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## Clues on Blazars Phenomenology from the FIRST Flat Spectrum Sample

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**Abstract.** We highlight some results of our work on the FIRST Flat Spectrum Sample (FFSS) of blazars, in particular concerning the relationship between their luminosity and Spectral Energy Distribution (SED), including preliminary results on the power of the emission of their Broad Line Region (BLR). The current analysis shows that within the FFSS, which captures at once a broad range of blazar phenomenology, the SED-power correlation which constituted the observational basis of the blazar sequence hypothesis seems to be present. We also find that FFSS BL Lac and FSRQ sources, despite having been selected together, tend to stay separate with respect to several properties, such as SED type and luminosities (e.g. radio,  $\gamma$ -ray, BLR). The BLR analysis suggests that in BL Lac objects the BLR is indeed under-luminous compared with FSRQ. This in turn suggests that ratio between thermal and non-thermal emission in the two classes of objects is different. Finally, we discuss some clues emerging from the study of the sample of blazars detected at GeV  $\gamma$ -rays by Fermi/LAT, focusing again on the question of power of SED properties.

### 1. Introduction

Over the last several years we have seen limited progress in our understanding of radio-loud AGNs (Urry & Padovani 1995). Important questions remain open about their demographics and understanding of their broad phenomenology. While disputed, the general concept of the blazar sequence introduced by Fossati et al. (1998) and Ghisellini et al. (1998) (see also Ghisellini & Tavecchio 2008) has remained the leading “general” framework for organizing and hopefully understanding the properties of blazars. Fossati et al. (1998) showed that blazar SEDs exhibit a systematic change with luminosity: the most powerful objects are red, while relatively weak sources are associated with blue SEDs<sup>1</sup>. Observations also suggested a trend where red blazars, i.e. more powerful jets, are accompanied by stronger “thermal” emission component (e.g. broad line, accretion disk emission) than blue blazars (these latter thus almost coinciding with BL Lacs). The idea was that blazars indeed constitute a spectral sequence, with source power as the fundamental parameter, and the existence of a connection between jet and disk. Accretion rate may be the main parameter governing total power and ratio between jet and accretion luminosities (e.g. Maraschi & Tavecchio 2003; Wang et al. 2004; Xie et al. 2007)

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<sup>1</sup>SED color is defined on the basis of the energy of the synchrotron component peak ( $\nu F_\nu$ ).

The *Fermi*/*LAT* all sky survey is providing a wealth of new data (Abdo et al. 2009a) in a frequency band that offers crucial clues about two properties of the IC component that are fundamental to address the open questions on blazar unification: its position and luminosity. The first *Fermi* results suggest a correlation between  $L_\gamma$  and the  $\gamma$ -ray spectral index (an indicator of the peak frequency of the  $\gamma$ -ray component) consistent with the blazar sequence hypothesis (Abdo et al. 2009a,b). Ghisellini et al. (2009a) were the first to highlight the remarkable separation of BL Lac and FSRQ objects in the first *Fermi* sample (see Figure 1), and proposed an interpretation in terms of critical accretion rate determining the connection between accretion, jet and thermal component powers. Ghisellini et al. (2009b), by means of SED physical modeling of *Fermi* bright blazars, find a positive correlation jet and accretion disk luminosity for FSRQs, while BL Lacs deviates from it, suggesting a radiatively inefficient accretion regime.

## 2. FIRST Flat Spectrum and *Fermi* samples and blazar sequence

Because of the broad range of their spectral properties, blazar samples have traditionally been affected by severe observational biases in particular with respect to the sensitivity to SED color and thermal properties. Motivated by the need of better samples of blazars overcoming these limitations, we have been working on the characterization of the FIRST Flat Spectrum Sample (FFSS, Fossati 2005), a new kind of deep radio sample, unbiased with respect to X-ray emission, designed to capture the widest possible range of phenomenology at once. The FFSS comprises about 600 objects representing a very diverse mix of FSRQ, BL Lacs, “galaxies”, and SED colors. Here we highlight preliminary results concerning their BLR luminosity,  $L_{BLR}$ . We combine them with findings from the *Fermi*/*LAT* one year sample to address observationally the question of the differences between BL Lacs and FSRQs. There are aspects that we don’t discuss here, such as the effect of possible different beaming, especially relevant at the low luminosity end of the population. However, working with a large sample should allow us to draw results that are robust in a population, statistical sense. We are conducting a more sophisticated analysis by population synthesis modeling, including finer effects and observational biases.

