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The properties of galaxies at $z > 5$

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ABSTRACT

In a recent paper Lehnert & Bremer have photometrically selected a sample of galaxies at $z > 4.8$ from a single VLT/FORS2 pointing and spectroscopically confirmed half of them to be at $4.8 < z < 5.8$. To study the properties of such galaxies further, we have photometrically selected a similar sample ($V_{AB} > 28, i_{AB} < 26.3, i_{AB} - z_{AB} > 0$) from the HST ACS images of the *Chandra* Deep Field South. This selection results in a sample of 44 sources from ~ 150 arcmin^2. We find that such galaxies are often barely resolved in the ACS images, having half-light radii of 0.1-0.3 arcsec ($<$ 2kpc). They show no difference in spatial clustering from sources selected by $i_{AB} < 26.3, i_{AB} - z_{AB} > 0$, which are generally galaxies of lower redshift. However, their distribution over the field is not uniform and their surface density varies considerably over areas comparable to a single 8m or HST pointing. A reliable determination of the surface and volume densities of such galaxies requires a sky area considerably larger than the current ACS imaging of this field. No individual $z > 5$ candidate was detected to a 3-σ limit of 6×10^{-17} erg s^{-1} cm^{-2} at 0.5-5 keV by *Chandra* (a limiting luminosity of below 2×10^{43} erg s^{-1} at $z \sim 5.3$). By summing over all positions, we find that the mean source must be undetected at a level at least a factor 4 times fainter than this. This rules out anything other than a weak AGN contribution to the emission from these objects and thus luminous AGN made little contribution to the final stages of re-ionization of the Universe.

Key words: cosmology: observations - early universe - galaxies: distances and redshifts - galaxies: evolution - galaxies: formation

1 INTRODUCTION

With the advent of high throughput cameras on 8m-class telescopes and the Advanced Camera for Surveys (ACS) on the Hubble Space Telescope it is now possible to detect and study galaxies at, or close to the epoch of reionization, about 1 billion years after the Big Bang. Recently, many such galaxies have been selected photometrically (*e.g.* Stanway et al., 2003, Bouwens et al., 2003, Iwata et al., 2003) and some have been confirmed to be at high redshift by spectroscopy (Lehnert & Bremer, 2003; Bunker et al., 2003; Cuby et al., 2003)

In a recent paper, we used perhaps the simplest technique to select and confirm redshifts for a high redshift galaxy sample drawn from a single 40 arcmin^2 field imaged by the VLT (Lehnert & Bremer 2003). The opacity of neutral hydrogen along the line-of-sight to the galaxies means that the light shortward of 1216 Å in their rest-frame is strongly absorbed, leading to a sharp drop in their spectra at the corresponding redshifted wavelength. By selecting objects detected in the $I-$band to $I_{AB} = 26.3$, but undetected at $R_{AB} > 27.8$ ($i.e.$ R-band "dropouts"), we identified 13 candidate $z > 4.8$ galaxies. Spectroscopy of 12 of these confirmed that 6 were at $4.8 < z < 5.8$, as they possessed a Lyman α emission line at the same wavelength as a break in their spectra. The spectra were consistent with the objects being strongly starforming galaxies. Similar techniques have been used by other groups to identify other unobscured star forming galaxies at even higher redshifts (Stanway et al. 2003, Bouwens et al., 2003). From the study of galaxies at z>5, Lehnert & Bremer (2003) concluded that relatively luminous galaxies ($M_{AB}(1700\AA) > -21$) have insufficient numbers and ionizing luminosity to keep the universe at z>5 ionized and, since no broad line objects were detected, that QSOs contribute very little to the overall ionization. This last conclusion is supported by Barger et al. (2003) who found that the number of luminous X-ray-selected QSOs in the Chandra Deep Field North is insufficient to contribute greatly to the overall ionization of the IGM at z≈5.5.

However, our original study was limited by the size of the field imaged by the VLT (40 arcmin^2), the ground-based seeing (0.8-0.9 arcsec) of the imaging and spectroscopy, and the lack of multi-wavelength data for this field. Of particular concern was the AGN fraction in faint galaxies at these redshifts and the possible contribution of "hidden AGN" to the overall ionization budget of the high redshift universe. Classes of AGN exist that have strong X-ray emission with the spectral characteristics of AGN but with only subtle or no signs of AGN activity in the rest-frame UV or optical (e.g., Giacconi et al. 2001). However, by performing a comparable selection on a larger field imaged by HST and other telescopes over a range in wavelengths, we can determine scale sizes for such sources, determine if any are AGN, and examine their spatial distribution and clustering. All these properties are required for comparisons between the observations and models of the evolution of the earliest galaxies. To this end in this paper we discuss the properties of candidate $z > 5$ galaxies in the Chandra Deep Field South (CDF-S). In this paper, unless noted otherwise all magnitudes are on the AB scale, and the cosmology used is $H_0 = 70$kms^{-1} Mpc^{-1}, $\Omega_\Lambda = 0.7$ and $\Omega_M = 0.3$.

