

Two-phase nature of the ICM of the Centaurus cluster

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Introduction

Recent issues about the cluster center

Central cool component can be understood by Cooling Flow ? → **NO**

Heating source and mechanism ?

Temperature structure of the ICM (Intra-Cluster Medium) ?

single-valued function of the radius? “Single-phase (1P)”

co-existence of hot and cool plasmas? “Two-phase (2P)” *cf.* ASCA

the Centaurus cluster ($z = 0.010$)

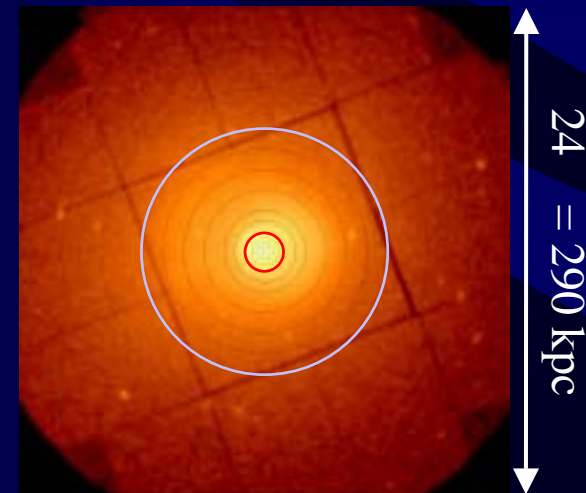
Outstanding central cool emission

Representative cluster of “ASCA picture”

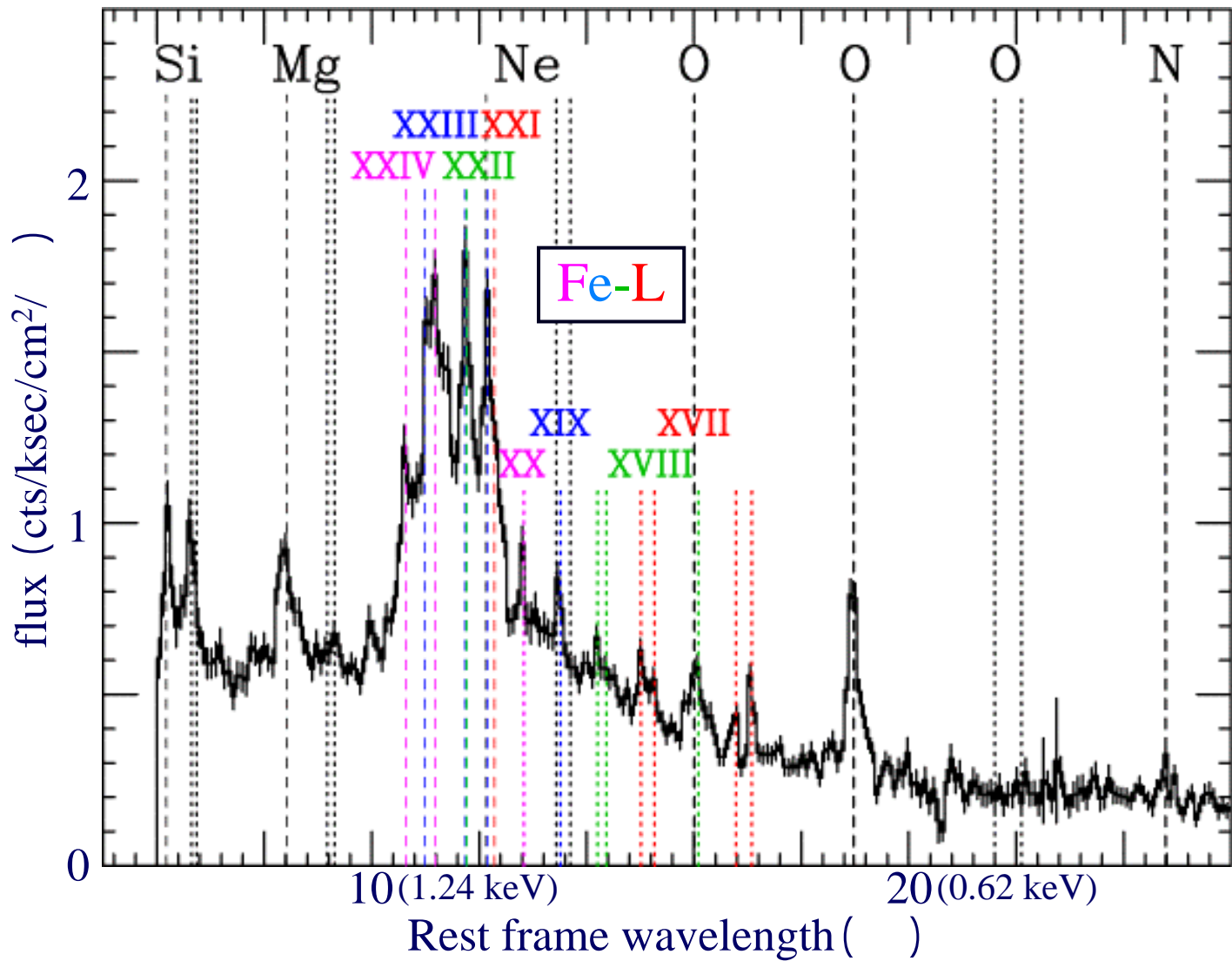
Fukazawa et al. (1994), Ikebe et al. (1999)

{ at very center ($r < 1' = 12 \text{ kpc}$) ... RGS
near center ($r < 12'$) ... EPIC
cf. periphery ($r > 6'$) ... nearly isothermal ($\sim 4 \text{ keV}$)

XMM Observation;
January 2002, $\sim 40 \text{ ksec}$



RGS diagnostics of the center ($< 1' = 12$ kpc)



