Quenching Process of Galaxies in Low Redshift Regular Clusters

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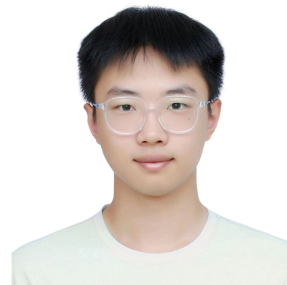

Introduction

The quenching of star formation in galaxies is an important aspect of galaxy evolution, which is well known to depend on both their mass and environment (Peng et al. 2010). More massive galaxies lose more gas through internal stellar or AGN feedback, and denser environments can strip more gas out of galaxies. Both processes may cause the cessation of star formation and subsequently quench the galaxies. Several works have studied the quenching process by combining observations and simulations in the projected phase space (PPS), which provides us opportunities to investigate the quenching process in more detail from an observational perspective.

Method

1. Structure Identification

We use the Blooming Tree Algorithm (Yu et al. 2018) to separate galaxies belonging to clusters and surrounding groups from those isolated in field, to compare the impact from different environments.

2. Infall extent quantification

We take the reference line given by Oman et al. (2013) as a boundary in the projected phase space (PPS). This boundary works well in separating the virialized region (i.e., cluster members, see left penal in Figure 1), and it roughly corresponds to a constant value of the fraction of star-forming galaxies ($f_{SF} = 0.4$, see the right penal).

We define a phase-space distance **Δd** as the distance from the galaxy's position in PPS to the reference line, with outward as positive. The Δd is taken as an indicator of the infall extent.

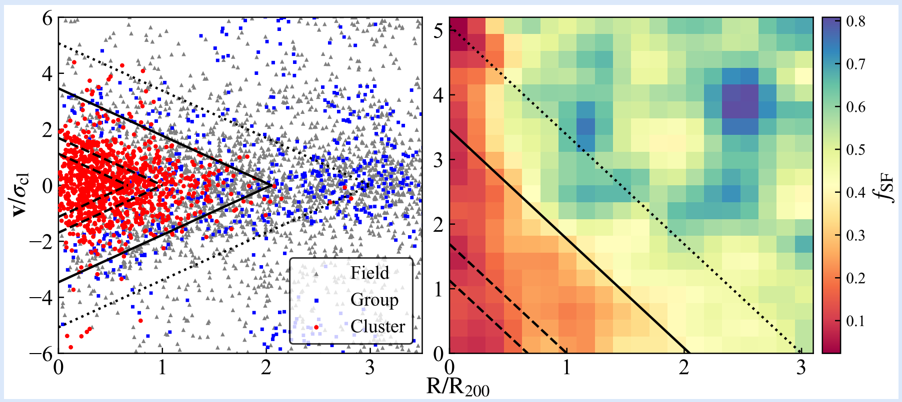

Figure 1. Left: The distribution of cluster galaxies (red), group galaxies (blue), field galaxies (grey) in the PPS. **Right:** The (smoothed) distribution of the fraction of star-forming galaxies (f_{SF}). The solid line is the boundary line from Oman et al. (2013). The dashed lines parallel to the boundary are counterparts in PPS of R_{500} and R_{200}. The dotted lines corresponds to the $3R_{200}$ completeness limit.

Data

- **19 Cluster samples:** from MCXC (Meta-Catalog of X-Ray Detected Clusters of Galaxies, Piffaretti et al. 2011) and required to be:
  1. $0.06 < z < 0.1$
  2. $L_{X,500} > 10^{44}$erg/s
  3. SDSS coverage $> 3R_{200}$
- **5299 Galaxy samples:** from SDSS-DR18 (Sloan Digital Sky Survey Eighteenth Data Release, Almeida et al. 2023) and required to be:
  1. $R < 3R_{200}$
  2. $z \in z_0 \pm 0.03$
- **Galaxy parameters:** star formation rate (SFR) and stellar mass (M_*) from GSWLC-2 (the Second Version of GALEX–SDSS-WISE Legacy Catalog, Salim et al. 2016, 2018) and morphological classification from KIAS VAGC (the Korea Institute for Advanced Study Value-Added Galaxy Catalog, Choi et al. 2010).

