Direct Lyman continuum and Ly α escape observed at redshift 4

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ABSTRACT

We report on the serendipitous discovery of a z = 4.0, M_{1500} ≃ −22.20 star-forming galaxy (Ion3) showing copious Lyman continuum (LyC) leakage (∼60 per cent escaping), a remarkable multiple peaked Ly α emission, and significant Ly α radiation directly emerging at the resonance frequency. This is the highest redshift confirmed LyC emitter in which the ionizing and Ly α radiation possibly share a common ionized channel (with N_{HI} < 10^{17.2} cm^{-2}). Ion3 is spatially resolved, it shows clear stellar winds signatures like the P-Cygni N V emission close to the ionization threshold, and has blue ultraviolet continuum (β ≃ −2.5 ± 0.25, F_{β} ∼ λ^{β}) with weak low-ionization interstellar metal lines. Deep VLT/HAWKI Ks and Spitzer/IRAC 3.6 and 4.5μm imaging show a clear photometric signature of the H α line with equivalent width of 100 Å rest-frame emerging over a flat continuum (Ks − 4.5μm ≃ 0). From the SED fitting, we derive a stellar mass of 1.5 × 10^9 M⊙, SFR of 140 M⊙ yr^{-1} and age of ∼10 Myr, with a low dust extinction, E(B − V) ≲ 0.1, placing the source in the starburst region of the SFR−M^* plane. Ion3 shows similar properties of another LyC emitter previously discovered (z = 3.21, Ion2, Vanzella et al. 2016). Ion3 (and Ion2) represents ideal high-redshift reference cases to guide the search for reionizing sources at z > 6.5 with JWST.

Key words: gravitational lensing: strong – galaxies: formation – galaxies: starburst – ultraviolet: general.

1 INTRODUCTION

The definition of a reference sample of Lyman continuum (LyC) emitters at z ≲ 4.5 is crucial to guide the identification of the sources that reionized the Universe at z > 6.5, an epoch when the LyC is not directly observable (Worseck et al. 2014). Several LyC leakers showing escape fraction of f_{esc} ≲ 4−15 per cent have been confirmed in the nearby universe, z ≲ 0.3 (see Izotov et al. 2016a, and references therein). Recently, Izotov et al. (2017) identified another LyC emitter with f_{esc} ≃ 46 per cent, the highest value currently measured for the local sample. Most searches at high redshift have proved unsuccessful, due to contamination by foreground sources (Siana et al. 2015), or have yielded fairly stringent limits of f_{esc} < 0.1 (e.g. Vanzella et al. 2012; Grazian et al. 2017). However, three LyC emitters have been confirmed at cosmological distances, 2.5 < z < 3.2 with f_{esc} ≃ 30−100 per cent (de Barros et al. 2016; Shapley et al. 2016; Vanzella et al. 2016; Bian et al. 2017). As shown in Verhamme et al. (2017) the available sample of LyC emitters, both at low and high redshift, show very consistent observational features. Such features include the high Ly α equivalent width EW >40Å, a high ratio of [O II]λ5007/ [O III]λ3727, and narrow signatures in the Ly α emission like narrow double peaked profiles (<300−400 km s^{-1}) or Ly α emission close to the
systemic velocity ($<100$ km s$^{-1}$). Also intense nebular optical lines \([\text{O} \, \text{II}]\lambda\lambda 4959, 5007 + \text{H} \beta\) with EW of 1000–1500 Å rest-frame seem often associated with LyC emitters (e.g. Schaerer et al. 2016), as well as their compact star-forming region (Heckman et al. 2011) and the weakness of the low-ionization interstellar absorption lines (e.g. Jones et al. 2013; Chisholm et al. 2017). Overall, these quantities correlate with $f_{\text{esc}}$, as was predicted by radiation transfer models (Verhamme et al. 2015) and photoionization models (e.g. Jaskot & Oey 2013; Zackrisson, Inoue & Jensen 2013; Nakajima & Ouchi 2014). In this work, we report on a serendipitously discovered LyC emitter at redshift 4, dubbed here \(\text{Ion3}\), the highest redshift case currently known. We assume a flat cosmology with $\Omega_M = 0.3$, $\Omega_{\Lambda} = 0.7$, and $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$.

