

Physical properties of $z \sim 4$ LBGs: differences between galaxies with and without $\text{Ly}\alpha$ emission

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ABSTRACT

Aims. We analysed the physical properties of $z \sim 4$ Lyman Break Galaxies observed in the GOODS-S survey, in order to investigate possible differences between galaxies where the $\text{Ly}\alpha$ is present in emission, and those where the line is absent or in absorption.

Methods. The objects were selected from their optical color and then spectroscopically confirmed by Vanzella et al. (2005). From the public spectra we assessed the nature of the $\text{Ly}\alpha$ emission and divided the sample into galaxies with $\text{Ly}\alpha$ in emission and objects without a $\text{Ly}\alpha$ line (i.e. either absent or in absorption). We then used complete photometry, from U band to mid-infrared from the GOODS-MUSIC database, to study the observational properties of the galaxies, such as UV spectral slopes and optical to mid-infrared colors, and the possible differences between the two samples.

Lastly, we used standard spectral fitting techniques to determine the physical properties of the galaxies, such as total stellar mass, stellar ages and so on, and again we looked at the possible differences between the two samples.

Results. Our results indicate that LBG with $\text{Ly}\alpha$ in emission are on average a much younger and less massive population than the LBGs without $\text{Ly}\alpha$ emission. Both populations are forming stars very actively and are relatively dust free, although those with line emission seem to be even less dusty on average. We briefly discuss these results in the context of recent models for the evolution of Lyman break galaxies and $\text{Ly}\alpha$ emitters.

Key words. galaxies: distances and redshift – galaxies: evolution – galaxies: high-redshift – galaxies: fundamental parameters

1. Introduction

Over the past few years large samples of galaxies of up to the highest redshifts have been found (Iye et al. 2006; Kashikawa et al. 2006; Bouwens et al. 2004) using techniques that rely on various color-selection criteria. Among the various methods, one of the more efficient is the Lyman break dropout technique (Steidel & Hamilton 1993), which is sensitive to the presence of the 912 Å break and is effective in finding star-forming galaxies. This method requires a blue spectrum, implying low to moderate dust absorption. It was first designed to select ~ 3 galaxies (Steidel et al. 1996; Madau et al. 1996) with a typical magnitude limit of $R < 25.5$, and then extended to higher redshift (Steidel et al. 1999; Ouchi et al. 2004; Giavalisco et al. 2004; Dickinson et al. 2004).

An alternative technique for finding such distant objects is to search for $\text{Ly}\alpha$ emission, through very deep, narrow-band imaging in selected redshift windows, as first shown by Cowie & Hu (1998). $\text{Ly}\alpha$ emitters (LAEs) are generally selected to have high restframe $\text{Ly}\alpha$ equivalent width, typically $EW \gtrsim 20$ Å, with no constraint on the continuum. Consequently, this method tends to select much fainter galaxies, compared to the general LBGs population. Many $\text{Ly}\alpha$ emitters have now been found (e.g. Iye et al. 2006; Ouchi et al. 2004; Fujita et al. 2003) and several distant large-scale structures or protoclusters have been discovered (e.g. Ouchi et al. 2005; Venemans et al. 2007).

Each of the two methods suffers from a different selection bias: the two resulting populations of galaxies overlap partially and the relationship between them is not clear.

Various scenarios have been proposed to explain the properties of $\text{Ly}\alpha$ emitters. Based on rest-frame optical photometry

of LBGs, Shapley et al. (2001) concluded that LBGs with $\text{Ly}\alpha$ in emission are “old” (ages greater than a few $\times 10^8$ yr), while “young” (ages less than ~ 100 Myr) LBGs exhibit $\text{Ly}\alpha$ in absorption. This could be explained if the young galaxies contain dust, which absorbs the $\text{Ly}\alpha$ photons, while the older galaxies are more quiescent with less dust and superwinds, thus allow the $\text{Ly}\alpha$ photons to escape.

