Search for features in astrophysical objects close to cosmic neutrinos: An indirect approach to cosmic neutrino association with astrophysical objects

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Motivation

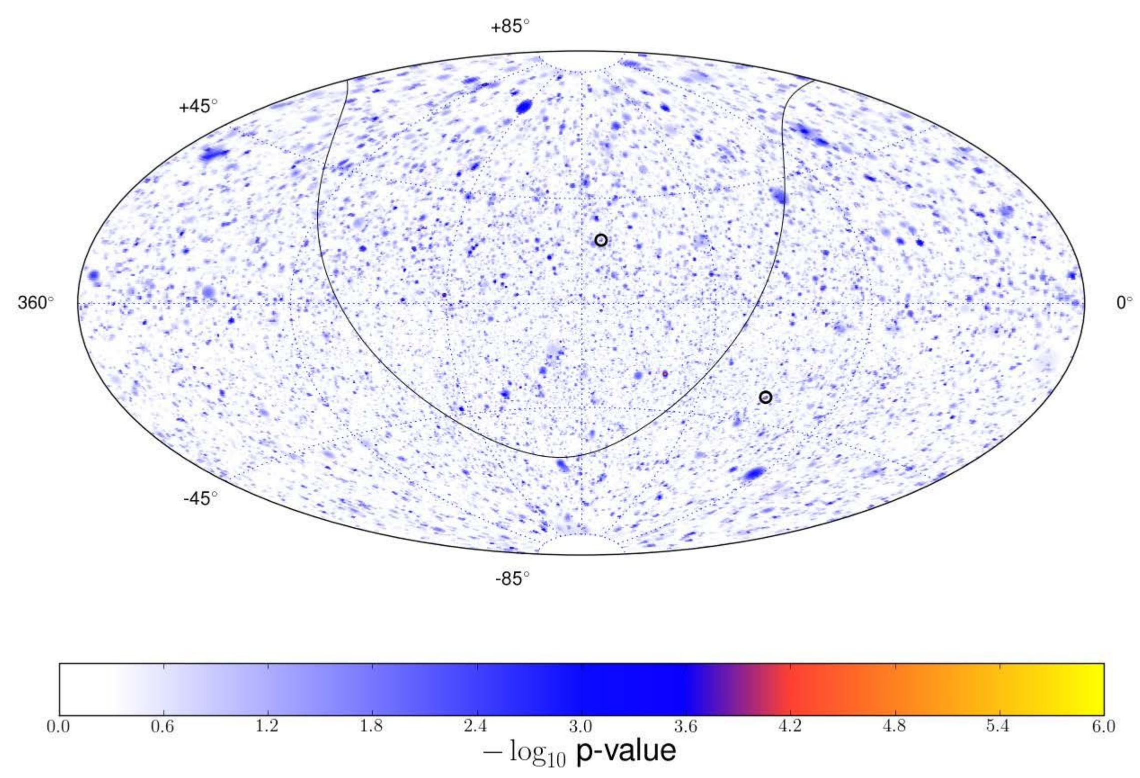
- We propose here a project, called **Co**smic **N**eutrino **I**nvestigation via (source) **C**lassification (**CoNIC**), in the field of **Astroparticle Physics**, a branch of Physics dealing with the understanding of the Universe through the detection of gamma rays, neutrinos, gravitational waves and cosmic rays.
- We focus on a **search for a connection between high-energy neutrinos and gamma rays in the extragalactic sky**.
- Two large observatories have been designed to be able to detect high-energy neutrinos from astrophysical environments: IceCube [1] and KM3NeT [2]. IceCube already has collected 10-years of data, which resulted in a catalogue of neutrinos having a high probability of being of cosmic origin, while KM3NeT is an observatory under construction.
- The significance of the signal of IceCube cosmic neutrinos in terms of excess above background, see plot on the right (taken from [1]), shows that still no firm conclusion can be drawn on the association of these with astrophysical objects.

Proposed solution

- We propose an indirect **statistical inference** approach to find possible correlations between IceCube neutrinos and extragalactic gamma-ray sources.
- The project takes advantage of published neutrino lists together with astrophysical objects catalogues and open data from the **Fermi observatory** [3].
- Technically, the project requires the development of a full Python analysis chain using Deep Learning.

Dataset Description

- The proposed work takes advantage of the existing real and **openly-available data from the IceCube and Fermi observatories**.
- IceCube continuously updates a catalogue of cosmic neutrinos containing the characteristics of the events: their position in the sky, their energy, their probability of being of cosmic origin.
- Fermi is an extraordinary astronomical facility in gamma-ray astronomy, which has an “open data” policy from NASA. Fermi data and software are therefore accessible freely and almost immediately.



Proposed Work

The project will be developed in the following steps:

- Using the *fermitools* Python package, access Fermi data and produce the Fermi time series, called light curves. Download Fermi catalogues.
- Define regions of interest in the sky (the “ON” regions), centred on the arrival direction of IceCube neutrinos.
- Set up the analysis chain needed **to search for patterns** in Fermi light curves and catalogues that we will use to categorize astrophysical objects in the vicinity of cosmic neutrinos (the “ON”-objects), from those objects instead lying far from them (the “OFF”-objects). The way features will be extracted from the Fermi light curves will be inspired from [4], where a combination of a ***Convolutional Neural Network*** **(CNN)** and a ***Recurrent Neural Network*** **(RNN)** is used.
- Given the relatively small dataset of the Fermi extragalactic objects (~ 4000), a procedure of data augmentation might be needed in order to artificially increase the dataset, through the addition of random noise via ***Generative Adversarial Networks*** **(GANs)** [5] or bootstrapping techniques.
- Finally, a classification procedure with all the above-mentioned inputs will help to understand if the “ON” astrophysical objects will show a significant deviation in their features with respect to the “OFF”-objects.

Expected results

- There are two possible outcomes of the work: either a difference in the characteristics of the “ON” and “OFF”-objects is found, which would lead to a discovery, or no difference is found, meaning that more data will need to be accumulated.
- Either conclusion will be of interest. In the first case, more cross-checks will be needed to strengthen the significance of the results, while in the latter case it will be crucial to plan for the future developments of the method.

References

[1] The IceCube Collaboration, R.Abbasi et al. *Astrophys. J.* 911 (2021) 1, 67
[2] The KM3NeT Collaboration, S’Aiello et al., *Astroparticle Physics* (111) 2019, Pages 100-110
[3] The Fermi Observatory, https://fermi.gsfc.nasa.gov/
[4] Lai, G. et al., (2018), SIGIR 2018
[5] Goodfellow, I., et al. (2014), *Advances in neural information processing systems* (pp. 2672–2680).

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