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An Approximation of the Observed Extragalactic Neutrino Background

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Neutrinos open a new page in multimessenger astronomy along with gravitational-wave events, the heralds of new discoveries in physics. In extragalactic astrophysics, neutrino sources add to the relatively well-studied electromagnetic objects. We have developed a program in C/Python to work with the extragalactic neutrino background. The program cuts out desired areas in the sky in equatorial or galactic coordinates, out of all objects taken from the input catalogs creates samples of potential neutrino sources falling into the given area, calculates the neutrino flux from each source via a number of model neutrino energy spectra for different types of sources, and draws 2D splines of the neutrino flux in the sky with parameterized smoothing, which are then taken as the observed extragalactic neutrino background.

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1. Introduction

Neutrino is a general name for neutral fundamental particles with half-integer spin[1] that participate only in the weak and gravitational interactions and belong to the class of leptons [1]. According to modern studies [e.g., 2–6], neutrino have a mass about 0.2–2.0 eV, although it is in conflict with the standard model of particle physics, where neutrinos are massless particles [7]. Information on the exact value of the neutrino mass is important for explaining the phenomenon of hidden mass in cosmology, since, despite its smallness, it is possible that the concentration of neutrinos in the Universe is high enough to significantly affect the average density [8, 9].

Unfortunately, modern neutrino observatories are unable to unambiguously determine the origins of neutrinos. Conclusions about their Galactic or extragalactic origin are made on the basis of observed statistics [10]. In order to solve this problem, we propose to use 2D splines of model neutrino fluxes from electromagnetic sources, an example of which is given below for the case of blazars. Our program can help solve problems of coordinate identification of detected neutrino events with transient and permanent electromagnetic sources.

2. The neutrino background estimate

Since neutrino detectors have a very limited angular resolution, the results of their observations can be compared with radio astronomy data. Point sources will be represented here as smeared spots in space with a dispersion proportional to the angular resolution of the neutrino detector. That is why to match neutrino observations with actual catalogs of neutrino sources, it is necessary to use a 2D spline. In this case, each source in the target area will have a probability that it is the source of the detected neutrino. Then this 2D spline will be an estimate of the probability density function (PDF) of these potential neutrino sources in a given energy range.

In order to study the problem, we have developed a C/Python program for processing catalogs of galaxies and approximation of a given sky area by a 2D-spline function with parameterized smoothing. If the direction of neutrino arrival, the angular resolution of the neutrino detector, and the energy of the particle are known, then, having a database of potential neutrino sources, it is possible to determine the source of an extra-atmospheric neutrino with some probability. As part of solving such a non-trivial problem, it is also necessary to have Galactic sources of neutrinos and an estimate of atmospheric neutrinos. However, this is beyond the frameworks of our narrow task of calculating the 2D spline of potential thermonuclear neutrino sources in the area of galactic coordinates.

The program cuts out the required areas in the sky in equatorial or galactic coordinates, creates a sample of all objects that have fallen into the given area according to the input catalogs of bright extragalactic electromagnetic sources, calculates the neutrino flux from each source as model function parameters, and draws a 2D spline with parameterized smoothing, which is taken as the neutrino background. Now the program uses catalogs of nearby galaxies and known blazars with a known position in the sky and an apparent magnitude in the R band as an input data source.

Further, for each blazar the program recalculates the apparent stellar magnitude and observed flux according to the magnitude and neutrino flux from the model neutrino spectrum. As a first

[1] https://pdg.lbl.gov/

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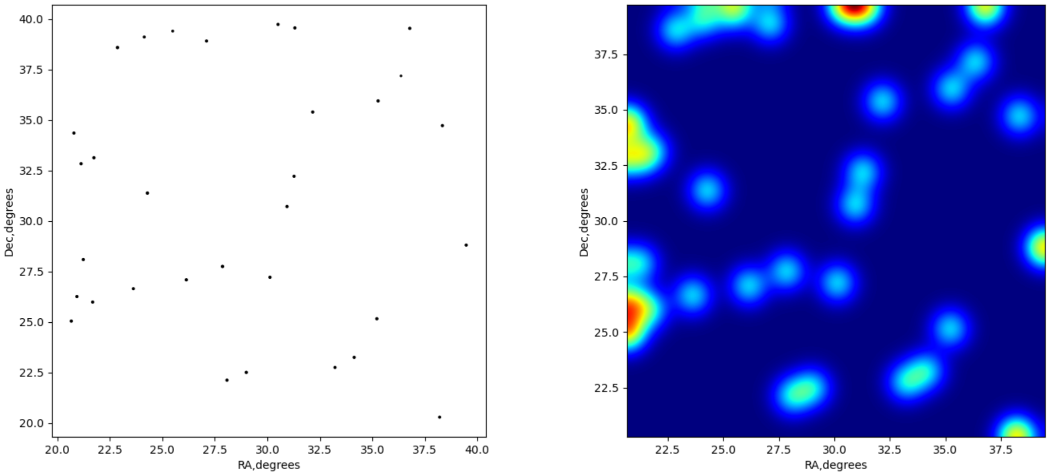

Figure 1: An area of 10×10 degrees of the Roma-BZCAT catalog in equatorial coordinates (left) and its 2D spline of extragalactic neutrino sources with a smoothing parameter (by Gaussian method) of $\sigma = 32$.

approximation, we use a log-normal distribution in the solar energy range normalized to the value corresponding to the apparent magnitude for a blazar in the R band and the solar neutrino flux at a distance of 1 pc as the default model. We use the solar model because it is simple and well known. An example of 2D spline is shown in Figure 1 for the Roma-BZCAT blazars. The blazar catalog contains cosmological redshifts z, so metric distances can be calculated immediately. The formulas for calculating the distances are presented, for example, in [11]. The user can manually change the model function for each input catalog, which then will be correctly recalculated with respect to the distance and the Universe geometry.

The program uses the standard command line interface for Linux utilities. As input data, it requires a CSV file containing objects with their sky coordinates (RA, Dec by default) and R magnitudes (or their estimates). Results are contained in a CSV file with its name based on the input name and (as an option) in a PNG/EPS file for smoothed images. For correct work, installed Python along with Matplotlib and Pandas libraries are required.

3. Conclusions

Neutrinos may carry important information about the evolution of the Universe (including relic neutrinos). Since in the late stages of stellar evolution up to 90% of the radiated energy is carried away due to neutrinos, the study of neutrino properties helps to better understand the dynamics of astrophysical processes [e.g., 10]. In addition, neutrinos travel great distances without absorption, which makes it possible to detect and study even more distant astronomical objects.

We have presented the first results of the calculations of the extragalactic neutrino background for the thermonuclear neutron flux component of blazars. The program calculates the observed neutrino spectra as a set of function parameters according to a model for a selected type of objects.

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This program is supposed to solve various problems of neutrino astronomy, and it can also be used in identifying neutrino and electromagnetic sources.

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