Scaling relation of X-ray properties from elliptical galaxies to rich clusters

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Based on

1.ASCA data analyses of Egals and clusters
(Fukazawa et al. 2004, PASJ 56)

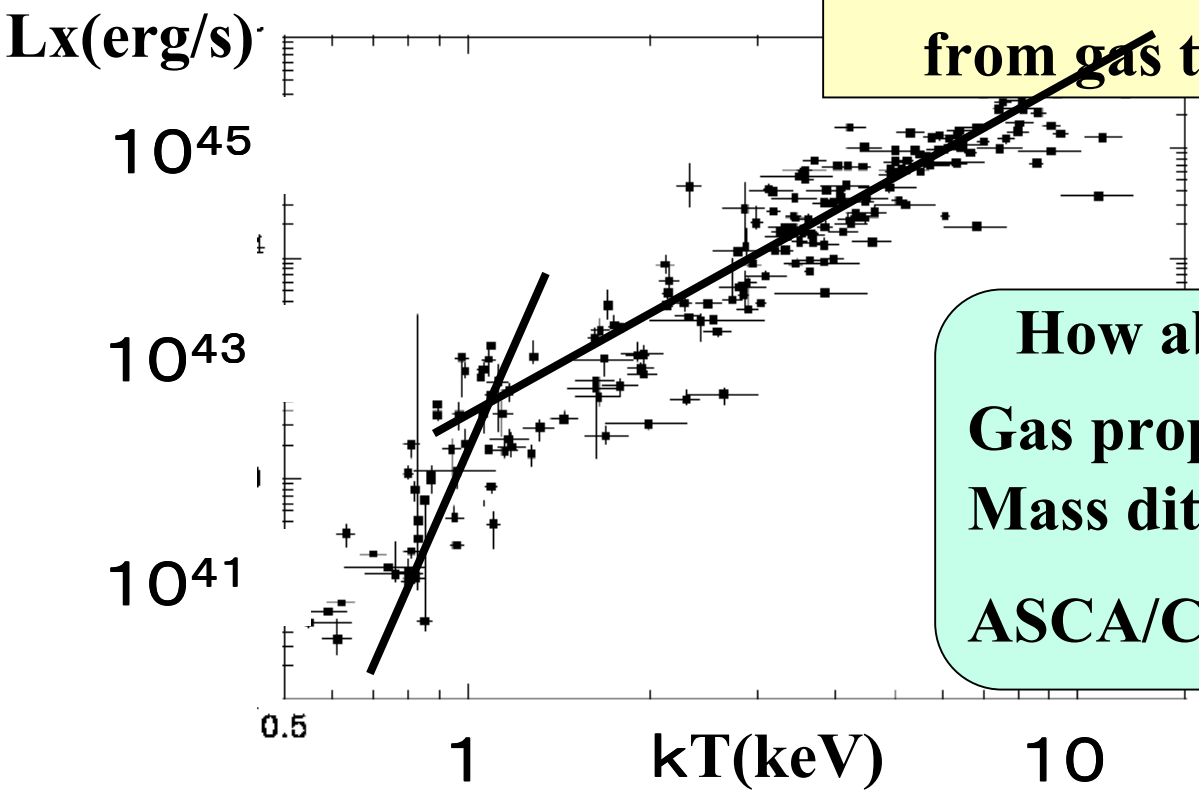
2. Chandra (and XMM-Newton) data analyses of Egals and galaxy groups
(Fukazawa et al. 2005, in preparation)

LT relation

Steep
Large scatters
Breaks around kT=1 keV

Simple self-similar scaling model

Non-gravity effects
(preheating /supernovae/ AGN)?
Dark matter properties?
Scatter of conversion efficiency from gas to stars?

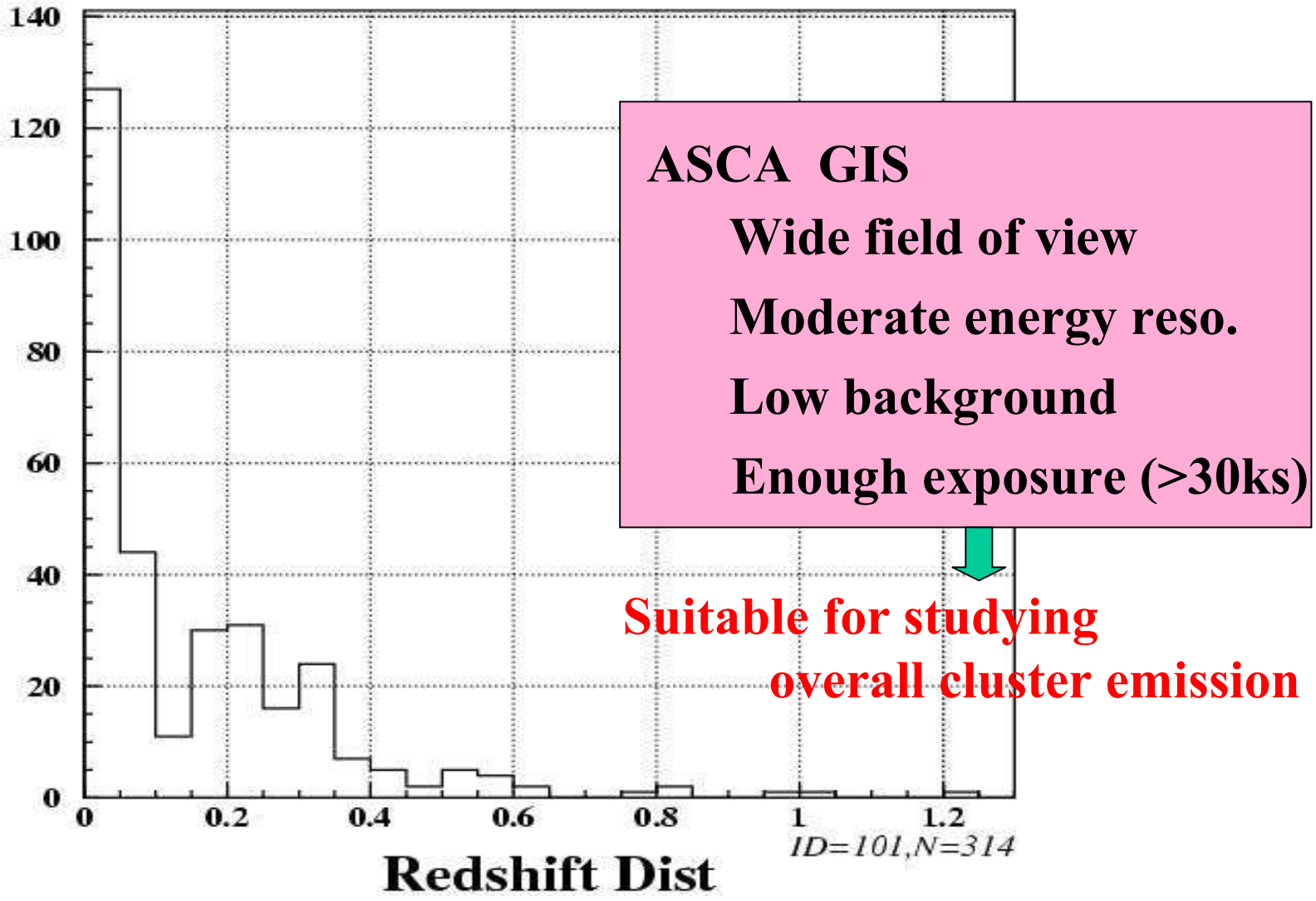


How about other relations?

Gas properties vs kT
Mass ditrbitution

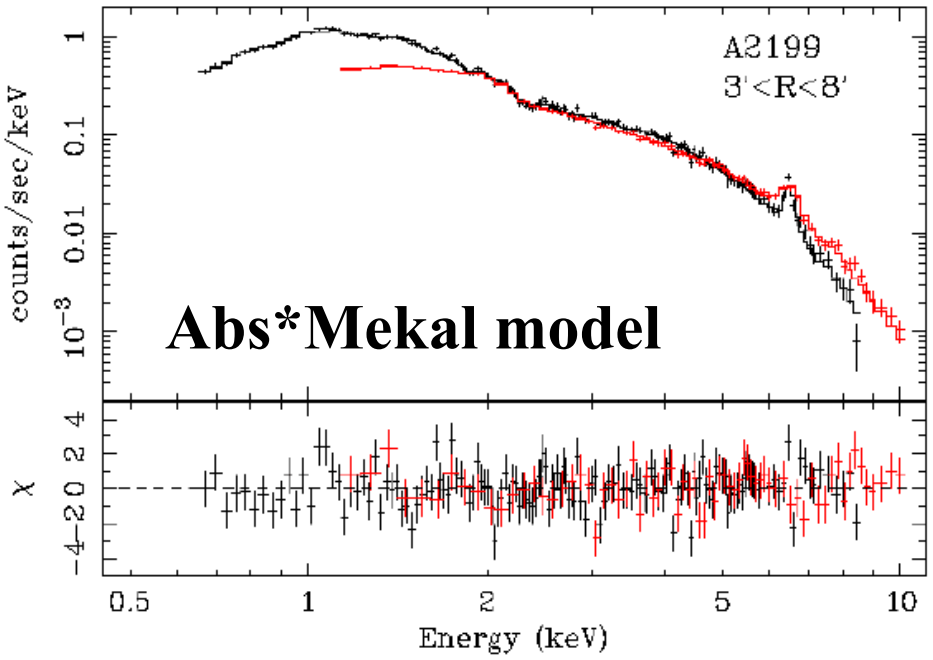
ASCA/Chandra analyses

ASCA ～300 clusters including galaxy groups and Egals



Redshift Distribution of our sample

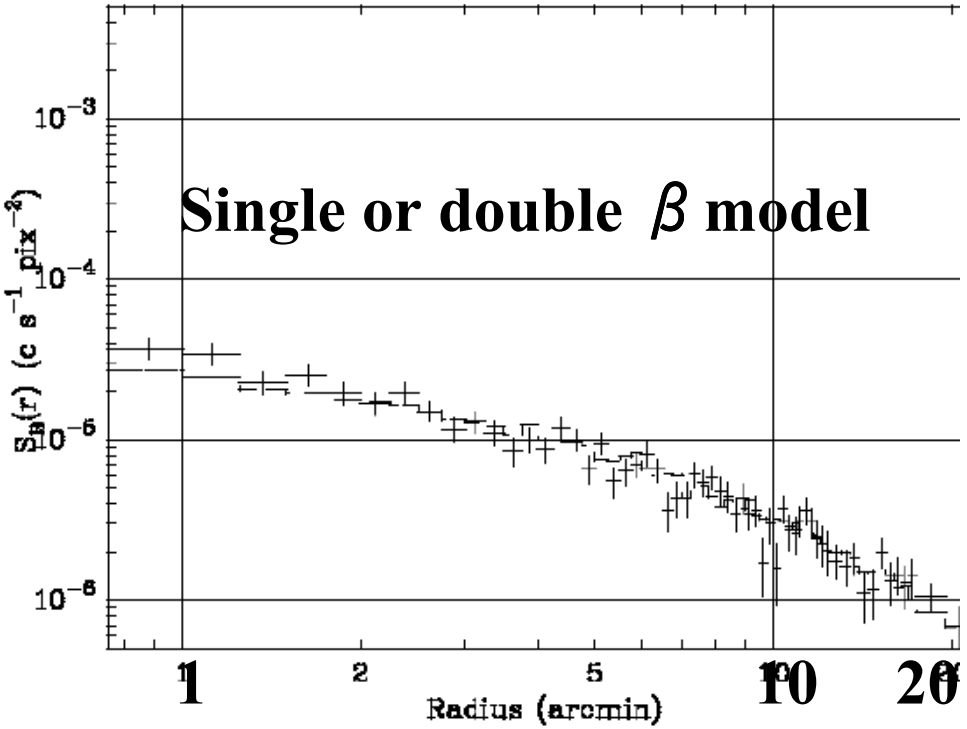
Example of spectra and surface brightness



Overall ICM temperature

(excluding central cool region)

