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The effect of the extragalactic environment on the evolution of S0-type galaxies

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Abstract. This research represents a comprehensive effort to unravel the complexities regarding the formation of S0 galaxies. This study employs the S-PLUS survey to select low- and high-mass S0 galaxies for a detailed investigation. We use GALFITM code to optimize the accuracy of morphological measurements across a range of wavelengths (3543 – 9134 Å). Specifically, we use two Sersic profiles to parameterize and better understand the morphological characteristics, capturing the contributions of S0 galaxies' light both to the bulge and disk components. Using morphological parameters and colours obtained from high-mass galaxies, this work successfully identifies analogous galaxies within the IllustrisTNG hydrodynamic simulation. Our approach facilitates the reconstruction of galaxy merger trees, allowing for a detailed analysis of correlations with environmental aspects, galaxy mass, stellar population properties, and presence of an active galactic nucleus and its evolutionary history. We are expanding our current sample to encompass intermediate- and low-mass S0 galaxies, which is a fundamental to discriminate between nature and nurture in the formation of these galaxies, as well as identifying primordial lenticular galaxies.

Resumo. Esta pesquisa representa um esforço abrangente para desvendar as complexidades relacionadas à formação de galáxias do tipo S0. Este estudo utiliza a pesquisa S-PLUS para selecionar galáxias S0 de baixa e alta massa, visando uma investigação detalhada. Utilizamos Funções de Propagação de Pontos (PSFs) e o código GALFITM para otimizar a precisão das medidas fotométricas em uma variedade de comprimentos de onda (3543 – 9134 Å). Além disso, empregamos dois perfis de Sérsic para parametrizar e compreender melhor as características morfológicas, capturando as contribuições da luz das galáxias S0 dos componentes de bojo e disco. Ao comparar os parâmetros morfológicos obtidos de galáxias de alta massa, este trabalho identifica com sucesso galáxias análogas dentro da simulação hidrodinâmica IllustrisTNG. Nossa abordagem facilita a reconstrução das árvores de fusão galáctica, permitindo uma análise detalhada das correlações com aspectos ambientais, massa da galáxia, propriedades da população estelar e a presença de um núcleo galáctico ativo, bem como sua trajetória evolutiva. Estamos ampliando nossa amostra atual para incluir galáxias S0 de massa intermediária, o que é crucial para obter uma visão abrangente da formação dessas galáxias S0.

Keywords. Galaxies: evolution – Galaxies: structure – Galaxies: elliptical and lenticular, cD

1. Introduction

S0-type galaxies are seen as hybrid galaxies, combining features of both spiral and elliptical galaxies. They possess spiral-like disks, but they lack substantial gas, which limits extensive star formation. This leads to their stars being generally older, resembling elliptical galaxies. In the literature, there are three main theories, regarding S0s formation paths. One theory proposes that when a gas-rich spiral galaxy enters a cluster environment, it loses its gas and dust content (Johnston et al. 2021). The second possibility is that galaxies result from minor or major mergers (Tapia et al. 2017). The third possibility is that galaxies are primordial objects that formed around redshift 2 (Saha & Cortesi 2018).

Lenticular (S0) galaxies, make up nearly 50% of the high mass galaxies in the Local Universe (Bernardi et al. 2010). S0-type galaxies give us information about the environment they live in. For example, on the effect of the hot intracluster gas. If they are primordial galaxies, they serve as crucial connections in the record of galactic evolution—an archive from an early era of galaxy formation. Our objectives are characterizing the observational properties of S0 galaxies using the S-PLUS survey, identify S0-type galaxies in simulations, searching for those that share key characteristics such as morphological parameters, stellar populations, and mass, with lenticular galaxies and compare the photometric properties of simulated galaxies with those derived from S-PLUS data.

