A model-independent analysis of neutrino flares detected in IceCube from X-ray selected blazars

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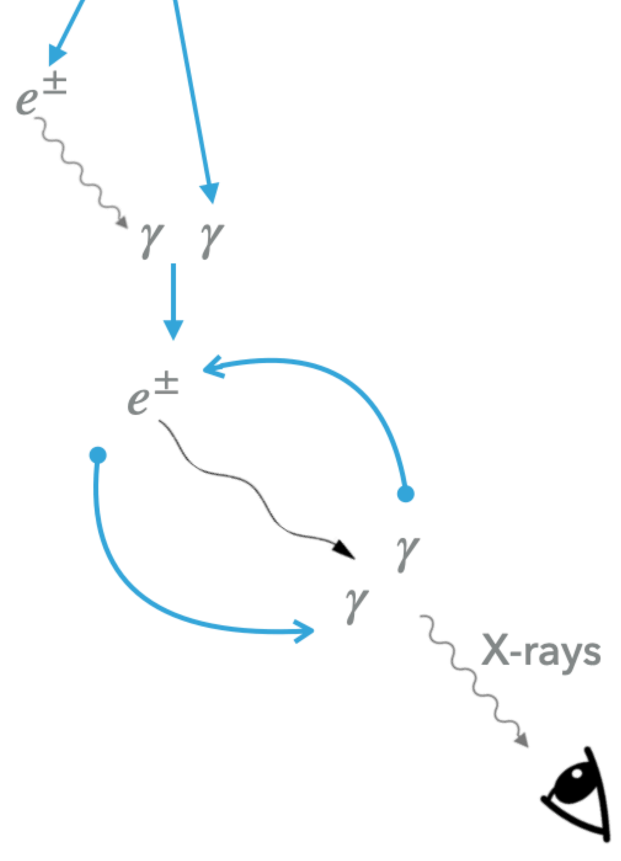
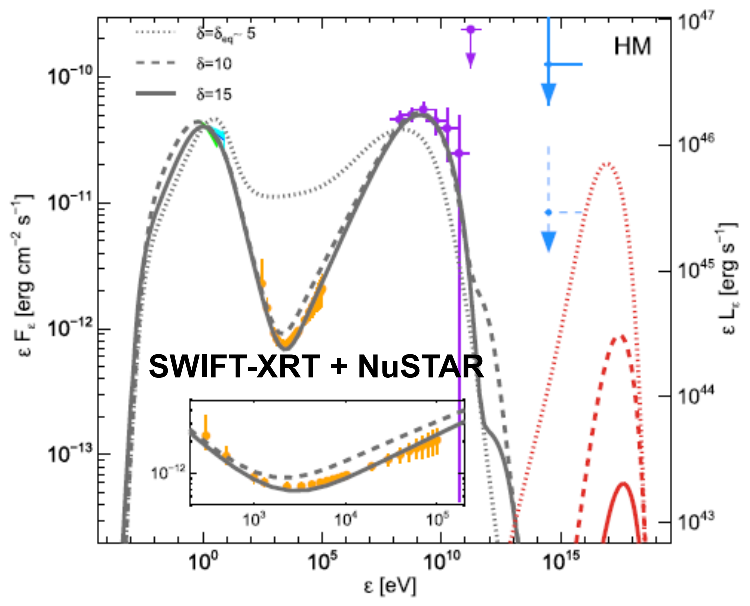
Motivation

- X-rays from blazar jets can be correlated to their neutrino emission

$$p + \gamma \rightarrow p/n + \pi^{\pm}, \pi^0 \rightarrow 2\gamma + 2\nu_\mu + \nu_e$$

- The pγ interactions that produce neutrinos also give rise to secondary pairs as pion decay products, that cascade down to X-ray energies before escaping
- X-ray observations simultaneous with IC170922A [1] and 2017 γ-ray flare used to disfavor single-zone lepto-hadronic scenario for TXS 0506+056 [2]