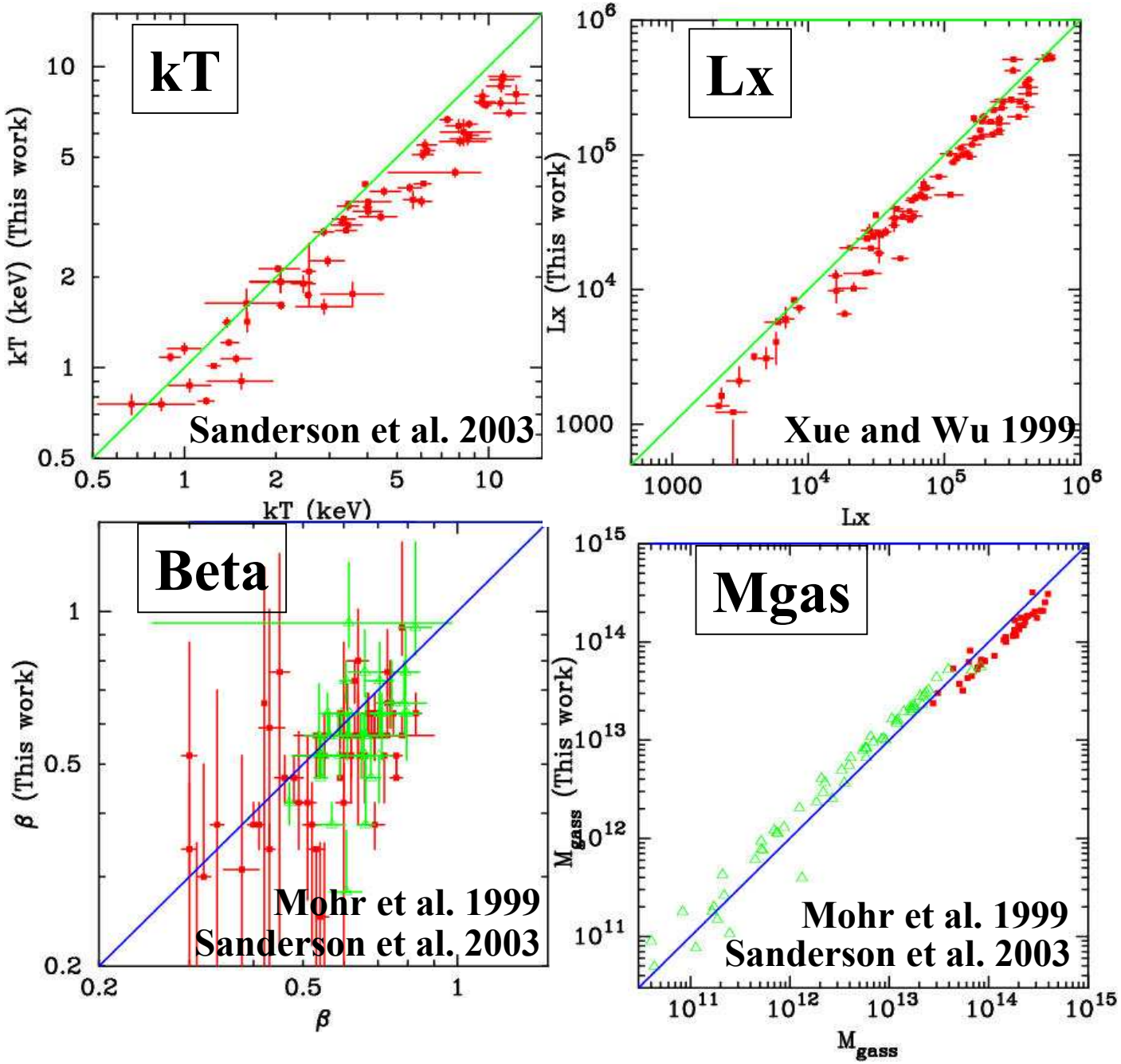
Considering XRT-PSF



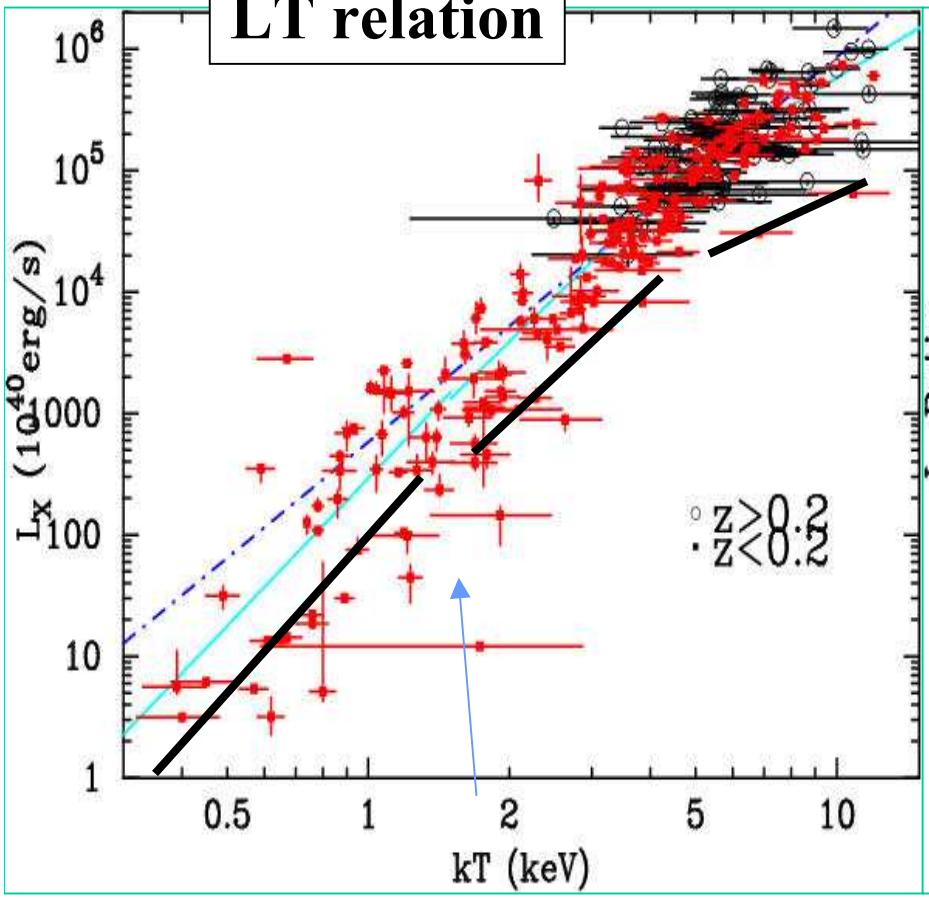
Radius (arcmin)

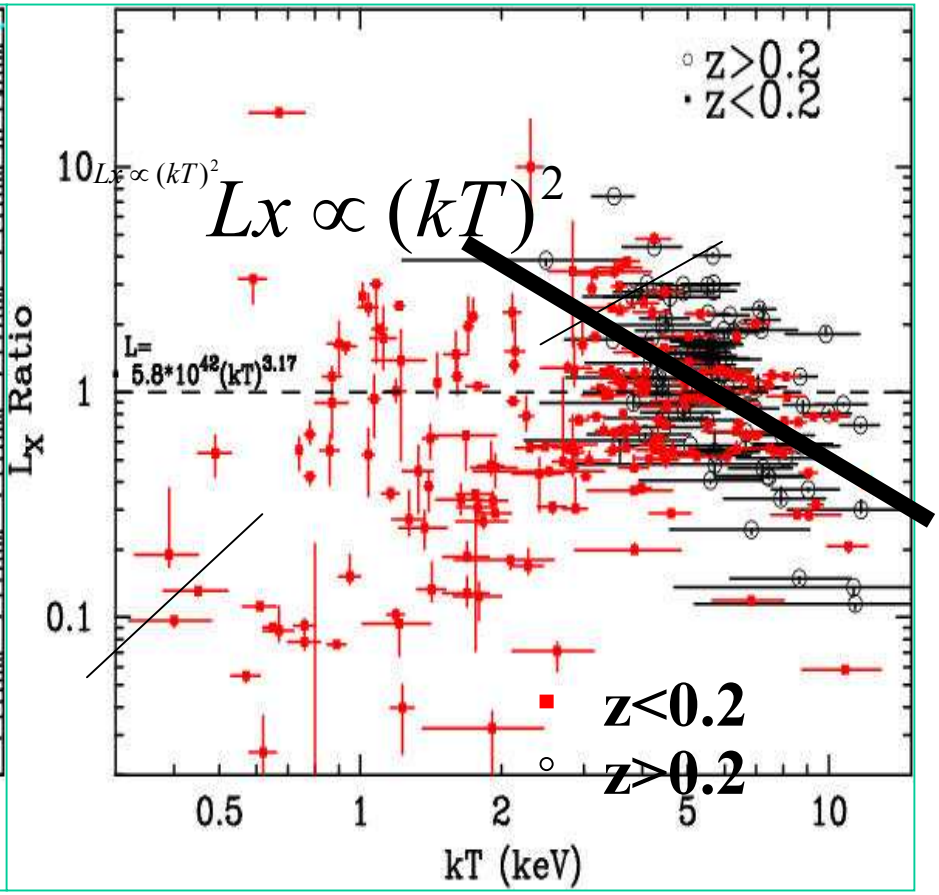
Gas density distribution

Consistency with the previous studies with Einstein/ROSAT



LT relation





Overall relation

$$Lx = 5.8\times10^{42}(kT)^{3.17}$$

Non-gravity effect is large

kT<1.5keV $Lx \propto (kT)^{4.03\pm1.07}$

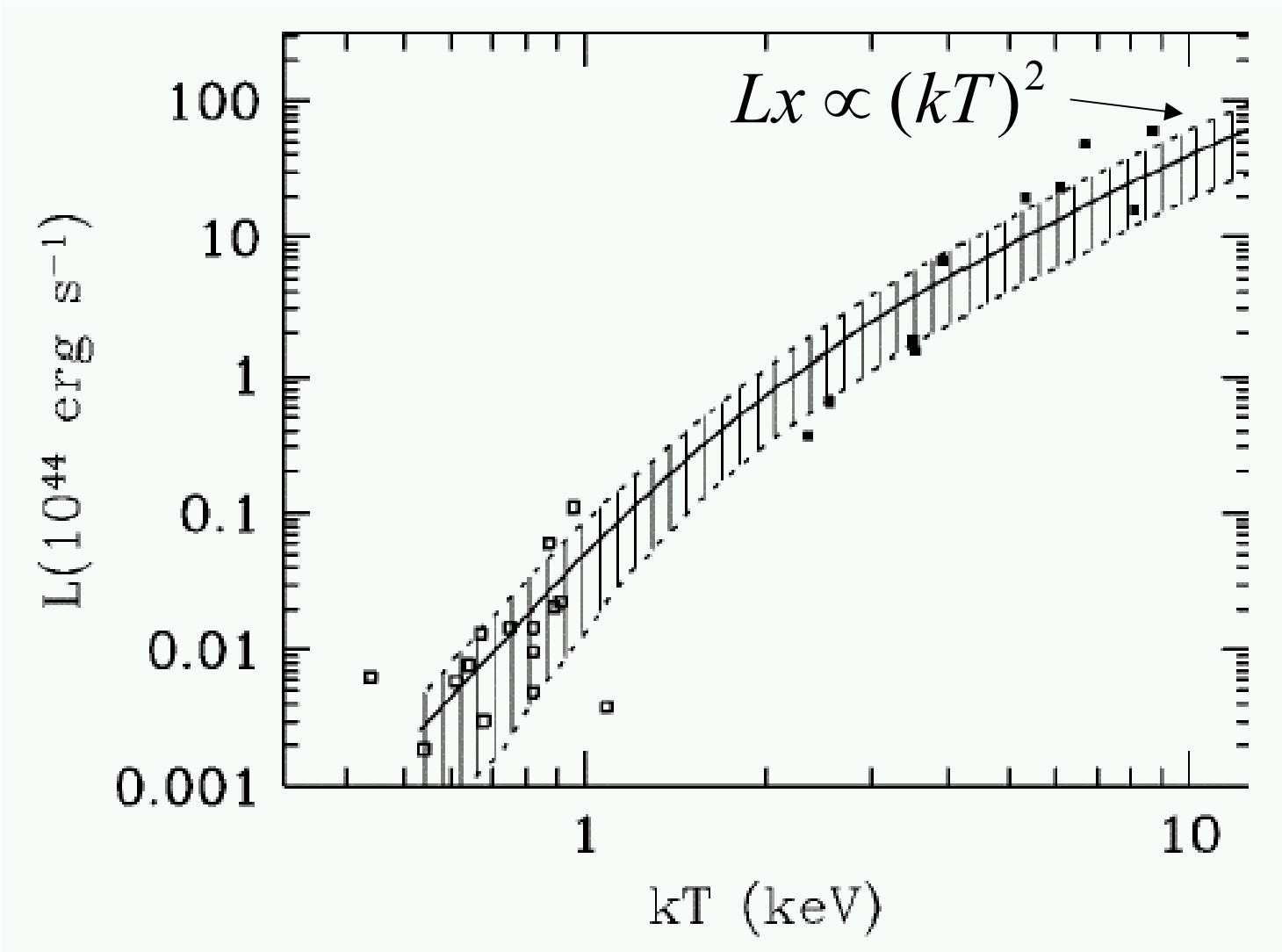
1.5<kT<5keV $Lx \propto (kT)^{3.74\pm0.32}$

