








LETTER TO THE EDITOR

# Strong Lyman continuum emitting galaxies show intense C IV $\lambda 1550$ emission

D. Schaerer<sup>1,2</sup> , Y. I. Izotov<sup>3</sup> , G. Worseck<sup>4</sup> , D. Berg<sup>5</sup> , J. Chisholm<sup>5</sup> , A. Jaskot<sup>6</sup> , K. Nakajima<sup>7</sup> ,  
S. Ravindranath<sup>8</sup>, T. X. Thuan<sup>9</sup> , and A. Verhamme<sup>1</sup>

<sup>1</sup> Observatoire de Genève, Université de Genève, Chemin Pegasi 51, 1290 Versoix, Switzerland  
e-mail: [daniel.schaerer@unige.ch](mailto:daniel.schaerer@unige.ch)

<sup>2</sup> CNRS, IRAP, 14 Avenue E. Belin, 31400 Toulouse, France

<sup>3</sup> Bogolyubov Institute for Theoretical Physics, National Academy of Sciences of Ukraine, 14-b Metrolohichna Str., Kyiv 03143, Ukraine

<sup>4</sup> Institut für Physik und Astronomie, Universität Potsdam, Karl-Liebknecht-Str. 24/25, 14476 Potsdam, Germany

<sup>5</sup> Department of Astronomy, University of Texas at Austin, Austin, TX 78712, USA

<sup>6</sup> Department of Astronomy, Williams College, Williamstown, MA 01267, USA

<sup>7</sup> National Astronomical Observatory of Japan, 2-21-1 Osawa, Mitaka, Tokyo 181-8588, Japan

<sup>8</sup> Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, USA

<sup>9</sup> Astronomy Department, University of Virginia, PO Box 400325, Charlottesville, VA 22904-4325, USA

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## ABSTRACT

Using the Space Telescope Imaging Spectrograph, we have obtained ultraviolet spectra from  $\sim 1200$  to  $2000 \text{ \AA}$  of known Lyman continuum (LyC) emitting galaxies at low redshift ( $z \sim 0.3\text{--}0.4$ ) with varying absolute LyC escape fractions ( $f_{\text{esc}} \sim 0.01\text{--}0.72$ ). Our observations include in particular the galaxy J1243+4646, which has the highest known LyC escape fraction at low redshift. While all galaxies are known Lyman alpha emitters, we consistently detect an inventory of additional emission lines, including C IV  $\lambda 1550$ , He II  $\lambda 1640$ , O III]  $\lambda 1666$ , and C III]  $\lambda 1909$ , whose origin is presumably essentially nebular. C IV  $\lambda 1550$  emission is detected above  $4\sigma$  in six out of eight galaxies, with equivalent widths of  $\text{EW}(\text{C IV}) = 12\text{--}15 \text{ \AA}$  for two galaxies, which exceeds the previously reported maximum emission in low- $z$  star-forming galaxies. We detect C IV  $\lambda 1550$  emission in all LyC emitters with escape fractions  $f_{\text{esc}} > 0.1$  and find a tentative increase in the flux ratio C IV  $\lambda 1550$ /C III]  $\lambda 1909$  with  $f_{\text{esc}}$ . Based on the data, we propose a new criterion to select and classify strong leakers (galaxies with  $f_{\text{esc}} > 0.1$ ): C IV  $\lambda 1550$ /C III]  $\lambda 1909 \geq 0.75$ . Finally, we also find He II  $\lambda 1640$  emission in all the strong leakers with equivalent widths from 3 to  $8 \text{ \AA}$  rest frame. These are among the highest values observed in star-forming galaxies and are primarily due to a high rate of ionizing photon production. The nebular He II  $\lambda 1640$  emission of the strong LyC emitters does not require harder ionizing spectra at  $>54 \text{ eV}$  compared to those of typical star-forming galaxies at similarly low metallicity.

**Key words.** galaxies: starburst – galaxies: high-redshift – dark ages, reionization, first stars – ultraviolet: galaxies

## 1. Introduction

In recent years, *Hubble* Space Telescope (HST) observations of star-forming galaxies at low redshift ( $z \sim 0.3\text{--}0.4$ ) with the Cosmic Origin Spectrograph (COS) have measured Lyman continuum (LyC) and the non-ionizing ultraviolet (UV) radiation for nearly 90 galaxies in total, as reported by various studies (see [Leitherer et al. 2016](#); [Izotov et al. 2016a,b, 2018a, 2021](#); [Wang et al. 2019](#)) and the Low- $z$  Lyman Continuum Survey (LzLCS; [Wang et al. 2021](#); [Flury et al. 2022a,b](#); [Saldana-Lopez et al. 2022](#)).

