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The properties of Lyα emitting galaxies in hierarchical galaxy formation models

M. Le Delliou*, C. G. Lacey, C. M. Baugh and S. L. Morris
Institute for Computational Cosmology, Department of Physics, University of Durham, South Road, Durham, DH1 3LE, UK.

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ABSTRACT

We present detailed predictions for the properties of Lyα-emitting galaxies in the framework of the ΛCDM cosmology, calculated using the semi-analytical galaxy formation model `GALFORM`. We explore a model which assumes a top-heavy IMF in starbursts, and which has previously been shown to explain the sub-mm number counts and the luminosity function of Lyman-break galaxies at high redshift. We show that this model, with the simple assumption that a fixed fraction of Lyα photons escape from each galaxy, is remarkably successful at explaining the observed luminosity function of Lyα emitters over the redshift range $3 < z < 6.6$. We also examine the distribution of Lyα equivalent widths and the broad-band continuum magnitudes of emitters, which are in good agreement with the available observations. We look more deeply into the nature of Lyα emitters, presenting predictions for fundamental properties such as the stellar mass and radius of the emitting galaxy and the mass of the host dark matter halo. The model predicts that the clustering of Lyα emitters at high redshifts should be strongly biased relative to the dark matter, in agreement with observational estimates. We also present predictions for the luminosity function of Lyα emitters at $z > 7$, a redshift range which is starting to be be probed by near-IR surveys and using new instruments such as DAzLE.

Key words: galaxies:evolution – galaxies:formation – galaxies:high-redshift – galaxies:luminosity function – cosmology:theory

1 INTRODUCTION

After an unpromising start, searches for Lyα emission are now proving to be a powerful means of detecting star-forming galaxies at high redshift (e.g. Hu, Cowie & McMahon 1998; Pascarelle, Windhorst & Keel 1998; Kudritzki *et al.* 2000), competing in observing efficiency with techniques such as broad-band searches for Lyman-break galaxies. The next generation of near-infrared instrumentation (e.g. Horton *et al.* 2004) will in principle allow Lyα emitting galaxies to be found up to $z \sim 20$, permitting a probe of the star formation history of the Universe before the epoch when reionization is thought to have taken place.

There are in fact a number of different mechanisms which can produce Lyα emission from high redshift objects. (1) Gas in galaxies which is photo-ionized by young stars will emit Lyα as hydrogen atoms recombine; this was originally proposed as a signature of primeval galaxies by Partridge & Peebles (1967). (2) Gas can alternatively be ionized by radiation from an active galactic nucleus (AGN). (3) Intergalactic gas clouds are predicted to emit Lyα recombination radiation due to ionization of the gas by the intergalactic ultraviolet background (e.g. Hogan & Weymann 1987; Cantalupo *et al.* 2005). (4) Gas within a dark matter halo which is cooling and collapsing to form a galaxy may radiate much of the gravitational collapse energy by collisionally-excited Lyα emission (e.g. Haiman, Spaans & Quataert 2000; Fardal *et al.* 2001). (5) Finally, Lyα can also be emitted from gas which has been shock heated by galactic winds or by jets in radio galaxies (e.g. McCarthy *et al.* 1987). The majority of high-redshift Lyα emitters (LAEs) detected so far are compact, and appear to be individual galaxies in which the Lyα emission is powered by photoionization of gas by young stars. Lyα surveys have also found another class of emitter, the so-called Lyα blobs, in which the Lyα emission is much more extended than individual galaxies, and may be powered partly by AGNs or gas cooling (Steidel *et al.* 2000; Bower *et al.* 2004; Matsuda *et al.* 2004). We will be focusing in this paper on Lyα emission powered by young stars, and so will not consider the Lyα blobs further.

