Mapping highly-energetic Messengers throughout the Universe

# The physical properties of candidate neutrino-emitter blazars

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## Summary

We study the physical properties of a subsample of 52 blazars, that have been proposed as candidate neutrino emitters, based on a positional cross-correlation statistical analysis between IceCube data and the Fifth Roma BZCat catalog (5BZCat). Using archival and proprietary data, we provide new insights into the intrinsic properties of this sub-population of candidate neutrino-emitter blazars. We carry out a comprehensive investigation of the observational and physical properties that govern the physics of these blazars, among which redshifts, black hole masses, accretion regimes, radiation fields. The sample of candidate neutrino-emitter blazars displays properties compatible with those of the overall population. We observe a mild tendency to prefer objects with intense radiation fields, which are typical of radiatively efficient accretors, and high radio power. Half of the blazars in our sample are detected in gamma rays; they cover various ranges of γ-ray luminosities, compatible with the overall population.

## Context

Blazars are candidates for the production of high-energy IceCube neutrinos. They are Active Galactic Nuclei (AGN) with the relativistic jet pointing in the observer's line of sight. The central engine is mainly powered by the accretion of mass on the supermassive black hole hosted in the core, which is surrounded by clouds of ionized gas very close or further out (broad and narrow line regions, BLR and NLR, respectively), an accretion disk and a toroidal region of molecular dust. The emitted radiation is strongly Doppler boosted, therefore AGN are able to span the whole electromagnetic spectrum, from the radio band up to very high-energy $\gamma$-rays. The traditional picture of the internal structure of an AGN and the properties in the different bands may change depending on the intrinsic nature of the individual source of interest. Differences in the characteristic features are usually associated with different classes of objects, BL Lacertae (BL Lacs) vs. flat spectrum radio quasars (FSRQs) or high- and low- excitation galaxies (HERGs and LERGs, respectively) among others. Some blazars ("blue flat spectrum radio quasar" a.k.a "masquerading BL Lacs") show behavior somewhere in between the two classes [1-2].

