Astrophysics and Space Science
DOI 10.1007/s●●●●●-●●●-●●●●-●

Interactions and star formation activity in Wolf-Rayet galaxies

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Abstract We present the main results of the PhD Thesis carried out by López-Sánchez (2006), in which a detailed morphological, photometrical and spectroscopical analysis of a sample of 20 Wolf-Rayet (WR) galaxies was realized. The main aims are the study of the star formation and O and WR stellar populations in these galaxies and the role that interactions between low surface companion objects have in the triggering of the bursts. We analyze the morphology, stellar populations, physical conditions, chemical abundances and kinematics of the ionized gas, as well as the star-formation activity of each system.

1 Introduction

WR galaxies are a subtype of H II galaxies whose integrated spectra show broad emission lines attributed to WR stars, indicating the presence of an important population of massive stars and the youth of the starburst. Studying a sample of WR galaxies, Méndez (1999) and Méndez & Esteban (2000) suggested that interactions with or between dwarf objects could be the main star formation triggering mechanism in dwarf galaxies and noted that the interacting and/or merging nature of WR galaxies can be detected only when deep and high-resolution images and spectra are available. We have performed a detailed analysis of a sample of 20 of these objects extracted from the latest catalogue of WR galaxies (Schaerer et al. 1999) combining deep optical and near-infrared (NIR) broad band and Hα imaging together with optical spectroscopy data. Additional X-ray, far-infrared (FIR) and radio data were compiled from literature. An example of this analysis is found in our detailed study of the star formation activity and stellar populations in the starburst galaxy IRAS 08339+6517 (López-Sánchez et al. 2006).

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2 Optical and NIR imaging

Deep and high spatial resolution imagery in optical and NIR broad band filters have been used to study the morphology of the stellar component of the galaxies, looking for morphological features that reveal interaction processes with external galaxies or low surface brightness objects. In Figure 1 we show false color images of 6 galaxies of our sample. The quality of the data has allowed to detect faint features surrounding the galaxies, including tails (i.e, IRAS 08208+2816 and Arp 252, see Figure 1), independent dwarf galaxies [i.e., Mkn 1087 (López-Sánchez et al. 2004b)], mergers [i.e. HCG 31 (López-Sánchez et al. 2004a)] and candidate to tidal dwarf galaxies (TDGs) and arcs [i.e., IRAS 08339+6517 (López-Sánchez et al. 2006)]. The photometric analysis of the galaxies and the use of population synthesis models as STARBURTS99 (Leitherer et al. 1999) and PEGASE.2 (Fioc & Rocca-Volmerange 1997) has permitted to analyze their colors, stellar populations and the age of the last star-forming burst.

3 Hα imaging

Deep continuum-subtracted Hα images have been used to know the distribution and intensity of the ionized gas throughout the galaxies. The data have been also used to estimate the Hα luminosity, the number of ionizing stars, the mass of the ionized gas and the star formation rate (SFR) of each burst. The SFR derived from Hα data is compared with that obtained using other methods (FIR or 1.4 GHz luminosities).

