Massive star formation in Wolf-Rayet galaxies

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Summary. We present the main results of the PhD Thesis carried out by López-Sánchez (2006) [8], 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.

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, [14] and [15] 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. Subsequent works (i.e., [5, 19, 20, 18]) also found a relation between massive star formation and the presence of interaction signatures in this kind of galaxies. Therefore, we have performed a detailed analysis of a sample of 20 of these objects extracted from the latest catalogue of WR galaxies [16] combining deep optical and near-infrared (NIR) broad band and Hα imaging together with optical spectroscopy (long slit and echelle) data. Additional X-ray, far-infrared and radio data were compiled from literature.

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

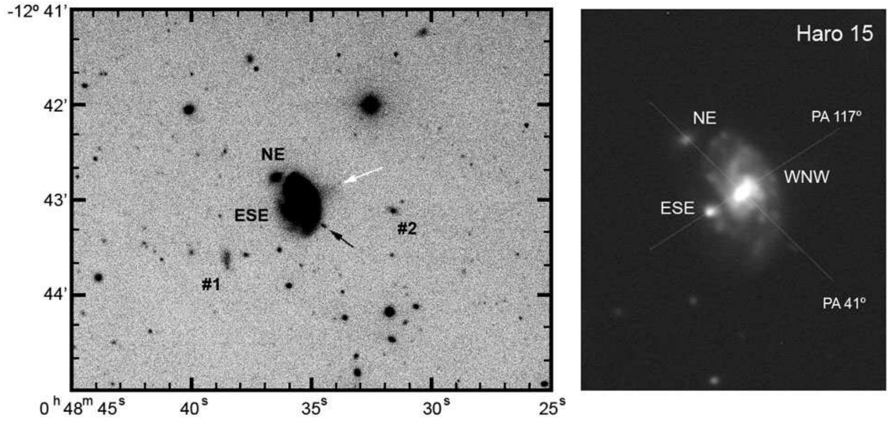

Fig. 1. (*Left*) Deep optical image of the WR galaxy Haro 15 in *R* filter, that has been saturated to reveal weakest features. (*Right*) The same object in a non-satured image. Some important regions inside the galaxy and the position of the slits used for spectroscopy are indicated. The grayscale is in logarithmic scale in both cases.

(merger remants, arcs, ripples, tails, tidal dwarf galaxies) with external galaxies or low surface brightness objects. For example, in Figure 1 we show our deep *R* image of the BCG Haro 15 [9], that reveals that it is in interaction with two nearby objects (labeled as ESE and NE in the figure). The photometric analysis of the galaxies and the use of population synthesis models (i.e. STARBURTS99 [7]; PEGASE.2, [3]) has permitted to analyze their colors, stellar populations (young, intermediate and old) 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 (see Figure 2 showing the galaxy IRAS 08208+2816 as an example). 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.

4 Intermediate resolution spectra

Long slit and echelle spectroscopy have been used to study the physical conditions (electron density and temperature, reddening, ionization nature), the chemistry of the gas (chemical abundances of O, N, S, Ne, Ar, Fe, Cl ...)

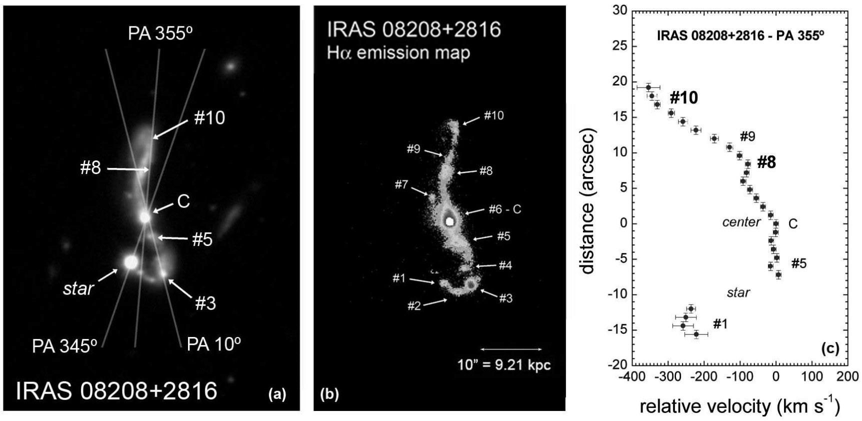

Fig. 2. (a) Deep optical image of the WR galaxy IRAS 08208+2816 showing the position of the slits used for spectroscopy. (b) Continuum-subtracted Hα of this galaxy labeling all the different objects. (c) Position-velocity diagram for the slit position with PA 355°, in which a tidal tail is clearly detected.

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 3 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. In objects in which solid-body rotation is found, the Keplerian mass have been estimated. Sometimes, prominent tidal tails have been detected (i.e. HCG 31 [10], Mkn 1087 [11] and IRAS 08208+2816, see Figure 2).