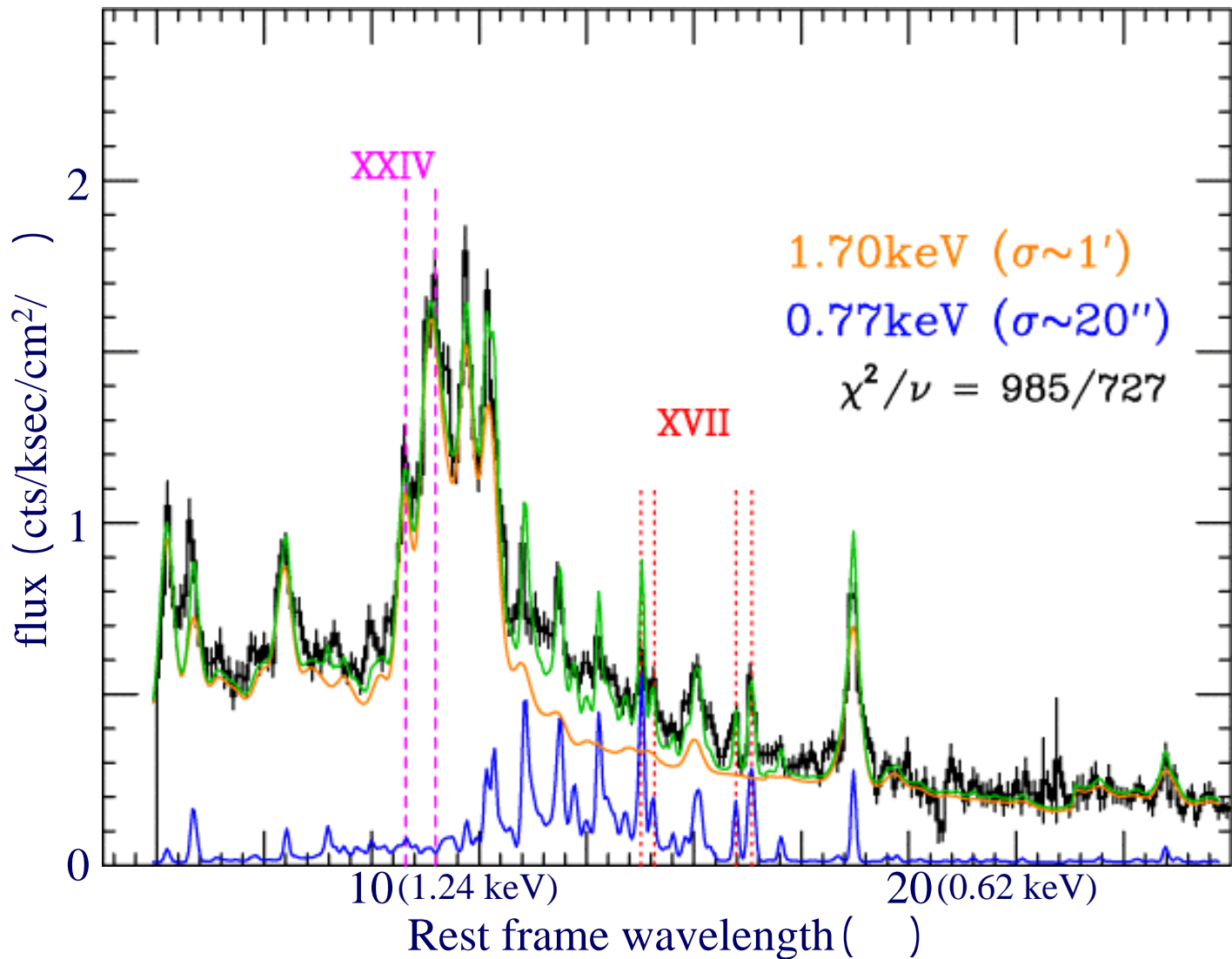
Fe-L lines

XVII ~ XXIV

All states are seen

→ two or multi kT

RGS diagnostics of the center ($< 1' = 12$ kpc)



