Population Statistics of Beamed Sources

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Abstract

Our understanding of relativistic jets is hindered by the large diversity in observed properties induced by relativistic effects. With this work, we aim to lift this obscuring veil through a population-model approach, and get to the intrinsic variability properties of jets in their rest frame. The questions we address are: **(a)** What is the relativistically induced spread in observed event timescales? Could blazar behaviors in the time domain observed to be very varied be in fact very similar in the jet rest frame? **(b)** How different is the beaming between sources in flux-limited samples? Lacking any additional information, is it useful to make statistics-based assumptions for the viewing angle of a single source? **(c)** Do BL Lacs and Flat Spectrum Radio Quasars (FSRQ) have different beaming properties? Could differences observed between them in the time domain be attributed to how relativistic effects differently affect each population? **(d)** Do single-blazar Doppler factor estimation techniques (such as equipartition Doppler factors and self-synchrotron Compton Doppler factors) yield distributions consistent with population models when applied to flux-limited samples?

Population models

We have modeled blazars as a population assuming single power law distributions for the Lorentz factor (Γ) and the intrinsic luminosity under pure luminosity evolution, while cosθ, where θ is the viewing angle, is uniformly distributed (0,1). We produce separate models for the BL Lac objects and the Flat Spectrum Radio Quasars (FSRQs). We optimized these models using as observables the apparent velocity and redshift distributions (Lister et al. 2009; Lister et al. 2013) from MOJAVE (Monitoring Of Jet in Active galactic Nuclei with VLBA Experiments, Lister & Homan 2005). For our models flux-limit, we used the 1.5 Jy flux-limit of the MOJAVE sample (Liodakis & Pavlidou 2014a).

Beaming and Timescale Modulation

Using the products (Γ,θ,z,δ, where δ is the Doppler factor and z is the redshift) of our optimized models we produced the Γθ and the timescale modulation factor (Δt'/Δt) distributions for both classes. Figure (1a) shows the Γθ distribution for the BL Lacs (solid red) and the FSRQs (dashed green). The distribution has a clear peak (~0.55) for both classes and a large spread (68% is between 0-1.1). Figure (2a) shows the timescale modulation factor (solid red for the BL Lacs and dashed green for the FSRQs). The Δt'/Δt follows an exponential distribution with mean ~0.28 for both the BL Lacs and the FSRQs.

