Regulating Gas Accretion and Star Formation Rates: Insights from Halo-scale Environments of Galaxies in Observations and Cosmological Simulations

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The Association of Star Formation and Quenching on Environment

Most galaxy properties are impacted by their multiscale environments, which facilitate galaxy interactions, influence the gas content and accretion, star formation, and structures of galaxies. By examining multiscale environmental indicators spanning from ~ 50 kpc to 10 Mpc for nearby galaxies in the observations and cosmological simulations, we find correlations between small scale (halo-scale) environment, star formation rate, and merger activity (Yesuf 2022; Omari et al. 2023). Specifically, star-forming galaxies exhibiting higher-than-average SFRs, at fixed stellar mass, tend to live in lower-density environments and lower-mass halos (Figure 1). Remarkably, nearly 90% of starbursts appear isolated, lacking massive nearby neighbors for merger events. Could their enhanced SFRs be triggered by direct gas accretion?

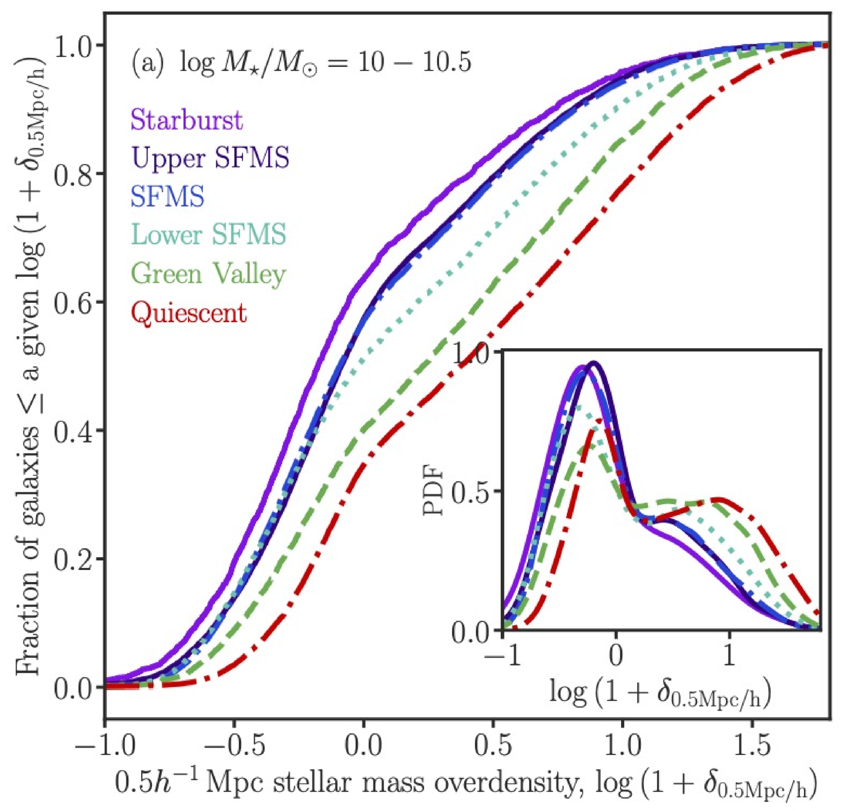

Figure 1. The cumulative distributions of the normalized environmental mass densities within $0.5\,h^{-1}$Mpc and their trends with SFR. Most starbursts live in the lowest density environments, while most quiescent galaxies live in the highest density ones, at fixed mass; galaxies in between occupy moderate density environments. The low-density environments of starbursts favor gas accretion (Yesuf 2022).

Using similarity of environments, stellar population properties, and structural analyses as consistency checks indicates that recently quenched post-starburst galaxies can be linked to some starbursts, AGNs, and quiescent galaxies (Yesuf 2022). This family of galaxies demonstrate that the fast evolution of nearby galaxies is primarily due to rapid gas consumption by starbursts, illustrating limited impacts of AGNs and high-density quenching mechanisms.