2 DATA: FORS AND X-SHOOTER OBSERVATIONS

\(\text{Ion3}\) was discovered during a FORS2 spectroscopic program executed in visitor mode during the period 2017 September 15–19 (prog. 098.A-0804(B), P.I. Vanzella). \(\text{Ion3}\) is a relatively bright object and was inserted as a filler in the MXU FORS mask (\(I\)-band magnitude 23.64 ± 0.38) and located at 3′′41′′ from the Frontier Field galaxy cluster AS1063 (Lotz et al. 2017), which lies outside the HST coverage. Given the large separation from the galaxy cluster the resulting magnification is low, a well-constrained $\mu = 1.15 ± 0.02$ (or $\Delta m = 0.15$, Caminha et al. 2016). In the following, all the reported quantities are corrected for $\mu$.

The data reduction was carried on as described in several previous works (e.g. Vanzella et al. 2014) in which the AB-BA sky subtraction scheme was implemented. The final spectrum consists of 14 h integration with an average seeing of 0.8 arcsec and spectral resolution $dv \simeq 600$ km s$^{-1}$ at $\lambda \approx 7000$ Å ($R = \lambda/dv = 500$, grism 300V). Fig. 1 shows the FORS2 spectrum covering the wavelength range 3700–9300 Å. During the same program 098.A-0804(B), an additional 1 h integration was obtained with the grism 600B, doubling the spectral resolution ($dv \simeq 300$ km s$^{-1}$, $R = 1000$). We clearly confirmed the double peaked Ly $\alpha$ profile of \(\text{Ion3}\) not well resolved with the 300V grating (see Fig. 1, top left). Additional four hours X-Shooter integration on \(\text{Ion3}\) was subsequently obtained during 2017 November with an average seeing conditions of 0.8 arcsec (prog. 098.A-0665, P.I. Vanzella), providing a final spectrum spanning the range 3 400–24 000 Å with spectral resolution $dv \simeq 35 − 60$ km s$^{-1}$. We refer the reader to Vanzella et al. (2014, 2017) for details about FORS and X-Shooter data reduction.

3 RESULTS

3.1 The Lyman continuum emission

The most intriguing feature emerging from \(\text{Ion3}\) is the LyC leakage at $\lambda < 912$ Å rest-frame detected in the FORS spectrum with S/N=6.4(11.1) if averaged over the interval 880–910(800–910) Å, and corresponding to magnitude 27.5 (AB). Fig. 1 shows the two-dimensional spectrum with the LyC signal spatially aligned with the non-ionizing radiation. The possible presence of a foreground object at $z < 4$ mimicking the LyC signal represents a serious problem in this kind of observations (e.g. Vanzella et al. 2012; Siana et al. 2015), especially when HST imaging is not available. However, we can reasonably exclude such an interloper. First, we note that the probability chance of a superposition is low, less than 1 per cent adopting the above magnitude and the seeing of 0.8 arcsec (see Vanzella et al. 2010). Secondly, there is no trace of any spectral line arising from a foreground object, both in the deep FORS spectrum (that excludes \([\text{O} \, \text{II}]\lambda 3727, 3729 at z < 1.45 and \text{Ly} \alpha at z > 1.9\) and wide X-Shooter spectrum, that easily would have captured several UV and/or optical rest-frame emission lines in the redshift range $0 < z < 4$. Moreover, all the properties of \(\text{Ion3}\) support a very low column density of neutral gas along the line of sight, making the entire picture consistent with the emerging LyC signal.

