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Blue Elliptical galaxies in the Fornax cluster through S-PLUS

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Resumen / En el contexto del proyecto Fornax de S-PLUS (S+FP), recuperamos una población de galaxias azules elípticas en el cúmulo de Fornax, utilizando los datos multi-banda de S-PLUS. A partir del diagrama color-magnitud, seleccionamos objetos azules y los inspeccionamos visualmente mediante las imágenes gri obtenidas por el DESI Legacy Imaging Survey. Estudiando los parámetros morfológicos de estas galaxias encontramos que algunas de ellas se encuentran clasificadas como irregulares y podrían ser remanentes de fusiones. Un aspecto interesante es que ellas parecen haber caído al cúmulo en épocas tempranas.

Abstract / In the context of the S-PLUS Fornax Project (S+FP), we recover a population of blue elliptical galaxies in the Fornax cluster, making use of S-PLUS multi-wavelengths data. From the colour magnitude diagram we selected blue objects and visually inspect the correspondent gri images obtained using Legacy data. Studying morphological parameters of these galaxies we find that some of them are classified as irregular and might be merger remnants. Interestingly, they seem to have fallen in the cluster at early ages.

Keywords / surveys — methods: observational — galaxies: clusters: individual (Fornax) — galaxies: elliptical and lenticular, cD

1. Introduction

Elliptical galaxies (Es) present a smooth ellipsoidal morphology, reflecting the random and often very elongated orbits of their constituent stars. Generally, Es live in the densest regions of the Universe (Dressler, 1980), i.e. in the centre of clusters and groups, and are characterised by an old stellar population, rendering their integrated colour red. With the advent of large scale surveys (SDSS; York et al. 2000), blue Es have been discovered and studied (Strateva et al., 2001; Dhiwar et al., 2022). The blue colour of these galaxies could be due to AGN activity, Post AGB stars, or recent star formation. In the latter case, it is interesting to investigate weather the star formation activity was caused by the accretion of a gas rich dwarf or by the effect of the environment. In this context, blue Es act as a tracer of the mass build-up of galaxies clusters and possibly filamentary structures of the cosmic web (Kuchner et al., 2020). The number of blue Es increases with decreasing redshift, while the number density of the red sequence galaxies is also enhanced (Bundy et al., 2005). It implies that blue rest-frame colors can be the result of minor events of star formation (Gebhardt et al., 2003). Blue Es are generally found in low density environments and present $Log(M_\star) \simeq 9.6\ M_\odot$ (Bamford et al., 2009). Of particular interest is, therefore, studying their location in galaxy clusters. In this work we study a sample of blue Es in the Fornax Cluster, using SPLUS data(Mendes de Oliveira et al., 2019; Smith Castelli et al., 2022).

2. Data

The S-PLUS Fornax Project (S+FP) aims at studying the Fornax galaxy cluster using the images and catalogs provided by the Southern Photometric Local Universe Survey (S-PLUS; Mendes de Oliveira et al. (2019)). The S+FP data consist of wide field (1.4×1.4 deg^2) images obtained in 12 photometric (7 narrow- and 5 broad-) bands of 43 pointings covering $\sim$2.5 Rvir of the cluster (Rvir$\sim$0.7 Mpc$\sim$2 deg) and 63 additional frames covering Fornax outskirts. In addition, we have homogeneous photometry of resolved and unresolved sources located in those 98 S+FP fields from the iDR4 of S-PLUS, as well as additional photometry from two SExtractor runs aimed at recovering bright and faint galaxies not detected in the iDR4 (see Haack et al. in this publication). From the literature, we also compiled a list of $\sim$900 galaxies reported as spectroscopically confirmed ($\sim$20%) or likely Fornax members ($\sim$80%), all of which

