Gamma-ray Clues to the Relativistic Jet Dichotomy

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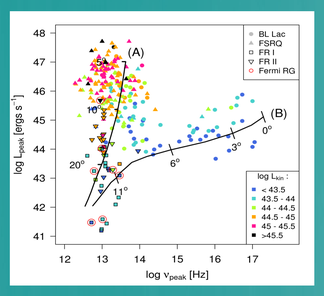

Figure 1. The synchrotron υ_{peak} – L_{peak} plane appears to contain two populations. Color indicates the jet kinetic power (L_{kin}), as estimated from extended radio flux measurements at 300 MHz. Track (A) shows an example de-beaming path of the synchrotron peak for a single-component "strong" jet. Track (B) is one possible path of a decelerating, low-power jet as angle increases (from 0 degrees at far right). The horizontal motion is characteristic of this jet model, which has also been used to explain the discrepancies in VLBI jet speeds measured for TeV blazars and those implied by their γ-ray emission (Georganopoulos & Kazanas, 2003). *Adapted from Meyer, et al., 2011*

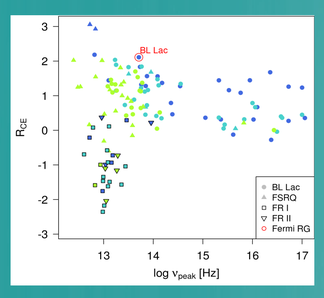

Figure 2. Radio core dominance (R_{CE}) at 1.4 GHz versus υ_{peak} for all sources with L_{kin} below $10^{44.5}$ (L_{300} below 10^{42}) ergs s^{-1}. All radio galaxies of low L_{kin} have lower R_{CE} than blazars of similar power, but there are apparently two broad locations of more aligned low-power blazars − one at lower υ_{peak}, with relatively higher RCE values (up to 3), and another at higher υ_{peak}, with slightly lower R_{CE} values (1−1.5). While all sources at high peaks (> 10^{15} Hz) are BL Lacs (i.e., HBLs), the low-peaking aligned sources include mixture of FSRQ and BL Lac spectral types. Color scale is the same as used in figure 1. *From Meyer, et al., 2011.*

Abstract

In examining a select sample of over 200 blazars of known jet kinetic power (L_{kin}) and well-characterized SEDs, we found (Meyer *et al.,* 2011) that Intermediate synchrotron-peaking (ISP) blazars may have lower gamma-ray output than high synchrotron-peaking (HSP) blazars of similar L_{kin}, consistent with our hypothesis that ISP blazars are less-beamed versions of HSP blazars, rather than a distinct population. Further, by using the radio core dominance as a measure of relative beaming, we find that gamma-ray luminosity depends on beaming in a consistant way for blazars ranging over all jet kinetic powers (10^{42} – 10^{46} ergs s^{-1}). We re-examine the gamma-ray properties of this core sample of blazars using an updated analysis of the 2.5 year Fermi dataset to confirm the initial finding (based on the 1-year LAT catalog, Abdo *et al.,* 2010a). **We find that for weak jets, the IC to synchrotron ratio remains constant with increased beaming, consistent with an SSC model for the jet emission, versus EC for the most powerful strong jets.**

Methods

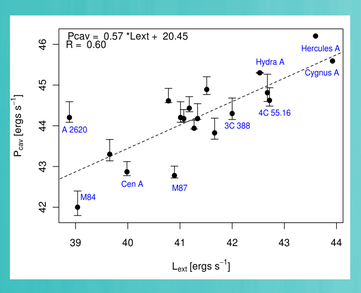

Figure 3. Twenty AGN with estimates of L_{kin} from cavity clusters clearly show the relationship between low-frequency radio power (L_{ext}) and jet kinetic power. Sources from McNamara *et al.,* 2011.

Measuring Kinetic Jet Power (Lkin): L_{kin} was estimated for several hundred blazars and dozens of radio galaxies by utilizing the low-frequency, steep lobe emission at 300 MHz. As shown in figure 3, L_{ext} traces jet power. For many core-dominated sources (or those without adequate low-frequency observations), L_{ext} was taken from published values using 1.4 GHz VLA maps (subtraction method). Typical L_{kin} values for our sources range from 10^{42} to 10^{46} ergs s^{-1}.

Characterising the SED: From a sample of over 1200 blazars, sources with well-sampled SEDs were selected and fit using a phenomenological parametric model (in some cases, an accretion disk template was added). Over 600 blazars have been characterized to yield accurate synchrotron υ_{peak}, L_{peak} values. Radio galaxy nuclear emission was also fit using this same model (12 sources) or a statistical model (25).

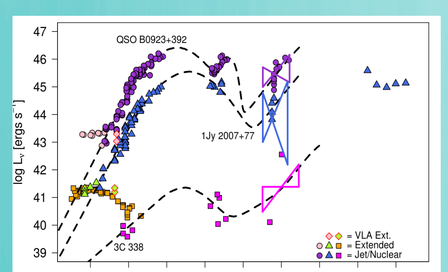

Figure 4. The FSRQ QSO B0923+392 (top) has a very clear steep component at low frequencies, and a prominent 'big blue bump' from the accretion disk, suggesting that it is relatively misaligned compared with the Fermi -detected BL Lac 1Jy 2007+77 (middle). This latter source has a similar extended radio spectrum to the radio galaxy 3C 338 (bottom).

