Investigating the Radial Density Distribution in Galaxy Cluster Cores

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Scientific Background and Objectives

Studying the dynamics and structure of galaxy clusters can provide important insights into a variety of astrophysical effects and dark matter properties. These structures are often investigated through the creation of galaxy density profiles, in which the average density of satellite galaxies in a set of clusters is plotted as a function of distance from the clusters' bright central galaxies (BCGs). Of particular interest in these density profiles is the distribution of satellite galaxies in the innermost region of clusters. The high matter densities that are present within these "cluster cores" result in interesting interactions such as galaxy stripping and disruption that play a key role in current models of galaxy evolution. However, characterizing the density profiles of cluster cores from observational data is often extremely difficult, as the high density of satellites close to the BCG produces a blending effect that interferes with our ability to accurately recover the properties of individual cluster members. The goal of this project is to develop a method that can more effectively probe these dense inner regions and provide insights into the processes of galaxy evolution. Using machine learning methods, we aim to evaluate the biases of current observational measurement techniques and derive corrections that can mitigate blending effects, thus leading to the creation of more accurate density profiles within cluster cores. By comparing our measurements to simulations of cluster evolution under different dark matter frameworks, we will be able to provide new evidence about intra-cluster interactions and processes that until recently have been out of reach due to blending effects and measurement limitations.

Using Balrog to Investigate Measurement Biases

Balrog is an image simulation and bias-detection software developed within the Dark Energy Survey (DES) that can be used to mitigate the difficulties of obtaining accurate observational measurements. In the Balrog approach, simulated galaxies with predetermined properties are injected into raw observational data of galaxy clusters. The images are then processed with the official DES reduction pipeline. By comparing the pipeline-extracted properties of the Balrog galaxies to their known, true properties, it is possible to estimate the biases that are affecting the pipeline's measurements and derive appropriate corrections that can be applied to the real data.

One of the most important quantities that the DES pipeline recovers for each satellite galaxy is the magnitude of the galaxy in a variety of different filters. Preliminary investigations have revealed that magnitude measurements within cluster cores are heavily biased such that galaxies closer to the BCG are often measured as brighter than they truly are. This is demonstrated in Figure 1, which shows the residuals between the measured and true magnitudes of 20,083 Balrog objects as a function of several different parameters. Galaxies below the dashed line are biased to be brighter. From this plot, it is obvious that the strength of the measurement bias is dependent on other parameters. By modeling these dependencies with machine learning methods such as random forest, corrections can be derived to recover the true magnitudes.

