XMM-Newton Observations of the Toothbrush and Sausage Clusters

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INTRODUCTION

Galaxy clusters are the largest gravitationally-bound objects in the universe. The member galaxies are embedded in a hot X-ray emitting Intra Cluster Medium (ICM) that has been enriched with metals produced by supernovae over the last billion years. Here we present new results from XMM-Newton archival observations of the merging clusters 1RXSJ0603.3+4213 and CIZA J2242.8+5301. These two clusters, also known as the Toothbrush and Sausage clusters, respectively, show a large radio relic associated with a merger shock North of their respective core [4,5].

The Fe abundance distribution and enrichment history in major mergers have not been studied yet in detail. In this work, we re-analyse archival XMM-Newton observations of these two clusters [1,2]. In both cases, the investigation of the regions close to the shock by XMM-Newton data is presented for the first time. We show the distribution of temperatures and Fe abundances with respect to the merger structures in these two clusters. The results are derived from spatially resolved X-ray spectra from the EPIC instrument on board XMM-Newton.

METHODS

The X-ray images presented here (Figs. 1 and 3) are adaptively smoothed for both clusters. For the Toothbrush, we use the XMM-Newton data from the observation on 3 October 2011. The observation of the Sausage cluster was taken on 13 December 2010. The total net exposure times are 74 ks and 72 ks for the Toothbrush and the Sausage clusters, respectively.

The EPIC MOS 1, MOS 2 and pn data reduction is performed using the XMM Science Analysis System (SAS), the point sources have been detected and discarded. The spectral analysis is conducted with SPEX. To fit the spectra we used Gaussian differential emission measure (GDEM) model and we fit MOS 1, MOS 2, and pn simultaneously. Apart from the normalizations and temperature, abundances of O, Ne, Mg, Si, S, Ar, Ca, Fe and Ni are left free and allowed to vary between 0-3 proto-solar [5]. We binned the spectra optimally following the method of [6]. Note that the background has been carefully modeled using 5 components [3]. The temperature and Fe abundance distributions of the two clusters are presented in Figs. 5, 6, 7, and 8.

