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# The Lyman Continuum Escape Fraction of Emission Line-selected $z \sim 2.5$ Galaxies Is Less Than 15%

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## Abstract

Recent work suggests that strong emission line, star-forming galaxies (SFGs) may be significant Lyman continuum leakers. We combine archival *Hubble Space Telescope* broadband ultraviolet and optical imaging (F275W and F606W, respectively) with emission line catalogs derived from WFC3 IR G141 grism spectroscopy to search for escaping Lyman continuum (LyC) emission from homogeneously selected $z \sim 2.5$ SFGs. We detect no escaping Lyman continuum from SFGs selected on [O II] nebular emission ($N = 208$) and, within a narrow redshift range, on [O III]/[O II]. We measure $1\sigma$ upper limits to the LyC escape fraction relative to the non-ionizing UV continuum from [O II] emitters, $f_{\rm esc} \lesssim 5.6\%$, and strong [O III]/[O II] $> 5$ ELGs, $f_{\rm esc} \lesssim 14.0\%$. Our observations are not deep enough to detect $f_{\rm esc} \sim 10\%$ typical of low-redshift Lyman continuum emitters. However, we find that this population represents a small fraction of the star-forming galaxy population at $z \sim 2$. Thus, unless the number of extreme emission line galaxies grows substantially to $z \gtrsim 6$, such galaxies may be insufficient for reionization. Deeper survey data in the rest-frame ionizing UV will be necessary to determine whether strong line ratios could be useful for pre-selecting LyC leakers at high redshift.

*Key words:* galaxies: general – galaxies: star formation – ultraviolet: galaxies

## 1. Introduction

Star-forming galaxies (SFGs) likely reionize neutral hydrogen in the early universe (see the review in Loeb & Barkana 2001), when quasars are not sufficiently numerous to contribute significantly to the ionizing background (Ricci et al. 2017; cf. Giallongo et al. 2015). Verifying this assumption by directly measuring the ionizing output of Lyman continuum (LyC; $\lambda < 912$ Å) is impossible—the IGM effectively attenuates all LyC flux emitted along the line of sight to $z > 6$ redshift galaxies. Instead, the ionizing output of high-redshift SFGs must be constrained by surveys of low-redshift *analogs*, or indirectly (e.g., Jones et al. 2013). Criteria for pre-selecting LyC emitting candidates from among the class of all SFGs that produce LyC are crucial for such studies—large, blind, deep surveys are infeasible with the *Hubble Space Telescope* (*HST*), the only telescope currently capable of obtaining high-resolution LyC imaging and spectroscopy.

Previously, pre-selection was made on actively SF galaxies (Schaerer 2003; young, massive stars emit copious ionizing radiation, $Q_H > 10^{47}$ s$^{-1}$;). Studies with the HUT (Leitherer et al. 1995) and the *HST* SBC (e.g., Malkan et al. 2003; Siana et al. 2010) do not detect escaping LyC. Large archival studies of LyC emission from SFGs (Cowie et al. 2009) and H$\alpha$-selected emission line galaxies (Rutkowski et al. 2016) have generally reported non-detections, likely indicating that the strong star formation may be *conducive* to LyC escape, but does not guarantee it. Until recently, few LyC leakers were known; local starbursts Tol 0440-381, Tol 1247-232, Mrk 54, and Haro11 (e.g., Leitherer et al. 2016; Puschnig et al. 2016) and, at $z \gtrsim 2$, fewer than ∼10, UV-selected SFGs (e.g., de Barros et al. 2016; Mostardi et al. 2016; Smith et al. 2016).

Recently, five (of five galaxies targeted) $z \lesssim 0.3$ compact ($r_e \lesssim 1$ kpc) SFGs selected for their anomalously high nebular oxygen ratios ($O_{32}$ = [O III]$\lambda$5007 Å/[O II$\lambda\lambda$3727,3729 Å] $> 5$) have been confirmed as LyC leakers ($f_{\rm esc} \sim 5\%$–15%; Izotov et al. 2016a, 2016b), with an additional 2–3 compact $O_{32}$ galaxies predicted to be LyC leakers based upon their Ly$\alpha$ profiles (Verhamme et al. 2017). Furthermore, Naidu et al. (2017) applied an F275W–F336W color selection to identify three SFG LyC leakers at $z \lesssim 2$ in the HDUV (PID: 13779; PI: P.Oesch), each with $O_{32} \gtrsim 3$. The success rate of LyC detection in $O_{32}$ emitters makes this nebular-line diagnostic appealing for pre-selection. Here, we investigate that potential utility. In Section 2, we discuss the selection of ELGs using *HST* IR grism spectroscopic catalogs combined with rest-frame UV–optical imaging in the CANDELS fields. In Section 3, we present new measurements to the absolute escape fraction, $f_{\rm esc}$, for these ELGs. We assume ΛCDM cosmology with $\Omega_m = 0.27$, $\Omega_\Lambda = 0.73$, and $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$ (Komatsu et al. 2011).

