# X-ray Study of the Mass Profile in the Outer Region of A1413

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Abstract

We present Suzaku results for the outer region of the relaxed galaxy cluster A1413 ($z = 0.143$). The XIS spectra of four annular regions from $2'.7$ to $20'.0$ were analyzed, with the foreground Galactic component constrained to have a common surface brightness. The measured temperature is about 7 keV at $3'$ and drops to about 3 keV in the outermost region. We calculated entropy profile and equilibration timescale, which indicated possibility of difference between electron and ion temperatures. The equilibration timescale is about 0.7 Gyr at $13'$ (compared with $r_{200} = 14'.8$). The inferred average temperature is about 15% higher than the electron temperature. The use of average temperature gives about 37% increase for the integrated gravitational mass at $15'.0$.

Key words: workshop: proceedings, — galaxies: clusters: individual (Abell 1413) — X-rays: galaxies: clusters — X-rays: ICM

## 1. Introduction

Outer regions of clusters are important to investigate the cluster evolution, accretion flow, the connection with WHIM (Warm-Hot Intergalactic Medium) and LSS (Large-Scale Structure). Recent works reported flattening of entropy profiles in the outer region, which were explained by deviation from equilibrium (George et al. 2008; Bautz et al. 2009). Because Takizawa 2000 showed that electron and ion temperatures can be quite different at the radius over $0.5r_{200}$, we looked into these features in the outer region of A1413.

## 2. Suzaku Observation of Abell 1413

A1413 was observed in November 2005 with 72 ks of net exposure. We observed northern region of A1413 from $2'.7$ to $26'.0$ with XIS detectors. The XIS instrument consists of 4 CCD chips with one back-illuminated one (BI: XIS1) and 3 chips with front-illuminated type (FI: XIS0, XIS2, XIS3). IR/UV blocking filters show significant contamination in the present observation. XIS was operated with normal clocking mode, in $5 \times 5$, and $3 \times 3$ editing modes.

## 3. Spectral Analysis

We divided Suzaku FOV into four regions: $2'.7 - 7'.0$, $10'.0 - 20'.0$, $20'.0 - 26'.0$, from the cluster center. Stray light contamination is less than 30%. We subtracted NXB using night earth database. We fitted spectra (FI: 0.4-10.0 keV in $7'.0 - 10'.0$, $10'.0 - 20'.0$, $20'.0 - 26'.0$ and 0.4-5, and 7-10 keV in $2'.7 - 7'.0$, BI: 0.5-10.0 keV in all regions) with a model including ICM (*wabs*apec*) + CXB(*wabs*powerlaw*) + Galactic components (*apec+wabs*apec*). All regions and data from all detectors were fit simultaneously. We linked temperature in $10'.0 - 15'.0$ and $15'.0 - 20'.0$ due to poor photon statistics. ICM components were not included in $20'.0 - 26'.0$, where CXB and Galactic components could fit the data. Finally we obtained temperature profile with $\chi^2/dof = 568.41/570$ as shown in Fig. 1 (a).

## 4. Systematic Errors

We considered reproducibility of NXB, fluctuations of CXB, $\pm 20\%$ uncertainty of contamination on IR-UV blocking filters in front of XIS detectors, and difference of abundance model between Anders & Grevesse (1998) and Feldman (1992) as systematic errors. We considered $\pm 3\%$ error on the NXB reproducibility (Tawa et al. 2008). We calculated CXB fluctuation by scaling the previous Ginga result to be less than 18.3 % ($2'.7 - 7'.0$).

## 5. Discussion

### 5.1. Entropy

We considered entropy profile in A1413, with the following definition, $S = k_B T n_e^{-2/3}$. Takizawa 2000 suggested that difference in electron and ion temperatures

