Where is the Action? Galaxy Evolution and Environment at Redshift 1

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ABSTRACT

Cluster samples, across a redshift range of \(0.6 < z < 1.3\), taken from research conducted on the Observations of Redshift Evolution in Large Scale Environments survey (ORELSE) were analyzed to explore the role of dense environments in galaxy evolution. Using the spectroscopic and photometric data coverage, this research project studied the evolutionary states, luminosity, and mass properties of the galaxies in the cluster sample. Galaxy membership was determined by comparing three methods to make luminosity and mass functions: using the spectroscopic data, using spectroscopic and photometric data, and using photometric data. Results showed a one-to-one correlation between the spectroscopic and photometric data. From taking the spectroscopic fraction, it was determined that at fainter magnitudes, there is less spectroscopic coverage for each cluster. Luminosity and mass functions indicated that the projected density of galaxies in each of the clusters in the sample is proportional to the distance from the cluster core. The luminosity functions demonstrated that the cluster sample followed the trend that as the distance from the cluster core increased, there were more low luminous galaxies present than high luminous galaxies. The mass functions displayed a trend that clusters with low redshifts and low masses have approximately an equal distribution of high and low mass galaxies. Additionally, clusters with low redshifts and high masses have more massive galaxies near the cluster core but as the distance from the core increases, there tend to be more low mass galaxies. For clusters with a high redshift and a high mass there tend to be more massive galaxies throughout the cluster. Results also showed that clusters at high redshifts contain a higher disparity between the number density of high mass galaxies and low mass galaxies.

1. INTRODUCTION

The change of basic galaxy properties (such as morphology, color, and mass) with time is commonly used to study the underlying physical processes that drive galaxy evolution. This direction of study is useful because it investigates questions such as how long will a galaxy maintain its current morphology (Conselice 2014). From data obtained through various deep field surveys, it is obvious that galaxy properties in the early universe are different from those today (Conselice 2014). A progression of high redshift, high star-forming peculiar galaxies transforming to low redshift, passive star-forming galaxies occurs (Conselice 2014). It is still unclear what processes cause these transformations and how these processes vary in a range of environments.

This project investigates the question of what role do the densest environments play in galaxy evolution to see which specific environmental processes cause star formation rates and nuclear activity to be quenched in a galaxy (Lubin et al. 2009).

Environmental effects are any processes external to a galaxy that affect its evolutionary development (Vulcani et al. 2018). Studies (e. g. Bundy et al. 2005; Vergani et al. 2008) have determined that a galaxy's stellar mass is not only correlated to a galaxy's evolutionary progression over cosmic time but is also related to a variety of physical properties such as star formation rate, color, and internal structure (Kauffmann et al. 2003). Additionally, the distribution of galaxy stellar mass depends on the local environment (Baldry et al. 2006; Bolzonella et al. 2009). As time progresses,
the environment a galaxy resides in changes drastically as overdense regions are formed (Muzzin et al. 2012, 2014; Balogh et al. 2016; Owens et al. 2017; Tomczak et al. 2017, 2019; Lemaux et al. 2017). By studying large-scale structures at redshifts close to 1, the full environment a galaxy progresses through during the formation of dense regions in established clusters can be studied (Hung et al. 2019).

Clusters are observed to contain more blue, star-forming galaxies (Butcher Oemler 1984; Dressler et al. 1997; van Dokkum et al. 2001; Lubin et al. 2002) and a higher fraction of galaxies with nuclear emission (e.g., Dressler et al. 2004; Tran et al. 2003; De Lucia et al. 2004; Tanaka et al. 2005; Koyama et al. 2007; Best 2003; Eastman et al. 2007. Kocevski et al. 2009). These high-density regions are subject to a number of processes that hinder a galaxy's star formation rate and its ability to retain a spiral structure (Vulcani et al. 2018); however, the exact processes responsible for the decrease in the star formation rate and transformation are unknown (Lubin et al. 2009). Suggested mechanisms include galaxy harassment (Moore et al. 1996), ram pressure stripping (Gunn Gott 1972), starvation (Larson et al. 1980), cluster tidal forces (Byrd Valtonen 1990), and merging (Mihos 1995, 1999). However, most of these suggested processes are associated with lower-density environments far from the core of the cluster (Lubin et al. 2009). Even with these suggested mechanisms, there is an incomplete picture of how galaxy evolution occurs in dense environments. This project contributes to the current study on the effect of dense regions.

