Lyα ESCAPE FROM z ∼ 0.03 STAR-FORMING GALAXIES: THE DOMINANT ROLE OF OUTFLOWS

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Received 2012 October 21; accepted 2013 January 29; published 2013 February 26

ABSTRACT

The usefulness of H I Lyα photons for characterizing star formation in the distant universe is limited by our understanding of the astrophysical processes that regulate their escape from galaxies. These processes can only be observed in detail out to a few ×100 Mpc. Past nearby (z < 0.3) spectroscopic studies are based on small samples and/or kinematically unresolved data. Taking advantage of the high sensitivity of Hubble Space Telescope’s Cosmic Origins Spectrograph (COS), we observed the Lyα lines of 20 Hα-selected galaxies located at (z) = 0.03. The galaxies cover a broad range of luminosity, oxygen abundance, and reddening. In this paper, we characterize the observed Lyα lines and establish correlations with fundamental galaxy properties. We find seven emitters. These host young (≤10 Myr) stellar populations have rest-frame equivalent widths in the range 1–12 Å, and have Lyα escape fractions within the COS aperture in the range 1%–12%. One emitter has a double-peaked Lyα with peaks 370 km s⁻¹ apart and a stronger blue peak. Excluding this object, the emitters have Lyα and O Balmer offsets from Hβ in agreement with expanding-shell models and Lyman break galaxies observations. The absorbers have offsets that are almost consistent with a static medium. We find no one-to-one correspondence between Lyα emission and age, metallicity, or reddening. Thus, we confirm that Lyα is enhanced by outflows and is regulated by the dust and H I column density surrounding the hot stars.

Key words: galaxies: evolution – galaxies: ISM – galaxies: starburst – galaxies: stellar content – ultraviolet: galaxies

1. INTRODUCTION

The potential of H I Lyα to identify young galaxies at high redshift was noted over 40 years ago by Partridge & Peebles (1967). Lyα corresponds to the n = 1–2 transition and is in principle the strongest emission line originating in an H I region. In the absence of dust, the Lyα/Hα line intensity ratio is expected to be in the range 7–12 for recombination theory cases B–A (Osterbrock & Ferland 2006), and the Lyα equivalent width, EW(Lyα), is expected to be in the range 100–300 Å for metallicities between Z = 0.020–0.004, a normal initial mass function (IMF), a constant star formation rate (SFR) of 1 M⊙ yr⁻¹, and ages below 10 Myr (Verhamme et al. 2008). In the case of a single burst of star formation, the range of EW(Lyα) is ∼0–300 under the same conditions. A few times 10⁻⁶–10⁻⁵ yr after a burst of star formation, EW(Lyα) drops to zero (Charlot & Fall 1993; Valls-Gabaud 1993; Verhamme et al. 2008). The above predictions do not account for the underlying stellar contribution at Lyα. This contribution is not a concern in galaxies dominated by populations of O and early B stars. For reference, the mean Lyα EW of the eight early and mid-O supergiants in Bouret et al. (2012) is ∼1 Å. On the other hand, the correction can be significant for stellar populations dominated by A and late B stars. In addition, the above predictions do not account for the effects of Lyα radiation transfer in the medium surrounding the starburst. Due to its resonant nature, a Lyα photon is absorbed and re-emitted multiple times in H I. Resonant trapping reduces the mean free path of the Lyα photons, increasing significantly their probability of being destroyed by dust, shifted in frequency, or transformed to two-photon emission. On the other hand, some effects are favorable to the escape of Lyα photons from galaxies. Neutral gas outflows Doppler-shift the Lyα photons from the optically thick line core to the optically thin line wings, making it possible for some Lyα photons to escape (Kunth et al. 1998; Verhamme et al. 2006).

Lyα photons may also escape through holes of sufficiently low dust and H I column densities (Giavalisco et al. 1996; Atek et al. 2009).

In spite of the various Lyα attenuation effects, today star-forming galaxy candidates have been detected out to redshift z ∼ 10 using various techniques. Galaxies with redshifts of z ∼ 2–5 are detected via the drop-out technique based on the opacity at the Lyman limit of the galaxy and the intervening intergalactic medium (IGM; Giavalisco 2002; Steidel et al. 2003; Shapley et al. 2003; Ouchi et al. 2004). Galaxies with z ∼ 6 are detected via the drop-out technique based on the opacity of the IGM at Lyβ (Bouwens et al. 2007; Oesch et al. 2010; Bouwens et al. 2011a, 2011b). Galaxies with z ∼ 2–7 are also detected using deep narrowband surveys that target the Lyα emission line (Cowie & Hu 1998; Hu et al. 1998, 2004, 2010; Rhoads et al. 2000; Ouchi et al. 2005, 2008; Taniguchi et al. 2005; Venemans et al. 2005; Nilsson 2007; Nilsson et al. 2009; Gronwall et al. 2007). Finally, galaxies at the highest redshifts are detected using gravitationally lensing clusters (Ota et al. 2012). Hundreds of galaxy candidates have been spectroscopically confirmed (Steidel et al. 1996; Rhoads et al. 2003; Dawson et al. 2007; Iye et al. 2006; Cowie et al. 2010; Bradač et al. 2012), and a few galaxies show impressively high rest-frame EWs of EW(Lyα) ≥ 150 Å (Malhotra & Rhoads 2002; Shimasaku et al. 2006; Finkelstein et al. 2008), which could alternatively be due to the presence of an active galactic nucleus (AGN; Charlot & Fall 1993).

In principle, after removing the observational and astrophysical biases, Lyα can be used for various applications. (1) To probe cosmic SFRs (Kudritzki et al. 2000; Fujita et al. 2003; Gronwall et al. 2007; Zheng et al. 2012). (2) To probe the ionization fraction of the intergalactic medium during the final stages of re-ionization (Kashikawa et al. 2006; Malhotra & Rhoads 2002; Dawson et al. 2007; Zheng et al. 2010; Bradač et al. 2012). (3) To probe the large-scale structure (Ouchi et al. 2001, 2003, 2004, 2005; Venemans et al. 2002, 2004; Wang et al. 2005;
Stiavelli et al. 2005; Gawiser et al. 2007). (4) To identify potential hosts of population III star formation (Malhotra & Rhoads 2002; Shimasaku et al. 2006; Schaerer 2007). (5) To constrain the nature and evolution of high-redshift galaxies (Giavalisco 2002; Nilsson et al. 2007; Finkelstein et al. 2009; Shapley 2011; Malhotra et al. 2012; González et al. 2012). However, the use of Lyα as a cosmological tool is limited by our understanding of the astrophysical processes that regulate the escape of Lyα photons from galaxies and affect them on their way to telescopes.

The Lyα escape problem can be approached from two complementary angles, performing statistically significant studies of the global properties of the sources and their cosmological context, or studying individual sources in detail. The former is better done in the distant universe, whereas the latter can only be accomplished locally, where the effect of the intergalactic medium is a non-issue, the kinematical and spatial resolutions are higher, and ancillary data is abundant. The challenges of studying Lyα locally are the necessity of a UV space-based observatory optimized for studying Lyα; contamination with the geocoronal Lyα line, which saturates the spectra at very low redshift; and contamination with the Milky Way Galaxy Lyα line trough. Indeed, the interstellar H i in our Galaxy produces a damped absorption along many sight lines, which hides the potential Lyα line from star-forming galaxies with redshifts below a few ×100 km s−1.

There are several observational Lyα studies of galaxies at low redshift (z < 0.3). Giavalisco et al. (1996) studied low-resolution spectra of 21 galaxies taken with the International Ultraviolet Explorer (IUE) and studied the effects of reddening and metallicity on EW(Lyα) and Lyα/Hβ. They found no correlation between these quantities and the UV extinction, the Balmer decrement, or the oxygen abundance. They concluded that rather than the amount of dust, the ISM geometry determines the Lyα escape fraction. Unfortunately, the spectral resolution of IUE is insufficient to study the effect of gas outflows on the Lyα escape. Kunth et al. (1998) studied high-dispersion Hubble Space Telescope (HST) G HRS spectra of eight nearby H ii galaxies. They found four emitters, all of which have a velocity offset between the H i and the H ii gas of up to 200 km s−1, while the non-emitters show no velocity offset. However, their study suffers from small number statistics. Scarlata et al. (2009) analyzed the optical spectra of a sample of 31 (z) ~ 0.3 Lyα emitters identified by Deharveng et al. (2008) in low-resolution (~8 Å) Galaxy Evolution Explorer (GALEX) data. They tried to reproduce the stellar-absorption corrected Lyα/Hα and Hα/Hβ ratios using different dust geometries and assumptions for the Lyα scattering in H i. They found that the ratios are well reproduced by a clumpy dust distribution, while a uniform dust screen model results in Lyα/Hα larger than the case B recombination theory value. Unfortunately, the spectral resolution of GALEX is insufficient for kinematical studies, and the latter authors were unable to assess the relative importance of dust geometry and outflows. Atek et al. (2009) used a 3D Lyα radiation transfer code to model HST observations of the very metal-poor dwarf galaxy I Zw 18, which shows Lyα in absorption. Their analysis shows that it is possible to transform a strong Lyα emission of EW(Lyα) ~ 60 Å into a damped absorption, even with low extinction, if the H i column density is large. Finally, Ostlin et al. (2009) used HST to produce Lyα, Hα, and UV continuum maps of six galaxies covering a wide range in luminosity and metallicity, including known Lyα emitters and non-emitters. They found that the bulk of Lyα emerges in a diffuse component resulting from scattering events. They also found the simultaneous presence of Lyα in emission and absorption within spatial scales ranging from a few ×10 pc to a few ×100 pc.

Although these studies have addressed main factors affecting the Lyα escape, we still do not understand the relative importance of starburst phase, gas kinematics, gas geometry, and dust extinction, in determining the profile and strength of the Lyα line from star-forming galaxies. We took advantage of the high sensitivity and medium resolution of the Cosmic Origins Spectrograph (COS) on board HST in order to obtain Lyα spectroscopy of a sample of 20 galaxies located a mean redshift of 0.03 and covering a broad range of luminosity, oxygen abundance, and reddening. We used these and ancillary data for establishing correlations between Lyα and fundamental galaxy properties. In Section 2 we describe the sample, the observations, and the ancillary data; in Section 3 we present our analysis; in Section 4 we discuss our results; and in Section 5 we summarize and conclude.