2 SAMPLE SELECTION

In this paper we use data from the Advanced Camera for Surveys (ACS, Ford et al. 2003) on HST, released as part of the public Great Observatories Origins Deep Survey (GOODS - Dickinson & Giavalisco 2002) programme. Specifically, we utilise data from the v0.5 release of GOODS data from the Chandra Deep Field South (CDF-S). The data in this release comprises that from the first 3 epochs of the CDF-S survey. At each epoch, a given field is imaged in three of the four bands used in the survey: V (F606W), i (F775W) and z (F850LP). Observations in the $B-$band (F435W) were all taken during epoch 1. The field is mosaiced into a pattern of 15 (epochs 1 and 3) or 16 (epoch 2) 'tiles'. Exposure times at each epoch in each tile are 0.5, 0.5 and 1 orbits in the V, i and z bands respectively. Exposure time in the $B-$band (epoch 1) was 3 orbits per tile. At each epoch, the observations of each tile are broken into 2, 2 and 4 frames, in V, i and z respectively, to allow for the removal of cosmic rays and other defects. The B-band observations are broken into 6 frames. The released data set includes pipeline-processed, cosmic-ray cleaned, drizzled (Fruchter & Hook 2002) and co-added frames of each tile for each epoch for each of the 4 bands.

The tiles from epochs 1 and 3 are based on the same mosaic pattern covering the total survey area, although the epoch 3 frames have a PA 90 degrees offset from those of epoch 1. The tiles of epoch 2 are based on a different mosaic pattern (of 16 tiles). Hence, we decided to create co-added V, i and z tiles from each of the sets of 15 tiles in epochs 1 and 3. The z tile from epoch 1 was used as a reference tile in each case. The z tile from epoch 3, and the V and i tiles from epochs 1 and 3, and the B tiles from epoch 1 were aligned to the equivalent epoch 1 z tile using the wcsalign task in KAPPA. Each pair of co-aligned z, i and V frames were then co-added using the makemos task in CDDPACK. For each co-added image, all areas which had blank values in either input image were set to blank in the final co-added image. This included the gap between the two ACS CCDs on the i, z and V frames.

As we are searching specifically for objects which are securely detected in the redder bands, a catalogue of sources was constructed based on the 15 co-added z tiles. The detection and photometry of objects in the co-added $z-$band tiles were conducted automatically using the SExtractor software package (Bertin & Arnouts 1996) as implemented within the Starlink GAIA image display and analysis package. For object identification we demanded at least 4 contiguous pixels above a threshold of 1.5σ per pixel. We measured Kron (1978) magnitudes taken within an aperture radius of 2.5r$_{\rm kron}$. These magnitudes have not been corrected for the extremely low Galactic extinction of $A_V = 0.024$. The positions and apertures defined by the SExtractor source detection algorithm as run on the co-added $z-$band tiles were then used on the equivalent i, V and B frames. In this way we measured the apparent i, V and B magnitudes for those objects detected on the z tiles inside identical apertures. We used the zero-points for AB magnitudes determined by the GOODS team: mag$_{\rm AB}$ = zeropoint - 2.5 log(Count rate/s^{-1}) where the zeropoints were 25.662, 26.505, 25.656, 24.916 for the B, V, i and z bands respectively.

Having created and verified the catalogue, we then selected candidate high redshift galaxies. Lehnert & Bremer (2003) selected objects with $25 < I_{AB} < 26.3$, and $R_{AB} - I_{AB} > 1.5$, with all of the final selection having $R_{AB} > 27.8$. They noted that at $z > 4.8$, the predicted $I - z$ colours of galaxies became increasingly red, from ~ 0 at $z < 4.8$ to ~ 1.3 at $z > 5.8$. The observed colours of the spectroscopically-confirmed high redshift galaxies roughly agreed with this. Stanway et al. (2003) have used a selection of $i_{AB} - z_{AB} > 1.5$ to select $z \sim 6$ candidates from the ACS data of the CDF-S (see their Figure 3).

