CLUSTERING PROPERTIES OF REST-FRAME UV-SELECTED GALAXIES. II. MIGRATION OF STAR FORMATION SITES WITH COSMIC TIME FROM GALEX AND CFHTLS

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ABSTRACT

We analyze the clustering properties of ultraviolet-selected galaxies by using GALEX-SDSS data at $z < 0.6$ and CFHTLS deep $u^*$ imaging at $z \sim 1$. These data sets provide a unique basis at $z \lesssim 1$ which can be directly compared with high-redshift samples built with similar selection criteria. We discuss the dependence of the correlation function parameters ($r_0$ and $\delta$) on the ultraviolet luminosity, as well as the linear bias evolution. We find that the bias parameter shows a gradual decline from high ($b_0 \gtrsim 2$) to low redshift ($b_0 \simeq 0.79^{+0.11}_{-0.08}$). When accounting for the fraction of the star formation activity enclosed in the different samples, our results suggest that the bulk of star formation migrated from high-mass dark matter halos at $z > 2$ ($10^{12} \lesssim M_\text{halo} \lesssim 10^{13} M_\odot$, located in high-density regions) to less massive halos at low redshift ($M_\text{min} \lesssim 10^{12} M_\odot$, located in low-density regions). This result extends the ”down-sizing” picture (shift of the star formation activity from high stellar mass systems at high $z$ to low stellar mass at low $z$) to the dark matter distribution.

Subject headings: stars: formation — ultraviolet: galaxies

1. INTRODUCTION

Accumulated evidence shows that the cosmic star formation rate (SFR) has been decreasing from $z \sim 1$ by a dramatic factor of about 5 (Hopkins 2004; Lilly et al. 1996; Madau et al. 1996; Schiminovich et al. 2005; Sullivan et al. 2000; Wilson et al. 2002). This is linked to the decrease of the contribution of the faint galaxies that dominate the star formation density, and to the strong decline of the most ultraviolet-luminous galaxies with time, given the redshift evolution of the 1500 Å luminosity function (Arnouts et al. 2005). Another aspect of this evolution, known as ”down-sizing” (Cowie et al. 1996), is the observation that star formation activity shifts with time from high to low stellar mass systems (Bundy et al. 2006; Jimenez et al. 2005; Juneau et al. 2005; Heavens et al. 2004 and references therein).

The star formation history results from the interplay between the physical processes driving the star formation fueling (gas cooling) and regulation (feedback), both closely related to galaxy environment. Recent simulations show that about half of the galaxy gas is accreted through a cold mode, which dominates at high redshift in high-density environments, and shifts to low-density environments in the local universe (Kereş et al. 2005). The type of the dominant feedback process is expected to depend on galaxy host halo mass: supernovae explosions (e.g., Benson et al. 2003) at low mass, and AGNs (e.g., Croton et al. 2006) at high mass. Cattaneo et al. (2006) show that the introduction of a critical halo mass above which there is a complete shutdown of cooling and star formation is efficient in reproducing the bimodality in galaxy properties observed in the local universe (e.g., Baldry et al. 2004).

In this paper we propose to set constraints on the roles of these different processes through cosmic time by assessing the spatial distribution of star formation in the universe from high to low redshifts. A convenient method is to study the clustering properties of rest-frame ultraviolet (UV) selected galaxies. This has already been performed at high redshifts using Lyman break galaxies (LBGs) samples to show that, at these epochs, star formation is highly clustered and concentrated in overdense regions (Adelberger et al. 2005; Allen et al. 2005; Arnouts et al. 2002; Foucaud et al. 2003; Giavalisco & Dickinson 2001). The study of the redshift evolution of the clustering properties of actively star-forming galaxies has now been made possible in a homogeneous way with the combination of rest-frame UV data collected from $z \sim 4$ to $z = 0$. To extend high-$z$ studies, we use GALEX observations in the recent universe and CFHTLS deep imaging at $z = 1$. We compute the angular correlation function (ACF) of star-forming galaxies and derive their bias and its evolution.

