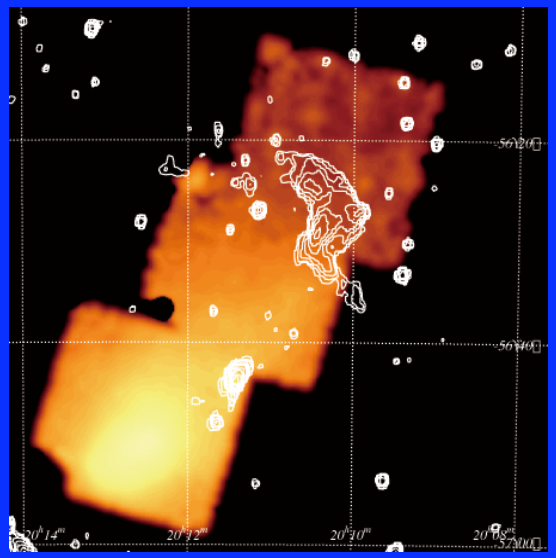
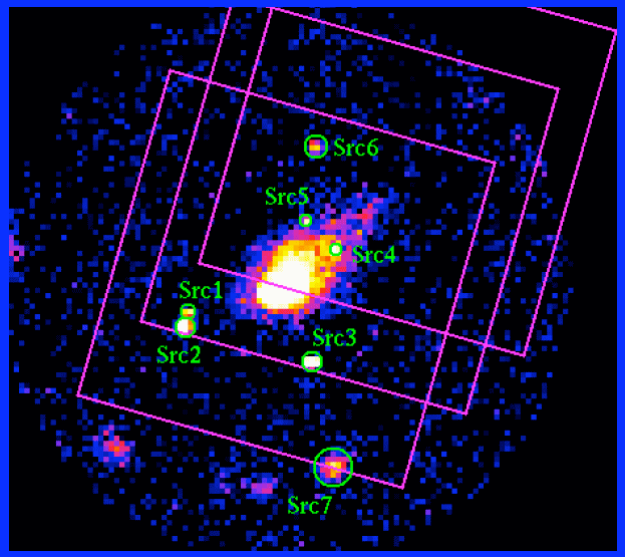
Thermal and Nonthermal Emission at Large Radii in the Merging Cluster Abell 3667



XIS images and radio contours

Craig Sarazin

University of Virginia



PIN FOVs on Rosat Image

Collaborators

Kazuhiro Nakazawa (Univ. Tokyo) ** SEE POSTER **

Daniel R. Wik (Univ. Virginia) ** SEE POSTER ON COMA **

Alexis Finoguenov (MPE, Univ. Maryland Balt. County)

Madoka Kawaharada (RIKEN)

Kazuo Makishima, Takao Kitaguchi, Sho Okuyama (U. Tokyo)

Naomi Kawano, Yasushi Fukazawa (Hiroshima Univ.)

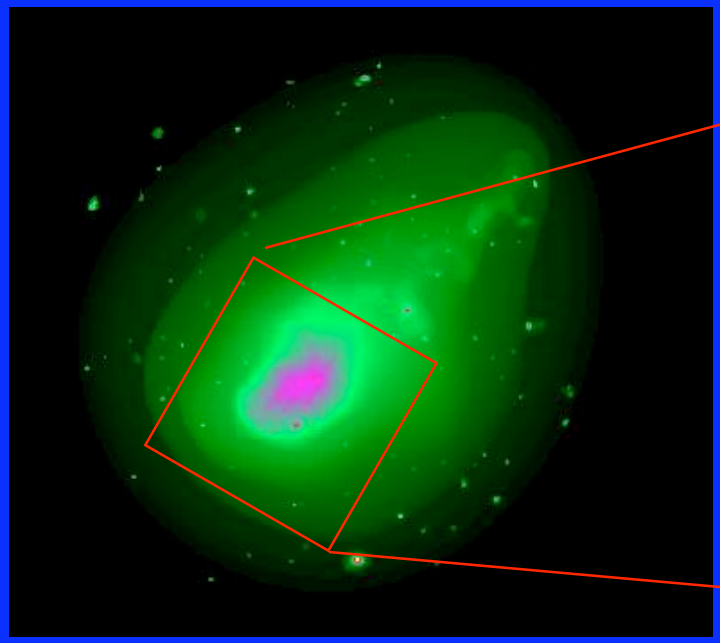
Susumu Inoue (NAOJ)

Motokazu Takizawa (Yamagata Univ.)

