THE MASSIVE STELLAR POPULATION IN THE DWARF STARBURST GALAXIES

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ABSTRACT. The analysis of the long-slit spectral observations of 39 Wolf-Rayet (WR) galaxies with heavy element mass fraction ranging over 2 orders of magnitudes from $Z_\odot/50$ to $2Z_\odot$ are presented. We derive the number of O stars from the luminosity of the Hβ emission line, the number of early carbon Wolf-Rayet stars (WCE) from the luminosity of the red bump (broad CIV λ5808 emission) and the number of late nitrogen Wolf-Rayet stars (WNL) from the luminosity of the blue bump (broad emission near λ4650). We identified some of weak WR emission lines, most often the N III λ4512 and Si III λ4565 lines, which have very rarely or never been seen and discussed before in WR galaxies. A new technique for deriving the number of WNL stars (WN7-WN8) from the N III λ4512 and the number of WN9-WN11 from Si III λ4565 emission lines has been proposed. This technique is potentially more precise than the blue bump method because it does not suffer from contamination of WCE and early WN (WNE) stars and nebular gaseous emission. We find that the fraction of WR stars relative to all massive stars increases with increasing metallicity, in agreement with predictions of evolutionary synthesis models. The relative number ratios N(WC)/N(WN) and the equivalent widths of the blue and red bumps derived from observations are also in satisfactory agreement with theoretical predictions, except for the most metal-deficient WR galaxies. A possible source of disagreement is too low a line emission luminosity adopted for a single WCE star in low-metallicity models.

Key words: Blue compact galaxies: starburst galaxies: Wolf-Rayet stars: Wolf-Rayet galaxies: HII regions: galaxies abundance.

1. Introduction

The dwarf galaxies with starburst activity (so-called blue compact galaxies) have high star formation rate during short episodes. Such burst of star formation results in a large population of hot massive stars. The total number of O stars responsible for the blue continua and strong narrow emission lines in these galaxies can reach 10^2-10^5 (Kunth & Sargent 1983; Vacca & Conti 1992). The most massive stars evolve through the WR phase.

Galaxies with Wolf-Rayet star features in their spectra have long been known, beginning with 1976 (Allen, Wright & Goss, 1976). Individual WR stars cannot be usually observed as single stars in distant galaxies. They have been observed only in our Galaxy and in some members of the Local Group. WR stars in more distant objects are detected indirectly by observing integrated galaxy spectra.

Osterbrock & Cohen (1982) and Conti (1991) introduced the concept of WR galaxies, defining them to be those galaxies which show broad stellar emission lines in their integrated spectra mainly in a broad emission excess in the blue region near λ4650, so called "blue bump".

More than 130 WR galaxies are now known (Conti 1999; Schaerer, Contini & Pindao 1999). We present a uniform, high signal-to-noise sample of WR galaxies, selected from a large sample of a low-metallicity blue compact galaxies. Our main goal is to search for WR (WN and WC) stars in these galaxies, compare the relative number of WR stars to all massive stars with predictions from evolutionary synthesis models and test massive stellar evolution models in a wide range of metallicities.

2. Results of observations and comparison with evolutionary synthesis models

2.1. Observations

We analyze long-slit spectral observations of 39 Wolf-Rayet (WR) galaxies. These spectra were obtained at the Kitt Peak National Observatory (KPNO) 4m and 2.1m telescopes. Recently the WR stars were discovered in 2 galaxies with extremely low metallicity, I Zw 18 ($Z = Z_\odot/50$) (Izotov et al.(1997) and Legrand et al. (1997)) and SBS 0335-052 ($Z = Z_\odot/40$) (Izotov et al. (1999). The spectrum of I Zw 18 was obtained with the Multiple Mirror Telescope (Izotov et al. 1997). The spectrum of SBS 0335-052 was obtained with the Keck telescope (Izotov et al. 1999a). All observations and data reduction were performed in the same way with the IRAF software package.

While some of these objects are known to contain WR stars from previous studies, the majority are newly discovered WR galaxies.

2.2. Wolf-Rayet stellar population

All spectra in our sample have high signal-to-noise ratio and therefore allow to detect WR features not only in the blue region, but also in the rarely observed C IV λ5808 region, so-called “red bump”. The broad WR emission in the blue region of the spectrum at λ4650 (the blue bump), an unresolved blend of N V λ4605, 4620, N III λ4634, 4640, C III λ4650, C IV λ4658 and He II λ4686 emission lines, is present in 37 galaxies and is suspected in 2 more. The red bump mainly produced by the emission of broad C IV λ5808 is detected in 30 galaxies. The WR population in the majority of our galaxies is dominated by late WN and early WC stars. However, a nonnegligible population of early WN stars can be present in the highest-metallicity galaxies in our sample.