### 2.1. *Fermi* blazars: SED-power relationship

Knowledge of the  $\gamma$ -ray luminosity is crucial to have a meaningful discussion about the power of blazar jets. Figure 1 shows two ways of looking at the question of the existence of a connection between jet power (approximated by  $\gamma$ -ray luminosity) and SED type, for which we take two “estimators”: the *Fermi*/*LAT* spectral shape (indicative of the position of the IC peak) and  $\alpha_{RO}$  (a tracer of the synchrotron peak). These latter parameter is completely independent from  $L_\gamma$ . In both cases the SED-estimators are well correlated with  $\gamma$ -ray power, in the sense of lower peak energies for higher jet radiative power.

It is natural to wonder if the lack of objects at low  $\gamma$ -ray luminosity and soft  $\gamma$ -ray spectrum (i.e. low IC peak frequency) is an observational bias. Simulations are in progress and will be necessary to address this question on a sound statistical basis. We would, however, like to note that most of the sources below

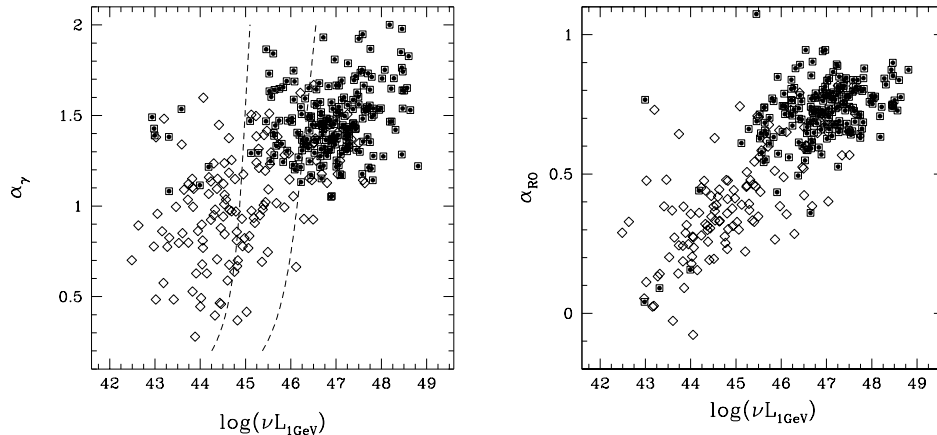


Figure 1. Relationship between SED spectral shape and source power, here represented by means of the 1 GeV  $\nu L_\nu$  luminosity, for about 340 blazars from the 1FGL catalog (those for which we found a redshift). Diamonds are BL Lac objects, and dotted-squares are FSRQs. On the left side, the classic (Ghisellini et al. 2009a)  $\gamma$ -ray Fermi/LAT spectral index, which can be regarded as a rough measure of the peak position of the inverse Compton component. Dotted lines represent the luminosity corresponding to the *Fermi/LAT* flux limit at  $z = 0.3$  and  $1.0$ . On the right panel the SED-shape estimator is the broad band radio-optical spectral index, which is a somewhat robust parameter, although it is not very sensitive to the most extreme blue SEDs.

$\log(L_\gamma) \simeq 45.0$  are at  $z < 0.3$ , and most of those between 45 and 46.5 have  $0.3 < z < 1.0$ , and in this second group the detection of objects with soft  $\alpha_\gamma$  if anything it seems to be better than for their harder siblings. This is to say that at first glance we don't see an obvious interpretation of the absence of soft-low power sources in terms of selection effects.

## 2.2. FFSS blazars: BLR luminosity

We have good-high quality optical spectra for all FFSS sources, and we estimate the BLR total emission with a technique similar to the one of Celotti et al. (1997), based on the scaling of the flux of a set of emission lines to the total BLR flux by means of a template spectrum (Francis et al. 1991). Not surprisingly, we could not estimate  $L_{BLR}$  for a large fraction of BL Lac objects, but in most cases the inferred upper limits seems to be distributed as to suggest that the properties of the detected objects might be representative of the whole sample (also on this, a careful analysis based in population synthesis simulations is in progress).

Here we would like to highlight the comparison of the BLR luminosity with optical<sup>2</sup> and radio powers, summarized in Figures 2 and 3. BL Lac objects span a broader range, in particular extending to significantly lower relative BLR luminosities. This is of course to be expected by virtue of the definition, and

<sup>2</sup>For weak blazars in bright host galaxies, we “corrected” the total observed optical flux to obtain the jet contribution by means of the observed Ca break value.

