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THE REST-FRAME ULTRAVIOLET LUMINOSITY DENSITY OF STAR-FORMING GALAXIES AT REDSHIFTS $z > 3.5$[1]

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ABSTRACT

We have measured the rest-frame $\lambda \sim 1500$ Å comoving specific luminosity density of star-forming galaxies at redshift $3.5 < z < 6.5$ (Lyman break galaxies [LBGs]) selected from deep, multiband images taken with the *Hubble Space Telescope* and the Advanced Camera for Surveys, obtained as part of the Great Observatories Origins Deep Survey (GOODS). The samples cover ∼0.09 deg^2 and are also relatively deep, reaching between $0.2L_3^*$ and $0.5L_3^*$, depending on the redshift, where L_3^* is the characteristic UV luminosity of LBGs at $z \sim 3$. The specific luminosity density appears to be nearly constant with redshift over the range $3 < z < 6$, although the measure at $z \sim 6$ remains relatively uncertain, because it depends on the accurate estimate of the faint counts of the $z \sim 6$ sample. If LBGs are fair tracers of the cosmic star formation activity, our results suggest that at $z \sim 6$, namely, at less than ∼7% of the current cosmic age, the universe was already producing stars as vigorously as it did near its maximum several gigayears later, at $1 \lesssim z \lesssim 3$.

Subject headings: cosmology: observations — galaxies: distances and redshifts — galaxies: evolution — galaxies: formation

On-line material: color figure

1. INTRODUCTION

The amount of star formation that took place early in the cosmic history and its evolution with redshift are key pieces of information to constrain theories of galaxy evolution. Evidence of the possible signature of the trailing edge of the cosmic reionization epoch at redshifts $z \gtrsim 6$ (e.g., Fan et al. 2002) has also renewed interest in measuring the star formation activity at these epochs, since starburst galaxies can contribute a significant fraction of the ionizing photons (Madau, Haardt, & Rees 1999; Haiman, Abel, & Madau 2001; Steidel, Pettini, & Adelberger 2001). Initial estimates based on the evolution of the cosmic H I mass density measured from damped Lyα absorption (DLA) systems (Fall, Charlot, & Pei 1996) and on direct measures of the observed UV radiation of relatively unobscured star-forming galaxies up to $z \sim 5$ (Madau et al. 1996) suggested that star formation activity peaked in the past at around $z \sim 1$ and then decreased at higher redshifts. However, subsequent measures based on the systematic spectroscopic identification of hundreds of Lyman break galaxies (LBGs) at $z \sim 3$ and ∼4 showed that the star formation density traced by these sources, after reaching a maximum value somewhere between $z \sim 1$ and ∼2, remains nearly constant up to the highest redshift observed with some confidence, i.e., $z \sim 4$ (Steidel et al. 1999, hereafter S99). Recent LBG samples at $z \leq 5$ from deep surveys with the Subaru telescope (Iwata et al. 2003) and with *Hubble Space Telescope* (*HST*; Bouwens et al. 2003) show very mild evolution at $z > 3$, although possible evidence to the contrary has also been reported (Stanway, Bunker, & McMahon 2003a; Stanway et al. 2003b). Measures based on photometric redshifts also show a nearly constant activity of star formation up to $z \sim 6$ (Thompson, Weymann, & Storrie-Lombardi 2001; Thompson 2003; Fontana et al. 2003; Kashikawa et al. 2003), with some even suggesting that it might actually increase with redshift (Lanzetta et al. 2002, hereafter L02).

Surveys of LBGs with *HST* are limited by the very small area, and thus cosmic volume, that they typically cover, which makes them prone to cosmic variance. For example, S99 argue that the original result by Madau et al. (1996), which was based on the Hubble Deep Field (HDF), was, at least in part, biased by cosmic fluctuations. Ground-based surveys cover a much larger area but at high redshifts are sensitive to only the bright end of the luminosity function. The expected characteristic magnitude of LBGs is $z_{850}^* \sim 26$ at $z = 6$, based on the Adelberger & Steidel (2000, hereafter AS00) UV luminosity function at $z = 3$, if no luminosity evolution occurs between $z \sim 3$ and ∼6. Thus, for redshifts $z > 4$, one needs to reach very faint flux limits to account for most of the light from LBGs.

