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 $z \leq 1$ 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 δ) on the ultraviolet luminosity, as well as the linear bias evolution. We find that the bias parameter shows a gradual decline from high ($b_8 \gtrsim 2$) to low redshift ($b_8 \simeq 0.79^{+0.1}_{-0.08}$). 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 $z > 2$ ($10^{12} M_\odot \leq M_{\min} \leq 10^{13} M_\odot$, located in high-density regions) to less massive halos at low redshift ($M_{\min} \leq 10^{12} M_\odot$, located in low-density regions). This result extends the “downsizing” 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 “downsizing” (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 (Kereš 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

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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.

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 δ 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: $\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$, $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$.

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 $\text{FUV} < 22$ or $\text{NUV} < 22$.

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 spirals, and blue irregulars. We here-

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.

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).¹⁴ 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 ($3587 \text{ \AA}$) corresponds to $1848 \text{ \AA}$ at our mean redshift ($z = 0.94$). The fraction of objects lost (without any redshift selection) with a $i' = 26$ 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/CFHLS/> and <http://www.ast.obs-mip.fr/article204.html>.

TABLE 1
GALEX SAMPLES DESCRIPTION, POWER-LAW BEST-FIT PARAMETERS, COMOVING CORRELATION LENGTHS, AND BIAS

PARAMETER	FUV SAMPLES			NUV SAMPLES		
	All	FUV _{abs} < -18.3	FUV _{abs} > -18.3	All	NUV _{abs} < -18.8	NUV _{abs} > -18.8
$N_{\text{gal}}^{\text{a}}$	42065	22082	19983	97038	52567	44471
$\langle \text{FUV}_{\text{abs}} \rangle$	-18.3	-18.96	-17.57	-18.23	-18.76	-17.61
$\sigma_{\text{FUV}_{\text{abs}}}$	0.91	0.52	0.67	0.96	0.72	0.82
$\langle \text{NUV}_{\text{abs}} \rangle$	-18.58	-19.15	-17.95	-18.8	-19.43	-18.05
$\sigma_{\text{NUV}_{\text{abs}}}$	0.84	0.52	0.67	0.91	0.44	0.69
$\langle z \rangle^{\text{b}}$	0.18	0.23	0.13	0.25	0.32	0.17
σ_z^{b}	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
$A_W \times 10^3$	$9.4^{+2.4}_{-1.7}$	$7.3^{+3.4}_{-2.2}$	$33.9^{+17.4}_{-10.3}$	$3.6^{+0.6}_{-0.5}$	$4.1^{+1.0}_{-0.8}$	$22.4^{+5.7}_{-4.6}$
δ	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)	$4.6^{+0.6}_{-0.5}$	$4.6^{+0.9}_{-0.7}$	$5.4^{+1.5}_{-1.0}$	$4.1^{+0.3}_{-0.3}$	$4.9^{+0.4}_{-0.4}$	$5.5^{+0.8}_{-0.7}$
b_8	$0.74^{+0.08}_{-0.07}$	$0.76^{+0.13}_{-0.1}$	$0.83^{+0.17}_{-0.12}$	$0.69^{+0.05}_{-0.05}$	$0.83^{+0.07}_{-0.07}$	$0.86^{+0.09}_{-0.07}$

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.

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

FIG. 3.—Redshift selection based on the $(g' - r')$ vs. $(r' - i')$ diagram for the CFHTLS-D1 field. The small dots show galaxies with $z_{\text{phot}} < 0.7$ and big dots show galaxies with $z_{\text{phot}} > 0.7$. The line represents the adopted color-color selection criterion.

$\sigma[\Delta z/(1+z)] = 0.03$ 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

FIG. 4.—Redshift distribution of the CFHTLS sample. The dashed histogram shows the photometric redshift distribution of the galaxies selected with the color criterion alone, while the solid histogram shows the final redshift distribution after selecting objects with $0.7 < z_{\text{phot}} < 1.3$. The dotted and dot-dashed histograms show the redshift distributions of $\text{FUV}_{\text{abs}} < \langle \text{FUV}_{\text{abs}} \rangle$ and $\text{FUV}_{\text{abs}} > \langle \text{FUV}_{\text{abs}} \rangle$, respectively.

