Exploring The Characteristics of Low-Mass Elliptical Galaxies in Cosmic Voids

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Abstract

In this work, we investigated low-mass elliptical galaxies in the void environments at z=0 based on semi-analytical Millennium simulation data. According to our results, there are two populations of galaxies in the low-mass part of elliptical void galaxies that have different half-mass radii despite the same mass ranges. According to our results, these two populations of compact and diffuse elliptical galaxies have different mass assemblies and, as a result, different evolutionary histories. In this article, we analyzed the morphology, the mass of the central black hole, and the virial mass of each galaxy, and we used MassFromMergers, MassFromBursts, and MassFromInSitu for comparison. Differences in these parameters could be different evolution of these low-mass galaxies.

Keywords: galaxies: evolution – galaxies: structure –galaxies: stellar content – galaxies: fundamental parameters

INTRODUCTION

The characteristics of galaxies have been observed to be influenced by their surrounding environments. In 1980, Dressler highlighted that areas with lower local density tend to have a higher proportion of late-type spiral galaxies. The pattern was alike for star formation rates (SFRs): galaxies that are actively forming stars are found in less dense areas. Conversely, the largest elliptical galaxies and those with low SFRs are more likely to be located in highly populated environments, particularly within rich clusters of galaxies. (e.g. Postman & Geller 1984; Dressler et al2004).
Hogg et al. (2004) demonstrated that bulge-dominated galaxies, which are characterized by large S´ersic indices, exhibit a color-magnitude diagram where red galaxies are predominant in various local environments. The study also found that the most luminous galaxies tend to be situated in high-density regions, while blue galaxies are predominantly found in low-density regions.
The mechanisms of galaxy evolution can generally be divided into two groups: effects driven by the environment and effects driven by mass. The former category includes processes such as galaxy harassment (e.g. Moore et al. 1996), ram pressure stripping (Gunn & Gott 1972), viral shock heating (e.g. Dekel & Birnboim 2006; Cen 2011) and mergers (Toomre & Toomre 1972), whilst the latter include secular processes such as active galactic nucleus (AGN) feedback (e.g. Croton et al. 2006) and mass quenching (e.g. Kauffmann et al. 2003; Geha et al. 2012). Generally, it is difficult to separate these processes throughout a galaxy's lifetime, especially in high-density environments where many of these mechanisms act on a galaxy simultaneously.
The distribution of galaxies and matter on a large scale is mainly influenced by various structures like groups, clusters, filaments, and walls. However, voids, which are large under-dense regions, occupy most of the volume of the Universe and are the prominent structures at large scales. To understand the influence of the environment on galaxy formation, most of the previous studies have focused on the properties of galaxies in high-density regions (e.g. Scarlata et al. 2007; Bower et al. 2008) and few studies have focused on field and void galaxies. Since there are no complex processes such as close encounters and galaxy mergers in void regions, void galaxies are excellent probes of the effect of environment and cosmology on structure formation and galaxy evolution.
The population of void galaxies tends to be dominated by low-mass, blue, star-forming galaxies with young stellar populations (see for instance: Rojas et al. 2004; Hoyle et al. 2005) Galaxies in these environments may experience lower gravitational forces due to the lower matter density, potentially resulting in slower star formation and, consequently, smaller stellar masses (Rodr´ıguez-Medrano et al .2024).
Several recent studies provide evidence of the growth in the size of galaxies from redshift 2–3 to the present.

(Daddi et al. 2005; Trujillo et al2006). Evidence is especially strong for the most massive early-type galaxies which have increased in size by a factor 4.3 since z~2.3. There is also evidence that late-type systems have increased their size 2.6 times over the same z interval (Buitrago et al. 2008). Scenarios have been proposed to explain this size evolution including environmentally dependent and independent processes. The most likely and accepted mechanism involves growth from dry minor mergers (Bell et al. 2005; van Dokkum 2005) believed to be more efficient for increasing the size than the stellar mass of galaxies.