These data have launched us into a new era, allowing us to study in detail LyC emitting galaxies, their interstellar medium (ISM) properties and stellar populations, the conditions that favor the escape of ionizing photons from galaxies, and more (see above references and [Schaerer et al. 2016](#); [Gazagnes et al. 2018](#); [Chisholm et al. 2018](#)). In addition, these observations have served to empirically establish “indirect indi-

cators” of LyC escape, which can potentially be used at all redshifts, including for galaxies in the epoch of reionization, where direct observations of the LyC are not possible. Among these indirect indicators are properties of the resolved Lyman alpha ( $\text{Ly}\alpha$ ) line profile (the peak separation), weak UV absorption lines, Mg II emission, a high ratio of [O III]  $\lambda\lambda 4959, 5007$ /[O II]  $\lambda 3727$ , and a deficit of the [S II]  $\lambda\lambda 6717, 6731$  line (see [Jaskot & Oey 2013](#); [Verhamme et al. 2017](#); [Gazagnes et al. 2018](#); [Henry et al. 2018](#); [Chisholm et al. 2020](#); [Ramambason et al. 2020](#); [Wang et al. 2021](#)).

For the exploration of the early Universe and to track the sources of cosmic reionization, the rest-UV spectral range remains fundamental as it is accessible with the largest ground-based telescopes (and soon with 30 m class telescopes) and with the recently launched *James Webb* Space Telescope. Recent efforts have been undertaken to obtain reference spectra of low-redshift star-forming galaxies covering the range of  $\sim 1200\text{--}2000 \text{ \AA}$  (e.g., [Rigby et al. 2015](#); [Berg et al. 2016, 2019a](#);

Senchyna et al. 2017). These include Ly $\alpha$ , C IV  $\lambda$ 1550, He II  $\lambda$ 1640, O III]  $\lambda$ 1660,1666, C III]  $\lambda$ 1907,1909, and other emission lines, which provide important diagnostics of their ISM and radiation field (see, e.g., Feltre et al. 2016; Gutkin et al. 2016; Nakajima et al. 2018). However, to study sources of reionization and to relate the UV line properties to LyC escape, it is mandatory to observe the same galaxies both in the LyC and in the non-ionizing UV out to  $\sim 2000$  Å. So far, very few such observations have been obtained, and the first spectrum of a low- $z$  LyC emitter with a high escape fraction of LyC photons ( $f_{\text{esc}} \sim 43\%$ ) has been obtained only recently (Schaerer et al. 2018).

Here, we present the first results of an HST program to observe the UV emission lines of known LyC emitters, sampling a range of LyC escape fractions from very low ( $f_{\text{esc}} = 1.4\%$ ) to the highest escape currently known ( $f_{\text{esc}} = 72\%$ ), which was observed in the compact star-forming galaxy J1243+4646 by Izotov et al. (2018a). Our observations show strong emission lines, in particular strong C IV  $\lambda$ 1550 emission in the strongest LyC emitters. This demonstrates for the first time a connection between LyC escape and nebular C IV emission, from which we propose a new empirical criterion to select galaxies with strong LyC escape. Furthermore, our results shed new light on the recently detected C IV emitters at high redshift (see Stark et al. 2015; Mainali et al. 2017; Schmidt et al. 2017; Tang et al. 2021; Vanzella et al. 2021; Richard et al. 2021), suggesting that some of them could be strong LyC emitters.

