

PopIII-star siblings in IZw18 and metal-poor WR galaxies unveiled from integral field spectroscopy

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Here, we highlight our recent results from the IFS study of Mrk178, *the closest metal-poor WR galaxy*, and of IZw18, *the most metal-poor star-forming galaxy known in the local Universe*. The IFS data of Mrk178 show the importance of aperture effects on the search for WR features, and the extent to which physical variations in the ISM properties can be detected. Our IFS data of IZw18 reveal its entire nebular HeII λ 4686-emitting region, and indicate for the very first time that peculiar, hot (nearly) metal-free ionizing stars (called here *PopIII-star siblings*) might hold the key to the HeII-ionization in IZw18.

1 Introduction

Studying the WR content and radiative feedback from WRs in metal-poor star-forming (SF) galaxies is crucial to test evolutionary models for massive stars at low metallicity (Z), where the disagreement between observations and such models is stronger (e.g., Leitherer et al. 2014). In this context, we have initiated a program to investigate nearby low- Z WR galaxies using integral field spectroscopy (IFS). IFS has many advantages in a study of this kind, in comparison with long-slit spectroscopy (e.g., Kehrig et al. 2008, 2012; Pérez-Montero et al. 2011, 2013). By means of IFS one can locate and find WRs where they were not detected before. Also, IFS is a powerful technique to probe issues related with aperture effects, and allows a more precise spatial correlation between massive stars and nebular properties (e.g., Kehrig et al. 2008, 2013, hereafter K13). As a part of this program, we have obtained new integral field unit (IFU) data of the low- Z galaxies Mrk178 and IZw18, published in K13 and Kehrig et al. (2015, hereafter K15), respectively. Below we summarize the main results from these two articles.

2 IZw18: PopIII-star siblings as the source of HeII-ionization

We performed new IFS observations of IZw18 using the PMAS IFU (Roth et al. 2005) on the 3.5m telescope at CAHA (fig.1; K15). IZw18 is a nearby SF galaxy, well known for its extremely low $Z \sim 1/32 Z_{\odot}$ (e.g., Vílchez & Iglesias-Páramo 1998), and it is considered an excellent local analog of primeval systems. Our IFS data reveal for the first time the entire nebular HeII λ 4686-emitting region (fig.2) and corresponding total HeII-ionizing photon flux [$Q(\text{HeII})_{\text{obs}}$] in IZw18. Narrow HeII emission in SF galaxies has been suggested to be mainly associ-

ated with photoionization from WRs, but WRs cannot satisfactorily explain the HeII-ionization in all cases, particularly at lowest metallicities where HeII emission is observed to be stronger (e.g., Guseva et al. 2000; Kehrig et al. 2004; Shirazi & Brinchmann 2012). Why is studying the formation of HeII emission relevant? HeII emission indicates the presence of high energy photons ($E \geq 54$ eV), and HeII-emitters are apparently more frequent among high-redshift (z) galaxies than for local objects (e.g., Kehrig et al. 2011; Cassata et al. 2013). Narrow HeII emission has been suggested as a good tracer of PopIII-stars (the first very hot metal-free stars) in high- z galaxies (e.g., Schaerer 2003; Pallottini et al. 2015); these stars are believed to have contributed significantly to the reionization of the Universe, a challenging subject in contemporary cosmology. However, the origin of narrow HeII lines remains difficult to understand in many nearby SF galaxies/regions (e.g., Kehrig et al. 2011; Shirazi & Brinchmann 2012). So before interpreting high- z HeII-emitters, it is crucial first to understand the formation of HeII emission at low redshift. IZw18, as the most metal-poor HeII-emitter in the local Universe, is an ideal object to perform this study.

Our observations combined with stellar model predictions point out that conventional excitation sources (e.g. single WRs, shocks, X-ray binaries) cannot convincingly explain the total $Q(\text{HeII})_{\text{obs}}$ derived for IZw18 (e.g., Meynet & Maeder 2005; Crowther & Hadfield 2006; Leitherer et al. 2014). Other mechanisms are probably also at work. If the HeII-ionization in IZw18 is due to stellar sources, these might be peculiar very hot stars. Based on wind models of very massive O stars (Kudritzki 2002), ~ 10 -20 stars with $300 M_{\odot}$ at Z_{IZw18} (or lower, down to $Z \sim 1/100 Z_{\odot}$) can reproduce our total $Q(\text{HeII})_{\text{obs}}$ (see also Szécsi et al. 2015). However, the super-massive star scenario requires a cluster mass much higher than the mass of the IZw18 NW knot

(where the HeII region is located), and it is not hard enough to explain the highest HeII/H β values observed. Also, stellar sources with 300 M_{\odot} are not observed in IZw18 to date. Next, as an approximation of (nearly) metal-free stars in IZw18 – the so-called *PopIII-star siblings* – we compared our observations with models for rotating $Z=0$ stars (Yoon et al. 2012), which reproduce our data better: ~ 8 – 10 of such stars with $M_{\text{ini}}=150 M_{\odot}$ can explain the total $Q(\text{HeII})_{\text{obs}}$ and the highest HeII/H β values observed. The PopIII-star sibling scenario, invoked for the first time in IZw18 by K15, goes in line with the reported metal-free gas pockets in the HI envelope near the IZw18 NW knot (Leboutteiller et al. 2013). These gas pockets could provide the raw material for making such *PopIII-star siblings*.

