Study of the Large-scale Temperature Structure of the Perseus Cluster with Suzaku

Sho NISHINO[1], Yasushi FUKAZAWA[1], Katsuhiro HAYASHI[1],
Kazuhiro NAKAZAWA[2] and Takaaki TANAKA[3]

[1] Department of Physical Science, Hiroshima University, 1-3-1 Kagamiyama, Higashi-Hiroshima, Hiroshima 739-8526, Japan
[2] Department of Physics, University of Tokyo, 7-3-1 Hongo, Bunkyo, Tokyo 113-0033, Japan
[3] Stanford Linear Accelerator Center, 2575 Sand Hill Road M/S 29 Menlo Park, CA 94025, USA
E-mail(SN): nishino@hep01.hepl.hiroshima-u.ac.jp

Abstract

We report the study of the large-scale temperature structure of the Perseus cluster with Suzaku. We performed Suzaku observations of the Perseus cluster with four pointings of 30' offset from the cluster center, together with the observation of the central region, in order to investigate the temperature of the outer region, with the Hard X-ray Detector (HXD: 10 - 60 keV). We performed the spectral analysis of the Perseus cluster with a model of the temperature structure, by considering the collimator response of the PIN correctly. As a result, we found that the upper limit of the temperature in the outer region is $\sim$ 14 keV, and an extreme hot gas, that was reported for RXJ 1347.5-1145 and A 3667, was not found in the Perseus cluster. This indicates that the Perseus cluster has not recently experienced a major merger.

Key words: Cluster of Galaxies, X-ray, Suzaku

1. Introduction

In this paper, we report the study of the large-scale temperature structure of the Perseus cluster (Abell 426). The Perseus cluster is a nearby (z = 0.0183), massive, largely extended cluster, and is the most luminous cluster in the X-ray band. An X-ray bright active galaxy NGC 1275, with a radio mini-halo, is located at the cluster center, and non-thermal power-law emission from NGC 1275 was confirmed by past observations (e.g., Sanders et al, 2005). ASCA found a large fluctuation of temperature in this cluster, and indicated that a very hot region with the temperature exceeding $\sim$ 10 keV exists in the outer region of the cluster. Information on cluster merging may have remained in the low-density outer regions in comparison with the dense central region. Therefore, it is very valuable to investigate the temperature structure in the outer region of the cluster carefully. Combination of the XIS and HXD-PIN gives a broad band X-ray spectrum, and is important to recognize multi-temperature structure in the Perseus cluster.

2. Observation

We observed the outer regions of the Perseus cluster on September 2-4, 2006, with Suzaku. Four pointing observations of 30' offset regions from the cluster center were carried out. These observations make use of a narrow FOV of the PIN, by reducing the contribution of intense emission from the cluster center. Additionally, we also analyzed the Suzaku public data of observations of the Perseus cluster center, on February 1–2, 2006, August 29 – September 2, 2006, and February 5–6, 2007. The FOV of these obsevations are shown in the Fig 1 (left).

3. Analysis and Results

3.1. Center region

In this subsection, as a preliminary step prior to the detailed analysis, we investigate the temperature structure in the central region, with the XIS data of the center observation. We divided the XIS events into 4 annular regions of $0' - 2'$, $2' - 4'$, $4' - 6'$, $6' - 8'$ in radius from the cluster center (Fig 1 right). At First, we performed spectral fitting for the region of $0' - 2'$, with a single temperature APEC plus POWERLAW model, to take into account nuclear X-ray emission from NGC 1275, which is located at the cluster center. The temperature of 3.3 keV is obtained and the estimated power-law luminosity is $\sim 5.6 \times 10^{43}$ erg s^{-1} (0.8-10 keV). For the regions of $2' - 4'$, $4' - 6'$, $6' - 8'$, we performed spectral fitting with a single temperature APEC model. Here, each region was assumed to be isothermal. Then, the temperatures of 4.6 keV ($2' - 4'$), 5.9 keV ($4' - 6'$), 6.5 keV ($6' - 8'$) are obtaind. As above, the center region of the cluster shows strong cooling core structure.