OBSERVATIONS

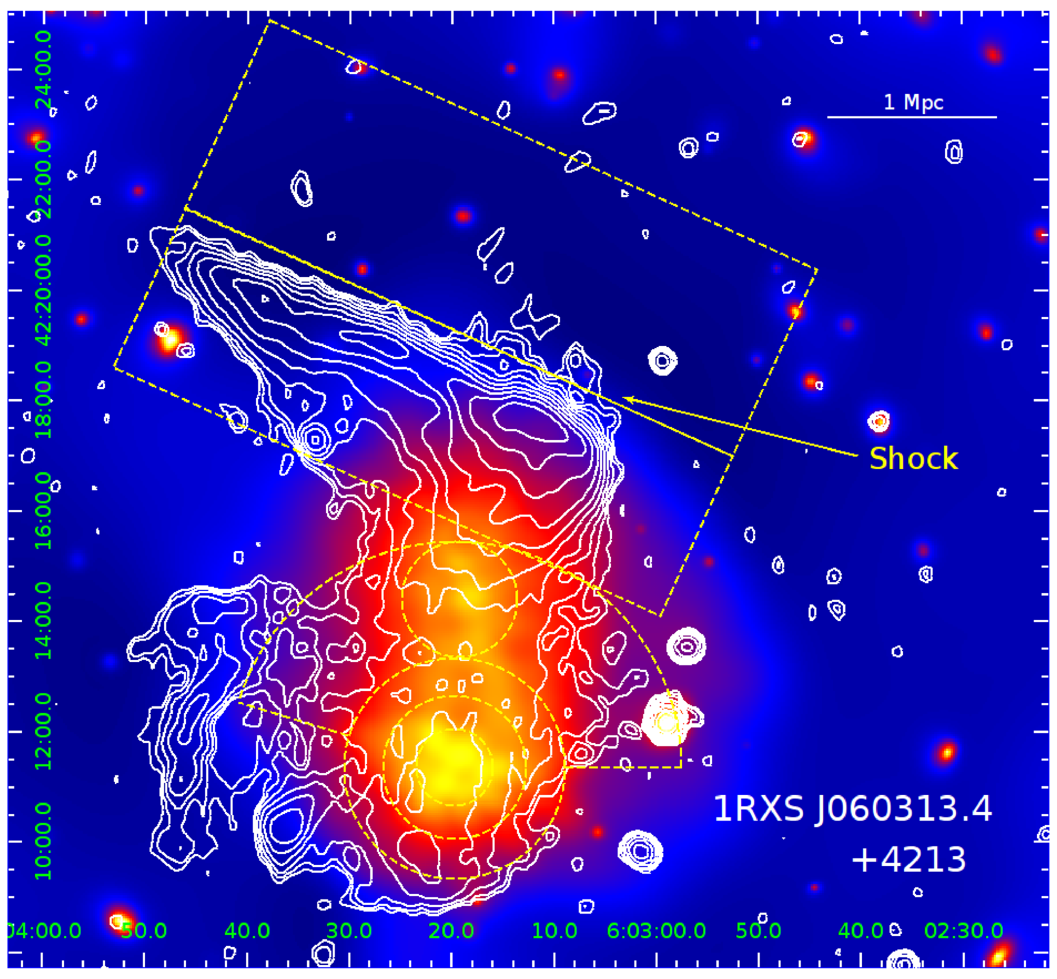

Figure 1: EPIC image of the Toothbrush cluster.
The radio contours (white) are adapted from [4]. The energy range is 0.2-2 keV.
The yellow dashed lines show the regions we investigated for spectroscopy.

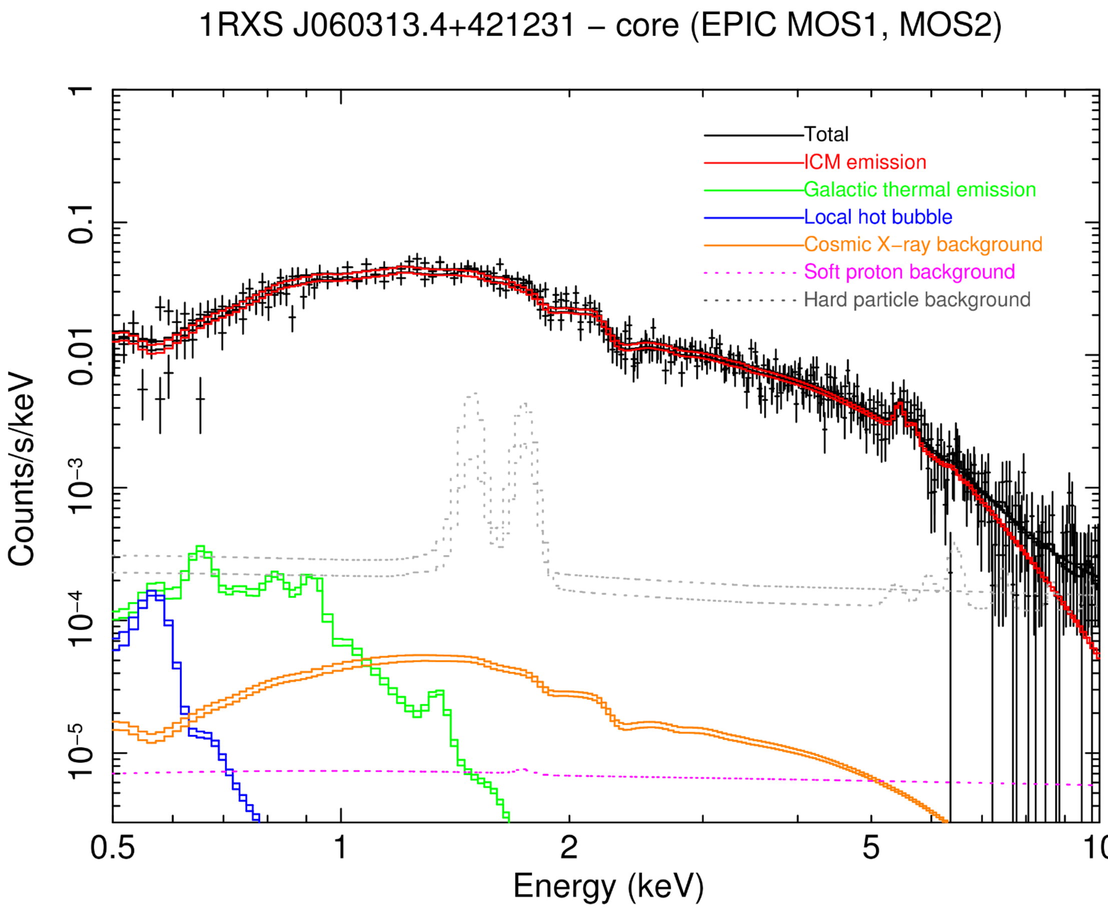

Figure 2: EPIC spectra of the core of the Toothbrush cluster.
The background components have been carefully modelled.