To address these questions, the Observations of Redshift Evolution in Large Scale Environments (ORELSE) survey targets large-scale structures at high redshifts (Lubin et al. 2019). Hung et al. (2019) used the ORELSE survey catalog to search for new clusters in areas not originally targeted by the survey. From the research by Hung et al. (2019), an order-of-magnitude larger sample than the original survey was created by detecting new overdensity candidates over the survey imaging area. This unique catalog of clusters contains both collected spectroscopic and photometric data (Hung et al. 2019). Because of the wide spectroscopic coverage provided by the ORELSE survey, the catalog from the work of Hung et al. (2019) provides the data for the research in this project.

This paper is organized as follows: The methodology section reviews the original ORELSE survey, and describes the characteristics of the new candidates added to the catalog as found by Hung et al. (2019). The methodology section also explains the analysis method performed in this project. After methodology, the results of the project are discussed along with the discussion and concluding remarks. This paper assumes a flat ΛCDM cosmology with \( H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1} \), \( \Omega_m = 0.27 \), and \( \Omega_A = 0.73 \).

2. METHODOLOGY

The goal of the project is to use the ORELSE Survey cluster catalog to analyze dense environments and their corresponding galaxies. The ORELSE survey collected spectroscopic and photometric data across 15 fields over a redshift range of 0.6 < \( z < 1.3 \) (Lubin et al 2009). The survey imaging spans the optical to near-infrared bands, using typical filters such as B, V, R, I, Z, J, and K, and the survey covers an area of about 5 square degrees (Hung et al. 2019). The unique feature of the survey includes ORELSE’s spectroscopic coverage of 11,000 objects (Hung et al. 2019).

Hung et al. (2019) searched for new overdensity candidates using more than 15 fields in the original ORELSE survey. The researchers restricted their search for overdense candidates to clusters with mean redshifts within the range of 0.55 to 1.37 (Hung et al. 2019). Overdensity maps were created by using a technique called Voronoi Tessellation Monte-Carlo (VMC). With VMC, a 2D plane gets divided into an equal number of polygons as there are number of objects in the plane (Lemaux et al. 2017). Each object in the plane has its own Voronoi cell. A Voronoi cell can be defined as the region closest to the object. If an object has a small Voronoi cell, it is in a high-density region and if it has a larger Voronoi cell, it is in a low dense region. The local density at the position of the object can be determined by taking the inverse of the area of the object’s cell. Each of the redshift slices that the 2D plane is divided into overlaps with the slice directly before it to prevent a single overdensity candidate being separated over a range of slices. The advantage of using VMC is that this technique is scale-independent and it can be used over large physical lengths (Hung et al. 2019).

Any overdensity candidate discovered that contained \( \sigma_x \) (standard deviation of the Gaussian) > 0.05 was regarded as too unphysically large and was excluded from being in the new catalog (Hung et al. 2019). Additionally, only candidates with a 5% spectroscopic fraction were included (Hung et al. 2019). In the research conducted by Hung et al. (2019), the spectroscopic fraction was defined by the following relation

\[
Q_{\text{true}} = \left( N_{\text{conf},A} + N_{\text{conf},\text{out}} \right) / N_{\text{phot}}
\]