However, the ACS data were obtained in B, V, i and $z-$bands. Consequently we had to select galaxies that dropped out in V rather than in R. This will potentially select galaxies at $z > 4.5$, rather than at $z > 4.8$ as did the $R-$ band dropout selection of our previous work. We therefore also required that $i_{AB} - z_{AB} > 0$ to minimise the number of lower redshift dropouts. We also required that there was no sign of a detection in V, placing a limit of $V_{AB} > 28$ in the aperture matched to the $z-$band. Objects brighter than this could always be detected in the $V-$band frame. The $V-$band number counts show that $V > 28$ marked a transition from true detection to non-detection in our catalogue. Thus our final selection was $V_{AB} > 28$, $i_{AB} < 26.3$ (to be consistent with our previous work) and $i_{AB} - z_{AB} > 0$ (in order to reject lower redshift dropouts).

Based upon the above magnitude and colour cuts, we selected objects from our catalogue. We examined each of them in turn in order to exclude obvious problem or bogus sources, such as parts of larger sources or spurious sources at the edges of CCD frames where extreme colours were caused by missing counts in one band off the edge of the frame. The final selection consisted of 44 objects spread over the ~ 150 arcmin^2 of the ACS image of the CDF-S. Images of these sources are shown in Figure 1 and their properties are given in Table 1. Note that in principle, with our selection criteria, we could have included two of Stanway et al's $z \sim 6$ objects; one is indeed detected (their object 4, our object 8), the other (their object 3) just misses our magnitude cut (due to our re-measurement of the $i-$band photometry).

What contamination do we expect in our catalogue from sources other than galaxies at $z > 5$? At magnitude levels above $i_{AB} \sim 24-25$ we expect some cool stars with red $V-I$ and $I-z$ colours (*e.g.* see Fig 2 in Iwata et al., 2003). Based upon the results in Lehnert & Bremer (2003) we can expect up to ~ 10 such stars brighter than $i_{AB} = 25$ (both the CDF-S and the field in Lehnert & Bremer are at high Galactic latitudes), although many of these may be rejected by our strong $V-$band limit. The work of Stanway et al. (2003) on the CDF-S indicate there are only one or two substellar objects in the field at fainter magnitudes. Given our previous results, and those of Stanway et al, our colour selection will also detect several Extremely Red Objects (EROs) in the field, either old ellipticals or reddened galaxies at around $z \sim 1$ (*c.f.* Cimatti et al 2002). These objects will appear resolved on scales of > 0.3 arcsec.

Some publically-available ground-based data in R and J and Ks are available from the VLT for part of this field. We can use these data to attempt an estimation of the likely contamination from lower redshift sources, even though the data are not ideal for this. The R-band data is shallower than that used by Lehnert & Bremer (which went to $R_{AB} = 27.8$) to select $R-$ band dropouts. For the CDF-S, $3-\sigma$ detection limits in 2 arcsecond diameter apertures