Gravity effect is large

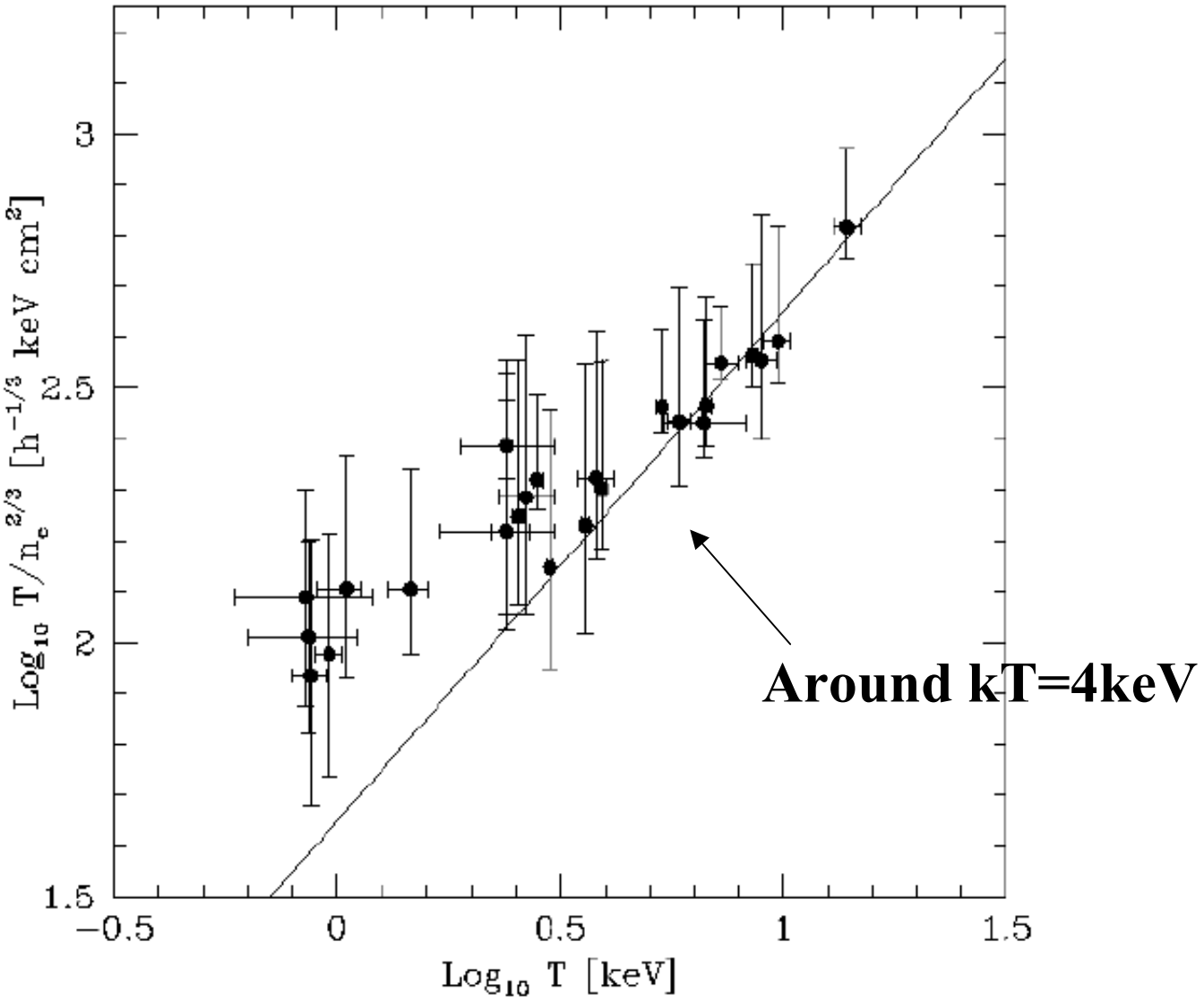
kT>4keV $Lx \propto (kT)^{2.34\pm0.29}$

Cavaliere et al. 1997

Theoretical prediction considering shocks in mergers

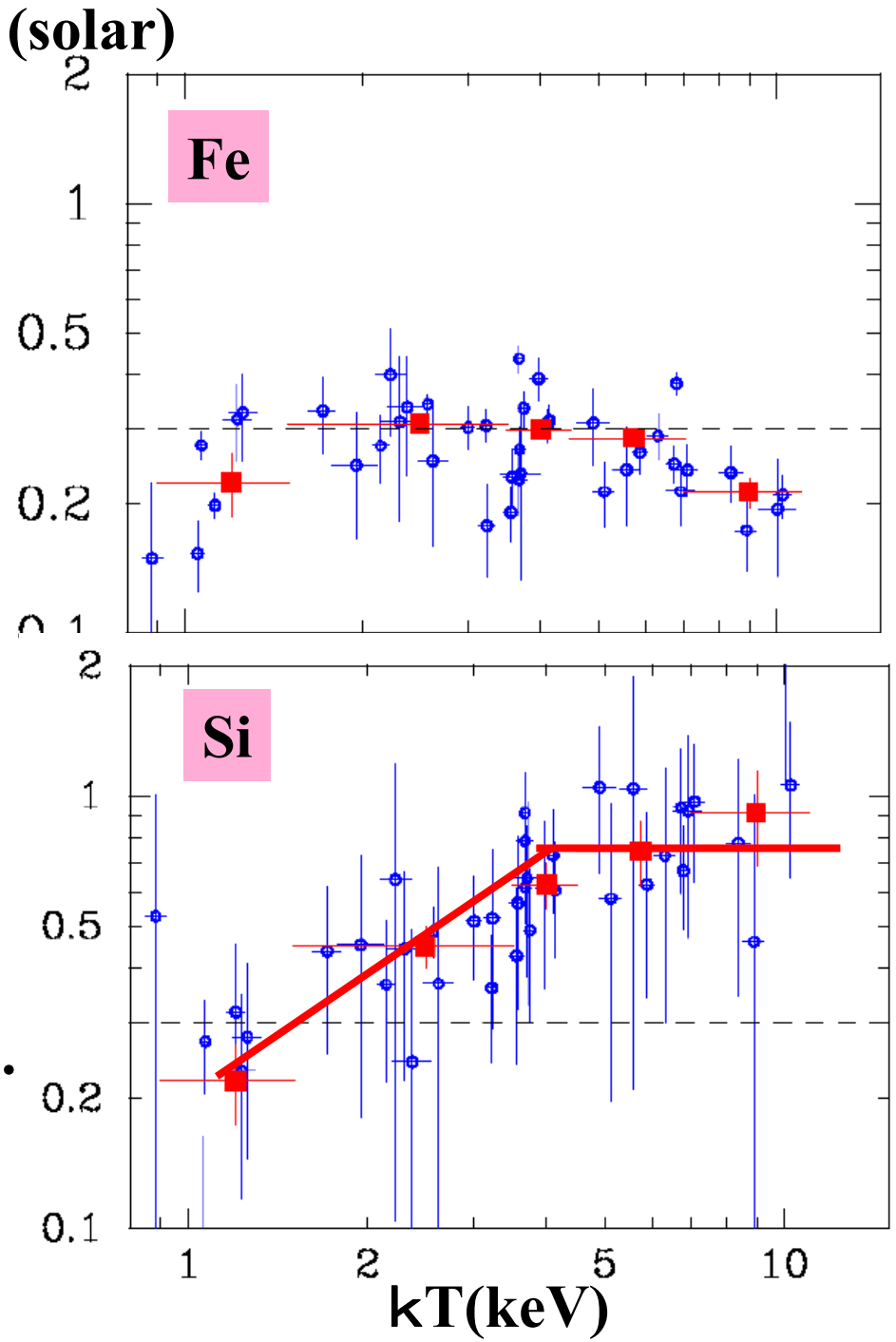


Entropy floor (Ponman et al. 1998)



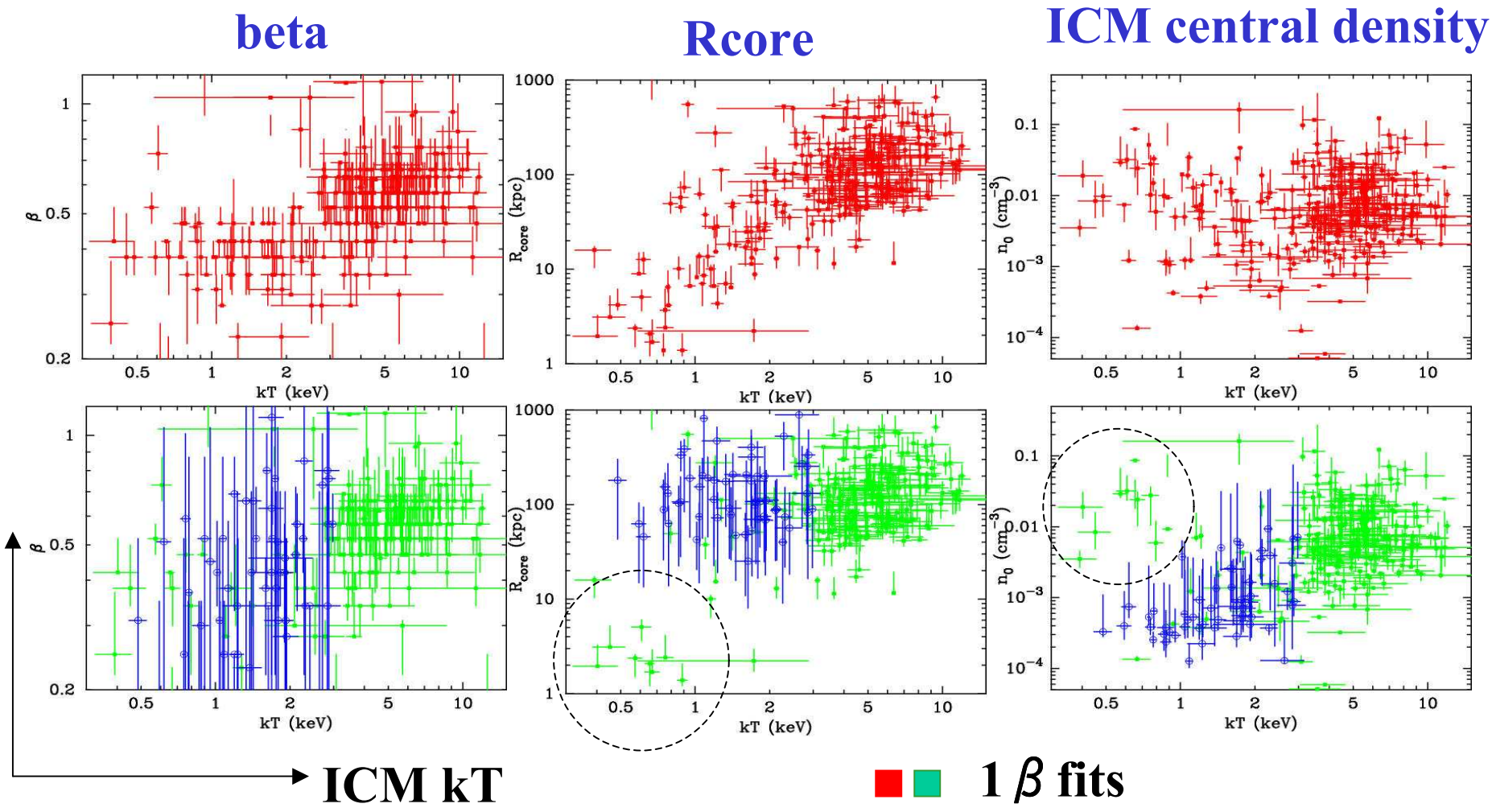
Metal abundance of ICM

Fukazawa et al. 1998



A significant amount of Si produced in the early galaxy phase in SNe II were lost in lower kT clusters (kT<4keV).

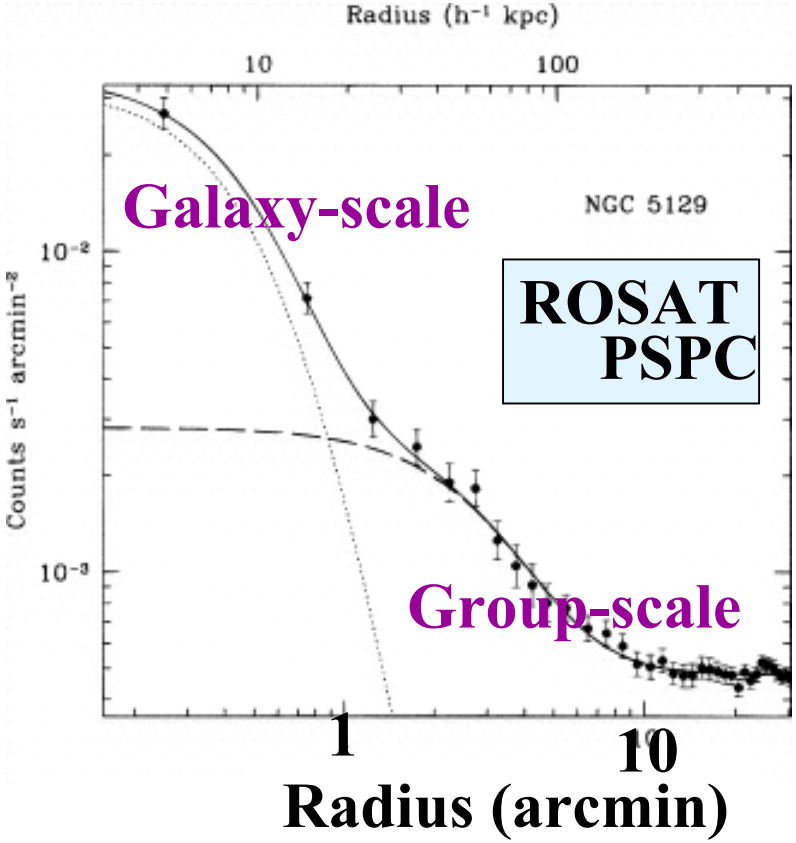
Parameters of Imaging fits

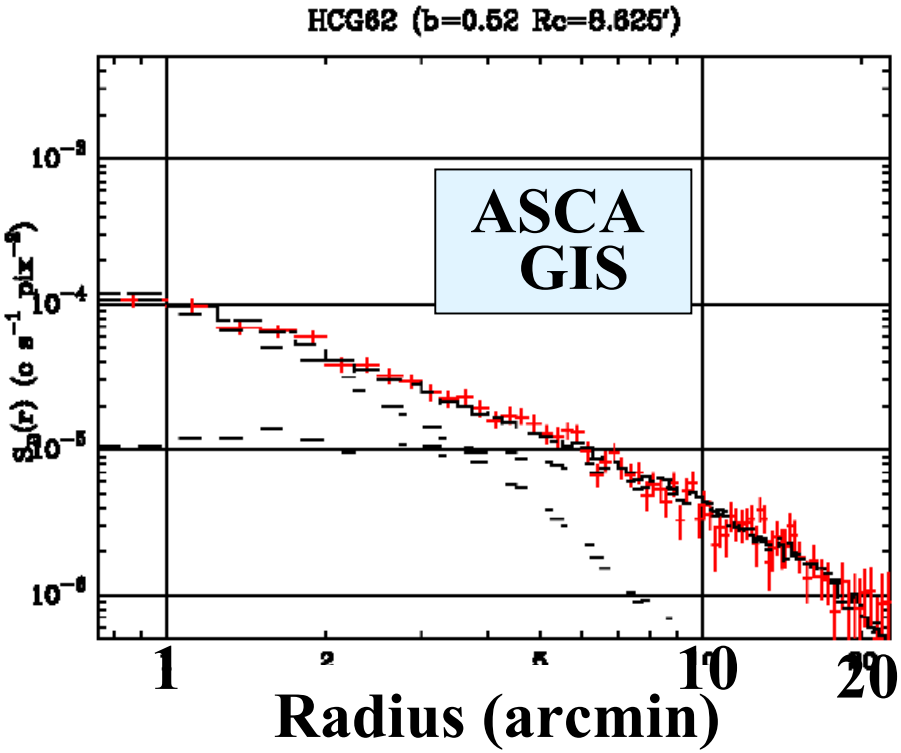


Most objects with kT<2keV prefers 2 β model,

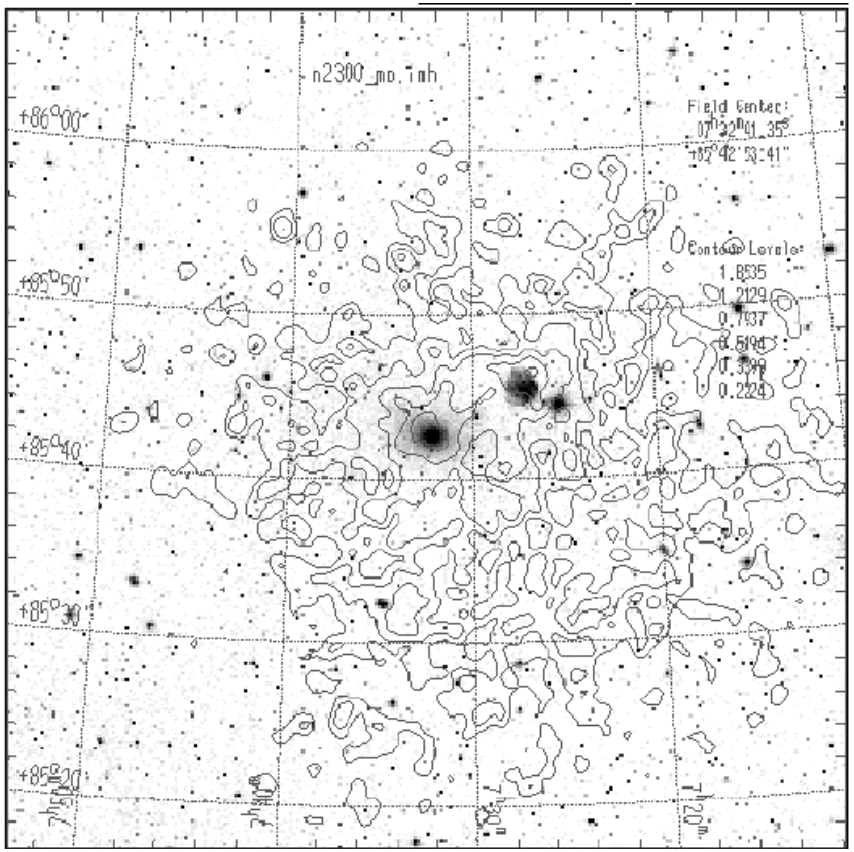
Ikebe et al. 1996, Matsushita et al. 1997

Mulchaey et al. 1998





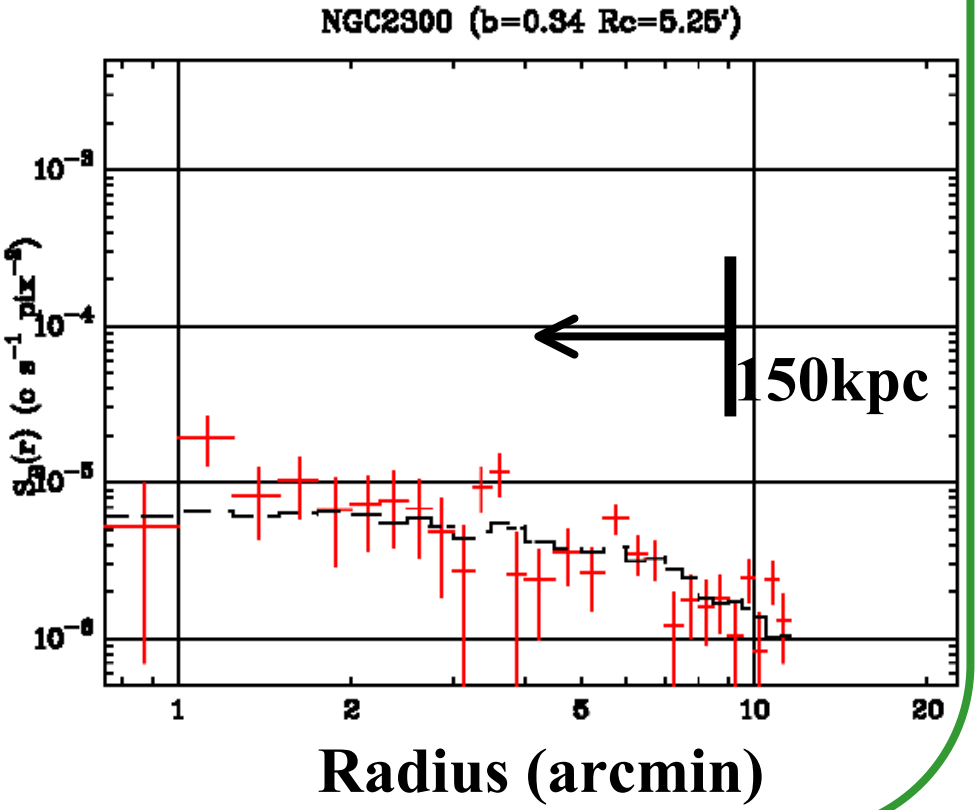
X-ray faint groups often have a very low gas density.



