Impact of *Suzaku* measurements on astroparticle physics

Naomi Ota (Nara Women's University)
in collaboration with
T. Kitayama, E. Komatsu, K. Nagayoshi,
T. Oshima, G. W. Pratt, T. H. Reiprich

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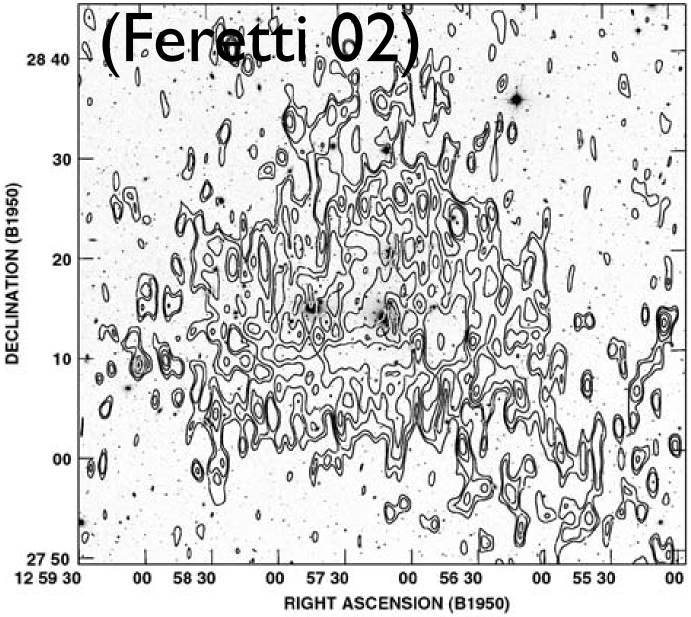
Agenda

- Introduction
  - Cluster mergers and non-thermal phenomena
- Purpose
  - Search for non-thermal hard X-ray emission
- Analysis & results
  - Cases of A2163, Bullet, RXJ1347
- Discussion
  - Limits on non-thermal emission and magnetic fields in 10 clusters
- Summary and future prospects

Cluster mergers and non-thermal phenomena

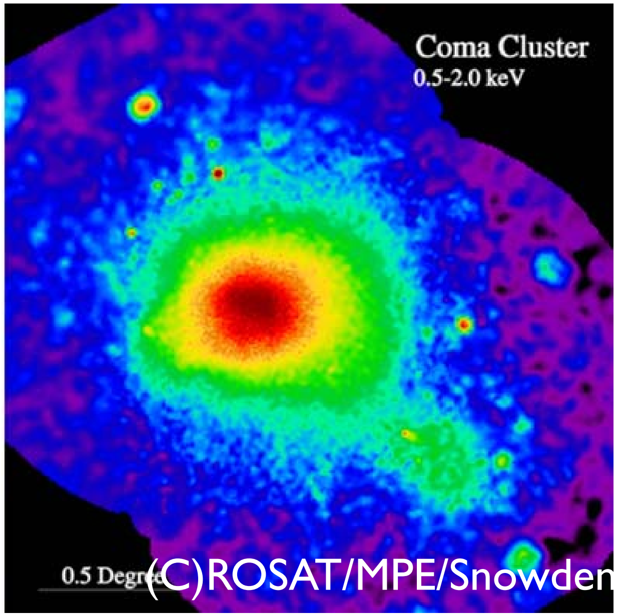
- Clusters grow into the present shape via mergers
- Kinetic energy of a cluster merger ~10^{64} erg
  - ➡ gas heating and particle acceleration
  - ➡ thermal emission and non-thermal emission?

Radio 90cm



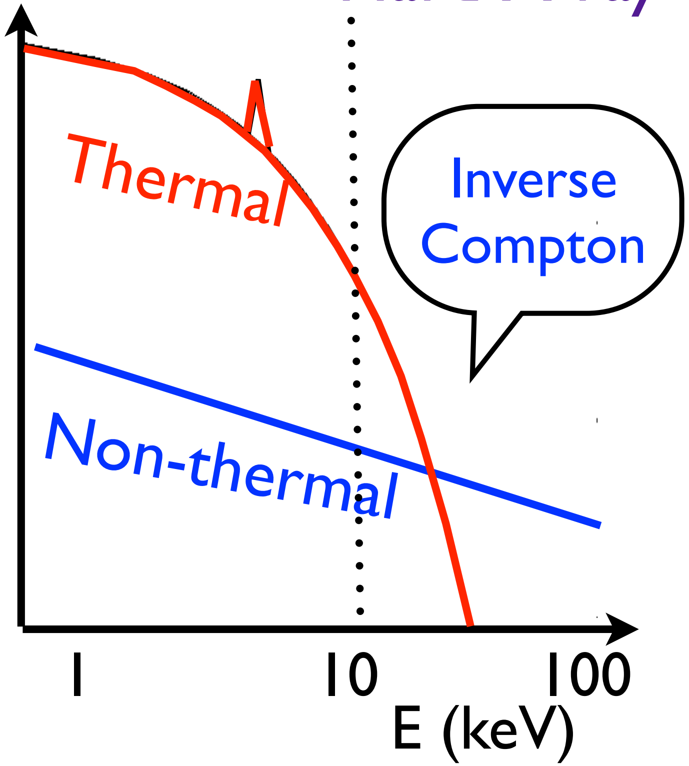
Synchrotron

X-ray 0.5-2keV

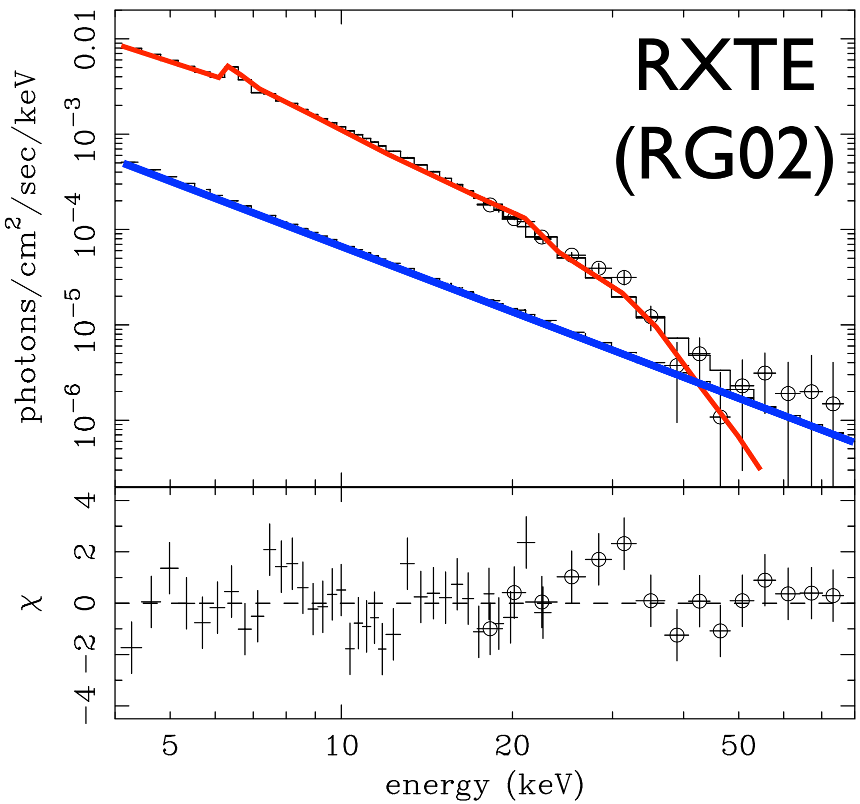


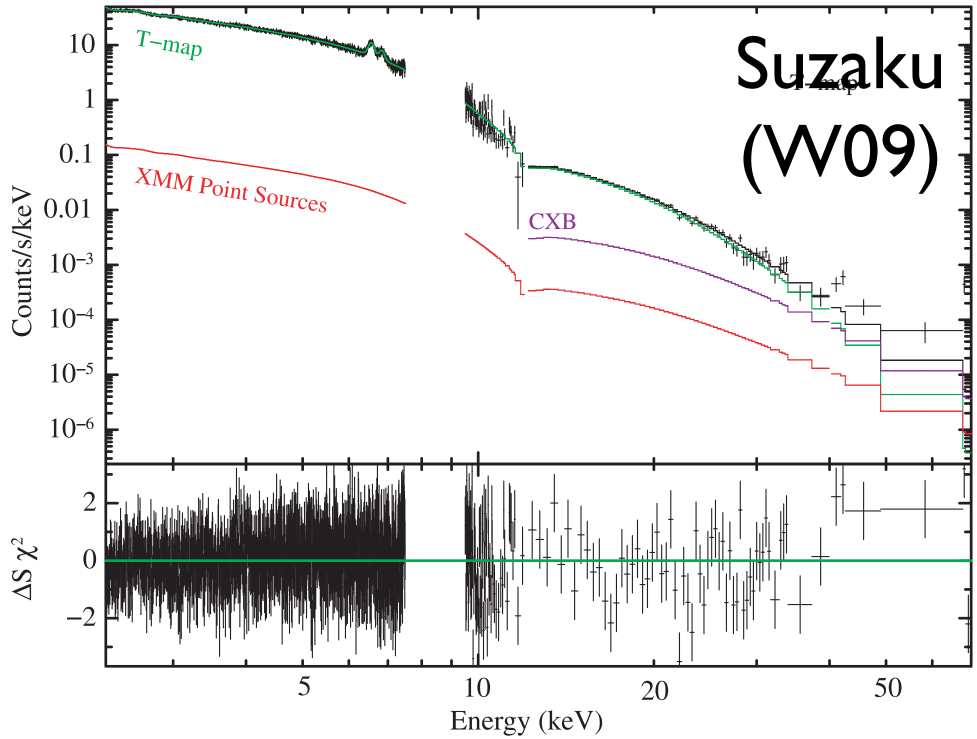
Thermal Bremss.

