Are z~5 QSOs Found in the Most Massive High Redshift Halos?

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Abstract

Luminous high redshift quasars are thought to exist within the most massive dark matter halos ($M > 10^{12} M_{\odot}$) in the young universe, where simulations suggest the strongest evolution is expected to have occurred in the relatively brief time since the Big Bang. Given the expected halo clustering behaviour, the quasars may trace volumes containing an overdensity of other high redshift galaxies (e.g. Lyman Break Galaxies, LBGs). To test this hypothesis we searched three z=5 quasar fields (each covering ~7' x 7' or ~2.5 x 2.5 Mpc at z=5) for LBGs at the quasar redshift. We compared the numbers of spectroscopically-confirmed LBGs in these fields to those found through an identical procedure in blank sky fields (ESO Remote Galaxy Survey, ERGS; Douglas et al. '09, '10). Overall we find evidence of clustering in the quasar fields but not at the level seen in the most clustered ERGS fields. One of our fields covers a volume containing two quasars at a similar redshift and should represent a strong overdensity. While this field shows more LBG clustering than our other fields, it is still not as significant as that in the densest ERGS fields. This suggests that either high redshift quasars are not found in the most massive peaks of the high redshift mass distribution, or if they are, that LBGs are not perfect tracers of the mass distribution in such high-redshift environments.

High Redshift Quasars

The extreme luminosity of high redshift quasars implies that they are powered by accretion onto supermassive black holes (SMBHs). From the strong correlation of SMBH mass and mass of the host galaxy, this suggests quasars reside in large galaxies with a massive dark matter halo. Large dark matter halos are seen in simulations to arise in the most overdense regions in the young universe. Consequently we expect significant clustering of forming galaxies around and in the environment of such quasars. Therefore we may **expect clustering of LBGs**.

Lyman Break Galaxies (LBGs)

LBGs are **UV luminous, (relatively unobscured) star forming galaxies** observed at high redshift. Their UV radiation shortward of Lyman alpha is absorbed by intervening neutral hydrogen which causes a break in their spectra, allowing them to be photometrically selected from their unusual colours.

Imaging

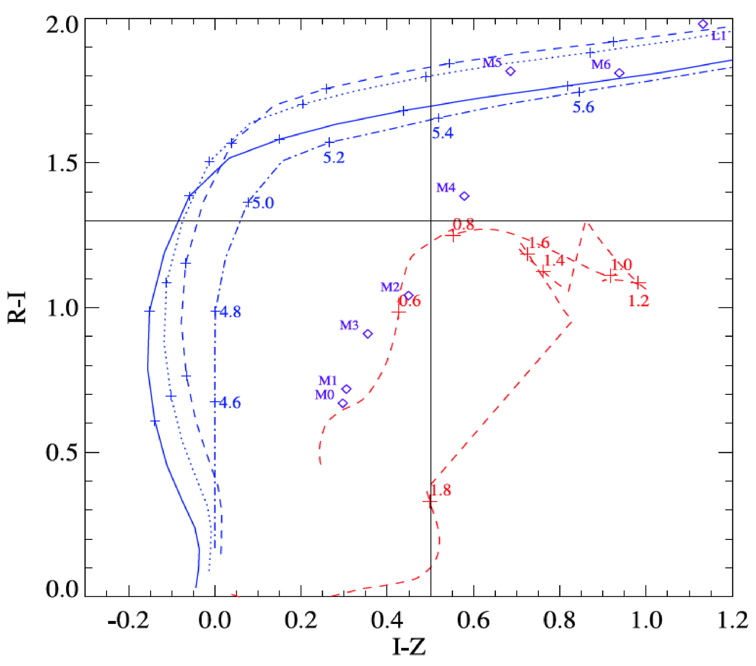

Fig. 1: R-I versus I-z selection plot showing various stellar age star-forming, high redshift galaxies (blue) with their redshifts marked on. It also shows intermediate-redshift elliptical galaxies (red) from Maraston '05[3] models and cool, low-mass stars from Hawley et al. '02[4] (purple diamonds). The solid black lines show the colour selection cut with z~5 LBGs in the top left corner (adapted from Douglas '09[1]).

· Three ~7' by 7' fields centred on z~5 quasars were observed in R, I and z wavebands with VLT/FORS2.
· Fields were observed and images reduced **identically to** ESOs Remote Galaxy Survey (**ERGS**)[1,2] to allow comparisons.
· Catalogues of objects were obtained using SExtractor in dual image mode.
· Objects were then identified as likely z~5 LBGs by applying a standard colour selection cut (see Figure 1) and subsequently examining the individual and combined RIz images to rank objects in likelihood of z~5 LBGs (see Figure 2).
· This ranking was used to populate MOS masks for each field (2 masks, ~60 objects, per field of which ~50% high rank).
· From photometry the fields don't look any richer than the ERGS blank sky fields. Spectroscopy is required to confirm any clustering.