To date, there has been relatively little theoretical work on trying to predict the properties of star-forming Lyα-emitting galaxies within a realistic galaxy formation framework. Haiman & Spaans (1999) made predictions for the number of emitters based on the halo mass function and using ad-hoc assumptions linking Lyα emission to halo mass, while Barton *et al.* (2004) made predictions for very high redshifts ($z > 7$) based on a gas-dynamical simulation. Furlanetto *et al.* (2005) used gas-dynamical simulations to calculate Lyα emission both from star-forming objects and from

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* E-mail: delliou@alfmail.cii.fc.ul.pt (MLeD)

the intergalactic medium in the redshift range $0 < z < 5$. However, the first calculation of the abundance of Lyα emitters based on a detailed hierarchical galaxy formation model was that of Le Delliou *et al.* (2005, hereafter Paper I). In Paper I, we used the `GALFORM` semi-analytical galaxy formation model to predict the abundance of star-forming Lyα emitters as a function of redshift in the cold dark matter (CDM) model. The `GALFORM` model computes the assembly of dark matter halos by mergers, and the growth of galaxies both by cooling of gas in halos and by galaxy mergers. It calculates the star formation history of each galaxy, including both quiescent star formation in galaxy disks and also bursts triggered by galaxy mergers, as well as the feedback effects of galactic winds driven by supernova explosions. In Paper I, we found that a very simple model, in which a fixed fraction of Lyα photons escape from each galaxy, regardless of its other properties, gave a surprisingly good match to the total numbers of Lyα emitters detected in different surveys over a range of redshifts. We also explored the impact of varying certain parameters in the model, such as the redshift of reionization of the intergalactic medium, on the abundance of emitters.

In this paper, we explore in more detail the fiducial model of Paper I (based on an $\Omega_m = 0.3$, spatially flat, ΛCDM model with a reionization redshift of 10). We use the full capability of the `GALFORM` model to predict a wide range of galaxy properties, connecting various observables to Lyα emission. The galaxy formation model we use is the same as that proposed by Baugh *et al.* (2005). A critical assumption of this model is that stars formed in starbursts have a top-heavy initial mass function (IMF), while stars formed quiescently in galactic disks have a solar neighbourhood IMF. We showed in Baugh *et al.* that, within the framework of ΛCDM, the top-heavy IMF is essential for matching the counts and redshifts of sub-millimetre galaxies and the luminosity function of Lyman break galaxies at $z = 3$ (once dust extinction is included), while remaining consistent with galaxy properties in the local universe such as the optical and far-IR luminosity functions and galaxy gas fractions and metallicities. More detailed comparisons of this model with observations of Lyman-break galaxies and of galaxy evolution in the IR will be presented in Lacey *et al.* (2005a, 2005b, in preparation). The assumption of a top-heavy IMF is controversial, but underpins the success of the model in explaining the high-redshift sub-mm and Lyman-break galaxies. It is therefore important to test this model against as many observables as possible. Nagashima *et al.* (2005a) showed that a top-heavy IMF seems to be required to explain the metal content of the hot intracluster gas in galaxy clusters, and Nagashima *et al.* (2005b) showed that a similar top-heavy IMF also seems to be necessary to explain the observed abundances of α-elements (such as Mg) in the stellar populations of elliptical galaxies. In the present paper, we explore the predictions of the Baugh *et al.* (2005) model for the properties of Lyα-emitting galaxies and compare them with observational data. We emphasize that our aim here is to explore in detail a particular galaxy formation model which has been shown to satisfy a wide range of other observational constraints, rather than to conduct a survey of Lyα predictions for different model parameters.

In Section 2, we give an outline of the `GALFORM` model, focusing on how the predictions we present later on are calculated. Section 3 examines the evolution of the Lyα luminosity function, and compares the model predictions with observational data over the redshift range $3 \lesssim z \lesssim 7$. In Section **??**, we compare a selection of observed properties of Lyα emitters with the model predictions. In Section **??**, we look at some other predictions of the model, most of which cannot currently be compared directly with observations. Section **??** extends the predictions for the Lyα luminosity function to $z > 7$. We present our conclusions in Section **??** .