Hard X-ray



The Coma cluster (z=0.023)

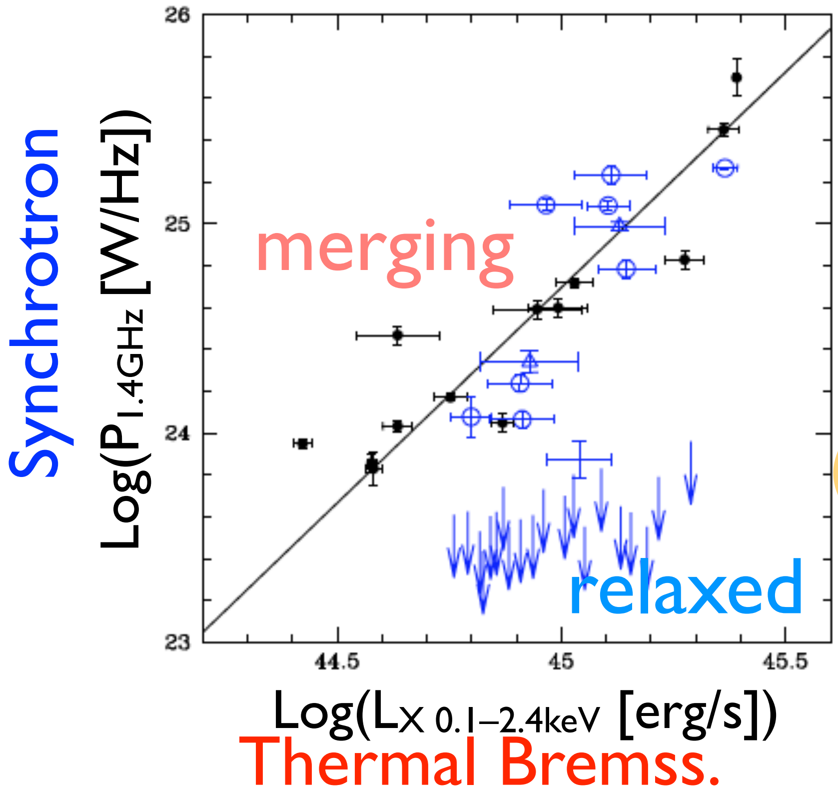




- ✤ Non-thermal X-ray emission
  - RXTE 21±6 10^{-12} erg/s/cm^2 (Rephaeli & Gruber 02)
  - BeppoSAX 15±5 10^{-12} erg/s/cm^2 (Fusco-Femiano+04;11)
  - Suzaku < 6 x10^{-12} erg/s/cm^2 (Wik+09)
  - Swift < 4.2 x10^{-12} erg/s/cm^2 (Wik+11)

Radio – X-ray connection

- ✤ Radio bi-modality (Brunetti+09)
  - merging clusters hosts diffuse radio emission and follows $P_{1.4GHz}$–L_X correlation



"Is there any scaling relation for non-thermal X-ray emission?"

- generation of high-energy particles is connected to dynamical evolution of clusters

Purpose

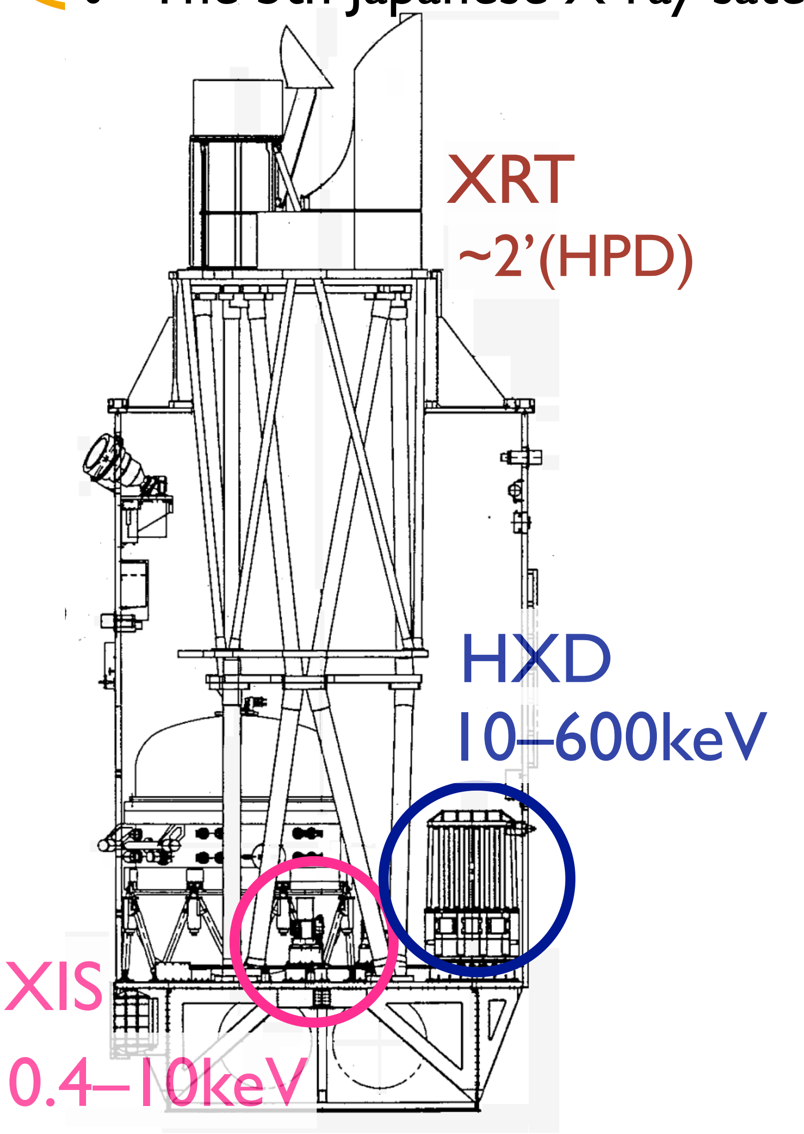
✤ Search for non-thermal hard X-ray emission from merging clusters using the *Suzaku* broad-band X-ray spectroscopy

➡ reveal the origin of hard X-ray emission and understand the cluster dynamical evolution

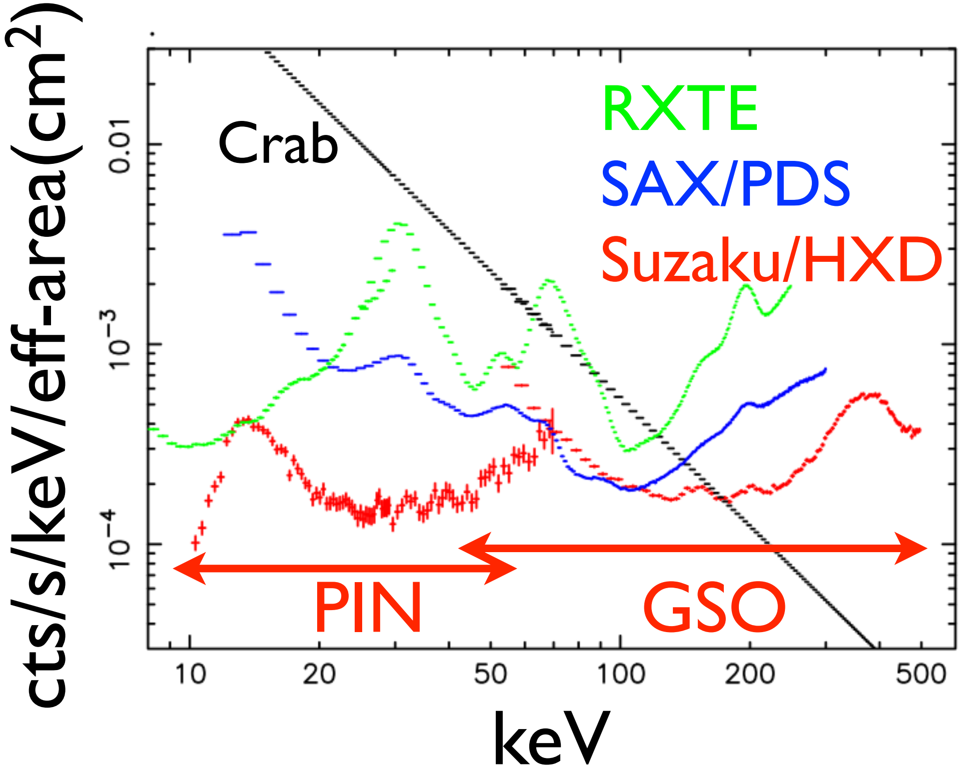
✤ Constrain magnetic fields in clusters using the relation $S_{IC}/S_{sync} = U_{CMB}/U_{B}$ (e.g., Rybicki's textbook)

