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Diving deeper into jellyfish: The rich population of jellyfish galaxies in Abell 901/2

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Abstract. Jellyfish galaxies are the most striking examples of galaxies undergoing ram pressure stripping – the removal of gas as a result of a hydrodynamic friction in dense environments. As part of the OMEGA (OSIRIS Mapping of Emission-line Galaxies in Abell 901/2) survey, we have identified the largest sample of jellyfish galaxies in a single system to this date, located in the Abell 901/2 multi-cluster system at $z \sim 0.165$. We present our results with a detailed description of this sample regarding their very high star formation rates and their unique spatial distribution pattern that can be explained as a result of the merging system triggering ram pressure stripping events. Furthermore, we also show the results of our most recent morphometric studies where we use Morfometryka as a tool to characterise the morphologies and structural evolution of jellyfish galaxies. Our morphometric analysis shows that jellyfish galaxy candidates have peculiar concave regions in their surface brightness profiles. Therefore, these profiles are less concentrated (lower Sérsic indices) than other star forming galaxies that are not experiencing such extreme ram pressure effects.

Keywords. galaxies: evolution, galaxies: structure, galaxies: clusters: general, galaxies: intergalactic medium

1. Introduction

The evolution of a galaxy is significantly shaped by the environment. The absence of late-type galaxies in the densest environments suggests that environmental mechanisms are an important factor when it comes to galaxy quenching and morphological evolution (Dressler 1980). By interacting with its surroundings, a galaxy can undergo gravitational and hydrodynamic effects, such as tidal interactions, mergers and harassment (Barnes 1992; Moore *et al.* 1996) or ram pressure stripping (Gunn & Gott 1972). The most extreme cases of galaxies undergoing ram pressure stripping are known as jellyfish galaxies. They received this name as they can have extensive tails of material being stripped that also host intense star formation (Ebeling *et al.* 2014; Owers *et al.* 2012). These galaxies are excellent objects to understand the role of ram pressure stripping in the scenario of galaxy evolution within dense galaxy clusters.

2. Overview

We present the results of a systematic search and analysis of 73 ram pressure stripping candidates in the Abell 901/2 multi-cluster system (Roman-Oliveira *et al.* 2019). The sample was selected through visual inspection in the Hubble Space Telescope F606W

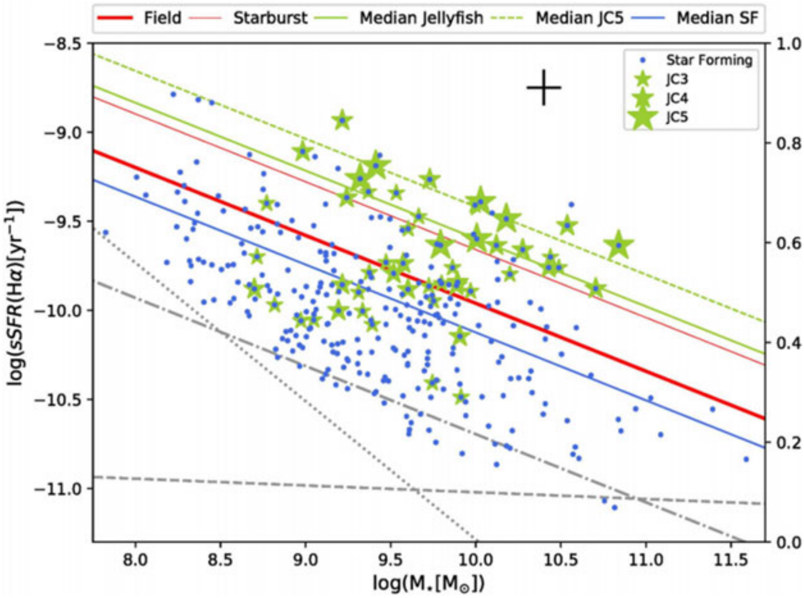

Figure 1. Specific star formation rate versus mass plot (adapted from Roman-Oliveira *et al.* 2019). We represent different JClasses by green star markers according to the legend. The blue dots represent the star forming galaxies without ram pressure stripping morphological features. The star formation main sequence for the SDSS field galaxies is shown as a thick red line, the thin red line is used to identify starbursts. The green and blue lines represent the median SSFR for the ram pressure stripping and star forming populations. The black dash-dot, dotted line, and dashed lines are the observation limits of OMEGA and the cross represents the uncertainty of the data points.