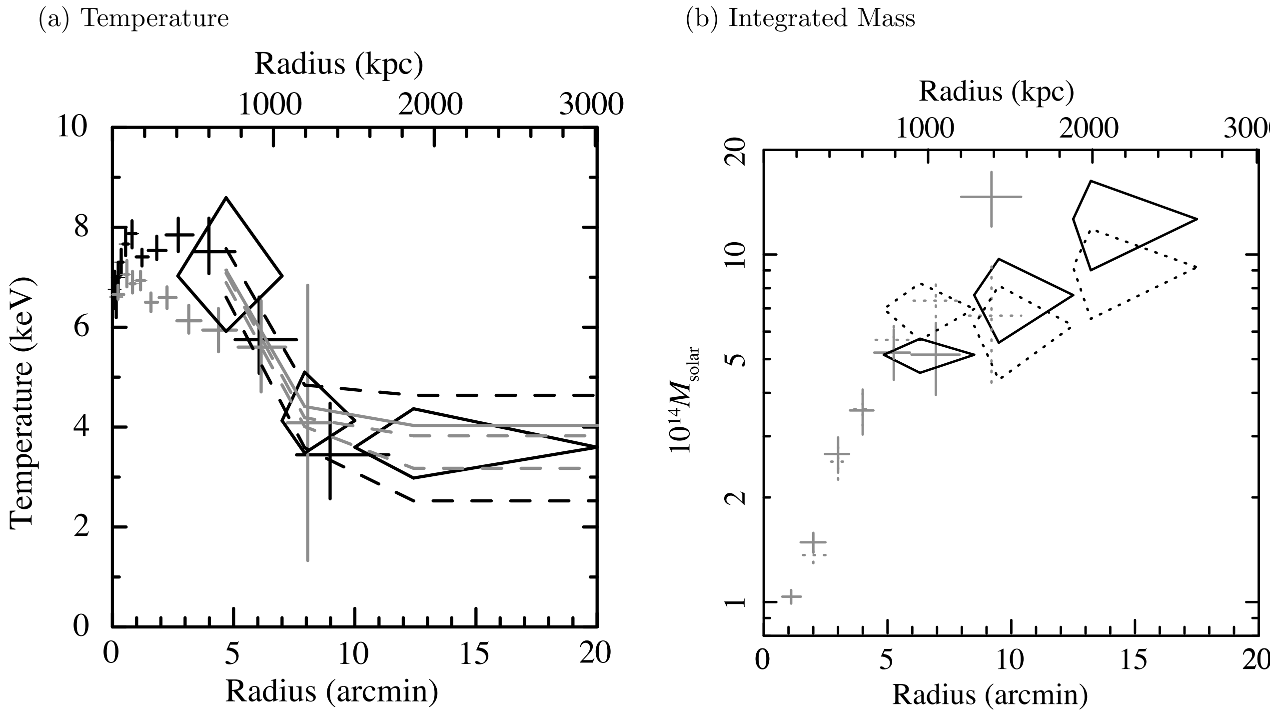


Fig. 1. Temperature and integrated mass profiles. (a) black cross: Chandra (Vikhlinin et al. 2006), grey cross: XMM (Pratt et al. 2002), diamond: Suzaku, black dashed lines: NXB±3%,CXB-min/max, grey dashed lines: contamination±20%, and grey solid line: abundance model with Feldman (1992). (b) grey solid cross: XMM with $kT_{ave}$, grey dotted cross: XMM with $kT_e$, black solid diamond: Suzaku with $kT_{ave}$, and black dotted diamond: Suzaku with $kT_e$.

cause flattening in the slope (to be 0.42) of entropy profile based on simulations. We compared our data with adiabatic numerical simulation, which assumed accretion flow of cool gas and predicted $S \propto r^{1.1}$ (Voit 2005). Assuming this entropy profile extends out to $r_{200}$, we derived "averaged" temperature, $kT_{ave}$ given by the definition of $S$. Because the lower $kT_e$ compared to $kT_{ave}$ yields the lower entropy values with the same $n_e$, the flattening in the entropy profile at $\sim 0.5r_{200}$ suggests difference in electron and "averaged" temperatures.

### 5.2. Equilibration Timescale

According to Takizawa 2000, the electron-ion relaxation timescale including contribution from both protons and $He^{++}$ is estimated as

$$t_{ei} \approx 2.0 \times 10^8 \mathrm{yr}\ \frac{(T_e/10^8\mathrm{K})^{3/2}}{(n_i/10^{-3}\mathrm{cm}^{-3})(\ln\Lambda/40)}, \quad (1)$$

Electron-ion relaxation takes 2000 times longer period than e-e process and about 45 times longer than i-i process. We can estimate the position-dependent elapsed time as,

$$t_{\rm elapsed} \simeq \frac{3(r_{200}-r)}{v_{\rm ff}}, \mathrm{with}\ \ \frac{1}{2}m_p v_{\rm ff}^2 = \frac{GMm_p}{r_{200}}, \quad (2)$$

which is the time for gas to have spent after experiencing an accretion shock. The different timescale implies that the electron temperature is significantly lower than the ion temperature in the outer region of $\sim 13'$ corresponding to $0.9r_{200}$.

### 5.3. Mass estimation

We looked into the integrated mass based on $kT_{ave}$ and $kT_e$. As shown in Fig. 1 (b), the integrated mass with $kT_{ave}$ is about 37% larger than that with $kT_e$. Considering the difference between projected and 3-dimensional temperatures, the mass difference can possibly be about 30 % (Rasia et al. 2005).

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