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Statistical Effects of Doppler Beaming and Malmquist Bias on Flux-Limited Samples of Compact Radio Sources

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Abstract. We examine the effects of Doppler beaming on flux-limited samples of compact extragalactic radio sources using Monte Carlo simulations. We incorporate a luminosity function and z-distribution for the parent population, and investigate models in which the unbeamed synchrotron luminosity L of a relativistic jet is related to its bulk Lorentz factor Γ. The predicted flux density, redshift, monochromatic luminosity, and apparent velocity distributions of our simulated flux-limited samples are compared to the Caltech-Jodrell Bank (CJF) sample of flat-spectrum, radio core-dominated active galactic nuclei (AGNs).

We find that a relation between L and Γ is not needed to reproduce the characteristics of the CJF sample. Introducing a positive correlation between these quantities results in an underabundance of objects with high viewing angles, while a negative correlation gives generally poor fits to the data.

1. Introduction

Flux-limited samples of flat-spectrum AGNs are thought to contain a particularly complicated form of selection bias, since they are expected to include not only sources of high intrinsic luminosity, but also lower-luminosity sources whose emission is Doppler boosted by virtue of their orientation with respect to the observer. The exact composition of such a sample is therefore highly dependent on certain aspects of the parent population. These include the dispersion of jet Lorentz factors, the distribution of jet orientations, and the intrinsic (non-boosted) luminosity function (LF).

2. Monte Carlo Simulations

We investigate these selection effects using Monte Carlo techniques, whereby we define the parameters of a simulated parent population from which flux-limited samples are drawn and compared to the CJF sample. The latter is a flat-spectrum survey at 5 GHz consisting of 293 AGN (Taylor et al. 1996).

The objects in our simulated parent population are described by four parameters:

- A viewing angle (θ) between the observer and jet axis.
- A redshift, assuming a constant, co-moving space density out to $z = 4$.
- An intrinsic (unbeamed) synchrotron luminosity (L). The LF of the parent population is modeled after a two-power law fit to the FR-II radio galaxy LF, as defined by Padovani & Urry (1992) (the PULF).
- A bulk jet Lorentz factor (Γ), which is drawn from the distribution $N(\Gamma) \propto \Gamma^a$, where $1 \leq \Gamma \leq 15\ h^{-1}$, a is a free parameter, and $h = 0.65$: the Hubble constant in units of 100 km s^{-1} Mpc^{-1}.

3. Goals of This Study

There are several important questions that we seek to address using our simulations: Can the simple relativistic beaming model successfully reproduce the observed properties of a well-defined flux-limited sample? If so, how large a parent population is required, and what is the distribution of Lorentz factors?

Vermeulen (1995) has reported an upper envelope to the apparent velocity versus emitted power diagram for the CJF. Is this envelope an indication of a correlation between unbeamed jet luminosity and Lorentz factor? We investigate this question by letting $L \propto \Gamma^{\xi}$ in our models, where ξ is a free parameter.

4. Results

In this section we briefly summarize our findings, which are discussed in greater detail in Lister & Marscher (1997).

The predictions of models containing no correlation between L and Γ (i.e. $\xi = 0$) closely match the CJF data for $-1.75 \lesssim a \lesssim -1.25$ (i.e. the parent population is dominated by slow jets). The β_{app} vs. P envelope of the CJF is reproduced in this case, and is a result of the combined effects of the Malmquist bias, Doppler beaming, and the Γ distribution. Our simulations require approximately 5×10^7 parent objects to reproduce the CJF sample. This translates into a space density of approximately 14% of that observed for L_* elliptical galaxies (Marzke et al. 1994).

Simulated samples of jets that have $\xi < 0$ generally do not fit the CJF data, in that they i) do not reproduce the β_{app} vs. P envelope, ii) predict too few low-P sources, and iii) contain very few objects with large ($\gtrsim 20°$) viewing angles. This last point is inconsistent with the large number of radio galaxies found in the CJF, which are thought to lie at viewing angles $\gtrsim 45°$ (Barthel 1989).

For populations in which faster jets are more intrinsically luminous ($\xi > 0$), the fits to the CJF data are as good as the $\xi = 0$ case, with the exception that there are an insufficient number of objects predicted to be seen at large viewing angles. When compared to the latter model, this model predicts more sources with high Doppler factors ($\delta > 20$), and a parent population that is a factor of ~ 9 smaller.

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