Relativistic Jets and the their Parsec-scale Environments

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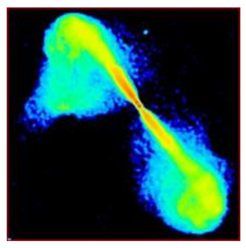
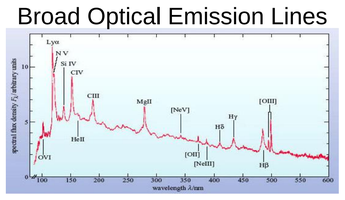
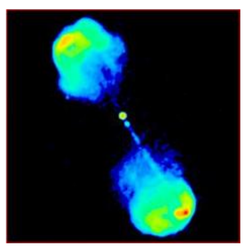
***Abstract**: We investigate the systematics of the properties of highly relativistic jets at multiple frequencies, including Fermi and MOJAVE data. We test the hypothesis that the blazar divide constitutes a dichotomy. We also explore possible measures of the Doppler factor for these highly Doppler-beamed active galactic nuclei.*

Introduction







Most if not all accreting supermassive black holes appear to produce bipolar synchrotron-emitting plasma jets. In most active galactic nuclei (AGN) these jets appear quenched well within their host galaxies (referred to as "radio-quiet" AGN in the literature) and are non-relativistic in the majority of the cases (e.g., Lal et al. 2011; Middelberg et al. 2004) except in the case of the Narrow-Line Seyfert 1 types (e.g., J. Richards 2015). In a small minority (15-20%) of the AGN, however, the jets are launched with large kinetic power and at bulk relativistic speeds, and reach scales of several hundred kpc and even a Mpc - referred to as "radio-loud" in the literature. When such jets are oriented close to our line of sight, relativistic aberration strongly affects their observed parameters (e.g., Blandford & Konigl 1979). Objects with strong signatures of such aberration and Doppler beaming, viz., Blazars, dominate surveys at gamma-ray energies (e.g., Ackermann et al. 2011), and have also been the primary candidates for the measurement of the apparent proper motion of the jet components via Very Long Baseline Interferometry (e.g., the MOJAVE project: Lister et al. 2009). We explore the systematics of the gamma-ray properties of Blazars and the question of whether BLLacs and Quasars show a continuity of properties (Ghisellini et.al. 2009) or whether the Blazar Divide is a dichotomy.

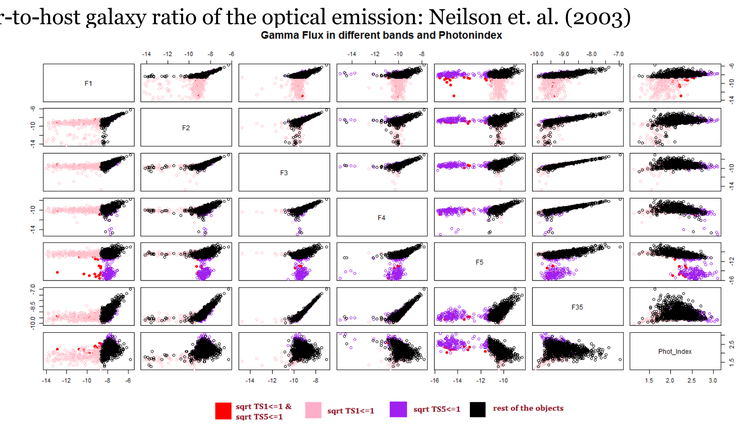
Observations

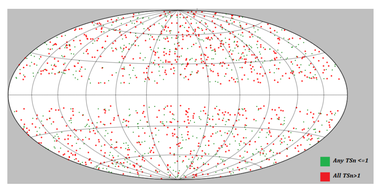
Gamma-ray fluxes and photon indices from:
The Third Fermi Source Catalogue & The Third LAT AGN Catalogue
(3FGL: Acero+ 2015 and Ackermann+ 2015: 1444 objects)

Sources selected to have high statistical significance of the gamma-ray flux measurement (Acero et.al. 2015: TSn>1 in all gamma-ray bands)

Maximum apparent proper motion speed of the jet component: from the MOJAVE VLBI data (Lister et.al. 2009)

