Letter to the Editor

One-sided Jets in Extragalactic Radiosources

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Received May 22; accepted August 15, 1980

Summary

Some explanations for the existence of one-sided jets in symmetrical extended radio sources are discussed. It is shown that in the case of the quasar 4C32.69, a relativistic Doppler interpretation is improbable. Observational constraints on a model involving anisotropic radiation are also examined. This model cannot be ruled out, although non-relativistic interpretations of one-sided jets are considered to be most likely.

Key Words: Extragalactic radiosources - jets - circular polarization

I. Introduction

There is now considerable evidence that the jet-like structures seen in some extragalactic radio sources are intimately connected with the quasi-continuous transport of energy from the parent galactic nucleus to the extended lobes (Miley 1980). An important question is why a radio source with relatively symmetrical lobes is sometimes observed to have a radio jet on one side only. The problem of how such an asymmetric jet could power the symmetric radio source has a variety of possible solutions. Amongst these, one of the most popular is that relativistic bulk motions of intrinsically similar jets cause apparent weakening and strengthening of the receding and the approaching jet respectively (Rees 1978, Blandford and Königl 1979). A second solution is that an anisotropic distribution of the radiating relativistic electrons can produce a focussing of the jet emission. This would make the observed intensity of jets strongly dependent on aspect and could thus produce an apparent asymmetry. Other solutions require either distinct intrinsic differences in the radiative properties of the two jets or a complete absence of one jet. Here we will investigate some constraints on the relativistic models which follow from recent observations of jets. In Section II we will show that at least in one case, the relativistic Doppler explanation is unlikely to be correct. The constraints implied in the case of an anisotropic pitch angle distribution are dealt with in Section III, and in Section IV we mention alternative explanations for one-sided jets.

II. The Doppler Shift Hypothesis

The high resolution map of the quasar 4C32.69, recently made with the VLA at 5 GHz, shows two outer lobes roughly equal in intensity and a bright jet associated with the north-western lobe (Potash and Wardle 1980). Let us assume that the jet and the (invisible) counterjet are similar, that both radiate isotropically and that the difference in observed intensities is produced by the relativistic Doppler effect. Several constraints can then be placed on the range of possible flow velocities \( v = \beta c \) in the jet, and the angle \( \theta \) that the direction of the jet makes with the line of sight. First, the Doppler effect will cause the observed intensities of the jet and counter jet to differ. The observed ratio is given by

\[
\frac{K_1}{K_2} = \frac{1}{\alpha^2} \left( \frac{\cos \psi + \sin \psi \sin \theta \cos \phi}{\sin \psi \sin \theta \cos \phi} \right)
\]

where \( \alpha \) is the spectral index defined by \( S_\nu \propto \nu^{-\alpha} \). For 4C32.69 Potash and Wardle find \( K_1 > 30 \) implying \( \cos \psi > 0.59 \). This constraint excludes the region of the \( \psi \theta \) plane under the line defined by \( \cos \psi = 0.59 \) as shown in Fig. 1. A second constraint on the possible ranges of \( \beta \) and \( \theta \) is provided by the absence of an apparent change in intensity over a bend in the jet. At \( 8^\circ \) north west of the nucleus the jet bends through an angle of \( 16^\circ \) without changing its intensity by more than 30% (Potash and Wardle, private communication). If the jet is relativistic and pointing towards us we would expect to observe a large change in intensity over the bend. To calculate the quantitative implications we adopt the coordinate system of Fig. 2. Let us assume that the jet velocity and radiative properties of the jet do not vary over the bend and that the jet curves along a circular arc with fixed center (A) and radius of curvature (R). The angle through which the jet swings (\( \phi \)) is observed as an angle (\( \phi' \)) given by \( \cos \phi' = -A \sin \phi \). Here the index 1 indicates projection onto \( |A_1| |S_1| \) the plane of the sky and \( \phi \) is the position vector of the jet after the bend as viewed from A (see Fig. 2.). We now find an upper limit for \( \beta \) given by:

\[
K_{11} = \frac{1}{\alpha^2} \left[ \frac{\text{observed intensity before the bend}}{\text{observed intensity after the bend}} \right] \frac{1}{\alpha^2}
\]

