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Are relativistic jets monoparametric engines?

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Abstract. We adopt as a working hypothesis that relativistic jets are essentially monoparametric entities, and that their physical properties are a function of a single physical parameter, the same way the physical properties of main sequence stars are mainly a function of the star mass. We propose that the physical parameter is the jet kinetic power, and we use as a proxy for this quantity the low frequency extended radio luminosity (LFERL), an orientation insensitive quantity. We discuss the consequences of this hypothesis for the collective properties of relativistic jets and we show that a blazar sequence should spontaneously emerge on the peak frequency vs luminosity plot as the locus of those sources that are well aligned to the observer's line of sight. We also show that the sources of the same LFERL should form tracks that start from a location on the blazar sequence and move to lower luminosities and peak frequencies in a way that encodes information about the emitting plasma energetics and kinematics and velocity gradients, as well as about the inverse Compton (IC) emission seed photons. We are currently working on collecting the observations that will allow us to put this idea to the test.

Key words. Galaxies: active, BL Lacertae objects, Gamma-rays: theory, Radiation mechanisms: non-thermal

1. Introduction

The phenomenon of Active Galactic Nuclei (AGN) requires supermassive ($10^7 - 10^{10} M_\odot$) black holes, which provide the only mechanism that can achieve the necessary efficiency to extract the enormous luminosities we see (up to 10^{49} erg s^{-1}) within regions that are less than light-days in size. Pairs of relativistic radio emitting jets can reach lengths of hundreds of kpc, many times the host galaxy size and have a kinetic power that can rival the AGN's bolometric luminosity (Rawlings and Saunders 1991).

Blazars are those radio loud active galaxies with their relativistic jets pointing close to the line of sight. Their radiative output extends from radio to TeV energies and comes from locations close to the central engine that remain unresolved, even with VLBI techniques. Their emission comes in two distinct spectral components: the low frequency one is synchrotron emission and peaks at IR to X-ray energies, while the high energy one peaks at MeV to TeV energies and is thought to be inverse Compton (IC) emission off synchrotron photons (synchrotron self Compton -SSC) for low power sources and IC emission of the sub-pc

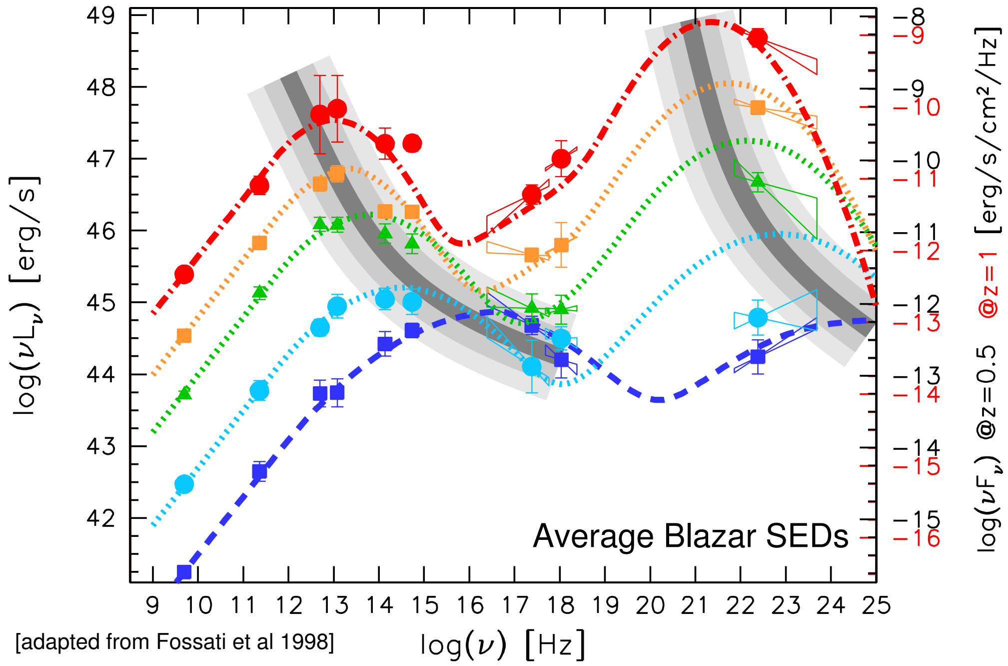

Fig. 1. This is the blazar sequence, conceived twelve years ago: more powerful sources have peaks at lower energies for both their synchrotron and inverse Compton (IC) components and the dominance of the IC component seems to increase with source power. The average spectral energy distributions (SEDs) of sources of increasing power are shown in color. The wide gray bands depict the locus of sources on the peak frequency-peak luminosity plot. Since its inception (Fossati et al. 1998), the blazar sequence has been explained theoretically, challenged by some observations, supported by even more, and is still considered the most important collective pattern that has emerged for blazars. How does the blazar sequence have to evolve to incorporate the 'renegade' sources that do not conform with it and what will this reveal for the jet physics?