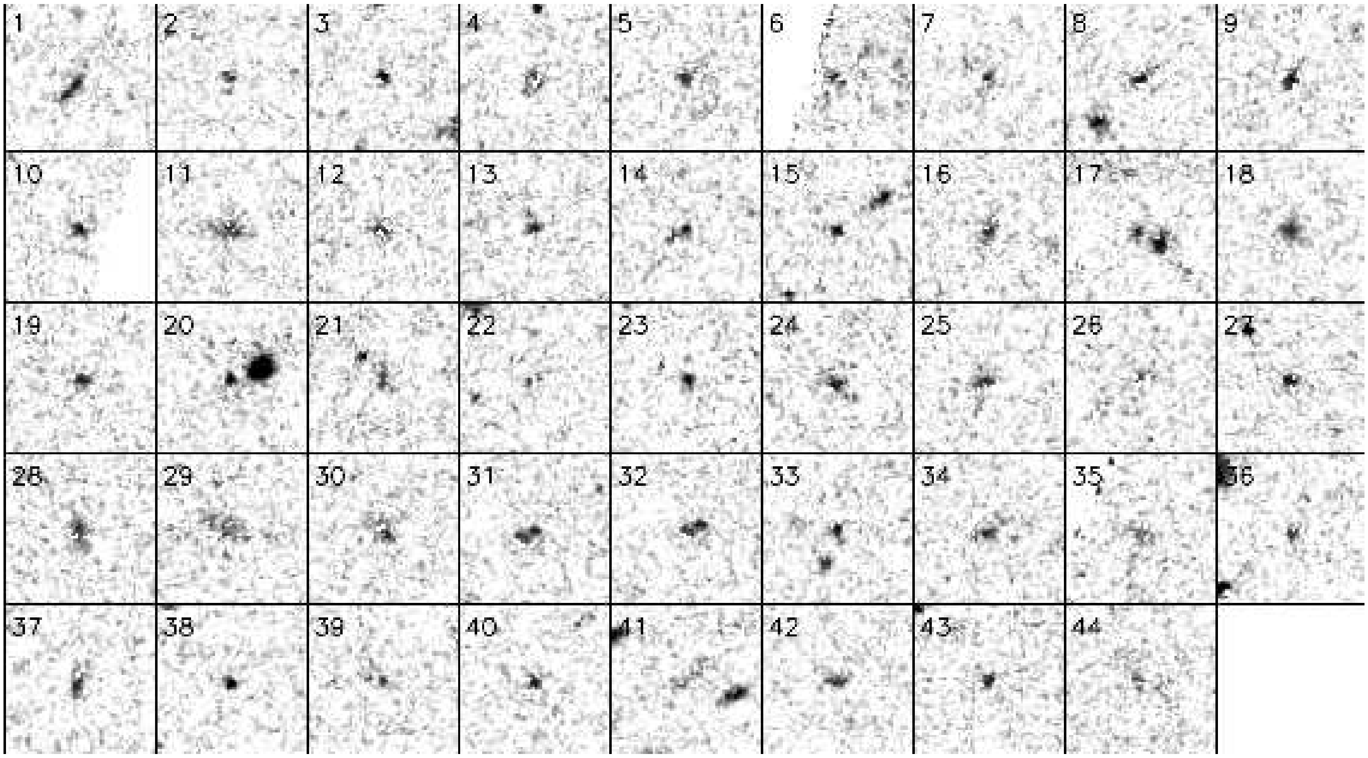

Figure 1. 3×3 arcsec Viz-composite images of all 44 objects in the sample. In each case the selected object is at the centre of the image and north is at the top and east is to the left.

vary between $R_{AB} = 27.4$ and 26.7 depending upon the particular image. Nevertheless the data has some utility in ruling out $V-$band dropouts at below $z = 4.8$ and lower redshift red galaxies. About 15 per cent of the candidate distant galaxies are detected (4 were detected out of 27 imaged in R-band), including objects 24, 34 and 42 at $R = 26.5 \pm 0.2$, $R = 26.2 \pm 0.2$ and $R = 26.4 \pm 0.3$ respectively which are among the galaxies with the largest half-light radii. This supports our contention that the galaxies with the largest half-light radii are likely to be lower redshift galaxies.

The J and Ks images also covered only part of the ACS area. The data is useful to detect intrinsically red objects, as opposed to those with breaks between V and i. Ten of our candidates were covered by this data. Six were reliably detected in both J and Ks to $2-\sigma$ detection limits of $J_{Vega} = 24.5$ and $Ks_{Vega} = 23.5$ in 1 arcsec apertures. These all had $z_{AB} - J_{Vega}$ colours > 1.6 and $J - Ks$ colours ranging from 1.3 to 2.6. These are the colours of intrinsically red objects and redder than expected for a galaxy formed within a few hundred Myrs of $z = 5.3$. In order to determine the near-IR colours we might expect from an unreddened galaxy at $z \sim 5.3$, we ran a series of PEGASE models (Fioc & Rocca-Volmerange 1997) of ellipticals which started forming stars between $z = 6.5$ and $z = 20$. $z_{AB} - J_{Vega}$ colours varied between ~ 0.8 and ~ 1.2 and $J - Ks_{Vega}$ colours between ~ 0.9 and ~ 1.6. These are similar colours to those of Irregular galaxies redshifted to $z > 5$, see *e.g.* Figure 4 of Stanway et al. (2003). Thus the six red objects appear redder than these models of high redshift galaxies with unobscured ongoing star formation.