Fe-L lines

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All states are seen

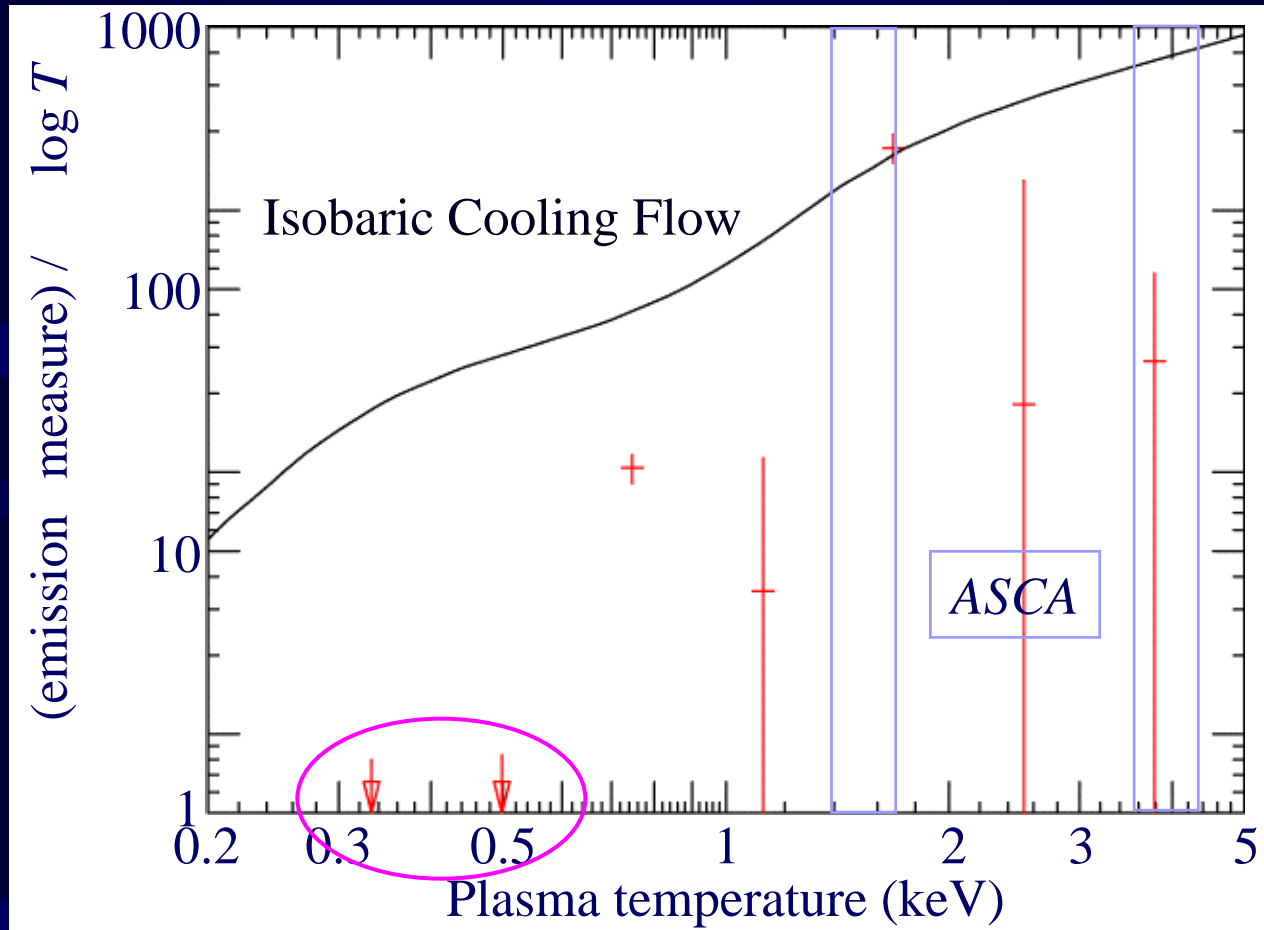
→ two or multi kT

Two temperature plasmas ($kT \sim 1.7 + 0.8$ keV)
can reproduce the data reasonably

Differential emission measure analysis

multi components fit ($T_i / T_{i+1} = 1.5$) *cf.* Tamura et al. 2003

determine T_{MAX} and each normalization

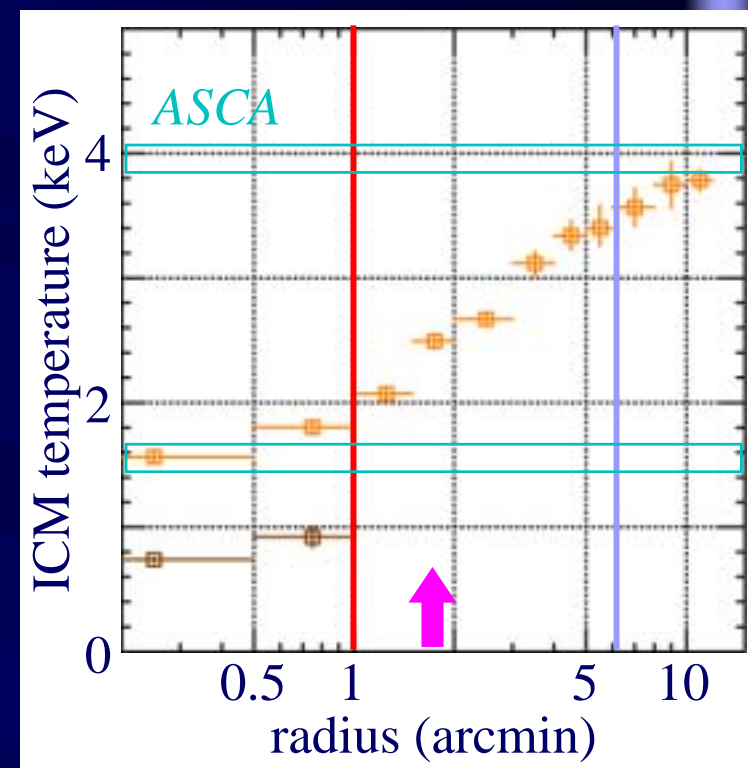
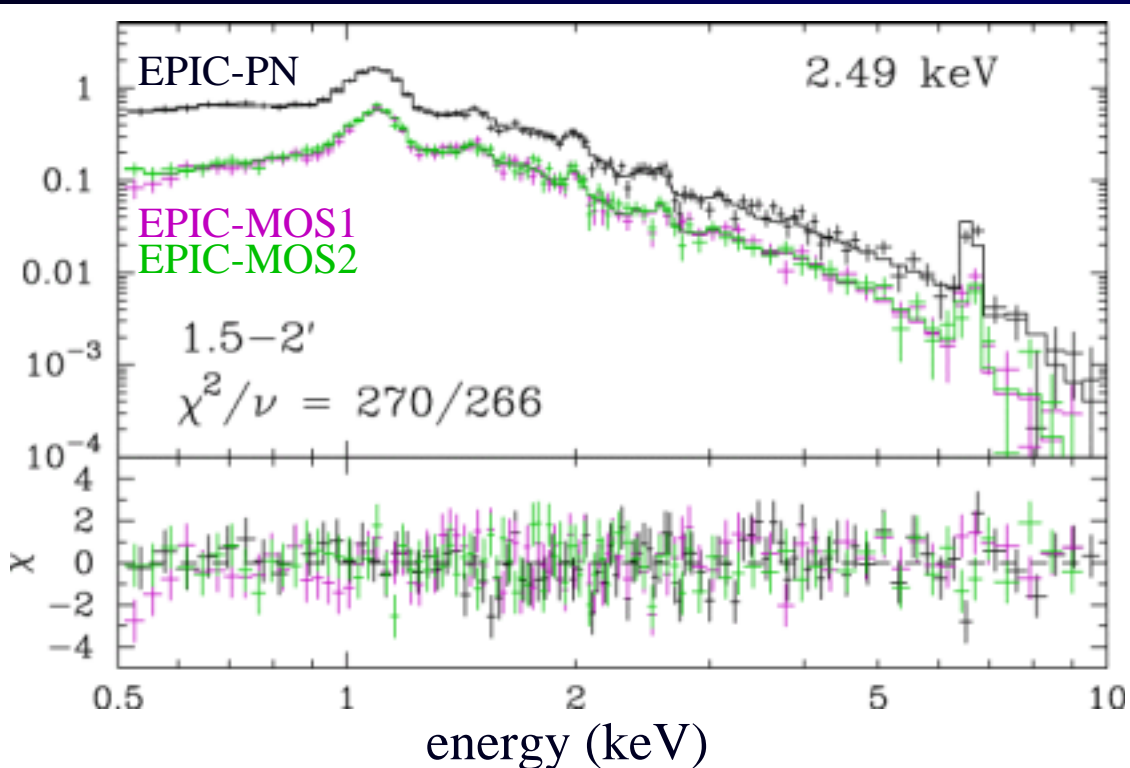