Star
· Unresolved half-light radius.

High redshift LBG
· Red colour and small half-light radius.

Low redshift galaxy
· Blue colour and resolved.

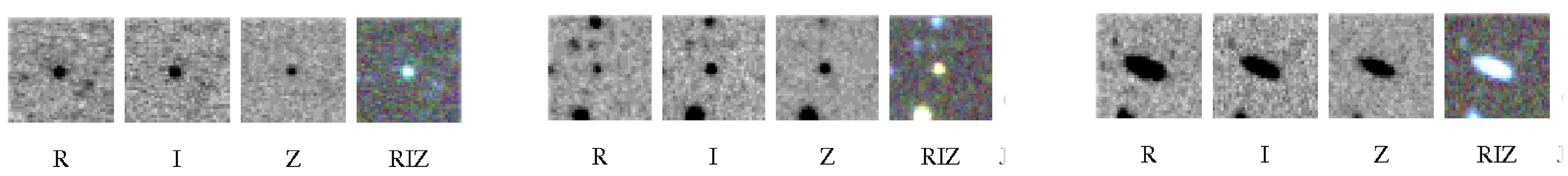

Fig. 2: Example R, I, z and combined RIz images of a typical star, high redshift LBG and low redshift galaxy.

Contaminants

· Both **M stars** and passive **early type galaxies** at z~1 give similar RIz colours to z~5 LBGs given the photometric errors (see Figure 4).
· Some low ranking objects were placed on our mask to a. confirm the ranking and b. because there was space.
· Results of our spectroscopy generally confirm this ranking and show for fainter objects contaminant discrimination is increasingly difficult from photometry alone. Of the highest ranking objects, ~25-30% are spectroscopically confirmed as LBG. The majority of the rest have no clear spectroscopic classification.

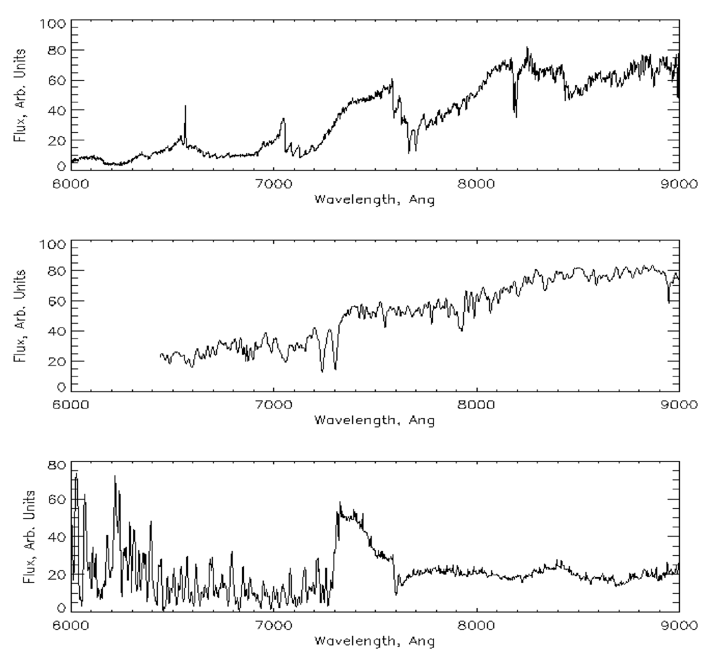

Fig. 4: (top) An example spectrum of a M3 star (SDSS template). (middle) An example spectrum of an early-type galaxy at z=0.84 (SDSS template). (bottom) An example z=5 quasar spectrum showing the position of the break in z~5 LBGs.

Spectroscopy

· Spectroscopy of the most likely sources was obtained with VLT/FORS2.
· Again spectroscopy was reduced identically to ERGS for comparison.

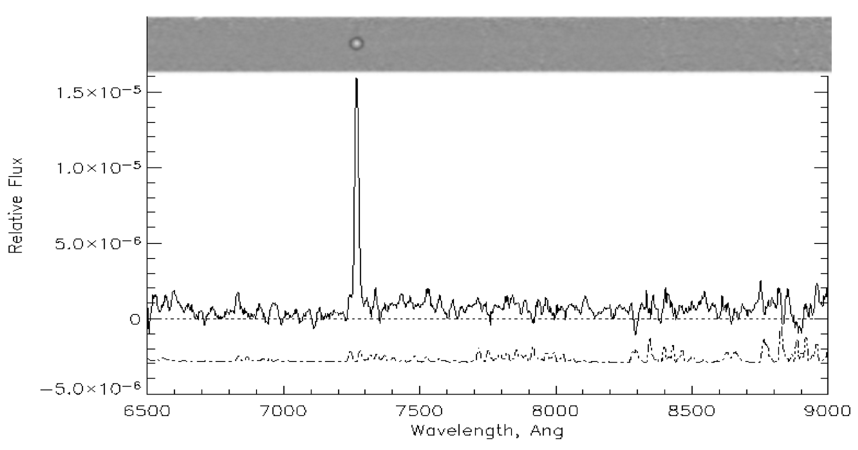

Fig. 3: The 2D and 1D spectrum of an example z~5, class A LBG with Lyman alpha emission (circled).