where \( N_{\text{conf},A} \) are the \( z_{\text{spec}} \) galaxies in the redshift range that correspond to a \( z_{\text{phot}} \) galaxy in the redshift range,
$N_{\text{conf, out}}$ are the $z_{\text{phot}}$ galaxies that correspond to a $z_{\text{spec}}$ galaxy out of the redshift range, and $N_{\text{phot}}$ is the total number of $z_{\text{phot}}$ galaxies in the redshift range (Hung et al. 2019). The VMC technique was applied to the full ORELSE imaging area. A total of 402 new overdensity candidates were discovered (Hung et al. 2019) and 51 of the 56 previously known clusters or groups were recovered (Hung et al. 2019). The 402 new overdensity candidates have redshifts of $0.565 < z < 1.371$, have spectroscopic fractions between 5% and 76.9%, and have estimated masses between $10.2 < \log(M_{\text{fit}}/M_{\odot}) < 14.8$ (Hung et al. 2019). The purity and completeness tests for high spectroscopic coverage produced results of $\log(M_{\text{fit}}/M_{\odot}) \geq 14.5$ (Hung et al. 2019).

The main scientific question proposed will be addressed by studying the evolutionary states, luminosity, and mass properties of the new clusters discovered by the work of Hung et al. (2019). This project will create luminosity and mass functions for a variety of clusters at different redshifts to investigate the evolutionary effects the local environment contributes.

3. RESULTS

Using the catalog developed by Hung et al. (2019), we utilized the spectroscopic and photometric redshifts to examine our ability to accurately recover galaxy mass and luminosity functions. Because there is only partial spectroscopic coverage for each cluster, the galaxy population in each cluster is not fully known. Photometric redshifts are not accurate enough to determine whether a galaxy is in a cluster. Therefore, it is important to examine the reliability of the photometric redshifts. A variety of graphs were created including photometric vs. spectroscopic diagrams, histograms depicting the spectroscopic and photometric coverage at various ranges of virial radii, color-stellar mass diagrams, and histograms detailing the variety of galaxy stellar mass values in each cluster. Additionally, the spectroscopic fraction was computed for each cluster at each virial radius interval.

The purpose for examining the spectroscopic, photometric, stellar mass coverage was to determine the extent of the data in the catalog. With the pureness of the data tested, the galaxy members of each cluster within the specific redshift range of $\Delta z \pm 0.05$ were determined by creating luminosity and mass functions. This analysis was accomplished by three distinct methods. The first method consisted of only using the spectroscopic data for each galaxy in each cluster. The second method was comprised of the galaxies with spectroscopic data and galaxies with photometric redshifts in the desired redshift range. The third approach was using only the photometric redshifts and ignoring any spectroscopic redshifts. These three techniques determined which galaxies we considered to be in each cluster.

Plots of photometric versus spectroscopic redshifts for galaxies in each of the fields discovered by the work of Hung et al. (2019) were created. These graphs can be seen in figure 1. These fields contain high-quality spectroscopic redshifts and the photometric redshifts were compared to these values. Each panel shows the respective redshift distribution for each of the fields. From these plots, it can be concluded that there is a one-to-one correlation between the spectroscopic and photometric data.

In order to compare the spectroscopic and photometric coverage in the U band, histograms of the spectroscopic and photometric members were created for each field. An example of these subplots can be seen in figure 2. The remaining clusters can be seen in figure 10. From these histograms, it was observed that on average, there typically are more spectroscopic members within the first two virial radii ranges (0-0.5 $R_{\text{vir}}$, 0.5 $R_{\text{vir}}$-1 $R_{\text{vir}}$) than in the last range (1 $R_{\text{vir}}$-1.5 $R_{\text{vir}}$). However, in general, there are more photometric members in the virial radii ranges of 0.5 $R_{\text{vir}}$-1 $R_{\text{vir}}$ and 1 $R_{\text{vir}}$-1.5 $R_{\text{vir}}$. Regarding galaxy populations at certain virial radii ranges, a wide assortment of conclusions can be drawn. For clusters SC1604Lz, SC1604A, SC1604B, SC1604G, SC1604H, SC1604Hz, SC1324A, SC1324I, SC1324I, RCS0224A, RCS0224B, RXJ1221B, RXJ1053, there tend to be more photometric members detected as the magnitude gets lower. In contrast, clusters SC0849D, SC0849E, and RXJ1053Hz have more high luminous photometric members.