The Great Observatories Origins Deep Survey/Advanced Camera for Surveys (GOODS/ACS) observations offer a good compromise, covering an area ∼33 times larger than the combined HDFs, with much deeper sensitivity out to wavelengths of nearly 1 μm than that of most ground-based samples. This makes it possible to detect galaxies with luminosity fainter than L_3^* up to $z \sim 6.5$. In this Letter we present measures of the comoving specific luminosity density over the range $3.5 \lesssim z \lesssim 6.5$ based on the stack of three epochs of observations (out of five) in the two GOODS fields. In a companion Letter by Dickinson et al. (2004, hereafter D04), we discuss in greater detail the selection of galaxies at $z \sim 6$, including the first spectroscopic identifications. Throughout, magnitudes are in the AB scale (Oke 1974), and the world model, when needed, is that of a flat universe with density parameters $\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$, and Hubble constant $H_0 = 70$ km s^{-1} Mpc^{-1}.

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2. DATA AND SAMPLE SELECTION

The data used in this letter are described in Giavalisco et al. (2004, hereafter G04). They consist of mosaics in the B_{435}, V_{606}, i_{775}, and z_{850} bands in both GOODS fields, covering a total area of 316 arcmin^2. Source catalogs were made using SExtractor, as described in G04. Source detection was done in the z_{850} band, and colors were measured in isophotal apertures defined in the z_{850} image. Apparent magnitudes are the SExtractor AUTO magnitudes.

Samples of LBGs were extracted from the catalogs using color criteria fine-tuned to the GOODS/ACS survey. Specifically, we have defined LBGs at $z \sim 4$ (B_{435}-band dropouts) using the color equations

$$(B_{450} - V_{606}) \geq 1.2 + 1.4 \times (V_{606} - z_{850}) \;\; \wedge$$
$$(B_{450} - V_{606}) \geq 1.2 \;\; \wedge \;\; (V_{606} - z_{850}) \leq 1.2,$$

and LBGs at $z \sim 5$ (V_{606}-band dropouts) by

$$[(V_{606} - i_{775}) > 1.5 + 0.9 \times (i_{775} - z_{850})] \;\; \vee$$
$$[(V_{606} - i_{775}) > 2.0] \;\; \wedge \;\; (V_{606} - i_{775}) \geq 1.2 \;\; \wedge$$
$$(i_{775} - z_{850}) \leq 1.3,$$

where $\vee$ and $\wedge$ are the logical "OR" and "AND" operators, respectively. Without a third band in the near-infrared, it is not possible to use a similar two-color selection to define samples of LBGs at $z \sim 6$. Instead, we have used the single-color threshold $(i_{775} - z_{850}) \geq 1.3$ to define our sample of $z \sim 6$ i_{775}-band dropouts. For bands that are entirely shortward of the Lyman discontinuity (the B_{435} for the V_{606}- and i_{775}-band dropouts and the V_{606} band for the i_{775}-band dropouts) we have also required a *nondetection* with signal-to-noise ratio (S/N) of less than 2. D04 discuss the selection and robustness of the $z \sim 6$ dropouts in detail, including the use of available near-IR photometry as an a posteriori test of the selection criteria.

We have included in the samples only galaxies with S/N ≥ 5 in the z_{850} band, and we have visually inspected each of them and removed sources that were deemed as either artifacts or spurious detections (estimated using counts of negative sources detected in the same data set). These amount to a negligible number for the B_{435} and V_{606} samples and ≈12% of the i_{775} dropout sample. We have also eliminated sources with stellar morphology down to $z_{850} \sim 26$, where such a classification is reliable, namely 3.1%, 8.3%, and 4.6% for the B_{435}, V_{606}, and i_{775} samples, respectively. While the procedure biases our samples against LBGs that are unresolved by the ACS, it prevents contamination by galactic stars. In practice, it results in negligible changes to the measured specific luminosity density. Furthermore, while the vast majority of galaxies at $z \ll 6$ have $i_{775} - z_{850} < 1.3$, photometric errors scatter some of these galaxies into our selection window. As a statistical correction, we measured the color distribution of a subsample of bright-field galaxies, for which the photometry is very accurate, and estimated the number of interlopers using photometric errors as a function of magnitude derived from Monte Carlo simulations (see D04).

