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Classifying cluster galaxies using UV emission and optical data

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Abstract. We study the early type galaxies with emission UV in the projected phase space of clusters using data from GALEX and SDDS for the classification and analysis of these galaxies. For this, we rebuilt the C4 catalog and selected the early type galaxies using the T-Type and concentration index parameters, and a final check with the Galaxy Zoo ratings. Our sample has 1632 galaxies that were divided into four types according to the degree of UV emission determined in the color space (FUV − NUV, NUV − r, FUV − r). Our partial results indicate that objects with strong ultraviolet emission (corresponding to 11% of our sample) are less massive and are found in the periphery of more massive clusters $\log M_{200} > 14.62$. We also saw that all galaxies in the sample in massive clusters have an excess in the peripheral region of these systems, but only in those with strong emission (NUV − r < 4) is this related to the stelar mass of the galaxies. These results, together with the correlation found between degree of UV emission, position of peak density in the phase space of the clusters, and fraction of lenticular galaxies, seem to indicate that environmental effects act on early type objects and are related to their UV emission.

Resumo. Estudamos as galáxias de tipo precoce com emissão UV no espaço de fase projetado de aglomerados usando dados do GALEX e SDDS para a classificação e análise dessas galáxias. Para isto, reconstruímos o catálogo C4 e selecionamos as galáxias de tipo precoce usando os parâmetros T-Type e índice de concentração, além de uma verificação final com as classificações do *Galaxy Zoo*. A nossa amostra conta com 1632 galáxias que foram divididas em quatro tipos de acordo com o grau de emissão UV determinado no espaço de cores (FUV − NUV, NUV − r, FUV − r). Nossos resultados parciais indicam que objetos com emissão forte no ultravioleta (correspondendo a 11% de nossa amostra) são menos massivos e encontram-se nas periferias de aglomerados mais massivos $\log M_{200} > 14.62$. Vimos também que todos as galáxias da amostra em aglomerados massivos têm um excesso na região periférica desses sistemas, mas que apenas no caso daqueles com emissão forte (NUV − r < 4) isto está relacionado com a massa estelar das galáxias. Estes resultados, juntamente com a correlação encontrada entre grau de emissão UV, posição do pico de densidade no espaço de fase dos aglomerados, e fração de galáxias lenticulares, parecem indicar que efeitos ambientais atuam sobre os objetos de tipo precoce e estão relacionados com sua emissão de UV.

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

1. Introduction

Early-type galaxies (ETGs) are generally characterized by low star formation rates (eg, Kennicutt & Kent 1983). They are believed to be evolved galaxies, formed by a series of gas-rich galaxy fusions, occurring at cosmological (especially elliptical) time scales; or through a process of continuous secular evolution that slowly transformed into late-type galaxies into early-type galaxies (mainly S0 galaxies, see, for example, Laurikainen et al. 2010). Their star formation rates are low, usually presenting SFR < 0.6 $M_\odot$ yr^{-1} for objects of type T < 0. However, several observational evidences has found that early type objects can be much less relaxed and inactive than previously considered. Most SFR studies are based on the emission of H_α, but another tracer, the continuous emission in the ultraviolet (UV) region, can also be considered. Massive young stars emit most of their energy in this part of the spectrum, and the UV emitted flux in spiral galaxies is an excellent measure of their current SFR. One point to note is that the intensity of this UV recovery varies greatly between galaxies (see O'Connell 1999), objects can be classified according to their UV color (Yi et al. 2007, 2011). Burstein et al. (1988) showed that galaxies with greater abundance of heavy elements show higher UV recoveries. These results suggest that star formation may continue to be active in ETGs at a rate sufficiently low to be undetectable in the optic but to be observed in UV. It is important to note that the spatial distribution and spectral shape of the UV recovery phenomenon cannot be explained by a simple increase in recent star formation, requiring some other explanation.