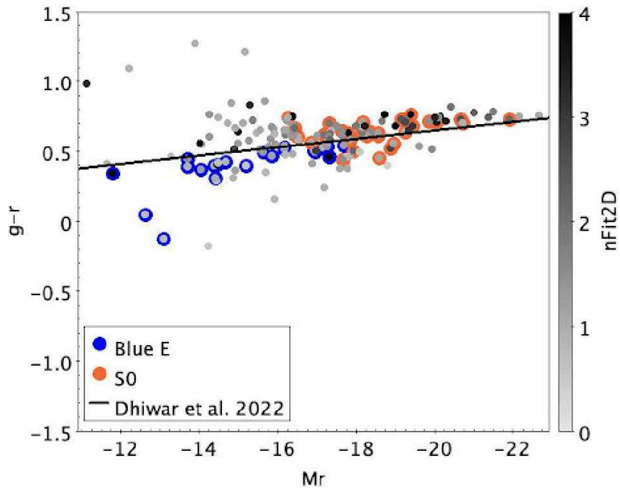

Figure 1: Colour magnitude diagram of Fornax cluster galaxies with confident photometry in the 12 S-PLUS filters. Their absolute magnitudes are obtained as explained in the text. Objects are colour coded according to their Sérsic indices. Brighter objects tend to have higher Sersic indexes. A less evident connection is found between the Sérsic indices and colours. Objects below the black line are defined blue. Symbol codes are as in the legend.

are located in the S+FP fields.

3. Method

In the context of the S+FP, we used a colour-magnitude diagram built from S-PLUS photometry (see Haack et al. in this Boletin) to identify blue Es (Fig. 1). The absolute magnitudes, Mr, are obtained using standard cosmological parameters and the luminosity distances (DL), estimated from the spectroscopic redshifts. The colours are corrected for galactic extinction using values provided by the Nasa Extragalactic Database in the SDSS filters (Schlafly & Finkbeiner, 2011). The best-fit line used to separate objects belonging to the blue cloud is taken from Dhiwar et al. (2022). Then, we visually inspected all the selected objects creating gri colour images from the DESI Legacy Imaging Surveys, which is $\simeq 4$ magnitudes deeper than S-PLUS. We selected objects having smooth spheroidal shapes, shown as blue circles in Fig. 1. In Fig. 2 we show the location of the blue Es, as well as of S0 galaxies, and the two brightest galaxies in Fornax: NGC 1316 and NGC 1399.

Moreover, we obtained morfometric parameters of r-band Legacy images for the whole sample, using the Morfometrika (MFMTK) software (Ferrari et al., 2015b). MFMTK is an algorithm designed and developed to perform structural, photometric and morphometric measurements on galaxy images (Ferrari et al., 2015a). The program estimates, among other quantities, single Sérsic 1D and 2D fit parameters and non-parametric morphometric parameters like concentration, asymmetry, M20, σ_ϕ (used to computed as the image-gradient of the polar map etc.). Detailed explanation of the parameters can be found in Ferrari et al. (2015b).

4. Results

We studied the relation between galaxy morphological visual classification and the morfometric parameters. For example, Fig. 3 shows the location of galaxies in the Asymmetry versus Concentration diagram: lenticular galaxies are shown as orange points and blue Es as blue points. Regions where galaxies of a given morphological type tend to fall (see Neichel et al., 2008) are separated by black lines and labeled accordingly. The majority of the blue Es populate the part of the diagram of early-type galaxies. Two of them are classified as irregulars and other two as disks.

Then, we investigated the location of the blue Es in the cluster environment, comparing the location of galaxies in the cluster with simulations (Rhee et al., 2017), and the connection between morfometric parameters and the environment. Specifically, we assigned to every galaxy a probability of belonging to a given region of the projected phase-space (PPS) of the Fornax cluster, as recovered using radial velocities from Maddox et al. (2019). The regions where defined as in Rhee et al. (2017), who made use of cosmological hydrodynamic N-body simulations of groups and clusters to define a projected phase-space diagram and split it up into distinct regions (labelled A–E), chosen to try to maximize the fraction of a particular time since infall population. For example, region A is dominated by a population of recent infallers, while region E is populated by ancient infallers (see Rhee et al., 2017, and Brambilla et al. 2023). In Fig. 4 we show the location of the galaxy sample in the M_{20} vs σ_{psi} plane, where M_{20} is the moment of the fluxes of the brightest 20% of the light in a galaxy, normalized by the total light moment of all pixels (Lotz et al., 2004; Conselice et al., 2008). It is affected by spatial variations and it is sensitive to possible mergers. The parameter σ_{psi} (Ferrari et al., 2015a) is a measure of the presence of coherent substructures in the galaxy image, and it is a good proxy to separate between early and late type galaxies. Surprisingly, blue Es inhabiting region E, where ancient infallers are found, show a high disturbance in their isophotal profiles. Could it be the result of mergers or simply the effect of the continuum harassment of the other cluster galaxies? We are now exploring the galaxies stellar populations, in order to date the last star formation episode and characterize the cause of the blue color.