· The spectra were examined for a Lyman break and/or Lyman alpha emission.
· As for ERGS they were graded into Class A spectra which had a definite break or emission line indicating a precise redshift (see Figure 3) and Class B spectra which broke within a skyline complex indicating a less secure redshift (Δz=0.05).

Redshift Distribution

J0338+0021 | **J1204-0021** | **J2130+0026**

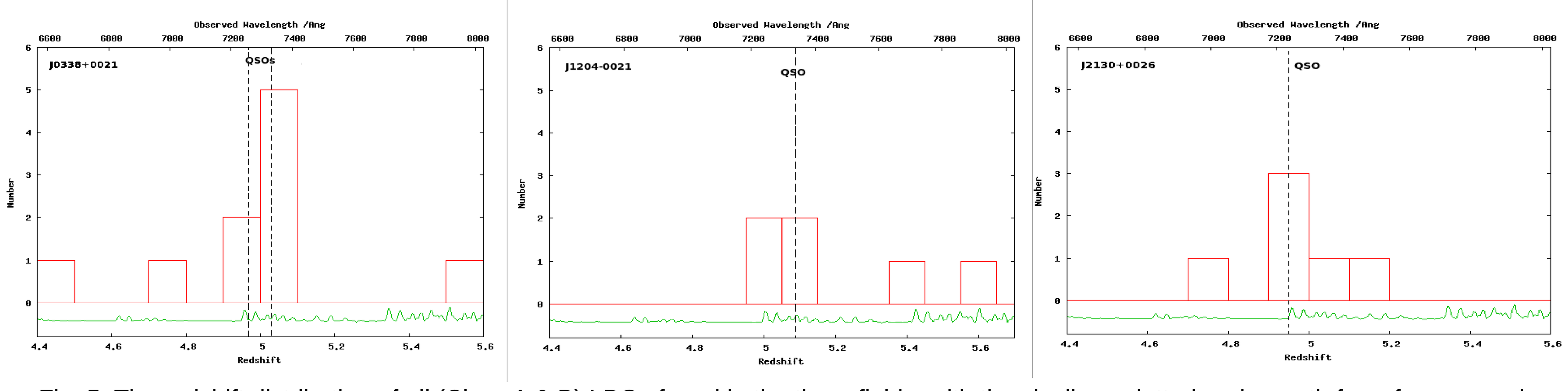

Fig. 5: The redshift distribution of all (Class A & B) LBGs found in the three fields, with the sky lines plotted underneath for reference and the redshift of the quasar highlighted.

