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BL Lac population study: early results using *Fermi* 11-month catalogue and the perspectives with CTA.

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In the framework of AGN unification, BL Lacs and their parent population would share the same intrinsic characteristics, the observational differences being due to the orientation of the jet compared to our line of sight (LOS). BL Lacs would be those objects whose jet is oriented towards us, Doppler boosting the emission. The growing number of BL Lacs detected at HE (> 100MeV) and VHE (>100GeV) is a challenge for this scheme, since the high values of Doppler factors needed to explain the emission of these sources imply a large density for the parent population.
We studied the BL Lac source sample detected by *Fermi* after 11 months of observation. Using the data presented in *Fermi*'s first AGN catalogue, we put constraints on the intrinsic characteristics of this BL Lac population, such as the intrinsic luminosity and Lorentz factor distributions. Based on these results, we used Monte Carlo simulations to constrain the space density of the parent population and the jet opening angle. The current number of AGNs detected at VHE energies is not yet large enough to put constraints on the statistical properties of the detected sources, but the next-generation Cherenkov Telescope Array (CTA) should change this situation.
In this paper, we present the preliminary study using *Fermi*'s results and then comment on CTA's future impact upon this kind of study.

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1. Introduction

One of the key issues of the study of AGNs is to explore the possibility to organize the different classes of objects within a unified vision. In this unification scheme, AGNs would share the same intrinsic characteristics and the observed differences would be due to the orientation of those highly anisotropically emitting objects compared to our line of sight (LOS). In the particular case of blazars, the relativistic jet would be directed towards us, Doppler boosting the emission and the parent population would be composed of the objects whose jet is directed away from us.

In the simplest emission models which generally reproduce fairly well the observed average emission of most AGNs, the opening angle of the jet depends only on the relativistic beaming – this angle decreasing as the Lorentz factor increases. In this context, the growing number of blazars detected at HE (> 100 MeV) and VHE (> 100 GeV) – mainly BL Lac at VHE energies – implies a large density for the parent population. Indeed, the high values of Doppler factors needed to explain the emission of these sources at such energies require large Lorentz factors and a jet directed close to our LOS. The probability to see a blazar is then very much reduced, leading to the so-called "Doppler factor crisis" [1] which denotes the contradiction between the high values of Doppler factor needed in the simple one zone emission model and those, much smaller, inferred from the unification between blazars and radio-galaxies. The BL Lacs detected at HE and VHE are used to test the unification model. The large population detected by *Fermi* is mainly used to constrain some of the intrinsic characteristics of these objects before using Monte Carlo simulations to investigate the density of the parent population and the jets of these objects whose geometry is still poorly known. The preliminary results of this study are presented in section 2. Conclusions and perspectives using CTA are reviewed in section 3.

2. Study presentation and preliminary results

The spectral energy distributions (SEDs) of blazar-type AGNs are characterized by a two-bump structure. This study focusses on the average emission of the peak located at the highest energies, partially covered with *Fermi* and the Atmospheric Cherenkov Telescopes (ACT). For BL Lacs, the observed emission is Doppler boosted. If we assume a universal spectral shape, the SED is completely characterized by two parameters: the energy position E_p and luminosity L_p of the peak. The boost doesn't affect the shape of the SED but simply shifts it in energy and luminosity and so the study of the statistical distribution of E_p and L_p will allow to put constraints on the intrinsic characteristics and the geometrical parameters of the jet.

2.1 Intrinsic characteristics of *Fermi*'s BL Lac population

We use the fluxes and the spectral indexes measured by *Fermi* and presented in the 11-month catalogue [2]. The study is limited to the objects whose redshift is known and below 0.5. To estimate E_p and L_p for each BL Lac, we use the relation between E_p and the spectral index measured by *Fermi* [3] and assume a unique empirical spectral shape – a broken power law with curved transition – whose only ambition is to account for the fluxes measured at HE and VHE. E_p and L_p are

