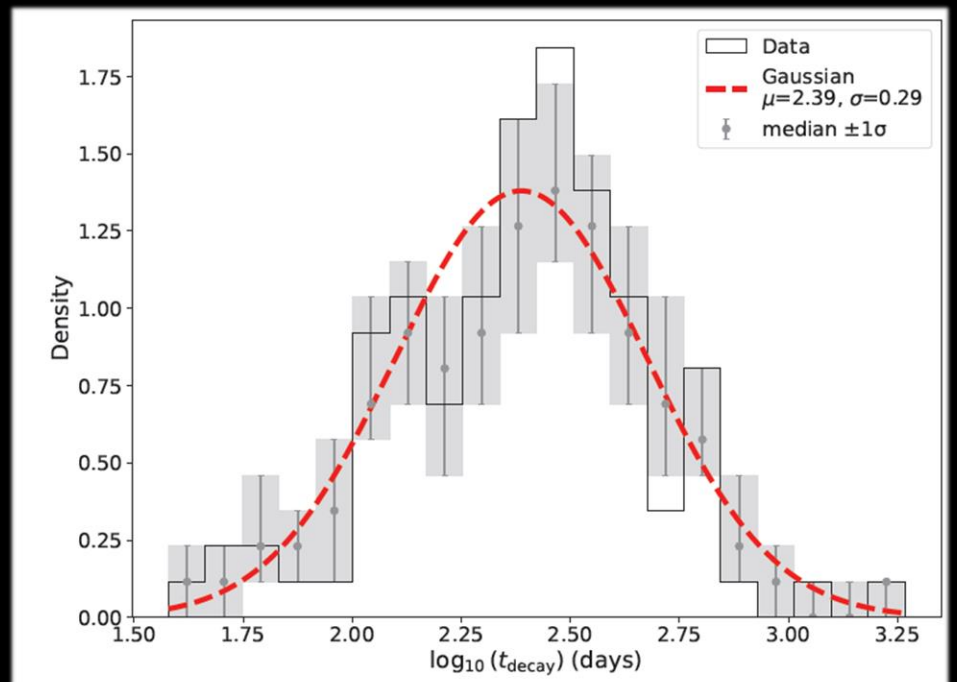
Simulations: Setup

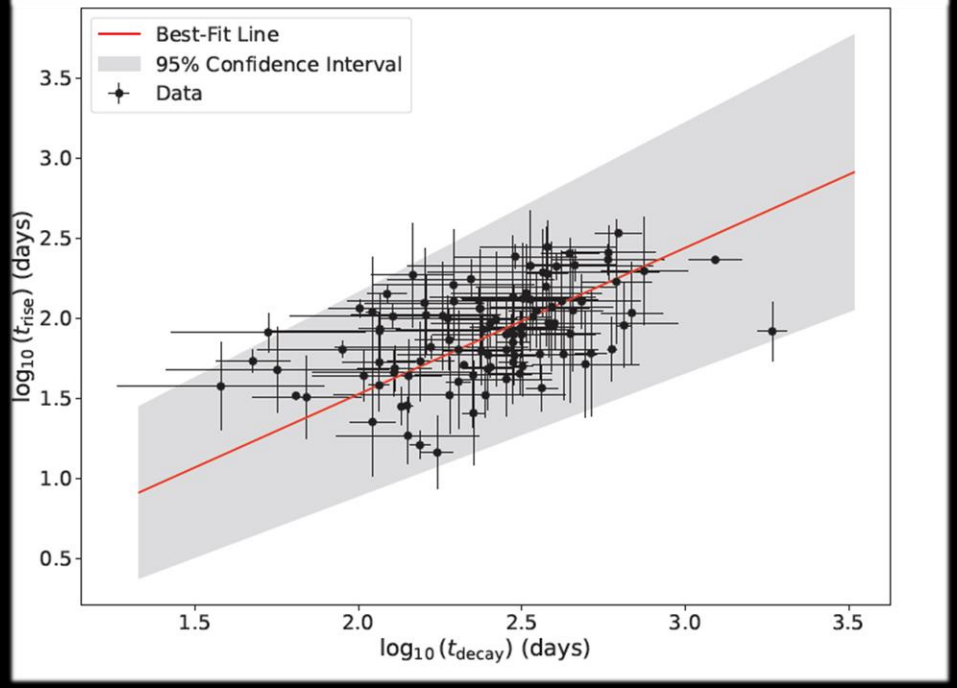
Datasets → real neutrino data and mock TDE data

Timescales → Generated from *Langis et al. 2025* (in press)

Correlated → forced spatiotemporal associations of neutrinos with TDEs

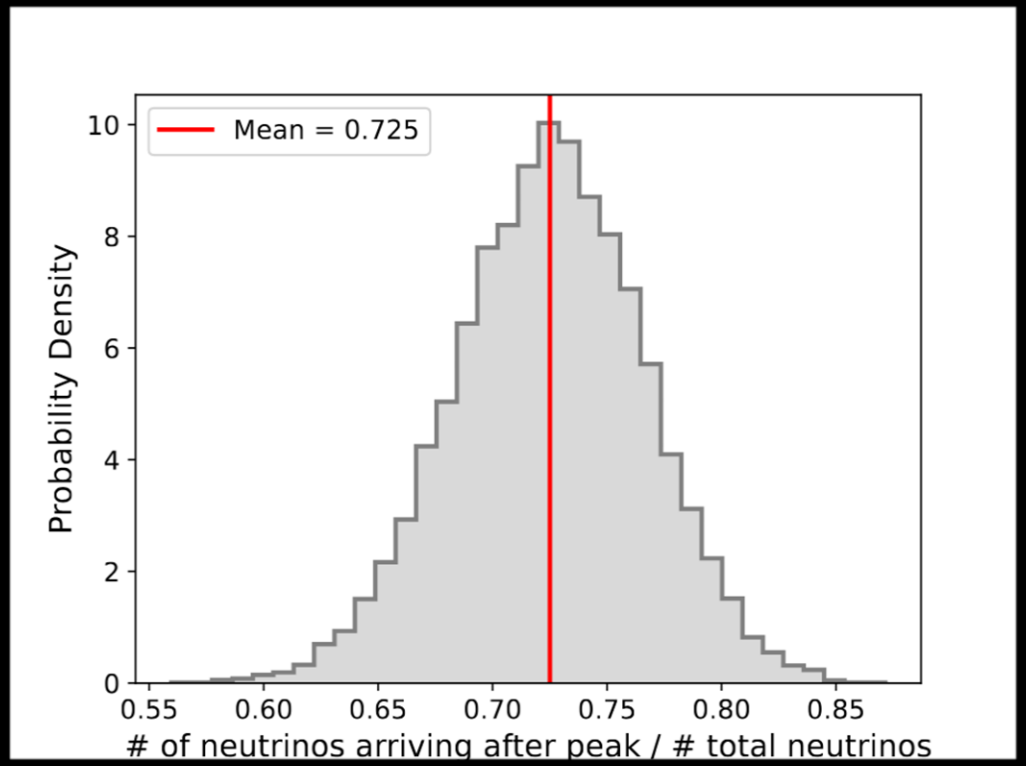
Random → random TDE mock TDE data





Correlated simulations: Results

- Which ones are astrophysical ?
- Signalness → draw x randomly from [0,1) and compare with the real signalness of the neutrino events, S
- If S > x then the event is astrophysical