Down to $z_{850} \leq 26.5$, roughly the 50% completeness flux limit for unresolved sources (see Fig. 4 of G04), the culled samples include 1115, 275, and 122 B_{435}-, V_{606}-, and i_{775}-band dropouts, respectively. With a survey area of 316 arcmin^2, this corresponds to surface density $\Sigma = 3.50 \pm 0.10$, 0.87 ± 0.05, and 0.39 ± 0.03 galaxies arcmin^{-2}, respectively, where the error bars are 1 σ Poisson fluctuations.

3. THE UV COMOVING SPECIFIC LUMINOSITY DENSITY

Lacking spectroscopic observations, we have used Monte Carlo simulations to estimate the redshift distribution function of the three samples. Artificial LBGs were distributed over the range $2.5 \leq z \leq 8$ with assumed distribution functions of UV luminosity, spectral energy distribution (SED), morphology, and size. We adjusted the input distribution functions of SED and size by requiring that the distributions recovered from the simulations match the observation at $z \sim 4$. In this way, both simulations and observations are subject to similar incompleteness, photometric errors in flux and color, blending, and other measurement errors. We have obtained the SED using the unobscured synthetic spectrum of a continuously star-forming galaxy with age of 10^8 yr, Salpeter initial mass function (IMF), and solar metallicity (Bruzual & Charlot 2003), and reddened it with the starburst extinction law (Calzetti 2001) and $E(B-V)$ randomly extracted from a Gaussian distribution with $\mu_{E(B-V)} = 0.15$ and $\sigma_{E(B-V)} = 0.15$. For the cosmic opacity, we have used the Madau (1995) prescription extrapolated to $z = 8$. We have used an equal number of $r^{1/4}$ and exponential profiles with random orientation and size-extracted from a log-normal distribution function, as described by Ferguson et al. (2004).

For a given dropout sample, the main output from the simulations is the probability function $p(M, z, m)$ that an LBG with absolute magnitude M at redshift z is observed as having apparent magnitude m. A commonly used technique to derive the specific luminosity density of LBGs is that of the "effective volume" (S99), where the spatial volume occupied by sample galaxies with apparent magnitude m is

$$V_{\rm eff}(m) = \int\int p(M, z, m)\, dM \frac{dV(z)}{dz}\, dz.$$

The comoving specific luminosity density contributed by such galaxies is then estimated as $d\mathcal{L}(m) = n(m)L(m, \bar{z})V_{\rm eff}^{-1}(m)\, dm$, where $\bar{z}$ is the average redshift of the simulated galaxies that have been selected into the sample, $n(m)$ are the number counts of real LBGs observed with magnitude m, and $L(m, \bar{z})$ is the specific luminosity of one such galaxy if placed at redshift $\bar{z}$. The specific luminosity density is then $\mathcal{L} = \int d\mathcal{L}(m)$. The method provides a relatively accurate estimate in the case of the color-color–selected B_{435}- and V_{606}-band dropouts, regardless of the assumptions about the UV luminosity distribution function used in the simulations, because these galaxies are selected only on the basis of their observed SED, i.e., redshift, with little dependence of their intrinsic luminosity. In other words, these LBGs have a relatively tight correlation of m and M up to the detection limit.

