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F. Prada, D. Martínez Delgado, and T. J. Mahoney

Tidal Dwarfs in Wolf–Rayet Galaxies

Ángel R. López-Sánchez and César Esteban

Instituto de Astrofísica de Canarias, E-38200 La Laguna, Tenerife, Spain

Abstract. Wolf–Rayet (WR) galaxies are ideal objects for investigating the triggering mechanisms of star formation. Interactions between dwarf galaxies could explain the triggering in many cases. We present the conclusions of our morphological and spectroscopy analysis of the WR galaxies Mrk 1087 and HCG 31, where interactions between more than two galaxies seem to be operating. We emphasize the nature and probable evolution of the tidal dwarfs found in these particular WR galaxies.

1. Introduction

WR galaxies are a subset of emission line galaxies whose integrated spectra have broad emission features that have been attributed to the presence of a substantial population of WR stars. The WR phase is short-lived and offers the possibility of studying an approximately coeval sample of starburst galaxies. Making use of population synthesis models, it is possible to determine the age of the WR bursts and to study the star formation processes and its causes. Several authors have suggested that interaction between dwarf companion objects is one of the main mechanism of the triggering of these starbursts. Méndez & Esteban (2000) have noted that if an external companion object has induced the star formation the interrelation should be very evident. They performed a systematic study of thirteen WR galaxies and found that seven of them were clearly interacting, and that another four had probable interaction features.

We are now extending this study and performing a morphological and spectroscopic analysis of a sample of WR galaxies selected from the latest WR catalogue by Schaerer et al. (1999). We present here our results for Mrk 1087 and HCG 31. Intermediate long-slit resolution spectroscopy of both systems were carried out with the ISIS spectrograph at the 4.2 m William Herschel Telescope (WHT). V imaging of Mrk 1087 was carried out at the 2.2 m telescope at Calar Alto Observatory, whereas optical U, B, and V images of HCG 31 were carried out at the 2.56 m Nordic Optical Telescope (NOT) with the ALFOSC camera. We used the 1.55 m Carlos Sánchez Telescope (CST) to obtain near-infrared images in J (1.2 μm), H (1.6 μm), and K_s (2.18 μm) broad band filters.

2. Mrk 1087

Mrk 1087 is at a distance of 111 Mpc. Our new deep larger field V image (Figure 1) shows a new faint companion dwarf galaxy to the north of Mrk 1087 with a similar radial velocity. It shows nebular emission, indicating that star formation is in progress or has been very recent in the object, perhaps owing to the interaction. The O/H ratio suggests that objects #1 and #3 are tidal dwarfs originating from material stripped from Mrk 1087. The lower O/H ratio obtained for the northern companion suggests that it should be interpreted as an independent nearby dwarf galaxy that is very probably interacting with Mrk 1087. This could explain the presence of the tidal dwarf #1 and its associated bridge, which is almost aligned with the N knot.

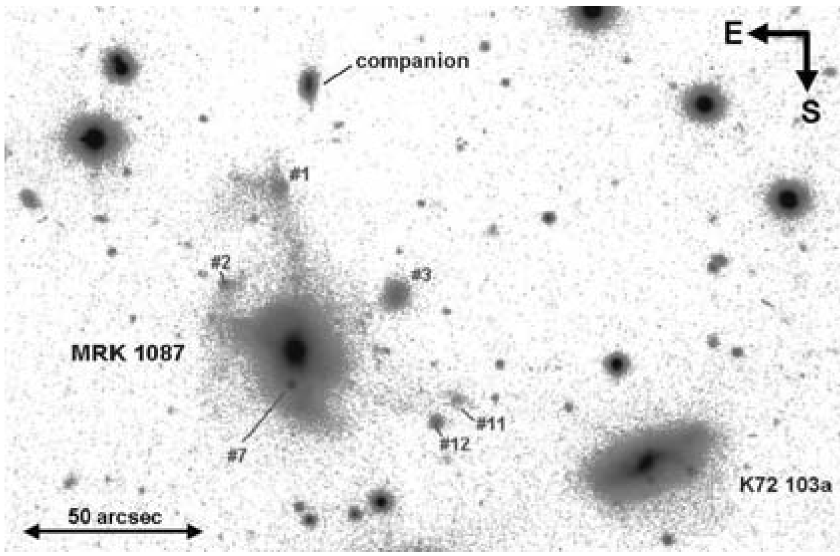

Figure 1. Deep V image of Mrk 1087 and its surroundings.

We have used Leitherer et al.'s (1999) and Schaerer & Vacca's (1998) spectral synthesis models to estimate the age of the bursts. A good agreement in all the age estimates has been obtained. We have found that the burst in the northern companion is around 5 Myr old, whereas the main body of Mrk 1087 is around 7 Myr old. The complex geometry of the filamentary structure of Mrk 1087, the existence of several tidal tails, the position–velocity diagrams, the O/H ratios, and ages obtained indicate that it is udergoing a strong star formation event owing to interaction with at least two external galaxies, the relatively bright K72 103a at 70 kpc and the new dwarf companion at 60 kpc. We consider that Mrk 1087 and its surroundings can be interpreted as a compact group of galaxies

Table 1. M_B, O/H ratio, Δv_r, and age for Mrk 1087 and surrounding objects

Mrk 1087	Center	Northern companion	# 1	# 3	# 7
M_B	−21.7	−16.2	−16.2	−16.9	−17.3
12 + log[O/H]	8.70	8.30	8.70	8.70	8.55
Estimated age [Myr]	7	5	–	6–7	5–7
Radial velocity [km s^{-1}]	0	+117	−63	+10	+144

3. Hickson Compact Group 31

The compact group HCG 31, at a distance of around 55 Mpc, is one the best studied compact groups of galaxiesbecause of its peculiar morphology. Members A and C are clearly interacting and form NGC 1741. Objects E and F, Mrk 1090 (object G), and the far member Q are also included in HCG 31. We show our V image of the system in Figure 2 (*left*). The H I map of the group (Williams et al. 1991) shows that all the galaxies are embedded in the same gas cloud. H I column density maxima are coincident with the optical galaxies, indicating they are gas-rich.