and \( \phi \) is the angle between the plane in which the bending occurs and the plane of the sky. The observed upper limit of a 30% intensity change over the bend then results in either \( K_1 = 1.11 \) if the jet is bending towards us or \( K_1 = 0.92 \) if the jet is bending away from us. A second domain can therefore be excluded from the \( \beta \theta \) plane. This depends on the value of \( \psi \). As examples two dashed lines are shown in Fig. 1. corresponding to \( \psi = 60^\circ \) and \( \psi = 20^\circ \). A third constraint on the probable values of the projection angle \( \theta \) arises from the fact that the total angular size observed for 4C32.69 is relatively large compared with other quasars in the same redshift range. The projected angular distance between the two lobes is \( < 60^\circ \) whereas for the 31 quasars with redshifts between 0.5 and 0.7 in the "LAS-z" plot of Wardle and Miley (1974) only one quasar has a LAS which is larger than 50\(^\circ\). It is possible that 4C32.69 is anomalously large because it has such a dominant jet. We believe this to be unlikely. The quasars 1004+13 and
Fig. 1. The range of jet velocities ($v_{jet}=8c$) and the angles between the jet direction and the line of sight (θ), consistent with a relativistic Doppler interpretation of the one-sided jet in 4C32.69. The absence of a visible counter jet excludes the region below the line $\cos\theta=0.59$. The lack of intensity change along the bend in the jet excludes values of θ and ψ which depend on $\psi$ (see Fig. 2.). The domain to the left of the line $\theta=25^\circ$ is excluded by the "LAS-2" argument. The only combinations of θ and $\beta$ that can explain the observed intensity distribution (for $\psi=60^\circ$), now lie within the small triangle around $\theta=0.7$ and $\theta=30^\circ$.

Fig. 2. The coordinate system used to analyse the expected intensity change in a bending jet. The x-coordinate is directed toward the observer. The y-coordinate has the direction of the projected velocity of the jet in the plane of the sky before the bend. The jet moves in the plane with a unit of curvature $\alpha$ around a centre of curvature $\Delta$. The position of the jet before the bend is the origin and the bend $\beta$. The angle between the plane of the sky and plane $\beta$ is $\theta$ and the jet is taken to swing through an unprojected angle $\psi$. The angle between $\gamma$-axis and $\Delta$.

1047+09 and 1058+11 also have radio jets (Miley 1980) but have sizes typical of their redshift range. We argue therefore that the large size argues in favour of values of $\theta=60^\circ$ (corresponding to an unprojected size of $\sim 78^\circ$) and strongly against values of $\theta=25^\circ$ (corresponding to an unprojected size of $\sim 160^\circ$). The latter constraint has been used to exclude the left part of the $\theta=0^\circ$ plane in Fig. 1. Using the above three constraints we have estimated, by integrating graphically over parameter space, i.e., $\gamma < \psi < \Delta$, $0 < \theta < \psi$ the probability that the observed brightness distribution is consistent with and can be explained by, relativistic velocities in the jet. We find this probability is $\sim 2\%$ for $\theta=25^\circ$ and essentially zero for $\theta=60^\circ$. Without giving to much weight to the exact probability figures, it is clear that the simple relativistic Doppler interpretation of the one-sided jet in 4C32.69 is unlikely. We emphasize here that we have considered jets whose energy flow is along streamlines parallel to the jet. If however the jet is ballistic with purely radial streamlines our method cannot be applied successfully since the change in direction of the fluid due to the bend is significantly smaller than if the fluid is moving in a channel. Note, however, that Potash and Wardle argue strongly against the free jet hypothesis since in order to stop the momentum input calculated for a free jet an extragalactic density is required of the order of $<10.2$ cm$^{-3}$ which is rather high. Another argument against the relativistic interpretation comes from observations of lower luminosity tailed radio sources, which have several properties in common with double radio sources and a continuous sequence of source "bending" connects the extreme morphologies (Miley 1980). The bending is most reasonably explained as distortion of an initially double morphology by translational motion of the galaxy with respect to a surrounding extragalactic medium (Miley et al. 1972). It is difficult to reconcile the severe bending seen in tailed radio sources with relativistic transport of an energy beam (Blandford and Rees 1978, Begelman et al. 1979, Smith and Norman 1980). One-sided jets are frequently seen in tailed radio sources. An example is 3C129, a well known twin-tailed source (van Breugel and Miley 1977) where VLA observations reveal a distinct jet on one side of the nucleus and no counter jet to a level of $\sim 15\%$ intensity of the jet (Owen et al. 1979). The relativistic Doppler effect is unlikely to occur in tailed radio sources and there is no reason to suggest that the mechanism which causes this asymmetry differs from that responsible for one-sided jets in double radio sources.