The other six objects covered by this imaging were either undetected or had colours consistent with being unreddened $z > 5$ galaxies. What implication does this have for the contamination of our $z > 5$ candidate sample by low redshift red objects? The J and Ks data only cover part of the ACS field, we need to use a

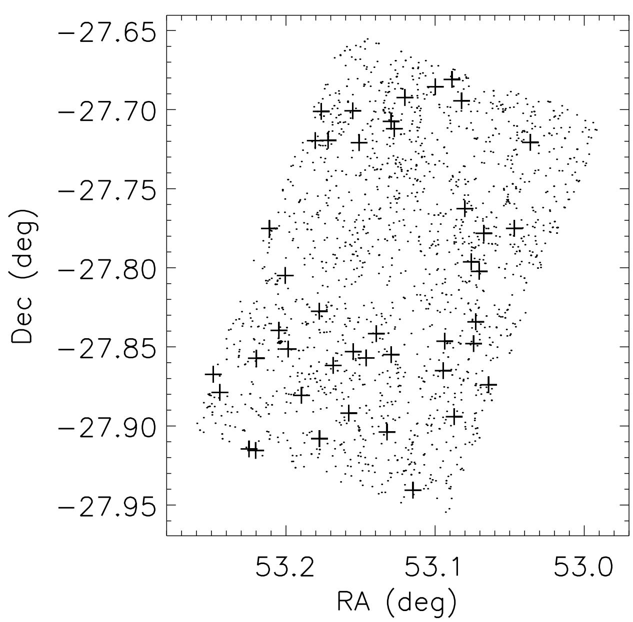

Figure 2. Spatial distribution of our $z > 5$ candidates over the field (crosses). Underlying points are 2000 objects chosen to have $i_{AB} < 26.3$ and $i_{AB} - z_{AB} > 0$. Note the ~ 25 arcmin^2 "hole" in the distribution of candidates (centred at approximately RA=53.15, Dec=-27.77), not reflected in the distribution of the non dropout sources.

Number	RA	Dec	i	$V-i$	$i-z$	R_h
1	03 32 08.68	-27 43 14.6	25.9	>2.1	0.7	0.35
2	03 32 11.26	-27 46 30.4	26.3	>1.7	0.3	0.18
3	03 32 15.40	-27 52 26.3	26.1	>1.9	0.1	0.13
4	03 32 16.16	-27 46 41.5	26.2	>1.8	0.1	0.20
5	03 32 16.91	-27 48 08.2	26.3	>1.7	0.2	0.27
6	03 32 17.47	-27 50 03.1	26.1	>1.9	0.8	0.27
7	03 32 17.80	-27 50 52.6	25.7	>2.3	0.7	0.30
8	03 32 18.18	-27 47 46.5	25.3	>2.7	1.5	0.10
9	03 32 19.22	-27 45 45.5	24.9	>3.1	1.3	0.10
10	03 32 19.74	-27 41 40.1	26.2	>1.8	0.6	0.27
11	03 32 20.94	-27 53 39.0	25.3	>2.7	0.3	0.24
12	03 32 21.29	-27 40 51.3	25.9	>2.1	0.3	0.20
13	03 32 22.46	-27 50 47.1	26.3	>1.7	1.7	0.10
14	03 32 22.69	-27 51 54.1	26.2	>1.8	0.2	0.32
15	03 32 23.98	-27 41 08.0	26.1	>1.9	0.7	0.13
16	03 32 27.56	-27 56 26.3	25.3	>2.7	0.1	0.30
17	03 32 28.87	-27 41 32.6	26.1	>1.9	0.2	0.45
18	03 32 30.57	-27 42 43.5	25.8	>2.2	0.9	0.20
19	03 32 31.07	-27 51 17.7	25.8	>2.2	0.1	0.20
20	03 32 31.09	-27 42 26.8	26.1	>1.9	0.9	0.35
21	03 32 31.74	-27 54 13.9	26.2	>1.8	0.0	0.17
22	03 32 33.47	-27 50 29.9	26.2	>1.8	0.4	0.15
23	03 32 35.10	-27 51 25.2	26.1	>1.9	0.1	0.20
24	03 32 36.23	-27 43 15.3	26.0	>2.0	0.4	0.37
25	03 32 37.18	-27 51 10.9	26.0	>2.0	0.1	0.30
26	03 32 37.25	-27 42 02.7	26.0	>2.0	0.3	0.25
27	03 32 37.90	-27 53 30.9	26.2	>1.8	0.8	0.18
28	03 32 40.40	-27 51 42.4	26.0	>2.0	1.0	0.25
29	03 32 41.22	-27 43 10.0	26.2	>1.8	0.9	0.45
30	03 32 42.33	-27 42 04.1	25.6	>2.4	0.6	0.27
31	03 32 42.60	-27 54 28.8	26.3	>1.7	0.4	0.32
32	03 32 42.62	-27 54 28.9	26.3	>1.7	0.7	0.30
33	03 32 42.65	-27 49 39.0	26.0	>2.0	0.3	0.20
34	03 32 43.29	-27 43 10.7	26.1	>1.9	0.1	0.35
35	03 32 45.51	-27 52 50.3	26.1	>1.9	0.3	0.35
36	03 32 47.64	-27 51 05.0	26.3	>1.7	0.7	0.10
37	03 32 48.13	-27 48 17.7	25.8	>2.2	0.4	0.27
38	03 32 49.14	-27 50 22.5	26.2	>1.8	0.7	0.10
39	03 32 50.66	-27 46 30.5	26.1	>1.9	0.0	0.15
40	03 32 52.77	-27 51 25.7	25.4	>2.6	1.2	0.13
41	03 32 52.87	-27 54 55.9	26.2	>1.8	0.2	0.45
42	03 32 53.95	-27 54 52.3	26.2	>1.8	0.0	0.18
43	03 32 58.65	-27 52 43.7	26.1	>1.9	0.0	0.15
44	03 32 59.70	-27 52 02.6	26.1	>1.9	0.2	0.20

