# AGN Environments at 1 < z < 1.5

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## 1. Introduction

The environments of both X-ray and radio-loud AGN with respect to galaxies within the UKIDSS Ultra-deep survey (UDS) between redshifts 1 < z < 1.5 are investigated using angular cross-correlation techniques; as this is the era where the galaxy colour bimodality is established and there is a prevalence of AGN. It is found that both X-ray AGN and radio-loud AGN are both preferentially reside in overdense environments, which is not the case in the low-redshift Universe where X-ray AGN are found to span a range of environments. Both types of AGN are also found to be more strongly clustered to those galaxies which are classified as passive, rather than those which are actively star-forming. It can also be seen that both X-ray AGN and radio-loud AGN avoid underdense environments at this redshift. A closer look at the nearby neighbours of these AGN within the same redshift range shows that the neighbours of radio-loud AGN tend to be galaxies which reside in the 'green valley' and red sequence of a U-B colour-magnitude diagram, whereas the neighbours of X-ray AGN show no significant deviance from the general galaxy population.

## 2. The Data

The UDS (Ultra Deep Survey) is one of the five surveys which make up UKIDSS (UKIRT Infrared Deep Sky Survey, where UKIRT is the UK Infrared Telescope; Lawrence et al, 2007). The UDS covers an area of 0.77 square degrees, and is centred on the Subaru-XMM Deep Survey and is therefore the deepest near-infrared survey to date. The overall aim of the survey is to determine when and how galaxies were formed, and then to relate this to our understanding of galaxy formation by producing a detailed map of the distant Universe.

The galaxies chosen from the UDS are those from the third data release with photometric redshifts between 1 < z < 1.5.

The Subaru/XMM-Newton Deep Survey (SXDS; Ueda et al, 2008) covers an area of 1.14 deg$^2$ and is centred at R.A. = 02h18m and Dec. = -05d, hence providing X-ray coverage of the UDS field. Within this survey, there were found to be 381 X-ray point sources, of which 104 are within the redshift range 1 < z < 1.5.

The radio data was taken from the 100mJy catalogue (Simpson et al. 2006). The SXDF was observed with the VLA using 14 overlapping pointings. 505 radio sources were observed of which 72 are within a redshift of 1 < z < 1.5.

