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# Cluster dwarfs galaxies and the [$\alpha$/Fe]-mass relation.

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## Abstract

Using spectral data from the SAMI Integral Field Spectrograph and full spectral fitting techniques, we obtain and study the stellar population properties of a sample of dwarf galaxies in the Fornax Cluster. Our analysis focuses on the relation of stellar populations properties with the environment and internal properties of dwarfs.
We covered the stellar mass range from $10^4$ to $10^{12} M_\odot$ by adding massive galaxies from the ATLAS$^{3D}$ project and satellite galaxies of the Milky Way. Using the whole sample we find that the mass–metallicity relation is not linear and that the [$\alpha$/Fe]-stellar mass relation shows a U-shape, with a minimum in [$\alpha$/Fe] for masses between $10^9 - 10^{10} M_\odot$.
In addition to the [$\alpha$/Fe]-stellar mass relation, we find that the [$\alpha$/Fe] of dwarfs also relates with clustercentric distance in nearby clusters and in the the Milky Way. This shows that when the faintest galaxies fall to the environment a rapid burst of star formation is induced, leading to high [$\alpha$/Fe] values. Then different quenching mechanisms blow the gas content away. More massive galaxies are barely affected by the environment, maintaining their gas and producing several bursts of star formation, thus, regulating their stellar populations by internal processes, leading to [$\alpha$/Fe] increasing with mass.

## 1 Introduction

The Local Group used to be our main source of knowledge of dwarf galaxies, but with the newest instruments and telescopes our knowledge of dwarf galaxies is constantly being updating. Dwarf galaxies come in different types such as star-forming and quiescent dwarf galaxies, and each of them is subdivided into high and low surface brightness objects. In this work, we will focus only on the 'classical' low surface brightness dwarfs, mainly on the quiescent dwarf ellipticals (dEs)[2].

Physical mechanisms acting in high density environments like ram-pressure stripping [11] or strangulation [14] can remove the gas from galaxies and stop their star formation [15], thus, changing the morphology of the galaxies and transforming star-forming to quiescent galaxies. Apart from an external process, low-mass galaxies are also sensitive to an internal process that can quench or trigger star formation [12]. Studying the stellar populations, and their relation with internal and external properties of the galaxies, is a way to find out which one of these is more relevant. In clusters of galaxies, dwarf ellipticals are usually old and metal-poor [20], and have solar-like abundance ratio $[\alpha/Fe]$ [10, 27], although, in the core of a cluster, such as Coma, they could also be slightly more $\alpha$-enhanced than in the outskirts [19]. Massive stars, which are the progenitors of SN Type II, live very short lives, and produce mostly $\alpha$-elements, like C, N, O, Mg etc. On the other hand SN Type Ia comes from binaries with at least one white dwarf, and the material produced by these systems is richer in iron than in $\alpha$-elements. Thus, the [$\alpha$/Fe] parameter is a useful parameter to measure how fast star formation proceeded [26]. For giant galaxies there is a strong relation between $[\alpha/Fe]$ and mass [22, 17], which is thought to be due to a much faster enrichment in the more massive galaxies. For dwarfs less massive than $\sim 10^9 M_\odot$, it is unknown what the situation is, and if the relation from the massive galaxies can be extended to the low mass regime.

## 2 Data and analysis

From the Fornax Cluster Catalogue [9] and the Fornax Deep Survey catalogue[25] galaxies with absolute magnitudes in the r-band fainter than -19 mag were selected for spectroscopic observations. Between 2015 and 2018 a total sample of 118 galaxies was observed using the Multi-Object Integral-Field Spectrograph called SAMI [7]. For more details of the spectroscopic observations and target selection see [18]. From the primary targets the kinematic analysis could be performed for 38 dwarfs [18], which constitute our main sample. The sample contains four objects associated with the Fornax A group, and also late-type dwarf irregulars and spirals, as classified by [24], that will not be part of our main analysis.

To analyse the spectra we used the full spectral fitting algorithm pPXF ([6, 5]). Each galaxy spectrum is fitted with a combination of template spectra from a stellar model library, and the properties are obtained as a combination of the model properties. For more details on how to work with pPXF we refer to [5]. For each galaxy we integrated the spectra inside the aperture of SAMI and using the models of the Vazdekis/MILES library [21, 23] we study the stellar population properties. In order to estimate the errors, after the first fit of the stellar population properties we applied a Monte-Carlo (MC) method to retrieve the uncertainties of each parameter. Finally, the age, metallicity and [$\alpha$/Fe] parameters are the mean values of the distribution and the errors are the standard deviation.