As an alternative explanation other groups have suggested that strong $\text{Ly}\alpha$ emitters are instead young star-forming galaxies, based on the blue colors and high equivalent widths of the $\text{Ly}\alpha$ emitters (e.g. Le Fevre et al. 1996; Malhotra & Rhoads 2002; Rhoads & Malhotra 2001; Tapken et al. 2004; Keel et al. 2002). Finally, some authors have suggested that galaxies could have more than one $\text{Ly}\alpha$ bright emission phase (e.g. Thommes & Meisenheimer 2005). An initial–primeval–phase in which dust is virtually non-existent, and a later, secondary phase in which strong galactic winds, as observed in some Lyman break galaxies, facilitate the escape of $\text{Ly}\alpha$ photons after dust has already been formed.

Clearly, it is worthwhile understanding the real relation between galaxies with $\text{Ly}\alpha$ emission and the general LBG population, so that properties of the overall high-redshift galaxy population, such as the total stellar mass density, can be better constrained. With this in mind we analysed a sample of LBGs selected as B-dropouts from the GOODS-South sample, and with VLT spectroscopic confirmation (Vanzella et al. 2005; Vanzella et al. 2006). Given the good quality of the spectra, it was possible to assess whether the galaxies exhibit $\text{Ly}\alpha$ emission or the line is absent and/or appears as an absorption line. We then analysed how the observed properties and the derived

physical properties, such as total stellar mass and age, depend on the nature of the Ly α emission.

All magnitudes are in the AB system (except where otherwise stated) and we adopt the Λ -CDM concordance cosmological model ($H_0 = 70$, $\Omega_M = 0.3$ and $\Omega_\Lambda = 0.7$).

2. Sample and observational properties

From the GOODS-S public data survey we selected all galaxies with spectroscopic redshift in the range $3.4 < z < 4.8$. These galaxies were initially selected as B -band (or V band for those at $z \geq 4.5$) dropouts by Giavalisco et al. (2004: see this paper for the color selection criteria adopted) and with a z -band constraint $z < 26$. Spectroscopic observations were carried out with FORS2 within the framework of the GOODS project (Vanzella et al. 2005, 2006). The lower redshift cut is simply given by the actual availability of FORS2 spectra, given that the Ly α line falls at $\sim 5300 \text{ \AA}$, which is at the limit of efficiency for the observational setup used by Vanzella et al. (2006) (FORS2 plus the 300I grism)¹. The highest redshift cut was chosen since, at redshift higher than ~ 4.8 , the spectroscopic confirmations are almost exclusively based on the presence of the Ly α line in emission, while the objects with possible Ly α in absorption (or absent) become progressively more difficult to identify. In fact, the most distant object identified exhibiting Ly α absorption is at $z = 4.788$.

We retrieved the A and B quality spectra from the public-domain GOODS data. Spectra with quality flag C were only included if our independently measured photometric redshift (from 14 bands photometry, Grazian et al. 2006) was in agreement with the spectroscopic redshift, within the uncertainties of the photometric redshift. In the GOODS survey spectra are classified as emitters or absorbers, depending on the nature of the Ly α line. After removing AGNs, there are 47 galaxies in the above redshift range of which 19 feature the line in emission, and 28 exhibit Ly α as an absorption line or do not have it at all. The implied ratio of line emitters/total is quite similar to the proportion of Ly α emitters that was found at redshift $z \sim 3$ in a large sample of LBGs by Steidel et al. (2000). We will call the first sample LBG_L (LBG with Line emission) and the second sample LBG_N (LBGs with No line).

In Fig. 1 (upper panel) we show the redshift distributions of the two samples, which are similar. From our GOODS-MUSIC database we then gathered the complete 14 band multicolor information, extending from the U band to the Spitzer $8 \mu\text{m}$ band (for details of the catalog see Grazian et al. 2006). We then studied the observational properties: in particular we derived the rest-frame luminosity at 1400 \AA , the UV continuum slope β and the $z - [3.6]$ color which encompasses the 4000 \AA break. The average observational properties of the two samples, as well as the physical properties that will be derived in the next section, are reported in Table 1, together with the uncertainties, derived using the standard deviation of the mean. In the last column of the table we report, for each parameter, the probability value P given by the Kolmogorov-Smirnov test (KS-test), which tries to determine if the two datasets differ significantly. The KS-test has the advantage of making no assumption about the distribution of data.