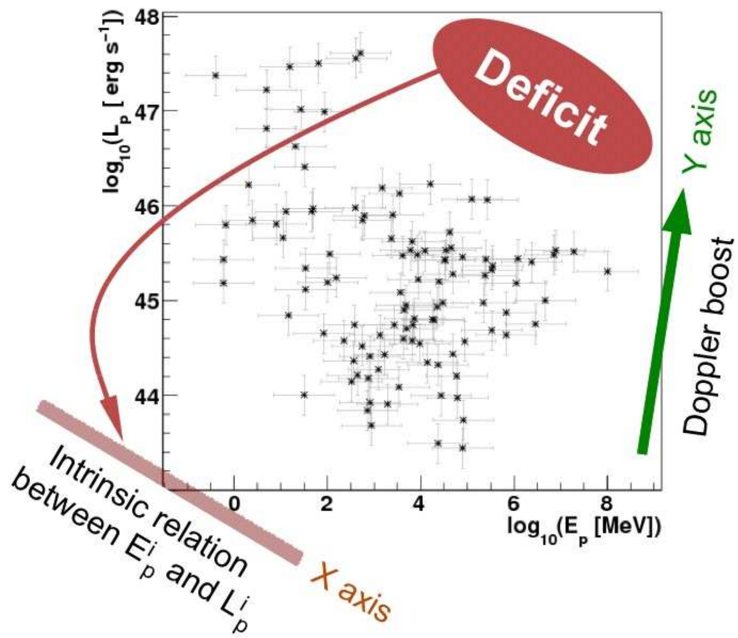

Figure 1: *Peak luminosity and energy position of the BL Lacs detected by Fermi, with known redshift. The errors represent the uncertainties in the determination of L_p and E_p using the method described in the text. The red axis (X) represent the direction of the relation between intrinsic value of the energy position E_{p_i} and luminosity L_{p_i} of the peak. The green one (Y) represent the direction of the Doppler boost.*

linked to their intrinsic values E_{p_i} and L_{p_i} – where the *i* stands for "intrinsic" – such as :

$$E_p = \frac{\delta}{1+z} E_{p_i} \tag{2.1}$$

$$L_p = \delta^p L_{p_i} \tag{2.2}$$

where δ is the Doppler factor, p is equal to 3 which correspond to a continuous jet flow and z is the redshift.

Figure 1 features the E_p and L_p of the BL Lacs detected by *Fermi* used in this study. A deficit at high E_p and high L_p is observed. Neither the Doppler boost – translating the objects along the green axis represented in figure 1, named "Y axis" – nor *Fermi*'s sensitivity can explain this effect. On the other hand, such an effect would be expected in the case of an intrinsic relation between the values E_p and L_p, namely E_{p_i} and L_{p_i}. This relation is symbolized by the direction of the red axis in figure 1, named "X axis".

We assume this intrinsic relation – expected in case of a the blazar sequence [4] – and estimate the link between E_{p_i} and L_{p_i} to be such as $\ln(E_{p_i}) = -0.45\ln(L_{p_i}) + C$ – where C is an unknown constant. The distribution of intrinsic luminosities is obtained by projecting the objects along the Doppler boost axis onto the X axis – thus canceling the boost effect – and taking *Fermi*'s horizon into account. The objects distributed along the direction of the assumed intrinsic relation are supposed to have the same Doppler factor value. Considering this effect, the Doppler factor distribution is constructed, using the same method: now projecting the objects along the X axis onto Y axis. Both the intrinsic luminosity and Doppler factor distributions are compatible with power laws: $\mathrm{d}N/\mathrm{d}L_{p_i} \propto L_{p_i}^{-1.75\pm0.4}$ and $\mathrm{d}N/\mathrm{d}\delta \propto \delta^{-2.8\pm0.4}$ respectively. The slope of the distribution of Doppler factors excludes a unique Lorentz factor for the entire population and is used to constrain the distribution of Lorentz factors.

2.2 Monte Carlo simulation of parent populations

Since there are few non-blazar AGN detected at HE and VHE, we test the unification scheme with Monte Carlo simulations using the previous working hypothesis and constraints. We assume an intrinsic relation between E_p and L_p. We also assume the previously determined distribution of intrinsic luminosities and a power law distribution of Lorentz factors with an index of -1.8 if we consider jets without geometrical opening, or -3.8 for jets with geometrical opening of 16 degree, in order to reproduce the distribution of Doppler factors obtained in the previous section. The parent populations are simulated for different values for the geometric opening angles of the jet, minimal values of Lorentz factors and intrinsic positions of the objects in the E_p-L_p plane (constant C in the relation between E_{p_i} and L_{p_i}) – these are the free parameters of the simulations. Objects are simulated as being isotropically distributed up to a redshift of 0.5, with two symmetrical jets randomly oriented compared to our LOS. The effects of Doppler boost and red-shift of the SED are simulated using the relations presented in equations 2.1 and 2.2. For each AGN the flux in the energy band covered by Fermi is calculated and compared to the 11-month sensitivity of the instrument in order to select the detectable objects.

To determine the valid sets of free parameters, we compare, the distributions of objects simulated as detectable by *Fermi* to the distribution of those experimentally detected by *Fermi*. To do this, the total number of objects simulated as detectable by *Fermi* is normalized to the experimental value. The E_p-L_p plane is divided in bins, whose size depends on the uncertainties in the determination of the experimental values of L_p and E_p. The likelihood between the simulated and observed distributions of objects in the E_p-L_p plane is calculated using the Poisson probability law associated to the number of objects in each bin.

The BL Lac population detected by *Fermi* could be reproduced with a single parent population with jets randomly oriented compared to our LOS. The density of the simulated parent population and the mean value of the Doppler factors corresponding to the population of AGNs simulated as detectable by *Fermi* are the results of the simulations. Figure 2 shows this results for those simulations with the best likelihood when comparing distributions of AGNs detectable by *Fermi* to the observed one. Various sets of free parameters are acceptable and experimental constraints on the density of the parent population and the Doppler factors of the objects detected by *Fermi* are needed to remove the free parameters degeneracy. The density of the parent population is normalized in order to account for the number of BL Lacs detected by *Fermi*. This density has to be considered as a very conservative lower limit, calculated above the intrinsic luminosity value below which no constraint is available because it would not be possible to detect AGN with *Fermi*'s 11-month sensitivity.