From the FORS spectrum the observed fluxes at 900 and 1500 Å rest-frame are $F_{900}^{\text{flux}} = (5.6 \pm 0.08) \times 10^{-20}$ erg s$^{-1}$ cm$^{-2}$ Å$^{-1}$ and $F_{1500}^{\text{flux}} = (3.8 \pm 0.09) \times 10^{-19}$ erg s$^{-1}$ cm$^{-2}$ Å$^{-1}$, respectively, corresponding to a flux density ratio of $f_s(1500)/f_s(900) = 19.1 \pm 3.3$. Following Vanzella et al. (2012), this ratio translates to a relative escape fraction $f_{\text{esc}, \text{rel}} = 20–100$ per cent, assuming an intrinsic ratio of the luminosity densities $L_s(1500)/L_s(900) = 1–5$ and the median intergalactic medium (IGM) transmission at 900 Å, $T_{\text{IGM}}^{\text{900}} > 0.26$ (with a central 68 per cent interval of 0.05–0.40, Inoue et al. (2014); Vanzella et al. (2015). Being a single line of sight the real $T_{\text{IGM}}^{\text{900}}$ is unknown, therefore, any combination of $L_s(1500)/L_s(900) > 1$ and IGM transmission lower than 100 per cent produces $f_{\text{esc}, \text{rel}}$ in the range 10 per cent–100 per cent, with a fiducial value of 60 per cent adopting median $< T_{\text{IGM}}^{\text{900}} > = 0.26$ and $L_s(1500)/L_s(900) = 3$. The inferred ionizing photon production rate from $F_{900}^{\text{flux}}$ is $N_{\text{H}0}(900) = 3.5 \times 10^{52}$ s$^{-1}$, which compared to Starburst99 models for instantaneous bursts (Salpeter IMF; Salpeter 1955, and upper mass limit of 100 M$_\odot$; Leitherer et al. 2014) yields a stellar mass involved in the starburst event of $4 \times 10^8$ M$_\odot$ with the age not larger than 20 Myr, and a number of O-type stars dominating the ionizing radiation of $\simeq 1.6 \times 10^4$ (with uncertainties mainly dominated by the aforementioned IGM transmission).
The highest redshift stellar ionizer

3.2 The non-ionizing properties

The continuum redward the Ly α line up to ≈ 1850 Å rest-frame is well detected in the FORS spectrum (Figs 1 and 2) with a best-fitting ultraviolet spectral slope of \( \beta = -2.50 \) with 68 per cent central interval \([-2.73, -2.28]\) \(( F_{\beta} \sim \lambda^{\beta} \) ).

Such a steep slope is not significantly affected by the atmospheric dispersion (the atmospheric dispersion compensator, LADC, is part of the system at UT1), and is fully consistent with being powered by massive and hot stars (O and early B stars), which are also responsible for the ionizing photons. The strongest spectroscopic signature of these stars is provided by the broad P-Cygni profiles in the resonance transitions of highly ionized species that arise in the stellar winds (e.g. Leitherer et al. 2014). In our FORS spectrum, a N v\( \lambda 1240 \) P-Cygni profile is clearly present (see Fig. 2), observed also in local star-forming galaxies (e.g. Heckman et al. 2011, see also fig. 4 of Jaskot et al. 2017). In particular, the height and depth of the N v\( \lambda 1240 \) line suggest an age of the burst of a few Myr. We superimposed a Starburst99 (Leitherer et al. 2014) spectral population synthesis model to the FORS spectrum with instantaneous burst with age 1, 10, and 20 Myr old, 0.4 solar metallicity (Salpeter IMF and 100 \( M_{\odot} \) upper mass limit), which reproduces the observations well (especially the 1–10 Myr old templates, Fig. 2). Low ionization interstellar absorption lines like [Si ii]\( \lambda 1260 \), [O i]\( \lambda 1303 \), and [C ii]\( \lambda 1334 \) are very weak or even absent, indicating a very low gas covering fraction consistent with the measured LyC leakage (Heckman et al. 2011; Jones et al. 2013; Chisholm et al. 2017). Interestingly, Ion3 also shows the non-resonant fluorescent emission line [C ii]\( \lambda 1335.71 \) (see Fig. 2). Such a feature has been detected by Jaskot & Oey (2014) on local LyC candidates and interpreted as an evidence of the complex geometry of the neutral gas outside the line of sight, like anisotropic ionizing emission. The systemic redshift \( z_{\text{sys}} \) has been derived from the [C ii]\( \lambda 1335.71 \) line and more accurately from the X-Shooter detection of the [O ii]\( \lambda 3727, 3729 \) doublet, providing \( z_{\text{sys}} = 3.999 \pm 0.001 \). At such redshift, the doublet [N v]\( \lambda 1239, 1243 \) lies in the middle of its P-Cygni profile and the possible He ii\( \lambda 1640 \) line is also recognized, though with low significance, 2.7σ. Table 1 summarizes the most relevant spectroscopic properties.

