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High-redshift radio galaxies: the most massive galaxies at every epoch

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Abstract. Radio galaxies are identified with the most massive host galaxies known out to $z = 5$ and can put strong constraints on galaxy evolution models, provided their space density is accurately determined. Here, I present the important role low-frequency radio surveys will have in this by selecting the highest redshift radio galaxies using the steepness of their radio spectra.

Keywords. galaxies: high-redshift, radio continuum: galaxies

1. The massive hosts of radio galaxies

The best studied type 2 AGN at high redshift are radio galaxies. Their radio selection allows the construction of samples which are unbiased against dust properties. The very wide area of the parent radio surveys (up to 75 % of the sky for NVSS; Condon *et al.* 1998) also allows the selection of objects with a very low space density.

The host galaxies of nearby radio galaxies are almost uniquely identified with massive elliptical galaxies (Matthews *et al.* 1964). Over the past two decades, there has been mounting evidence that the host galaxies of higher redshift powerful radio sources are also amongst the most massive at each epoch. Much of this evidence is based on the Hubble K - z diagram (e.g., Lilly & Longair 1984; Eales *et al.* 1997; van Breugel *et al.* 1998; De Breuck et al. 2002, Rocca-Volmerange *et al.* 2004). However, the interpretation of the K-z diagram in terms of stellar masses has been complicated by (i) strong band-shifting effects: the observed K-band at $z = 4$ corresponds to rest-frame B band; and (ii) the uncertain contributions of the obscured AGN. To remedy these problems, we have started a major project to determine the stellar masses of a sample of 70 radio galaxies from $z = 1$ to 5.2 covering a range in redshift and 3 GHz radio power. Our results confirm that radio galaxies have stellar masses between 10^{11} and 10^{12} $M_{\odot}$ (Seymour *et al.* this volume; Seymour *et al.* in preparation). They thus trace the very upper end of the stellar mass function, even at high redshift. As such, they can provide some of the strongest constraints on galaxy formation models, provided that their space density is well determined. It is therefore important to construct large and complete samples of high redshift radio galaxies. This is an area where future low-frequency radio surveys will be able to make an important impact.

2. Ultra-steep spectrum selection techniques

The main difficulty in deriving samples with complete redshift information is the often extreme optical faintness of radio sources. Often, the redshift determination is only possible thanks to bright optical emission lines photo-ionized by the AGN (e.g., the pioneering work on the 3CR sample by Spinrad *et al.* 1985). However, this emission-line luminosity is correlated with the radio power (Willott *et al.* 1999), meaning that it is very difficult to obtain redshifts of progressively fainter radio sources. Optical redshift determinations of the highest redshift radio galaxies often require integrations of more than 1 hr on 8 - 10 m class telescopes.

As present-day radio surveys contain up to 2 million sources, a drastic culling of the catalogues is needed to allow follow-up redshift determinations. In particular, one is mostly interested in the highest redshift radio galaxies. To select these, the most successful technique has been the selection of radio sources with ultra steep radio spectra (USS, $\alpha < -1.0$ for $S_\nu \propto \nu^\alpha$). This technique is based on the empirical correlation between spectral index and redshift (De Breuck *et al.* 2002).

It has been by far the most successful filter to find the highest redshift radio galaxies to the extent that all known $z > 3.5$ radio galaxies have been found from such USS samples. The physical interpretation of this z-α correlation has generally been sought in a band-shifting of the steeper high-frequency part of the radio spectrum into the observed low-frequency window. However, Klamer *et al.* (2006) have recently challenged this interpretation based on the observation of straight radio spectra in 92 % of the observed USS radio galaxies. Such an absence of high-frequency steepening has been previously reported by Mangalam & Gopal-Krishna (1995). The alternative explanation is that the highest redshift radio galaxies are located in increasingly denser media, which would lead to steeper radio spectra, as seen in low-redshift radio sources in dense environments (Athreya & Kapahi 1998).

If the radio spectra are indeed straight at rest frequencies of $\sim$1 GHz, one thus has to move to lower frequencies to find the spectral downturn due to synchrotron self-absorption. Selecting USS at rest frequencies of a few hundred MHz is thus expected to be a very efficient selection technique of $z > 5$ radio galaxies, as they should stand out even more compared to low-redshift sources having much flatter spectra. The wide-field capabilities of the new low-frequency observatories such as LOFAR, LWA, and SKA will likely open a completely new window for USS searches of high redshift radio galaxies. In addition, the broadband spectral capabilities may allow us to directly obtain redshifts in the radio regime using the H I 21-cm line and/or the 21-cm forest (Carilli 2006, these proceedings).

References

Athreya, R., & Kapahi, V. 1998, *JAA*, 19, 63
Condon, J., Cotton, W. D., Greisen, E. W., *et al.* 1998, *AJ*, 115, 1693
De Breuck, C., van Breugel, W., Stanford, S. A., *et al.* 2002, *AJ*, 123, 637
Eales, S., Rawlings, S., Law-Green, D., Cotter, G., & Lacy, M. 1997, *MNRAS*, 291, 593
Klamer, I. J., Ekers, R. D., Bryant, J. J., *et al.* 2006, *MNRAS*, 371, 852
Lilly, S., & Longair, M. 1984, *MNRAS*, 211, 833
Mangalam, A., & Gopal-Krishna 1995, *MNRAS*, 275, 976
Matthews, T., Morgan, W., & Schmidt, M. 1964, *ApJ*, 140, 35
McCarthy, P. J., Kapahi, V. K., van Breugel, W., *et al.* 1996, *ApJS*, 107, 19
Rocca-Volmerange, B., Le Borgne, D., De Breuck, C., Fioc, M., & Moy, E. 2004, *A&A*, 415, 931
Spinrad, H., Marr, J., Aguilar, L., & Djorgovski, S. 1985, *PASP*, 97, 932
van Breugel, W., Stanford, S. A., Spinrad, H., Stern, D., & Graham, J. R. 1998, *ApJ*, 502, 614
Willott, C., Rawlings, S., Blundell, K., & Lacy, M. 1999, *MNRAS*, 309, 1017