Three characteristic temperatures (~ 4 keV, ~ 1.8 keV, ~ 0.7 keV)

Very cool plasma (< 0.5 keV) is not significant

Test of Single-phase (1P) picture

Analysis of deprojected spectra



generally reproduce the spectrum of each shell

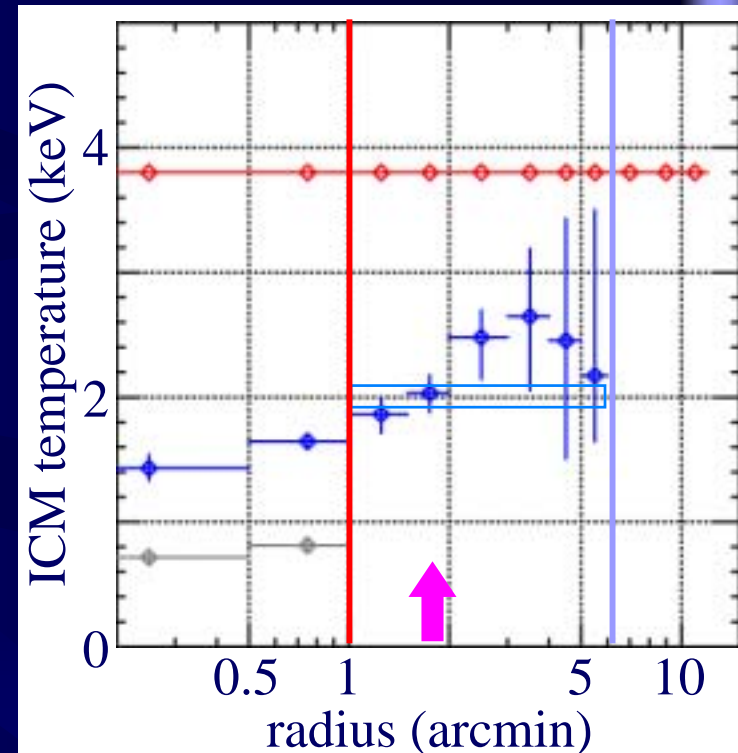
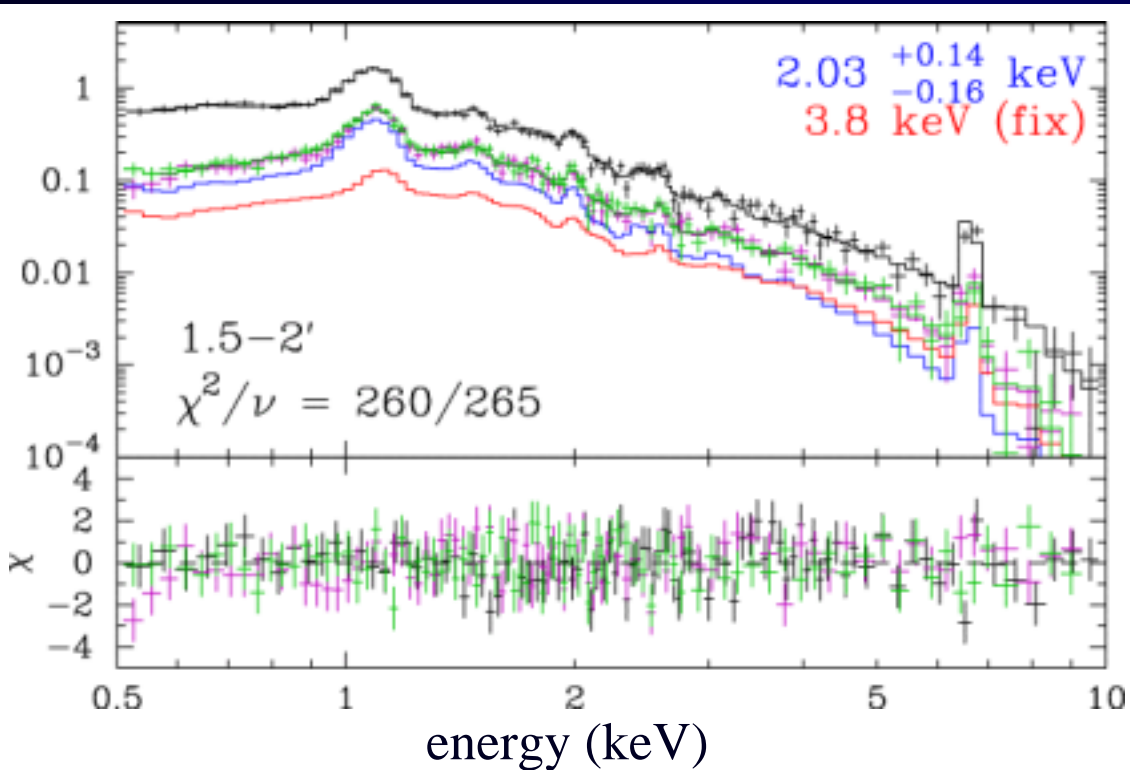
Characteristic kT ... consistent with ASCA