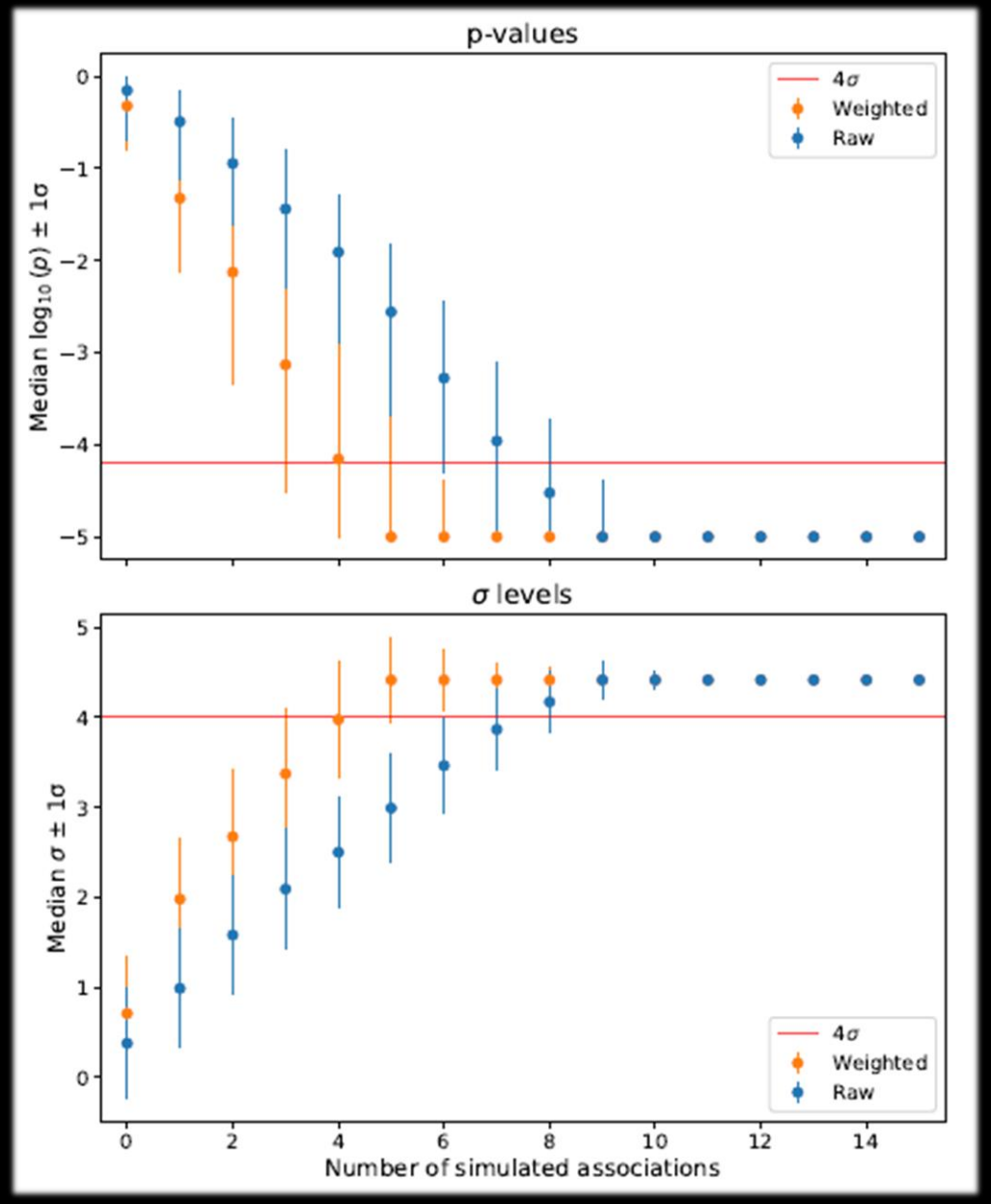


Required associations

Start from 108 associations and remove 1 association each time until the samples are random

Raw : 9 simulated associations for 4σ

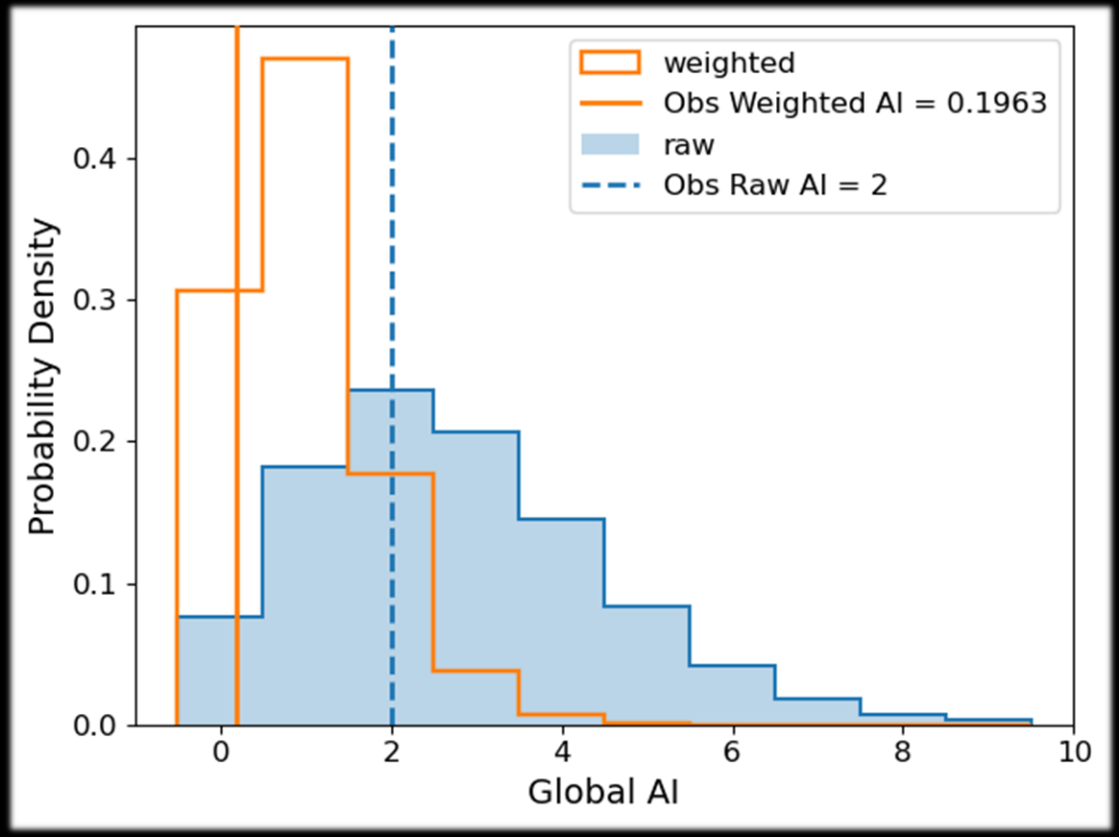
Weighted : 6 simulated associations for 4σ