band images following identification methods used previously in Ebeling *et al.* (2014) and Poggianti *et al.* (2016). This selection also accounts for categories of intensity of the morphological evidence of ram pressure stripping, known as JClasses. These categories range from 1 to 5, being that 5 is the strongest case possible. Our sample of 73 candidates only comprises JClasses 3 to 5, the strongest cases. We also visually assigned trail vectors to the galaxies, which is a vector that infers the direction of motion for a jellyfish galaxy on the plane of the sky.

2.1. *Star Formation Rates and AGN activity*

To probe the effects of ram pressure stripping on the star formation activity in the galaxies, we show in Figure 1 a plot of the Specific Star Formation Rate (SSFR) versus mass. We compare the sample of ram pressure stripping candidates against other star forming galaxies that do not show jellyfish morphological features. We see that the jellyfish galaxy candidates show a systematic enhancement in the SSFR, which is in agreement with other recent studies (Vulcani *et al.* 2018; Poggianti *et al.* 2016). Another interesting result, is that the scatter is correlated with the JClasses of the candidates: JClass 5 galaxies show much higher specific star formation rates than the JClass 3 galaxies.

As for the Active Galactic Nuclei (AGN), we did not find any evidence for a correlation between ram pressure stripping and AGN. In fact, only 5 of our candidates are hosts to an AGN. This is in conflict with what was found in Poggianti *et al.* (2017b), in which 5 of the 7 strongest candidates in the GAs Stripping Phenomena in galaxies with MUSE survey (GASP) (Poggianti *et al.* 2017a) hosted an AGN and another one was a Low-Ionization Nuclear Emission-line Region (LINER). To fully investigate these results, we compare in

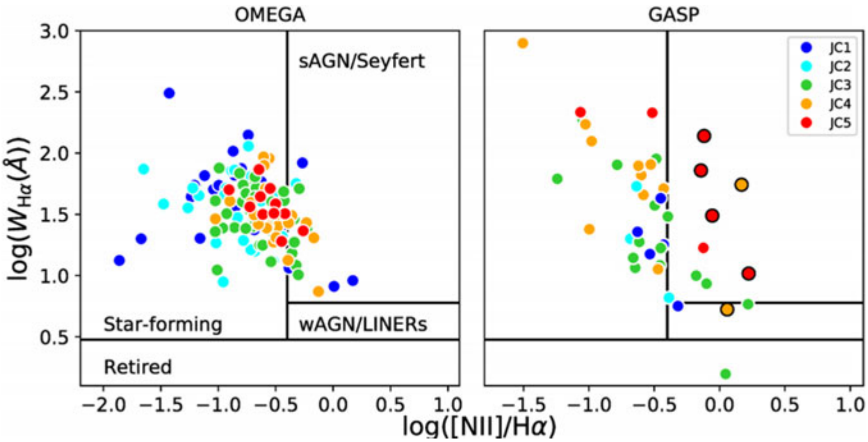

Figure 2. The WHAN diagram for the Abell 901/2 ram pressure stripping candidates in the left panel and for the public GASP sample in the right panel (adapted from Roman-Oliveira *et al.* 2019). The markers with a black ring are the galaxies present in Poggianti *et al.* (2017b).

Figure 2 the Abell 901/2 ram pressure stripping candidates to the GASP public sample in a WHAN diagram (equivalent Width of Hα versus [NII]/Hα). We find that the scatter and AGN fraction of both samples are similar and that the majority of the galaxies are star forming and do not host an AGN.