TABLE 2
CFHTLS SAMPLES DESCRIPTION, POWER-LAW BEST-FIT PARAMETERS,
COMOVING CORRELATION LENGTHS, AND BIAS

Parameter	All	FUV _{abs} < −19.41	FUV _{abs} > −19.41
$N_{\text{gal}}^{\text{a}}$	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
$\langle z \rangle^{\text{b}}$	0.94	1.04	0.84
σ_z^{b}	0.16	0.15	0.09
$n_{\text{gal}} (10^{-3} \text{ Mpc}^{-3})$	3.27 ± 2.90	0.62 ± 0.41	2.66 ± 2.58
$A_w \times 10^3$	$2.7^{+1.4}_{-1.0}$	$2.8^{+1.2}_{-0.8}$	$3.3^{+1.0}_{-0.7}$
δ	0.7 ± 0.09	0.74 ± 0.09	0.76 ± 0.07
r_0 (Mpc)	$4.92^{+0.5}_{-0.5}$	$5.48^{+0.5}_{-0.5}$	$4.66^{+0.24}_{-0.23}$
b_8	$1.24^{+0.08}_{-0.07}$	$1.38^{+0.06}_{-0.07}$	$1.16^{+0.03}_{-0.04}$

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 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: $w(\theta) = A_w \theta^{-\delta}$; we use a variable integral constraint (IC) with δ 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 red-

shift distribution. These quantities, as well as the bias parameter,¹⁵ 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 $\langle \text{UV}_{\text{abs}} \rangle$ of each sample. The angular scales probed for the *GALEX* samples are 0.005° – 0.4° (corresponding to comoving distances of 0.07 and 5.7 Mpc, respectively, at $z = 0.2$), and 0.002° – 0.4° 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 ($z \geq 2$).¹⁶ 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

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 Sawicki & Thompson (2006).

FIG. 5.—Angular correlation function of the *GALEX* subsamples cut in absolute UV magnitude: $M < \langle M \rangle$ is shown by squares, and $M > \langle M \rangle$ is shown by triangles; for comparison, the total sample (circles) is shown. Left: FUV. Right: NUV. The curves show the best-fit power law, not corrected for the integral constraint bias. The upper axis shows the comoving scales corresponding to angular scales at $z = 0.18$ (left) or $z = 0.24$ (right).

FIG. 6.— Angular correlation function of the CFHTLS subsamples cut in absolute UV magnitude: $M < \langle M \rangle$ is shown by squares, and $M > \langle M \rangle$ is shown by triangles; for comparison, the total sample (circles) is shown. The curves show the best-fit power laws with the integral constraint correction terms subtracted. The upper axis shows the comoving scales corresponding to angular scales at $z = 0.9$.

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.

FIG. 7.— Dependence on absolute FUV magnitude of the correlation length r_0 for low- and high-redshift rest-frame UV-selected galaxies (Adelberger et al. 2005, open squares; Arnouts et al. 2002, open star; Foucaud et al. 2003, open triangles; Giavalisco & Dickinson 2001, open circles). Our results are presented as filled circles (FUV) and filled squares (NUV) for the GALEX samples and as filled stars for the CFHTLS samples. The mean redshifts of the samples are color-coded. Note that the results from a given study (including ours) are not all obtained from independent samples. Hence, we distinguish global samples by plotting them with a bigger symbol size, in this figure and in the following ones as well, unless otherwise stated.

FIG. 8.— Same as Fig. 7, but vs. $\text{FUV}_{\text{abs}} - \text{FUV}_*(z)$.

3. At $z \lesssim 0.3$, 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 anticorrelation at the bright end $\text{FUV}_{\text{abs}} \leq -19$ 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 $\langle \text{FUV}_{\text{abs}} \rangle - \text{FUV}_*(z)$, where the evolution of FUV_* with z is 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 $\text{FUV}_{\text{abs}} - \text{FUV}_*$, 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 $\text{FUV}_{\text{abs}} - \text{FUV}_*$ 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 $\text{FUV}_{\text{abs}} - \text{FUV}_*$ 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.