2. Data

First, we obtain data from the Southern Photometric Local Universe Survey (S-PLUS; (Mendes de Oliveira et al. 2019)). S-PLUS is a survey that will capture images of approximately 9300 square degrees of the celestial sphere in 12 optical bands using a dedicated 0.8 m robotic telescope, the T80-South, located at the Cerro Tololo Inter-American Observatory in Chile. That sample was selected by Geferson Lucatelli and Arianna Cortesi (in prep.) utilizing PS0 data from Galaxy Zoo, combined with ambiguous galaxies (Bom et al. 2021), and further refined through visual inspection. We obtained a sample of 974 bona-fide lenticular galaxies.

3. Methodology

We use LePHARE[1] to recover the galaxy stellar population properties. LePHARE fits stars and galaxies spectral energy distribution (SED) using theoretical and empirical libraries. For our study, we use the Cosmos library (which is based on real observations) and the BC03 library (which is theoretical).

At the same time, we adjust galaxy images with GALFITM ((Häußler et al. 2022)), a two-dimensional fitting algorithm, designed to extract their structural components, simultaneously in several bands, see Figure 1. In particular, we use the Sersic law, to describe how the intensity, I, of the galaxy light varies with

[1] `https://www.cfht.hawaii.edu/~arnouts/LEPHARE/lephare.html`

the distance, R, from its center, to describe the bulge and disk light as below:

$$I(R)_{bulge} = I_n\, exp\left\{-b(n)\left[\left(\frac{R_n}{R}\right)^{1/n} - 1\right]\right\}$$

$$I(R)_{disk} = I_n\, exp\left\{-b(n)\left[\left(\frac{R_n}{R}\right) - 1\right]\right\}$$

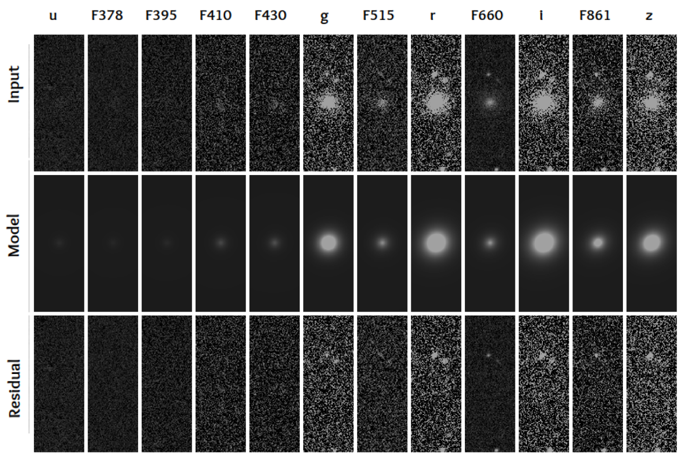

Figure 1. This is a photometric model for a low-mass S0 galaxy. The top row displays the galaxy images in 12 bands, the galaxy is faint in the bluer wavelengths, as expected. The middle row is a bulge-disk model generated by GALFITM, using two Sersic profiles. The bottom row presents the residuals obtained subtracting the model from the input image.

We use the recovered parameters, star-forming gas fraction, specific star formation rate, Sersic index, concentration index, Gini coefficient, M-20 statistic, and color indices, to identify S0 like analogs in the IllustrisTNG simulation. IllustrisTNG () is a group of hydrodynamic simulations that allow us to trace back galaxies' formation histories.

4. Results

From the GALFITM model, we obtained the single Sersic index (n) for 100 galaxies. In Figure 2, we see that low mass S0s have lower Sersic indexes and bluer colours. The value of n should ideally range from 1 to 8. A substantial increment in the value of n may indicate the presence of an Active Galactic Nucleus (AGN), as illustrated in Figure 3.

Furthermore, using the morphological parameters for high mass lenticular galaxies, we identified a total of 51 S0 analogs in IllustrisTNG. Following a visual inspection, 34 of them have been confirmed to exhibit S0-like characteristics.

