Astrophysical interpretation of small-scale neutrino angular correlation searches with IceCube

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Abstract
IceCube, a cubic-kilometer sized neutrino detector at the Geographic South Pole, has recently discovered a diffuse all-flavor flux of astrophysical neutrinos [1]. However, the corresponding astrophysical sources have not yet been identified in current IceCube analyses. We present a method to interpret the results of an angular correlation analysis in IceCube searching for spatial clustering of muon neutrino events [2] in terms of astrophysical models (given by an arbitrary source count distribution). We exemplarily show how to use a scale factor, angular correlation analysis on experimental data, perform source count distribution parameterizations from Fermi-LAT measurements, and solve for the best-fit values of neutrino fluxes and astrophysical spectral indices.

Input
1) IceCube angular correlation analysis [2]
The analysis tests signal hypotheses, characterized by
- Number of sources \( N_{\text{total}} \)
- Mean number of neutrinos per source \( \nu \) (source strength)
- Astrophysical spectral index \( \gamma \)

Limit from experimental data:
\[ \Sigma_{\text{lim}} = 1.38 \]

\[ \sum \propto N_{\text{total}} \cdot \mu^2 \]

Limit conversion
\[ \Sigma = \int \frac{dN}{d\Psi} = \int d\Psi \sum \frac{dN}{d\Psi} \mu^2 \]

Solve for parameters of the source count distribution (here: \( \beta, \mu \))

Observe the colored lines

Fermi-LAT best-fit variation
Assumption:
Each source emits \( \nu \) times as many neutrinos as photons in each energy range
\[ B(\mu) \]

Fermi-LAT best-fit variation for neutrinos with universal \( \nu/\gamma \) ratio, the corresponding limits and predictions are

\[ \gamma = 2.0 \]

\[ \gamma = 2.5 \]

Changing parameter space
Repeat above procedure, varying \( \beta_1, \beta_2 \)

Dependent on \( \beta_1 \) and \( \beta_2 \) and the tested energy spectra, figures show:
- \( 1^\text{st} \) column: prediction of \( \nu \) corresponding to the astrophysical neutrino flux
- \( 2^\text{nd} \) column: limit on \( \nu \), corresponding to the astrophysical neutrino flux
- \( 3^\text{rd} \) column: ratio between prediction and limit
- \( \nu \) predicted \( \nu \) excluded to be larger than the \( \nu \) limit
- \( \nu \) ratios \( > 1 \) are excluded

2) Observed atmospheric neutrino flux by IceCube [1]
Energy spectra \( \nu/\gamma \) with \( \gamma = 2.0 \) and \( \gamma = 2.5 \) are tested. Used best-fit fluxes:

\[ \nu/\gamma = 2.0 \text{ or } 2.5 \]

3) Fermi-LAT high-latitude source count distribution [3]
Fermi-LAT measured the source count distribution of photons from resolved blazars in dependence of the particle flux \( \gamma \):

\[ \frac{dN_{\text{total}}}{d\gamma} = A_S^{\gamma-2}, S \geq S_0 \]

\[ A = 16.46 \times 10^{-14} \text{ cm}^{-2} \text{ s}^{-1} \]

\[ \frac{dN_{\text{total}}}{d\gamma} = 0 \text{ for } S < S_0 \]

\( \beta = 2.0 \times \gamma_0 \)

Conclusions

- \( \gamma = 2.0 \): For the best-fit values \( \nu \) are excluded to be the only origin of the discovered flux for \( \nu/\gamma \) ratio with a source count distribution parameterization from Fermi-LAT.

Fermi-LAT sources are excluded to be the only origin of the discovered flux for \( \nu/\gamma \) ratio with a source count distribution parameterization from Fermi-LAT. However, the uncertainty interval of \( \beta_1 \) reaches into the allowed region.

References

Funded by:
Helmholtz Gemeinschaft
Alaric/I Astroparticle