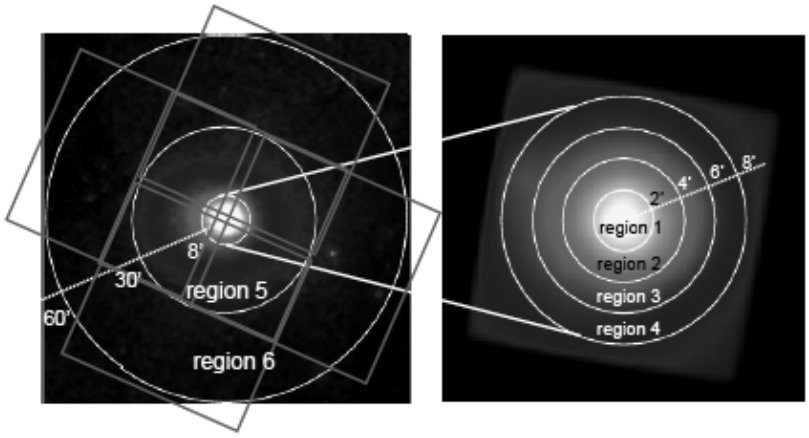

Fig. 1. Definition of six cluster regions. The radii of white circles are 2', 4', 6', 8', 30', 60' from the cluster center. (left) ROSAT-PSPC image, (right) XIS image of the center observation

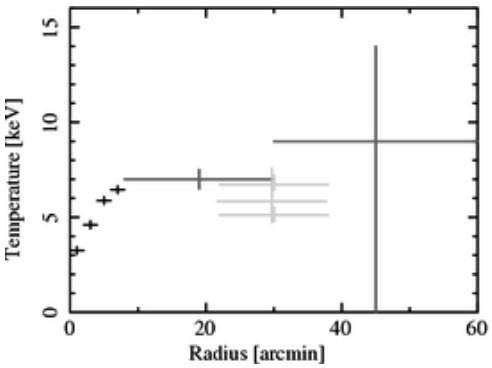

Fig. 2. Radial temperature profile of the Perseus cluster, obtained in this work. Black crosses are obtained with the XIS in §3.1, red crosses are obtained with the PIN in §3.2.

3.2. Outer region

Observed PIN spectra contain photons coming from a large sky area of the cluster, due to its FOV of $34' \times 34'$ (FWHM). Therefore, we have to consider the collimator response of the PIN correctly, to determine the temperature structure of the cluster. For that purpose, we implement the Monte-Carlo simulator that reproduces the PIN spectra of the Perseus cluster with an assumed temperature structure by considering the collimator angular response of the PIN. By comparing simulated spectra with actual observed spectra, we searched the temperature structure that reproduces the observed data the best. Here, we divide the cluster into six annular regions, region 1 - 6 as shown in Fig 1. The definition of region 1–4 is the same as the previous XIS analysis of the center observation. As a first step, assuming the emission model parameters of region 1–4 to be those as measured by XIS in the previous subsection, we obtain the temperature of region 5 (8' < r < 30') by using the PIN data of the center observation. The temperature of region 5 is tested from 5 keV to 12 keV with a step of 0.5 keV, with metal abundance fixed to 0.35 solar. We compare the simulated spectrum with the observed spectrum by adjusting the model normalization. A χ^2 test is performed by varying the model temperature of region 5. As a result, The best-fit temperature of region 5 is 7.0 keV, and the error range is 6.6–7.4 keV at 90% confidence level.

Next, assuming the temperature of region 5 to be 7 keV obtained in the first step, as well as the region 1-4 temperature, we obtain the temperature of region 6 (30' < r < 60') by using PIN data of the offset observations. The temperature of region 6 is tested from 5 keV to 15 keV with a step of 1 keV, with metal abundance fixed to 0.25 solar. We investigated the averaged-temperature of the four offset regions, by using the PIN spectrum summed over the four observations and comparing it with the simulated spectrum. The best-fit temperature of region 6 is ∼9.0 keV. The upper limit is ∼ 14 keV at the 90% confidence level, while the lower limit is not well constrained.

4. Summary

The radial temperature profile obtained in this work is shown in Fig 2. Most importantly, we found that the upper limit of the temperature of the offset region, where hot components seem to exist, is approximately at most 14 keV (< 19 keV within the systematic errors). Considering XIS spectra in the offset region do not require hot components, it seems that extremely hot gas as reported in RXJ 1347.5-1145 (Ota et al. 2008) or A3667 (Nakazawa et al. 2009) does not exist in the Perseus cluster. That is, the Perseus cluster has been already relaxed, and has not recently experienced a violent cluster merger, which greatly influences the temperature structure of the cluster.

Additionally, we estimate the non-thermal emission hidden by the thermal emission in the cluster. Then, tight upper limit of 4.4×10^{-12} erg cm^{-2} s^{-1} is obtained in the offset region, by subtracting the simulated central emission models.

5. References

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