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GLACE: freezing the environment of line–emitting cluster galaxies

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Abstract

GLACE is performing a survey of emission-line galaxies in clusters with the main aim of studying the effect of the environment in the star formation activity. The innovation of this work is the use of tunable filters in scan mode to obtain low resolution spectra of the desired emission lines. Although the survey is in its initial stage, we have analysed two line datasets in two different clusters: Hα in Cl0024 at $z = 0.4$ and [OII] in RXJ1257 at $z = 0.9$. The first is a well known intermediate redshift cluster that has been used to test the observational strategy. We reached the planned SFRs and we could deblend the [NII] component, thus being able to discriminate the AGN population from the star-forming galaxies. Also the spectral resolution is allowing us to exploit the data for dynamical analysis. The second target is a recently discovered cluster, that we have studied regarding its FIR and [OII] emission. The [OII] observations are revealing a fainter and less massive sample, when compared with the FIR emitters, showing two different populations of star-forming galaxies. The cluster emitters have shown that no evident correlation exist between the SFR (or sSFR) and the environment. Nevertheless, we have found that both samples, FIR- and [OII]-emitters, are concentrated in the areas of intermediate to even high local density. Additionally, we explored the morphological properties of the cluster galaxies using the non-parametric galSVM code.

1 Introduction

A comprehensive view of galaxy evolution in clusters is the clue to disclose what role plays the environment. Evidences of the evolution in galaxies in clusters are widely observed over the last decades, as the galaxy morphology-density relation [3], the existence of the colour-magnitude relation [2], the larger number of blue galaxies in high-redshift clusters (the Butcher-Oemler effect [1]), or the increment of the obscured star formation in distant clusters [5]. Nevertheless, to disentangle the relative importance of internal and external physical mechanisms responsible for this relations is difficult. In this context arises the GaLAxy Cluster Evolution (GLACE) survey, a project designed as an innovative survey of emission-line galaxies (ELGs) in a well-studied and well-defined sample of clusters, exploiting the novel capabilities of tunable filters (TFs) to map a set of important optical emission lines. The GLACE programme is undertaking a panoramic census of the star formation and active galactic nucleus (AGN) activity within a sample of clusters at three redshift bins, $z \sim 0.40$, 0.63, and 0.86. These redshifts were defined to map a set of important lines (Hα,Hβ, [OII] $\lambda3727$, and [OIII] $\lambda5007$) within the windows relatively free of strong atmospheric OH emission lines. Currently the survey has analysed the Hα line in the Cl0024+1654 cluster at $z = 0.395$ (see poster of M. Sánchez-Portal in these proceedings), and the [OII] in the RXJ1257+4738 cluster at $z = 0.866$, whose results are presented below. Additionally, we also show here the multi-wavelength optical to far-infrared (FIR) study and the morphological classification of the RXJ1257 cluster galaxy sample we have performed.

2 Results for the RXJ1257.2+4738 galaxy cluster

The analysis of the RXJ1257 cluster was carried out in three stages: a multi-wavelength optical to FIR study, a TF survey of the [OII] ELGs, and a morphological classification of the full cluster galaxy sample. For the multi-wavelength study we worked with new OSIRIS/GTC and *Herschel* imaging data, along with ancillary data, that have enabled us to perform SED-fitting and Monte Carlo simulations to build a catalogue of reliable cluster members. The identification of a large number of cluster galaxies has allowed us to investigate galaxy properties as function of the cluster environment. Our main results are summarised below:

1. We calculated $L_{\rm IR}$ luminosities for each of the 38 FIR-detected galaxies, obtaining a sample that is complete in infrared luminosity down to $L_{\rm IR} = 5.2 \times 10^{10}\,{\rm L}_\odot$, i.e. $SFR = 5\,{\rm M}_\odot\,{\rm yr}^{-1}$.

2. We estimated that around 8 % of FIR emitters are AGN candidates, using a selection criterion based on the IRAC colors [6], and we confirm that none of them have X-ray emission. The resulting two candidates are located in the low-density regime, both are MIPS-detected and one has *Herschel* detected emission.

3. We found four structures in the cluster density map with a local density above four times the background density fluctuation. The filament-like appearance of some overdensities

and the spatial distribution of the FIR emitters within them suggest that RXJ1257 is still in the process of formation (see density map and red and orange symbols in Fig. 1).

