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Blue Elliptical Galaxies in the Fornax Cluster through S-PLUS Data

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Abstract. Elliptical galaxies (E) are known for being located in dense regions of the universe and to exhibit a smooth and regular ellipsoidal shape. One of their main characteristics is their reddish color, related to their old stellar population. However, recent studies have revealed the existence of blue elliptical galaxies, typically low-mass galaxies found in low-density regions. Their formation still an open field of study. Our particular interest lies in studying their location in galaxy clusters. Using data from the S-PLUS catalog, we aim to study the blue elliptical galaxies of the Fornax Cluster using multi-band photometry. The S-PLUS data are complemented by data from the DES Legacy Imaging Surveys, which are deeper than the S-PLUS data and allow for the identification of substructures and satellites. Morphometric parameters were obtained using the Morfometryka software, based on the r-band images from the Legacy survey. With the aid of Principal Component Analysis (PCA), we identified the parameters that best separate galaxy morphology obtained by visual classification. We identify blue elliptical galaxies using a colour magnitude diagram and visual inspection (in total 25 objects). We find that the majority of the identified blue elliptical galaxies are consistent with being dwarf spheroids ($M_r < -19$), spanning a range of morphological parameters, which suggest they are a composite class of objects, whose blue colour could be the result of different processes, such as star formation and AGN activity.

Resumo. Galáxias elípticas (E) são conhecidas por habitarem regiões densas do universo e por sua forma elipsoidal suave e regular. Uma de suas principais características é sua cor avermelhada, associada a uma população estelar antiga. No entanto, estudos recentes revelaram a existência de galáxias elípticas azuis, que são tipicamente sistemas de baixa massa encontrados em regiões de baixa densidade. Sua formação ainda é um campo de estudo em aberto. Nosso interesse particular é investigar sua localização dentro de aglomerados de galáxias. Usando dados do catálogo S-PLUS, buscamos estudar as galáxias elípticas azuis no Aglomerado de Fornax por meio de fotometria multibanda. Os dados do S-PLUS são complementados por observações mais profundas dos DES Legacy Imaging Surveys, permitindo a identificação de subestruturas e galáxias satélites. Os parâmetros morfométricos foram obtidos utilizando o software Morfometryka, com base em imagens na banda-r do levantamento Legacy. Com o auxílio do Principal Component Analysis (PCA), identificamos os parâmetros que melhor diferenciam as morfologias das galáxias obtidas por classificação visual. As galáxias elípticas azuis foram identificadas por meio de um diagrama cor-magnitude, combinado com inspeção visual, resultando em um total de 25 objetos. Nossos resultados indicam que a maioria desses objetos identificados são consistentes com anãs esferoidais ($M_r < -19$), abrangendo uma variedade de parâmetros morfológicos. Isso sugere que elas constituem uma classe mista de objetos, cuja cor azul pode ser resultado de diferentes processos, como formação estelar em andamento ou AGNs.

Keywords. Galaxies: evolution – Galaxies: clusters: general – Galaxies: elliptical and lenticular, cD

1. Introduction

Hubble's classification scheme (Tuning Fork diagram, Hubble 1936) categorizes galaxies based on their morphology into two primary types: early type galaxies (elliptical and lenticular), typically red because of their older, metal-rich stellar populations, and late type galaxies (spiral and irregular), exhibit a blue color reflecting the presence of star formation. The morphology-density relation (Dressler, 1980), a well-known trend in galaxy evolution, shows that elliptical galaxies are commonly found in dense cores of galaxy clusters, while spirals dominate less dense regions such as galaxy outskirts and the field. However, a class of galaxies known as "Blue Ellipticals" has emerged as an intriguing subject of study (Bamford et al., 2009). Our research focuses on studying these galaxies within the Fornax cluster (D∼20 Mpc; Smith Castelli et al. 2024) to better understand their origins and the role of the environment in their formation.

2. Data

The S-PLUS Fornax Project (S+FP: Smith Castelli et al. 2024) aims to study the Fornax cluster using images provided by the Southern Photometric Local Universe Survey (Mendes de Oliveira, 2019). The S+FP data consist of wide-field (1.4×1.4 deg^2) images obtained in the 12 photometric bands of S-PLUS, of 106 pointings that cover ~ 208 deg^2 around NGC 1399. In addition, we have obtained improved photometry to detect faint and compact objects in the surroundings of bright galaxies and optimize the detection and characterization of star-forming and large galaxies. It also solves the non-detection or excessive subdivision of galaxies into more than one object, which is an issue found in the S-PLUS released catalogs. Our data is complemented by the DES Imaging Survey (DES Coll., 2016), which provides deeper images than those of S-PLUS.

3. Methodology

In the context of the S+FP, we started with a visual inspection of the galaxies contained in the sample derived from the literature, to perform an initial classification of their morphologies (Smith Castelli et al., 2024). In this pilot study, we focus on galaxies within two virial radiuses with know spectroscopic redshift, containing 241 objects.

