MASSIVE STAR POPULATIONS IN I ZW 18: A PROBE OF STELLAR EVOLUTION IN THE EARLY UNIVERSE

D. Schaerer $^{1,2}$, D. de Mello $^2$, C. Leitherer $^2$, J. Heldmann $^3$

$^1$ Observatoire Midi-Pyrénées, F-31400 Toulouse, France.
$^2$ STScI, Baltimore, MD 21218, USA.
$^3$ Colgate University, Hamilton, NY 13346, USA.

Abstract

We present a study of the gaseous and stellar emission in I Zw18, the most metal-poor star-forming galaxy known. Archival HST WFPC2 and FOS data have been used to analyze the spatial distribution of $[\text{O III}]$, H$\alpha$, and He II $\lambda$4686. The latter is used to identify Wolf-Rayet stars and to locate nebular He II emission. Most of the He II emission is associated with the NW stellar cluster, displaced from the surrounding shell-like $[\text{O III}]$ and H$\alpha$ emission. We found evidence for He II sources compatible with 5–9 WNL stars and/or compact nebular He II emission as well as residual diffuse emission. New evolutionary tracks and synthesis models at the appropriate metallicity predict a mass limit $M_{\text{WR}} \approx 90 \, M_\odot$ for WR stars to become WN and WC/WO. The observed equivalent widths of the WR lines are in good agreement with an instantaneous burst model with a Salpeter IMF extending up to $M_{\text{up}} \sim 120-150 \, M_\odot$. Our model is also able to fully reproduce the observed equivalent widths of nebular He II emission due to the presence of WC/WO stars. This finding together with the spatial distribution of nebular He II further supports the hypothesis that WR stars are responsible for nebular He II $\lambda$4686 emission in extra-galactic H II regions.

Finally we discuss the implications of our results on stellar mass loss, chemical yields, final stellar masses, and the ionizing flux of starburst galaxies at very low metallicities.

1 Introduction and motivation

The main aims of our work are the following:
• **Probe the evolution of massive stars in low metallicity systems.** Since environments with massive stars at metallicities $Z < 1/10 \, Z_\odot$ are not available in the Local Group we use star-forming regions and super star clusters in BCDs. It is important to constrain the populations of massive stars in different environments, since their evolution is dictated by mass loss whose metallicity dependence is not well known.

As a consequence all predictions related to massive stars depend on the adopted mass loss prescriptions. E.g. chemical yields are $Z$ dependent ([8]), and the P-Cygni lines detected in several high redshift galaxies (e.g. [19]) depend on the mass loss properties.

To constrain the evolution we analyse the Wolf-Rayet (WR) star content since these stars represent bare stellar cores revealed by mass loss. From the WR and O star content we can also derive constraints on the upper mass and the slope of the IMF (cf. [15], [7]).

• **Explain the origin of nebular HeII emission frequently observed in low metallicity extragalactic HII regions.** The nature of this emission remained puzzling until recently (cf. [2] and [15], [16]) and indicates a harder ionizing spectrum than commonly thought.

## 2 Observations of I Zw 18

Signatures of WR stars were detected very recently in I Zw 18 by [4] and [6]. Although their spectra differ considerably they clearly establish the presence of WR stars in the most metal-poor galaxy known. Their discovery raises, however, a few interesting questions, namely: 1) Can the observed WR population be reproduced by stellar evolution models at the metallicity of I Zw 18, and if so what mass loss rates are required? 2) Is the observed nebular He II $\lambda$4686 emission due to WC stars as suggested by [15]? To answer these questions we have analysed HST images of I Zw 18 and calculated new stellar evolution tracks and synthesis models. A detailed account of this work is given in [11].

