The Environments of AGN at z~1

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The environments of $z \sim 1$ Active Galactic Nuclei at $3.6\ \mu m$

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ABSTRACT

We present an analysis of a large sample of AGN environments at $z \sim 1$ using stacked *Spitzer* data at 3.6 μm. The sample contains type-1 and type-2 AGN in the form of quasars and radio galaxies, and spans a large range in both optical and radio luminosity. We find, on average, that 2 to 3 massive galaxies containing a substantial evolved stellar population lie within a $200-300$ kpc radius of the AGN, constituting a > 8-σ excess relative to the field. Secondly, we find evidence for the environmental source density to increase with the radio luminosity of AGN, but not with black-hole mass. This is shown first by dividing the AGN into their classical AGN types, where we see more significant over-densities in the fields of the radio-loud AGN. If instead we dispense with the classical AGN definitions, we find that the source over-density as a function of radio luminosity for all our AGN exhibits a positive correlation. One interpretation of this result is that the Mpc-scale environment is in some way influencing the radio emission that we observe from AGN. This could be explained by the confinement of radio jets in dense environments leading to enhanced radio emission or, alternatively, may be linked to more rapid black-hole spin brought on by galaxy mergers.

Key words:
galaxies: active - galaxies: high-redshift - galaxies: clusters: general - (galaxies:) quasars: general - galaxies: statistics.

1 INTRODUCTION

It is now widely accepted that high-luminosity Active Galactic Nuclei (AGN) harbour accreting super-massive black holes implying that their host galaxies are amongst the most massive objects in existence at their respective epochs. Indeed, many studies have now shown that AGN preferentially reside within fields containing over-densities of galaxies (e.g. Hall & Green 1998; Best et al. 2003; Wold et al. 2003; Hutchings, Scholz & Bianchi 2009). Together these points support the idea that AGN can be utilized as signposts to extreme regions of the dark matter density and thus the most massive dark matter haloes (e.g. Pentericci et al. 2000; Ivison et al. 2000; Stevens et al. 2003) at any given epoch. Combining this technique with large multiwavelength surveys, like the Sloan Digital Sky Survey (SDSS; Adelman-McCarthy et al. 2006) which has identified up to 100000 broad-line quasi-stellar objects (hereafter quasars) up to the highest measured redshifts (i.e. z=6.4, Fan et al. 2003), has opened up a new era in AGN research.

Many authors have addressed the question of whether the environments of radio-loud AGN, such as radio-loud quasars (RLQs) or radio galaxies (RGs), are any different from those of radio-quiet AGN, such as radio-quiet quasars (RQQs), with conflicting results. The first work that compared directly the environments of RLQs and RQQs was Yee & Green (1984), in which a marginally more significant over-density was detected around the RLQs in their sample of objects at $0.05 < z < 0.55$. However, a later improved study with more data and refined techniques removed the significance of this result (Yee & Green 1987). More work on the topic was conducted by Ellingson, Yee & Green (1991) who added more faint RQQs to the Yee & Green (1987) sample.