Observed: Statistical association?

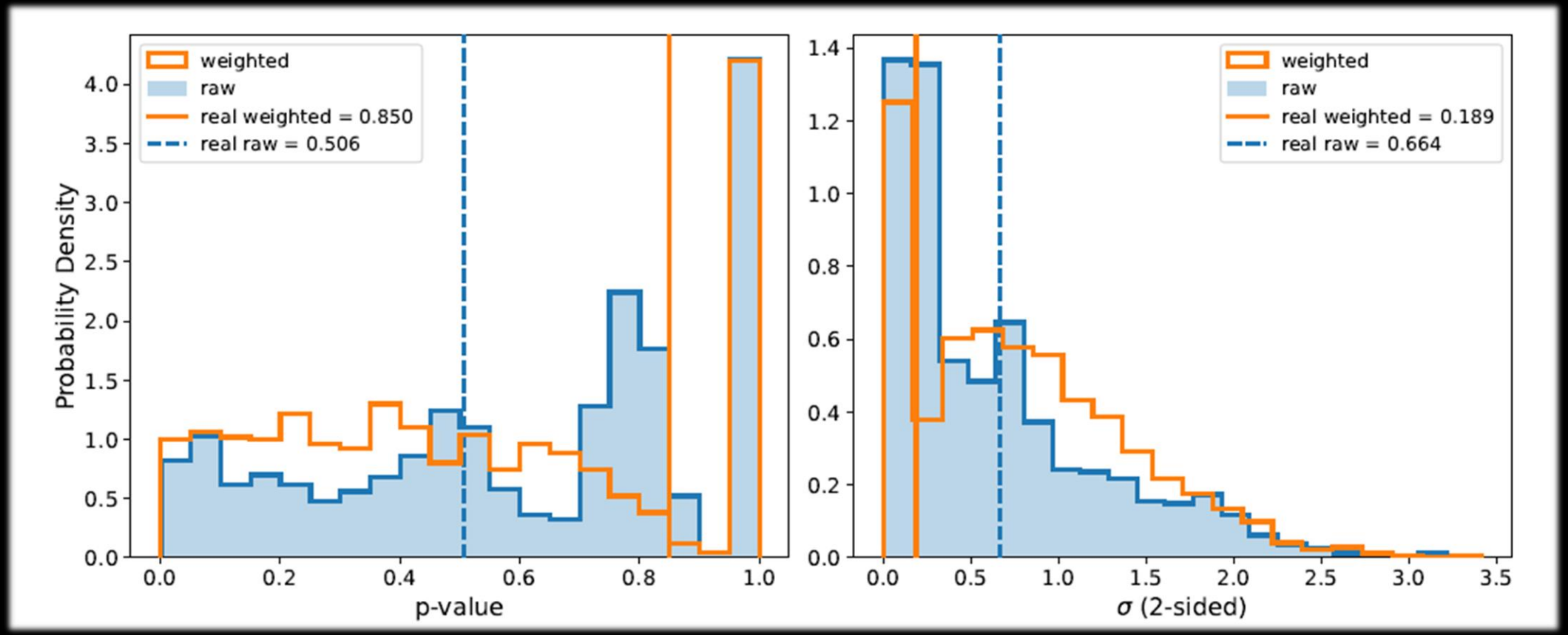
- Raw: global AI TS = 2 → p=0.51

- Weighted: global AI TS = 0.196 → p=0.85



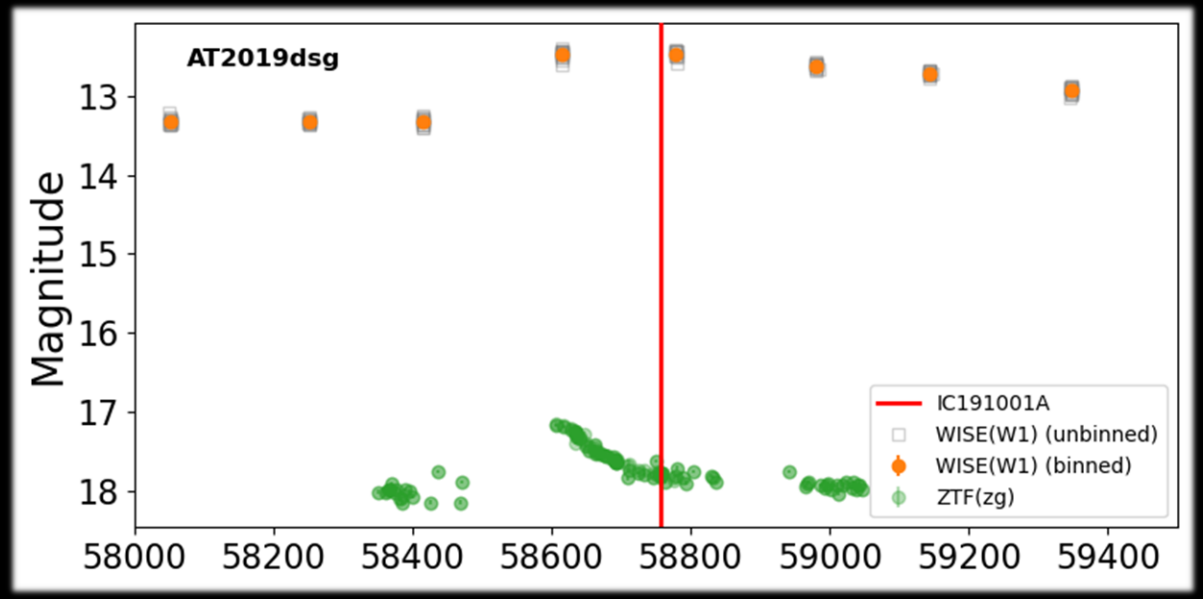
Random simulations: Results

