Star-formation at z=2–4 : going below the spectroscopic limit with FORS1

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1 Introduction

The population of bright galaxies at z=2–4 has been studied intensively using the Lyman-Break technique (Steidel et al. 1996; Cristiani et al. 2000). Currently redshifts can be determined from absorption features of galaxies selected in this way down to R≈25.5 (e.g. Steidel et al. 2000), which is commonly referred to as the spectroscopic limit. Currently, very little is known about the galaxy population below the spectroscopic limit. This is an unfortunate situation since all the information on the chemical enrichment of young galaxies (Damped Ly-α Absorbers) accessible through QSO absorption lines seems to be valid mainly for galaxies significantly fainter than R=25.5 (Fynbo et al. 1999; Haehnelt et al. 2000). In order to select and study galaxies fainter than the current spectroscopic limit one has to rely on other selection criteria than the Lyman-Break. Two promising possibilities are *i)* to select galaxies with Ly-α emission lines, and *ii)* to study the host galaxies of Gamma-Ray Bursts (GRBs).

2 Ly-α selected galaxies

Ly-α selection of high redshift galaxies has been attempted for many years, but only recently with significant success (Møller and Warren 1993; Francis et al. 1995; Cowie and Hu 1998; Pascarelle al. 1998; Kudritzki et al. 2000; Fynbo et al. 2000a; Steidel et al. 2000; Kurk et al. 2000). In 1998 we detected 6 candidate Ly-α emitting galaxies (called S7–S12) in the field of the QSO Q1205-30 at z=3.036 with deep NTT narrow-band imaging (Fynbo et al. 2000b). In March 2000 we carried out follow-up Multi-Object-Spectroscopy with FORS1 on the 8.2m

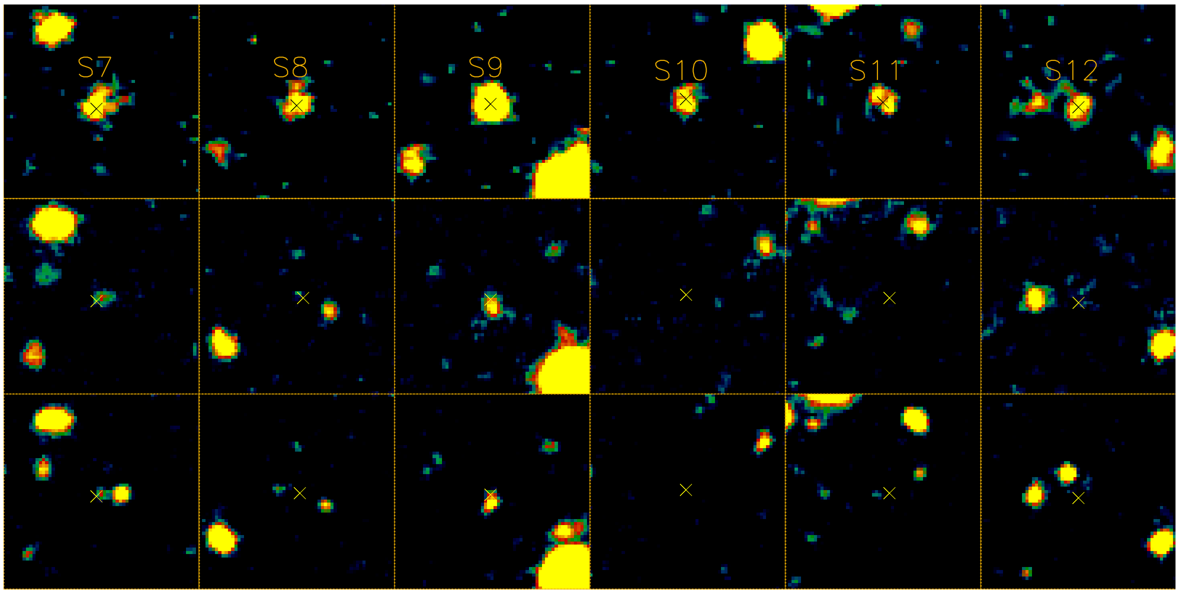

Figure 1: Image sections (12×12 arcsec^2) from the NTT narrow-band (top), VLT B-band (middle) and VLT I-band (bottom) for each of the six candidate emission line galaxies S7–S12 (Fynbo et al. 2000a). East is to the left and north up.

Antu telescope (UT1). We also obtained deeper broad band B and I imaging reaching $5(2)\sigma$ detection limits in 1 arcsec^2 circular apertures of 25.9(26.9) in the I-band and 26.7(27.7) in the B-band (both on the AB-system). The results of these observations are presented in Fynbo et al. (2001a), and summarized here.

Imaging:

In Fig. 1 we show image sections with Ly-α (top), VLT B-band (middle) and VLT I-band (bottom) for S7–S12. As seen, despite the faint detection limits, only for S7 and S9 is there a corresponding source detected in the broad bands (B(AB)=25.6 and 25.4 respectively). For the sources S8 and S10–S12 no convincing broad band counterpart is detected.