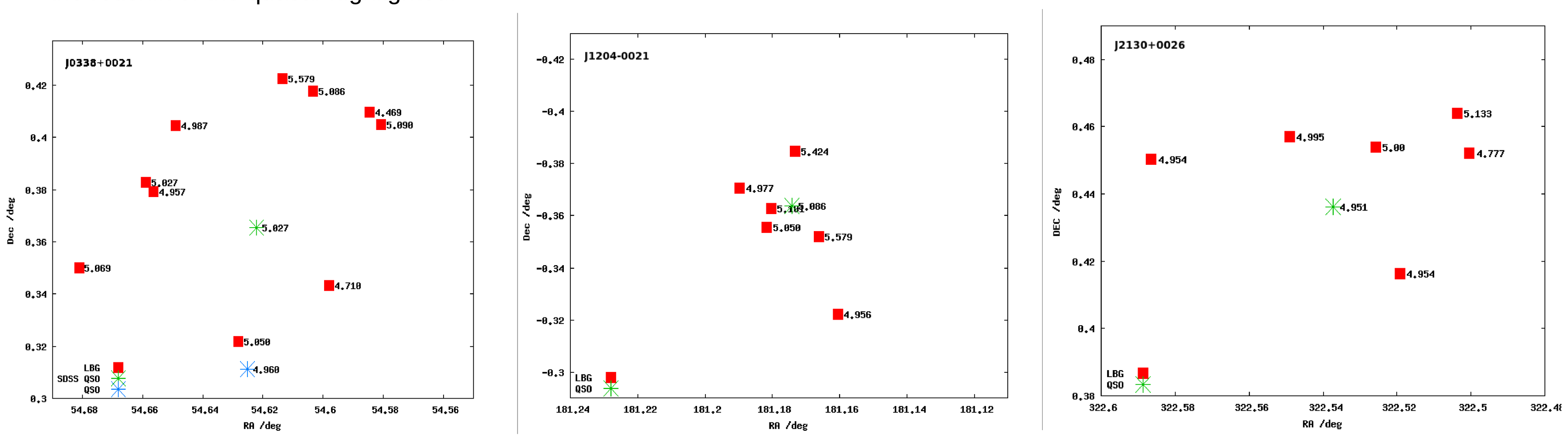

Fig. 6: The spatial distribution of all (Class A & B) LBGs found in the three fields, with the redshift of the sources labelled and the position of the quasars marked on. Note that it is the redshift distribution which dominates their 3D separation.

· This field has **two quasars** at a similar redshift.
· We observe **clustering** of LBGs around the quasars, although not at the levels of the most clustered fields in ERGS.

· **Some clustering** of LBGs is observed at the redshift of the quasar. However, total number and redshift distribution similar to typical unclustered ERGS fields.

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Discussion/Comparison to ERGS

· Overall we see evidence for clustering around the quasars, in the LBGs redshift distribution. However stronger clustering is seen in 2 out of the 10 ERGS fields (see Figure 7).
· One of the differences between this and the ERGS study is that the photometrically richest fields in ERGS had 3 or 4 spectroscopic masks applied. Nevertheless the effect of this is marginal, while we see clear clustering around two of the quasars, the ERGS survey has fields within that are richer and more clustered.
· We find no evidence of quasar suppression of the star formation in nearby LBGs, as suggested by Utsumi et al.[6] (photometric only study). The closest LBG to a quasar in our fields has a 3D separation of 0.5±1.0 Mpc (dominated by redshift uncertainty).
· It is clear that, in 2 out of 3 cases, we are spectroscopically identifying clustering of LBGs around these quasars, however it is also clear that the signature is not overwhelming and not easily visible using purely photometric means.
· There may not be a one-to-one correspondence of strength (mass) of overdensity and number of LBGs because of their short-lived and stochastic nature. Over time the same structure may be marked out by a variable number of LBGs.

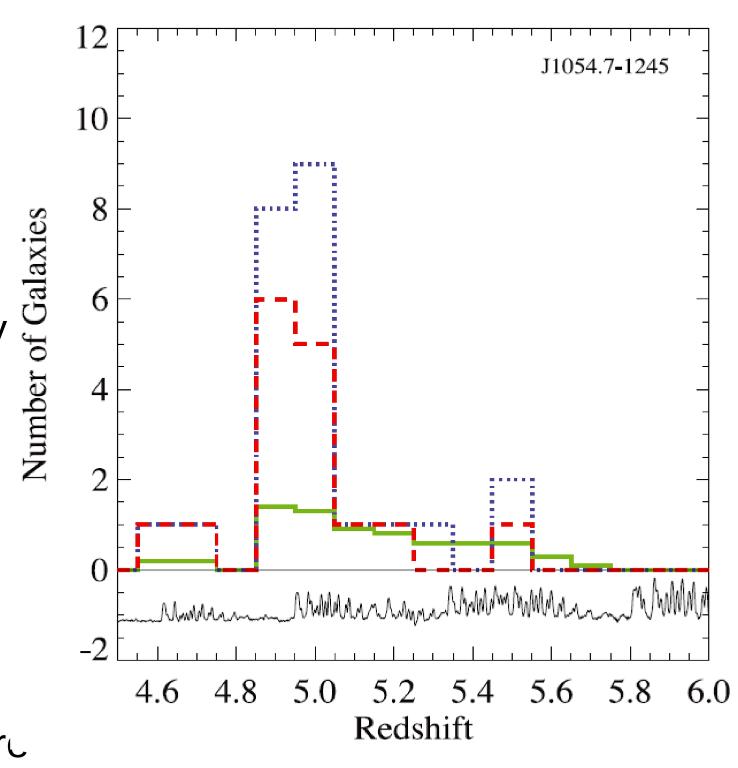

Fig. 7: The redshift distribution of Class A & B LBG in a random field in ERGS (blue dotted line) with the sky lines plotted underneath for reference. The red dotted line shows just the Class A LBGs and the green solid line the average distribution for a blank ERGS field.

Conclusions

We show in two out of three cases spectroscopic evidence for association of LBGs with z~5 quasars indicating the quasars do trace significant overdensities in the young universe. However, the lack of clustering signal in one of the fields and the stronger clustering seen in some blank (non-quasar) fields implies either the quasars do not match the strongest overdensities or the LBGs are an imperfect tracer of such structures.

References & Acknowledgements

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