Tracy E. Clarke (NRL, Interferometrics)

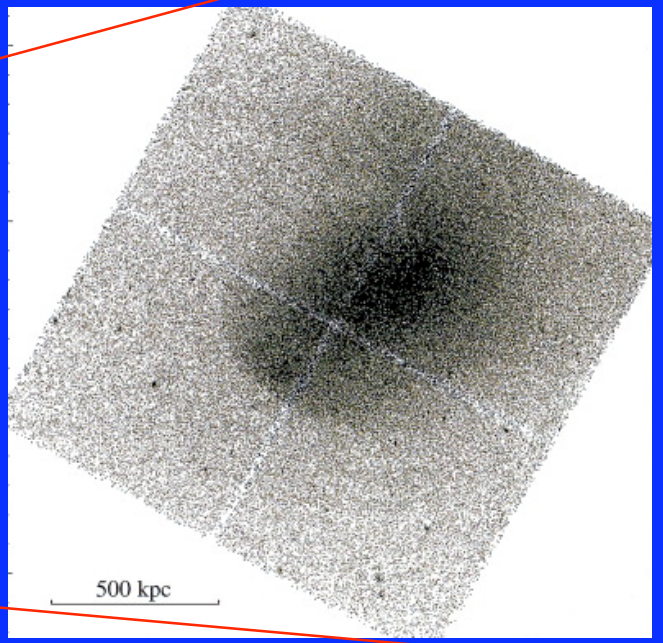
Abell 3667 – Merging Cluster

XMM



Briel et al. 2004; this work

Chandra



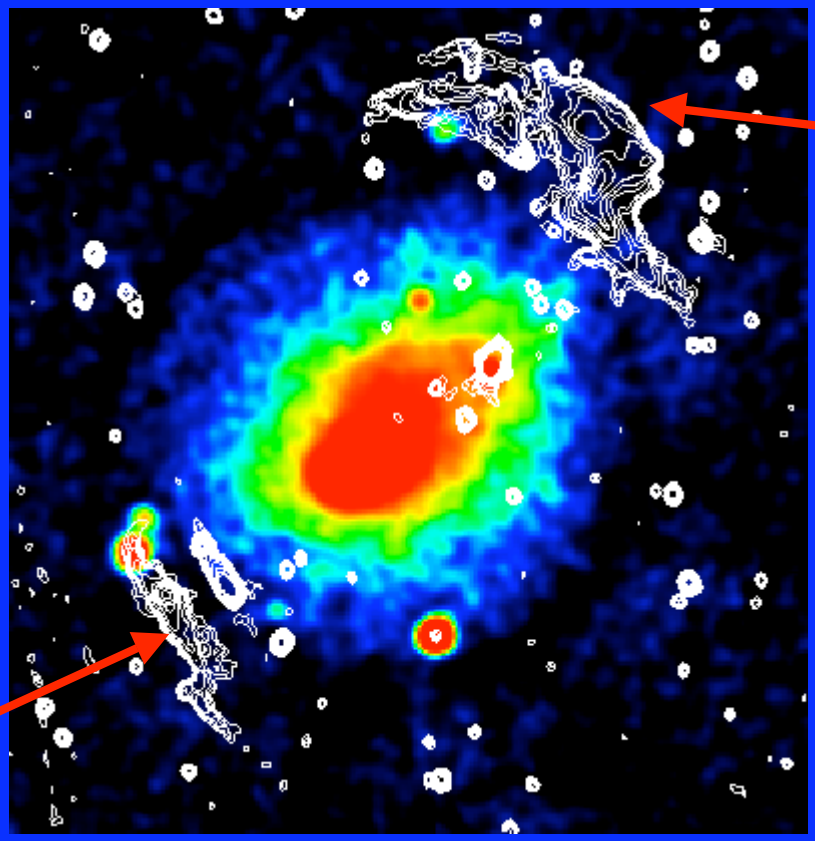
Vikhlinin et al. 2000

- Major merger along NW-SE axis
- z = 0.0552

- Cold front, remnant of cool core of one subcluster

Double Radio Relics

ROSAT (color), radio contours



NW Radio Relic

SE Radio Relic

Röttgering et al. 1997

Cluster Radio Relics and Halos

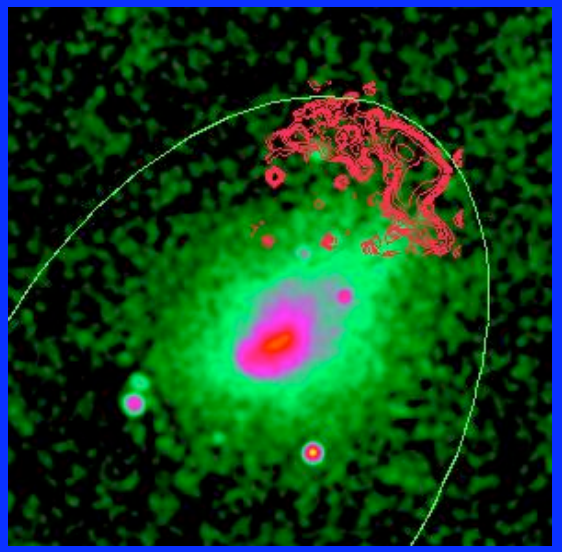
- Diffuse, cluster-scale radio emission
- No associated radio galaxy
- Steep radio spectra
- Only in merging clusters
- Cluster radio halos: central and symmetric