## 2. Emission Line Galaxy Selection in CANDELS

The *HST* WFC3/IR grism has been remarkably successful for surveying SFGs with strong emission lines at $z \sim 1$–3, as the [O II]$\lambda\lambda$3726,3729 Å doublet, a well-calibrated signature of star formation (Kewley et al. 2004), can be detected with the G141 grism ($\lambda_c \simeq 1.4\,\mu$m) in $2 \lesssim z \lesssim 3.5$ SFGs. The G141

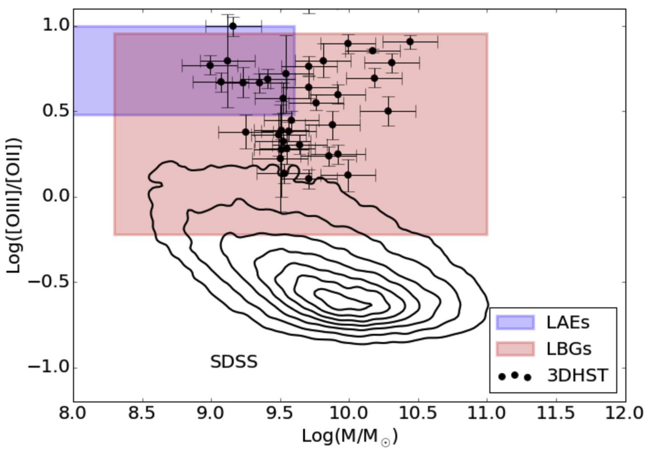


**Figure 1.** We identify 41 $z \sim 2.3$ $O_{32}$-emitters in the CANDELS fields. Here, we plot $O_{32}$ for the sources as measured from their G141 grism spectra against stellar masses derived from SED fits in Momcheva et al. (2016). We overplot contours indicating the $O_{32}$ distribution measured for SDSS galaxies (Tremonti et al. 2004) and indicate with shaded regions the parameter space populated by high-redshift Ly$\alpha$ emitters and Lyman Break galaxies at $z \sim 2{-}3$ (Nakajima & Ouchi 2014).

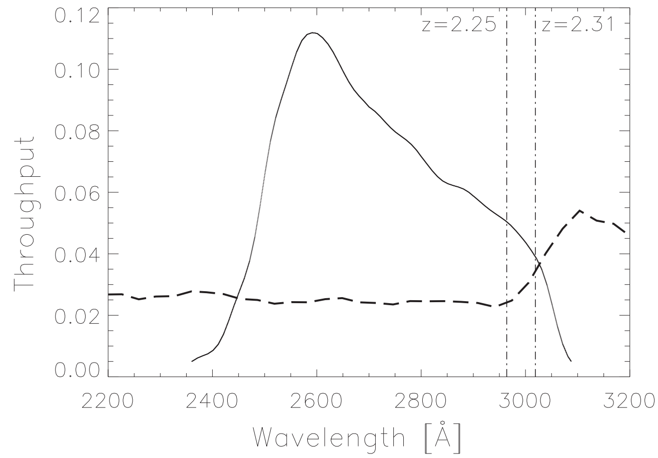


**Figure 2.** *HST* F275W broadband filter throughput, $T$ (solid curve), declines to $<1\%$ at $\lambda \gtrsim 3086$ Å, corresponding to $\lambda = 910$ Å at $z > 2.39$. Thus, the Lyman edge falls within the bandpass for SFGs selected at $2.25 < z < 2.31$ (indicated by dashed-dotted vertical lines), implying the measurement of LyC can be contaminated by non-ionizing emission. For a 1 Myr, solar-metallicity burst simple stellar population model (with no correction for attenuation by gas applied) from Bruzual & Charlot (2003; dashed curve, scaled, in $f_\nu$), this contamination is $\lesssim 0.5\%$ *only* if $f_{esc} = 100\%$. For $f_{esc} < 100\%$, contamination by the *non*-ionizing continuum to the LyC photometry will necessarily increase to 100% as $f_{esc}$ decreases to zero.