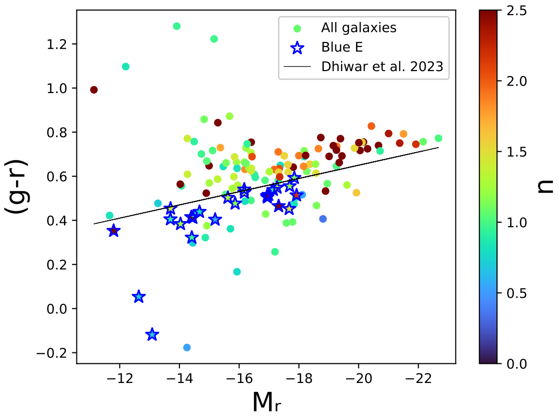

Figure 1. Colour magnitude diagram of Fornax cluster galaxies. The absolute magnitude is obtained from the Photometric redshift. Objects are colour coded according to their Sersic Index.

Initially, we built a color-magnitude diagram from S-PLUS photometry (g-r vs. Mr) to identify blue objects, see Smith Castelli et al. (2024). The magnitudes were corrected for galactic extinction and the absolute magnitudes were obtained using standard cosmological parameters and the luminosity distance (D_L) estimated from the photometric redshift, based on the following relation: $M_r = m_r - 5(log(D_L) - 1$, where m_r is the *auto* magnitude in the $r - band$.

In Fig.1, the objects characterized as blue are the ones that fall in the blue cloud, as determined by the black line (Dhiwar et al., 2022). Then, we created images of all the blue galaxies using the DES Legacy Imaging Survey, which is $\simeq$ 4 times deeper than the S-PLUS survey, allowing us to see substructures and satellites. After that, we selected objects that seemed to exhibit an ellipsoidal morphology, without spiral arms, and referred to them as blue early type galaxies, leading to a total of 25 objects. Our main goal is to study the relation with the environment and the stellar population of the identified blue early type galaxies.

In order to obtain a more precise analysis of the morphology of the galaxies in our sample, We obtain the non parametric estimations (e.g. Concentration (C), Asymmetry (A)...) using the code Morphometryka (MFMTK, Ferrari et al. 2015). MFMTK is a cutting-edge program for retrieving the morphometric parameters of galaxies. In order to identify the parameters that better separate the objects in our sample in different categories with regard to their visual morphology, we employed Principal Component Analysis (PCA), a statistical technique designed to simplify data analysis by reducing its dimensionality while preserving as much variability as possible in the reduced-dimensional space from the original dataset.

Fig. 2 shows the parameters used in the PCA analysis and their variance within the first principal component, PC1. This result highlights the contribution of each parameter to this component, which has the largest variance and thus exerts the strongest influence on the classification of galaxies. For example, Fig. 2 shows that the two parameters that best separates galaxies due to their morphology, according to PC1, are smoothness (S_3) and petrosian radius (R_p).

Fig. 3 shows how the combination of PC1 and PC2 is able to separate galaxies presenting different morphologies. The points are color-coded based on the galaxy morphology, as described in the caption, showing a clear separation between early and late type galaxies.

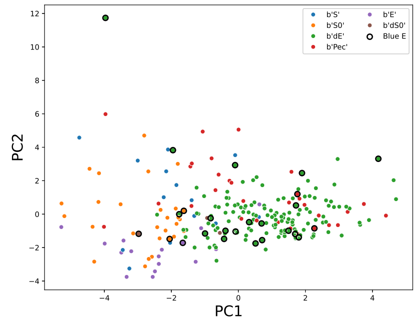

Figure 2. Result of the PCA, showing the variance of the parameters associated to the first component, PC1

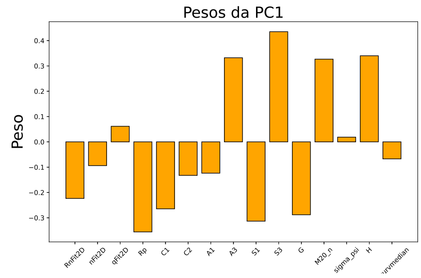

Figure 3. 2D plot showing the morphological classification of the sample based on the results obtained from the PCA. Color-coded based on its morphology, as described in the caption.

4. Conclusion

Throughout this work, 25 galaxies were classified as blue ellipticals. Fig. 2 illustrates a result of the PCA, showing that, while PC1 and PC2 can correctly separate S, S0, E, and dE, blue E galaxies seem to be a composite class of objects. In order to further investigate, we intend to obtain the color gradient of these blue galaxies and study its relationship with their morphological characteristics and environment (through the phase-space diagram) to better understand their formation processes. Finally, our study will be expanded to include AGNs, by performing a SED fitting of the 12 S-PLUS bands.

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