- Cluster radio relics: peripheral and elongated
  - Due to merger shock (re)acceleration (?)
- Should also emit hard X-rays by Inverse Compton scattering of CMB
- HXR IC and radio synchrotron _ determine B and energy in relativistic electrons

NW Radio Relic in Abell 3667

- Brightest diffuse cluster source

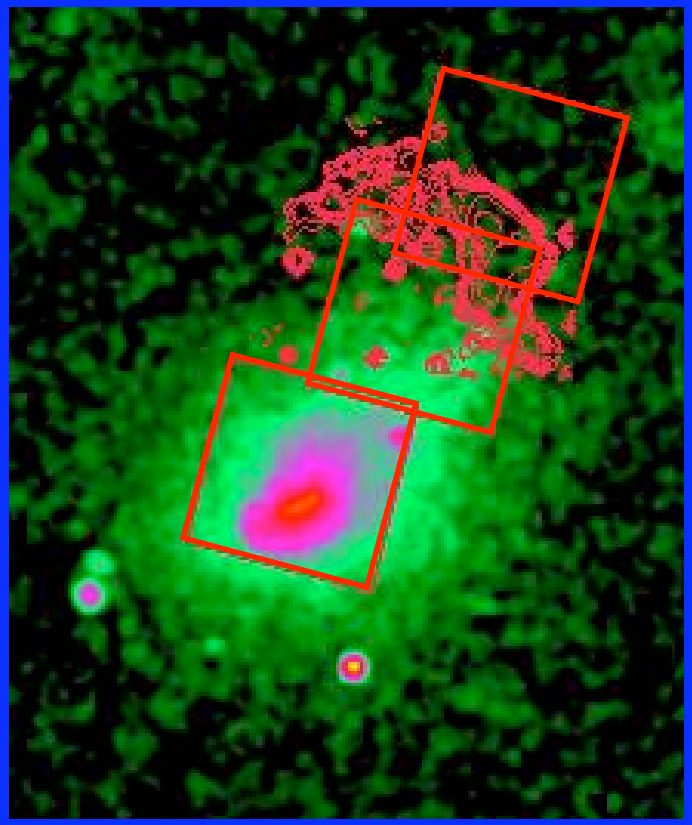
  3.7 Jy at 20 cm (Johnston-Hollitt 2004)
- Located at large projected radius ~2.2 Mpc _ expect weak B field
- Should be a very strong IC HXR source!
- Steep radio spectra, α =1.1

  Γ = 2.1 at 20 cm
- Sharp outer edge, flatter spectrum, B parallel to outer edge
- Merger Shock at outer edge !?