Table 1. Coordinates are J2000. All magnitudes are in AB. Errors on magnitudes are typically 0.1 in i. $V-i$ colours determined assuming $V > 28$. Errors on $i-z$ are typically 0.15. R_h is the half-light radius measured in arcseconds. Unresolved sources have $R_h = 0.1$, although given the uncertainties on determining the half-light radii of objects at $i \sim 26$, the uncertainty on this measurement should be assumed to be approximately 1 pixel or 0.05 arcsec.

proxy for red near-IR colours in order to estimate the contamination. Five of the six objects with $z_{AB} - J_{Vega}$ and $J - Ks_{Vega}$ colours redder than the model galaxies also had $i-z \geq 0.8$; we can simply assume that all objects in our sample with such a colour are potentially intrinsically red or reddened objects at some arbitrary redshift. There are nine such objects in our sample. Thus under this assumption, we might expect up to about 20 per cent contamination of our $z > 5$ candidate sample by lower redshift red objects. For now we choose not to remove these objects, as these could potentially be obscured AGN at $z > 5$ (the reddened nucleus dominating at the longer wavelengths). As we will consider later the number of potentially obscured AGN in our sample, by cross-correlation with the *Chandra* data for the field, we will retain the objects in the full sample.

Thus, between the $R-$band detected sources and those with red near-IR colours we have a contamination rate of no more than 35 per cent (about 15 sources). Some of the reddest objects could still be at $z > 5$ and there could be overlap of this sample with the $R-$band detected sample (we cannot tell with the current data as the two ground-based fields do not overlap effectively). Thus contamination by lower redshift objects could be somewhat less than this. For a smaller sample of higher redshift candidates, Stanway et al. estimated a contamination rate of about 25 per cent.

3 SURFACE DENSITY AND DISTRIBUTION OF THE OBJECTS

The density of candidates with these colours and magnitudes, 1 per 3 arcmin^2, is similar to that found by Lehnert & Bremer for their sample of 13 candidates and is approximately twice as high as for their spectroscopically confirmed $z > 4.8$ galaxies. It is not clear how to compare these surface densities, given that both samples could be contaminated by lower redshift objects. As was argued in Lehnert & Bremer (2003), the high success rate of spectroscopic confirmation would seem to indicate that most of the unconfirmed high redshift candidates are also at $z > 4.8$ as only about 50 per cent of lower redshift dropout samples appear to have strong Lyman α emission. In addition, Lehnert & Bremer were able to spectroscopically confirm that many of the color-selected sources at the bright end of their sample (I $\lesssim$ 24.5) were not high redshift galaxies or QSOs.

A more likely problem is contamination in our CDF-S source list. We cannot fully exclude EROs on the basis of our photometric cuts and there could be slightly reddened lower redshift dropouts in our sample. In any event, the completeness of the ACS sample studied here will be higher as the ACS data are deeper in i and z and have much higher spatial resolution than the VLT data (0.08 arcsec as opposed to 0.8 arcsec).

Rather than attempt to determine a comoving volume density for these sources, our purpose here is to note merely how the candidates are distributed across the field. Figure 2 shows that they appear to cluster, or at least show a wide range in their surface density. One area of ~ 25 arcmin^2 shows no detected sources. We determined that the total catalogue of all objects showed no such "hole" or under-density in sources in the same area. We also checked the photometry and number counts in each band in this area against the rest of the catalogue to ensure the lack of dropouts was not caused by problems in the photometry. No differences were found. We compared the nearest-neighbour statistics of the sources to random selections of 44 sources taken from our catalogue using the cuts $i_{AB} < 26.3, i_{AB} - z_{AB} > 0$, but with no V-band cut. This selection would tend to select galaxies at lower redshifts than the dropout sample. Using a K-S test we found no significant difference between the distributions of nearest neighbours for the high redshift sample and the randomly-selected samples. Due to the low surface density of the randomly-selected samples, they sometimes showed similar-sized areas devoid of sources to that seen in the distribution of our high redshift candidates.