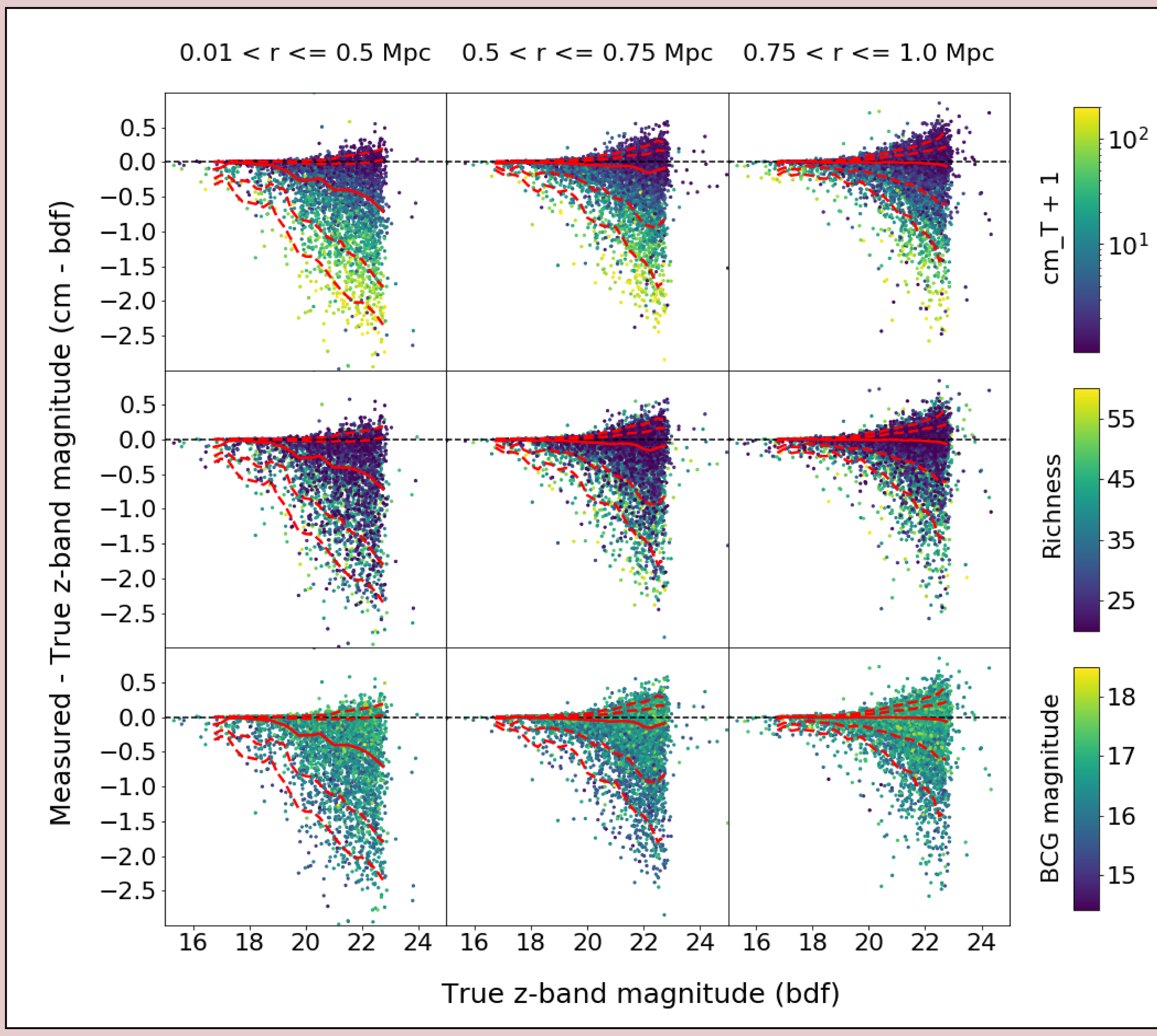
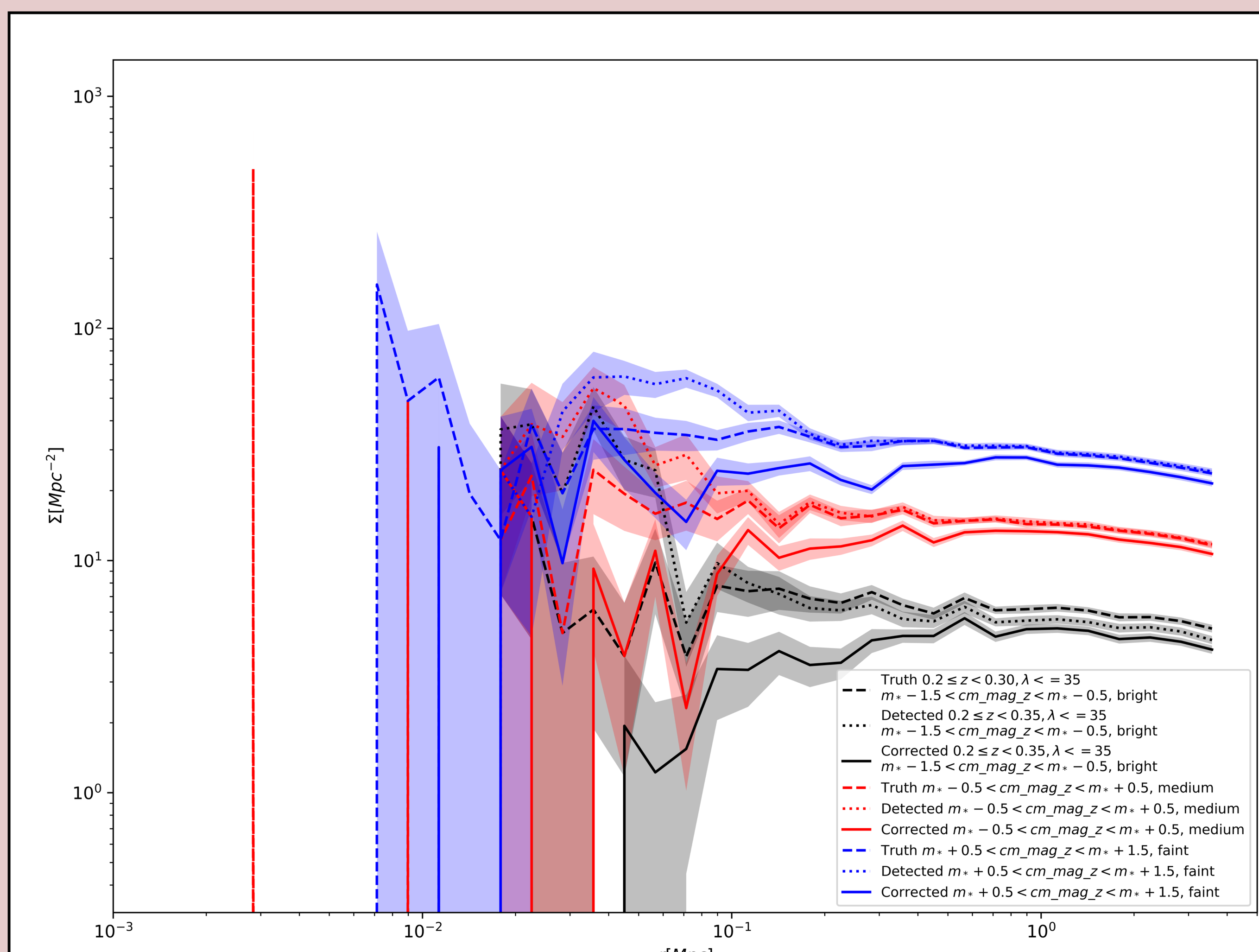


FIGURE 1 (top right): The residual bias of the measured Balrog magnitudes as a function of distance to the cluster center (columns) and several other variables (colorbars).

FIGURE 2 (left): Random forest methods can be used to reduce the amount of bias in the recovered magnitude measurements. The biases of the original measurements are shown in grey and overplotted with the biases after the RF correction is applied. The scatter is significantly reduced by the correction.

FIGURE 3 (right): Preliminary density profiles for the raw and corrected Balrog samples as a function of distance to the cluster center.



Applying Corrections and Creating Galaxy Density Profiles

Accurate magnitude measurements are important for the creation of galaxy density profiles because they determine which galaxies are considered cluster members. Figure 2 above shows that the bias in the DES magnitude measurements can be significantly reduced with a simple random forest regression that estimates the necessary correction based on a galaxy's size and distance to the cluster center, as well as the cluster's BCG magnitude and richness. Once applied to real DES data, these corrections will enable the creation of more accurate density profiles, an example of which is shown in Figure 3. Our goal is to continue refining this profile and our magnitude corrections by experimenting with different machine learning techniques. Though the random forest method is effective, it is far from perfect. Continued refinement will allow for even more accurate results.

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