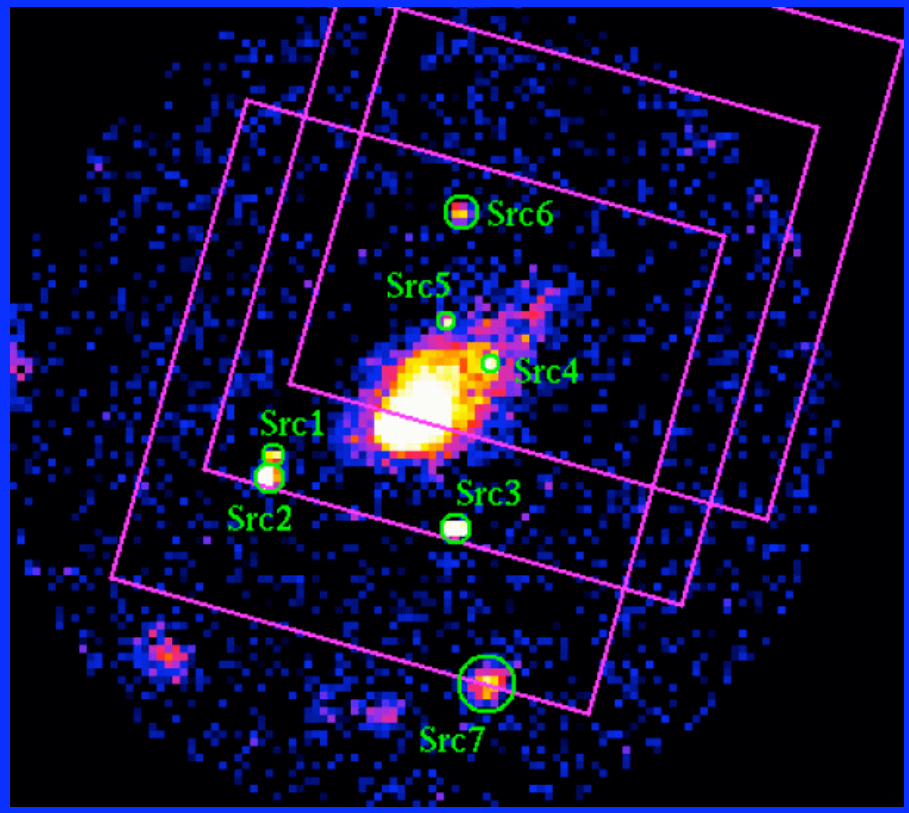


Sarazin et al. 2007

3 Suzaku Observations



XIS FOVs

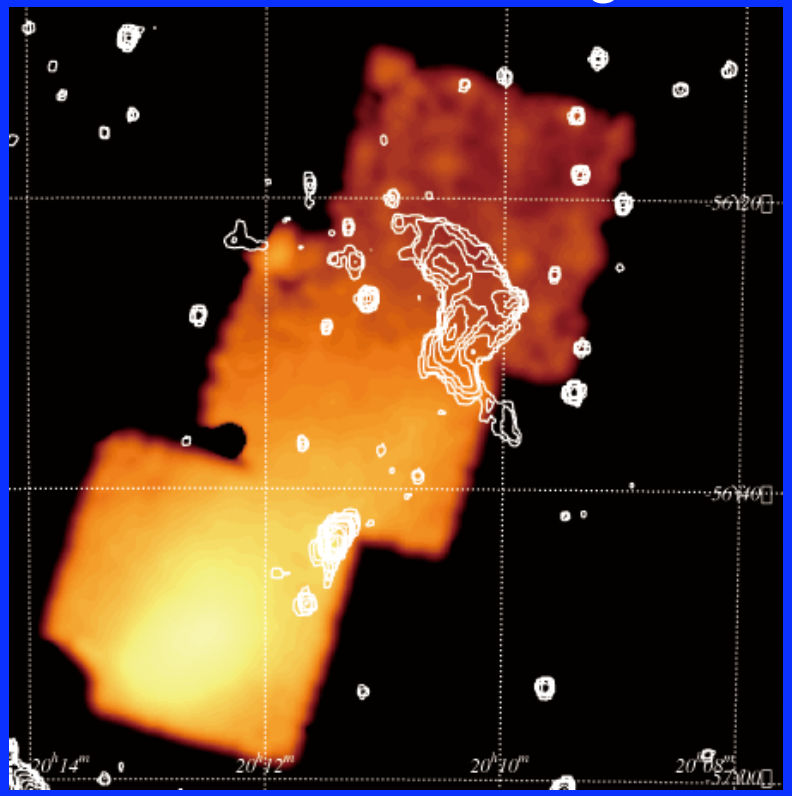


HXD/PIN FOVs

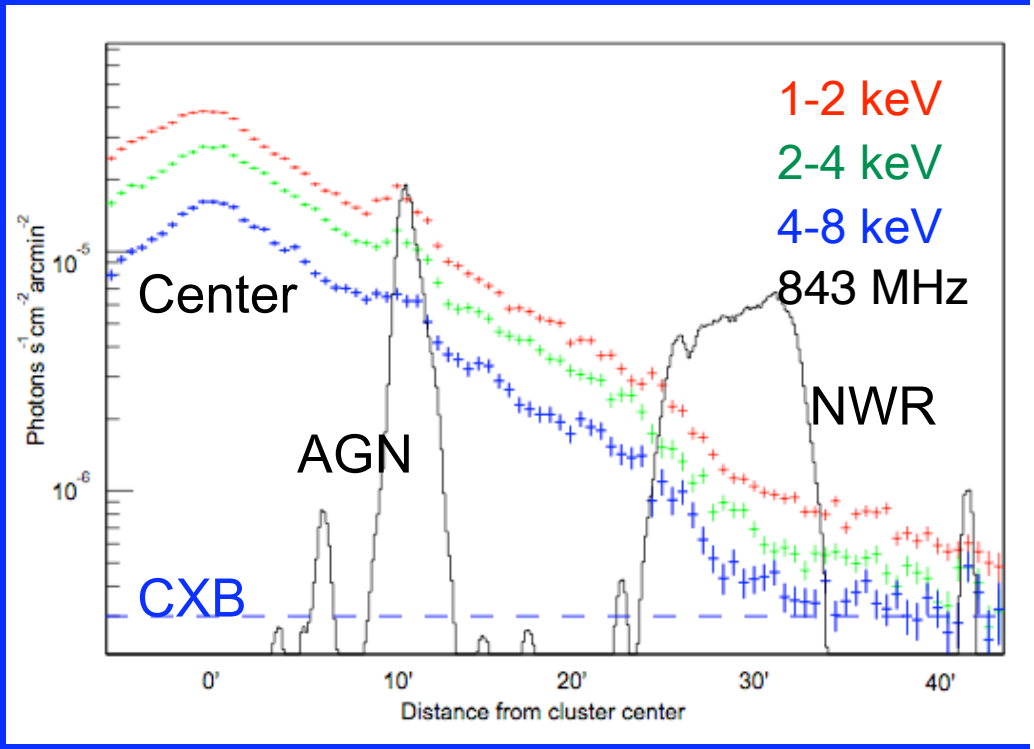
- 3 observations, 3-7 May 2006
- Exposures of ~20, ~17, ~78 ksec