NGC2300 group

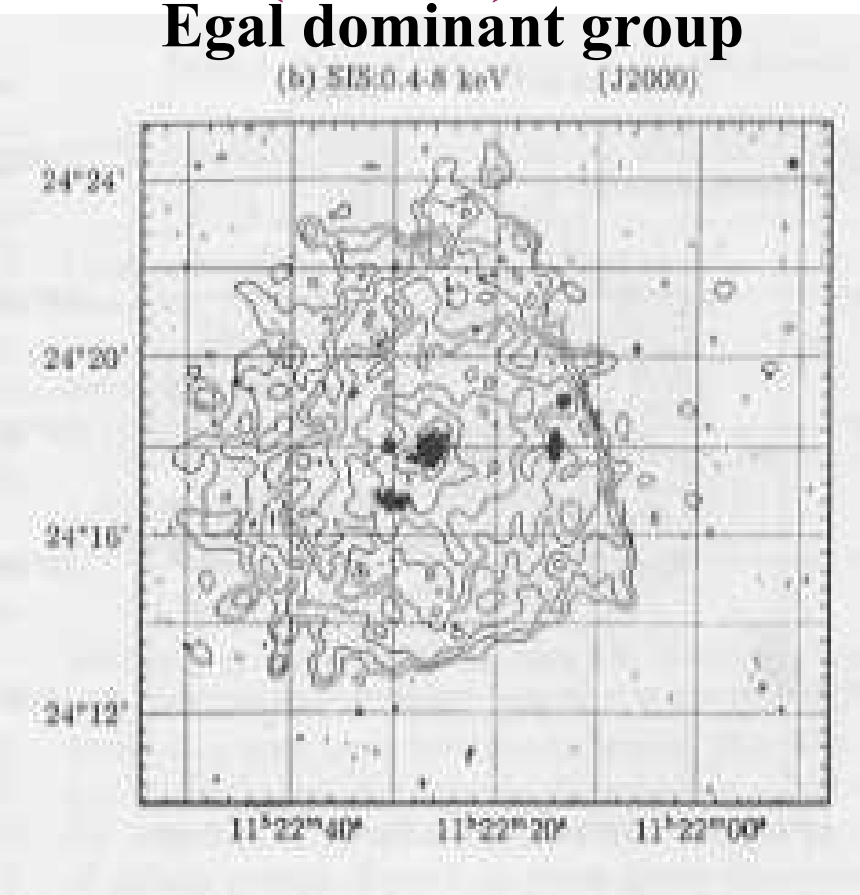
Center density

$\sim 5 \times 10^{-4} \mathrm{cm}^{-3}$



HCG51(z=0.026)

Egal dominant group

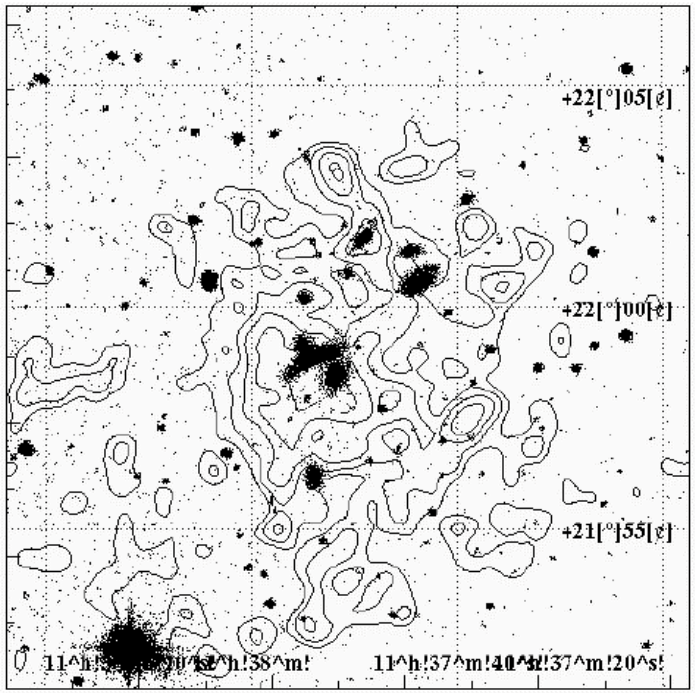


5×10^{42}erg/s

(Fukazawa et al. 1996)

HCG57 (z=0.030)

Spiral dominant group

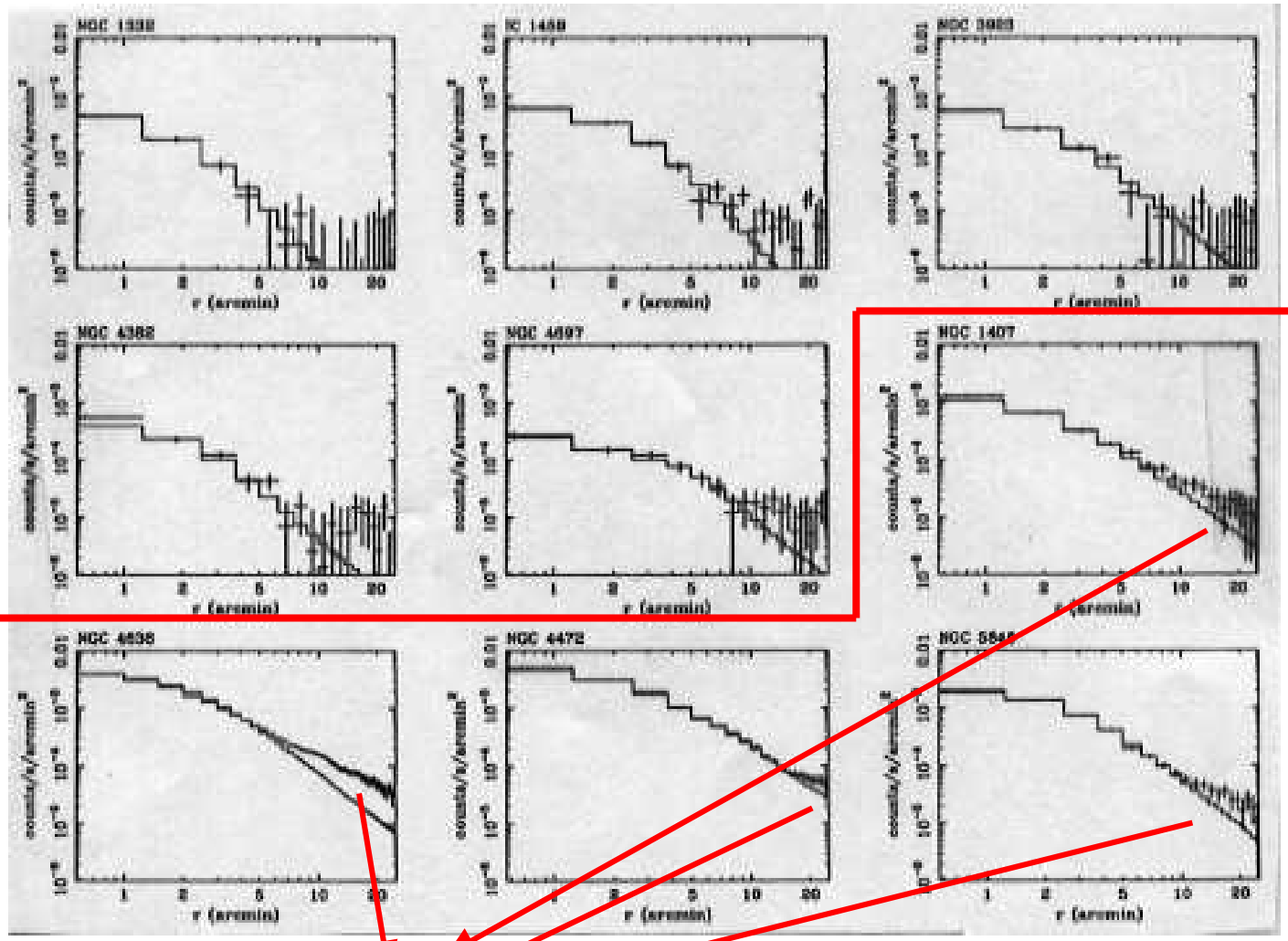


5×10^{41}erg/s

(Fukazawa et al. 2002)

X-ray surface brightness of Egals observed with ASCA (Matsushita 1997)

X-ray faint Egals



X-ray bright Egals

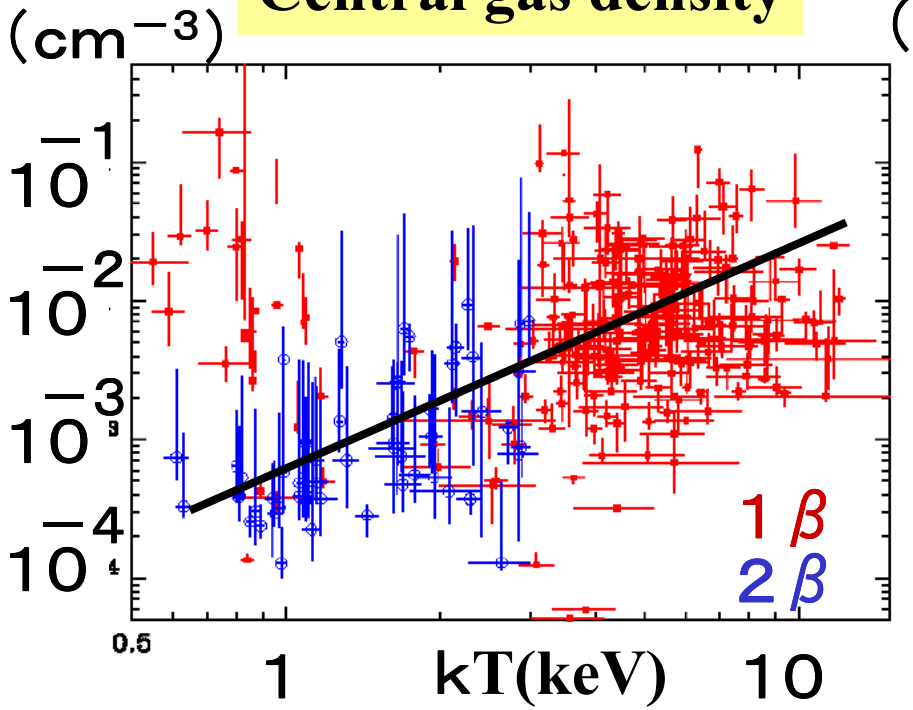
Another extended emission possibly due to group emission

Why lower temperature systems have a lower Lx?

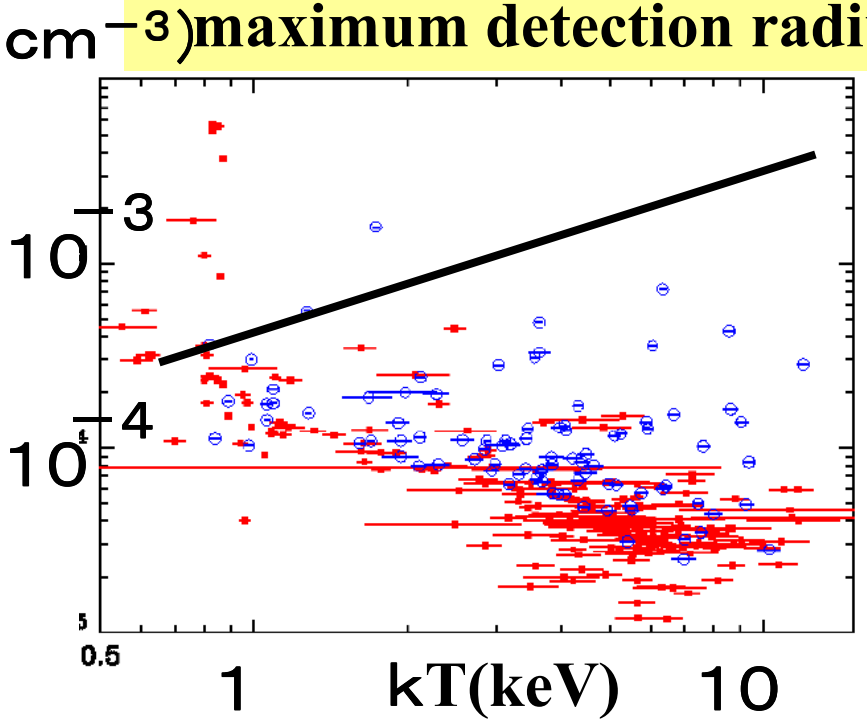
Why X-ray faint Egals do not have an extended emission?