Suzaku overview

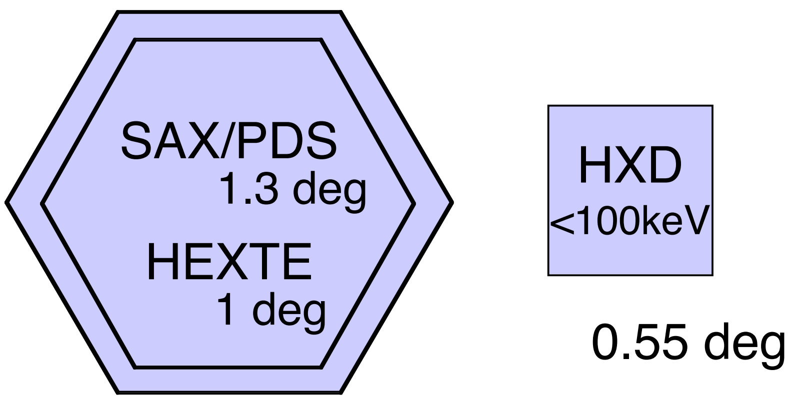
- ✤ The 5th Japanese X-ray satellit



- ✤ The lowest background



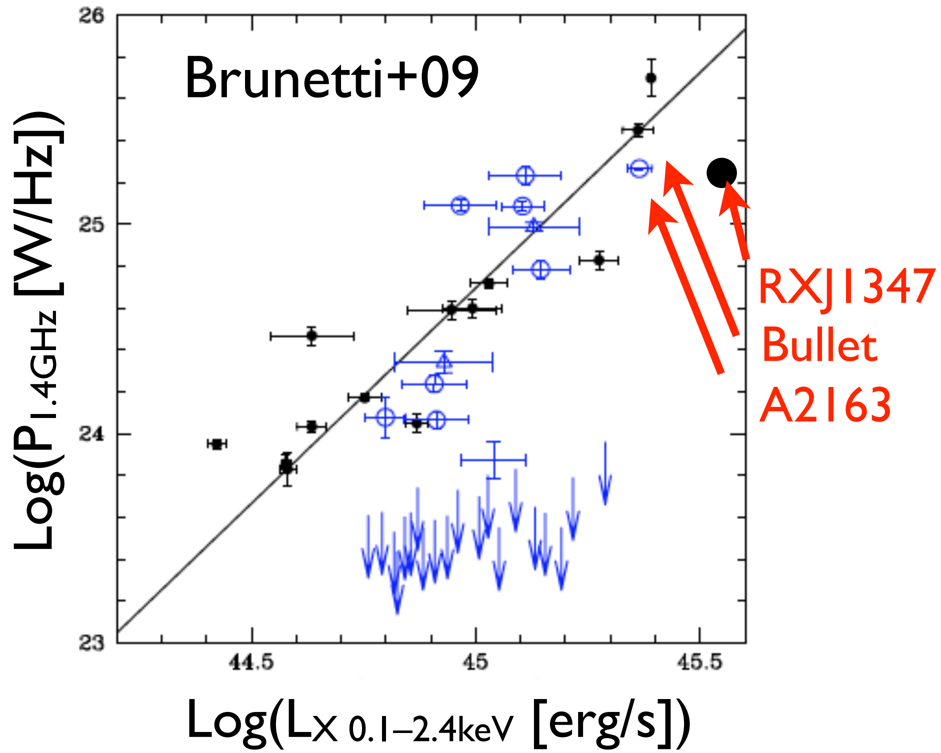
- ✤ Narrower field of view



Targets

- ✤ We have observed objects
  - that are bright in X-rays
  - that have radio halos, indicative of recent merger

Object	Redshift	k<T> [keV]
A2163	0.20	14
Bullet	0.30	13
RXJ1347	0.45	13



- ✤ We'll make a comparison with nearby objects (Coma, Centaurus, A2199, A3376, A3667 etc.)

Analysis strategy

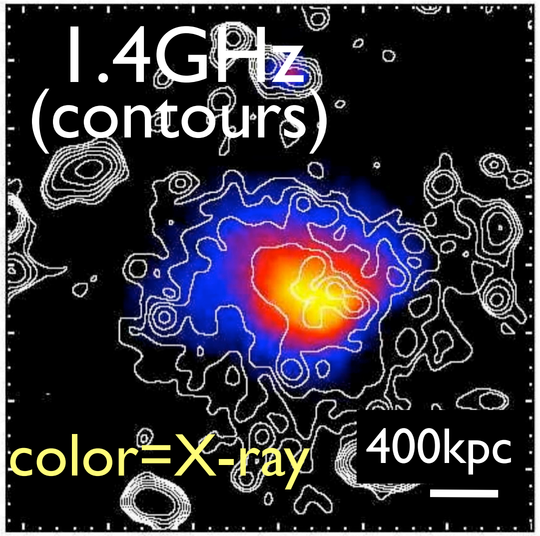
✤ To measure non-thermal hard X-ray emission, we need:

1. Careful assessment of background
   - Systematic error of non-X-ray background for *Suzaku*/HXD is ~2%
2. Detailed modeling of thermal component
   - Single-, two-, multi-temperature models are applied.
   - ✓ mergers can have multi-T structure including very hot thermal gas that emits hard X-rays (e.g., Ota+08)

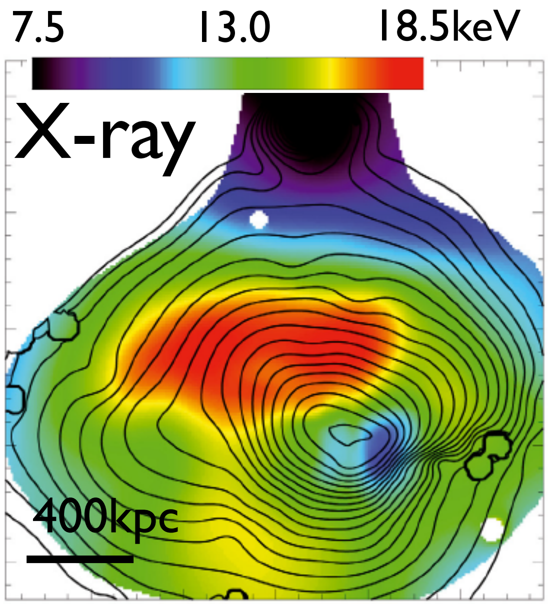
➡The Suzaku+XMM/Chandra joint analysis allow us to take advantage of Suzaku's spectral sensitivity and XMM/Chandra's spatial resolution.

A2163: Previous observations

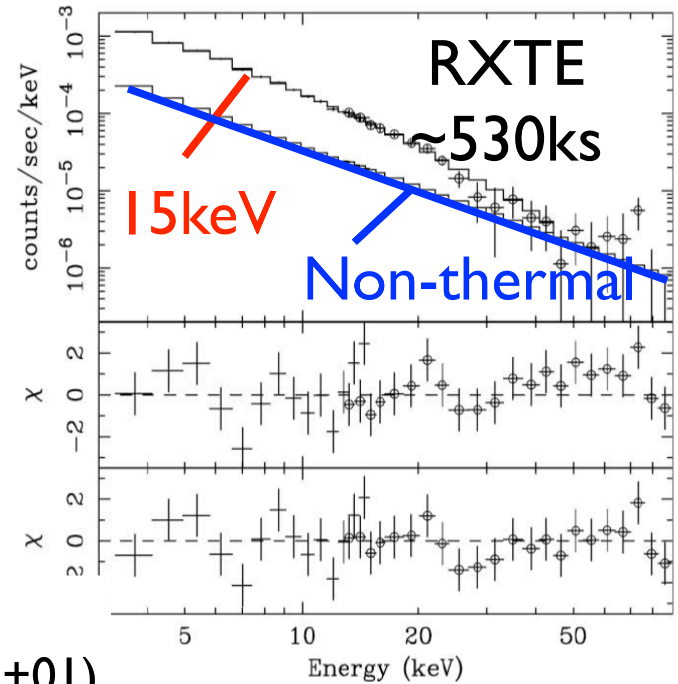
✤ *The hottest Abell cluster*



(Govoni+04; Feretti+04)

