THE H$\alpha$ LUMINOSITY FUNCTION AND STAR FORMATION RATE AT $z \approx 0.24$
IN THE COSMOS 2 SQUARE DEGREE FIELD


ABSTRACT

To derive a new H$\alpha$ luminosity function and to understand the clustering properties of star-forming galaxies at $z \approx 0.24$, we have made a narrowband imaging survey for H$\alpha$-emitting galaxies in the Hubble Space Telescope (HST) COSMOS 2 square degree field. We used the narrowband filter NB816 ($\lambda_c = 8150 \, \AA$, $\Delta \lambda = 120 \, \AA$) and sampled H$\alpha$ emitters with EW$_{\text{H}$\alpha$}(H$\alpha$ + [N II]) $> 12 \, \AA$ in a depth range between $z = 0.233$ and 0.251 corresponding to a depth of 70 Mpc. We obtained 980 H$\alpha$-emitting galaxies in a sky area of 5540 arcmin$^2$, corresponding to a survey volume of $3.1 \times 10^4$ Mpc$^3$. We derive a H$\alpha$ luminosity function with a best-fit Schechter function parameter set of $\alpha = -1.35^{+0.11}_{-0.13}$, $\log L_*/L_{\odot} = -2.65^{+0.27}_{-0.38}$, and $\log L_{\text{dust}}(\text{ergs s}^{-1}) = 41.94^{+0.38}_{-0.23}$. The H$\alpha$ luminosity density is $2.7^{+0.6}_{-0.7} \times 10^{44}$ erg s$^{-1}$ Mpc$^{-3}$. After subtracting the AGN contribution (15%) to the H$\alpha$ luminosity density, the star formation rate density is evaluated as $1.8^{+0.7}_{-0.4} \times 10^{-2} M_\odot$ yr$^{-1}$ Mpc$^{-3}$. The angular two-point correlation function of H$\alpha$-emitting galaxies of log $L$(H$\alpha$) $> 39.8$ is well fit by a power-law form of $w(\theta) = 0.013^{+0.002}_{-0.001} \theta^{-0.88^{+0.03}_{-0.03}}$, corresponding to the correlation function of $\xi(r) = (r/1.9 \, \text{Mpc})^{-1.88}$. We also find that the H$\alpha$ emitters with higher H$\alpha$ luminosity are more strongly clustered than those with lower luminosity.

Subject headings: galaxies: distances and redshifts — galaxies: evolution — galaxies: luminosity function, mass function

Online material: machine-readable table

1. INTRODUCTION

It is important to understand when and where intense star formation occurred during the course of galaxy evolution. Although the star formation history in individual galaxies is interesting, a general trend of star formation in galaxies as a function of time (or redshift) also provides important insights on the global star formation history as well as on the metal enrichment history in the universe. Therefore, the star formation rate density (SFRD) is one of the important observables for our understanding of galaxy formation and evolution. In the last decade, many works have followed the pioneer work of Madau et al. (1996), which compiled the evolution of SFRD, $\rho_{\text{SFR}}$, as a function of redshift for the first time. The evolution of $\rho_{\text{SFR}}$ is now widely accepted as follows: $\rho_{\text{SFR}}$ steeply increases from $z \approx 0$ to $z \approx 1$, and seems to be constant between $z \approx 2$ and $z \approx 5$ and may decline beyond $z \approx 5$ (Hopkins 2004 and references therein; Giavalisco et al. 2004; Taniguchi et al. 2005; Bouwens & Illingworth 2006).

Recent observations by the Galaxy Evolution Explorer (GALEX) and the Spitzer Space Telescope have confirmed that $\rho_{\text{SFR}}$ increases from $z \approx 0$ to $z \approx 1$ (e.g., Schiminovich et al. 2005; Le Floc’h et al. 2005). However, their observations show that the IR luminosity density evolves as $(1 + z)^4$, while the UV luminosity density evolves as $(1 + z)^2$. This may imply that extinction by dust and reradiation from dust becomes to play a more important role at higher redshift. One of the remaining problems in this field is a relation between star formation activity and large-scale structure formation. To study this issue, wide-field deep surveys are important.