Table 1. Properties of galaxy types

type	D4000	$M_{stellar}$	M_{200}
I	$1.47^{+0,04}_{-0.04}$	$10.83^{-9,32}_{-9,40}$	$14.34^{-12.83}_{-12.91}$
II	$1.82^{-0.31}_{-0.39}$	$10.99^{-9.48}_{-9.56}$	$14.29^{-12.78}_{-12.86}$
III	$1.93^{-0.42}_{-0.49}$	$11.06^{-9.55}_{-9.63}$	$14.17^{-12.65}_{-12.73}$
IV	$1.95^{-0.43}_{-0.51}$	$11.14^{-9.63}_{-9.71}$	$14.19^{-12.68}_{-12.76}$

2. Methods

We have compiled a sample of 1403 nearby ($0.03 < z < 0.13$) early type galaxies from an updated version of the C4 catalog (Miller et al. 2005), selected by matching the Galaxy Evolution Explorer (GALEX) Medium Imaging Survey (MIS) with the Sloan Digital Sky Survey (SDSS) Data Release (DR15). Our sample has galaxies with $Mr \leq -20.5$ and have FUV (far ultraviolet) an NUV (near ultraviolet) emission. For morphology, we associate the T type classification of Domínguez Sánchez et al. (2018). The early-type sample is defined according to $T < 0$ and $C > 2.5$. Following Yi et al. (2005) we use $NUV - r = 5.4$ as a criterion that separates quiescent galaxies from star-forming elliptical galaxies. The spectral slope is indicative of the temperature of the hot stars required for the upturn UV, so we adopt $FUV - NUV \leq 0.9$ as a criterion for increasing UV slope with the wavelength. The typical and corrected FUV-V value adopted by Yi. et al. (2011) is $FUV - V \leq 6.6$. Finally, galaxies bluer than $NUV - r = 4$ are classified as a recent SF population. The galaxy distribution in the color-color space is presented in Figure 1.

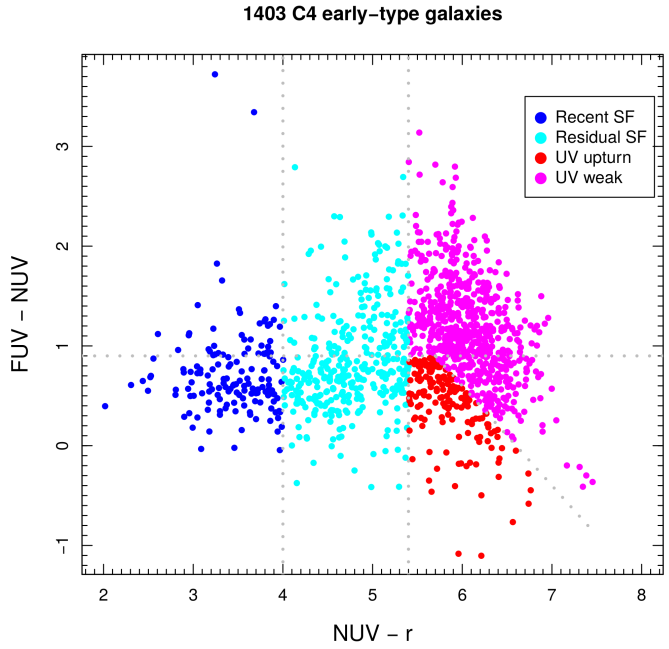

Figure 1. Color-color diagram of UV upturn classification of the elliptical galaxies in our sample. The dotted lines separate the classes of UV galaxies.