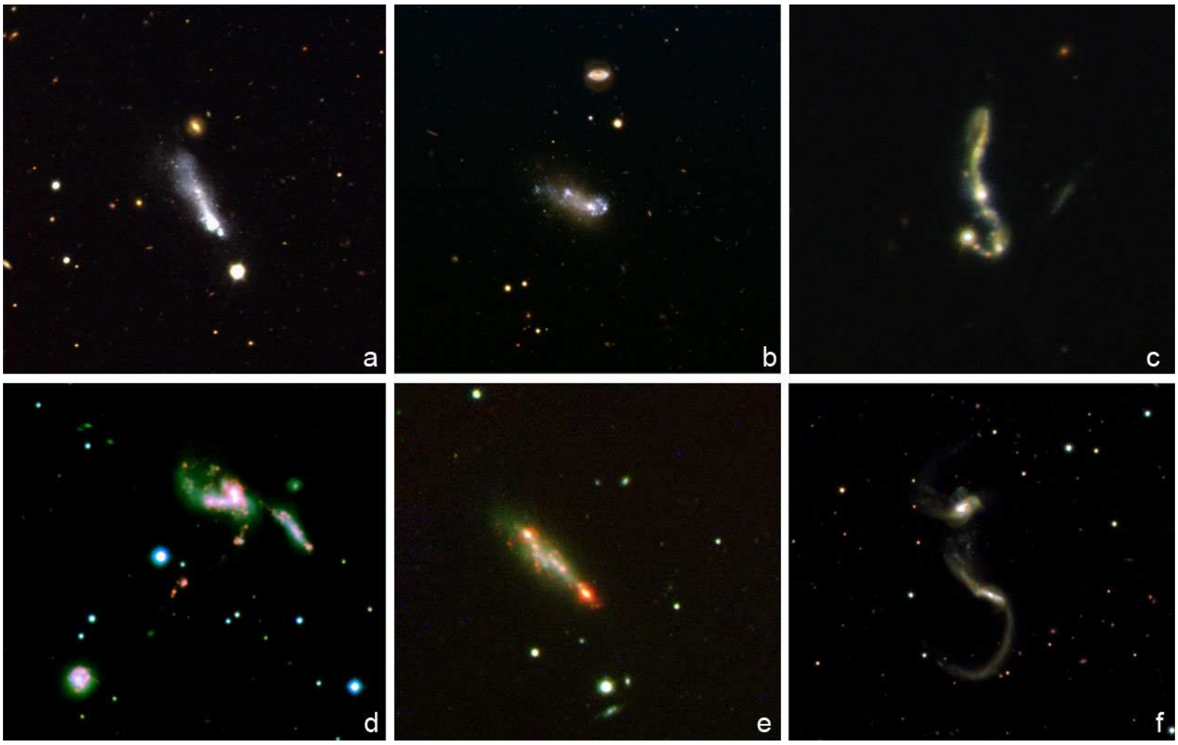

Fig. 1 False color images of six of the WR galaxies analyzed. (a) SBS 1415+437 combining images in B (blue), V (green) and R (red) filters. (b) SBS 1054+365 using $U + B + V$. (c) IRAS 08208+2816 using $U + B + V$. (d) HCG 31 using $V + R + \mathrm{H}\alpha$. (e) SBS 1319+579 using $B + R + \mathrm{H}\alpha$. (f) Arp 252 using $U + B + R$

4 Intermediate resolution spectra

Long slit spectroscopy have been used to study the physical conditions (electron density and temperature, reddening, ionization nature), the chemistry of the gas (chemical abundances of He, O, N, S, Ne, Ar, Fe, Cl) and the kinematics of the ionized gas, as well as the massive star population content and its spatial location in each galaxy. The metallicity of each galaxy has be estimated by the direct method (assuming that electron temperature is known) and by the so-called empirical calibrations.

In Figure 2 we show our deep spectrum of the BCDG POX 4, showing the emission features that reveal the presence of WR stars (the so-called *WR bump* and the He II emission line at λ4686). Our study also led to disentangle the tidal/pre-existing nature of the companion objects surrounding the main galaxies. For example, the oxygen abundance of object NE in Mkn 1199 is 12+log(O/H)=8.46, whereas its center has 8.75, confirming that NE is an external galaxy in interaction with it. This interaction triggers star-formation activity in the external zone of Mkn 1199.

The kinematics of the ionized gas was studied via the analysis of emission line profiles using the 2D spectra. In objects in which solid-body rotation is found, the Keplerian mass have been estimated. Sometimes, prominent tidal tails [i.e. HCG 31 (López-Sánchez et al. 2004a), Mkn 1087 (López-Sánchez et al. 2004b) and the evident case of IRAS 08208+2816] or outflows (Tol 9) have been detected.

5 Interactions and star formation in galaxy groups

Specially interesting are the cases of the groups of galaxies HCG 31 (López-Sánchez et al. 2004a) and Mkn 1087 (López-Sánchez et al. 2004b), where interactions involving more than two objects are needed to explain the tails, bridges, mergers and TDGs observed in them. We find that member F in HCG 31 hosts the youngest starburst of the group ($\sim$2.5 Myr), showing a substantial population of WR stars and, like member E, seems to be a TDG formed from material stripped from the brightest galaxy of the group.