There are several star formation rate (SFR) estimators, e.g., UV continuum, H$\alpha$ emission, [O ii] emission, far-infrared (FIR) emission (Kennicutt 1998), and radio continuum (Condon 1992). Each estimator has both advantages and disadvantages to estimate the SFR. UV continuum and nebular emission lines are considered to be direct tracers of hot massive young stars. However, they are often affected by dust obscuration. On the other hand, FIR and radio continuum are insensitive to dust obscuration. FIR emission is due to the dust heated by the general interstellar radiation field. If most of the bolometric luminosity of a galaxy absorbed by dust
is radiated from young stars, as in the case of dusty starbursts, the FIR luminosity is a good SFR estimator. For early-type galaxies, much of the FIR emission is considered to be related to the old stars and the FIR emission is not a good SFR estimator (Sauvage & Thuan 1992; Kennicutt 1998). For star-forming galaxies, there is a tight radio-FIR correlation (Condon 1992). This relation suggests that the radio continuum also provides a good SFR estimator. The radio continuum is considered to be dominated by synchrotron radiation from relativistic electrons, which are accelerated in supernova remnants (SNRs; Lequeux 1971; Kennicutt 1983a; Gavazzi et al. 1986). We note that the radio continuum emission of some galaxies is dominated by the AGN component, although such galaxies are distinguished from star-forming galaxies by using the tight radio-FIR correlation (Sopp & Alexander 1991; Condon 1992). The nearly linear radio-FIR correlation also suggests that the radio continuum is affected by the efficiency of cosmic-ray confinement, since the degree of dust attenuation becomes larger for more luminous galaxies (Bell 2003). Although SFRs evaluated from different SFR estimators are consistent with each other within a factor of 3 if the appropriate correction is applied for each case (e.g., Hopkins et al. 2003; Charlot & Longhetti 2001; Charlot et al. 2002), samples selected with a different method may have different biases. For example, samples selected by an objective-prism imaging survey are biased toward the systems with large equivalent width (e.g., Gallego et al. 1995), while those selected by UV radiation are biased against heavily dusty galaxies (Meurer et al. 2006). To evaluate the true SFRD, it is important to correct the obtained SFR appropriately and to know probable biases for the sample selection.

In this work, we use the H$_\alpha$ luminosity as a SFR estimator. The H$_\alpha$ luminosity is directly connected to the ionizing photon production rate. There are two approaches to measure H$_\alpha$ luminosities of galaxies. One is a spectroscopic survey, and the other is a narrowband imaging survey. Although spectroscopic observations tell us details of emission line properties, e.g., Balmer decrement, metallicity, and so on, it is difficult to obtain spectra of a large sample of faint galaxies. On the other hand, narrowband imaging observations make it possible to measure an emission-line flux of galaxies over a wide field of view. Another advantage of narrowband imaging is that aperture corrections do not need to evaluate the total flux of H$_\alpha$ emission. However, there are some shortcomings with this method: e.g., a narrowband filter cannot separate H$_\alpha$ emission from [N II] 2.6548, 6583 emission, and we cannot evaluate the obscuration degree for each galaxy. Therefore, we must correct these effects statistically. Since the redshift coverage of emission-line galaxies discovered by the narrowband imaging method is restricted, the survey volume of emission-line galaxies is small. Therefore, it is difficult to obtain a large sample of H$_\alpha$ emitters. If this is the case, brighter (i.e., rarer) H$_\alpha$ emitters could be missed in such an imaging survey. In order to study the H$_\alpha$ luminosity function unambiguously, we need a large sample of H$_\alpha$ emitters covering a wide range of H$_\alpha$ luminosity. On the other hand, this restriction allows us to investigate large-scale structures of emission-line galaxies (mostly, star-forming galaxies) at a concerned redshift slice.

Motivated by this in part, we have carried out a narrowband imaging survey of the HST COSMOS field centered at $\alpha$(J2000.0) = 10$^h$06$^m$28.6$^s$ and $\delta$(J2000.0) = +02$^\circ$12$^\prime$21.0$''$ (the Cosmic Evolution Survey, Scoville et al. 2007). Since this field covers 2 deg$^2$, it is suitable for our purpose. Our optical narrowband imaging observations of the HST COSMOS field have been made with the Suprime-Cam (Miyazaki et al. 2002) on the Subaru Telescope (Kaifu et al. 2000; Iye et al. 2004). Since the Suprime-Cam consists of 10 2k $\times$ 4k CCD chips and provides a very wide field of view (34’’ $\times$ 27’’), this is suitable for any wide-field optical imaging surveys. In our observations, we used the narrow-passband filter, NB816, centered at 8150 Å with the passband of $\Delta\lambda = 120$ Å. Our NB816 imaging data are also used to search both for Ly$\alpha$ emitters at $z \approx 5.7$ (Murayama et al. 2007) and for [O III] emitters at $z \approx 1.2$ (Takahashi et al. 2007). In this paper, we present our results on H$_\alpha$ emitters at $z \approx 0.24$ in the HST COSMOS field.

Throughout this paper, magnitudes are given in the AB system. We adopt a flat universe with $\Omega_{\text{matter}} = 0.3$, $\Omega_{\Lambda} = 0.7$, and $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$.