In a companion paper, Milliard et al. (2006, hereafter Paper I), we describe in detail the methodology and the first results of the angular correlation function measurements of UV-selected galaxies using a GALEX sample at $z \leq 0.6$. Section 2 summarizes...
the sample properties and presents a new rest-frame UV-selected sample from the $u'$-band deep CFHTLS imaging survey that we use to extend the analysis to higher redshift ($z \sim 1$). We then investigate the dependence on redshift and UV luminosity of the clustering properties: $r_0$ and $\delta$ in § 3, and bias in § 4. In the last section we discuss the evolution of the preferred sites of star formation over the last 90% of the age of the universe.

All magnitudes have been corrected for Galactic extinction using the $E(B-V)$ value from the Schlegel et al. (1998) maps and the Cardelli et al. (1989) extinction law. Throughout the paper, we adopt the following cosmological parameters: $\Omega_m = 0.3$, $\Omega_{\Lambda} = 0.7$, $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$.

2. SAMPLES DESCRIPTION

2.1. GALEX

In this work, we use the same subsample of GALEX Release 2 (GR2) Medium Imaging Survey (MIS) fields cross-matched with SDSS DR5 presented in Paper I, and we refer to this paper for a full description. We recall here the main characteristics of the selection. We only keep GALEX objects with SDSS counterparts within a search radius of 4$''$ and use the closest SDSS match. We select galaxies as objects with SDSS type equal to 3. We use the half of the MIS fields from the GR2 data set with the lowest Galactic extinction ($\langle E(B-V) \rangle \leq 0.04$). Photometric redshifts are computed using an empirical method (Connolly et al. 1995) trained on SDSS spectroscopic counterparts. The standard deviation estimated from the SDSS spectroscopic redshifts is $\sigma = 0.03$. We then use a template fitting procedure (S. Arnouts & O. Ilbert 2008, in preparation) to derive UV luminosities. Our starting samples include objects with FUV $< 22$ or NUV $< 22$.

The NUV absolute magnitude versus photometric redshift relation is shown in Figure 1. The colors code the galaxy type determined using a SED template fitting procedure: red represents elliptical types, green represents spirals, and blue represents irregulars. We here-

![Fig. 1: NUV absolute magnitude—photometric redshift relation in the GALEX sample. The colors code the type according to the best-fitting template: red represents elliptical types, green represents spirals, and blue represents irregulars. The dashed lines indicate the additional cuts adopted: $z_{\text{phot}} < 0.6$ and $-21.5 < \text{NUV}_{\text{abs}} < -14$. The same cuts hold for FUV.](image1.png)

![Fig. 2: Redshift distribution of the subsamples cut in absolute UV magnitude. $M < \langle M \rangle$ is shown by solid lines, and $M > \langle M \rangle$ is shown by dashed lines; FUV is shown as blue and NUV as red.](image2.png)

after restrict the samples to $-21.5 < \text{NUV}_{\text{abs}} < -14.0$ and $0.0 < z_{\text{phot}} < 0.6$ (Fig. 1, dashed lines). The same cuts have been applied to the FUV sample.

In the following, we consider both FUV and NUV bands, and we divide the samples into two bins according to the mean UV absolute magnitude. Figure 2 shows the photometric redshift distributions of the GALEX samples; Table 1 summarizes the properties of the samples.

2.2. CFHTLS

The CFHTLS-Deep survey consists of deep multicolor images collected through the $u'g'r'i'z'$ filters over four independent areas of 1 deg$^2$ each and reaching the limiting magnitude of $i'_{\text{AB}} \sim 26$. In this work, we use the official CFHTLS data release T0003. For a full presentation of the CFHTLS-Deep survey, we refer to Schultheis et al. (2006). We built specific masks from the $u'$-band images to mask out stars, chips edges, and artifacts. The total solid angle of the four fields used after masking is 3.1 deg$^2$. The star/galaxy separation is based on the same method as McCracken et al. (2003) with the half-light radius versus $u'$ magnitude plot. This selection has been applied down to $u' = 23$. Beyond this limit, we combine the photometric criterion with the star/galaxy classification derived from the photometric redshift code Le Phare (S. Arnouts & O. Ilbert 2008, in preparation).