5 Interactions and star formation in galaxy groups

Specially interesting are the cases of the groups of galaxies HCG 31 [10] and Mkn 1087 [11], where interactions involving more than two objects are needed to explain the tails, bridges, mergers and tidal dwarf galaxies (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 to 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

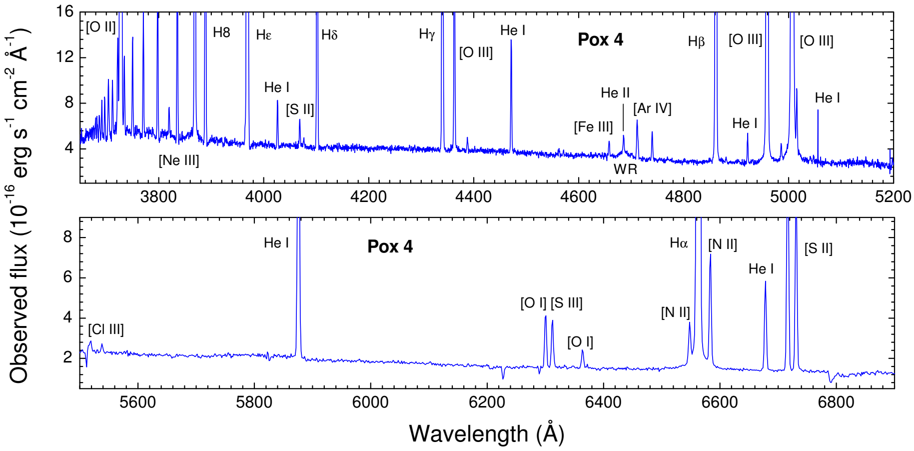

Fig. 3. Redshift-corrected spectrum of POX 4 obtained with ISIS spectrograph at 4.2m WHT. The most important emission lines are labeled. Note the He II emission line at λ4686, indicating the presence of Wolf-Rayet stars.

tail. However, other surrounding objects seem to be TDGs. Mkn 1087 can be classified as a low-z Luminous 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 [2].

6 Star formation and stellar populations in IRAS 08339+6517

We have performed a detailed analysis of the star formation activity and stellar populations in the galaxy IRAS 08339+6517 [12], where WR features are detected for the first time, and is in interaction with an independent nearby dwarf object. The prominent H I tidal tail previously found [1] has been mainly formed from material stripped from the main galaxy. We estimate that the age of the most recent burst is around $4-6$ Myr, but a more evolved underlying stellar population, with a minimal age between $100-200$ Myr, is also detected and fits an exponential intensity profile. A model which combines 85% young and 15% old populations can explain both the spectral energy distribution and the H I Balmer and He I absorption lines. The star formation rate of the galaxy is consistently derived using different calibrations, giving a value of $\sim$9.5 $M_\odot$ yr^{-1}. IRAS 08339+6517 does satisfy the criteria of LCBG. There are very few local LCBGs nowadays detected but nearly half of them have optical companions, present disturbed morphologies and/or are clearly interacting [4]. If interactions were the responsible of the activity in LCBGs, it would indicate that they were perhaps more common at high redshifts, as the hierarchical

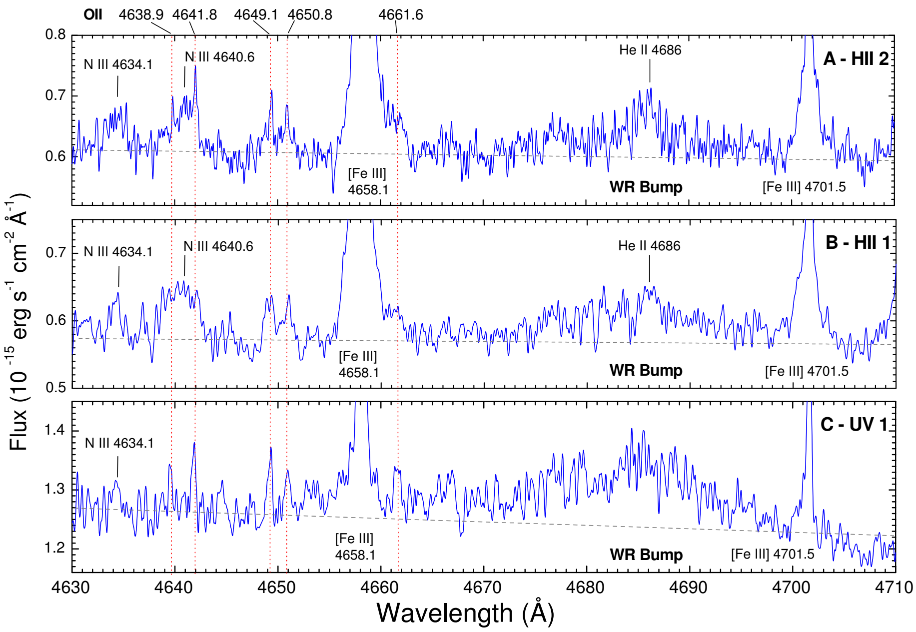

Fig. 4. Sections of echelle spectra of zones A, B, and C of NGC 5253 showing the lines of multiplet 1 of O II and the WR bump. Note the broad N III λ4641 emission line blended with O II $\lambda\lambda$4639,4642 emission lines in regions A and B. That line is absent in region C. A broad N III λ4634 seems to be also present in region A.

galaxies formation models predict (i.e., [6, 17]). This fact would also support the idea that interaction with dwarf companion objects could be an important trigger mechanism of the star formation activity in local starbursts.

7 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 (see Figure 4 and [13]). 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.

8 Conclusions

The analysis of WR features in our sample suggests that aperture effects and localization of the bursts with WR stars seem to play a fundamental role in the detection of this sort of massive stars in starburst galaxies. Our multi-wavelength 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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