2 GALAXY FORMATION MODEL

We use the semi-analytical model of galaxy formation, `GALFORM`, to predict the Lyα emission and many other properties of galaxies as a function of redshift. The general methodology and approximations behind the `GALFORM` model are set out in detail in Cole *et al.* (2000). The particular model that we use in this paper is the same as that described by Baugh *et al.* (2005). The background cosmology is a cold dark matter universe with a cosmological constant ($\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$, $\Omega_b = 0.04$, $h \equiv H_0/100\mathrm{km\,s^{-1}Mpc^{-1}} = 0.7$, $\sigma_8 = 0.93$). Below we review the physics behind the particular model predictions that we highlight in this paper.

The `GALFORM` model follows the main processes which shape the formation and evolution of galaxies. These include: (i) the collapse and merging of dark matter halos; (ii) the shock-heating and radiative cooling of gas inside dark halos, leading to formation of galaxy disks; (iii) quiescent star formation in galaxy disks; (iv) feedback both from supernova explosions and from photo-ionization of the IGM; (v) chemical enrichment of the stars and gas; (vi) galaxy mergers driven by dynamical friction within common dark matter halos, leading to formation of stellar spheroids, and also triggering bursts of star formation. The end product of the calculations is a prediction of the number of galaxies that reside within dark matter haloes of different masses. The model predicts the stellar and cold gas masses of the galaxies, along with their star formation and merger histories, and their sizes and metallicities.

The prescriptions and parameters for the different processes which we use in this paper are identical to Baugh *et al.* (2005). Feedback is treated in a similar way to Benson *et al.* (2003): energy injection by supernovae reheats some of the gas in galaxies and returns it to the halo, but also ejects some gas from halos as a "superwind" - the latter is essential for reproducing the observed cutoff at the bright end of the present-day galaxy luminosity function. We also include feedback from photo-ionization of the IGM: following reionization (i.e. for $z < z_{\mathrm{reion}}$), we assume that gas cooling in halos with circular velocities $V_c < 60\,\mathrm{km\,s^{-1}}$ is completely suppressed. We assume in this paper that reionization occurs at $z_{\mathrm{reion}} = 10$, chosen to be intermediate between the low value $z \sim 6$ suggested by measurements of the Gunn-Peterson trough in quasars (Becker *et al.* 2001) and the high value $z \sim 20$ suggested by the WMAP measurement of polarization of the microwave background (Kogut *et al.* 2003). Our model has two different IMFs: quiescent star formation in galactic disks is assumed to produce stars with a solar neighbourhood IMF (we use the Kennicutt (1983) paramerization, with slope $x = 0.4$ below $1M_\odot$ and $x = 1.5$ above), whereas bursts of star formation triggered by galaxy mergers are assumed to form stars with a top-heavy, flat IMF with slope $x = 0$ (where the Salpeter slope is $x = 1.35$). In either case, the IMF covers the mass range $0.15 < m < 120M_\odot$. As mentioned in the Introduction, the choice of a flat IMF in bursts is essential for the model to reproduce the observed counts of galaxies at sub-mm wavelengths. The parameters for star formation in disks and for triggering bursts and morphological transformations in galaxy mergers are given in Baugh *et al.* (2005).

The sizes of galaxies are computed as in Cole *et al.* (2000): gas which cools in a halo is assumed to conserve its angular momentum as it collapses, forming a rotationally-supported galaxy disk; the radius of this disk is then calculated from its angular momentum, including the gravity of the disk, spheroid (if any) and dark halo. Galaxy spheroids are built up both from pre-existing stars in galaxy mergers, and from the stars formed in bursts triggered by these mergers; the radii of spheroids formed in mergers are computed using an energy conservation argument. In calculating the sizes of disks and spheroids, we include the adiabatic contraction of the dark halo due to the gravity of the baryonic components.

Given the star formation and metal enrichment history of a galaxy, `GALFORM` computes the spectrum of the integrated stellar population using a population synthesis model based on the Padova stellar evolution tracks (see Granato *et al.* 2000, for details). Broadband magnitudes are then computed by redshifting the galaxy spectrum and convolving it with the filter response functions. We include extinction of the stellar continuum by dust in the galaxy; this is computed based on a two-phase model of the dust distribution, in which stars are born inside giant molecular clouds and then leak out into a diffuse dust medium (see Granato *et al.* 2000, for more details). The optical depth for dust extinction of the diffuse component is calculated from the mass and metallicity of the cold gas and the sizes of the disk and bulge. We note that the extinction predicted by our model in which the stars and dust are mixed together is very different from what one obtains if all of the dust is in a foreground screen (as is commonly assumed in other theoretical models). Finally, we also include the effects on the observed stellar continuum of absorption and scattering of radiation by intervening neutral hydrogen along the line of sight to the galaxy; we calculate this IGM attenuation using the formula of Madau (1995), which is based on the observed statistics of neutral hydrogen absorbers seen in quasar spectra.