FIG. 9.—Dependence on absolute FUV magnitude of the slope δ of the correlation function for low- and high-redshift rest-frame UV-selected galaxies. Results shown here come from studies allowing δ as a free parameter (Adelberger et al. 2005, *open squares*; Giavalisco & Dickinson 2001, *open circles*; Ouchi et al. 2005, *crosses*) (results from the fit with integral constraint). Our results are presented as filled circles (FUV) and filled squares (NUV) for the *GALEX* samples and as filled stars for the CFHTLS samples; the error on δ comes from the fitting procedure, and the horizontal bars for our samples reflect the standard deviations of FUV_{abs} . The mean redshifts of the samples are color-coded.

3.2. ACF Slope Segregation with FUV Luminosity

3.2.1. ACF Slope

The slope of the ACF (δ), 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 ($\delta \simeq 0.81 \pm 0.07$) 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 δ 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 ($r \lesssim 0.35$ Mpc). This effect produces an apparent steepening of the observed slope δ .

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 , δ , and bias b_8) 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 ~ 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 $\sim 1.5\text{--}3$ 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 ~ 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., Giavalisco & Dickinson 2001; 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 Mo & White (2002) models. For galaxies, we assume a linear bias to convert r_0 in $\sigma_{8,g}$, a common, although questionable, assumption (see, e.g., Marinoni et al. 2005).

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 $b_8 = \sigma_{8,g}/\sigma_{8,m}$ (see, e.g., Magliocchetti et al. 2000) for the different samples discussed above.¹⁷ 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

¹⁷ For Adelberger et al. (2005) subsamples, δ values are not available; we assumed that the slopes are the same as those of their global samples. The expected relative error on the inferred bias is lower than 10% if $0 < \delta < 1$.

FIG. 10.—Evolution with redshift of the bias of rest-frame UV-selected galaxies (symbols are the same as in Fig. 7). The curves show the effective bias of halos more massive than $M_{\min}$ (color-coded) according to Mo & White (2002; see also Paper I). The inset is an enlargement of the low-redshift area.

biased (Giavalisco & Dickinson 2001; Foucaud et al. 2003), with $b_8 \gtrsim 2$, and at a given redshift the bias increases with FUV luminosity (FUV luminosity segregation). At $z \sim 1$, the mean bias is $\langle b_8 \rangle = 1.26 \pm 0.06$, 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 ($\langle b_8 \rangle = 0.79^{+0.1}_{-0.08}$), 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 $z \geq 2$, $10^{11} M_{\odot} \lesssim M \lesssim 10^{12} M_{\odot}$ at $z \simeq 1$, and $M \leq 10^{12} M_{\odot}$ at $z < 0.4$. There is an obvious degeneracy of the models at low redshifts, but the locally observed bias is definitely in the region of low cutoff masses. This is a hint that observed star-forming galaxies at low redshift reside more preferentially in less massive halos than do high- z star-forming galaxies.

4.2. Bias and Galaxy Number Density

In Figure 11 we show the bias as a function of the galaxy number density n_{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

FIG. 11.—Bias of rest-frame UV-selected galaxies as a function of galaxy number density. The curves show the expected relation for the effective bias of dark matter halos at redshifts $z = 0, 0.5, 1, 2$, and 3 , from bottom to top. We plot only independent samples here. The symbols are the same as in Fig. 10.

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_{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 be not 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

FIG. 12.—Bias of rest-frame UV-selected galaxies as a function of the fraction of the FUV total luminosity density represented by each sample. The symbols are the same as in Fig. 10.

& Thompson [2006]) to the LD enclosed by each sample according to its flux limits converted to FUV luminosity cuts.¹⁸

Note that we do not attempt to correct for galaxy internal dust attenuation. As brighter UV galaxies present higher extinction in the local universe (Buat et al. 2005), the strong brightening of FUV_{*} with redshift (e.g., Arnouts et al. 2005) may introduce a small bias, as a given LD fraction could not correspond exactly to the same star formation rate fraction at the different redshifts we explore here.

The plot confirms the result already apparent in Figure 10 of a significant decrease in the bias of UV-selected galaxies from high to low redshifts, but now selected on the basis of a physically defined parameter, the fraction of the FUV luminosity density. Near an LD fraction of 0.5, the bias is divided by a factor of 3, shifting from 2.5 in the redshift range 2–3 down to 0.8 in the local universe.

5. DISCUSSION

In Paper I we reported on the overall clustering properties of the UV-selected galaxies in *GALEX* samples, the largest ones available to date at low redshift and at these wavelengths. These samples allow for the first time an investigation of the clustering properties of UV-selected galaxies as a function of different parameters at $z \lesssim 1$, which can be compared to higher redshift samples also selected in the rest-frame FUV.

