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Post-starburst galaxies in groups and clusters at $0.05 \leq z \leq 0.1$

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Abstract. We analyse the properties of post-starburst (PSB) galaxies in groups and clusters from the SDSS database to investigate the role of the environment on the formation of these objects. By comparing our PSBs with a sample of control galaxies (CGs), we find that PSBs are two times more likely to be centrals in groups than the CGs. Besides, PSBs that are centrals in groups are significantly more compact than their CGs, and 84% of them have S0 morphologies (T-type < 0 and $P_{S0} > 0.5$ values), which is a higher fraction than that of centrals CGs with negative T-type and $P_{S0} > 0.5$ values (47%). Our results are compatible with the scenario of dissipative wet-merger events being an important mechanism responsible for the origin of central PSBs in groups. However, other processes may be leading to the formation of satellite PSB galaxies in non-central regions of group and cluster environments, where mergers are less likely to occur.

Resumo.
Analisamos as propriedades de galáxias *post-starburst* (PSB) em grupos e aglomerados a partir de dados do SDSS para investigar o papel do ambiente na formação desses objetos. Ao comparar nossas PSBs com uma amostra de galáxias de controle (CGs), descobrimos que as PSBs são duas vezes mais prováveis de serem centrais em grupos do que as CGs. Além disso, as PSBs que são centrais em grupos são significativamente mais compactas do que suas CGs, e 84% delas têm valores morfologias de galáxia S0 (valores de T-type < 0 e $P_{S0} > 0.5$), que é uma fração maior do que CGs centrais com valores negativos de *T-type* e $P_{S0} > 0.5$ (47%). Nossos resultados são compatíveis com o cenário de fusões ricas em gás sendo um importante mecanismo responsável pela origem de PSBs centrais em grupos. No entanto, outros processos podem estar levando à formação de galáxias PSB satélites em regiões não centrais de grupos e aglomerados, onde fusões são menos prováveis de ocorrer.

Keywords. Galaxies: evolution – Galaxies: interactions – Galaxies: starburst

1. Introduction

Post-starburst (PSB) galaxies are a class of objects with atypical spectral properties, such as strong Balmer absorption lines – a signature of A-type stars (Dressler & Gunn 1983) – and low Hα equivalent widths. Studies show that those spectral characteristics can only be reproduced by models of a starburst followed by a rapid quenching (e.g., Wild et al. 2007). There are pieces of evidence, such as PSB disturbed morphologies and their high frequency in poor groups of galaxies, indicating that PSBs are formed thanks to wet (gas-rich) mergers (e.g., Zabludoff et al. 1996). On the other hand, PSBs are found in rich clusters of galaxies where such mergers are rare due to the high velocity dispersions within it (e.g., Gunn & Gott 1972). Therefore, there might be more than one physical mechanism responsible for the formation of PSBs in different environments.

In this study, we analyse the properties of PSB galaxies in groups and clusters from the SDSS database. Our goal is to investigate the role of the environment and to put constraints on the processes leading to the formation of PSBs in groups and clusters.

2. Methodology

Galaxies are selected from SDSS-DR12 (Alam et al. 2015) at $0.05 \leq z \leq 0.1$ and with $M_r \leq -20.4$, where M_r is the k-corrected absolute magnitude in the r-band. We use stellar masses and star formation rates (SFRs) from the GSWLX-X2 catalogue by Salim, Boquien & Lee (2018). We take halo masses from an updated version of the catalogue of groups and clusters by Yang et al. (2007) and then reassign the galaxies to groups and clusters following the method described in Trevisan, Mamon & Stalder (2017). We separate star-forming (SF) and non-star-forming (NSF) galaxies at $\log(sSFR/\mathrm{yr}^{-1}) = -11$, and groups and clusters at $\log(M_{\mathrm{halo}}/\mathrm{M}_\odot) = 14$. We select the PSBs according to the criteria: (*i*) EW(Hα) $\leq$ 1Å, and (*ii*) Lick H$\delta_A \geq$ 1.5Å. We retrieved the EW(Hα) and Lick Hδ_A from the SDSS database (Brinchmann et al. 2004). These criteria lead to a sample of 599 PSBs; 432 reside within $R/r_{\mathrm{vir}} < 3$ and $\Delta v/v_{\mathrm{vir}} < 3$ of groups and clusters.

We built samples of control galaxies (CGs) with similar stellar masses and specific SFRs (sSFRs) by applying the Propensity Score Matching technique. We selected two sets of CG samples, each one being 20 times larger than the PSB sample. In the first set, the CGs reside in environments similar to those of the PSB, i.e., central in groups ($R/r_{\mathrm{vir}} = 0$ in haloes with $M_{\mathrm{halo}} < 10^{14}\,\mathrm{M}_\odot$; 185 PSBs and 3700 CGs), satellites in groups ($R/r_{\mathrm{vir}} < 3$ and $\Delta v/v_{\mathrm{vir}} < 3$ in haloes with $M_{\mathrm{halo}} < 10^{14}\,\mathrm{M}_\odot$; 173 PSBs and 3460 CGs), and satellites in clusters ($R/r_{\mathrm{vir}} < 3$ and $\Delta v/v_{\mathrm{vir}} < 3$ in haloes with $M_{\mathrm{halo}} \geq 10^{14}\,\mathrm{M}_\odot$; 74 PSBs and 1480 CGs). In the second set of CG samples, we put no constraints on the CG environment and included field galaxies that are at distances $R > 3\,r_{\mathrm{vir}}$ from the centres of groups and clusters. The frequencies of the CGs and PSBs in groups, clusters and field are presented in Table 1.