Intracluster Gas at Large Radii

XIS 1-4 keV image



XIS and Radio Surface Brightness

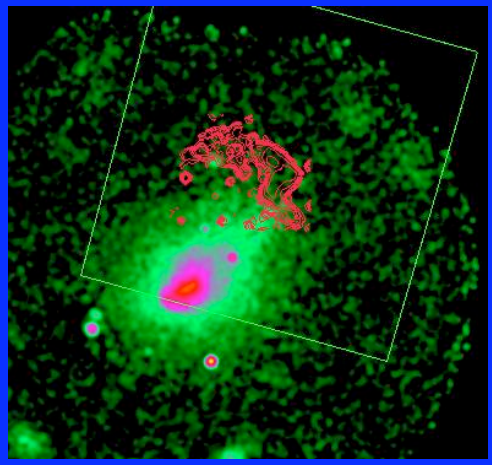


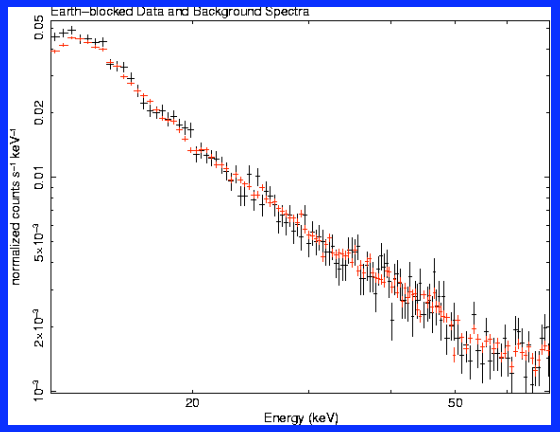
→ Hot gas out to ≈ 42 arcmin = 2.6 Mpc ≈ virial radius

(but, along merger axis of merging cluster?)