The measurements from the *GALEX* samples confirm previous results for rest-UV-selected galaxies at low redshifts indicating that they are weakly clustered (Heinis et al. 2004), with an autocorrelation function well approximated by a power law in the range 0.2–5 Mpc.

At $z \sim 1$, the correlation length of the rest-UV-selected galaxies from CFHTLS u' data is found comparable to those of the emission-line samples from Coil et al. (2004) in the same redshift

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 $\langle b_8 \rangle = 1.26 \pm 0.06$, 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 ($\langle b_8 \rangle = 0.79^{+0.10}_{-0.08}$) 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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¹⁸ Note that while LBG samples are by construction volume-limited, we cannot adopt this approach for the *GALEX* samples due to limited statistics. This means that faintest galaxies are underrepresented, especially in our higher redshift *GALEX* samples. However, as we do not observe a strong luminosity dependence of the bias within the *GALEX* samples, we expect that this has only a small impact.

REFERENCES

- Abbas, U., & Sheth, R. K. 2005, *MNRAS*, 364, 1327
- Adelberger, K. L., Steidel, C. C., Giavalisco, M., Dickinson, M., Pettini, M., & Kellogg, M. 1998, *ApJ*, 505, 18
- Adelberger, K. L., Steidel, C. C., Pettini, M., Shapley, A. E., Reddy, N. A., & Erb, D. K. 2005, *ApJ*, 619, 697
- Allen, P. D., Moustakas, L. A., Dalton, G., MacDonald, E., Blake, C., Clewley, L., Heymans, C., & Wegner, G. 2005, *MNRAS*, 360, 1244
- Arnouts, S., et al. 2002, *MNRAS*, 329, 355
- . 2005, *ApJ*, 619, L43
- Baldry, I. K., Glazebrook, K., Brinkmann, J., Ivezić, Ž., Lupton, R. H., Nichol, R. C., & Szalay, A. S. 2004, *ApJ*, 600, 681
- Benoist, C., Maurogordato, S., da Costa, L. N., Cappi, A., & Schaeffer, R. 1996, *ApJ*, 472, 452
- Benson, A. J., Bower, R. G., Frenk, C. S., Lacey, C. G., Baugh, C. M., & Cole, S. 2003, *ApJ*, 599, 38
- Benson, A. J., Frenk, C. S., Baugh, C. M., Cole, S., & Lacey, C. G. 2001, *MNRAS*, 327, 1041
- Berlind, A. A., et al. 2003, *ApJ*, 593, 1
- Blaizot, J., Guiderdoni, B., Devriendt, J. E. G., Bouchet, F. R., Hatton, S. J., & Stoehr, F. 2004, *MNRAS*, 352, 571
- Buat, V., et al. 2005, *ApJ*, 619, L51
- Budavári, T., et al. 2003, *ApJ*, 595, 59
- Bundy, K., et al. 2006, *ApJ*, 651, 120
- Cardelli, J. A., Clayton, G. C., & Mathis, J. S. 1989, *ApJ*, 345, 245
- Cattaneo, A., Dekel, A., Devriendt, J., Guiderdoni, B., & Blaizot, J. 2006, *MNRAS*, 370, 1651
- Coil, A. L., et al. 2004, *ApJ*, 609, 525
- Connolly, A. J., Csabai, I., Szalay, A. S., Koo, D. C., Kron, R. G., & Munn, J. A. 1995, *AJ*, 110, 2655
- Cowie, L. L., Songaila, A., Hu, E. M., & Cohen, J. G. 1996, *AJ*, 112, 839
- Croton, D. J., et al. 2006, *MNRAS*, 365, 11
- Foucaud, S., McCracken, H. J., Le Fèvre, O., Arnouts, S., Brodwin, M., Lilly, S. J., Crampton, D., & Mellier, Y. 2003, *A&A*, 409, 835
