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GASP: Gas stripping and the outskirts of galaxies as a function of environment

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Abstract. We present GASP, an ongoing ESO Large Program with MUSE aiming to study gas removal processes from galaxies at low redshift. GASP targets 100 galaxies with tails, tentacles and one-sided debris. MUSE data allows a detailed investigation of the ionized stripped gas, as well as of the gas and stars within the galaxy out to large distances from the galaxy center. We show the first results for two of the GASP galaxies that are striking cluster jellyfish galaxies of stellar masses $\sim 10^{11} M_{\odot}$.

Keywords. Galaxies:evolution, galaxy:intergalactic medium, galaxies:ISM, galaxies:peculiar

1. Introduction

The gas supply regulates the histories of galaxies, as gas inflows and outflows drive the star formation history and indirectly affect also the galaxy structure. Several factors can influence a galaxy gas content: galactic winds due to star formation or an active galactic nucleus, gas-only processes such as ram pressure stripping and strangulation, tidal effects and mergers affecting both gas and stars, and others. Processes removing gas from galaxies can lead to an interruption of the star formation activity and be a fundamental cause of galaxy quenching.

Jellyfish galaxies exhibit tentacles of material that appear to be stripped from the main galaxy body, and are a striking example of gas stripping processes. Prototypes of jellyfish galaxies are for example VCC1217 in the Virgo cluster (Hester *et al.* 2010, Fumagalli *et al.* 2011), ESO137-001 in the Norma cluster (Fumagalli *et al.* 2014, Fossati *et al.* 2016), and the sample observed in intermediate redshift clusters by Ebeling *et al.* (2014).

We conducted the first systematic search for galaxies with optical asymmetric morphologies, with tails and one-sided debris, suggestive of unilateral forces such as stripping. We visually searched for "stripping candidates" in the images of the OMEGAWINGS sample of X-ray selected clusters at low redshift (z = 0.04-0.07) and of a comparison field sample at similar redshifts. This search yielded an atlas of 344 stripping candidates in clusters and 75 in groups and low-mass haloes in the field (Poggianti *et al.* 2016). Not all the candidates are classical jellyfishes, but all show unilaterally disturbed morphologies. They cover a broad range of galaxy stellar masses, between 10^9 and $10^{12}\ M_{\odot}$, and have a star formation rate on average a factor of 2 higher than galaxies of similar mass.

2. The GASP program

In order to study gas removal processes in different environments and understand in detail the physics of such processes, we initiated GASP (GAs Stripping Phenomena in

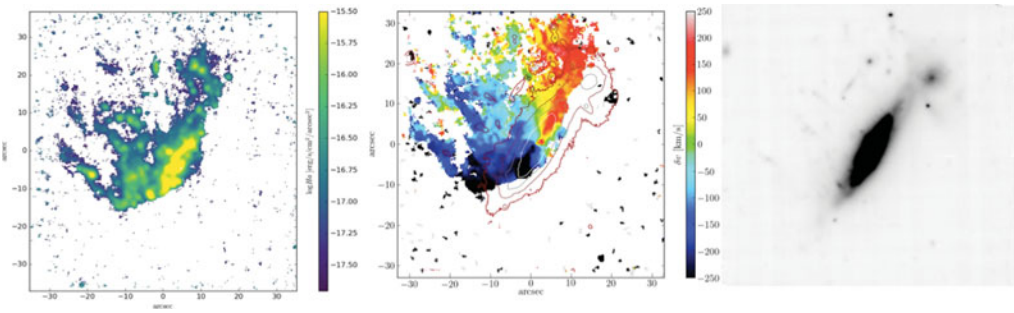

Figure 1. One of the GASP galaxies, JO204, as seen by MUSE. Left. Hα map. Center. Hα velocity map (colours). Contours are the galaxy stellar isophotes. The stripped gas still rotates coherently with the galaxy disk. Right. MUSE white image. From Poggianti *et al.* in preparation.

galaxies with MUSE), an ESO Large Program with the IFU MUSE spectrograph. This program started in October 2015 and will use 120 hours of VLT over four semesters to study 100 stripping candidates from the Poggianti *et al.* (2016) sample. The sample includes both cluster and group galaxies and a control sample with "normal morphologies". The minimum exposure time per galaxy is 2700 sec and, while most galaxies are observed with one pointings, those with the longest tails require two or even three MUSE pointings to cover the main region of interest.

