WOLF–RAYET GALAXIES AND MASSIVE STELLAR POPULATION

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On the basis of up-to-date models we analyze the results of investigation of the large sample a newly discovered WR galaxies ($\sim$40 galaxies) obtained with various big telescopes. There are 10 galaxies in this sample with heavy element abundances less $1/10\ Z_{\odot}$ [4] and some galaxies are with abundances more than solar [13]. The statistics of massive stellar population including WR population has been analysed. The metallicity effects on the determination of $N(\mathrm{WR})/N(\mathrm{O+WR})$ and $N(\mathrm{WC})/N(\mathrm{WN})$ ratio, constraints on the initial mass function, the age and duration of star formation bursts as well as the origin of He II λ 468.6 nm emission line in WR galaxies are discussed.

INTRODUCTION

Wolf-Rayet galaxies show broad stellar emission lines in the integrated spectra of the whole galaxy or its part produced by all Wolf-Rayet stars in unresolved stellar clusters. This definition of Wolf-Rayet galaxy distinguishes a distant Wolf-Rayet galaxies from nearby galaxies, where Wolf-Rayet stars can be studied individually. The Wolf-Rayet galaxies are undergoing star formation now or very recently. Therefore, most massive O stars evolve to the Wolf-Rayet stage. The age of Wolf-Rayet stars is a few million years. Hence, the existence of Wolf-Rayet stars in these galaxies means very young age of star-forming regions.

Different parameters of WR populations in WR galaxies are very strongly dependent on the metallicity. However, the observational data and models are well studied only for the regions with metallicity close to solar one. We increase the range of metallicity and study the properties of Wolf-Rayet galaxies with both extremely small and extremely large metallicities.

From the observations of Wolf-Rayet galaxies and up-to-date models we derived the number of Wolf-Rayet stars, the number of all massive stars, the number of different subtypes of Wolf-Rayet stars (nitrogen and carbon sequences), and obtained the constraints on the parameters of IMF (slope and upper limit), the age and duration of the burst of star formation.

WOLF–RAYET GALAXIES

In 1999 Schaerer, Contini and Pindao [12] presented a new catalog of 139 Wolf-Rayet galaxies compiled from all literature data, including 39 Wolf-Rayet galaxies which are taken from original catalog of Guseva, Izotov and Thuan [4]. The majority galaxies in this catalog are newly discovered Wolf-Rayet galaxies. All spectra in [4] were obtained with high signal-to-noise ratio at the Kitt Peak National Observatory 4-m and 2.1-m telescopes and were performed in the same way, therefore, we detect Wolf-Rayet features not only in the blue bump, but also in the rarely observed so-called red bump. The spectrum of I Zw 18 was obtained with the Multiple Mirror Telescope [6]. The spectrum of SBS 0335-052 was obtained with W. M. Keck telescope [5]. The examples of two Wolf-Rayet galaxies SBS 1130+495 (Mrk 178) and SBS 1036-069 (Mrk 1259) with oxygen abundance $12+\log(\mathrm{O/H})=7.82$ and 8.95 ($Z=1/12\,Z_{\odot}$ and $Z\sim Z_{\odot}$, respectively) are shown in Fig. 1.

In 1991 Smith [15] showed that the WR features are observed only in galaxies with oxygen abundances $12+\log(\mathrm{O/H})$ more than 7.9 (solar oxygen abundance $12+\log(\mathrm{O/H})=8.90$ [3]). The decrease of the blue bump luminosity with decreasing metallicity is expected from massive stellar evolution models of Maeder [9], Meynet [10], Schaerer and Vacca [14]. These models predict Wolf-Rayet features at low metallicities which are below the detectability limit.

The earlier observations of Wolf-Rayet galaxies had in fact no galaxies with abundance less 7.9. In this connection the discovery of the WR features in the most metal-deficient galaxies I Zw 18 (metallicity is $1/50\,Z_{\odot}$) in 1997 independently by Izotov *et al.* [6] and by Legrand *et al.* [8] was especially surprising. Wolf-Rayet features in the spectrum of second most metal-deficient galaxy SBS 0335-052 (metallicity is $1/40\,Z_{\odot}$) have been also revealed [5] (Fig. 2).