2. PHOTOMETRIC CATALOG

In this analysis, we use the COSMOS official photometric redshift catalog, which includes objects whose total $i$ magnitudes ($i^\prime$ or $i$) are brighter than 25. The catalog presents 3” diameter aperture magnitude of Subaru Suprime-Cam $B$, $V$, $r^\prime$, $i^\prime$, $z^\prime$, and NB816. Details of the Suprime-Cam observations are given in Taniguchi et al. (2007). Details of the COSMOS official photometric redshift catalog is also described in Capak et al. (2007) and Mobasher et al. (2007). Since the accuracy of standard star calibration ($\pm 0.05$ mag) is too large to obtain an accurate photometric redshift, Capak et al. (2007) recalibrated the photometric zero points for photometric redshift using the SEDs of galaxies with spectroscopic redshift. Following the recommendation of Capak et al. (2007), we apply the zero-point correction to the photometric data in the official catalog. The offset values are 0.189, 0.04, $-0.040$, $-0.020$, 0.054, and $-0.072$ for $B$, $V$, $r^\prime$, $i^\prime$, $z^\prime$, and NB816, respectively. The zero-point–corrected limiting magnitudes are $B = 27.4$, $V = 26.5$, $r^\prime = 26.6$, $i^\prime = 26.1$, $z^\prime = 25.4$, and NB816 = 25.6 for a 3 σ detection on a 3” diameter aperture. The catalog also includes 3” diameter aperture magnitude of CFHT $i^\prime$. We use the CFHT $i^\prime$ magnitude for bright galaxies with $i^\prime < 21$ because such bright galaxies appear to be slightly affected by the saturation effect in $i^\prime$ obtained with Suprime-Cam. We also apply the Galactic extinction correction adopting the median value $E(B - V) = 0.0195$ (Capak et al. 2007) for all objects. A photometric correction for each band is as follows (see Table 8 of Capak et al. 2007): $A_B = 0.079$, $A_V = 0.061$, $A_r = 0.050$, $A_i = 0.037$, $A_z = 0.028$, $A_{NB816} = 0.034$, and $A_r = 0.037$.

3. RESULTS

3.1. Selection of NB816-Excess Objects

We select H$_\alpha$ emitter candidates using 3” diameter aperture magnitude in the official catalog. In order to select NB816-excess objects efficiently, we need the magnitude of a frequency-matched continuum. Since the effective frequency of the NB816 filter (367.8 THz) is different either from those of the $i^\prime$ (394.9 THz) and $z^\prime$ (333.6 THz) filters, we make a new frequency-matched continuum, the “$i^\prime$z” continuum, using the following linear combination; $f_{i^\prime} = 0.57f_i + 0.43f_z$, where $f_i$ and $f_z$ are the $i^\prime$ and $z^\prime$ flux densities, respectively. Its 3 σ limiting magnitude is $i^\primez \approx 26.3$ in a 3” diameter aperture. For the bright galaxies with $i^\prime < 21$, the “$i^\primez$” continuum is calculated as $f_{i^\prime} = 0.57f_i + 0.43f_z$, where $f_i$ is the $i^\prime$ flux density, since the $i^\prime$ magnitude is incorrect because of the saturation effect.

Since we use the ACS catalog prepared for studying weak lensing (Leauthaud et al. 2007) to separate galaxies from stars, our survey area is restricted to the area mapped in the $i_{605}$ band with the Advanced Camera for Surveys (ACS) on HST. After subtracting...
the masked-out area, the effective survey area is 5540 arcmin$^2$. Since the covered redshift range is between 0.233 and 0.251 ($\Delta z = 0.018$) and the corresponding survey depth is 70 Mpc, our effective survey volume is $3.1 \times 10^6$ Mpc$^3$.

We selected NB 816-excess objects using the following criteria:

$$iz - NB816 > 0.1$$

and

$$iz - NB816 > 3\sigma(iz - NB816),$$

where

$$3\sigma(iz - NB816) = -2.5\log\left[1 - \sqrt{(f_{3\sigma_NB816})^2 + (f_{3\sigma_{iz}})^2 / f_{NB816}}\right].$$

In the calculation of $3\sigma(iz - NB816)$, we applied the Galactic extinction correction to the limiting magnitudes of the $i'$ and $z'$ bands. The former criterion corresponds $EW_{\text{obs}} > 12$ Å. This criterion is exactly same as that of Fujita et al. (2003) and similar to that of Tresse & Maddox (1998) [EW(H$\alpha + [\text{N II}])_{\text{rest}} > 10$ Å]. Taking account of the scatter of the $iz - NB816$ color, we added the latter criterion. These two criteria are shown by the solid and dashed lines, respectively, in Figure 1. As we will describe in the next section, we use the broadband colors of galaxies to separate H$\alpha$ emitters from other emission-line galaxies. To avoid the ambiguity of broadband colors, we select galaxies detected above $3 \sigma$ in all bands. Finally, we find 6176 galaxies that satisfy the above criteria.