2. SAMPLE, OBSERVATIONS, AND ANCILLARY DATA

2.1. Sample

The galaxies in our sample were Hα-selected from the Kitt Peak International Spectroscopic Survey data release (KISSR; Salzer et al. 2001). The sample is composed of 12 irregular and eight spiral galaxies distributed in the redshift range z = 0.02–0.06. At these redshifts, we avoid contamination with the geocoronal and Milky Way (MW) Lyα lines. We cover a factor of three in redshift, which makes it possible to study the effect of distance on the observed properties of Lyα. In addition, we cover a broad range in oxygen abundance, 12 + log(O/H) = 7.9–9.1, which makes it possible to study the effect of metallicity on the Lyα escape. Metallicity is expected to correlate with the dust content, and dust destroys Lyα photons. We also cover a wide range in Hα equivalent width, EW(Hα) = 27–578 Å. The value of EW(Hα) is sensitive to the starburst evolutionary phase and to the IMF, e.g., see Leitherer et al. (1999). Finally, we cover an order of magnitude in GALEX (Martin et al. 2005) far-UV (FUV) continuum luminosity, log L(1500) = 39.0–40.2 erg s−1 Å−1 (uncorrected for reddening). For a given star formation history (SFH), age, and IMF, L(1500) is proportional to the stellar mass in the population dominating the FUV emission of the galaxy. Therefore, L(1500) can be used to determine the SFR of this population (SFR = stellar mass/time since beginning of star formation). Table 1 summarizes the properties of the sample. The morphological types are based on Sloan Digital Sky Survey (SDSS) images. The Hα EWs are from the SDSS spectra when available or from the KISS data otherwise, as indicated in Column 10 of Table 1.

2.2. Spectral Class of the Galaxies

We are interested in galaxies where the principal photoionization source is the strong UV radiation from OB stars. This helps in the interpretation of the observed Lyα properties because we do not need to worry about non-stellar ionizing sources such as AGNs, which account for some of the high Lyα EWs at z > 2

3 The R in “KISSR" stands for data with red spectra, i.e., from 6400 to 7200 Å.

4 In this paper, metallicity is the mass ratio of all elements excluding H and He to all elements.
(Charlot & Fall 1993; Zheng et al. 2010), and low-ionization nuclear emission-line regions (LINERs), whose nature is not well understood (Tanaka 2012). We verified the spectral class of our galaxies using the so-called BPT diagnostic diagram (Baldwin et al. 1981). This was not possible for KISSR 271, for which an optical spectrum was unavailable. As Figure 1 shows, most galaxies are dominated by star formation, but KISSR 1084 may be of composite type.

### 2.3. Observations

Our observations are part of COS-GTO programs 11522 and 12027 (PI: J. Green). Descriptions of the COS and its on-orbit performance can be found in Osterman et al. (2011). We used one orbit with HST to observe the brightest FUV knot detected by GALEX in each galaxy. We acquired the targets using the ACQ/IMAGE mode and mirror A. Therefore, we obtained two images of each galaxy in the observed-frame wavelength range 1700–3200 Å. One after the initial telescope pointing, and the second after the final telescope pointing. We then used the G130M grating to obtain a spectrum of each target in the observed-frame wavelength range 1138–1457 Å. We achieved continuous wavelength coverage by using central wavelengths, λ1291 and λ1318 at the default focal plane offset position (FP-POS = 3). Table 2 lists the epochs and exposure times corresponding to these central wavelengths. The spectra were taken through the circular Primary Science Aperture (PSA), which is 2.5′ in diameter. They contain the aberrated light from objects located up to 2″ or up to 0.9–2.4 kpc from the aperture’s center, depending on the distance to the galaxy. The data were processed with CALCOS v2.13.6 and combined with the custom IDL co-addition routine described in Danforth et al. (2010).

**Table 1**

| Galaxy | Morph. | z | d (Mpc) | M_B (mag) | E(B − V)K_1 (mag) | 12+log(O/H) (dex) | EW(Hα) (Å) | log L_1500 (erg s⁻¹ Å⁻¹) | Note |
|--------|--------|---|---------|-----------|-------------------|------------------|-----------|-------------------|------|
| 40     | Irr    | 0.026 | 112     | −18.0     | 0.03              | 8.18             | 58        | 39.29             | 1    |
| 108    | Irr    | 0.024 | 101     | −17.6     | 0.01              | 8.17             | 108       | 39.22             | 1    |
| 178+   | Irr    | 0.057 | 246     | −20.1     | 0.01              | 8.52             | 100       | 40.13             | 1    |
| 182    | Irr    | 0.022 | 96      | −17.8     | 0.01              | 8.34             | 114       | 39.33             | 1    |
| 218    | S      | 0.021 | 90      | −19.4     | 0.01              | 8.87             | 66        | 39.65             | 1    |
| 242+   | Irr    | 0.038 | 162     | −19.4     | 0.01              | 8.38             | 435       | 40.25             | 1    |
| 271*   | Irr    | 0.023 | 97      | −17.6     | 0.02              | 8.39             | 29        | 39.13             | 2    |
| 298*   | S      | 0.049 | 210     | −20.0     | 0.02              | 9.07             | 51        | 40.06             | 1    |
| 326*   | S      | 0.028 | 120     | −20.0     | 0.02              | 8.74             | 78        | 39.65             | 2    |
| 1084*  | S      | 0.032 | 137     | −20.5     | 0.05              | 8.79             | 87        | 39.7              | 1    |
| 1567*  | S      | 0.045 | 194     | −20.0     | 0.02              | 8.75             | 29        | 40.18             | 2    |
| 1578*  | Irr    | 0.028 | 120     | −19.6     | 0.02              | 8.14             | 576       | 40.29             | 1    |
| 1637   | Irr    | 0.035 | 149     | −19.6     | 0.01              | 8.55             | 34        | 39.92             | 1    |
| 1785−  | Irr    | 0.021 | 90      | −17.6     | 0.01              | 7.99             | 199       | 39.07             | 1    |
| 1942   | Irr    | 0.039 | 169     | −19.3     | 0.03              | 8.59             | 25        | 39.83             | 1    |
| 2019   | S      | 0.034 | 146     | −17.9     | 0.02              | 7.96             | 465       | 39.48             | 1    |
| 2021   | S      | 0.04  | 171     | −19.6     | 0.02              | 8.79             | 79        | 39.93             | 1    |
| 2023   | S      | 0.036 | 155     | −19.4     | 0.02              | 9.00             | 58        | 39.77             | 1    |
| 2110   | Irr    | 0.025 | 108     | −17.3     | 0.01              | 7.86             | 511       | 39.36             | 2    |
| 2125   | S      | 0.025 | 108     | −18.7     | 0.01              | 8.76             | 85        | 39.31             | 1    |
| Min…  |…      | 0.021 | 90      | −20.5     | 0.01              | 7.86             | 25        | 39.07             | …    |
| Max…  |…      | 0.057 | 246     | −17.3     | 0.05              | 9.07             | 576       | 40.29             | …    |

**Notes.** (1) KISSR ID. We mark the Ly α emitters with asterisks and the furthest/nearest galaxies with plus/minus signs. The last two rows give the minimum and maximum values in each column. (2) Morphological type. S = spiral. Irr = irregular. (3) Redshift of Hα line. (4) Distance computed from the redshift using $d = c z / H_0$, where $c$ is the speed of light, $z$ is the redshift, and we adopt $[\Omega_M, \Omega_{\Lambda}, H_0] = [0.7, 0.3, 70$ km s⁻¹ Mpc⁻¹]. (5) Absolute blue magnitude. (6) Color excess based on the Milky Way extinction maps of Schlegel et al. (1998) and the reddening law with $A_B = 0.70 A_V$. (7) Oxygen abundance derived as in Salzer et al. (2005). (8) Hα equivalent width. (9) Luminosity at 1500 Å from GALEX, uncorrected for reddening. (10) Source of the ancillary optical spectrum. 1 = SDSS. 2 = Same as in Salzer et al. (2005).
This is in agreement with the finding of Østlin et al. (2009) that in spite of the TA failure, KISSR 1567 turned out to be an emitter. Note that emitters KISSR galaxies 40 and 1567, and 2110, which do not have SDSS spectra, we were able to recover the optical 2′-wide slit spectra of Jangren et al. (2005). Unfortunately, we do not have an optical spectrum for KISSR galaxy 271.

3. ANALYSIS

3.1. Wavelength Zero Point and Effective Spectral Resolution

The COS spectra include the intrinsic lines Lyα and a number of low-ionization (LIS) and higher-ionization interstellar lines. We are interested in comparing the offsets of these lines with respect to Hz. This is for two reasons. First, as mentioned in the introduction, velocity offsets between the H\textsc{i} gas traced by Hz and the H\textsc{i} gas traced by the LIS lines have been showed to favor the escape of Lyα from galaxies. Second, in expanding-shell radiation transfer models the Lyα emission line is redshifted to a few times the shell expansion velocity (e.g., Verhamme et al. 2006). A similar offset is observed at high redshift when comparing the Lyα redshift to the blueshift of the LIS lines, which give the expansion velocity (e.g., Shapley et al. 2003). Thus, offset measurements are useful for establishing how the Lyα strength relates to the interstellar gas kinematics and for constraining radiation transfer models. The accuracy of the velocity offset measurements depends on the accuracy of the wavelength zero point and on the effective spectral resolution of the data.

In ultraviolet spectroscopic studies of low-redshift galaxies, it is common to use geocoronal emission lines to check if the wavelength zero point is shifted due to instrumental effects.

2.6. Ancillary Spectra

We used ancillary optical spectroscopy of the galaxies for determining their redshift, spectral class, metallicity, reddening, SFR, and Wolf–Rayet (WR) star content. Sixteen targets have spectra from the SDSS seventh data release (Abazajian et al. 2009). The SDSS spectra are of higher spectral resolution than the KISSR spectra, and they were taken through a circular fiber of 3′ in diameter that closely matches the size of the COS aperture. The difference between the SDSS and the COS pointings is relevant to the interpretation of the Lyα/Hα ratio, and to the comparison of the strength of Lyα and the value of EW(Hz). Indeed, the COS aperture encompasses only a portion of each galaxy. Table 3 lists the KISSR identifier (Column 1, the emitters are marked with asterisks), the right ascension (R.A., J2000), and declination (decl., J2000) of the first HST pointing (Columns 2 and 3), the R.A. and decl. of the SDSS spectroscopic pointings (Columns 4 and 5), and the difference between the COS and the SDSS pointings (Columns 6–8). As Table 3 shows, on average, the SDSS pointings are within 0′.3 of the COS initial pointings, with a standard deviation of 0′.4. Since the diameter of the COS aperture is 2′,5, we do not expect the difference in pointings to constitute a major issue. For KISSR galaxies 326, 1567, and 2110, which do not have SDSS spectra, we were able to recover the optical 2′-wide slit spectra of Jangren et al. (2005). Unfortunately, we do not have an optical spectrum for KISSR galaxy 271.

