Draft version December 7, 2023
Typeset using LaTeX **twocolumn** style in AASTeX631

Environmental Effects on the Galaxy Stellar Mass Function at z ∼ 2.5

Derek Sikorski,[1] Roy Gal,[1] Brian Lemaux,[2] Ben Forrest,[3] Ekta Shah,[3] Lu Shen,[3] and Lori Lubin[3]

[1] *Institute for Astronomy, University of Hawai'i, 2680 Woodlawn Drive, Honolulu, HI 96822, USA*
[2] *Gemini Observatory, NSF's NOIRLab 670 N. A'ohoku Place, Hilo,HI 96720, USA*
[3] *Department of Physics and Astronomy, University of California, One Shields Ave., Davis, CA 95616, USA*

1. CONTEXT

Historically, galaxies are observed to populate two distinct classes: those that are bluer, more spiral-like, and have active star formation with moderate-to-high star formation rates (SFRs); and those that are redder, more elliptical, and have little-to-no active star formation. In addition to the bimodality of stellar properties, observations in the local universe paint a picture in which the "red-and-dead" elliptical galaxies tend to inhabit denser environments - such as groups and clusters - compared to their blue, star-forming analogues. Although efforts have been made to characterize the dominant mechanisms that lead to the quenching of (i.e. cessation of star formation in) star-forming galaxies, it is vital we understand how these mechanisms which drive star-forming galaxies to quiescence evolve with redshift. Previous studies have attempted to trace quenching in the local universe (e.g., Peng et al. 2010) and out to moderate-redshifts of z < 2 (e.g., Kawinwanichakij et al. 2017; Tomczak et al. 2017; Papovich et al. 2018; Webb et al. 2020; van der Burg et al. 2020), but the mechanisms responsible for the development of quiescence - and the enhanced star formation that must precede it - in the high-redshift regime ($z > 2$) remains largely ambiguous.

Broadly speaking, the physical mechanisms that drive galaxy quenching can be categorized into two distinct processes: "mass quenching" or "environmental quenching" (Peng et al. 2010). As suggested by the name, mass quenching encapsulates processes that are directly correlated with the mass of the galaxy itself. Examples may include feedback from supernovae and stellar winds (e.g., Dekel & Silk 1986), feedback from active galactic nuclei (e.g., Somerville et al. 2008), and the shock-heating of cold inflows in halos above a given mass (Dekel & Birnboim 2006). On the other hand, environmental quenching are processes linked to properties of the local environment in which the galaxy is situated. These processes preferentially occur in overdense environments (such as galaxy clusters), and include mechanisms such as the stripping of circumgalactic gas via ram pressure as a result of a galaxy's motion relative to the diffuse intracluster medium (e.g., Abadi et al. 1999), or an increased frequency of major galaxy-galaxy mergers (e.g., Lin et al. 2010).

One of the most important and natural ways of tracking the evolution of an ensemble of galaxies is via the galaxy stellar mass function (SMF). The SMF is a volume-based number density of galaxies as a function of stellar mass, and will thus be affected by both mass and environmental quenching mechanisms in various ways. Using SDSS (z < 0.1) and zCOSMOS (0.3 < z < 0.6), Peng et al. (2010) show that the ways in which the SMF is affected by mass and environmental quenching mechanisms are largely separable. This means there are environmental mechanisms that act to increase the quiescent fraction of galaxies, independent of the mass of the galaxies, and vice versa.

On the other hand, it has become more apparent that at higher redshifts (0.5 < z < 2.0), there is a positive correlation between the overdensity of a region and the fraction of galaxies that are quiescent in the regime down to stellar-masses of $\log(M_*/M_\odot) \gtrsim 9.5$ (e.g., Kawinwanichakij et al. 2017; Tomczak et al. 2017; Papovich et al. 2018; Webb et al. 2020; van der Burg et al. 2020). Additionally, it has been shown that the environmental quenching mechanisms that drive this correlation become more efficient for higher mass galaxies (Papovich et al. 2018; van der Burg et al. 2020; Webb et al. 2020), suggesting that environmental and mass quenching do not act independently of one another. Despite this general consensus, the processes responsible for environmental quenching remain unclear.

In this project, we will use HST observations of the Hyperion proto-supercluster at z ∼ 2.5 (Figure 1) to create SMFs as a function of overdensity. By comparing SMFs of galaxies in the overdense regions of Hyperion with the SMF of field galaxies at similar redshifts, we can constrain the importance of environmental quenching mechanisms in high-redshift, overdense regions. Additionally, by comparing the environmental dependencies of the SMF of Hyperion with the SMF of overdense regions at lower redshifts, we can constrain the

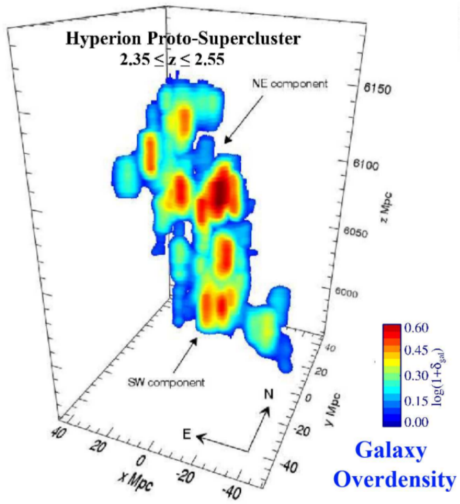

Figure 1. 3D Sky Distribution of Hyperion: A galaxy overdensity map of the Hyperion proto-supercluster (from Cucciati et al. (2018)).