The UV continuum slope was derived from the $i - z$ color, which spans a restframe wavelength range from $\sim 1500 \text{ \AA}$ to

¹ At lower redshift spectroscopic observations have been carried out with VIMOS, but the data are still not available to the public.

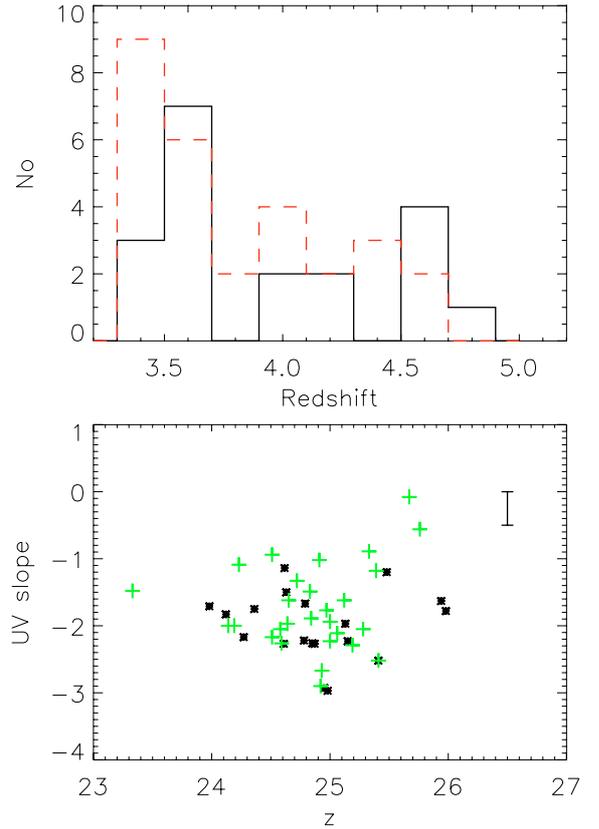


Fig. 1. *Upper panel:* the redshift distribution for the two samples. Full black line are the LBG_L , light dashed line are the LBG_N . *Lower panel:* the UV slope calculated from the $i - z$ colors: squares are the LBG_L and plus signs are the LBG_N .

$\sim 1800 \text{ \AA}$ (at the mean redshift of the sample $z \sim 4$, and considering the central wavelengths of the ACS filters). Although the restframe wavelength baseline is not large (and perhaps a $i - J$ color would be preferred), we used the $i - z$ color for two reasons: for a very few galaxies we do not have J band information available (see Grazian et al. 2006, for details); secondly, the UV slope derived in such way is more easily comparable to other UV slope values in the literature. Like other authors, we assume a standard power law spectrum with slope β ($f_\lambda \propto \lambda^\beta$, so that a spectrum that is flat in f_ν has $\beta = -2$). The 1216 \AA break only starts to enter the i filter at $z > 4.7$ so we neglect the impact of neutral hydrogen absorption for all galaxies. The measured slopes are plotted in Fig. 1 (lower panel) and range between -1 and -2.5 (with few exceptions). The uncertainties on the determined values range from 0.2 for the brightest objects to 0.8 for the fainter ones: in the figure we have indicated a median error on the individual values of 0.5 in the upper right-hand corner. The average value is $\langle \beta \rangle = -1.8 \pm 0.13$ for the overall sample, and $\langle \beta \rangle = -2.0 \pm 0.11$ and -1.7 ± 0.13 considering the LBG_L and LBG_N separately. The UV slopes we find are consistent with the prediction of models for unobscured continuously star forming galaxies (e.g. Leitherer et al. 1999). They are also consistent with what other authors have found at a similar redshift: for example Overzier et al. (2006), for redshift $z = 4.1$ LBGs and LAEs, find $\beta = -1.95$, Venemans et al. (2005) find $\beta = -1.65$ for Ly α emitters at $z = 3.1$. The values are also similar to the average $\beta = -1.8 \pm 0.2$ of V606 dropouts in GOODS found by Bouwens et al. (2006).