1000 simulated random data sets → p-value for each one



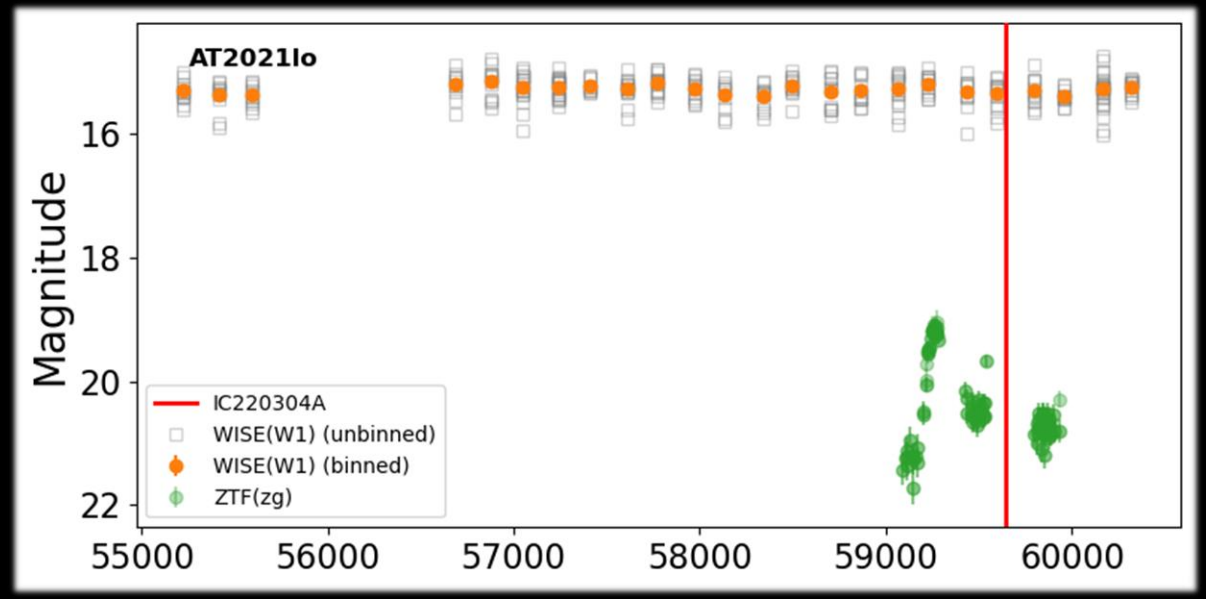
AT2019dsg/IC191001A

"Neutrino 1"

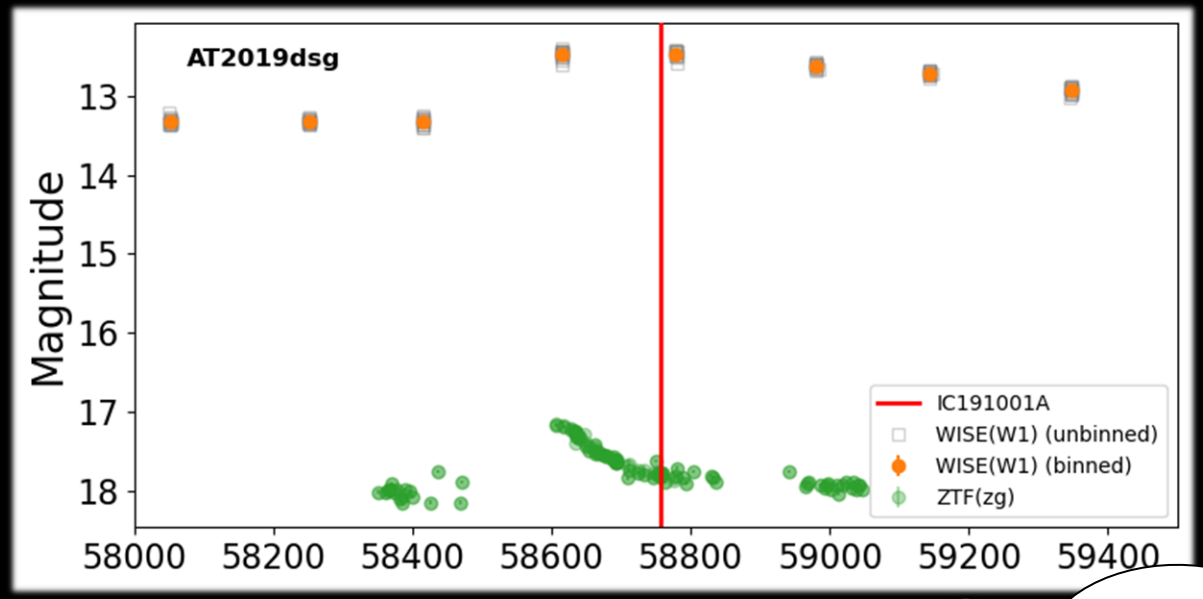


AT2021lo/IC220304A

"Neutrino 2"



AT2019dsg/IC191001A
"Neutrino 1"