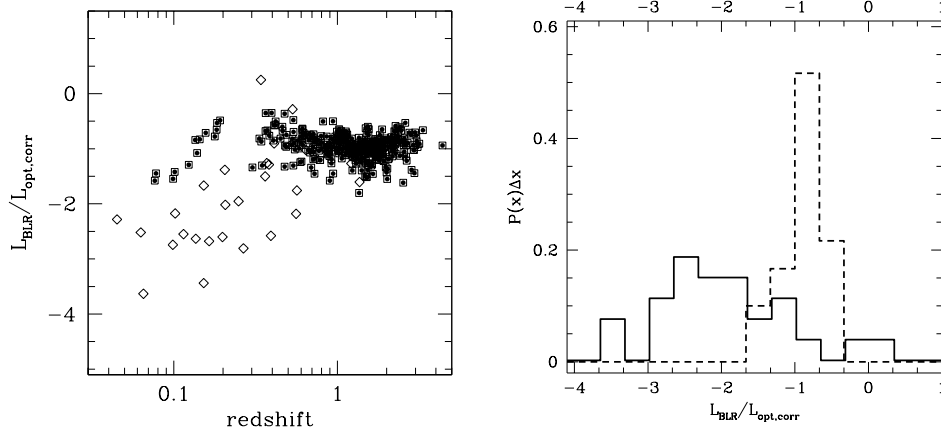


Figure 2. For the FFSS, ratio of the BLR luminosity to the corrected optical luminosity (see text). The histograms are limited to objects at  $z \leq 0.7$ .

in turn classification, of BL Lac object. What is rather more interesting is the remarkably narrow range of values for FSRQ around a mean value of about 1/10, which is a clue about some universal property of the broad line region.

We also looked at the ratio between BLR and radio luminosity, that seems to be a good tracer of the jet radiative power (Fossati et al. 1998, see also next section). The comparison of luminosities, as expected, suggests the existence of a correlation between the two, that is mostly driven by the common redshift dependence. More interesting is to note that at fixed radio luminosity BL Lacs consistently have less luminous broad line emission. A strict interpretation of the blazar sequence hypothesis would yield a transition to BL Lac-only at low  $L_{radio}$ , whereas these data show the appearance of a BL Lac “branch”, but still co-existing with a low (radio) power FSRQ one.

### 2.3. Broad line power vs. jet power

Having looked at the relationship between SED and source power, and BLR and source power, we took a look at how we could connect them to say something about the relationship between emission line and jet kinetic power. Our approach is quite empirical and statistical in nature, as we don’t have enough information on enough individual objects to perform a detailed analysis “physical” analysis. Recent work tackling this question directly on a individual bright sources has been presented by Celotti & Ghisellini (2008) and Ghisellini et al. (2009c,b).

What we did was looking for a connection based on observables between various quantities that could build a relationship between  $L_{BLR}$  and  $L_{kin}$ .

$$\frac{L_{BLR}}{L'_{jet}} = \frac{L'_{bol}}{L'_{kin}} \frac{L_{bol}}{L'_{bol}} \frac{L_{\gamma}}{L_{bol}} \frac{L_{radio}}{L_{\gamma}} \frac{L_{BLR}}{L_{radio}} = \epsilon \Gamma^2 \mathcal{R}_{\gamma,bol} \frac{L_{radio}}{L_{\gamma}} \frac{L_{BLR}}{L_{radio}}$$

$\mathcal{R}_{\gamma,bol}$  can be guesstimated by simple considerations about the peak IC luminosity vs. what observed in the *Fermi/LAT* bandpass, and about the relative

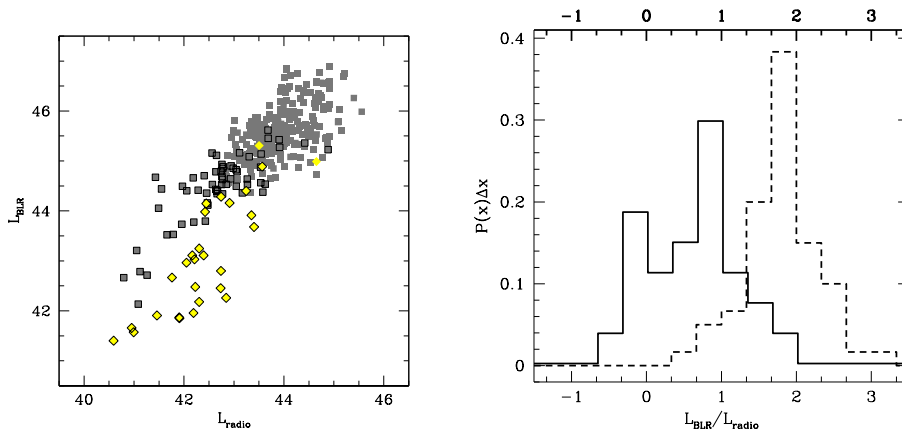


Figure 3. Comparison between BLR and radio luminosities for FFSS sources. Dark grey symbols and dashed line are used for the FSRQ subsample, and light grey symbols and solid line for the BL Lac subsample. The symbols with the black border identify sources at  $z \leq 0.7$ . The histograms in right panel show the distribution of the ratio for FSRQs and BL Lacs, restricted to the  $z \leq 0.7$  range, where both populations are present.