HXD/PIN Observation of NW Radio Relic

- 73.5 ksec exposure in PIN
- NXB model agrees well with Earth-blocked flux (2.1%) and spectrum
- Model CXB
- Model AGN point srcs
- Relic at large projected radius _ thermal emission weak but still very important
- Model thermal based on XIS and/or XMM (see also Nakazawa poster)

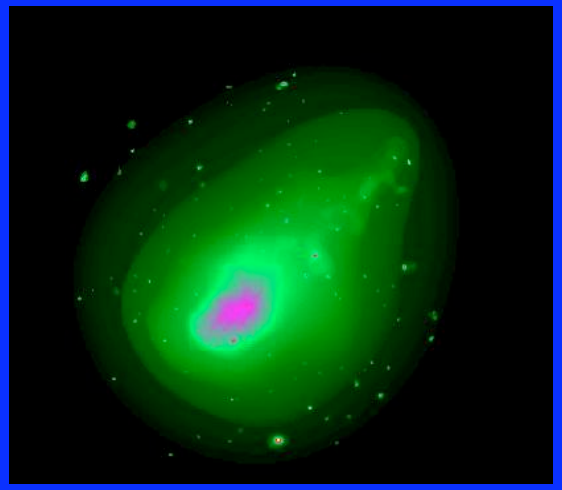




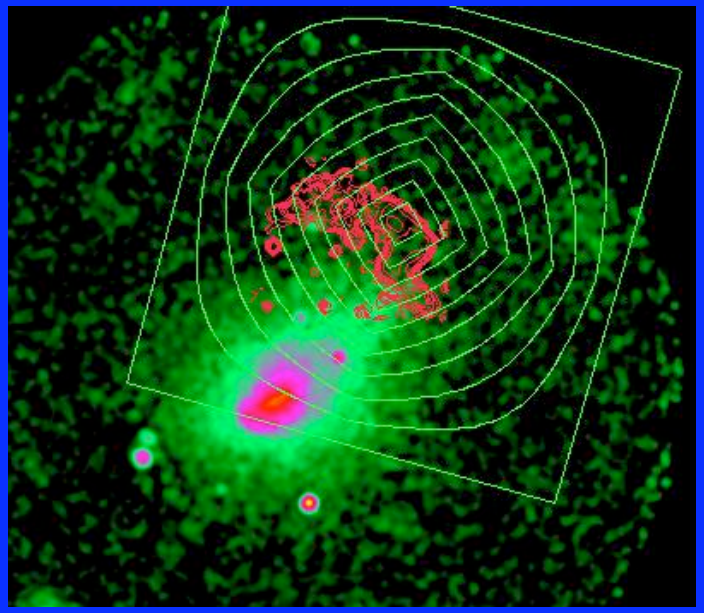
Earth-blocked data vs. NXB model

Joint XMM - PIN Analysis

- Mosaic of XMM/Newton exposures to cover cluster
  (Briel et al. 2004; this work)
- Extract XMM spectra in regions of ~constant PIN area
- Weight by PIN area, combine
- Gives thermal spectrum as seen by PIN, correct shape and flux
- Fit PIN and XMM jointly