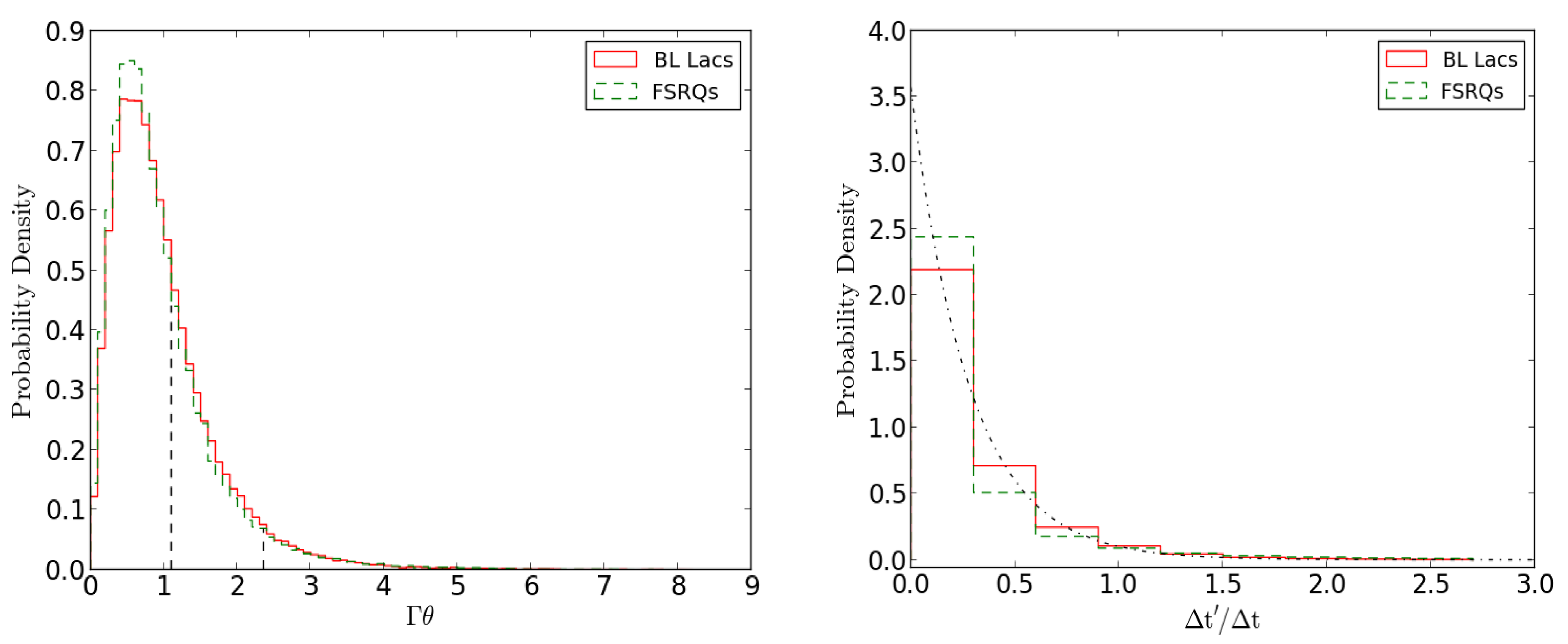

Figure 1. *Left panel: (a) Distribution of Γθ for both classes. The solid red line is for BL Lacs and dashed green for the FSRQs. The first dotted vertical line at 1.1 is 1σ and the second is 2σ. Right Panel: (b) Timescale modulation factor distribution for the BL Lacs (solid red) and the FSRQs (dashed green). The dotted line is an overplotted exponential distribution with the same mean ~0.28.*

Evaluation of Doppler factor estimation techniques

We compared the Doppler factor distributions derived from our optimized models, with distributions from the literature in order to evaluate which of the single-blazar Doppler factor estimation techniques can adequately describe blazars as a population (Liodakis & Pavlidou 2014b). Our comparison accounted for sample size and flux-limit. **We found that:** the variability Doppler factors (Valtaoja et al., 1999; Lähteenmäki et al. 1999; Hovatta et al. 2009) can adequately describe both BL Lacs and FSRQs (Fig. 3a); the inverse Compton Doppler factors (Ghisellini et al 1993) can adequately describe the FSRQs (Fig. 3b).

