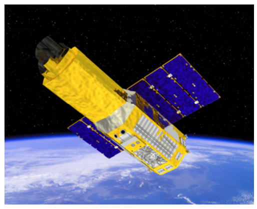
Hard X-ray Properties of a Merging Cluster Abell 3667 as Observed with Suzaku



Kazuhiro Nakazawa[1], Craig L. Sarazin[2], Madoka Kawaharada[3], Kazuo Makishima[1,3], Takao Kitaguchi[1], Sho Okuyama[1], Naomi Kawano[4], Yasushi Fukazawa[4], Susumu Inoue[5], Motokazu Takizawa[6], Daniel R. Wik[2], Alexis Finoguenov[7,8], and Tracy E. Clarke[9,10]

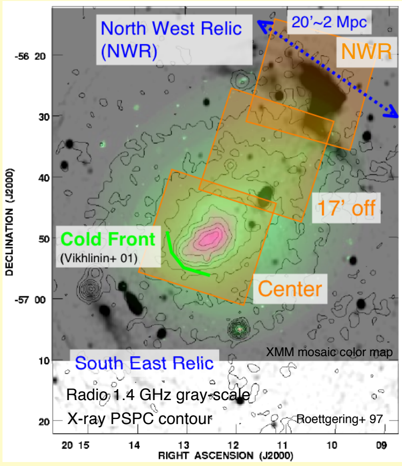
[1]University of Tokyo; [2]University of Virginia; [3]RIKEN; [4]Hiroshima University; [5]National Astronomical Observatory of Japan; [6]Yamagata University; [7]Max Planck Institute for Extraterrestrial Physics; [8]University of Maryland Baltimore County; [9]Naval Research Laboratory; [10]Interferometrics Inc.

Abstract

Wide-band Suzaku data of 3 mapping observations on the merging cluster Abell 3667 were examined for excess hard X-ray emission. **X-ray emission out to 2.6 Mpc from the cluster center was clearly detected**, thanks to Suzaku XIS high sensitivity. Suzaku wide-band spectra of the 0.5-40 keV band suggested **existence of a hot (kT > 13 keV) thermal component located around the cluster center**. No signature of power-low emission with photon index similar to the radio emission is observed. Using the HXD, we derived the overall upper-limit flux on **the non-thermal emission as < 4.3x10^{-12} erg/s/cm2 in the 10-40 keV band**. In addition, the XIS data right on the North West Radio Relic with a size of ~18'x6', located 40' (=2.6 Mpc) apart from the center, provides us with strict **upper limit on the inverse Compton emission as < 2.6x10^{-13} erg/s/cm2** in the 2-8 keV band. The lower limit on the **magnetic field thus obtained is ~2 μGauss.**

See also C. Sarazin et al. talk on Tuesday PM.

1: Merging cluster Abell 3667



The cluster has highly elongated shape, in both optical and in X-ray morphologies. The cocoon-shaped pair of Mpc scale Radio Relic suggests the existence of strong particle acceleration. The North West Relic is the brightest among the Mpc-scale radio objects associated with galaxy clusters. Three pointings were made with Suzaku.

$kT \sim 7.2$ keV, $z = 0.0556$

$F_{(0.4\text{-}2.4\ \mathrm{keV})}$ = 2x10^{-10} erg/s/cm^2 (e.g. Fukazawa+ 05)

NWR flux = 3.7 Jy @1.4 GHz
1.5x10^{-13} cgs (0.5-2 GHz) (Johnston-Hollitt 04)

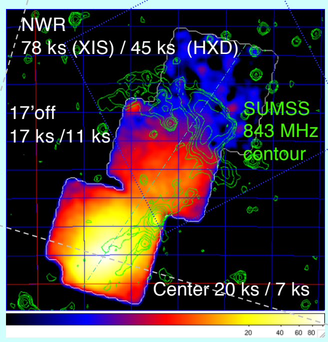
Temperature Inhomogeneity (e.g. Markevitch+ 99, Briel+ 05)

Non-thermal hard X-rays < 7x10^{-12} erg/cm^2 (20-80 keV) (SAX/PDS, e.g. Nevalainen+ 03)

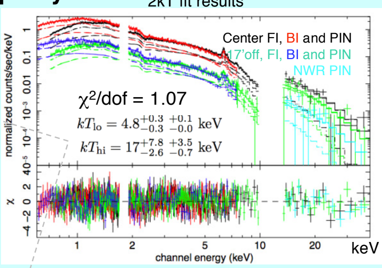
2: Suzaku data analysis

2-1: XIS image to the cluster periphery

Presented beneath is the XIS mosaic image in the 1-8 keV band (color map). Exposure and vignetting correction is applied after CXB and NXB are subtracted. X-ray emission is detected out to the NWR region, 30' = 1.9 Mpc apart from the center. There are no apparent emission associated with the NWR. As a reference, FWHM field of view (FOV) of the HXD/PIN detector are shown in dotted blue, while bottom-to-bottom FOV in dashed gray.



2kT fit results



2-2: A very hot component

Combined spectra of the XIS (center and 17'off data), and the HXD (all data). Wide-band coverage of 0.6-40 keV is obtained. The HXD detects signals from all three pointings, stronger to the center of A3667. Using an arf file generated from the PSPC image, a 1 kT model fitting is unacceptable. A very hot component with kT > 13 keV is required to explain the slight excess above ~8 keV in the XIS spectra and large excess around 10-30 keV in the HXD spectra. Although the excess could also be of non-thermal origin, with Γ~1.5 and E_{fold} ~ 40 keV, the ">13 keV component" is likely to be thermal, because it is present in the cluster center (away from the NWR) and seems to follow the distribution of the thermal emission. The HXD count rate distribution among the three pointings are also consistent with those predicted from the PSPC image, i.e. the thermal distribution. Fitted temperatures are shown in the panel. There, systematic errors associated with XIS and HXD's NXB estimation and CXB fluctuation is included as second error bars.