cannot resolve this doublet; thus, to avoid potential line misidentification of a candidate [O II] emission line, a photometric redshift is critical. In the *HST* CANDELS fields, the broadband UV–optical SED for galaxies is well sampled, ensuring the robust identification of $z \gtrsim 2$ [O II]-emitters. Unfortunately, rest-frame, broadband LyC imaging is not available across the entire survey footprint. Thus, in our search here for LyC emission from $z \sim 2.5$ SFGs, we are limited to probing ∼40% of the area in GOODS-South and GOODS-North.

Within these regions, we select [O II]-emitters identified by the 3D-HST G141 grism survey. We selected ELGs requiring (1) $(S/N)_{[O\,II]} > 3$ and (2) within the redshift range $2.38 < z < 2.9$, where $z \equiv$ "z_best" measured by Momcheva et al. (2016) using both grism and broadband photometry. The lower-redshift limit of this sample is fixed to ensure the broadband (WFC3/UVIS F275W) imaging is strictly sensitive to rest-frame LyC emission. In total, we select 208 [O II]-emitters (74, 109, and 25 in ERS, GOODS-N, and UVUDF, respectively), with a mean (median) SFR = 8.0 (3.9) $M_\odot$ yr$^{-1}$ and stellar mass $M_\star \simeq 10^{9.9}(10^{9.6})$, respectively. Included in this sample are 13 ELGs that were also considered in the unpublished LyC survey in the ERS field presented by Smith et al. (2016).

We note that within a narrow redshift range the G141 grism is simultaneously sensitive to [O II] and [O III]. Thus, we select a second, independent sample of SFGs requiring: (1) $2.25 < z < 2.31$; (2) $(S/N)_{[O\,III]} > 3$; and (3) $(S/N)_{H\beta} > 1.5$.

This redshift range implies that the sample's LyC photometry could include a contribution from non-ionizing emission in the bandpass. As illustrated in Figure 2, the F275W throughput, $T$, $\gtrsim 1\%$ at $\lambda < 3086$ Å (910 Å at $z = 2.39$). Only in the case of *zero* attenuation by intervening neutral gas and dust (i.e., $f_{esc} \equiv 100\%$) will the contribution redward of the Lyman edge to the F275W photometry be negligible ($<0.5\%$). The contribution by non-ionizing photons to the measured ionizing flux will introduce a systematic uncertainty to $f_{esc}$ strictly less than unity measured using the broadband method we apply in Section 3. Any candidate LyC leakers identified in this sample must be considered tentative pending spectroscopic follow-up.

We identify 41 $O_{32}$ emitters (22 and 19 in the GOODS-N and ERS, respectively; Figure 1). For the measurement of $O_{32}$, we require [O III]$\lambda$5007, which we derive from [O III] $\lambda\lambda$4959,5007 Å reported in 3D-HST catalogs, applying a uniform correction that assumes an intrinsic ratio of $\lambda5007/\lambda4959 = 2.98$ (Storey & Zeippen 2000) to correct for the contribution of [O III]$\lambda$4959. Of these $O_{32}$ emitters, 13 are identified with $O_{32} > 5$. By comparison with the [O II]-emitter sample, these ELGs have a similarly high mean (median) SFR = 6.8 (4.1) $M_\odot$ yr$^{-1}$ and moderate stellar mass $M_\star \simeq 10^{10.0}(10^{9.7})$.

In the following analysis of both samples, we use publicly available F275W imaging mosaicked by the individual survey teams (see Table 1). In GOODS-North, the HDUV team has prepared public mosaics "v0.5" combining five of eight HDUV pointings with CANDELS-Deep data. We note that the WFC3/UVIS is susceptible to significant (∼50% losses) charge transfer inefficiencies. To mitigate this, UVUDF and GOODS-North imaging programs (referenced in column 4 of Table 1) included a $\sim 10e^-$ post-flash to minimize charge losses. In the case of the ERS, these data were among the first data obtained with the then newly installed WFC3 and were minimally affected by the CTE (see Smith et al. 2016 for details). In preparation for analysis, we extracted $12'' \times 12''$ postage stamps from the science and associated rms maps centered on each ELG. For uniformity, all stamps were rebinned to a common pixel frame of 0."09 pix$^{-1}$, the coarsest scale for which mosaics are available.