3.3 The multiple peaked Ly α emission

In the conventional scenario for Ly α emission, Ly α scatters many times before escaping, which significantly alters and broadens the original line profile. The kinematics, the column density, and geometry of the H i gas are the main ingredients that shape the Ly α emission (not to mention the dust attenuation). A prominent Ly α emission line with rest-frame EW = 40 ± 3 Å is clearly detected in the FORS spectrum (Fig. 1). Fig. 3 shows the same line at the X-Shooter spectral resolution (\( \sigma = 35 \text{ km s}^{-1} \)), in which we identify four emitting structures marked as 0, 1, 2, and 3. While the presence of blue peaks typically suggest a low column of H i gas (e.g. Henry et al. 2015; Yang et al. 2016), the emission at peak (2) is remarkably high and emerges at the resonance frequency (\( z = 3.9984 \), i.e. \( \lesssim 40 \text{ km s}^{-1} \) from the systemic), where the opacity to Ly α photons would be the highest (Fig. 3). This is fully consistent with a scenario in which the LyC and (part of) the Ly α photons are escaping along the same optically thin direction (to LyC, \( N_{\text{H}1} < 10^{17.2} \text{ cm}^{-2} \) and likely from the same cavity (e.g. Zackrisson, Inoue & Jensen 2013; Behrens, Dijkstra & Niemeyer 2014; Verhamme et al. 2015). The LyC–Ly α escape through a ionized channel discussed in Behrens et al. (2014) consider the possibility that the gas is outflowing perpendicular to a galactic disc (and is reminiscent of a wind breaking out of a galactic disk). In this scenario, the quadruply peaked Ly α emission observed in Ion3 might be associated with a face-on disc. Ion3 represents the highest redshift empirical evidence of such a LyC–Ly α escaping mode. The Ly α escape degenerates with the H i column and the outflow velocity such that fast winds can mimic low columns (Verhamme et al. 2015). In this case, both the LyC emission and a relatively fast wind are detected. The evidence of an outflowing gas is imprinted in the blueshifted interstellar metal lines [S iv]\( \lambda 1393.76 \) and [S iv]\( \lambda 1402.77 \), with an average

<table>
<thead>
<tr>
<th>Line/( \lambda_{\text{vacuum}} )</th>
<th>Flux/(S/N)</th>
<th>( z_{\sigma} )</th>
<th>Resolution/(\text{km s}^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ly α(0) 1215.7</td>
<td>0.37(5)</td>
<td>3.9902(4), 35 (XSHO)</td>
<td></td>
</tr>
<tr>
<td>Ly α(1) 1215.7</td>
<td>1.16(12)</td>
<td>3.9590(3), 35 (XSHO)</td>
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</tr>
<tr>
<td>Ly α(2) 1215.7</td>
<td>1.37(15)</td>
<td>3.9984(3), 35 (XSHO)</td>
<td></td>
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<tr>
<td>Ly α(3) 1215.7</td>
<td>6.23(32)</td>
<td>4.0033(3), 35 (XSHO)</td>
<td></td>
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<tr>
<td>Ly α(total)</td>
<td>9.13(73)</td>
<td>--, 580 (FORS)</td>
<td></td>
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<tr>
<td>[C ii]( \lambda 1335.71 )</td>
<td>0.14(4)</td>
<td>4.0000(4), 580 (FORS)</td>
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<tr>
<td>[He ii]( \lambda 1640.42 )</td>
<td>0.12(2.7)</td>
<td>4.0000(4), 580 (FORS)</td>
<td></td>
</tr>
<tr>
<td>[O ii]( \lambda 3727.09 )</td>
<td>0.38(4.5)</td>
<td>3.9991, 55 (XSHO)</td>
<td></td>
</tr>
<tr>
<td>[O ii]( \lambda 3729.88 )</td>
<td>0.25(3)</td>
<td>3.9991, 55 (XSHO)</td>
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SED-fitting output: Value | Uncertainty

M(solar) \(( \times 10^9 \text{ M}_{\odot} )\) | 1.5 | [1.4–2.2] |
Age (Myr) | 11 | [10–20] |
SFR [M_{\odot} \text{ yr}^{-1}] | 140 | [110–150] |
E(B – V) | \( \lesssim 0.1 \) | [0–0.1] |
\( M_{\odot} (1500) \) | \(-22.20 \) ±0.15 |
\( H_Z \text{ EW(rest)} (\text{Å}) \) | \( \geq 1000 \) | [700–1300] |
\( \text{Nphot}(900Å)(s^{-1}) \) | \( 3.0 \times 10^{33} \) | [10^{33–54}] |
\( \log_{10}(\xi_{\text{900 Å}}(\text{Hz erg}^{-1})) \) | 25.6 | 25.4–25.8 |
\( f_{\text{esc, rel}} \) | 0.60 | [0.10–1.00] |