In regard to the spectroscopic coverage, clusters SC1604Lz, SC1604H, SC1324H, and Cl1137, contain more spectroscopic members at low magnitudes. Clusters RCS0224A, RXJ1221B, SC1604Lz, SC1604B, SC1604G, RCS0224A, and RCS0224B, contain more low magnitude spectroscopic members in the 1-1.5 times the virial radius range. More low magnitude spectroscopic members in clusters SC1324A, SC1324H, and Cl1137 are found in the 0.5-1 times the virial radius range. Cluster SC1324H does not follow this trend as this cluster contains more low magnitude spectroscopic members in the range of 0-0.5 time the virial radius.

Clusters SC1604A, SC1604B, SC1604H, SC1324A, SC0849D, RXJ1221B, and RXJ1053 contain a greater extent of high magnitude spectroscopic members at a range of 0-0.5 times the virial radius. Similarly, clusters SC1604Hz, SC0849A, SC0849E, enclose more high magnitude spectroscopic members at a range of 0.5-1 times the virial radius. Clusters that have approximately
Figure 1. Subplot showing the distribution of the spectroscopic and photometric redshift data. The black data points are outliers as they have a fractional ratio value greater than 0.05. The black line is a line of best fit for the purple colored data points. The cyan colored line is the one-to-one ratio line. The x-axis is the measured spectroscopic redshift for each galaxy and the y-axis is the corresponding measured photometric redshift for each galaxy. Each panel represents each of the 8 fields being studied in this project. The purple colored data points are galaxies that have a value of $|z_{\text{photo}} - z_{\text{spec}}|/(1+z_{\text{spec}}) \leq 0.05$. 
Figure 2. Subplots displaying histograms of the spectroscopic and photometric members of each field. The blue bars represent the spectroscopic members and the orange bars represent the photometric members. The x-axis is the rest frame absolute magnitude in the U band measurements.

<table>
<thead>
<tr>
<th></th>
<th>RXJ1716B</th>
<th>RXJ1716C</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 0.5R_{vir}</td>
<td>0.3333</td>
<td>0.1875</td>
</tr>
<tr>
<td>0.5 - 1R_{vir}</td>
<td>0.3117</td>
<td>0.3000</td>
</tr>
<tr>
<td>1 - 1.5R_{vir}</td>
<td>0.2178</td>
<td>0.2500</td>
</tr>
</tbody>
</table>

Table 1. An example of the calculated spectroscopic fractions for two clusters for varying I band magnitude limits. The limited I band values are indicated above the first virial radius range for each set.

Spectroscopic fraction results can be seen in table 1. This table displays an example of the spectroscopic fractions computed for two of the fields and for each of the virial radii ranges. Additionally, it contains the spectroscopic fractions for each cluster at specific ranges of I band magnitudes. In this report, the spectroscopic fraction was computed from the following relation:

\[ N_{z,spec} / (N_{z,spec} + N_{z,pz}) \]

where \( N_{z,spec} \) is the total number of \( z_{\text{spec}} \) galaxies and \( N_{z,pz} \) is the total number of \( z_{\text{pz}} \) galaxies. Generally, the range with 0.5 times the virial radius contains the highest spectroscopic fraction and as the I band magnitude became more restrictive, the spectroscopic fraction increased. At fainter magnitudes, there is less spectroscopic coverage.