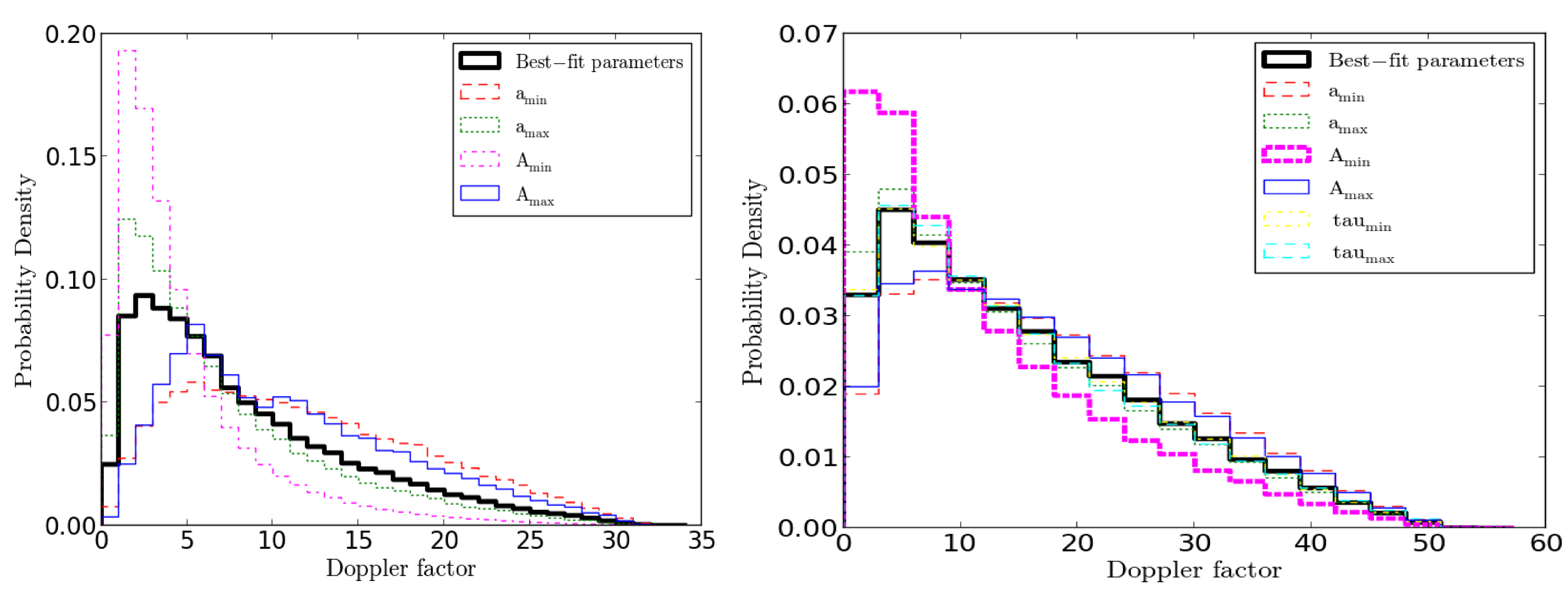

Figure 2. *Doppler factor distributions for the BL Lacs (left panel) and the FSRQs (right panel). The black thick line represents the distribution from the best-fit parameters of the models, whereas the other lines the limits of the parameters that still produced acceptable models.*