Figure 2. The FORS spectrum is shown with the main spectral features reported at the systemic redshift (blue crosses). In particular, the P-Cygni N v\( \lambda 1240 \), [C ii]\( \lambda 1335.71 \), [S iv]\( \lambda 1393.76 \), and the He ii\( \lambda 1640 \) lines are highlighted with thick lines. The N v\( \lambda 1240 \) region (square) is zoomed and shown in the top-right inset (black line), in which three Starburst99 stellar models of 1, 10, and 20 Myr are superimposed to the spectrum (coloured lines).
indicative of a possible perforated channel of very low H I optical (2017), in which the central peak is also at the systemic redshift and growing system with a specific star formation rate of \( \sim 0 \). 15 Gyr, (see Castellano et al. 2016 for details). It has been applied to the ground-based ESO/WFI imaging \( B [842], V [843], R [844], \) and \( I_c[879] \), and deep ESO VLT/HAWKI \( K_i \) (obtained with 0.39 arcsec seeing, Brammer et al. 2016) and space-based Spitzer/IRAC 3.6 and 4.5\( \mu \)m bands1 (see Fig. 4). While Ion3 is detected at \( S/N \lesssim 5 \) in the ESO/WFI bands, the optical rest-frame continuum is detected with \( S/N \gtrsim 10 \) in the Ks and IRAC bands. The most interesting features are the flat continuum at rest-frame wavelengths 4400 and 9000\( \AA \), and the clear excess in the 3.6\( \mu \)m band consistent with an \( H\alpha \) emission with rest-frame EW of 1000\( \AA \). The best-fitting model implies Ion3 is a relatively low stellar mass \( (1.5 \times 10^9 M_{\odot}) \) system undergoing a starburst phase (SFR \( \sim 140 M_{\odot}\) yr\(^{-1}\)) consistently with the presence of prominent \( H\alpha, N\nu, 1.240 P\)-Cygni profile, strong \( H\beta \) and measured LyC. Ion3 appears as a still rapidly growing system with a specific star formation rate of \( \sim 90 \) Gyr\(^{-1}\) (see Table 1 for a summary of the properties of Ion3). The photometric estimate of the \( H\alpha \) line luminosity \( \sim 2 \times 10^{43} \) erg s\(^{-1}\) implies a high LyC photon production efficiency, \( \xi_{\text{ion}} \) = 25.6 ± 0.2 Hz erg\(^{-1}\)). It resembles the values derived by Bouwens et al. (2016) for the bluest galaxies \( (\beta < -2.3, \text{see also} \) Shivaei et al. 2017), and consistent with the values reported from local candidate and confirmed LyC emitters, that also show large rest-frame EW(\( H\alpha \)) \( \sim 1000 \)\( \AA \) (e.g. Izotov et al. 2017; Jaskot et al. 2017), and eventually similar to those inferred at \( z > 6 \) reported by Stark et al. (2017).

It is also worth noting that Ion3 belongs to the starburst region of the \( z \approx 4.5 \) SFR\(-M^* \) bimodal distribution recently identified by Caputi et al. (2017). Based on current data, there is no evidence of, nor any need for, any contribution to the UV emission by an AGN. The relatively large ratios of \( H\alpha/N\nu \approx 17 \pm 2 \) and \( Ly\alpha/C\nu \gtrsim 20 \) tend to exclude the presence of an obscured AGN (e.g. Alexandroff et al. 2013). A relatively shallow Chandra exposure of 130 ksec in the 0.5–2 kev band available in the field 1 yields a limit of \( 1.6 \times 10^{-15} \) erg s\(^{-1}\) cm\(^{-2}\) (3\( \sigma \)), corresponding to an upper limit to the X-ray luminosity of \( 3 \times 10^{31} \) erg s\(^{-1}\), which rules out a luminous AGN. Assuming a low-luminosity AGN is present, the very young burst detected would imply the ionizing photons are a mixture of stellar and non-stellar radiation escaping along a transparent medium \( (N_{HI} < 10^{17} \text{ cm}^{-2}) \), that, however, should not be able to attenuate the expected high-ionization emission lines, making Ion3 either a very special case among the AGN category or a pure star-forming dominated object. Another possibility is that Ion3 has been captured just after the AGN has turned off, such that the optically thin channel produced by the previous nuclear activity enables the \( Ly\alpha \) and LyC stellar radiation to escape towards the observer.