2.4. COS Images

Figure 2 shows the near-UV (NUV) target acquisition (TA) confirmation images of the galaxies with the COS aperture overlaid. The center of the aperture is indicated by the small black cross. In 12 cases, a clear source centroid associated with young star clusters is present. However, in eight cases, there is no clear centroid of the emission. This is due to the short exposure times of the TA images and in two cases, i.e., for KISSR galaxies 40 and 1567, to TA failures. In spite of the TA failures, spectra were taken. The galaxies that turned out to have net Lyα emission are marked with asterisks. Hereafter, we will call the latter galaxies the emitters. Note that emitters KISSR 271, 326, and 1567 do not show source centroids. Also note that in spite the TA failure, KISSR 1567 turned out to be an emitter. This is in agreement with the finding of Østlin et al. (2009) that the Lyα emission is not necessarily coincident with regions of high FUV surface brightness.

2.5. Ancillary Images

We obtained information about the morphology and orientation of the galaxies from archival images. At the time of our analysis, there were no HST images available for our targets. The galaxies were imaged by GALEX in the FUV at low spatial resolution (∼0′.5). Unfortunately, in these images, the galaxies look like large blobs. However, we found useful SDSS (York et al. 2000) images of all the targets in our sample. These are shown in Figure 3, where we have overlaid the COS footprint at the approximate location of the telescope pointing and marked the emitters with asterisks.

Figure 3 shows that most spiral galaxies in our sample have low inclinations except KISSR 2125. While some low-inclination spirals have Lyα in emission, others do not. KISSR 1084, the spiral of composite spectral class is an emitter, and as expected, the highly inclined spiral is a non-emitter. Our two most metal-poor irregulars, KISSR 2019 and 2110, are Lyα absorbers, but irregulars KISSR 242 and 1578 are Lyα emitters. In summary, there are emitters and absorbers among both morphological types. Finally, note that the COS aperture only covers an area of 0.9–2.4 kpc in radius, depending on the distance to the galaxy. This needs to be considered when comparing with Lyα observations at higher redshifts, since at higher redshift, more of the galaxy is enclosed within the aperture and Østlin et al. (2009) found that the bulk of the Lyα photons from nearby galaxies are in the diffuse halo.

## Table 2

| Galaxy | Start Time | Exp. Time | Start Time | Exp. Time |
|--------|------------|-----------|------------|-----------|
|        | 1291 Å     | 1318 Å    | 291 Å      | 1318 Å    |
| (1)    | (2)        | (3)       | (4)        | (5)       |
| 40     | 2011/06/11 | 02:07:49  | 2011/10/11 | 02:26:08  |
| 108    | 2011/07/31 | 04:47:42  | 2011/07/31 | 05:09:24  |
| 178    | 2011/06/17 | 20:55:13  | 2011/06/17 | 21:16:55  |
| 182    | 2011/07/26 | 08:13:51  | 2011/07/26 | 08:35:33  |
| 218    | 2010/02/23 | 20:33:10  | 2010/02/23 | 20:39:06  |
| 242    | 2009/12/26 | 23:56:45  | 2009/12/27 | 20:18:33  |
| 271    | 2010/05/07 | 17:41:45  | 2010/05/07 | 18:03:27  |
| 298    | 2010/01/21 | 12:41:22  | 2010/01/21 | 13:03:04  |
| 326    | 2011/04/22 | 13:36:31  | 2011/04/22 | 13:58:13  |
| 1084   | 2010/02/05 | 05:13:19  | 2010/02/05 | 05:35:01  |
| 1567   | 2010/08/13 | 05:09:19  | 2010/08/13 | 05:31:46  |
| 1578   | 2010/02/18 | 22:07:27  | 2010/02/18 | 22:29:57  |
| 1637   | 2009/10/24 | 09:51:17  | 2009/10/24 | 10:13:44  |
| 1785   | 2011/08/09 | 10:38:26  | 2011/08/09 | 11:00:55  |
| 1942   | 2011/06/13 | 22:46:13  | 2011/06/13 | 23:08:28  |
| 1904   | 2011/06/19 | 15:57:20  | 2011/06/19 | 16:19:49  |
| 2021   | 2009/11/40 | 00:02:53  | 2009/11/40 | 00:25:17  |
| 2023   | 2011/06/14 | 16:29:53  | 2011/06/14 | 16:52:08  |
| 2110   | 2011/06/16 | 16:16:21  | 2011/06/16 | 16:38:50  |
| 2125   | 2011/06/16 | 17:52:32  | 2011/06/16 | 18:15:01  |

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Figure 2. Near-ultraviolet (1700–3200 Å) COS TA confirmation images. North is up and east is to the left. The numbers are the galaxy identifiers. The circles represent the 2′′.5 in diameter COS PSA aperture. The emitters are marked with asterisks. In the rainbow scale, red represents the region of maximum counts, while pink represents regions of low counts.

| Galaxy | COS R.A. (deg) | COS Decl. (deg) | SDSS R.A. (deg) | SDSS Decl. (deg) | ΔR.A. (deg) | ΔDecl. (deg) | Δtot (arcsec) |
|--------|----------------|-----------------|-----------------|-----------------|-------------|-------------|--------------|
| 40     | 185.59833      | 29.44383        | 185.59825       | 29.44394        | 8E−05       | −1E−04      | 0.49         |
| 108    | 190.98042      | 29.36964        | 190.98044       | 29.36961        | −2E−05      | 3E−05       | 0.13         |
| 178    | 195.42306      | 29.38118        | 195.42304       | 29.38135        | 2E−05       | −2E−04      | 0.62         |
| 182    | 195.60688      | 28.85808        | 195.60688       | 28.85807        | −5E−06      | 1E−05       | 0.05         |
| 218    | 197.31725      | 29.36739        | 197.31703       | 29.36766        | 2E−04       | −3E−04      | 1.24         |
| 242*   | 199.01625      | 29.38161        | 199.01632       | 29.38169        | −7E−05      | −8E−05      | 0.38         |
| 271*   | 200.42000      | 28.88308        | ...             | ...             | ...         | ...         | ...          |
| 298*   | 202.45746      | 29.57972        | 202.45748       | 29.57972        | −2E−05      | 2E−06       | 0.08         |
| 326*   | 204.81708      | 28.87361        | ...             | ...             | ...         | ...         | ...          |
| 1084*  | 252.27192      | 29.75878        | 252.27195       | 29.75878        | −3E−05      | −2E−06      | 0.12         |
| 1567*  | 201.22750      | 43.79889        | ...             | ...             | ...         | ...         | ...          |
| 1578*  | 202.18354      | 43.93069        | 202.18357       | 43.93070        | −3E−05      | −6E−06      | 0.10         |
| 1637   | 205.50020      | 42.76004        | 205.50038       | 42.76000        | −4E−04      | 4E−05       | 1.30         |
| 1785   | 216.62029      | 43.47083        | 216.62029       | 43.47082        | 2E−06       | 1E−05       | 0.05         |
| 1942   | 230.70200      | 43.77347        | 230.70197       | 43.77347        | 3E−05       | 2E−06       | 0.11         |
| 2019   | 236.43554      | 44.26439        | 236.43552       | 44.26439        | 2E−05       | −1E−06      | 0.08         |
| 2021   | 236.46992      | 44.26322        | 236.46991       | 44.26322        | 7E−06       | 2E−06       | 0.03         |
| 2023   | 236.67746      | 43.24367        | 236.6774        | 43.24359        | 6E−05       | 8E−05       | 0.35         |
| 2110   | 242.04625      | 43.63175        | ...             | ...             | ...         | ...         | ...          |
| 2125   | 242.58508      | 43.00975        | 242.58507       | 43.00975        | 1E−05       | 0E+00       | 0.05         |
and MW metal absorption lines to check if the wavelength zero point is shifted due to the asymmetry of the target in the aperture (e.g., see Kriss et al. 2011). Figures 4–8 show the COS spectra of the galaxies. They are contaminated with some or all of the geocoronal emission lines H\textsc{i} λ1216, N\textsc{i} λ1200, and/or O\textsc{i} λ1302, 1305; and with the MW absorption lines, Si\textsc{ii} λ1990, 1193, 1260, 1304, Si\textsc{iii} λ1206, O\textsc{i} 1302, 1305, and/or C\textsc{ii} λ1334, 1336. We measured the centroids of the contaminating lines using a custom routine developed by COS science team member K. France. The routine takes into consideration the COS line-spread function. Table 4 lists the mean wavelength offsets of the geocoronal and MW lines. We find that the mean velocity offsets of the geocoronal and MW lines are in the ranges $-33$ to 18 km s$^{-1}$ and $-1$ to 110 km s$^{-1}$, respectively.

The MW lines arise from absorption in halo clouds that may have non-negligible heliocentric velocities. For this reason, we analyzed the H\textsc{i} 21 cm emission from intermediate velocity clouds (IVCs) along the lines of sight to our targets. The data are from the Leiden/Argentine/Bonn H\textsc{i} survey (LAB; Kalberla et al. 2005). In Figure 9 we compare the centroids of the H\textsc{i} IVC emission lines and the MW Si\textsc{ii} λ1990 absorptions. The Si\textsc{ii} absorptions are corrected for the wavelength offset given by the geocoronal lines. The H\textsc{i} 21 cm emission is the mean within the radio beam at each velocity. We chose Si\textsc{ii} λ1990 because it is the only MW line that is not blended with other lines for any of the targets. The H\textsc{i} component near 0 km s$^{-1}$ originates in the MW disk. We find that the maximum IVC cloud velocity is $\sim$50 km s$^{-1}$ in the local

Figure 3. Sloan Digital Sky Survey 25″ × 25″ u-, g-, r-, i-, and z-band composite images of the galaxies. The KISSR and SDSS galaxy identifiers are provided. North is up and east is to the left. The Ly$\alpha$ emitters are marked with asterisks. The yellow circles show the COS footprint and pointing.
Figure 4. COS spectra of galaxies KISSR 40, 108, 178, and 182 from top to bottom (KISSR ID provided on the upper left of each panel). The spectra are corrected for the redshift and uncorrected for the reddening. They were first binned to 16 km s\(^{-1}\) (nominal resolution of the COS spectra) and then smoothed for clarity. We identify foreground (Foregr.) and intrinsic (Intr.) lines at the bottom of each panel. Geocoronal lines are marked with an encircled plus. The intrinsic lines are marked with vertical gray lines. We did not clip the geocoronal lines in order to show the extent to which they affect the profiles of nearby lines.

standard of rest frame (e.g., KISSR 40, 1567, and 1578). Although the comparison between the 21 cm emission and the COS data is difficult in cases where the signal-to-noise ratio (S/N) of the COS data is low, in general, the 21 cm emission and the Si \textsc{ii} absorption overlap. However, in some of the highest S/N cases (e.g., KISSR 242, 1578, 2019, and 2110), the minimum of the absorption is blueward of the bluest 21 cm emission peak. Note that the radio beam is large in comparison with the COS aperture, which makes this wavelength calibration method imperfect. Since large offsets between the 21 cm and the COS data are unlikely to be due to shifts in the wavelength zero point, we decided to only correct the COS data for the small shift in the geocoronal lines.