To explore the evolutionary states of the galaxies, color-stellar mass diagrams were generated for all of the clusters. These diagrams depict the rest frame U-V color vs. the stellar mass values in each field. These plots can be seen in figure 3. These graphs provide a distribution of the types of galaxies present in each of the clusters. This is helpful to see where each galaxy falls with regards to the stellar mass present in it. Therefore, the evolutionary states of the galaxies in each of the clusters at different redshifts can be determined and the galaxies can be classified as being either star-forming or quiescent.

Figure 4 shows the composition of the stellar mass of each galaxy in each cluster from the catalog. These results are important because they clarify the extent of the same number of high magnitude and low magnitude spectroscopic members in various radii ranges are RXJ1716B and RXJ1716C. The clusters RXJ1716B and RXJ1716C have excellent spectroscopic coverage. In all three of the radii ranges, RXJ1716B and RXJ1716C have approximately equal members of low magnitude and high magnitude.

Finally, clusters Cl1137 and SC1604A encompass so few spectroscopic members in the 1-1.5 times the virial radius range a conclusive conclusion cannot be drawn. Similarly, clusters SC0849A, RXJ1053Hz, SC0849E, SC1604Hz accommodate few spectroscopic members in the 0.5-1 times the virial radius range.
stellar mass data collected and help classify the galaxies within each cluster.

From the previous sets of figures, the purity and completeness of the cluster catalog has been demonstrated. With these results, we were able to create luminosity and mass functions using the three methods described above. The clusters were divided into subsamples based on redshift and mass. The subsamples were clusters with low redshift and low mass, low redshift and high mass, high redshift and low mass, and high redshift and low mass. For the subsample division, the low redshifts were between 0.5995 ≤ z ≤ 0.8528. For the low redshift division, the low masses were between 2.3 · 10^{13} M_{\odot} - 4.5 · 10^{14} M_{\odot} and the high masses were between 5.1 · 10^{14} M_{\odot} - 1.4 · 10^{15} M_{\odot}. The high redshifts are between 0.8648 ≤ z ≤ 1.2703. For the high redshift division, low masses are between 6.8 · 10^{13} M_{\odot} - 2.6 · 10^{14} M_{\odot} and the high masses are between 2.8 · 10^{14} M_{\odot} - 6.1 · 10^{14} M_{\odot}.

The clusters in the low redshift and low mass subsamples were SC1604H, SC1324H, RXJ1221B, RXJ1716C, and RCS0224B. The clusters with a low redshift and a high mass were SC1604Lz, SC1324A, SC1324I, RXJ1716B, and RCS0224A. The high redshift and low mass sample had clusters SC1604G, SC0849E, SC1604Hz, SC0849D, and Cl1137. Finally, for the high redshift and high mass category the cluster members were SC1604B, RXJ1053, RXJ1054Hz, SC1604A, and SC0849A.

Figure 5 depicts the luminosity function graph for cluster RXJ1716C at the three virial radii ranges. The number of galaxies per absolute magnitude value in the U band was normalized to be able to compare the clusters. From the luminosity functions produced, it was determined that there is a high density of galaxies in the center of each of the clusters. As the radii division increased, the projected density of galaxies decreased. At highly luminous absolute magnitude values, roughly equal amounts of spectroscopic and photometric members were detected. When the absolute magnitude values approached less luminous values, more photometric members were detected than spectroscopic members. Generally, it was demonstrated that clusters at a high redshift and a high mass, tend to contain more high luminous galaxies present at each of the radii ranges. Two exceptions, SC1604A and SC1604B, were found where these clusters contained more luminous galaxies near the cluster but as the virial radii range increased, there were more less luminous galaxies. For clusters with a low redshift and a low mass, there was an evenly distributed amount of high luminous and low luminous galaxies. For clusters with a high redshift and a low mass there were
Figure 4. Histograms depicting the stellar mass of the galaxies in each cluster. The x-axis shows the log galaxy stellar mass in units of solar masses. The histogram is restricted to galaxies within $\Delta z \pm 0.05$ of the cluster core. The selection of the galaxies included in the histogram have an I band magnitude greater than or equal to 19 but less than or equal to 24.5.

more high luminous galaxies closer to the core. As the distance from the core increased, there was a small rise in the number of low luminous galaxies and a decrease in the number density of high luminous galaxies. The cyan dotted line depicting the sum of the photometric and spectroscopic members demonstrates the full data coverage for each cluster.