## 2. UV spectra of compact star-forming galaxies at $z \sim 0.3\text{--}0.4$ with varying LyC escape fractions

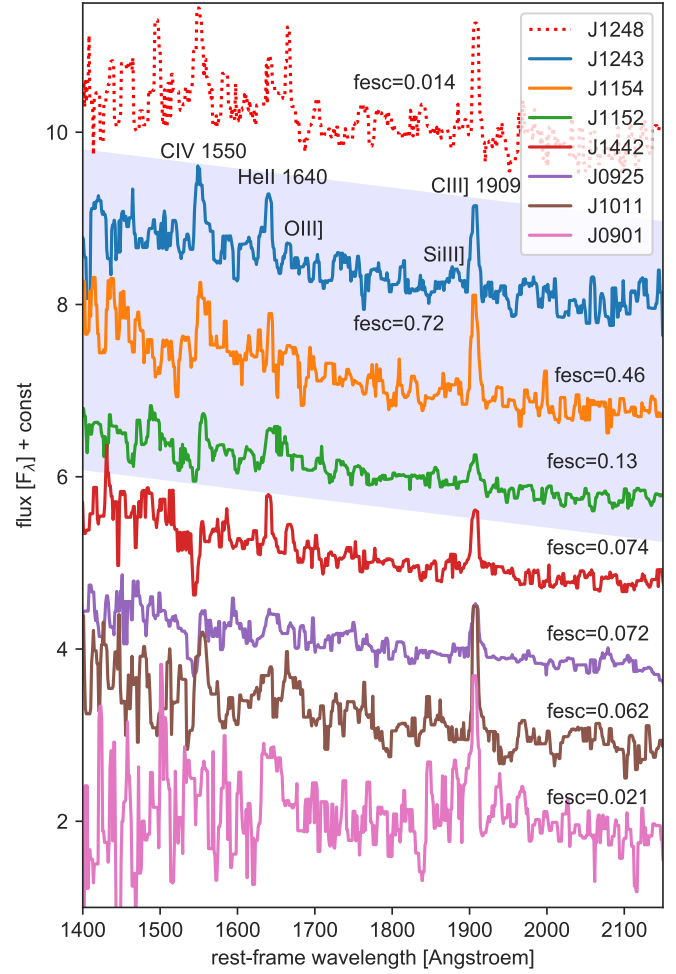
### 2.1. HST observations

Eight out of eleven compact star-forming galaxies with LyC measurements from our 2016–2018 campaign (Izotov et al. 2016a,b, 2018a,b) have been observed in Cycle 27 (GO 15941; P.I. Schaerer) and earlier (Schaerer et al. 2018)<sup>1</sup>. The sources span a broad range of LyC escape fractions ( $f_{\text{esc}} \sim 1.4\text{--}72\%$ ), metallicities in the range  $12 + \log(\text{O}/\text{H}) = 7.64\text{--}8.16$  with a median of 7.92, and  $[\text{O III}]\lambda 5007/[\text{O II}]\lambda 3727$  from 5 to 27.1.

The observations were taken with the Space Telescope Imaging Spectrograph (STIS) NUV-MAMA using the grating G230L with the central wavelength 2376 Å and the slit  $52'' \times 0''.5$ , resulting in a spectral resolution of  $R \sim 700$  for the targeted compact galaxies. The data were reduced with the CALSTIS v3.4.2 pipeline and including data from additional observations of J1154+2443 that were not available to Schaerer et al. (2018), which improved the signal-to-noise ratio (S/N) to  $\approx 7$  per pixel for this galaxy. Wavelength shifts between sub-exposures were insignificant, which allowed for the co-addition of gross and background counts per pixel, approximately preserving Poisson statistics. In the wavelength range of interest, the continuum S/N (accounting for Poisson flux uncertainties) ranges between 3 and 8 per  $\approx 1.55$  Å pixel, with six out of eight spectra reaching  $S/N > 5$ .

For the remainder of this Letter, we define “strong” leakers as galaxies with a LyC escape fraction above 10% (i.e.,  $f_{\text{esc}} > 0.1$ ) to distinguish such sources, which could significantly contribute to cosmic reionization, from those with a low or negligible escape of ionizing photons. In our current sample, three out of eight galaxies are classified as strong leakers.

<sup>1</sup> The galaxies are J1243+4646, J1154+2443, J1152+3400, J1442–0209, J0925+1403, J1011+1947, J0901+2119, and J1248+4259.

