PROJECTED CLUSTERING AROUND $1 < Z < 2$ RADIOGALAXIES

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Abstract. We have taken deep R-band images of fields around five radiogalaxies: 0956+47, 1217+36, 3C256, 3C324 and 3C294 with $1 < z < 2$. We found a statistically significant excess of bright ($19.5 < R < 22$) galaxies on scales of 2 arcmin around the radiogalaxies. The excess has been determined empirically to be at $\gtrsim$99.5% level. It is remarkable that this excess is not present for $22 < R < 23.75$ galaxies within the same area, suggesting that the excess is not physically associated to the galaxies but due to intervening groups and then related to gravitational lensing.

1. Introduction

Observations of the environment of AGNs indicate that these objects tend to lie in regions with galaxy density richer than average. The amplitude of this enhancement increases with the radio luminosity of the AGN, as has been found for FR I and II radiogalaxies (Lilly and Prestage 1987, Hill and Lilly 1991) and for radio-loud and radio-quiet QSOs (Yee and Green 1987, Ellingson et al. 1991) for $z\lesssim0.5$. Recent observations of both types of QSOs (Boyle and Couch 1993, Hintzen et al. 1991) seem to indicate that this trend is also present at $0.9 < z < 1.5$. The environments of radio-selected BL Lac objects have been studied by Fried et al. (1993). They found clustering around objects at redshifts $z\lesssim0.7$ but not for the $z \approx 0.9$ ones.

M. Kafatos and Y. Kondo (eds.), Examining the Big Bang and Diffuse Background Radiations, 493–496.

There have been several reports of statistically significant associations of high redshift QSOs and radiogalaxies with foreground objects: galaxies (Hammer and Le Fevre 1990), Zwicky clusters (Seitz and Schneider 1994), IRAS galaxies (Bartelmann and Schneider 1993), X-ray photons taken from the ROSAT All Sky Survey (Bartelmann et al. 1994). These associations are interpreted as a lensing effect with the lens being either a single galaxy or clusters of galaxies. Powerful radio sources are particularly well suited to detect associations due to gravitational lensing, because of the steep slope of their number counts (Wu and Hammer 1994).

Here we search for excesses of objects around $1 < z < 2$ radiogalaxies with apparent magnitudes $R \approx 21.4$ and spanning a range of one order of magnitude in radio luminosity.

2. Observations and results

Observations were carried out during the night of 1992 April 1 at the prime focus of the 2.5m Isaac Newton Telescope (INT) on the island of La Palma (Canary Islands, Spain). The detector used was an EEV 1280 × 1180 CCD camera with a scale of 0.57 arcsec/pixel and readout noise of 6 electrons. We took 7 exposures of 500 seconds each in the direction of the radiogalaxies 0956+47, 1217+36, 3C256, 3C294 and 3C324 using the Kitt Peak R-band filter. All the fields have $b \gtrsim 50$ deg. Photometric standard stars in NGC4147 were also observed in order to calibrate the frames. The night was not photometric and the seeing was approximately 1.2 arcsec FWHM. There is no vignetting in the field. The final images, obtained by coadding the individual frames for each object, were flat-fielded using sky and dome exposures. Their final sizes, after removing the borders, are 1200 × 1090 pixels ($11.4 \times 10.3 \mathrm{arcmin}^2$). We searched for objects in the frames using the standard package PISA (Position Intensity and Shape Analysis, Draper and Eaton 1992). Our detection threshold was of 9 connected pixels above 1σ level per pixel. In order to test our detection algorithms we generated frames with Poisson noise. From these simulations we estimate the number of spurious detections as $\lesssim 7\%$. This estimation was also confirmed by the results of the search for 'negative' objects in the real images.

We have studied the clustering of objects in 2 arcmin × 2 arcmin boxes around each radiogalaxy which corresponds to a scale of ≈ 1 Mpc ($\Omega_o = 1, h = 0.5$), at redshift $1 < z < 2$. We have divided the objects into two groups, one with magnitudes similar or brighter than the radiogalaxies: $19.5 < R < 22$, and another with fainter magnitudes: $22 < R < 23.75$. The main results for the 2 arcmin × 2 arcmin boxes are listed in the table below. In order to find the expected background value (ne in the table) we multiply the 'unspoilt' surface within the considered central region by the average

https://doi.org/10.1017/S0074180900110460 Published online by Cambridge University Press

density of galaxies within the given range of magnitudes on that field. We determined the rms empirically, although many of the quoted authors find the statistical significance taking the variance as if the distribution of galaxies were poissonian, what certainly it is not the case. We find that the empirical rms number of objects in the boxes are $\approx 1.5 \times \sqrt{N}$.

The sum of the number of objects found within the central regions of the five fields give us 91 objects against 59.7 ± 12.5 with $19.5 < R < 22$ (i.e. an empirical excess of 2.5σ) and 215 objects against 220.4 ± 22.3 with $22 < R < 23.75$. Therefore, no significant excess is found at fainter magnitudes. In order to determine the statistical significance of the excess found at brighter magnitudes, we have constructed an empirical probability distribution law. This distribution is formed by the sum of the objects contained in all the possible combinations of five boxes, each of them from a different field. We have normalized the results of each box by the useful surface of the radiogalaxy box of that field. Then we have excluded all the combinations of boxes that have an added useful surface smaller than a given threshold which is less or equal than the sum of the useful surfaces of the radiogalaxy boxes (94% of 5 2 arcmin $\times$ 2 arcmin boxes). The shape of the distribution so obtained is very close to a Gaussian. We obtain that the excess is significant at a $\gtrsim$99.5% level for the 2 arcmin scale.

Table: Projected number of objects in 2×2 arcmin^2 boxes

Field	N_b	N_f	s(%)	n_b	ne_b	n_f	ne_f
1217+36	11.7± 4.5	50.5± 8.8	100	25	11.7± 4.5	55	50.5± 8.8
0956+47	13.2± 5.7	47.4± 9.5	100	21	13.2± 5.7	54	47.4± 9.5
3C256	13.8± 7.8	54.2± 12.1	94	21	12.8± 7.6	50	50.8± 11.7
3C324	14.2± 4.9	44.6± 9.3	87	14	12.3± 4.6	32	38.8± 8.6
3C294	10.9± 4.9	36.8± 11.5	89	10	9.7± 4.6	24	32.9± 10.9

Notes: N_b and N_f are the average of bright ($19.5 < R < 22$) and faint ($22 < R < 23.75$) objects within a box (the errors are the empirically found rms). s(%) is the percentage of useful surface of the box centered on the radiogalaxy. n_b,n_f are the number of bright and faint objects found and ne_b,ne_f the expectation within that box.

3. Discussion and conclusions

It is remarkable that no excess is detected at fainter magnitudes: for $22 < R < 23.75$ we only found 215 objects against 220.4 within a 2 arcmin box. Assuming that the spectral distribution of cluster galaxies is consistent with a model with no evolution then the magnitude expected for these galaxies at $z \gtrsim 1$ would be $R > 24$ (as it is the case for the galaxies in the cluster found around 3C324, Dickinson 1994). Thus we do not expect to see in our images any early type galaxy at those high redshifts and therefore the only possibilities are either that the objects forming the excess are at $z > 1$ and then blue or they are at an intermediate redshift $z \sim 0.5$. Considering the sizes of the objects the most likely possibility is the later one.

Finally, the previous discussion strongly suggests that the excess is not physically associated to the radiogalaxies but due to intervening groups and then related to gravitational lensing.

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