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BL Lac population study at high energies

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Abstract. The population of BL Lacs emitting at High Energy ($>$ 100 MeV) is used in order to constrain the jet characteristics of the objects: its intrinsic luminosity, Lorentz factor and geometrical opening angle. The density of the AGN population associated with BL Lacs and the Doppler factor of the objects detectable at HE are estimated as a function of the jet parameters. The study is based on Monte Carlo simulations and *Fermi*'s 2nd AGN catalog results.

Keywords: AGN, BL Lacs, FRI, Unification, Jet, High energy
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INTRODUCTION

BL Lacs are blazars, AGN whose jet is believed to be directed towards us. Their observed emission is thus amplified by the relativistic Doppler boost. In the framework of AGN unification, blazars are associated with a parent population. The objects from both populations intrinsically have the same characteristics and the observed differences are explained by the orientation of the jet compared to the line of sight. Fanaroff Riley type I (FRI) radio galaxies form the parent population usually associated with BL Lacs on the basis of radio, optical and X-ray observations (see [1] and references therein).

BL Lacs are also the most energetic type of AGN. At Very High Energy ($>$ 100 GeV), $\sim$50 blazars have now been detected with the current generation of Atmospheric Cherenkov Telescopes (ACT). At High Energies (between 100 MeV and 100 GeV), more than a thousand blazars have been reported in *Fermi* 2nd AGN catalog. To explain emission of blazars at these energies and considering the constraints arising from fast variability and/or large optical depth to pair production, simple radiative models need high values of Doppler factors δ $(30-50)$, thus high velocity (Lorentz factor Γ) jets oriented close to the line of sight[1]. Since large Γ lead to small radiative opening angles for the jet, blazars are statistically rare objects. The large population of BL Lacs detected at extreme energies implies a much larger parent population, composed of the same type of AGN but with their jets directed away from us. With such high values of δ the density of the parent population of BL Lacs could be larger than that of FRI, their common counterpart. A possible way out of this Doppler factor crisis [2] is to consider a jet with a geometrical opening angle increasing the probability of seeing an object within the jet's cone.

In this study, the population of BL Lacs emitting at HE is considered to constrain the

[1] Doppler factor is defined as $\delta = [\Gamma(1-\beta\cos\theta)]^{-1}$, where θ is the radiative opening angle of the jet and $\beta = v/c$ where v is the jet velocity.

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intrinsic properties of these objects. The focus is on investigating the jet characteristics, particularly its geometric opening angle and how this characteristic scales with the density of the parent population. Extensive Monte Carlo simulations of the parent population are performed and the distribution of objects detectable by current instruments is compared to data, mainly *Fermi*'s 2$^{\text{nd}}$ AGN catalog [3].

PRESENTATION OF THE STUDY

For a population study, the sample of AGN detected at VHE is still statistically limited and suffers from not being complete and unbiased. Detected under sky survey mode of observation, the sample of AGN reported in *Fermi*'s 2$^{\text{nd}}$ AGN catalog is better suited to such a study. From this catalog, the AGN labeled as BL Lacs – belonging to the clean sample and with known redshift (z) – their flux measured between 100 MeV and 100 GeV, spectral index and reported redshift as well as *Fermi*'s sensitivity are used. The relation between the spectral index and the energy of the peak emission presented in [4] is also used.

Simulation

The spectral energy distribution of BL Lacs is characterized by a double bump structure. This study concentrates exclusively on the high energy peak of the emission - covered by *Fermi* and the ACTs. Looking at this emission coming from the jet, the intrinsic properties of the objects are screened by the Doppler boost. The observed emission is completely characterized by the spectral shape, the energy (E_p) and the luminosity (L_p) of the emission peak. The observables chosen to access the intrinsic characteristics are $E_p = \delta E_p^i$ and $L_p = \delta^3 L_p^i$ (where i stands for intrinsic). The spectral shape is not modified by the Doppler boost. For the high energy peak emission of the parent population, we assume a unique empirical spectrum shape, a broken power law with curved transition derived from contemporaneous spectrum of BL Lacs measured with *Fermi* and ACTs. We also assume a power law distribution for the jet luminosity and Lorentz factor, and a relation between E_p^i and L_p^i ($L_p^i = e^C (E_p^i)^{-0.45}$). Finally, we make the hypothesis that AGN have two symmetrical jets with continuous out flow and a homogeneous spacial distribution up to $z = 0.5$.

For each object of the parent population, the intrinsic characteristics (Γ, L_p^i, E_p^i), the redshift, and the orientation of the jets compared to the line of sight are simulated. The Doppler boost is applied to the emission. Using the empirical spectral shape, the fluxes in the energy ranges covered by *Fermi* and by the ACTs are calculated. The absorption due to the extragalactic background light is taken into account considering Franceschini's model [5]. The simulations are performed for different jet characteristics: geometrical opening angle, minimal value for the Lorentz factor ($\Gamma_{\min}$), power law index of the Lorentz factor distribution (α_Γ) and that of the intrinsic luminosity distribution (α_L), and normalization of the relation between L_p^i and E_p^i (C). The number of objects found to be detectable by *Fermi* (or by the ACTs), their distribution in the $E_p - L_p$ plan and their Doppler factor are the output of the simulations.