kT decreases 3.8 keV ($r > 6'$) \rightarrow 2 keV ($r = 1'$)

~ 0.7 keV component exists at the very center (*cf.* RGS)

Test of Two-phase (2P) picture

kT_{hot} is fixed at 3.8 keV (= periphery)



2P model can reproduce the data as well as 1P

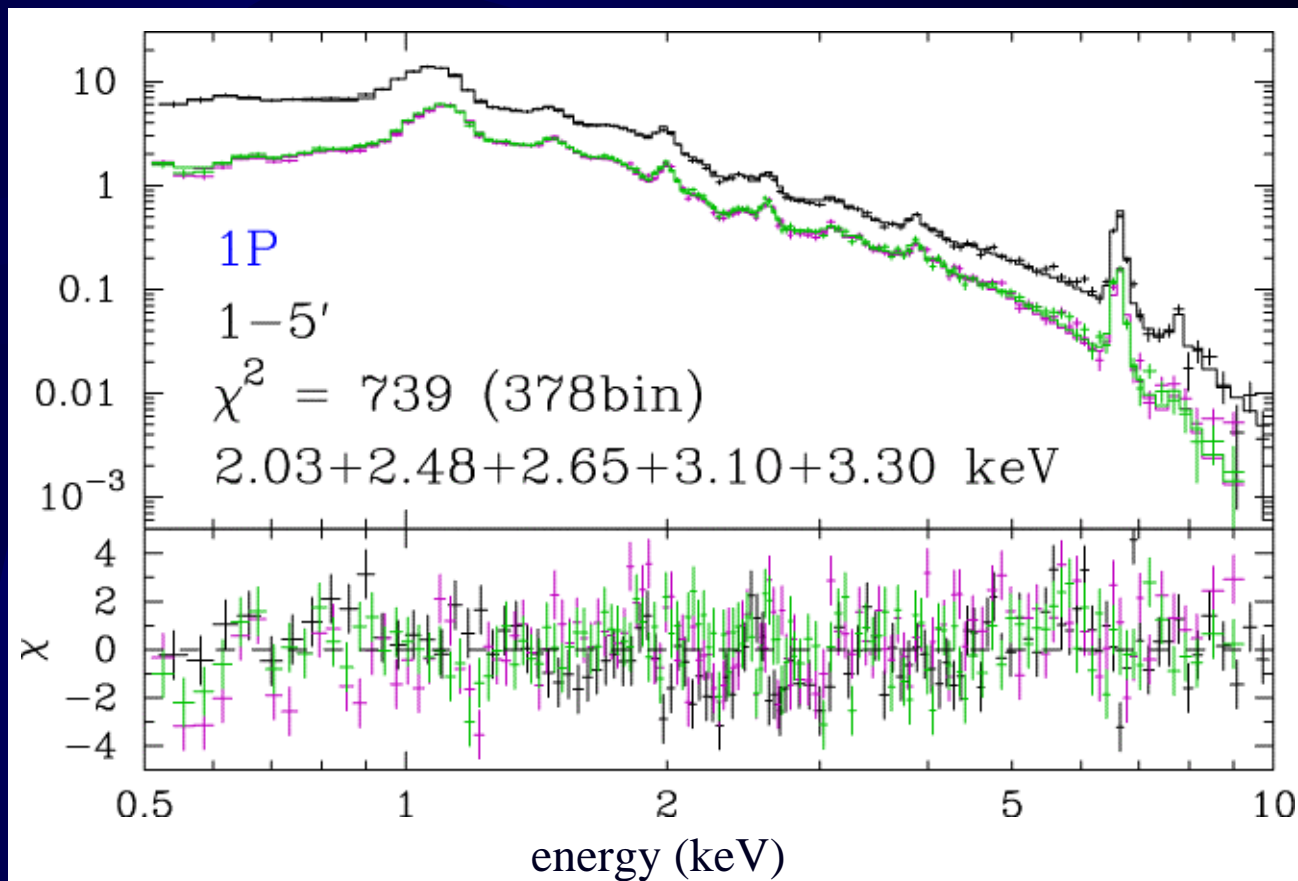
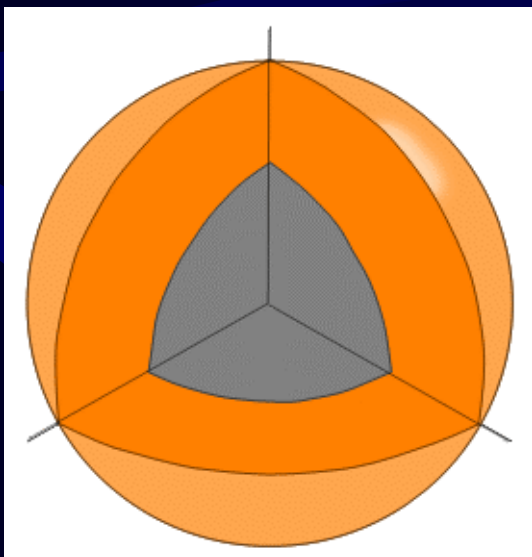
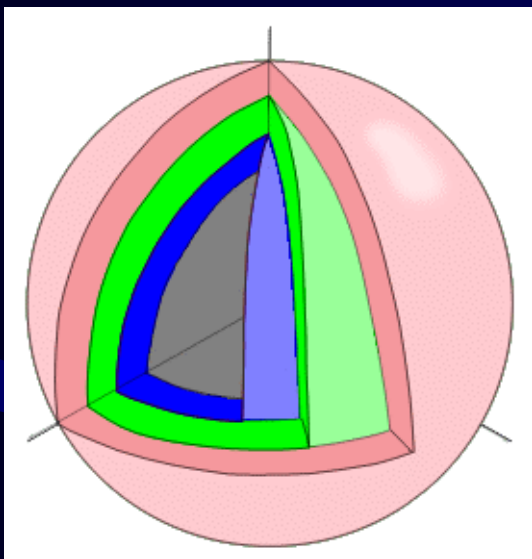
$kT_{\text{cool}} \sim 2$ keV, more contribution toward the center
Inside 1', similar temperature structure to 1P