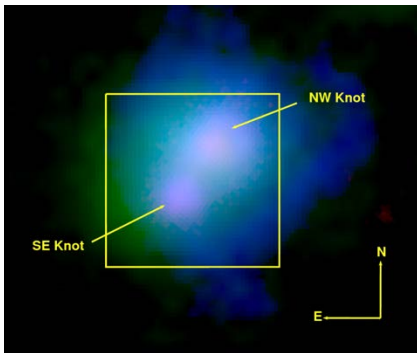


Fig. 1: Color-composite image of IZw18. The box represents the FOV ($16'' \times 16''$) of the PMAS IFU over the galaxy main body which hosts the NW and SE knots (K15).

3 Mrk178

In K13 we present the first optical IFS study of Mrk178, the closest metal-poor WR HII galaxy. IFS data of Mrk 178 were obtained with the INTEGRAL IFU at the 4.2m WHT. In this work we examine the spatial correlation between its WRs and the neighbouring ionized ISM. The strength of the broad WR features and its low metallicity ($\sim 1/10 Z_{\odot}$) make Mrk178 an intriguing object. We have detected the blue and red WR bumps in different locations across the FOV ($\sim 300 \text{ pc} \times 230 \text{ pc}$) in Mrk178 (fig.3). The study of the WR content has been extended, for the first time, beyond its brightest SF knot (knot B in fig.3) uncovering new WR star clusters (knots A and C in fig.3). Using SMC/LMC template WRs (Crowther & Hadfield 2006), we empirically estimate a minimum of ~ 20 WRs in our Mrk178 FOV, which is already higher than that currently found in the literature. Regarding the ISM abundances, localized N and He enrichment, spatially correlated with WRs from knot B, is suggested by our analysis. Neb-

ular HeII $\lambda 4686$ emission is shown to be spatially extended reaching well beyond the location of the WRs (fig.4). Shock ionization and X-ray binaries are unlikely to be significant ionizing mechanisms since Mrk178 is not detected in X-rays. The main excitation source of HeII in Mrk178 is still unknown.

From SDSS spectra of metal-poor WR galaxies, we found a too high $\text{EW}(\text{WR bump})/\text{EW}(\text{H}\beta)$ value for Mrk178, which is the most deviant point in the sample (fig.4). Using our IFU data, we showed that this curious behaviour is caused by aperture effects, which actually affect, to some degree, the $\text{EW}(\text{WR bump})$ measurements for all galaxies in Fig.4. Also, we demonstrated that using too large an aperture, the chance of detecting WR features decreases, and that WR signatures can escape detection depending on the distance of the object and on the aperture size. Thus, WR galaxy samples constructed on single fiber/long-slit spectrum basis may be biased.

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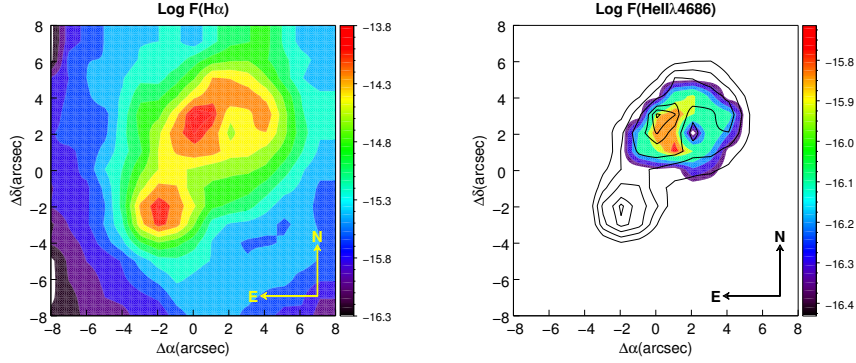


Fig. 2: IZw18: intensity maps of H α (*left panel*) and nebular HeII λ 4686 (*right panel*) in logarithmic scale; fluxes are in units of $\text{erg s}^{-1} \text{cm}^{-2}$. The maps are presented as color-filled contour plots (K15).