To construct the sample of UV-selected galaxies at $z \sim 1$, we adopt a $u'$ magnitude limit of $u' = 24$, which ensures a genuine UV-selected sample, as the $u'$ effective wavelength (3587 Å) corresponds to 1848 Å at our mean redshift ($z = 0.94$). The fraction of objects lost (without any redshift selection) with a $i'$ cut is on average 0.07% over the four fields at $u' = 24$. The redshift selection of the sample is based first on a color-color selection and then on the photometric redshift selection. We do not adopt a single selection based on the photometric redshifts because of the variable accuracy of the method due to inhomogeneous exposure times in the five bands for the different fields.

14 See also http://www.cfht.hawaii.edu/Science/CFHTLS/ and http://www.ast.obs-mip.fr/article204.html.
First, we use a color-color selection to isolate galaxies with $z \geq 0.7$, based on VVDS photometric redshift estimations, relying on multicolor data (Ilbert et al. 2006). As shown in Figure 3, the $(g'-r')$ versus $(r'-i')$ selection criterion is efficient to separate galaxies at $z \geq 0.7$ (big dots) from the lower redshift population (small dots). The line shows our separation criterion. There are 96% of galaxies with $z_{\text{phot}} \geq 0.7$ located below the line, while less than 10% of low-$z$ objects ($z_{\text{phot}} \leq 0.7$) fall in the same region.

The photometric redshifts are computed by using the Le Phare code and by adopting the method described by Ilbert et al. (2006). The comparison with the spectroscopic redshifts, obtained by the VVDS in the best photometric field (CFHTLS-D1; Le Fèvre et al. 2005), for our $u'$-selected sample shows an accuracy of $\sigma(\Delta z/(1 + z)) = 0.03$ with 4% of outliers [defined as $\Delta z \geq 0.15(1 + z)$].

In Figure 4 we show the photometric redshift distribution of the galaxies selected with the color criterion (dashed histogram). The final sample is obtained by further selecting objects with $0.7 < z_{\text{phot}} < 1.3$ (solid histogram). The absolute magnitudes in the GALEX bands are derived from the best-fitting SEDs whose NUV-rest fluxes are well constrained by the $u'$, $g'$, and $r'$ bands in the redshifts range ($0.7 \leq z \leq 1.3$). Note that as the $u'$ filter shifts to FUV wavelengths at $z \sim 1$, absolute magnitudes depend very weakly on $k$-correction and best-fitting SEDs. As for GALEX samples, we divide the CFHTLS sample into two bins according to $z_{\text{phot}}$. The line represents the adopted color-color selection criterion.

**TABLE 1**

| PARAMETER | FUV SAMPLES | NUV SAMPLES | FUV$_{\text{abs}} < -18.3$ | FUV$_{\text{abs}} > -18.3$ | NUV$_{\text{abs}} < -18.3$ | NUV$_{\text{abs}} > -18.3$
|-----------|-------------|-------------|-----------------|-----------------|-----------------|-----------------|
| $N_{\text{gal}}$ | 42065 | 22082 | 19983 | 97038 | 52567 | 44471 |
| $(\text{FUV}_{\text{abs}})$ | $-18.3$ | $-18.96$ | $-17.57$ | $-18.23$ | $-18.76$ | $-17.61$ |
| $(\text{NUV}_{\text{abs}})$ | 0.91 | 0.52 | 0.67 | 0.96 | 0.72 | 0.82 |
| $(\text{FUV}_{\text{abs}})$ | $-18.58$ | $-19.15$ | $-17.95$ | $-18.8$ | $-19.43$ | $-18.05$ |
| $(\text{NUV}_{\text{abs}})$ | 0.84 | 0.52 | 0.67 | 0.91 | 0.44 | 0.69 |
| $\sigma(g-i)$ | 0.18 | 0.23 | 0.13 | 0.25 | 0.32 | 0.17 |
| $\sigma(i-z)$ | 0.08 | 0.07 | 0.05 | 0.11 | 0.09 | 0.06 |
| $n_{\text{gal}}$ ($10^{-2} \text{ Mpc}^{-3}$) | 2.78 ± 1.03 | 0.15 ± 0.03 | 2.54 ± 0.95 | 2.16 ± 1.19 | 0.14 ± 0.03 | 1.95 ± 1.06 |
| $D_{\text{A}} \times 10^3$ | 9.4_{-1.7}^{+2.4} | 7.3_{-1.2}^{+1.4} | 33.9_{-10.3}^{+17.4} | 3.6_{-0.5}^{+0.6} | 4.1_{-0.8}^{+1.0} | 22.4_{-1.6}^{+3.7} |
| $\delta$ | 0.74 ± 0.05 | 0.79 ± 0.1 | 0.48 ± 0.09 | 0.86 ± 0.04 | 0.87 ± 0.05 | 0.52 ± 0.05 |
| $r_0$ (Mpc) | 4.6_{-0.6}^{+0.9} | 4.6_{-0.9}^{+0.9} | 5.4_{-0.9}^{+1.4} | 4.1_{-0.5}^{+0.3} | 4.9_{-0.7}^{+0.4} | 5.5_{-0.5}^{+0.8} |
| $b_g$ | 0.74_{-0.07}^{+0.08} | 0.76_{-0.11}^{+0.13} | 0.83_{-0.12}^{+0.17} | 0.69_{-0.05}^{+0.05} | 0.83_{-0.07}^{+0.07} | 0.86_{-0.07}^{+0.07} |