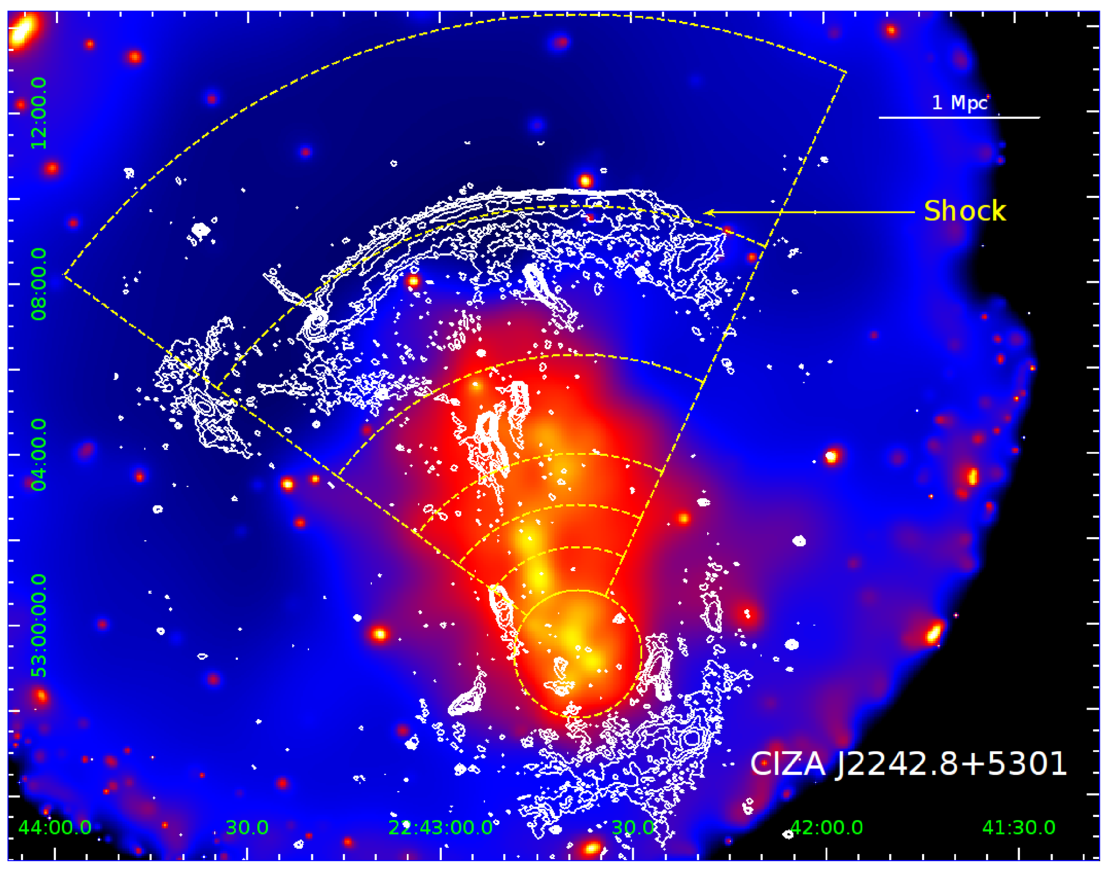

Figure 3: EPIC image of the Sausage cluster.
The radio contours (white) are adapted from [5]. The energy range is 0.2-2 keV
The yellow dashed lines show the regions we investigated for spectroscopy.

