RADIO BENDING AT HIGH REDSHIFTS - A NEW PROBE OF PROTOGALAXIES?

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ABSTRACT. Evidence is presented that radio sources are more bent at larger redshifts. This effect is interpreted as due to interaction of the radio source with an ambient circumgalactic medium which must then have been clumpier at early epochs. It is suggested that the increased clumpiness could be associated with the late stages of galaxy formation and possibly also with CIV absorption line systems.

1. INTRODUCTION

Studies of the redshift dependance of radio source structure have been part of the cosmological scene for almost two decades (Miley, 1967). As Dr. Kapahi has pointed out, one of the main problems in making such studies has been entangling effects due to the geometry of the Universe from those due to physical evolution of the radio sources and of their surroundings.

Here I shall use radio sources as a probe of their environment and provide evidence that this environment is epoch-dependant. In particular, I shall discuss the results of a project to map a large sample of high-redshift quasars with the VLA (Barthel and Miley 1986), which show that the high redshift objects are systematically smaller and more distorted than similar quasars at low redshift.

Until now such statistical studies have been hampered severely at high redshifts by (i) inadequate resolution and (ii) insufficient sensitivity to map objects of low enough luminosity to be comparable with those seen at low redshifts. Our observations with the VLA were designed to overcome both these problems. The data consist of maps of 80 steep spectrum (extended) quasars with $z > 1.5$, observed with ~0.4" resolution at λ6cm. We compared the structures with data taken from the literature for similar sources having $z < 1.5$ and constructed subsamples of each of these matched in radio luminosity.

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2. RESULTS

2.1. Smaller Sizes.

We reach similar conclusions to Dr. Kapahi concerning the decrease of median linear size as a function of redshift for currently reasonable values of q_o and Ω. However, we are still unable to establish that this effect is unambiguously one of redshift dependance rather than luminosity dependance. As Dr. Kapahi has stated, the dependance of size on redshift can be naturally interpreted as due to interaction of the radio sources with a denser confining medium at early epochs (Miley,1971; Wardle and Miley, 1972).

2.2. Bending.

The most striking and important new result from our data concerns the appearance of the radio morphologies. Whereas at small redshifts,

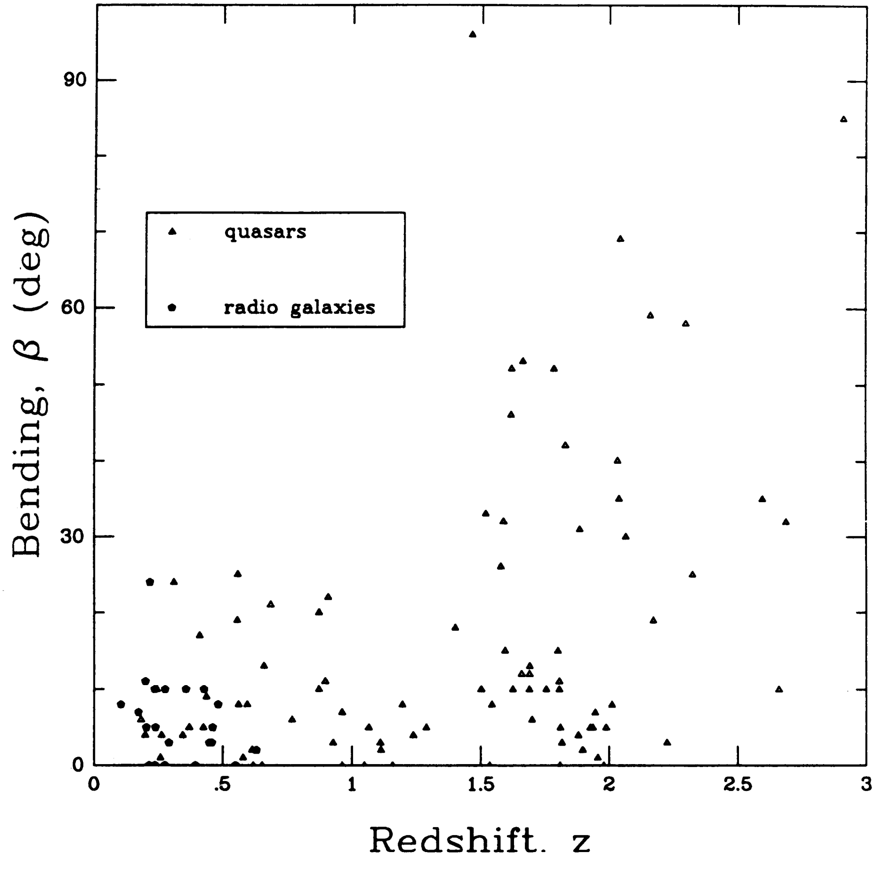

Figure 1. Bending of quasar radio sources as a fuction of redshift. β = 0 refers to a straight source. All sources have steep spectra ($\alpha < -0.6$: $S \propto \nu^{\alpha}$) and high luminosity ($P_{1.4GHz} > 10^{27}$ W Hz^{-1}).

