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Spatially-resolved stellar population properties of galaxies in voids with the CAVITY project

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Abstract

Galaxies in voids have been found to be of a later type, bluer, less massive, and to have a slower evolution than galaxies in denser environments (filaments and walls). However, the effect of the void environment on their stellar population properties is still unclear. We aim to address this question using 118 optical integral field unit datacubes from the CAVITY project, to study the effect of the void environment on different regions of the galaxies for the first time. We used the non-parametric full spectral fitting code STARLIGHT to estimate their stellar population properties: stellar mass, stellar mass surface density, age, star formation rate (SFR), and specific star formation rate (sSFR), and compared them with a control sample of galaxies in filaments and walls from the CALIFA survey, matched in stellar mass and morphological type. Key findings include void galaxies having a slightly higher half-light radius (HLR), lower stellar mass surface density, and younger ages across all morphological types, and slightly elevated SFR and sSFR (only significant enough for Sas). Many of these differences appear in the outer parts of spiral galaxies in voids (HLR > 1), which are younger and exhibit a higher sSFR, indicative of less evolved discs. This trend is also found for early-type spirals, suggesting a slower transition from star-forming to quiescent states in voids. Our analysis indicates that void galaxies, influenced by their surroundings, undergo a more gradual evolution, especially in their outer regions, with a more pronounced effect for low-mass galaxies.

1 Introduction

Galaxies in the Universe are not distributed homogeneously: they tend to group in large clusters, which are joined together by filaments and walls, and leave vast, almost empty voids in between. The location in the large-scale structure in which a galaxy develops has a great impact on its evolution.

This effect has been mostly studied in the denser structures, but not that much in the less dense: the voids. Galaxies in voids have been found to be less massive [9], bluer, later-type [14, 8, 7] and have a slower evolution [3] than galaxies in denser environments. However, when it comes to their stellar population properties, as the SFR (star formation rate) or sSFR (specific SFR, divided by the stellar mass), there are discrepancies in the literature.

For the first time, we tackle this problem making use of integral field spectroscopy (IFS) data, with the data cubes observed with PMAS/PPaK in the 3.5m telescope in Calar Alto, as part of the CAVITY project [13]. IFS gives us the opportunity to derive spectroscopic properties of every region of the galaxy, and build maps of them. This way, we can study the effect of the low dense environment on different parts of the galaxy and study them in more detail, and compare with the stellar population properties of galaxies in environments closer to the mean density of the Universe.

This oral contribution summarizes some of the results published in [2].

2 Methodology

2.1 Void galaxy sample

We select 118 void galaxies bright and big enough to perform spatially-resolved studies from those observed with the CAVITY project until January 2023. More details about the data quality and the observations are available in the DR1 paper [5]. We use the morphological classification from Domínguez-Sánchez et al. 2018 [4], and find that most of our void galaxies are late-type, and populate the brightest end of the color-magnitude diagram due to the selection criteria and the observation strategy.

2.2 Spectral fitting and stellar population properties

We employ the non-parametric full spectral fitting algorithm STARLIGHT [1] to obtain the stellar population properties in each spaxel of the data cubes. We use as SSP templates a combination of EMILES [17, 18] and the synthetic Granada models [6]. As a result, we obtain the population vectors in light and mass, from which we can derive our desired properties: stellar mass, light or mass-weighted ages, SFR (as the sum of the stellar mass created in the last 32 Myr, divided by this interval) and sSFR (the SFR divided by the stellar mass).

Given that we have not just single spectra but data cubes, we need to process them before the fitting. We mask those spaxels with SNR lower than 3, and perform a Voronoi binning to ensure that the analysed spectra have a SNR larger or equal to 20. We then fit each zone in the wavelength range between 3750 and $7000\mathring{A}$, and get an output data cube from which we can construct the maps of our desired properties. Lastly, we calculate the radial profiles of each property map with the mean values inside elliptic annuli with increasing galactocentric radii, taking into account the ellipticity and position angle of each galaxy. We normalise the radial profiles with their half-light radius (HLR), the radius that contains half of the total luminosity of the galaxy. Fitting the integrated spectrum (the resulting from summing the spectra from all non-masked spaxels), we can obtain the global properties for each galaxy.

2.3 Comparison with galaxies in filaments

We build a control sample with galaxies from the CALIFA survey [15], that were observed with the same setup as those from CAVITY. To ensure that they belong to environments close to the mean density of the Universe (filaments and walls), we remove those that are located in other environments cross-checking with cluster [16] and void [10] catalogues.

We know that galaxies in voids tend to be less massive and later-type as galaxies in other environments. To do a fair comparison with galaxies in filaments and walls, we select a pair filament galaxy for each void galaxy, with the same morphological type and the closest stellar mass. This way, we end up with the same number of galaxies in both samples, and similar stellar mass distributions for each morphological type, with a slight difference towards lower masses in void elliptical galaxies.

3 Results and discussion

When comparing the global properties of galaxies in both environments (voids and filaments and walls), we find that void galaxies have lower stellar mass surface density, lower ages, slightly higher SFR and sSFR, and larger HLRs. To check whether these differences are significant, we perform a two sample K-S test, accepting that the distributions are different if the p-value is smaller than 0.05. We find that the described trends are significant, except for the SFR and sSFR. However, if we check by morphological types, we get larger differences in the case of the Sas, with p-values smaller than the threshold as well. We also find a lower percentage of quenched (those with SFR = 0) early-type galaxies in voids, which can be a sign of a slower transition between star-forming and quiescent states, consistent with what was found in previous CAVITY works [3].