We suggest that the strong presence of AGN in the 7 strongest GASP jellyfish galaxy cases might be due to a bias in stellar mass or environment rather than the ram pressure stripping phenomenon. However, it is important to note that these 7 galaxies were selected due to their very extended tails, a selection we cannot reproduce in our sample.

2.2. *Environment*

When it comes to the environment, we could not find any evidence for a spatial distribution pattern nor on the infalling direction of the galaxies provided by the trail vectors. This differs significantly from the pattern in the jellyfish galaxies found in Smith *et al.* (2010), in which the majority of the sample was directed to the centre of the Coma cluster.

We have simulated the Abell 901/2 multi-cluster system assuming that the four main substructures will be merging in the future. Our results reveal the existence of a region in which the ram pressure stripping phenomenon is highly enhanced, as illustrated in Fig. 3 (Ruggiero *et al.* 2019). This happens because of the high relative velocity between the galaxies and the merging subclusters. These narrow regions can enhance the efficiency of the ram pressure stripping by a factor of a thousand in a few kiloparsecs, being an optimal trigger to ram pressure stripping events. When we compare the spatial distribution of the observed ram pressure stripping candidates, we find that they are systematically closer to these boundaries when compared to the other cluster members. We then propose that the multi-cluster system, or merging systems in general, can act as triggers to the creation of new jellyfish galaxies around these boundaries. This reinforces tentative findings from previous works (McPartland *et al.* 2016; Owers *et al.* 2012).

2.3. *Morphology*

In order to explore the morphological transformation of jellyfish galaxies, we have performed a morphometric analysis with MORFOMETRYKA (Ferrari *et al.* 2015). Our first result is the proposition of a new way of characterising trail vectors in a robust and

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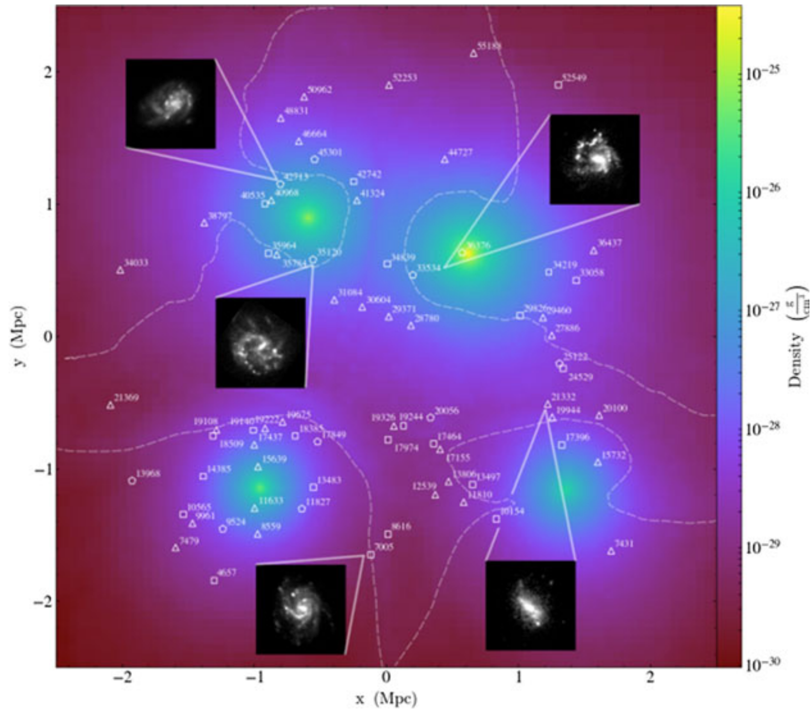

Figure 3. Spatial distribution of the Abell 901/2 ram pressure stripping candidates over the simulated system (adapted from Ruggiero *et al.* 2019). The dashed lines are the locations of the ram pressure boundaries. The small inset images are HST thumbnails of jellyfish galaxies and the triangles, squares, pentagons are the JClass 3, 4 and 5 galaxies, respectively (for more details see Ruggiero *et al.* 2019).

automatic manner, completely independent of visual inspection. This can simply be done by tracing a vector from the centre of light to the peak of light in an image of a galaxy, as can be seen in the illustration shown in Figure 4 left panel.