Regarding the spectral resolution, the more extended the source, the worse the effective spectral resolution, and the worse the accuracy in the determination of line centroids. Figure 2 shows that some targets are more extended than others. We used the MW lines Si \textsc{ii} \(\lambda 1190, 1193, 1260\), Si \textsc{iii} \(\lambda 1206\), and/or C \textsc{ii} \(\lambda 1334\) for determining the effective spectral resolution of the COS spectra. The dispersion of the G130M grating is 9.97 m\(\text{Å}\) pixel\(^{-1}\) and the resolution element is 6 pixels. Therefore, the nominal resolution is 0.06 \(\text{Å}\) or \(\sim 16 \text{ km s}^{-1}\). The effective spectral resolution of each spectrum is given by the FWHM of the MW absorption lines. For each galaxy, Column 4 of Table 4 lists the mean effective spectral resolution. The mean FWHM of the MW lines is in the range 74–305 km s\(^{-1}\). We can derive the centroids of the LIS lines with an accuracy of a tenth of the effective spectral resolution, as long as the S/N is sufficient.

3.2. Ly\(\alpha\) and ISM Kinematics

Here we present the velocity offsets of the intrinsic lines mentioned in the previous section. Figure 10 shows the Ly\(\alpha\) profiles of the galaxies. Seven objects have net Ly\(\alpha\) emission (emitters), eleven objects have damped Ly\(\alpha\) absorptions (absorbers), and two objects KISSR 2021 and 2023 have noisy Ly\(\alpha\) profiles blended with MW lines and that appear to be in absorption with perhaps some Ly\(\alpha\) emission. We measured the Ly\(\alpha\) centroids as follows. For the emitters, the centroid is the point of maximum Ly\(\alpha\) flux. For the absorbers, we used the center of the best-fit Voigt profile. The fits to the Ly\(\alpha\) absorptions were done by eye using a custom routine written by J. Tumlinson. We overlay the Voigt profiles in Figure 10.
Excluding KISSR 298, the emitters have P-Cygni-like profiles with the emission component redshifted to a mean velocity of $\langle v(\text{Ly} \alpha) \rangle = 172 \pm 49 \text{ km s}^{-1}$. KISSR 298 is a face-on spiral with two Ly$\alpha$ peaks separated by 370 km s$^{-1}$, such that one peak is redshifted and the other is blueshifted and twice as strong. The absorbers have Ly$\alpha$ troughs centered at a mean velocity of $\langle v(\text{Ly} \alpha) \rangle = 0 \pm 38 \text{ km s}^{-1}$. The Ly$\alpha$ mean velocities exclude KISSR 2021 and 2023 due to their noisy Ly$\alpha$ profiles.

The COS spectra include the H$\text{i}$ gas tracers O$\text{i} \lambda 1302$, Si $\text{ii} \lambda 1190$, and C $\text{ii} \lambda 1334$. They also include Si $\text{iii} \lambda 1206$, which traces gas in a higher-ionization stage. Figure 11 shows the profiles of the previous metal lines in cases where the lines are not severely blended with contaminating lines. We omit emitter KISSR 1567, because for this object the TA failed and the only observable line is Ly$\alpha$. The figure shows that C $\text{ii} \lambda 1334$ and C $\text{ii} \lambda 1336$ are resolved in the highest S/N spectra, e.g., for KISSR 242 and 1578.

For the emitters, the mean blueshifts of O$\text{i} \lambda 1302$ and C $\text{ii} \lambda 1334$ are $\langle v(\text{O} \text{i}) \rangle = -117 \pm 47 \text{ km s}^{-1}$ and $\langle v(\text{C} \text{ii}) \rangle = -94 \pm 20 \text{ km s}^{-1}$, respectively. For the absorbers, the corresponding mean velocity offsets are $\langle v(\text{O} \text{i}) \rangle = -23 \pm 28 \text{ km s}^{-1}$ and $\langle v(\text{C} \text{ii}) \rangle = -21 \pm 31$, which is almost consistent with a static medium. Note that for spiral KISSR 2023, whose Ly$\alpha$ profile is very noisy, O$\text{i} \lambda 1302$ has a large blueshift ($-153 \text{ km s}^{-1}$), such that Ly$\alpha$ emission would be expected. As previously mentioned, there appears to be some Ly$\alpha$ emission in this galaxy which has poor S/N. Interestingly, the SDSS image of KISSR 2023 is very similar to that of double-peaked emitter KISSR 298.

Our kinematical results are shown in Table 5, which lists the KISSR ID (Column 1); the Ly$\alpha$ profile shape (Column 2); the centroid of the Ly$\alpha$ line (Column 3); the velocity offsets between H$\alpha$ and intrinsic interstellar absorption lines Si $\text{ii} \lambda 1190$, Si $\text{ii} \lambda 1193$, Si $\text{iii} \lambda 1206$, O$\text{i} \lambda 1302$, Si $\text{ii} \lambda 1304$, and C $\text{ii} \lambda 1334$ (Columns 4–9); the mean velocity offsets and standard deviations excluding Si $\text{iii} \lambda 1206$ (Columns 10 and 11); the difference between the velocity offset of Si $\text{iii} \lambda 1206$ and the value in Column 10 (Column 12); and for the Ly$\alpha$ absorbers, the H$\text{i}$ column density of the Voigt profile (Column 13).

In summary, excluding the double emitter KISSR 298, we find that (1) Ly$\alpha$ is in emission and redshifted when high velocity outflows corresponding to expansion velocities of $\sim 100 \text{ km s}^{-1}$ are present, (2) Ly$\alpha$ is in absorption and at a velocity close to that of H$\alpha$ when null or low velocity gas flows are present, and (3) the Ly$\alpha$ redshift is higher than the blueshift of the LIS lines by a factor of 1.5–2. These results are further discussed in Section 4. In addition, in cases were the centroid of Si $\text{iii} \lambda 1206$ was measured, we find that this line tends to have a blueshift larger than that of the LIS lines by about 30–50 km s$^{-1}$.
3.3. EW(Lyα), Lyα Escape Fraction, and L1500

In order to characterize the strength of Lyα, we computed the Lyα luminosity $L(\text{Ly} \alpha)$, EW, and escape fraction within the COS aperture. Although the relevant quantity for cosmological studies is the global integrated escape fraction of the galaxy, our measurements are useful for comparing with global values derived from Lyα line images, as they give an idea of the concentration of the emission and of how coincident it is with regions of high FUV surface brightness. Such Lyα maps have been or will be obtained for a portion of our targets. We computed two values of the escape fraction, one using Hα and the other using Hβ. Both adopt the case B recombination theory predictions of Osterbrock & Ferland (2006) for $T_e \sim 10^4 \text{ K}$ and $n_e = 10^2 \text{ cm}^{-3}$, i.e., Lyα/Hα = 8.1 and Lyα/Hβ = 23.1 $L(\text{Ly} \alpha)$. The escape fractions were computed before and after correcting for the dust attenuation. We also computed the COS luminosity of the continuum at 1500 Å, $L_{1500}$, for comparison with the value from GALEX, which is given in Table 1. In order to obtain $L_{1500}$, we extrapolated beyond the red edge of our data, which is less than 1500 Å. In this paper, $L_{1500}$ is used for deriving the mass of the dominant stellar population and the SFR (see below).

For correcting the hydrogen line fluxes and $L_{1500}$ for the dust attenuation, we derived the total color excess, $E(B - V)_t$, from the observed Hα/Hβ line intensity ratio, after correcting the Balmer lines for the underlying stellar absorption. The stellar absorption correction was done by adding 2 Å to the EWs of the Balmer lines, following (McCall et al. 1985). This increases the Hα flux by 2% and the Hβ flux by 13% (median values for the sample). We did not correct the interstellar Lyα for the stellar contribution at Lyα, since as mentioned in the introduction, this correction is expected to be small for stellar populations dominated by O and early B stars, as is the case for the Lyα emitters in our sample. That O and early B stars dominate for the emitters is shown in Section 3.5. The Lyα emission-line fluxes were obtained by numerical integration. The Balmer line fluxes were obtained from the SDSS data when available and from the KISS data otherwise. The SDSS spectra have higher spectral resolution.

The total color excess is given by $E(B - V)_t = E(B - V)_G + E(B - V)_i$, where $E(B - V)_G$ and $E(B - V)_i$ are the Galactic and intrinsic contributions, respectively. According to the MW reddening maps of Schlegel et al. (1998), $E(B - V)_G$ is small toward our targets (see Table 1); thus most of the extinction must be intrinsic. Since Valls-Gabaud (1993) and Calzetti & Kinney (1992) showed that by using a metallicity-dependent reddening law one could recover the theoretical Lyα/Hβ ratio, we tried using an MW law for the spiral galaxies and an SMC law for the irregular galaxies. For this purpose, we used the reddening laws tabulated in Osterbrock & Ferland (2006). However, we found that the $E(B - V)_t$ values derived from these two laws are very
similar. In the end, and as in Calzetti et al. (2000), we adopted an MW law for deriving $E(B - V)$, For the theoretical $H\alpha/H\beta$ ratio we used 2.86, which is the case B recombination theory prediction for $T_e = 10^4$ K and $n_e = 100$ cm s$^{-3}$ of Osterbrock & Ferland (2006).