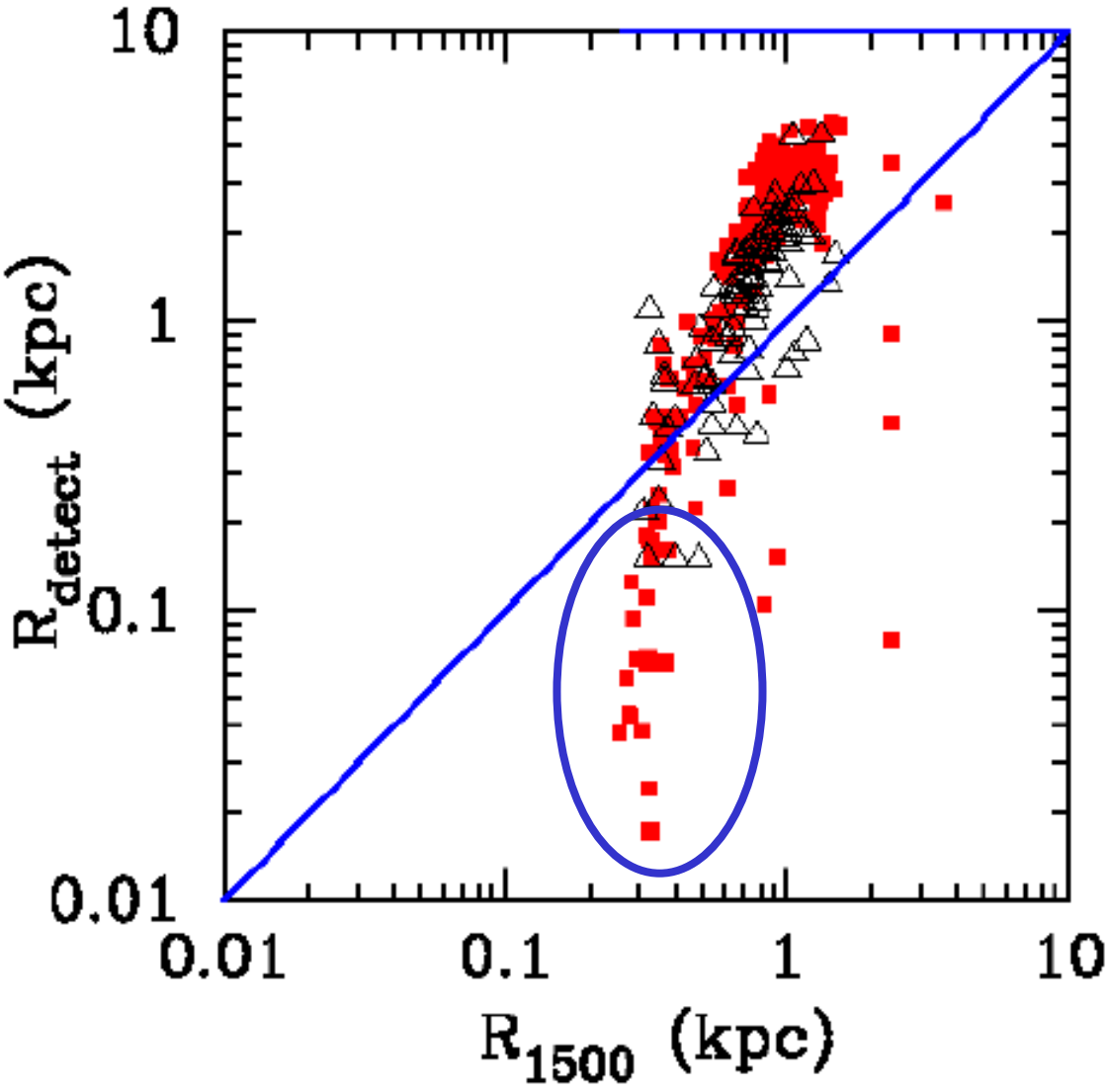
□ **Beyond GIS field of view**

Central gas density



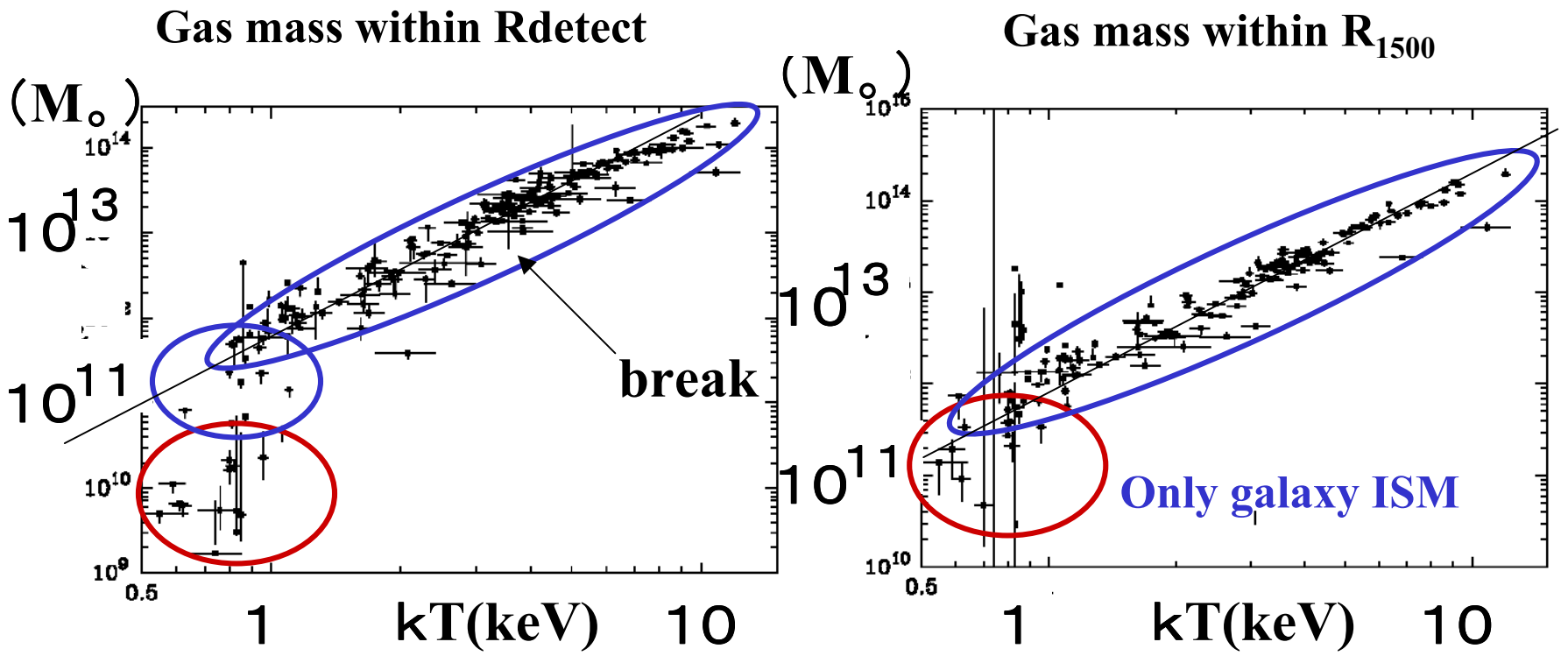
Gas density at the maximum detection radius





In many low-kT systems,

X-ray emission at the outer region is not detected?

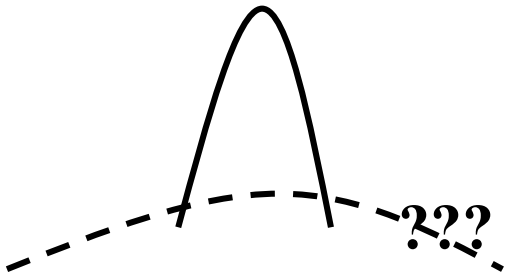


$$M_{gas} = 1.0 \times 10^{12} (kT)^{2.33 \pm 0.07}$$

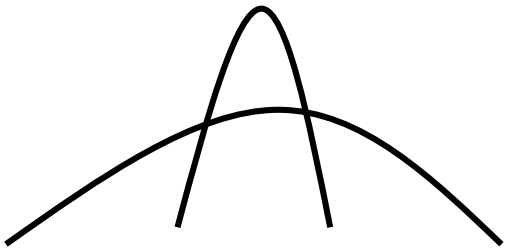
In poorer systems, gas at the outer region exists but not detected?

Two components of X-ray emission

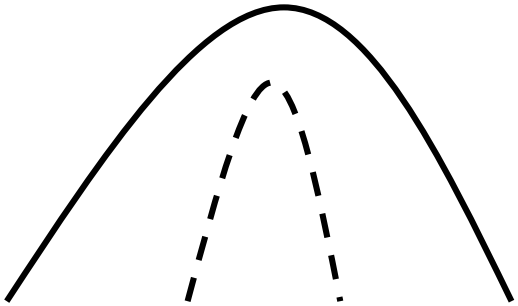
X-ray faint E-galaxy



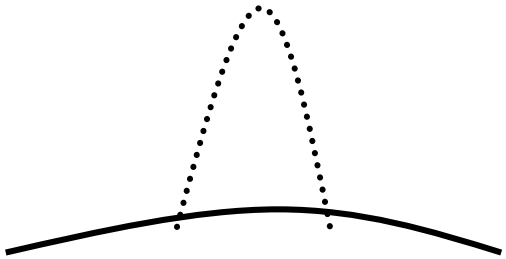
Galaxy groups
X-ray bright E-galaxy



Rich clusters



Spiral dominant
Galaxy groups



From ASCA data analyses, ….

What are galaxy and cluster/group-scale components?

Two-different scale of dark matter?

not predicted by CDM model

Gas does not follow the scaling law.

How about dark matter?

NFW?

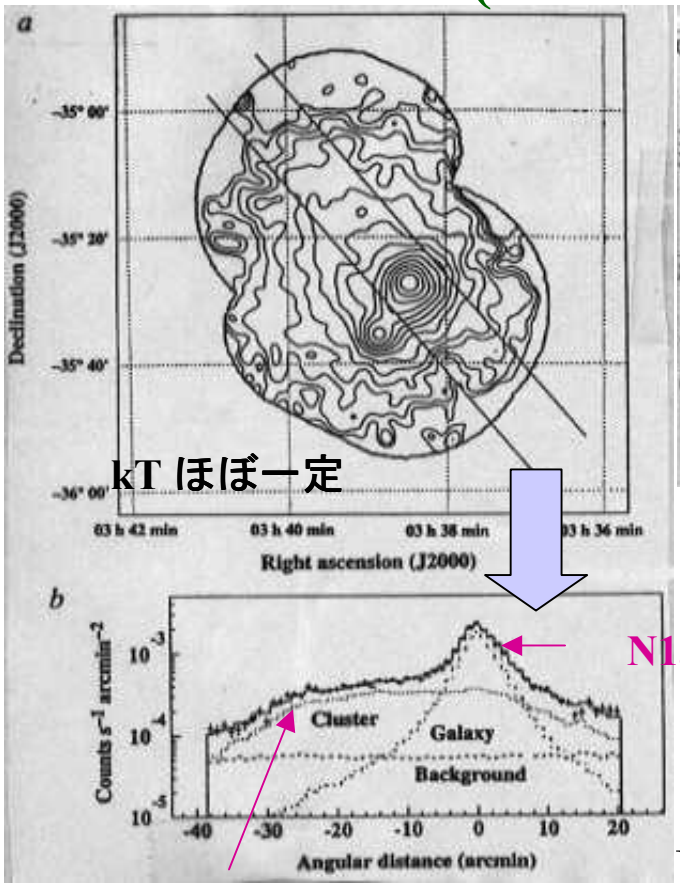
Chandra/XMM-Newton Era

Chandra data analyses of Egals

(Analyses of clusters are referred to other works)

Double structure in the gravitational mass profile

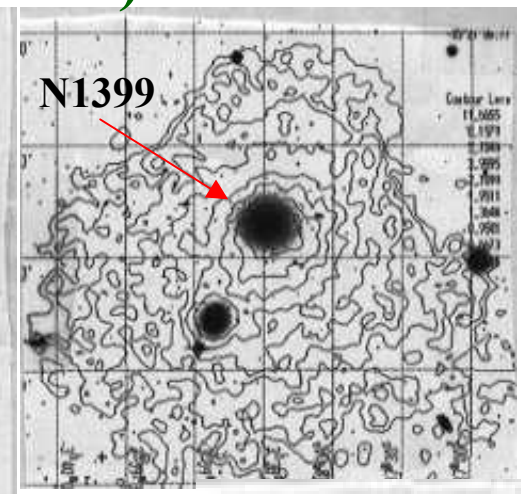
Fornax cluster (kT～1keV)



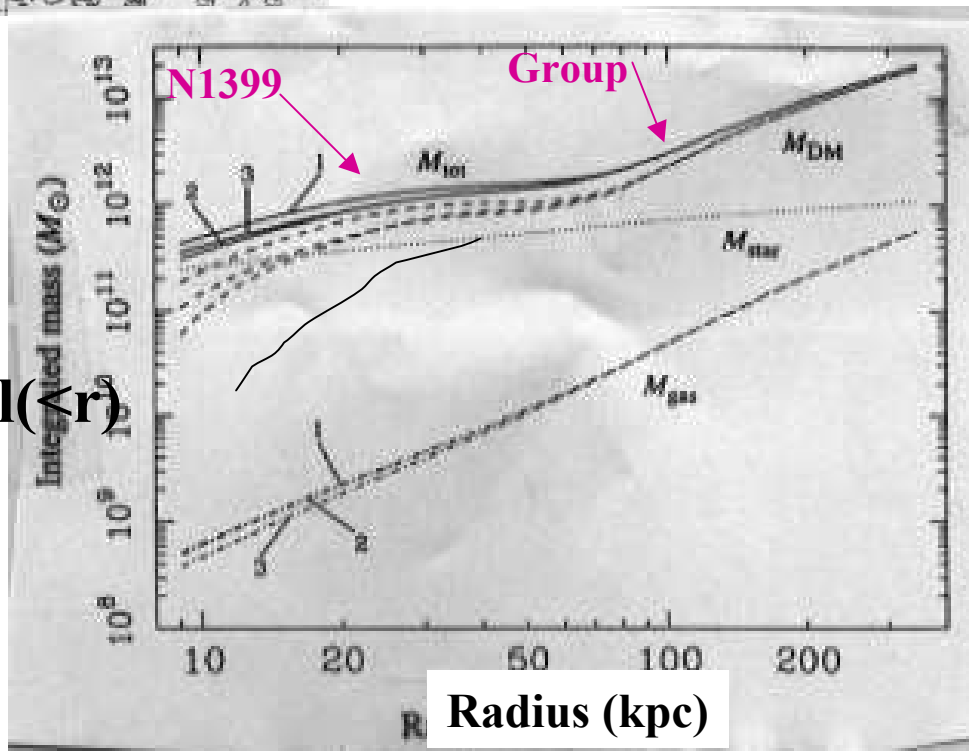
kT ほぼ一定

N1399

Group



Two different DM?