We compute the Lyα luminosities of galaxies by the following procedure: (i) The model calculates the integrated stellar spectrum of the galaxy as described above, based on its star formation history, and including the effects of the distribution of stellar metallicities and of variations in the IMF. (ii) We compute the rate of production of Lyman continuum (Lyc) photons by integrating over the stellar spectrum, and assume that all of these ionizing photons are absorbed by neutral hydrogen within the galaxy. We assume photoionization equilibrium applies within each galaxy, producing Lyα photons according to case B recombination (e.g. Osterbrock 1989). We note that for solar metallicity, 11 times as many Lyc and Lyα photons are produced per unit mass of stars formed for our top-heavy (burst) IMF as compared to our solar neighbourhood (disk) IMF. (iii) The observed Lyα flux or luminosity of a galaxy depends on the fraction $f_{\rm esc}$ of Lyα photons which escape from the galaxy. Lyα photons are resonantly scattered by neutral hydrogen, and absorbed by dust. Early estimates of this process (e.g. Charlot & Fall 1991) showed that only a tiny fraction of Lyα photons should escape from a static neutral galaxy ISM if even a tiny amount of dust is present. Many star-forming galaxies are nonetheless observed to have significant Lyα luminosities (e.g. Kunth *et al.* 1998; Pettini *et al.* 2001), and this is generally ascribed to the presence of galactic winds in these systems, which allow Lyα photons to escape after many fewer resonant scatterings. Radiative transfer calculations of Lyα through winds have shown that this process can explain the asymmetric Lyα line profiles which are typically observed (e.g. Ahn 2004). The effects of radiative transfer of Lyα through clumpy dust and gas have been considered by Neufeld (1991) and Hansen & Oh (2005).

Calculating Lyα escape fractions from first principles is clearly very complicated, and so we instead adopt a simpler approach. In Paper I, we found that assuming a fixed escape fraction $f_{\rm esc}$ for each galaxy, regardless of its dust properties, resulted in a surprisingly good agreement between the predicted number counts of emitters and the available observations. In that paper, we chose $f_{\rm esc} = 0.02$ to match the number counts at $z \approx 3$ at a flux $f \approx 2\times10^{-17}{\rm erg\,s^{-1}}$, and we use the same value of $f_{\rm esc}$ in this paper. Although this extreme simplification of a constant escape fraction may seem implausible, it does give a reasonably good match to the observed Lyα luminosity functions and equivalent widths at different redshifts, as we show in the next sections.

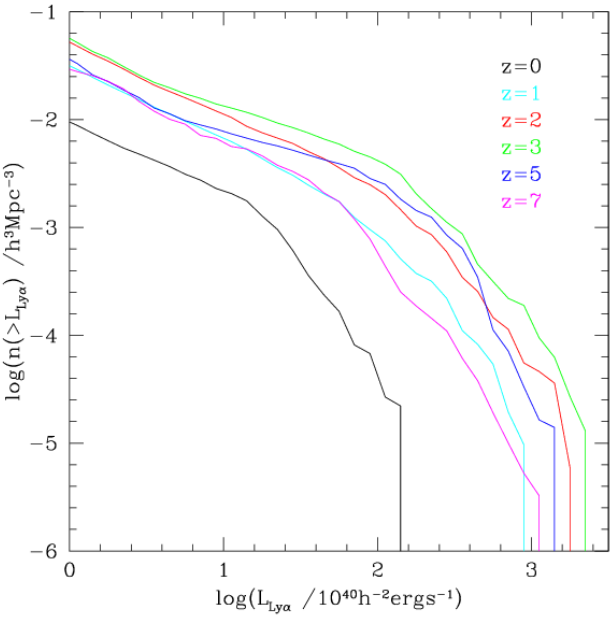

Figure 1. The predicted evolution with redshift of the cumulative Lyα luminosity function, defined as the comoving number density of galaxies with Lyα luminosities brighter than $L_{Ly\alpha}$. The model predictions are shown for selected redshifts in the interval $z = 0$ to $z = 7$.

