The cluster environments of radio loud quasars

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Abstract.

We have carried out multi-colour imaging of the fields of a statistically complete sample of low-frequency selected radio loud quasars at $0.6 < z < 1.1$, in order to determine the characteristics of their environments. The largest radio sources are located in the field, and smaller steep-spectrum sources are more likely to be found in richer environments, from compact groups through to clusters. This radio-based selection (including source size) of high redshift groups and clusters is a highly efficient method of detecting rich environments at these redshifts. Although our single filter clustering measures agree with those of other workers, we show that these statistics cannot be used reliably on fields individually, colour information is required for this.

1. Introduction

Powerful radio sources at low redshift, (Cyg A, 3C295), are known to reside in massive elliptical galaxies such as those commonly found at the centre of clusters. AGN at low redshift have been shown to exist in environments of above average galactic density (Yee & Green 1987) and studies extending these measurements to higher redshift show no evolution in this trend (Ellingson, Yee, & Green 1991; Hill & Lilly 1991; Yee & Ellingson 1993; Wold et al. 2000). It is therefore reasonable to expect that at high redshift we may be able to find clusters by looking at the environments of AGN. This is further substantiated by theoretical arguments regarding the formation of extended lobe-dominated radio structures (e.g. Miley 1980). Such models require a confining medium to exist over hundreds of kpc, the scale lengths and pressures being comparable with those found in clusters of galaxies. An advantage of instigating a search in this manner is provided by the fact that a quasar will pinpoint the redshift of interest and through careful choice of filters facilitate the identification of associated galaxies by way of their colours.

These reasons make it possible to build a sample of distant groups and clusters from a study of radio loud quasars (RLQs), although care must be taken to understand the selection function. With reasonable estimates regarding the lifetime of the AGN and its effect on the cluster this can be achieved. In any case the opportunity to study clusters and their constituents is not lost. A related benefit is that we may find and study small and compact groups at high redshift. Current optical and X-ray methods will be insensitive to such low mass/luminosity systems and the environments of RLQs may
Figure 1. Values of the spatial cross correlation amplitude as a function of redshift for radio loud quasar fields. Filled squares, this work. Diamonds, Wold et al. (2000). Triangles, Yee & Ellingson (1993). Squares, Ellingson et al. (1991). Crosses, Yee & Green (1987). Asterisks, McClure & Dunlop (2000). The horizontal lines represent the Abell classes quoted in McClure & Dunlop.

offer the best method of finding significant numbers of these systems at high redshift for some time to come.

2. Sample and observations

The quasars used for this study are drawn from the Molonglo quasar sample (MQS, Kapahi et al. 1998) of low frequency selected radio loud quasars. This is a complete sample of 111 RLQs with $S_{408} > 0.95$ Jy in a contiguous area of southern sky ($-30^\circ > \delta > -20^\circ$, but excluding the R.A. range $14^h03^m - 20^h03^m$).

Within the range $0^h0m < RA < 14^h0m$ there are 30 MQS objects which have $0.6 < z < 1.1, 22$ for which we have data. Eight sources with these criteria were randomly excluded due to observing time restrictions. This sample has many merits. Firstly it has a single selection criterion, that of low frequency radio luminosity. Thus it does not attempt to “match” catalogues of what may be intrinsically different objects. Secondly, of all objects in our chosen redshift range none are excluded based on optical or radio bias. The remaining objects can therefore be thought of as a representative sample. Also, the low frequency selection avoids preferentially selecting core dominated objects, i.e. those which may be of intrinsically lower luminosity but have Doppler boosted emission due to their orientation to the line of sight. The MRQ is thus useful as a “complete and unbiased” sample on which to study the environmental properties of RLQs.

We have observed our objects in 2 or more filters which straddle the redshifted 4000Å break in order to maximise the contrast for early type galaxies. In several cases we also have near infrared (NIR) $J$ and $K'$ filters. The telescopes used were the CTIO 4m, the ESO 2.2m and 3.6m and the AAT.

3. Single filter analysis

Previous investigators have sought to quantify the excess of objects around quasars, (or radio galaxies, or any other object), by counting sources within a certain radius in a single filter (0.5 Mpc in most cases). We initially analyse clustering around quasars with reference to such a measure, the galaxy-quasar spatial cross correlation amplitude,
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Figure 2. The surface density of objects as a function of position in the fields of three of our quasars, binned according to colour range. Cluster cores at the redshift of the quasar would produce peaks in the density maps indicated by the arrow. While all three fields produce high values of $B_{q\ell}$, we can see that in the second case the overdensity is at the wrong colour for the quasar redshift. The position of the quasar is marked by the circle.

$B_{q\ell}$. A detailed derivation can be found in Yee & Green (1984) and Longair & Seldner (1979).

The results of applying this method to our data can be seen in figure 1, as well as those for other investigators. Our results confirm that the quasars occupy a variety of environments and show no evidence for evolution to a redshift of 1.

There are, however, reasons why these methods are not necessarily the most accurate to use at high redshift. Firstly, they assume that the AGN is at the centre of any (roughly circular) overdensity. As we progress to higher redshifts, clusters are less likely to be in relaxed spheroidal systems and may exhibit significant substructure which can extend further than 0.5 Mpc from the quasar. Secondly, the number density of objects at the magnitude levels of interest displays variation on the scale-lengths of distant clusters making it difficult to estimate the background to subtract from any overdensity. Thirdly, even when an obvious overdensity is discovered, it may consist of objects which have the wrong colours to be galaxies at the redshift of the quasar (see fig. 2b). In this case these statistical analyses will not only be wrong, they may bias the average result systematically and in doing so render any measure of the average properties of a sample incorrect.

4. Multi-colour results

By choosing optical filters which straddle the 4000Å break, we can select the passively evolving elliptical galaxies at the redshift of the quasar. Figure 2. shows the density of objects around three of our quasars separated according to colour. We can identify agglomerations as having the potential to be at the quasars redshift by using these sort of plots. Further analysis looking at the colour dispersion or for a red sequence or using NIR filters can then quantify accurately which galaxies belong to the cluster core and which do not. Examples of these techniques are to be found in Baker et al. (2001) and Bremer et al. (2001).
Figure 3. Our sample divided into small and large steep spectrum sources. Clustered environments are more often associated with smaller radio structures.

Because of the arguments regarding the formation of the radio lobes being dependent on a large scale medium, we would expect to see a correlation between the size of the source and the clustering around it. We see just such a correlation in figure 3. Our sample is separated into those sources with a radio size $< 20''$ and those with $> 20''$. Unresolved flat spectrum sources, ($\alpha < 0.6$), are rejected in order to prevent beamed sources with intrinsically lower luminosity from being included. The remaining sample of 19 steep spectrum objects is thus split approximately in half. If we loosely define our clusters as those with more than 10 associated core members, we see that five out of our six clusters are associated with smaller radio structures. We wouldn’t expect to see a 1:1 relationship between size and clustering. The age of the source may have allowed it to expand despite a clustered environment, or conversely, perhaps we see a young source which is expanding unconfined. Projection effects may also hide the true size of the source.

5. Summary

We have found that RLQs exist in a variety of environments from the field through compact groups to rich clusters. In order to correctly quantify the environments of these sources, multicolour information must be used. There is evidence for a radio size - environment relation with smaller sources located in richer systems. By selecting small, powerful RLQs we can efficiently create a sample of distant groups and clusters. We also have the ability to “dial up” clusters at a specific redshift by looking at AGN.

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