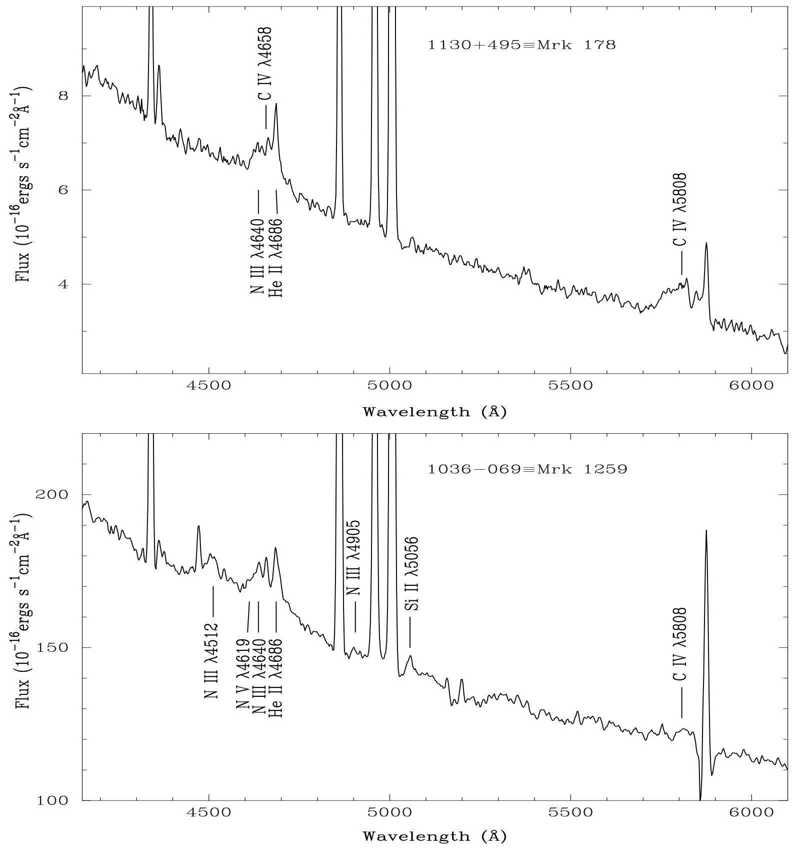

Figure 1: The 4-m and 2.1-m Kitt Peak telescopes spectra of the galaxies Mrk 178 and Mrk 1259 with Wolf-Rayet features in the blue and red bumps [4]

The data of new sample of WR galaxies [4] confirm the dependences of blue bump luminosity and number ratio of WR stars to all massive stars on oxygen abundance. The luminosity of blue bump and the fraction of Wolf-Rayet stars relative to other massive stars increases with increasing metallicity in agreement with predictions of evolutionary synthesis models [9, 10].

The dependence of the WC-to-WN star number ratio on oxygen abundance for the low-metallicity WR galaxies can be quite well explained in terms of the bursting nature of the star formation. The dependence of the N(WR)/N(O+WR) ratio and the equivalent widths of the blue and red bumps as a function of the age of an instantaneous burst is a strong function of the heavy element mass fraction Z and has a good general agreement with the theoretical predictions of evolutionary synthesis models by [14] with Salpeter slope of initial mass function and upper mass limit 120 $M_\odot$. However, the agreement is not so good for the most metal-deficient galaxies. It is likely that the disagreement comes from the different properties of Wolf-Rayet stars at low metallicities as compared to those in our Galaxy and Local Group galaxies. We suspect that the luminosity of single WCE star in the blue and red bumps at low metallicity are $\sim$ 2–4 times larger than those adopted in models. Note that observational data for single Wolf-Rayet stars are not available at such low metallicities.

The observations of Wolf-Rayet galaxies with highly super solar metallicities (2–4 times larger than solar) are well reproduced by models with $Z = Z_\odot$, Salpeter slope of initial mass function and upper mass limit 120 $M_\odot$, assuming extended burst of star formation with duration 4–10 Myr seen at ages of 7–15 Myr as indicated by EW(H$_\beta$) [13]. This naturally explains both the observed Wolf-Rayet populations and the presence of red supergiants (indicated by TiO bands) simultaneously in the same spectra of Wolf-Rayet galaxies. A very good fit between observations and models is obtained to the overall spectral energy distribution. This requires, however, less extinction for the stellar continuum than for the gas. For the metal-rich WR galaxies we put a lower limit on the value of upper limit of initial mass function M_{up} from the intensities of the WR lines. Our data compatible with a large upper mass cut-off $M_{up} \leq 30$ $M_\odot$ for a Salpeter slope. We also find similar values $M_{up} \sim$ 30–50 $M_\odot$ from comparison of H$_\beta$ equivalent widths in metal-rich H II regions with models [13].

So far the origin of strong nebular He II λ4686 emission line is not yet understood and this problem is often discussed. Its intensity is several orders of magnitude larger than theoretical values predicted by models of