Comparison of Single- and Two-phase picture

Project the best-fit model obtained with thin shells

→ spectra of thick shell data

1P ... multi kT 2P ... still two kT (3.8 + 2 keV)

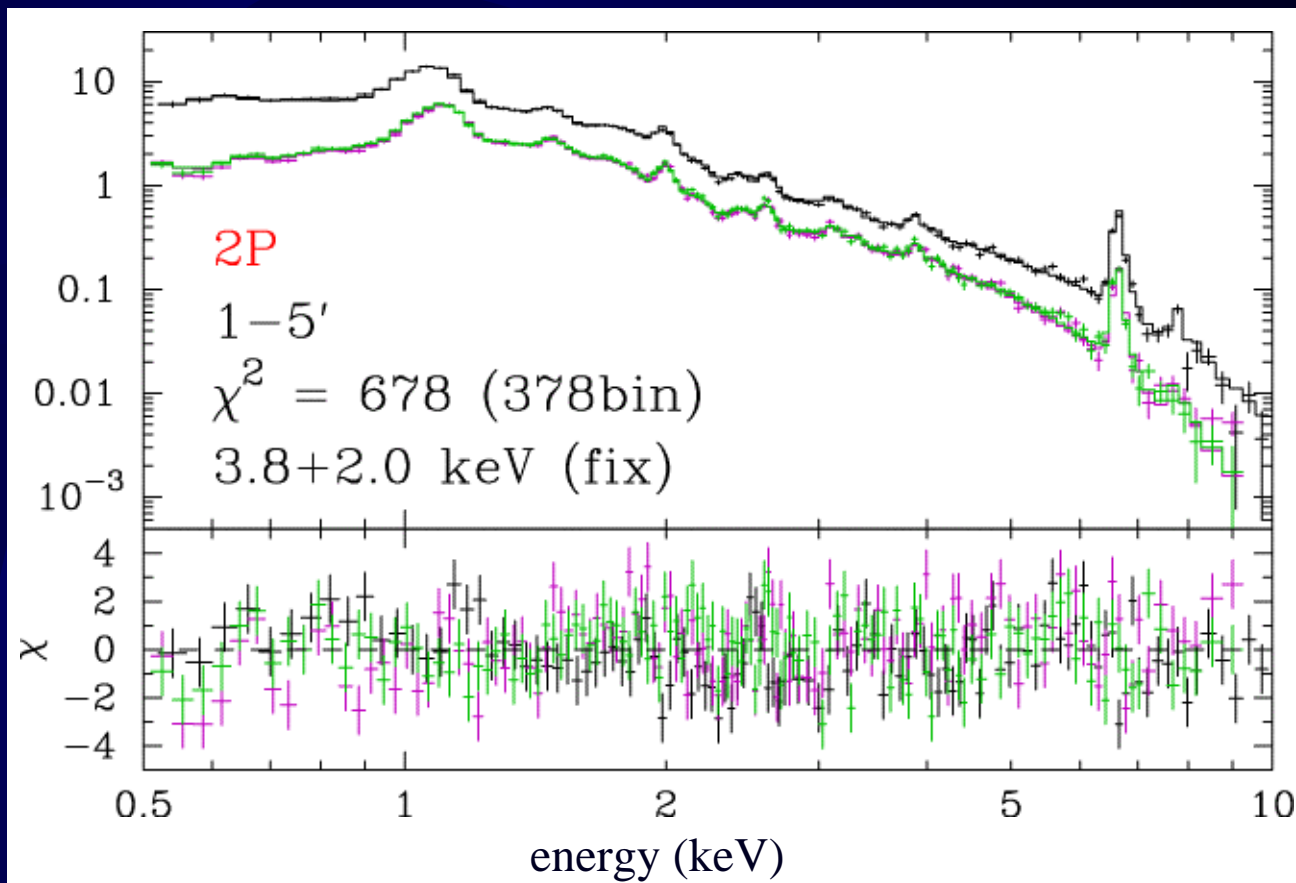
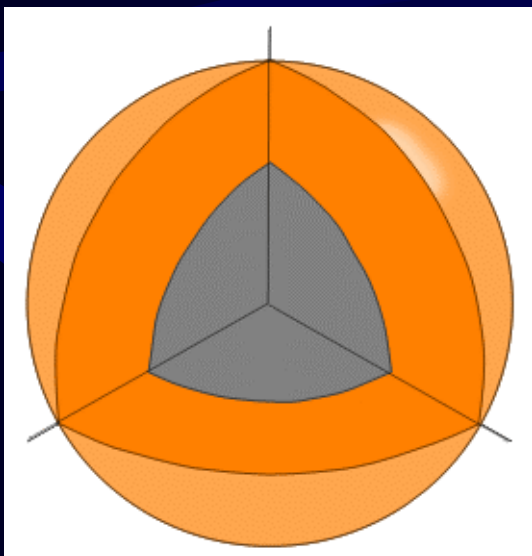
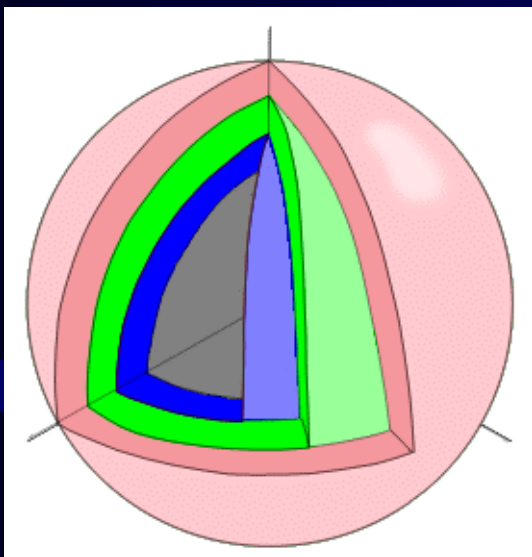