Both simulations and observations indicate that star formation quenching (quenched fraction) depends on both stellar mass and environment (Figure 2). However, preliminary results indicate that simulations fail to accurately reproduce SFR or quenched fractions of galaxies in different environments, questioning the effectiveness of cumulative AGN feedback in the simulations.

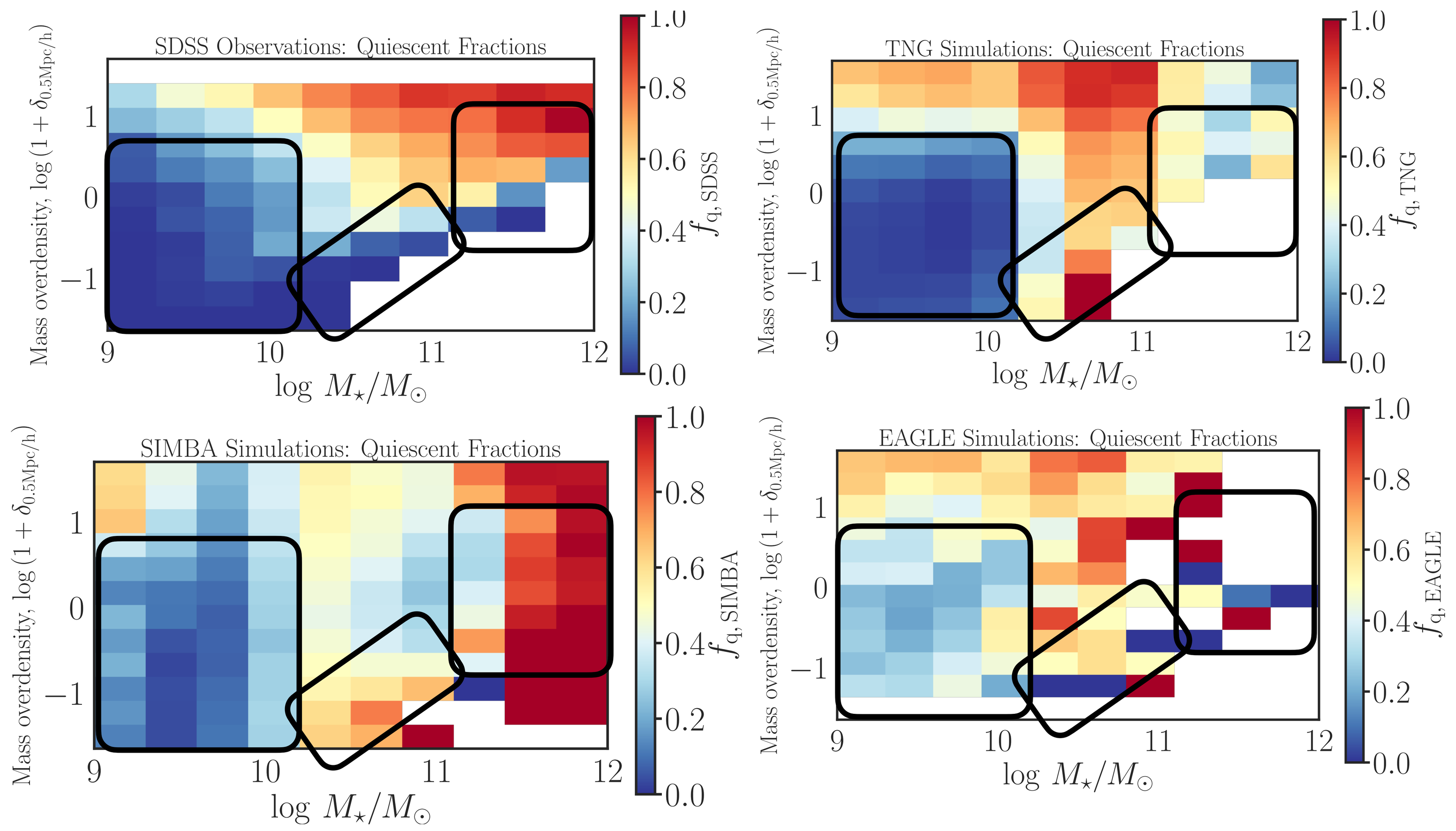

Figure 2. Stellar mass vs. environment; Comparing trends of quiescent galaxy fractions in SDSS observations and three cosmological simulations. The simulations fail to reproduce the observed trends and they also differ from each other, making this diagnostic effective and questioning the long-term effects of AGN feedback in the simulations. However, the agreements in low-mass and low-density environment is reasonable (Yesuf 2022; Yesuf & Bottrell 2024).