3. Results

We find that PSBs are two times more likely to be centrals in groups than the CGs (table 1). The fractions of central SF-PSBs and NSF-PSBs are 25.7% and 33.2%, while central SF-CGs and NSF-CGs represent only 9.3% and 17.8%, respectively.

We compared the sizes of PSBs and CGs residing in similar environments (first set of samples). We used measurements of the effective radii, R_{hlr}, by Simard et al. (2011) and computed the distance of R_{hlr} from the mass-size relation for passive galaxies

Table 1. Fractions of PSBs and CGs that are centrals and satellites in groups and clusters and field galaxies. We show the *p*-values of Fisher exact tests.

Environment		$\log(M_{\rm halo}/M_\odot) \leq 14$				$\log(M_{\rm halo}/M_\odot) > 14$				Field	
Galaxies		Centrals		Satellites		Centrals		Satellites			
SF	PSB	47	25.7%	49	26.8%	0	0.0%	24	13.1%	63	34.4%
	CG	342	9.3%	1284	35.1%	1	0.0%	435	11.9%	1597	43.6%
	p-value	5×10^{-10}		0.02		1.00		0.64		0.01	
NSF	PSB	138	33.2%	124	29.8%	1	0.2%	50	12.0%	103	24.8%
	CG	1481	17.8%	2991	35.9%	13	0.2%	1446	17.4%	2390	28.7%
	p-value	3×10^{-13}		0.01		0.50		4×10^{-3}		0.09	

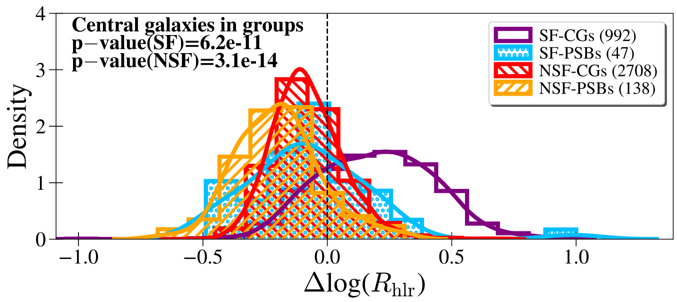

Figure 1. Normalized distributions of $\Delta\log(R_{\rm hlr})$ for central SF-CGs (*purple distribution*), SF-PSBs (*blue*), NSF-CGs (*red*), and NSF-PSBs (*orange*) in groups. The solid curves are Gaussian kernel smooths with standard deviations calculated by Scott Rule. The *p*-values of Kolmogorov-Smirnov two-sample tests are shown.

at $0 \leq z \leq 0.5$ defined by van der Wel et al. (2014), $\Delta\log(R_{\rm hlr})$. We find that central PSBs are more compact than their CGs in groups, as shown in Fig. 1, with Kolmogorov-Smirnov tests indicating high statistical significance (p–values $< 10^{-10}$).

To investigate the PSBs morphologies, we used the T-type values from the catalogue by Domínguez Sánchez et al. (2018). We find that a large fraction of central SF-PSBs (93.6%) and NSF-PSBs (93.5%) in groups have early-type morphologies (i.e., negative T-type values). Central SF-CGs and NSF-CGs in groups have 28.5% and 87.3% of galaxies with negative T-type values, respectively. The *p*-values of Fisher tests indicate that the difference between the fractions of central PSBs and CGs with T-type < 0 is statistically significant, with p–values $= 6 \times 10^{-20}$ and 0.03 for the SF and NSF samples, respectively.

We then select only the galaxies with T-type < 0 and compare their $P_{\rm S0}$ values, where $P_{\rm S0}$ is the probability of being a S0 galaxy, as defined by Domínguez Sánchez et al. (2018). We find that 95.5% of central SF-PSBs and 89.9% of central NSF-PSBs in groups have $P_{\rm S0} > 0.5$, while these fractions for SF-CGs and NSF-CGs are 88% and 64%, respectively. Fisher tests indicate statistical significance for the difference we find between the fraction of NSF-PSBs and NSF-CGs with $P_{\rm S0} > 0.5$ (p–value $< 10^{-10}$).

Finally, we compare $\Delta\log(R_{\rm hlr})$, T-type, and $P_{\rm S0}$ values for central and satellite PSBs in groups, and satellite PSBs in clusters with each other. We find statistically significant lower $\Delta\log(R_{\rm hlr})$ and T-type values for our central NSF-PSBs compared to the satellite NSF-PSBs. However, the results for the satellite NSF-PSBs in groups and clusters are not significant.

4. Discussion

Are PSBs formed through wet-merger events? We find that:

i) PSB galaxies are more likely to be central galaxies than CGs (table 1);
ii) In groups, central PSBs are significantly more compact than their CGs (figure 1); and
iii) more than 84% of our central PSBs in groups have S0 morphologies (T-type < 0 and $P_{\rm S0} > 0.5$ values).

These results are consistent with the wet-merger scenario, since mergers are more frequent in the inner parts of groups galaxies. Besides, galaxies are expected to become more compact after a wet merger, since the gas is driven to the central parts of the galaxy, triggering a starburst in this region. It has also been proposed that mergers can produce galaxies with S0 morphologies (e.g., Blanton & Moustakas 2009).

Are there other mechanisms responsible for the formation of PSBs in different environments? We can summarize our results as being compatible with the scenario of dissipative wet-merger events being an important mechanism responsible for the origin of central PSBs in groups. However, other processes may be leading to the formation of satellite PSB galaxies in non-central regions of group and cluster environments, where mergers are less likely to occur.

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