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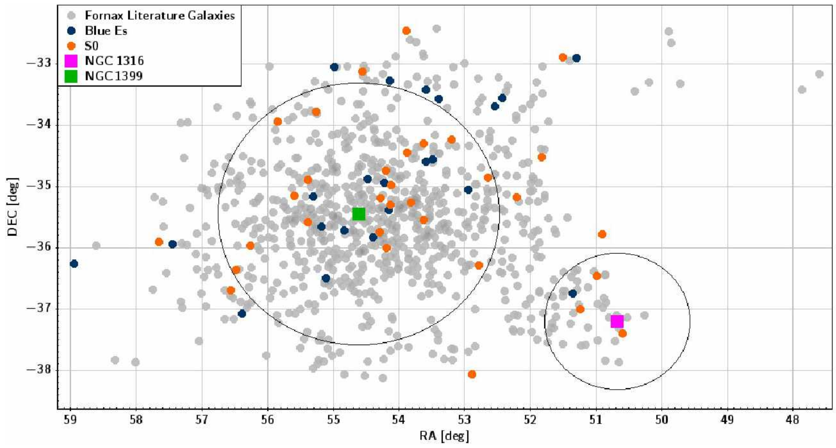

Figure 2: Spatial distribution of Fornax cluster galaxies. The great circles define the virial radius of the Fornax cluster (Rvir∼0.7 Mpc, big circle) and that of the infalling subgroup around NGC 1316 (Rvir∼0.35 Mpc, small circle), respectively (Iodice et al., 2019). Symbol codes are as in the legend.

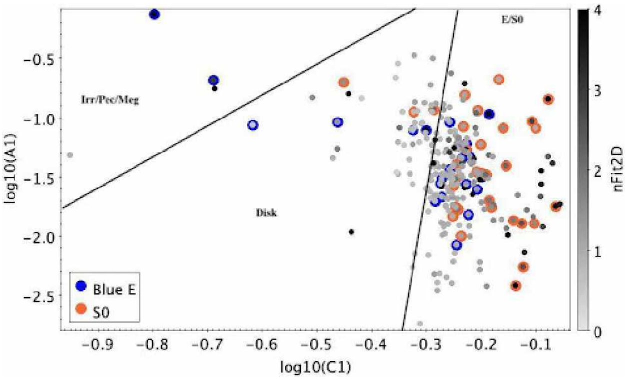

Figure 3: Asymmetry vs concentration plot. Galaxies with different morphologies occupy different areas of the plot, black lines are from Neichel et al. (2008). Mergers remnants tend to have larger values of A1 and lower concentrations, early type galaxies occupy the right part of the plot and disk galaxies lie in between. Objects are color coded according to their Sérsic index. Symbol codes are as in the legend. Blue Es seem to be composed by different types of galaxies.

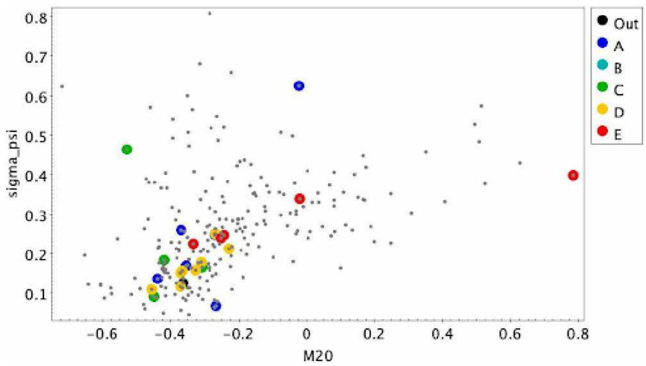

Figure 4: Second moment of light (M_{20}) vs spirality (σ_{psi}). Larger dots correspond to blue Es, colour coded according to the PPS region they belong to (see diagram from Rhee et al., 2017). Ancient infallers seem to have high spirality, suggesting recent encounters.

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*http://www.starlink.ac.uk/topcat/(TOPCAT)