In this work, we investigated elliptical galaxies in the void environment using Millennium semi-analytical simulation data. Our knowledge of ellipticals is strongly biased towards over-dense regions such as clusters. But what of the fine structure of ellipticals in voids? According to theoretical predictions, void galaxies should have different merger histories than those in clusters.

DATA AND SAMPLE SELECTION

To investigate the characteristics of elliptical galaxies in a void environment, we use simulated galaxies from the Millennium cosmological simulation (Springel et al., 2005). We use the full simulation box which is a cube with a size of 500 Mpc. We choose our simulated galaxies from catalogs (MRscPlanck1) of galaxy merger trees generated by applying the semi-analytic code L-Galaxies, as outlined in Ayromlou et al. 2021, to subhalo merger trees adjusted to conform to the Planck cosmology with $\Omega_\Lambda = 0.685$, $\Omega_m = 0.315$, $n_s = 0.961$, $\sigma_8 = 0.826$, m_p (M_{sun}/h) = 9.61104×10^8, L (Mpc/h) = 480.279 and $h = 0.673(\mathrm{kms^{-1}\,Mpc^{-1}})$ for comparison with other studies analyzing the relation between stellar mass and size. The L-Galaxies model comes equipped with a comprehensive chemical enrichment scheme developed by Yates et al. in 2013. Additionally, it includes galaxy stellar and gas discs that are resolved radially, as described in Fu et al.'s work from 2013. The database for this model also encompasses the Local Background Environment properties of subhaloes, which were outlined by Ayromlou et al. in 2019.

We selected all simulated galaxies brighter than ~ -18 in the r-band filter and lie in the z $\sim$ 0 (snapshot 57). These leave ~4,000,000 galaxies in our final simulated sample.

Furthermore, we aimed to find galaxies located in under-density environments (voids) that were identified from the initial data. To accomplish this, we utilized the void finder algorithm initially presented by Aikio & Mähönen (1998; hereafter referred to as the AM algorithm). This algorithm has been upgraded to its 3D version by Tavasoli et al. (2013). Finally, the total count of galaxies found in the voids was $\sim$180,000.

We have categorized the galaxies by their morphological traits in voids environment to achieve our objective. For this purpose, we have specifically chosen elliptical galaxies with a bulge-to-total ratio $(B/T) \geq 0.8$. For a more detailed investigation of low-mass elliptical galaxies, we considered galaxies in the mass range of $10^8 \leq {}^{\mathrm{Stellarmass}}/_{\mathrm{M_\odot}} \leq 10^{9.3}$, because these galaxies have a different 3D half-mass radius $(\mathrm{R_{hm}})$ despite the same mass range. We think these two samples have different mass assembly histories. Therefore, we divided this part of the mass range into two parts with compact ellipticals with $0 \leq \log(\mathrm{R_{hm}}) \leq 0.48$ (kpc) and diffuse ellipticals with a size range of $0.52 \leq \log(\mathrm{R_{hm}}) \leq 1$ (kpc). Table 1 exhibits the final datasets for the void environment. Also, Figure 1 shows all the elliptical galaxies in the void and Compact ellipticals and Diffuse ellipticals that were selected.

Table 1. The final sample includes the count of galaxies galactic void environments distinguished by galaxy half-mass radius.

	Voids	Compact Ellipticals	Diffuse Ellipticals
Ellipticals	$\sim$6100	$\sim$700	$\sim$1300