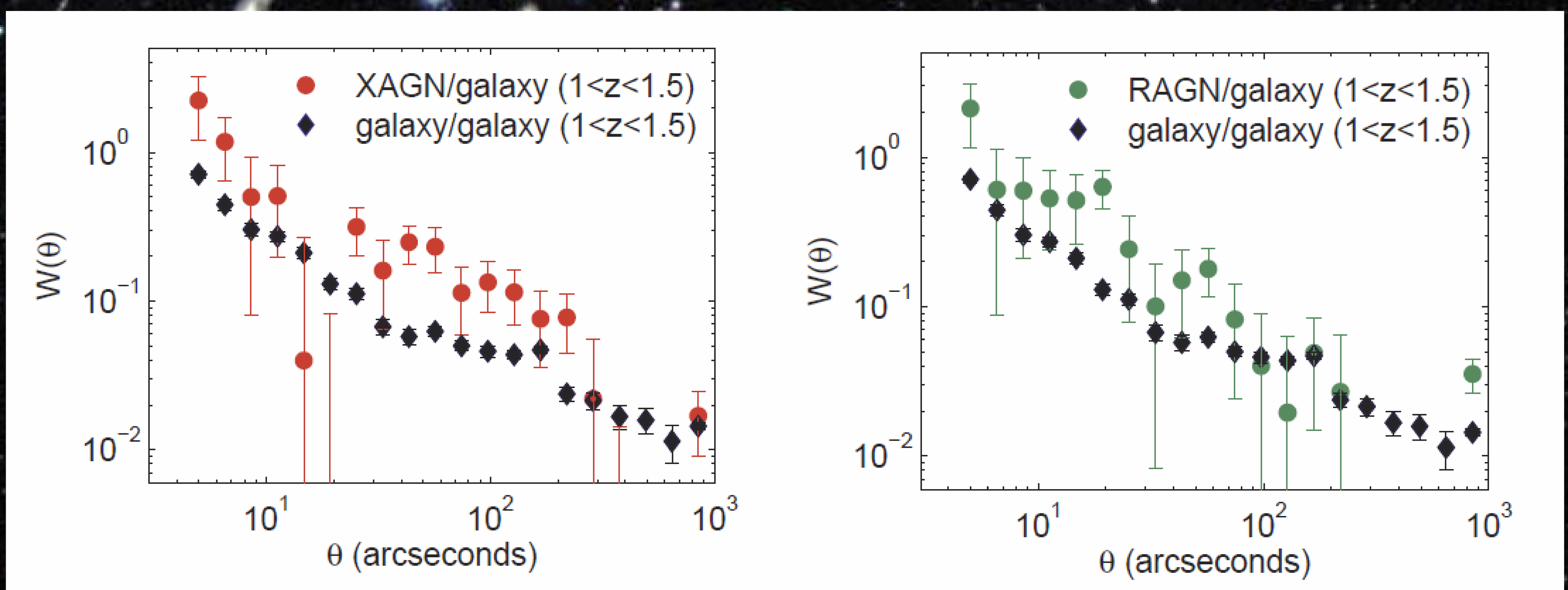


**Figure 1: (Left)** The cross-correlation of X-ray AGN (XAGN) with all galaxies in the UDS survey and (Right) the cross-correlation of radio AGN with all galaxies in the UDS survey. Both in a redshift range 1 < z< 1.5 and compared to the general galaxy-galaxy auto-correlation function.

## 3. Cross-Correlations

The environments of AGN are investigated using an angular two-point cross-correlation analysis. The correlation function is defined as the probability of finding a galaxy in a volume element at a given separation from an object compared to a random distribution of galaxies, which can be calculated using the estimator of Landy and Szalay (1993);

$$\omega(\theta) = \frac{N_{DD} - 2N_{DR} + N_{RR}}{N_{RR}}$$

where $N_{DD}$, $N_{DR}$ and $N_{RR}$ are the number counts of data-data, data-random and random-random pairs respectively at angular separation $\theta$. The random galaxies in this case were generated using a catalogue 50 times larger than the amount of galaxies in the UDS. This estimator can introduce small errors to the correlation function at large scales due to the finite size of the field. This can be corrected using an integral constraint (Roche and Eales, 1999) which takes the form

$$C = \frac{\sum N_{RR}(\theta)\theta^{-0.8}}{\sum N_{RR}(\theta)},$$

where the sums extend to the largest separations within the field. Figure 1 shows the cross-correlation of both types of AGN with other galaxies in the field. Both types of AGN are found in overdense environments. Figure 2 shows the the cross-correlation of both types of AGN with passive and starburst galaxies. Both types of AGN are more closely correlated with passive galaxies.