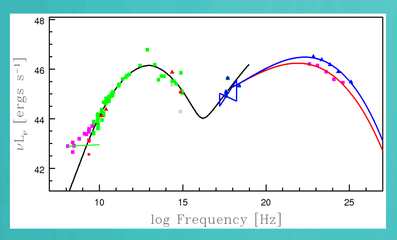

Figure 5. As an example of a typical SED, this is the spectral energy distribution of LSP BL Lac [HB89] 1823+568, with the fermi 1-year LAT catalog points (pink) and the new averages over 2.5 years of operation (blue). This sources has a moderate jet power, with L_{IC}/L_{synch} ~ 1.

Fitting the IC component: For the 216 sources in Meyer *et al.,* 2011, 5-band fluxes for Aug 2008 to March 2011 were computed using standard Fermi tools (v9r18p6), following the method of Abdo *et al.,* 2010. Individual bands with test statistic (TS) values > 10 were considered significant. Using Fermi data and X-ray/TeV (where appropriate) fluxes, parabolic fits were made the high energy SED, as in figure 5. (139 sources were significant detections).

The Inverse Compton Blazar Envelope

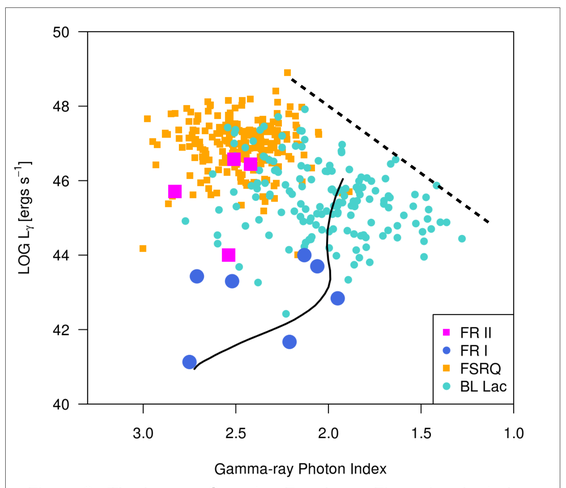

Figure 6. The Inverse Compton Envelope. Figure is adapted from Abdo *et al.,* 2010b (-π/2 rotation). The fermi-detected AGN (dark blue and magenta points) show that alignment plays a strong effect in the gamma-ray output. Interestingly, while the FR II sources appear to drop directly below the powerful FSRQ sources, FR I radio galaxies appear to follow a more horizontal track, similar to our findings in the synchrotron envelope (figure 1). The presence of a "forbidden zone" (marked off with dotted line) suggests that there is a sequence in the IC plane, similar to that found in the synchrotron.

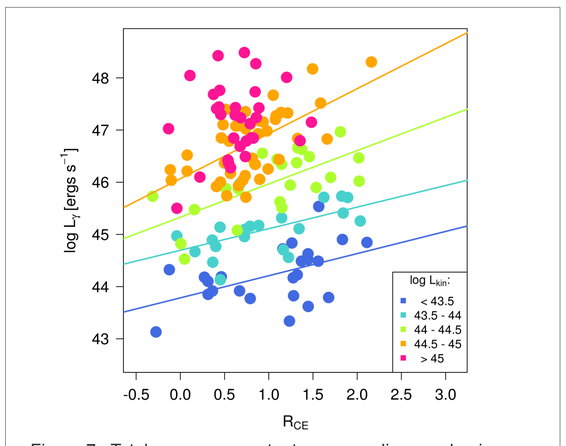

Figure 7. Total gamma ray output versus radio core dominance for our 130+ sources detectible by Fermi. Jet power has a very strong effect on the gamma-ray luminosity, but when sources are sorted by their jet powers, the dependence on radio core dominance also becomes apparent. The slopes shown are statistically significant at the 95% level.

Several hundred blazars were detected in the 11-month LAT catalog (Abdo *et al.* 2010a). These sources are shown in figure 6, forming the high-energy analog to the blazar envelope shown in figure 1. Here, the γ-ray photon index is analagous to the IC peak (increasing as υ_{peak} decreases). Both L_γ and υ_{peak} should decrease with misalignment of the relativistic jet, suggesting that **the blazars increasingly distant from the dotted line are more misaligned. The absence of sources beyond this line appears to indicate a "forbidden zone" similar to that seen in the blazar sequence** (Fossati *et al.,* 1998, Ghisellini *et al.,* 1998). However, the two populations suggested in figure 1 are not as separated in this view of the IC envelope.