## 3 Results

In order to compare our results we re-analysed the spectra of massive early-type galaxies from the ATLAS$^{3D}$ Project [3] using the same methodology described in Section 2. These galaxies are located in the Virgo region of the sky, and as for our SAMI-Fornax dwarfs, we used the integrated spectra. We labeled them as cluster members if the local mean surface density of galaxies is higher than $\log(\Sigma_{10}) > 0.6$ Mpc$^{-2}$ [4].

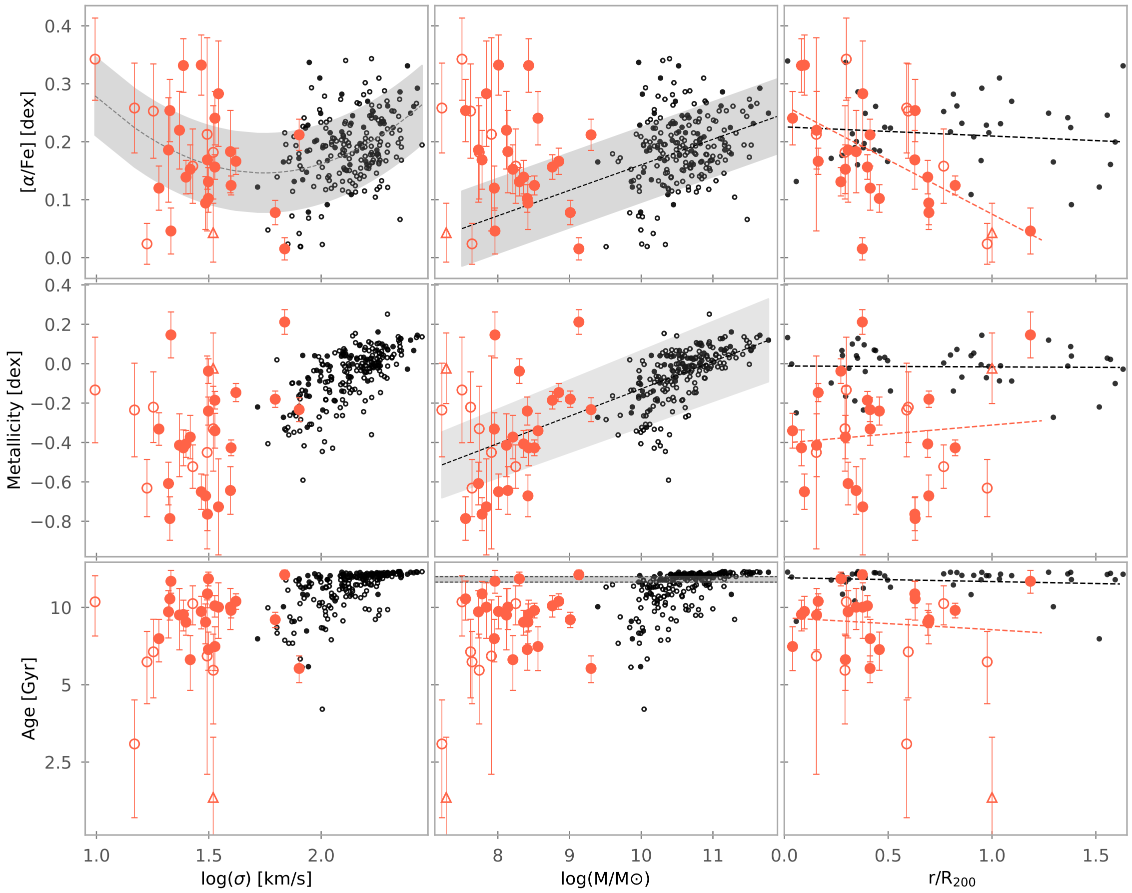

Figure 1: Stellar population properties as a function of the logarithmic velocity dispersion, the stellar mass and the cluster-centric distance, in the left, middle and right column, respectively. The rows show, from top to bottom, the $[\alpha/Fe]$, metallicity and age. For our dwarfs, red circles are for those in the main Fornax cluster and triangles for the ones in the Fornax A group, and the symbols are filled if the S/N is higher than 15. For ATLAS$^{3D}$ we used black-filled circles for cluster galaxies and non-filled black circles for the rest. The black dashed line and grey shaded area on the top left represent a second-degree polynomial fit to all the data, making a U-shape. In the top-center we present the linear fit [$\alpha$/Fe]-log(M/$M_\odot$) taking into account only the galaxies from ATLAS$^{3D}$ project. Since stellar mass and velocity dispersion are tightly related, it is clear that this U-shape can also be applied to the [$\alpha$/Fe]-log(M/$M_\odot$) relation. In the middle center the black dashed line and grey shadow represent the metallicity-mass linear relation for both samples. On every panel of the right column we show with a red or black dashed line the respective linear fit between the stellar population property and the distance to the center of the cluster.

In general our dwarfs show intermediate-old and metal-poor populations, while the massive galaxies are older with solar-like metallicities. Both samples follow the a linear metallicity-mass relation (central panel of Fig. 1), and do not exhibit any kind of trend with the cluster-centric distance for the age nor the metallicity.

For the [$\alpha$/Fe] both samples range between 0.0 and 0.4 dex, which are the limits of the $\alpha$-enhancement grid of the MILES models. The massive galaxies follow a linear relation between [$\alpha$/Fe] and stellar mass, or velocity dispersion, while the dwarfs are disperse above this linear relation. To fit both samples at the same time we used a second-degree polynomial, conforming a U-shape that can be seen in the top left panel of Fig. 1. When looking at the environment the massive galaxies do not show any trend between [$\alpha$/Fe] and the cluster-centric distance. However the dwarf galaxies show a strong relation with the distance, where more $\alpha$-enhanced galaxies are closer to the center.