Mtotal(<r)

Ikebe et al. 1996

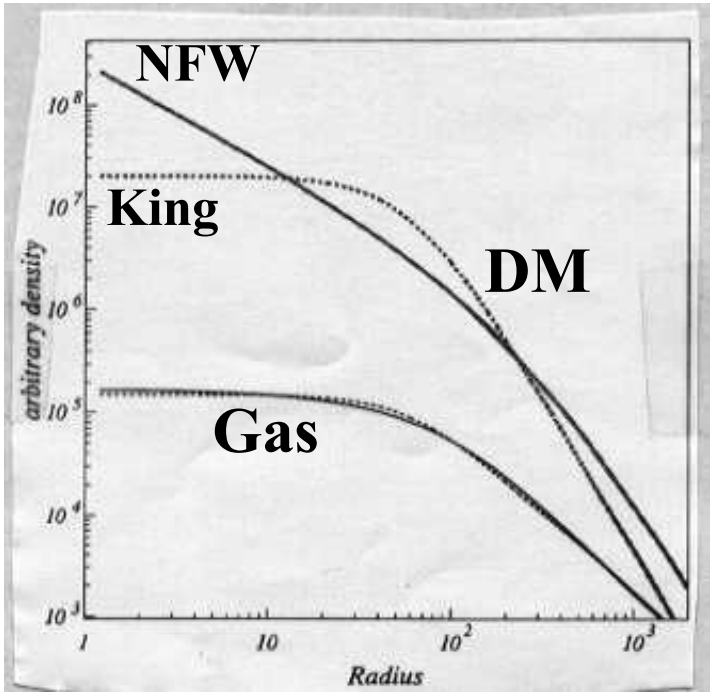
NFW profile

$$\rho_{NFW} = \frac{\delta_c \rho_{crit}}{(r/r_s)(1+r/r_s)^2}$$

King model

$$\rho_{King} = \frac{\rho_0}{\left[1+\left(r/r_c\right)^2\right]^{3/2}}$$

Density Profile



Tamura 1998

NFW is prefered.
A1060 ASCA data

Deprojection technique cannot be applied to the ASCA data

NFW mass profile

$$M_{NFW} = 4\pi\delta_c \rho_{crit} r_s^2 \left[\ln(1+\frac{r}{r_s}) - \frac{r/r_s}{1+r/r_s} \right]$$

$$r_{200} = 3.69 \left(\frac{T}{10keV} \right)^{0.5} (1+z)^{-1.5} \quad [Mpc] = cr_s$$

(Evrard et al. 1997)

Scaled NFW mass profile

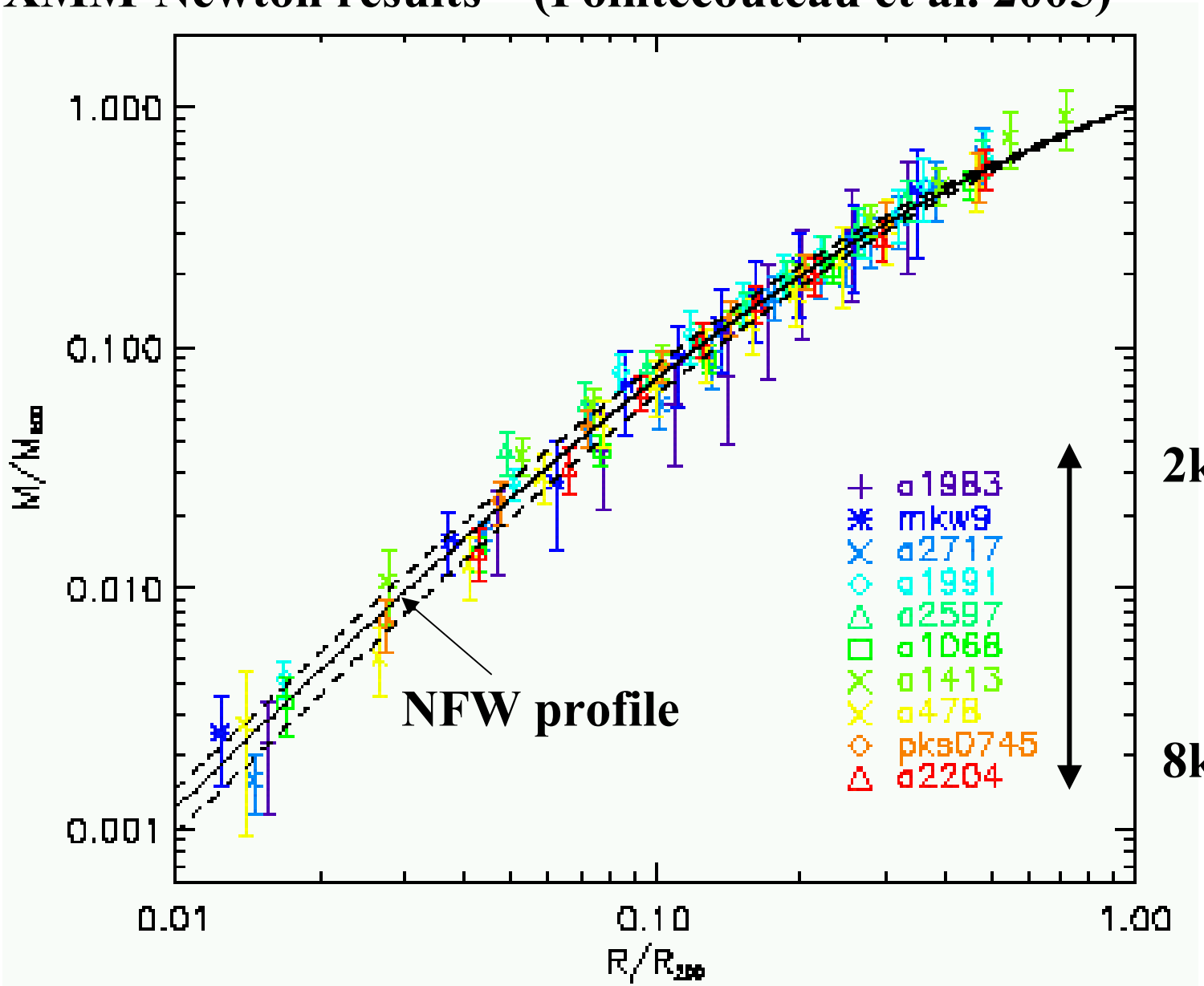
$$\frac{M_{NFW}}{M_{200}} = \frac{\ln(1+cx) - cx/(1+cx)}{\ln(1+c) - c/(1+c)}$$

$$x = r / r_{200}$$

$$c = 4 - 7$$

Simulation/observation

XMM-Newton results (Pointecouteau et al. 2005)

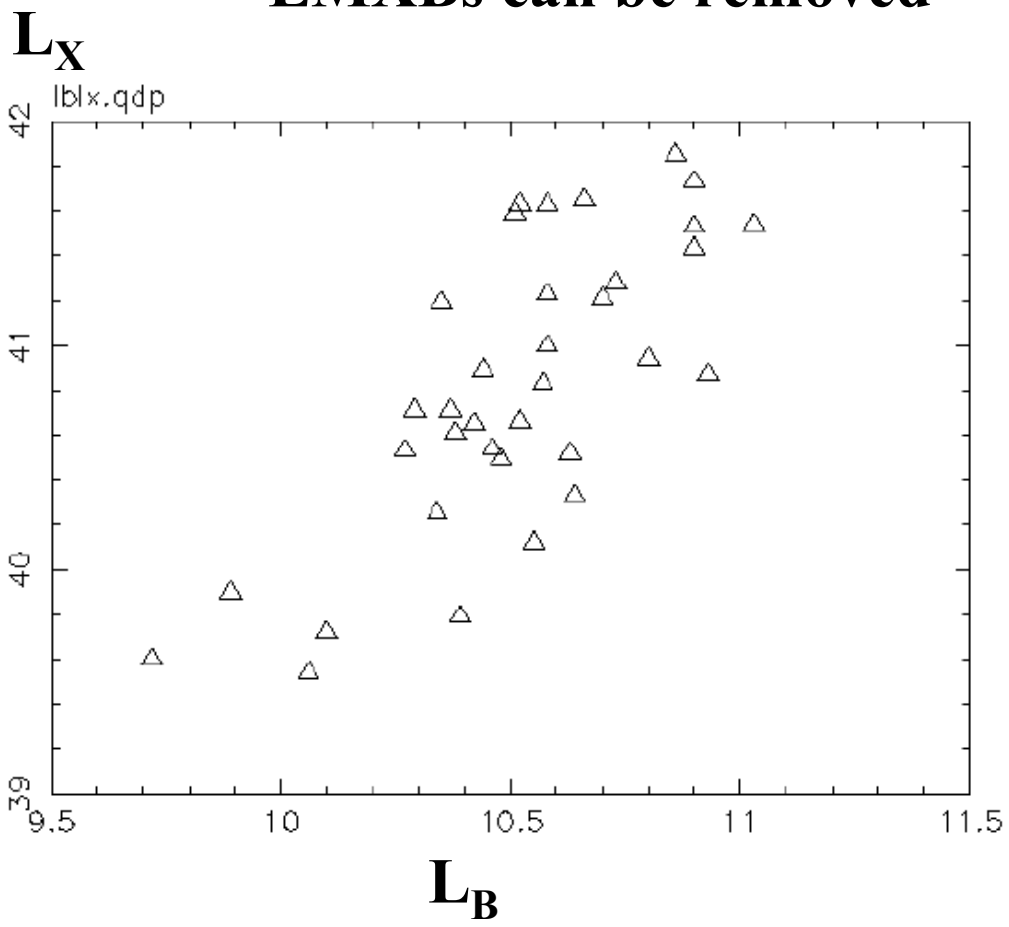


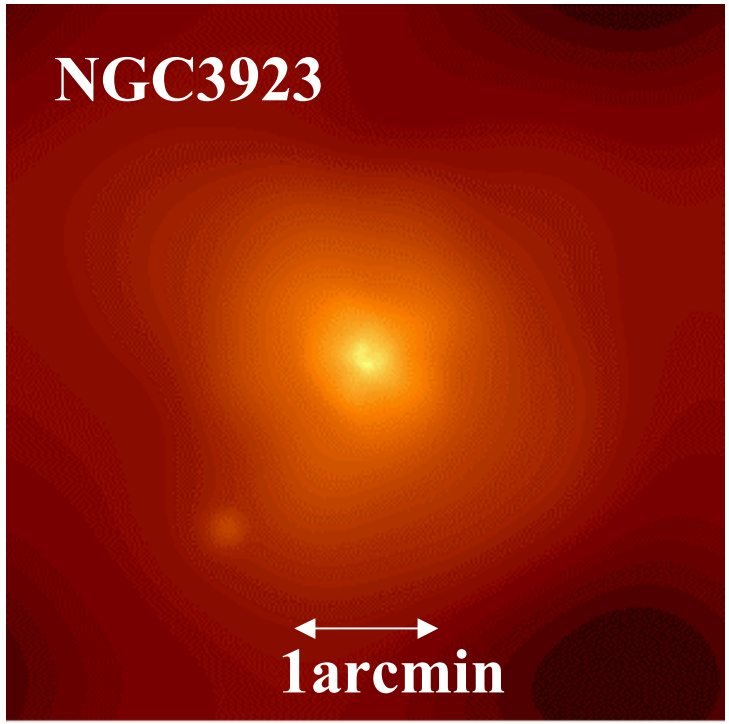
Also, Chandra data analyses (Lewis/Buote/Katayama)