Note.—The amplitude and slope of best-fit power laws to the angular correlation function, and hence the comoving correlation length, account for the integral constraint correction, as described in Paper I.

$^a$ Number of galaxies in the samples.

$^b$ According to photometric redshifts.
to the mean FUV absolute magnitude, and the resulting redshift distributions are shown in Figure 4.

The global properties of the CFHTLS UV samples are given in Table 2.

### 3. REDSHIFT EVOLUTION OF THE CORRELATION FUNCTION OF UV-SELECTED GALAXIES

We compute the ACF using the Landy & Szalay (1993) estimator. We assume that the ACF is well approximated by a power law: $w(\theta) = A_\theta \theta^{-\delta}$; we use a variable integral constraint (IC) with $\delta$ as free parameter during the power-law-fitting process, and estimate the IC with the same method used by Roche & Eales (1999). We derive correlation lengths ($r_0$) for each sample from the Limber equation (Peebles 1980), using the corresponding redshift distribution. These quantities, as well as the bias parameter, are summarized in Tables 1 and 2. The effects of the dust internal to galaxies have again been neglected.

In Figures 5 and 6, we show the ACFs of the GALEX and CFHTLS samples respectively. The ACFs are derived for the global samples and for two subsamples with UV absolute luminosity brighter and fainter than the mean UV luminosity of each sample. The angular scales probed for the GALEX samples are $0.005^\circ-0.4^\circ$ (corresponding to comoving distances of $0.07$ and $5.7$ Mpc, respectively, at $z = 0.2$), and $0.002^\circ-0.4^\circ$ for the CFHTLS samples ($0.11$ and $23$ Mpc, respectively, at $z = 1$). These ACFs are fairly well fitted by power laws, even if a small dip appears at small scales in the FUV GALEX samples and also in the CFHTLS bright one (see § 3.2.2). The higher surface density of UV-selected galaxies at $z \sim 1$ allows a less noisy estimation of the ACF at these epochs than at $z < 0.4$.

#### 3.1. Clustering Segregation with FUV Luminosity

The dependence of $r_0$ on FUV luminosity in GALEX and CFHTLS samples is shown in Fig. 7, along with results from higher redshift studies ($z \geq 2$). As the different surveys probe different parts of the UV luminosity function with little overlap, it is difficult to draw firm conclusions. Nevertheless, significant differences between the samples are apparent:

1. We use as reference the correlation function results from Adelberger et al. (2005), Allen et al. (2005), Foucaud et al. (2003), Giavalisco & Dickinson (2001), Lee et al. (2006), and Ouchi et al. (2001) at $z > 2$. At these redshifts, all studies conclude a