Mass functions were created to visualize the projected density of galaxies within certain mass intervals. Figure 6 shows the mass function for cluster RXJ1716C at all three virial radii ranges. Similarly, to the luminosity functions, it was demonstrated that there is a higher density of galaxies closer to the core of the cluster. It was determined that clusters with low redshifts and low masses typically have an equal distribution of high and low mass galaxies at all three of the virial radius range. It was concluded that generally the clusters in our sample with low redshifts and high masses have more massive galaxies closer to the core but as the distance from the core increases, there tends to be more less massive galaxies present than high massive galaxies. The cluster subsample with a high redshift and a high mass had no clear trend displayed. Clusters SC1604G, SC1605HZ, and SC0849D showed more massive galaxies near the core, but more less massive galaxies were present as the distance from the cluster core increased. Cluster Cl1137 had more less massive galaxies throughout the cluster.

Finally, cluster SC0894E had more less massive galaxies near the cluster core. For half of the clusters sampled, as the distance from the core increased, there were more less massive galaxies present than massive galaxies.

The average mass function of each of the subsample was taken. These figures are shown in figure 9. From these figures, it was concluded that for clusters in our sample at low redshifts there is less of a deviation between the number density of high and low mass galaxies than for clusters at high redshifts. This confirms the expected result that clusters at high redshifts contain a higher contrast between the number density of high mass galaxies and low mass galaxies.

4. SUMMARY AND CONCLUDING REMARKS

In this project, we explored the effects the local environment contributes to galaxy evolution by comparing cluster surroundings at high redshifts. We used the cluster catalog, developed by the work of Hung et al. (2019), which houses extensive spectroscopic and photometric data coverage for large scale structures. We tested the purity and completeness of the catalog by creating various histograms and diagrams, and by computing spectroscopic fractions for various absolute magnitude ranges. Using the results of the purity and completeness tests, luminosity and mass functions were plotted using three different methods.
Results determined that there was a one-to-one correlation between the spectroscopic and photometric data for the galaxies inside each cluster. In general, for the clusters produced by the work of Hung et al. (2019), spectroscopic coverage increases as the virial radii range decreases and photometric coverage increases as the virial radii range increases. This trend was demonstrated by computing the spectroscopic fraction for each virial radius range and by constraining the spectroscopic coverage by limiting the fraction to only include values within a certain I band magnitude range. This calculation showed that for most of the clusters, the most spectroscopic members were contained in the $\leq 0.5 R_{\text{vir}}$ range. As the I band magnitude range got fainter, generally, the spectroscopic members would decrease.

Once the purity and completeness tests were completed, luminosity and mass functions were created in

Figure 5. Panels showing an example of the luminosity functions produced. The y-axis is the normalized value of the number of galaxies per absolute magnitude value per Mpc$^2$. The x-axis is the rest frame absolute magnitude values from the U band measurements. The black dotted line is the spectroscopic members, the red dotted line is the photometric members present, and the cyan dotted line is the sum of the spectroscopic and photometric members in each cluster. The $x$ is the distance a galaxy is from the center of the cluster. Another luminosity function example can be seen in figure 7.