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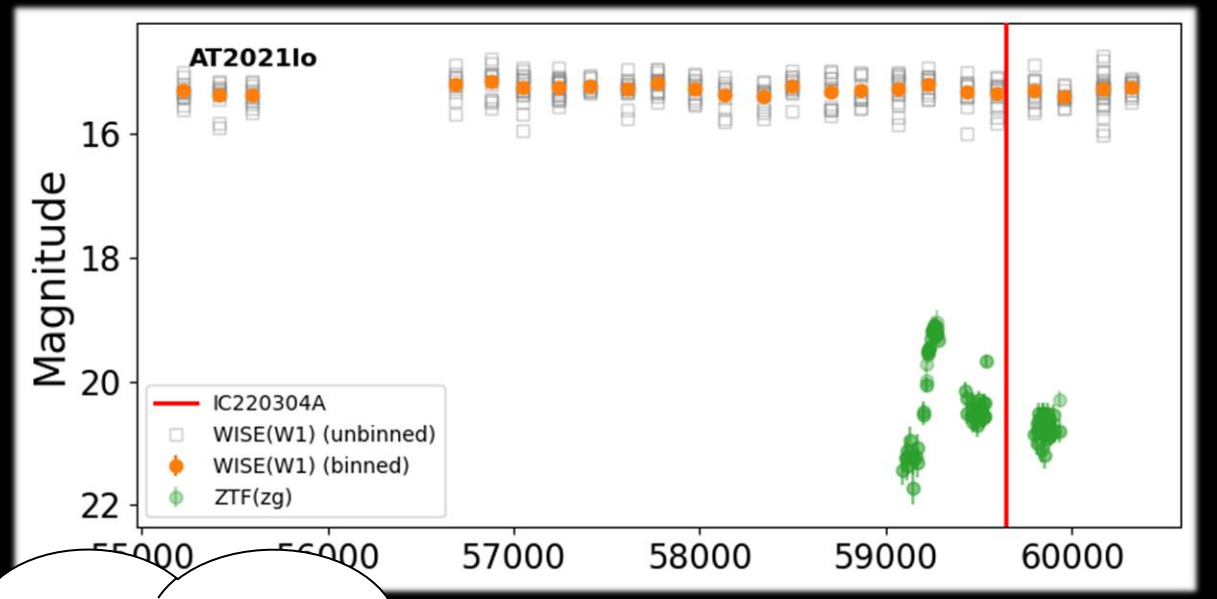


pp or pγ

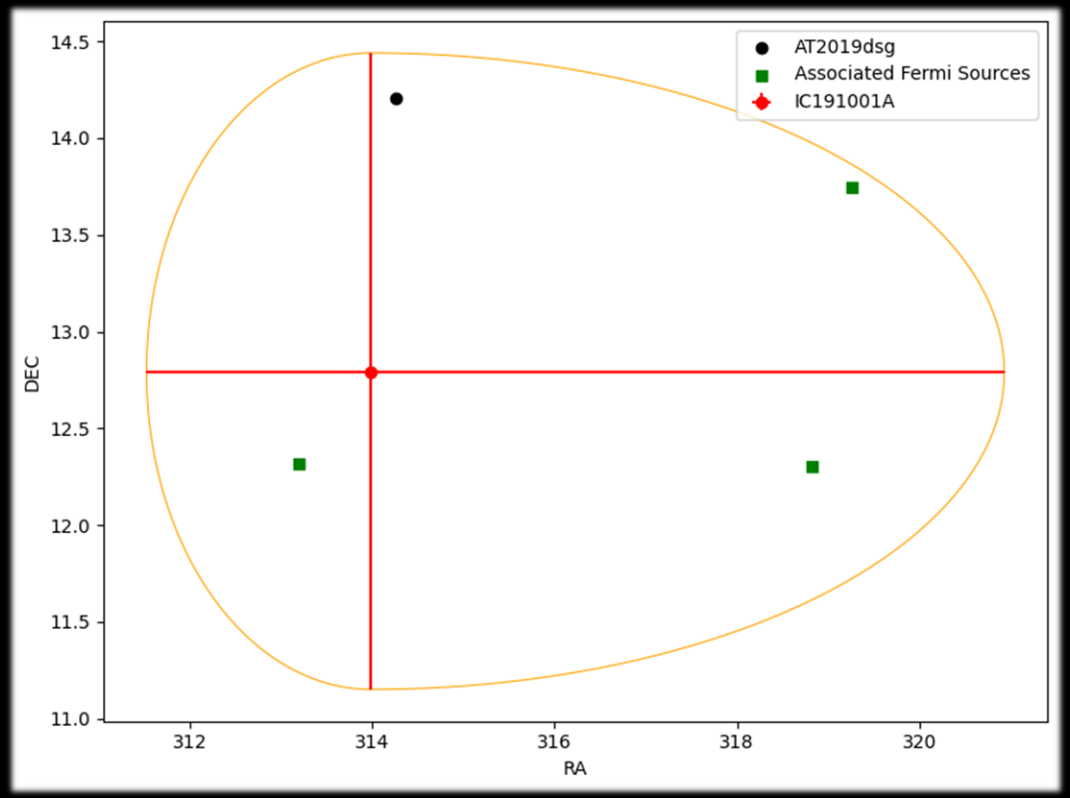
↓

Neutrinos and γ-rays

AT2019dsg/IC191001A

"Neutrino 1"

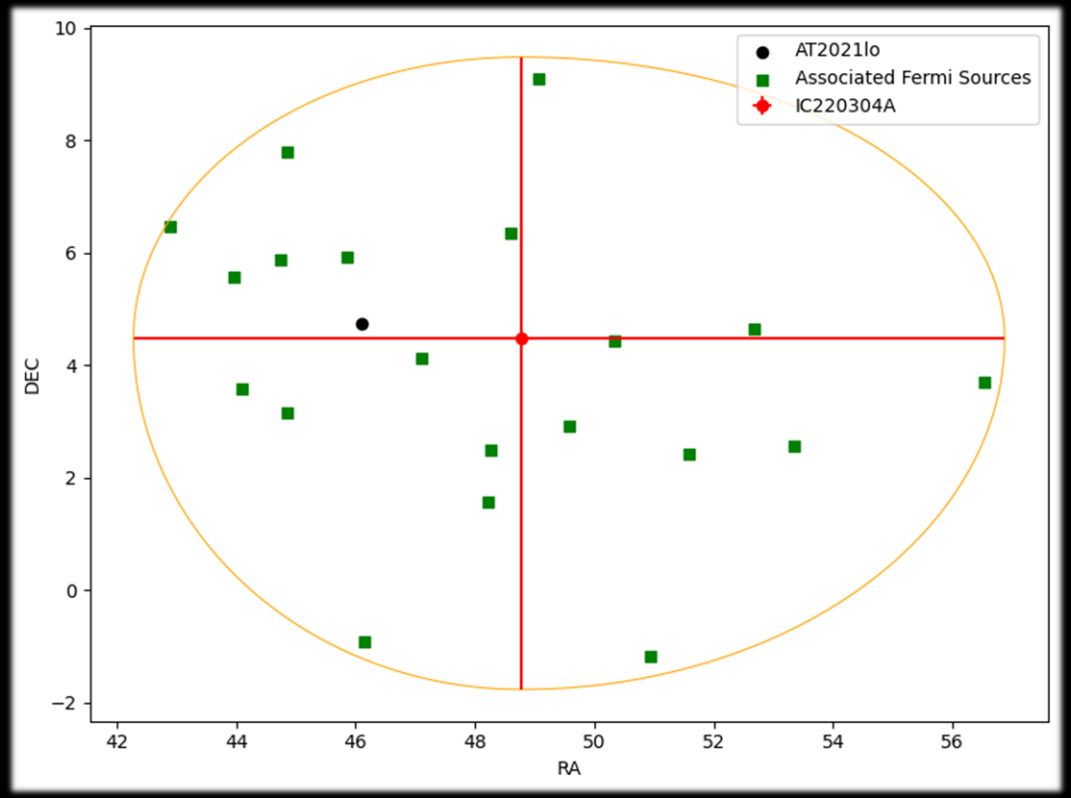
3 gamma-ray sources inside the neutrino error region