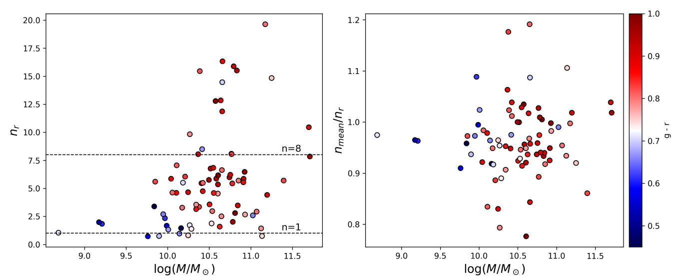

Figure 2. Analyzing 100 selected galaxies from a pool of 974, we depict the relationship between mass and Sersic index. The colorbar indicates the distribution of points based on (g-r) color.

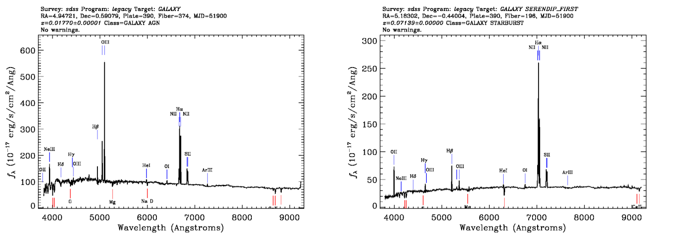

Figure 3. The two SDSS spectra are part of the 100 analyzed galaxies and have a Sersic index greater than 8. Their values are 8.28 (AGN) and 13.66 (Starburst), respectively. Thus, we can observe that the increase in emission lines might lead to an increase in the Sersic index.

Additionally, we successfully reconstructed the merger tree of the analogous galaxies, see Figure 4 for an example.

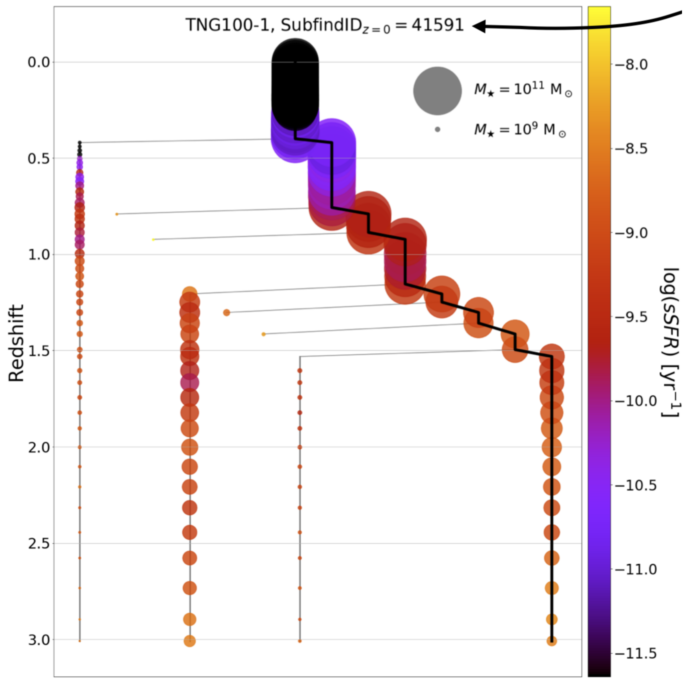

Figure 4. This is the first example of a merger tree for one of the S0 galaxies discovered by our collaborators in Illustris, utilizing the morphological and stellar population parameters recovered with S-PLUS.

In the next steps, by combining the formation histories of high low-mass simulated objects, we will determine the influence of environment, mass, and the presence of an active galactic nucleus in the formation of lenticular galaxies.

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References

Bernardi M., Shankar F., Hyde J. B., Mei S., Marulli F., Sheth R. K., 2010, MNRAS, 404, 2087

Bom C. R., et al., 2021, MNRAS, 507, 1937

Häußler B., et al., 2022, A&A, 664, A92

Johnston E. J., et al., 2021, MNRAS, 500, 4193

Mendes de Oliveira C., et al., 2019, MNRAS, 489, 241

Saha K., Cortesi A., 2018, ApJ, 862, L12

Tapia T., Eliche-Moral M. C., Aceves H., Rodríguez-Pérez C., Borlaff A., Querejeta M., 2017, A&A, 604, A105