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 ($\gamma$) and number of excess neutrinos ($N_{\text{fit}}$) to model steady neutrino emission.
> This defines the signal probability to background probability per event ($S/B$).

Consecutive Event Pairs

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

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.

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, $\Delta t$.

Figure 4: Both distributions have 20 signal events at declination $23.5^\circ$ 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 $2.97 \sigma$ significance.

References
