Dark Matter Distribution and Its Impact on Galaxy Cluster Properties: A Weak Lensing Approach

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Dark matter is the primary component of galaxy clusters and a driver of cosmic structure formation, yet its impact on cluster properties remains poorly understood. While the Navarro-Frenk-White (NFW) dark matter distribution profile is the theoretical standard, some observations suggest deviation from its predictions, particularly in cluster cores. This study analyzed 56 galaxy clusters ($0.02 < z < 1.3$) to identify the mass distribution model that best describes o bservational data and determines correlations between model parameters and physical cluster properties. Using weak gravitational lensing integrated with stellar and intracluster gas mass reconstruction through optical and X-ray analysis, respectively, we reconstructed dark matter distributions for each cluster. We evaluated models through statistical fitting. The beta-model provided the best overall fit, with an average R^2 of 0.956, showing an improvement over other standard theoretical profiles. This is the comprehensive systematic study suggesting the beta-model as the optimal empirical description of dark matter distributions in clusters. Furthermore, we discovered unreported correlations between the core radius and redshift (z), as well as a correlation between core radius and the shape parameter (ß) which might indicate a physical relation. These relationships enabled a novel redshift-based model that simplifies the dark matter analysis pipeline, reducing computational time by 36.69%. Analysis also revealed an evolutionary trend: younger clusters exhibit more extended dark matter distributions, while older clusters are more centrally concentrated. These findings provide new empirical constraints for large-scale dark matter studies and an empirical insight into the growth of cluster across cosmic time.

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