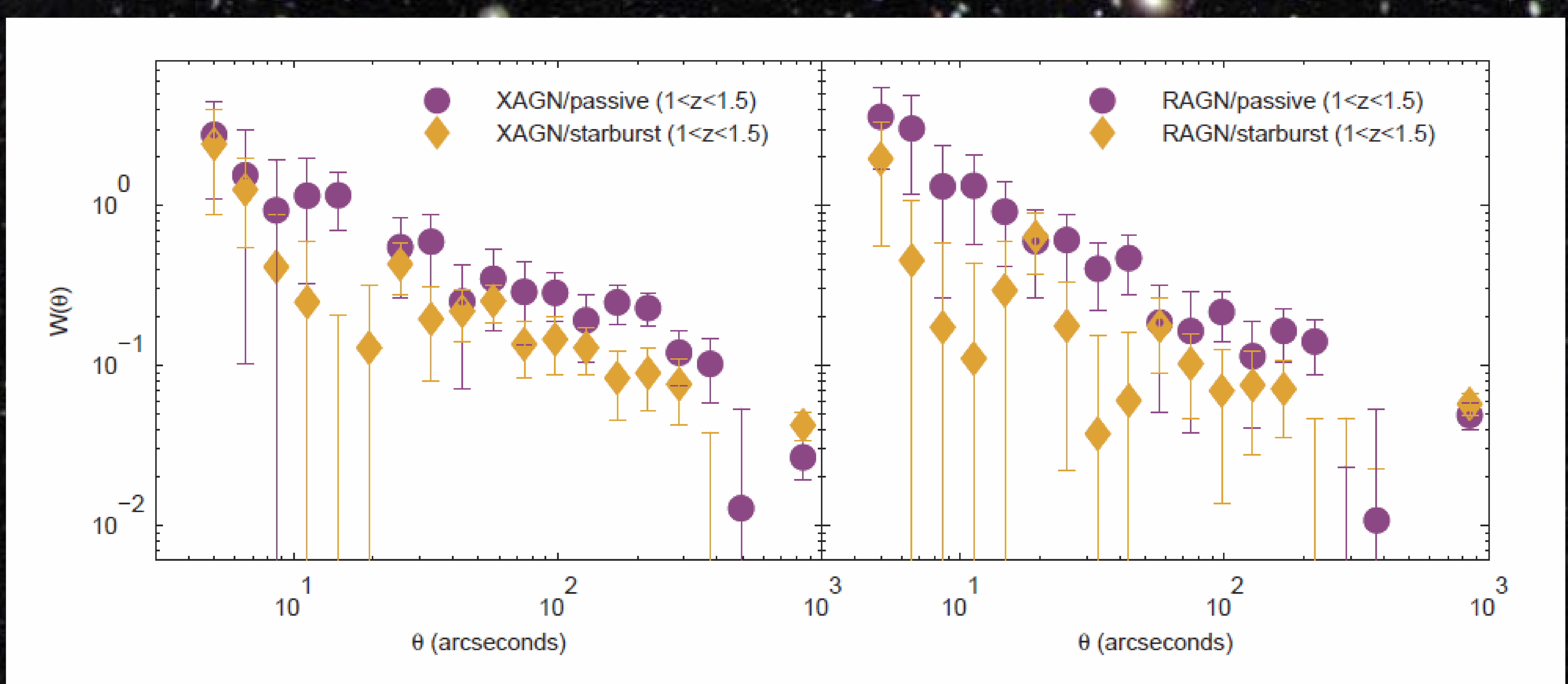


**Figure 2: (Left)** The cross-correlation of X-ray AGN (XAGN) with both passive and starforming galaxies in the UDS survey and (Right) the same for radio AGN. Both in a redshift range 1 < z< 1.5.

