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THE EXTENDED He II λ4686-EMITTING REGION IN IZw 18 UNVEILED: CLUES FOR PECULIAR IONIZING SOURCES

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ABSTRACT

New integral field spectroscopy has been obtained for IZw 18, the nearby lowest-metallicity galaxy considered to be our best local analog of systems forming at high redshift (z). Here we report the spatially resolved spectral map of the nebular He II λ4686 emission in IZw 18, from which we derived for the first time its total He II-ionizing flux. Nebular He II emission implies the existence of a hard radiation field. He II-emitters are observed to be more frequent among high-z galaxies than for local objects. Therefore, investigating the He II-ionizing source(s) in IZw 18 may reveal the ionization processes at high z. He II emission in star-forming galaxies has been suggested to be mainly associated with Wolf–Rayet stars (WRs), but WRs cannot satisfactorily explain the He II-ionization at all times, particularly at the lowest metallicities. Shocks from supernova remnants, or X-ray binaries, have been proposed as additional potential sources of He II-ionizing photons. Our data indicate that conventional He II-ionizing sources (WRs, shocks, X-ray binaries) are not sufficient to explain the observed nebular He IIλ4686 emission in IZw 18. We find that the He II-ionizing radiation expected from models for either low-metallicity super-massive O stars or rotating metal-free stars could account for the He II-ionization budget measured, while only the latter models could explain the highest values of He IIλ4686/Hβ observed. The presence of such peculiar stars in IZw 18 is suggestive and further investigation in this regard is needed. This letter highlights that some of the clues of the early universe can be found here in our cosmic backyard.

Key words: galaxies: dwarf – galaxies: individual (IZw 18) – galaxies: ISM – galaxies: stellar content – ISM: lines and bands

1. INTRODUCTION

He II recombination emission indicates the presence of very hard ionizing radiation with photon energies $\geqslant$ 54 eV. Star-forming galaxies with lower metallicities tend to have larger nebular He IIλ4686 line intensities compared to those with higher metallicities (e.g., Guseva et al. 2000; Schaerer 2003). While nebular He II emission has been observed in some local low metallicity (Z) starbursts (e.g., Schaerer et al. 1999; Guseva et al. 2000; Kehrig et al. 2004; Thuan & Izotov 2005), He II-emitters are apparently more frequent among high-redshift (z) galaxies than for local objects. Recent work has found that $\geqslant$ 3% of the global galaxy population at z~3 shows narrow He II lines (Cassata et al. 2013), while this number is much lower at z~0 (Kehrig et al. 2011). The He II lines have been suggested as a good tracer of Population III stars (PopIII-stars; the first very hot metal-free stars) in high-z galaxies (e.g., Schaerer 2003, 2008). These stars, which should produce a large amount of hard ionizing radiation, are believed to have contributed significantly to the universe's reionization, a challenging subject in contemporary cosmology (e.g., Bromm 2013). Before interpreting the emission-line spectra of distant star-forming galaxies, it is crucial to understand the formation of high-ionization lines in the nearby universe. The ideal place to perform this study is in extremely metal-poor nearby galaxies with nebular He II emission, which are the natural local counterparts of distant He II-emitters.

In this regard, we have been carrying out a program to investigate nearby low-Z starburst systems using the integral field spectroscopy technique (e.g., Kehrig et al. 2008, 2013; Pérez-Montero et al. 2011, 2013). As a part of this program, we have recently obtained new deep integral field spectroscopic (IFS) data of IZw 18. This is a nearby (D = 18.2 Mpc; Aloisi et al. 2007)[5] HII galaxy, well known for its extremely low Z ~ 1/32 solar (e.g., Vílchez & Iglesias-Páramo 1998), which places IZw 18 among the three most metal-poor galaxies known in the local universe (e.g., Thuan et al. 2004). Its observational characteristics make IZw 18 an excellent local analog of primeval systems (see e.g., Lebouteiller et al. 2013 and references therein).

The presence of the nebular He IIλ4686 line in the spectrum of IZw 18 has been reported before, although the precise location and extension of this He IIλ4686 emission is not known (e.g., Garnett et al. 1991; Izotov et al. 1997; Legrand et al. 1997; Vílchez & Iglesias-Páramo 1998). Our unique IFS data unveil for the first time the entire He IIλ4686-emitting region and its structure in IZw 18 (see Section 3.2).