Table 1. Average properties of LBG_L and LBG_N .

Property	LBG_L	LBG_N	$P(K-S)$
N_{gal}	19	28	
z	24.89 ± 0.13	24.85 ± 0.10	0.99
[3.6]	24.6 ± 0.2	23.8 ± 0.15	0.02
β	-2.0 ± 0.11	-1.7 ± 0.12	0.32
$L(1400)$ (cgs)	1.1×10^{29}	1.0×10^{29}	0.65
SFR ($M_\odot \text{ yr}^{-1}$)	76 ± 34	74 ± 22	0.90
Age (Myr)	200 ± 50	410 ± 70	0.02
$E(B - V)$	0.07 ± 0.01	0.10 ± 0.02	0.58
Mass (M_\odot)	$5 \pm 1 \times 10^9$	$2.3 \pm 0.8 \times 10^{10}$	<0.002
Metallicity ^a	0.55 ± 0.10	0.48 ± 0.08	1.0
τ	4.5 ± 1.4	5.5 ± 1.3	0.96
Age/ τ	0.33 ± 0.13	0.99 ± 0.23	0.06

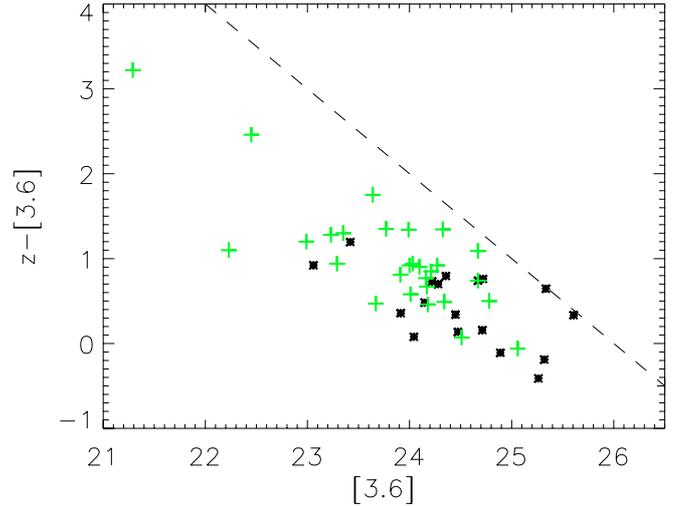
Average observational and physical properties for the samples of LBG_L and LBG_N separately: β is the UV slope derived from the $i - z$ color, $L(1400)$ is the total luminosity at 1400 Å resframe; SFR is the total instantaneous star formation rate; Mass is the total stellar mass assembled in the galaxies; τ is the star formation e -folding timescale. ^a We remind that this parameter is the most uncertain from the SED fit output, and that only four values of metallicity were considered in the fitting procedure, see text for more details.

On the other hand, our values are a bit steeper than those found by Papovich et al. (2001) for LBGs at $z = 3$ ($\langle\beta\rangle = -1.4$). Finally, Shapley et al. (2003), found less steep values and claim a considerable difference between the LBG_L and LBG_N at $z \sim 3$, with the former having a steeper slope, with a positive dependence of slope on the Ly α equivalent width.