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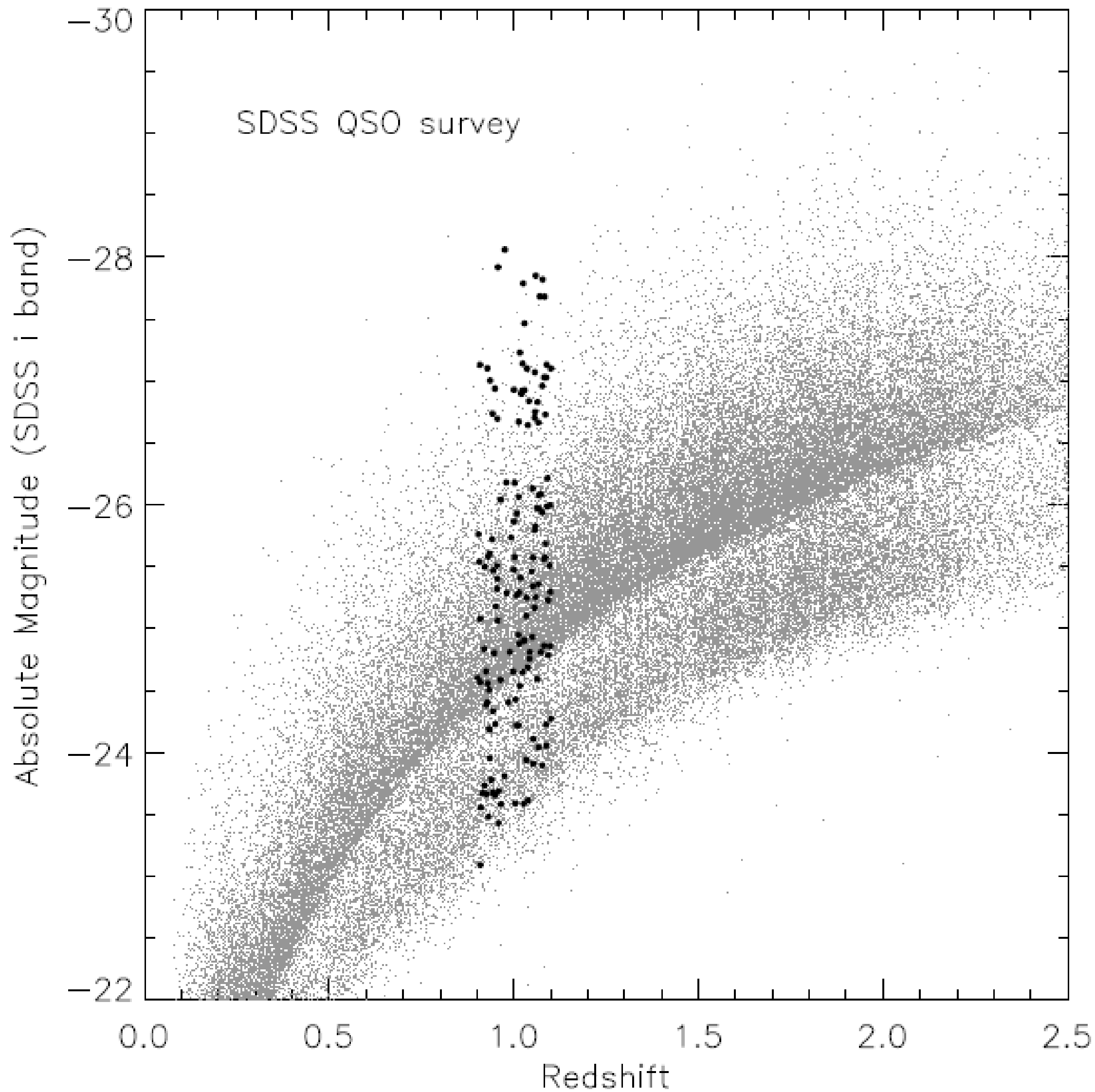
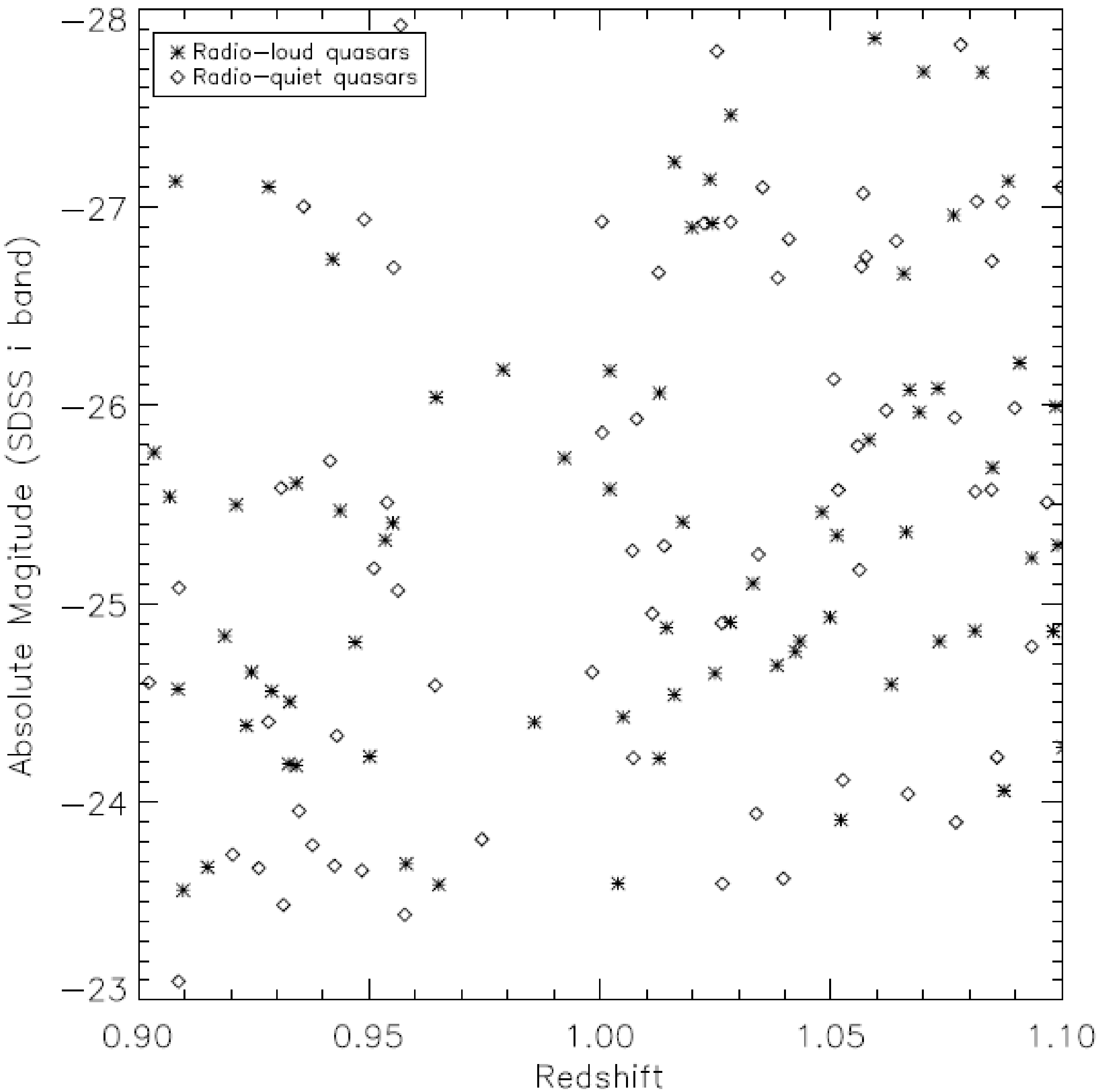
Sample

- ~170 AGN
- Type-1 (SDSS QSOs) and Type-2 (Radio-galaxies).
- $0.9 < z < 1.1$
- Aim to decouple evolutionary and luminosity effects.