Despite various attempts to explain the origin of the nebular He II emission in HII galaxies/regions, it still remains difficult to understand in many cases; several potential mechanisms (e.g., hot Wolf–Rayet (WR) stars, shocks from supernovae remnants, X-ray sources) have been proposed to account (in part or fully) for the He II ionization in these objects (e.g., Garnett et al. 1991; Schaerer 1996; Dopita & Sutherland 1996; Cerviño, Mas-Hesse & Kunth 2002; Thuan & Izotov 2005; Kehrig et al. 2011; Shirazi & Brinchmann 2012). Although hot WRs have previously been suggested as the source of

[5] A distance of 18.2 Mpc is assumed in this work.

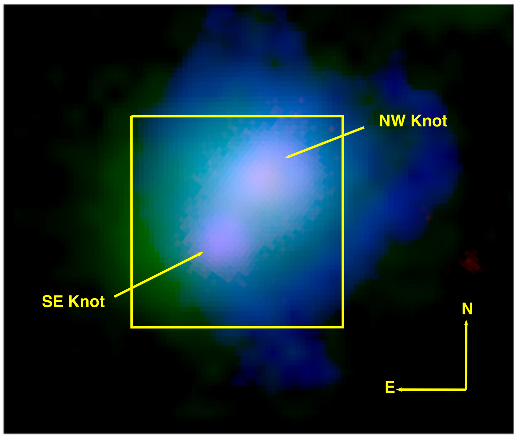

Figure 1. Color-composite image of IZw 18 (blue = Hα from Palomar, green = far-UV/*GALEX*, red = SDSS r'). The box represents the FOV (16"×16") of the PMAS spectrograph over the galaxy main body and the extended Hα halo. The PMAS FOV is centered on the coordinates R.A. (J2000.0) = 09^h:34^m:$02\overset{s}{.}2$ and decl. (J2000.0) = +55°:14′:25″.

He II-ionizing photons in IZw 18 (e.g., Izotov et al. 1997; de Mello et al. 1998), the main mechanism powering the nebular He II emission in this galaxy is still an open issue.

In this Letter, using new IFS data, we derive for the first time the total He IIλ4686-ionizing flux in IZw 18 and provide new clues to constrain the sources of high ionization.

2. INTEGRAL FIELD SPECTROSCOPIC DATA

We carried out new IFS observations of IZw 18 using the Potsdam Multi-Aperture Spectrophotometer (PMAS; Roth et al. 2005) on the 3.5 m telescope at the Calar Alto Observatory (Almeria, Spain). The data were taken in 2012 December with a typical seeing of 1". Each spaxel has a spatial sampling of 1" × 1" on the sky resulting in a field of view (FOV) of 16" × 16" (~1.4 kpc × 1.4 kpc on IZw 18; see Figure 1). One pointing of IZw 18, encompassing its main body which hosts the two brightest stellar clusters (referred to as the NW and SE knots), was taken during a 2.5 hr integration split into six exposures of 1500 s each. We used the V500 grating, which covers from ~3640 to 7200 Å and provides a linear dispersion of ~2 Å/pixel and an FWHM effective spectral resolution of ~3.6 Å. Calibration images (exposures of standard star, arc, and continuum lamps) were also obtained. The data reduction was performed following the procedure described in Kehrig et al. (2013).

3. RESULTS

3.1. Emission-line Flux Maps

The emission-line fluxes were measured using the IRAF[6] task SPLOT. The flux of each emission line was derived by integrating between two points given by the position of a local continuum placed by eye. For each line, this procedure was repeated several times by varying the local continuum position. The final flux of each line and its associated uncertainty were assumed to be the average and standard deviation of the independent, repeated measurements (e.g., Kehrig et al. 2006).

We used our own IDL scripts to create the emission-line maps presented in Figure 2. The spaxels where we measure He IIλ4686 are indicated with pluses.

3.2. The Spatially Resolved He IIλ4686-emitting Region

An extended He IIλ4686-emitting region with a diameter of ≈ 5" (≈440 pc) is revealed from our IFS data (see Figure 2). The narrow line profile for the He IIλ4686 emission and its spatial extent are evidence of its nebular nature. The spectra of certain Of stars may exhibit somewhat narrow He IIλ4686 lines (e.g., Massey et al. 2004), so He II emission observed in starburst galaxies could be thought to arise in the atmospheres of such stars (e.g., Bergeron 1977). However, if these Of stars were present in appreciable numbers in IZw 18, then broad Hα emission would be expected (Massey et al. 2004). Thus, the non-detection of this feature in our spectra supports the nebular origin for the He IIλ4686 line in IZw 18.