Our calculations do not include any attenuation of the Lyα flux from a galaxy by propagation through the IGM. Lyα photons can be scattered out of the line-of-sight by any neutral hydrogen in the IGM close to the galaxy. If the emitting galaxy is at a redshift before reionization, when the IGM was still mostly neutral, this could in principle strongly suppress the observed Lyα flux (Miralda-Escude 1998). However, various effects can greatly reduce the amount of attenuation: ionization of the IGM around the galaxy (Madau & Rees 2000; Haiman 2002), clearing of the IGM by galactic winds, gravitational infall of the IGM towards the galaxy, and redshifting of the Lyα emission by scattering in a wind (Santos 2004). In any case, since measurements of Gunn-Peterson absorption in quasars show that reionization must have occured at $z \gtrsim 6.5$, attenuation of Lyα fluxes by the IGM should not affect our predictions for $z \lesssim 6.5$, but only our predictions for very high redshifts given in Section **??**.

3 EVOLUTION OF THE LYα LUMINOSITY FUNCTION

A basic prediction of our model is the evolution of the luminosity function of Lyα emitters with redshift. This depends on the distribution of star formation rates in quiescent and starburst galaxies (with solar neighbourhood and top-heavy IMFs respectively), and on the metallicity with which the stars are formed. Paper I showed predictions for the cumulative number counts of emitters per unit redshift as a function of observed Lyα flux. Here we focus on a closely related quantity, the cumulative space density of emitters as a function of Lyα luminosity at different redshifts. Fig.1 shows the cumulative luminosity function of Lyα emitters predicted by our standard model for a set of redshifts over the interval $z = 0-7$. The model luminosity function initially gets brighter with increasing redshift, peaking at $z = 3$, before declining again in number density at even higher redshifts. The increase in the luminosity function from $z = 0$ to $z \sim 3$ is driven both by the increase in galaxy star formation rates, and by the increasing fraction of star formation occuring in bursts (which have a top-heavy IMF). As shown in Fig.1 in Baugh *et al.* (2005), the model predicts that the fraction of all star formation occuring in bursts increases from $\sim 5\%$ at $z = 0$ to 50% at $z \sim 3.5$ and then to $\sim 80\%$ at $z \gtrsim 6$.

Some data are given in Table 1:

REFERENCES

Ahn, S.-H., 2004, ApJ, 601, L25

Ajiki, M., Taniguchi, Y., Fujita, S.S., Shioya, Y., Nagao, T., Murayama, T., Yamada, S., Umeda, K., & Komiyama, Y., 2003, AJ, 126, 2091

Barton, E.J., Dave, R., Smith, J-D.T., Papovich, C. Hernquist, L. Springel, V., 2004, ApJ 604, L1

Baugh C.M., Lacey C.G., Frenk C.S., Granato G.L., Silva L., Bressan A., Benson A.J., & Cole S., 2005, MNRAS, 356, 1191

Becker R.H., Fan, X., White, R.L., Strauss, M.A., Narayanan, V.K., Lupton, R.H., Gunn, J.E., Annis, J., Bahcall, N.A., Brinkmann, J., and 20 coauthors, 2001, AJ, 122, 2850.

Benson, A.J., Lacey, C.G., Frenk, C.S., Baugh, C.M., Cole, S., 2002, MNRAS 333, 156

Benson, A.J., Bower, R.G., Frenk, C.S., Lacey, C.G., Baugh, C.M., Cole, S., 2003, ApJ 599, 38

Bower, R. G., Morris, S. L., Bacon, R., Wilman, R. J., Sullivan, M., Chapman, S., Davies, R. L., de Zeeuw, P. T., Emsellem, E., 2004, MNRAS, 351, 63

Cantalupo, S., Porciani, C., Lilly, S., Miniati, F., 2005, ApJ 628, 61

Charlot, S., Fall, S.M., 1991, ApJ 378, 471

Charlot, S., Fall, S.M., 1993, ApJ 415, 580

Cole S., Lacey C.G., Baugh C.M., Frenk C.S., 2000, MNRAS, 319, 168.

