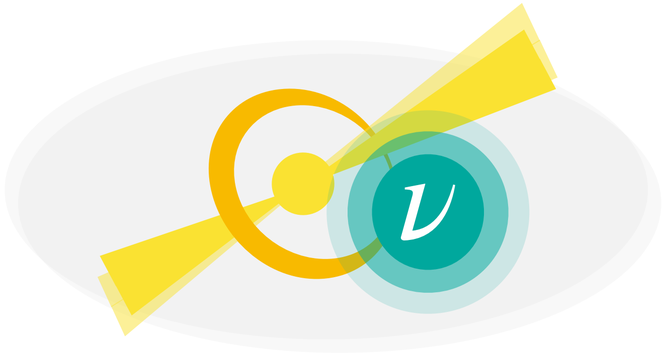
EVALUATING COSMIC COINCIDENCES



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MOTIVATION

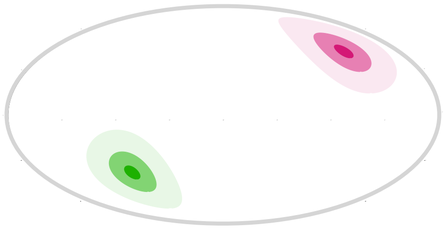
- Multi-messenger data gives new insights into astrophysical sources
- As the amount of data increases, so do chance coincidences

TXS 0506+056 and IceCube event

- 3σ significance
- “Signalness” of ν is ~ 0.6
- Blazars are relatively common
- Blazar flare duration of ~ 6 months
- ν-γ connection is still unclear

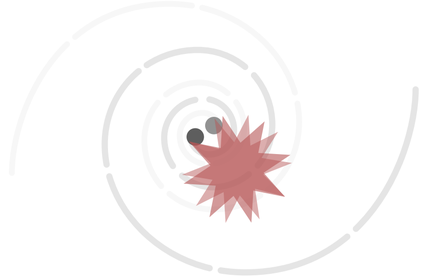
IceCube Collaboration et al. (2018)

Signals from different directions



Flaring blazar and a high-energy neutrino

GW170817 and GRB 170817A



Definitely not connected

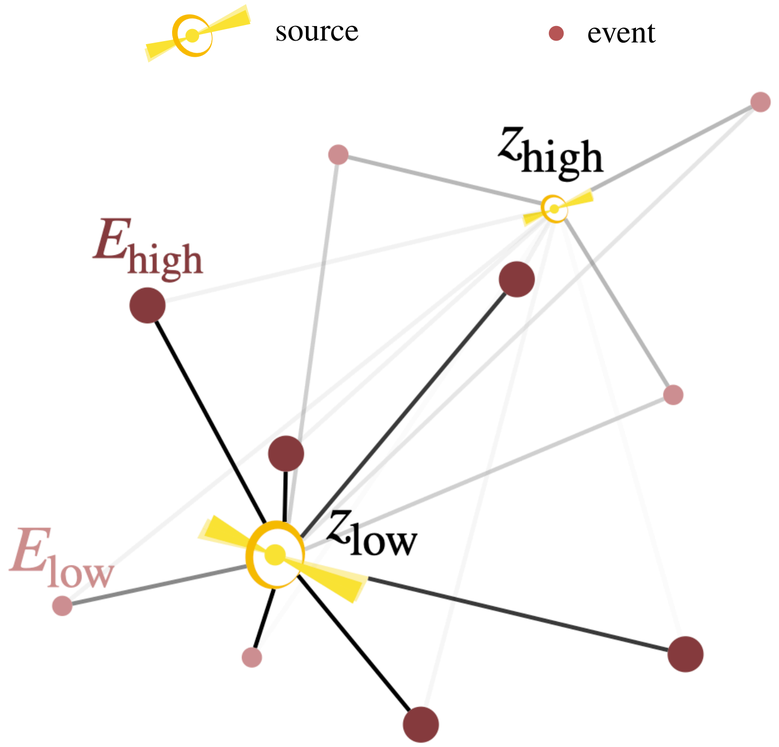
Definitely connected

INDIVIDUAL ASSOCIATIONS

Idea

Decide if individual observations are connected based on **all available information**

- Directions
- Energies
- Distances
- Fluxes
- Spectra
- Uncertainties
- Physical connections
- …



$$P(\text{associated} \mid \text{data})$$

Statistical methods

Likelihood-based

- Mixture models
- Poisson processes
- Bayesian hierarchical models

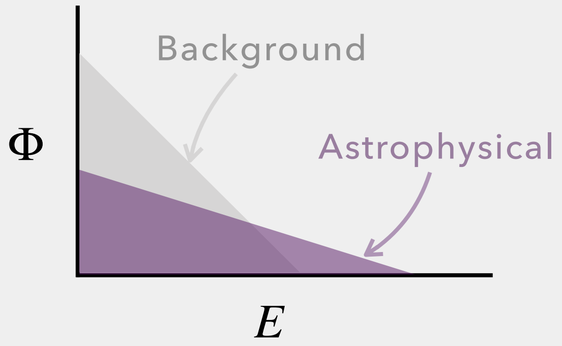
Some examples

- Braun et al. 2008 and 2010
- Budavári & Loredo 2016
- Ashton et al. 2018
- Bartos et al. 2019
- Capel & Mortlock 2019