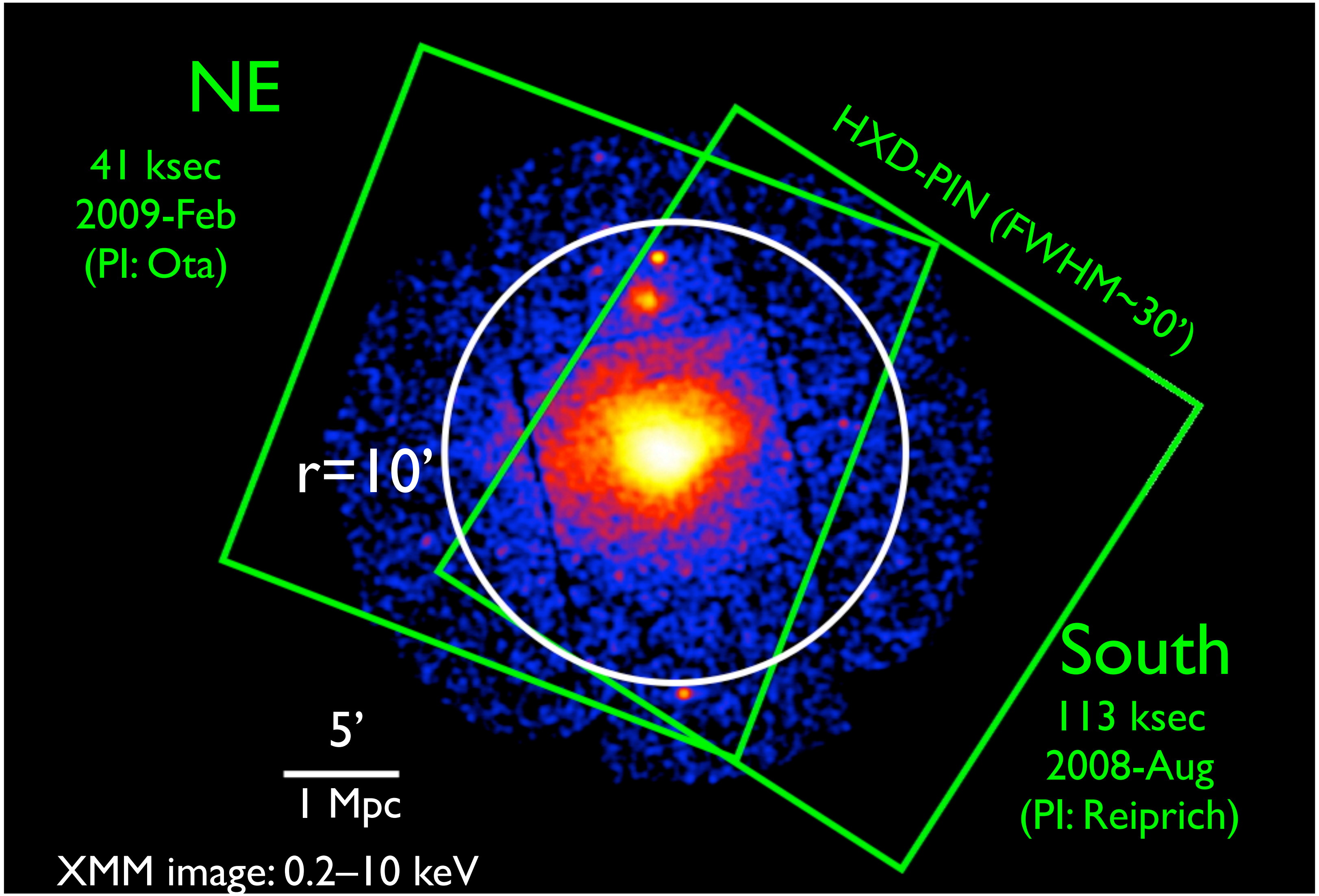


Shock in the North-East
(e.g., Bourdin+11;Markevich+01)

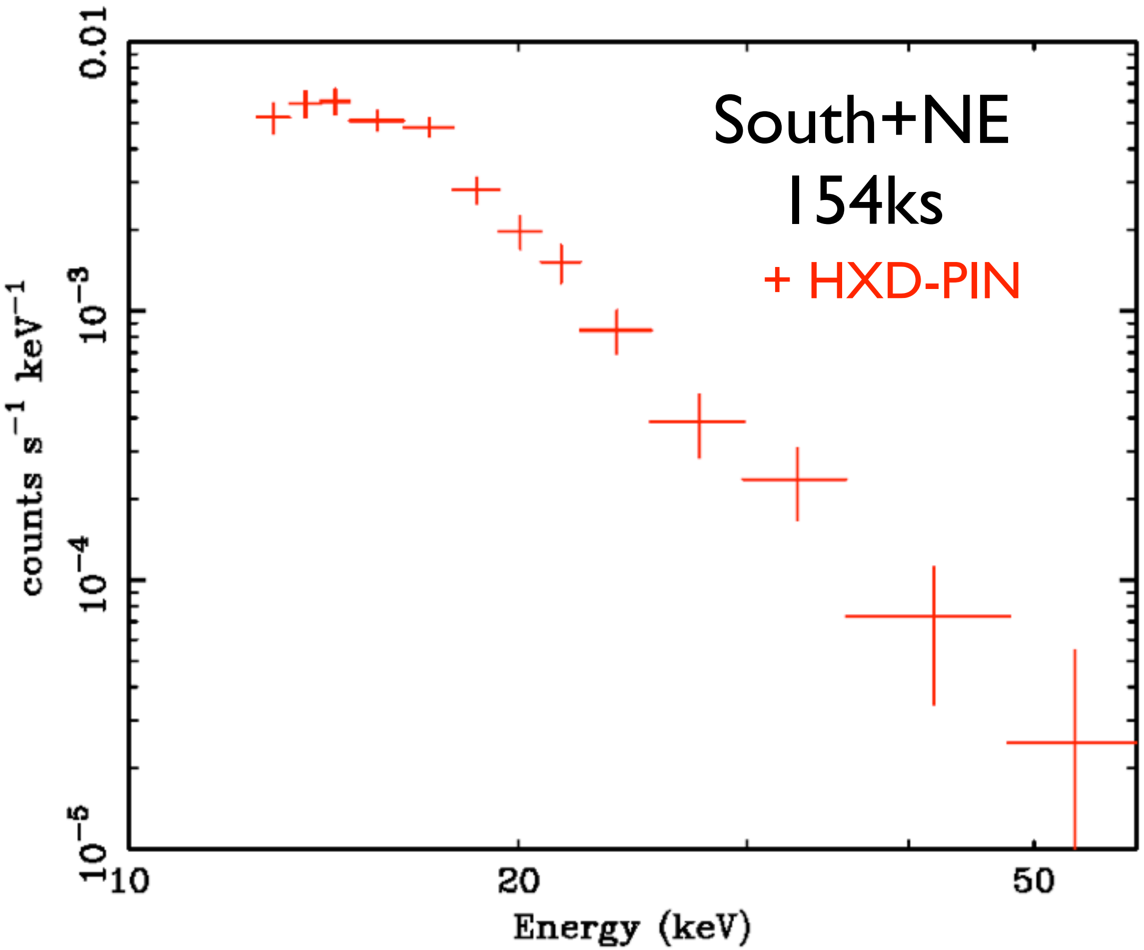


- RXTE F_{NT}= 1.1 $^{+1.7}_{-0.9}$ x 10^{-11} erg/s/cm^2 (Rephaeli+06)
- BeppoSAX F_{NT} < 5.6 x 10^{-12} erg/s/cm^2 (Feretti+01)
- see also Million & Allen+09

