Substructure in redMaPPer clusters and its link to X-ray morphology and scaling relations

The hierarchical structure formation theory has been the standard paradigm for structure formation for almost half a century. Larger structures form via collisions and mergers of smaller structures in a bottom-up fashion. This also applies to galaxy clusters. As galaxy clusters are one of the largest gravitationally bound systems in the entire Universe, their mergers are the most energetic events since the Big Bang. Cluster mergers lead to the formation of substructures and can affect the shape and properties of the cluster.

Galaxy clusters are an important probe in the study of the large-scale structure and structure formation. Improving the precision of cosmological studies requires improvements in all aspects of cluster studies, including the identification and understanding of cluster mergers. Cluster identification is a prerequisite to any study. Modern surveys give us large datasets to work with, and thus multiple different cluster identification algorithms have been invented. One of the most popular tools is the red-sequence matched-filter Probabilistic Percolation (redMaPPer) cluster finder. Catalogs of clusters identified with redMaPPer have become a standard tool in the field. Our main sample consists of clusters from the DESI Legacy Imaging Surveys that were originally identified with redMaPPer.

By using the Hierarchical Density-Based Spatial Clustering of Applications with Noise (HDBSCAN) algorithm, we study whether redMaPPer objects form a single object or if they can be broken into subclusters. By combining optical and X-ray data, we can carry out a comprehensive study of substructure in galaxy clusters. We cross-match the redMaPPer catalog with published eROSITA sources and present the catalog. We obtain a classification for each cluster and produce membership catalogs. We study how the presence of optical substructure reflects on the X-ray morphology and scaling relations of the clusters.

We find that substructure is a common attribute in galaxy clusters. Our results demonstrate that the fraction of clusters with substructure is highly sensitive to the detection threshold of the substructure. We compare the morphological properties of clusters with and without substructure. We find that clusters with substructure are clearly more disturbed. The difference is more pronounced in massive clusters, while at intermediate and low-richness the differences are reduced, possibly due to cooling and feedback from active galactic nuclei. Additionally, we find that the morphological parameters themselves are correlated with richness. Smaller clusters are more disturbed regardless of substructure.

We show that substructure determination in redMaPPer objects is feasible with HDBSCAN and leads to improvements in the use of clusters for precision cosmology. Most notably, by using our updated richness estimate, we can reduce the scatter in the X-ray luminosity vs. richness scaling relation by 7%. We find that clusters with substructure exhibit higher normalization and greater scatter in the relation. These effects are only pronounced at low redshifts. This could be explained by the known growing importance of cool cores at low redshift.