# JOINT COMMISSION MEETING ON

# BEAMS AND JETS IN EXTRAGALACTIC SOURCES

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SMALL-SCALE RADIO JETS

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Here I shall interpret 'small-scale' to mean a few kpc or less. Such jets occur over a wide range of emitted energies (e.g. $10^{39}$erg $s^{-1}$ in M87, $10^{46}$ in 3C273) and we do not know if they are manifestations of the same basic phenomenon or whether Nature is fooling us in some way despite the morphological similarities. For the moment, it seems sensible to assume an underlying unity and to use the observations to explore the jet phenomenon in different guises.

With the highest resolutions obtainable with VLBI, our goal is to elucidate the nature and properties of the central energy source. To this end, we can ask various questions which our observations are expected to bear upon both now and in the future. How do jets form and propagate from the energy source? Are the jets confined/collimated or ballistic? Why are some jets much stronger than others - is this intrinsic or an evolutionary or relativistic effect - or all three? Why are only some sources superluminals? Why are most jets one-sided? Does the relativistic velocity implied by superluminal motion on the pc-scale continue into the kpc-scale jets?

The answers are almost certainly inter-related but at present we are not sure of any. With improvement in observational quality, strong clues to some of the answers are now emerging. Before summarising the observations, I must remind you that our data is much inferior to that being obtained on large-scale jets with synthesis arrays. Limited range and lack of polarization information mean that VLBI maps are similar in quality to 'run-of-the-mill' maps from the Cambridge One-Mile telescope 15 years ago. However, experience with the Jodrell Bank MERLIN shows that an order of magnitude better dynamic range can be achieved within a few years.

## Jets in superluminal sources

The subject was reviewed last year by Cohen & Unwin (1982). No new sources have since been unequivocally shown to be superluminal though there are suspicions regarding BL LAC and AO 0235. Hybrid maps of



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superluminals reveal the same basic structures; a) a bright flat-spectrum core, b) steep spectrum 'blobs' or 'knots' on one side of the core - often called a 'jet', c) large apparent bends in the jet on a pc-scale. The bends could be caused by interaction with a surrounding medium (ram-pressure or static-pressure refraction) or be artefacts due to the rotation of the energy source (for ballistic flow of material). If the blobs really 'bend' around corners and have relativistic velocities, they should brighten and fade as they approach or recede from the line of sight. The apparent angular velocities measured by VLBI should also show secular changes if large changes of the velocity vector direction actually occur. Conversely ballistic motion means that the blobs actually travel in straight lines and these second order effects would not be observed.

Observations are not yet good enough to settle this question, but work on 3C345 and 3C273 is getting close to differentiating between the possibilities. 3C345 shows a change in p.a. of $\geq 120°$ between the pc and kpc-scale (Browne et al. 1982; Readhead et al.- preprint), with most of this occuring on the pc-scale. The sense of curvature is the same on all scales and the simplest explanation is that the jet direction is rotating with time. To first approximation, since the angular velocity is 0.36 mas $y^{-1}$ and the p.a. changes by $\sim 75°$ over the VLBI scale, one expects to see apparent rotation at a rate of 5°-10° per year for ballistic motion. This has not been seen in 3C345 whose p.a. has not changed by > 5° since 1977. This goes against the ballistic model and continuing studies of 3C345 at 23 GHz are important to put better limits on the rotation. However, VLBI observations of 0735+178 at 23 GHz (Baath, private communication) appear to show a change in p.a. of tens of degrees in a few years, so the ballistic explanation may be appropriate here.

Perhaps potentially the most important observation would be to determine whether the separation between core and blobs is due to " o o→ " or " ←o o→ " or " o→ o⟶ " all of which could give the same relative motion. The required positional information could now be achieved by differential phase measurements between closely-spaced sources. Using the Mk III VLBI system Marcaide (1982, Ph.D. Thesis, M.I.T.) has measured the relative positions of 1038+528 A and B to $\sim 10^{-5}$ arcsec. Careful work on 3C345 (with NRAO 150 as reference) should therefore answer this question in the next few years.