By adding the emission from the spaxels showing He IIλ4686 (see Figure 2), we created the one-dimensional spectrum for the He IIλ4686 region (see Figure 3). Using this spectrum, we obtained a very small logarithmic extinction coefficient $c(\mathrm{H}\beta) = 0.08 \pm 0.02$ from the observed ratio Hα/H$\beta = 2.92 \pm 0.04$, assuming an intrinsic case B recombination Hα/Hβ = 2.75 (Osterbrock & Ferland 2006, OF06). Using PYNEB (Luridiana et al. 2015), we derived the electron temperature, T_e=(2.18± 0.05)×10^4 K, and density, $n_e \leqslant 100\,\mathrm{cm}^{-3}$, from the [O III]$\lambda$4363/[O III]$\lambda\lambda$4959,5007 and [S II] λ6717/[S II]λ6731 ratios, respectively. The integrated flux of the He IIλ4686 line, corrected for reddening, is $(2.84 \pm 0.18) \times 10^{-15}$ erg s^{-1} cm^{-2} which translates to an He IIλ4686 luminosity of $L_{\mathrm{HeII}\lambda4686}$= $(1.12 \pm 0.07) \times 10^{38}$ erg s^{-1}. The corresponding He II ionizing photon flux, $Q(\mathrm{He\ II})_{\mathrm{obs}} = (1.33 \pm 0.08) \times 10^{50}$ photon s^{-1}, was derived from the measured $L_{\mathrm{HeII}\lambda4686}$ using the relation $Q(\mathrm{He\ II}) = L_{\mathrm{HeII}\lambda4686}/[j(\lambda4686)/\alpha_{\mathrm{B}}(\mathrm{He\ II})]$ (assuming case B recombination, and $T_e = 2 \times 10^4$ K; OF06). We checked that different CLOUDY models (Ferland et al. 2013) computed for the typical n_e and T_e in the He IIλ4686 region, and considering several effective temperatures and geometries with no dust, provide a ratio L(He IIλ4686)/Q(He II) which agrees with the assumed ratio (OF06) within 10%. The total $Q(\mathrm{He\ II})_{\mathrm{obs}}$, a quantity not reported before for IZw 18, will allow us to constrain possible ionizing sources of He II in IZw 18.

4. DISCUSSION

4.1. Ionizing Sources of He II

One widely favored mechanism for He II ionization in H II galaxies involves hot WRs (e.g., Schaerer 1996). Nevertheless, it has been demonstrated that nebular He IIλ4686 does not appear to be always associated with WRs, as is the case of the He II nebulae LMC N44C, LMC N159F, and M33 BCLMP651, among others (Kehrig et al. 2011 and references therein). This indicates that WRs cannot explain He II ionization in all cases, particularly at low Z (e.g., Guseva et al. 2000; Kehrig et al. 2008, 2013; Schaerer 2003; Shirazi & Brinchmann 2012). Besides, it has been shown that for a sample of He IIλ4686-emitting star-forming galaxies, current models of massive stars predict He IIλ4686 emission and He IIλ4686/Hβ ratios only for $Z > 0.20\ Z_\odot$ instantaneous bursts (Shirazi & Brinchmann 2012). In the particular case of IZw 18, previous work claimed that the ratio He IIλ4686/Hβ could be

[6] IRAF is distributed by the National Optical Astronomical Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