QSOs



- SDSS provides five magnitudes of optical luminosity at this redshift.
- Samples of ~70 radio-loud QSOs (RLQs) and radio-quiet QSOs (RQQs), selected in identical ways.
- KS-test gives their spread of optical luminosities as matched at the 94% level.
- QSO sample described fully in Jarvis et al. 2010 in prep.

Radio Galaxies

Name	S_{325} (Jy)	α	z
3C 175.1	6.939	0.85	0.920
3C 184	9.097	0.87	0.994
3C 22	8.348	0.90	0.936
3C 268.1	15.615	0.58	0.970
3C 280	16.025	0.81	0.996
3C 289	8.278	0.84	0.967
3C 343	13.413	0.68	0.988
3C 356	6.820	1.04	1.079
6C E0943+3958	1.182	0.85	1.035
6C E1011+3632	1.190	0.79	1.042
6C E1017+3712	1.540	1.00	1.053
6C E1019+3924	1.690	0.94	0.923
6C E1129+3710	1.543	0.89	1.060
6C E1212+3805	1.408	1.06	0.95
6C E1217+3645	1.402	0.94	1.088
6C E1256+3648	1.760	0.81	1.07
6C E1257+3633	1.036	1.08	1.004
6C*0128+394	1.322	0.50	0.929
6C*0133+486	0.742	1.22	1.029
5C 6.24	0.839	0.77	1.073
5C 7.17	0.469	0.93	0.936
5C 7.23	0.546	0.78	1.098
5C 7.242	0.304	0.94	0.992
5C 7.82	0.371	0.93	0.918
TOOT1066	0.098	0.87	0.926
TOOT1140	0.298	0.75	0.911
TOOT1267	0.282	0.80	0.968

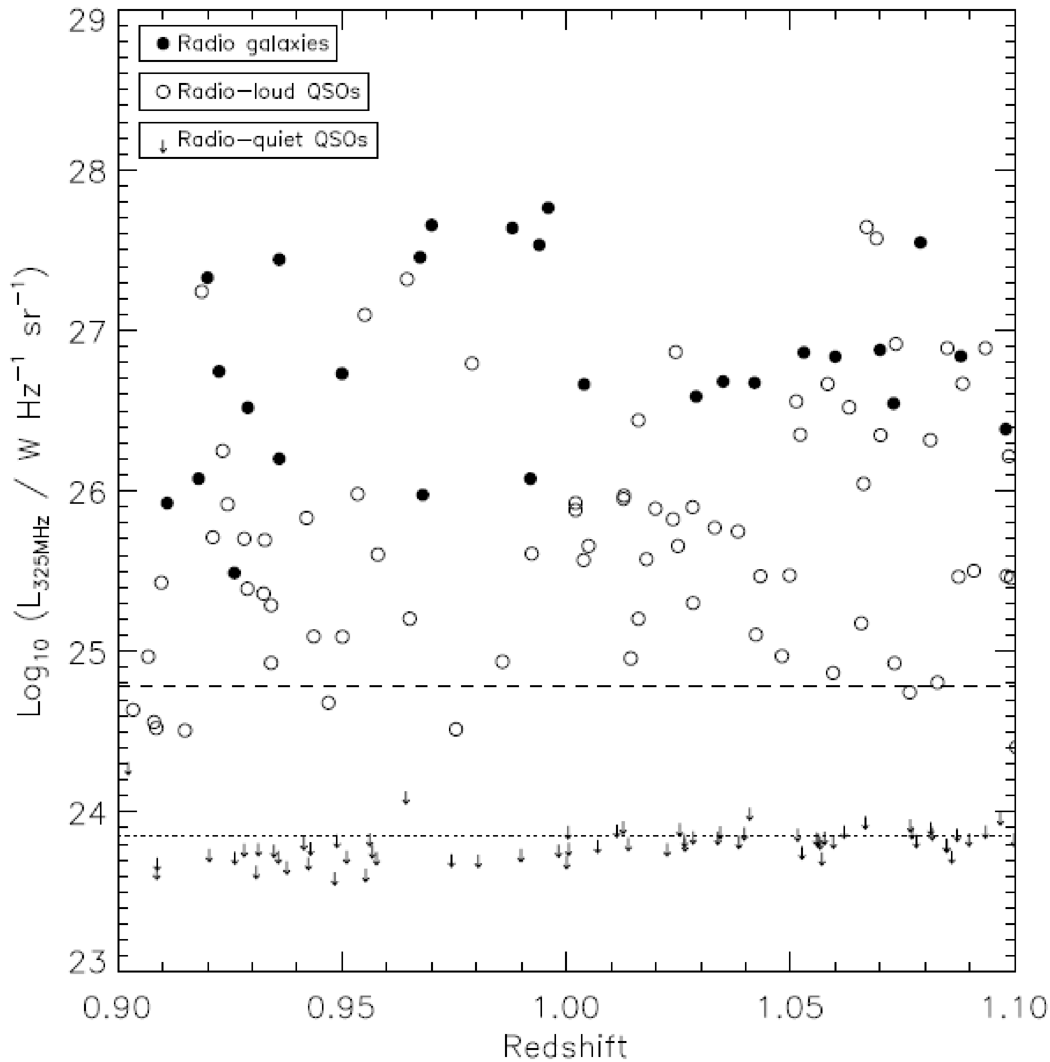
- Also added all known Radio-galaxies in the same redshift range.
- Using the 3CRR, 6CE and 7CRS and also the TOOT (Hill & Rawlings 2003), 27 RGs in total.
- Low radio frequency so are thus orientation independent, i.e. no beaming effects.