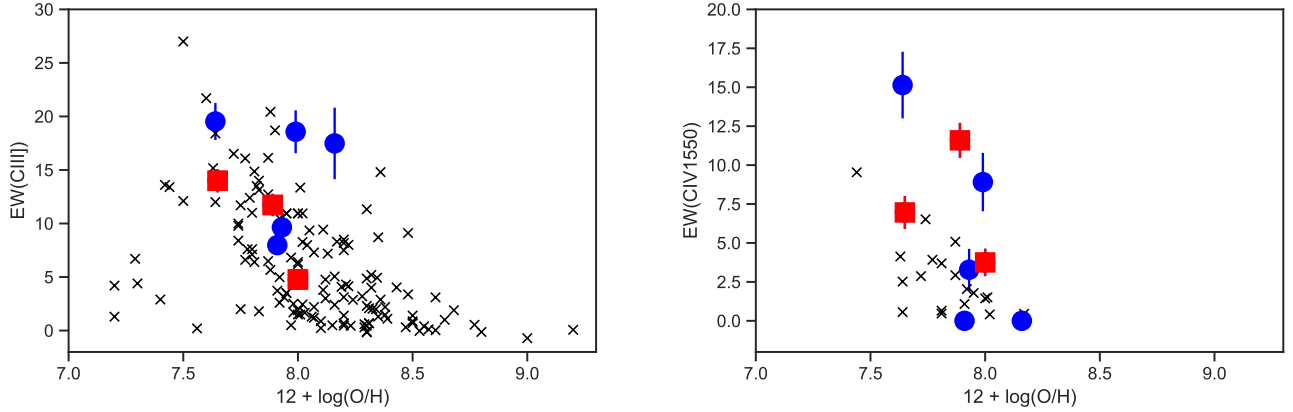


**Fig. 1.** STIS rest-frame spectra of eight  $z \sim 0.3\text{--}0.4$  LyC emitters. They are ordered by decreasing  $f_{\text{esc}}$  from top to bottom, except for J1248+4259, which is shown at the top with a dotted line (see text for details). The colored area shows the spectra of the three strong LyC leakers ( $f_{\text{esc}} > 0.1$ ). The C IV  $\lambda$ 1550, C III]  $\lambda$ 1909, and He II  $\lambda$ 1640 lines are clearly detected in the strongest LyC leakers (J1243+4646, J1154+2443, and J1152+3400), with escape fractions between  $f_{\text{esc}} = 0.13$  and 0.72), which are characterized by a high C IV/C III] ratio. All the spectra show C III]  $\lambda$ 1909 emission (with EWs of  $\sim 5\text{--}20$  Å rest frame) and other weaker lines.

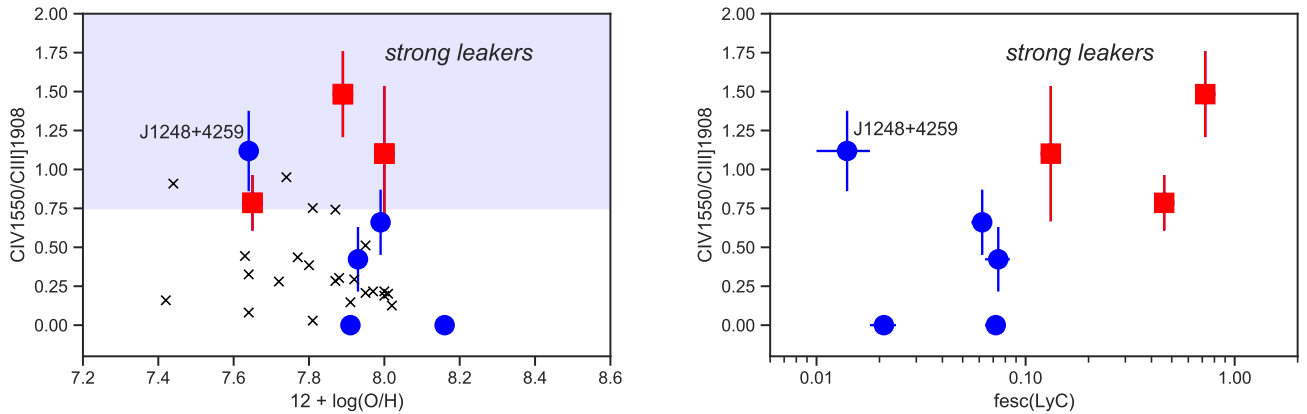
### 2.2. Main UV emission line features

Examples of the observed STIS spectra are shown in Fig. 1, ordered – from top to bottom – by decreasing LyC escape fractions. In the spectral range covered by the observations (rest-frame wavelengths of  $\sim 1200\text{--}2000$  Å), the main detected emission lines are Ly $\alpha$  (not illustrated here), C IV  $\lambda$ 1550, He II  $\lambda$ 1640, O III]  $\lambda$ 1666, and C III]  $\lambda$ 1909. We note that with the given resolution, the C IV  $\lambda$ 1550 and C III]  $\lambda$ 1909 doublets are not resolved. Hints of blended Si III]  $\lambda$ 1883,1892 are also visible in some of the spectra (see Fig. 1).

We now mainly focus on the carbon and helium lines, and leave a more exhaustive report and analysis for subsequent publications. We note that the low resolution of our spectra does not allow us to exclude some contribution from stellar emission (from O, B, and Wolf-Rayet stars) to the C IV  $\lambda$ 1550 and He II  $\lambda$ 1640 emission lines. However, we think that the emission is predominantly nebular in both cases, at least for sources with



**Fig. 2.** Rest-frame C III]  $\lambda 1909$  (left panel) and C IV  $\lambda 1550$  (right panel) EWs as a function of metallicity O/H for the LyC emitters (large red squares: strong leakers,  $f_{\text{esc}} > 0.1$ ; blue circles: other leakers) and low- $z$  comparison samples from the literature taken from the compilation of Schmidt et al. (2021). All measurements are for galaxies with direct metallicity measurements. The typical relative errors for our sources are 10–20% for all EW(C III]) and for EW(C IV)  $\geq 5$  Å, and larger otherwise (shown).