Cowie L.L., Hu E.M., 1998, AJ, 115, 1319.

Dawson, S., Rhoads, J.E., Malhotra, S., Stern, D., Dey, A., Spinrad, H., Jannuzi, B.T., Wang, J., Landes, E., 2004, ApJ 617, 707

Ellis, R., Santos, M.R., Kneib, J.-P., Kuijken, K., 2001, ApJ, 560, L119

Fardal, M.A., Katz, N., Gardner, J., Hernquist, L., Weinberg, D.H., Dave, R., 2001, ApJ 562, 605

Furlanetto, S.R., Hernquist, L., Zaldarriaga, M., 2004, MNRAS 354, 695

Furlanetto, S.R., Schaye, J., Springel, V., Hernquist, L., 2005, ApJ, 622, 7

Gnedin, N.Y., Prada, F., 2004, ApJ 608, L77

Granato, G.L., Lacey C.G., Silva, L., Bressan, A., Baugh C.M., Cole S., Frenk C.S., 2000, ApJ 542, 710

Haiman, Z., 2002, ApJ 576, L1

Haiman, Z., Spaans, M., 1999, ApJ, 518, 138

Haiman, Z., Spaans, M., Quataert, E., 2000, ApJ, 537, L5

Hamana, T., Ouchi, M., Shimasaku, K., Kayo, I., Suto, Y., 2004, MNRAS 347, 813

Hansen, M., Oh, S.P., 2005, submitted to MNRAS (astro-ph/0507586)

Hogan, C.J., Weymann, R.J, 1987, MNRAS, 225, 1P

Horton, A., Parry, I.R., Bland-Hawthorn, J.. Cianci, S., King, D, McMahon, R., Medlen, S., 2004, Proceedings of SPIE Vol. 5492, “Ground-based Instrumentation for Astronomy”, 1022 (astro-ph/0409080)

Hu E.M., Cowie L.L., McMahon R.G., 1998, ApJ, 502, L99.

Hu, E. M., Cowie, L. L., Capak, P., McMahon, R. G., Hayashino, T., & Komiyama, 2004, AJ, 127, 563

Kennicutt R.C., 1983, ApJ, 272, 54.

Kogut A., *et al.* (the WMAP team), 2003, ApJS, 148, 161.

Kudritzki, R.-P., Mendez, R. H., Feldmeier, J. J., Ciardullo, R., Jacoby, G. H., Freeman, K. C., Arnaboldi, M., Capaccioli, M., Gerhard, O., Ford, H. C., 2000ApJ, 536, 19

Kunth, D., Mas-Hesse, J.M., Terlevich, E., Terlevich, R., Lequeux, J., Fall, S.M., 1998, A&A, 334, 11

Le Delliou, M., Lacey, C., Baugh, C.M., Guiderdoni, B., Bacon, R., Courtois, H., Sousbie, T., & Morris, S.L., 2005, MNRAS, 357, L11 (Paper I)

Madau, P., 1995, ApJ 441, 18

Madau, P., Rees, M.J., 1995, ApJ 542, L69

Maier, C., Meisenheimer, K., Thommes, E., Hippelein, H., Roser, H. J., Fried, J., von Kuhlmann, B., Phleps, S., Wolf, C., 2003, A&A, 402, 79 (CADIS)

Mas-Hesse, J.M., Kunth, D., Tenorio-Tagle, G., Leitherer, C., Terlevich, R., Terlevich, E., 2003, ApJ 598, 858

Matsuda, Y., Yamada, T., Hayashino, T., Tamura, H., Yamauchi, R., Ajiki, M., Fujita, S.S., Murayama, T., Nagao, T., Ohta, K., and 5 coauthors, 2004, AJ 128, 569