### 3.2. Selection of NB816-Excess Objects at $z \approx 0.24$

The emission-line galaxy candidates selected above include not only H$\alpha$ emitters at $z = 0.24$, but also possibly [O III] emitters at $z = 0.63$, or H$\beta$ emitters at $z = 0.68$, or [O III] emitters at $z = 1.19$ (Tresse et al. 1999; Kennicutt 1992b). We also note here that the narrowband filter passband is too wide to separate [N II] $\lambda\lambda 6548, 6583$ from H$\alpha$.

In order to distinguish H$\alpha$ emitters at $z \approx 0.24$ from emission-line objects at other redshifts, we investigate their broadband color properties by comparing the observed colors of our 6176 emitters with model ones that are estimated by using the model spectral energy distribution derived by Coleman et al. (1980). In Figures 2 and 3, we show the $B - V$ versus $V - r'$ and $B - r'$ versus $i' - z'$ color-color diagrams of the 6176 sources and the loci of model galaxies. Then we find that H$\alpha$ emitters at $z \approx 0.24$ can be selected by adopting the following three criteria: (1) $B - V > 2(V - r') - 0.2$; (2) $B - r' > 5(i' - z') - 1.3$; and (3) $B - r' > 0.7(i' - z') + 0.4$. We can clearly distinguish H$\alpha$ emitters from [O III] or H$\beta$ emitters using the first criterion. We can also distinguish H$\alpha$ emitters from [O III] emitters using the second and third criteria. We have checked the validity of our photometric selection criteria using both the photometric data and spectroscopic redshifts of galaxies in the GOODS-N region (Cowie et al. 2004). Galaxies with redshifts corresponding to our H$\alpha$, [O III], H$\beta$, and [O III] emitters are separately plotted in Figures 2 and 3. It is shown that our criteria can well separate H$\alpha$ emitters from [O III], H$\beta$, and [O III] emitters. These criteria give us a sample of 981 H$\alpha$-emitting galaxy candidates. The properties of GOODS-N galaxies presented in Figures 2 and 3 suggest that there is little contamination in our H$\alpha$ emitter sample.

### 3.3. H$\alpha$ Luminosity

As we mentioned in §1, one of the advantages of narrowband imaging is to measure the total flux of H$\alpha$ emission directly without any aperture correction. To derive the total H$\alpha$ flux, we have used the total flux of $i'$ (or $i''$), $z'$, and NB816 using public images. Our procedure is the same as that given in Capak et al. (2007): MAG_AUTO in SExtractor (Bertin & Arnouts 1996). Because of the contamination of the foreground galaxies, one galaxy has a negative value of $iz - NB816$ based on the total magnitudes. We do not use this object in further analysis. Therefore, our final sample contains 980 H$\alpha$ emitters.

Adopting the same method as that used by Pascual et al. (2001), we express the flux density in each filter band as the sum of the line flux, $f_L$, and the continuum flux density, $f_C$:

$$f_{NB} = f_C + \frac{F_L}{\Delta NB},$$

$$f_i = f_C + \frac{F_L}{\Delta i'},$$

$$f_{i'} = f_C,$$

where $\Delta NB$ and $\Delta i'$ are the effective bandwidths of NB816 and $i'$, respectively. The $iz$ continuum, $f_{iz}$, is expressed as

$$f_{iz} = 0.57f_{i'} + 0.43f_{i'} = f_C + 0.57\frac{F_L}{\Delta i'}.$$  

Using equations (4) and (7), the line flux $F_L$ is calculated by

$$F_L = \Delta NB \frac{f_{NB} - f_{iz}}{1 - 0.57(\Delta NB/\Delta i')}.$$  

The line flux evaluated above includes both H$\alpha$ and [N II] $\lambda\lambda 6548, 6583$ emission since the narrowband filter cannot separate...
the contribution of these lines. The flux of the H\textalpha emission line is also affected by the internal extinction. Therefore, we have to correct the contamination of the [N\textsc{ii}] \lambda6548, 6583 emission and the internal extinction $A_{H\alpha}$. Although several correction methods have been proposed (e.g., Kennicutt 1992a, Gallego et al. 1997, Tresse et al. 1999, and Helmboldt et al. 2004 for [N\textsc{ii}] contamination; Kennicutt 1983b, 1998, Niklas et al. 1997, Hopkins et al. 2001, and Afonso et al. 2003 for $A_{H\alpha}$), there are few studies that give both corrections based on a single sample of galaxies. Helmboldt et al. (2004) derived the relation between [N\textsc{ii}]/H\textalpha and $M_R$ and that between $A_{H\alpha}$ and $M_R$ based on the data of the Nearby Field Galaxy Survey (Jansen et al. 2000a, 2000b). We
therefore adopt their relations to correct the [N II] contamination
and \( A_H \). After correcting to the AB magnitude system (Meurer
et al. 2006), the relation between [N II]/H\( \alpha \) and \( M_R \) is

\[
\log w_{6583} = -0.13 M_R - 3.30, 
\]

where

\[
\log w_{6583} = \frac{F_{[\text{NII}6583 \, \AA]}}{F_{H\alpha}},
\]

and that between \( A_{H\alpha} \) and \( M_R \) is

\[
\log A_{H\alpha} = -0.12 M_R - 2.47. 
\]

To derive \( M_R \) used in equations (9) and (11) for each galaxy, we
assume that the redshift of the galaxy is \( z = 0.242 \). We have also
calculated the \( k \)-correction using the average SED of the Coleman
et al. (1980) Sbc and Irr. Taking account of the luminosity distance
and \( k \)-correction (average value of Scd and Irr), \( M_R \) is calculated
from \( r' \)-band total magnitude, \( r' \), as \( M_R = r' - 40.90 \).