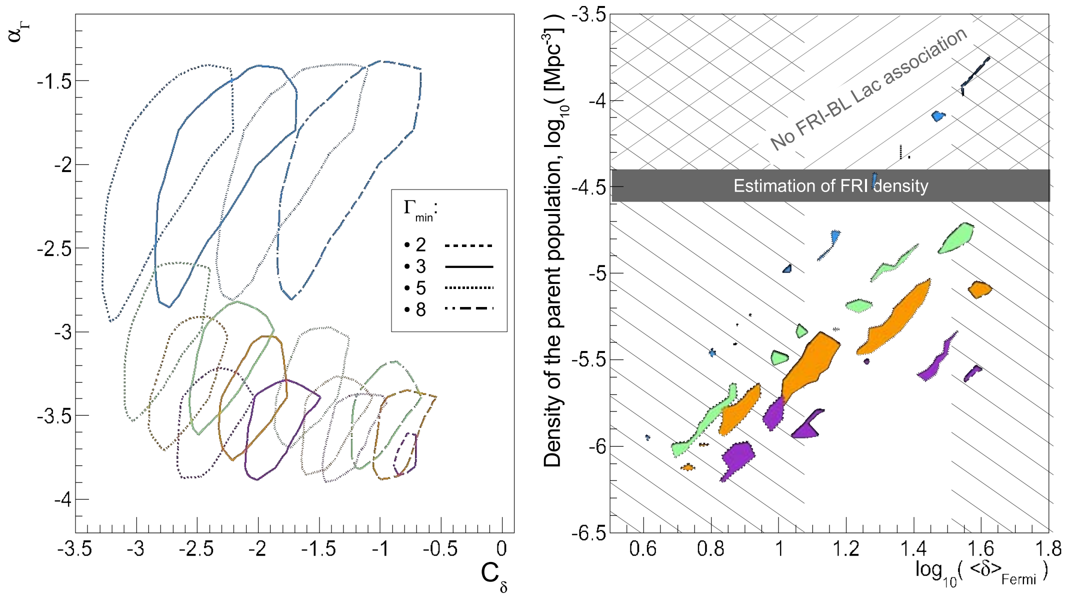

FIGURE 1. Constraints on the jet characteristics. Colors represent different geometrical opening angle of the jet, from top to bottom: 0°, 5°, 10°, 20° in respectively blue, green, orange and purple. **Left**: Within the contours are the simulated jet characteristics for which the $E_p - L_p$ objects distribution is compatible within 3σ with the distribution of BL Lacs detected by *Fermi*. For a given C, $C_\delta = \log(\delta_{\text{min}})$ where δ_{min} is the minimal Doppler factor needed for an object at $z = 0.001$ to be detectable by *Fermi*. **Right**: Colored region are the densities of parent population simulated with the jet parameters contained in the 3σ contours of the left figure. $< \delta >_{Fermi}$ is the mean Doppler factor of the AGN found to be detectable by *Fermi*. The usual range of δ for BL Lacs in Synchrotron Self Compton models lies in the un-hatched region.

RESULTS

The simulated distribution - in the $E_p - L_p$ plane - of AGN detectable by *Fermi* is compared to the experimental one using a likelihood measure. The intrinsic luminosity distribution of the parent population is found consistent with a power law of index $\alpha_L = -2$. The full range of simulated jet characteristics compatible with *Fermi* data is represented on Fig.1-Left. Since no value of geometric opening angle could be excluded, other observables have been extracted from the simulation to get further constraints.

The simulated density of the parent population is calculated, normalizing the number of objects detectable at HE to the number of BL Lacs detected by *Fermi*. This density is a lower limit. Indeed, it only considers the objects above the minimal intrinsic luminosity below which AGN could not be detected by current instruments - regardless of their boost. This lower limit is bound to increase as the sensitivity of the instruments gets better with time. Fig.1-Right represents the density of parent population as a function of the mean δ of the AGN found to be detectable by *Fermi*. The filled regions represent densities compatible with Fermi data. The simulated parent population density cannot be higher than that of FRI type AGN, if those AGN are associated with BL Lacs. The density of FRI can be roughly estimated supposing they represent $\sim 10\%$ of the elliptical galaxies. As illustrated on Fig.1-Right, within this limit it seems difficult to reach high δ without considering a geometric opening angle for the jet.

The number of AGN found to be detectable at VHE does not further constrain the results as it is compatible with the number of BL Lacs detected by the current generation of ACTs.

BL Lacs with unknown redshift cannot be taken into account in this kind of study. It has been argued that most of these objects could have $z > 0.5$ [6], so in order to lessen the affect of this biased we limited our work to $z < 0.5$. A toy Monte Carlo simulation showed that the distribution of BL Lacs detected by Fermi can be reproduced under the hypothesis of the previously described intrinsic relation between the luminosity and energy of the emission peak. The impact of this relation on the data remains to be fully investigated.

CONCLUSION

Within the framework of AGN unification, and assuming simple hypotheses for the parent population, we investigated the jet properties of BL Lacs using *Fermi*'s 2$^{\text{nd}}$ AGN catalog and extensive Monte Carlo simulations. The intrinsic luminosity distribution and jet velocity of BL Lacs emitters at high energy are constrained. Lower limits on the density of their parent population were derived. For Doppler factors higher than 20, it appears difficult to consider FRI as the parent population of BL Lacs without a geometric opening of the jet.

The current sample of AGN detected at VHE is not fit for population studies. It is highly biased and not flux limited. A blind sky survey would be the answer. If this mode of observation is not achievable by the current generation of ACT, the next one, CTA should be able to do it [7].

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