Suzaku observations of A2163



Suzaku/HXD spectrum of A2163



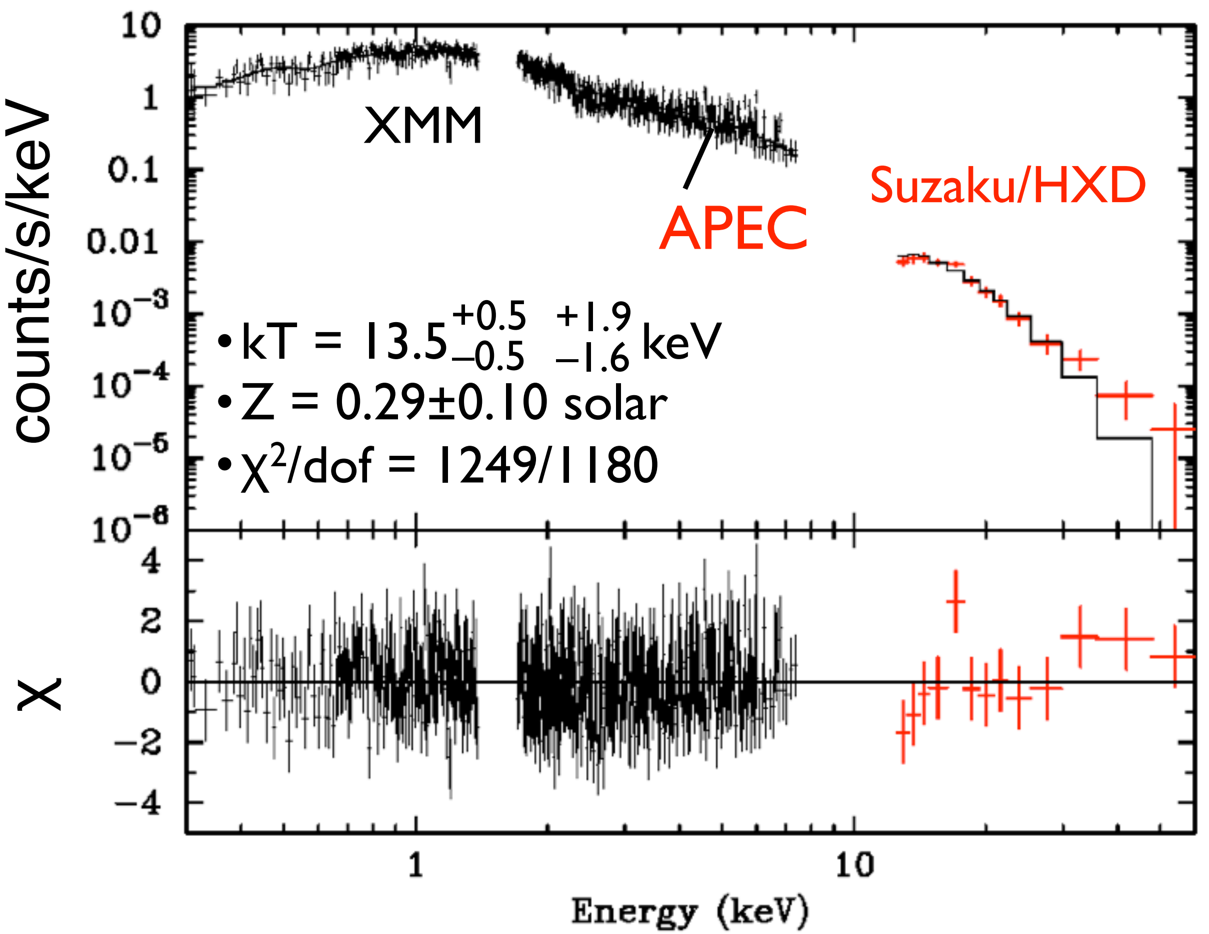
NXB, CXB subtracted
Point sources are negligible
NXB systematic error ~2%

>5σ significance

- 12–60 keV flux
  F = 1.52 ± 0.06 (± 0.28) x 10^{-11} erg/s/cm^2

XMM+HXD broad-band spectral analysis

✤ APEC thermal emission model

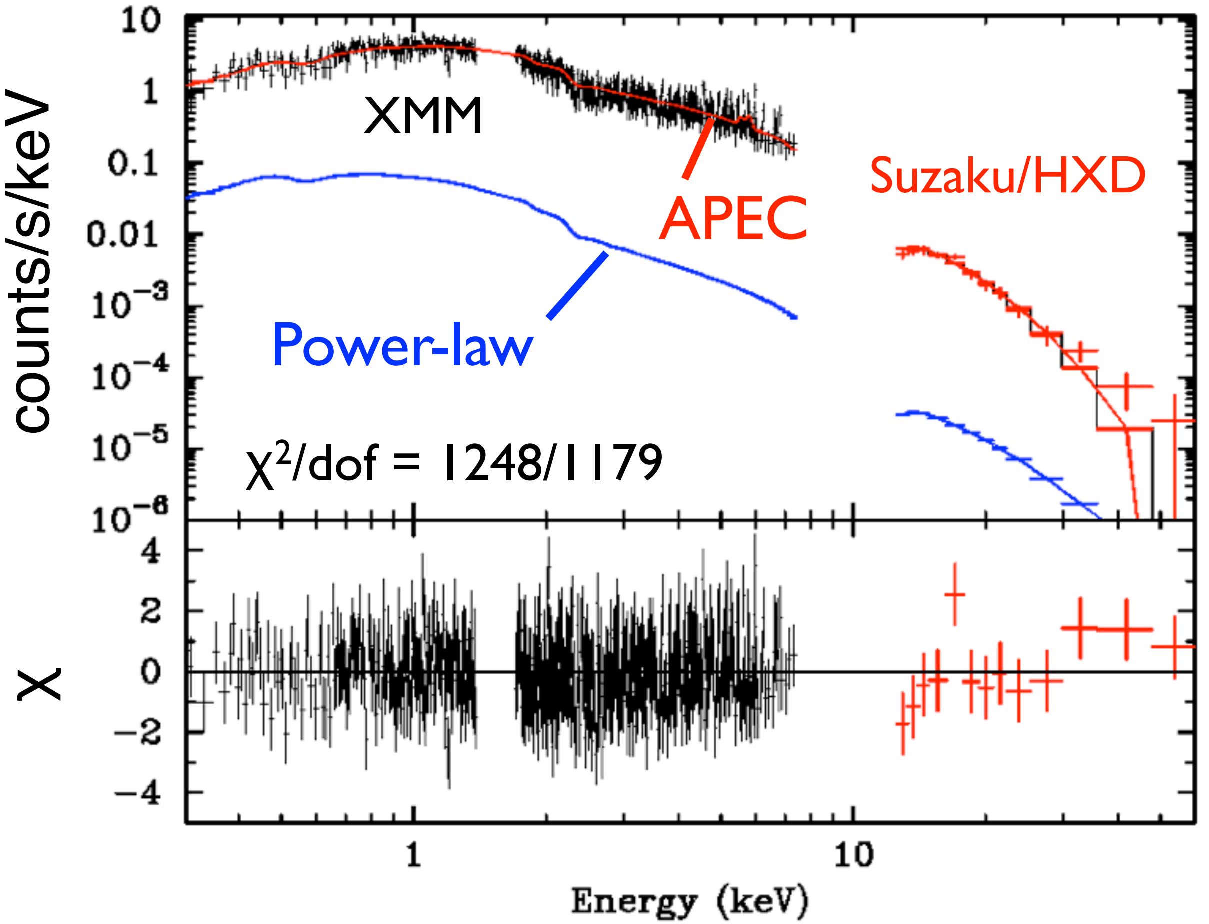


- 0.3~60 keV spectra can be fitted with a kT~14 keV thermal model

➡Hard X-ray emission is likely to be dominated by thermal emission

Constraint on non-thermal emission

✤ APEC + Power-law with Γ=2.18 (the same index in radio; Feretti+04)



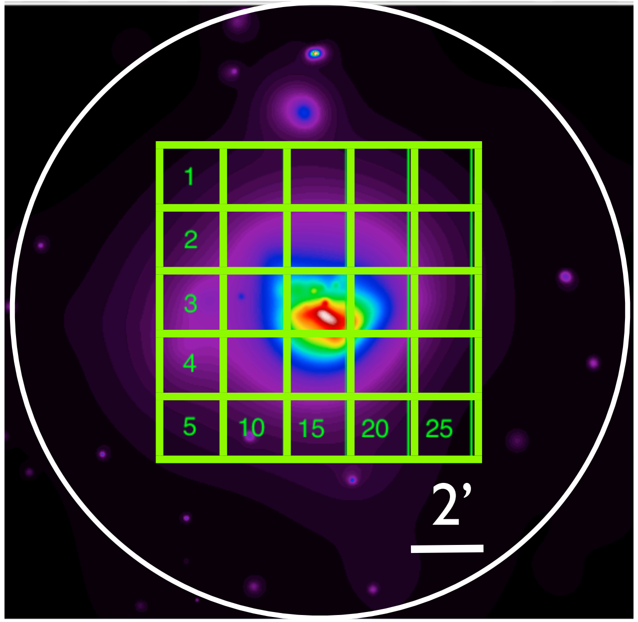
Free parameters
APEC: *kT*, *Z*, *norm*
Power-law: *norm*

