IL NUOVO CIMENTO **44 C** (2021) 105
DOI 10.1393/ncc/i2021-21105-7

COMMUNICATIONS: SIF Congress 2020

Characterizing the Spectral Energy Distribution of blazars as candidates for neutrino emission

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received 14 January 2021

Summary. — Blazars are potential neutrino emitters as suggested by the detection of a high-energy neutrino in the direction of the flaring Blazar TXS 0506+056, in 2017. However, the origin of neutrinos from this source is still unclear. This work aims at finding and characterizing other Blazars with similar features as TXS 0506+056. We selected sources from the most recent Fermi Catalogue, the 4LAC, finding 4 candidates. They were characterized through a multiwavelength analysis, which revealed some peculiarities in the SED of the candidates.

1. – Introduction

In the context of multi-messenger astrophysics, high-energy neutrinos provide information on the composition of their sources and the acceleration mechanism(s) at work. However, the very small event rates make it difficult to firmly identify the emitting objects. Among the possible extragalactic neutrino sources, blazars are particularly interesting. They are a subclass of Active Galactic Nuclei (AGNs) with a relativistic jet pointing towards Earth which is a natural accelerator of particles and thus a potential cradle of high-energy neutrinos. The possibility of blazars being neutrino emitters has become particularly interesting when a very highly energetic neutrino in the direction of the flaring Blazar TXS 0506+056 was detected by IceCube in 2017 [1]. Since then, several models were produced to explain this association, but the origin of neutrinos from TXS 0506+056 is still unclear. In this work we aim at finding other potential neutrino emitters within the blazar class by selecting sources with similar features as TXS 0506+056 and characterizing them by building their Spectral Energy Distribution (SED). The selection of candidates is described in sect. **2**. Data analysis is reported in sect. **3**, while in sect. **4** the recovered SEDs are discussed. Finally, conclusions and future perspectives are reported in sect. **5**.

2. – Selection of candidates

The data used to select candidates were taken from the 4LAC Catalogue [2], containing γ-ray sources detected in the first 8 years of Fermi activity, associated with objects

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showing AGN-type spectral features. We considered three parameters: the photon index in the Fermi/LAT energy range, Γ_γ, the synchrotron peak frequency, ν_S, both taken directly from the catalogue; the integral luminosity from 1 to 100 GeV, L_γ, derived by using the energy flux in the same range and the redshift of the sources. Due to the luminosity-based selection, all sources with no measured redshift were excluded *a priori*. The choice of the selected ranges of the parameters is driven by those of TXS 0506+056: $\Gamma_{\gamma,TXS}-0.3 < \Gamma_\gamma < \Gamma_{\gamma,TXS}+0.3$, $\log_{10}(L_{\gamma,TXS})-0.3 < \log_{10}(L_\gamma) < \log_{10}(L_{\gamma,TXS})+0.3$ and $\log_{10}(\nu_{S,TXS})-0.5 < \log_{10}(\nu_S) < \log_{10}(\nu_{S,TXS})+0.5$. From this selection, a sample of 12 candidates emerged, including TXS 0506+056, all of which classified as BL Lac objects (BL Lacs) belonging to the Intermediate Synchrotron Peak (ISP) class. Seven of them present an unusually high value of the redshift [3], larger than 0.8. Since the lines identified in their spectra are not clearly distinguishable from the background noise, we excluded them from the selection. The remaining sources are B2 2114+33, B3 1307+433, GB6 J0114+1325, GB6 J0154+0823 and, obviously, TXS 0506+056, the redshifts of which were measured in the works [4], [5], [6, 7], [8] and [9], respectively.