III The Anisotropic Radiation Hypothesis

Another possible reason for the presence of one-sided jets in symmetric radio sources is that the jets are anisotropic radiators. This would be the case for jets having a well organized, parallel magnetic field and associated relativistic electrons that move predominantly along the fieldlines. Such jets would behave like flashlights (since the electrons radiate only in their forward direction) making the approaching jet seemingly brighter than the receding one. There is a directly observable consequence of such a scenario. It is well known from synchrotron radiation theory that anisotropic pitch angle distributions give rise to emission of circularly polarized radiation (see e.g. Legg and Westfold 1968). Up to now no observations of circular polarization from jets have been reported, although in some cases upper limits of 0.5% at 50 GHz have been set. In this section we will show how the width of the pitch angle distribution can be constrained by the observations of one-sided jets and we will discuss the applicability of the flashlight model. In general a given electron velocity will make an angle $\xi$ with the direction of the uniform magnetic field $B_0$. We will assume that the number of electrons having pitch angle in the range $\langle \xi, \xi+d\xi \rangle$ is given by a Gaussian distribution function $\phi(\xi)\exp(-\xi^2/2\xi_0^2)$, although other distributions will give similar results. The large fractional linear polarization observed in jets indicates that the strength of the chaotic magnetic field is on the order of or less than the uniform field strength. We will therefore consider the case of a jet with a homogeneous, parallel magnetic field. The range of possible values of the width of the pitch angle distribution $\xi_0$ can now be constrained in two ways. 1) The jet/counterjet intensity ratio $I_0/I_0$ will give an upper limit for $\xi_0$ as a function of $\theta$, the angle between the jet and the line of sight: $I_0/I_0 < 70^\circ/(\theta-20^\circ)$ 2) Pitch angle distributions which are very sharp (that is, small $\xi_0$) will give a high degree of circular polarization. Thus, an upper limit on the degree of circular polarization will set a lower limit on $\xi_0$. For an observing frequency $\nu_{obs}$ and electrons with a Lorentz factor...
The percentage of circular polarization $\eta$ can be written as (Legg and Westfold 1968):

$$\eta = 1 - \frac{B}{10^5 G} \frac{v_{\text{obs}}}{10^3 \text{GHz}} \frac{f(x)}{f(x)} \frac{G(x)}{G(x)} \frac{1}{\gamma^2} \frac{1}{\sin \theta}$$

Here, $x = \frac{v}{v_{\text{crit}}} = 0.27(1+z)$, $\gamma = \frac{1 + v}{1 - v}$. The functions $F(x)$, $H(x)\{\frac{1}{x^{1/2}}[F_p(x) - IF(x)]\}$, and $G(x)\{\frac{1}{x^{1/2}}[F_p(x) - IF(x)]\}$ are tabulated by Legg and Westfold (1968). For $B > 10^5$ G, the second term between the square brackets will not add an observable amount to $\eta$. So we find (since $B(x)/B(0.2)$ for $0.001 < x < 10$):

$$\eta = 5.4 \times 10^{-3} \frac{v_{\text{obs}}}{10^3 \text{GHz}} \frac{f(x)}{f(x)} \frac{G(x)}{G(x)} \frac{1}{\gamma^2} \frac{1}{\sin \theta}$$

Combining the two constraints (1) and (2) shows that for the flashlight model to work there is an upper limit to $\theta$ for a given measured fractional polarization. This is given by:

$$\theta < \frac{1}{2} \left( \frac{1 + 3.4 \times 10^{-3} - \eta}{10^{-5}} \right) \frac{v_{\text{obs}}}{10^3 \text{GHz}} \frac{G(x)}{G(x)} \frac{1}{\gamma^2} \frac{1}{(1+z) \sin \theta}$$