Given the current data, there appears no obvious difference in the clustering characteristics of our $z > 5$ sample and other faint sources. However, the fact that there is such a wide variation in the surface density on scales of about 25 arcmin^2 indicates that a proper treatment of the clustering properties and densities of these sources requires imaging over an area considerably larger than that covered by the ACS CDF-S data. Given that 25 arcmin^2 is comparable in size to a single pointing of 8m telescope cameras such as FORS and GMOS, and is larger than a single pointing of the ACS, caution must be exercised over interpreting clustering properties and source densities derived from single pointings.

The projected proper area of the field is about 20 Mpc^2 at $z \simeq 5$. If we very crudely estimate that we probe of order 0.5 in redshift around $z = 5$ (in fact the effective volume will be less than this as the completeness at faint levels is always less than 100 per cent, *e.g.* see Lehnert & Bremer), the comoving volume covered by the field is roughly 10^5 Mpc^3. Given the "hole" in the distribution of candidate $z > 5$ sources is of order 10-20 per cent of the imaged area, this corresponds to a "void" with a size of order $\sim 10^4$ Mpc^3. Thus it is not surprising that significant "holes" in the distribution exist, as they correspond to relatively small comoving volumes.

4 THE MORPHOLOGIES OF THE SOURCES

About half of the sources in Table 1 and Figure 1 are convincingly resolved, but with half light radii of typically no more than 0.2-0.3 arcsec (< 2 kpc). Several sources are unresolved but at least two are resolved on rather larger scales of order 0.4-0.5 arcsec (17 and 41). These latter sources are most likely red $z \sim 1$ galaxies (41, for example, has a secure R-band detection as noted in §2). Several sources appear as a double source or with a nearby lower surface brightness component, though usually only a single component makes our magnitude cut. An exception to this is the pair with catalogue numbers 31 and 32. Such sources appear similar to the pair of $z = 5.3$ galaxies discovered in the HDF-N by Spinrad et al (1998). Overall, the sizes of the sources are comparable to those found by Stanway et al. for their $i-$band dropouts, showing clearly that galaxies at $z > 5$ have scale-lengths of only <0.5 to 2 kpc (assuming a redshift range of 4.8-5.8 and our adopted cosmology). Lowenthal et al. (1997) noted that $z = 3$ dropouts in the HDF-N had typical half light radii of 0.2-0.4 arcsec (2-3 kpc in our assumed cosmology). Results from Roche et al., (1998) indicate that typical $z = 4$ galaxies have half light radii smaller than those at lower redshift. Their $z = 4$ half-light radii are comparable to ours at $z > 5$ (when transformed to our cosmology), so our results appear to support a decrease in galaxy scale-lengths with increasing redshift. It is not clear whether the sources we are detecting at $z > 5$ are representative of the entire collapsed mass in a galactic halo at these redshifts, or simply high surface brightness regions of strong star formation within larger, lower surface brightness systems.

5 AGN CONTAMINATION

What fraction of sources selected by our criteria are AGN? A simple expectation of currently favoured structure-formation scenarios is that the first galaxies form in the most overdense halos in the early universe. These are also most likely to be the place where the first supermassive black holes form, given the known correlation between central black hole mass and spheroid mass (*e.g.* Gebhardt et al., 2000, Ferrerese & Merritt 2000). Clearly, in order to confront models of early structure formation with data requires knowledge of what fraction of these sources contain active AGN. All the objects in Lehnert & Bremer (2003) with spectroscopically-determined redshifts had narrow emission-lines and showed no evidence for the broad lines expected from relatively unobscured AGN. However, it is possible that some may have contained optically obscured AGN (as observed by, for example, Giacconi et al. 2001). These would be detectable in sufficiently deep X-ray observations sensitive to rest-frame hard X-ray emission from the sources.