The $V_{\rm eff}$ method underestimates $\mathcal{L}$ of the i_{775}-band dropouts, because there is no tight correlation between absolute and apparent magnitude in samples of these one-color–selected LBGs. Galaxies with a given apparent magnitude m now have absolute magnitude M distributed in a much larger interval, because whether or not they enter the sample depends on both their redshift and on their absolute magnitude. Specifically, the lower redshift bound is set by the color threshold, while the upper bound depends strongly on galaxy luminosity, as intergalactic medium (IGM) opacity suppresses the z_{850}-band flux at higher redshifts. Hence, the effective volume $V_{\rm eff}(m)$ is overestimated (unless in the simulation one uses the same intrinsic luminosity function for the real galaxies), because in the simulations galaxies with widely different absolute magnitude are equally represented. In this case we have measured $\mathcal{L}$ with a different procedure, performing a χ^2 minimization to find the intrinsic luminosity function $\phi(M)$ of the simulated galaxies such that, once inserted into the real images and retrieved, their number count is best fitted to the number count of the real galaxies. We use a Schechter function with slope fixed to the value found at $z \sim 3$ (AS00), namely, $\alpha = 1.6$, and derive the parameters M^* and ϕ^* from the fit. In practice, since our data only reach down to $L \sim 0.2L^*_3$ at most, the assumption of a fixed value of α is a relatively minor one (we verified that values in the range $1.4 \leq \alpha \leq 1.8$ change our results by at most ∼12%). The specific luminosity density is then simply $\mathcal{L} = \int L\phi(M)\,dM$, and for each redshift value this is computed using the corresponding sample's best-fit luminosity function.

We found the average and standard deviation of the redshift distribution of the samples to be $z_B = 3.78$ and $\mathcal{S}_B = 0.34$, $z_V = 4.92$ and $\mathcal{S}_V = 0.33$, and $z_i = 5.74$ and $\mathcal{S}_i = 0.36$, respectively. For each sample we have estimated $\mathcal{L}$ at 1500 Å ($\mathcal{L}_{1500}$) using *K*-corrections derived from a template LBG with the same UV color as the average one in the B_{435}-band dropout sample. We have integrated the luminosity function down to the "observed" limit of $z_{850} = 26.5$, and we have also estimated the (relatively small) corrections so that all the measures reach the same absolute magnitude, chosen to be that of the B_{435}-band dropouts ($0.2L^*_3$). Finally, for the $V_{\rm eff}$ method, we have estimated from the Monte Carlo simulations the magnitude-dependent corrections for light losses due to finite aperture photometry.

The top panel of Figure 1 shows $\mathcal{L}_{1500}$ as a function of redshift from the GOODS samples derived with the two methods above, both the observed values and those corrected to the same absolute magnitude, compared to the measures at $z \sim 3$ and ∼4 by S99. The two methods provide similar results for the B_{435}- and V_{606}-band dropout samples but differ for the i_{775}-band dropouts. Note that the luminosity function correction is relatively small for the V_{606}-band dropouts but increases for the i_{775}-band ones, as the $z_{850} = 26.5$ limit of the sample corresponds to a brighter intrinsic luminosity at higher redshift. The bottom panel shows the star formation density computed as SFD $= 1.4 \times 10^{-28}\mathcal{L}\ M_\odot\ \mathrm{yr}^{-1}\ \mathrm{Mpc}^{-3}$ (Madau, Pozzetti, & Dickinson 1998), after conversion to our world model and correcting for the smaller range of absolute luminosity, i.e., greater than $0.2L^*_3$ instead of greater than $0.1L^*_3$. Both the observed values and those corrected for dust obscuration, as suggested by AS00, are plotted.