On the contrary, one nearby dwarf companion object located at the north of Mkn 1087 is not a TDG but an independent dwarf galaxy that is in interaction with it. A nearby encounter between them created a long tidal tail. However, other surrounding objects seem to be TDGs. Mkn 1087 can be classified as a low-z Luminous

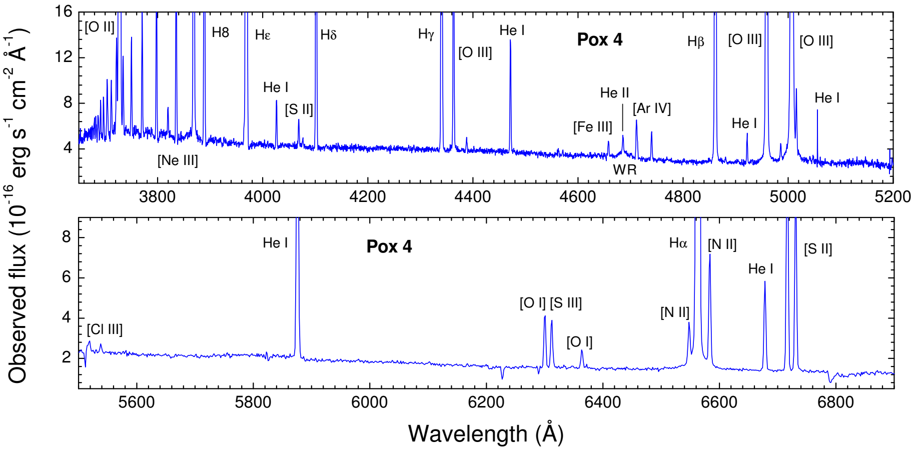

Fig. 2 Redshift-corrected spectrum of POX 4 obtained with ISIS spectrograph at 4.2m WHT. The most important emission lines are labeled. Note the He II emission line at λ4686, indicating the presence of Wolf-Rayet stars.

Compact Blue Galaxy (LCBG), rare objects in the local Universe but common at high redshift. LCBGs are especially interesting for studies of galaxies evolution and formation because they could be the equivalent of the high-z Lyman-break galaxies in the local universe Erb et al. (2003).

6 The localized chemical pollution in NGC 5253

One of our main goals is the detection of the weak O II and C II recombination lines in our deep VLT spectra of the dwarf galaxy NGC 5253, the first time reported in a starburst (López-Sánchez et al. 2007). The ionic abundances derived from the recombination lines are from 0.20 to 0.40 dex higher than those calculed from collision excited lines, in agreement with the result found in other Galactic and extragalactic H II regions. This conclusion suggests that temperature fluctuations may be present in the ionized gas of this galaxy. Furthermore, we detect a localized nitrogen enrichment in two of the central starburst of the galaxy, an well as a possible slight helium pollution in the same zones. The enrichment pattern completely agrees with that expected by the pollution of the winds of massive stars in the WR phase. The amount of enriched material needed to produce the observed overabundance is consistent with the mass lost by the number of WR stars estimated in the starbursts.

7 Wolf-Rayet features

We detect the so-called blue WR bump (around He II λ4686) in 16 of the galaxies of our sample, but sometimes detections are very weak. Although the galaxy IRAS 08339+6517 was not catalogued so far as WR galaxy, our observations suggest that this sort of massive stars is presented in its central burst (López-Sánchez et al. 2006). The He II λ4686 emission line is unambiguously detected only in five objects (HCG 31 F1 & F2, POX 4, SBS 0948+532 and SBS 1415+437C). Surprising, the so-called red WR bump (around C IV λ5808, emission line from WC stars) is detected in none objects, although Guseva, Izotov & Thuan (2000) found it in the nine galaxies that we have also analyzed. The no detection of the red WR bump could be explained because WC stars are hardly formed in low metallicity environments (the majority of our objects lie in this range), as evolutionary synthesis models predict (Schaerer & Vacca 1998; Leitherer et al. 1999) and observations suggest (Fernandes et al. 2004).