In order to see if the relation $E(B - V)_{s} = 0.44 \times E(B - V)_{t}$ of Calzetti et al. (2000) holds for our data, we computed the color excess of the stellar continuum, $E(B - V)_{s}$, using the slope of the FUV continuum, $\beta$. For obtaining $E(B - V)_{s}$ we used the method outlined in Wofford et al. (2011), where the slope of the MW de-reddened continuum is compared to that of a dust-free model of the appropriate metallicity. Following Calzetti et al. (2000), $E(B - V)_{s}$ was derived using the starburst reddening law. The comparison was done over the wavelength range from 1200 Å to the red edge of the data. The red edge is redshift dependent, as shown in Figures 4–8, and it is always less than 1500 Å. This range is different from what is used in Calzetti et al. (2000), i.e., 1250–1950 Å.

Our results are shown in Table 6, which gives the KISSR ID of the galaxy (Column 1); the rest-frame value of EW(Ly$\alpha$) (Column 2); $L(Ly\alpha)$, $L_{1500}$ from the COS spectra, $L(H\alpha)$, and $L(H\beta)$ (Columns 3–6, uncorrected for dust extinction); the escape fractions within the COS aperture, i.e., $Ly\alpha/H\alpha/8.1\times100$ and $Ly\alpha/H\beta/23.1\times100$ (Columns 7 and 8); $E(B - V)$, from the Balmer lines and $E(B - V)_{s}$ from the slope of the FUV continuum (Columns 9 and 10); and the reddening-corrected values of $L_{1500}$, $H\alpha/H\beta$, and the escape fractions (Columns 11–14).

In summary, we find that $E(B - V)_{s} = 1.27 \times E(B - V)_{t}$ (adopting the median of the sample), i.e., that the stellar continuum is more reddened than the nebular continuum, contrary to what was found by Calzetti et al. (2000). The different result is attributed to the larger optical and ultraviolet apertures used by Calzetti et al. (2000), and to the different wavelength range used by the latter authors for fitting the UV continuum. We also find that the rest-frame EWs of the emitters are in the range 1–12 Å, and that the reddening-corrected escape fractions of the emitters are in the range 1%–12%. The latter two results are further discussed in Section 4. Finally, we found that $L_{1500}$ from the COS data is lower by a factor of a few compared to the value from GALEX (compare Column 4 of Table 6 with Column 9 of Table 1). This is attributed to the larger aperture of GALEX.

### 3.4. SED Models

We studied how the strength of $Ly\alpha$ relates to the starburst phase and SFR of the dominant stellar population by comparing the COS observations with synthetic dust-free spectra computed with the widely used package Starburst99 (S99; Leitherer et al. 1999, 2010; Vázquez & Leitherer 2005). The observed SFR is that within the COS aperture. The value of EW(Ly$\alpha$) depends on...
the metallicity, IMF, SFH, and evolutionary phase of the stellar population (see models by Valls-Gabaud 1993; Charlot & Fall 1993; Verhamme et al. 2008). Because empirical spectral stellar libraries in the UV are only available at the Galactic (\(Z_{\odot} = 0.013\); Asplund et al. 2009) and LMC/SMC (\(Z_{\text{LMC}} = 0.007\) and \(Z_{\text{SMC}} = 0.002\); Maeder et al. 1999) metallicities, we have to rely on theoretical libraries at other metallicities. We used the theoretical libraries of Leitherer et al. (2010) corresponding to \(Z = 0.001, 0.004, 0.008, 0.020,\) and \(0.040\). For comparison, we also computed models with the empirical Galactic and LMC/SMC stellar libraries. We will refer to simulations based on the theoretical and empirical libraries as the theoretical and empirical models, respectively. The theoretical models use stellar evolution tracks corresponding to \(Z = 0.020\) and model atmospheres corresponding to \(Z = Z_{\odot}\). The empirical models use tracks corresponding to \(Z = 0.020\) or \(Z = 0.004\). Our grid of models includes single stellar population (SSP) and continuous star formation (CSF) scenarios. CSF is more appropriate in our case, as the observed spectra include light from regions of a few kpc in size and such large regions must contain UV-bright star clusters that span a range of ages. The SSP models are for comparison. We adopted a Kroupa IMF (Kroupa 2001), as at the high-mass end, it is considered to be universally applicable (Bastian et al. 2010). We used the Geneva stellar evolution tracks for non-rotating single stars with high-mass loss (Schaller et al. 1992; Meynet et al. 1994) because models that account for stellar rotation and binarity (Eldridge et al. 2008; Levesque et al. 2012) are still under development and require calibration against observations over our range of metallicities. Finally, we did not compute models for times earlier than 2 Myr because this is the age of the youngest LMC main-sequence O stars, or greater than 30 Myr after the beginning of star formation since the SSP models are affected by incompleteness of the stellar libraries beyond this time and the continuum slope and age-sensitive stellar-wind lines of CSF models do not significantly change beyond this time.

3.5. Starburst Phase, Stellar Mass, and Star Formation Rate

The age of an FUV-bright stellar population can be derived spectroscopically by comparing the observed profiles of age-sensitive lines originating in the winds of massive stars with model spectra. The strong N\(\text{v} \lambda\lambda 1238.8, 1242.8, \) Si\(\text{iv} \lambda\lambda 1393.8, 1402.8,\) and C\(\text{iv} \lambda\lambda 1548.2, 1550.8\) resonant doublets are widely used for this purpose (Tremonti et al. 2001; Chandar et al. 2003; Wofford et al. 2011). In summary, the P-Cygni profiles of the N\(\text{v}\) and the C\(\text{iv}\) doublets decrease in strength as the O stars evolve and expire. On the other hand, the Si\(\text{iv}\) doublet develops a P-Cygni profile in giant and supergiant O stars. Unfortunately, the C\(\text{iv}\) doublet and sometimes the Si\(\text{iv}\) doublet fall outside of the wavelength range that we observed with COS. In addition, the N\(\text{v}\) doublet is sometimes contaminated with
geocoronal emission. However, for targets showing clean and strong N\textsc{v} P-Cygni profiles, the age of the dominant population is younger than $\sim 10$ Myr (see Figure 5 in Wofford et al. 2011). Furthermore, a large Hz equivalent also indicates the presence of a young population (Kennicutt 1998; Leitherer et al. 1999).

We compared the COS spectra with SSP and CSF models of 5 and 10 Myr. We select this age range because between 5 and 10 Myr, the strength of N\textsc{v} noticeably decreases and these ages are sufficient for our purpose of demonstrating how young the dominant stellar populations are. We found the best-fit model to the N\textsc{v} and Si\textsc{iv} profiles by eye. The comparison was performed on the rectified spectra, as the models are dust-free but the data are not. The metallicity of the model is that most appropriate for the galaxy based on its oxygen abundance. Figures 12 and 13 show the comparisons of the observed N\textsc{v} and Si\textsc{iv} profiles with the theoretical models. Similarly, Figures 14 and 15 show the comparisons with the empirical models.

A comparison of the theoretical and empirical models in Figures 12 and 14 shows that at both ages and at all metallicities, N\textsc{v} is stronger for the CSF models than for the SSP models, although the difference is less at the lowest metallicity (e.g., for 2019 and 2110). Furthermore, the theoretical CSF models yield stronger N\textsc{v} profiles than the empirical models at similar ages and metallicities (e.g., 40 and 242). Conversely, the theoretical Si\textsc{iv} profiles show weaker emission components than the empirical ones. These differences do not severely affect our results.

The observed N\textsc{v} profiles of Ly\textalpha emitters 298, 326, and 1567 are contaminated with geocoronal O\textsc{i} lines, and the Si\textsc{iv} profiles of 11 targets, including four of the seven emitters, are either incomplete or have low S/N. For this reason, and because the Si\textsc{iv} profiles from the theoretical models are too weak compared to observations at young ages (e.g., compared to the empirical models), in the rest of our age-dating analysis, we concentrate on the N\textsc{v} profiles. For targets with clean N\textsc{v} profiles, we find that the theoretical SSP models tend to be a better fit than the theoretical CSF models, except at the lowest metallicity (e.g., KISSR 2019 and 2110), where the SSP and CSF N\textsc{v} profiles are very similar. This is true for the Ly\textalpha emitters as well as for the Ly\textalpha absorbers. One exception is 1084, which is better fitted by a CSF model. In any case, Ly\textalpha absorbers such as spiral galaxy KISSR 218 and metal-poor galaxies KISSR 2019 and 2110 have

Figure 9. IVC H\textsc{i} 21 cm emission along the lines of sight to our targets (thick gray curves) and MW Si\textsc{ii} $\lambda 1190$ absorptions (thin black curves). The spectral binnings are the nominal for the LAB and COS data, i.e., 1 km s$^{-1}$ for the former and 16 km s$^{-1}$ for the latter. We give the KISSR ID on the upper left of each panel. The seven galaxies with net Ly\textalpha in emission are marked with asterisks. The x-axis gives the velocity in the local standard of rest. The y-axis gives the continuum subtracted flux divided by a constant. The two vertical dotted lines correspond to $v_{LSR} = 0$ and 50 km s$^{-1}$.

We adopted stellar evolution tracks with a metallicity

$\log_{10}(Z/Z_{\odot}) = \log_{10}([O/H])/(O/H)_{\odot}$, where $Z_{\odot} = 0.020$ corresponds to $12 + \log_{10}(O/H)_{\odot} = 8.83$, i.e., to the old solar value of Grevesse & Sauval (1998).
strong $N\,\!\!\!\nu$ profiles and large $H\alpha$ EWs indicative of ages younger than $\sim 10$ Myr. Thus, they would be expected to have strong $Ly\alpha$ emission. However, they are absorbers, which is consistent with their low gas flow velocities (see Table 5). In addition, one cannot rule out attenuation of $Ly\alpha$ due to the presence of dust. We also find that the emitters have $Ly\alpha$ EWs that are consistent with their young ages, but that are small compared to model predictions for young starbursts. Thus, the emitters also require the presence of scattering in $H\,\!\!\!\iota$ and attenuation by dust. The takeaway point is that even at young ages ($< 10$ Myr) targets can show $Ly\alpha$ in absorption if the gas surrounding the starburst is almost static or if the dust column density surrounding the hot stars is significant.

