Suzaku Detection of the ICM Emission out to the Virial Radius in Abell 1689

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Abstract

Using Suzaku, we detected X-ray emission from the intra cluster medium (ICM) in Abell 1689 out to its Virial radius ($15'.8 = 2.9$ Mpc). The ICM temperature gradually decreases from ~ 9 keV at the center to ~ 2 keV at outskirts. Moreover, we found that the temperature of a northeast region at the Virial radius is higher (~ 5 keV) than the other azimuth regions at the same distances, and that X-ray surface brightness at the 5 keV region is ~ 2 times higher than that of the other regions. Since the cooling function at 5 keV is $\sim 50\%$ larger than that at 2 keV assuming the metal abundance is 0.1 solar, the difference of ICM densities between the 5 keV and 2 keV regions is not large, at most $\sim 20\%$. By combining the temperature and ICM density, entropy of the 5 keV region becomes ~ 2 times larger than those of the other azimuth regions. This suggests that some heating process such as cosmological structure formation shock or sub-cluster mergers in the northwest region. The Sloan Digital Sky Survey (SDSS) data, however, shows no significant luminosity excess in i band in this region. Now we are comparing the temperature profile we obtained with that derived from the mass profile of Abell 1689 which has been obtained precisely by strong and weak lensing analyses of Subaru/Suprime-Cam and HST/ACS. By this analysis, the hydrostatic equlibrium around the Virial radius will be tested.

Key words: galaxies: clusters: general — galaxies: clusters: individual (Abell 1689) — intergalactic medium — X-rays: galaxies: clusters

1. Introduction

Inter cluster medium (ICM) is a major baryon component in the universe and has been a fascinating research object for X-ray astronomy since 1970's. However, the detection of X-ray singnals was limited to ~ 0.6 times the Virial radius due to low signal-to-noise ratios obtained by observations in cluster outskirts. This means only $\sim 20\%$ of a cluster volume was observed in X-rays. *Suzaku* has improved the situation drastically with excellent sensitivity for low surface brightness X-ray emission achived by its low and stable background. In fact, several authors have reported detection of the ICM around the Virial radius (Reiprich et al. 2009; George et al. 2009; Bautz et al. 2009; Fujita et al. 2008).

In this paper, we report another detection of the ICM emission out to the Virial radius from Abell 1689. Since the mass profile of Abell 1689 was obtained precisely by strong and weak lensing analyses of Subaru/Suprime-Cam and HST/ACS (Umetsu & Broadhurst 2008), this cluster is an ideal target to test hydrostatic equilibrium around the Virial radius.

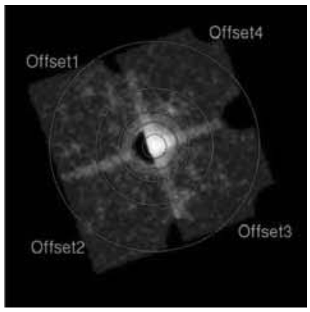

Fig. 1. XIS-0 mosaic image of Abell 1689. Annular Regions for the spectral analysis are shown in circles.

2. Observation and Data Reduction

As shown in Figure 1, we performed four pointing observations, named Offset1 through Offset4, of Abell 1689

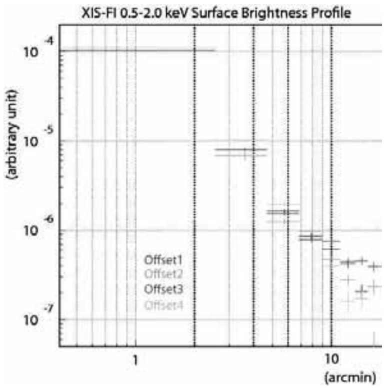

Fig. 2. XIS-FI (XIS0 + XIS3) surface brightness profiles of the Offset1 through Offset4 observations.

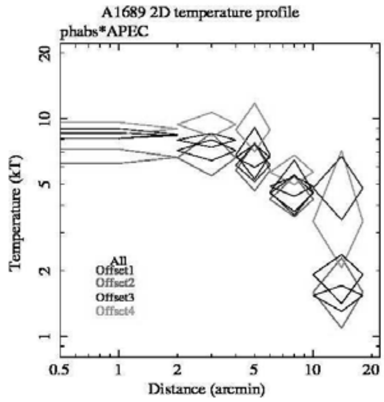

Fig. 3. Temperature profiles in the four pointing directions, together with that when the data of all the pointings is summed.

with *Suzaku* in July 2008, which covered the cluster region up to the Virial radius ($15'.8 = 2.9$ Mpc). Exposure of each pointing was 38 ks. We processed the XIS data with version 2.2 pipe-line data processing, and extracted clean events by following the standard event screening criteria of the XIS.

3. Results

After subtracting background and point sources detected in *XMM-Newton* MOS1 image with **ewavelet** task, we made X-ray surface brightness profiles. We subtracted Non X-ray background (NXB) model created by **xisnxbgen**, and estimated X-ray background (XRB) from nearby two blank-sky observations; one is Q1334-0033 which is $6^\circ.325$ offset from Abell 1689 and the other is NGC4636_GALACTIC_1 which is $8^\circ.683$ offset from Abell 1689. The result is shown in Figure 2. The signal is detected up to the Virial radius. Especially, the emission in Offset1 region (NE direction) is ~ 2 times higher than those in the other regions.

Since X-ray signal was significantly detected around the Virial radius, we extracted XIS spectra from the 5 annular regions (Fig. 1). After subtracting NXB, specta were fitted with **phabs** $\times$ **apec** model. An XRB model was also added to the model by simultaneously fitting spectra from the two blank-sky observations with absorbed power law (representing CXB) and three **apec** components (Galactic foreground emission, see Henley & Shelton 2008).

Figure 3 shows the temperature profiles. We found that the temperature decreases from $\sim$ 9 keV at the center to $\sim$ 2 keV at outskirts. In the of outermost Offset1 region, however, the temperature is $\sim$ 5 keV, which is significantly higher than temperatures of other regions at the same distance.

4. Discussion

Since the cooling function at 5 keV is $\sim 50\%$ larger than that at 2 keV assuming the metal abundance to be 0.1 solar, the difference of ICM densities between the 5 keV and 2 keV regions is not large, at most $\sim$ 20%. By combining the temperature and ICM density, entropy of the 5 keV region becomes $\sim$ 2 times larger than those of the other azimuth regions. This suggests that some heating process such as cosmological structure formation shock or sub-cluster mergers in the NE region. In the NE direction, there is another cluster, MAXBCG 5052, just outside XIS field-of-view of the Offset1 observation. However, its redshift ($z = 0.09$) is totally different from that of Abell 1689 ($z = 0.1832$), meaning that these two clusters are three-dimensionally separated. In addition, the Sloan Digital Sky Survey (SDSS) data shows no significant luminosity excess in i band in this region. Therefore, the origin of high temperature in the NE direction is a mystery at present.

5. Future Works

Mass profile of Abell 1689 has been obtained precisely by strong and weak lensing analyses of Subaru/Suprime-Cam and HST/ACS (Umetsu & Broadhurst 2008). Now we are comparing the temperature profile obtained with *Suzaku* with that derived from the mass profile of Abell 1689. By this analysis, we are trying to test hydrostatic equlibrium around the Virial radius with the best precision ever achieved.

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