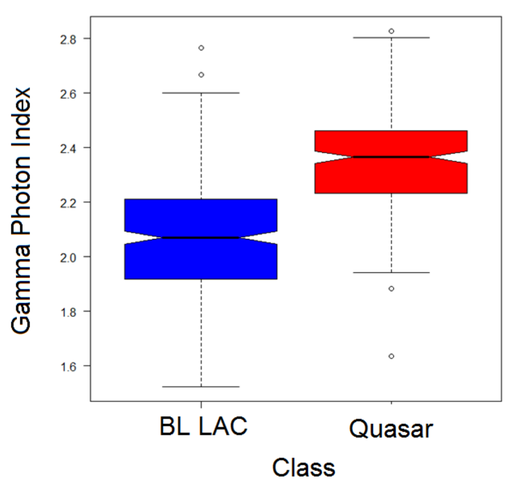
Nuclear-to-host galaxy ratio of the optical emission: Neilson et. al. (2003)

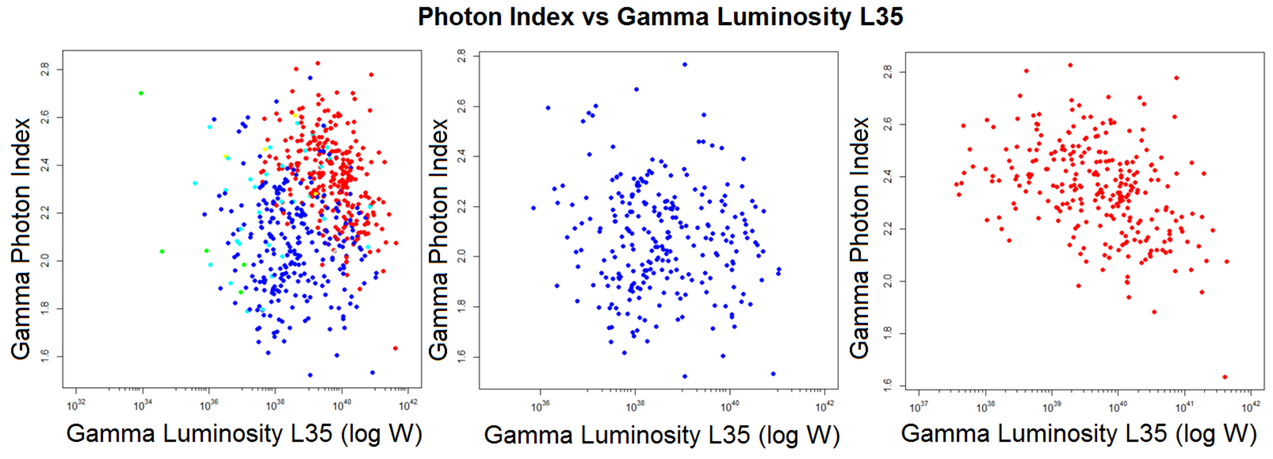




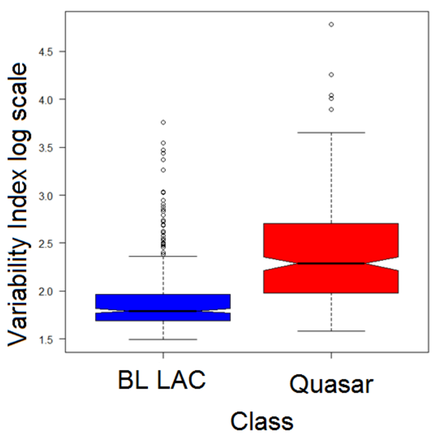
Top: The flux-flux and photon index plots of the gamma-ray fluxes in the various Fermi bands. The points in pink, red and purple are those with low statistical significance. Right: The sky distribution of the active galactic nuclei in the third Fermi source catalogue, (green dots) and the objects with data of high statistical significance (black points in the plot above) which have been used for the analysis.