| Parameter | All | FUV$_\text{abs} < -19.41$ | FUV$_\text{abs} > -19.41$ |
|-----------|-----|------------------|------------------|
| $N_{\text{gal}}$ | 17098 | 8507 | 8591 |
| $\langle \text{FUV}_{\text{abs}} \rangle$ | $-19.41$ | $-19.89$ | $-18.94$ |
| $\sigma_{\text{FUV}_{\text{abs}}}$ | 0.6 | 0.34 | 0.36 |
| $\langle \text{NUV}_{\text{abs}} \rangle$ | $-19.81$ | $-20.19$ | $-19.43$ |
| $\sigma_{\text{NUV}_{\text{abs}}}$ | 0.53 | 0.4 | 0.33 |
| $\langle z \rangle$b | 0.94 | 1.04 | 0.84 |
| $\sigma_z$b | 0.16 | 0.15 | 0.09 |
| $n_{\text{gal}}$ (10$^{-3}$ Mpc$^{-3}$) | $3.27 \pm 0.90$ | $0.62 \pm 0.41$ | $2.66 \pm 2.58$ |
| $A_\theta \times 10^3$ | $2.7^{+2.0}_{-1.0}$ | $2.8^{+1.2}_{-0.8}$ | $3.3^{+1.0}_{-1.0}$ |
| $\delta$ | $0.7 \pm 0.09$ | $0.74 \pm 0.09$ | $0.76 \pm 0.07$ |
| $r_0$ (Mpc) | $4.92^{+0.05}_{-0.05}$ | $5.48^{+0.05}_{-0.05}$ | $4.66^{+0.24}_{-0.23}$ |
| $b_0$ | $1.24^{+0.07}_{-0.07}$ | $1.38^{+0.06}_{-0.07}$ | $1.16^{+0.03}_{-0.04}$ |

Note.—The amplitude and slope of best-fit power laws to the angular correlation function, and hence the comoving correlation length, account for the integral constraint bias.

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15 See Paper I for details on the computations.
16 We choose the FUV absolute magnitude for the comparison, as most of high-redshift samples are FUV rest-frame selected, and GALEX results are not strongly dependent on the UV band. The mean absolute magnitudes of the LBG samples have been obtained by deriving an average apparent magnitude from the galaxy counts, and assuming a k-correction of 2.5 log (1 + z). Ouchi et al. (2005) do not provide their counts, so we computed the expected mean absolute magnitude given their limiting absolute magnitude and the luminosity function of Savicki & Thompson (2006).
significant segregation of $r_0$ with UV luminosity (the more luminous the more clustered) in the range $-23 \leq \text{FUV}_{\text{abs}} \leq -20$.

2. At $z \sim 1$, a positive correlation of $r_0$ with FUV is still observed for $-20 \leq \text{FUV}_{\text{abs}} \leq -19$. Notably, our value of $r_0$ at $\text{FUV}_{\text{abs}} \sim -20$ is very close to that of Adelberger et al. (2005) obtained from $z \sim 2$ samples.

3. At $z \leq 0.3$, we probe a fainter luminosity range ($-19 \leq \text{FUV}_{\text{abs}} \leq -17$), and a weak anticorrelation of $r_0$ with FUV is apparent, although given the error bars, it is compatible with no FUV luminosity segregation of $r_0$.

The values of $r_0$ as a function of FUV luminosity for FUV-selected samples at different redshifts follow a unique smooth curve, with a significant slope at the bright end $\text{FUV}_{\text{abs}}$ and a flat or slightly negative slope at the faint end. A similar segregation is observed with $B$ luminosity at low redshift, with optical selection criteria (Benoist et al. 1996; Guzzo et al. 2000; Norberg et al. 2002; Willmer et al. 1998; Zehavi et al. 2005). In particular, Norberg et al. (2001) showed that for blue-selected galaxies $r_0$ increases only slowly for galaxies fainter than $L_B$, while it varies strongly for galaxies brighter than $L_B$. Indeed, using N-body simulations Benson et al. (2001) showed that $L_B$ could be a natural boundary in the distribution of the halos hosting galaxies, galaxies fainter than $L_B$ being hosted by a mix of low- and high-mass halos, while galaxies brighter than $L_B$ are hosted by more and more massive halos. To check whether FUV could play a similar role in UV samples, we show in Figure 8 $r_0$ as a function of $\text{FUV}_{\text{abs}}$, where the evolution of FUV, with $z$ taken from Arnouts et al. (2005) for $z < 1$ and Sawicki & Thompson (2006) (for $z > 1$). The luminosity dependence of $r_0$ changes noticeably when expressed as a function of $\text{FUV}_{\text{abs}}$, as two different trends are observed according to the redshift range:

1. At $z \geq 1$, for the high-$z$ samples and our CFHTLS sample, the behavior of $r_0$ with $\text{FUV}_{\text{abs}}$ is qualitatively compatible with the monotonic trend described above, the brighter galaxies being more clustered.