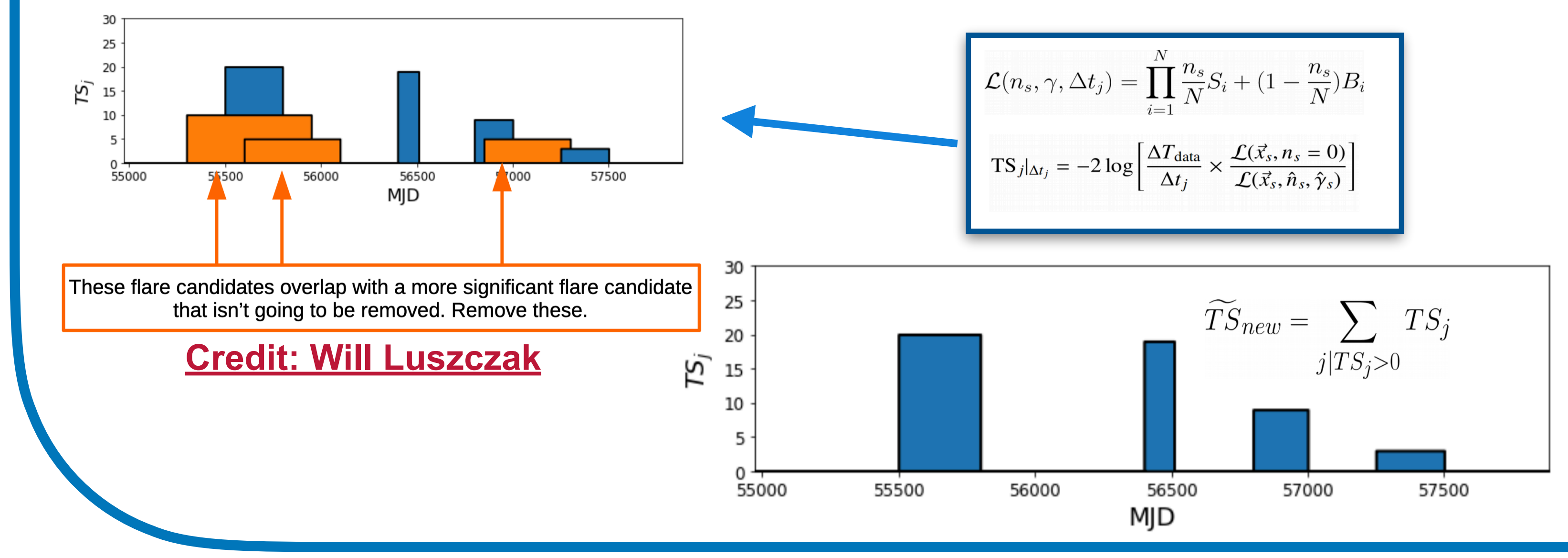
Analysis Fundamentals

Objective: Test the hypothesis 'X-ray bright blazars can be sources of high-energy astrophysical neutrinos'….under the assumption that blazars can flare > 2 times on average over the period of observation

- A **model independent,** time-dependent, untriggered multi-flare search:
  - ➡ search for neutrino flares in 10 years of IceCube data from a catalog of blazars curated by X-ray fluxes, and obtain a local p-value for each source
  - ➡ perform a population test using the binomial test statistic to determine the sub-population with statistically significant emission

Multi-flare method

- Test flare hypothesis for each source direction using seed events that pass the S/B (Signal to Background) threshold
- Remove overlapping flares by selecting the highest significance flare and stack the significance of all remaining flares to obtain the multi-flare TS [4]



$$\mathcal{L}(n_s, \gamma, \Delta t_j) = \prod_{i=1}^{N} \frac{n_s}{N} S_i + \left(1 - \frac{n_s}{N}\right) B_i$$

$$TS_j|_{\Delta t_j} = -2\log\left[\frac{\Delta T_{data}}{\Delta t_j} \times \frac{\mathcal{L}(\vec{x}_s, n_s = 0)}{\mathcal{L}(\vec{x}_s, \hat{n}_s, \hat{\gamma}_s)}\right]$$