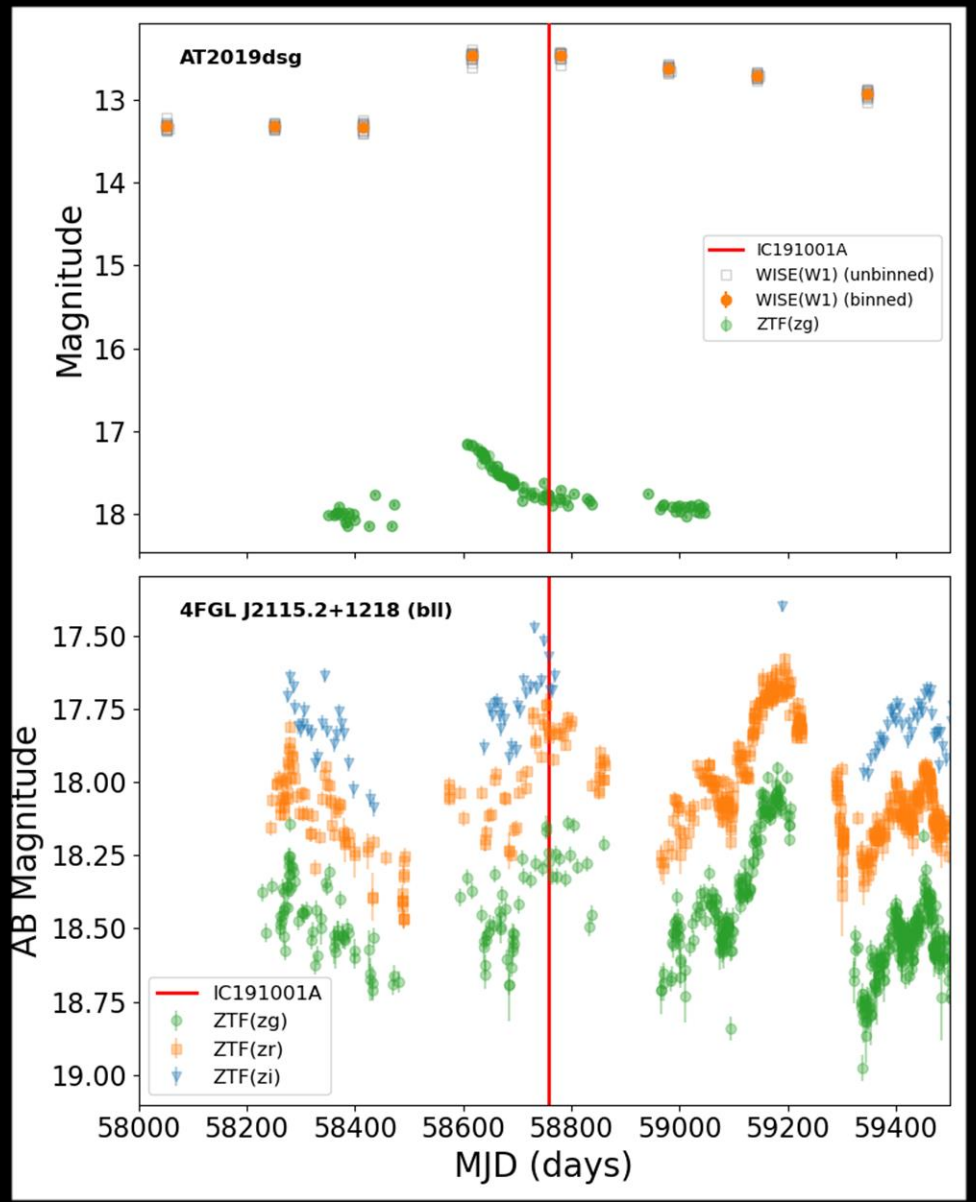
AT2021lo/IC220304A

"Neutrino 2"

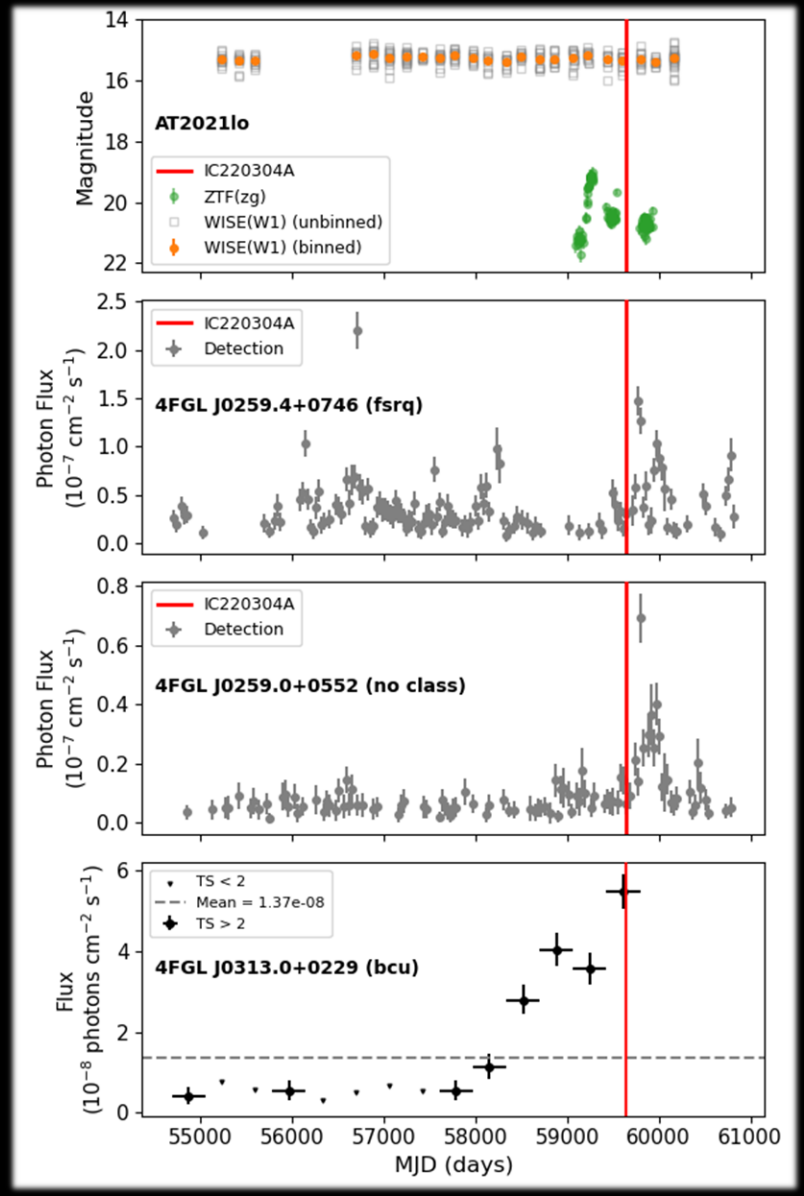
20 gamma-ray sources inside the neutrino error region