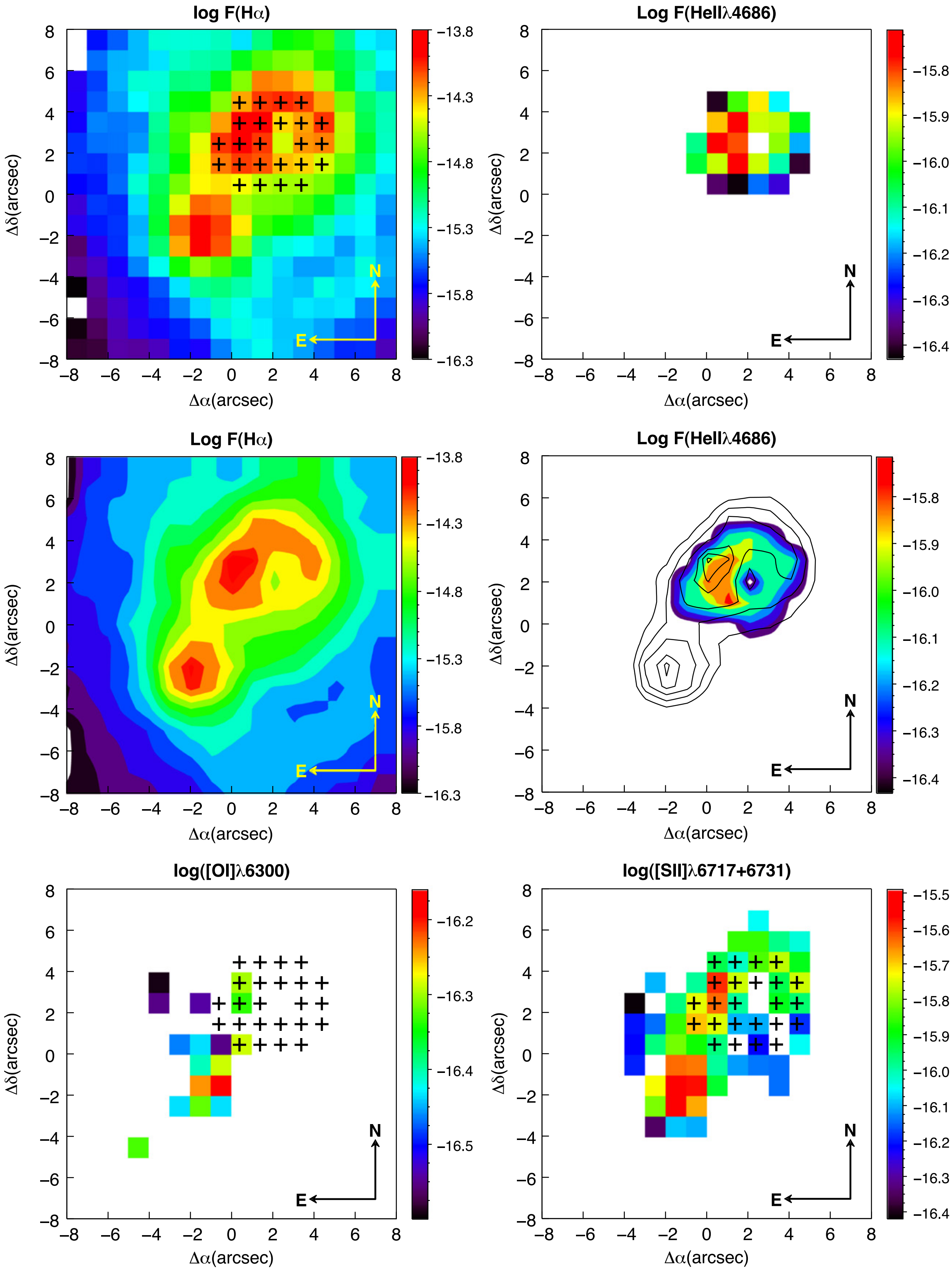

Figure 2. Emission-line flux maps of IZw 18. Maps are displayed in logarithmic scale and the fluxes are in units of erg s^{-1} cm^{-2}; the area of each spaxel is 1 $arcsec^2$ on the sky. *Top row*: Hα and He ii λ4686 maps. *Middle row*: for display purposes, the maps of Hα and He ii λ4686 are presented as color-filled contour plots and were smoothed using bilinear interpolation. Isocontours of the Hα emission line flux are shown overplotted for reference. *Bottom row*: [O i] λ6300 and [S ii] λλ6717 + 6731 maps. The spaxels where we detect nebular He ii λ4686 are marked with pluses on the maps of Hα (*top row*), and [O i] λ6300 and [S ii] λλ6717 + 6731 (*bottom row*). The spaxels with no measurements available are left blank.

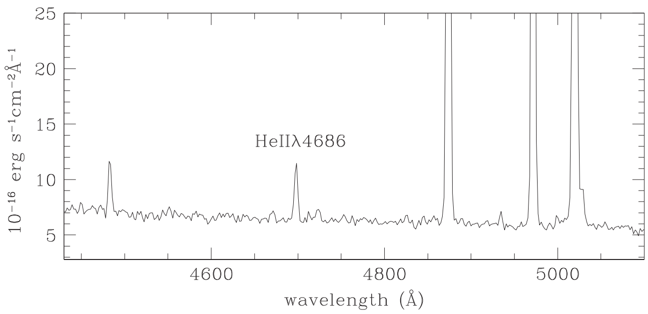

Figure 3. Portion (~4425–5100 Å) of the integrated spectrum of the He iiλ4686-emitting region of IZw 18.

reproduced using highly density-bounded photoionization models while underpredicting the electron temperature measurement (Stasińska & Schaerer 1999); these models have been challenged by Péquignot (2008).

