STABILITY PROPERTIES OF VLBI JETS +

M. Birkinshaw
Mullard Radio Astronomy Observatory, Cavendish Laboratory,
Madingley Road, Cambridge CB3 OHE, U.K.

ABSTRACT

The growth lengths of Kelvin-Helmholtz instabilities are calculated for three vortex-sheet bounded beams with v = 0.9c. These beams survive the action of the instability for distances of several hundred beam radii, but no prediction of a single dominant mode of breakup can be made.

MODEL AND METHOD

It is of interest to estimate the Kelvin-Helmholtz instability growth lengths for fluid-dynamical beams of the type that may be responsible for observed VLBI structures. Some investigation of this problem has already appeared (Ferrari, Trussoni & Zaninetti 1981), but this work was done in the temporal domain, so that some assumption about the convection velocities of the modes of instability is required in order to estimate their growth lengths. In highly unstable situations, such as jets, it is better to work in the spatial domain, when estimates of the survival length for a beam appear directly, and this method is used here.

The calculation described here considered the first-order stability of a vortex-sheet bounded cylindrical beam with bulk velocity v = 0.9c (γ = 2.3). An adiabatic equation of state was assumed for the beam and the ambient medium, and the effects of gravity and magnetic fields were ignored. The speed of sound in the ambient medium was assumed to be 750 km/s, and stability was considered for beams with densities 0.1, 1.0 and 10 times that of the external medium (cases L, E and H respectively). The dispersion relation obtained in the linear stability analysis was solved for various perturbation frequencies, and the results were interpreted as curves of the rest-frame e-folding instability length, λ_e, as a function of the wavelength, λ_o, for each assumed azimuthal mode number, n. n describes the variation of

+ Discussion on page 448

R. Fanti et al. (eds.), VLBI and Compact Radio Sources, 229–230.

https://doi.org/10.1017/S0074180900078104 Published online by Cambridge University Press

solutions around the cylindrical beam: n = 0 are pinching modes, n = 1 are helical modes, and n > 1 are fluting modes (Hardee 1979). For any n, a wide range of modes are obtained; these may be labelled by the radial mode number, N, which describes the radial variation of solutions (N = 0 have least variation and are the ordinary modes of Ferrari *et al*. 1981; N > 0 are their reflection modes). In general the N = 0 mode is the least unstable and appears at the greatest λ_o; higher N modes are more unstable and appear at smaller λ_o.

RESULTS

The results of this analysis may be summarized as follows. All the (n,N) modes investigated in all three beams are unstable. The minimum growth lengths for any observed wavelength are given by the lower envelope of the stability curves as

$$\lambda_e^{min}/R \sim \begin{Bmatrix} 550 \\ 190 \\ 70 \end{Bmatrix} (\lambda_o/R)^{0.2} \qquad \begin{Bmatrix} H \\ E \\ L \end{Bmatrix}$$

where R is the beam-radius. If the periods of variations of the fluid parameters imposed by the (growing) perturbations are assumed to be of the order of the sound crossing time for the beam, then the low-order (small n,N) modes occur with characteristic wavelengths and e-folding lengths

$$\begin{array}{lll} \lambda_o/R \sim 1100 & \lambda_e/R \sim 2000 & H \\ \lambda_o/R \sim 350 & \lambda_e/R \sim 600 & E \\ \lambda_o/R \sim 100 & \lambda_e/R \sim 200 & L \end{array}$$

Thus if low-order modes are excited, the beams will only be affected by Kelvin-Helmholtz instabilities on scales greater than a few hundred beam radii, but the beam stability is always dominated by the highest-frequency modes that are assumed to be excited. Since the variation of λ_e^{min} with λ_o is fairly slow, however, the survival distances are not strongly dependent on the maximum input frequency. It is clear that higher-density (higher inertia) beams are more stable to Kelvin-Helmholtz instabilities than lower-density beams, and hence are to be preferred in explaining the survival of VLBI beams to kpc scales; for any one (n,N) mode the minimum e-folding distance increases as the square root of the beam overdensity.

REFERENCES

Ferrari, A., Trussoni, E. & Zaninetti, L., 1981. Mon. Not. R. astr. Soc., 196, 1051.
Hardee, P.E., 1979. Astrophys. J., 234, 47.

https://doi.org/10.1017/S0074180900078104 Published online by Cambridge University Press