**Fig. 3.** C IV  $\lambda 1550$ /C III]  $\lambda 1909$  line ratio (C43) as a function of metallicity (O/H, left panel) and the LyC escape fraction (right panel). The symbols have the same meaning as in Fig. 2. The colored area shows the region of C43  $\geq 0.75$ , where we propose that strong LyC leakers, i.e., galaxies with  $f_{\text{esc}} > 0.1$ , are found empirically. We note that for the sake of simplicity for comparisons with high- $z$  studies the line ratios of the leakers are not corrected for internal reddening and could thus be slightly higher, although the corrections should be small.

high equivalent widths (EW(C IV)  $\geq 3$  Å), since absorption from stellar P-Cygni C IV profiles is not detected in high EW sources and since no Wolf-Rayet signatures are seen in the available deep optical spectra of LyC emitters (Guseva et al. 2020).

After Ly $\alpha$ , the lines with the highest EWs are C III]  $\lambda 1909$  and C IV  $\lambda 1550$ , with EW(C III]) = 4–20 Å and EW(C IV) = 3–15 Å. The C III]  $\lambda 1909$  line is detected in all the sources, and C IV  $\lambda 1550$  in five out of eight galaxies above  $4\sigma$ .

In Fig. 2 we plot the C III] and C IV EWs of our targets as a function of metallicity (using O/H as a proxy) along with measurements from other low-redshift galaxies for comparison. The C III] EWs of the LyC emitters do not occupy a particularly unique domain in this figure, and EW(C III]) does not show a dependence on the LyC escape fraction. The “envelope” of the observed distribution of the C III] EWs show a metallicity dependence that is fairly well reproduced by photoionization models using the spectral energy distributions of young stellar populations, as shown in several studies (Jaskot & Ravindranath 2016; Nakajima et al. 2018; Ravindranath et al. 2020).

Interestingly, the C IV EWs of the strong leakers are among the highest observed so far. Furthermore, J1248+4259 stands out as the low- $z$  galaxy ( $z \leq 0.4$ ) with the highest C IV  $\lambda 1550$  EW (EW(C IV) =  $15.14 \pm 2.14$  Å); however, it shows a low escape

fraction ( $f_{\text{esc}} = 0.014 \pm 0.004$ ). Again, the observed EWs are also in fair agreement with the predictions from photoionization models (Nakajima et al. 2018; Ravindranath et al. 2020).

He II  $\lambda 1640$  emission is detected at  $\sim 4\text{--}6\sigma$  in all strong leakers, showing EWs of EW(He II) = 3.7–8.0 Å, which are among the highest values observed in star-forming galaxies. The He II line is also detected above  $3\sigma$  in two other sources (i.e., in five of the eight spectra). We comment on the strength of the He II  $\lambda 1640$  emission below.

### 2.3. Strong LyC leakers show strong C IV $\lambda 1550$ emission and a high C IV/C III] ratio

In addition to exhibiting strong C IV and He II  $\lambda 1640$  emission lines, the main distinguishing feature of the strong leakers is the high ratio, C43 =  $I(\text{C IV } \lambda 1550)/I(\text{C III] } \lambda 1909) \geq 0.75$ , of the carbon line intensities, which is fairly exceptional, as shown in Fig. 3 (left panel), in comparison with other low- $z$  galaxies where both carbon lines have been detected. And interestingly, except for the galaxy J1248+4259 discussed below, the carbon line ratio increases with the LyC escape fraction, as shown in the right panel. Although the sample of galaxies for which both observations of the LyC and the non-ionizing UV spectrum, including C III] and C IV, are covered is admittedly small, we

suggest that, based on the available data, star-forming galaxies with  $I(\text{C IV } \lambda 1550)/I(\text{C III] } \lambda 1909) \geq 0.75$  have escape fractions  $f_{\text{esc}} > 0.1$  and hence show “significant” amounts of LyC emission.

If generally applicable, our postulate implies that the galaxy J1248+4259 reported by Izotov et al. (2018a) should be a strong LyC emitter; that is, it should have a true LyC escape fraction of at least  $\sim 5$  times that measured from the COS spectrum, which could be possible if, for example, the emission of LyC photons is not isotropic. There are indeed other indications that J1248+4259 could be a strong leaker: First, it shows a very strong Ly $\alpha$  emission with an EW of  $\text{EW}(\text{Ly}\alpha) = 256 \pm 5.2 \text{ \AA}$ , comparable to strong leakers. Second, the Ly $\alpha$  line profile is clearly double-peaked, with a fairly low separation of the two peaks ( $v_{\text{sep}} = 283.8 \pm 15.9 \text{ km s}^{-1}$ ), which would yield  $f_{\text{esc}} = 0.13$  if the mean relation between  $f_{\text{esc}}$  and  $v_{\text{sep}}$  from Izotov et al. (2018a) was applied. Finally, J1248+4259 is also somewhat of an “outlier” in the scattered relation between  $\text{O32} = [\text{O III}]/[\text{O II}]$  and  $f_{\text{esc}}$ , showing a lower-than-average escape fraction for its high  $\text{O32} = 11.8$  (see Izotov et al. 2021).