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high luminosity radio sources associated with quasars typically have linear structures resembling that of Cygnus A, there appears to be a significant excess of bent sources at high redshifts. We have partially quantified this effect using a "bending angle", β, defined using the source extremities and the nucleus. For linear (straight) sources, $\beta = 0$. About 50 high-redshift sources were resolved sufficiently to allow β to be estimated. Figure 1 shows β as a function of redshift. There is a striking increase in the curvature of the sources with increasing redshift. For $z < 1.4$, no objects have $\beta > 30°$, whereas 30% of the high redshift sources have $\beta > 30°$.

3. DISCUSSION

Our results that high-redshift radio sources are both crookeder and smaller than lower redshift sources can be best understood as caused by interaction with a denser and clumpier ambient medium at earlier epochs. At small redshifts we have a direct demonstration that such interaction can cause bending in radio sources. There are now several cases where bends in radio sources are observed to occur close to extranuclear emission-line gas (e.g. Miley 1984).

Perhaps the most dramatic example is 3C277.3 (Coma A) at $z = 0.09$ (van Breugel et al 1984) where a radio jet is observed to bend and decollimate close to a bright optical-line knot. Collision with the line-emitting gas cloud appears to cause the bending. For 3C277.3 simple Newtonian arguments show that collision with a mass of $7 \times 10^5\ M_\odot$ would deflect the jet (assuming minimum energy), whereas the observed mass of the ionized gas cloud is $\sim 2 \times 10^6\ M_\odot$. Extrapolating to the larger luminosities and redshifts of typical sources in our sample, similar arguments require gas clouds of $>10^8\ M_\odot$ to produce corresponding deflections.

It is interesting to enquire how many preexisting clouds would be needed to intercept a typical jet, thereby explaining the observed statistics.

$$\text{No. of Clouds per Galaxy} \sim \left(\frac{4\pi}{\text{Radio Opening Angle}}\right) (\text{Observed Fraction Bent})$$

This argument would imply typically a few hundred of these 10^8 M clouds per galaxy and a total mass per galaxy of $>5 \times 10^{10}\ M_\odot$.

As Dr. Silk has described, current models of galaxy formation invoke collapse of the galaxy nucleus before the rest of the galaxy (Silk and Norman 1979). Since the radio bending takes place typically within about several tens of kiloparsecs of the QSO, it seems reasonable to attribute the increased bending at high redshift as being caused by interaction with a clumpy protogalactic disk. If this interpretation is correct, radio sources provide a unique new probe of the late stages of galaxy formation. Also, significant clumpiness would have to persist in the disks of protogalaxies until an epoch corresponding to about $z = 1.5$.

A $10^8\ M_\odot$ cloud with a size comparable to the observed emission-line knot in 3C277.3 (~3 kpc) would have a column density of

10^{21} cm^{-2}. Since this is comparable with the column densities observed from absorption line systems in QSOs, it is tempting to associate the clouds responsible for bending the radio sources with quasar absorption lines. A possible culprit may be provided by the CIV systems, which are reported to occur excessively frequently with redshifts close to the emission redshifts of QSOs (Weymann et al 1979, Foltz et al 1986).

4. FUTURE PROSPECTS

We are at present pursuing several follow-up projects related to this work:

First, we are mapping several of the more bizarre sources at higher resolution with the VLA (Barthel, Lonsdale, Miley). There is the possibility that a study of the bending as a function of distance from the nucleus will provide information about the mass distributions in protogalactic disks. Also, the statistics of polarization distributions will be another tool for such an investigation.

Secondly, a comparison of the statistics of absorption lines between QSOs having straight radio sources and those having crooked ones is being made with the 200" telescope at Mount Palomar (Barthel, Miley, Tytler). A significant difference would be unambiguous proof that there is a connection between gas clouds that bend the radio sources and those responsible for the absorption.

Thirdly, we are engaged in a search for optical emission lines occurring close to the radio bends (Barthel, Heckman, Macchetto, Miley).

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DISCUSSION

WAMPLER: You find a sudden "turn on" of sharp bending at $z \approx 1.5$. Is this consistent with the observed gradual departure of the largest angular size from the expected cosmological models?

MILEY: Yes, there does appear to be a sudden "turn on" in the bending. However, even above $z = 1.4$ only about 30% of the sources are bent by more than 30^{o}. In view of the large dispersion in linear sizes, the resultant effect on the LAS - z relation is not great.

TURNER: It might be worth noting that the gravitational field of an intervening object could distort and bend the image of a distant radio source. The cross section for such a distortion is substantially larger than for multiple imaging. This process might also play some role in explaining the effect you report.

MILEY: Yes it might be important in a few cases but in general the strange morphologies observed would be difficult to explain as the effect of gravitational lenses.

SWARUP: Do you exclude flat spectrum sources for which relativistic beaming can enhance apparent bending?

MILEY: Yes. The sources in the sample were all selected to have steep spectra.

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