2. Morphological Transition

The fraction of late-type galaxies (f_{LT}) in star-forming galaxies is also considered. A descending trend is obvious, indicating a morphological transition **prior** to the quenching.

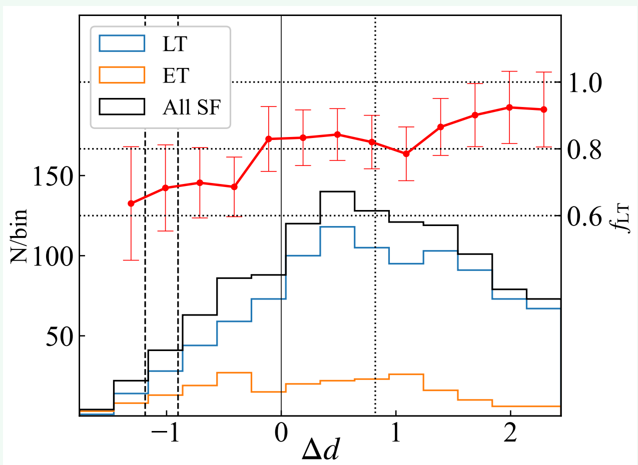

Figure 4. The trends of f_{LT} of star-forming galaxies.

Results

1. SF Quenching

We investigate the quenching process by taking f_{SF} as a function of Δd, as shown for the entire sample in Figure 2, then shown separately for three mass intervals and three environments in Figure 3.

Taking each sample in Figure 3 as a whole, the overall pattern is clear: more massive samples or denser environments include less star-forming galaxies.

Please pay attention to the f_{SF} trend in Figure 2 for a more detailed quenching process. Galaxies are quenched **gradually but not uniformly** as infalling to the center: f_{SF} decreases very **slowly** outside the boundary, even like a constant, but **drops steeply** around the boundary. After the first descent, the decreasing trend **slows down again** until **another apparent descent** around R_{500}. Finally, more than 90% galaxies have been quenched after the second descent.

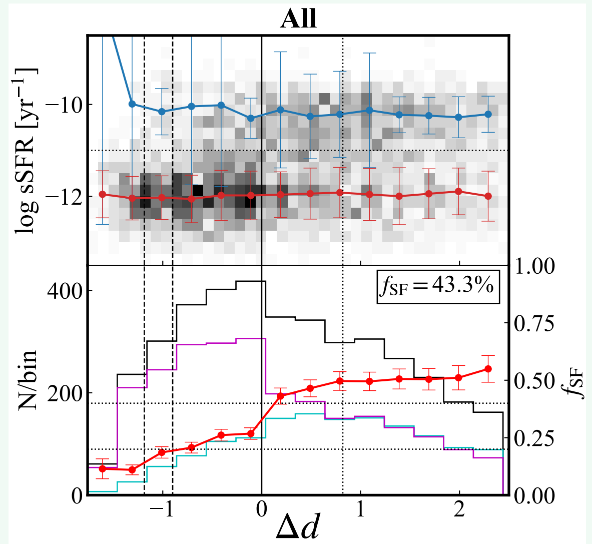

Figure 2. The specific SFR and f_{SF} as functions of Δd. The vertical lines from inside to outside represent R_{500}, R_{200}, the boundary and the completeness limit.

Considering galaxies with different stellar mass, we notice different quenching patterns. **Low mass galaxies** are affected uniformly in the whole process until a steeper descent at R_{500}, while **more massive galaxies** are dramatically quenched at their first arrival (i.e., around the boundary), and nearly all intermediate-mass and massive galaxies are quenched after this descent.