4. DISCUSSION AND CONCLUSIONS

The specific luminosity density of LBGs appears to depend rather weakly on redshift over the range $2.5 \lesssim z \lesssim 6.5$. Integrating down to $L \sim 0.2L^*_3$, S99 report $\mathcal{L}_{1500}(z = 3) = 1.50 \pm 0.10$, while from the GOODS data we find $\mathcal{L}_{1500}(z = 4) = 1.63 \pm 0.05$, $\mathcal{L}_{1500}(z = 5) = 1.04 \pm 0.08$, and $\mathcal{L}_{1500}(z = 6) = 1.15^{+0.24}_{-0.19}$ in units of 10^{26} ergs s^{-1} Hz^{-1} Mpc^{-3} (1 σ error bars). Note that while the points at $z \leq 5$ are relatively robust, the constraint at $z \sim 6$ is still somewhat weak, because it critically depends on the measure of the number counts near the sensitivity limit of the survey (see D04). For example, if we restrict the sample to z_{850}-band photometry with S/N ≥ 6.5 (roughly $z_{850} < 26$), then we find that the best-fit specific luminosity density drops down to $\mathcal{L}_{1500}(z = 6) = 0.42^{+0.33}_{-0.30} \times 10^{26}$ ergs s^{-1} Hz^{-1} Mpc^{-3} ($0.42^{+0.60}_{-0.40}$ 2 σ). At face value this is still a relatively mild drop from the $z \sim 3$ value, a factor of ≈3.5, smaller than the factor of ≈7 proposed by Stanway et al. (2003a, 2003b), but the error is too large for the constraint to be meaningful. We note, however, that the $z \sim 5$ point, which is more robust than the $z \sim 6$ one and does not need as big an extrapolation down the luminosity function, is reasonably consistent with the mild evolution scenario, lending support to our best estimate at $z \sim 6$.

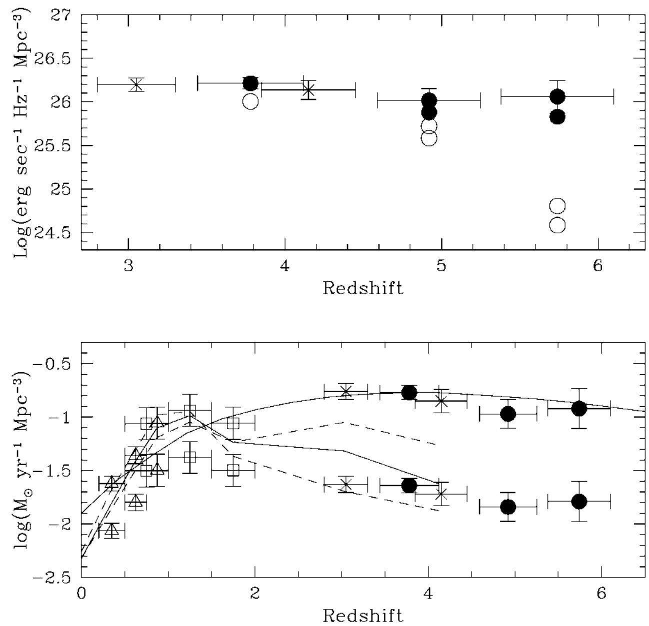

FIG. 1.—*Top*: Specific luminosity density at $\lambda = 1500$ Å of LBGs as a function of redshifts. Circles represent the GOODS B_{435}-, V_{606}-, and i_{775}-band dropout samples; crosses are from S99. The open circles are the $V_{\rm eff}$ measures, the filled circles the χ^2 ones. Error bars of the GOODS points are the 68% confidence interval of the fitting procedure. *Bottom*: Average star formation density of UV-bright star-forming galaxies as a function of redshift. The GOODS points have been obtained from the specific luminosity density using the conversion factor by Madau et al. (1998). The other points are from S99, Connolly et al. (1997), and Lilly et al. (1996) after conversion to our world model. The top filled circles are as observed; the bottom filled circles have been corrected for dust obscuration as proposed by AS00. The lower solid curve and dot-dashed lines are derived from the evolution of the H I mass density as traced by damped Lyα absorbers (Pei et at. 1999); the upper solid curve is from semianalytical models (Somerville et al. 2001). [*See the electronic edition of the Journal for a color version of this figure.*]