power of the IC and synchrotron components. It does not vary too much between BL Lacs and FSRQ, and it is a factor of the order of  $1/10$ – $1/3$  (low value for FSRQ). The last two ratios can be estimated from observations. The BLR–radio ratio (for FFSS) is shown in Figure 3 for BL Lacs and FSRQs. We adopt values of 50 and 5 for FSRQ and BL Lacs respectively. The distribution of the  $\gamma$ –ray–radio ratios (for the *Fermi/LAT* sample) is plotted in Figure 4, which shows that the suggestion that they are in a fixed ratio (i.e. correlated) remains strong (though somewhat mysterious). Using the above mentioned values for BL Lacs and FSRQs, and the  $\gamma$ –ray–radio ratio of each individual *Fermi/LAT* detected object, we obtained the distributions plotted in the right panel of Figure 4. With values “typical” for FSRQ we get

$$\frac{L_{\text{BLR}}}{L'_{\text{jet}}} = 2.5 \epsilon \left( \frac{\Gamma}{10} \right)^2 \left( \frac{\mathcal{R}_{\gamma, \text{bol}}}{1/5} \right) \left( \frac{L_{\text{radio}}/L_{\gamma}}{1/400} \right) \left( \frac{L_{\text{BLR}}/L_{\text{radio}}}{50} \right)$$

while for BL Lacs the value would be about a factor of  $> 10$  lower, i.e.  $\simeq 1/6$ . Distributions derived from the data are shown in Figure 4.

The final difference between BL Lacs and FSRQs is mostly determined by their respective differences in their BLR/radio power ratio, with possible adjustments due to the “bolometric” correction and  $\gamma$ –ray/radio ratio. It is in fact interesting that the data on this latter don’t show any major difference between FSRQs and BL Lacs or red vs. blue SED types.

This preliminary analysis relies on some pieces of evidence and assumptions that will require further verification. For instance, for some sources we can compare the inferred jet power with estimates based on direct modeling of their spectra (see references above).

It will be interesting to extend the analysis of observed BLR luminosities to all *Fermi* detected sources. This would allow us to investigate the relationship

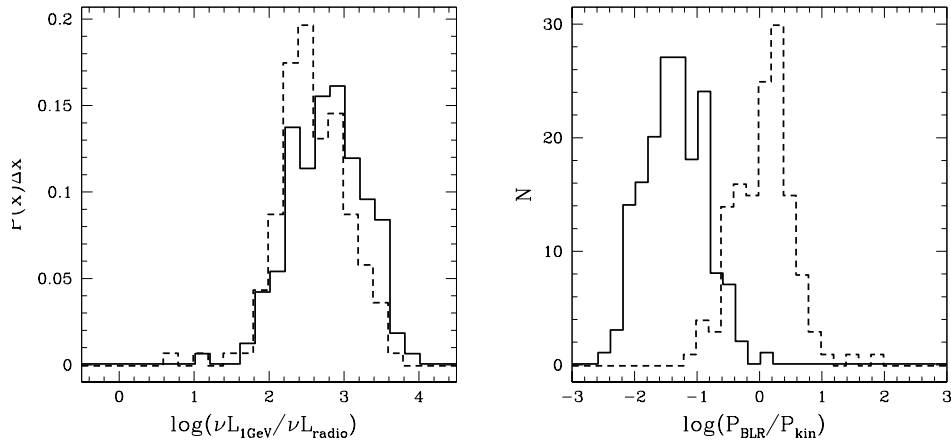


Figure 4. For about 340 blazars from the 1FGL catalog (those for which we found a redshift). Left: distribution of the  $\gamma$ -ray/radio power ratio for FSRQ and BL Lac objects. Right: ratio between BLR and jet power.

between BLR and jet properties without having to combine results from samples (i.e. FFSS and *Fermi*) that could be selecting different populations of blazars. It would indeed be interesting to verify if there are any significant differences between the  $\gamma$ -ray, IC, selected sample and those selected at frequencies sampling the synchrotron component. In this respect it is worth noting the relatively limited overlap between the *Fermi* sample and the collection of traditional blazar surveys.

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