- Giavalisco, M. 2002, *ARA&A*, 40, 579
- Giavalisco, M., & Dickinson, M. 2001, *ApJ*, 550, 177
- Gómez, P. L., et al. 2003, *ApJ*, 584, 210
- Guzzo, L., et al. 2000, *A&A*, 355, 1
- Heavens, A., Panter, B., Jimenez, R., & Dunlop, J. 2004, *Nature*, 428, 625
- Heinis, S., Treyer, M., Arnouts, S., Milliard, B., Donas, J., Gal, R., Martin, D. C., & Viton, M. 2004, *A&A*, 424, L9
- Hopkins, A. M. 2004, *ApJ*, 615, 209
- Ilbert, O., et al. 2006, *A&A*, 457, 841
- Jimenez, R., Panter, B., Heavens, A. F., & Verde, L. 2005, *MNRAS*, 356, 495
- Juneau, S., et al. 2005, *ApJ*, 619, L135
- Kashikawa, N., et al. 2006, *ApJ*, 637, 631
- Kereš, D., Katz, N., Weinberg, D. H., & Davé, R. 2005, *MNRAS*, 363, 2
- Kravtsov, A. V., Berlind, A. A., Wechsler, R. H., Klypin, A. A., Gottlöber, S., Allgood, B., & Primack, J. R. 2004, *ApJ*, 609, 35
- Landy, S. D., & Szalay, A. S. 1993, *ApJ*, 412, 64
- Lee, K.-S., Giavalisco, M., Gnedin, O. Y., Somerville, R. S., Ferguson, H. C., Dickinson, M., & Ouchi, M. 2006, *ApJ*, 642, 63
- Le Fèvre, O., et al. 2005, *A&A*, 439, 845
- Lewis, I., et al. 2002, *MNRAS*, 334, 673
- Lilly, S. J., Le Fèvre, O., Hammer, F., & Crampton, D. 1996, *ApJ*, 460, L1
- Madau, P., Ferguson, H. C., Dickinson, M. E., Giavalisco, M., Steidel, C. C., & Fruchter, A. 1996, *MNRAS*, 283, 1388
- Madgwick, D. S., et al. 2002, *MNRAS*, 333, 133
- Magliocchetti, M., Bagla, J. S., Maddox, S. J., & Lahav, O. 2000, *MNRAS*, 314, 546
- Magliocchetti, M., & Porciani, C. 2003, *MNRAS*, 346, 186
- Marinoni, C., et al. 2005, *A&A*, 442, 801
- McCracken, H. J., et al. 2003, *A&A*, 410, 17
- Meneux, B., et al. 2006, *A&A*, 452, 387
- Milliard, B., et al. 2006, *ApJS*, 173, 494 (Paper I)
- Mo, H. J., & White, S. D. M. 2002, *MNRAS*, 336, 112
- Norberg, P., et al. 2001, *MNRAS*, 328, 64
- . 2002, *MNRAS*, 332, 827
- Ouchi, M., et al. 2001, *ApJ*, 558, L83
- . 2004, *ApJ*, 611, 685
- . 2005, *ApJ*, 635, L117
- Peebles, P. J. E. 1980, *The Large-Scale Structure of the Universe* (Princeton: Princeton Univ. Press)
- Roche, N., & Eales, S. A. 1999, *MNRAS*, 307, 703
- Sawicki, M., & Thompson, D. 2006, *ApJ*, 642, 653
- Schiminovich, D., et al. 2005, *ApJ*, 619, L47
- Schlegel, D. J., Finkbeiner, D. P., & Davis, M. 1998, *ApJ*, 500, 525
- Schultheis, M., Robin, A. C., Reylé, C., McCracken, H. J., Bertin, E., Mellier, Y., & Le Fèvre, O. 2006, *A&A*, 447, 185
- Steidel, C. C., Adelberger, K. L., Dickinson, M., Giavalisco, M., Pettini, M., & Kellogg, M. 1998, *ApJ*, 492, 428
- Sullivan, M., Treyer, M. A., Ellis, R. S., Bridges, T. J., Milliard, B., & Donas, J. 2000, *MNRAS*, 312, 442
- Tasker, E. J., & Bryan, G. L. 2006, *ApJ*, 642, L5
- Willmer, C. N. A., da Costa, L. N., & Pellegrini, P. S. 1998, *AJ*, 115, 869
- Wilson, G., Cowie, L. L., Barger, A. J., & Burke, D. J. 2002, *AJ*, 124, 1258
- Zehavi, I., et al. 2002, *ApJ*, 571, 172
- . 2004, *ApJ*, 608, 16
- . 2005, *ApJ*, 630, 1