Faint broad emission signatures, attributable to WRs, are observed in the spectrum of IZw 18 despite its low Z (e.g., Izotov et al. 1997; Legrand et al. 1997; Brown et al. 2002). A comprehensive study of WRs in IZw 18, using UV STIS spectroscopy, revealed signatures of carbon-type WRs (WC) in two clusters: one in the NW star-forming region and a second one on the outskirts of this region (Brown et al. 2002). Here we deal with the NW one, since it is in the He iiλ4686-emitting region (see Figure 2). The C ivλ1550 flux measured from the NW WR cluster (Brown et al. 2002) provides a C ivλ1550 luminosity of $L_{1550} = 4.67 \times 10^{37}$ erg s^{-1}. Taking the L_{1550} luminosity of the metal-poor, early-type WC (WCE) model by Crowther and Hadfield (2006, CH06), which mimics a single WCE star in IZw 18, this implies ~9 IZw 18-like WCE stars present in the NW cluster. From these nine WCE stars, a total flux of Q(He ii) = 2.8 ×10^{48} photon s^{-1} is expected (assuming Q(He ii) = 10$^{47.5}$ photon s^{-1} for one IZw 18-like WCE; CH06), i.e., about 48 times lower than the Q(He ii)$_{\rm obs}$ = (1.33 ± 0.08)×10^{50} photon s^{-1} derived from our data (see Section 3.2).

Based on the He ii-ionizing flux expected from these IZw 18-like WRs, a very large WR population is required to explain the He ii-ionization budget measured; for instance, taking the Q(He ii) = 10$^{47.5}$ photon s^{-1} for one IZw 18-like WCE (CH06), the number of these WCEs needed to explain our derived Q(He ii)$_{\rm obs}$ = (1.33 ± 0.08)×10^{50} photon s^{-1} would be >400. In principle, the presence of hundreds of WRs in IZw 18 should not be discarded on the basis of empirical arguments for reduced WR line luminosity at low Z (CH06). However, assuming a Salpeter initial mass function (IMF; Salpeter 1955; $M_{\rm up}$ = 150 $M_\odot$) and the initial mass needed for a star to certainly become a WC (Meynet & Maeder 2005), a cluster with >8 times the total stellar mass of the NW region ($M_{*,\rm NW}$= 2.9 × 10^5 $M_\odot$ from Stasińska & Schaerer 1999 scaled to 18.2 Mpc distance) is required to provide >400 WC in IZw 18. Also, such a high number of WRs is not supported by state-of-the-art stellar evolutionary models for single (rotating and non-rotating) massive stars in metal-poor environments (Leitherer et al. 2014). Furthermore, given the decrease in the ratio of WR/O stars with decreasing metallicity, shown by observations and theoretical models (Maeder & Meynet 2012 and references therein), such a large number of WRs appears clearly unreasonable considering the extremely low Z and the O star content of IZw 18 (CH06). All this suggests that WRs are not solely responsible for the He iiλ4686 emission in IZw 18.

The binary channel in massive star evolution is suggested to increase the WR population (e.g., Eldridge et al. 2008), but the WR population in Local Group galaxies does not show an increased binary rate at lower Z (e.g., Foellmi et al. 2003; Neugent & Massey 2014); thus, the binary channel does not seem to favor the formation of WRs at lower-Z, in contrast to what we need. Nevertheless, we should bear in mind the possible uncertainties still unsolved in the models (Maeder & Meynet 2012). Further investigation awaits the calculation of evolutionary models for binary stars at very low Z.

As mentioned before, nebular He iiλ4686 emission observed in the spectra of Hii galaxies and extragalactic Hii regions has also often been attributed to shocks and X-ray sources (e.g., Pakull & Mirioni 2002; Garnett et al. 1991; Thuan & Izotov 2005). In the following, we discuss these two candidate sources for He ii ionization in IZw 18.

