A SIMPLIFIED VIEW OF BLAZARS: COMPARISON WITH MULTI-FREQUENCY OBSERVATIONS

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We have recently proposed a new scenario where blazars are classified as flat-spectrum radio quasars or BL Lacs according to the prescriptions of unified schemes, and to a varying combination of Doppler boosted radiation from the jet, emission from the accretion disk, the broad line region, and light from the host galaxy. This mix of different components leads to strong selection effects, which are properly taken into account in our scheme. We describe here the main features of our approach, which solves many long-standing issues of blazar research, give the most important results, and discuss its implications and testable predictions.

Keywords: blazars; radiation processes; active galactic nuclei

1. The problem

Blazars are radio loud active galactic nuclei (AGN) pointing their jets in the direction of the observer.1,2 Historically, they have been divided in two main subclasses, whose major difference is in their optical properties: 1) Flat Spectrum Radio Quasars (FSRQs), which show strong, broad emission lines in their optical spectra, just like classical quasars; and 2) BL Lacertae objects (BL Lacs), which at most show weak emission lines, sometimes display absorption features, and in some cases can be completely featureless. These two classes display many other differences in their: 1) extended radio powers; 2) redshift distributions; 3) cosmological evolutions; 4) synchrotron peak energy ($\nu_{\text{peak}}$) distributions. Finally, radio, X-ray, and $\gamma$-ray selected blazar samples show a very different mix of FSRQs and BL Lacs.

Some of these differences have been explained by the so-called unified schemes, which posit that BL Lacs and FSRQs are simply Fanaroff-Riley (FR) I/low excitation radio galaxies (LERGs) and FR II/high excitation radio galaxies (HERGs) with their jets forming a small angle with respect to the line of sight.2 However, unified schemes per se cannot account for transitional objects (that is, sources which sometimes move from one class to the other), which include, for example, even BL Lacertae itself and 3C 279, the different $\nu_{\text{peak}}$ distributions of FSRQs and BL Lacs (with the latter reaching much higher values), and the very different evolutions of radio and X-ray selected BL Lacs.
2. Our solution

To explain all of the above differences, in a series of papers\textsuperscript{3–5} we have proposed a new scenario (dubbed a simplified blazar view), which we kept as simple as possible and tied as much as possible to observational data. Our starting point is the observational fact that the optical spectrum of blazars is the sum of three components: a non-thermal, jet related one, one due to the accretion disk, and one host-galaxy related. Different mixes of these components determine the appearance of the optical spectrum and therefore the classification of sources in FSRQs (dominated by strong lines), BL Lacs (with diluted, weak lines, even if a standard accretion disk is present), and radio-galaxies (where the host galaxy swamps both the thermal and non-thermal nuclear emission). Our novel approach assumes a unique non-thermal “engine” for the two classes (based on a simple homogeneous synchrotron model), whereas the disk can be different. Namely, we associate a standard accretion disk only with HERGs, given that LERGs either do not possess one, or if they do, it is much less efficient (i.e., of the Advection Dominated Accretion Flow [ADAF] type).\textsuperscript{6} The other novel component is a single luminosity function (LF) whose evolution depends on radio power, with lower luminosity ($P_r < 10^{26}$ W/Hz) radio sources displaying a much weaker cosmological evolution than high luminosity ones. Further ingredients include the intrinsic (before dilution from the jet) distributions of the equivalent width (EW) of the broad lines, a “standard” elliptical host galaxy, and a disk-to-jet power ratio distribution, all derived from observations.\textsuperscript{3}

We thoroughly tested this new approach using Monte Carlo simulations and showed that it is consistent with the results of radio and X-ray blazar surveys and provides simple answers to most, if not all, long-standing, open issues mentioned above. A key result is that selection effects play a very important role in the diversity observed in radio and X-ray samples (and also in the correlation between luminosity and $\nu_{\text{peak}}$, the so-called “blazar sequence”).\textsuperscript{3,4} We also extended our approach to

![Fig. 1. Left panel: the spectral index of blazars in our simulated survey of 1,000 $\gamma$-ray sources vs. the $\gamma$-ray flux. FSRQs are plotted as filled red circles, BL Lacs as open blue circles. Right panel: the distribution of $\nu_{\text{peak}}$ for blazars in the Fermi 2LAC catalogue (black solid histogram) and our simulations (red dot-dashed histogram) for FSRQs (top panel) and BL Lacs (bottom panel).]
the $\gamma$-ray band by deriving the $\gamma$-ray to radio flux density ratio, $f_\gamma/f_r$, from the Compton dominance (the ratio between inverse Compton and synchrotron peak luminosities) and $\nu_{\text{peak}}$ for radio selected blazars.$^5$ Our $\gamma$-ray simulations are in agreement with the Fermi-Large Area Telescope (LAT) survey data, including the observed percentages of BL Lacs and FSRQs, the fraction of redshift-less objects and the redshift, $\nu_{\text{peak}}$, and $\gamma$-ray spectral index distributions (see, e.g., Fig. 1).