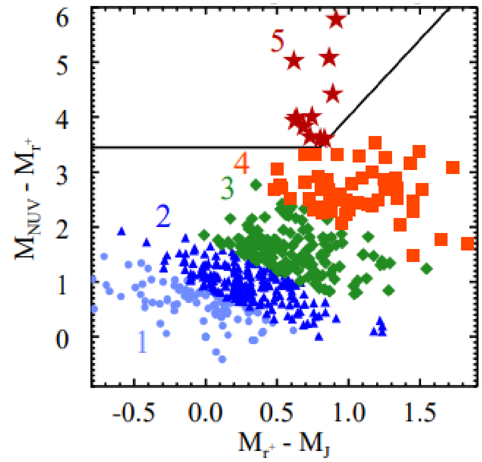

Figure 2. Predicted Quiescent Population of Hyperion: The predicted rest-frame NUVrJ color-color diagram of the Hyperion proto-supercluster, broken into 5 different color classes. The black line acts as a demarcation between galaxies that are quiescent (above) and star-forming (below). Taken from the HST proposal.

timescales over which certain environmental quenching mechanisms must act. In doing so, we can develop a better understanding of the environmental quenching mechanisms that dominate at higher redshifts, the interplay of these processes with the stellar mass of the galaxies they quench, and how the efficiency of these mechanisms may evolve with redshift.

2. METHODS

In order to study the effects of environmental quenching, I will be using observations of the Hyperion proto-supercluster at z $\sim$ 2.5. The data is a combination of photometric observations from COSMOS 2020 (Weaver et al. 2022), spectroscopic data from the VIMOS Ultra Deep Survey (VUDS; Le Fèvre et al. 2015) and zCOSMOS (Lilly et al. 2007), and HST grism data targeting Hyperion. Hyperion hosts 7 distinct overdensity peaks, which are the constituent protogroups and proto-clusters that make up the larger protosupercluster. The ability to compare SMFs of galaxies not only with field galaxies but with galaxies within Hyperion's complex density structure makes it a unique candidate for analyzing how environments can shape the SMF of galaxy populations.

With the combined data set, I will have access to spectra of $\sim$ 250 member galaxies in Hyperion, as well as $\sim$ 300 field galaxies within the same redshift range. The galaxy sample is effectively complete in stellar mass to $\log(M_*/M_\odot) \gtrsim 9.0$ for all galaxy types (Tal et al. 2014), and an SFR of $\sim 10\,\mathrm{M_\odot/yr}$. Hyperion is therefore a unique opportunity to explore a high-redshift, overdense environment to a completeness level comparable to low-redshift surveys. The Hyperion data have been fully reduced by Ekta Shah and Lu Shen. Additionally, the cluster membership of each galaxy using spectroscopic redshifts is currently being determined using a program written by Lu Shen. With this in mind, the first step of the project will be to create a color-color diagram to distinguish quiescent and semi-quiescent galaxies from star-forming galaxies, as in Figure 2. Using existing overdensity maps of Hyperion produced by Brian Lemaux, I can then classify the relationship between SFRs of galaxies in the cluster and the overdensity of the region in which they are located. This will establish a general idea of how quenching efficiencies vary with environment.

The next step will be to construct the SMFs as a function of overdensity. Before doing so, I will need to fit spectral energy distributions (SEDs) to the existing spectra in order to extract the stellar masses of the galaxies. With the assistance of Ben Forrest, I will use the SED-fitting program `LePhare` to fit the SEDs according to the photometric and spectroscopic data of each galaxy. These fits can be compared with fits from other SED algorithms, such as `EAZY`, to better constrain the physical parameters of the galaxies. With the SED-fits in hand, I can then create SMFs for various overdensities and quantify the interplay between environmental and mass quenching mechanisms. One way of doing this is to compare the observed SMFs to previous studies that simulated the effect of major mergers on the SMF (e.g., Tomczak et al. 2017). By comparing the observations and simulated SMFs (see Figure 3), I can

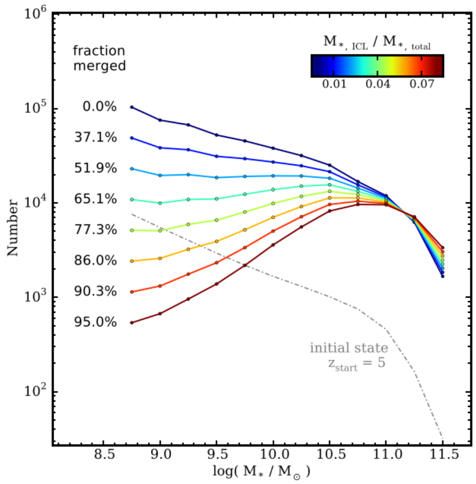

Figure 3. Effects of Mergers on the SMF: The simulated effects of mergers on SMFs, taken from Tomczak et al. (2017). The colored curves indicate different fractions of galaxies that experience mergers.

constrain the integrated merging history of galaxies in various overdensity regimes.

Finally, it will be important to establish the completeness of the study and explore any potential biases in the sample. Given we expect a relationship between environmental quenching and stellar masses, it will be important to identify any biases which may result from incomplete sampling of a given galaxy mass. One way of characterizing the completeness is to construct SMFs for galaxies with photometric and spectroscopic redshifts separately to verify they produce consistent results. However, it's important to note that the analysis of the environmental quenching effects does not hinge on a mass-completeness down to $\log(M_*/M_\odot) \gtrsim 9.0$ as measurable differences in the SMF exist at all galaxy masses (e.g., Figure 3).

3. TIMELINE

Jan-Feb: Examine the data set, identify quiescent and star-forming populations, and begin fitting SEDs

Mar-Apr:Finish fitting SEDs and construct SMFs, and begin comparison with previous studies

May-Jun: Finish analysis of SMFs, test completeness of study, and begin write-up

Jul-Aug: Finish write-up and allow time for contingencies

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