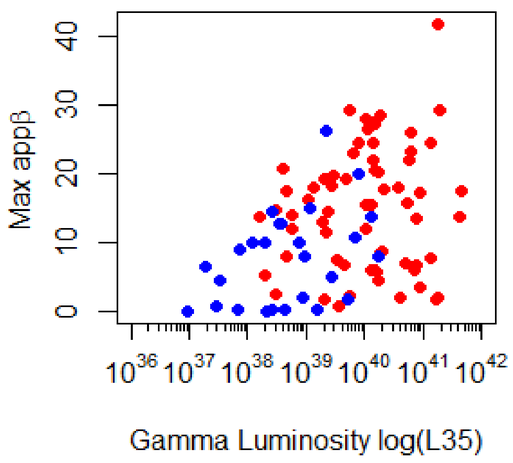
Results

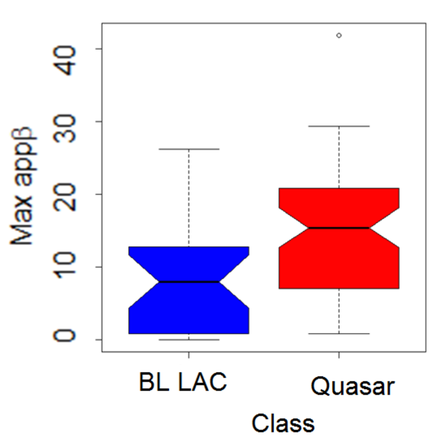




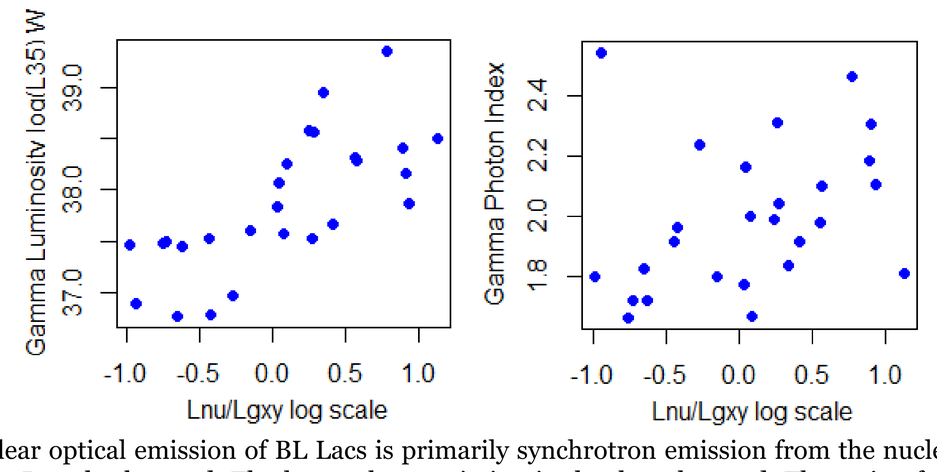
The BL Lacs have systematically harder photon indices than the quasars, and occupy different regions of the gamma-ray luminosity-photon index plane, consistent with the findings of Ghisellini et.al. 2009, and Ackermann et al (2011, 2015). However, when the BL Lacs and quasars are considered separately, they show qualitatively different behaviour of the photon index with gamma-ray luminosity (as also suggested by Ackermann et. al. (2011).) The BL Lacs show no significant trend, whereas the quasars show a trend opposite to that for the Blazars as a whole. While the accretion in BL Lacs may be less efficient, the data are not consistent with a continuity of properties between BL Lacs and beamed quasars, and indicate a dichotomy.







The variability index for the quasars is systematically higher than for the BL Lacs (left panel). While the maximum apparent proper motion speed of the jet measured by the MOJAVE VLBI observations over their time baselines appears to correlate with the gamma-ray luminosity as expected (middle panel), this is largely due to the systematically higher gamma-ray luminosities and proper motion speeds in the quasars (right panel).



The nuclear optical emission of BL Lacs is primarily synchrotron emission from the nuclear jet and is Doppler beamed. The host galaxy emission is clearly unbeamed. The ratio of the nucleus to host-galaxy emission can therefore be used as a statistical proxy for the angle to the line of sight. The gamma-ray emission which is expected to be highly Doppler-beamed, significantly correlates with this parameter. We also see that the gamma-ray photon index appears to soften with higher optical nuclear-to-host galaxy ratio, i.e., larger Doppler factors.

Conclusions

- *813 of the 1444 AGN detected and classified in the 3rd Fermi LAT AGN catalogue have data with reliably high statistical significance, of which 571 have redshifts and enable investigation of their systematics.*
- *These selected BL Lacs also have systematically harder photon indices relative to quasars, just as in the whole sample (Ackermann+2015).*
- *Data suggest that the blazar-divide is indeed a dichotomy.*
- These selected BL Lacs also have systematically harder photon indices relative to quasars, just as in the whole sample (Ackermann+2015)
- The quasars have systematically higher variability index in the gamma-ray band.
- *The data is qualitatively consistent with the hypothesis that BL Lac jets are launched in a relatively photon-starved environment.*
- *The gamma-ray luminosity in the BL Lacs correlates as expected with the optical nuclear-to-host galaxy ratio.*
- *BL Lacs with higher optical nuclear-to-host galaxy ratio have softer gamma-ray photon indices.*
- *The optical nuclear-to-host galaxy ratio may be an alternative proxy for the angle of inclination of the jet to the line of sight.*

References

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