## 3. The LyC Escape Fraction of $z \simeq 2.3$ ELGs

Broadband imaging surveys readily make *differential* measurements of the ionizing (LyC) to non-ionizing (UV, measured at $\lambda_{rest} \simeq 1500$ Å) luminosity from galaxies. At high redshift, LyC from young stars within galaxies will be attenuated by neutral gas and dust in the ISM, as well as by

**Table 1**
Archival F275W imaging

| Field | Survey | Area[a] | Survey Depth ($3\sigma$)[b] | References | $N_{\rm O\,II}$ | $N_{\rm O32}$ | $N_{\rm O32>5}$ |
|---|---|---|---|---|---|---|---|
| GOODS-North | CANDELS-Deep | 120 | 27.8 | Koekemoer et al. (2011) | 52 | 7 | 4 |
| | HDUV[c] | 70 | 27.9 | [d] | 57 | 15 | 4 |
| GOODS-South | UVUDF | 4.5 | 28.2 | Rafelski et al. (2015) | 25 | ⋯ | ⋯ |
| | ERS | 60 | 26.5 | Windhorst et al. (2011) | 74 | 19 | 5 |

**Notes.**
[a] Approximate area in square arcminutes.
[b] We report published point-source completeness limits [AB mag] but estimate the depth from the sky variance for the HDUV GOODS-N public mosaic.
[c] For HDUV, mosaics are available at http://www.astro.yale.edu/hduv/DATA/v0.5/.
[d] *HST* Program 13872.

neutral H I in the IGM along the line of sight. This partly motivates a definition of the *relative* escape fraction, following Steidel et al. (2001):

$$f_{\rm esc,rel} = \frac{(L_{\rm UV}/L_{\rm LyC})_{\rm int}}{(L_{\rm UV}/L_{\rm LyC})_{\rm obs}} \cdot \exp[\tau_{\rm IGM}], \quad (1)$$

$\tau_{\rm IGM}$ is the (redshift-dependent) IGM attenuation of LyC by neutral H I, typically modeled on measurements from absorption line surveys toward high-redshift bright quasars (e.g., Fardal et al. 1998). The intrinsic UV-to-LyC ratio must be modeled for each galaxy individually, but typically ranges between 2 and 10 for SFGs with ages less than $\sim 10^8$yr. If the magnitude of extinction due to dust in the ISM can be estimated from the SED, then the *absolute* escape fraction can be directly related to $f_{\rm esc,rel}$ as

$$f_{\rm esc} = f_{\rm esc,rel} \times \exp[-\tau_{\rm UV,dust}]. \quad (2)$$

We measured ionizing and non-ionizing photometry in the F275W and F606W postage stamps, respectively, using *Source Extractor* (Bertin & Arnouts 1996) in dual image mode, with the F606W as the detection image.[10]

The median F275W S/N for all ELGs is consistent with a statistical non-detection ($\langle SNR \rangle = 0.12$), as measured within each ELG's corresponding F606W aperture defined in source extraction. A visual inspection of *all* F275W stamps confirms that *no* individual ELGs are LyC leakers, including those [O II]-emitters in the Smith et al. (2016) sample. Note that for the median F606W (rest-frame UV) continuum $m = 25$ AB of this sample, the surveys limit $f_{\rm esc,rel} \lesssim 2\%$ in the deepest (UVUDF) and $f_{\rm esc,rel} \lesssim 12\%$ in the shallowest (ERS) mosaics. Smith et al. report a detection of $f_{\rm esc} = 0.14\%$ for the sample that overlaps with the [O II]-emitter sample. Within the HDUV field, no LyC leakers have been previously identified.[11]

To measure $f_{\rm esc}$, we apply the stacking procedure defined in Siana et al. (2010), summing over all pixels in the F275W and F606W stamps associated with the F606W-defined segmentation map. Furthermore, we sum in quadrature the associated errors from the error maps, applying a (small) correction for correlated noise introduced in the rebinning of the error maps where necessary (Casertano et al. 2001). This stacking yields no statistically significant detections of LyC leakers. A visual inspection of the associated stacked LyC frames (combined using IRAF `imcombine`; Figure 3) reveals no perceptible LyC flux within an aperture defined by the non-ionizing UV image stack. Here, we have cleaned all LyC stamps before stacking, using the segmentation maps, to replace pixels not associated with the ELG with randomly assigned pixel values consistent with the sky background measured within each stamp. In Table 2, we report $f_{\rm esc}$ for each stack as upper limits.