scale broad line region (BLR) photons (*e.g.* see the review article by Böttcher (2007) that describes blazar models). Blazars appear in the optical as either the featureless BL Lac objects or quasar–like (broad) emission line Flat Spectrum Radio Quasars (FSRQ), corresponding to end-on orientations of low-power FR I or high-power FR II radio galaxies, respectively [1]. Fossati et al. (1998) showed that the luminosity of the synchrotron peak (L_{peak}) in blazars decreases as the peak location (ν_{peak}) shifts to higher frequencies, and that this shift is accompanied by a change in population, from predominantly powerful FSRQ sources at the low-peak, high-luminosity end through LBLs and finally HBLs, at the low-power end. Ghisellini et al. (1998) suggested that more efficient cooling in the high-powered blazars is responsible for the lower peak frequencies. The blazar sequence has remained the most successful unification scheme for blazars over the last decade.

2. Monoparametric jets?

According to the unification scheme of radio loud AGN (Urry & Padovani 1995), the parent population of the FSRQs are the FR II radio galaxies and the parent population of BL Lacs are FR I radio galaxies. This unification

[1] Fanaroff & Riley (1974) found the dividing line between type I and II to be $P_{178MHz} \propto 2x10^{25} h_{100}^{-2}$ W Hz^{-1}

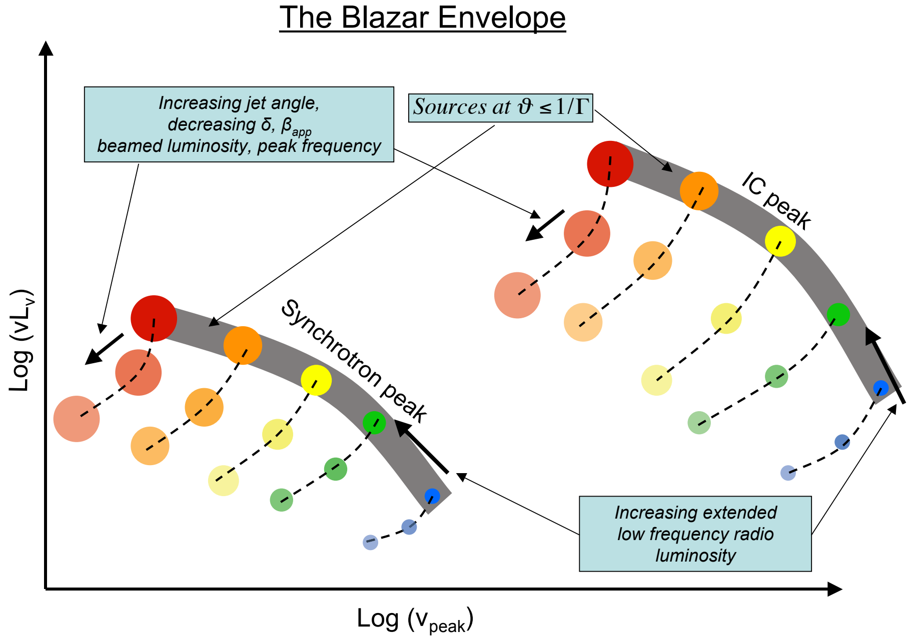

Fig. 2. This sketch of beamed luminosity versus peak frequency for both the synchrotron and the IC components encapsulates the thesis we propose to test: sources of similar extended radio power have similar jets. Sources at $\theta \lesssim 1/\Gamma$ populate the blazar sequence (gray strips). The color of the sources on the sequence, from blue to red is used to denote a decreasing peak frequency for each component. The extended radio luminosity increases with the size of the circle used. No sources are expected above the gray strips defining the sequence, because these are the optimally beamed sources (see text for discussion). For a given level of extended radio power (given circle size in this sketch), sources forming gradually larger angles θ to the line of sight are found along paths denoted by broken lines, with the distance from the sequence increasing with increasing angle. Sources of comparable extended emission are expected to be found along zones following these broken lines. As the distance from the blazar sequence increases along these paths, the jet emission becomes less beamed (gradually dimmer circles) and the sources shift to lower luminosities and peak frequencies, while the superluminal motions in the VLBI jet decreases.

is based on the similar extended and therefore non-beamed low frequency radio power of FSRQs and FR II's, and BLs and FR I's respectively. It suggests that sources of similar extended radio power (an isotropic source power indicator) have jets that are physically similar. The thesis we want to test is the following:

All sources with similar extended radio power have physically similar jets and their observed properties depend primarily on the jet orientation to the line of sight.