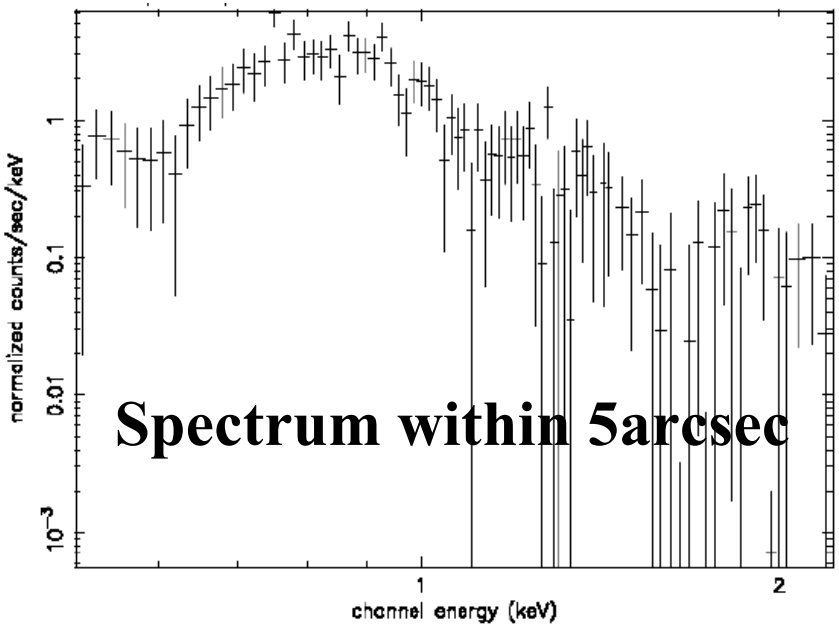
Chandra data of ～50 Egals

X-ray faint Egals can be studied very well

LMXBs can be removed

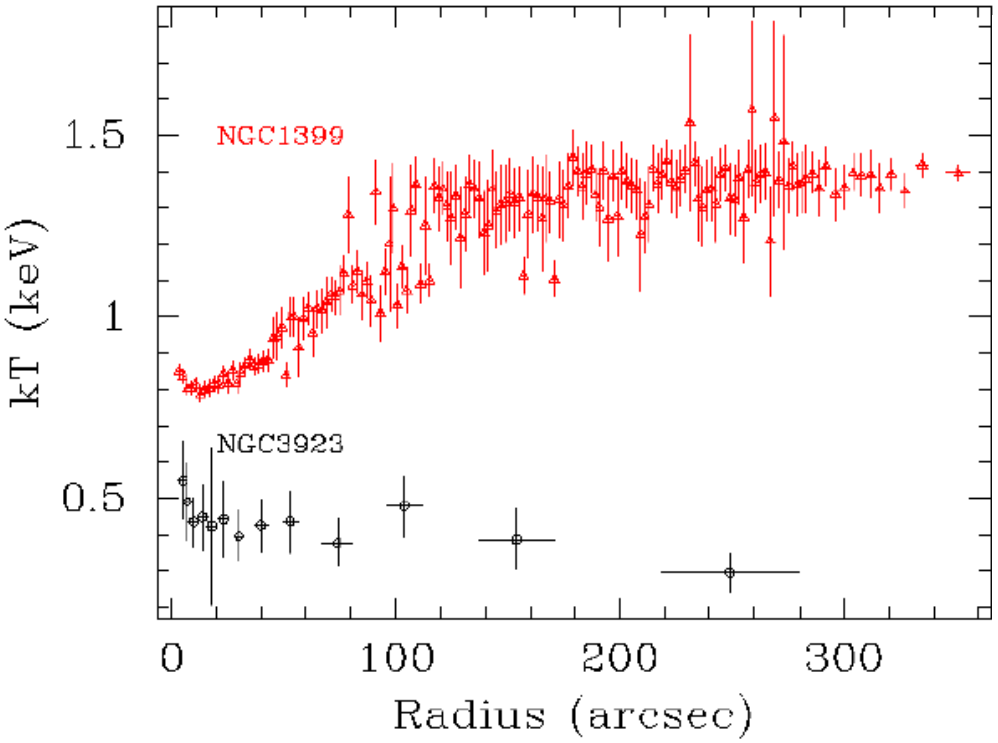




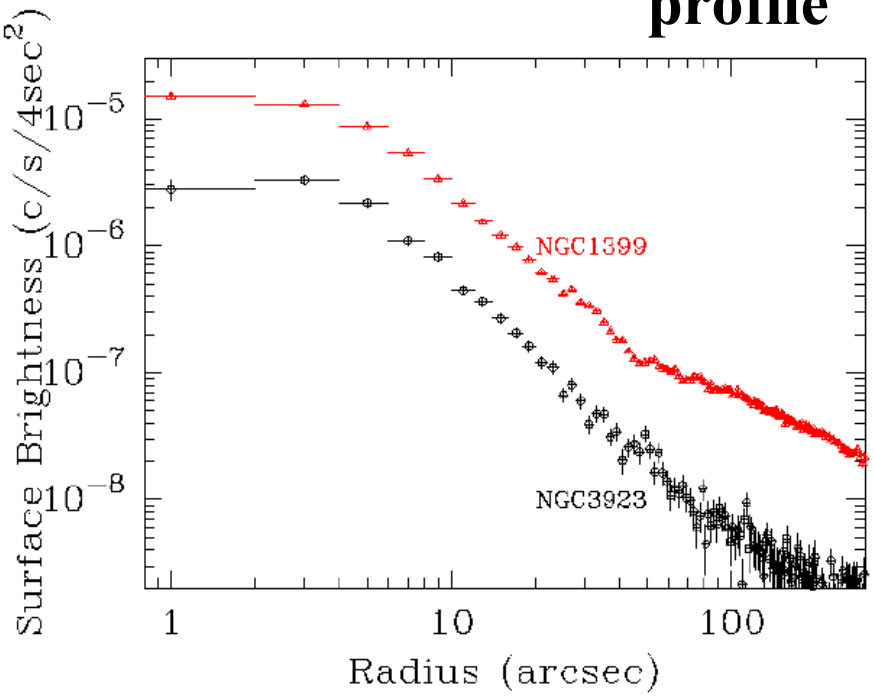


Two types of Egals

Temperature profile



X-ray surface brightness profile



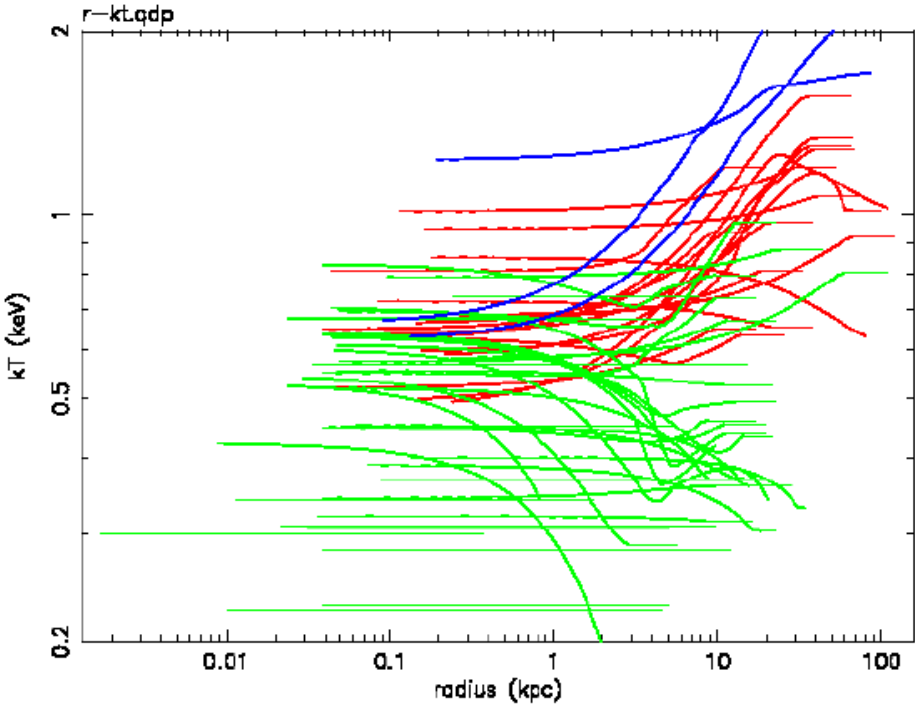
Profiles of all objects

Egals with $<10^{-3}cm^{-3}$at 10kpc

Egals with $>10^{-3}cm^{-3}$at 10kpc

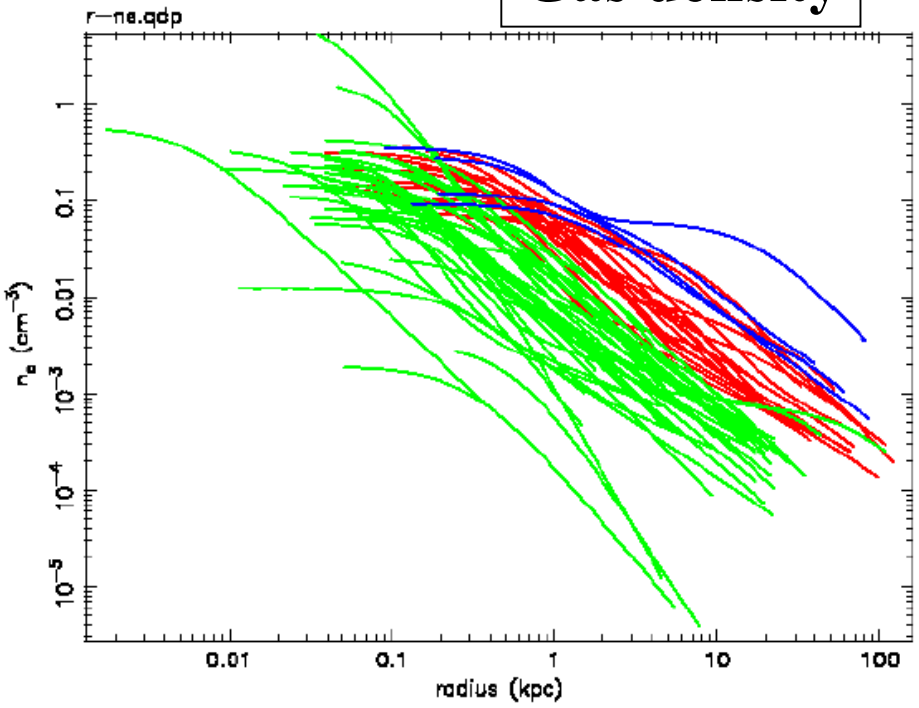
Galaxy clusters

kT



Radius (kpc)

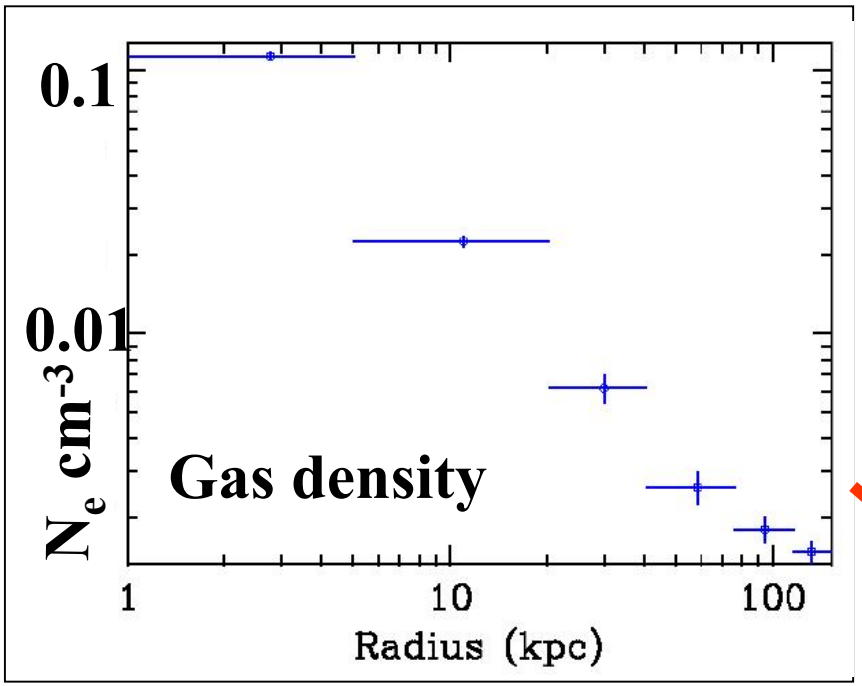
Gas density

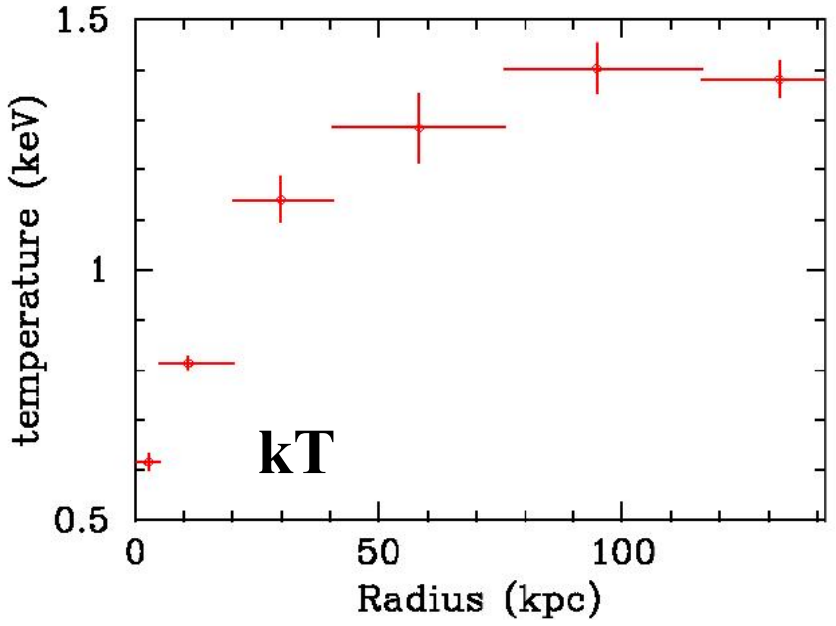


Radius (kpc)

X-ray bright Egals **certainly surrounded by the group emission**

X-ray faint Egals **only the galaxy ISM**



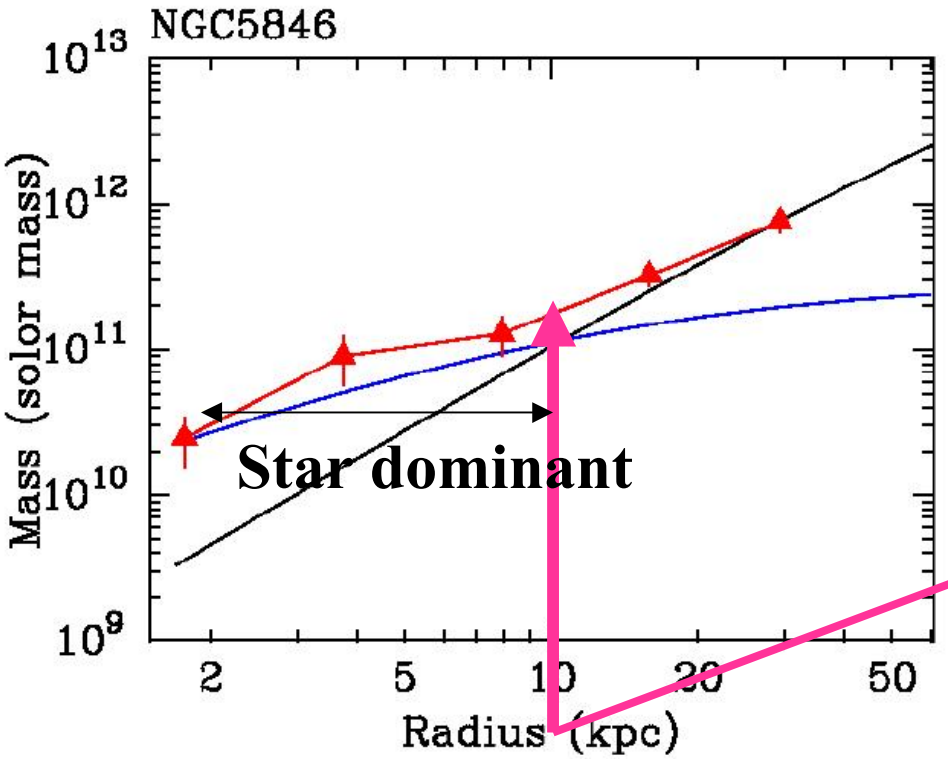


Deprojection analyses

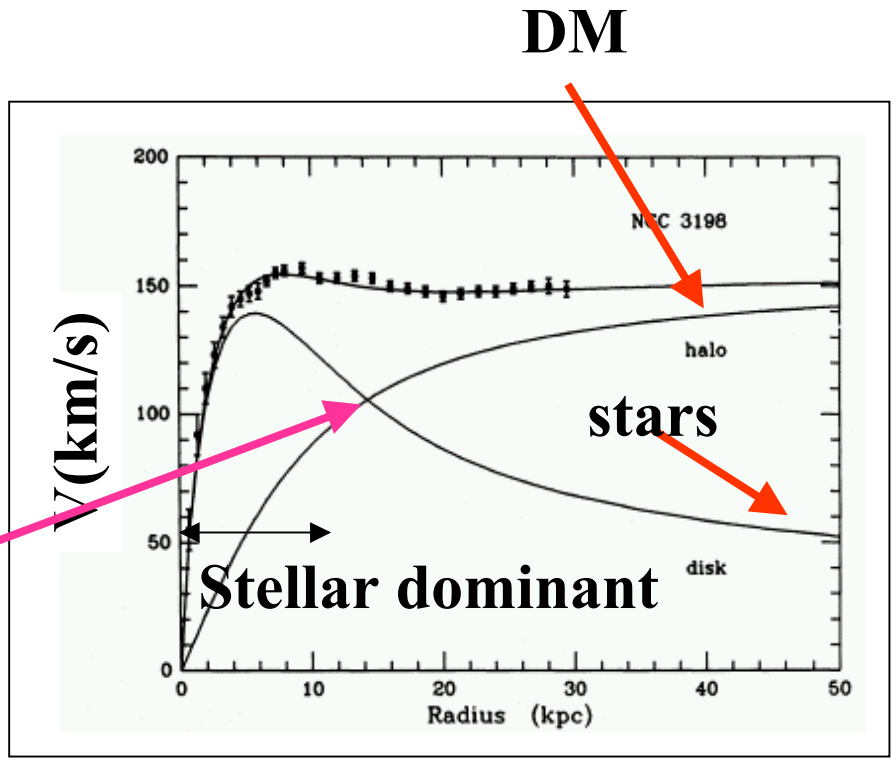
Total mass distribution

$$M_{tot}(R) = -\frac{kT(R)R}{\mu m_p G}\left(\frac{d\log n_{gas}(R)}{d\log R} + \frac{d\log T(R)}{d\log R}\right)$$