Comparison of Single- and Two-phase picture

Project the best-fit model obtained with thin shells

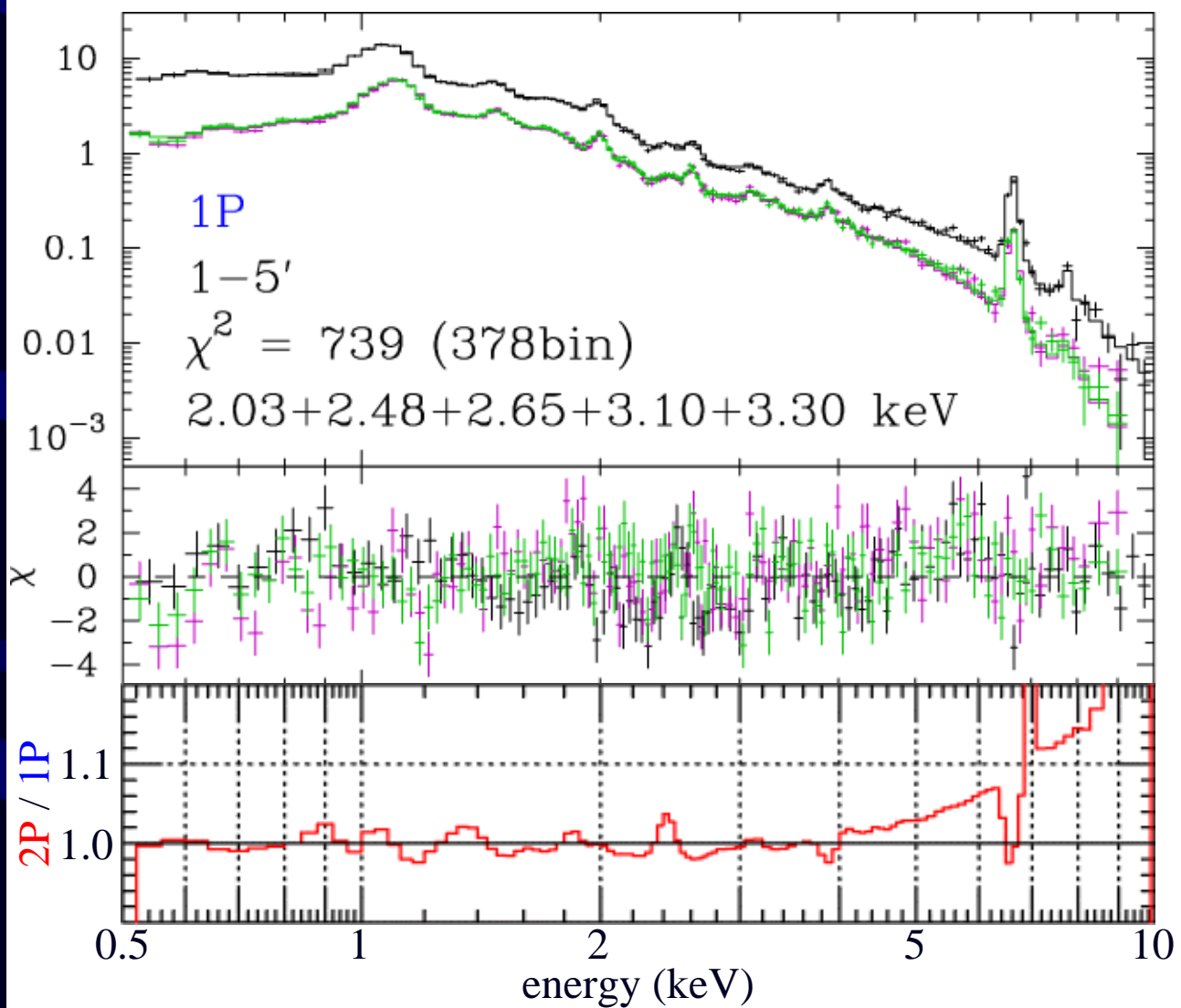
→ spectra of thick shell data

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2P reproduces the data better than 1P

Systematic uncertainty



$${}^2_{1P} = 739 \quad (\quad = 61)$$

$${}^2_{2P} = 678$$

Increase background
by 3% (1)

→ ${}^2 \sim 2$
(data vary by $\sim 0.2\%$)