4. We analysed the dependence of the star formation activity with the environment in three density regions (low-, intermediate-, and high-densities) and two mass samples (low- and high-mass galaxies). The average value of the SFR and the sSFR was shown to be roughly independent of the environment, although we should bear in mind that the data are highly biased to high SFRs. On the other hand, the fraction of star-forming galaxies was found to change with environment, showing the same behaviour for low- and high-mass samples. We observed that the fraction of low-mass SF galaxies increases from low- to intermediate-density environments and falls almost to zero towards the densest regions (as shown by red symbols in Fig. 2). Both the spatial distribution and the fraction of FIR emitters lead us to consider the intermediate-density cluster environment as the appropriate region to observe the enhancement of star formation activity. The lack of an environmental dependence of the average SFR/sSFR of the FIR emitters against the dependence of their fraction suggests that the physical mechanism causing the variation of the star formation activity at intermediate densities could be a fast process.

5. The analysis of the extinction distributions of the optically red and blue FIR-emitters supports the assumption of the red SF galaxies as a dusty population.

Mapping the [OII] emission line with the TF tomography technique we have identified a significant number of [OII] cluster members, which has allowed us to study a fainter star-forming population and compare its properties with those derived from the FIR emission. The main results are:

1. We estimated the [OII]-line flux for the 87 [OII]-emitters in an homogeneous and $v_{\rm LoS}$ complete sample. The completeness limit of this sample is $\sim 2.7 \times 10^{-17}\,{\rm erg\,cm^{-2}\,s^{-1}}$.

2. We found that the properties ($M_\star$, Age, extinction, $L_{\rm NUV}$) for the 87 [OII]-emitters sample covered the same range as for the full cluster sample. However, the optical colour distribution of the [OII] sample is clearly dominated by a blue population (96 % of the sample are optically blue galaxies).

3. We could not make a reliable estimation of the AGN contamination, since we have IRAC colors for only 12 % of the sample and we still have not the Hβ data available. Therefore, when studying the star formation activity we are affected by at least 15–20 % of the population being galaxies dominated by an AGN, that could reach even more than 50 % of the [OII]-emitters sample. We considered that this effect will not be so significant when analysing the fraction of star-forming galaxies.

4. The analysis of the updated density map, we found that many [OII]-emitters are located in the densest areas of the map (see green and orange symbols in Fig. 1).

5. As we observed with the FIR emission, the average star-forming galaxy forms the same stellar mass per unit time in all local density environments, since no correlation

was found when analysing the SFR as a function of the local density. Nevertheless, an interesting result was found when we studied the relative number of [OII]-emitters respect to the total of cluster members (see green symbols in Fig. 2). That fraction significantly grows from low- to intermediate-density regions, and, moreover, contrary to the FIR population, there is a significant number of [OII]-emitters that are located in the densest environments indicating that the quenching of the star formation activity in the RXJ1257 densest structures has not happened yet.

6. The comparison of the [OII]-emitters, [OII]- and FIR-detected, and FIR-only emitters samples suggests that the most plausible explanation to the lack of [OII] detection in the most massive and reddest FIR-emitters is caused by dust attenuation. In this regard, we found that the extinction needed to place the FIR-only emitters below the $\mathrm{SFR}_{[OII]}$ completeness limit ranges from less than 1 mag to slightly more than 4 mag at the wavelength of the [OII] line.

The morphological analysis performed prove that a partial morphological classification of galaxies in clusters at redshift almost unity is possible with data from ground-based telescopes, as GTC, using non-parametric methods as implemented in the galSVM code [4]. Additionally, the analysis of this morphological classification has produced the following results:

1. From the input sample of cluster galaxies, we have morphologically classified 90 galaxies (approximately 30 % of the input sample). This classification was performed by defining restrictive probability threshold for the early- and late-types, and applying a $g' - z'$ colour cut. So that we classified galaxies in three morphological categories: LT (18), ET (26), and "blue" ET (46).

2. The study of the possible bias in our morphologically classified sample shows that the main incompleteness is the magnitude: while the full cluster sample reaches magnitudes as fainter as 26 mag, we are unable to classify galaxies above a magnitude in r' of 24.5. The incompleteness in magnitude indicates that we are biased towards massive galaxies, although we have been able to classified galaxies with stellar masses below $10^9\,\mathrm{M}_\odot$.

3. We calculated and compared morphological parameters, SED-derived properties, and other physical properties (as those related with the star formation activity and the environment, for example) for the three morphological types, finding that none of the three types showed a clear difference.

4. We found similar numbers for the cluster galaxies selection methods in the three morphological samples and significant percentages of "blue" ET galaxies morphologically classified with very high probabilities. These facts support the existence of such "blue" ET galaxies as a different population. This population could be formed by ET galaxies with recent star formation activity, or maybe some of them related with the luminous compact blue galaxies (LCBG) population, but, in any case, a further detailed study is necessary to draw any conclusion.