- Central: the most massive galaxy in a group or cluster, located near the center of the gravitational potential well.
- Satellite: lower mass galaxy around the central in a group or cluster.

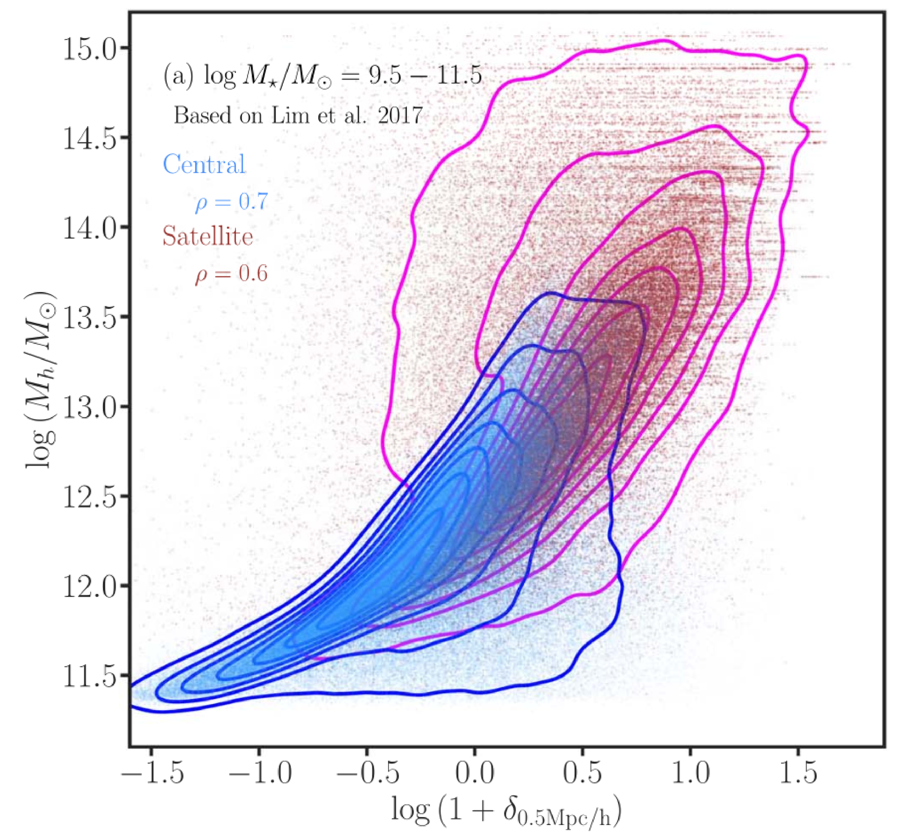

Figure 3. The small-scale mass overdensity (environment) is a good proxy for the halo mass, which is estimated from galaxy group properties and a calibration from cosmological simulations (Yesuf 2022).

Merger and Environment Connection

In IllustrisTNG simulations and SDSS and GAMA observations, major and minor mergers are more prevalent in lower density environments on scales of 0.5 to 10 Mpc.