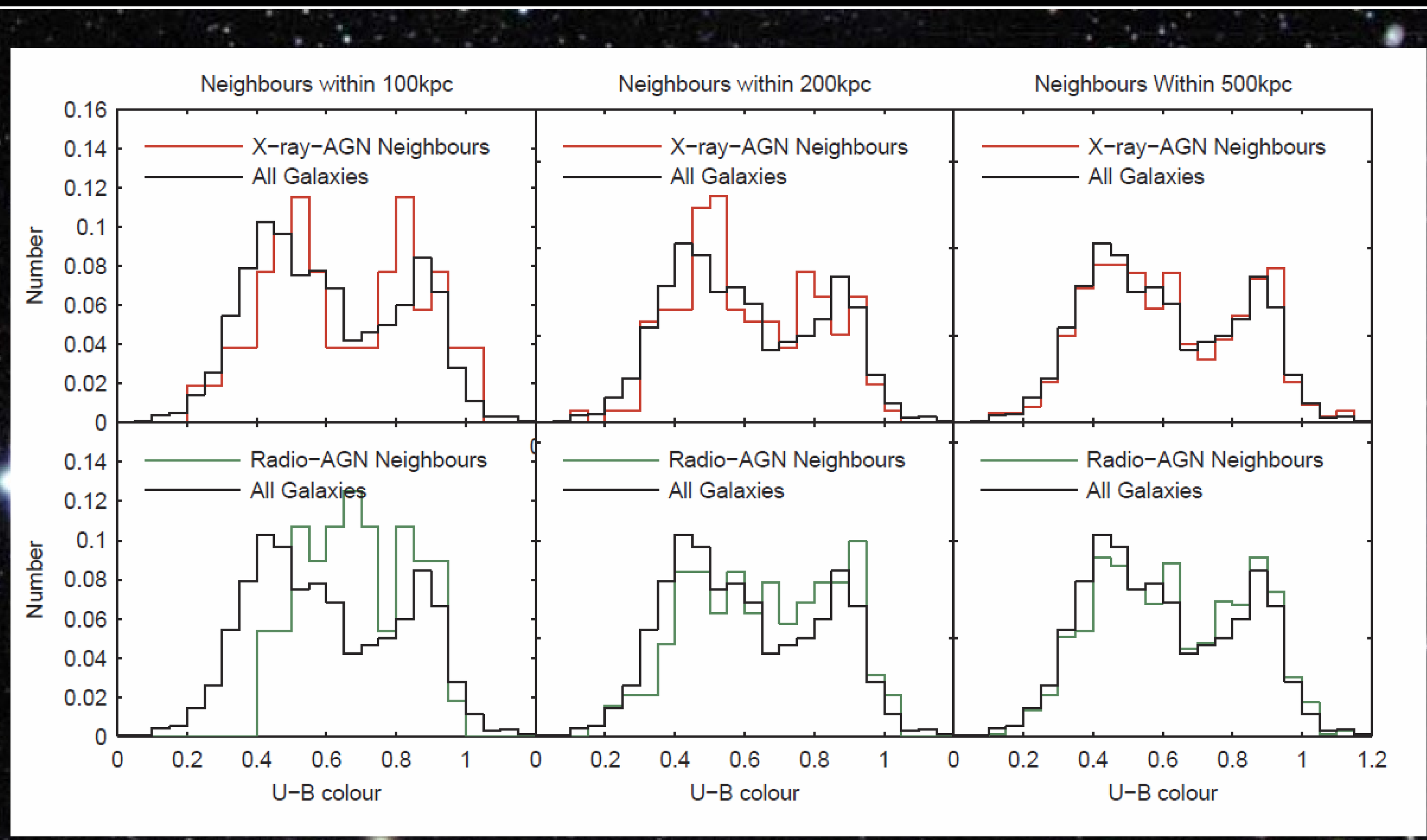


**Figure 3:** The U-B colour of the neighbours within 100kpc, 200kpc and 500kpc of X-ray and radio AGN within the redshift 1 < z < 1.5 compared to the general population.

## 4. Small-Scale Environments

We studied the properties of the immediate galaxies surrounding the AGN by making three separate samples of the neighbouring galaxies. The first sample includes those that are within a physical distance of 100kpc from an AGN and should therefore include the nearest one or two neighbouring galaxies. A second and third sample was drawn of those galaxies that are found within 200kpc and 500kpc of an AGN, which should be representative of larger-scale environments.

We used a two-sample Kolmogorov-Smirnov test (KS test) of the U-B colour with the null hypothesis that all six samples are drawn from the same continuous distribution as the general galaxy population. All three samples of galaxies surrounding the X-ray AGN compared with the general galaxy population show that the two populations are drawn from the same continuous distribution. A KS test of the radio-loud AGN neighbours at 100kpc, 200kpc and 500kpc with the general population reveals however that the two populations are drawn from different distributions, with 99.994%, 99.98% and 99.8% significance levels.

Figure 4 shows a histogram of the overdensities of AGN compared to a random sample of galaxies in a 1Mpc area. X-ray AGN appear to avoid underdense environments.