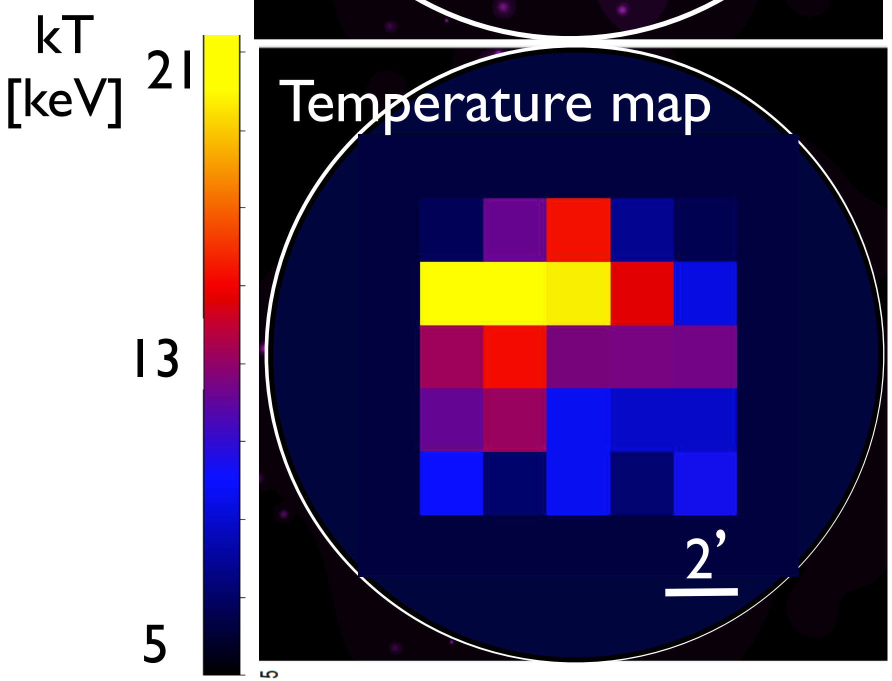
- No significant non-thermal emission in 12-60keV

$F_{NT} <$ 1.2 x 10^{-12} erg/s/cm^2 for Γ=2.18 (90% upper limit)

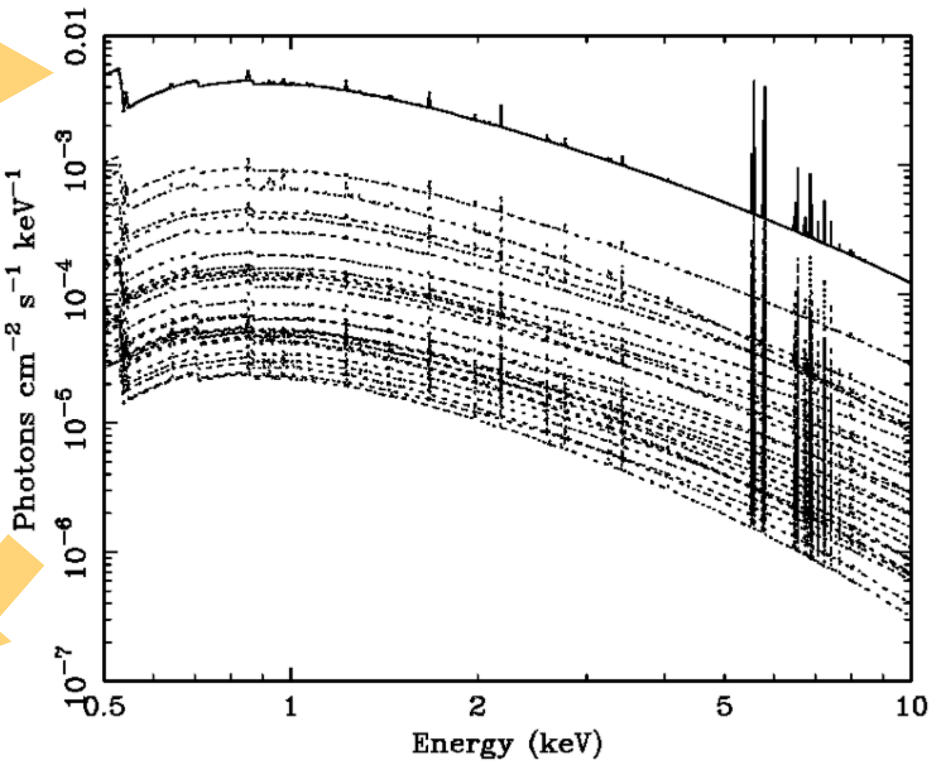
Multi-temperature modeling with XMM

✤ Use XMM spectra in 2'x2' grids to construct the Multi-T model





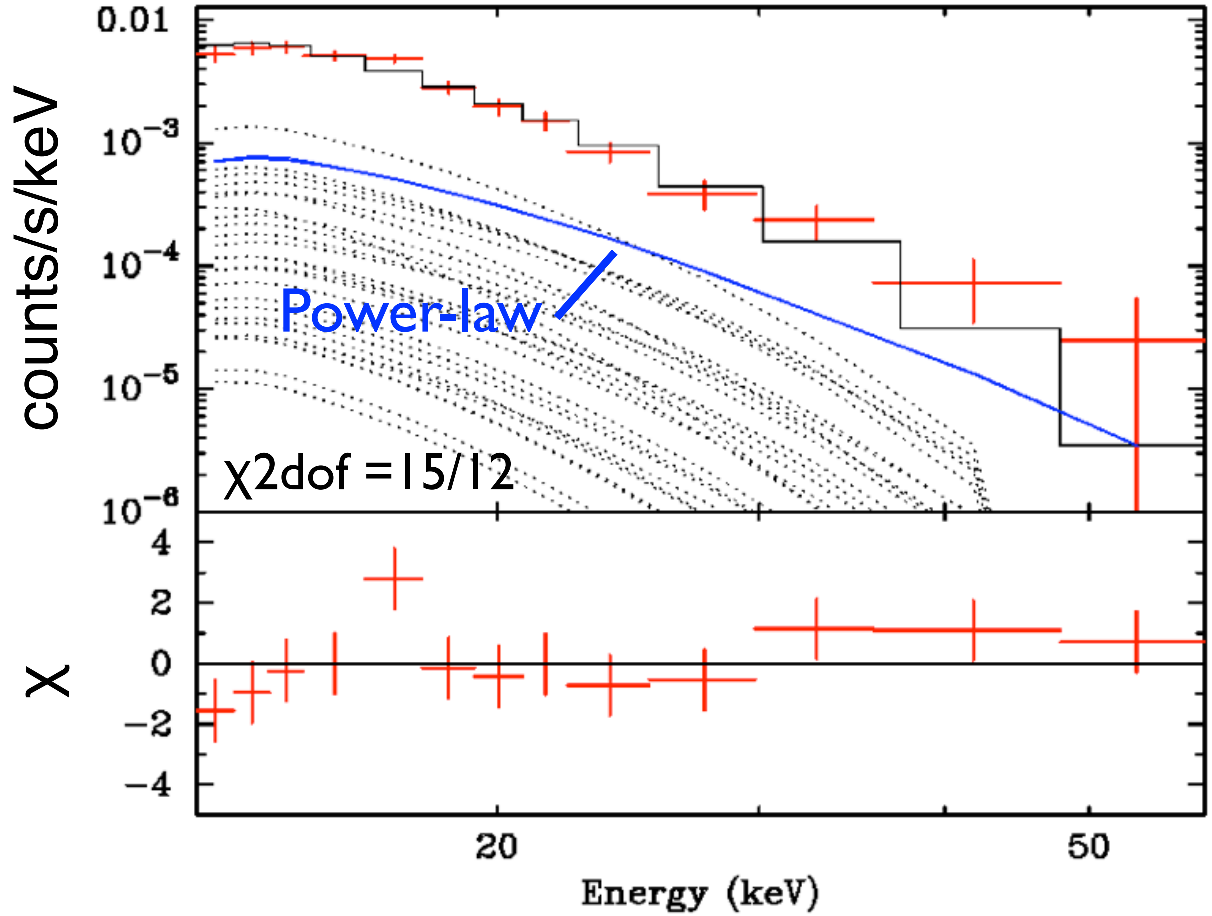
Multi-T model



Temperature of the NE "shock" region:
kT_{NE}~18 keV, L_{NE}~5x10^{44} erg/s

HXD spectral fitting with Multi-T + Power-law model

✤ Multi-T APEC + Power-law



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

- The 90% upper limit on the non-thermal emission

$F_{NT} < 9.4 \times 10^{-12}$ erg/s/cm^2 for Γ=2.18

Ota et al. in prep

A2163: Summary & Discussion

✤ Origin of hard X-ray emission from A2163

- Emission in the HXD band is well represented by the thermal models
- Very hot (~18 keV) gas in the NE shock contributes by ~15%

➡ The existence of high-temperature gas supports the scenario of recent ~0.5Gyr merger (Bourdin+11; Takizawa+99; see also Ota+08 for the case of RXJ1347)