The CDF-S field has a 1Msec *Chandra* exposure (Rosati et al. 2002) publically available. We cross-correlated our source-list with the catalogue of Giacconi et al. (2002). None of our V-band dropouts were among the catalogued sources. Having determined the (small) offset between the X-ray coordinate frame and that of the ACS from this cross-correlation, we then determined the 0.5-5keV X-ray fluxes in 2 arcsec radius apertures centred on the positions of our 44 dropout sources. None were detected at a 3-σ level of 8×10^{-6} counts sec^{-1} above background and only one at 2-σ (and one is expected from Poissonian noise in the background). The distribution of counts in the apertures was indistinguishable from Poissonian. A total of 286 background plus object counts is consistent with the expected background level of 306 counts. Consequently, no individual source was detected, and the collective mean flux of a dropout source is less than 2 counts (at $3 - \sigma$). These limits corresponds to a flux of 7×10^{-17} erg cm^{-2}s^{-1} for an individual source, and 2×10^{-17} erg cm^{-2}s^{-1} for the mean source. At $z \sim 5.3$ these give a > 2.5 keV luminosity of $< 2 \times 10^{43}$ erg s^{-1} and $< 5 \times 10^{42}$ erg s^{-1} for individual and mean sources respectively. This rules out contamination by powerful AGN since AGN are generally prominent X-ray sources. These results are consistent with those of Barger et al. (2003) but also extend them by going over a magnitude deeper in the optical selection of sources allowing us to investigate the most heavily obscured sources which have been shown to contribute substantially to the total X-ray emission (e.g., Giacconi et al. 2001) and by investigating the X-ray emission from significantly more high redshift sources. These results are entirely consistent with the sources having comparable X-ray luminosities to those of $z = 3$ Lyman break galaxies, which have $L_x \sim 3 \times 10^{41}$ erg s^{-1} above 2.5 keV (Brandt et al. 2001). The most X-ray luminous starburst galaxies have similar luminosities to this (e.g., Moran, Lehnert & Helfand 1999). Given that our sources are selected to have the colours of unobscured starbursts at $z > 5$, any future X-ray detection at this low level can be attributed to the starburst rather than a weak AGN. Such a detection would require a > 10Msec *Chandra* exposure.

All of the above reinforces one of the conclusions of Lehnert & Bremer (2003) (and of Barger et al. 2003 for brighter optical sources), *viz.* that emission from AGN played little part in the final stages of the reionization of the Universe. Only if there were an early dominant population of AGN that had completely died out by $z = 5 - 6$, when strong star formation had been initiated, could AGN have played a major part in the reionization of the Universe.

6 CONCLUSIONS

We have selected a sample of 44 objects from the ACS data of the CDF-S with properties consistent with galaxies at $z > 5$ by using photometric cuts to include objects similar to those spectroscopically confirmed to be at $z > 5$ by Lehnert & Bremer (2003). The sample is likely to contain a small number of contaminating sources at lower redshift, and certainly does not contain all sources at $z > 5$ due to its $i-$band flux limit. Specifically, it will miss most objects of the type selected by Stanway et al. as they had $i - z > 1.5$ in order to detect galaxies at $z \sim 6$ and such objects are rare at $i < 26.3$.

We found that these sources were often resolved on scales of $\sim 0.2-0.3$ arcsec, with several appearing double or with extended lower surface brightness regions close to them, quite similar to the $z = 5.3$ source in the HDF-N described by by Spinrad et al. (1998). The candidate $z > 5$ dropout galaxies appear to be smaller than those studied by Lowenthal et al. (1997) at $z = 3$, likely indicating that the scale lengths of galaxies decrease with increasing redshift.

The distribution of the selected objects over the 150 arcmin^2 area is not uniform, there is a patch of area $\sim$ 25 arcmin^2 where there are no selected sources. Comparing nearest-neighbour distributions of these sources and randomly selected samples of the same number of faint, non-dropout sources leads to no detectable differences. Similarly, "holes" of a similar size occasionally arise in the areal distributions of the random samples. Nevertheless, structures on this scale imply that fields considerably larger than the ACS CDF-S field are required to probe the clustering and density of high redshift sources with any degree of reliably. Interpretation (and indeed field-placement) of smaller fields are complicated by such a non-uniform distribution of sources.

None of the selected sources was conclusively detected as an X-ray source, and the total flux from the 44 sources is also consistent with zero. This limits the > 2.8 keV X-ray luminosities of the individual sources at $z \sim 5.3$ to considerably below 2×10^{43} erg s^{-1} (3-σ upper limit on an individual source). This rules out strong AGN contamination for the bulk of the sources. Given the short timescale between $z \sim 5.3$ and the end of reionization at $z \sim 6$, this supports the idea that AGN made little contribution to the final stages of the reionization of the Universe.

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