2. At $z \leq 0.5$ (GALEX samples) a radically different behavior of $r_0$ versus $\text{FUV}_{\text{abs}}$ is seen. An anticorrelation or no correlation (given the error bars) is observed, with brighter samples showing slightly lower $r_0$ than fainter ones.

This suggests that the luminosity segregation mechanisms of the clustering at low redshifts work in a different regime, or that FUV is not the relevant variable.
3.2. ACF Slope Segregation with FUV Luminosity

3.2.1. ACF Slope

The slope of the ACF ($\delta$), which describes the balance between small- and large-scale separations, is an important indicator on the nature of the spatial distribution of a given population. In Paper I we found that the estimates of the slope inferred from the global GALEX samples ($\delta \approx 0.81 \pm 0.07$) are steeper than those derived from optically selected blue galaxies in the local universe: $\delta \sim 0.6$ (Budavári et al. 2003; Madgwick et al. 2002; Zehavi et al. 2002, 2005).

In Figure 9 we analyze the dependence of $\delta$ on UV luminosity for the different samples (GALEX FUV samples, filled circles; GALEX NUV samples, filled squares; CFHTLS samples, filled stars; high-z samples, open squares, open circles, and crosses; all points are color-coded with redshift).

At $z > 3$, the compilation of measurements showed here, and especially those at $z = 4$, from Ouchi et al. (2005) indicate that the ACF slope steepens at higher UV luminosities.

Ouchi et al. (2005) claimed that this trend, well modeled in the halo occupation distribution (HOD) framework, is not an actual slope variation but is related to the halo occupancy. Based on HOD models, they show that the contribution of satellite galaxies (“one-halo term”; see, e.g., Zehavi et al. 2004) increases when selecting brighter galaxies, by enhancing the small-scale signal of the ACF ($r \leq 0.35$ Mpc). This effect produces an apparent steepening of the observed slope $\delta$.

Our GALEX sample at $z < 0.4$ seems to produce a similar although less pronounced effect. Our current low-$z$ GALEX data do not allow us to perform detailed comparison between observations and HOD models, but we have investigated whether the observed steepening with luminosity can be partially due to the small-scale component. We fitted the GALEX ACF only at scales $r > 0.4$ Mpc (see § 3.2.2) or $r > 0.7$ Mpc in order to not include the one-halo-term component. We do not observe any significant change with respect to our initial slopes. However, in doing so we face at large scales the problems of lower signal-to-noise ratio and more important contribution of the IC bias that prevent us to make firm statements. This test thus relies on the efficiency of our power-law-fitting process in recovering the true ACF (see Paper I).

In other words, at low redshift we do not see evidence that the one-halo term plays a major role in the slope of the ACF, as observed at high redshift, which is expected from simulations (Kravtsov et al. 2004). Hence, this indicates that our clustering parameters ($r_0$, $\delta$, and bias $b_0$) reflect the large-scale clustering of star-forming galaxies, which enables us to make comparisons with analytical predictions for the clustering of dark matter halos.

3.2.2. Dip in the ACF?

The ACFs derived for the various GALEX and CFHTLS samples are globally well described by a power law, but some of our ACFs show a little dip around 0.35 Mpc — the GALEX FUV ones, for instance — and also the brightest CFHTLS sample at $z \sim 1$ (at a slightly larger scale $\sim 0.5$ Mpc). This recalls the departure to the power law observed in other surveys and interpreted as the transition between the one and two halo terms in the HOD framework. Zehavi et al. (2004) showed that this transition occurs at $\sim 1.5$–3 Mpc for $r$-band-selected galaxies. It is expected that this scale should be shorter for bluer galaxies, residing in less massive halos, as showed by Magliocchetti & Porciani (2003) in observations and Berlind et al. (2003; see their Fig. 22) in simulations, with a transition scale for late-types galaxies at $\sim 0.45$ Mpc, close to what we observe. Finally, and very interestingly, Ouchi et al. (2005) observe this transition for LBGs at $z \sim 4$ at 0.35 Mpc, the same comoving scale as we get.

