

# Hard X-ray Mapping of Galaxy Clusters

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## ABSTRACT

Hard X-ray emission from clusters of galaxies is important to probe the acceleration phenomena in the largest system in the universe. Here we presented Suzaku observations of A3376 and A3667. Upper limit of nonthermal hard X-ray emission gives a reasonable lower limit of intracluster magnetic field. Extremely hot gas component is found in A3667, indicating a suprathermal emission. We will suggest a possible hard X-ray mapping with MAXI to constrain the spatial distribution of hard X-ray emission.

KEY WORDS: Clusters: X-ray — Acceleration: hard X-ray

## 1. Introduction

Clusters of galaxies are the largest systems in the universe, but they are still evolving. The released gravitational energy will lead to particle acceleration of high energy particles up to  $10^{16-17}$  eV, through such as shock wave around the mass inflow of intergalactic gas or hydromagnetic turbulence in the intracluster medium. Powerful jets from central dominant galaxies also cause particle acceleration. Therefore, clusters of galaxies are now believed to be a possible particle acceleration site. At fact, radio synchrotron halo is often observed from clusters of galaxies, indicating that high energy electrons really exist in the intracluster space. Such nonthermal energy in high energy particles has a small entropy, and thus past information is expected to be preserved. Also if nonthermal energy is not negligible in comparison with thermal energy, it causes some important impacts, such that gravitational mass estimated from only thermal pressure will be modified. In addition, clusters of galaxies are possible sources of extragalactic cosmic rays.

Such high energy particles can be probed by nonthermal hard X-rays and gamma-rays. Gamma-ray survey with CGRO/EGRET did not find any significant emission from galaxy clusters (Reimer et al. 2003). Then, gamma-ray observatory *Fermi* is promising for exploring the gamma-ray view of galaxy clusters. On the other hand, recent hard X-ray survey has reported possible nonthermal emission from galaxy clusters. First reports were BeppoSAX/PDS detection of hard tail from the Coma cluster (Fusco-Femiano et al. 1999, 2000, 2001), but this is still under debate (Rossetti et al. 2007). Nevalainen et al. (2004) reported hard power-law component from 7 galaxy clusters above  $3\sigma$  level. Hard X-

ray from clusters has also been reported with RXTE (Rephaeli et al. 1999, 2003, 2006). Nonthermal X-ray emission from galaxy groups is also detected with ASCA (Fukazawa et al. 2001; Nakazawa et al. 2006). However, significance of detection is still very low and distinguishment from AGN emission is difficult now. Therefore, further confirmation with high sensitivity or imaging detectors is necessary, and Suzaku/HXD and MAXI are suitable for such studies.

## 2. Suzaku Observations of Nonthermal Emission

The HXD/PIN (Takahashi et al. 2007; Kokubun et al. 2007; Fukazawa et al. 2009) onboard Suzaku has a very low background in the 10–30 keV band than any past instruments. In addition, its narrow field of view ( $34' \times 34'$  FWHM), compared with the BeppoSAX/PDS ( $1.3^\circ$  hexagonal FWHM) and RXTE/PCA ( $1^\circ$  hexagonal FWHM), yields several advantages. First, the confusion from hard point sources is reduced, as is the contribution of the ICM thermal emission, and finally the nonthermal emission may be localized better. Suzaku/XIS also achieves the lowest background level of any previous X-ray CCDs, and it is useful to constrain the hard X-ray emission.

Abell 3376 is a nearby on-going merger cluster ( $z=0.046$ ), and revealed to have a symmetric strong radio relic (Bagchi 2005, 2006). Significant hard X-ray detection is also reported with BeppoSAX/PDS (Navaleinen et al. 2004). Suzaku observed this cluster, focusing on the cluster center containing the diffuse radio emission to the east, and cluster peripheral region to the west. For both observations, we detect no excess hard X-ray emission above the thermal cluster emission (Kawano et

al. 2009). An upper limit on the non-thermal X-ray flux of  $2.1 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$  (15–50 keV) at the  $3\sigma$  level from a  $34 \times 34 \text{ arcmin}^2$  region, derived with the HXD/PIN, is similar to that obtained with the BeppoSAX/PDS. Using the XIS data, the upper limit on the non-thermal emission from the West Relic is independently constrained to be  $< 1.1 \times 10^{-12} \text{ erg s}^{-1} \text{ cm}^{-2}$  (4–8 keV) at the  $3\sigma$  level from a  $122 \text{ arcmin}^2$  region. Assuming Compton scattering between relativistic particles and the cosmic microwave background (CMB) photons, the intracluster magnetic field  $B$  is limited to be  $> 0.03 \mu\text{G}$  (HXD) and  $> 0.10 \mu\text{G}$  (XIS).