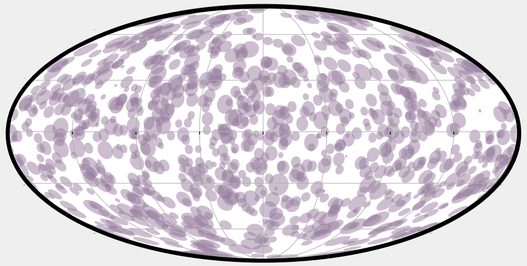
SOURCE POPULATIONS

- Sources are part of an astrophysical population
- Individual associations must also make sense in this bigger picture

IceCube neutrino observations

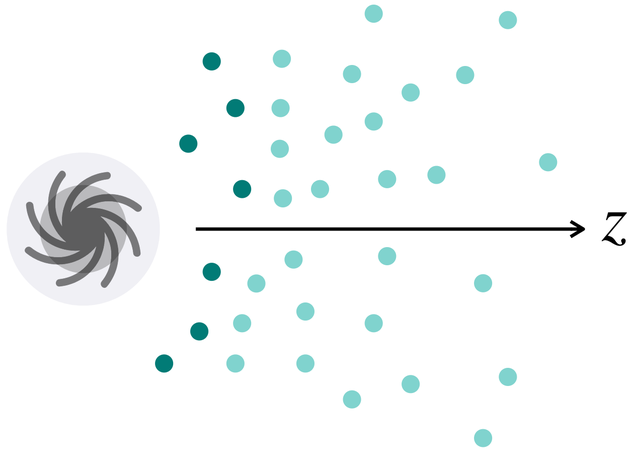


An astrophysical flux...



...but no obvious point sources

Physical picture



Extragalactic sources characterised by a **density, luminosity and cosmological evolution**

CONSTRAINTS

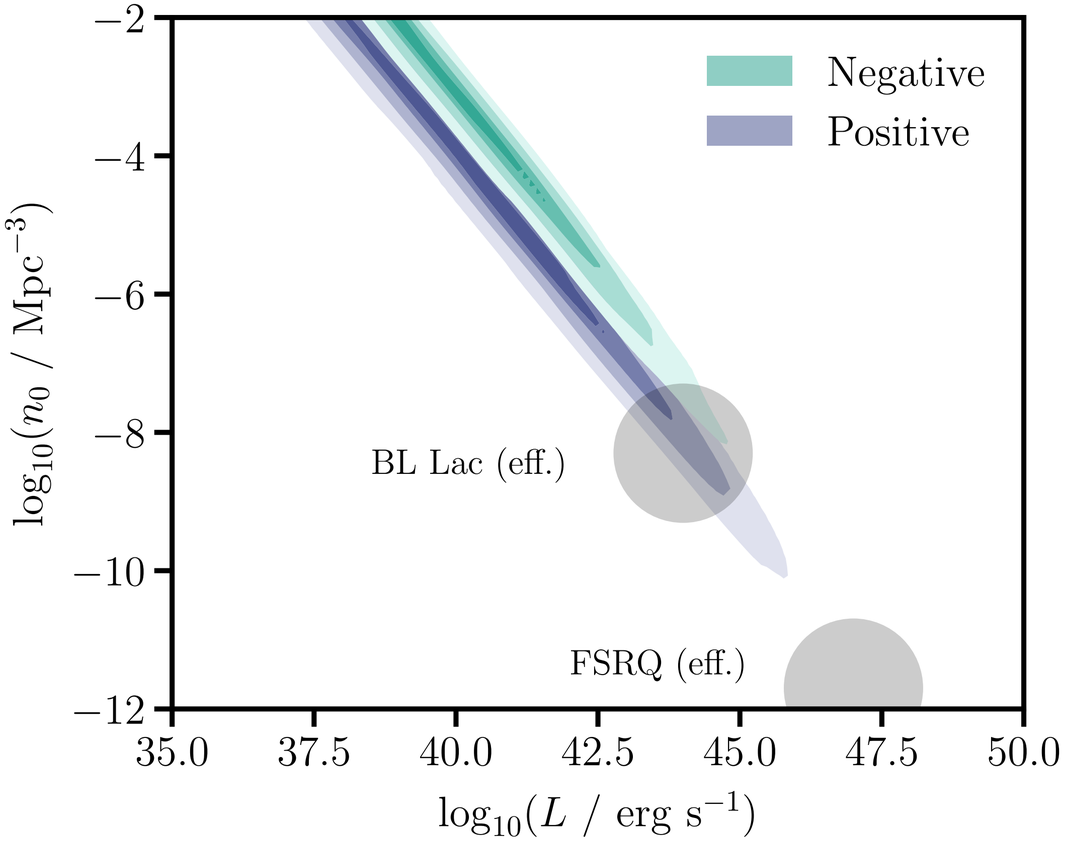
If blazars are the main neutrino sources:

- They must be numerous and powerful enough to produce the observed astrophysical flux
- They cannot be too rare or bright, as then point sources would be detected

We used a Bayesian hierarchical model to find the constraints on the **density** and **luminosity** of neutrino sources

- TXS 0506+056 is either a BL Lac or FSRQ blazar (e.g. Padovani et al. 2019)
- In both cases sources are **strongly constrained**

Capel, Mortlock & Finley 2020



See also: Lipari et al. 2008, Silvestri & Barwick 2010, Ahlers & Halzen 2014, Kowalski 2015, Murase & Waxman 2016, Palladino et al. 2020

CONCLUSIONS

- Current work: Forward modelling to connect source associations and populations
- Cannot consider individual associations in isolation from their populations

PAPERS

arXiv:1811.06464

arXiv:2005.02395

CODE

github.com/cescalara/uhecr_model

github.com/cescalara/nu_pop

THANK YOU!