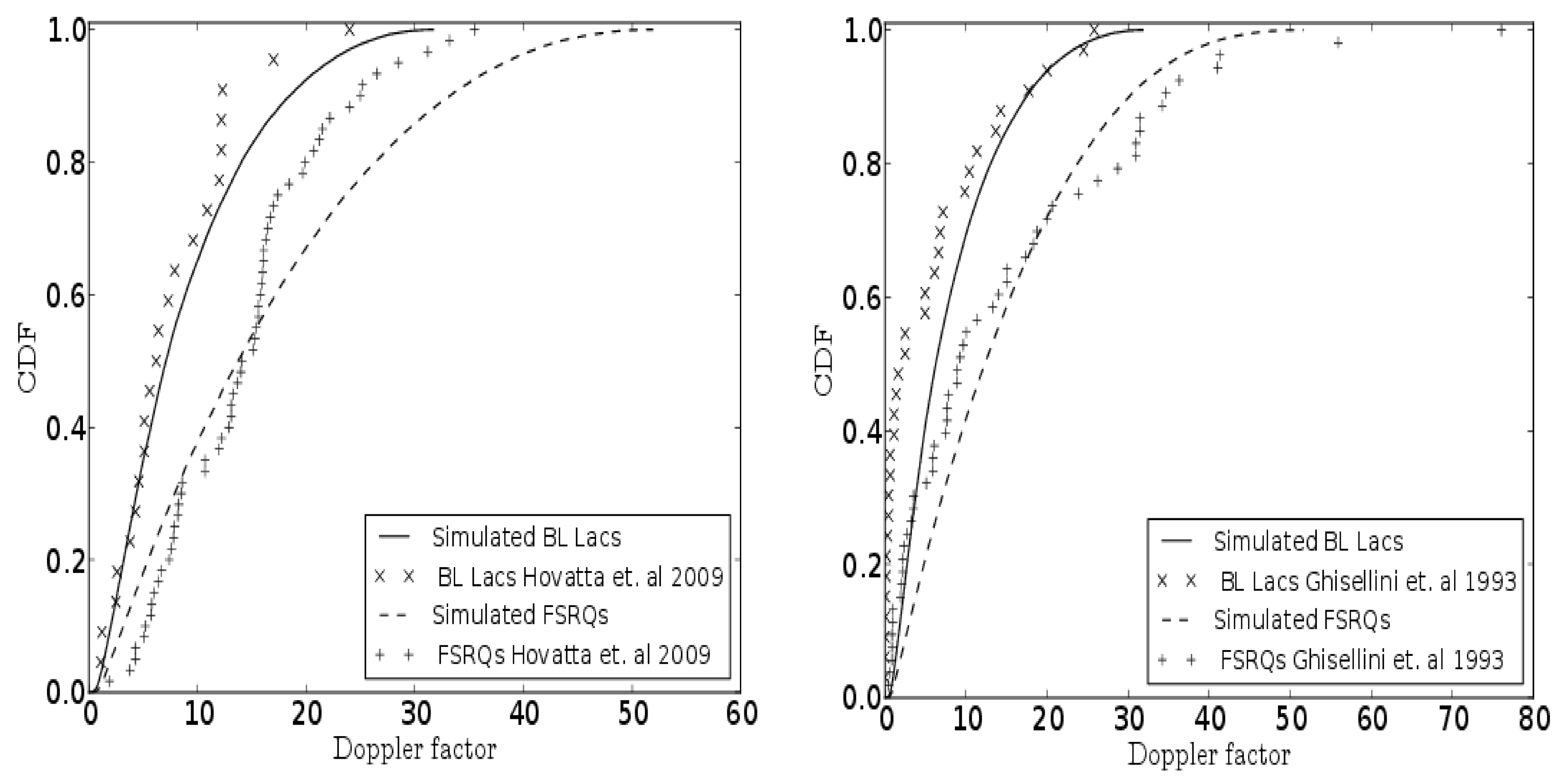

Figure 3*. Left panel:(a) Doppler factor distributions for the BL Lacs (solid) and FSRQs (dashed) against Variability Doppler factors (Hovatta et al. 2009). Right panel:(b) Doppler factor distributions for the BL Lacs (solid) and FSRQs (dashed) against inverse Compton Doppler factors (Ghisellini et al. 1993)*

Conclusions

We were able model blazars as a population, using single power-law distributions for the Lorentz factor and intrinsic monochromatic luminosity. We produced separate models for the BL Lac objects and the FSRQs that can adequately describe the observed apparent velocity and redshift distributions from the MOJAVE sample.

Using our optimized population models for the BL Lacs and the FSRQs, **we found that:**

(a) The timescales of blazars are modulated (compressed) following an exponential distribution with mean ~0.28 for both classes. This result can be used to deduce the distribution of rest-frame timescales from observed timescales in flux-limited samples of blazars (Liodakis, Hovatta & Pavlidou in preparation).

(b) The peak of the Γθ distribution is at ~0.55 for both classes, but with a large spread (68% is between 0-1.1). **This would suggest that the beaming is very different between sources in flux-limited samples, thus statistics-based assumptions on the viewing angles of beamed sources (e.g. θ~1/Γ) on a blazar-by-blazar basis vary by 50% at 1σ.**

(c) There is no difference in beaming between BL Lac and FSRQ classes, judging from the timescale modulation factor and the Γθ distributions. **Thus any difference in the properties of these classes in the time domain, translates to intrinsic differences in the properties of these sources.**

(d) Using the Doppler factor distributions from our models, we evaluated the different Doppler factor estimation techniques. **We have found that: the variability Doppler factors can adequately describe both classes, and the inverse Compton Doppler factors can adequately describe FSRQs as a population,** suggesting that the arguments put into these methods, such as the equipartition brightness temperature (Readhead 1994) and the self-synchrotron Compton model are valid and the adequately describe physical conditions in blazar jets.

References

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