Detection of Hard X-ray Emission from the Hottest Abell Galaxy Cluster A2163 with Suzaku

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Motivation

Search for non-thermal/very hot thermal gas in merging clusters
- A cluster merger has a typical kinetic energy $\sim 10^{64}$ erg
  - gas heating and particle acceleration
- Radio halo in merging clusters
- Inverse Compton hard X-ray emission

See e.g., Rephaeli+08 for review

“Is there any scaling relation for non-thermal X-ray emission?”
The hottest Abell cluster A2163 at $z=0.2$

- **Purpose of this study**
  - Constrain non-thermal hard X-ray emission with Suzaku+XMM
  - Origin of hard X-ray emission and physics of shock heating due to merging
  - Magnetic field in the cluster

**Previous observations**

- $1.4\,\text{GHz (contours)}$
- $X$-ray
- $400\,\text{kpc}$
- Non-thermal
- $15\,\text{keV}$
- $18.5\,\text{keV}$
- $7.5\,\text{keV}$

- RXTE $F_{\text{NT}} = 1.1^{+1.7}_{-0.9} \times 10^{-11}\,\text{erg/s/cm}^2$ (Rephaeli+06)
- see also Feretti+01; Million & Allen+09

(Govoni+04; Feretti+04)

(e.g., Bourdin+11; Markevich+01)
Suzaku observations of A2163

XMM image: 0.2–10 keV

41 ksec
2009-Feb
(PI: Ota)

HXD-PIN (FWHM~30')

r=10'

South
113 ksec
2008-Aug
(PI: Reiprich)

1 Mpc

5'

Suzaku observations of A2163

XMM image: 0.2–10 keV
HXD spectrum of A2163

- 12–60 keV flux
  \[ F = 1.52 \pm 0.06 \ (\pm 0.28) \times 10^{-11} \text{ erg/s/cm}^2 \]

- South+NE
- 154ks
- + HXD-PIN

NXB, CXB subtracted
Point sources are negligible
NXB systematic error ~2%

>5σ significance
XMM+HXD broad-band spectral analysis

- **APEC model**
  - $kT = 13.5^{+0.5}_{-0.5}^{+1.9}_{-1.6}$ keV
  - $Z = 0.29 \pm 0.10$ solar
  - $NH = 1.65 \times 10^{21}$ (fix)
  - $\chi^2/dof = 1249/1180$

- 0.3~60 keV spectra can be fitted with a $kT \sim 14$ keV thermal model
  - Hard X-ray emission is likely to be dominated by thermal emission
Constraint on non-thermal emission

- **APEC + Power-law with \( \Gamma = 2.18 \) (the same index in radio; Feretti+04)**

- No significant non-thermal emission in 12-60\,keV
  
  \[ F_{NT} < 1.2 \times 10^{-12} \text{ erg/s/cm}^2 \text{ for } \Gamma = 2.18 \text{ (90\% upper limit)} \]
  
  \[ F_{NT} < 14.3 \times 10^{-12} \text{ erg/s/cm}^2 \text{ for } \Gamma = 1.5 \text{ (90\% upper limit)} \]
Multi-temperature modeling with XMM

胚 Use XMM spectra in 2’x2’ grids to construct the Multi-T model

Temperature map

Temperature of the NE “shock” region: $kT_{\text{NE}} \sim 18$ keV, $L_{\text{NE}} \sim 5 \times 10^{44}$ erg/s
HXD spectral fitting with Multi-T + Power-law model

* Multi-T APEC + Power-law

- The 90% upper limit on the non-thermal emission
  \[ F_{NT} < 9.4 \times 10^{-12} \text{ erg/s/cm}^2 \text{ for } \Gamma=2.18 \]
  \[ F_{NT} < 12.8 \times 10^{-12} \text{ erg/s/cm}^2 \text{ for } \Gamma=1.5 \]

Multi-T model gives an acceptable fit to the PIN data.
Additional power-law does not improve the fit.

**3-times stronger constraint than RXTE**
Discussion

• Origin of hard X-ray emission from A2163
  - Emission in the HXD band is well represented by the thermal models
    - Very hot (\(\sim 18\) keV) gas in the NE shock contributes by \(\sim 15\%\)
    - The existence of high-temperature gas supports the scenario of recent \(\sim 0.5\)Gyr merger
      (Bourdin+11; Takizawa+99; see also Ota+08 for the case of RXJ1347)
    - We did not find any significant non-thermal hard X-ray emission

• Estimation of cluster magnetic field
  - Using the relation \(S_{IC}/S_{sync} = U_{CMB}/U_B\) & the radio flux \(S_{syn}=155\) mJy@1.4GHz,
    - \(S_{IC} < 0.26\) \(\mu\)Jy @12 keV \(\rightarrow\) \(B > 0.09\) \(\mu\)G for \(\Gamma=2.18\)
    - \(S_{IC} < 0.20\) \(\mu\)Jy @12 keV \(\rightarrow\) \(B > 0.006\) \(\mu\)G for \(\Gamma=1.50\)
Discussion #2

- Comparison with other clusters
  
  Non-thermal hard X-ray flux

  The upper limits on NT emission were reported in ~10 clusters with Suzaku → no clear scaling relation is seen

  Cluster magnetic field

  If B~1μG, x100 sensitivity is required to detect NT emission from A2163

RXTE & SAX (Rephaeli+08 review), Swift (Ajello et al. 09,10), Suzaku (Kitaguchi+07; Kawaharada+10; Kawano+09; Wik+09; Sugawara+09; Nakazawa+09; Fujita+08; Ota+08)
Summary

- We have detected significant hard X-ray emission from A2163 with Suzaku
  - From the XMM+Suzaku joint analysis, the hard X-ray emission is well represented by the single-T or multi-T thermal model
    - Very hot ($kT \sim 18$ keV) gas in the NE shock contributes by $\sim 15\%$
  - Non-thermal X-ray flux is tightly constrained as $F_{NT} < 9 \times 10^{-12}$ erg/s/cm$^2$
    - thermal emission is dominant at hard X-ray
      $\rightarrow$ determination of thermal component to high accuracy is indispensable!
  - Magnetic field in A2163 is estimated to be $B > 0.09$ $\mu$G

- What’s next?
  - Study more detailed property of shock-heated gas in the A2163 NE
  - Application of this method to other clusters

- ASTRO-H!
  - Imaging ability at hard X will enable
    - more accurate measurement of high-T thermal component which will dominate in hard band & identification of shock region to get higher S/N
    $\rightarrow$ detection of IC to $B \sim 1\mu$G level