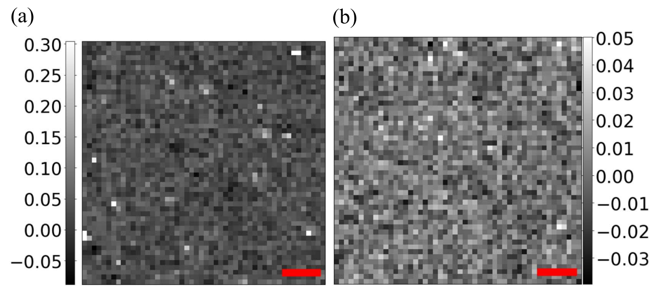


**Figure 3.** Stacked rest-frame LyC images for the (a) [O II] and (b) strong ($O_{32} > 5$) emitters. A linear grayscale appropriately scaled for each stack is provided. A 1″ scale-bar is overplotted (red) on each stacked image. All $f_{\rm esc}$ measurements are provided in Table 2.

In rest-frame UV morphology, these galaxies are compact. For reference, an aperture defined to include 90% of the segmentation pixels common to *all* galaxies has an area of ~0.3 square arcseconds (physical radius, $r \lesssim 4$ kpc), in good agreement with the measurements of $z \sim 2$ galaxy sizes from Shibuya et al. (2015). Many galaxies (>70%) do show faint irregular UV features. Though we used the segmentation map (defined by the rest-frame UV morphology) to define pixels to include in the stacking of each galaxy, in principle these asymmetric low surface brightness features could be lost to the sky when stacked.

We measure $f_{\rm esc,rel}$, correcting each galaxy for IGM attenuation using the correction factor from the piecewise parameterization of the redshift distribution and column density of intergalactic absorbers (see Haardt & Madau 2012). For reference, $\exp[\tau_{\rm IGM}] = 1.72$ (2.56), at $z = 2.29$ (2.56), the median redshift of the $O_{32}$ ([O II])-selected samples. Assuming $(L_{\rm UV}/L_{\rm LyC})_{\rm int} = 3$, appropriate for a young ($\sim 10^7$ yr), solar-metallicity stellar population (Rutkowski et al. 2016), we measure $f_{\rm esc,rel} \lesssim 7.0\%$, 7.8%, and 18.9% ($1\sigma$) for the [O II]-, all $O_{32}$-, and high $O_{32}$-selected samples. We measure $f_{\rm esc}$ correcting for dust attenuation for each galaxy individually. We measure $\tau_{\rm UV,dust}$ assuming a Calzetti et al. (2000) reddening law ($R_V = 4.05$) and calculating stellar $E(B\text{–}V)$ from the best-fit $A_V$ measured from the broadband SED by Skelton et al. (2014).

We report $f_{\rm esc} < 5.6\%$ for the [O II]-selected sample. Note that the upper limit on $f_{\rm esc}$ measured for random sub-samples of

[10] We use the relevant detection parameters DETECT_MINAREA = 6, DETECT_THRESH = 3, BACK_SIZE = 10, BACK_FILTERSIZE = 5, and BACK_FILTTHRESH = 1.5, found by extensive testing to determine those parameters that most accurately differentiated source from sky pixels in the segmentation maps.
[11] Naidu et al. (2017) identified six candidate LyC leakers, all at $z \simeq 2$.

**Table 2**
Measured UV/LyC Flux Ratios: Upper Limits to $f_{esc}$

| Selection | $N_{objs}$ | $\Delta(z)$ | Observed $f_{\nu,LyC}$[a] | Observed $f_{\nu,UV}$ | IGM corr. UV/LyC | $f_{esc,rel}^{LyC}$[b] | $f_{esc}^{LyC}$ |
|---|---|---|---|---|---|---|---|
| [O II] | 208 | $2.38 < z < 2.9$ | $0.45 \pm 0.27$ ($1.6\sigma$) | 9.12 | >41.49 | <7.0% | <5.6% |
| All $O_{32}$ | 41 | $2.25 < z < 2.31$ | $0.16 \pm 0.140$ ($1.1\sigma$) | 4.53 | >38.44 | <7.8% | <6.7% |
| $O_{32} > 5$ | 13 | $2.25 < z < 2.31$ | $-0.02 \pm 0.090$ ($-0.16\sigma$) | 1.15 | >15.81 | <18.9% | <14.0% |

**Notes.**
[a] Flux densities reported here in $\mu$Jy.
[b] We assume $(L_{UV}/L_{LyC})_{int} = 3$; italicized entries indicate non-detections and should be interpreted as limits.

