Interactions and star formation activity in Wolf-Rayet galaxies

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Figure 1. Color images of some of our galaxies obtained 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 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.

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

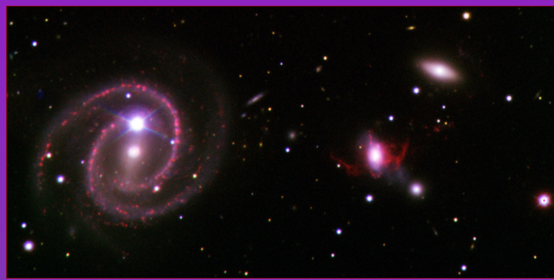


Figure 2. False color image of the starburst galaxy Tol 9 (right) and the beauty spiral ESO 436-46 (left) within the Klemola 13 group, combining data in B (blue), R (green) and Hα filters obtaining using ALFOSC @ 2.56m NOT. Note the peculiar Hα distribution of Tol 9, suggesting a kind of galactic wind in the galaxy.

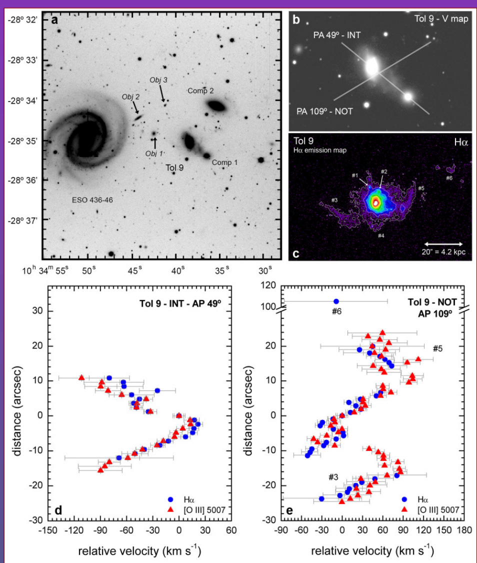
OPTICAL AND NIR IMAGING

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).



TOL 9 WITHIN THE KLEMOLA 13 GROUP

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. The images also reveal a **bridge from Tol 9 towards a dwarf companion object** located 10 kpc at SW (**Figure 3a,b**), indicating probable interaction phenomena between both galaxies. No ionized gas is detected in the bridge (**Figure 3c**), 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.

However, the continuum-subtracted Hα emission map of Tol 9 (Figure 3c) 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 and reveal a velocity pattern that can not be attributed to rotation (**Figure 3e**). Our analysis suggests that it could be explained considering a **bipolar bubble** expanding at about 80 km s^{-1}.

Figure 3. (a) Deep optical image of Tol 9 and its surroundings in V filter (2.56m NOT). (b) Non-saturated V image showing the slit positions used for spectroscopy. (c) Continuum-subtracted Hα emission map of Tol 9. (d & e) Position-velocity diagrams of Tol 9 obtained with our long-slit spectroscopy using 2.5m INT (AP 49º) and 2.56m NOT (AP 109º). The kinematics of the ionized gas was analyzed via the study of the profiles of the Hα and [O III] λ5007 emission lines. North is up in both diagrams.

OPTICAL SPECTROSCOPY

Long slit and echelle spectroscopy have been 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 3d**) have been detected.

GLOBAL PROPERTIES

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.

Physical and chemical properties are **in agreement** with both previous observations and models of chemical evolution of galaxies (**Figure 5a**). 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 5b**). We have derived an **X-ray based SFR** for this kind of starburst galaxies.

We find a good correlation between the **dynamical mass** (M_{Dyn}) derived from H I data and the **luminosity** (absolute magnitude in B, V, R and J) of the galaxy (**Figure 5c**). 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 5d**. This fact suggests that extinction is mainly produced within the starburst.

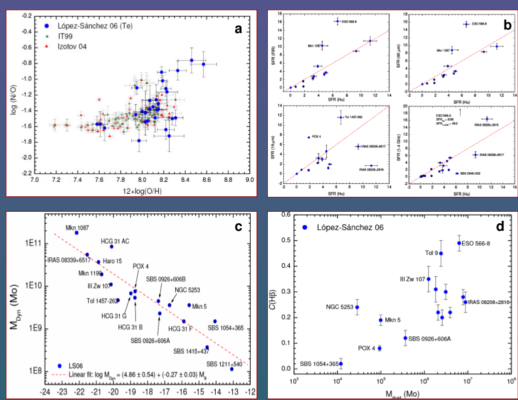


Figure 5. (a) N/O vs. O/H diagram comparing the data obtained for our sample with those presented by Izotov & Thuan (1999) and Izotov et al. (2004). (b) Comparison of the SFR derived from our Hα data with that obtained using other methods (FIR, 60 μm, 15 μm and 1.4 GHz). (c) M_{dyn} vs. M_B and (d) C(Hβ) vs. M_{dust} for our galaxy sample.

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 **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.

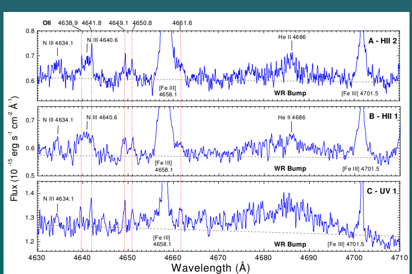


Figure 4. Sections of echelle spectra of zones A, B, and C of NGC 5253 showing the lines of multiplet 1 of O II and the WR bump. Note the broad N III λ4641 emission line blended with O II λλ 4639,4642 emission lines in regions A and B. That line is absent in region C. A broad N III λ 4634 seems to be also present in region A.

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.

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