The result at $z \sim 6$ is sensitive to the apparently substantial amount of light contributed by the faint galaxies. To the best of our knowledge, the galaxies with $5 \leq$ S/N ≤ 6.5 are real $z \sim 6$ candidates. On the basis of the observed dispersion of colors of faint galaxies, our simulations, and the expected colors of galaxies of various spectral types, we believe that our statistical correction for contamination is adequate and is not introducing a major systematic error in our measures. The very good agreement with the measure by S99 at $z \sim 4$, which is supported by systematic redshift identification of the galaxies, adds credence to this assertion. The current spectroscopic identifications at $z \sim 6$ (Bunker et al. 2003; D04; Stanway et al. 2003b) agree well with our predicted redshift distribution and also support this conclusion. The samples are still too sparse, however, to attempt a measure of the efficiency of the selection criteria and, thus, the contamination. Clearly, the measure of $\mathcal{L}_{1500}(z = 6)$ needs to be revisited with deeper data.

In any case, our measure at $z \sim 6$ is in overall good agreement with other similar measures from *HST* and ground-based data (Bouwens et al. 2003; Lehnert & Bremer 2003). Stanway et al. (2003a, 2003b) report a factor of ≈7 decrease of the specific luminosity density, although this is also very likely in agreement with our result, because they limit their measure to bright galaxies, i.e., $L > L^*_3$. Actually, a direct quantitative comparison is difficult because of the difference in the sample selection and the pronounced dependence of $\mathcal{L}_{1500}$ on the faint counts. These authors also use the GOODS data, but they base their source detection on single-epoch images (we use a stack of three epochs), therefore necessarily reaching a shallower flux level and larger incompleteness.[10] Down to $z_{850} < 25.6$ they find a total of 14 galaxies over 350 arcmin^2 (0.040 arcmin^{-2}), while to the same flux level and using their same criteria we find 35 galaxies over 316 arcmin^2 (0.11 arcmin^{-2}). Also, note that they use the $V_{\rm eff}$ method to derive $\mathcal{L}$, which, as we have detailed above, underestimates the specific luminosity density for the i_{775}-band dropouts.

Our measures also agree well with the deep, large-area LBG survey at $z \sim 5$ by Iwata et al. (2003) and with photometric redshift surveys (Thompson et al. 2001; Thompson 2003; Fontana et al. 2003; Kashikawa et al. 2003). They differ from the HDF results of L02, who, after correcting for bias in the photometry due to the $(1+z)^4$ cosmological dimming, conclude that the specific star formation density either remains constant up to $z \sim 6$ and then increases afterward, or increases monotonically. While we do explicitly account in our measure corrections for light losses due to finite aperture photometry (estimated from the Monte Carlo simulations), we do not find corrections as large as theirs. Very likely, much of the difference is that our corrections are derived by requiring that the galaxy size distribution used as input in our Monte Carlo simulations is such that the output distribution matches the observations at $z \sim 4$ (this roughly corresponds to the sizes evolving as $\sim H(z)^{-1}$; see Ferguson et al. 2004), while the L02 corrections are based on the light distribution of galaxies at $1 \lesssim z \lesssim 1.5$, i.e., at considerably lower redshifts.

If the dust obscuration properties of LBGs are similar to local starburst galaxies (Meurer, Heckman, & Calzetti 1999; Calzetti 2001; AS00) and do not significantly change over the range $3 < z < 6.5$, then their star formation activity decreases very mildly with increasing redshift, at $z \sim 6$ being ∼25% lower than it was around its maximum at $1 \lesssim z \lesssim 3$.

Thus, it appears that the onset of substantial cosmic star formation takes place earlier than $z > 6$. Note that Figure 1 shows reasonable agreement between the dust-corrected data points and the semianalytical models by Somerville, Primack, & Faber (2001; *upper solid curve*), and between the uncorrected data points and the predictions based on the observed evolution of the neutral H I mass density as traced by DLA (Pei, Fall, & Hauser 1999; *lower solid curve and dot-dashed lines*) at least up $z \sim 4$, which include the effect of dust obscuration.