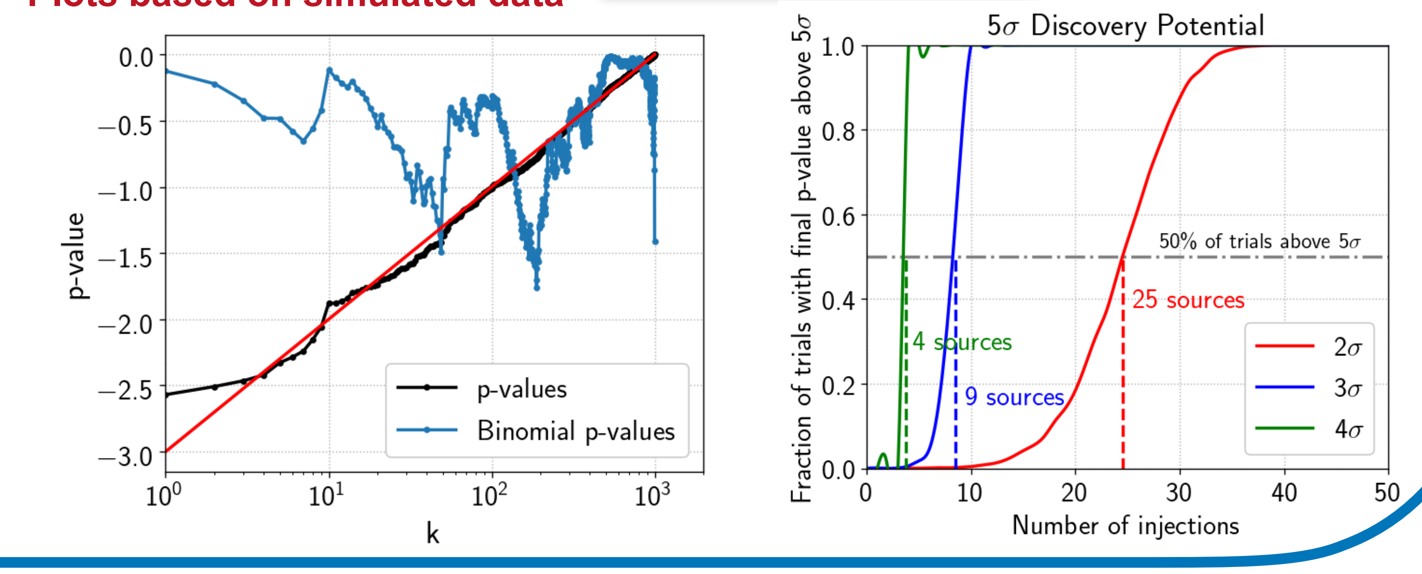
$$\widetilde{TS}_{new} = \sum_{j|TS_j > 0} TS_j$$

Binomial Test

If a sub-population within the catalog has statistically significant emission, the test can reveal how many and which sources are of interest

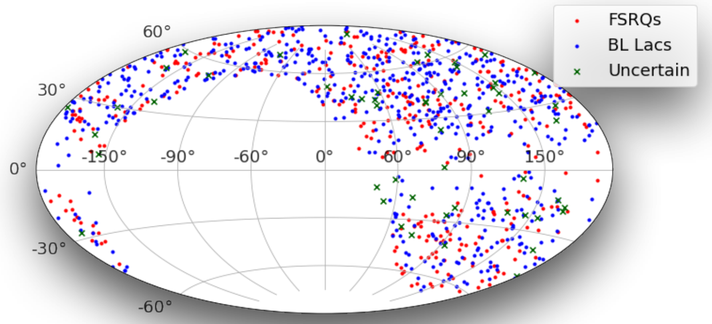
$$P(k) = \sum_{m=k}^{N} \binom{N}{m} p_k^m (1 - p_k)^{N-m}$$

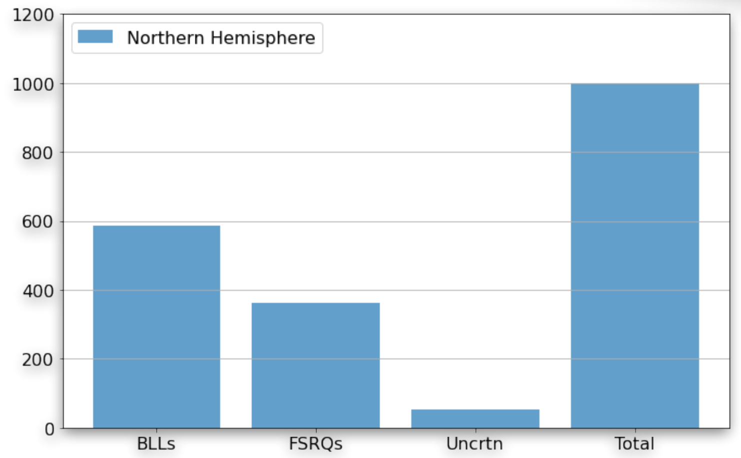
*Plots based on simulated data

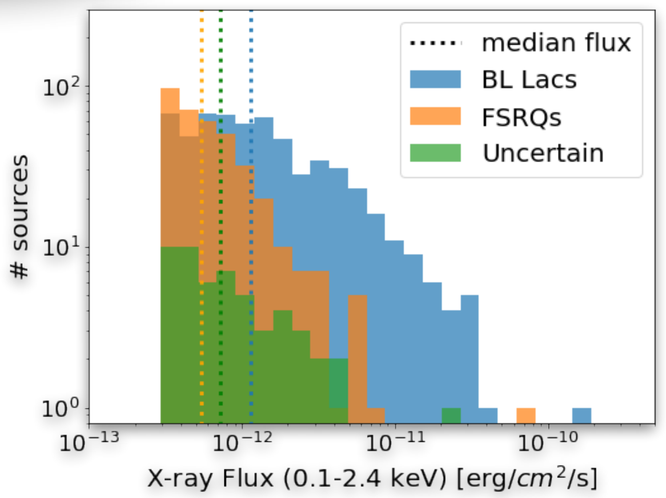


Source catalog: RomaBZCat 5

- A multi-frequency blazar catalog [3]: X-ray fluxes (0.1 -2.4 keV) taken from ROSAT
- **Down-selection**:Select 1000 sources with the highest X-ray flux in the Northern sky (-5, +85) deg.