Radio-luminosity

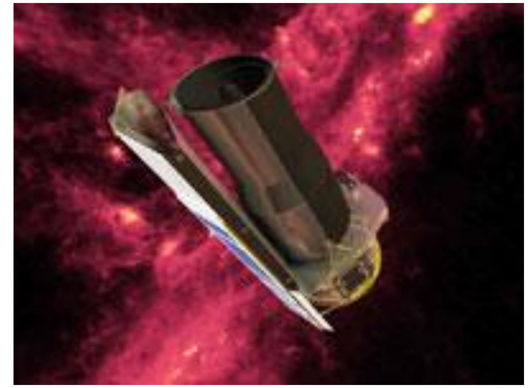
• To select RLQs we used WENSS, fluxes of greater than 18 mJy (5-sigma survey limit).

• Overlap between the RLQs and RGs, but on average the RGs are more radio-loud.

• The RQQs were selected as being non detections in the FIRST survey.



Observations



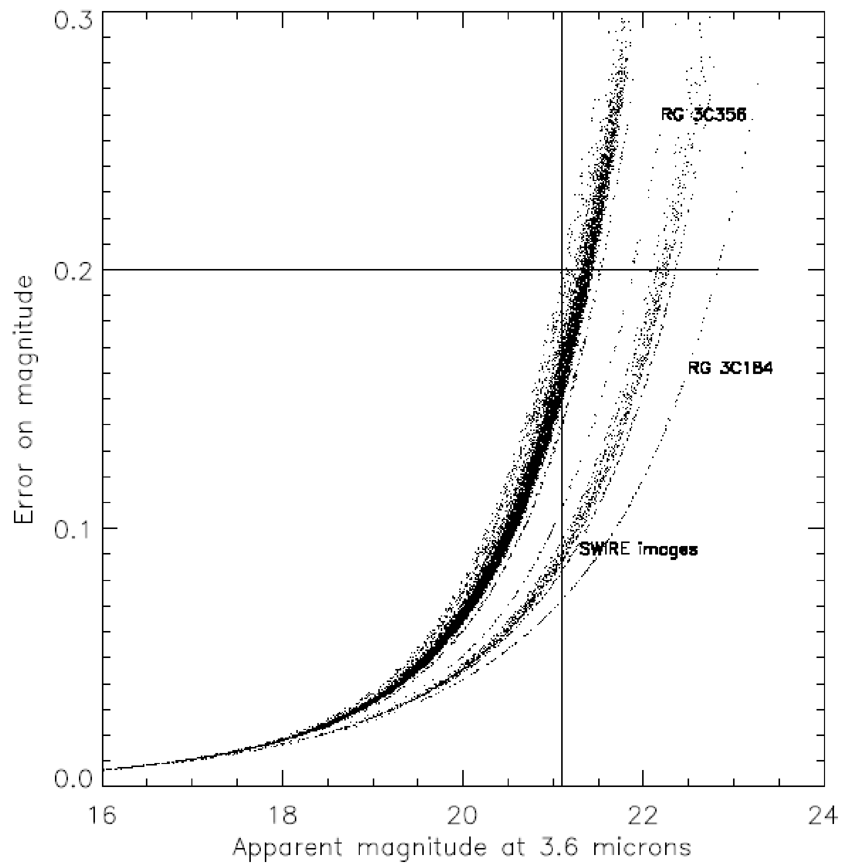
• *Spitzer* Space Telescope, IRAC and MIPS.

• See Poster by Liz Dodd for 24μm environments.

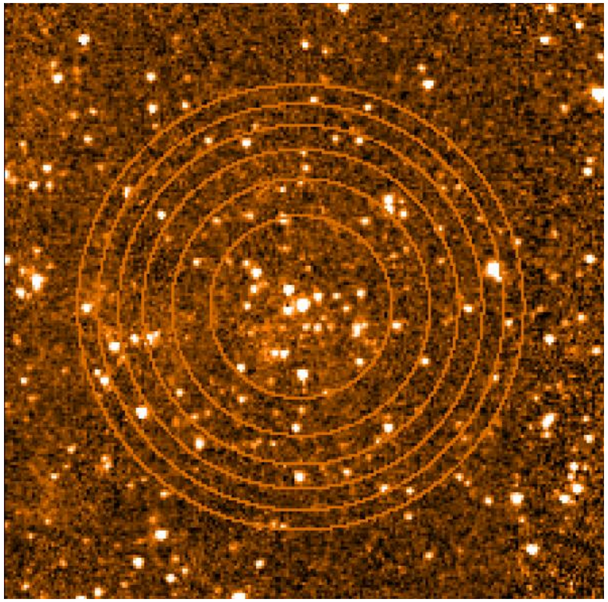
• 3.6μm samples light nearest the 1μm micron stellar bump at z~1.

• 5-sigma depth of 13μJy or 21.1 magnitude (AB system), in channel 1 (3.6μm).

