Interactions and star formation activity in Wolf-Rayet galaxies

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Figure 1. Color images of some of our galaxies combining B, V, R or Hα data.

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 aims are to study their star formation, their O and WR stellar populations 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.

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 8 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, Arp 252 or Tol 9), **independent dwarf galaxies** (i.e., Mkn 1087, **López-Sánchez et al. 2004b**), **mergers** (i.e. Mkn 1199, López-Sánchez & Esteban 2003), candidate to **tidal dwarf galaxies** (i.e., IRAS 08339+6517, **López-Sánchez et al. 2006**). The photometric analysis of the galaxies and the use of population synthesis models as **STARBURTS 99** (Leitherer et al. 1999) and **PEGASE.2**, (Fioc & Rocca-Volmerange 1997) has permitted to analyze their colors, stellar populations (young, intermediate and old) and the age of the last star-forming burst.

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).

OPTICAL SPECTROSCOPY

Long slit and echelle spectroscopy was used to study the **physical conditions** (n_e T_e, reddening, ionization nature), the **chemistry** (chemical abundances of He, O, N, S, Ne, Ar, Fe and 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** (HCG 31, López-Sánchez et al. 2004a; Mkn 1087, López-Sánchez et al. 2004b, IRAS 08208+2816) or **outflows** (Tol 9, see **Figure 2**) have been detected.

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 calculated 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 bursts.

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 such 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** (long slit and echelle) data. Additional **X-ray**, **far-infrared** and **radio data** were compiled from literature.

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 (see **López-Sánchez et al. 2006**). Only in five objects (HCG 31 F1 & F2, POX 4, SBS 0948+532 and SBS 1415+437C) the He II λ4686 emission line is unambiguously detected. **Aperture effects and/or the position of the slit** are probably playing a fundamental role in the detection of the WR features .

Surprising, the so-called **red WR bump** (around **C IV λ5808** from WC stars) is detected in **none objects**, although Guseva et al. (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 and **this work**).

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 compared 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.

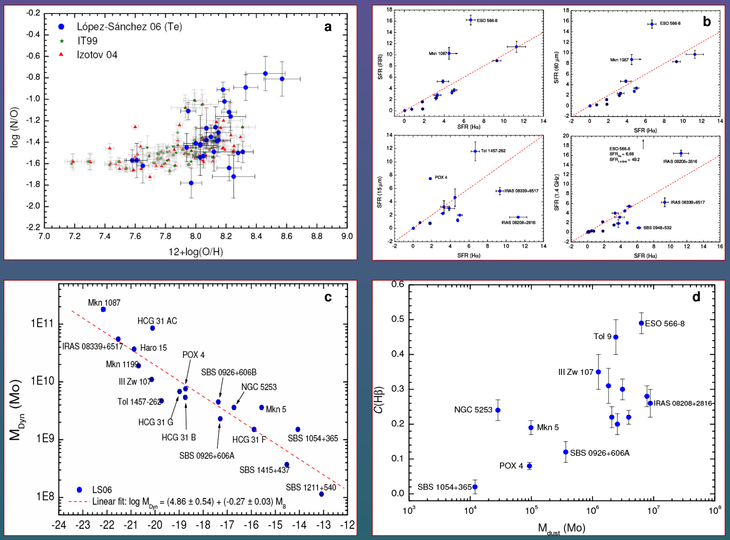

Figure 4. (a) N/O vs. O/H diagram comparing the data obtained for our sample with those presented by Izotov & Thuan (1999) and Izotov et al. (2004). (b) Comparison of the SFR derived from our Hα data with that obtained using other methods (FIR, 60 μm, 15 μm and 1.4 GHz). (c) M_{dyn} vs. M_B and (d) C(Hβ) vs. M_{dust} for our galaxy sample.

CONCLUSIONS

Our multiwavelength analysis 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.

Figure 2. False color image of the starburst galaxy Tol 9 (right) 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 @ 2.56m NOT. Note the peculiar Hα distribution of Tol 9, suggesting a kind of galactic wind in the galaxy.

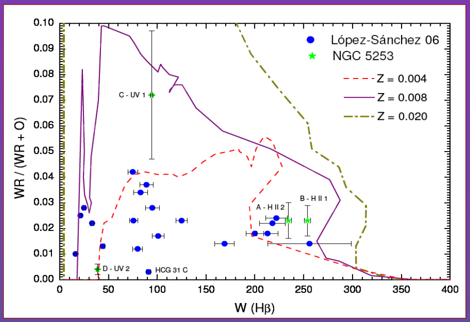

Figure 3. WR/(WR+O) ratio vs. W(Hβ) for Schaerer & Vacca (1998) WR models compared with our observational values. Except for data of objects belonging to NGC 5253 (see López-Sánchez et al. 2007), errors in the vertical axis have not been included.

OTHER GLOBAL PROPERTIES

Physical and chemical properties are **in agreement** with both previous observations and models of chemical evolution of galaxies (**Figure 4a**). We have compared the abundances obtained by the **direct method** with those obtained for **several empirical calibrations**: Pilyugin (2001a,b) seems to give the best results whereas calibrations based in photoionization models give abundances **higher (~0.20 dex)** than expected.

The **SFR derived from our Hα data** (corrected by both extinction and [N II] emission) is in **good agreement** with the SFR obtained using other **multiwavelength relations** (**Figure 4b**). We have derived an **X-ray based SFR** for this kind of starburst galaxies.

We find a good correlation between the **dynami-cal mass** (M_{Dyn}) derived from H I data and the **luminosity** (absolute magnitude in B, V, R and J) of the galaxy (**Figure 4c**).

We also find a good relation between the **reddening coefficient** derived from the Balmer decrement ($C_{H\beta}$) and the **dust mass** obtained from FIR fluxes (M_{dust}), see **Figure 4d**. This fact suggests that extinction is mainly produced within the starburst.

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