For the brightest source, S9, there is an offset of 0.6$\pm$0.2 arcsec between the Ly-α centroid and then centroid of the continuum source. The same offset is also seen in the 2-dimensional spectrum of the source (Fig. 2, the slit was nearly aligned along the direction of the offset). To assess whether a likely explanation for this is that we see two sources superposed we calculate the probability for a chance alignment. The surface density of galaxies down to the 5σ detection limit in the VLT B-band image is 50 per arcmin^2. The probability to find a galaxy by chance within 0.6 arcsec from a given position on the sky is therefore roughly

$\pi \times 0.6^2 \times 50/3600 = 1.6\%$. The probability of such a chance alignment in one of six cases is hence roughly 10%, which is small but not negligible. Therefore, we cannot with the present data conclude whether S9 is a single object with strong Lya emission centred 0.6 arcsec from the continuum emission, or a chance aligment of two objects. Note here that evidence that the spatial distribution of Ly-α emission of high redshift galaxies can be different from that of the continuum emission of the same galaxy, was reported by by Møller and Warren (1998) and Roche et al. (2000).

Spectroscopy:

The individual spectra of S7–S12 are shown in Fynbo et al. (2001a). All 6 sources have confirmed emission lines. In the middle panel of Fig. 3 we show the composite spectrum of all 6 sources in the spectral region 4600Å–5270Å around the emission line (left) and in the spectral region 6050Å–6720Å (right). As seen, there is one strong emission line detected in the blue part of the spectrum. This line could be due to a foreground emission line galaxy at z=0.313 with OII in the narrow filter, or Ly-α at z=3.036. To discriminate between the two possibilities we look for the presence of other lines. In the lower panel we show the spectrum of a z=0.224 (B(AB)=24.2) emission line galaxy detected in one of the redundant slits. This spectrum has been redshifted to z=0.313 so that the OII(3727) emission line falls at the same wavelength as the observed emission lines of S7–S12. With dashed, vertical lines we indicate the positions of the NeIII, Hβ and OIII emission lines seen in the spectrum of the z=0.313 galaxy. As seen, there is no hint of these lines in the composite spectrum of S7–S12, which confirms that S7–S12 indeed are high redshift Ly-α emitters and not foreground emission line galaxies. In the upper panel we show the spectrum of Q1205-30 in the same spectral regions as for S7–S12 to illustrate, in the same way, that there is no CIV emission from S7–S12. Hence, the Ly-α emission is most likely powered by star-formation.

These results show that Ly-α selection allows the study of high redshift galaxies that are currently not accessible with the Lyman-Break technique. The inferred space density of S7–S12 is about 10 times higher than that of R<25.5 Lyman-Break galaxies (Fynbo et al. 2000a). Only $\sim$20% of the Lyman-Break galaxies show Ly-α in emission (Steidel et al. 2000). This may be an underestimate if Ly-α and continuum emission often have different spatial distributions. However, if this fraction is valid further down the luminosity function then there could be 50 times more galaxies like S7–S12 than R<25.5 Lyman-Break galaxies. Of course we need to measure the space density of faint Ly-α emitters to similar depths as in the field of Q1205-30 in several (blank) fields before this conclusion can be drawn.

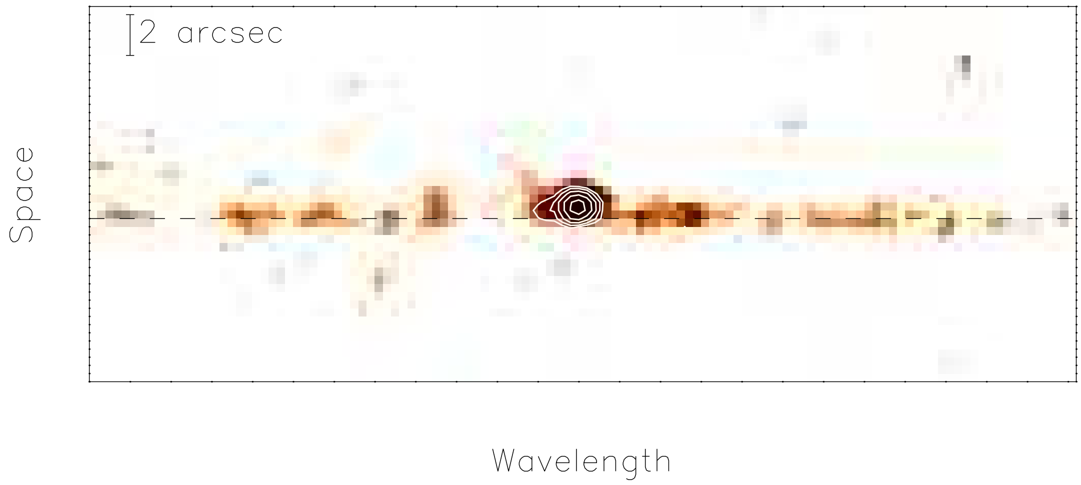

Figure 2: The 2-dimensional spectrum of the brightest Ly-α source, S9, showing the offset between the Ly-α emission and the continuum emission.