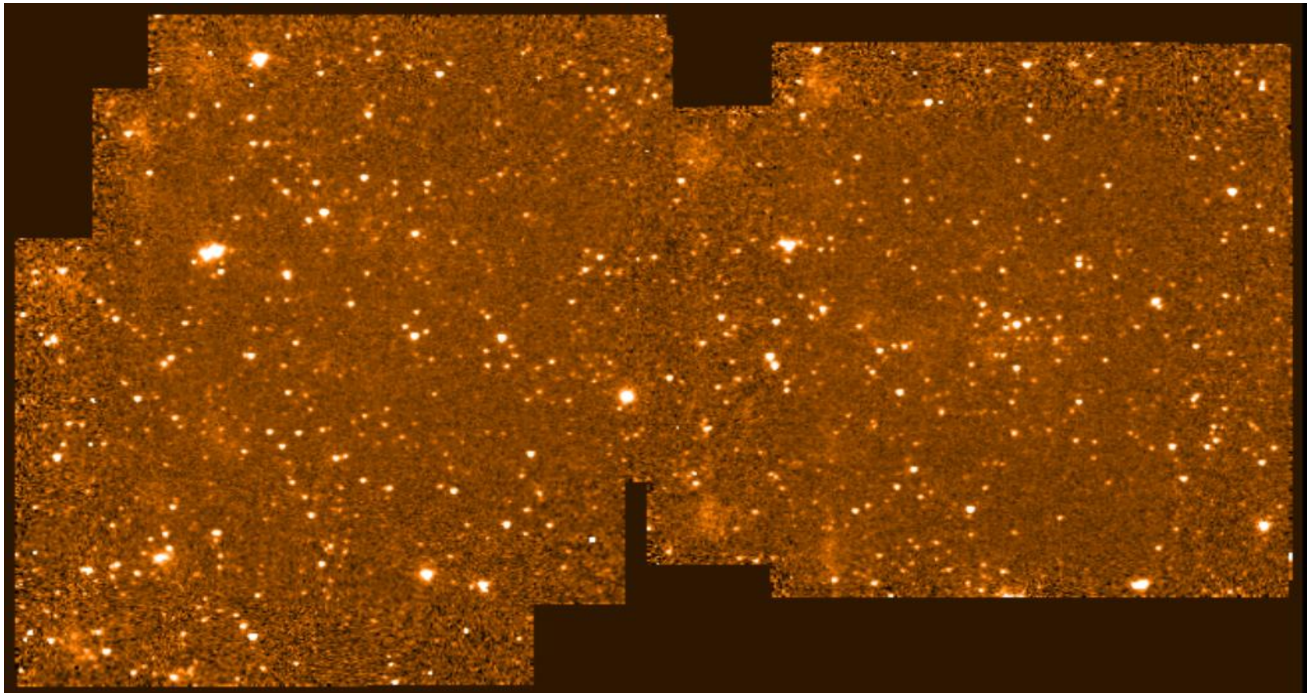
• 12 QSOs had data from the SWIRE survey and two RGs from PI's Stern and Fazio.



Radial Search and Blank Fields

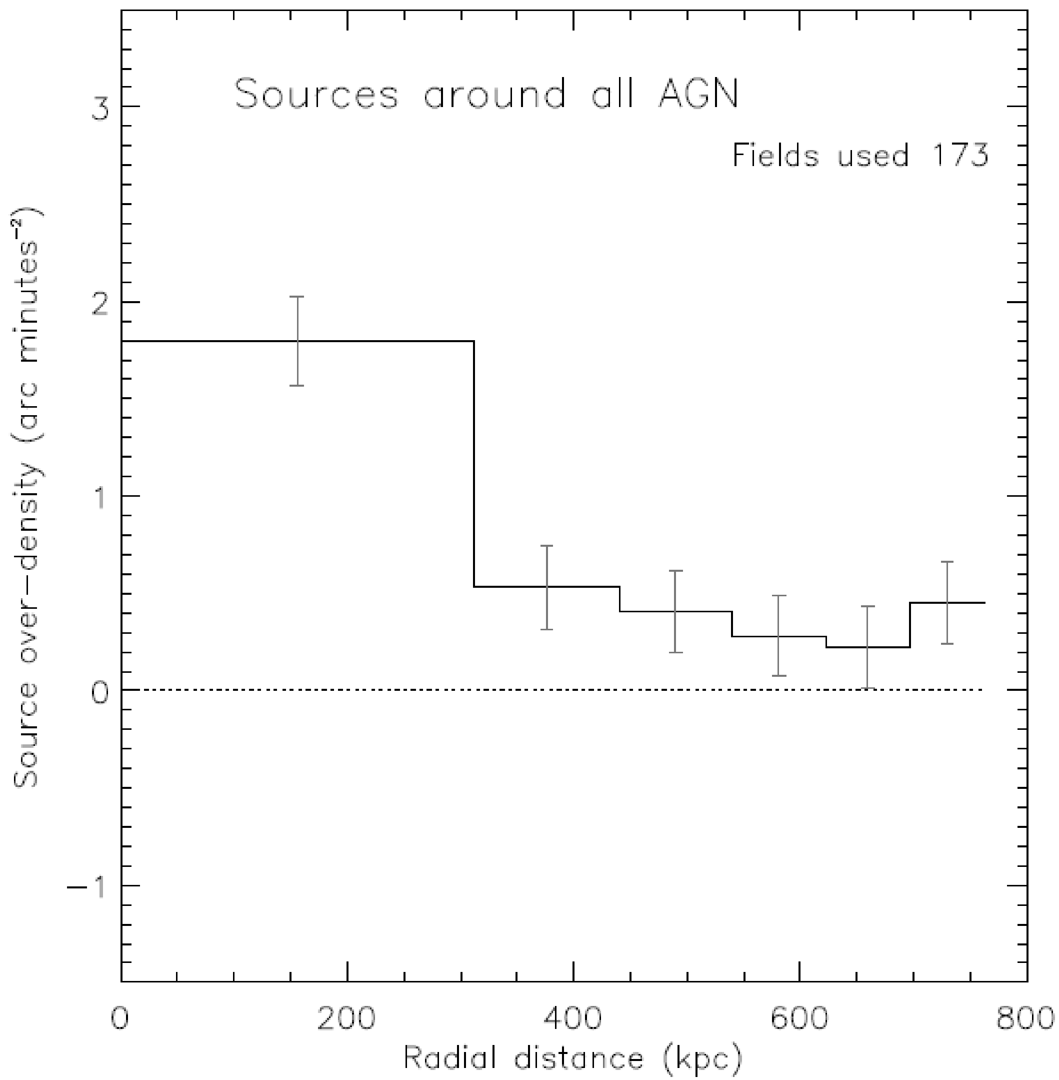


- Catalogues made using SExtractor (Bertin & Arnout 1996).