The other low- $z$  galaxies that show  $I(\text{C IV } \lambda 1550)/I(\text{C III] } \lambda 1909) \geq 0.75$  in Fig. 3 are J084236 and J104457. They are low-mass low-metallicity galaxies at  $z \sim 0.01$  that both show very strong C IV emission with  $\text{EW}(\text{C IV}) \sim 6\text{--}10 \text{ \AA}$  (Berg et al. 2019a,b). Based on high-resolution COS spectra, which show strong nebular C IV emission in the two doublet lines and indications for minor radiation transfer effects in these lines, Berg et al. (2019b) have suggested that J104457 is optically thin to ionizing radiation, at least at energies above 47.9 eV, the ionization potential of  $\text{C}^{3+}$  (see also Senchyna et al. 2021). It also shares other properties of strong LyC leakers, such as a very high  $\text{O32} = 16.2$ . Although no direct observations of the LyC are possible at these low redshifts, the available data for J104457 appear fully consistent with our postulate that this galaxy is a strong LyC leaker. We suggest that J084236 may also be a strong LyC leaker.

Intrinsically, the C43 ratio traces the ionization structure of the nebula, similarly to O32, which has already been suggested as a potential indicator of LyC escape (Jaskot & Oey 2013; Nakajima & Ouchi 2014). However, since C IV  $\lambda 1550$  is a resonance line, it is a priori affected by radiation transfer effects; this is in contrast to the nebular oxygen lines, which should be optically thin. Therefore, the C IV  $\lambda 1550$  line and the C43 ratio could be a more sensitive tracer of LyC escape than O32. To first order, both C43 and O32 trace the ionization parameter,  $U$ , and are independent of metallicity. Furthermore, an examination of photoionization models shows that both C43 and O32 vary with the LyC escape fraction. For moderate to high  $U$ , the predicted variations in C43 appear stronger than in O32, again providing some theoretical support for our empirically based postulate. A detailed comparison with models will be presented in future work.

### 3. Discussion and implications

#### 3.1. Comparison with high- $z$ LyC emitters and candidates

We first compared our results with confirmed high- $z$  LyC emitters, although relatively few high- $z$  galaxies with established or potentially strong LyC escape (absolute escape fractions  $f_{\text{esc}} \geq 0.1$ ) are known. Well-studied sources with the highest LyC escape fractions are Ion2, the Sunburst arc, and probably Ion3, with relative escape fractions  $f_{\text{esc,rel}} \gtrsim 0.5$ , accord-

ing to Vanzella et al. (2020)<sup>2</sup>. VLT/X-shooter spectroscopy of Ion2 at  $z = 3.2$  indeed shows the presence of nebular emission in both C IV and C III], with a ratio  $I(\text{C IV } \lambda 1550)/I(\text{C III] } \lambda 1909) = 0.61 \pm 0.23$ ; this is compatible with our findings, although the lines are relatively weak (e.g.,  $\text{EW}(\text{C IV}) = 2.6 \text{ \AA}$  and  $\text{EW}(\text{He II}) = 2.8 \text{ \AA}$ ; Vanzella et al. 2020). For the other objects, the reported data are insufficient to examine C IV and C III]. Similarly, no detailed rest-UV spectra have been published for the  $z = 3.1$  LyC emitting galaxies of Fletcher et al. (2019). The robust sample of  $z \sim 3$  LyC emitters from Steidel et al. (2018) and Pahl et al. (2021) provides average properties to avoid the inherent limitations in determining  $f_{\text{esc}}$  for individual sources that are due to the stochastic intergalactic medium transmission at high  $z$ . Their LyC emitting sample has an average escape fraction of  $f_{\text{esc}} = 0.06 \pm 0.01$ , which is below our definition of strong emitters, and the stacked UV spectrum illustrated in Steidel et al. (2018) does not show strong C IV emission, although no details on carbon emission lines are reported in their study.

Another comparison is possible with Ly $\alpha$  emitters at  $z \sim 2$ , where the LyC escape fraction was recently estimated using indirect empirical spectral indicators by Naidu et al. (2022) and Matthee et al. (2021). Stacking rest-UV spectra of Ly $\alpha$  emitters with estimated  $f_{\text{esc}} \gtrsim 0.2$  (high escape) and  $f_{\text{esc}} \lesssim 0.05$  (low escape), they find several significant differences between the two subsamples, in particular the presence of nebular C IV  $\lambda 1550$ , C III]  $\lambda 1909$ , He II  $\lambda 1640$ , and O III]  $\lambda 1666$  emission in the high escape sources, whereas the low escape sources only show C III] and O III] emission. Although the C IV emission of their strong leakers ( $\text{EW}(\text{C IV}) = 2.0 \pm 0.4 \text{ \AA}$ ) is weaker than that of our three sources with  $f_{\text{esc}} > 0.1$ , which show  $\text{EW} > 2.5 \text{ \AA}$ , and despite C III]  $\lambda 1909$  being stronger than C IV, their finding of nebular C IV and He II  $\lambda 1640$  emission in strong leaker candidates is compatible with our results.