[O II]-emitters drawn exclusively from the individual (unbinned) mosaics scale approximately as $N^{-1/2}$, as expected from purely Poisson statistics. Thus, in future work, using a re-reduction of all available F275W imaging in the CANDELS fields to improve the size of the [O II]-selected sample emitters, we will test for variations in $f_{esc}$ in sub-samples selected on, e.g., UV luminosity or inclination.

For the full $O_{32}$-selected sample, we measure $f_{esc} < 6.7\%$; for the $O_{32} > 5$ sample, $f_{esc} < 14\%$, consistent with the expectation for Poissonian statistics if the extinction correction is appropriately re-normalized to reflect the higher average extinction reported for the $O_{32} > 5$ sample. The mean IGM transmission for the $O_{32}$- and [O II]-selected samples differs by a factor of $\sim$1.5, the $O_{32}$-emitters are intrinsically more luminous ($\sim$3×), and the possibility of a non-negligible contribution from non-ionizing flux in the F275 bandpass (see Section 2) makes a direct comparison of $f_{esc}$ upper limits for these samples more difficult.

## 4. Discussion

If these SFGs are analogs to the high-redshift sources of reionization, the measured upper limits can be informative. First, the $1\sigma$ upper limit to $f_{esc}$ measured for [O II]-emitter sample is inconsistent with the threshold of $f_{esc} \gtrsim 13\%$ required if high-redshift SFGs reionize the universe (see Robertson et al. 2015) compatible with the independent constraints on the ionization history of the IGM from the CMB (the electron scattering opacity, $\tau_{es}$; see Planck Collaboration et al. 2016) and QSO absorption line studies (Mesinger & Haiman 2007). This tension is alleviated considering the $3\sigma$ $f_{esc}$ upper limit and noting that dwarf galaxies less massive than these ELGs (with median $M \simeq 10^{9.5-10} M_{\odot}$) are expected to contribute most significantly to reionization (Wise et al. 2014; Robertson et al. 2015).

Note Rutkowski et al. (2016) measured, for (H$\alpha$-selected) $z \sim 1$ SFGs, $f_{esc} < 4\%$ ($3\sigma$). Selecting more distant SFGs using the same grism spectroscopy here, we are more sensitive to intrinsically brighter line luminosities, $\sim$4 brighter at $z \sim 2.5$ than $z \sim 1$, though intrinsically we can expect [O II]/H$\alpha \lesssim 1$ ($\simeq$0.5 at $z \simeq 0.1$; Mouhcine et al. 2005). As such, the average SFR for the [O II]-selected sample is $\sim$2× that of the H$\alpha$ sample in previous work, though the median SFR is measured for 3D-HST sources from the broadband SED in contrast to, e.g., Rutkowski et al. (2016), which used the extinction-corrected H$\alpha$ luminosity. Thus, we caution any strict interpretation of the $f_{esc}$ upper limits derived here for $z \simeq 2.5$ SFGs and previous work at $z \simeq 1$ as evidence for an evolution in $f_{esc}$.

Our observations are not deep enough to detect $f_{esc} \sim 10\%$, typical of the low-redshift LyC emitters (Izotov et al. 2016b), which have comparably high nebular emission line ratios or similar star formation rate surface densities, $\Sigma_{SFR}$.[12] Our upper limit on $f_{esc}$ derived for the high $O_{32}$ ELGs is marginally consistent ($f_{esc,rel}$ ($3\sigma$) $\lesssim 0.57$) with the detection of LyC in a similar galaxy (*ion2*; $f_{esc,rel} = 0.64^{1.1}_{-0.1}$) studied by de Barros et al. (2016), though difficult to reconcile with the high $f_{esc} >$ 50% observed for the $z = 3.2$ strong $O_{32}$ ($\gtrsim$10%) emitter observed by Vanzella et al. (2016).