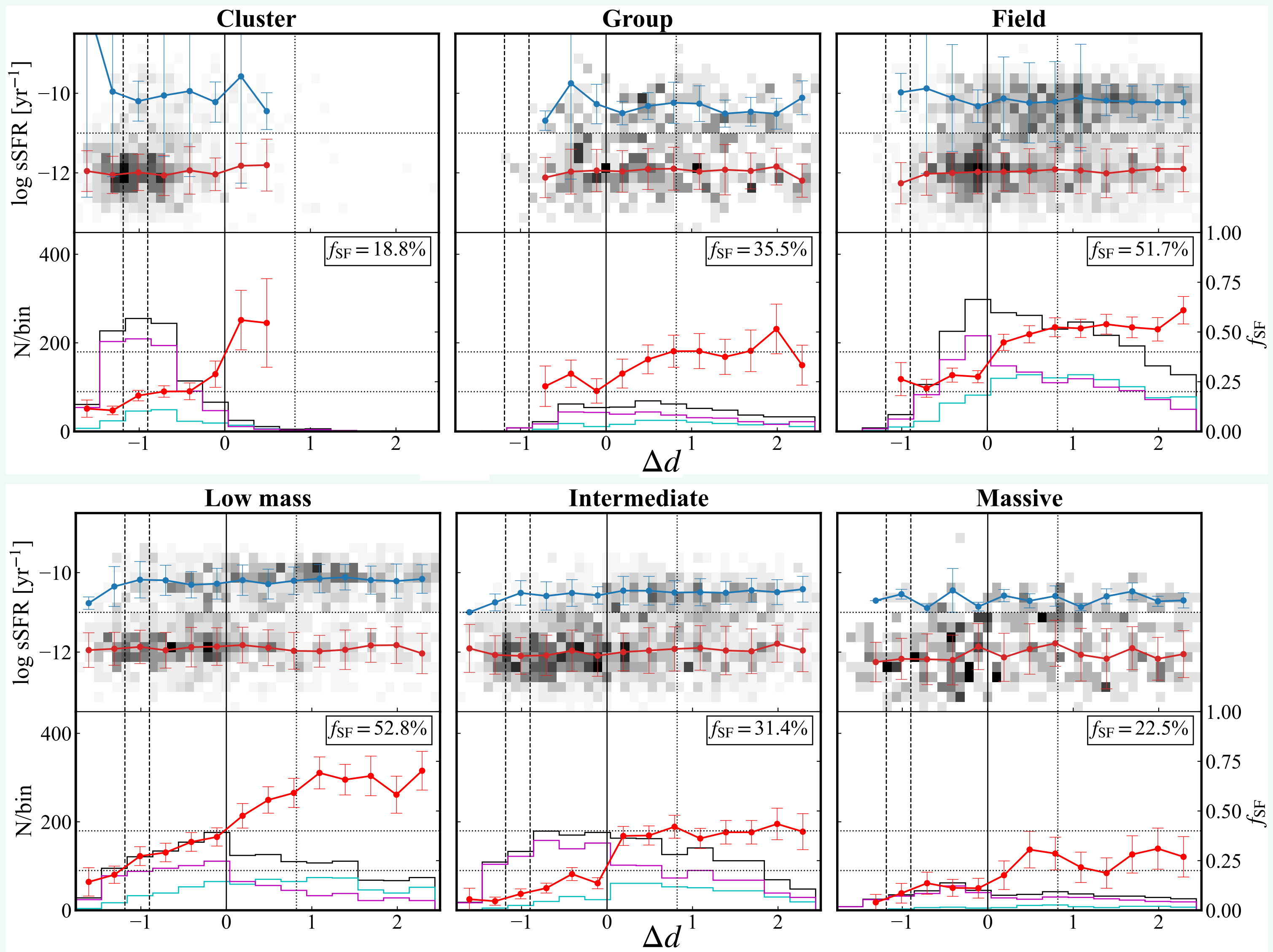

Figure 3. Similar to Figure 2, but for three different environments (top panel) and three mass intervals (bottom panel, $\log M_*/M_\odot \in [10,10.5], [10.5,11], [11,11.5]$).