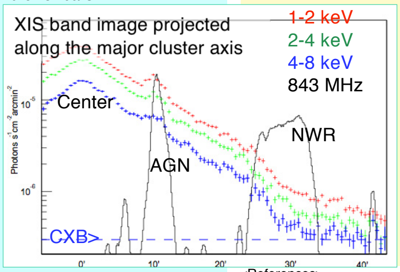
2-3: Upper limits on the IC emission

Radio synchrotron spectra shows a power-law like spectra with a photon index Γ= 2.1 (e.g. Roettgering+ 97). To estimate the inverse Compton (IC) scattering off the CMB emission, we added a power-law (PL) component with fixed Γ=2.1. Here we assumed no cut-off in the PL.

1: **The HXD spectra** were fitted with a 2 kT+PL model. In all pointings, only an upper-limit is obtained, For the PL component, as shown here. This is because the HXD spectra is consistent with being totally thermal.

$F_{PL(NWR)}$ < 8x10^{-12} cgs

(10-40 keV flux in 90% conf.)



With the highest S/N ratio, the NWR pointing provides the best upper-limit as 8x10^{-12} erg/s/cm^2 (10-40 keV) within 34'x34' around the NWR, i.e. the northern half of the cluster as a whole. Here we included an NXB syserr of 5.0% and CXB fluctuation (35'x35' 90% conf.) of 18%.

2: **The XIS spectra** extracted from the region right at the NWR (18'x6' size) is well fitted with a 1kT model with kT = $4.7_{+/-0.6+/-1.0}$ keV. Total flux in this region is 5x10^{-13} erg/s/cm^2 in the 2-8 keV band. The XIS projected image shows no enhancement in any energy band at the NWR region. If the IC emission has a distribution similar to the radio image, most of the X-rays emitted within 25'~29' cannot be of IC origin. Including the CXB fluctuation of 19% (in 90% conf.), the upper-limit on the IC emission should be < 50% of the X-rays, i.e. < ~2.5x10^{-13} erg/s/cm^2 in the 2-8 keV band.

3: Discussion

1: Signature of strong heating of the ICM

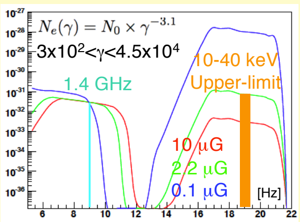
Suzaku wide-band spectra revealed a signature of a very hot component, with kT > 13 keV in combination with a ~4 keV component, around the cluster center (and 17'off as well). The hotter component temperature is a bit higher than those suggested by the XMM hardness ratio (Briel+ 05), which showed a distribution around 4--8 keV. Follow up work to spatially resolve the component is in progress. If the emission is truly of thermal origin, our results suggest a strong heating take place in the merging cluster.

2: Non-thermal IC emission upper-limits

1: The HXD result of < 8x10^{-12} erg/s/cm^2 (10-40 keV) around the northern half of the cluster gives the upper limit in GeV electron population in the cluster vicinity as $E_{total\ (GeV\ e)}$ < 1.1x10^{62} erg.

2: The XIS result of < ~2.5x10^{-13} erg/s/cm^2 (2-8 keV) at the 18'x6' region on the NWR gives the upper limit as $E_{NWR\ (GeV\ e)}$ < 4x10^{60} erg. By comparing the result with the radio flux, we obtain a volume averaged intra cluster magnetic field as > 2.2 μG. Wide-band emission models based on the synchrotron and IC emission from a population of relativistic electron are shown in the bottom right panel. The energy density around the NWR thus obtained as, 1.2 eV/cm^3 for ICM thermal component, > 0.1 eV /cm^3 for the magnetic field, and < 0.1 eV /cm^3 for the non-thermal electrons. From this point of view, the tendency of shortfall of X-ray emission around the NWR may suggest relatively strong non-thermal pressure.

Right) SED spectra calculated from relativistic electron distributions modeled to be consistent with the radio observations assuming the magnetic field.



<References>

Briel, U. G., Finoguenov, A., Henry, J. P.,& Anders E., 2004, A&A, 426, 1
Fukazawa Y., Makishima K., & Ohashi T. 2004, PASJ, 56, 965
Fusco-Femiano R., et al.. 2001, ApJ, 552, L97
Johnston-Hollitt M. 2004, in Proc. *The Riddle of Cooling Flows in Galaxies and Clusters of Galaxies.* Ed. T. H. Reiprich, J.C. Kempner, & N. Soker
Knopp G. P., Henry J. P., & Briel U. G., 1996, ApJ, 472, 125
Kokubun M., et al. 2007, PASJ, 59, 53
Koyama K., et al. 2007, PASJ, 59, 23
Markevitch M., Sarazin C. L., & Vikhlinin A. 1999, ApJ, 521, 526
Mazzotta P., Fusco-Femiano R., & Vikhlinin A. 2002, ApJ, 569, L31
Mitsuda K., et al. 2007, PASJ, 59, 1
Nevalainen J., et al. 2004, ApJ, 608, 166
Rottgering H. J. A., et al. 1997, MNRAS, 290, 577
Rephaeli Y. & Gruber D., 2004, ApJ, 606, 825
Serlemitsos P.J., et al. 2007, PASJ, 59, 9
Takahashi T., et al. 2007, PASJ, 59, 35
Vikhlinin A., Markevitch M., & Murray S.S. 2001, ApJ, 549, L47