McCarthy, P.J., Spinrad, H., Djorgovski, S., Strauss, M.A., van Breugel, W., Liebert, J., 1987, ApJ 319, L39

Miralda-Escude, J., 1998, ApJ 501, 15

Nagashima, M., Lacey, C.G., Baugh, C.M., Frenk, C.S., Cole, S., 2005, MNRAS 358, 1247

Nagashima, M., Lacey, C.G., Okamoto, T., Baugh, C.M., Frenk, C.S., Cole, S., 2005, MNRAS, 363, L31

Neufeld, D.A., 1991, ApJ 370, L85

Osterbrock D.E., 1989, *Astrophysics of Gaseous Nebulae and Active Galactic Nuclei*, University Science Books

Ouchi, M., Shimazaku, K., Furusawa, H., Miyasaki, M., Doi, M., Hamabe, M., Hayashino, T., Kimura, M., Kodaira, K., & Komiyama, Y., and 10 coauthors, 2003, ApJ, 582, 60

Ouchi, M., Shimazaku, K., Akiyama, M., Sekiguchi, K., Furusawa, H., Okamura, S., Kashikawa, N., Iye, M., Kodama, T., Saito, T., and 7 coauthors, 2005, ApJ 620, L1

Papovich, C., Dickinson, M., Ferguson, H.C., 2001, ApJ 559, 620

Partridge, R.B., Peebles, P.J.E., 1967, ApJ, 147, 868.

Pascarelle, S.M., Windhorst, R.A., Keel, W.C., 1998, AJ 116, 2659

Pettini M., Steidel C.C., Adelberger K.L., Dickinson M., Giavalisco M., 2001, ApJ, 528, 96.

Rhoads, J.E., Dey, A., Malhotra, S., Stern, D., Spinrad, H., Jannuzi, B.T., Dawson, S., Brown, M.J.I., Landes, E., 2003, AJ, 125, 1006 (LALA)

Santos, M.R., 2004, MNRAS 349, 1137

Santos, M.R., Ellis, R.S., Kneib, J.-P., Richard, J., Kuijken, K., 2004, ApJ 606, 683

Shapley, A.E., Steidel, C.C., Adelberger, K.L., Dickinson, M., Giavalisco, M. Pettini, M., 2001, ApJ 562, 95

(1) z	(2) Δz	(3) f	(4) $\frac{d^2N}{dzd\Omega}(>f)$	(5) $\Delta\left(\frac{d^2N}{dzd\Omega}\right)$	(6) Nobj	(7) Area	(8) Fcorr	(9) method	(10) confirmation	(11) ref.
2.42	0.14	20	0.33	0.04	58	1200	0.65	NBF	EW/colour	Sti01
3.09	0.07	2	2.3*	0.3	12*	78	0.94	NBF	EW/colour	Ste00
3.13	0.04	2	3.8	1.3	8	49	0.7	NBF	spec on 10	K00
3.43	0.06	1.5	3.5	0.9	16	75	0.87	NBF	spec on 15	H98
3.72	0.23	6.4	0.26	0.09	8	130	0.35	NBF	colours	F03
4.39	0.07	2.6	0.97	0.11	75	1100	0.33	NBF	spec on 3	R00
4.54	0.06	1.5	1.3	0.9	2	24	0.67	NBF	spec on 3	H98
4.79	0.08	0.5	0.46	0.07	41	1100	0.8	NBF	–	S04
4.86	0.06	0.5	0.52	0.09	34	1100	0.8	NBF	spec on 5	S03
4.86	0.06	0.3	1.6	0.2	52	540	0.6	NBF	colours	O03
5.1	1.0	0.012**	48**	48	1	0.02**	–	LS	–	Sa04
“	“	0.037**	30**	15	4	0.14**	–	“	–	“
“	“	0.12**	4.0**	2.3	3	0.75**	–	“	–	“
“	“	0.37**	0.89**	0.51	3	3.4**	–	“	–	“
“	“	1.2**	0.14**	0.14	1	7.5**	–	“	–	“
5.3	1.0	2?	2.3	1.0	5	2.2	–	LS	–	D01
5.7	0.13	1.5	0.14	0.04	13	710	0.75	NBF	spec on 4	R03
6.56	0.10	0.6**	20**	20	1	0.46**	1	NBF	spec on 1	H02
6.56	0.11	0.9	0.18	0.05	16	810	0.22	NBF	spec on 9	K03

