

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

This research focuses on studying the relationships between dark matter distributions and its relationship with physical properties of galaxy clusters, including redshift  $z$ , luminosity distance  $D_L$ , and stellar luminosity enclosed within the core. The dark matter distributions were reconstructed through a combination of weak lensing analysis, gas mass beta modelling, and mass-to-light ratio stellar mass reconstruction. These distributions were parameterized using 5 selected dark matter models, from which the best-fitting model was chosen for further analysis. This study has analyzed 56 clusters, spanning a redshift range of 0.2 to 1.3; However, 6 clusters need to be excluded due to the single-cored assumption of the models.

Method and Result

1. The data of galaxy clusters were obtained from the SUBARU telescope [1], NASA source catalogs [2], XMM-Newton [3]. The total mass distribution was constructed using weak lensing analysis, the stellar mass distribution was derived using the mass-to-light ratio method, and the gas mass distribution was modeled using beta-modeling technique.

2. The dark matter distribution was then obtained by subtracting the stellar and gas mass components from the total mass distribution. The dark matter distribution was then parameterized using 5 selected dark matter models, and the best-fitting model, as determined by the  $R^2$  criterion, was chosen for further statistical and data analysis. These processes were carried out using custom Python codes developed by the authors together with the XMM-Newton SAS software [4].

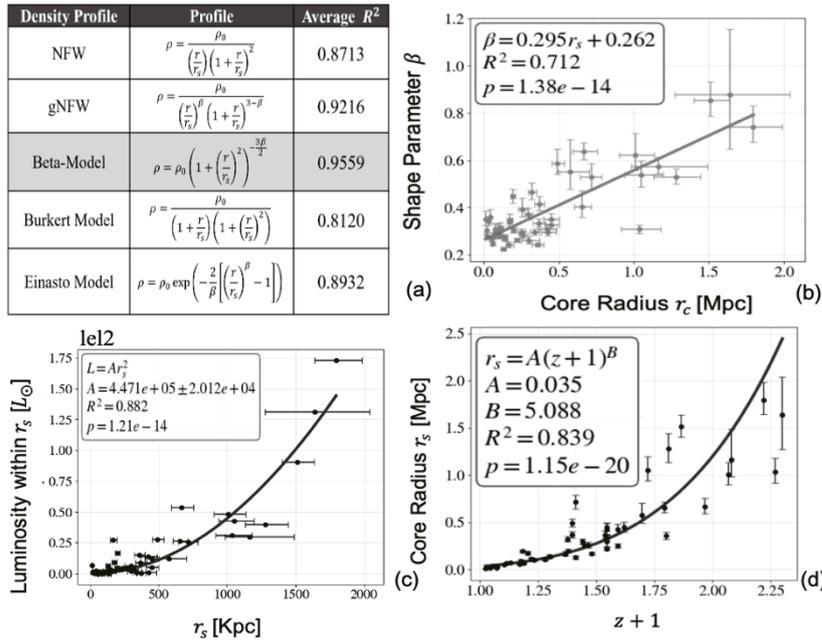


Figure 1. (a) Summarizing 5 dark matter models, (b) relationship between core radius  $r_c$  and shape parameter  $\beta$ , (c) relationship between core radius  $r_c$  and  $z + 1$  (d) relationship between the luminosity enclosed within  $r_c$  and  $r_c$

3. The results showed that the beta model provided the best fit (Figure 1a), and the data and statistical analysis of the relationships between the beta-model parameters and the physical properties of the galaxy clusters are presented in Figure 1. (b, c, and d)

Data analysis and Conclusion

The results (as shown in Figure 2) show that the beta-model parameters, the core radius  $r_c$  and the slope parameter  $\beta$ , are strongly correlated, with clear linear statistical evidence, thereby reducing the degeneracy of the model. Furthermore, a strong exponential correlation is observed between  $r_c$  and redshift plus one  $z + 1$ . This suggests that more distant (or younger) galaxy clusters exhibit more diffuse dark matter distributions compared to nearer (or older) clusters, reflecting the evolutionary behavior of dark matter within galaxy clusters. In addition, the analysis indicates a lower limit for the core radius, with the minimum  $r_c$  value of approximately 35 kpc. Based on these two relationships, the traditional

beta model can be modified into a redshift-based beta model  $\rho(r) = \left(1 + \frac{815r^2}{(z+1)^{10}}\right)^{-(0.0154(z+1)^5+0.40)}$ , reducing the number of free parameters from three to two. This modification allows the use of redshift alone to estimate the dark matter distribution shape directly, avoiding the need for a complex analysis pipeline. Finally, a positive quadratic relationship is found between the stellar luminosity enclosed within  $r_c$  and the core radius  $r_c$ , reflecting galaxy cluster evolution: younger clusters tend to be more dynamically active and exhibit stronger baryonic feedback than older clusters. Moreover, this result is consistent with the cosmological principle of large-scale homogeneity.

Selected References

[1] Subaru-Mitaka-Okayama-Kiso Archive (SMOKA), NAOJ Science Archive, <https://smoka.nao.ac.jp/>  
 [2] NASA/IPAC Extragalactic Database (NED), galaxy cluster data accessed via the Cone Search service, <https://ned.ipac.caltech.edu/conesearch>  
 [3] ESA XMM-Newton Science Archive (XSA), XMM-Newton Data Access Portal, <https://www.cosmos.esa.int/web/xmm-newton/xsa>  
 [4] Gabriel et al. (2004) The XMM-Newton Science Analysis System (SAS), ASP Conf. Ser. 314, 759.