As can be seen in Fig. 1, the values of the UV slopes for LBG_L and LBG_N overlap to a considerable degree and a K-S test fails to reject the hypothesis that the two samples could be drawn from the same underlying distribution (the probability P is at $\sim 1\sigma$, see Table 1). However, the median values are indeed somewhat different, and the trend is the same as that found by Shapley et al. (2003), given that the LBG_L are bluer on average than the LBG_N . The difference between our two samples ($\Delta\beta \sim 0.3$) is actually similar to that found by Shapley et al. (2003), who report $\Delta\beta = 0.36$ between their more extreme groups, i.e. the strong emitters and the strong absorbers (see Table 3 of the paper mentioned), but the significance of their $\Delta\beta$ is higher, given that they have a much larger sample with 800 objects in total. Consequently, the uncertainties on the average β values are much lower than in our case. In conclusion, although we cannot claim such a strong dependence of β on the Ly α properties, we do indeed find a mild indication that LBG_L are bluer than LBG_N . To support this result, a similar difference is also found for LBG galaxies by Vanzella et al. (2006), who performed spectroscopy on B dropouts from the GOODS sample, and then, stacking the spectra of galaxies with Ly α in emission and in absorption separately, found that the former have a systematically bluer UV continuum than the latter.

We find no evidence for a slope-magnitude relation as found by some other authors (e.g. Overzier et al. 2006), but the errors on the slope are quite large and the wavelength baseline for the slopes is rather small.

In Fig. 2 we show the $z - [3.6]$ color plotted versus the total [3.6] magnitude: this color encompasses the 4000 Å/Balmer breaks and is sensitive both to dust and stellar ages. The [3.6] magnitude corresponds to a rest-frame optical magnitude. The strong correlation between the optical flux and color is due to the magnitude cut at $z = 26$ that was used for the sample (see dotted line). It is clear from the figure that the LBG_N are on average

**Fig. 2.** The $z - [3.6]$ color plotted vs. observed flux in [3.6]. Squares are the LBG_L and plus signs are the LBG_N .

both brighter (by ~ 0.7 mag) at restframe optical wavelengths and redder (by more than half a magnitude) than the LBG_L . Given that all objects are relatively dust free (as inferred from the UV spectral slopes and consistently with the Lyman Break selection criteria), these differences indicate that the LBG_N feature a more evolved stellar population in general and are more massive. We will derive the physical properties in the next section.

3. Physical properties

3.1. Method

Using the multiwavelength GOODS-MUSIC data and the spectroscopic redshifts, we then determined the physical properties of these galaxies, through a spectral fitting technique. The spectral fitting technique adopted here is the same that has been developed in previous papers (Fontana et al. 2003, 2006), and similar to those adopted by other groups in the literature (e.g. Dickinson et al. 2003; Drory et al. 2004). Briefly, it is based on a comparison between the observed multicolor distribution of each object and a set of templates, computed with standard spectral synthesis models (Bruzual & Charlot 2003, in our case), chosen to broadly encompass the variety of star-formation histories, metallicities and extinction of real galaxies. For purposes of comparison with previous research, we used the Salpeter IMF, ranging over a set of metallicities (from $Z = 0.02 Z_\odot$ to $Z = 2.5 Z_\odot$) and dust extinction ($0 < E(B - V) < 1.1$, with a Calzetti or a Small Magellanic Cloud extinction curve). Details are given in Table 1 of Fontana et al. (2004). For each model of this grid, we computed the expected magnitudes in our filter set, and found the best-fitting template with a standard χ^2 minimization. The stellar mass and other best-fit parameters of the galaxy, such as SFR estimated from the UV luminosity and corrected for dust obscuration (with a typical correction factor of $A_V \sim 0.4$), age, τ (the star formation e -folding timescale), metallicity and dust extinction, are fitted simultaneously to the actual SED of the observed galaxy. The derivation of these parameters is explained in detail in the above paper and in Fontana et al. (2006), where the uncertainties are also discussed. In particular, we note here that the stellar mass generally turns out to be the least sensitive to variations in input model assumptions, and the extension of the SEDs to the IRAC mid-IR data tends to reduce considerably the formal uncertainties on the derived

