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Through the green valley: investigating the mechanisms behind the decrease in the star formation rate of galaxies

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Abstract. It is well known that there is a bimodality in the distribution of galaxies in the star-formation rate versus stellar mass plane. Between the group composed of galaxies with significant star formation activity and the group of galaxies that no longer form stars significantly, there is an intermediate region known as the green valley (GV). In this study, we investigate the neutral gas fraction ($f_{\rm gas}$), the environment, and the relationship of these quantities with the morphology of GV galaxies. We defined two control samples of star-forming (SF) galaxies, one selected in terms of stellar mass and redshift and the other matched in velocity dispersion, concentration, mass and redshift. We found that SF galaxies in both control samples have slightly higher neutral gas fractions compared to GV galaxies. To analyse the local environment, we computed the projected density to the fifth-nearest neighbour for the GV and SF galaxies. We found an excess of GV galaxies in denser environments compared to both control samples of SF galaxies. Our results suggest that the GV galaxies have lower $f_{\rm gas}$ and reside in denser environments regardless of their morphology.

Resumo. É bem conhecido que existe uma bimodalidade na distribuição de galáxias no plano da taxa de formação estelar como função da massa estelar. Entre o grupo composto por galáxias com atividade de formação estelar significativa e o grupo de galáxias passivas, que já não formam estrelas significativamente, há uma região intermediária conhecida como *green valley* (GV). Neste estudo, nós investigamos a fração de gás neutro ($f_{\rm gas}$) das galáxias e o ambiente para entender qual a relação dessas quantidades com a morfologia das galáxias do GV. Nós definimos duas amostras de controle de galáxias que ainda formam estrelas, uma selecionada em termos da massa estelar e do *redshift* (z) e outra pareada em dispersão de velocidades, concentração, massa e z. Encontramos que galáxias SF em ambas amostras de controle tem uma fração de gás neutro maior quando comparadas com galáxias do GV. Para analisar o ambiente, nós calculamos a densidade projetada até a quinta vizinha mais próxima para as galáxias do GV e as galáxias SF. Em comparação com as amostras de controle, nós encontramos uma maior presença de galáxias do GV em ambientes mais densos. Nossos resultados sugerem que as galáxias GV têm menor $f_{\rm gas}$ e residem em ambientes mais densos, independentemente de sua morfologia.

Keywords. Galaxies: evolution – Galaxies: star formation – Galaxies: structure

1. Introduction

By analyzing the distribution of star formation rate (SFR) as a function of galaxy mass, we can identify distinct groups of galaxies: the main sequence of star-forming (SF) galaxies, comprising galaxies that are actively forming stars; the red sequence (RS), composed of galaxies that have ceased their star formation activity; and the green valley (GV), containing galaxies with intermediate properties.

The GV is thought to be a transition region between the main sequence and red sequence, where blue galaxies undergo a suppression of their SFR. Several studies find that the distribution of morphologies of GV galaxies is different from that of SF galaxies, implying that galaxies must experience a morphological transformation before becoming passive red galaxies. In this region, one can also find RS galaxies undergoing a rejuvenation process (Salim 2014). Another possibility to explain the differences in morphology of GV galaxies is that there are SF galaxies that are more likely to have their SF suppressed, for example, those that are more compact than the general population of SF galaxies (Estrada-Carpenter et al. 2023). To investigate the latter scenario and understand the mechanism responsible for leading SF galaxies to the GV, we define samples of SF and GV galaxies with similar morphologies and analyze their environment and neutral gas fractions. We compare the results for the morphology-matched samples with those obtained for GV and SF samples that do not have similar morphologies.

2. Methods and data

We used data from the Sloan Digital Sky Survey DR17 and GALEX-SDSS-WISE legacy catalogue that contains more accurate star-forming rates from joint UV+optical+mid-IR SED fitting (Salim et al. 2018).

We selected a sample of GV using the criteria by Trussler et al. (2020). In Fig. 1, we show our subsamples limited to local universe galaxies within the redshift range $0.02 < z < 0.1$.

We use the catalogue of groups and clusters by Lim et al. (2017) to separate central and satellite galaxies. In this study, we use the central galaxies only. To analyze the effect of morphology, we selected two control samples from SF galaxies: one matched in stellar mass ($M_\star$) and redshift (z), and the other matched in $M_\star$, z, stellar velocity dispersion ($\sigma_{\rm v}$), and concentration (C). To define the size of the samples, we computed the 5%, 25%, 50%, 75% and 95% percentiles of the $M_\star$, z, $\sigma_{\rm v}$ and C distributions. We then randomly discarded GV galaxies until we could define a control sample of SF galaxies for which the property distributions are as close as possible to those of the GV galaxies. We required a maximum difference of 5% in those percentiles.