Table 1. Data Compilation. The data are divided into unit redshift intervals: the following symbols are used to denote data from each redshift interval in the figures (■ :[$z<3$], ▼ :[$3<z<4$], ▲ :[$4<z<5$], ○:[$z=5.1$], ●:[$5<z<6$], **X**:[$6<z<7$]). **Col.1:** redshift; **Col.2:** redshift interval; **Col.3:** Ly-α flux (in 10^{-17}ergs cm^{-2}s^{-1}); **Col.4:** cumulative counts per unit solid angle per unit redshift (in arcmin^{-2}); **Col.5:** Poisson error on counts (in arcmin^{-2}); **Col.6:** number of Ly-α emitters; **Col.7:** area of survey (in arcmin^{2}); **Col.8:** factor applied to correct for contamination by low-z interlopers; **Col.9:** method (NBF=narrow band filter, LS=long-slit spectroscopy); **Col.10:** method used to reject or correct for low-z interlopers (EW=equivalent width, spec on N = follow-up spectroscopy of N objects); **Col.11:** reference (D01: Dawson *et al.* 2001; F03: Fujita *et al.* 2003; H98: Hu *et al.* 1998; H02: Hu *et al.* 2002; K03: Kodaira *et al.* 2003; K00: Kudritzki *et al.* 2000; O03: Ouchi *et al.* 2003; R00: Rhoads *et al.* 2000; R03: Rhoads *et al.* 2003; Sa04: Santos *et al.* 2004; S03: Shimasaku *et al.* 2003; S04: Shimasaku *et al.* 2004; Ste00: Steidel *et al.* 2000; Sti01: Stiavelli *et al.* 2001)

* corrected for factor 6 overdensity ** corrected for gravitational lensing

Shapley, A.E., Steidel, C.C., Pettini, M., Adelberger, K.L., 2003, ApJ 588, 65

Sheth, R.H., Mo, H.J., Tormen, G., 2001, MNRAS 323, 1

Shimasaku, K., Ouchi, M., Okamura, S., Kashikawa, N., Doi, M., Furusawa, H., Hamabe, M., Hayashino, T., Kawabata, K., Kimura, M., and 15 coauthors, 2003, ApJ, 586, L11

Shimasaku, K., Hayashino, T., Matsuda, Y., Ouchi, M., Ohta, K., Okamura, S., Tamura, H., Yamada, T., Yamauchi, R., 2004, ApJ 605, L93

Stanway, E.R., Bunker, A.J., McMahon, R.G., Ellis, R.S., Treu, T., McCarthy, P.J., 2004, ApJ, 607, 704

Stark, D.P., Ellis, R.S., 2005, submitted to New Astronomy (astro-ph/0508123)

Steidel, C.C., Adelberger, K.L., Shapley, A.E, Pettini, M., Dickinson, M., Giavalisco, M., 2000, ApJ, 532, 170

Taniguchi, Y., Ajiki, M., Nagao, T., Shioya, Y., Kashikawa, N., Kodaira, K., Kaifu, N., and 32 coauthors, 2005, PASJ, 57, 165

Tenorio-Tagle, G., Silich, S.A., Kunth, D., Terlevich, E., Terlevich, R., 1999, MNRAS 309, 332

Thommes, E., Meisenheimer, K, 2005, A&A 430, 877

Tran, K.-V., Lilly, S.J., Crampton, D., & Brodwin, M., 2004, ApJ, 612, L89

Willis, J.P., Courbin, F., 2005, MNRAS 357, 1348.

Willis, J.P., Courbin, F., Kneib, J.-P., Minniti, D., 2005, submitted to New Astronomy (astro-ph/0509600)

Wyithe, J.S.B., Loeb, A., 2005, ApJ 625, 1