Growing the Seeds of Cosmic Dawn: Environmental Impact on Stellar Mass Assembly at z~2.5

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Abstract

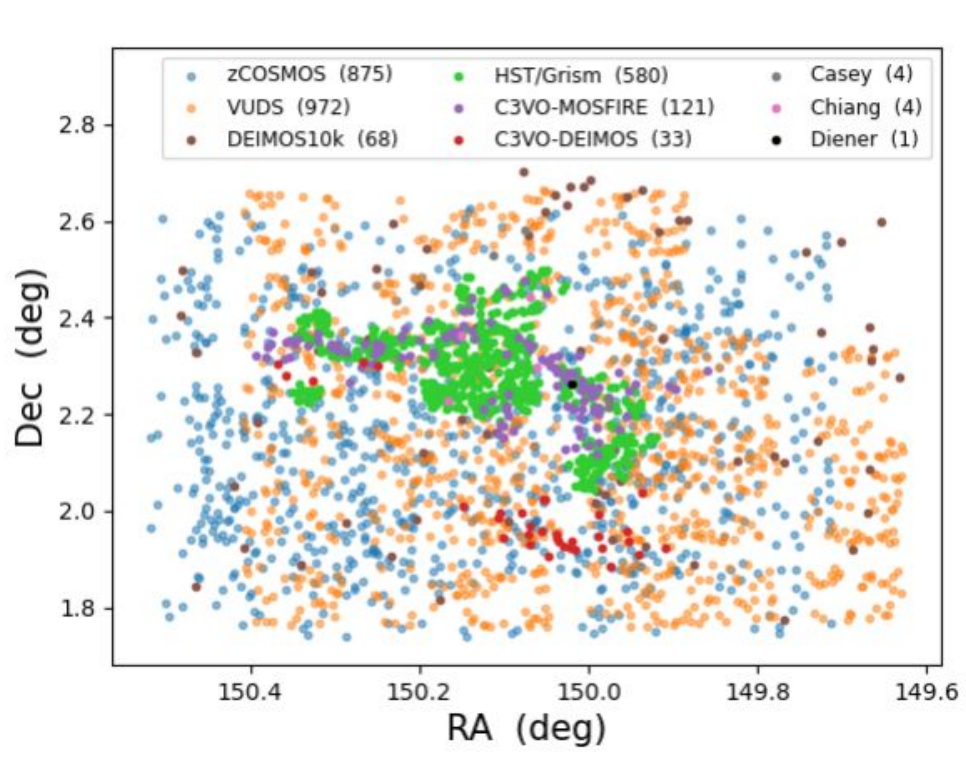
We investigate the relationship between local-overdensity and the galaxy stellar mass function (SMF) for the Hyperion proto-supercluster at z ~ 2.5. With a mix of COSMSOS2020 photometry and > 2500 spectra, we are able to map the structure of Hyperion and its multiple extremely overdense peaks. We find the shape of the SMF depends on local-overdensity and is typically flatter in the most overdense regions, showing a higher ratio of high-to-low mass galaxies than in the field. This result is consistent with similar works in the literature, and may indicate processing of galaxies at this redshift in proto-structures is driven through galaxy mergers.

Data

The Hyperion proto-supercluster lies in the heart of the Cosmic Evolution Survey (COSMOS; Scoville et al., 2007) field. As such, this work leverages the abundant photometric and spectroscopic survey data available, as well as data from targeted spectroscopic programs and *HST* grism spectroscopy. The data broadly comes from 3 sources:

1. COSMOS2020 photometry (Weaver et al., 2022)
2. Ground-based spectroscopy
3. Targeted *HST* grism spectroscopy (Forrest et al., in prep).

Below, we show high-quality spectroscopic redshift measurements from 2 ≤ z ≤ 3 used in this study.