Targets cover a wide range of galaxy masses, environments and degrees of morphological asymmetry. The MUSE observations provide an unprecedented view of the stars and of the ionized gas within galaxies and outside of galaxies, in their outskirts, their surroundings and their tails, out to over 100 kpc from the galaxy. In fact, one of the most important characteristics of GASP compared to other IFU surveys such as CALIFA, SAMI and MANGA, is the focus on the galaxy outer regions and surroundings, together with the wide range of dark matter halo masses explored.

The main goals of GASP are to observe how (physics), where (environment) and why (by what mechanism) gas gets removed from galaxies, by measuring the timescale and efficiency of gas removal as a function of galaxy mass and environment. The MUSE data also allow quantifying the amount of star formation involved in these processes and how the galaxy quenching proceeds within these galaxies.

3. The first two examples

At the time of speaking, 21 of the 100 targets have been observed by MUSE. We present here the two most striking examples of jellyfish galaxies observed so far, to illustrate the power of the MUSE data and the kind of information that is obtained.

JO204 and JO201 are two massive galaxies of similar galaxy stellar mass ($\sim 8-9 \times 10^{10}\, M_{\odot}$ for a Salpeter IMF). Both of them are members of a cluster and are close in projection to the cluster center, but the clusters they inhabit are quite different from each other: while JO204 is a member of Abell 957x, a low-mass cluster with a velocity dispersion of $\sim 600\,\mathrm{km\,s^{-1}}$ and an X-ray luminosity $L_x = 10^{43.9}\,\mathrm{erg\,s^{-1}}$, JO201 is part of a small group infalling into Abell 85, a massive $\sim 1050\,\mathrm{km\,s^{-1}}$ cluster 10 times more luminous in X-ray than Abell 957x, with $L_x = 10^{44.9}\,\mathrm{erg\,s^{-1}}$. Interestingly, both of these galaxies host a central AGN.

The MUSE data strikingly show the stripped gas that is ionized and emits in Hα (Figs. 1 and 2). This gas forms tails and tentacles that have both knots of intense Hα

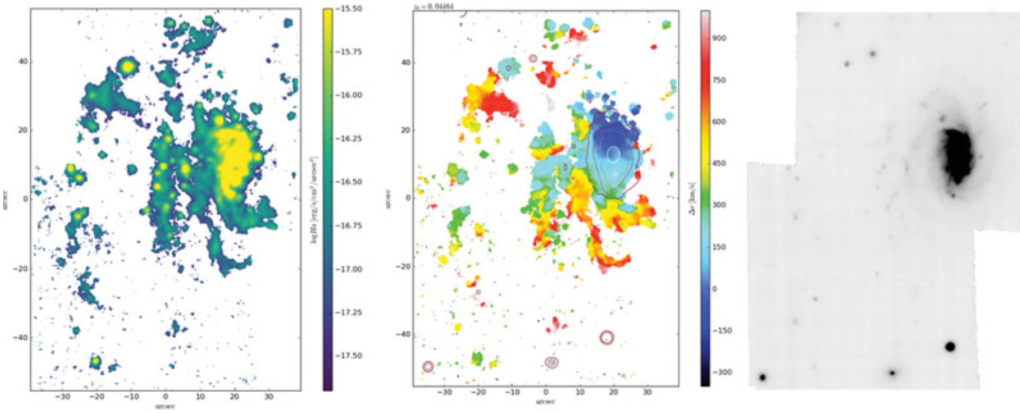

Figure 2. *Left*. Hα map of another GASP galaxy, JO201. A 100 kpc tail of stripped ionized gas is seen with two MUSE pointings and possibly extends even further. Center. JO201 Hα velocity map. Right. MUSE white image. From Bellhouse *et al.* in preparation.

emission and regions of more diffuse emission. The stripping is much more obvious from the Hα image than from the optical broad band image (right panels in Figs. 1 and 2).

The emission-line ratios of the knots are typical of HII regions, revealing that the gas is photoionized. In both galaxies, the metallicity of the gas in the knots varies with position, decreasing going further away from the galaxy center, as expected if the gas in the outer disk was stripped first. The stripped gas retains the disk rotational velocity (stellar rotation not shown due to space limits), indicating that the galaxies are moving fast through the intergalactic medium.

All the other galaxies observed so far show evidence of extraplanar ionized gas and/or clear stripping, and display a variety of gas morphologies that might reveal different processes at work. As we acquire the necessary statistics, GASP will provide an unprecedented view of galaxy outskirts and surroundings and of the processes affecting the gas.

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