AT2019dsg/IC191001A

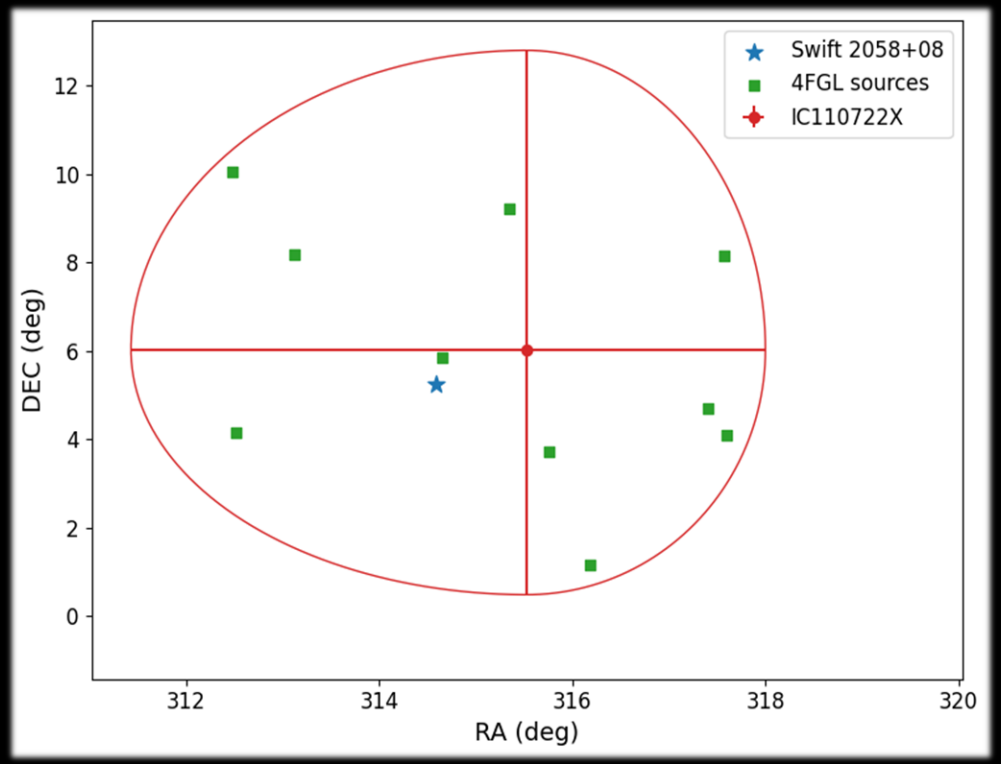


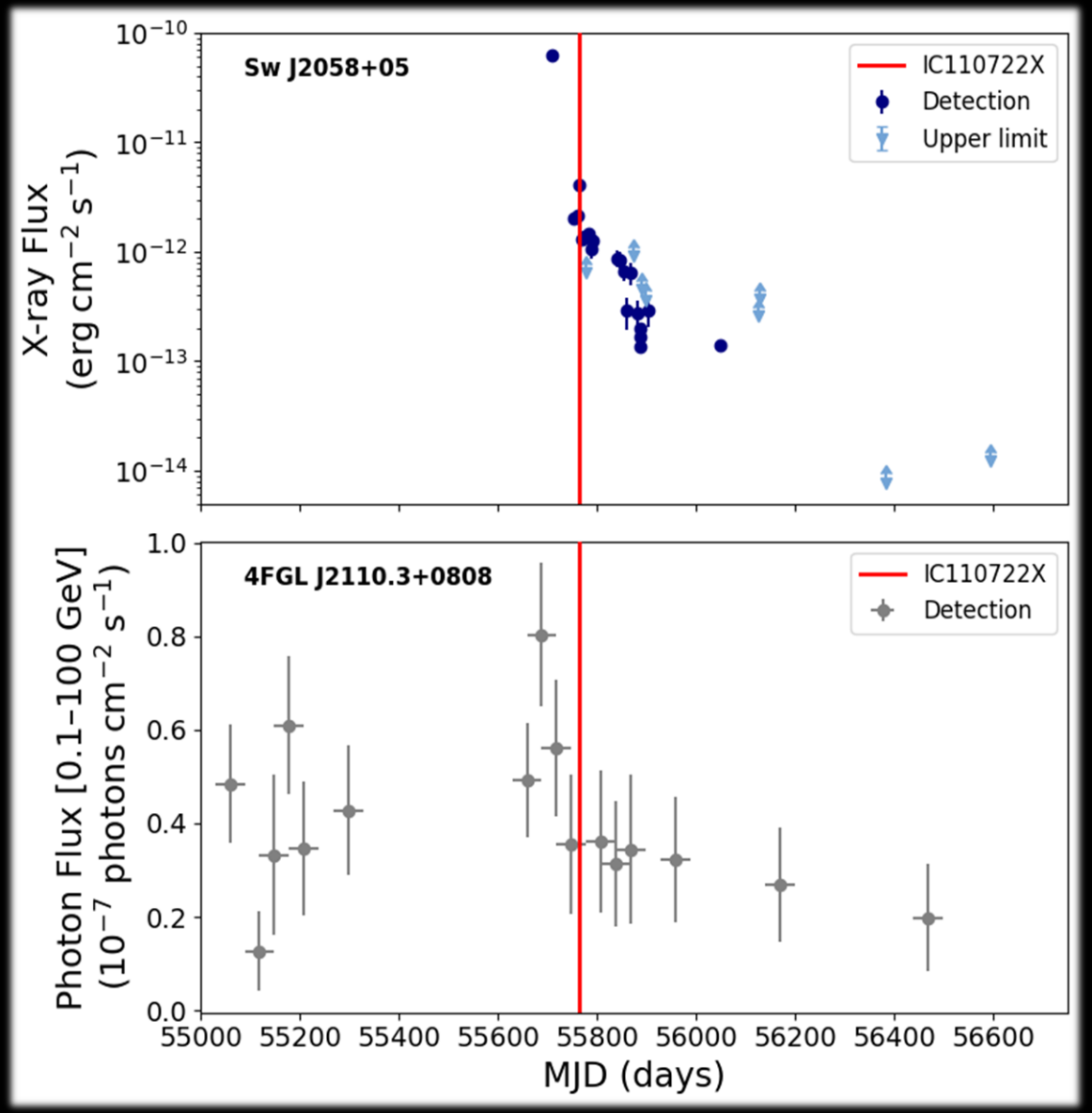
AT2021lo/IC220304A



Jetted TDEs

- Spatio-temporal association → Swift J2058+05/IC110722X





Summary

- No statistical correlation between neutrinos and TDEs so far
- Required associations for $4\sigma \rightarrow 9$ or 6
- Individual cases → spatiotemporally associated with neutrino events (AT2019dsg, AT2021lo, Swift J2058)
- Future is bright: LSST + KM3NeT

