Blazar origin of some IceCube events

Sarira Sahu, Luis Salvador Miranda, Alberto Rosales de León
Instituto de Ciencias Nucleares
Universidad Nacional Autónoma de México

Introduction

Interactions of ultra high energy cosmic rays (UHECRs) with the background medium photons and protons produce high energy γ-rays and neutrinos. The IceCube detector located at South Pole in Antarctic ice is precisely built to look for high energy neutrinos (above few TeV) by measuring the Cherenkov radiation of the secondary particles created in each neutrino event.

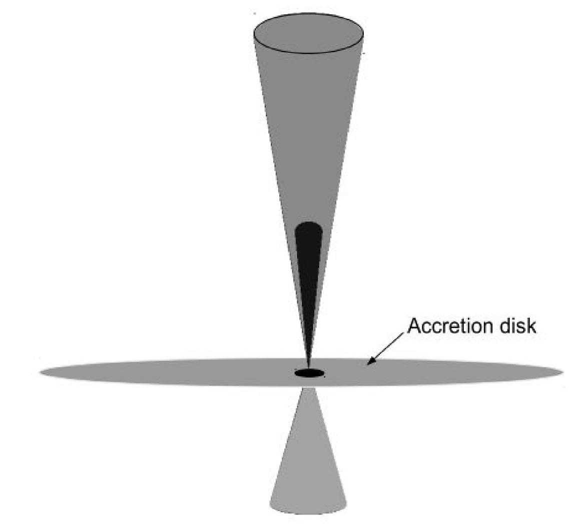
In 2014 the IceCube collaboration published an analysis of 3 years of data (2010–2013) in which 37 neutrino events with energies between 30 and 1200 TeV were observed [1].

In 2015 ANTARES collaboration presented a time dependent analysis [2] to look for upward going muon tracks events from flaring blazars selected from the Fermi-LAT catalog and TeV γ-ray observed by ground based telescopes H.E.S.S, MAGIC, and VERITAS, respectively.

In this work we analyzed this list of 41 Fermi-LAT flaring blazars to see if there is any correlation with the IceCube neutrino events. We used the unbinned maximum likelihood method (UMLM) to analyze the positional correlation with these objects.

Flaring Model

Blazars are believed to be possible candidates to produce UHECRs and neutrinos [3-5]. Using the flaring model of Sahu et al. [5-8] it is assumed an inner jet region where the photon density is very high compared to the external jet, making the photohadronic process efficient enough to produce multi-TeV γ-rays and neutrinos.



In this model Fermi accelerated high energy protons can interact with the seed photons in the Self-Synchrotron Compton (SSC) zone producing neutrinos and γ-rays through Δ-resonance.

$$p+\gamma \to \Delta^+ \to \begin{cases} p\,\pi^0 \to p\gamma\gamma, \\ n\,\pi^+ \to n e^+ \nu_e \nu_\mu \bar{\nu}_\mu \end{cases}$$

Methodology

To identify the possible sources we employed the Unbinned Maximum Likelihood Method (UMLM) [9] to look for spatial correlation between the blazar sample and the IceCube events:

$$\mathcal{L}(n_s, \mathbf{x}_s) = \prod_{i=1}^{N} \left[\frac{n_s}{N} S_i(\mathbf{x}_s) + \left(1 - \frac{n_s}{N}\right) B_i \right]$$

The background Bi was constructed from the integrated effective areas of the IceCube 79 string configuration:

$$B_i = \mathcal{B}(E_i, \delta_i)$$

The signal PDF is a function of the deposited energy E_i, the declination angle δ_i and the spectral index κ:

