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Photometric estimator of galaxy cluster masses

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Abstract. In this study, we utilize Kopylova and Kopylov's (2023) cumulative galaxy number profile method to determine splashback radii for SDSS galaxy clusters. Employing photometric redshifts for cluster membership, we calibrate our measurements with weak lensing and X-ray derived masses, achieving precise cluster mass estimates with a remarkable dispersion of 0.06 dex. Our results exhibit robustness across varying magnitude limits, highlighting the accuracy of photometric-only cluster mass estimation.

Resumo. Neste estudo, utilizamos o método de perfil cumulativo de números de galáxias de Kopylova e Kopylov (2023) para determinar os raios de *splashback* para aglomerados de galáxias do SDSS. Utilizando *redshifts* fotométricos para a *membership* dos aglomerados, calibramos nossas medições com massas derivadas de lentes fracas e raios-X, obtendo estimativas precisas da massa do aglomerado com uma dispersão notável de 0,06 dex. Nossos resultados demonstram robustez em diferentes limites de magnitude, destacando a precisão da estimativa da massa de aglomerados apenas com dados fotométricos.

Keywords. Galaxies: clusters: general

1. Context

Fillmore & Goldreich (1984) and Bertschinger (1985) highlighted a density jump at the splashback radius (R_{sp}), marking the location where infalling matter reaches its first apocenter. This radius serves as a crucial tracer of a cluster's history. Our study aims to validate R_{sp} estimates derived from photometric data and establish a scale relation between cluster masses and R_{sp} using photometry alone. We compared R_{sp} estimations from Sloan Digital Sky Survey (SDSS) DR16 spectroscopic and photometric data, leveraging spectroscopy for robust cluster membership determination. We assessed the impact of magnitude limits and photometric redshift errors on our findings. Additionally, we used weak-lensing and X-ray analyses for mass estimation, establishing relations between masses and photometrically estimated R_{sp}. Employing a flat Λ CDM cosmology with parameters $\Omega_M = 0.28$, $\Omega_\Lambda = 0.72$, and $H_0 = 100h$ km/s/Mpc (with $h = 0.7$), we utilized M_Δ notation for masses within a sphere of radius R_Δ at mean overdensity $\Delta \times \rho_c(z)$, where ρ_c signifies the critical closure density of the universe.

2. Materials and methods

For estimating the splashback radius, we utilized the method proposed by Kopylova & Kopylov (2023) (referred to as K&K), enabling a straightforward determination of this radius based on the integrated distribution of galaxy counts as a function of squared cluster-centric distances. Using the Brightest Galaxy Cluster (BGC) galaxy as a reference, we conducted a cumulative object count within concentric rings. This cumulative distribution reveals two distinct regions: a dense core displaying a shell-like increase in galaxy count and an outer region where the distribution follows a linear trend, revealing a significant slope discontinuity denoting R_{sp}. According to K&K, this discontinuity marks the average position within the cluster where surrounding galaxies become uniformly distributed, signifying the apoastron radius of bound objects.

Figure 1 demonstrates the application of K&K's method to estimate the splashback radius for the Virgo cluster, presenting the cumulative distribution with the red dotted line indicating R_{sp}. In this specific example, R_{sp} was estimated at 2.4 h^{-1}Mpc.

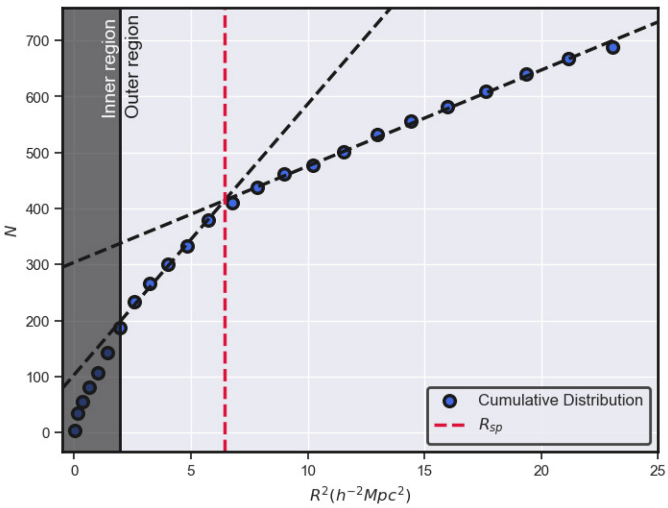

FIGURE 1. Splashback radius estimation for Virgo Cluster using the method developed in Kopylova and Kopylov (2023).