We call attention to $f_{esc}$ measured for the small number of SFGs identified with high $O_{32}$ emission and the implication for the contribution of their high-redshift analogs to reionization. Generally, reionization proceeds when a sufficient ionizing background can be maintained by either a large number of relatively inefficient LyC leakers or relatively fewer emitters that efficiently source LyC. The number of ionizing background photons in a cosmological volume is proportional to $f_{esc} \times n_{SFG}$, where $n_{SFG}$ is the volume density of SF galaxies and $f_{esc} \simeq 10\%$ is necessary for reionization. However, not all SF galaxies are LyC leakers. In fact, it is well established that the general population of SFGs have an escape fraction $\ll$10% (Siana et al. 2010; Grazian et al. 2016), and only the extreme $O_{32}$ galaxies appear to meet the requisite $f_{esc}$ (Izotov et al. 2016b). If $f_{leak}$ is the fraction of SF galaxies that are LyC leakers, then the previous relationship for the number of ionizing photons, $N_{ion}$, can be rewritten as $N_{ion} \propto f_{esc} \times f_{leak} \times n_{SFG}$. In the WFC3 spectroscopic parallel survey (WISP; Atek et al. 2010), sensitive to both [O II] and [O III] emission at $1.4 \lesssim z \lesssim 2.3$, 50% of the cataloged galaxies are detected in both oxygen lines (Ross et al. 2016). Only $\sim$4% of these sources are $O_{32} > 5$ emitters. With the upper limits presented here, assuming $f_{leak} \sim 4\%$ and that this fraction does not evolve substantially to $z \sim 6$, such extreme objects would not support reionization. High-redshift ($z > 3$) SFGs do exhibit, on average, an enhanced ionization state relative to low-redshift SFGs (e.g., Stanway et al. 2014), inferred from the [O III]/H$\beta$ ratio. Recently, Faisst (2016) modeled this increased ionization state with redshift to predict the evolution of the escape fraction evolution with redshift of $O_{32}$-emitters and found such galaxies to be nearly sufficient to reionize the universe at $z \sim 6$. Clearly, direct measurement of the median escape fraction for strong emitters ($O_{32} > 5$) with *HST* at $z < 3$ is critical. This, in combination with the direct measure of the evolution of the number density of such extreme $O_{32}$ galaxies toward the epoch of reionization ($z > 7$), a key result for *JWST*, will ultimately determine whether such sources may reionize the universe.

[12] We measure $-2 \lesssim \log(\Sigma_{SFR}) \lesssim 1$ [$M_{\odot}$ yr$^{-1}$ kpc$^{-2}$] for $O_{32}$-emitters, using the 3D-HST broadband SFR and area from each galaxy's F606W segmentation map.

## 5. Conclusion

We have combined archival high-resolution *HST* UV imaging in the rest-frame LyC for $z \sim 2.5$ galaxies in the CANDELS deep fields, selected on the presence of nebular oxygen emission lines in the 3D-HST IR grism spectra. We do not detect LyC escaping from [O II]- or $O_{32}$-selected emitters individually.

We stack the individual non-detections, and measure for each stack upper limits to the absolute escape fraction less than 5.6%, 6.7%, and 14% ($1\sigma$), respectively. Our limits on $f_{esc}$ ($3\sigma$) for such relatively massive galaxies do not rule out the possibility that SFGs are able to sustain reionization. However, whether at $z \gtrsim 2$, strong star formation and high $O_{32}$ ratios alone are indicative of significant LyC escape remains uncertain. Furthermore, we note that at $z \sim 2$ the class of galaxies with extreme $O_{32}$ ratios remain exceedingly rare. In order for galaxies to be able to sustain reionization, SFGs must evolve substantially from $z \sim 6$ to present, such that at high redshift most have such highly ionized ISM conditions indicated by the high $O_{32}$ ratio. Such galaxies will be prime targets for *JWST* at $z > 3$, and future grism surveys and further constraints on LyC emission from lower-redshift $O_{32}$-selected ELGs will be important for calibrating the evolution of LyC toward the epoch of reionization. Deep *HST* surveys of large volumes at intermediate redshift will be necessary to obtain the large sample sizes of strong $O_{32}$-emitters necessary to determine whether LyC escape is linked to these observable parameters such that their contribution can be meaningfully extrapolated to the epoch of reionization probed by *JWST*.

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