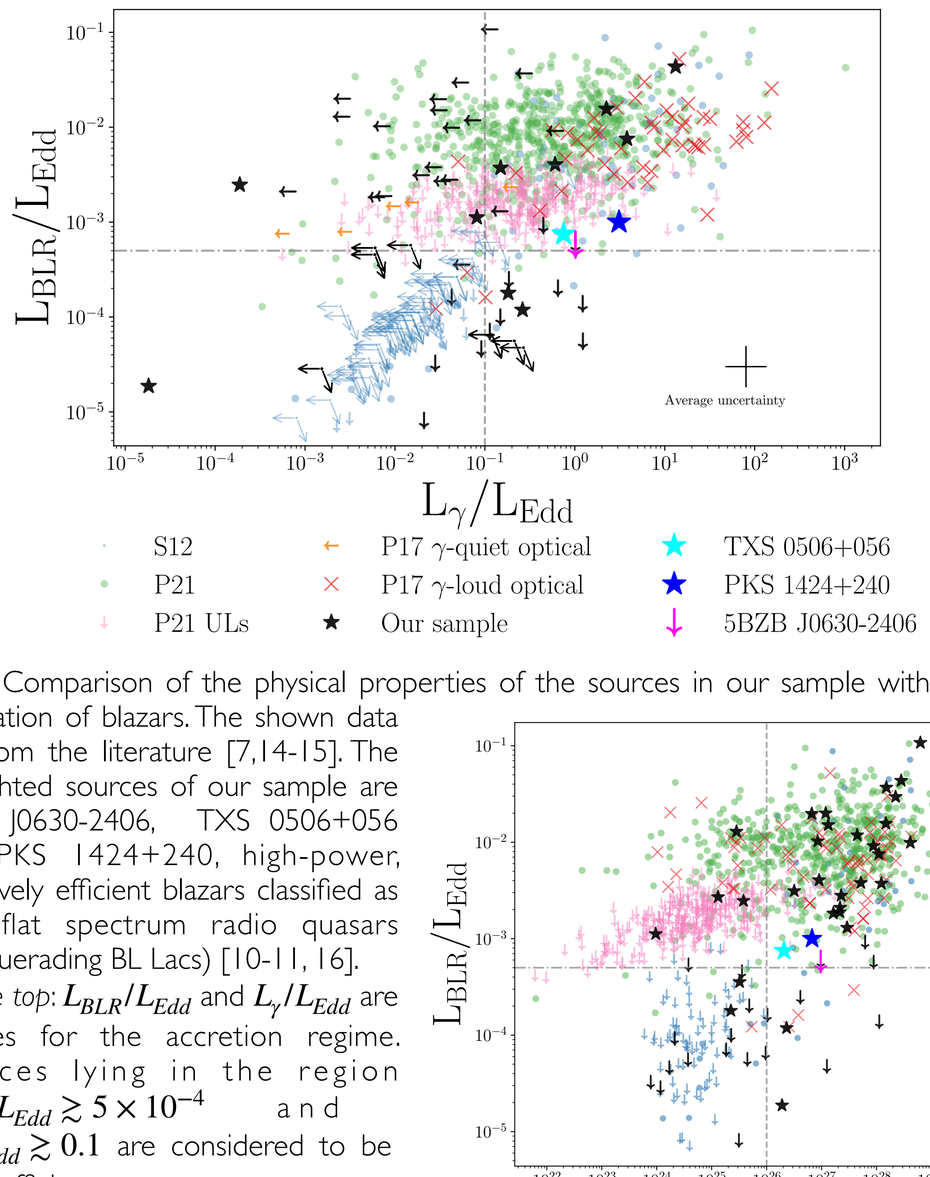


Fig. 1: Comparison of the physical properties of the sources in our sample with the overall population of blazars. The shown data are from the literature [7,14-15]. The highlighted sources of our sample are 5BZB J0630-2406, TXS 0506+056 and PKS 1424+240, high-power, radiatively efficient blazars classified as blue flat spectrum radio quasars (masquerading BL Lacs) [10-11, 16].
*On the top*: $L_{BLR}/L_{Edd}$ and $L_\gamma/L_{Edd}$ are proxies for the accretion regime. Sources lying in the region $L_{BLR}/L_{Edd} \gtrsim 5\times10^{-4}$ and $L_\gamma/L_{Edd} \gtrsim 0.1$ are considered to be highly efficient accretors.
*On the right*: $L_{BLR}/L_{Edd}$ vs. the power of the jet as probed by the radio power. The dashed line corresponds to the value $P_{1.4\,GHz} > 10^{26}\,W\cdot Hz^{-1}$, above which the population of HERGs (high-luminosity and radiatively efficient sources) dominates over LERGs.




## The PeVatron blazars candidates

Our work focuses on the investigation of the multi-wavelength properties of the 5BZCat blazars [6] found as candidate astrophysical counterparts of IceCube high-energy neutrinos through the positional cross-correlation analysis presented in [3-5]. These objects, i.e. candidate PeVatron blazars, include 10 located in the southern ($-85° < \delta < -5°$) and 42 in the northern ($-3° \leq \delta \leq 81°$) celestial hemisphere.

**METHODS:**

- *Optical data* were collected from public archives, the literature and proprietary data with ESO Very Large Telescope (VLT) X-Shooter, Gran Telescopio Canarias (GTC) OSIRIS and Gemini South Multi-Object Spectrographs (GMOS). We exploited the emission spectral lines (or placed upper limits when absent) from the BLR to estimate the physical properties, i.e. the redshift, luminosity of the BLR,, black hole mass and Eddington luminosity. The ratio $L_{BLR}/L_{Edd}$ traces the accretion properties of blazars [1, 7].
- The *γ-ray* luminosity was estimated using the Data Release 3 of the Fermi Fourth Catalog of Active Galactic Nuclei (4LAC-DR3). We estimated upper limits for the sources with no LAT detection. The ratio $L_\gamma/L_{Edd}$ traces the accretion regime and $L_\gamma$ is a proxy for the power of the jet [7].
- Information about the *radio power* were derived from the NRAO VLA Sky Survey (NVSS) at 1.4 GHz. $P_{1.4\,GHz}$ is a complementary proxy for the jet power [8-9].

## The physical properties

Our sample includes blazars traditionally classified as both BL Lacs and FSRQs. We followed a physical classification based on the accretion properties and the radio power: blazars with radiatively efficient mass accretion are characterized by $L_{BLR}/L_{Edd} \gtrsim 5\times10^{-4}$ and $L_\gamma/L_{Edd} \gtrsim 0.1$ [7]; at $P_{1.4\,GHz} \gtrsim 10^{26}\,W\cdot Hz^{-1}$, HERGs dominate over LERGs [8-9]. We compared the properties of the candidate PeVatron blazars to three literature samples in which our same methodology is used:

- S12 [7] contains blazars with both measurements and limits in both optical and γ-rays from the Sloan Digital Sky Survey (SDSS-DR7) and 1LAC.
- P17 [14] lists blazars with and without LAT detection ("γ-loud" and "γ-quiet" subsamples, respectively), in which the physical properties are estimated through serveral methods. We narrow down to the objects that were analyzed by optical spectroscopy.
- P21 [15] includes all the γ-ray emitting blazars listed in 4FGL-DR2 with optical counterpart in SDSS. The properties from optical spectroscopy list both measurements and limits.

Compared to the overall blazars population, the candidate neutrino-emitter blazars (see Fig. 1):

- ✦ Show a mild tendency toward intense radiation fields (~61% of the candidates), which are typical of radiatively efficient accretors, and high radio power (HERG-like);
- ✦ Half of the blazars are detected by Fermi-LAT; they cover *various ranges of γ-ray luminosities*, $L_\gamma \in [1.43\times10^{42}, 1.21\times10^{48}]\ erg\cdot s^{-1}$;
- ✦ Display properties compatible with those of the overall population [12-13];
- ✦ The sample includes *5BZB J0630-2406*, traditionally classified as BL Lac due to lack of emission lines in the optical spectrum, and then proposed as "blue FSRQ" in [10-11] (a.k.a. "masquerading BLLac"). We estimate accretion rates $L_{BLR}/L_{Edd} \lesssim 5.79\times10^{-4}$, $L_\gamma/L_{Edd} \lesssim 1.02$ [13].

**SUMMARY:** We observed a mildly higher representation of HERG sources, indicating a preference for objects with relatively high accretion efficiency, strong radiation fields, and higher radio power. In a multimessenger view, this would be consistent with theoretical models that predict enhanced neutrino production in such environments as well as with evidences supporting radio-bright objects as neutrino candidate emitters.

The difficulty in ascertaining the individual neutrino/blazar associations prevents us from drawing definite conclusions. Forthcoming dedicated studies will tackle the genuineness of the associations, in order to shed light on the link between blazars and neutrinos.

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