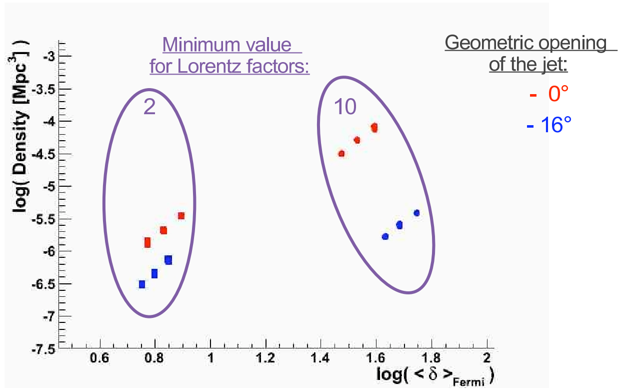

Figure 2: *Lower limit of the parent population density versus the Doppler factor mean value of the AGN simulated as detectable by Fermi. These values are obtained for sets of parameters giving a distribution of AGN in the E_p-L_p plane compatible with the observed distribution measured by Fermi. Results of the simulations with jets with or without a geometric opening angle and represented blue or red respectively.*

3. Conclusions and perspectives with CTA

Some intrinsic characteristics of the BL Lac population has been constrained using *Fermi* 11-month catalogue. As expected within the framework of AGN unification, Monte Carlo simulations have shown that it is possible to account for the BL Lacs detected by *Fermi* with a single parent population. To further constrain the jet geometry of these objects one needs to consider the experimental density of the parent population. Since only few non-blazars are detected at HE and VHE, this density has to be looked for at other wavelength where the emission is dominated by the isotropic component which will have to be taken into account in the simulations. Assuming the jet luminosity is independent of the galaxy luminosity (see e.g. [5]), another way to experimentally determine the density of the parent population is to consider the luminosity distribution of the host galaxies. Using the blue luminosity as a proxy for the galaxy luminosity, the density of FRI type AGN is estimated to be around $10^{-4.5}$ Mpc^{-3}[6]. If we assume the association between BL Lac and FRI, the simulated parent population density has to be below this limit. Considering this constraint, it is difficult to reach high Doppler factor without considering a geometrical opening angle for the jet. This work is also to be continued with *Fermi*'s second AGN catalogue. The flux sensitivity of the instrument increasing with time, new constrains on the lower limit of the density of the parent population will be derived thanks to this new data set.

The tools used for this study have been adapted in order to select the BL Lacs that would be visible by CTA among those detected by *Fermi*. The sensitivity of *Fermi* after 11 months of observation, that of the current generation of ACT, as well as that expected for CTA [7] are

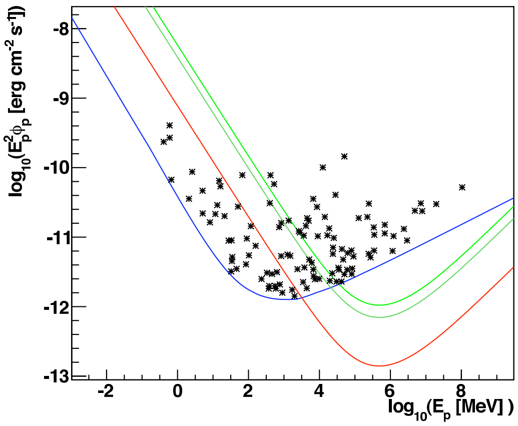

Figure 3: *Power and energy position of the emission peak for the BL Lac detected by Fermi, with known redshift. The sensitivities, above 200 GeV, are represented in green, for the current ACT generation in 20h and 50h of observation (flux sensitivities for both observation time: 2 and* $3 \times 10^{-12}\,\mathrm{ph\,cm^{-2}\,s^{-1}}$*), and in red for CTA in 50h of observation (flux sensitivity:* $4 \times 10^{-13}\,\mathrm{ph\,cm^{-2}s^{-1}}$*). Fermi sensitivity after 11-month of observation is represented in blue.*

represented in figure 3, together with the BL Lac population detected by *Fermi*. We estimate that 66 objects among the ~ 110 *Fermi* BL Lacs with known redshift[1] would be detectable with CTA – twice the number compared to the current generation of ACT. This is a lower limit, since the VHE flux cannot be calculated for half of the BL Lac detected by *Fermi* with unknown redshift, and because part of the fluxes that would be accessible with CTA are not seen with *Fermi*. With this rough estimation, we can be confident that CTA will provide a population of BL Lacs at least as large as *Fermi*'s current one. It will then be possible to carry out the same kind of study and derive constrains from the VHE observations of the sources.

References

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[7] CTA Consortium, 2010, ArXiv:1008.3703

[1]This information is needed in order to estimate the extragalactic background light absorption in the energy range to be covered with CTA.