In addition to the above corrections, we also apply a statistical
correction (21%; the average value of flux decrease due to the
filter transmission) to the measured flux because the filter transmis-
sion function is not square in shape (Fujita et al. 2003). Note
that this value is slightly different from the value (28%) used
in Fujita et al. (2003). Our new value is re-estimated by using the
latest filter response function. The H\( \alpha \) flux is given by

\[
F_{\text{cor}}(H\alpha) = F_L \frac{f(H\alpha)}{f([\text{NII}])} \times 10^{0.4 \Delta m} \times 1.21. 
\]

Finally, the H\( \alpha \) luminosity is estimated by

\[
L(H\alpha) = 4\pi d_L^2 F_{\text{cor}}(H\alpha). 
\]

In this procedure, we assume that all the H\( \alpha \) emitters are located at
\( z = 0.242 \), which is the redshift corresponding to the central
wavelength of our NB816 filter. Therefore, the luminosity
distance is set to be \( d_L = 1213 \) Mpc.

We summarize the total magnitude of \( i', z' \), NB816, and \( i \) and
the color excess of \( i - NB816 \) for our H\( \alpha \) emission-line galaxy
candidates in Table 1. Table 1 also includes \( \log F_L, \log F_{\text{cor}}(H\alpha) \),
and \( \log L(H\alpha) \).

4. DISCUSSION

4.1. Luminosity Function of H\( \alpha \) Emitters

Figure 4 shows the H\( \alpha \) luminosity function (LF) at \( z \approx 0.24 
for our H\( \alpha \) emitter sample. The H\( \alpha \) LF is constructed by the
relation

\[
\Phi(\log L) = \frac{1}{\Delta \log L} \sum_i \frac{1}{V_i}, 
\]

with

\[
|\log L - \log L_1| < \frac{1}{2} \Delta \log L, 
\]

where \( V_j \) is the volume of the narrowband slice in the range of
redshift covered by the filter. We have used \( \Delta \log L(H\alpha) = 0.2 \).
If the shape of the filter response is square, our survey volume is
\( 3.1 \times 10^6 \) Mpc\(^3 \). However, the effective survey volume is
affected by the shape of the filter transmission curve. For example,
since the transmission at 8092 Å is one-half of the peak value,
the color excess, \( i - NB816 \), of an H\( \alpha \) emitter at \( z = 0.233 \) with
EW(H\( \alpha \) + [N II]) = 12 Å is observed as 0.05, which does not
satisfy our selection criterion, \( i - NB816 > 0.1 \). Taking account
of the filter shape in the computation of the volume, the correction
can be as large as 23% for the faintest galaxies. Adopting the
Schechter function form (Schechter 1976), we obtain the follow-
ring best-fit parameters for our H\( \alpha \) emitters with \( L(H\alpha) > 10^{38} \) ergs
s\(^{-1} \): \( \alpha = -1.35^{+0.11}_{-0.13}, \log \phi_0 = -2.65^{+0.27}_{-0.38}, \) and
\( \log L_\ast(\text{ergs s}^{-1}) = 41.94^{+0.23}_{-0.23} \) (black solid line).

![Fig. 4.—Our H\( \alpha \) luminosity function (filled squares and thick solid line) and H\( \alpha \) luminosity functions from previous works. The Tresse & Maddox (1998) H\( \alpha \) luminosity function at \( z \leq 0.3 \) is shown by the dashed line. The H\( \alpha \) luminosity functions derived by Fujita et al. (2003), Hipplein et al. (2003), and Ly et al. (2007) are shown by the dotted line, the dot-dashed line, and dashed and double-dotted line, respectively. Data points of the Ly et al. (2007) H\( \alpha \) LF are shown as gray crosses.](image-url)
Together with our Hα LF, Figure 4 shows Hα LFs of previous studies in which Hα emitters at z < 0.3 are investigated: Tresse & Maddox (1998, which is characterized by $\alpha = -1.35, \phi_s = 10^{-2.56} \text{Mpc}^{-3}$, and $L_\alpha = 10^{41.92} \text{ergs s}^{-1}$; note that these parameters were converted by Hopkins [2004] to those of our adopted cosmology), Fujita et al. (2003), Hippelein et al. (2003) and Ly et al. (2007). Fujita et al. (2003), Ly et al. (2007), and this work are based on the NB816 imaging obtained with the Subaru Telescope. Tresse & Maddox (1998) is based on the Canada-France Redshift Survey (CFRS), and Hippelein et al. (2003) is based on the Calar Alto Deep Imaging Survey (CADIS).

