Interactions and starburst phenomena in Wolf-Rayet galaxies

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Summary. We present some 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. Some of the data were obtained using ALFOSC instrument at 2.56m NOT. 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

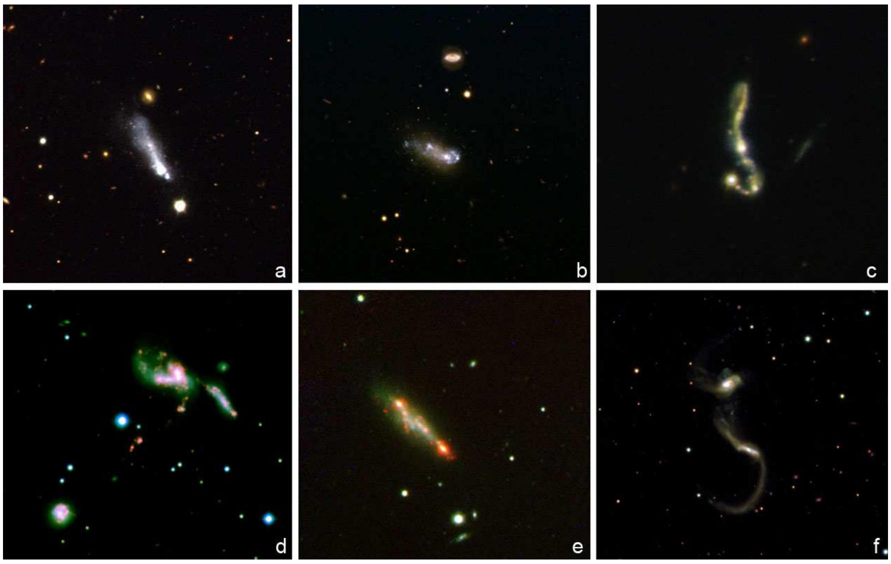

Fig. 1. False color images of six of the WR galaxies analyzed. (a) SBS 1415+437 combining images in B (blue), V (green) and R (red) filters. (b) SBS 1054+365 using U + B + V. (c) IRAS 08208+2816 using U + B + V. (d) HCG 31 using V + R + Hα. (e) SBS 1319+579 using B + R + Hα. (f) Arp 252 using U + B + R. Except R and Hα in HCG 31, all images were obtained with ALFOSC at NOT.

galaxies, looking for morphological features that reveal interaction processes with external galaxies or low surface brightness objects. Optical imagery was mainly obtained with ALFOSC instrument at 2.56m NOT. In Figure 1 we show false color images of 6 galaxies of our sample. The quality of the ALFOSC 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 [11]) and candidate to tidal dwarf galaxies and arcs (i.e., IRAS 08339+6517, [12]). The photometric analysis of the galaxies and the use of population synthesis models (i.e. STARBURTS99 [7]; PEGASE.2, [2]) has permitted to analyze their colors, stellar populations (young, intermediate and old) and the age of the last star-forming burst.

An interesting object is the WR galaxy Tol 9 within the Klemola 13 group, located a 43.3 Mpc. Our false color image of Tol 9 is shown in Figure 2: several independent objects are found in its neighbourhood, being the more important the nearby spiral galaxy ESO 436-46 (at 96" $\sim$ 20.2 kpc). The images also reveal a bridge from Tol 9 towards a dwarf companion object located 10 kpc at SW, indicating probable interaction phenomena between both galaxies. No ionized gas is detected in the bridge, indeed, the analysis of its optical and NIR colors suggests that it is mainly dominated by a relatively old stellar population with ages higher than 500 Myr.

Fig. 2. False color image of starburst galaxy Tol 9 (left) and the beauty spiral ESO 436-46 (left) within the Klemola 13 group, combining data in B (blue), R (green) and Hα filters obtaining using ALFOSC at NOT. Note the peculiar Hα distribution of Tol 9, suggesting a kind of galactic wind in the galaxy.

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 1 d & e and Figure 2 as examples). 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.

