COLD MATERIAL IN DISTANT RADIO GALAXIES

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Abstract. Dust, H I and molecular gas must be important components of distant radio galaxies. Recent observations to detect these constituents are discussed.

1. Introduction

Radio galaxies are important probes of the early universe. During the last few years extensive surveys for distant radio galaxies have been carried out using different selection techniques (eg. McCarthy 1993; Miley 1994). At the moment more than 60 radio galaxies are known at redshifts larger than two. The main advantage of studying these galaxies, as opposed to studying other objects known at $z > 2$, such as absorption systems and quasars, is that radio galaxies contain three extended components that are easily resolved with conventional techniques. These components are the radio synchrotron plasma, the ionised gas and the IR/optical/UV continua. Studying these components and their relation to one another has revealed a great deal about the nature of these systems. One of the most interesting parameters is the maturity of the stellar population. Unfortunately, it is difficult to use the observations of the three different components just mentioned to probe the stellar content directly. The main reason for this is that it is difficult to determine the relative contribution from stars and non-thermal emission from the IR/optical/UV continuum data. In nearby galaxies an important probe of star formation is molecular gas. The sensitivity of present day instruments is good enough that at least attempting to detect cold material in distant radio galaxies seems a worthwhile exercise.
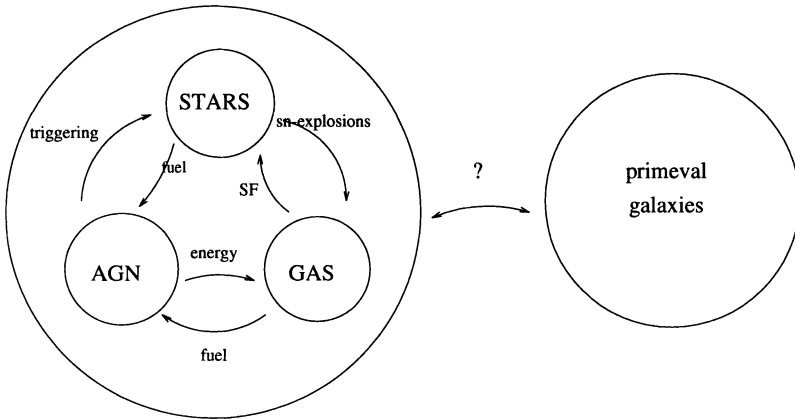
Figure 1. This diagram shows schematically the relation between the various con-
stituents together with their interactions within a distant radio galaxy. One of the main
questions is what such systems tell us about primeval galaxies.

2. The importance of cold gas in distant radio galaxies

Figure 1 is an illustration of how complicated the systems we call distant
radio galaxies are. The three main constituents of these objects are the
active nucleus, stars and gas in various phases. All three constituents are
related to one another. It is clear that the stars in these systems have to be
formed from gas and that stellar mass loss, mostly in the form of supernovae
explosions, will transfer material from stars back to the ISM. This symbiotic
relation between stars and gas is complicated by the presence of the AGN.
The AGN is being fuelled by surrounding material (eg. gas/stars) and as
a result it inputs energy in various forms to the gas. In some models of
distant radio sources it is assumed that the radio jet emerging from the
AGN triggers star formation in the ISM.

It is clear that we have to understand these processes in a certain amount
of detail before we can decide what the relation is between distant radio
galaxies and young and forming galaxies. Questions that should be an-
swered include how profound the impact of the AGN is on these objects
and what age these stellar systems are.

Cold material such as dust and cold gas ($T \ll 10^4$ K) must play an
important role in these systems. Since in some models the radio galaxies
are producing stars at a prodigious rate, this is the phase of the ISM that
provides the building material for stars. In nearby AGN such as Seyferts
the observation of molecular material shows that a large fraction of the CO
gas, for example, is concentrated within one kpc of the active nucleus. This
suggests that at least some of the molecular gas will ultimately fuel the
AGN.

In the rest of this contribution I will concentrate on the observational evidence for this gas phase in distant radio galaxies.

3. Dust

There are several ways of probing the dust content in high redshift radio galaxies. One of the first attempts was to measure the $Ly\alpha/H\alpha$ ratio. For two radio galaxies McCarthy et al. (1992) found values within a factor of 2 of case B recombination, implying E(B-V)=0.1. Cimatti et al. (1993) found dust masses of order $10^8 M_{\odot}$ from modelling the optical polarisation of radio galaxies. The most spectacular measurement of dust is probably the detection of submillimetre emission from the radio galaxy 4C41.17 (z=3.8) implying dust masses of order a few times $10^8 M_{\odot}$ (Dunlop et al. 1994). Van Ojik et al. (1994) discovered that the radio galaxy $0211-122$ ($z = 2.34$) has a peculiar emission line spectrum, with $Ly\alpha$ very much fainter with respect to the high ionisation lines than in typical high redshift radio galaxies. They suggest that this galaxy is undergoing a vigorous starburst producing enough dust to attenuate the $Ly\alpha$ emission.

4. Neutral Hydrogen

There are two important methods of detecting H I associated with radio galaxies. The first method is to measure the redshifted 21 cm absorption line against the radio continuum. The only distant radio galaxy for which this has been measured is 0902+34 (z=3.4). Uson et al. (1991) found an absorber in this system with a column density of 4.4×10^{22} atoms cm^{-2}, assuming a spin temperature of 10^4 K. The existence of this absorber was confirmed by Briggs et al. (1993).