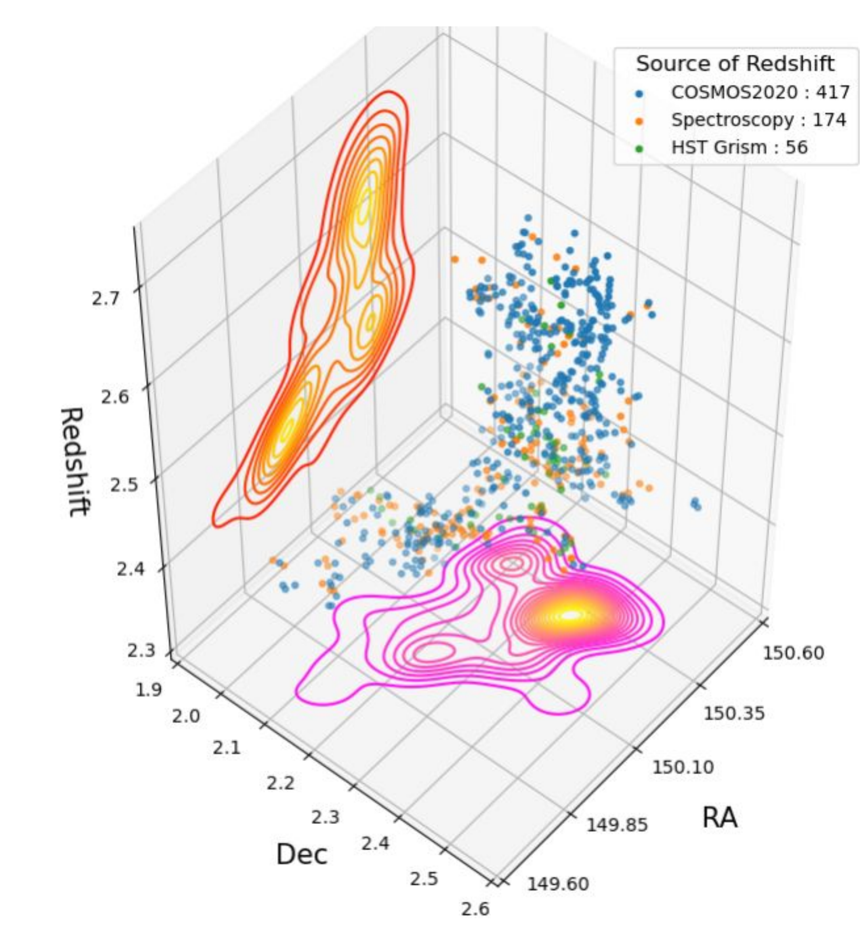
Methods

Redshift uncertainties can affect the SMFs in different ways. Changing the redshift of a galaxy can change its stellar mass (from SED fitting), if it is a part of Hyperion, and what overdensity it is in. To account for this, we create 100 Monte Carlo realizations for our data set. For each galaxy in each MC realization, we:

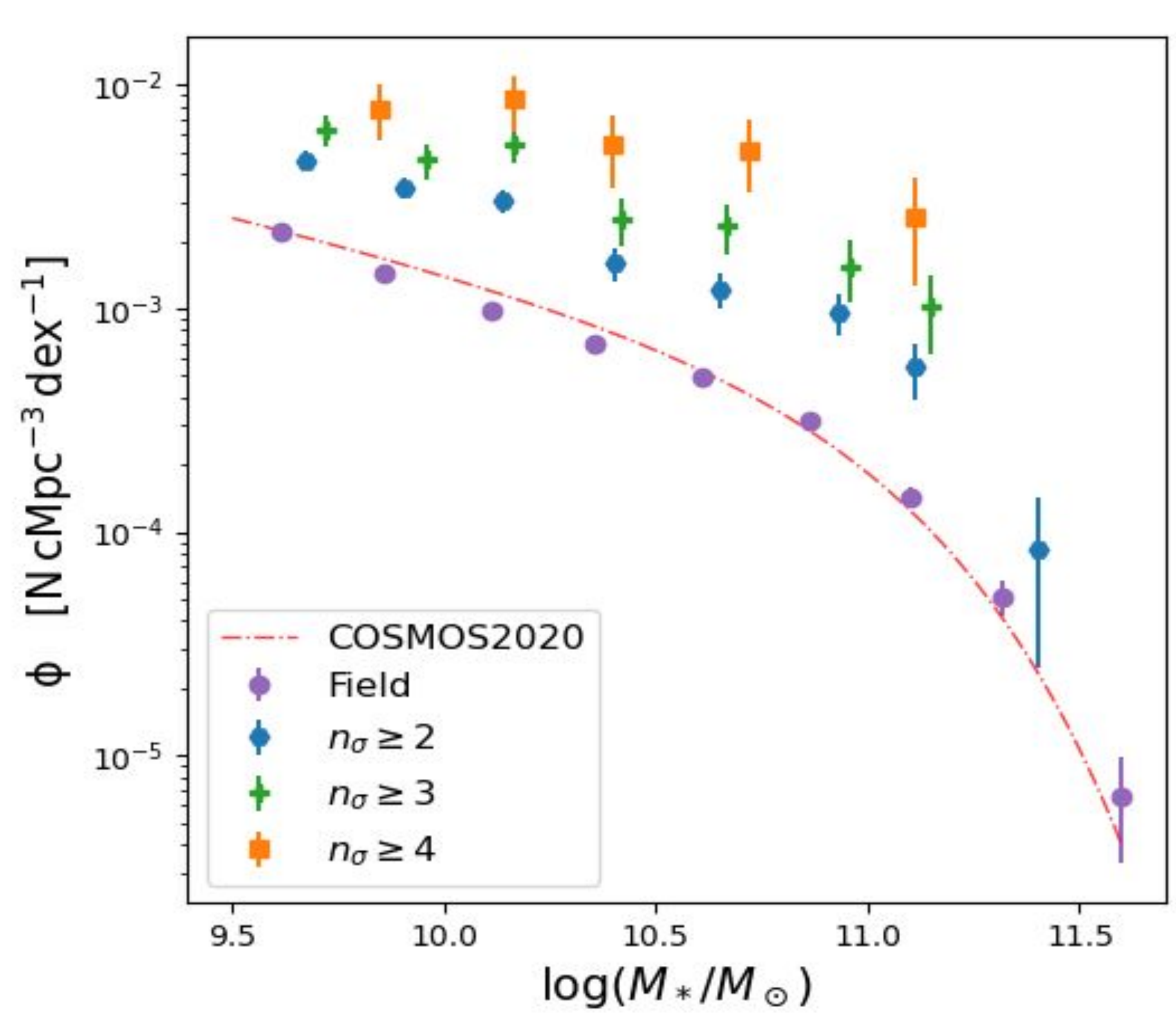
1. Either draw a redshift from from a distribution based on COSMOS2020 statistics, or use the spectroscopic redshift proportionally to its quality
2. Refit the stellar mass with LePhare (Arnouts et al. 1999; Ilbert et al. 2006) using the new redshift and COSMOS2020 photometry
3. Assign an overdensity to the galaxy
   a. Overdensity map made via a Voronoi Monte Carlo method (see Lemaux et al., 2022)
4. Build a SMFs for Hyperion and a field sample
   a. Define Hyperion as a contiguous region at least 2 standard deviations above the average overdensity at the redshift
   b. Define two field samples (2.15 ≤ z ≤ 2.25 and 2.8 ≤ z ≤ 2.9)