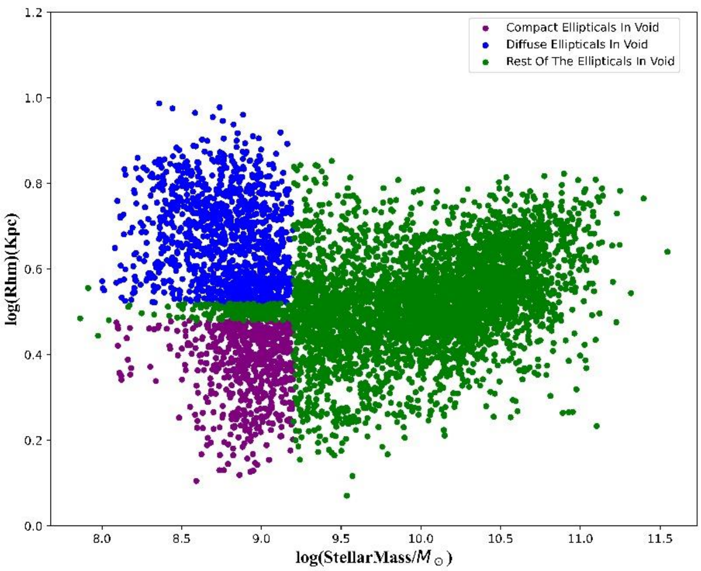

Figure 1. (Half mass radii)$\mathrm{R_{hm}}$- stellar mass of elliptical galaxies in void environments. We selected two populations, compact elliptical and diffuse elliptical galaxies in void environments.

RESULTS

Compact Ellipticals VS Diffuse Ellipticals

To examine the differences and similarities of the two selected samples in detail, we examine these two samples based on their morphology, star formation, the amount of mass accumulated through MassFromInSitu (Mass formed in-situ in the galaxy, rather than accreted or formed in merger-induced starbursts. I.e., the total mass of stars formed secularly in progenitors along this galaxy's main progenitor branch) and MassFromMergers (Mass accreted onto the galaxy in mergers, rather than formed in-situ or via merger-induced starbursts. I.e. total mass of stars formed in progenitors, not along this galaxy's main progenitor branch.), MassFromBursts (Mass formed in merger-induced starbursts in the galaxy, rather than accreted in mergers formed secularly) and blackHoleMass.

In Figure 2, we plotted the morphological (Bulgemass/Totalstellarmass) histogram of the two populations. Diffuse elliptical galaxies appear to be more spherical compared to compact elliptical galaxies. In Figure 3, we examined the specific star formation rate(sSFR) in two samples and concluded that the two populations have almost the same (sSFR), which decreases with increasing mass for both samples. These results suggest that void environments, on average, provide a nurturing environment for dwarf galaxy evolution allowing for higher specific star formation (M. Moorman et al .2014). In Figure 4, we compare our two samples by viral mass (Mvir) of galaxies (The mass enclosed within a radius (R200) where the mean density within that sphere is 200 times the critical density). The virial mass of compact elliptical galaxies is marginally greater than that of diffuse elliptical galaxies, as evidenced by the data.

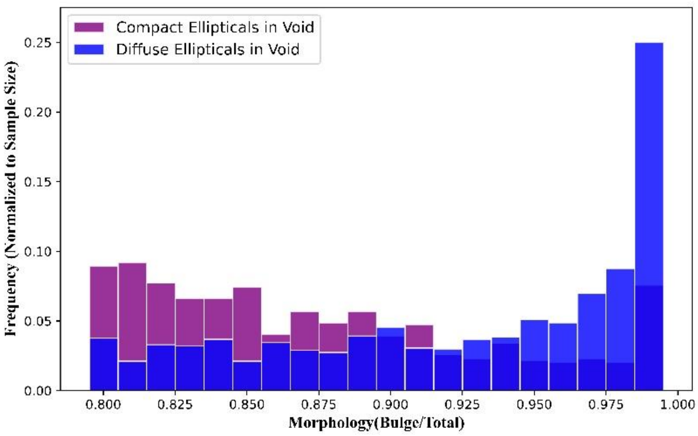

Figure 2. In our samples, diffuse elliptical galaxies are more spherical than compact elliptical galaxies.

In Figure 5, we also compared our samples based on the mass of the central black hole of the galaxy, so that diffuse elliptical galaxies statistically have a larger central black hole mass than more compact ones.