For our mass fittings, we employed publicly available data from Umetsu et al. (2020) and Kiiveri (2021) et al., referred to as the XXL and CODEX samples, respectively. These datasets originated from weak-lensing analyses of galaxy clusters selected from X-ray and optical surveys. Additionally, we utilized X-ray temperature data from Shang & Scharf (2009) and Eckert et al. (2011) to estimate cluster masses based on the scale relations derived from Evrard et al. (1996):

$$M_{500} = 2.22 h_{50}^{-1} \times 10^{15} \left(\frac{kT_x}{10(1+z)keV} \right)^{3/2} M_\odot \quad (1)$$

$$M_{200} = 1.4 M_{500} \quad (2)$$

In selecting clusters for our analysis, we relied on spectroscopic and photometric redshift data from SDSS, ensuring a minimum number of spectroscopic members for reliable measurements.

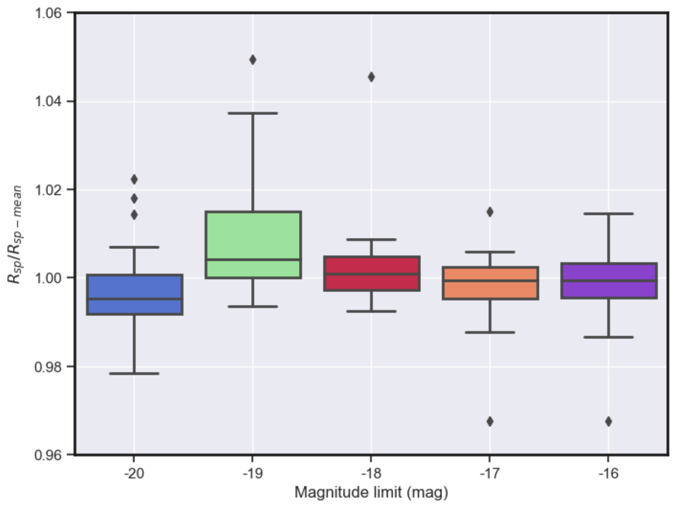

Figure 2. Normalized splashback radius distributions for our entire X-ray samples as a function of magnitude limit in the r band.

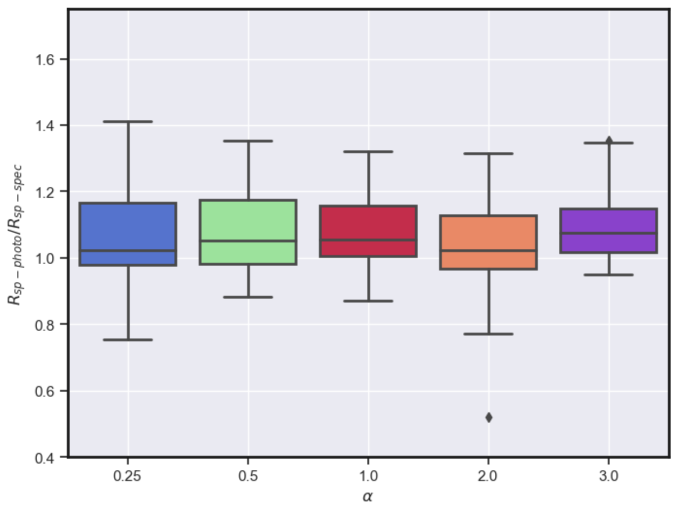

Figure 3. Photometric splashback radius distributions normalized by spectroscopic values for our entire X-ray samples as a function of photometric error multiples (α).

3. Results and conclusions

Understanding the reliability of R_{sp} estimates across varying magnitude limits is critical. Figure 2 illustrates R_{sp} distributions within our X-ray sample under different r-band magnitude thresholds. Despite fluctuations, R_{sp} discontinuities persist consistently, revealing nominal dispersion across diverse limits.