The X-ray emission from IZw 18 is dominated by a single X-ray binary apparently located in the field of the NW knot (Thuan et al. 2004). We have computed a CLOUDY photoionization model (Ferland et al. 2013) using as input a power-law spectral energy distribution (SED) with the same X-ray luminosity, column density, and slope that have been reported for IZw 18 (Thuan et al. 2004). This CLOUDY model provides an He iiλ4686 luminosity of $L_{\rm HeII\lambda4686}$ = 10$^{35.7}$ erg s^{-1}, which is ~100 times lower than the $L_{\rm HeII\lambda4686}$ measured. This result rules out the X-ray binary as the main source of He ii ionizing photons in IZw 18. We note here that the emission from X-ray ionized nebulae has been successfully reproduced by CLOUDY models before (e.g., Pakull & Mirioni 2002).

Guided by the existence of He iiλ4686 emission associated with supernova remnants (e.g., Kehrig et al. 2011) we explored the conjecture that the He iiλ4686 region represents such a shock-ionized nebula. The [O i]λ6300 line, often strong in remnants, has frequently been used as a sensitive shock-emission test (e.g., Skillman 1985). We checked that, in fact, most of the [O i]λ6300 emission in IZw 18 is concentrated on the SE knot (see the [O i]λ6300 map in Figure 2) with only 12% of the He iiλ4686-emitting spectra showing [O i]λ6300 flux above the 3σ detection limit. Additionally, we find no evidence for [S ii] enhancement (a usual sign of shock excitation; e.g., Dopita & Sutherland 1996) associated with the He iiλ4686 region (see the [S ii] map in Figure 2). Therefore, the He iiλ4686-emitting zone in IZw 18 is unlikely to be produced by shocks.

4.2. Peculiar Very Hot Stars in IZw 18?

Our new observations have allowed us to empirically demonstrate why conventional He ii-ionizing sources (e.g., WRs, shocks, X-ray binaries) cannot account for the total He ii-ionization budget in IZw 18. What could the nebular He iiλ4686 emission in IZw 18 originate from?

We have also explored the possibilty of very massive, metal-poor O stars to account for our observations of IZw 18. Using current wind models of very massive O stars at low Z, we can derive their He ii-ionizing fluxes (Kudritzki 2002). According to the hottest models (T_e = 60,000K), between 10 and 20 super-massive stars with 300 $M_\odot$ (with Q(He ii) ≈(0.70–1.4) × 10^{49} photon s^{-1} each) would be sufficient to explain the derived $Q(\text{He II})_{\text{obs}}$ budget. Very massive stars of up to 300 $M_\odot$ were claimed to exist in the LMC R136 cluster (Crowther et al. 2010); however, the existence of such super-massive 300 $M_\odot$ stars remains heavily debated (Vink 2014). Additionally, assuming a Salpeter IMF, 10–20 stars with 290 $\leqslant M_*/M_\odot \leqslant$ 310 would imply a cluster mass of ∼10–20 × $M_{*,\text{NW}}$. We should bear in mind that an extrapolation of the IMF predicting 300 $M_\odot$ stars remains unchecked up to now. If we instead consider the 150 $M_\odot$ star hottest models (with $Q(\text{He II}) \leqslant 1.9 \times 10^{47}$ photons^{-1} each, for $Z \leqslant 1/32\ Z_\odot$; K02), the number of these stars required to explain the $Q(\text{He II})_{\text{obs}}$ would be >650. For a Salpeter IMF, 650 stars with 145 $\leqslant M_*/M_\odot \leqslant$ 155 would require a cluster mass ∼200 × $M_{*,\text{NW}}$. Besides the $Q(\text{He II})_{\text{obs}}$ budget, in the He IIλ4686 region we have measured He IIλ4686/Hβ ratios as high as 0.08. These values appear too big to be explained even by the models for the hottest, most metal-poor super-massive 300 $M_\odot$ stars (K02) under ionization-bounded conditions. Further constraints to the observations should await the calculation of new evolutionary tracks and SEDs for single O stars at the metallicity of IZw 18 including rotation.