Observations of the extended structures associated with superluminals with the VLA, MERLIN and Westerbork (Schilizzi et al. - preprint) do not show such sources to be statistically very different from the general run of radio sources. Particularly important is 3C179, which Porcas (1981) has shown to be superluminal with an apparent velocity of 7.6c ($H_o$ = 50 km $s^{-1}$ $Mpc^{-1}$). MERLIN maps however reveal a 'normal' double source on the arcsec scale suggesting that superluminals may be more common than was anticipated. Browne et al. (1982) have shown that the axis of 3C179 could lie at $\sim 20°$ to the line of sight and still be consistent with the relativistic beaming interpretation (Scheuer & Readhead 1979; Blandford & Konigl 1979). Far more observations are

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clearly needed to clarify the range of circumstances and sources in which the superluminal phenomenon can be observed. Perhaps the only way to obtain good statistics on $\gtrsim$ 50 sources is through a dedicated VLB array.

Extended structures in the superluminals raise another important point. Since they all show one-sided jets on the kpc-scale (on the same side as the pc-scale jet) we are led to the inescapable conclusion that if the nuclear flux is relativistically amplified, so must be the extended jet flux, for otherwise we should observe 'disembodied' jets when the nuclear jet does not point close to the line of sight (Moore et al. 1982).

## Jets in double sources

In classical double sources the nucleus is usually weak and VLBI work difficult. The best work has been by Linfield (1981, 1982) and can be summarised by saying that these nuclei also consist of one-sided jets although the extended lobes are quite symmetrical. Particularly in Cyg-A, which is likely to be at a large angle to the line of sight, the beaming explanation is difficult to maintain and we could be forced to accept that jets are intrinsically one-sided (Linfield 1982). However, recent data on 3C390.3 (Linfield - preprint) and 3C236 (Schilizzi et al. 1981) show that nuclei in classical doubles can be two-sided and bent. Thus, we are in no position to make pronouncements on the physics of the nuclear region. Perhaps the best chance to test the theories in a weak galactic nucleus may be in M87. Reid et al. (preprint) have shown that the nucleus of M87 has a one-sided core-jet structure in the same p.a. as the 2 kpc jet. Second epoch observations should soon tell if relativistic motions can account for this asymmetry.

## Jets in compact steep spectrum sources

Until recently the importance of this type of source was not widely recognised. However, it is now known (Kapahi 1981; Peacock & Wall 1982) that > 25% of all steep spectrum objects selected at high frequencies are compact (< few arcsec). MERLIN and VLBI work on these sources is beginning to reveal a wide range of peculiar structures, more diverse than seen in superluminals. In particular 3C286 (Shaffer & Phillips - preprint) and 3C309.1 (Wilkinson & Kus - in preparation) show 2-sided jets on 10 mas scale while 3C380 (Wilkinson et al. - in preparation; Pearson & Readhead 1981) and 3C147 (Preuss et al. 1982) show distorted structures at right angles to the main ejection axis in the nucleus. Two-sidedness is evidence for relatively low ($\beta \lesssim 0.5$) velocities in these nuclei because for $\beta \gtrsim 0.95$, as in the superluminals, the angle to the line of sight would have to be > 85° to preserve the observed degree of flux symmetry. Another recent discovery is that the nucleus of 3C147 varies at 327 MHz (Simon et al. - in preparation). Following the arguments used to discover the superluminal NRAO 140 (Marscher & Broderick 1982), we believe that 3C147 is likely also to be superluminal.

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It has been suggested that the compact steep spectrum sources are ordinary doubles seen end-on, distorted by projection effects and relativistic boosting of some components. However, 0.25 is too large a fraction to be explained easily by projection effects and it is likely that at least part of the reason for their small size is containment by, and interaction with, the inter-stellar medium in the host galaxy, just as the structures of the weaker sources are affected by the interstellar and intra-cluster media (Ekers 1982; Sparke 1982).

## A precessing jet

Muxlow (preprint) has recently combined data from MERLIN and the European VLBI network to make a map of 3C418 (LAS $\sim$ 3 arcsec) with 80 mas resolution and a dynamic range of several hundred to one. This shows a twisted, one-sided, structure which can be explained by a precessing relativistic jet whose axis lies at $\sim$ 15° to the line of sight. Neff (private communication) has obtained observations of the nucleus with mas resolution and if subsequent observations reveal superluminal motion then severe constraints on radio source models will be obtained.

## Conclusion

Our observational data are of insufficient quality to answer many of the questions posed earlier. It is clear however that the galactic jet phenomenon is more complicated than was apparent even a year ago - not all VLBI maps consist of a core and a one-sided jet. The ability of the VLBI technique to make a big leap in the quality of data is no longer in doubt and perhaps before the next IAU General Assembly answers to some of the outstanding questions will have been obtained.

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