Universal Profiles of the Intracluster Medium from Suzaku X-Ray and Subaru Weak Lensing Obesrvations

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We conduct a joint X-ray and weak-lensing study of four relaxed galaxy clusters (Hydra A, A478, A1689 and A1835) observed by both {\it Suzaku} and Subaru out to virial radii, with an aim to understand recently-discovered unexpected feature of the intracluster medium (ICM) in cluster outskirts. We show that the average hydrostatic-to-lensing total mass ratio for the four clusters decreases from ~70 % to ~40 % as the overdensity contrast decreases from 500 to the virial value. The average gas mass fraction from lensing total mass estimates increases with cluster radius and agrees with the cosmic mean baryon fraction within the virial radius, whereas the X-ray-based gas fraction considerably exceeds the cosmic values due to underestimation of the hydrostatic mass. We also develop a novel advanced method for determining normalized cluster radial profiles for multiple X-ray observables by simultaneously taking into account both their radial dependence and multivariate scaling relations with weak-lensing masses. Although the four clusters span a range of halo mass, concentration, X-ray luminosity and redshift, we find that the gas entropy, pressure, temperature and density profiles are all remarkably self-similar when scaled with the weak-lensing M_{200} mass and r_{200} radius. As shown in Figure 1 [1], the entropy monotonically increases out to $\sim 0.5\,r_{200} \sim r_{1000}$ following the accretion shock heating model $K(r) \propto r^{1.1}$ [2], and flattens at $\gtrsim 0.5\,r_{200}$. The universality of the scaled entropy profiles indicates that the thermalization mechanism over the entire cluster region ($> 0.1\,r_{200}$) is controlled by gravitation in a common way for all clusters, although the heating efficiency in the outskirts needs to be modified from the standard $r^{1.1}$ law. The bivariate scaling functions of the gas density and temperature reveal that the flattening of the outskirts entropy profile is caused by the steepening of the temperature, rather than the flattening of the gas density. Thus, gas clumpiness [4], leading to an overestimate of the observed gas density, cannot be responsible for all of the flatness of the outskirts entropy.

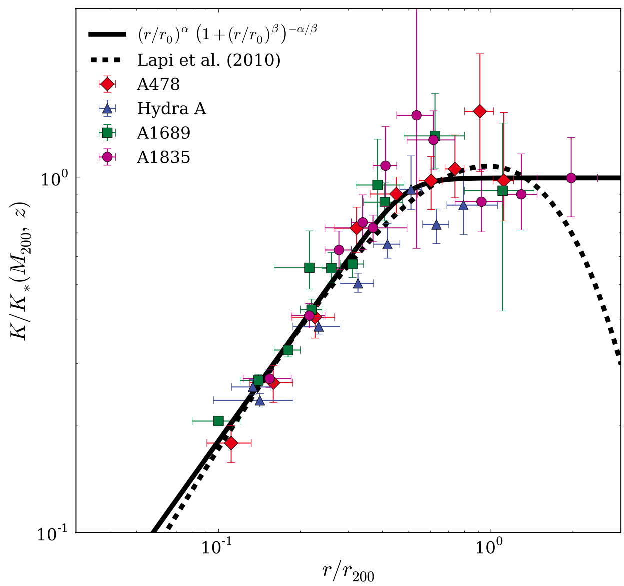

Figure 1: Normalized entropy profile as a function of the radius scaled by r_{200}. Red diamonds, blue triangle, green squares and magenta circles denote the normalized entropy for A478, Hydra A, A1689, and A1835, respectively. The normalization is $K_*(M_{200}, z)=K_0 E(z)^{-4/3} (M_{200} E(z)/10^{14} h_{70}^{-1} M_\odot)^a$, where K_0=359.61 [keV cm^2] and $a = 0.63$. The black solid curve represents the best-fit universal entropy profile. The entropy profile at $r \lesssim 0.5\,r_{200}$ follows $r^{1.1}$ as predicted by the standard model [2] and becomes flat at $r \gtrsim 0.5\,r_{200}$. The black-dashed curve shows the best-fit profile for the other model [3].

References

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