We therefore conclude that both low- and high-redshift observations seem to consistently show (i.e., in about three out of four cases) that the UV spectra of strong leakers (with  $f_{\text{esc}} \gtrsim 0.1\text{--}0.2$ ) are characterized by nebular C IV  $\lambda 1550$  and C III]  $\lambda 1909$  emission and  $\text{C43} \gtrsim 0.75$ . Although the available data are still relatively scarce, our observations provide the first such quantitative estimate.

#### 3.2. Implications for high- $z$ C IV emitters

So far, very few high-redshift galaxies showing nebular C IV  $\lambda 1550$  emission have been reported. Since the recent discoveries of several lensed galaxies at  $z \sim 6\text{--}7$  with nebular C IV (Stark et al. 2015; Mainali et al. 2017; Schmidt et al. 2017), other C IV emitters have been found both in blank fields (e.g., at  $z \sim 2.2$ ; Tang et al. 2021) and in lensed galaxies (see Stark et al. 2014; Vanzella et al. 2021; Richard et al. 2021). The stacked rest-UV spectrum of lensed sources with median  $z = 3.2$  and median  $M_{1500} = -17.1$  from Vanzella et al. (2021) shows strong nebular C IV  $\lambda 1550$ , C III]  $\lambda 1909$ , and numerous other emission lines. The C IV line in several of these sources is strong, with EWs of up to  $\text{EW}(\text{C IV}) = 38 \pm 16 \text{ \AA}$  in A1703-zd6 (Stark et al. 2015; Schmidt et al. 2021) and  $\text{C43} > 0.8$  in several of them. Our results suggest that these sources are strong LyC emitters, which is overall in agreement with the other observational properties they share with LyC emitters (e.g., strong Ly $\alpha$  emission). The

<sup>2</sup> We here refer to relative escape fractions since absolute values cannot reliably be determined for individual sources at high  $z$  (e.g., Steidel et al. 2018).

fact that C IV emission is found in many strongly lensed sources probably also indicates that the fraction of strong LyC emitters increases toward fainter, lower-mass galaxies, a trend also found in the  $z \sim 0.3\text{--}0.4$  reference samples (see Izotov et al. 2021; Flury et al. 2022b).

### 3.3. Strong emission lines and high C43 ratios explained

This leads us to the questions of what the strong observed UV emission lines (high EW of nebular lines) tell us and how they can be understood. Since EWs measure the strength of the emission line with respect to the continuum, the EW of a UV recombination line such as He II  $\lambda 1640$  can be cast in the following simple form,

$$\text{EW}(1640)/\text{\AA} = \xi_{\text{ion}}^{\text{H}} \frac{Q_{\text{He}^+}}{Q_{\text{H}}} \frac{c_{1640}\lambda^2}{3 \times 10^{18}}, \quad (1)$$

where  $\xi_{\text{ion}}^{\text{H}} = Q_{\text{H}}/L_{1500}$  is the ionizing photon efficiency per unit intrinsic monochromatic UV luminosity in the commonly used units of  $\text{erg}^{-1} \text{Hz}$ ,  $c_{1640} = 5.67 \times 10^{-12} \text{erg}$  relates the recombination line flux to the ionizing photon flux (e.g., Schaerer 2003), and  $\lambda \approx 1640 \text{\AA}$ . This shows that the EW is proportional to  $\xi_{\text{ion}}$  and to the hardness of the ionizing spectrum, expressed here as  $Q_{\text{He}^+}/Q_{\text{H}}$ , the ratio of the ionizing photon flux above 54 eV and 13.6 eV, respectively. From this we can easily see that the observed EWs in our three strongest leakers,  $\text{EW}(1640) \approx 3\text{--}8 \text{\AA}$ , are plausible. Indeed, the EWs can be explained with a relatively high ionizing photon production,  $\log(\xi_{\text{ion}}) \approx 25.6\text{--}25.8 \text{erg}^{-1} \text{Hz}$  (cf. Schaerer et al. 2018), which then implies  $Q_{\text{He}^+}/Q_{\text{H}} \approx 0.01\text{--}0.04$ . This hardness translates to optical line ratios of  $I(\text{He II } \lambda 4686)/I(\text{H}\beta) \approx 1.74 Q_{\text{He}^+}/Q_{\text{H}} \sim 0.016\text{--}0.07$ , similar to the observations of J1154+2443 and J1248+4259, which are  $I(4686)/I(\text{H}\beta) \sim 0.02\text{--}0.03$  (Guseva et al. 2020), and comparable to the line intensities typically observed in galaxies at comparable metallicity (at  $12 + \log(\text{O}/\text{H}) \sim 8.0$ ; see, e.g., Schaerer et al. 2019). This simple estimate shows that the high He II  $\lambda 1640$  EWs reached in these leakers do not require exceptional conditions and/or exceptionally hard ionizing spectra compared to other galaxies (weak or non-leakers) at similarly low metallicity. The same conclusion also applies to, for example, the strong leaker candidates found by Naidu et al. (2022) among their Ly $\alpha$  emitter sample. However, the observed spectra are clearly harder at  $>54 \text{eV}$  than predicted by normal stellar population models, and the source of these He<sup>+</sup>-ionizing photons remains to be elucidated (see, e.g., Stasińska et al. 2015).

