Temperature, entropy, and mass profiles to the virial radius of Abell 2199 with Suzaku

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ABSTRACT

We studied the temperature and entropy profiles of the intracluster medium in the whole Abell 2199 galaxy cluster and around the cluster outskirts beyond the virial radius from the 22 pointing Suzaku observations as the Suzaku key project. The observations show the temperature drop from the central to the outer region around $r_\text{200}$ by $\sim 60\%$. The derived entropy profile has a flatter slope compared to that from the numerical simulation, particularly in $r > r_\text{500}$. We also found that the radial ratios of the entropy from cluster observations with Suzaku to the expected values from the simulations had a similar index slope among the clusters. This would suggest a universality that all the clusters have passed similar evolution processes. We also discuss the temperature dependence, which corresponds to the system size, of the derived entropy and baryon fraction derived from the calculated gas mass and total mass under the assumption of hydrostatic equilibrium, to the virial radius.

KEY WORDS: galaxies: clusters — intergalactic medium: X-rays

1. Introduction

Abell 2199 is a bright nearby ($z = 0.03$) galaxy cluster characterized by a smooth distribution of the intra-cluster medium (ICM) with the mean temperature $\langle kT \rangle = 4$ keV, and located on the filamentary structure in the Hercules supercluster (Barmby & Huchra 98). Because cluster outskirts around the virial radius would leave a evidence of shock-heated accreting matters from the cosmic filamentary structure into the cluster, the outskirts is the real front of the cluster evolution.

2. Observation and Spectral Analysis

Suzaku carried out 22 pointing observations of Abell 2199 galaxy cluster with total 420 ksec as the “Suzaku key project” as shown in figure 1. In the spectral analysis, we assumed the cosmic X-ray background and two Galactic emissions as the back- and foreground emissions, and a thermal (ICM) model for the inner region of the virial radius, $r_\text{200}$ within which the cluster mean mass density is 200 times the cosmic baryon density, and which is derived by the formula with the mean temperature in Henry et al. (2009).

3. Results & Discussion

The ICM emission to the virial radius is clearly detected, and the azimuthal average temperature drops to the cluster outskirts by $60\%$ as shown in figure 2. Assuming spherical symmetry and hydrostatic equilibrium, we de-
Fig. 1. Suzaku legacy mosaic of Abell 2199 galaxy cluster as “Suzaku key project” in 0.5–5.0 keV. Inner and outer white circles correspond to \( r_{500} \) and \( r_{200} \), respectively.

Fig. 2. Radial temperature and electron density profile of Abell 2199 observed with Suzaku. The radius is normalized by \( r_{500} \).

derived the cluster total mass from the temperature and electron density profile. The gas mass to the total mass ratio was lower than the cosmic baryon density within \( r_{500} \). We note that, because the derived total mass profile started flattening or decreasing beyond the \( r_{500} \) region, it would indicate a flaw in the assumption in \( r > r_{500} \).

An entropy profile traces the thermal process and history of the ICM, particularly for the gas heated by the accreting matter from outside of the cluster. In X-ray astronomy, we define the entropy as \( K = kTn_e^{-2/3} \). The resultant entropy profile in the annular regions is shown in the lower panels of figure 3. The entropy increased with the radius to \( \sim r_{500} \), and the profile had a flatter slope at \( r > r_{500} \). We compared our result with other results from Suzaku, Abell 1689 (Kawaharada et al. 2010), Abell 2142 (Akamatsu et al. 2011), Coma (Simionescu et al. 2013), Abell 1835 (Ichikawa et al. 2013), Abell 2129 (Walker et al. 2012a), Abell 1413 (Hoshino et al. 2010), PKS0745-191 (Walker et al. 2012), Abell 478 (Mochizuki et al. 2014), Perseus (Urban et al. 2013), Abell 1795 (Bautz et al. 2009), and Hydra A (Sato et al. 2012) as shown in figure 3. Here, in order to compare with the other results with Suzaku in the same unit, the radii are normalized by \( r_{200} \) with the mean temperature as shown in figure 3, for each cluster, by the formula in Henry et al. 2009. All the clusters observed with Suzaku had a similar tendency that the entropy increased with radius until \( r_{500} \sim 0.5 \) \( r_{200} \), and they had a flatter slope in \( r > r_{500} \).

We need to estimate the cluster properties in several ways, such as X-ray, a gravitational weak lensing, and Sunyaev-Zel’dovich effect observations. These methods are complementary probe to each other and can be used to derive the cluster density, mass, and so on, without bias effects.

References
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Fig. 3. A comparison of entropy profiles normalized by the mean temperature for each cluster with Suzaku. The radius is also normalized by \( r_{200} \) with the mean temperature by the formula in Henry et al. 2009. The dashed line indicates the predicted entropy on the basis of numerical simulations of adiabatic cool gas accretion as a power-law with an index of 1.1.