Figure 6. Panels showing an example of the mass functions produced. The y-axis is the normalized value of the number of galaxies per stellar mass per Mpc$^2$. The x-axis is the log of the galaxy stellar mass values measured in units of solar masses. The black dotted line is the spectroscopic members, the red dotted line is the photometric members present, and the cyan dotted line is the sum of the spectroscopic and photometric members in each cluster. The $x$ is the distance a galaxy is from the center of the cluster. Another mass function example can be seen in figure 8.
three distinct methods. Method one consisted of only using spectroscopic members. Method two consisted of using both spectroscopic and photometric members that were in the desired redshift range. Method three consisted of only using the photometric members in the specific redshift range for each cluster. From the luminosity functions, it was determined that the projected density of galaxies in a cluster is proportional to the distance the galaxy is from the cluster core. There was less spectroscopic coverage for less luminous galaxies. Additionally, the cluster sample demonstrated that clusters with high redshifts and high velocity dispersion tend to have more high luminous galaxies at each of the virial radii divisions. Another result showed that clusters with high redshifts and low masses have more high luminous galaxies closer to the cluster but as the distance from the core increases, the number density of low luminous galaxies increase.

The results from the mass functions confirmed that at a distance closer to the core of the cluster, there is a higher projected density of galaxies. Clusters with low redshifts and low masses demonstrated an equal distribution of high and low mass galaxies in all three virial radii ranges. Generally, for the clusters in our sample, clusters with low redshifts and high masses have more massive galaxies near core. The subsample of clusters in the high redshift and low mass section did not produce a similar trend. Overall, for half the clusters in our sample, there was a trend that as galaxies go further from the core of the cluster, the galaxies tended to be less massive.

The average mass function graphs depicted a larger contrast between high mass and low mass galaxies for clusters at high redshifts than for clusters at low redshifts.

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REFERENCES


Koyama et al. 2007, Dependence of the build-up of the colour-magnitude relation on cluster richness at $z = 0.8$, MNRAS, 382, 1719


Mihos, C., 1999, Dynamics of Mergers, APSS, 266, 195


Vulcani, B., Poggianti, B., AragonÃşn-Salamanca, A., et al. 2011, Galaxy stellar mass functions of different morphological types in clusters, and their evolution between $z=0.8$ and $z=0$, MNRAS, 412, 246
Figure 7. Similar to figure 5. This figure is an example of the luminosity function for cluster RCS0224B. The black dotted line is the spectroscopic members, the red dotted line is the photometric members, and the cyan dotted line is the sum of the spectroscopic and photometric members. The x-axis is the rest frame absolute magnitude value in the U band. The x corresponds to the distance a galaxy is from the cluster core.
Figure 8. Similar to figure 6. This figure shows another example of the mass function graphs produced in this project. This is for cluster SC1324A. The spectroscopic members are represented by the black dotted line, the red line is for the photometric members, and the cyan line is the sum of the photometric and spectroscopic members. The $x$ corresponds to the distance the galaxy is from the cluster core. The $x$-axis corresponds to the log of the galaxy stellar mass in units of solar mass.
Figure 9. These figures show the average mass functions for the clusters classified into each category. The x-axis shows the log of the galaxy stellar mass in units of solar mass. For this comparison, low redshifts are between \(0.5995 \leq z \leq 0.8528\). For the low redshift division, the low masses were between \(2.3 \cdot 10^{13} M_{\text{sun}} - 4.5 \cdot 10^{14} M_{\text{sun}}\) and the high masses were between \(5.1 \cdot 10^{14} M_{\text{sun}} - 1.4 \cdot 10^{15} M_{\text{sun}}\). The high redshifts are between \(0.8648 \leq z \leq 1.2703\). For the high redshift division, low masses are between \(6.8 \cdot 10^{13} M_{\text{sun}} - 2.6 \cdot 10^{14} M_{\text{sun}}\) and the high masses are between \(2.8 \cdot 10^{14} M_{\text{sun}} - 6.1 \cdot 10^{15} M_{\text{sun}}\). The orange lines are for the high mass samples and the blues line are for the low mass samples.
Figure 10. Similar to figure 2. Subplots displaying histograms of the spectroscopic and photometric members of each field. The orange bars represent the photometric members and the blue bars represent the spectroscopic members. The x-axis is the rest frame absolute magnitude value in the U band.