RADIO AND X-RAY OBSERVATIONS OF LARGE SCALE JETS IN QUASARS

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The first big radio jet to be found in a quasar was in 4C32.69 (z=.659) (Potash and Wardle, 1980). A new higher resolution map of this jet, made with the VLA at 5 GHz, is shown in Fig. 1. Observationally the important points are 1) it is very luminous, 2) it is very well collimated, 3) the magnetic field is parallel to the jet over its entire length, 4) it bends at least three times along its path to the outer radio lobe. Physically this is interesting because 1) it is a very lossy pipeline to the outer lobe, 2) the high degree of collimation suggests either the jet is confined by external pressure or it is highly supersonic. But the minimum internal energy density is very high (>3×10^{-10} erg cm^{-3}), so if it is confined the external pressure must also be very high. On the other hand, if the jet is expanding freely, it is easy to show that the momentum flux is enormous (>4×10^{38} dynes). Such a jet is very rigid. It is difficult to stop and difficult to bend, but evidently both of these things happen. A detailed discussion of these problems is given in Potash & Wardle (1980), who concluded that the jet cannot be expanding freely. They suggested that the jet might be confined either by the thermal pressure of external hot gas, or by a helical component of magnetic field due to currents in the jet.

We have recently discovered five more quasars with large scale (>100 kpc) radio jets, using the VLA at 5 GHz. In Fig. 2 we show a map of 3C334 (z=.555) as an example. The other quasars with jets are 4C39.27, 4C29.68, 4C22.26 and 4C24.02. These observations will be discussed in detail elsewhere.

The six jets were discovered among a total of only thirteen quasars that we have looked at with the VLA. It seems that large scale jets are a fairly common occurrence among quasars, as they are among galaxies. In all six cases the jet is visible on only one side of the nucleus, and in the three cases for which we have sufficient sensitivity to measure the linear polarization distribution, the magnetic field runs parallel to the jet along its entire length. These features

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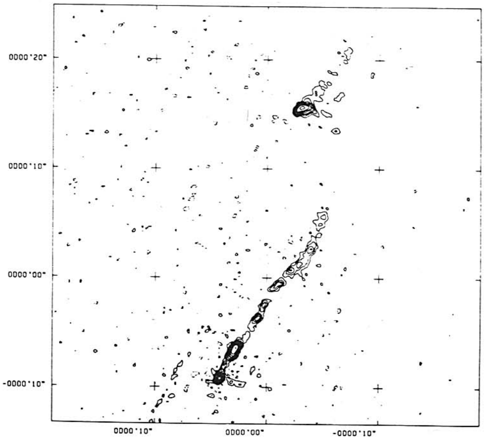
are in agreement with the trends for high luminosity jets discussed by Bridle (this volume). Most important, five out of the eight largest angular diameter quasars from Schmidt's (1975) complete sample of 4C quasars contain jets. Sources selected by angular diameter lie preferentially close to the plane of the sky. The observed "one-sidedness" of the jets is therefore unlikely to be due to the Doppler effect, and is probably an intrinsic feature of these structures.

Three of the six quasars (4C32.69, 4C39.27 and 3C334) have been detected in soft X-rays, using the IPC on board the Einstein Observatory. (The remaining three quasars have not been observed in X-rays.) The measured values of optical to X-ray spectral index, α_{OX}, are 1.12, 1.36 and 1.53 respectively.

The important question is whether the observed X-ray emission is consistent with the presence of enough hot gas surrounding the quasar to confine the jets. First we note that the measured values of α_{OX} are entirely typical of radio loud quasars (Zamorani et al, 1981), so there is no evidence for enhanced X-ray emission from these quasars. (Also, the images are unresolved in the IPC, <80 arc sec.) However, we shall consider a "best case" situation and assume a) <u>all</u> the X-ray emission comes from extended hot gas surrounding the quasar, b) the gas fills a uniform isothermal sphere whose extent is just enough to contain the observed radio structure, c) the gas is a pure H-He plasma, and line emission can be neglected. Since the IPC cannot yet determine good spectral parameters, we assume various temperatures and



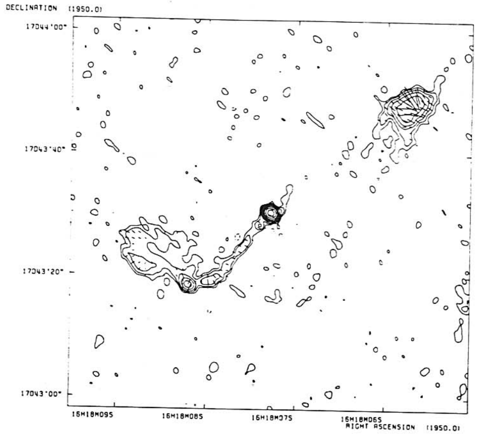


Fig. 1 (left) The nucleus, jet and Np radio lobe of 4C32.69, observed at 5 GHz with a resolution of ~0.5 arcsec.

Fig. 2 (right) 3C334, observed at 5 GHz with a resolution of ~1.5 arcsec.

then calculate the ion density that would produce the observed X-ray emission, and the corresponding thermal pressure. The result is as follows. In all three cases, the ion density (which is not very sensitive to the assumed temperature) is close to 10^{-2} ions cm^{-3}, and the lowest temperature necessary to confine the average pressure inside the jets (which itself is a minimum number calculated from standard synchrotron theory) is in excess of 10 keV.

It is clear that the required temperatures are very high, even making the most favorable assumptions, and they are probably inconsistent with the raw counts in the IPC energy channels which indicate the X-ray spectra are in fact comparatively soft. As an absolute minimum these temperatures are somewhat higher than temperatures found in X-ray emitting clusters of galaxies (Gursky & Schwartz, 1977). We also point out that any gas that can confine the jets must itself be confined, requiring a gravitational potential well considerably deeper than provided by a typical rich cluster of galaxies. In fact there is no direct evidence that such a component of the X-ray emission exists at all, and we conclude that it is improbable that the observed quasar jets are confined by the pressure of a hot ionized gas.

However, we consider the arguments presented in Potash & Wardle (1980) in favor of confinement to be compelling. The simplest alternative appears to be models in which magnetic fields due to currents in the jet itself help prevent rapid expansion (Benford, 1978; Chan & Henriksen, 1980). In this picture, the breaking up of the jet in 4C32.69 (Fig. 1) into discrete blobs might be attributed to pinching instabilities, which could also drive the particle acceleration necessary to maintain the brightness of the jet as it expands.

REFERENCES

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DISCUSSION

BENFORD: If some of your jets do indeed display pinching or helical instability, you can use the theoretical wavelengths and growth lengths to eliminate some parameters--for example, the Mach number--and thus sharpen your arguments. Also, to display such instabilities, a beam must be confined.

DE YOUNG: I would just like to comment that pinch instabilities disrupt, but do not confine, these flows.