Region of the off target *Spitzer* image that is exposed to same depth as the main field used as a blank field. This is at the nearest point 2.8 Mpc from the AGN at z~1.

Results



- Stacking required.

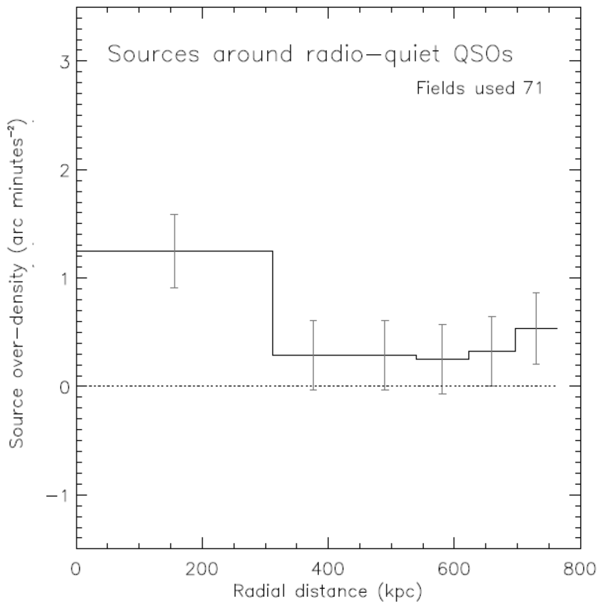
- Local background level for each field subtracted.

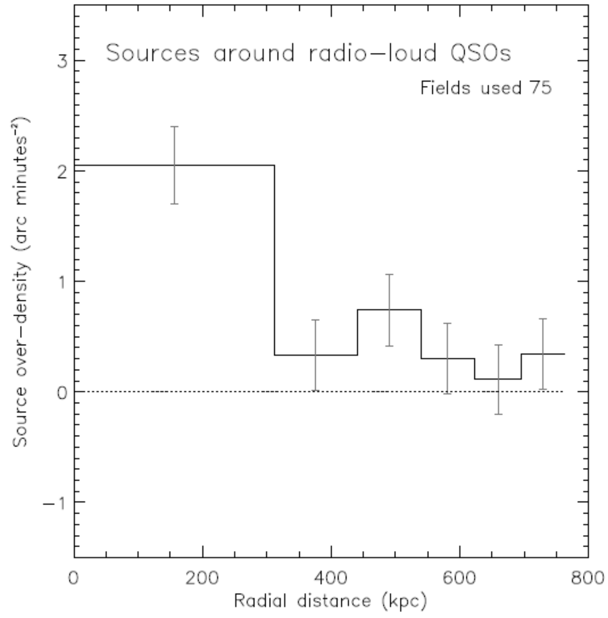
- 8-sigma over-density within 40” or 300 kpc of the AGN.

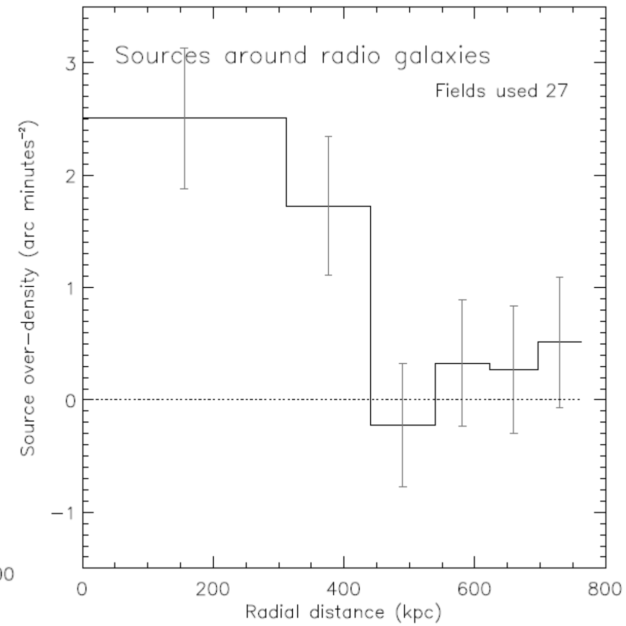
- This corresponds to 2-3 massive evolved galaxies per AGN on average above the field level.

- Possible lower level over-density out to at least 800 kpc.

AGN types







Significant over-densities around all but larger over-densities around the RLQs and RGs, and a larger though not significantly so over-density around the RGs than RLQs.

