"Search for features in astrophysical objects close to cosmic neutrinos"
An indirect approach using deep learning and statistical inference

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Context. The proposed work is in the field of Astroparticle Physics, focusing on the 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 shows that still no firm conclusion can be drawn on the association of these with astrophysical objects.

Research question. This internship concerns an indirect search for neutrino associations with astrophysical objects using a statistical inference approach. The project takes advantage of published neutrino lists together with astrophysical objects catalogues and open data from the Fermi observatory. Technically, the project needs the development of a full Python analysis chain using Deep Learning.

Proposed work and implementation. 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 a tremendous 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. The way features will be extracted from Fermi time series will be inspired from Lai, G. et al, (2018), where a combination of a *Convolution Neural Network* (CNN) and a *Recurrent Neural Network* (RNN) is used to extract short-term local dependency patterns and to characterize long-term patterns for time series trends. Given the relatively small dataset of the Fermi extragalactic objects (~ 4000), a procedure of data augmentation might be needed at this step, in order to artificially increase the dataset, through the addition of random noise via *Generative Adversarial Networks* (GANs) 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 difference with respect to the "OFF"-objects.

Internship info: This internship is supervised by Prof. Yvonne Becherini and Prof. Themis Palpanas. The selected intern will become a member of APC, which has world-leading expertise on astrophysics.

Prerequisites: Excellent Python programming skills, very good knowledge of deep learning frameworks (PyTorch/GPU, etc.) and libraries in data analysis workflow (NumPy, Matplotlib, etc.). Research/project experiments and publications on deep learning or data analysis is a plus.

How to apply: Apply by emailing your CV and transcripts to Prof. Yvonne Becherini: yvonne.becherini@apc.in2p3.fr

References

Lai, G., et al. (2018). Modeling Long- and Short-Term Temporal Patterns with Deep Neural Networks. *The 41st International ACM SIGIR Conference on Research & Development in Information Retrieval*

[1] https://icecube.wisc.edu/
[2] https://www.km3net.org/
[3] A light curve is a time series showing the variation in the flux received over a period of time.