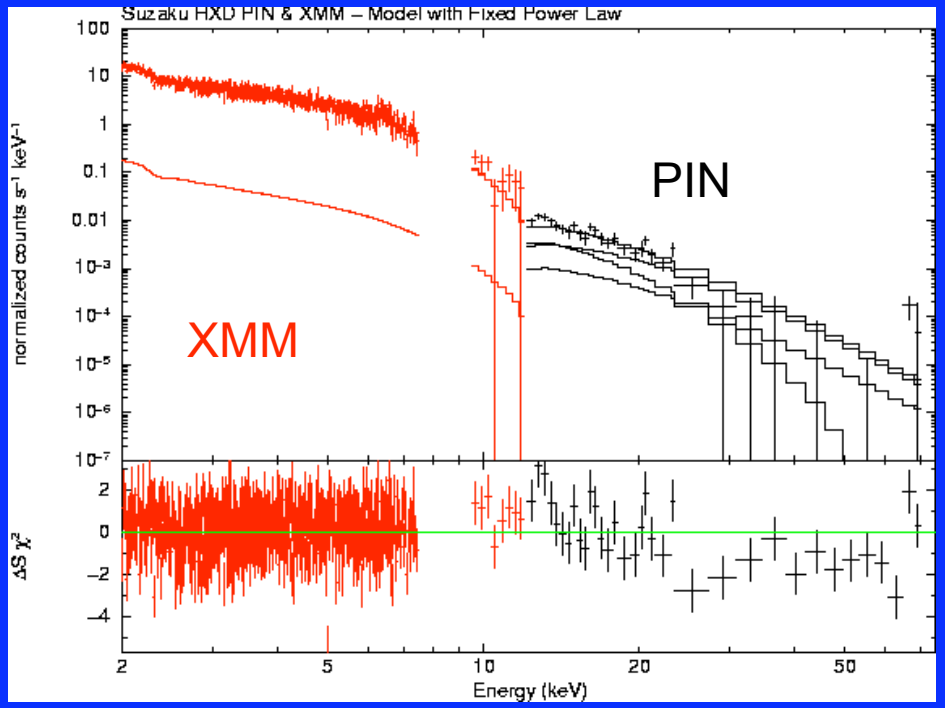


XMM Image from mosaic



Hard X-rays: PIN-XMM Results

- Detection of excess HXR
- Best-fit power-law $\Gamma = 3.2$, much steeper than radio
  _ really thermal?
- Assuming power-law with
  $\Gamma = 2.1$ (radio)
  $F_X = 3.4 \times 10^{-12}$ ergs/cm^2/s
  12-70 keV
- Doesn't include systematic errors!!



Hard X-rays: PIN-XMM Results (Cont.)

Systematic Errors:

- NXB: ±5%
- CXB: ±20% (HXR flux, cosmic variance)
- XMM/PIN calibration: ±25%

$F_X < 7.8 \times 10^{-12}$ ergs/cm^2/s 12-70 keV

PIN+XIS analysis (** Nakazawa poster **)

$F_X < 9.4 \times 10^{-12}$ ergs/cm^2/s 12-70 keV

BeppoSAX PDS

$F_X < 9.3 \times 10^{-12}$ ergs/cm^2/s 12-70 keV

(Nevalainen et al. 2004)

Lower Limit on Magnetic Field

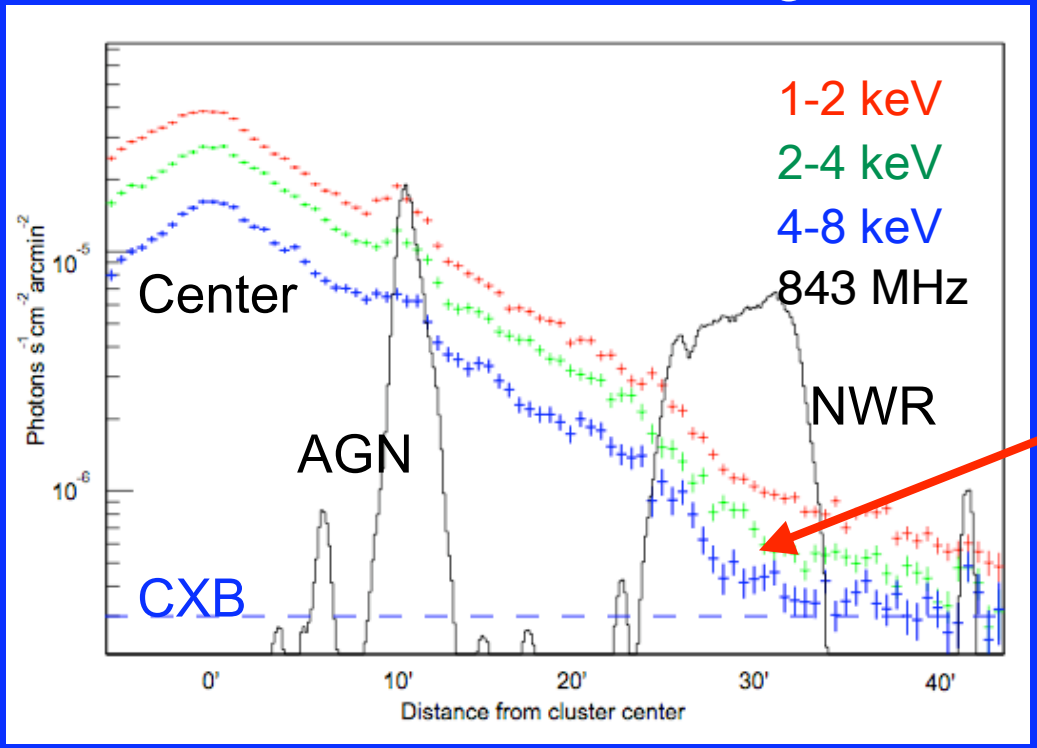
- Radio _ (energy in relativistic electrons) x (magnetic energy density)
- IC _ (energy in relativistic electrons) x (CMB energy density)
- Detect both _ E(rel. e) & B
- Upper limit on IC _ upper limit on E(rel. e).
  _ lower limit on B

→ E(rel. e) < 9×10^{61} ergs

B > 0.5 μG

Tighter Limit from XIS

XIS and Radio Surface Brightness



Hard X-rays

No evidence for excess hard X-rays in XIS image or spectrum on radio relic

Tighter Limit from XIS (Cont.)