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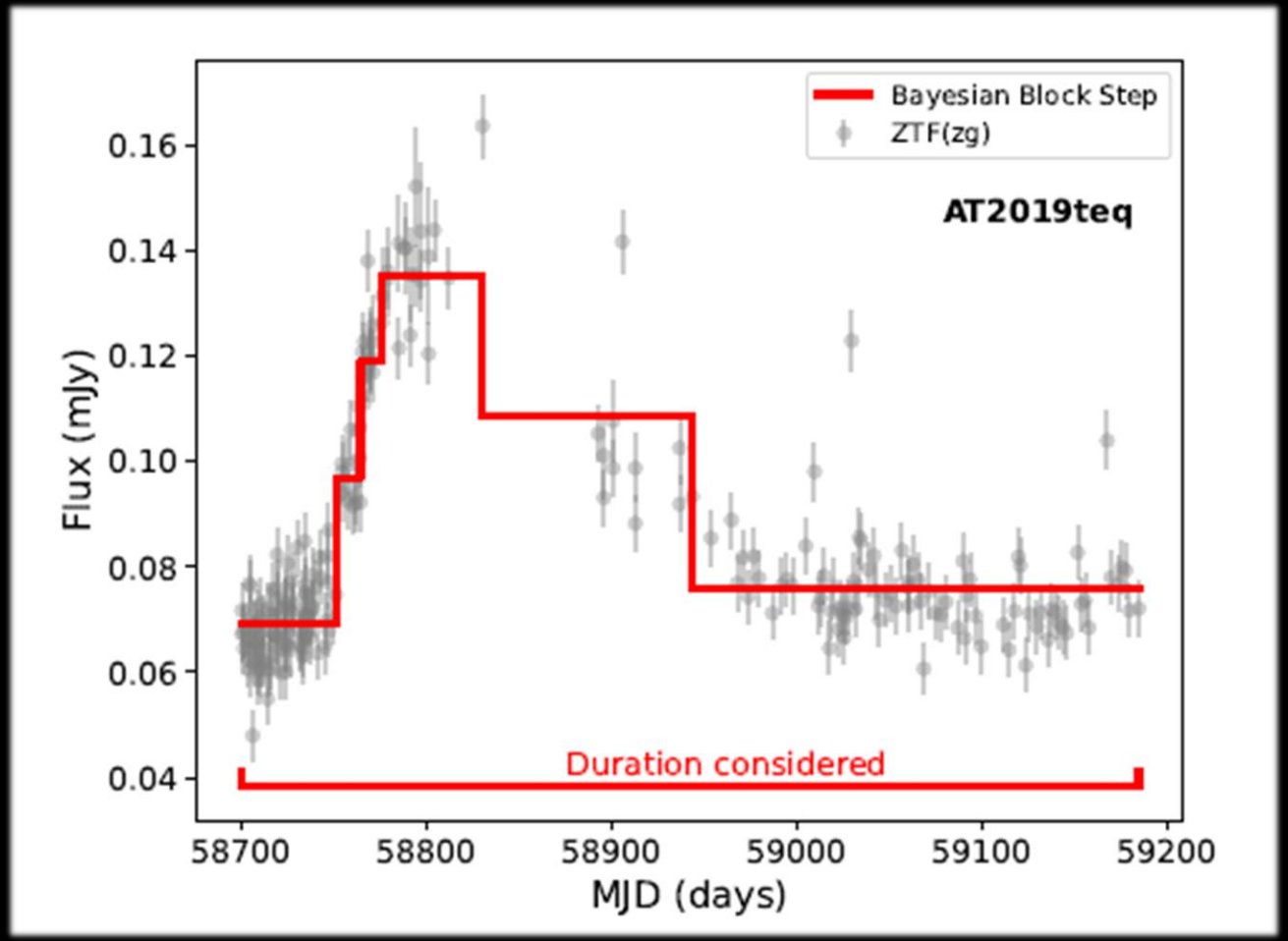
Backup: Duration of TDEs



Weighted scheme

$$W = \begin{cases} S, & \text{if } \Omega_{90} \leq \widetilde{\Omega}_{90}, \\ S \cdot \frac{\widetilde{\Omega}_{90}}{\Omega_{90}}, & \text{if } \Omega_{90} > \widetilde{\Omega}_{90}. \end{cases}$$

$$\Omega_{90} = \frac{\pi}{4}(\alpha^{+} \cdot \delta^{+} + \alpha^{-} \cdot \delta^{+} + \alpha^{-} \cdot \delta^{-} + \alpha^{+} \cdot \delta^{-})$$

$$\widetilde{\Omega} = 6.73\ deg^2$$