Table 7 gives the stellar masses and SFRs derived from the UV spectra by adopting the ages in the second column of the table. For a given age, metallicity, IMF, and SFH, the theoretical value of $L_{1500}$ only depends of the mass of the stellar population. We give two estimates of the mass and the SFR, one corresponding to the SSP and the other to the CSF model. The masses are derived from the comparison of the observed and computed luminosities of the stellar continuum at 1500 Å (both dust-free). For the computed luminosity, we use the mean of the theoretical and empirical predictions at the adopted age and metallicity. Note that for the SSP models, it is common practice to define a characteristic SFR as the ratio of the stellar mass to the age of the population. This is what we quote in Column 5 of Table 7. For comparison, the table also gives the SFR derived from the SDSS $H\alpha$ luminosity (corrected for reddening using the starburst attenuation law of Calzetti et al. 2000) and Equation (2) in Kennicutt (1998). We recall that the SDSS aperture is very similar to the COS aperture. This is not the case for the KISS data; therefore, we omit the optical SFR for targets without SDSS data. We also recall that the SFRs are not global values. We find that the SSP models yield higher masses and SFRs than the CSF models by a factor of 1.4 (median). This is because CSF models predict larger values of $L_{1500}$ than the SSP models at the adopted ages. We also find that the SSP models yield systematically higher SFRs than those derived using $H\alpha$ by a factor of five (median) with a standard deviation of 7. The UV SSP SFRs derived from $L_{1500}$ should be viewed with caution as they are inversely proportional to the ages, which are expected to be underestimated by a factor of a few in cases where $N\,\!\!\!\nu$ is contaminated with geocoronal emission or does not show a strong P-Cygni profile. This is the case for KISSR 298 and 1637, which show the largest disagreement between the optical and the UV SFRs. In addition, the UV SSP SFRs depend on the masses,
Figure 11. Velocity offsets between metal absorption lines intrinsic to the galaxies and Hα. We include O i \( \lambda 1302 \) (red), Si ii \( \lambda 1190 \) (blue), C ii \( \lambda 1334 \) (green), and/or Si iii \( \lambda 1206 \) (gray), except when they are blended with contaminating lines. We give the KISSR ID on the upper left of each panel. The emitters are marked with asterisks. The spectra are binned to 16 km s\(^{-1}\) and smoothed for clarity. The vertical dotted lines mark a velocity offset of zero. For KISSR 298, which is a double-peaked Lyα emitter, we mark the position of the point equidistant from the two Lyα peaks with a vertical dashed line.

3.6. Wolf–Rayet Stars

The detection of broad (FWHM \( \sim 10 \) Å; Conti 1991) He ii \( \lambda 4686 \) emission (hereafter, He ii emission) provides another way of estimating the age of a stellar population. In the absence of an AGN, such emission originates in the dense winds of WR stars (Beals 1929; Bibby & Crowther 2012), whose progenitors are massive stars (\( M_{\text{initial}} \gtrsim 25 \); Maeder & Meynet 1994) with lifetimes of \( \sim 5 \) Myr (Meynet & Maeder 2005). Other optical WR emission lines are C iii \( \lambda 4650 \) and N iii \( \lambda 4640 \), which are generally weaker. For each galaxy, we show in Figure 16 the spectral region around the He ii \( \lambda 4686 \) line. The figure shows that in some cases, the [Fe iii] \( \lambda 4658 \) peak is taller than the He ii \( \lambda 4686 \) peak. As in López-Sánchez & Esteban (2010), we used multiple Gaussians to fit the spectral region in the vicinity of 4686 Å. The Gaussian centers were fixed at wavelengths where lines were expected. We detect He ii at the 3σ level or better in six cases, i.e., the amplitude of He ii is at least three times the standard deviation of the nearby continuum in six cases. In five of the latter cases, the He ii line is broad, i.e., FWHM \( \sim 10 \) Å. Unfortunately, for four of the seven Lyα emitters, the optical spectrum is either unavailable (KISSR 271), of inadequate spectral resolution (KISSR 326 and KISSR 1567), or very noisy (KISSR 298). The three emitters with adequate optical spectra have He ii detections with FWHM \( \geq 6 \) Å. This includes KISSR 1084, which may be of composite spectral type, and whose broad He ii emission is accompanied by narrow/nebular He ii emission. Note that for the latter galaxy, the He ii peak is taller than the [Fe iii] \( \lambda 4658 \) peak, unlike in most galaxies with broad He ii emission. On the other hand, two of the non-Lyα emitters have He ii detections and FWHM \( \geq 7 \) Å. The lack of Lyα emission in galaxies with broad He ii emission could be due to the lack of significant gas flow in the direction toward the observer. This is the case of KISSR 178 and the highly inclined spiral KISSR 2125. Finally, the non-emitter KISSR 108 only shows narrow He ii emission. Shirazi & Brinchmann (2012) interpret the presence of narrow He ii emission without a broad component, as WR stars that are offset from the emitting gas.
We compared the observed values of EW(He ii) with Starburst99 (Leitherer et al. 1999, 2010; Vázquez & Leitherer 2005) model predictions. Note that the observed values constitute lower limits due to the dilution of the He ii line in the stellar continuum of older stellar generations. Table 8 lists FWHM(He ii) and EW(He ii). Figure 17 shows the comparison of observed and computed values of EW(He ii) corresponding to SSP and CSF at the metallicities of the galaxies. Although Figure 17 shows that a given value of EW(He ii) can be reached at multiple times, the range of times is restricted to 10^6–10^7 yr for the SSP models, and 10^6–10^8 yr for the CSF models. The presence of broad He ii emission rules out an IMF deficient in massive stars or a population dominated by late B and A stars. Therefore, according to the predictions by Charlot & Fall (1993) one would expect positive values of EW(Lyα) for the galaxies with broad He ii emission. As previously mentioned, the lack of Lyα emission in KISSR 178 and KISSR 2125 is probably due to the dust geometry and inclination. In conclusion, we find no one-to-one correspondence between the Lyα emission and the presence of WR stars. This is in agreement with our age-dating analysis based on the N v profiles, where we concluded that some of the galaxies with young stellar populations are absorbers.

4. DISCUSSION

4.1. Lyα and Gas Flows

Kunth et al. (1998) analyzed HST/GHRS observations of eight nearby H II galaxies covering metallicities from 12 + log(O/H) = 8.0 to solar, and reddenings from E(B - V) = 0.1 to 0.55. They found velocity offsets between the H i and the H II gas of up to 200 km s^{-1} in the four galaxies with Lyα emission (P-Cygni profiles), whereas they found broad damped

| Galaxy | Lyα Shape | Lyα 1216 (km s^{-1}) | Si ii 1190 (km s^{-1}) | Si ii 1193 (km s^{-1}) | Si iii 1206 (km s^{-1}) | O i 1302 (km s^{-1}) | Si ii 1304 (km s^{-1}) | C ii 1334 (km s^{-1}) | ⟨Δv⟩ (km s^{-1}) | σ(Δv) (km s^{-1}) | N(H i) cm^{-2} |
|--------|-----------|----------------------|------------------------|------------------------|------------------------|----------------------|------------------------|------------------------|------------------|------------------|---------------|
| 40     | Ab        | −22 …                | −29                    | …                      | −29                    | −29                  | 0                      | 5.0E+20                | 249 ± 17         |
| 108    | Ab        | 0 …                  | −57                    | −96                    | −48                    | −50                  | −52                    | 5                      | 44               | 7.5E+20         |
| 178    | Ab        | 2 …                  | …                      | −35                    | −48                    | −17                  | −33                    | 16                     | 2.3E+21          |
| 182    | Ab        | −37 …               | −46                    | −47                    | −34                    | −33                  | −47                    | 8                      | 2.0E+21          |
| 218    | Ab        | 10 …                | −32                    | −32                    | −32                    | −32                  | −32                    | 28                     | 9.0E+20          |
| 242    | P-Cygni   | 170 ± 46             | −68                    | −73                    | −130                   | −53                  | −104                   | −79                    | 19               | 55               |
| 271    | P-Cygni   | 152 ± 20             | …                      | −177                   | …                      | −113                  | −145                   | 45                     | …                | …                |
| 298    | 2 Em      | −118 ± 11            | …                      | −185                   | −162                   | −192                  | −100                   | −151                   | 47               | 33               |

Notes. (1) KISSR ID of the galaxy. We mark the emitters with an asterisk. The last two rows give the minimum and maximum values in each column. In cases where more than one line was measured, we give the standard deviation of the various measurements as the error. (2) Average heliocentric velocities, v_h, of gocoronal and MW lines, respectively. (4) Mean FWHM of MW and intrinsic ISM absorption lines. Values of <110 km s^{-1} in Column 5 are lower limits.

| Galaxy | Lyα Shape | Lyα 1216 (km s^{-1}) | Si ii 1190 (km s^{-1}) | Si ii 1193 (km s^{-1}) | Si iii 1206 (km s^{-1}) | O i 1302 (km s^{-1}) | Si ii 1304 (km s^{-1}) | C ii 1334 (km s^{-1}) | ⟨Δv⟩ (km s^{-1}) | σ(Δv) (km s^{-1}) | N(H i) cm^{-2} |
|--------|-----------|----------------------|------------------------|------------------------|------------------------|----------------------|------------------------|------------------------|------------------|------------------|---------------|
| 326    | P-Cygni   | 251 ± 24             | −162                   | −140                   | …                      | −83                   | −175                   | −88                    | −130             | 42               | …             |
| 1084   | P-Cygni   | 198 ± 20             | −169                   | −86                    | −146                   | −109                  | −125                   | −78                    | −113             | 36               | 33            |
| 1567   | P-Cygni   | 105 ± 41             | …                      | …                      | …                      | …                    | …                      | …                      | …                | …                | …             |
| 1578   | P-Cygni   | 158 ± 2              | −163                   | −147                   | −166                   | −116                  | −149                   | −127                   | −140             | 19               | 26            |
| 1637   | Ab        | −50 …                | −68                    | −65                    | −60                    | −54                   | −69                    | −9                     | −53              | 25               | 6             |
| 1785   | Ab        | 50 …                 | …                      | …                      | −24                    | −61                   | −42                    | −42                    | −42              | 19               | …             |
| 1942   | Ab        | −50 …                | −7                     | −2                     | …                      | 6                     | −63                    | −24                    | −18              | 27               | 9.5E+20       |
| 2019   | Ab        | 50 …                 | −54                    | −64                    | −37                    | −25                   | …                      | −59                    | −50              | 18               | −14          |
| 2021   | Ab        | −50 …                | −38                    | −28                    | −19                    | −18                   | −14                    | −12                    | −12              | −2               | 2.5E+20       |
| 2023   | Ab        | −50 …                | −38                    | −153                   | −62                    | −71                   | −128                   | −58                    | 1.0E+20          |
| 2110   | Ab        | 50 …                 | −13                    | −6                     | −76                    | 36                    | 15                     | −2                     | 8                | 19               | 85            |
| 2125   | Ab        | 0                    | −56                    | −38                    | …                      | −44                   | 48                     | −22                    | 48               | …                | 1.5E+21       |

Notes. (1) KISSR ID. (2) Profile shape of Lyα. Ab = absorption. P-Cygni = P-Cygni like. 2 Em = Two emission peaks. (3) Velocity offset between the centroid of the Lyα line and Hα. (4)–(9) Velocity offset between the centroid of the intrinsic metal absorption line and Hα. (10) Mean velocity offset of intrinsic metal lines excluding Si iii λ1206. (11) Standard deviation of the velocities of the intrinsic metal lines excluding Si iii λ1206. (12) Velocity offset between Si iii λ1206 and the mean of the lower-ionization intrinsic metal lines. (13) H i column density derived from Voigt profiles.
Lyα absorptions at the velocity of the H II gas in galaxies with no signs of H I outflows from the LIS lines. These authors concluded that outflows are the main determining factor of the Lyα escape from galaxies. Our kinematical results are in very good agreement with these findings. However, one still needs to assess the relative importance of scattering in H I and destruction by dust on the Lyα escape.