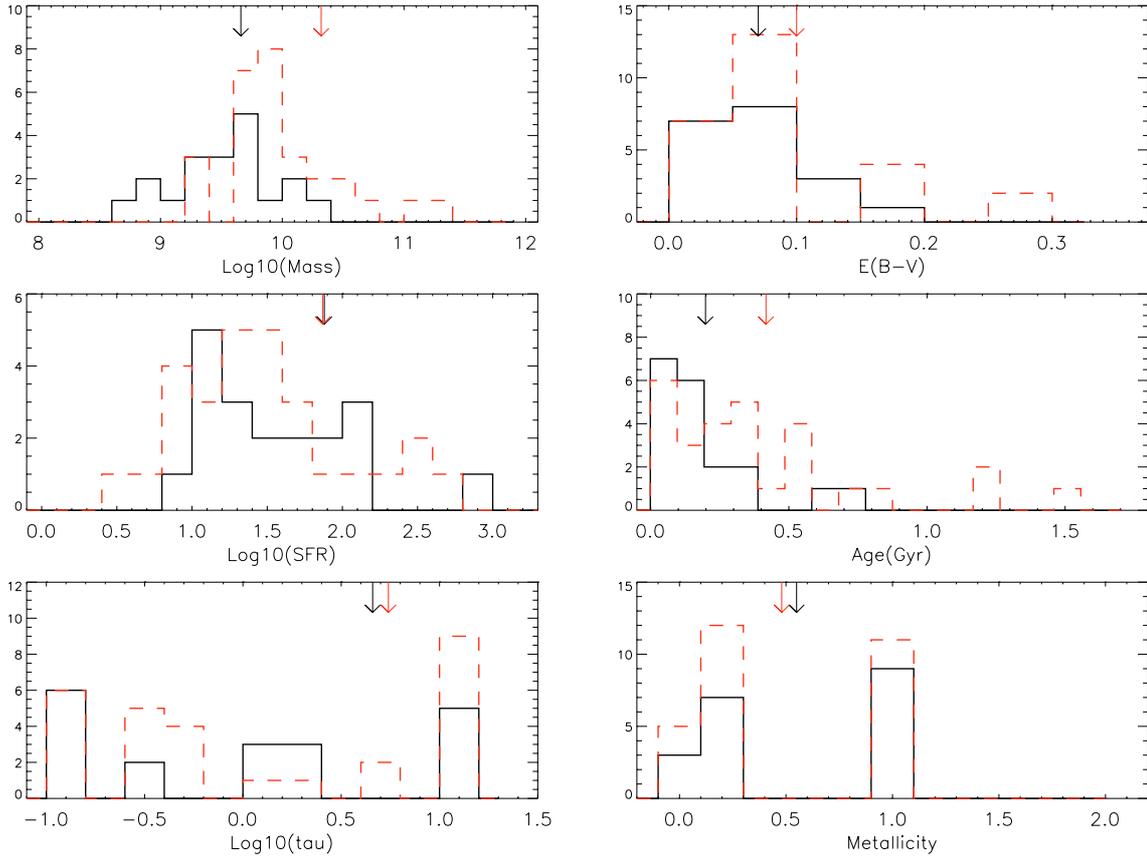


Fig. 3. The physical properties of B and V -dropouts. *Top left:* distribution of total stellar mass; *top right* the extinction parameter $E(B - V)$ derived from the spectral fitting; *middle left* the total star formation rate derived from the spectral fitting; *middle right:* stellar ages; *bottom left:* τ the star formation e-folding time-scale; *bottom right:* the metallicity. Solid black and dashed light histograms denote LBG_L and LBG_N respectively. The black and light arrows indicate the mean values of each sample.

stellar masses. On the other hand, the physical parameter with highest associated uncertainty is the metallicity, given that the models are strongly degenerate when fitting broad-band SEDs; a further limitation is that only four values were allowed in the modelling, namely 0.02, 0.2, 1 and 2.5 (subsolar, solar and supersolar metallicity, respectively), but in our samples none of the galaxies turned out to have a metallicity of 2.5.

3.2. Results

In Fig. 3 we plot the distribution of the four basic physical parameters for the two samples, namely the total stellar mass, the star formation rate, the derived stellar age and the $E(B - V)$. In each figure the average values calculated for each sample are also indicated by an arrow.