As it can be seen in Figure 3, the WR/(WR+O) ratio for a given metallicity and W(Hβ) is systematically lower that the values expected from the predictions given by Schaerer & Vacca (1998) theoretical models. This difference is even higher when we compare with the WR/(WR+O) ratio given by the last version of STARBURST 99 Leitherer et al. (1999) models. We do not find any relation between the WR/(WR+O) and the oxygen abundance, but we should expect an increasing of the number of WR stars with increasing metallicity because of the decreasing of the minimum mass that a massive star needs to reach the WR phase. Aperture effects and/or the position of the slit are probably playing a fundamental role in the detection of the WR features.

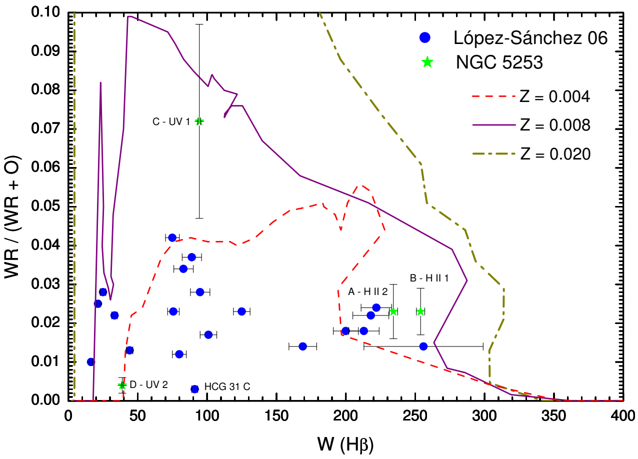

Fig. 3 WR/(WR+O) ratio vs. $W(\mathrm{H}\alpha)$ for Schaerer & Vacca (1998) WR models compared with our observational values. Except for data of objects belonging to NGC 5253 (López-Sánchez et al. 2007), errors in the vertical axis have not been included

8 Global properties

We have performed a global analysis of our sample of 20 Wolf-Rayet galaxies. It is the more complete and exhaustive data set of this kind of galaxies, involving multiwavelength results and being every one analyzed following the same procedures. The main global results are the following:

1. Photometric data have been corrected for both extinction and nebular emission using our spectroscopic values. A good agreement between our optical and NIR colors and theoretical models is found; small discrepancies are explained by the existence of several (young and older) stellar populations.
2. Physical and chemical properties are in agreement with both previous observations and models of chemical evolution of galaxies. We have compared abundances obtained by the direct method with those obtained for several empirical calibrations: Pilyugin (2001a,b) seems to give similar results whereas calibrations based in photoionization models such as McGaugh (1994) and Kewley & Dopita (2002) give abundances higher (∼0.20 dex) than expected.
3. The comparison of the SFR derived from our Hα data (corrected by *both* extinction and [N II] emission using our spectroscopic data) is in good agreement with the SFR obtained using multiwavelength relations. We have also derived an X-ray based SFR for this kind of starburst galaxies.
4. We have determine the ionized gas mass ($M_{H\,II}$, using our Hα images), neutral gas mass ($M_{H\,I}$, using 21 cm H I data from the literature), mass of the ionizing stellar cluster ($M_{\star}$), warm dust mass (M_{dust}, using FIR fluxes), Keplerian mass (M_{kep}, using the kinematics of the ionized gas) and the dynamical mass (M_{dyn}, considering the kinematics of the neutral gas). As it expected, all mass values increase with the luminosity of the galaxy. Furthermore, we find a good correlation between M_{dyn} and the luminosity (absolute magnitude in B, V, R and J filters) of the galaxy. We also find a good relation between the reddening coefficient derived from the Balmer decrement and M_{dust}. This fact suggests that extinction is mainly produced within the starburst.

9 Conclusions

Our multiwavelength study has allowed to achieve a global vision of the star formation activity and evolution of each system, but also have permitted to find general results involving all the galaxy sample. The main conclusion is that the majority of studied galaxies (16 up to 20, ∼80% of the objects) show clear interaction features such as plumes, tails, TDGs, regions with very different chemical abundances inside galaxies, perturbed kinematics of the ionized gas or lack of neutral hydrogen gas, confirming the hypothesis that interaction with or between dwarf objects triggers the star formation activity in Wolf-Rayet galaxies.

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