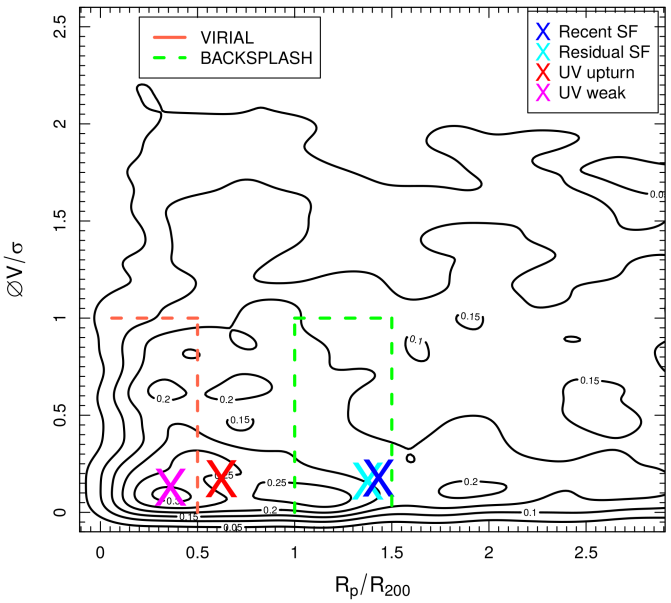

Figure 2. Projected phase space of the sample, each point indicates the density peak of the galaxy populations. The dashed lines limits the probability regions of Mahajan et al. (2011).

3. Results and Discussion

Our results indicate significant differences between the properties of galaxies classified this way – see Table 1. In addition, by analyzing the distribution of these galaxy types in the phase space of the clusters, we see that objects with weak UV emission are concentrated in the virial region, while UV upturn objects are slightly offset from this region, but still within R_{200}.

Interestingly, we see in Figure 2 that objects with recent and residual SF have backsplash-centered distributions, which is in agreement with the variation observed in D4000, which shows a clear division between systems I & II (blue and cyan) and III & IV (red and magenta). These objects also have higher fractions in more massive clusters - see Figure 3. In this figure we see that early-type galaxies with recent SF are clearly bimodal with respect to the mass of their host clusters. Objects taken from clusters with $\log M_{200}/M_{\odot} \leq 14.62$ (LMC) have smaller clustercentric distances compared to those taken from clusters with $\log M_{200}/M_{\odot} > 14.62$ (HMC).

We also found a slight (but significant) excess of type I objects in LMC at the upper end of stellar mass distribution, and an excess of type I objects in HMC at the lower end of the distribution.

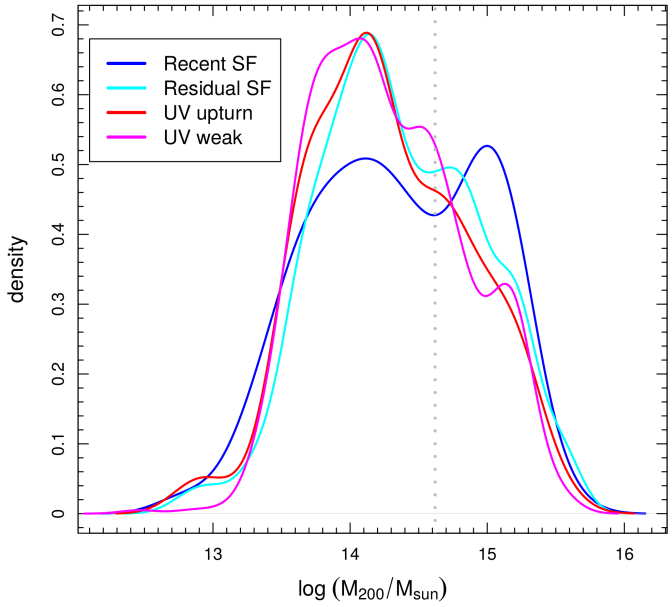

Figure 3. Distribution of galaxy types according to the mass of their host clusters. The dashed line indicates the antimode of the type I population.

4. Conclusion

Taken together, these results indicate that early-type galaxies classified in the UV color-color diagram are different in their intrinsic and kinematic properties, which suggests that environmental effects may be related to the UV emission phenomenon in early-type galaxies. This conclusion is corroborated by the fact that when removing S0 and AGN objects from our sample, the results are kept at the same significance. A more complete scenario for these objects can be traced after obtaining additional results that will be obtained in the fine stages of this work, which are still in progress.

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