Comparing measurements with predictions from HOD models is a natural perspective of this work, to probe the redshift evolution of the halo occupancy of star-forming galaxies. This will be addressed in details in a forthcoming paper with enlarged data sets.

4. BIAS OF STAR-FORMING GALAXIES

FROM $z = 4$ TO $z = 0$

The link between the properties of the galaxy distribution and the underlying dark matter density field can be accessed via the bias formalism. The bias parameter is indicative of the masses of the dark matter halos that preferentially host the observed galaxy population (e.g., Mo & White 2002; Ouchi et al. 2004), i.e., in our case actively star-forming galaxies. The DM halo bias is a direct output of simulations, with a transition scale for late-types galaxies at $\sim 0.45$ Mpc, close to what we observe. Finally, and very interestingly, Ouchi et al. (2005) observe this transition for LBGs at $z \sim 4$ at 0.35 Mpc, the same comoving scale as we get.

4.1. Redshift Evolution of the Bias

Figure 10 shows as symbols the redshift evolution of the bias parameter measured at $8 h^{-1}$ Mpc, defined as $b_0 = \sigma_{8,0}/\sigma_{8,m}$ (see, e.g., Magliocchetti et al. 2000) for the different samples discussed above. The bias values for our GALEX and CFHTLS samples are reported in Tables 1 and 2, respectively.

The observed bias of star-forming galaxies shows a gradual increase with look-back time: at $z > 2$, UV galaxies are strongly
biased (Giavalisco & Dickinson 2001; Foucaud et al. 2003), with \( b_s \gtrsim 2 \), and at a given redshift the bias increases with FUV luminosity (FUV luminosity segregation). At \( z \sim 1 \), the mean bias is \( \langle b_s \rangle = 1.26 \pm 0.06 \), indicating that star-forming galaxies are closer tracers of the underlying mass distribution at that time. At \( z \leq 0.4 \), given the error bars, the mean bias is consistent with 0.8 for all GALEX samples \( \langle b_s \rangle = 0.79^{+0.1}_{-0.08} \), a slight antibias independent of the UV luminosity.

In Figure 10 we also show the effective bias evolution derived from the Mo & White (2002) formalism for different minimum dark matter halo (DMH) mass thresholds. A comparison can be made to the bias of star-forming galaxies, if one assumes that most halos do not host more than one star-forming galaxy. This coarse assumption is likely inaccurate for star-forming galaxies selected at high redshifts in FUV with a well-developed one-halo term (Kashikawa et al. 2006; Lee et al. 2006), but is acceptable at low redshifts in the FUV, since the one-halo term does not seem to play a major role, as discussed in § 3.2.

The minimum masses of the DMH that produce the bias derived for galaxies are \( 10^{12} M_\odot \lesssim M \lesssim 10^{13} M_\odot \) at \( z \gtrsim 2 \), \( 10^{11} M_\odot \lesssim M \lesssim 10^{12} M_\odot \) at \( z \sim 1 \), and \( M \lesssim 10^{10} M_\odot \) at \( z < 0.4 \). There is an obvious degeneracy of the models at low redshifts, but the observed bias is relatively independent of the UV luminosity.

In Figure 11 we show the bias as a function of the number density \( n_{\text{gal}} \) for UV-selected samples and the predicted relation between the effective bias and the number density of DMHs at \( z = 0, 0.5, 1, 2, 3 \) (curves from bottom to top). At high redshift (\( z > 1 \)), we observe the well-known luminosity segregation effect, with brighter galaxies (less abundant) having a larger bias, in good agreement with DMH models predictions (the less abundant, the more clustered). In contrast, at low \( z (z < 1) \) a significant departure to this relation is observed. At \( z \sim 0.9 \), the CFHTLS data show a bias slightly lower than the expected one according to the observed density with \( n_{\text{gal}} \) approximately 3 times lower than expected. This seems even worse for our brightest samples at \( z \sim 0.3 \), as these galaxies are about 10 times less numerous than expected according to their bias values. In the model discussed here, we implicitly assume that one DMH hosts one galaxy, which provides a fairly reasonable description of the observations at high \( z \), to the level of precision allowed here (see, e.g., Adelberger et al. 2005; Ouchi et al. 2004, for more detailed discussions on this point). At \( z < 1 \), this assumption may not be valid anymore, and our results suggest that star-forming galaxies (especially the brightest) are not hosted by a significant fraction of the DMHs with similar clustering properties. This implies that the DMH occupation fraction, which is roughly \( >0.5 \) at high redshift \( (z > 2) \), drops to 0.3 and 0.1 at \( z = 1 \) and 0.3 respectively.