First, we compare our Hα LF with that derived by Ly et al. (2007). Their best-fit Schechter function parameters ($\alpha = -1.71, \log \phi_s = -3.7, \log L_\alpha = 42.2$) are quite different from those of our Hα LF. However, we note that the data points between $\log L(H\alpha) < 39.5$ and $\sim 41.0$, shown in Figure 10b of Ly et al. (2007), are quite similar to our results (Fig. 4). We therefore consider that the Hα LF of Ly et al. (2007) itself is basically consistent with ours except for the brightest point. The difference between our Schechter parameters and those of Ly et al. may arise from the data points of the brightest and the faintest ones, especially the brightest one. Since the field of view of the COSMOS is about an order of magnitude wider than that of the SDF, we consider that our Hα LF is more accurate than that determined by Ly et al. (2007) at the bright end.

Second, we compare our Hα LF with the other Hα LFs. Although our Hα LF is similar to those of Tresse & Maddox (1998) and Hippelein et al. (2003), the Hα LF of Fujita et al. (2003) shows a steeper faint-end slope and a higher number density for the same luminosity. These differences may be attributed to the following different source selection procedures: (1) Fujita et al. (2003) used their NB816-selected galaxies, while we used $i^\prime$-selected galaxies, Tresse & Maddox (1998) used I-selected Canada-France Redshift Survey (CFRS) galaxies, and Hippelein et al. (2003) used Fabry-Perot images for preselection of emission-line galaxies. As Fujita et al. (2003) demonstrated, samples based on a broadband selected catalog are biased against galaxies with faint continuum. (2) Fujita et al. (2003) used their $B-R_C$ versus $R_C-I_C$ color-color diagram to isolate Hα emitters from other low-$z$ emitters at different redshifts. However, we find that there are possible contaminations of [O iii] emitters if one uses the $B-R_C$ versus $R_C-I_C$ color diagram, because of the small difference between Hα and [O iii] emitters on that color-color diagram. On the other hand, we used $B-V$ versus $V-r'$ to isolate Hα emitters from [O iii] emitters. Due to the large separation between Hα emitters and [O iii] emitters on the $B-V$ versus $V-r'$ diagram, we can reduce the contamination of [O iii] emitters. (3) Fujita et al. (2003) used the population synthesis model GISSEL96 (Bruzual & Charlot 1993) to determine the criteria for selecting Hα emitters. To check the validity of the criterion, we compare colors of GOODS-N galaxies at z $\sim 0.24, 0.63, 0.68,$ and 1.19 with model colors at corresponding redshifts based on GISSEL96 (Fig. 5). Unfortunately, the predicted colors are slightly different from those of observed galaxies. We therefore redetermined the selection criteria using the SED of Coleman et al. (1980) as

$$(B-R_C) > 2.5(R_C-I_C) + 0.2.$$  

If we adopt this revised criterion, the number of Hα emitters in Fujita et al. (2003) is reduced by about 20% (Fig. 5). This is one reason why the number density of Hα emitters in Fujita et al. (2003) is higher than other surveys. Recently, Ly et al. (2007) pointed out that the fraction of [O iii] emitters in the Hα emitter sample of Fujita et al. (2003) may be about 50% using the Hawaii HDF-N sources with redshifts observed as NB816-excess objects. The Hα LF of Fujita et al. (2003) reduced by 50% appears to be quite similar to our Hα LF.

4.2. Luminosity Density and Star Formation Rate Density

By integrating the luminosity function, i.e.,

$$\mathcal{L}(H\alpha) = \int_0^\infty \Phi(L) L dL = \Gamma(\alpha + 2) \phi_s L_\alpha,$$

we obtain a total Hα luminosity density of $2.7^{+0.7}_{-0.6} \times 10^{49} \text{ergs s}^{-1} \text{Mpc}^{-3}$ at z $\approx 0.24$ from our best-fit LF. The star formation rate is estimated from the Hα luminosity using the relation $SFR = 7.9 \times 10^{-42} L(H\alpha) \text{M}_\odot \text{yr}^{-1}$, where $L(H\alpha)$ is in units of ergs s$^{-1}$ (Kennicutt 1998). Using this relation, the Hα luminosity density can be translated into the SFR density of $\rho_{SFR} \sim 2.1^{+1.0}_{-0.4} \times 10^{-2} \text{M}_\odot \text{yr}^{-1} \text{Mpc}^{-3}$.