3. – Data analysis

For each source in the sample a multiwavelength analysis was performed, aimed at the reconstruction of their SEDs in the high-energy band. Data were taken from Swift/UVOT, Swift/XRT and Fermi/LAT telescopes, covering the optical/UV, X-ray and γ-ray bands, respectively. Since all our candidates but TXS 0506+056 are poorly known objects, we took all available Swift data for them, while for TXS 0506+056 we took only those referring to observations before 2017 in order to avoid periods of flares. Fermi/LAT can acquire expositions of the whole sky every three hours, so data are continuously taken from all γ-ray sources. We chose data covering a period of 2 or 3 months to get significant results. Thus, Fermi observations are not precisely coincident with those from Swift, but Fermi data were chosen to be coincident with one or two Swift observations. Moreover, the interval selected for TXS 0506+056 was chosen to consider a low state of activity of the source. Concerning the analysis, in X-rays we used spectral fitting to convert raw photon counts into energy flux, in the optical/UV band we exploited photometric methods to recover the magnitude of each source in six different filters and then convert it into energy flux. Finally, in γ-rays, likelihood maximization was used to find the best-fit model parameters and the spectral points to put in the SED.

4. – Spectral Energy Distributions

The multiwavelength analysis performed allowed us to build the SED of the candidates in the high-energy band. Since Swift and Fermi observations are not precisely coincident in time, the SEDs do not correspond to a precise state of activity of the sources, but they show only time-averaged information.

For all sources in the sample, a comparison between their SED and the SED of TXS 0506+056 was made (see fig. 1) to investigate the similarities and differences in the electromagnetic emission of the sources. As we can see from fig. 1, although our candidates are all BL Lacs of the ISP class having similar selection parameters, not all of them show a SED behaviour similar to TXS 0506+056.

Concerning TXS 0506+056, from fig. 1 we can note that the reported behaviour is quite unusual [1]. Indeed, Fermi luminosity increases with increasing frequency, suggesting a high-energy peak beyond 300 GeV, while we expect it to be around 1–10 GeV,

in an intermediate state of activity. Moreover, in a low state, a soft slope of the SED is expected, but the analyzed data show a hard one in the Fermi band. Thus a deep investigation on the location of this peak would be necessary.

Concerning the other sources, we can make the following observations: B2 2114+33 and B3 1307+433 present a slightly lower luminosity than TXS 0506+056 in UVOT band, but, while B3 1307+433 shows a slope analogous to TXS 0506+056, B2 2114+33 shows a harder one, leading to a lower luminosity in XRT frequencies. In this band both sources seem to reach the local minimum between the peaks, while the SED of TXS 0506+056 is still decreasing. Unfortunately, there are very few Swift data for both these candidates, so we cannot draw a firm conclusion on their SED behaviour and additional observations are needed. GB6 J0114+1325 and GB6 J0154+0823 show a luminosity comparable to the one of TXS 0506+056 in UVOT band, but their trend is different: the former has a slope equal to TXS 0506+056, while the slope of the latter is clearly different, giving a softer SED. Concerning γ-rays, all sources but one show a trend analogous to TXS 0506+056, increasing in the 100 MeV–300 GeV range and suggesting a second peak of the SED at very high energies, a very unusual feature for this kind of sources [10]. The only source showing a different trend is GB6 J0114+1325, for which the SED in Fermi/LAT band decreases, suggesting a second peak around 1 GeV. Note that it is the trend we usually expect for TXS 0506+056, hence a deeper investigation on the behaviour of the candidates at high energies is needed.