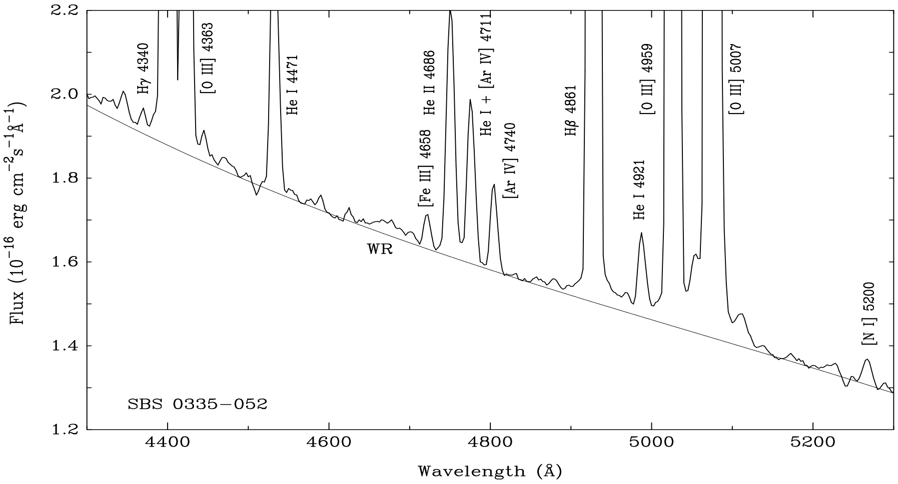

Figure 2: The 10-m W. M. Keck telescope spectrum of the second most metal deficient blue compact galaxy SBS 0335-052. The broad Wolf-Rayet feature is marked

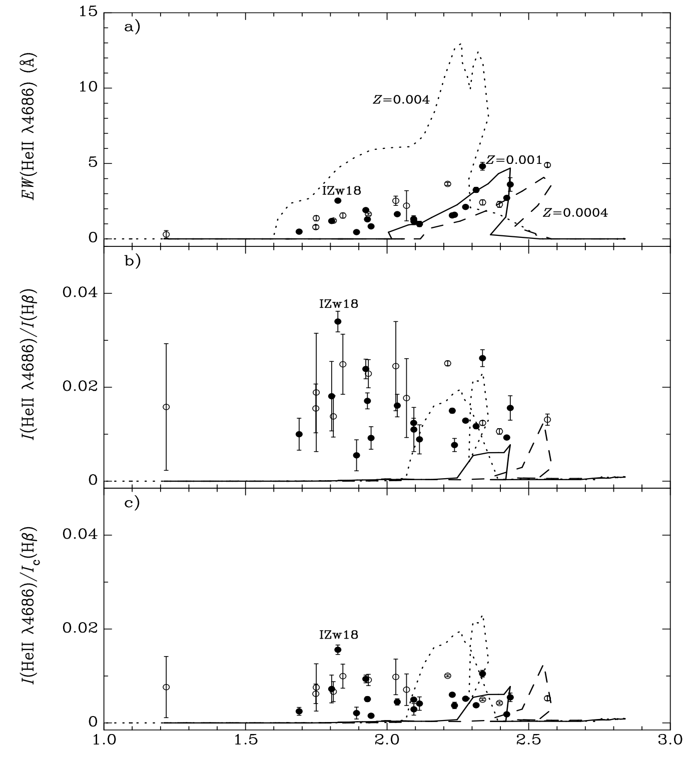

Figure 3: (a) Equivalent width of the He II λ4686 nebular emission line vs equivalent width of the H_β emission line for the data from [4]; (b) Intensity of the He II λ4686 nebular emission line relative to H_β, the latter not being corrected for aperture, vs equivalent width of the H_β emission line, (c) Intensity of the He II λ4686 nebular emission line relative to aperture-corrected H_β, vs equivalent width of the H_β emission line. The lines show the theoretical predictions for the heavy element mass fractions Z = 0.004 (dotted), 0.001 (solid) and 0.0004 (dashed), respectively [14]. H II regions with detected and non-detected WR features shown by filled and open circles, respectively

photoionized H II regions of Stasińska [16]. It was suggested by Bergeron [1] that the He II emission in dwarf emission-line galaxies could arise in the atmospheres of Of stars. Garnett *et al.* [2] examined several possible excitation mechanisms, concluding that the radiation field associated with star-forming regions can be harder than previously thought and suggested that radiative shocks in star-forming regions can produce relatively strong He II emission under certain conditions. Schaerer [11] predicted a strong nebular He II emission due to a significant fraction of WC stars for the WR galaxies with heavy element mass fraction $Z_{\odot}/5 \leq \mathrm{Z} \leq Z_{\odot}$ in the early Wolf-Rayet phases of the burst.

We gathered a sample of 30 galaxies with nebular He II emission line from our total sample of BCGs [4, 7]. Fig. 3 displays the dependence of the equivalent width and intensity of the nebular He II λ4686 emission line as a function of the H_{β} equivalent width. Theoretical predictions are also shown for stellar populations with Z = 0.0004, 0.001, 0.004 by dashed, solid and dotted lines, respectively [14]. Taking into account the model assumptions and observational uncertainties we find a satisfactory general agreement between models and our observations. The points representing galaxies with detected (filled circles) and non-detected Wolf-Rayet features (open circles) are mixed in this Figure. This implies that WR stars are probably not the sole origin of He II λ4686 emission in star-forming regions. Other mechanisms such as for example radiative shocks need to account for He II λ4686 nebular emission.

The high quality observational data of WR galaxies are important for the testing of stellar evolution models for most massive stars. We found a good general agreement between our observational data obtained with various big telescopes (with high signal-to-noise ratio) [4, 13] and predictions of present-day evolutionary synthesis models [14].

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