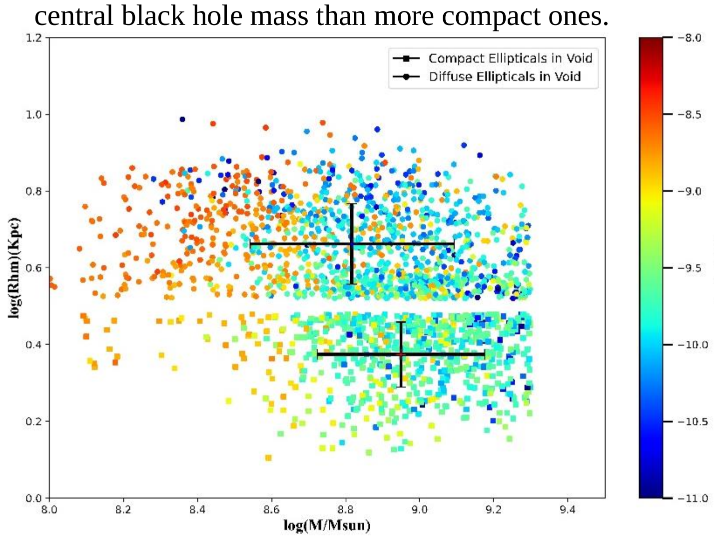

Figure 3. The stellar mass-size relation of elliptical galaxies in the void environment, so that the colors indicate the rate of specific star formation. Also, in this chart, the average mass and size of each sample are plotted, taking into account the error.

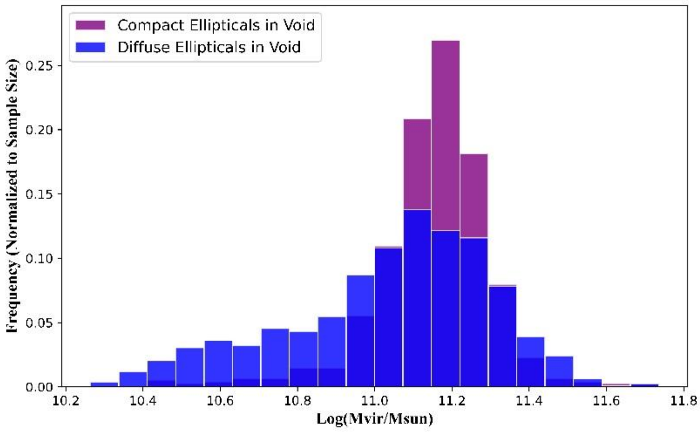

Figure 4. The virial mass frequency of our samples that compact ellipticals have a larger abundance.

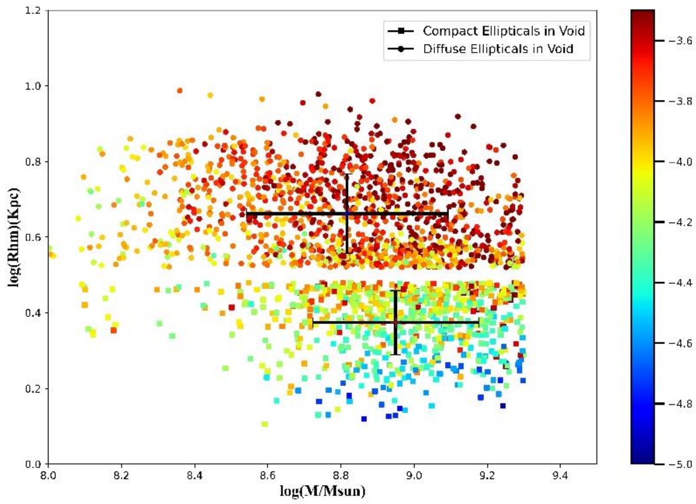

Figure 5. The stellar mass-size relation of elliptical galaxies in the void environment, so that the colors indicate the mass of central black hole of galaxies. Also, in this chart, the average mass and size of each sample are plotted, taking into account the error.