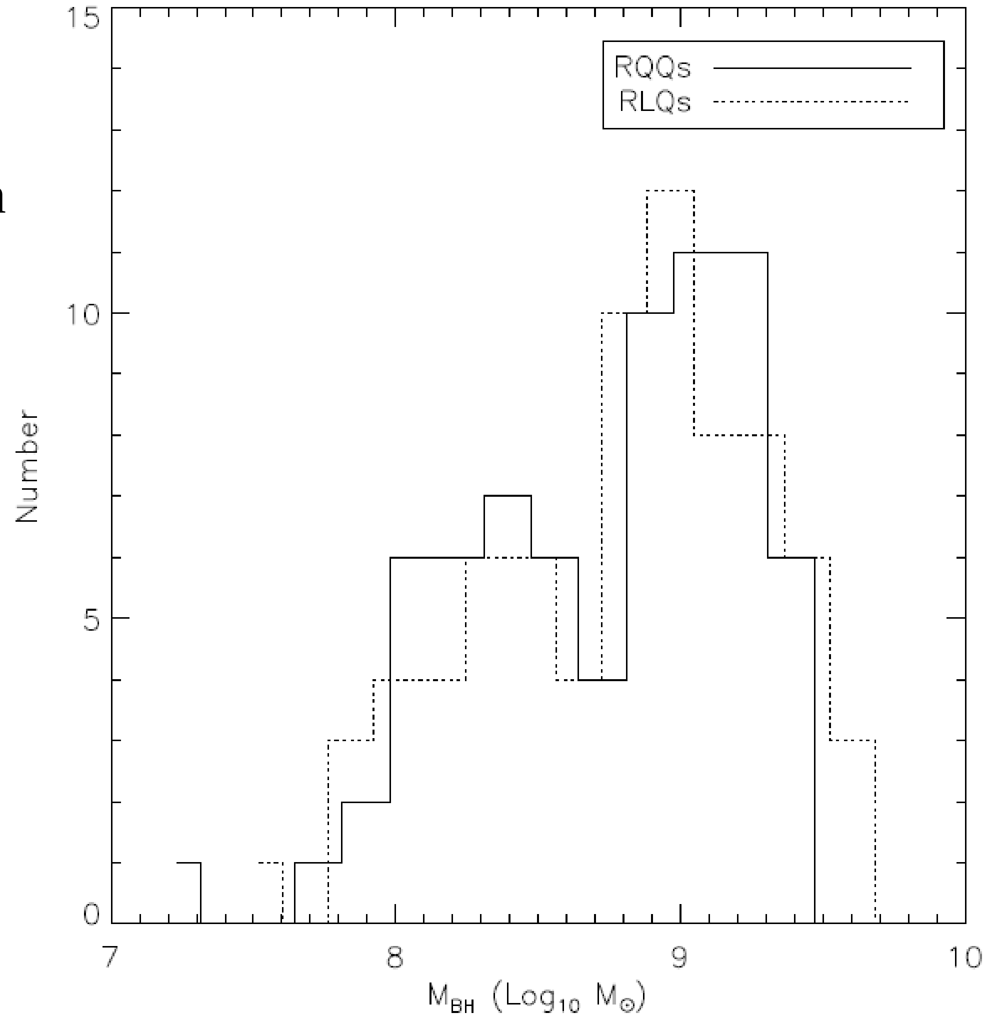
Difference between the RLQs and RQQs is significant at the 96% confidence level.

Black-hole masses

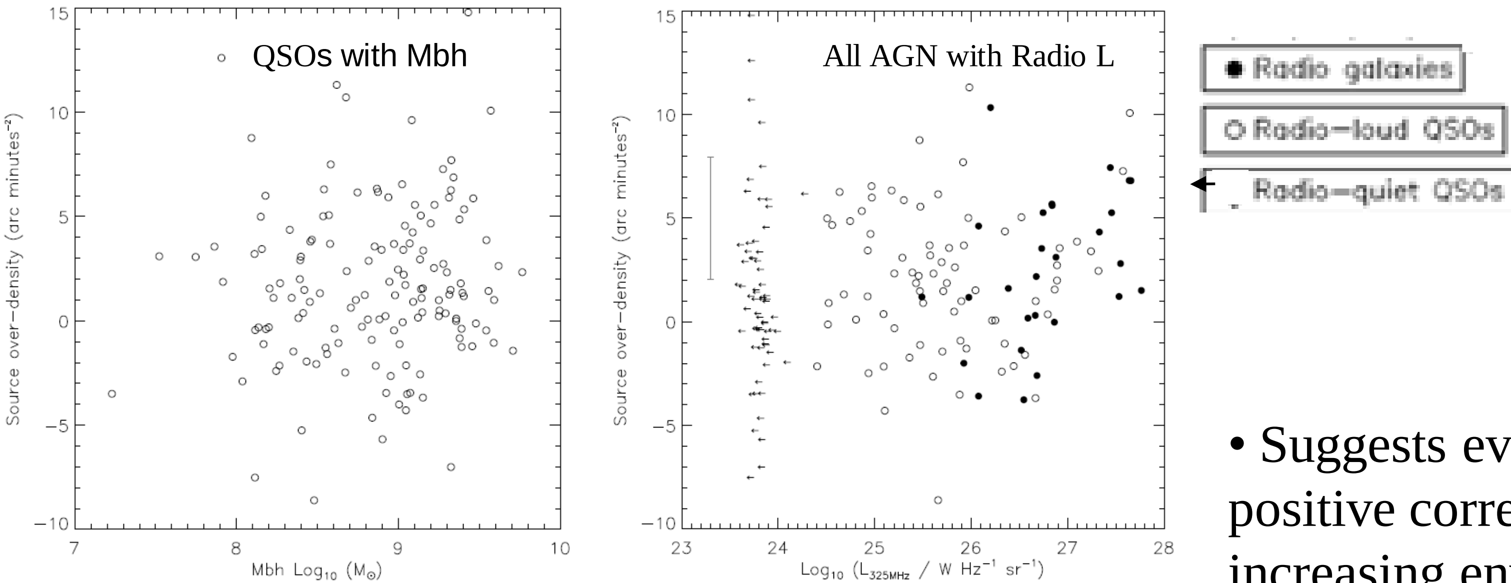
• Black-hole mass estimates for the QSOs using the Mg II line as a viral estimator (Jarvis et al. 2010 in prep).