To predict the strengths of the metallic lines of C IV and C III], which depend on the ionization parameter, spectral energy distribution, nebular abundances, and other factors, detailed photoionization models are required. The models of Nakajima et al. (2018), for example, show maximum values of  $\text{EW}(\text{C IV}) \sim 8\text{--}10 \text{\AA}$  and  $\text{EW}(\text{C III])} \sim 10\text{--}18 \text{\AA}$  at metallicities  $12 + \log(\text{O}/\text{H}) \sim 7.7\text{--}8$ , of the same order as our observed EWs. We also examined density-bounded models at appropriate metallicities, using the BOND set of CLOUDY models from the 3 Million Models Database of Morisset et al. (2015). The models indeed show an expected increase in the C IV/C III] ratio with increasing LyC escape fraction, and several models show C IV/C III] ratios comparable to those of our observations. From these simple comparisons, we conclude that both the observed EWs and UV line ratios of the strong low- $z$  leakers seem “reasonable” and that we probably do not need peculiar or extreme ionizing spectra to reproduce their emission line spectra.

Tailored photoionization models to examine the behavior of the major UV and optical emission lines of the LyC emitters and comparison sources will be presented in a subsequent publication.

## 4. Conclusion

With the STIS spectrograph on board HST, we have obtained new UV spectra from  $\sim 1200\text{--}2000 \text{\AA}$ , the rest-frame spectra of eight  $z \sim 0.3\text{--}0.4$  LyC emitters from Izotov et al. (2016a,b, 2018a,b), which cover a large range of LyC escape fractions. We detect multiple emission lines, including Ly $\alpha$ , C IV  $\lambda 1550$ , He II  $\lambda 1640$ , O III]  $\lambda 1666$ , and C III]  $\lambda 1909$ . The Ly $\alpha$  and C III] lines are detected in all the sources. Our main results can be summarized as follows:

- We report the detection above  $4\sigma$  of C IV  $\lambda 1550$  emission in six out of eight galaxies, with the EWs in two galaxies (J1243+4646 and J1248+4259),  $\text{EW}(\text{C IV}) = 12\text{--}15 \text{\AA}$ , exceeding the previously reported maximum in low- $z$  galaxies (J104457; Berg et al. 2019b).
- Strikingly, C IV  $\lambda 1550$  emission is detected in all LyC emitters with escape fractions  $f_{\text{esc}} > 0.1$ , and the flux ratio of C IV  $\lambda 1550/\text{C III] } \lambda 1909$  appears to increase with  $f_{\text{esc}}$ .
- Based on the available data, we suggest that strong leakers, galaxies with  $f_{\text{esc}} > 0.1$ , are characterized by C IV  $\lambda 1550/\text{C III] } \lambda 1909 \gtrsim 0.75$ , adding another indirect indicator of LyC escape to those already established.
- All strong leakers also show strong He II  $\lambda 1640$  emission with  $\text{EW}(\text{He II}) = 3.7\text{--}8.0 \text{\AA}$ , which are among the highest values observed in star-forming galaxies.
- A simple estimate shows that the high EW of the He II  $\lambda 1640$  line is primarily due to a high ionizing photon production,  $\xi_{\text{ion}}$ , and that it does not require unusually hard ionizing spectra, compared to normal galaxies at similar metallicity that frequently show optical He II  $\lambda 4686$  emission lines.

In short, our observations provide an important new reference for understanding the UV spectra of LyC emitting galaxies and thus also analogs of the sources of cosmic reionization. The spectra of the strong low- $z$  leakers share many similarities with those of the C IV  $\lambda 1550$  emitters recently discovered at high redshifts (e.g., Stark et al. 2015; Mainali et al. 2017; Schmidt et al. 2017), and our results suggest that these objects are good candidates for strong LyC escape. If universally applicable, the empirical criterion of using the carbon line ratio C IV  $\lambda 1550/\text{C III] } \lambda 1909 \gtrsim 0.75$  to identify strong LyC leakers could represent an additional important tool for studying the sources of cosmic reionization.

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