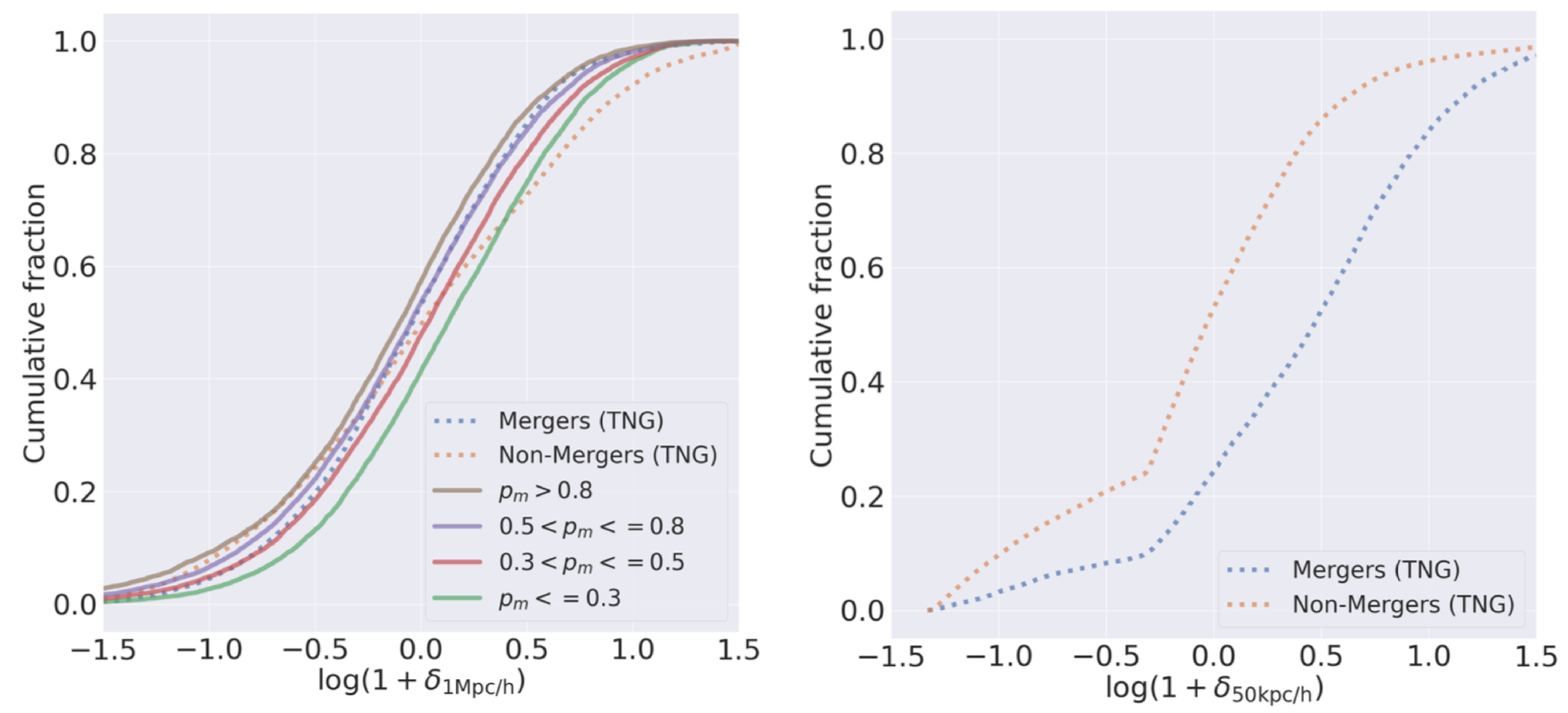

Figure 4. Environmental mass overdensity distributions of Illustris TNG mergers and non-mergers (dotted curves) and SDSS observations (solid curves, colors indicate merger probability, Omari et al. 2023).

High Star Formation Driven by Gas Accretion and Mini Mergers

A recent gas accretion (both diffuse and merger-related) in low-density environments causes starburst and structural asymmetry.