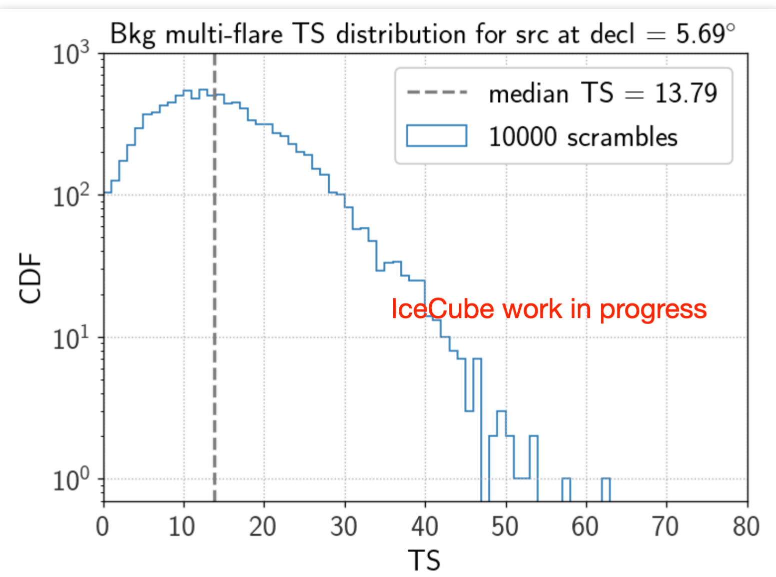


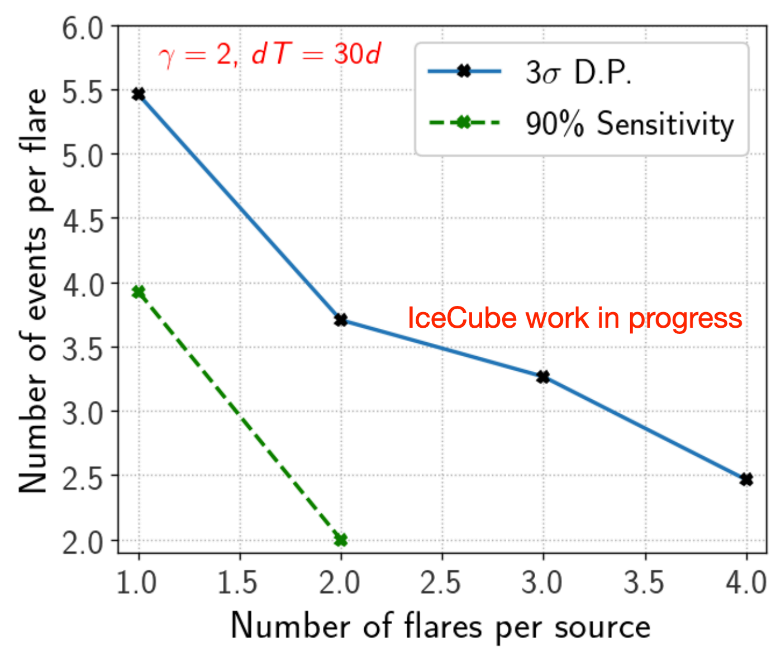




Per Source Sensitivity

- 10k trials for a single source location (at the declination of TXS 0506+056) with and w/o signal injection
- Fixed spectral index and flare duration for injected signal (γ = 2, δT = 30 days). Box profile flares





Bkg TS distribution and flare strength from a single source required for 3σ D.P .

Outlook

- X-ray data can be a useful tool to constrain neutrino emission in blazars. intrinsic variability of blazars motivates a multi-flare search
- BL Lacs and FSRQs will be tested separately, since the binomial test is more sensitive to smaller catalogs
- Currently running background trials for the whole catalog
- Full catalog sensitivity and unblinded results will be published soon

References

1. IceCube Collaboration++, M.G. Aartsen et al. Science **361** (2018) 147 -151
2. A. Keivani *et al* 2018 *ApJ* **864** 84
3. Massaro, E., Maselli, A., Leto, C. *et al. Astrophys Space Sci* **357,** 75 (2015)
4. IceCube Collaboration, W. Luszczak et al. PoS(ICRC2019) **950**

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