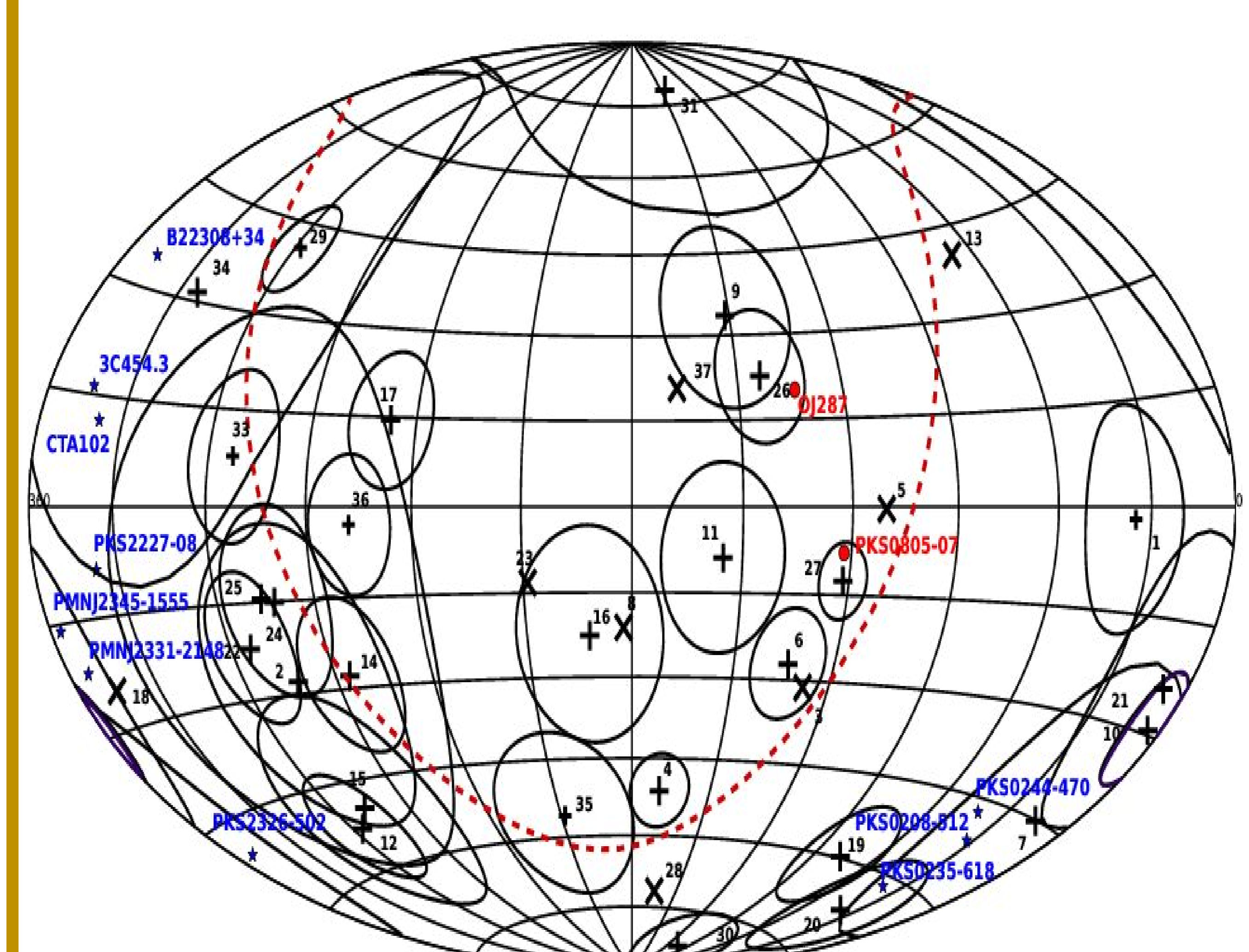
$$S_i = \mathcal{S}_i(|\mathbf{x}_i - \mathbf{x}_s|, \sigma_i)\, \mathcal{E}_i(E_i, \delta_i, \kappa)$$

To evaluate each point source we use the Test Statistic (TS):

$$\mathrm{TS} = -2 \log \left[\frac{\mathcal{L}(n_s = 0)}{\mathcal{L}(n_s = n_s^*)} \right]$$

Results

After running 10,000 simulations with a randomized right ascension for each source the p-value is calculated as the number of simulations with TS(sim) ≥ TS divided by the total number of simulations. The posterior p-value is estimated as the fraction of the randomized simulations that yields an equal or higher TS(sim) value for at least one of the 41 sources.



Object	ID	p-value	Post p-value
PKS2326-502	7	0.44	1
PKS0208-512	7	0.22	1
PKS0235-618	7, 20	0.18	1
PMNJ2345-1555	21	0.43	1
B22308+34	34	0.48	1
PKS0244-470	7	0.17	1
CTA102	34	0.53	1
PMNJ2331-2148	21	0.45	1
PKS2227-08	34	0.53	1
3C454.3	34	0.50, 0.49	1, 1
OJ287	26	0.31, 0.33	0.99, 1
PKS0805-07	27	0.24, 0.27	1, 1

We observed that, from the 41 flaring objects using a spectral index κ = 2, the UMLM gives 12 possible sources without prompt flux contribution (and three with prompt flux contribution) within the error circle of some IceCube events.

For all possible candidates the TS value was very small, which leads to a Post p-value ≥ 99%, therefore is consistent with the background fluctuation.

Conclusions

For our analysis we take into account: The energy dependence, a spectral index κ and the prompt contribution to the atmospheric flux, still there is not enough statistical evidence to claim a correlation of the 12 sources shown in the sky map. It is possible that the high energy neutrino flux from these objects is below the IceCube limit. We have to wait for more data to look for a possible correlation of flaring Blazars with the IceCube events.

Further Information

Published work:
L. S. Miranda, A. R. de León, S. Sahu
Eur. Phys. J. C 76,402 (2016)

Alberto Rosales de León
e-mail address:
albertoros4@ciencias.unam.mx

Site:
https://albertoros11.wixsite.com/physics

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