We used archival HST WFPC2 imaging and FOS spectroscopy (proposal ID 5309, 5434, 6536) to construct continuum free images of H$\alpha$, [O III] $\lambda$5007, and He II $\lambda$4686. Since the expected flux levels in He II $\lambda$4686 are close to the background and the noise level of the detector, careful cosmic ray and hot pixel removal, and background subtraction were done in addition to the standard pipeline processing (see [11]). Several procedures were experimented to construct the continuum free line maps. From this we conclude that our He II $\lambda$4686 map (see Fig. 1) is well-suited to detect any excess He II emission. As a conservative error we adopt 30% for its absolute flux calibration.

The He II map shown in Fig. 1 reveals several compact He II sources centered on the NW cluster of I Zw 18. The significance of the individual pixel detections is as follows: 62 pixels with $> 2 \, \sigma$, 25 with $> 3 \, \sigma$, and 12 with $> 3 \, \sigma$. Residual diffuse emission over a 9.9 arcsec$^2$ region is also found.

From the line flux the most significant sources are either compatible with $\sim 0.5 - 3$ WNL stars (using the line luminosity from [18]) or with very compact nebular sources (similar to the LMC nebula N44C with an angular diameter $\sim 0.03''$; cf. [2]). The spatial analysis of the He II sources, possible thanks to the high resolution of HST, reveals the following: Whereas the He II is centered on the stellar cluster the maximum of H$\alpha$ and [O III] $\lambda$5007 emission is clearly displaced from the cluster in a shell like structure (see [11]). The spatial distribution of He II $\lambda$4686 is also compatible with the ground-based data from [1] and [3] who find a spatial correlation between nebular He II and the WR features, suggestive of a link between the WR stars and nebular He II $\lambda$4686 emission.
HeII

Figure 1: Left: WFPC2 V (F555W) image of I Zw 18. The rectangle delineates the area in the NW region where the continuum-free helium sources were detected. The darkest pixels in the helium map are above the 3σ level. WR, WR?, and WR?? identify helium sources with fluxes equivalent to 3, 0.7, and 0.4-2. WNL stars, respectively. Upper right: Comparison of predicted relative line intensities of the WR bumps (4650 Å: dashed, 5808 Å: dotted) and nebular He II λ4686 (solid) with observations of [6] and [4]. Instantaneous burst model with Salpeter IMF. Lower right: Same as upper panel for equivalent widths. Note the good agreement between model and observations.

3 Comparison with synthesis models

For a quantitative comparison between observations and stellar evolution models we have calculated new evolutionary tracks at \( Z = 1/50 \) \( Z_\odot \) adopting either the high mass loss rates as in [13], or \( \dot{M} \) from the wind momentum - luminosity relation ([5]). Interestingly, for the purpose of the present work, both prescriptions yield (due to the “saturation effect” at high luminosities) the same results: 1) the WR mass limit at \( Z = 0.0004 \) is \( M_{\text{WR}} \sim 90 \) \( M_\odot \), and 2) the models predict both WN and WC/WO stars.

We have used these tracks in the synthesis models of [18] to predict the strength of the WR and nebular emission lines. The results are compared in Fig. 1 (right) to the observations of [6] and [4]. As shown in the upper panel the observed intensity ratios of the WR and nebular He II λ4686 lines are considerably larger than the predictions. This can easily be explained by the spatial offset between these emission features and the Hα emission (see [11]). On the other hand the predicted equivalent widths (lower panel) of the WR lines are in good agreement with the observations. The observed WR population in I Zw 18 can thus well be reproduced with a Salpeter IMF and an upper mass cut-off \( M_{\text{up}} \) of typically 120-150 \( M_\odot \). At the same time the observed nebular He II λ4686 emission (\( W(4686) \sim 2.4 \) Å) is naturally explained by the presence of WC/WO stars as suggested by [13] and [15].

4 Implications

Combining the results of various studies on WR and O stars populations in the Local Group and in young starbursts several conclusions can be drawn. First massive star evolution models
with high mass loss rates (cf. [13]), and/or to a certain extent also additional mixing ([12]), are clearly favored from a variety of studies including: the properties of individual WR stars ([10]), analysis of WR and O star populations in Local Group Galaxies ([10]) and in WR galaxies with $-0.9 \leq [\text{O/H}] \leq 0.2$ ([3], [4], [7], [1]). The present study now extends this result to the galaxy with the lowest metallicity known to date (I Zw 18: $[\text{O/H}] \sim -1.7$).

