Star Formation in SpARCS J0330: Bridging the Gap Between Protoclusters and Clusters

1. Background

All galaxies form a part of the hierarchical structure of clusters and groups of galaxies. Star formation in massive galaxies is often concentrated in the central regions, with lower star formation in the outer parts. The transition from a protocluster to a cluster is not well understood. However, recent studies suggest that massive protoclusters at $z \sim 2$ to 3 are transforming into clusters within a few billion years. This transition is thought to be driven by environmental quenching mechanisms, such as ram-pressure stripping and galaxy-galaxy interactions, which suppress star formation. The study of these massive protoclusters can provide insights into the early history of galaxy formation and evolution. We present an analysis of the SpARCS J0330 cluster, one of the most massive and high-redshift galaxy clusters known, to better understand the transition from protocluster to cluster.

2. SpARCS J0330

We present observations of SpARCS J0330, one of the most massive and high-redshift galaxy clusters ever discovered. The cluster is located at a redshift of $z = 1.626$, with a dynamical mass of $2.5 \times 10^{15}$ M$_\odot$. We combine the photometry and spectroscopy compiled by Nantais et al. (2017) with our own observations, as well as ancillary data in the field, to build up Spectral Energy Distributions (SEDs) for the 40 spectroscopically confirmed cluster members, as well as potential cluster members, with up to 20-band photometry. We use the photometric fitting code $CIGALE$ and $EASY$ (Boquien et al. 2019) to estimate the properties of these sources and hence map out distant, star-forming galaxies over a $\sim 1$ Mpc region in the cluster.

3. Sample Selection

1. Spec-z sample: Comprising the 40 spectroscopically confirmed cluster members. The photometric redshifts include $e$, n, and y bands from the 2MASS, SDSS, WISE, and SPIRE photometry from Spitzer and Hubble Space Telescope. We use the $EAZY$ code to estimate the photometric redshifts.

2. Photo-z sample: Sources in the wider field from the Spitzer Data Fusion catalogue. We use photometry from the Herschel, WISE, SPIRE, and WISE video-surveys, as well as CTIO MOSAIC2.

3. Field sample: We additionally assemble a field sample of sources from the Spitzer Data Fusion catalogue spread across the AWM-LSS field.

4. SED Fitting

We use the photometric fitting code $CIGALE$ to estimate photometric redshifts for the photo-z, spec-z and field samples, allowing us to select likely cluster candidates (see Figure 1). Then, we use $CIGALE$ to estimate galaxy properties for four samples. We use the $EASY$ code to parameterise the star formation history according to $t_{\text{rmed}} = t_{\text{age}}/(1 + z)$. We fit the models with a pseudo-continuum and a dust attenuation curve based on the Calzetti et al. (2000) dust extinction law. We use the starburst emission module and the $CIGALE$ dust module which models the FIR dust peak as a simple modified blackbody.

5. Results

In Figure 2 we present the SFR - $M_{\text{stellar}}$ relation for all four of our samples, as well as the SFR - $M_{\text{stellar}}$ relations for typical star-forming galaxies at $z = 1.626$. We find that the majority of our sources lie below the main sequence. In Figure 3 we show the spatial distribution of our spectroscopically confirmed cluster members, overlaid on the density maps of the photo-z sample (left) and the photo-z wide sample (right). We find some evidence of substructure, with the photo-z sample displaying four distinct peaks in the density distribution of the photo-z sample, as well as a further large density peak in the wider map to the North East.

6. Conclusions and Future Work

We have presented an analysis of the $z = 1.626$ cluster SpARCS J0330. By building SEDs of up to 20-band photometry, we used the photometric fitting codes $CIGALE$ and $EASY$ to estimate galaxy properties and map star formation in the cluster.

- We find that SFR remains constant with projected cluster-centric distance within the core with median SFRs higher than the Coma Cluster but lower than in higher redshift clusters and field galaxies.
- In the wider cluster region, SFR increases gently with cluster-centric distance, likely due to the truncation of star-formation as galaxies are accreted into the cluster.
- The majority of the sources in the redshift bin below $z = 2$, relative to $z = 1$.626, are located in the cluster core. The results suggest that the environmental quenching of cluster galaxies has already begun between $z = 2$ and $z = 1$.
- The spatial distributions of our samples are potentially indicative of substructure within the cluster core and in the larger scale cluster region.

There is still a great deal of exciting work to do for this project. Nantais et al. (2019) find that $\sim 1.6$ clusters have low quenching efficiencies based on their optical/NIR photometry and Nantais et al. (2020) find that the $H_{\alpha}$ based SFRs for three $\sim 1.6$ SpARCS clusters in agreement with field galaxies across a range of stellar masses. The disparity between these results and ours is likely due to methods used for estimating SFR and the inclusion of additional FIR data, but this requires further investigation, including a comparison between the CIGALE based SFRs for these SpARCS clusters in agreement with field galaxies across a range of stellar masses. The disparity between these results and ours is likely due to methods used for estimating SFR and the inclusion of additional FIR data, but this requires further investigation, including a comparison between the CIGALE based SFRs for these SpARCS clusters in agreement with field galaxies across a range of stellar masses.