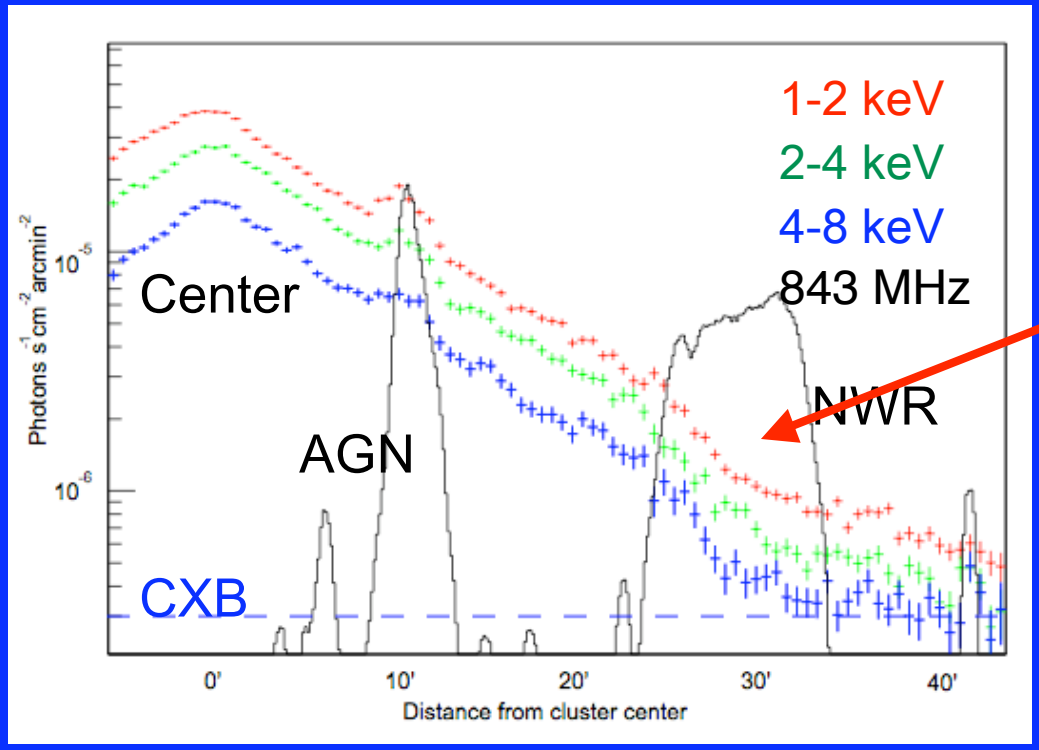
- Assume same spectral index at lower energies
- Assume XIS = thermal + IC
- Assume IC follows radio image
- Apply results to all of relic

→ $F_X < 2.6 \times 10^{-13}$ ergs/cm^2/s 10 - 40 keV

→ B > 2.2 μG, very strong magnetic field at projected radius of ~2 Mpc !!

Some previous evidence for a strong B in relic from Faraday rotation (Johnston-Hollitt 2004).

Evidence for Nonthermal Pressure of Relic



Soft X-rays: dip

X-ray/radio anticorrelation

Significant nonthermal pressure support?

Typical, or just due to merger and/or relic?

Component	ICM	B	Rel-e
P (eV/cm^3)	~1.2	> 0.1	< 0.4

Conclusions – Abell 3667

- ICM extends out to ≈ 2.6 Mpc ≈ virial radius
- PIN has hard excess, but may be thermal, and < systematic uncertainty
  - $F_X < 7.8 \times 10^{-12}$ ergs/cm^2/s 12-70 keV
  - E(rel. e) < 9×10^{61} ergs
  - B > 0.5 μG
- No IC in XIS image or spectra
  - $F_X < 2.6 \times 10^{-13}$ ergs/cm^2/s 10 - 40 keV
  - B > 2.2 μG, very strong B at 2 Mpc
- Significant nonthermal pressure support in radio relic?