Fermi blazars in our well-characterized sample do reveal that total γ-ray luminosity increases with radio core dominance (a measure of the alignment) as expected, a fact difficult to appreciate without binning sources by their jet power (figure 7). **As power of the source (L_{kin}) increases, the average gamma-ray output not only increases, but has a stronger dependence on R.**

In Meyer *et al.,* 2011, we proposed two populations of relativistic jets: strong ($10^{43.5}$ – 10^{46} ergs s^{-1}) and weak(10^{42}-$10^{44.5}$ ergs s^{-1}). In figure 8 we examine the differences in inverse Compton emission dominance between the most powerful ($L_{kin} > 10^{44}$) and least powerful ($L_{kin} < 10^{43.5}$) blazars, as these bins should correspond to entirely strong or weak jets according to our previous findings. The IC emission increases in dominance up to 100 times the synchrotron in the strong jet sources as they are increasingly aligned (R increases), supporting external Compton as the emission mechanism. In comparison, the weak jets (blue squares) show similar IC dominance irregardless of the degree of misalignment, supporting SSC models for low power blazars.

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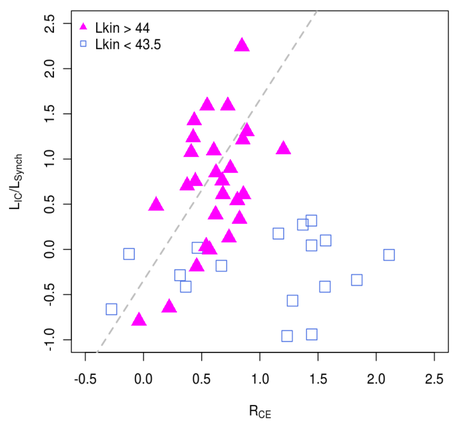
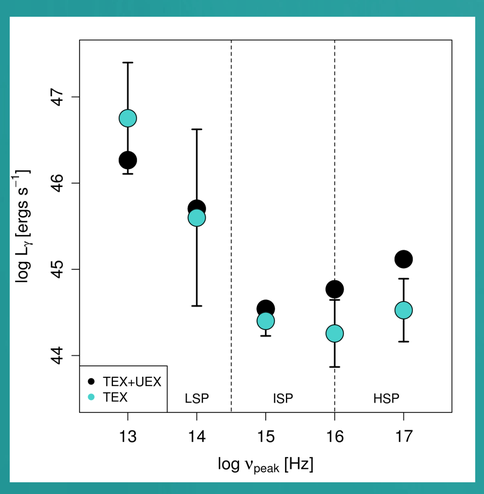


Figure 8. We compare very powerful ($L_{kin} > 10^{44}$) and very weak (Lkin < $10^{43.5}$) jets in terms of their inverse Compton dominance over synchrotron emission. This selection is useful because at intermediate jet powers both strong and weak jets may be present in a sample, while at the extremes only strong and weak are present, respectively. We find that for the strong jets, the inverse compton dominance increases dramatically (up to a factor of 100) with increasing alignment, as measured by radio core dominance. Conversely, the weak jets show no such increase. L_{IC} is measured by fitting the X-ray, γ-ray, and TeV (where available) points with a parabola and taking the peak luminosity. (Dashed line shows slope=2 for reference).



Are ISP blazars more misaligned than HSP?

According to the proposed two-population scenario, all ISP and HSP sources belong to the weak jet parent sample along with FR I radio galaxies. As blazars, they move from a population of HSP to ISP and finally LSP sources as they are misaligned. Contrary to the traditional interpretation of a continuous sequence, then, ISP blazars should have lower core dominance, lower overall luminosities, lower Doppler factors, and yet similar L_{kin} and accretion rates when compared with HSP sources (see figures 1 and 2). Moreover, we expect that ISP sources will have lower gamma-ray output, and decreased variability compared with HSP sources.

In figure 9 (left), total gamma-ray output versus synchrotron peak location is shown for several hundred blazars detected with Fermi in our sample (values have been averaged by bins of peak frequency). ISP sources appear to have lower gamma-ray output as expected.

Conclusions

► We find an anti-correlation between gamma-ray luminosity and spectral index, analagous to the synchrotron blazar sequence, with a similar forbidden zone of high-luminosity/low index.

► Sources falling below this forbidden zone are increasingly misaligned, as shown by the radio galaxies at lower luminosities and our findings of a decrease in gamma-ray luminosity with core dominance for sources of similar jet power.

► ISP Blazars appear to have lower gamma-ray output than HSP blazars, supporting the suggestion that they are more misaligned than HSP blazars

► Powerful sources show increased IC dominance with alignment to the line-of-sight (up to a factor of 100 over the synchrotron emission), suggesting that *external Compton* is responsible for the emission, versus low-power blazars which do not show high IC dominance.

Please also see related presentations:

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From the Blazar Sequence to the Blazar Envelope: Strong and Weak Jets and a Paradigm Shift in the Unification of Radio-loud AGNs. Fossati *et al.* (talk, Wednesday, Session C, 2:45)

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Meyer, Eileen T., Fossati, G., Georganopoulous, M., Lister, M. 2011a *From the Blazar Sequence to the Blazar Envelope: Revisiting the Relativistic Jet Dichotomy in Radio-Loud AGN (submitted to ApJ)*