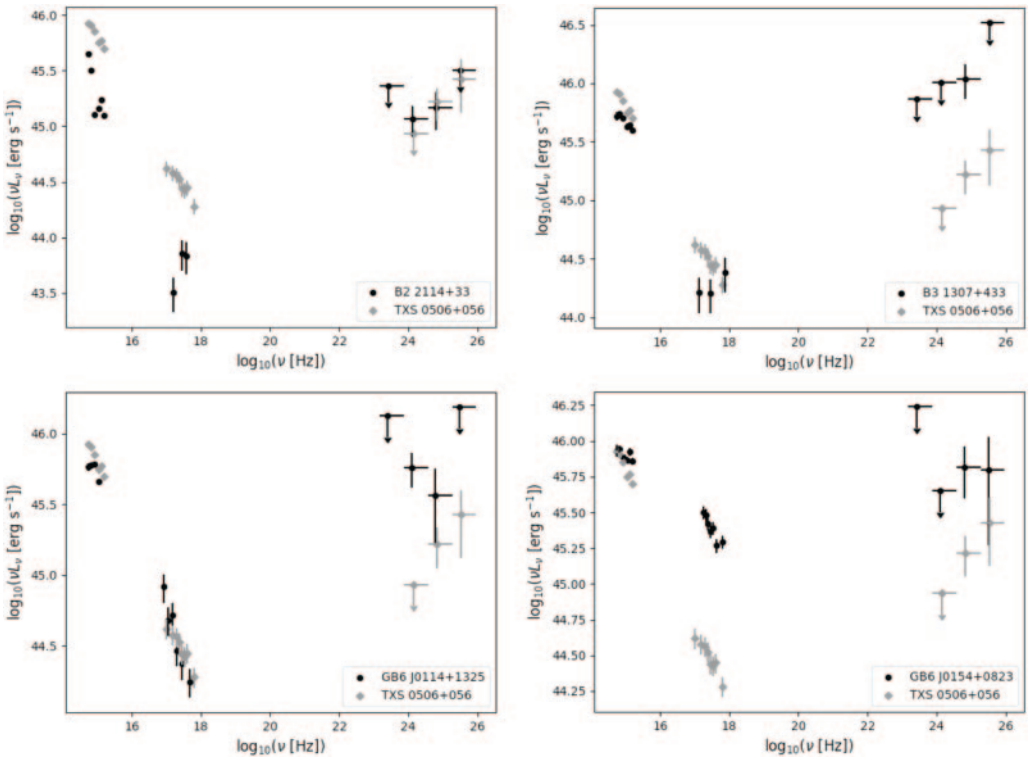

Fig. 1. – Comparison between the SED of each candidate and the SED of TXS 0506+056. In each plot the black circles refer to the interested source, while the grey diamonds to TXS 0506+056.

5. – Discussion and perspectives

In this work we looked for potential neutrino sources within the Blazar class of AGNs, starting from objects with similar features as TXS 0506+056, which is the only Blazar with a detected joint photon-neutrino emission with a chance coincidence probability disfavoured at the 3σ level. We selected sources by considering three parameters associated with the most important physical processes involved in their emission: the photon index, the γ-ray luminosity and the synchrotron-peak frequency. A set of 12 Blazars resulted, including TXS 0506+056, all classified as BL Lacs belonging to the ISP class. Seven of them present an unreliable redshift: additional measurements are needed and a proposal to the Telescopio Nazionale Galileo has already been submitted for a spectroscopic observation of these candidates. For the remaining sources a multiwavelength analysis was made, aimed at the reconstruction of their SED. Data were taken from Swift/UVOT, Swift/XRT and Fermi/LAT telescopes. We observed a somewhat different behaviour of these candidates with respect to TXS 0506+056. Further investigation is needed: an extension of the sample of course, but also an increase of data points in the X-ray band for the sources B2 2114+33 and B3 1307+433. To this aim, a proposal for Swift observations was submitted. In addition, the application of lepto-hadronic models would be of fundamental importance for a better understanding of the physical processes involved in the jet emission and the potential neutrino-emitting nature of these candidates. Finally, the increasing trend of the SED in Fermi frequencies must be investigated, for which an analysis of the light curves of the candidates started. It would confirm and generalize a previous study performed on TXS 0506+056, which discovered an anticorrelation between the flux and the spectral index during its 2015 flare [11].

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Part of this work is based on archival data, software or online services provided by the Space Science Data Center - ASI. We acknowledge the use of public data from the Swift data archive. IV and CR acknowledge Alessio Berti for the Fermi analysis.

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