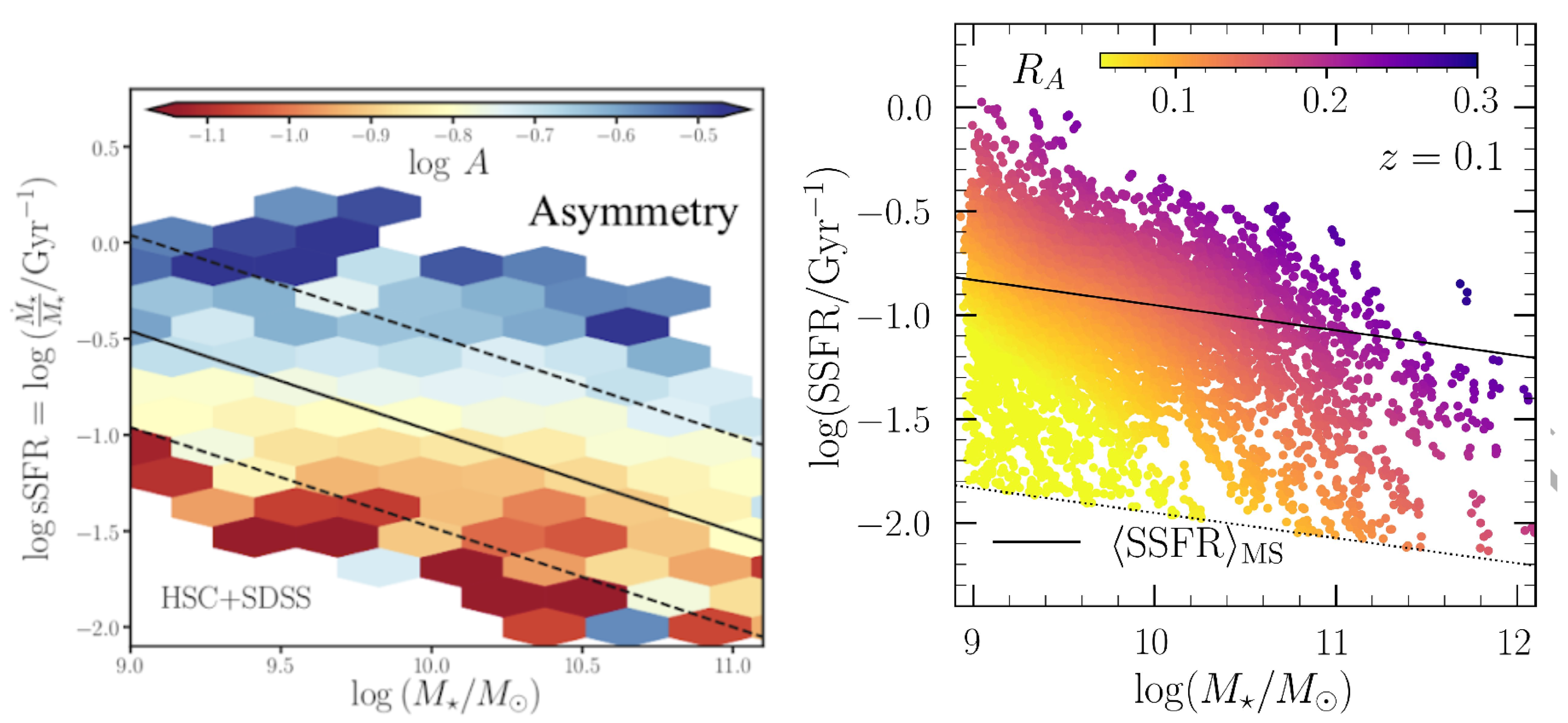

Figure 5. Star formation depends on both stellar mass and asymmetry. The left panel shows asymmetry patterns in observations while the right panels show residual asymmery trends in IllustrisTNG simulations, which qualitatively agree with observations (Yesuf et al. 2021; Bottrell, Yesuf et al. 2024).

•Bottrell, C., Yesuf, H. M., et al. 2024, MNRAS, 527, 6506. •Omori, K., Bottrell, C., et al. 2023. A & A, 679, 142 •Yesuf, H. M, 2022, ApJ, 936, 124 •Yesuf, H. M., Ho, L. C., & Faber, S. M. 2021, ApJ, 923, 205.

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