4.3. Bias and FUV LD Fraction

The very limited overlap in FUV luminosities of the data at different redshifts does not allow a derivation of the bias evolution with redshift at fixed FUV luminosity. However, despite the fact that low-\( z \) samples reach fainter luminosities than high-\( z \) ones, they happen to probe the same fraction of total FUV luminosity densities, owing to the strong evolution of the FUV luminosity function with \( z \) (Arnouts et al. 2005). In particular, at all redshifts the samples are able to probe the bulk of star formation, i.e., they encompass a fraction of the FUV luminosity density (LD) greater than 0.5. This can be seen in Figure 12, where we show the bias as a function of the fraction of the total FUV LD enclosed by the different samples. This favorable situation allows us to track the evolution with redshift of the clustering at a fixed fraction of the FUV LD, an essentially constant fraction of the SFR.

The fraction of the LD for each sample is computed by comparing the total LD at the relevant redshift (from the FUV luminosity function parameters of Arnouts et al. [2005] and Sawicki.
range, but slightly higher than those obtained by Meneux et al. (2006) for late-type and irregular galaxies (their types 3 and 4, selected in the visible). At those redshifts, according to our CFHTLS sample, star-forming galaxies are modestly biased with \( \langle b_h \rangle = 1.26 \pm 0.06 \), which under the linear bias hypothesis implies they are closer tracers of the mass distribution than their higher redshift counterparts. As opposed to the dependence found at redshifts above 2 (Giavalisco & Dickinson 2001; Foucaud et al. 2003), no strong positive correlation between the bias and the FUV luminosity is observed in the local universe, but rather a slight anti-correlation or no correlation. At \( z \leq 0.4 \), given the error bars, the mean bias is consistent with 0.8 for all GALEX samples (\( \langle b_h \rangle = 0.79^{+0.10}_{-0.08} \)) independently of the UV luminosity.

5.1. Migration of the Bulk of Star Formation Sites from \( z = 3 \) to the Local Universe

In this study we find a decrease by a factor 3.1 of the bias with respect to mass, from redshifts near 3 to the local universe in the UV flux-limited samples, and more importantly in samples selected in UV luminosity so that they encompass a constant fraction of the luminosity density at all \( z \). This decrease is slightly larger than the factor of 2.7 derived from the Mo & White (2002) model for the \( M \geq 10^{12} M_\odot \) halos that host most star formation at redshift 3, an indication that star-forming galaxies tend to be hosted by halos of lower mass in the local universe. This is the main conclusion of the present study.

The “downsizing” scenario (Cowie et al. 1996; Juneau et al. 2005; Bundy et al. 2006; Heavens et al. 2004) states that the star formation shifts from high stellar mass systems at high redshift to low ones at low redshift. Our results extend this vision in the sense that the same trend is observed for the mass of the dark matter halos that host actively star-forming galaxies.

The DMH mass migration of the bulk of the star formation might be associated with regions of different densities. At high redshifts, LBGs studies show that active star formation traced by the UV light resides preferentially in overdense regions (Adelberger et al. 1998; Blaizot et al. 2004; Giavalisco 2002; Steidel et al. 1998; Tasker & Bryan 2006). At low redshift, Abbas & Sheth (2005) showed that the slope of the fitted power law is steeper in underdense regions, and that the correlation length is smaller. The observed steeper ACFs for the more UV-luminous galaxies at low \( z \) suggest that the most star-forming objects reside preferentially in regions where the local galaxy density is lower than for the fainter ones, a result in agreement with direct optical based studies of star formation as a function of galaxy density in the local universe (Gómez et al. 2003; Lewis et al. 2002).

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