To further analyse our results we include in our comparison the results of [19] for dwarfs in the Coma cluster. This sample fills the small velocity dispersion gap between our SAMI-Fornax dwarfs and ATLAS$^{3D}$ galaxies. Also, to extend the the range in velocity dispersion in the low end, we include dwarf galaxies within our Local Group that are Milky Way satellites. For this sample we looked for abundances of individual stars in the literature and use as galaxy property the mean value of all its available stars and the standard deviation as the error. It is common to use [Fe/H] abundance as an approximation of the metallicity, and [Mg/Fe] for the overall $\alpha$-enhancement [22, 23].

Figure 2 shows the compilation of [$\alpha$/Fe] values for different types of galaxies and environment. On the top left-hand side panel we present how the metallicity-mass linear relation from Fig. 1 does not agree with the metallicity-mass relation of the Local Group [13]. To fit all the samples at the same time we need a second-degree polynomial. On the bottom left we show that the U-shape can be easily extended to the less massive galaxies of the Local Group. On the right side of Fig. 2 we show the [$\alpha$/Fe] as a function of the distance to the center of the galaxy cluster, or the Milky Way for the Local Group objects. As in our dwarfs in Fornax, those of the Coma cluster and the Local Group also present a trend with the distance, placing the more $\alpha$-enhanced galaxies at the center of the environment. For the dwarfs in the Virgo cluster the relation is almost flat, possibly because Virgo is a less relaxed cluster than Coma and Fornax.

## 4 Conclusions

After comparing the stellar population properties of our SAMI-Fornax dwarfs with more massive galaxies we conclude that the usually found [$\alpha$/Fe]-log($\sigma$) linear relation for massive galaxies, does not fit our dwarf galaxies. Instead a second degree polynomial is more fitting for the whole sample, conforming a U-shape where solar-like abundances are for galaxies of $10^9$-$10^{10}$ $M_\odot$ and then $\alpha$-enhancement values increase for both massive and less massive galaxies. We confirmed the extension of this relation for less massive dwarfs by comparing with abundances of Local Group galaxies. When looking at the environment the $\alpha$-enhancement show a trend with the projected distance to the Fornax cluster, where more enhanced dwarfs are closer to the centre. This relation is persistent in dwarfs in other environments like like Coma, or the Local Group, but to a lesser degree in Virgo. This is because the Virgo Cluster is not fully relaxed and the relation of abundance ratio with clustercentric distance is not fully in place yet.

We can explain both the mass-metallicity and the mass-$\alpha$-enhancement relations using a plausible combination of internal properties, like the mass of the galaxy, and environmental factors, like ram pressure, that can affect galaxies of different mass in different ways.