By investigating the surface brightness profiles of the candidates we find low Sérsic indices for many of the galaxies. This translates into a concave feature in their surface brightness profiles, like the one shown in Figure 4 right panel. One way of quantifying this occurrence is by using the curvature tool designed in Lucatelli *et al.* (2019). This tool analyses the concavity of a surface brightness profile curve revealing high and low light concentration features in galaxies, that can be related to structural components such as bulges or discs. By measuring the curvature of our ram pressure stripping candidates, we find that they have systematically more concave regions that are related to a low concentration in the surface brightness, or a broader profile. Our preliminary and tentative results suggest that ram pressure stripping alters the galaxy morphology by broadening the surface brightness profiles effectively creating galaxies that have the stellar component less concentrated than a pure disc.

3. Implications

The main findings of this study are:

• We find a systematic enhancement of the specific star formation rates in the jellyfish galaxy candidates. This suggests that the ram pressure stripping phenomenon can be an efficient trigger of star formation before it depletes the interstellar gas and can even lead to a starburst period.

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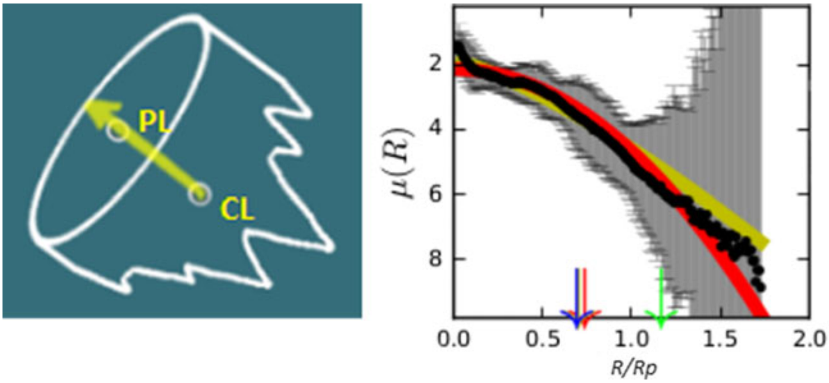

Figure 4. Left panel: Illustration of how to automatically define a trail vector. PL stands for peak of light, which is the brightest pixel in an image. CL stands for centre of light, which is the average point, weighted according to the intensity of light. Right panel: Surface brightness profile for one of the Abell 901/2 ram pressure stripping candidates. The black dots are the measurements from MORFOMETRYKA and the pale yellow and red lines are the 1D and 2D Sérsic law fits, respectively. Error bars on the background represent the error propagation for the surface brightness. The arrows represent different measured radii, for more details refer to Ferrari *et al.* (2015).

• We also could not find a strong correlation between ram pressure stripping and AGN (Roman-Oliveira *et al.* 2019).

• We propose a scenario in which merging clusters can efficiently trigger new ram pressure stripping episodes. These are the best laboratories to find and study more candidates (Ruggiero *et al.* 2019).

• We propose a robust and automatic way of defining trail vectors that is independent of visual inspection (Roman-Oliveira *et al.* submitted).

• Our surface brightness results suggest that the extreme ram pressure that produces jellyfish features also serves to broaden the surface brightness profiles, sometimes creating concave surface brightness profiles (Roman-Oliveira *et al.* submitted).

To validate our tentative findings, we plan on further investigating the morphology of jellyfish galaxies by performing the morphometric analysis (with MORFOMETRYKA and ELLIPSE) on the OMEGA Hα maps. With this, we could identify the Hα morphologies (Koopmann *et al.* 2004), discovering the extent and concentration of the star formation spatially, whether it is being enhanced or suppressed in different regions and maybe retrieving more information on how the morphology is being affected by looking into different regions of the spectrum.

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