Searches for very metal-poor starbursts and PopIII-hosting galaxies have been carried out in the distant universe using He II lines (e.g., Schaerer 2008; Cassata et al. 2013). This search is based on the high effective temperature for PopIII-stars which will emit a large number of photons with energy above 54eV, and also on the expected increase of the He II recombination lines with decreasing Z (e.g., Guseva et al. 2000; Schaerer 2003, 2008). Predictions for burst models of different metallicities show how their corresponding $Q(\text{He II})$ can increase by up to $\sim 10^3$ when going from $Z = 10^{-5}$ to 0 (Schaerer 2003). These models cannot explain the $Q(\text{He II})_{\text{obs}}$ when $Z \geqslant 10^{-5}$ (for a Salpeter IMF, $M_{\text{up}} = 100\ M_\odot$; see table 3 in Schaerer 2003) even assuming that the total $M_{*,\text{NW}}$ would come from He II-ionizing stars. So another more speculative possibility to explain the derived $Q(\text{He II})_{\text{obs}}$ could be based on nearly metal-free ionizing stars. These stars should ionize He II via their strong UV radiation expected at nearly zero metallicity (e.g., Tumlinson & Shull 2000; Schaerer 2003).

As an approximation of nearly metal-free single stars, we have compared our observations with the He II-ionizing radiation expected from state-of-the-art models for rotating $Z = 0$ stars (Yoon et al. 2012). According to these models, we found that a handful of such stars could explain our derived $Q(\text{He II})_{\text{obs}}$ (e.g., ∼8–10 stars with mass $M_{\text{ini}} = 150\ M_\odot$ or ∼13–15 stars with $M_{\text{ini}} = 100\ M_\odot$; with $Q(\text{He II}) \approx 1.4 \times 10^{49}$ (0.9×10^{49}) photon s^{-1} for each star with $M_{\text{ini}} = 150\ M_\odot (100\ M_\odot)$). Additionally, we note that the ionizing spectra produced by these star models are harder than the ones expected from the hottest models of super-massive 300 $M_\odot$ stars (K02), so they would also explain the highest He IIλ4686/Hβ values observed, providing that ionization-bounded conditions are met. While gas in IZw 18 is very metal-deficient but not primordial, Lebouteiller et al. (2013) have pointed out that the HI envelope of IZw 18 near the NW knot contains essentially metal-free gas pockets. These gas pockets could provide the raw material for making such nearly metal-free stars. Clearly, in this hypothetical scenario, these extremely metal-poor stars cannot belong to the NW cluster, which hosts more chemically evolved stars.

5. SUMMARY AND CONCLUDING REMARKS

This letter reports on new optical IFS observations of the nearby dwarf galaxy IZw 18. This is an extremely metal-poor system, which is our best local laboratory for probing the conditions dominating in distant low-Z starbursts. Our IFS data reveal for the first time the total spatial extent (≈440 pc diameter) of the He IIλ4686-emitting region and corresponding total He II-ionizing photon flux in IZw 18. The metal-poor sensitivity of the He II line is a primary motivation to develop diagnostics for unevolved starbursts, and strong nebular He II emission is expected to be one of the best signatures of massive PopIII-stars (e.g., Schaerer 2003, 2008). He II emission has been observed to be more frequent at higher-z than locally (Kehrig et al. 2011; Cassata et al. 2013). Thus the analysis of the origin of the He IIλ4686 nebular line in relatively close ionized regions, which can be studied in more detail, can yield insight into the ionizing sources in the distant universe.

Our observations combined with stellar model predictions point out that conventional excitation sources (e.g., WRs, shocks, X-ray binaries) cannot convincingly explain the He II-ionizing energy budget derived for IZw 18. Other mechanisms are probably also at work. If the He II-ionization in IZw 18 is due to stellar sources, these might be peculiar very hot stars (perhaps uncommon in local starbursts but somewhat more frequent in distant galaxies): according to theoretical stellar models, either super-massive O stars or nearly metal-free ionizing stars could in principle account for the total $Q(\text{He II})_{\text{obs}}$ of IZw 18. However, the super-massive O stars scenario would imply a cluster mass much higher than the mass of the NW knot derived from observations. On the other hand, though metal-free gas pockets were previously reported in IZw 18 (Lebouteiller et al. 2013), we highlight that the existence of nearly metal-free ionizing stars is not yet confirmed observationally. The work presented here can help in the preparation of prospective searches for primeval objects, one of the main drivers for next-generation telescopes (e.g., Bromm 2013).