Assessing the impact of photo-z errors, notably larger than cluster velocity dispersion, remains pivotal. Employing $\alpha(1+z)\sigma_z$ criteria and exploring α values (0.25, 0.5, 1, 2, and 3), Figure 3 showcases normalized R_{sp} distributions relative to spectroscopic estimates within the X-ray sample. Analogous to magnitude limits, fluctuations don't disrupt R_{sp} positions, emphasizing the robustness of photometry-exclusive R_{sp} estimations.

Our primary pursuit, establishing the connection between M_{200} masses and R_{sp}, focuses on $\alpha = 3$ estimations. Illustrated in Figure 4 are weak-lensing masses juxtaposed against photometric R_{sp}, displaying fitting and confidence intervals. The data reveal minimal scatter, showcasing robust model-data agreement (dispersion $\approx$ 0.06 dex). Additionally, Figure 5 presents X-ray mass fittings, exhibiting slightly amplified scatter (dispersion $\approx$ 0.08 dex), likely stemming from equation approximations for M_{200} estimates. Despite this, there exists significant alignment between the model and the observed data.

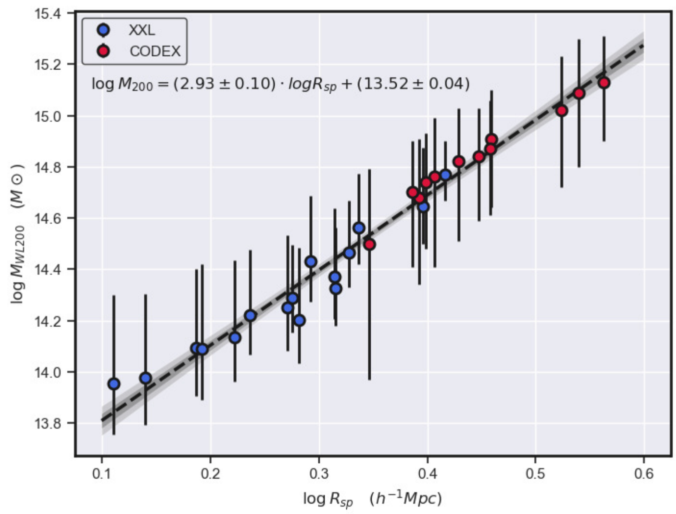

Figure 4. Fitted relation between photometric splashback radii and weak-lensing masses from XXL

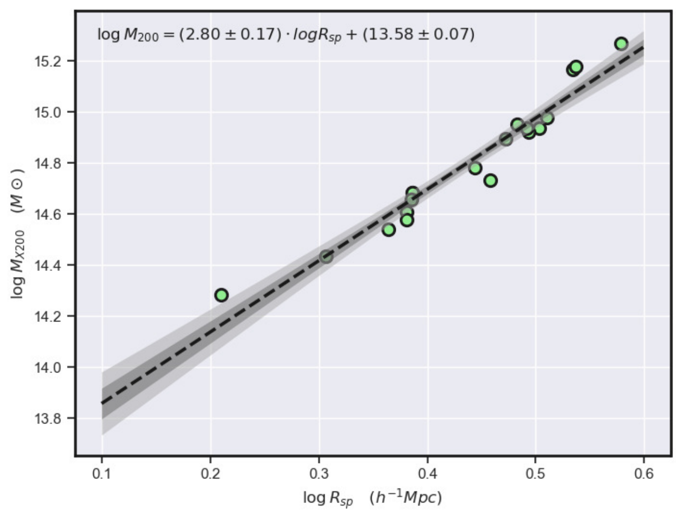

Figure 5. Fitted relation between photometric splashback radii and X-ray masses from our X-ray sample.

Our findings show minimal effects from magnitude limits and photo-z errors on R_{sp} estimations, strongly correlating with mass measurements. This underscores the viability of estimating splashback radii through photometry, offering precise galaxy cluster mass determinations and opening new avenues in observational cosmology.

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