However, not all the Hα luminosity is produced by star formation, because active galactic nuclei (AGNs) can also contribute to the Hα luminosity. For example, previous studies obtained the following estimates: 8%–17% of the galaxies in the CFRS low-$z$ sample (Tresse et al. 1996), 8% in the Universidad Complutense de Madrid (UCM) survey of local Hα emission line galaxies (Gadilgo et al. 1995), and 17%–28% in the 15R survey (Carter et al. 2001). Recently, Hao et al. (2005) obtained an Hα luminosity function of AGNs based on the sample of the Sloan Digital Sky Survey within a redshift range of 0 $< z < 0.15$. The Hα luminosity density calculated from the Schechter function parameters that are shown in the paper is $1.1 \times 10^{38} \text{ergs s}^{-1} \text{Mpc}^{-3}$.
(with no reddening correction). Taking account of the reddening correction and the H$_\alpha$ luminosity density radiated from star-forming galaxies (Gallego et al. 1995), the fraction of AGN contribution to the total H$_\alpha$ luminosity density is about 15% in the local universe. If we assume that 15% of the H$_\alpha$ luminosity density is radiated from AGNs, the corrected SFRD is $1.8^{+0.7}_{-0.4} \times 10^{-2} M_\odot$ yr$^{-1}$ Mpc$^{-3}$.

We note here that the error for $r_{SFR}$ and $\mathcal{L}(H \alpha)$ is probably underestimated, since it does not include the effects of different correction methods and selection biases. For example, adopting the different relation for correcting $A_{H\alpha}$ may cause a different value of SFRD.

We compare our result with the previous investigations compiled by Hopkins (2004) in Figure 6. We also show the evolution of SFRD derived from the observation of GALEX with mean attenuation of $A_{\text{FUV}}^\text{max} = 1.8$, evaluated from the FUV slope $\beta$ ($f_{25} \propto \lambda^\beta$) and the relation of $A_{\text{FUV}} = 4.43 + 1.99\beta$. If we adopt the more representative value $A_{\text{FUV}}^\text{min} = 1$ (Schiminovich et al. 2005) determined by using the $F_{\text{dust}}/F_{\text{UV}}$ ratio (Buat et al. 2005), their SFRD becomes smaller by a factor of 2, being similar to our SFRD.

The left panel of Figure 6 shows the evolution of the SFRD as a function of look-back time. It clearly shows that SFRD is monotonically decreasing for 10 Gyr with increasing cosmic time. We note here that the error for $r_{SFR}$ and $\mathcal{L}(H \alpha)$ is probably underestimated, since it does not include the effects of different correction methods and selection biases. For example, adopting the different relation for correcting $A_{H\alpha}$ may cause a different value of SFRD. We discuss further the effect of the selection criterion of $\text{EW}(H\alpha + [N \text{ ii}])_{\text{obs}} > 12$ Å on the evaluation of SFRD. Being different from the previous H$_\alpha$ emission-line galaxy surveys using the objective prism, the fraction of galaxies having EW(H$_\alpha$) $> 50$ Å is 12% in our sample, which is similar to or less than the value of the local universe (15%–20%; Heckman 1998) and SINGG SR1 (14.5%; Hanish et al. 2006). On the other hand, the fraction of the galaxies with EW(H$_\alpha$) $> 50$ Å are 42% and 35% in the KPNO International Spectroscopic Survey (KISS; Gronwall et al. 2004) and UCM objective-prism surveys, respectively.

Our SFRD evaluated above seems to be real; e.g., the cosmic variance. We discuss the clustering properties more quantitatively, we derive the angular two-point correlation function (ACF), $w(\theta)$, using the estimator defined by Landy & Szalay (1993):

$$w(\theta) = \frac{DD(\theta) - 2DR(\theta) + RR(\theta)}{RR(\theta)},$$

where DD(\theta), DR(\theta), and RR(\theta) are normalized numbers of galaxy-galaxy, galaxy-random, and random-random pairs, respectively. The random sample consists of 100,000 sources with the same geometrical constraints as the galaxy sample.
demonstrates that our Hα emitter sample is quite incomplete for \( \log(L(\text{H}_\alpha)) \text{ erg s}^{-1} < 39.8 \). We therefore show the ACF for 693 Hα emitter candidates with \( \log(L(\text{H}_\alpha)) \text{ erg s}^{-1} > 39.8 \) in Figure 8. The ACF is fit well by a power law, \( w(\theta) = 0.013^{+0.002}_{-0.003} \theta^{-0.88\pm0.03} \). Recently, the departure from a power law of the correlation function was reported (Zehavi et al. 2004; Ouchi et al. 2005). Such a departure may be interpreted as the transition from a large-scale regime, where a pair of galaxies resides in separate halos, to a small-scale regime, where a pair of galaxies resides within the same halo. We find no evidence for such a departure in our result. We, however, consider that the number of our sample is too small to discuss this problem.