As we see in Figure 2, the continuum-subtracted Hα emission map of Tol 9 reveals a kind of filamentary structure that is more extended than that seen in broad-band filters, suggesting that an outflow of material or a galactic wind exists in the starburst. The kinematics of the ionized gas was studied via the analysis of emission line profiles using the ALFOSC 2D spectrum. The position-velocity diagram reveals a velocity pattern that can not be attributed to rotation; our analysis suggests that it could be explained considering a bipolar bubble expanding at about 80 km s^{-1}. The total Hα luminosity of the galaxy indicates a total ionized mass of $M_{H\,II} = (3.4 \pm 0.2) \times 10^6\ M_\odot$ and a star formation rate of $SFR_{H\alpha} = 1.82 \pm 0.13\ M_\odot$ a^{-1}.

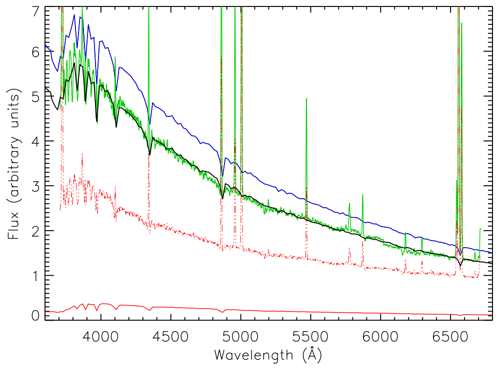

Fig. 3. Spectrum of IRAS 08339+6517 (obtained with ALFOSC at NOT) compared with synthetic continuum spectral energy distributions obtained using the PEGASE.2 [2] code. The dotted red line represents the observed spectrum uncorrected for extinction, whereas the green continuous line is the extinction-corrected spectrum. The upper continuous blue line corresponds to a model with an age of 6 Ma (young population model), whereas the lower continuous red line is a 140 Ma model (old population model). The shape of our observed derredened spectrum fits with a model with a contribution of 85% for the young population and 15% for the old population is considered (continuous black line over the galaxy spectrum).

4 Intermediate resolution spectra

Long slit and echelle (only for NGC 5253, see [13]) 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 ...) 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 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 [Figure 1c]).

5 Star formation and stellar populations in IRAS 08339+6517

An excellent example of the analysis we have performed for each system is found in our detailed study of the star formation activity and stellar populations in the bright starburst galaxy IRAS 08339+6517 [12]. All data (broad and narrow-band imagery and spectra) were obtained using ALFOSC at NOT. Our new deep images reveal interactions features between IRAS 08339+6517

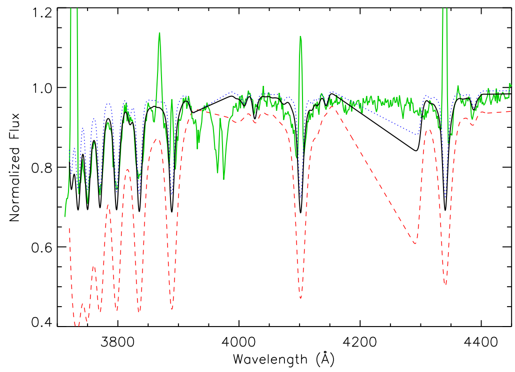

Fig. 4. Normalized dereddened spectrum of IRAS 08339+6517 (green continuous line) compared with [4] models with 4 Ma (dotted blue line) and 200 Ma (dashed line) at $Z_{\odot}$ metallicity. The best fit corresponds to a model with a contribution of 85% for the young population and 15% for the old population (continuous black line). Note that the models only give values for the position of the absorption lines and not for all wavelengths, being the reason of the straight lines presented between 3930 and 4000 Å and 4150 and 4300 Å.

and a nearby dwarf object, as well as strong Hα emission in its inner part. The chemical composition of the ionized gas of both galaxies is rather similar. Our deep spectra seem to show, for the first time, WR features in the center of IRAS 08339+6517. The kinematics also indicates interaction features and reveals an object that could be a candidate tidal dwarf galaxy or a remnant of an earlier merger. Our data suggest that a prominent H I tidal tail found by [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 Ma, but a more evolved underlying stellar population, with a minimal age between 100 – 200 Ma, 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 (see Figure 3) and the H I Balmer and He I absorption lines (see Figure 4) observed in our spectrum. We finally conclude that IRAS 08339+6517 does satisfy the criteria of Luminous Compact Blue Galaxy (LCBG), rare objects in the local Universe but common at high redshift. There are very few local LCBGs nowadays detected but nearly half of them have optical companions, present disturbed morphologies and/or are clearly interacting [3]. 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 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.

6 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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