This shows that although radio and X-ray AGN reside in overdense environments, the types of environment are different; possibly pointing at a different mechanism for their activation.

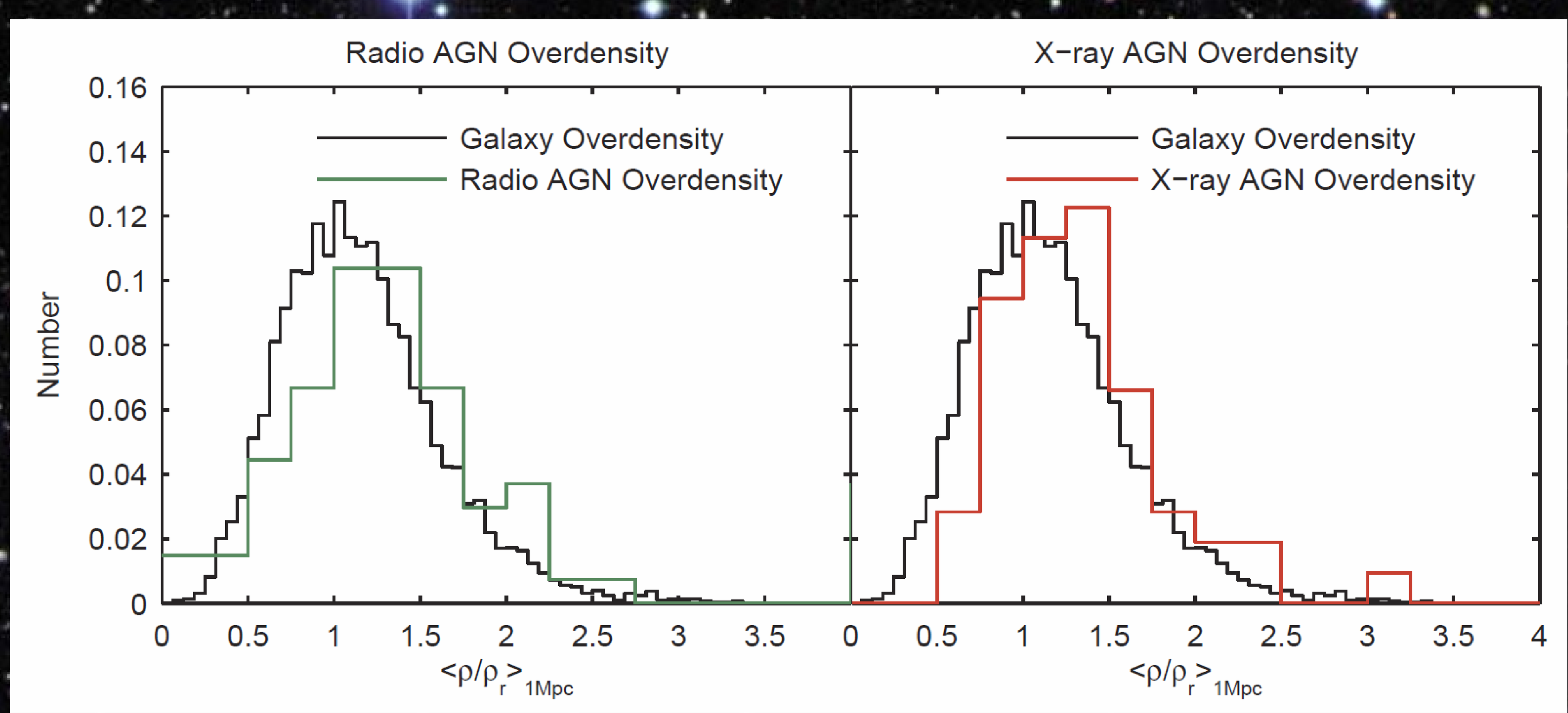


**Figure 4:** The overdensity of galaxies in a 1Mpc area around radio and X-ray AGN compared to a random distribution of galaxies.

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