• RLQs and RQQs black-hole masses are statistically indistinguishable.

• In general black-hole masses of RLQs are 45% more massive (McLure and Jarvis 04), but not in our sample.



Correlation Analysis



	Test	Coefficient	Significance
Quasars (M_{BH} vs over-density)	Spearman rank	0.080	0.666
	Kendall tau	0.054	0.669
All AGN (radio luminosity vs over-density)	Spearman rank	0.160	0.961
	Kendall tau	0.215	0.966
	Cox hazard	2.109	0.854
AGN(L_{radio}> 25) (radio luminosity vs over-density)	Spearman rank	0.226	0.963
	Kendall tau	0.155	0.966
AGN(L_{radio}> 26) (radio luminosity vs over-density)	Spearman rank	0.483	0.992
	Kendall tau	0.121	0.999

- Suggests evidence for a positive correlation of increasing environmental density with radio luminosity, but not with black hole mass.

- Seems to improve towards higher radio power.

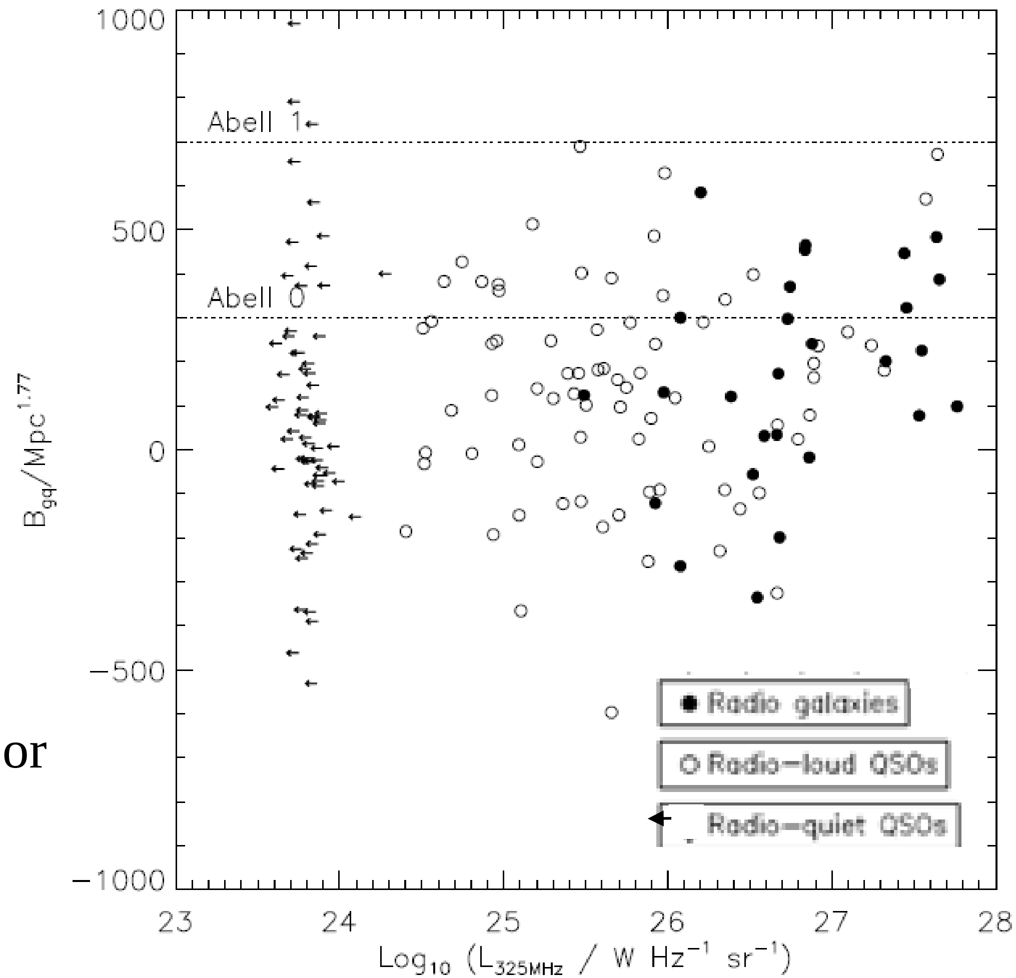
Bgq – Spatial clustering amplitude.

• For full description
(see Longair and Seldner 1979).

• K band luminosity function of Cirasuolo et al. 2009 with colour correction.

• Gives the same results and correlation as with number density alone.

• Sample is largely of Abell class 0 or lower with those in the most dense environments nearer class 1.



Conclusions / Discussion

• 8-sigma over-density found around all AGN when stacked together within 300 kpc.

• More significant over-densities around the RLQs and RGs than the RQQs.

• RLQs and RQQs black hole masses are statistically indistinguishable, leading to conclusion that the environmental difference is not a result of the RLQs being hosted by more massive galaxies.

• Correlation analysis gives a correlation at the 96% confidence level for environmental density increasing with radio power of AGN. Compared to no correlation being observed with black-hole mass. Correlation improves to 99% at the highest radio luminosities.

• If the environment is effecting the radio properties of AGN perhaps this is through the radio jets being boosted in denser environments (jet confinement).

• Alternatively perhaps if radio properties depend on black-hole spin, then this may be higher in denser environments due to increased exposure to mergers which could spin up the black-hole.