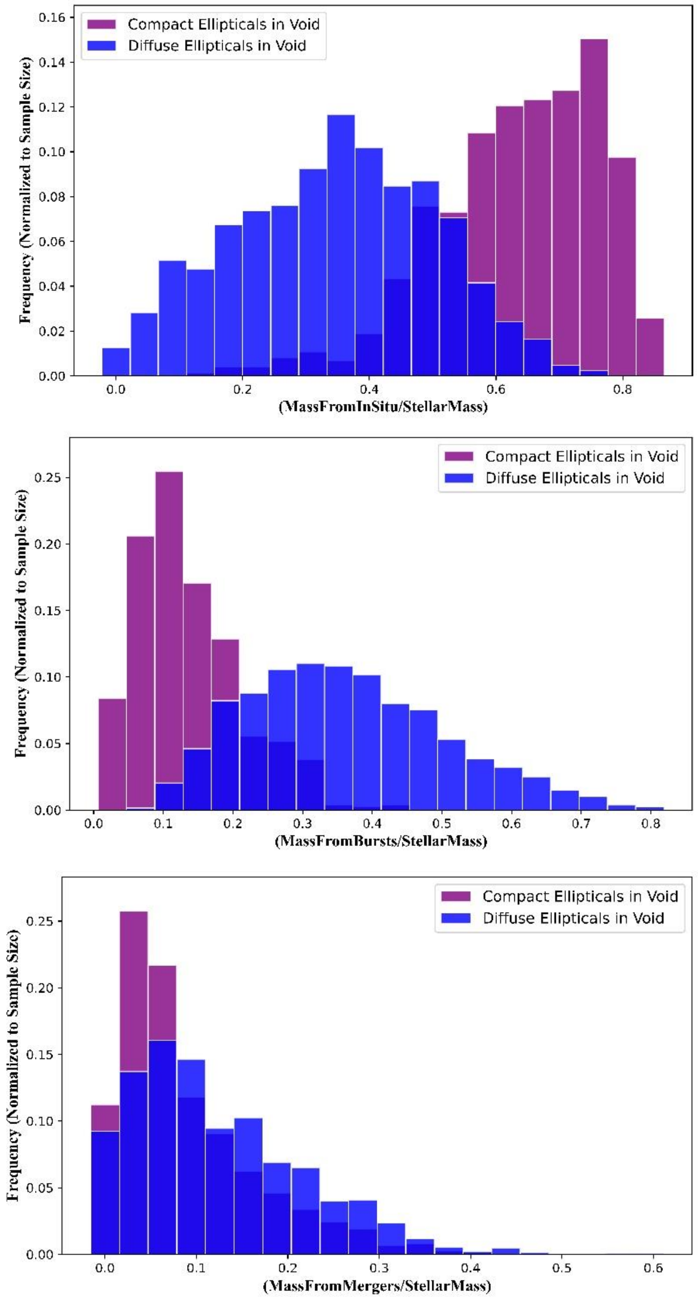

Figure 6. Compact and diffuse elliptical galaxies have different mass ratio in MassFromMergers, MassFromBursts and MassFromInSitu.

Minor mergers may contribute significantly to the growth of supermassive black holes in target galaxies by supplying extra material for accretion, leading to a difference in the mass of the central black hole (Sugata Kaviraj 2014). To investigate the history of stellar mass assembly within the samples, we examined MassFromMergers, MassFromBursts, and MassFromInSitu in Fig. 6. Due to the difference of these parameters in diffuse elliptical galaxies and compact elliptical galaxies, it can be concluded that these galaxies have different evolution despite having the same mass. As a result, it can be understood that the reason that diffuse galaxies have different half-mass radii in the same mass range, is the history of their evolution over cosmic time. It's possible that diffuse elliptical galaxies underwent a greater number of minor mergers over their evolution, resulting in their black holes being more massive in comparison to those of compact galaxies. Further studies on the merger history of these galaxies and their location inside voids can clarify this issue.

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