How many H I ionizing photons do the i_{775}-band dropouts contribute at $z \sim 6$? Since the UV continuum at 1500 Å is dominated by the same massive stars responsible for the emission shortward of the Lyman edge, the needed conversion factor, about 1 ionizing photon above 1 ryd for every 5 photons at 1500 Å, is fairly insensitive to the assumed IMF and is independent of the galaxy history for ages $\gg 10^7$ yr (Madau et al. 1999; Haiman et al. 2001). We normalize the number of ionizing photons to the *observed* 1500 Å flux bypassing the need to correct for dust extinction and compute a comoving production rate of H I ionizing photons $\dot{n}_{\rm ion} \approx 3 \times 10^{51}$ s^{-1} Mpc^{-3}, or about $5 f_{\rm esc}$ photons per H I atom per 5×10^8 yr escaping into the IGM. Here $f_{\rm esc}$ is the average escape fraction of ionizing radiation from the galaxy H I layers *relative to the escape fraction at* 1500 Å. Photoionization of intergalactic H I requires more than 1 photon above 1 ryd per atom, as extra photons are needed to keep the gas in overdense regions and filaments ionized against radiative recombinations. If $f_{\rm esc}$ is greater than a few tens of a percent, then the i_{775}-band dropouts contribute significantly to the UV metagalactic flux, and help reionize the universe by $z \sim 6$.

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[10] They also use a slightly different color selection criterion, namely, $i_{775} - z_{850} > 1.5$. As D04 observe, this misses one of the galaxies spectroscopically confirmed at $z = 5.8$.

REFERENCES

Adelberger, K. L., & Steidel, C. C. 2000, ApJ, 544, 218 (AS00)
Bouwens, R. J., et al. 2003, ApJ, 595, 589
Bruzual, G., & Charlot, S. 2003, MNRAS, 344, 1000
Bunker, A., et al. 2003, MNRAS, 342, 47
Calzetti, D. 2001, PASP, 113, 1449
Connolly, A. J., et al. 1997, ApJ, 486, L11
Dickinson, M., et al. 2004, ApJ, 600, L99(D04)
Fall, S. M., Charlot, S., & Pei, Y. C. 1996, ApJ, 464, L43
Fan, X., et al. 2002, AJ, 123, 1247
Ferguson, H. C., et al. 2004, ApJ, 600, L107
Fontana, A., et al. 2003, ApJ, 587, 544
Giavalisco, M., et al. 2004, ApJ, 600, L93 (G04)
Haiman, Z., Abel, T., & Madau, P. 2001, ApJ, 551, 599
Iwata, I., et al. 2003, PASJ, 55, 415
Kashikawa, N., et al. 2003, AJ, 125, 53
Lanzetta, K. M., et al. 2002, ApJ, 570, 492 (L02)
Lehnert, M. D., & Bremer, M. 2003, ApJ, 593, L630
Lilly, S. J., et al. 1996, ApJ, 460, L1
Madau, P. 1995, ApJ, 441, 18
Madau, P., Haardt, F., & Rees, M. J. 1999, ApJ, 514, 648
Madau, P., Pozzetti, L., & Dickinson, M. E. 1998, ApJ, 498, 106
Madau, P., et al. 1996, MNRAS, 283, 1388
Meurer, G. R., Heckman, T. M., & Calzetti, D. 1999, ApJ, 521, 64
Oke, J. B. 1974, ApJS, 27, 21
Pei, Y. C., Fall, S. M., & Hauser, M. G. 1999, ApJ, 522, 604
Somerville, R., Primack, J. R., & Faber, S. M. 2001, MNRAS, 320, 289
Stanway, E., Bunker, A., & McMahon, R. 2003a, MNRAS, 342, 439
Stanway, E., et al. 2003b, ApJ, submitted (astro-ph/0308124)
Steidel, C. C., Pettini, M., & Adelberger, K. L. 2001, ApJ, 546, 665
Steidel, C. C., et al. 1999, ApJ, 519, 1 (S99)
Thompson, R. I. 2003, ApJ, 596, 748
Thompson, R. I., Weymann, R. J., & Storrie-Lombardi, L. J. 2001, ApJ, 546, 694