A New Time Variability Test for Candidate Neutrino Sources in IceCube

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Abstract

A time-dependent archival search in the direction of the blazar TXS 0506+056 hinted [1] towards time variable neutrino sources that IceCube might be sensitive to. All prior studies of time-variability in IceCube assume a temporal profile for the signal. The temporal profile of an astrophysical neutrino signal is unknown. **We present a new method which tests arbitrary time variability against the steady signal + background hypothesis.**

Example Time-Variable Emission

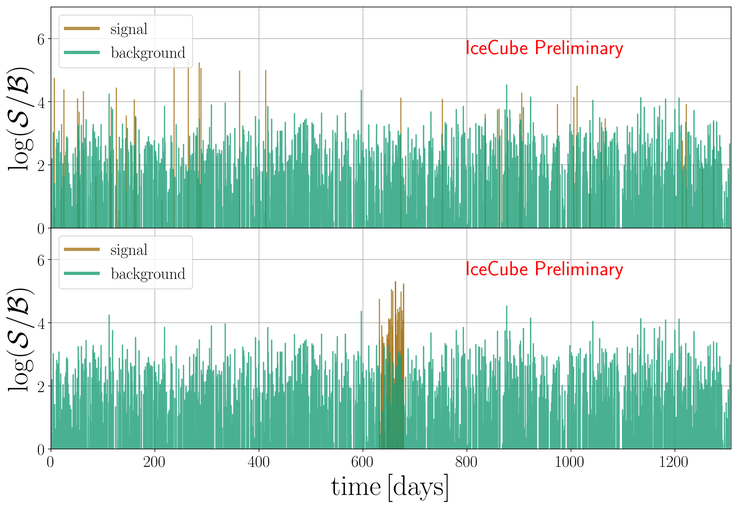

Figure 1:The log of spatial and energy signal probabilities over the background probabilities plotted for a selection of scrambled IceCube events. Signal events are clustered (bottom) as opposed to injected uniformly (top).

Time Integrated Fit

- Fit a time-integrated spectrum at the source of interest [2].
- Use the fitted values of spectral index (γ) and number of excess neutrinos (N_{fit}) to model steady neutrino emission.
- This defines the signal probability to background probability per event ($\mathcal{S}/\mathcal{B}$).

Consecutive Event Pairs

- Select N_{ev} events with highest $\mathcal{S}/\mathcal{B}$. N_{ev} depends on N_{fit}.
- Create the CDF of time difference between consecutive events.
- Each event pair contributes to the CDF following the geometrical mean of $\log(\mathcal{S}/\mathcal{B})$ values for each event in pair.

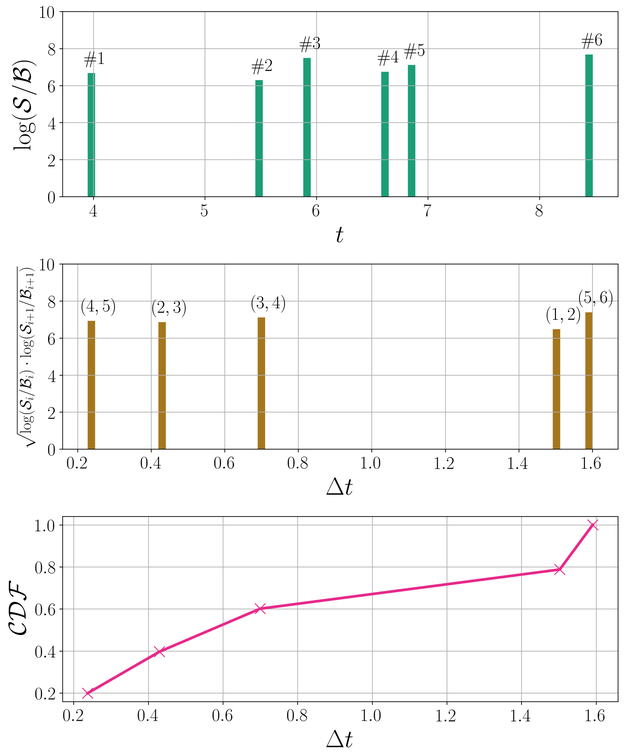

Figure 2:An example of how consecutive pairs in N_{ev} events are used to calculate a weighted CDF.