We also find that the Lyα redshift is higher than the blueshift of the LIS lines by a factor of 1.5–2. This is in agreement with the high-redshift observations of Shapley et al. (2003) and the expanding-shell radiation transport model of Verhamme et al. (2006).

Finally, note that the Lyα troughs are the result of a superposition of Lyα components. Therefore, the dominant component does not need to be at zero velocity. It is interesting that for our targets and for the targets in Kunth et al. (1998), the Lyα absorption centroid is consistent with the velocity of the H II gas.

4.2. KISSR 298

KISSR 298 is the double-peaked Lyα emitter. Such a profile is generally interpreted as a signature of Lyα radiation transfer through a non-static medium (see references given in Section 4.5 of Verhamme et al. (2008). For this object, we find an expansion velocity of $150 \pm 47 \text{ km s}^{-1}$ from the LIS lines. This is high compared to the expansion velocities for the two double-peaked spectra in Verhamme et al. (2008), which are almost consistent with a static medium (they are $<25 \text{ km s}^{-1}$).

In KISSR 298, the blueshifted peak is twice as strong as the redshifted peak. Stronger blue peaks have been observed in star-forming galaxies at redshifts of $z=2–3$ (Verhamme et al. 2007; Kulas et al. 2012). They are qualitatively consistent with an inflow (Verhamme et al. 2006) and could be due to infalling gas originating in a galactic fountain, as in the model of Tenorio-Tagle (1996). The fact that in this system the dip between peaks essentially reaches the continuum is an interesting feature. Another possibility is that KISSR 298 has a broad Lyα emission line blended with an absorption, and that the absorption center is shifted redward. The shift could be caused by the relative motion of the emission region and the absorbing gas. A system corresponding to this description is shown in panel f of Figure 3 of Wilman et al. (2005), which corresponds to the second cloud from the top in their Figure 4. Unfortunately, the metal absorption lines of KISSR 298 are noisy and it is hard to tell if there is are unexpected absorptions near the wavelength corresponding to the Lyα “absorption.” As can be seen in Figure 11, the point equidistant
Figure 13. Similar to Figure 12 but for the Si\textsc{iv} $\lambda\lambda 1400$ resonance doublets. The vertical gray lines mark the positions of the Si\textsc{iv} lines.

Table 6

| Galaxy | EW(Ly$\alpha$) (Å) | log $L$(Ly$\alpha$) (erg s$^{-1}$) | log $L$_{1500} (erg s$^{-1}$) | log $L$(H$\beta$) (erg s$^{-1}$) | f(H$\alpha$) (%) | f(H$\beta$) (%) | $E(B-V)_T$ (mag) | $E(B-V)_s$ (mag) | log $L$$_{1500}$ (erg s$^{-1}$) | He$\alpha$/H$\beta$ | f(H$\alpha$) (%) | f(H$\beta$) (%) |
|--------|------------------|-------------------------------|-----------------------------|-------------------------------|----------------|----------------|-----------------|----------------|-----------------|----------------|----------------|----------------|
| 40     | < 0              | 38.6                          | 40.02                       | 39.54                         | ...            | ...            | 0.04            | 0.21            | 39.5            | 3.1            | ...            | ...            |
| 108    | < 0              | 39.1                          | 40.38                       | 39.85                         | ...            | ...            | 0.15            | 0.17            | 39.9            | 3.5            | ...            | ...            |
| 178    | < 0              | 39.6                          | 41.21                       | 40.64                         | ...            | ...            | 0.23            | 0.20            | 40.5            | 4             | ...            | ...            |
| 182    | < 0              | 39.1                          | 40.41                       | 39.88                         | ...            | ...            | 0.16            | 0.19            | 39.9            | 3.6            | ...            | ...            |
| 218    | < 0              | 38.9                          | 40.49                       | 39.87                         | ...            | ...            | 0.33            | 0.41            | 40.6            | 4.6            | ...            | ...            |
| 242*   | 10               | 41.20                         | 40.1                        | 41.61                         | 41.07          | 5             | 0.18            | 0.21            | 41.0            | 3.7            | 12            | 14            |
| 271*   | 1                | 38.74                         | 38.5                        | ...                           | ...            | ...            | 0.17            | 0.28            | 39.7            | ...            | ...            | ...            |
| 298*   | 12               | 40.16                         | 39.3                        | 40.65                         | 40.06          | 6             | 2              | 0.28            | 0.39            | 41.0           | 4.3            | 12            | 15            |
| 326*   | 4                | 39.30                         | 38.7                        | 40.22                         | 39.61          | 2             | 0              | 0.16            | 0.38            | 40.3           | 4.4            | 7             | 9             |
| 1084*  | 1                | 38.99                         | 39.0                        | 41.03                         | 40.37          | 0             | 1              | 0.42            | 0.44            | 41.0           | 5.2            | 1             | 1             |
| 1567*  | 3                | 38.71                         | 38.3                        | 40.25                         | 39.63          | 0             | 1              | 0.15            | 0.31            | 39.6           | 4.7            | 2             | 3             |
| 1578*  | 7                | 41.00                         | 40.0                        | 41.55                         | 41.04          | 3             | 4              | 0.12            | 0.10            | 40.4           | 3.4            | 6             | 7             |
| 1637   | < 0              | 39.2                          | 40.43                       | 39.93                         | ...            | ...            | 0.10            | 0.30            | 40.5            | 3.3            | ...            | ...            |
| 1785   | < 0              | 38.5                          | 40.38                       | 39.83                         | ...            | ...            | 0.18            | 0.19            | 39.3            | 3.7            | ...            | ...            |
| 1942   | < 0              | 38.9                          | 40.00                       | 39.44                         | ...            | ...            | 0.21            | 0.28            | 40.1            | 3.9            | ...            | ...            |
| 2019   | < 0              | 39.1                          | 40.63                       | 40.17                         | ...            | ...            | 0.01            | 0.14            | 39.7            | 2.9            | ...            | ...            |
| 2021   | < 0              | 39.2                          | 40.59                       | 40.03                         | ...            | ...            | 0.21            | 0.30            | 40.5            | 3.8            | ...            | ...            |
| 2023   | ...              | 38.6                          | 40.58                       | 39.91                         | ...            | ...            | 0.45            | 0.31            | 39.9            | 5.5            | ...            | ...            |
| 2110   | < 0              | 39.1                          | 40.33                       | 39.86                         | ...            | ...            | 0.00            | 0.09            | 39.5            | 3             | ...            | ...            |
| 2125   | < 0              | 38.9                          | 40.73                       | 40.03                         | ...            | ...            | 0.49            | 0.30            | 40.2            | 5.7            | ...            | ...            |
| Min    | 1                | 38.71                         | 38.3                        | 40.00                         | 39.44          | 0             | 0              | 0.00            | 0.09            | 39.3           | 2.9            | 1             | 1             |
| Max    | 12               | 41.20                         | 40.1                        | 41.61                         | 41.07          | 6             | 6              | 0.49            | 0.44            | 41.0           | 5.72           | 12            | 15            |
dashed line, has a velocity coincident with the Si \( \lambda 1567 \) peak.

| Galaxy  | Age (Myr) | Mass \( (M_\odot) \) | Mass \( (M_\odot) \) | SFR \( (M_\odot \text{yr}^{-1}) \) | Mass \( (M_\odot) \) | SFR \( (M_\odot \text{yr}^{-1}) \) | SFR \( (M_\odot \text{yr}^{-1}) \) |
|---------|-----------|---------------------|---------------------|-----------------|---------------------|-----------------|-----------------|
| 40      | 10        | 7E+06               | 3E+06               | 0.7             | 0.3                 | 0.1             |
| 108     | 5         | 7E+06               | 5E+06               | 1.4             | 0.9                 | 0.3             |
| 178     | 5         | 7E+07               | 3E+07               | 6.8             | 2.7                 | 2.6             |
| 182     | 10        | 2E+07               | 6E+06               | 1.6             | 0.6                 | 0.3             |
| 218     | 5         | 4E+07               | 2E+07               | 7.2             | 5.0                 | 0.7             |
| 242*    | 5         | 9E+07               | 6E+07               | 17.6            | 12.1                | 5.6             |
| 271*    | 10        | 1E+07               | 5E+06               | 1.1             | 0.5                 | …               |
| 298*    | 10        | 2E+08               | 8E+07               | 19.7            | 7.9                 | 0.8             |
| 326*    | 5         | 2E+07               | 1E+07               | 3.8             | 2.6                 | …               |
| 1084*   | 5         | 9E+07               | 6E+07               | 18.5            | 12.8                | 3.1             |
| 1567*   | 5         | 4E+06               | 3E+06               | 0.8             | 0.5                 | …               |
| 1578*   | 5         | 3E+07               | 2E+07               | 5.0             | 3.5                 | 4.0             |
| 1637    | 10        | 6E+07               | 3E+07               | 6.5             | 2.6                 | 0.3             |
| 1785    | 10        | 5E+06               | 2E+06               | 0.5             | 0.2                 | 0.3             |
| 1942    | 5         | 1E+07               | 8E+06               | 2.3             | 1.6                 | 0.2             |
| 2019    | 5         | 5E+06               | 3E+06               | 1.0             | 0.7                 | 0.3             |
| 2021    | 5         | 3E+07               | 2E+07               | 5.2             | 3.6                 | 0.6             |
| 2023    | 5         | 7E+06               | 5E+06               | 1.5             | 1.0                 | 1.2             |
| 2110    | 5         | 3E+06               | 2E+06               | 0.6             | 0.4                 | …               |
| 2125    | 5         | 1E+07               | 1E+07               | 2.9             | 2.0                 | 1.9             |
| Min     | …         | 3E+06               | 2E+06               | 0.5             | 0.2                 | 0.1             |
| Max     | 2E+08     | 8E+07               | 19.7                | 12.8            | 5.6                 | …               |
| Mean    | 4E+07     | 2E+07               | 5.2                 | 3.1             | 1.4                 | …               |
| Sigma   | 5E+07     | 2E+07               | 6.2                 | 3.7             | 1.6                 | …               |

Notes. (1) KISSR ID. We mark the Ly\( \alpha \) emitters with asterisks. (2) Adopted age. (3)–(6) Stellar population masses and star formation rates corresponding to the COS aperture and derived by comparing the observed and computed UV spectra. The computed spectra correspond to the adopted ages and to SSP or CSF models. (7) Star formation rate derived from the reddening-corrected \( H\alpha \) luminosity. The last four rows give the minimum, maximum, mean, and standard deviation for each column.