Set norms of 5 components
of 1P to be free within 50%

→ ${}^2 \sim 15$ (739 → 724)
(models vary by $\sim 1.5\%$)

5% systematic error

$$\rightarrow {}^2_{1P} = 418$$

$${}^2_{2P} = 381 \quad (\quad = 37)$$

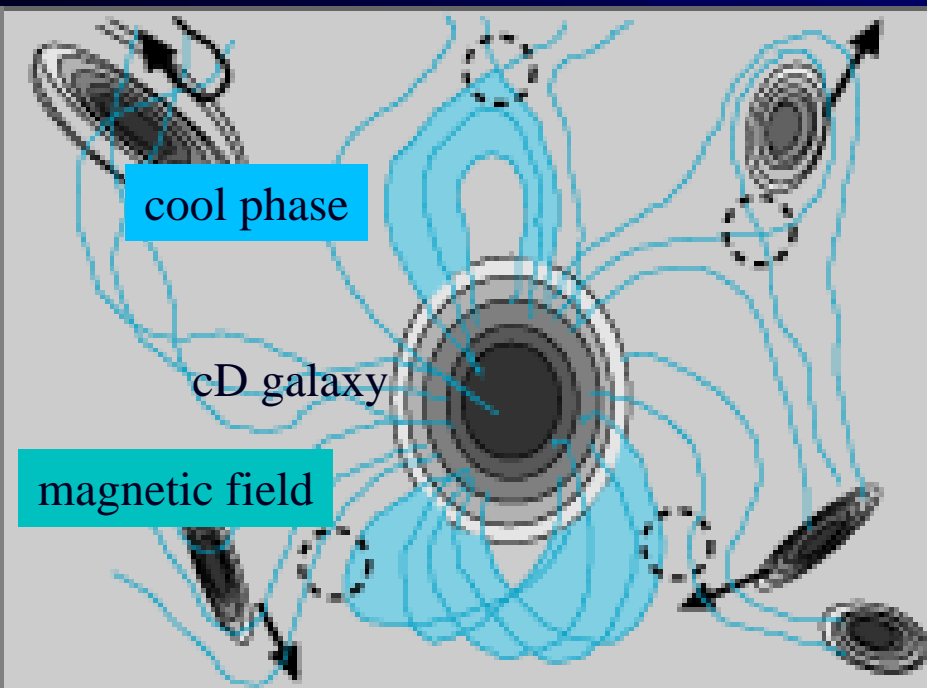
Interpretation: cD corona model (Makishima et al. 2001)

Co-existence of the hot and cool phase

// $B \dots$ thermal conduction effectively works, $B \dots$ hardly work

What configuration of magnetic fields can realize 2P situation ?

- The cool component is localized at the center (near the cD galaxy)
- The cD galaxy is at rest
- Magnetically open field ... be the same kT as the periphery by thermal conduction
- Magnetically closed loop ... can have different kT from the periphery



Heating source / mechanism ?

Kinetic energy of galaxies

→ the ICM thermal energy

via magnetic activity (reconnection etc.)

efficiency, gross energy ... OK

(Makishima et al. 2001)

Galaxies are expected to gradually fall to

→ center

Light is known to be more concentrated on

The cool component

Analogy to the solar corona Rosner, Tucker, and Vaiana (1978)

Stability

Magnetic loops self-regulate their thickness to balance the heating and cooling (radiation + conduction)

Temperature

$$T \sim 1.4 \times 10^3 (pl) \text{ [K]}, \quad \sim 1/3$$

$$p = 3.6 \times 10^{-11} \text{ dyn cm}^{-2} \quad (n = 3 \times 10^{-3} \text{ cm}^{-3}, kT = 3.8 \text{ keV})$$

$$l = 50 \text{ kpc} (= 4')$$

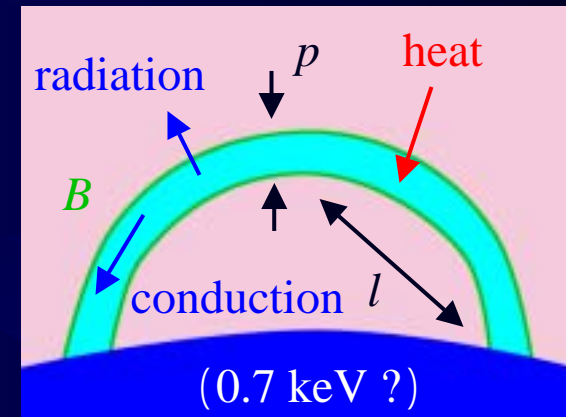
$$\rightarrow kT_{\text{cool}} \sim 2.2 \text{ keV}$$

Similarity ($T_{\text{cool}} / T_{\text{hot}} \quad 1/2 \sim 1/3$)

$$\left. \begin{array}{l} L \quad n^2 V = n^2 r^3 \\ L \quad T^x (x \sim 2.7; \text{empirical}) \end{array} \right\} n \quad T^{x/2} r^{-1.5}$$

$$\rightarrow T_{\text{cool}} \quad (n T l)^{1/3} = T^{x/6+0.33} r^{-0.17} \sim T_{\text{hot}}$$

3.8 keV 2.0 keV



Summary

- RGS reveals there are no significant emission cooler than 0.5 keV
- Single-phase (1P) model appears to reproduce the data, but two-phase model (2P) gives significantly better results
- Both higher and lower temperature components than the prediction of 1P are seen.

Two discrete plasma components (hot and cool) co-exist in the ICM and no much radiative cooling

Demonstrate the suggestion by *ASCA*

The comprehensive view of the ICM can be given by the picture proposed with *ASCA* (Makishima et al. 2001), in which the magnetic field plays a critical role (kinetic energy of galaxies → thermal energy of ICM)