Both the total stellar masses and the median ages are considerably lower for the LBG_L compared with the LBG_N . The average mass is $(5.0 \pm 1) \times 10^9 M_\odot$ for the LBG_L and $(2.3 \pm 0.8) \times 10^{10} M_\odot$ for the others, i.e. a factor of almost five higher. The K-S test gives a very low value, implying that the two populations are different from each other with $>99.8\%$ probability. We can therefore conclude that the LBG_L are less massive than the LBG_N by a factor of almost 5.

The median ages are also quite different, with an average of 200 ± 50 Myr for the LBG_L , an age distribution that is very peaked towards low age values and is basically confined to values below 300 Myr. The LBG_N on the other hand have an average age of 410 ± 70 Myr (older by a factor of more than 2) and

there are several galaxies with ages exceeding 1 Gyr, which is a considerable fraction of the cosmic time at redshift ~ 4 . Again performing a K-S test, the two populations are different with a probability $>98\%$. We can conclude that the LBG_L are significantly younger galaxies than the LBG_N .

The star formation rates do not differ much for the two samples, with median values that are almost equal, $\langle SFR \rangle = 76 \pm 34 M_\odot \text{ yr}^{-1}$ and $74 \pm 22 M_\odot \text{ yr}^{-1}$ respectively, and very similar distributions. The extinction values are slightly higher for the LBG_N , with $\langle E(B - V) \rangle = 0.10 \pm 0.02$, while the LBG_L have $\langle E(B - V) \rangle = 0.07 \pm 0.01$. In both cases the K-S test does not reject the hypothesis that the two groups are drawn from the same population of galaxies, although the average $E(B - V)$ is higher for the LBG_N . Consequently, both LBG_L and LBG_N are galaxies with relatively little dust content, and significant star formation rates. In particular the average $E(B - V)$ is quite a bit lower than the average values found by Shapley et al. (2003) at redshift ~ 3 and Ouchi et al. (2004) at redshift ~ 4 , but we find the same tendency for LBG_N to have somewhat higher dust content than LBG_L , which is also supported by the difference in the UV spectral slopes discussed in the previous section.

The final two physical parameters that emerge from the modelling are metallicity, and τ i.e. the star formation e-folding timescale. Each of them suffers from larger uncertainties as compared to the total stellar mass for example, as mentioned earlier. The mean values and the overall distributions for these two parameters are both very similar for LBG_N and LBG_L , with the K-S test indicating that they are drawn from the same population. A more interesting and better constrained quantity to

determine is the age/τ parameter that is an indication of the evolutionary state of the galaxies. It can be shown that passively evolving galaxies can be selected according to the physical criterion $age/\tau \geq 4$ (Grazian et al. 2006). All galaxies in our sample, both LBG_N and LBG_L , have $age/\tau \leq 4$ as expected: however the difference in age discussed before is reflected also in the difference in age/τ , which is relatively larger for LBG_N with a mean value of $\langle age/\tau \rangle_{LBG_N} = 0.99$ while, for LBG_L , the mean value is 0.33. Furthermore, all but one LBG_L have $age/\tau \leq 1$ whereas amongst LBG_N there are seven objects with values between 1 and 4.

From this data we conclude that the LBG_L seem to be a population of younger and less massive galaxies. Given that all galaxies have relatively low dust content, there are some indications that LBG_L might be relatively less dusty than LBG_N in general, based on the results presented here and by other authors (Vanzella et al. 2006; Shapley et al. 2003 and Overzier et al. 2006). The star formation rates are high in all cases and are independent of the nature of the Ly α emission.