For Lyman-break galaxies, brighter galaxies (with a larger star formation rate) tend to show more clustered structures than faint ones (with a smaller star formation rate; e.g., Ouchi et al. 2004; Kashikawa 2006). We also show the ACF of Hα emitters with larger Hα luminosity [\( \log(L(\text{H}_\alpha)) \text{ erg s}^{-1} > 40.94 = \log(0.1L_\odot) \)] and those with lower Hα luminosity [\( \log(L(\text{H}_\alpha)) \text{ erg s}^{-1} \leq 40.94 \)] in Figure 8. Both ACFs are well fit with a power-law form: \( w(\theta) = 0.019^{+0.004}_{-0.004} \theta^{-1.08\pm0.05} \) for objects with \( \log(L(\text{H}_\alpha)) \text{ erg s}^{-1} > 40.94 \), while \( w(\theta) = 0.011^{+0.002}_{-0.002} \theta^{-0.84\pm0.05} \) for objects with \( \log(L(\text{H}_\alpha)) \text{ erg s}^{-1} \leq 40.94 \), respectively. We conclude that galaxies with a higher star formation rate are more strongly clustered than ones with a lower star formation rate. This fact is interpreted as that galaxies with a higher star formation rate reside in more massive dark matter halos, which are more clustered in the hierarchical structure formation scenario.

It is useful to evaluate the correlation length \( r_0 \) of the two-point correlation function \( \xi(r) = (r/r_0)^{-\gamma} \). A correlation length is derived from the ACF through Limber’s equation (e.g., Peebles 1980). Assuming that the redshift distribution of Hα emitters is a top hat shape of \( z = 0.242 \pm 0.009 \), we obtain the correlation length of \( r_0 = 1.9 \text{ Mpc} \). Therefore, the two-point correlation function for all Hα emitters is written as \( \xi(r) = (r/1.9 \text{ Mpc})^{-1.88} \). The correlation length of Hα emitters with \( \log(L(\text{H}_\alpha)) \text{ erg s}^{-1} > 40.94 \) is 2.9 Mpc, while that of Hα emitters with \( \log(L(\text{H}_\alpha)) \text{ erg s}^{-1} \leq 40.94 \) is 1.6 Mpc. These values are smaller than those evaluated for nearby \( L_* \) galaxies (~7 Mpc; Norberg et al. 2001; Zehavi et al. 2005) and \( z \sim 1 \) galaxies (~4–5 Mpc; Coil et al. 2004).

It is known that the correlation length is smaller for fainter galaxies in the nearby (Norberg et al. 2001; Zehavi et al. 2005) and \( z \sim 1 \) universe (Coil et al. 2006). Figure 9 shows the relation between the \( L(\text{H}_\alpha) \)- and \( R_e \)-band absolute magnitude \( M_R \) for our sample. Our sample includes many faint (\( M_R > -18 \)) galaxies. However, the correlation length for galaxies with \( -18 < M_r < -17 \)
(3.8 Mpc; Zehavi et al. 2005) is still larger than that of our sample. This discrepancy may imply a weak clustering of emission-line galaxies.

5. SUMMARY

We have performed the Hα emitter survey in the HST COSMOS 2 square degree field using the COSMOS official photometric catalog. Our results and conclusions are summarized as follows:

1. We found 980 Hα emission-line galaxy candidates using the narrowband imaging method. The Hα luminosity function is well fit by a Schechter function with $\alpha = -1.35^{+0.11}_{-0.13}$, log $\phi_* = -2.65^{+0.37}_{-0.38}$, and log $L_*$(ergs s$^{-1}$) = $4.94^{+0.35}_{-0.33}$. Using the parameter set of the Schechter function, the Hα luminosity density is evaluated as $2.7^{+0.7}_{-0.6} \times 10^{19}$ ergs s$^{-1}$ Mpc$^{-3}$. If we adopt the AGN contribution to the Hα luminosity density to be 15%, we obtain a star formation rate density of $1.8^{+0.7}_{-0.4} \times 10^{-2}$ $M_\odot$ yr$^{-1}$ Mpc$^{-3}$. This error includes only random error. Our result supports the strong increase in SFRD from $z = 0$ to $z = 1$.

2. We studied the clustering properties of Hα emitters at $z \sim 0.24$. The two-point correlation function is well fit by a power law, $\omega(\theta) = 0.013^{+0.002}_{-0.003} \theta^{-0.88 \pm 0.03}$, which leads to the correlation function of $r/r_0 = 1.9$ Mpc for the power for nearby galaxies, the derived correlation length of $r_0 = 1.9$ Mpc is smaller than that for nearby galaxies with the same optical luminosity range. This discrepancy may imply a weak clustering of emission-line galaxies. The galaxies with higher SFR are more strongly clustered than those with lower SFR. Taking account of the fact that the SFR of a luminous galaxy is higher than that of a faint galaxy, this result is consistent with the previously known fact that luminous galaxies are more strongly clustering.

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REFERENCES

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