3 GRB host galaxies

In some widely accepted scenarios GRBs are related to the deaths of very massive, short-lived stars and furthermore gamma-rays are not obscured by dust. Hence, a sample of GRB host galaxies may be considered star-formation-selected independent of the amount of extinction of the rest-frame UV and optical emission.

Several high redshift galaxies have been localised as host galaxies of GRBs. A Lyman-Break type galaxy at redshift z=3.42 with an R-band magnitude of R=25.6 (and a prominent Ly-α emission line) was found to be the host galaxy of GRB 971214 (Kulkarni et al. 1998; Odewahn et al. 1998). GRB 990123 and GRB 990510 occured at nearly identical redshifts (z$\approx$1.6), but the host galaxy of the former (R=24.6) is more than 20 times brighter than the latter (R$\approx$28) (Holland and Hjorth 1999; Fruchter et al. 1999, 2000a). In the same way, GRB 000301C and GRB 000926 occured z=2.0404 and z=2.0375, but have very different host galaxies. The host galaxy of GRB 000301C remains undetected down to a detection limit of R=28.5 (Fruchter et al. 2000b; Smette et al. 2001; Jensen et al. 2001), whereas the host galaxy of GRB 000926 is relatively bright (R=24, Fynbo et al. 2001b). Finally, no host galaxy has been detected for GRB 000131, that occured at z=4.50, down to a limit of R=25.7 (Andersen et al. 2000).

If GRBs indeed trace star-formation these observations indicate that at these redshifts galaxies covering a broad range of luminosities contribute significantly to the over-all density

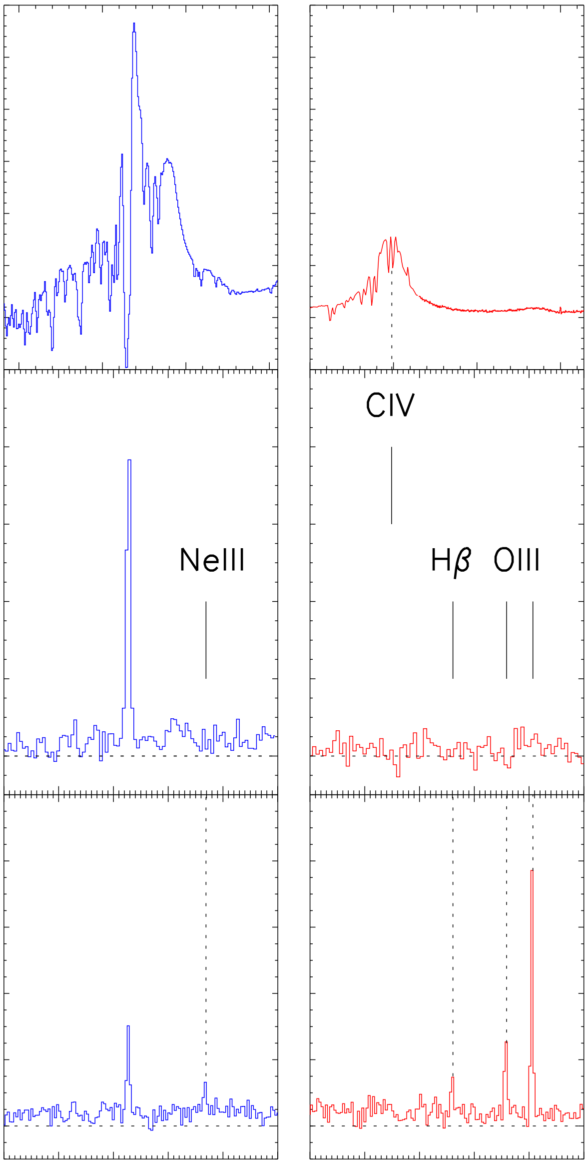

Figure 3: The middle panel shows the composite spectrum of S7–S12. The lower panels show the spectrum of an emission line galaxy redshifted to z=0.313 so that the OII line falls at the wavelength of the observed emission line of S7–S12. As seen, the composite spectrum of S7–S12 shows none of the lines expected if S7–S12 had been foreground emission line galaxies. The upper panels show the spectrum of Q1205-30 to indicate the position of the CIV emission expected for AGNs. The absence of CIV emission from S7–S12 shows that the Ly-α emission is powered by star-formation and not by a central AGN.

of star formation. Furthermore, as the observed R–band flux is proportional to the star formation rate, there must be 1–2 orders of magnitude more galaxies at the R=28 level than at the R=24 level at z≈2. Otherwise it would be unlikely to detect R=28 galaxies as GRB hosts.

4 Conclusion : faint galaxies at high redshifts

The study of Damped Ly-α Absorbers (Fynbo et al. 1999; Haehnelt et al. 2000), Ly-α selected galaxies and GRB host galaxies independently suggest that there are 1–2 orders of magnitude more galaxies fainter than R≈25.5 than brighter than this limit at z=2–4. The properties of galaxies at this faint end of the luminosity function are currently very uncertain. Since the population of bright, Lyman-Break selected galaxies is already (observationally) very well studied and characterized, progress in the understanding of the high redshift galaxy population will most likely come from the study of galaxies below the spectroscopic limit.

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