Results

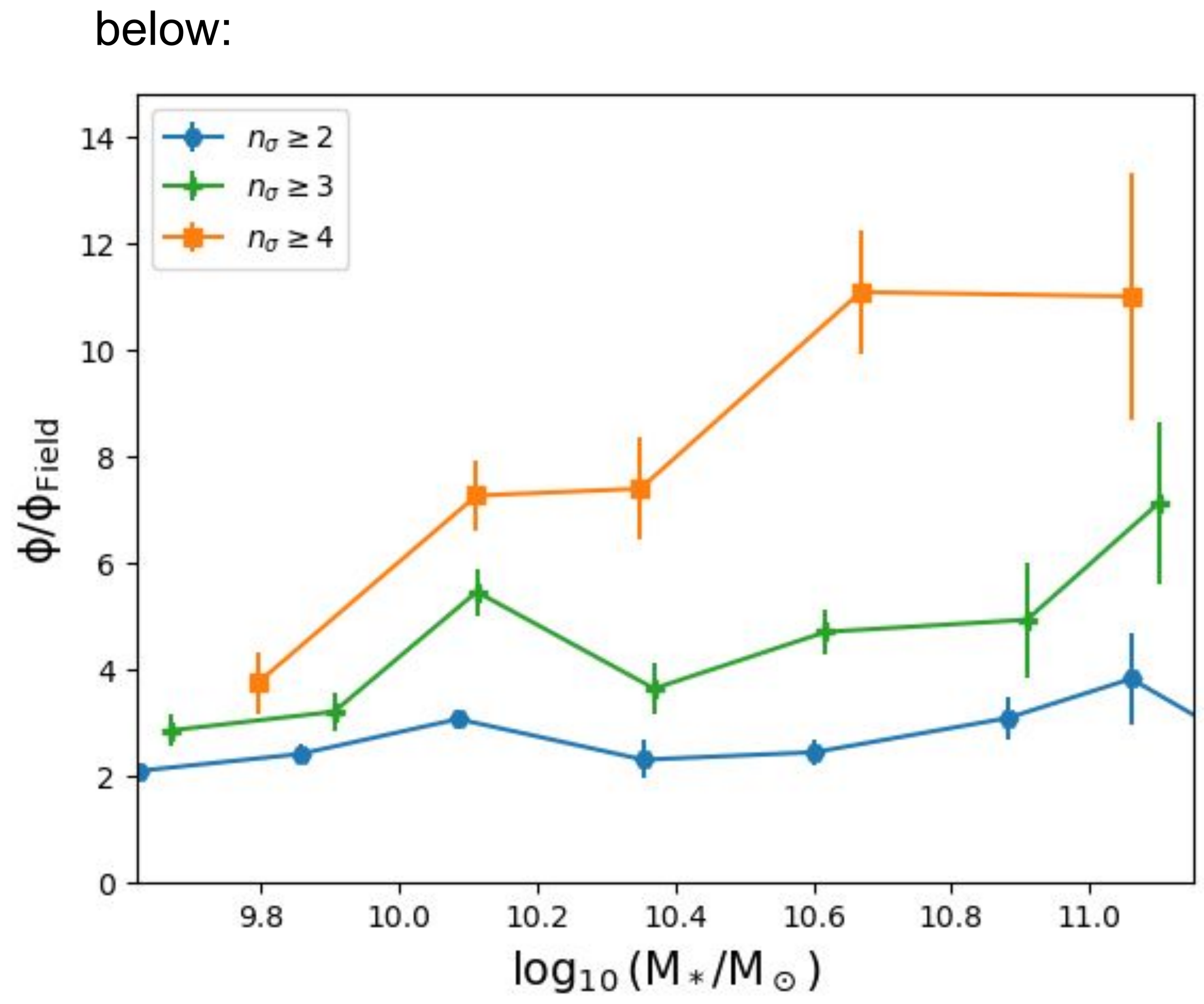
We make an updated map of Hyperion using the new *HST*/grism spectroscopy.



We build the stellar mass functions by averaging over the MC realizations. Below, we plot SMFs for 3 different minimum-overdensity-thresholds: 2, 3, and 4 standard deviations above the mean at the given redshift. We also plot the field sample and COSMOS2020 SMF for 2 ≤ z ≤ 2.5 (Weaver et al., 2023).



To compare the SMFs easier, we normalize the Hyperion SMFs by the field sample, shown below:



Discussion

The main result from this study is the finding that the most overdense regions of Hyperion seemingly have an excess of massive galaxies compared to the field. This result is consistent with trends found in lower redshift (z~1) clusters (Tomczak et al. 2017; van der Burg et al. 2018, 2020) as well as proto-structures at higher redshifts of z ~ 2.5 (Shimakawa et al. 2018a,b) and z ~ 3.3 (Forrest et al. 2024).

One explanation for this could be galaxies in the most overdense regions undergo earlier or more vigorous star formation. This would imply these galaxies are at an older evolutionary state than their counterparts in less-overdense regions and may be some of the first galaxies to quench. This also could imply proto-structures like Hyperion could be some of the first regions in the Universe to reionize their surrounding environments.

On the other hand, this enhanced stellar mass assembly could be the result of increased merger rates. Interestingly, some of these processes are more pronounced in intermediate-density environments rather than in the most extreme overdensities. For instance, Tomczak et al. (2017) demonstrated that galaxy mergers are most efficient in environments where the number density of galaxies is high, but the velocity dispersion remains moderate, facilitating a higher merger rate. In the local universe, the most overdense clusters often exhibit too high a velocity dispersion, limiting merger rates. Instead, mergers are more likely to occur in regions like groups and filaments, which exhibit similar overdensities to the most overdense regions of Hyperion. It is, therefore, plausible that the progenitors of present-day clusters – resembling the most overdense peaks of Hyperion host elevated merger rates, contributing to the excess of massive galaxies observed and potentially driving their eventual quenching.

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