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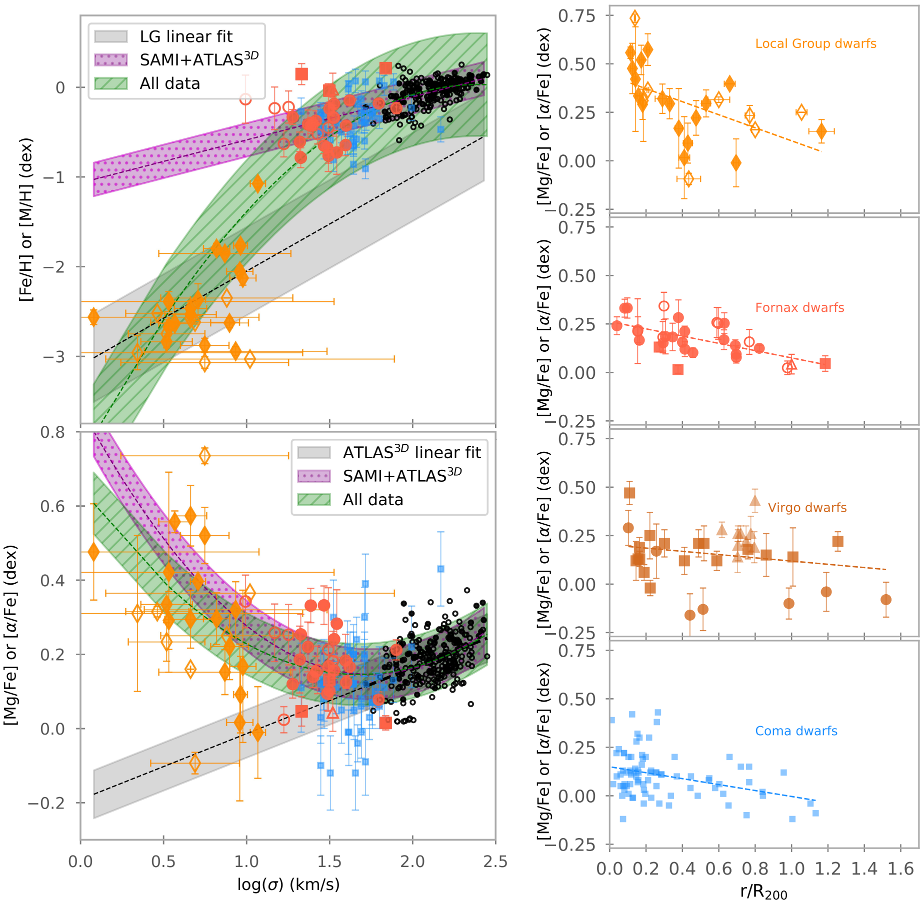

Figure 2: On the top and bottom of the left hand-side panels we show the relation between metallicity and [α/Fe] abundance ratio and stellar velocity dispersion, respectively. We also include a sample of dwarfs in the Coma cluster [19] and measurements of Local Group dwarfs from different works in the literature. Symbols for our SAMI-Fornax dwarfs and ATLAS$^{3D}$ galaxies are the same as in Fig. 1. Light blue squares are for Coma's dwarfs, the orange diamonds are for Local Group dwarfs and the empty orange diamonds are for those objects with 3 or fewer stars. On the top, the purple dashed line and shadow are the linear fit to metallicity-log($\sigma$) for SAMI-Fornax and ATLAS$^{3D}$ samples, the black dashed line and gray shadow is a linear fit the the Local Group objects and the green dashed line and shadow is a second-degree polynomial fit to metallicity-log($\sigma$) for all the objects in the figure. In the bottom, with a black dashed line and grey shadow is the linear relation [α/Fe]-log($\sigma$) only for ATLAS$^{3D}$ galaxies. Purple dashed line and shadow represent the U-shape fit for our SAMI-Fornax and ATLAS$^{3D}$ data, similar to that of Fig. 1, and the green dashed line and shadow represent a second-degree fit to all the data visible in the plot. On the right panels we show the [α/Fe] abundance as a function of the cluster-centric distance for the different environments analysed here. For the dwarfs in Virgo we used the results of [20] (brown squares), [1] (brown triangles) and [16] (brown circles). On every panel there is also a dashed line that represent the linear fit between [α/Fe] and the cluster-centric distance.