Galaxies and their Constituents at the Highest Angular Resolutions
IAU Symposium, Vol. 205, 2001
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Kiloparsec Jet Speeds in Classical Double Radio Sources

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Abstract. On the basis of an intrinsically symmetric relativistic jet model, analytical equations between the mean jet speed and the mean jet flux asymmetry, and between their variances are derived in the context of an orientation-based unification scheme. The mean jet speeds of classical double radio sources are estimated on kiloparsec scales by using the asymmetry of jet–counterjet flux densities taken from the 3CRR and B2 samples. For FRI radio sources the mean jet speed is $\sim (0.54 \pm 0.03)c$, while for FRII low-redshift radio galaxies and intermediate-redshift quasars the values found are $\sim (0.4 \pm 0.06)c$ and $\gtrsim 0.6c$ respectively.

1. The distribution function of jet speeds

In all work to date the determination of jet speeds amounts to a test by Monte-Carlo simulations of the consistency between the data and the model in which the jet properties are determined by relativistic beaming. I suggest an inverse problem approach for reconstructing the distribution function of jet speeds, estimating the mean jet speed and standard deviation directly from the observed jet–counterjet brightness of FRI (Laing et al. 1999, hereafter L99) and FRII radio sources (Bridle et al. 1994 and Hardcastle et al. 1998, hereafter B94 and H98). For intrinsically symmetric and relativistic jet the observed jet flux asymmetries are entirely due to Doppler beaming, $\omega \equiv (J^{1/\delta}-1)/(J^{1/\delta}+1) = \beta_{\rm j}\cos\theta$, where $J = S_{\rm j}/S_{\rm cj}$ is the ratio of the jet and counterjet flux densities, $\beta_{\rm j}c$ is the speed of the jet, which is inclined at an angle $\theta \in [0, \pi/2]$ to the line of sight of the observer, $\delta = 2.6$ and ω is the *jet flux asymmetry.* Under assumption that the radio axes are distributed isotropically in the sky one may express the distribution function of jet speeds by means of the distribution function of jet flux asymmetries, $g(\omega)$,

$$G(\omega) = -\,\omega\, g'(\omega). \tag{1}$$

Then the mean jet speed and the variance of jet speeds can be derived, those are, $\overline{\beta}_{\rm j} = 2\overline{\omega}$ and $\sigma^2_{\beta_{\rm j}} = 3\,\overline{\omega^2} - 4\,\overline{\omega}^2$. Also these equations are obtained (Arshakian 2000) in the context of orientation-based unification scheme for FRII radio galaxies and quasars (Scheuer 1987; Barthel 1989), which allows the mean jet speed and its variance to be estimated for orientation-dependent samples of radio galaxies and quasars (B94 and H98).

https://doi.org/10.1017/S0074180900220810 Published online by Cambridge University Press

2. Jet speeds in FRI-FRII radio sources

The principal results are:

- The mean jet speed of low-redshift FRII radio galaxies is in the range $\sim 0.4c \pm 0.06c$ and standard deviation $\sim 0.15c$, which is in agreement in the limits of error with the speeds obtained by Hardcastle et al. (1999).
- A lower limit on the mean jet speed of intermediate-redshift FRII quasars is $\gtrsim 0.6c$, which supports the presence of high-relativistic jet speeds in quasars (B94; Wardle and Aaron 1997).
- For FRI radio galaxies the mean jet speed and standard deviation of jet speeds at the flaring point is about $0.54c$ and $0.18c$ respectively.

Most of radio sources have only a lower limit on the jet flux asymmetries which are treated throughout this analysis as representing the true values. An important question is: what are the real values of jet flux asymmetry? Relativistic boosting of the jet emission is more important for quasars (B94) than for radio galaxies (H98), and hence a difference between the lower limits on jet flux asymmetry and the real values on the average should be higher for quasars than for radio galaxies. If the limits on ω are not far from the true values for FRI and FRII radio galaxies, then the mean speeds are $\sim (0.6 \pm 0.03)c$ and $\sim 0.5c \pm 0.05c$ respectively, when the lower limits on the jet-counterjet flux ratios are multiplied by 1.5. For FRII quasars, when the limits on the flux ratios are doubled, a mean speed between $0.7c$ and $0.8c$ is more acceptable.

Acknowledgements

I am very grateful to Malcolm Longair, Martin Hardcastle, Julia Riley and Robert Laing for useful discussions and valuable comments. I also gratefully acknowledge an ex-quota award from the Royal Society, and I thank Anton Zensus and Eugen Preuss for the hospitality of the Max-Planck-Institut für Radioastronomie, Bonn, were the finishing touches to this paper were applied.

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