### 3.4 Physical properties from the SED fitting and the nature of the ionizing radiation

SED fitting has been performed using BC03 templates (Bruzual & Charlot 2003) including the nebular prescription and assuming exponentially declining star formation histories with e-folding time \( 0.1 < \tau < 15 \) Gyr, (see Castellano et al. 2016 for details). It has been applied to the ground-based ESO/WFI imaging \( B [842], V [843], R [844], \) and \( I_c[879] \), and deep ESO VLT/HAWKI \( K_i \) (obtained with 0.39 arcsec seeing, Brammer et al. 2016) and space-based Spitzer/IRAC 3.6 and 4.5\( \mu \)m bands1 (see Fig. 4). While Ion3 is detected at \( S/N \lesssim 5 \) in the ESO/WFI bands, the optical rest-frame continuum is detected with \( S/N \gtrsim 10 \) in the Ks and IRAC bands. The most interesting features are the flat continuum at rest-frame wavelengths 4400 and 9000\( \AA \), and the clear excess in the 3.6\( \mu \)m band consistent with an \( H\alpha \) emission with rest-frame EW of 1000\( \AA \). The best-fitting model implies Ion3 is a relatively low stellar mass \( (1.5 \times 10^9 M_{\odot}) \) system undergoing a starburst phase (SFR \( \sim 140 M_{\odot}\) yr\(^{-1}\)) consistently with the presence of prominent \( H\alpha, N\nu, 1.240 P\)-Cygni profile, strong \( H\beta \) and measured LyC. Ion3 appears as a still rapidly growing system with a specific star formation rate of \( \sim 90 \) Gyr\(^{-1}\) (see Table 1 for a summary of the properties of Ion3). The photometric estimate of the \( H\alpha \) line luminosity \( \sim 2 \times 10^{43} \) erg s\(^{-1}\) implies a high LyC photon production efficiency, \( \xi_{\text{ion}} \) = 25.6 ± 0.2 Hz erg\(^{-1}\)). It resembles the values derived by Bouwens et al. (2016) for the bluest galaxies \( (\beta < -2.3, \text{see also} \) Shivaei et al. 2017), and consistent with the values reported from local candidate and confirmed LyC emitters, that also show large rest-frame EW(\( H\alpha \)) \( \sim 1000 \)\( \AA \) (e.g. Izotov et al. 2017; Jaskot et al. 2017), and eventually similar to those inferred at \( z > 6 \) reported by Stark et al. (2017).

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### Final Remarks

Ion3 is a bright star-forming galaxy showing copious LyC leakage identified just 1.5 Gyr after the Big-Bang (\( z = 4 \)). This makes Ion3 the highest redshift confirmed LyC emitter known so far. In particular,
(i) The spectral features and the SED-fitting suggest that Ion3 is a young, low-mass system undergoing a starburst phase containing hot and massive stars, with a specific star formation rate of 90 Gyr⁻¹.

(ii) The FORS and X-Shooter spectra reveal for the first time at such redshift a transparent ionized channel through which the Ly α photons escape at the resonance frequency, plausibly along the same path of the LyC photons.

The absence of HST imaging prevents us from deriving any conclusion on the morphology of the galaxy. The image with the best seeing is the VLT/HAWKI Ks-band (0.39 arcsec) from which Ion3 appears marginally resolved with a FWHM ∼2–3 kpc proper. We refer the reader to a future work focused on the detailed analysis of the spatial distribution of the ionizing and non-ionizing radiation, as well as a proper radiative transfer modelling of the Ly α emission. However, it is worth noting that Ion3 shows similar properties of another LyC emitter we identified at z = 3.21 (dubbed Ion2, Vanzella et al. 2016), e.g. a structured Ly α shape, the blue UV slope and weak low-ionization interstellar absorption lines. While in the case of Ion2 we confirmed also very strong [O III]λ5007 lines (EW > 1000 Å rest-frame) and large O32 index ([O III]λ5007/ [O ii]λ3727 > 10) making it among of the highest redshift Green Pea galaxy and suggesting a density-bounded condition, Ion3 might also have a perforated medium and will need JWST to probe the rest-frame optical wavelengths (imaging and spectroscopy) and HST to image directly the LyC. Irrespective of the nature of the ionizing radiation, Ion3 represents a unique high-redshift laboratory where ionized channels carved in the interstellar medium by one or more feedback sources can be studied. Ion3 and Ion2 represent ideal reference cases to guide the search for reionizing sources at z > 6.5 with JWST.

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