4. Discussion and conclusions

The results obtained here seem to point towards a scenario where LBG_L are young and relatively small galaxies compared to the general LBGs population, are basically unobscured and are forming stars at very high rates. LBG_N on the other hand, are more massive, with masses as high as $10^{11} M_\odot$, and span a larger range of ages from a few tens of Myrs to more than 1 Gyr. They are forming stars at comparable rates and are also relatively unobscured galaxies, although they appear slightly redder than LBG_L . This is therefore partially at variance with the only comparable large study, carried out at redshift ~ 3 by Shapley et al. (2003), who found a tendency for LBG_L to be older in general, have lower values of $E(B - V)$ and higher star formation rates. A very similar work by Iwata et al. (2005) on $z \sim 3$ LBGs from the Hubble Deep Field-South, also examined the relationship between spectroscopic features and parameters of the best-fit stellar population models in a sample of spectroscopically confirmed galaxies. They did not find any clear correlation between the Ly α emission, Ly α equivalent widths and the results of SED fitting. However, the absence of any clear trend may be attributed to the very small number of sample galaxies in their study (13 in total).

Some other observational studies seem to support our results: for example Overzier et al. (2006) find similar trends for a small sample of LBGs and LAEe in a $z = 4.1$ protocluster, with indications that LAEe are young, dust-free objects with blue UV optical colors and possibly less massive than UV-selected LBGs with comparable star formation rates.

At higher redshift, Lai et al. (2006) constrained the ages of Ly α emitters at redshift 5 and found typical ages of 50–100 Myr, i.e. comparable with our LBG_L . Lastly, at redshift 3, Gawiser et al. (2006) analyzed a sample of narrow-band selected Ly α emitters at $z \sim 3$ and concluded that they appear to have much less dust and lower stellar masses, compared to the generic LBG population at the same redshift. They were not able to constrain ages, which had a large range of allowed values. However, given that they started from a narrow band-sample, their objects are in general much fainter than the general LBGs population at the same redshift and clearly they are not selected to have the same broad-band optical colors as the LBGs at the same redshift. In our case the optical colors and absolute restframe UV luminosity of the LBG_N and LBG_L are equal.

Our results lend support to models that consider the Ly α emitters as precursors of spheroid galaxies, observed during the initial starburst phase, which is confined to a short period after its onset, due to the rapid formation of dust. Interestingly, one such model (Thommes & Meisenheimer 2005) attempts to constrain the duration of this initial phase from observational data, finding $T_{Ly\alpha} \leq 350$ Myr. A very similar result was recently found by Mori & Umemura (2006) from simulation with an N body/hydrodynamics code: they followed the early stages of galaxy formation and found a first phase characterized by strong Ly α emission which, after 3×10^8 years, quickly declines to fluxes below the observable level. The ages found in these models are very similar to the range of allowed ages for our LBG_L , as shown in Figure 3. On the other hand, many of the LBG_N have ages exceeding 300 Myr. Clearly, there are also very few LBG_L with greater ages and, above all, there are several LBG_N which are very young, with ages of a few tens of Myrs. The first few outliers could be easily accounted for given that the physical parameters modelled are obviously subject to uncertainties. However, the very young LBG_N , i.e. primeval objects without Ly α emissions are hard to fit within the simple scenario proposed above. Probably, more complex models in which the time scales for dust formation in primeval galaxies is variable and depends on other factors need to be invoked. In this context, several scenarios have been proposed, for example where the differential attenuation of the Ly α and continuum photons depends on the clumpiness of the medium (e.g. Hansen & Oh 2006), or where the timescales for the Ly α emission varies for galaxies residing in halos of different sizes, in the sense that in the most massive halos the Ly α luminosity declines abruptly after a much shorter time (10^7 ys) than in less massive halos (Mao et al. 2006). However, a full discussion of these models is beyond the scope of this paper.

Finally, it also remains unclear whether the LBG_N are actually dustier than the LBG_L , which would be a natural consequence of this model: we do indeed find that LBG_L are slightly bluer than LBG_N (with the slope β determined directly from the observed colors) and consequently have, on average, a lower $E(B - V)$ parameter, as derived from the spectral fitting. However, the differences are not very large. An important independent check would be to assess the dust content, e.g. from far IR observations, rather than through the $E(B - V)$, which is subject to greater uncertainties and is strongly degenerate with the fitted age.

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