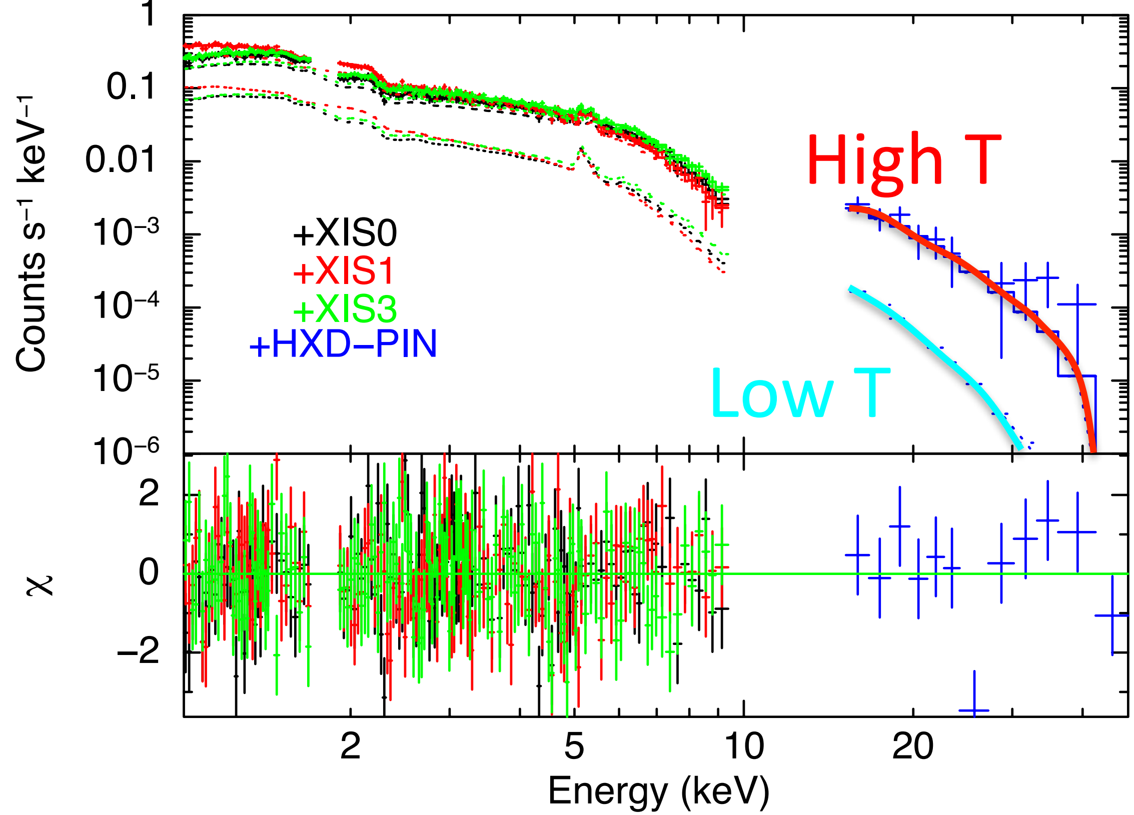
- We did not find any significant non-thermal hard X-ray emission

✤ Estimation of cluster magnetic field

- Using the relation $S_{IC}/S_{sync} = U_{CMB}/U_B$ & the radio flux S_{syn}=155mJy@1.4GHz,
  - S_{IC} < 0. 26 μJy @12 keV → B > 0.09 μG for Γ=2.18

The Bullet Cluster

Nagayoshi et al. in prep



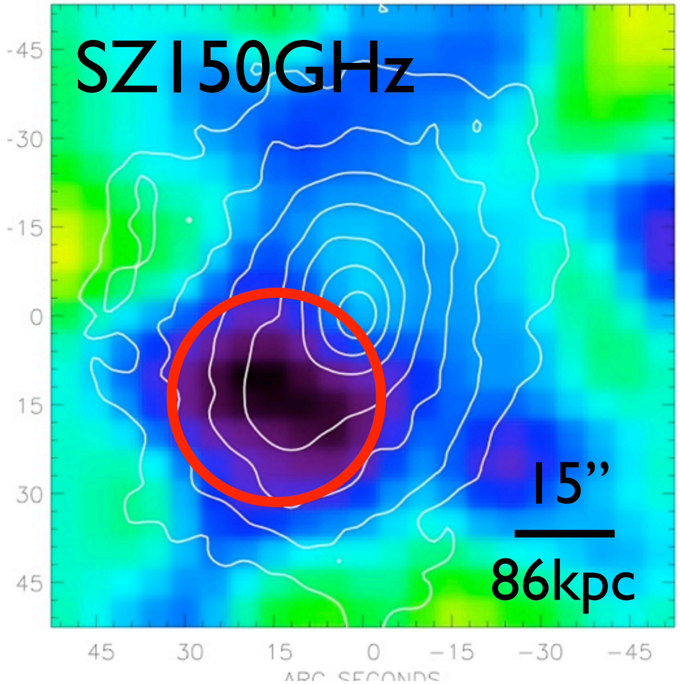
The Suzaku data is well fitted by 2-T model. Additional PL model does not improve the fit.
Non-thermal flux reported by *Swift* (Ajello +10) is not confirmed by *Suzaku*.

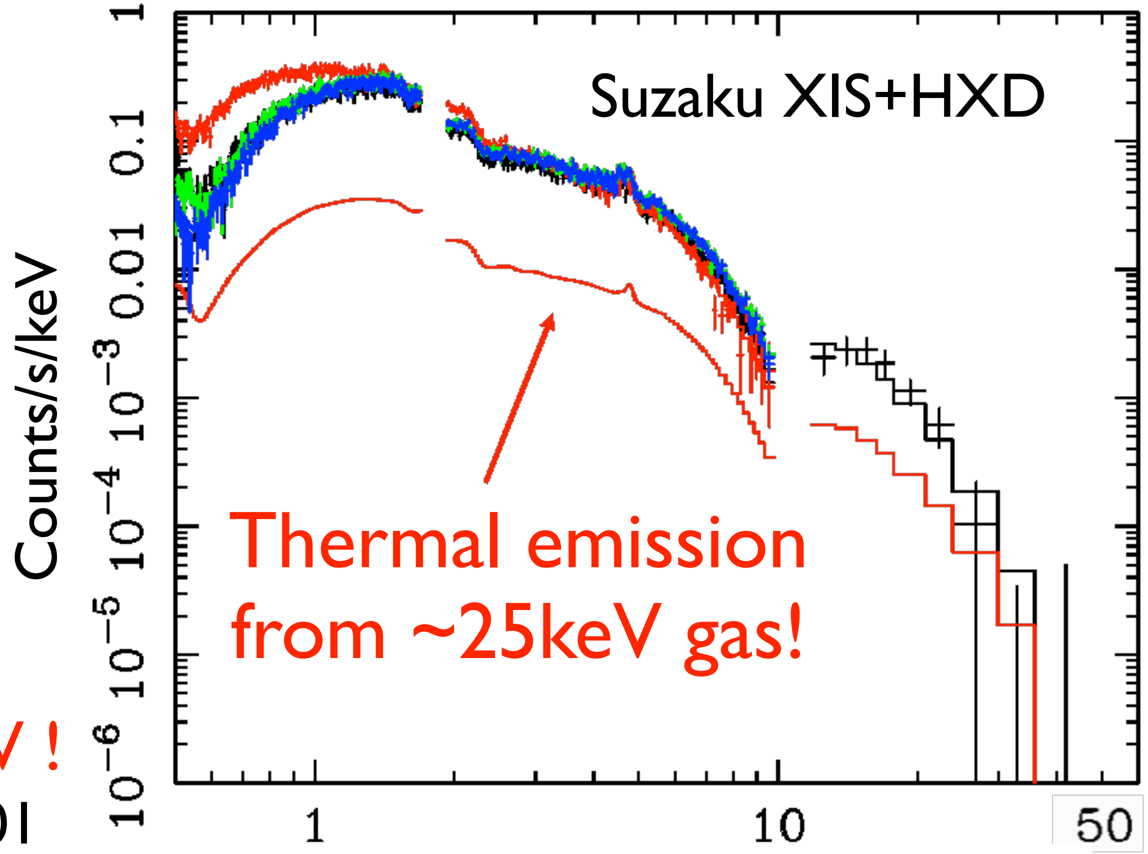
kT [keV]	Z [solar]	χ^2/dof
$13.3^{+0.5}_{-0.4}$	$0.27^{+0.04}_{-0.04}$	459.3/438
$7.2^{+3.4}_{-2.7}$ 17^{+7}_{-2}	$0.28^{+0.04}_{-0.04}$ ↑	450.8/436