We detected also several new lines in the spectra some of our WR galaxies which have rarely or never been seen before in the spectra of WR galaxies. The N III λ4512 and Si III λ4565 lines are most often present and they are tracers of WN7-WN8 and WN9-WN11 stars respectively. These features have been detected in particular in the most metal-deficient blue compact galaxy known, I Zw 18 (Izotov et al. 1997). Those new line identifications constitute one of the most important results of our work. We revealed C III λ5696 in 3 of our galaxies. This emission line is seen mainly in late-type WC stars (WC7-WC9). In some of our galaxy we detected C II λ4267 emission line, which are seen only in the spectra of central stars of planetary nebular and are classified as [WC10]-[WC12] (e.g. Leuenhagen &Hamann, 1994, 1998 and Leuenhagen, Hamann & Jeffery, 1996).

We derive the number of late nitrogen Wolf-Rayet stars (represented by WN7 stars) from the luminosity of the blue bump, the number of early carbon Wolf-Rayet stars (represented by WC4) from the luminosities of the red bump, and the number of O stars from the luminosity of the Hβ emission line.

We also propose a new technique for deriving the numbers of WNL stars (WN7-WN8) from the fluxes of the N III λ4512 emission line and the number of WN9-WN11 from the fluxes of the Si III λ4565 emission line. This technique is potentially more precise than the blue bump method because it does not suffer from contamination of WCE and WNE stars and nebular gaseous emission. All three determinations of WNL stars (blue bump, N III λ4512 and Si III λ4565) well agree. However, a more precise calibration of the N III λ4512 and Si III λ4565 emission lines in WR stars are necessary.

2.2. Comparison with evolutionary synthesis models

The luminosity of the blue bump decreases with decreasing metallicity. This decrease is expected from massive stellar evolution models (Maeder 1991; Meynet 1995; Schaerer & Vacca 1998). The earlier observations of WR galaxies had no galaxies with abundance less 7.9. A possible exception was the galaxy Zw 0855+06, although there was some controversy about its oxygen abundance (from 7.72 to 8.40) (Vacca & Conti, 1992; Kunth & Joubert, 1985).

The discovery of WR stars in the most metal-deficient galaxies I Zw 18 ($Z_\odot$/50, Izotov et al. 1997; Legrand et al. 1997) and SBS 0335–052 ($Z_\odot$/40, Izotov et al. 1999a) implies that the luminosity of the blue bump likely becomes not equal to zero for these low metallicities, as predicted by evolutionary synthesis models.

Good general agreement is found between the relative numbers of WR stars N(WR)/N(O+WR) infered from observations and those predicted by evolutionary systhesis models (N(WR)=N(WN)+N(WC)). The relative numbers of WR stars decrease with decreasing metallicity in the whole metallicity range ($Z_\odot$/50 - $2Z_\odot$), in agreement with predictions of massive stellar evolution models with enhanced stellar wind (Maeder & Meynet 1994).

The relative numbers N(WC) / N(WN) of WR stars of different subtypes in the galaxies of our sample can be explained by the bursting nature of star formation and are in general good agreement with predictions of evolutionary synthesis models by Schaerer & Vacca 1998. The N(WC) / N(WN) ratio derived for the galaxies in our sample is very different from that expected in the case of continuous star formation as derived empirically by observations of individual WR stars (Massey & Johnson, 1998) in the Local Group galaxies.

The relative numbers N(WR) / N(O+WR) and observed equivalent widths of the blue and red bumps also compare favorably with predictions of evolutionary synthesis models by Schaerer & Vacca 1998 for metallicities larger than $\sim 1/10$ solar. However, the agreement is not so good for galaxies at the low-metallicity end, where N(WC) / N(WN), EW(λ4650) and EW(λ5808) derived from observations are several times larger compared to model predictions. Part of the disagreement may come from the poor statistics of WR stars in these low-metalicity WR galaxies. In the case of I Zw 18 ($Z_\odot$/50) however, the difference between observations and models may be explained by too low single WCE star line luminosities adopted in the Schaere & Vacca 1998 models, or by an additional contribution by WR stars in binaries. In any case high signal-to-noise ratio two-dimensional spectroscopic mapping necessary to exclude the possibility that we are observing (Izotov et al. 1997) in I Zw 18 a region with a locally enhanced number of WCE stars.

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