Hence a sufficiently small limit to the fractional circular polarization can in principal rule out the flashlight model. For the 4C32.69 jet, adopting an equipartition value for the magnetic field $B = 10^5$ G, we find that circular polarization measurements at the level of $0.03$% at $0.6$ GHz would rule out the model for $B > 10^5$ G and $B < 0.005$ % for $B > 250$. In the previous section we have seen that because of its relatively large angular size large values of $\theta$ are preferred for 4C32.69. Circular polarization at the $0.52$% level at $0.6$ GHz can be routinely measured with the Westerbork telescope, and with special care an accuracy of $0.3$% can be achieved (Weiler and de Pater 1980). Although it will be clearly difficult to unambiguously rule out the flashlight model it would be well worth while to attempt it by carrying out a careful circular polarization experiment.

### IV Discussion

In sections II and III we have explored possible explanations for the absence of an observed counter jet, assuming throughout that the jet and the invisible counter jet are intrinsically the same. It is however possible that the observed intensity difference between the jet and the counter jet reflects differences in their intrinsic properties. One possibility is that the counter jet is temporally absent. Such an effect might be caused by time variable, asymmetric behaviour of the nuclear machine (Wills et al. 1978) or arise from disruption by flow instabilities or from occasional blocking of the jet by an inhomogeneous nuclear environment (Miley 1980). There is some evidence for the latter scenario in nuclei of Seyfert galaxies. VLA observations show "double radio source" like structures in some Seyfert nuclei (e.g. NGC 5548, Wilson and Willis 1980), which might be caused by two normal jets that cannot escape from the nuclear region. For double radio sources, however, this kind of variability models runs into severe problems when we consider the time scales that are involved. The time it takes a fluid element to get transferred from the nucleus to the lobes is typically on the order of $10^8$ years for sources like 4C32.69. Since there is no evidence for any jet like structure near the hot spot in the southern lobe, the jet has most likely been cut off for more than $10^8$ years. This is longer than the time scale for synchrotron losses in the hot spots (\textasciitilde $3 \times 10^5$ yrs with the usual assumptions e.g. Miley 1980). Hence if the particle acceleration in the hot spots is powered through energy carried by the jet, the jet has probably been present at some time during the last $2 \times 10^8$ yrs. Applying a similar argument statistically to double radio sources Longair and Riley (1979) concluded that if the energy supply is not continuous and there is no localized particle acceleration, the intergalactic space between successive bursts should not exceed $\approx 10^8$ yrs. Thus there is some, albeit marginal, evidence which argues against models which assume a real absence of the counter jet. The second possibility is that the jet and counter jet have distinctly different radiative properties. Pronounced gaps are sometimes seen between the compact nuclear radio component and the beginning of the observable jet (e.g. Miley 1980). Although these may well be caused by large temporal variations in the central energy generator, an attractive alternative is that the gaps reflect drastic changes in the radiation efficiency along the jet. In this picture both the gaps and invisible counter jet would be regions where the conversion of energy to radiation is inefficient. It is not clear what causes jets to radiate. There is considerable evidence that the radiating electrons undergo localized acceleration within the jets. In many suggested 'in situ' acceleration mechanisms, interaction of the jets with the galactic environment by means of flow instabilities or shocks plays an important role. Jet visibility might be critically dependent on a combination of several parameters characterizing the flow velocity, collimation, and physical condition of the internal and external media. We have discussed constraints pertaining to some models of one-sided jets. In particular we have concluded that in one case, the relativistic Doppler interpretation is improbable. We have considered only the case of jets in extended radio sources. One-sided jets are frequently seen in compact radio sources and these too have been explained using the relativistic Doppler effect (Scheuer and Readhead 1979). Our arguments do not directly constrain the relativistic nature or otherwise of these compact sources, although a similar origin for one-sided jets on both extended and compact radio sources would seem the most simple interpretation. If however compact jets were shown to be relativistic then we would conclude that they must be slowed down by non-relativistic velocities outside the core, probably by entrainment of the surrounding medium.

Acknowledgements: It is a pleasure to thank Imke de Pater for useful information. E.V.C. thanks the Netherlands Organization for the Advancement of Pure Research (Z.W.O.) for their financial support.

### References