To compute the HI gas fractions, $f_{\rm gas} = M_{\rm HI}/(M_{\rm HI} + M_\star)$, we retrieved the HI gas mass, $M_{\rm HI}$, from The Arecibo Legacy Fast ALFA Survey (Haynes et al. 2018). To explore the galaxy environment, we computed the projected density of galaxies around the GV and SF galaxies. The density was estimated considering all galaxies up to D_5, where D_5 is the distance to the fifth-nearest

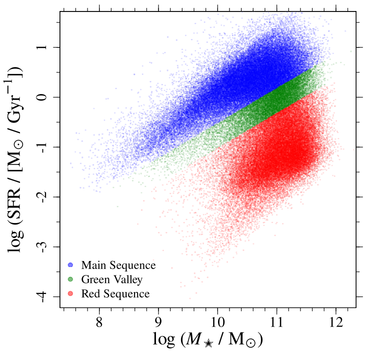

Figure 1. The distribution of galaxies in the star-formation rate versus stellar mass (SFR – $M_\star$) plane. The colors indicate galaxies that are classified as star-forming (SF, *blue symbols*), green valley (GV, *green symbols*), and galaxies in the red sequence (RS, *red symbols*).

neighbor, with stellar masses $M_\star \geq 10^{10.5}$ M$_\odot$ and velocity separations $\Delta v \leq 1500\,\mathrm{km\,s^{-1}}$. We then define the local environment density as $\delta_5 = 6/(\pi D_5^2)$.

3. Results

In Fig. 2, we show the comparison between f_{gas} distributions of GV galaxies and control samples. We find that, for both control samples, SF galaxies have a slightly higher f_{gas} compared to GV galaxies. We obtained the same result using the xGASS catalogue (Catinella et al. 2018), which is complete in volume.

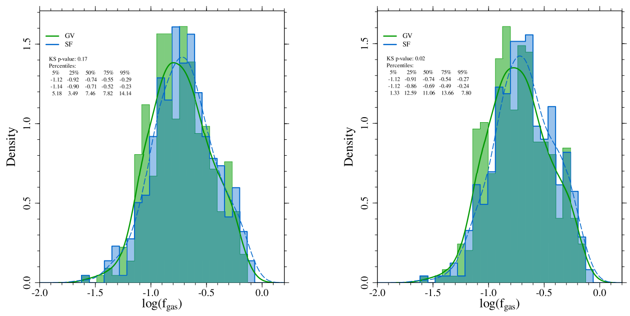

Figure 2. Fraction of HI gas in GV galaxies compared to the morphology-matched control sample (*left panel*) and the mass-matched control sample (*right panel*); we observe that SF galaxies in both samples have slightly higher fractions of neutral gas compared to those of GV galaxies.

In Fig. 3, we show the δ_5 distributions of the GV galaxies compared to the control samples of SF galaxies. We find that GV galaxies tend to reside in slightly denser environments compared to both control samples.

4. Discussion and conclusion

We find small differences between the HI gas mass fractions and the environment of GV and SF galaxies, with GV galaxies residing in denser environments and having slightly lower f_{gas}. These differences are observed for both control samples, i.e., SF galaxies with similar morphologies to those of GV galaxies also have

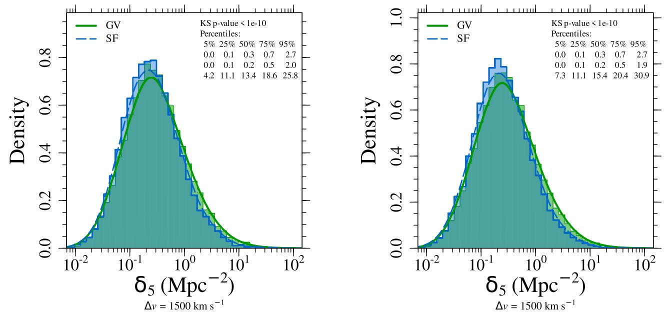

Figure 3. Projected density to the fifth-nearest neighbor of GV galaxies compared to the morphology-matched control sample (left panel) and the mass-matched control sample (right panel); we observe that the denser environment has a slightly higher number of GV galaxies for both samples.

higher f_{gas} and reside in less dense environments. These results suggest that the existence of a subpopulation of SF galaxies that are more likely to be driven to the GV is not enough to explain the differences in morphology between GV and SF galaxies. We will continue our investigation on the suppression of SFR and its relation to the galaxy morphologies.

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