4.3. \( \text{Ly} \alpha \) versus Aperture Size and Distance

We checked if there is an observational bias due to distance among the \( \text{Ly} \alpha \) emitters in our sample. We excluded KISSR 1084 and 1567 from the analysis as one is of composite type and for the other the TA failed. In order to separate the effect of distance and metallicity/reddening, we divided the emitters in two sets: the low metallicity irregulars (KISSR 242, 1578, and 271) and the higher metallicity spirals (KISSR 298 and 326). Each set spans a factor of about two in distance (1.75 for the spirals and 1.7 for the irregulars). The spirals have low inclinations. Therefore the inclination angle is a secondary effect. We find that \( L(\lambda 1500) \), \( \text{EW}(\text{Ly} \alpha) \), and \( L(\text{Ly} \alpha) \) simultaneously increase with distance for both metallicity sets (see Table 6). Note that this result is based on small number statistics and that the general trend at much higher redshifts is that bright objects have lower EWs (e.g., Ando et al. 2006).

For the emitters, we find that \( \text{EW}(\text{Ly} \alpha) \) is low compared to values determined in other studies at similar redshifts with larger apertures. Giavalisco et al. (1996) found that \( \text{EW}(\text{Ly} \alpha) = 30 \text{ Å} \) on average for a sample of galaxies observed through the \( 10'' \times 20'' \) aperture of \( IUE \). We attribute this to our smaller aperture. Indeed, as previously mentioned, Östlin et al. (2009) found that in nearby galaxies, the bulk of the \( \text{Ly} \alpha \) emission is in the diffuse component of the galaxies. We also find that the emitters in our sample have \( \text{EW}(\text{Ly} \alpha) \) slightly below the completeness limit of the \( z = 0.3 \) sample of Cowie et al. (2010), which is 15 Å. However, our sample has a median absolute \( B \) magnitude of \(-19.4\) (see Table 1), which is similar to that of the \( z = 0.3 \) sample (see their Figure 23). This again could be an aperture effect. For Lyman break galaxies (LBGs) at \( z \sim 3 \), the median value of \( \text{EW}(\text{Ly} \alpha) \) is zero (see Figure 8 of Shapley et al. 2003). Therefore, the EWs of the emitters in our sample are consistent with the latter median.

4.4. \( \text{Ly} \alpha \) versus Metallicity/Reddening

If a homogeneous H\( _\text{I} \) layer covers most of the H\( _\text{II} \) region, the value of \( \text{EW}(\text{Ly} \alpha) \) is expected to depend on the dust extinction because the \( \text{Ly} \alpha \) line flux is more strongly reduced (due to multiple scattering effects) than the adjacent continuum. Reddening due to the presence of dust is expected to increase with metallicity. We use oxygen as a gauge of metallicity. We re-derived the oxygen abundances of the 16 galaxies with SDSS spectra using the method described in Salzer et al. (2005). In summary, in cases where the weak [O\( _\text{III} \)] \( \lambda 4363 \) line was not detected, we used the mean of the oxygen abundances derived from the EP (Edmunds & Pagel 1984) and SDSS COARSE calibrations, and in cases where the R23 abundance could be computed, we used the mean of the EP, SDSS, and R23 abundances (all methods are defined in Salzer et al. 2005). The oxygen abundances from the KISSR and the SDSS data are in agreement within the uncertainties and the final values are those given in Table 1.
Figure 14. Similar to Figure 12 but the models are based on empirical (E) stellar libraries. The empirical models are contaminated with Milky Way lines, in particular, Ly\(\alpha\). Only two metallicities are available for the empirical models.

Figure 15. Similar to Figure 14 but for the Si\textsc{iv} \(\lambda 1400\) resonance doublets.
Figure 16. Spectral region around He ii λ4686. The legends give the KISSR ID and the ratios of the amplitude of He ii to the standard deviation of the nearby continuum. The spectra are from the SDSS DR7 except for galaxies KISSR 326, 1567, and 2110 whose spectra are from Salzer et al. (2005). We do not have an optical spectrum for 271. We degraded the SDSS spectral resolution to match that of the non-SDSS spectra, which is 2.4 Å. The spectra are corrected for redshift and uncorrected for reddening. The dashed vertical lines mark the positions of the [Fe iii] λ4658 and He ii λ4686 emission lines. We overlay in gray a fit to the continuum.

We find that the two most metal-poor and least-reddened galaxies, KISSR 2019 and 2110, show Lyα in pure absorption, while the most metal-rich and most reddened galaxy, KISSR 298, has the highest value of EW(Lyα). Strong Lyα emission is expected from KISSR 2019 and 2110 based on the strength of their N v profiles and their high values of EW(Hα) (∼500 Å), which are characteristic of a young burst of star formation. However, these two targets show Lyα in absorption. This is not surprising given that this is also the case for I Zw 18, the most metal-poor galaxy in the local universe (Atek et al. 2009). Although we suffer from small number statistics, the lack of one-to-one correspondence between the strength of Lyα and metallicity/reddening is in agreement with the work of Giavalisco et al. (1996), which is based on larger optical and ultraviolet apertures than what we use in the present study. Therefore, it is not clear that larger aperture measurements yield a different result regarding Lyα versus metallicity. Our upcoming Lyα plus Hα/Hβ ratio maps of three of the galaxies in our sample should help establish the role of dust and metallicity in regulating the Lyα escape. These maps will be obtained as part of HST GO-12951 and will enable the measurement of spatially resolved and integrated Lyα and reddening values.

5. SUMMARY AND CONCLUSION

1. We used HST/COS to observe 20 nearby (z ∼ 0.03) galaxies spanning a broad range in properties (Table 1). Our data cover the wavelength range 1138–1457 Å and sample circular regions of 0.9–2.4 kpc in radius within each galaxy. We studied correlations between the Lyα line properties and galaxy properties including distance, metallicity, reddening, starburst phase, and gas flow properties. Our study includes the analysis of ancillary optical spectroscopy from SDSS and KISS. Based on the BPT diagram (Figure 1), the galaxies are dominated by star formation except for KISSR 1084, which is of composite spectral type.

2. We found Lyα profile shapes representative of what has been observed between redshifts of z ∼ 0 and z ∼ 5 (e.g., Kunth et al. 1998; Tapken et al. 2007; Kulas et al. 2012), including strong absorptions, P-Cygni profiles with redshifted emission, and double emission (Figure 10).

3. Of the 20 galaxies, 7 have net Lyα emission, including spiral and irregular galaxies and composite galaxy KISSR 1084 (Figures 3 and 10). For these seven emitters, the Lyα EW is in the range 1–12 Å and the range of Lyα escape
fractions within the COS aperture is 1%–12% (Table 6). The comparison with escape fractions at higher redshifts is complicated by the fact that at higher redshifts, observations include more if not all of the galaxy in the aperture.

4. A face-on spiral, KISSR 298, shows two peaks of Ly$\alpha$ emission separated by 370 km s$^{-1}$, one blueshifted and one redshifted and half as strong. Unfortunately, we were unable to determine if this profile is a strong emission with absorption within, as the LIS lines for this galaxy are too noisy.

5. Excluding KISSR 298, the emitters have Ly$\alpha$ peaks redshifted to 172 ± 49 km s$^{-1}$ with respect to H$\alpha$ (mean ± standard deviation). Including all emitters, the mean O I $\lambda$1302 and C II $\lambda$1334 absorption blueshifts are $-117 \pm 47$ and $-94 \pm 20$ km s$^{-1}$. Therefore, excluding KISSR 298, the Ly$\alpha$ redshift is larger than the interstellar absorption blueshift by approximately a factor of 1.5–2, as found at high redshift (e.g., Shapley et al. 2003), and in agreement with radiation transfer models (e.g., Verhamme et al. 2006).

6. For the absorbers, Ly$\alpha$ is centered at $0 \pm 38$ km s$^{-1}$ and O I and C II have centroids at $-23 \pm 28$ and $-21 \pm 31$ km s$^{-1}$. Thus, most absorbers are consistent with having static or low velocity H I gas. This supports earlier findings (e.g., Kunth et al. 1998).

7. The outflow velocity of Si III $\lambda$1206 is typically 30–50 km s$^{-1}$ greater than that of the H I gas (Table 5).

8. We found no one-to-one correspondence between the strength of Ly$\alpha$ and the reddening/metallicity measured within the COS aperture (Tables 6 and 7). In particular, we found three low-inclination spirals each showing different Ly$\alpha$ profiles, i.e., pure absorption, double emission, and P-Cygni profile, and the two most-metal-poor and least-reddened galaxies in our sample are pure absorbers.

9. We find stellar populations consistent with SSPs of ages in the range 5–10 Myr among the Ly$\alpha$ emitters and the Ly$\alpha$ absorbers. Similarly, we detect signatures of the presence of WR stars among the emitters and the absorbers. Therefore, a young starburst does not guarantee strong Ly$\alpha$ emission.

10. In conclusion, a picture emerges where the Ly$\alpha$ photons escape through regions of low H I and dust column densities, where gas outflows are occurring.

11. In HST cycle 20, we will map three low-inclination spirals from the current sample in the Ly$\alpha$ line and the H$\beta$/H$\alpha$ ratio (proxy for dust attenuation). This will make it possible to study the relative importance of gas flows and dust content for regulating the Ly$\alpha$ escape.

Support for this work has been provided by NASA through an award to University of Colorado (Boulder) entitled “Cosmic Origins Spectrograph GTO.” Award number NNX08AC14G. We thank C. Danforth, K. France, and J. Tumlinson for their codes, which were used for reducing (C.D.) and analyzing (K.F.)