3. Implications

| LERG | HERG | viewing angle |
|------|------|---------------|
| strong optical jet dilution | BL Lac | \(\theta < \theta_{\text{blazar}}\) |
| weak optical jet dilution | radio galaxy\(^{(2)}\) | FSRQ | \(\theta < \theta_{\text{blazar}}\) |
| misdirected jet | radio galaxy | radio galaxy | \(\theta > \theta_{\text{blazar}}\) |

*Italic* denotes “masquerading” sources (see text), \(^{(1)}\)misclassified FSRQ, \(^{(2)}\)misclassified BL Lac

Table 1 summarizes the main implications of the *simplified blazar view*. Sources with their jets at small angles w.r.t. the line of sight (\(\theta < \theta_{\text{blazar}} \sim 15 - 20^\circ\)), and therefore dominated by non-thermal emission, are characterized by low values of the EWs and/or the so-called Ca H&K break. However, only LERGs belonging to this class are real BL Lacs, that is have intrinsically weak emission lines. HERGs, which have an accretion disk and therefore display strong emission lines, appear to show weak lines when these are swamped by non-thermal emission and are therefore “masquerading” BL Lacs (*italics* in the table), being in reality misclassified FSRQs. Sources with somewhat weaker optical jet dilution still oriented at small angles show some optical features, like the emission lines typical of FSRQs. In this category we find also “masquerading” radio galaxies, that is sources, which are “bona fide” blazars but have their non-thermal emission in the optical/UV part of the spectrum swamped by the host galaxy. Finally, misdirected jets characterize the true radio galaxy population. In short, starting from truly different objects like LERGs and HERGs, the combination of viewing angles and strong/weak optical/UV light dilution from the jet determines the commonly adopted classification in FSRQs, BL Lacs, or radio galaxies. This purely observational approach assigns in a number of cases intrinsically different objects to the same class, making the task of understanding blazars more complicated. It then turns out that sources so far classified as BL Lacs on the basis of their observed weak, or undetectable, emission lines are of two physically different classes: intrinsically weak-lined objects, more common in X-ray selected samples, and heavily diluted broad-lined sources, more frequent in radio and $\gamma$-ray selected samples, which explains some of the confusion in the literature. The implications of our results are far reaching. For example, the large fraction of redshift-less Fermi-LAT blazars, which is matched very well by our simulations, must have higher redshifts than those of BL Lacs with redshift information, as shown in Fig. 2. Therefore, one cannot assume for them a value typical
of the BL Lacs with measured redshift \((z \sim 0.4)\) but larger values \((z \approx 1 - 1.5)\) need to be used. Moreover, most of these sources are predicted to be quasars with their emission lines heavily diluted by the non-thermal continuum. These should therefore be included with the FSRQs when studying number counts, cosmological evolution, and LFs, since their exclusion will bias the results. Furthermore, “masquerading” radio galaxies, that is “bona fide” blazars having their optical non-thermal emission swamped by the host galaxy, could be the counterparts of a significant fraction of the still unassociated high-latitude Fermi \(\gamma\)-ray sources, which make up \(~20\%\) of the total at \(|b| > 10^\circ\). These would display a pure elliptical galaxy optical spectrum and would appear as radio sources typically fainter than currently known Fermi steep spectrum blazars (that are also characterized by large LAT error regions) thereby failing the association criteria applied by Ref. 7.

In conclusion, our scenario is consistent with the complex observational properties of blazars as we know them from all the surveys carried out so far in the radio, X-ray, and \(\gamma\)-ray bands, and solves at the same time a number of long-standing puzzles. Moreover, it also makes a number of testable predictions. These include, for example, the existence of high power – high \(\nu_{\text{peak}}\) blazars, which would be very hard to identify because of their featureless optical spectra and, therefore, lack of redshift. When both \(\nu_{\text{peak}}\) and radio power are large, in fact, the dilution by the non-thermal continuum becomes extreme and all optical features are washed away. Four such sources have already been discovered.\(^4\)

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