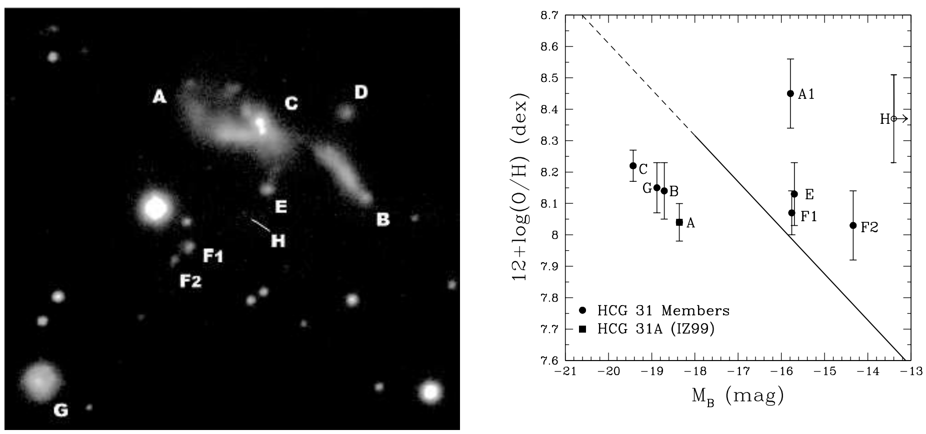

Figure 2. *Left:* Deep V image of HCG 31 indicating all its members, except Q. *Right:* Luminosity–metallicity relation for bursts in HCG 31. The solid line is the Richer & McCall (1995) relation for dwarf galaxies (extrapolated to non-dwarf galaxies). A is taken from Izotov & Thuan (1999).

Table 2. M_B, $(U-B)$ color, O/H ratio and age for HCG 31 members. [a]Calculated by empirical calibrations (see text)

HCG 31	A	B	C	E	F1	F2	G	H
$-M_B$	18.4	18.7	19.4	15.8	15.8	14.3	18.9	>13.1
$(U-B)$	−0.41	−0.38	−0.66	−0.65	−0.99	−1.01	−0.43	...
12 + log[O/H]	8.45[a]	8.14	8.22	8.13	8.07	8.03	8.15	8.37[a]
Est. age [Myr]	6–8	5–8	4–6	5–6	2–3	2–3	5–7	3–5

We have analyzed three slit positions observed for intermediate resolution spectroscopy in order to study the kinematics, physical conditions, and chemical abundances of the knots. We have estimated the electron temperature making use both the [O III] 4363 Å emission line (except for A and H) and empirical methods (Pilyugin 2000; Denicoló et al. 2002). The O/H ratios obtained from direct determination of the electron temperature are rather similar (between 8.0 and 8.2) and are consistent with previous results from the literature. We have obtained the first direct abundance determinations for members E, F2, and G.

We have used theoretical models of Leitherer et al. (1999), Stasińska & Leitherer (1996), and Schaerer & Vacca (1998) to estimate the age of the bursts. Similar values were obtained in each member, indicating that the possible underlying old population seems not to be important, especially in F objects (the youngest members).

The oxygen abundances of the galaxies are unusual when we take into account the luminosity–metallicity relation of Richer & McCall (1995). In Fig. 2 (*right*) we can see that the four brightest galaxies of HCG 31 (A, B, C, and G) show rather similar O/H, about a factor of 2 (0.3 dex) lower than the value expected from this relation. This is a real feature because the abundances are well determined, based on direct measurement of the electron temperature for most of the objects. We consider that perhaps the metallicity–luminosity relation of dwarf irregular galaxies is *not appropriate* for interpreting the properties of starburst galaxies because the contribution of the burst dominates the blue luminosity, in contrast to the situation in non-bursting dwarfs.

On the other hand, E and F show the same oxygen abundances as the brightest galaxies of the group, despite the difference of about 5 magnitudes. Furthermore, their position in the O/H vs. M_B diagram seems to be somewhat consistent with the Richer & McCall (1995) relation. However, this could be fortuitous, because the very blue colors (see Table 2) and small sizes derived for E and F may cause the relative contribution of the young population to be even more important than in the brightest galaxies of the group, as would be expected following population synthesis models. The future photometric evolution of their starbursts could move their positions away the relation toward lower luminosities after the first 10 Myr. If this prediction were correct, it would favor their tidal dwarf nature, as several authors have previously pointed out.

4. WR Features and Tidal Tails in Compact Systems

From 1994, an increasing number of morphological interaction signs, such as mergers and tidal tails, have been reported in compact groups of galaxies and similar systems where several interacting galaxies have been discovered. The finding of WR features in them permits study of the star formation and its triggering mechanism in greater detail, as well leading to a better knowledge of the nature and properties of their tidal dwarfs and structures.

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