Cramér–von Mises test

- We test the steady hypothesis by building $F(\Delta t)$ using equally weighted events distributed uniformly over the livetime of the detector.
- $F_n(\Delta t)$ is calculated using event pairs as described in Figure 2.
- The test statistic, TS, is calculated by:

$$TS^2 = N_{\text{ev}} \int_0^1 [F_n(\Delta t) - F(\Delta t)]^2 \, \Delta t$$

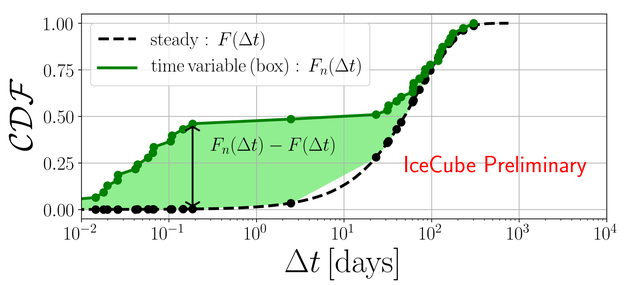

Figure 3:The weighted CDFs of consecutive pairs used to calculate the test statistic, TS.

Example Test Statistic Distributions

As an example, the TS distribution of a box profile is compared against the steady hypothesis.

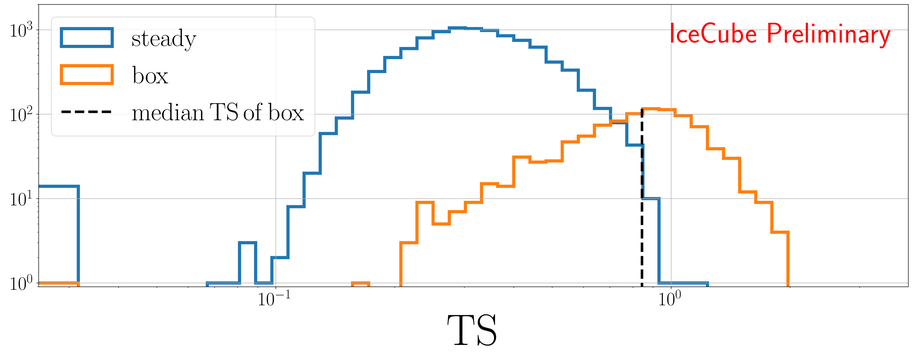

Figure 4:Both distributions have 20 signal events at declination $23.5°$ and $\gamma = 2.0$, while the box length is 300 days. The median of the box_TS is used to calculate the p-value under the steady_TS, which in this case yields 2.97 σ significance.

Testing Box-shaped Flares

- Single flares with varying sizes and signal strengths are tested for time variability.
- Double flares are the single flares broken up into 2 for comparison, retaining the total number of signal events, n_s, and the total flare size, Δt.

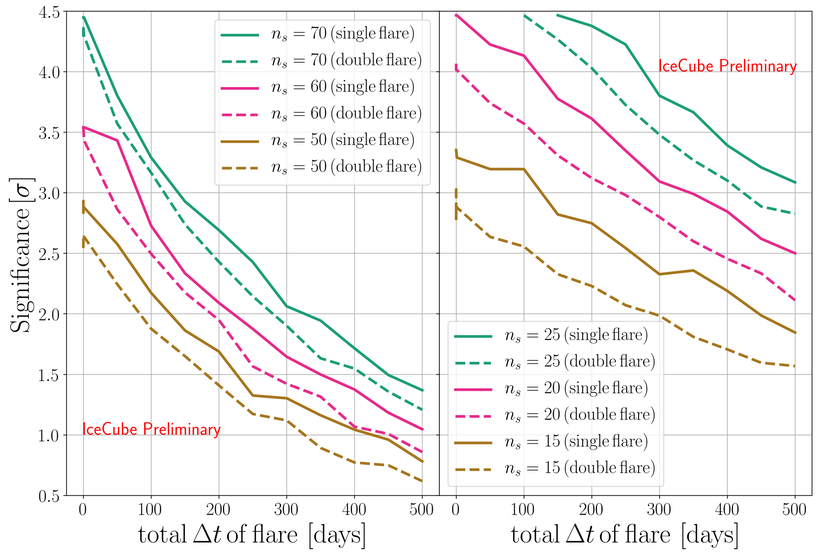

Figure 5:Single (solid) and double (dashed) flare tests for time variability in IceCube at declination $-0.01°$ (NGC 1068), $\gamma = 3.25$ (left) and declination $5.69°$ (TXS 0506+056), $\gamma = 2.0$ (right).

References

[1] M.G. Aartsen, M. Ackermann, J. Adams, J.A. Aguilar, M. Ahlers, M. Ahrens, C. Alispach, K. Andeen, T. Anderson, I. Ansseau, and et al. Neutrino emission from the direction of the blazar txs 0506+056 prior to the icecube-170922a alert. *Science*, 361(6398):147–151, Jul 2018.

[2] M.G. Aartsen, M. Ackermann, J. Adams, J.A. Aguilar, M. Ahlers, M. Ahrens, C. Alispach, K. Andeen, T. Anderson, I. Ansseau, and et al. Time-integrated neutrino source searches with 10 years of icecube data. *Physical Review Letters*, 124(5), Feb 2020.