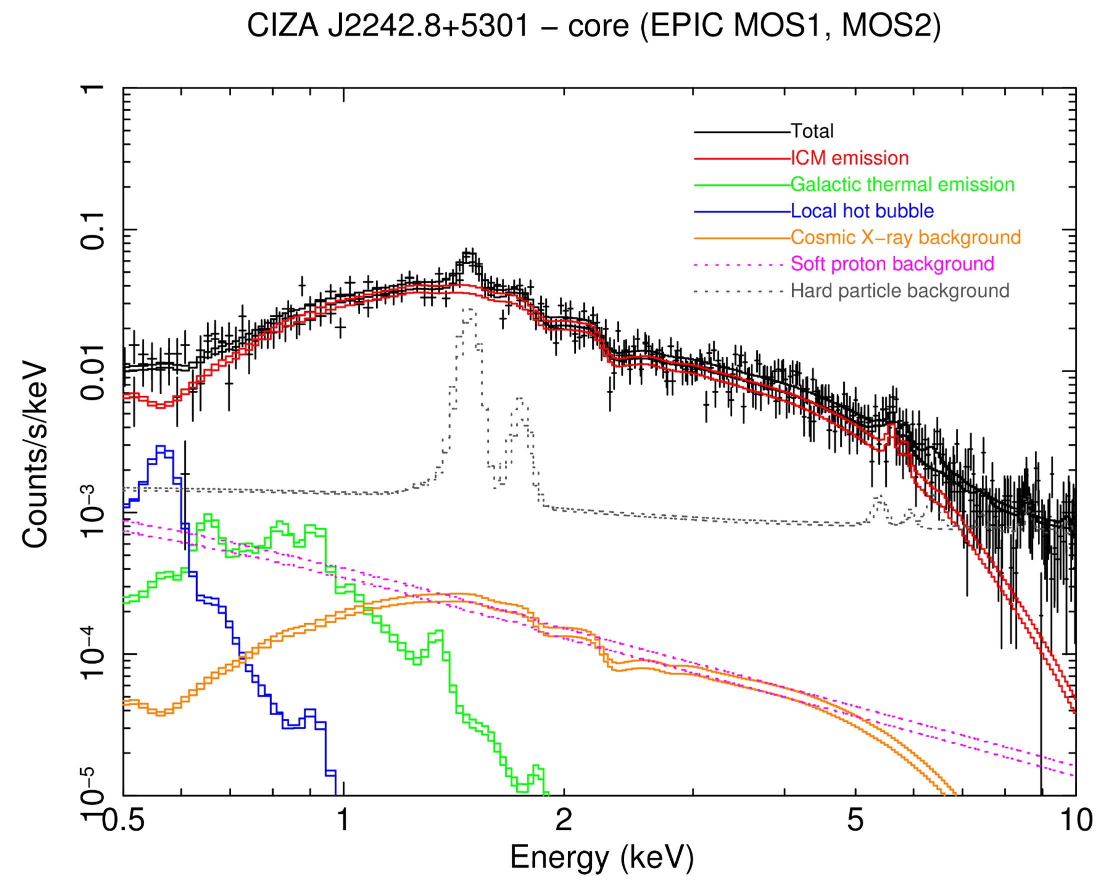

Figure 4: EPIC spectra of the core of the Sausage cluster.
The background components have been carefully modelled.