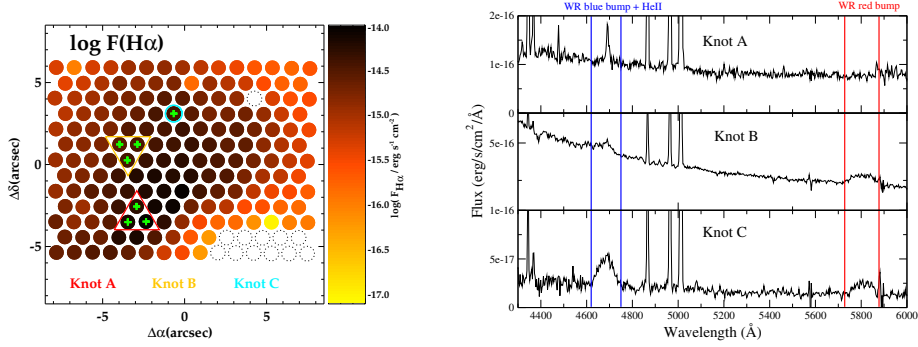


Fig. 3: Mrk178: intensity map of H α emission line (*left panel*) and integrated spectrum for the 3 knots in which WR features are detected (*right panel*). The spectral range for both blue and red WR bumps are marked (K13).

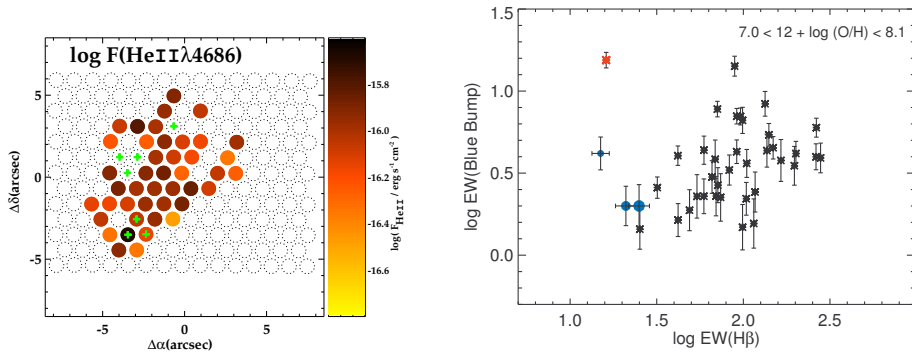


Fig. 4: *Left panel:* map of nebular HeII λ 4686 line; spaxels where we detect WR features are marked with green crosses. *Right panel:* EW(WR blue bump) vs EW(H β). Asterisks show values from SDSS DR7 for metal-poor WR galaxies; the red one represents Mrk178. The three blue circles, from the smallest to the biggest one, represent the 5", 7" and 10" diameter apertures from our IFU data centered at the SDSS fiber of Mrk178 (K13).

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Dany Vanbeveren: I suggest that you have a close look at the papers Van Bever and Vanbeveren (2003) or Eldridge et al. (2008). Both papers are cited by Brinchmann et al. (2008)

Carolina Kehrig: IZw18, the galaxy presented in Kehrig et al. (2015), has a metallicity of about 1/10 SMC-metallicity. The papers that you mention do not show model predictions at the metallicity of IZw18.

Wolf-Rainer Hamann: You told that more than 100 WRs would be needed to provide the He-ionizing photons. This might depend a lot on the models and their parameters. Which one did you use?

Carolina Kehrig: We compared the observations of IZw18 with the HeII-ionizing flux expected from WR stellar models which mimic single WR stars close to the conditions in IZw18. These model predictions are given by Crowther & Hadfield (2006).

Norbert Langer: It seems unlikely that we have metal-free gas pockets at low redshift. Perhaps, very metal-poor stars could also explain the HeII photons of IZw18 ?

Carolina Kehrig: Yes, I agree that it is hard to imagine metal-free gas at low redshift. But first it is important to remember that there are still many uncertainties regarding the fate of metals released by massive star winds and SNRs in H II regions. Additionally, the processes of metal dispersal and mixing

are still very difficult to model. Please, let me clarify something else here. We are not saying that metal-free ionizing stars are present in IZw18. In fact, the existence of metal-free ionizing stars is not observationally confirmed in any galaxy yet. What we did was to demonstrate that standard models for metal-poor massive/WR stars cannot reproduce the observations of IZw18. Based on current stellar models, the only way to explain the He II ionization budget observed in IZw18 using hot stars with 1/50th (or lower) Z_{\odot} requires super-massive stars ($\sim 300 M_{\odot}$). However, such very massive stars are not observed in IZw18 to date. Also the super-massive star scenario would imply a cluster mass much higher than the mass of the IZw18 NW knot (where the He II region is located), and this scenario does not explain the highest He II/H β values observed. In other words, our data challenge current models for metal-poor massive stars. We find that the models for rotating $Z=0$ stars do a better job in reproducing the data, and the presence of (nearly) metal-free gas pockets in IZw18 is empirically confirmed. So, the raw material for making such stars is there. In order to say anything else about the popIII-like stars scenario (e.g. how these stars have formed, how they reach the NW cluster), one needs to compute photoionization models and simulations which must take into account the detailed geometry of the He II region, the mass of the metal-free gas pockets, etc.

