Spines, Boundary Layers, and Doppler Hiding

-- or --

Finding the Fast Lane in Extragalactic Jets

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FRI jet deceleration (3C31)

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FRII jet boundary layer (3C353)

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FRII jet spine (3C219)

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Bottom Line:

All radio-galaxy and quasar jets are born with bulk relativistic velocities.

In FRI sources, these jets decelerate to subrelativistic velocities on kiloparsec scales that we can observe with the VLA.

In FRII sources, these jets do not fully decelerate until the hot spots (or even beyond).

Velocity fields in decelerating jets strongly control what we see of them in radio images.

We are biased towards imaging the slowest parts of the jet flows in all lobe-dominated sources. The fast lane is Doppler-hidden.

Relativistic Jet Birth

Central Engine Performance Specification:

(powerful radio-galaxy/quasar models)

Total Energy Available ~ $10^{6} M_{\odot} c^{2}$
Continuous Power ~ 0.02 $M_{\odot} c^{2}$ per year
Collimated jets formed on sub-parsec scales

Only plausible model:

B++

Black Hole (~$10^{8} M_{\odot}$)
plus
Accretion Disk
plus
Twisted Magnetic Fields

End-on Relativistic Jets

Early VLBI studied brightest, most compact sources:

Superluminal motions
Rapid variability
Low self-Compton X-ray fluxes
One-sided radio structures
Large apparent distortions

All consistent with bulk-relativistic jets
($\Gamma \sim 5$, $v \sim 0.98c$)
seen at small angles to line of sight

Time-of-flight effects--->superluminal motion.
Time dilation--->fast variability, low X-ray fluxes.
Doppler boosting of approaching jet--->one-sidedness,
dominance of compact over extended structure.

N.B. Not restricted to powerful radio galaxies and quasars. Similar phenomena in lower-power "blazars".

Main Points:

Strong evidence that all radio galaxy and quasar jets are born with bulk relativistic velocities.

In weak (plumed, FRI) sources these jets decelerate via interactions with E galaxy atmospheres on kpc scales.

Deceleration imposes a jet velocity field:
a fast spine and slower boundary layer.

Kinematics can be probed with VLA imaging and polarimetry in some nearby galaxies.

In lobed (FRII) sources, jet velocity field biases us toward seeing just a boundary layer until jet decelerates

In FRII sources, the jet spines may not decelerate fully until the hot spots.

The fast lane of energy transport --- the jet spine --- may thus stay Doppler-hidden to the very end.

High-Power Extended Sources

Fanaroff-Riley Class II

Well-bounded, edge-brightened, twin-lobed sources.

Lobes often have bright "hot spots"
(strong-shock jet terminations?)

One-sided jets, prominent in quasars (broad opt lines)
less prominent in radio galaxies (narrow opt lines)

Jets highly collimated
Jets dominated by axial field components