CONNECTIONS BETWEEN TURBULENCE AND JET MORPHOLOGY

Gregory Benford
Physics Department, University of California, Irvine
Irvine, California 92717

Radio jet morphologies may be caused by large-scale Kelvin-Helmholtz (KH) instabilities. If high-speed, pressure-confined fluid beams lie at the core of these jets, they are susceptible to KH modes, as studied by a number of authors.[1-5] The "wiggles" seen, for example, in 3C449, NGC 6251, M87 and Cen A, may arise from helical instabilities.[3,4] "Knots" may be radial oscillations (not necessarily unstable) forming sausage-like regions of compression, as in NGC 315, M87, Cen A etc. There seems no reason why such macroscopic modes should not appear. The smaller scale waves, however, cannot be easily resolved by radio astronomy, and can have profound effects, such as particle reacceleration. It would be rather more satisfying if there were observable large-scale implications of the microturbulence.

As discussed in Ref. 2, we expect morphology of scale $ka \sim 1$ (with k the wavenumber and a the beam radius) when the Alfven speed $v_A < v_s \emptyset$, where v_s is the sound velocity and $0.1 < \emptyset < 1$. When $v_A > v_s \emptyset$, coalescence of modes allows a cascade of turbulence from high k to low k, so that $ka \gg 1$ morphology appears, and cyclotron resonance is the primary damping agent. The crucial problem is how to generate large scale turbulence and convey the stored energy to reaccelerated particles, without simultaneously heating the jet so that it expands drastically. I shall assume that the cascade process of Ref. 2 is efficient enough, and allows estimations of the time scale for energy transfer. The magnetic perturbations created at $k_o = 1/a$ are weak in the sense that $[\delta B(k_o)] < B_o$, the ambient field. They are built up by the linear instability. In a time

$$t_c = \frac{a}{2\pi v_A(2-\nu)} \frac{[1 - (k_o/k)^{2-\nu}]}{[(\delta B/(k_o)/B_o]^2}$$

energy moves from k_o to k. This time scale is dependent on the power law spectrum of the (assumed) k-spectrum, $F(k) \propto k^{-\nu}$. Typically, $\nu \approx 1.5$. Note that t_c is insensitive to ν and k_o/k if $k_o/k \ll 1$. The

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central point of this paper is that this time scale may dictate some macroscopic signatures of the cascade.

Gaps. Consider a jet leaving an active nucleus. Its relativistic electrons soon exhaust their available synchrotron energy. They move to low-pitch-angle distributions and cannot radiate again until they are scattered into large pitch angles by the magnetic turbulence. This turbulence will not appear until the modes at k_o cascade to a scale $k^* > 10^6 k_o$. This will be true if the beam is generated without microturbulence already present at scales between k_o and k -- i.e., a "smooth start." Assuming this, the jet will be invisible for a distance $L \approx v_b t_c \approx 10a$ to $100a$. In principle this relation can be bounded by observations, and compared with the gaps observed in some cources, such as 3C388.

Expansion in Steps. Some jets display a step-like expansion as they move along their axis; for example, NGC 315. This can be explained by several gradients in the external pressure, but it could as well be an effect of increasing internal pressure, generated by downward cascade of magnetic energy. A possible sequence begins with a relatively "smooth" start for a beam, followed by a buildup in particle scattering after a time t_c. The beam expands under this new particle pressure, since all electrons and protons can be scattered by the waves. However, increasing radius increases t_c, slowing the transfer of energy into sidewise pressure. Thus the beam stops its expansion until new KH turbulence develops and then cascades down to $k \sim k^*$. Then expansion begins again. In some circumstances the pattern can have an on-off appearance, leading to several "steps" along z, with distance between the expansions, D, given approximately by

$$D = Ma\left(\frac{da}{\pi a}\right)\left(\frac{B_o}{\delta B}\right)^2_{k_o} \sim Ma$$

with M the Mach number; $2 \leq M \leq 20$ from theoretical work[1] so the steps are separated by distances considerably exceeding a.

Conclusion. The daunting details of turbulence theory in jets demand a formidable array of calculations to fit observations. The cascade model must be worked out to provide efficiencies, luminosities, etc. for particular sources. However, the simple physical arguments and scalings that I have made here may be testable without recourse to mammoth calculations. Systematic success would then allow us to distinguish cases in which the external medium does not dominate the gross morphology of jets.

References

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