The effect of metallicity dependent mass loss on pre-SN core masses and stellar yields has been discussed by [8]. If taken at face value the above conclusion implies that compared to [8] the chemical yields of He are even larger and those of CO smaller at low metallicities. In particular observations of the relative WN and WC star populations in WR galaxies which have only recently become available (see [17], [1]) should allow to place constraints on the relative yields of He and CO from massive stars. We also note that the favored high mass loss models lead to final (pre-SN) masses which are generally smaller than the results obtained by [14].

Another implication from our study concerns the far UV spectrum of young galaxies. As can be seen from the sample of low metallicity galaxies (mostly BCD) of Izotov and collaborators, approximately $\sim 70\%$ of their objects show nebular He $\lambda 4686$ emission. This indicates that the majority of low $[\text{O/H}]$ emission line objects have a fairly hard far UV spectrum, which we attribute to the presence of early type stars (cf. above). This finding may prompt a re-examination of the importance of young galaxies to the ionization of QSO absorption line systems and the ionization of the intergalactic medium (cf. [2], [11]).

As illustrated in this work studies on massive star populations in metal poor galaxies and the origin of nebular He $\lambda 4686$ emission provide interesting constraints on stellar evolution in the early universe.

Acknowledgments DS is grateful to the Swiss NSF and the “GdR galaxies” for financial support.

References

[1] Contini T., Schaerer D., Kunth D., Meynet G., 1998, *Astr. Astrophys*. in preparation.
[2] Garnett D.R., Kennicutt R.C., Chu Y.-H., Skillman E.D. 1991, *Astrophys. J*. 373, 458
[3] Izotov Y.I., Thuan T.X. 1998, *Astrophys. J*. 497, 227
[4] Izotov Y.I., Foltz C.B, Green R.F., Guseva N.G., Thuan T.X. 1997, *Astrophys. J*. 487, L37
[5] Lamers H.J.G.L.M., Cassinelli J.P. 1996, in *From Stars to Galaxies*, ASP Conf. Series, Vol. 98, eds. C. Leitherer, U. Fritze-v. Alvensleben, and J. Huchra, 162
[6] Legrand F., Kunth D., Roy J.-R., Mas-Hesse J.M., Walsh J.R. 1997, *Astr. Astrophys*. 326, L17
[7] Leitherer C., 1998, these proceedings
[8] Maeder A., 1992, *Astr. Astrophys*. 264, 105
[9] Maeder A., Conti P. 1994, *Annual Rev. Astron. & Astroph.**. 32, 227
[10] Maeder A., Meynet G. 1994, *Astr. Astrophys*. 287, 803
[11] de Mello D., Schaerer D., Heldmann J., Leitherer C., 1998, *Astrophys. J*. in press
[12] Meynet G., Maeder A., 1997, *Astr. Astrophys*. 321, 465
[13] Meynet G., Maeder A., Schaller G., Schaerer D., Charbonnel C., 1994, *Astr. Astrophys. Suppl. Ser*. 103, 97
[14] Portinari L., Chiosi C., Bressan A., *Astr. Astrophys*. 334, 505
[15] Schaerer, D. 1996, *Astrophys. J*. 467, L17
[16] Schaerer, D. 1997, in *Dwarf Galaxies: Probes for Galaxy Formation and Evolution*, ed. J. Andersen, Highlights of Astronomy, in press
[17] Schaerer D., Contini T., Kunth D., Meynet G., 1996, *Astrophys. J*. 481, L75
[18] Schaerer D., Vacca W.D. 1998, *Astrophys. J*. 497, 618
[19] Steidel C., et al., 1996, *Astrophys. J*. 462, L17