RXJ1347+1147

✤ *The most X-ray luminous cluster*

Ota et al. 2008





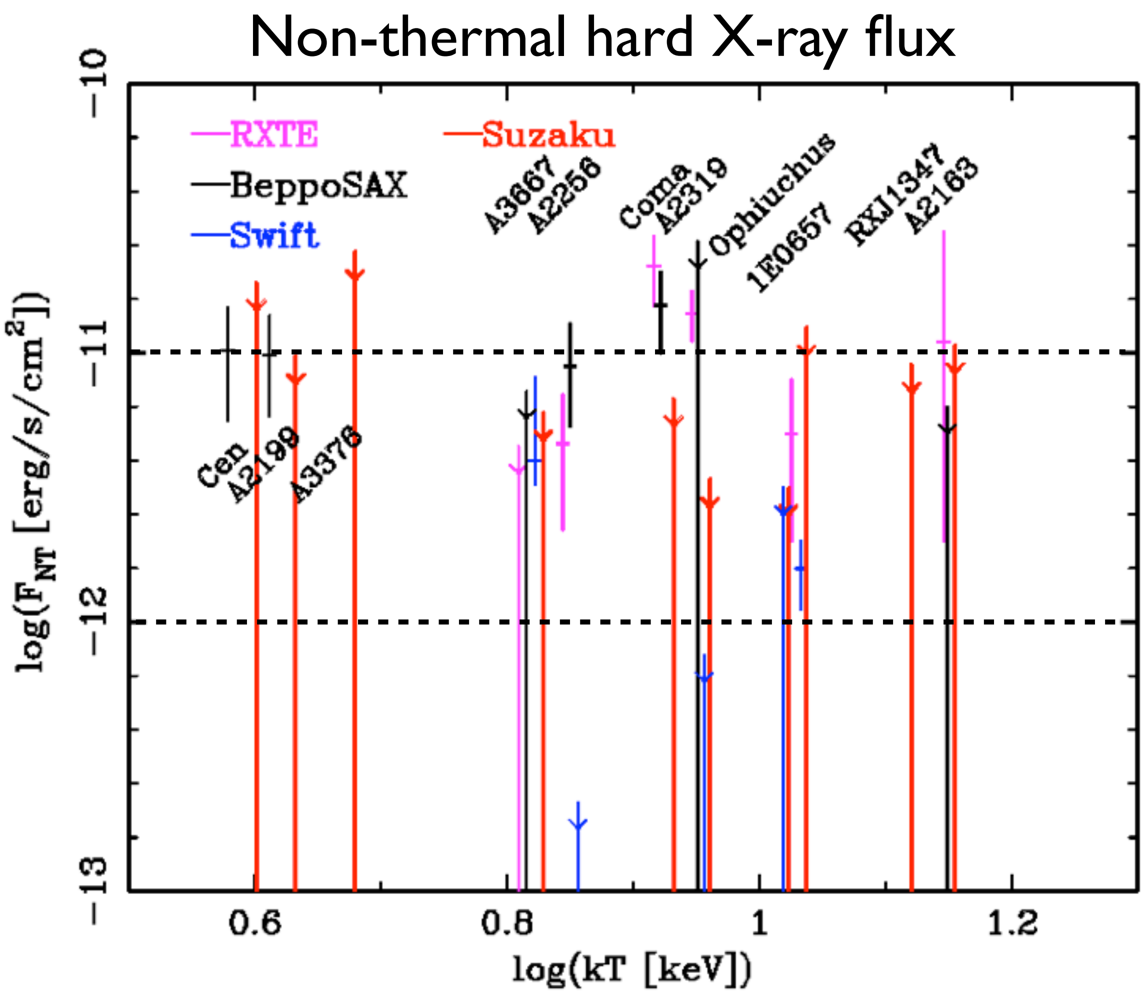
• SE clump kT_{ex} > 20keV !

Kitayama+04; Komatsu+01

✤ Hard X-ray emission is dominated by thermal emission from very hot thermal gas in the SE

→ Non-thermal X-ray emission is not significant < 8 x10^{-12} erg/s/cm^2

Comparison with other clusters



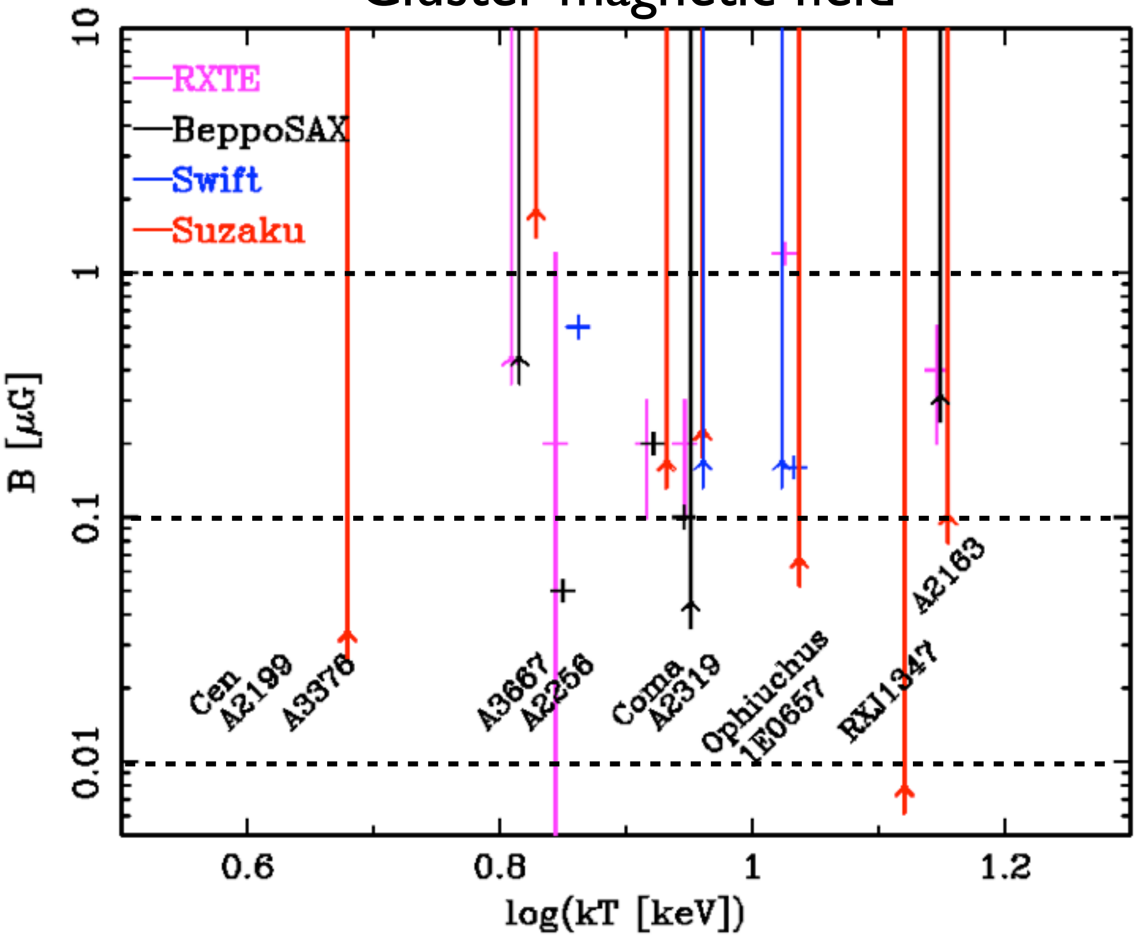
The upper limits on NT emission were reported in ~10 clusters with *Suzaku*

→ *No clear scaling relation is seen*

RXTE & SAX (Rephaeli+08 review), Swift (Ajello et al. 09,10; Wik+11; See also Wik+12),
Suzaku (Kitaguchi+07; Kawaharada+10; Kawano+09; Wik+09; Sugawara+09; Nakazawa+09; Fujita+08; Ota+08)

Comparison with other clusters

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; Wik+11; See also Wik+12),
Suzaku (Kitaguchi+07; Kawaharada+10; Kawano+09; Wik+09; Sugawara+09; Nakazawa+09; Fujita+08; Ota+08)

Summary

- ✤ To search for non-thermal emission, we observed hot clusters with radio halo, A2163, Bullet, & RXJ1347, with Suzaku.
  - The Suzaku/HXD spectra are well represented by thermal models
  - Very hot (~20 keV) thermal gas contributes to the hard X-ray emission
  - ➡ *determination of thermal component to high accuracy is indispensable!*
  - No significant non-thermal emission is detected

- ✤ Present limits on the non-thermal hard X-ray emission and magnetic field
  - The upper limits on NT emission were obtained in ~10 clusters with *Suzaku*
  - No clear scaling relations (L_{NT}-T, B-T) are seen so far

Future prospects

✤ What's next?

- Application of this method to other clusters observed with *Suzaku*

- ASTRO-H!
  - Hard X-ray Imagers will enable more accurate measurement of high-T thermal component & identification of shock region to get higher S/N

  → detection of IC to B ~ 1μG level

  - High spectral resolution of micro-calorimeter will enable measurements of bulk/turbulent gas motions

→ *Total view of the cluster dynamical evolution*


Thank you for your attention!