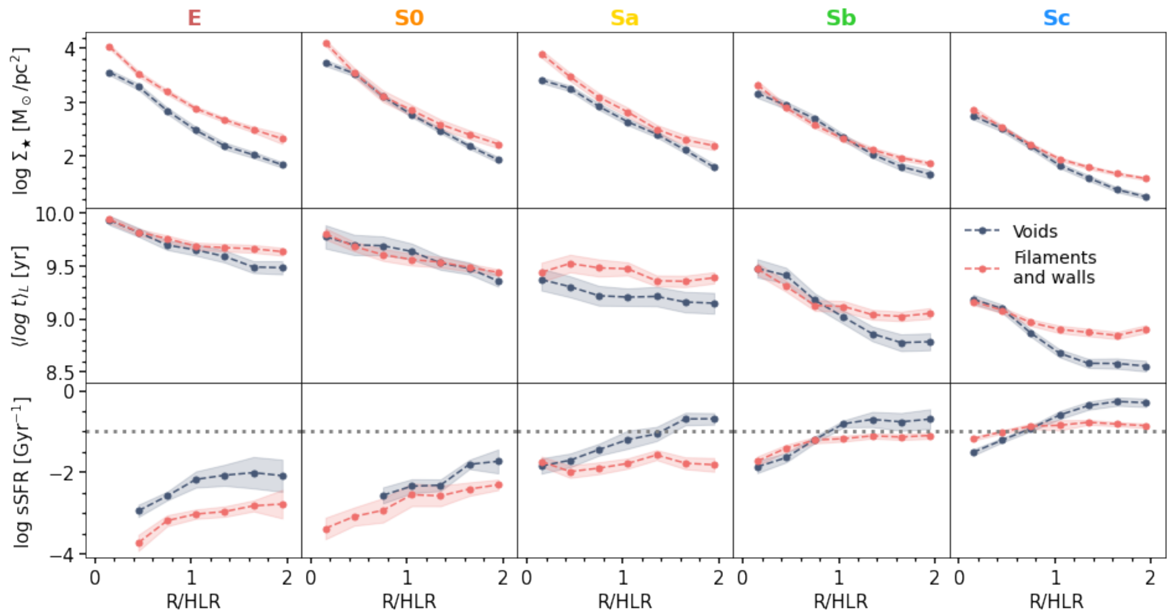

Figure 1: Radial profiles, stacked by morphological types for both environments. From top to bottom, stellar mass surface density, light-weighted age and sSFR. The grey dotted line marks the limit between quiescent and star-forming [12]. Picture taken from [2].

For the spatially-resolved properties, we stack the HLR-normalised radial profiles by morphological types, which can be seen in Fig. 1. For the stellar mass surface density, we find the strongest differences in the case of the Es, but it coincides with the bigger mismatch in total stellar mass between the samples. We find less dense outer parts in void galaxies, as well as less dense cores. In the ages and sSFR, we find that void late-type galaxies have younger and more star-forming discs (HLR > 1). In the case of the Sas, these differences hold at every galactocentric distance.

To assess the effect that stellar mass has on the evolution of galaxies in both environments, we plot in Fig. 2 the mass-weighted age (a better tracer of the star formation history) against the stellar mass, at two galactocentric distances: R = 0.5 HLR, as representative of the inner parts of the galaxies, and R = 1.5 HLR, representative of the outer parts. While one can not see big differences in the inner parts, we find lower ages for void galaxies until a threshold stellar mass between $10^{10.5}$ and 10^{11} $M_\odot$, above which both environments show matching values. Similar results have been found with both observations and simulations [11], where they attribute this phenomenon to the limit at which mass quenching starts gaining more influence than environmental quenching.

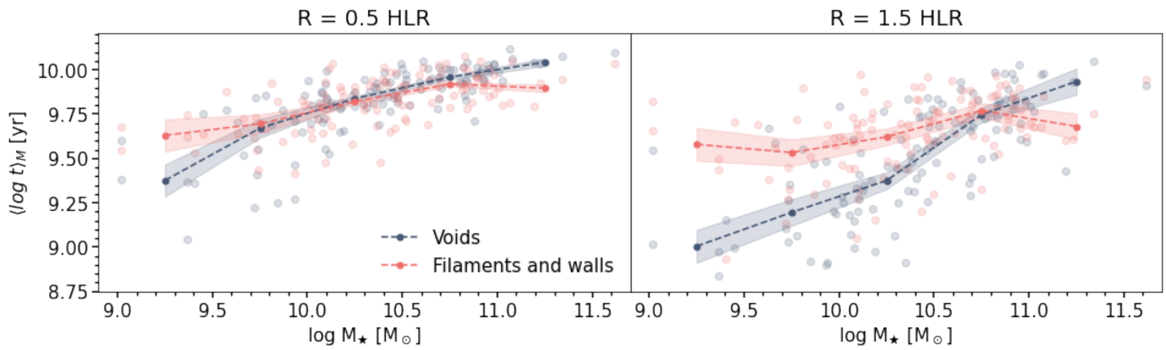

Figure 2: Mass-weighted age versus stellar mass for both environments. The darker points connected by dashed lines refer to the median values in bins of stellar mass. *Left*: age at a R = 0.5 HLR (inner part). *Right*: age at a R = 1.5 HLR (outer part).

4 Conclusions

We find that void galaxies are more extended and less dense than galaxies in filaments and walls. We see differences in the ages and sSFR in the outer parts of late-type galaxies, which point towards less evolved discs in void galaxies. In case of Sas, they tend to have higher sSFR and be younger. This, in addition to the lower % of quenched ETG, can be evidence of a slower transition to passive states in voids. We find a stellar mass threshold that limits the influence of environmental and mass quenching, which has a stronger effect on the outer parts of galaxies.

Access to the CAVITY DR1 data cubes, and the value-added maps and global properties derived in this work are available in https://cavity.caha.es.

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