Abell 3667 ( $z=0.056$ ) is famous of its pair of radio relics (Roettgering et al. 1997), which is the brightest and largest among the diffuse radio sources associated with galaxy clusters. Suzaku observed this cluster, focusing on the north radio relic. Nakazawa et al. (2009) reported that nonthermal hard X-ray is not detected with a HXD upper limit of  $5.3 \times 10^{-12} \text{ erg s}^{-1} \text{ cm}^{-2}$  in 10–40 keV for the entire cluster region and with an XIS upper limit of  $7.3 \times 10^{-13} \text{ erg s}^{-1} \text{ cm}^{-2}$  in 10–40 keV for the radio relic region. Combined with the radio flux, strong constraint on the magnetic field is obtained to be  $> 1.6 \mu\text{G}$ . Interestingly, Suzaku detected an extremely hot thermal component from this cluster; the spectrum is well represented by two-temperature model of  $\sim 5 \text{ keV}$  and  $> 13 \text{ keV}$ . Such a hot component is possible suprathermal emission caused by the strong shocks. Similar extremely hot component has been also found in RX J1347.5-1145 with Suzaku (Ota et al. 2008).

### 3. MAXI Observation

X-ray emission of nonthermal and suprathermal electrons from clusters of galaxies may be extended over wide regions. Wide field of view (FOV) with large effective area above 10 keV is needed to search for them. MAXI with 1.5 deg FOV can resolve several nearby clusters, as well as Ginga scanning observations (Takano et al. 1989; Ikebe et al. 1992). In addition, MAXI monitoring observation is useful to eliminate variable point sources. Therefore, we can measure the hard X-ray emission to compare their profile with that of soft thermal emission; Is there any extraordinary hot component? Is there any hard power-law component? How extended is it, if it exist?

### References

Bagchi, J., Durret, F., Lima Neto, G. B., Paul, S., & Chavan, S. 2005, Proceedings of the 29th International Cosmic Ray Conference.  
 Bagchi, J., Durret, F., Lima Neto, G. B., & Paul, S., 2006, *Science*, 314, 791  
 Fukazawa, Y., Nakazawa, K., Isobe, N., Makishima, K., Matsushita, K., Ohashi, T., & Kamae, T. 2001, *ApJ*,

546, 87  
 Fukazawa, Y. et al. 2009, *PASJ*, 61, in press  
 Fusco-Femiano, R., dal Fiume, D., Feretti, L., Giovannini, G., Grandi, P., Matt, G., Molendi, S., & Santangelo, A. 1999, *ApJ*, 513, 21  
 Fusco-Femiano, R. et al. 2000, *ApJ*, 534, 7  
 Fusco-Femiano, R., Dal Fiume, D., Orlandini, M., Brunetti, G., Feretti, L., & Giovannini, G. 2001, *ApJ*, 552, 97  
 Ikebe, Y. et al. 1992, *ApJ*, 384, L5  
 Kawano, N. et al. 2009, *PASJ*, 61, in press  
 Kokubun, M. et al. 2007, *PASJ*, 59, S53  
 Nakazawa, K., Makishima, K., & Fukazawa, Y. 2007, *PASJ*, 59, 167  
 Nakazawa, K. et al. 2009, *PASJ*, 61, in press  
 Ota, N. et al. 2008, *astro-ph/0805.0500* (*A&A* 2008, in press)  
 Nevalainen, J., Oosterbroek, T., Bonamente, M., & Colafrancesco, S. 2004, *ApJ*, 608, 166  
 Reimer, O. et al. 2003, *ApJ*, 588, 155  
 Rephaeli, Y. et al. 1999, *ApJ*, 511, L21  
 Rephaeli, Y. et al. 2003, *ApJ*, 595, 137  
 Rephaeli, Y. et al. 2006, *ApJ*, 649, 673  
 Rossetti, M. and Molendi, S. 2007, *astro-ph/0702417*  
 Rottgering, H. J. A. et al. 1997, *MNRAS* 290, 577  
 Takahashi, T. et al. 2007, *PASJ*, 59, S35  
 Takano, S. et al. 1989, *Nature*, 340, 289