The second method is to measure absorption against the $Ly\alpha$ emission of high-z radio galaxies. The main reason that this is possible is that the $Ly\alpha$ emission from distant radio galaxies can be very bright ($> 10^{-15}$ erg s^{-1}). We therefore started a programme to detect such absorption in distant radio galaxies. The high resolution AAT spectra (1.5 Å) of the $Ly\alpha$ region of the $z = 2.9$ radio galaxy $0943-242$ reveal a complex emission line profile which is dominated by a black absorption trough centered 250 $km\,s^{-1}$ blueward of the emission peak (Figure 2, see also Röttgering et al. 1994). The main H I absorber has a column density of $1 \times 10^{19}\,cm^{-2}$.

One of the fundamental limitations in the study of quasar absorption lines is that quasars are point sources so that in general no information can be obtained about the spatial scale of the absorber. In the case of radio galaxies however, the $Ly\alpha$ emission is extended, in some cases even up to 10 arcsec. The main absorption in the $Ly\alpha$ emission from $0943-242$ is black and it covers the entire $Ly\alpha$ emission region which has an angular scale of
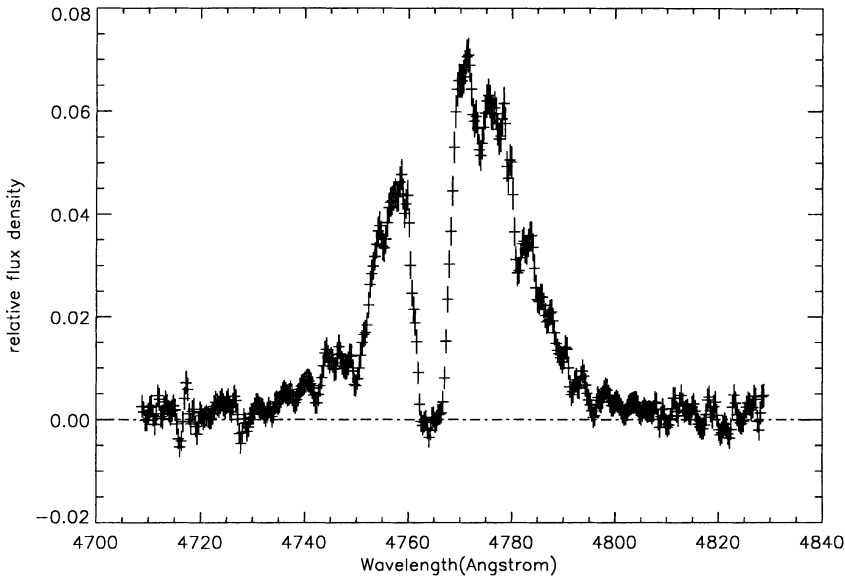
Figure 2. Part of the high resolution AAT spectrum spectra (1.5 Å) of the Lyα region of the $z = 2.9$ radio galaxy 0943−242. (see also Röttgering et al. 1994).

1.7 arcsec. Its linear size is then at least 13 kpc, making this the first direct measurement of the spatial scale of an absorber with a column density of $\sim 10^{19}\,\mathrm{cm}^{-2}$.

5. Carbon Monoxide

Since the CO molecule is a good tracer of star formation in galaxies, studying this molecule at cosmological distances is important for understanding the evolution of young galaxies. To date the two objects at high redshift that have a confirmed detection of a CO line are the ultra luminous IRAS galaxy F10214+4724 at z=2.3 (Solomon et al. 1992) and the cloverleaf quasar (Barvainis et al. 1994). The good news is that these two detections demonstrate convincingly that studying CO in the early universe is possible. The bad news is that the IRAS galaxy F10214+4724 is the only IRAS galaxy known at these distances. Studying a sample of such objects is therefore not (yet) possible. Since the cloverleaf quasar is a gravitationally lensed quasar for which the amplification factor is not well known, the estimate for the intrinsic CO luminosity of this object is uncertain.

The significant samples of quasars and radio galaxies that exist are

a good starting point for a further search for CO in the early universe. The expected width of the CO emission lines is a few hundred km s^{-1} (FWHM) and the bandwidth of the receivers and backend combination as used in major sub-millimetre observatories is limited to about 1000 km s^{-1}. It is therefore important that objects to be studied have well determined redshifts, preferably better than a few hundred km s^{-1}. Since the FWHM of the emission lines of radio galaxies is of order 1000 km s^{-1}, a factor of $5 - 10$ smaller than in quasars, there is some advantage using radio galaxies rather than quasars for a survey of CO in the distant universe. We have started a programme to detect CO emission from distant radio galaxies using the JCMT and IRAM telescopes. From our spectra we have clear indications that we are indeed detecting CO lines from some of these distant objects. Currently we are working to confirm these detections using new observations. If these lines are real, they indicate that the density of CO gas is in the range $10^4 - 10^5$ cm^{-3} and that the temperature is of order $50 - 100$ K. Using galactic conversion factors the total H_2 masses are then $10^{11} M_\odot$, comparable to the mass obtained for F10214+4724. If correct, these detections would support the idea that distant radio galaxies are undergoing vigorous starbursts. They might, therefore, be producing the bulk of their stellar content, as expected for a forming galaxy.

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