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REFERENCES

Aloisi, A., Clementini, G., Tosi, M., et al. 2007, ApJL, 667, L151
Bergeron, J. 1977, ApJ, 211, 62
Bromm, V. 2013, RPPh, 76, 112901
Brown, T. M., Heap, S. R., Hubeny, I., et al. 2002, ApJL, 579, L75
Cassata, P., Le Fèvre, O., Charlot, S., et al. 2013, A&A, 556, A68
Cerviño, M., Mas-Hesse, J. M., & Kunth, D. 2002, A&A, 392, 19
Crowther, P. A., & Hadfield, L. J. 2006, A&A, 449, 711
Crowther, P. A., Schnurr, O., Hirschi, R., et al. 2010, MNRAS, 408, 731
de Mello, D. F., Schaerer, D., Heldmann, J., & Leitherer, C. 1998, ApJ, 507, 199
Dopita, M. A., & Sutherland, R. S. 1996, ApJS, 102, 161
Eldridge, J. J., Izzard, R. G., & Tout, C. A. 2008, MNRAS, 384, 1109
Ferland, G. J., Porter, R. L., van Hoof, P. A. M., et al. 2013, Rev. Mex. Astron. Astrofis., 49, 137
Foellmi, C., Moffat, A. F. J., & Guerrero, M. A. 2003, MNRAS, 338, 360
Garnett, D. R., Kennicutt Jr., R. C., You-Hua, C., Skillman, E. D., et al. 1991, ApJ, 373, 458

Guseva, N. G., Izotov, Y. I., & Thuan, T. X. 2000, ApJ, 531, 776
Izotov, Y. I., Foltz, C. B., Green, R. F., Guseva, N. G., & Thuan, T. X. 1997, ApJL, 487, L37
Kehrig, C., Telles, E., & Cuisinier, F. 2004, AJ, 128, 1141
Kehrig, C., Vílchez, J. M., Telles, E., Cuisinier, F., & Pérez-Montero, E. 2006, A&A, 457, 477
Kehrig, C., Vílchez, J. M., Sánchez, S. F., et al. 2008, A&A, 477, 813
Kehrig, C., Oey, M. S., Crowther, P. A., et al. 2011, A&A, 526, A128
Kehrig, C., Pérez-Montero, E., Vílchez, J. M., et al. 2013, MNRAS, 432, 2731
Kudritzki, R. P. 2002, ApJ, 577, 389
Lebouteiller, V., Heap, S., Hubeny, I., & Kunth, D. 2013, A&A, 553, A16
Legrand, F., Kunth, D., Roy, J.-R., Mas-Hesse, J. M., & Walsh, J. R. 1997, A&A, 326, L17
Leitherer, C., Ekström, S., Meynet, G., et al. 2014, ApJS, 212, 14
Luridiana, V., Morisset, C., & Shaw, R. A. 2015, A&A, 573, A42
Maeder, A., & Meynet, G. 2012, RvMP, 84, 25
Massey, P., et al. 2004, ApJ, 608, 1001
Meynet, G., & Maeder, A. 2005, A&A, 429, 581
Neugent, K. F., & Massey, P. 2014, ApJ, 789, 10
Osterbrock, D. E., & Ferland, G. J. 2006, in Astrophysics of Gaseous Nebulae and Active Galactic Nuclei (CA: University Science Books)
Pakull, M. W., & Mirioni, L. 2002, Proc. Symp. "New Visions of the X-ray universe in the XMM-Newton and *Chandra* Era" (Noordwijk: ESTEC)
Péquignot, D. 2008, A&A, 478, 371
Pérez-Montero, E., et al. 2011, A&A, 532, A141
Pérez-Montero, E., Kehrig, C., Brinchmann, J., et al. 2013, AdAst, 837, 392
Roth, M. M., Kelz, A., Fechner, T., et al. 2005, PASP, 117, 620
Salpeter, E. E. 1955, ApJ, 121, 161
Schaerer, D. 1996, ApJ, 467, L17
Schaerer, D., Contini, T., & Pindao, M. 1999, A&AS, 136, 35
Schaerer, D. 2003, A&A, 397, 527
Schaerer, D. 2008, IAUSS, 255, 66
Shirazi, M., & Brinchmann, J. 2012, MNRAS, 421, 1043
Skillman, E. D. 1985, ApJ, 290, 449
Stasińska, G., & Schaerer, D. 1999, A&A, 351, 72
Thuan, T. X., Bauer, F. E., Papaderos, P., & Izotov, Y. I. 2004, ApJ, 606, 213
Thuan, T. X., & Izotov, Y. I. 2005, ApJS, 161, 240
Tumlinson, J., & Shull, J. M. 2000, ApJL, 528, L65
Vílchez, J. M., & Iglesias-Paramo, J. 1998, ApJ, 508, 248
Vink, J. S. 2014, arXiv:1406.4836
Yoon, S.-C., Dierks, A., & Langer, N. 2012, A&A, 542, A113