Putting aside for now the issue of an intrinsic spread of jet properties for a given extended radio power and the related issue of variability/duty cycle we present now the testable consequences/predictions of this thesis:

1. A blazar sequence emerges spontaneously from our thesis. Consider a collection of sources covering the entire range of extended radio power observed and let these sources have jets pointing within $\lesssim 1/\Gamma$ to our line of sight. These will be the most beamed sources we expect, since they are optimally aligned to the line of sight. In other words, for a given extended radio luminosity these sources will have the highest beamed luminosity. Let us now consider the location of these sources on a $\nu L\nu$ versus ν_{peak} diagram. As one moves to sources of higher extended radio luminosity, the location of the sources on the $\nu L\nu$ versus ν_{peak} diagram will trace two curves, one for the synchrotron and one for the IC component (gray strips in Figure 2). No sources are expected above these strips, because the jets that produce them are already pointing toward us. Blazars, being by definition sources with jets pointing close to the observer are expected to populate these strips. This explains the existence of the blazar sequence as a simple outcome of a one-to-one mapping between the extended radio power and the jet physics. *If our thesis of a one-to-one correspondence between extended radio power and jet physics is true we should expect that along the two strips defining the blazar sequence the extended radio luminosity increases as ν_{peak} decreases.*

2. The blazar envelope. Sources of similar extended power forming progressively larger angles θ to the line of sight will be found along zones starting from the blazar sequence and moving to lower luminosities and peak frequencies. Sources populating these zones will have similar extended luminosities (see Figure 2). In this way, the part of the $\nu L\nu$ versus ν_{peak} diagram below the blazar sequence will be populated by sources, forming a blazar envelope in which the region below the traditional blazar sequence is not forbidden anymore, but it is populated with sources of increasing θ as one departs further from the sequence. Moving away from the blazar sequence along a zone of sources of similar extended radio luminosity (depicted by broken lines in Figure 2), we expect the VLBI apparent speed β_{app} to decrease. This can be tested by compiling information on β_{app} for as many sources as possible.

Connection of the emission mechanisms and plasma kinematics to the shape of the blazar envelope zones. The shape of the locus of sources of the same extended radio luminosity but different orientation on the luminosity - peak frequency diagram that we depict in Figure 2 with broken lines, depends on the emission process we actually observe and the existence of velocity gradients. For emitters moving relativistically and emitting isotropically (this is the case for synchrotron and SSC emission), the peak luminosity $\propto \delta^4$, while the peak frequency $\propto \delta$, where δ is the usual Doppler factor. Two sources that have identical jets but different orientations and therefore different Doppler factors δ_1 and δ_2 will appear in different locations on the peak luminosity - peak frequency diagram. In the case of external Compton scattering, the shift in peak luminosity $\propto \delta^6$, while the shift in peak frequency depends on the scattering regime: for sources in the the Thomson regime the peak frequency $\propto \delta^2$ (Dermer 1995), while for sources in the Klein Nishina (KN) regime, the peak frequency does not change (Georganopoulos et al. 2001). Finally, in the case of sources characterised by velocity gradients, either due to a decelerating flow (Georganopoulos & Kazanas 2003) or to a spine sheath velocity profile (Ghisellin et al. 2005), although the path of the source depends on the particular characteristics of the velocity profile, a certain change of angle will produce a smaller drop on the synchrotron luminosity than that in one zone models, because at larger angles the slower, less beamed parts of the flow dominate. In the case of the IC emission the drop in luminosity will be greater than than expected from the SSC, but smaller than that expected from EC. It is clear from this discussion that the shape of the zones of sources with similar extended power depends *critically* on the actual emission mechanism and the existence of velocity profiles in the radiating plasma. *This offers us a unique and powerful tool, which we will use to determine the collective blazar physics as a function of jet power.*

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