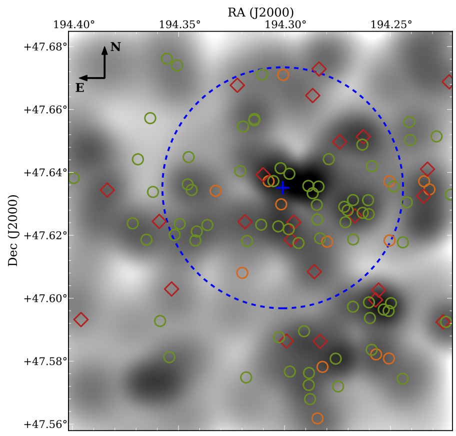

Figure 1: Density map with the [OII]-emitters (green circles), the [OII]-emitters FIR-detected (orange squares), and the FIR-only emitters (red diamonds).

5. We focused on the relation between the galaxies morphology and their star formation activity, stellar mass, and environment, and found that the only obvious tendency is related with the more massive and less effective forming stars ET population, which was placed mainly below the main-sequence region. For the SFR, σ_5, and cluster-centric distance properties we observed that the three morphological types spanned the full range.

6. The direct effect of the environment on the morphology was analysed studying the fraction of each morphological type in each density region and at different cluster-centric distances (see Fig. 3). We found a clear trend for the LT galaxies: they are scarce in densest environments and the cluster centre, increasing their number towards less dense and more distant regions. For the ET samples we found the opposite behaviour when considered as a unique population, i.e. the dominate the cluster core and densest environments. A clear fact is that the number of "blue" ET is the highest in all environments at all distances, being the dominant population in the RXJ1257 cluster.

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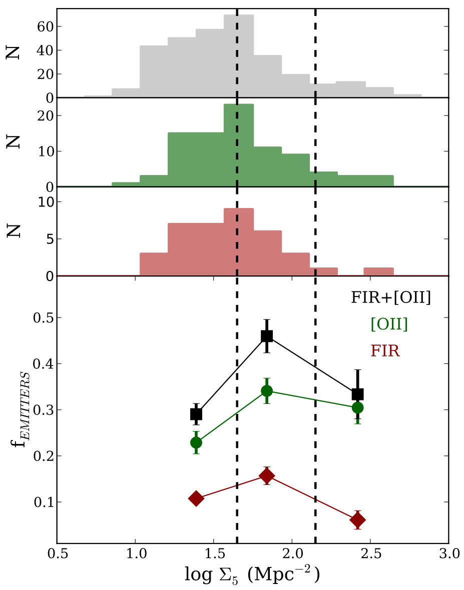

Figure 2: Fraction of FIR- (red diamonds) and [O II]-emitters (green circles) as function of the local density. Black squares represent the total fraction of emitters. Dashed lines indicates the three different local density environments.

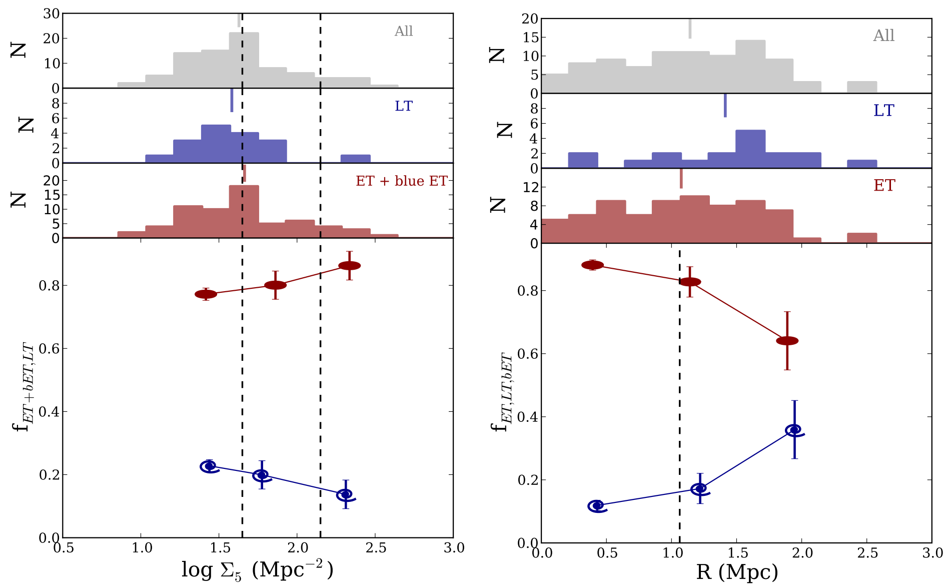

Figure 3: Fraction of ET (red) and LT (blue) as a function of the local density (*left*) and of the cluster-centric distance (*right*). Dashed lines indicates the three different environments (low, intermediate, and high) for the local density, and the virial radius for the cluster-centric distance.