ABUNDANCE AND TEMPERATURE DISTRIBUTION

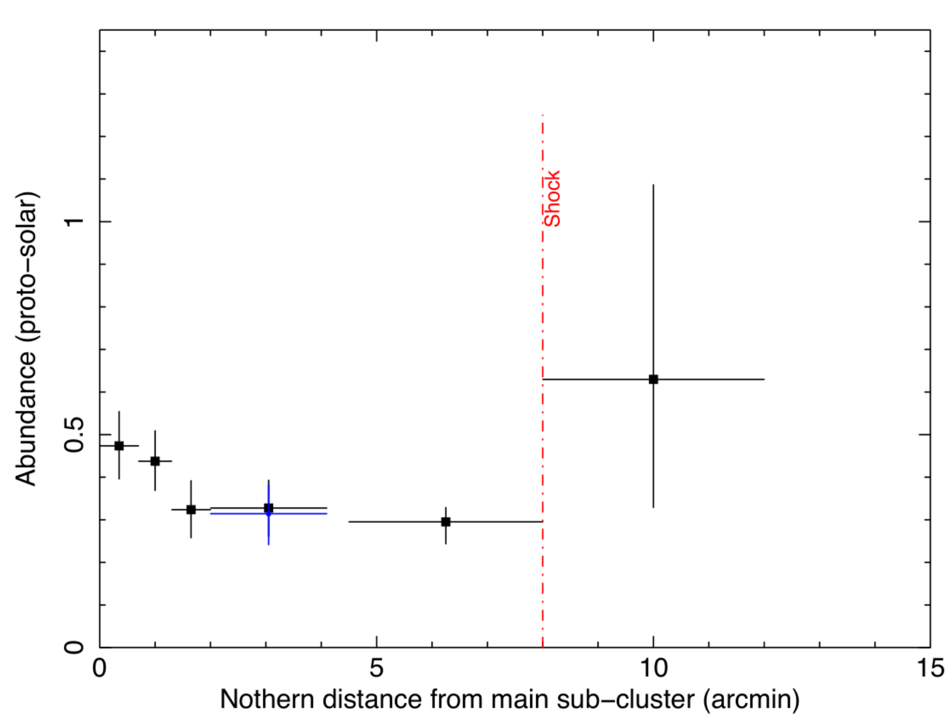

Figure 5: Fe Distribution of the Toothbrush Cluster

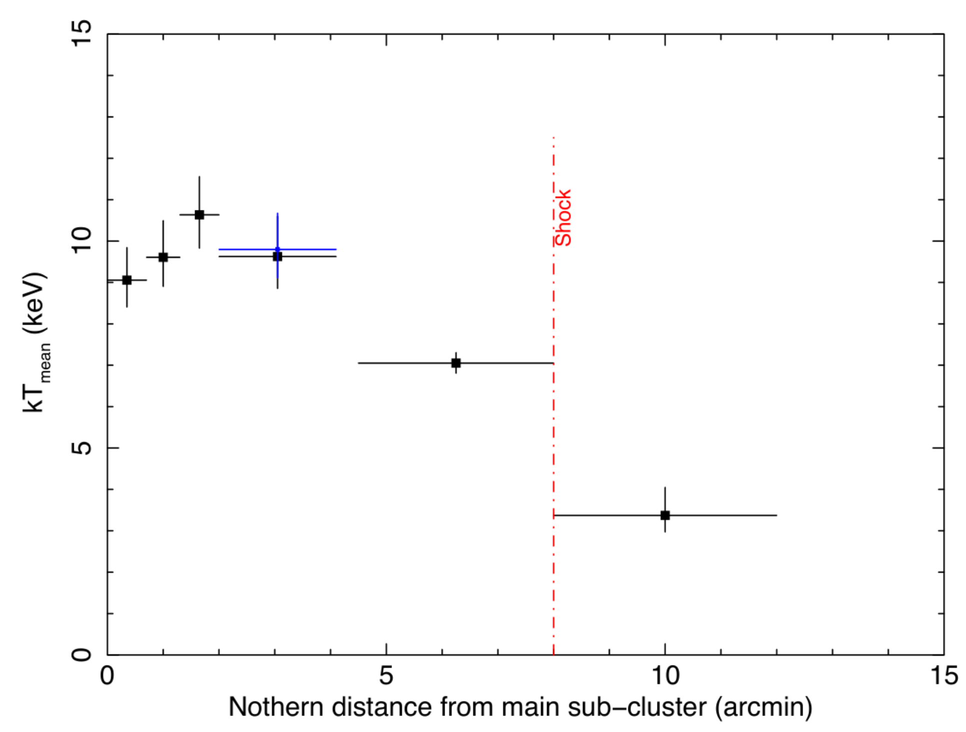

Figure 6: Temperature Distribution of the Toothbrush Cluster

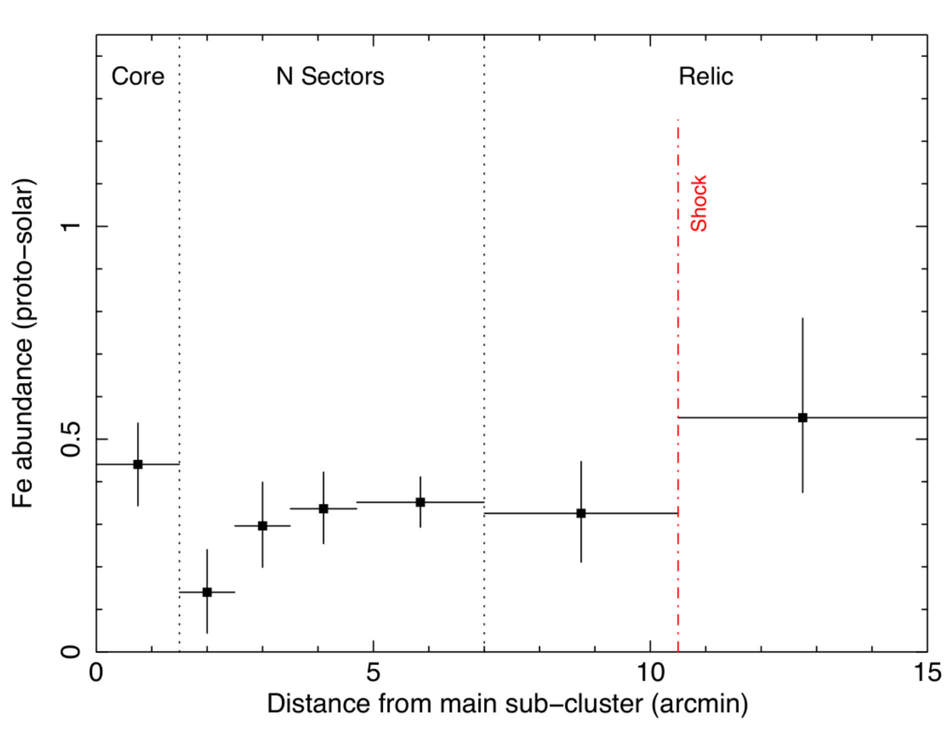

Figure 7: Fe Distribution of the Sausage Cluster

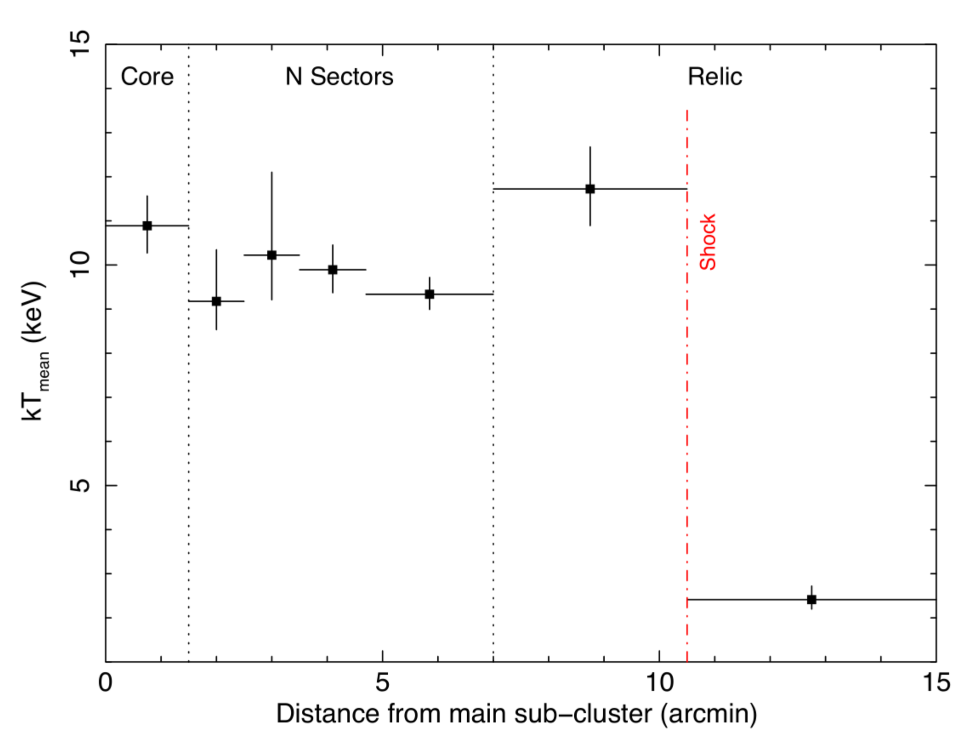

Figure 8: Temperature Distribution of the Sausage Cluster

RESULTS AND CONCLUSIONS

In the Toothbrush, we observe an abundance enhancement towards the core of the main subcluster. This Fe enhancement is accompanied by a slight temperature drop. These findings may point that before the merging, the main subcluster was cool-core and it has survived after the merging. Outside the core (>2 arcmin), the Fe distribution is uniform (~0.3 proto-solar) and the temperature decreases gradually. Based on the temperature profile, it is difficult to confirm the presence of a shock at the position of the radio relic.

The temperature distribution of the Sausage cluster shows a flat behavior until it decreases dramatically beyond the shock. The pre-shock temperature is about 3-4 keV, which is in agreement with the findings from Suzaku [6]. We observe a plateau with an uniform value of ~0.3, which is very similar to what is found in the outskirts of relaxed, non-merging clusters (Werner et al. 2013). Unlike the Toothbrush cluster, the violent merger in the Sausage cluster was very efficient in mixing the metals across the entire ICM.

Further confirmation of these preliminary results will be investigated with the archival Suzaku data. We will also study how background-related systematic uncertainties affect the present results.

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[4] van Weeren, R. J., Brunetti, G., Brüggen, M., et al., 2016, ApJ 818:204
[5] L odders et al. 2009
[6] J.S. Kaastra & Bleeker 2016

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