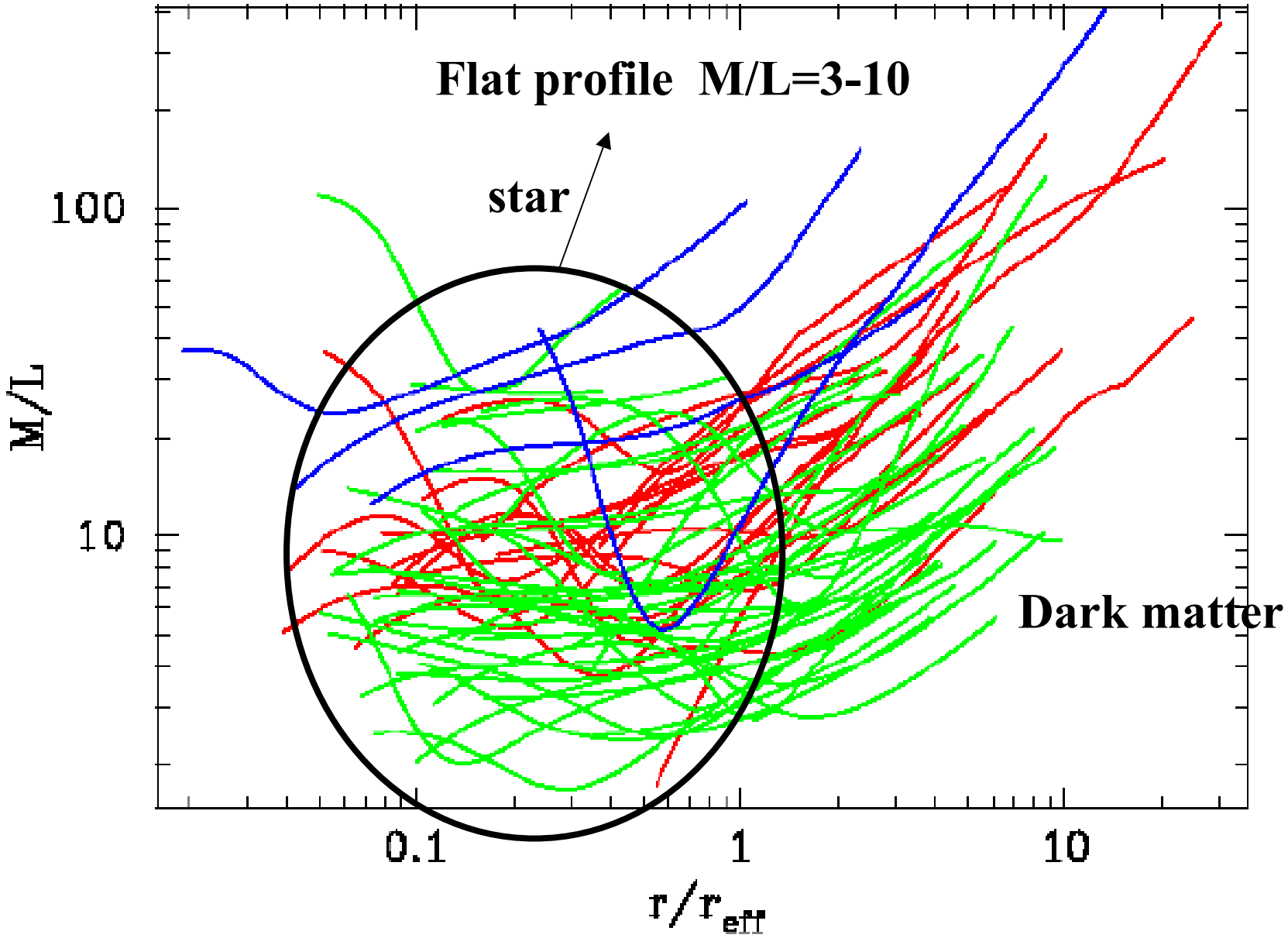
Example of mass profile



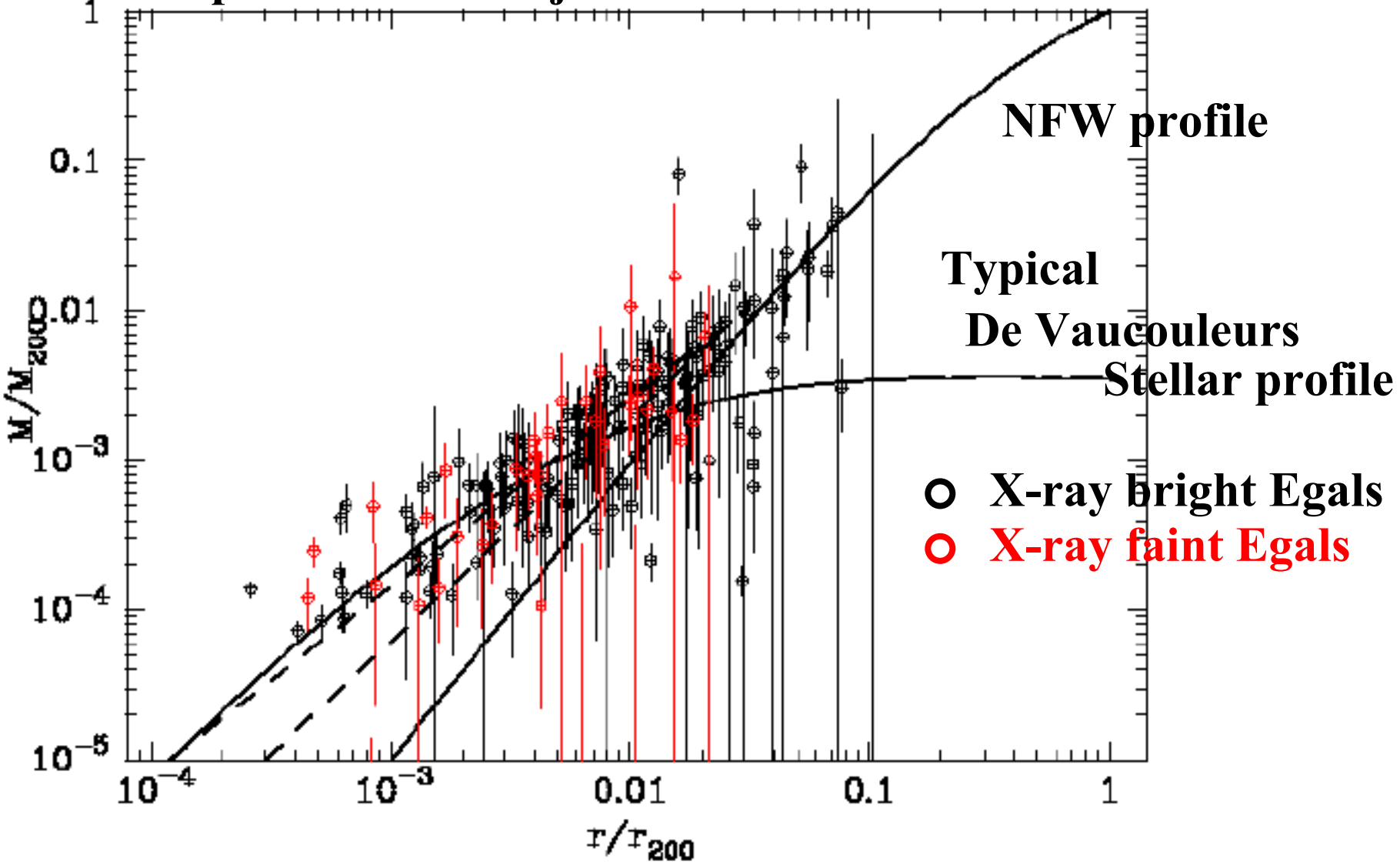
Rotation curve of spiral galaxy



Mass-to-light ratio profile



Scaled mass profiles of all objects



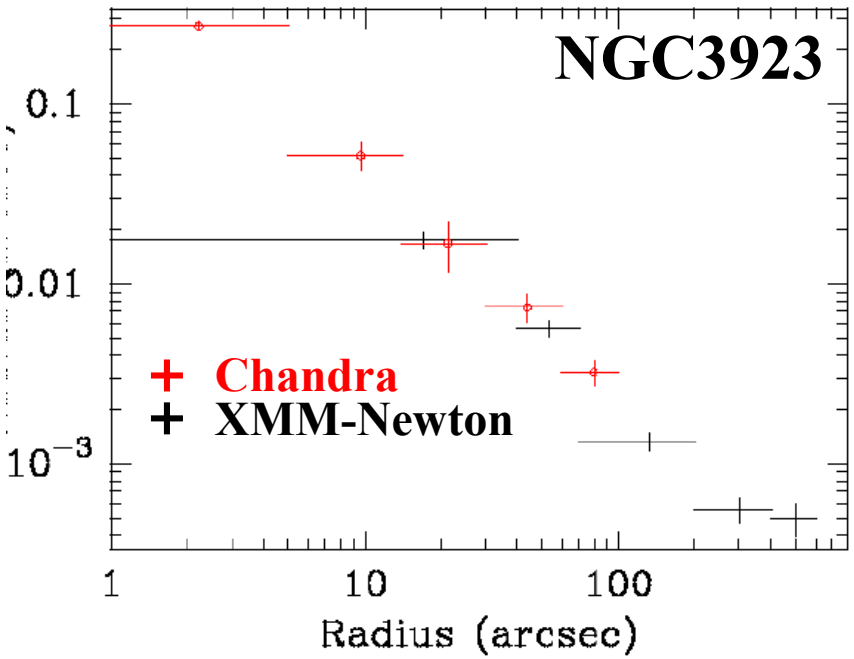
Two scales of gas distribution is due to the different scale of star and dark matter

Galaxy DM cannot be distinguished with group-scale DM.

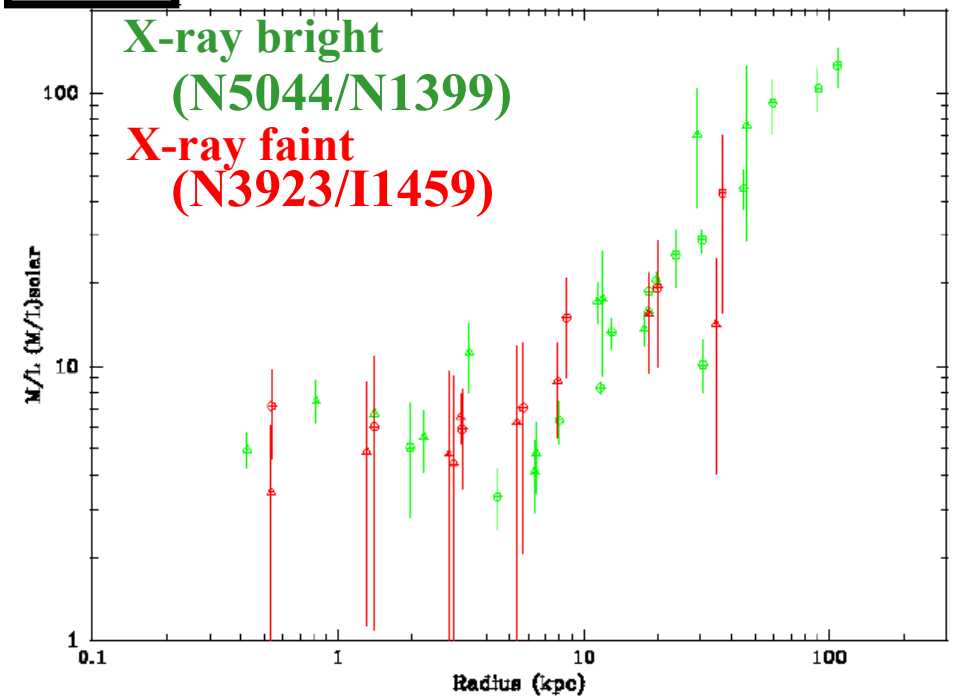
Combined with XMM-Newton data

in order to trace the mass at the outer region of X-ray faint Egals

Gas density



M/L



Radius(kpc)

X-ray faint Egals also have a dark matter ⟶ Group-scale hot gas?

Summary

ASCA data analyses of galaxy clusters

Two breaks in LT relation

at kT=4keV Non-gravity heating

at kT=1keV Low gas density

Two components of hot gas

galaxy-scale/cluster-scale

Chandra data analyses of Egals

X-ray bright Egals are certainly surrounded by the group emission

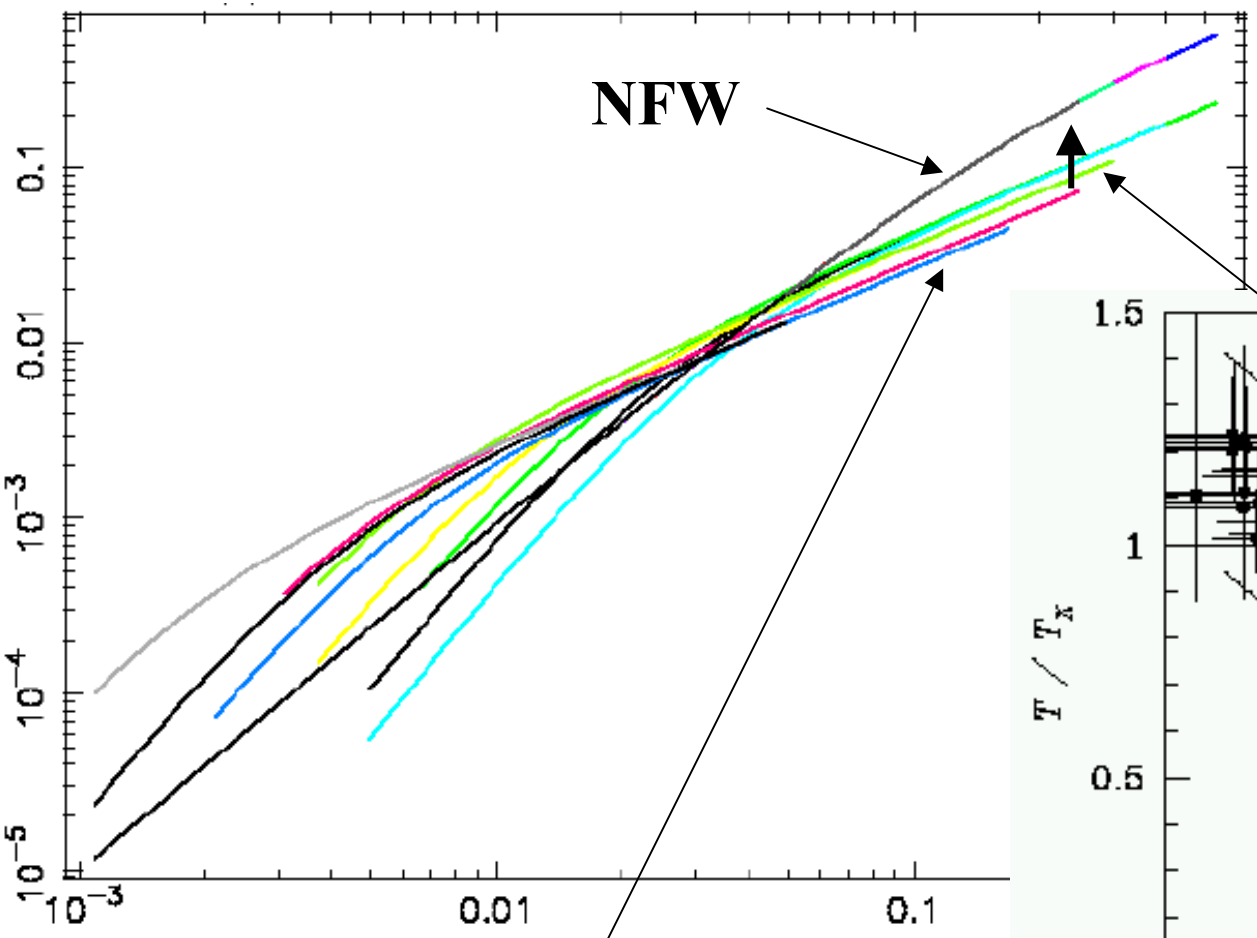
X-ray faint Egals are not.

Two scales of gas distribution is due to the different scale of star and dark matter

Do X-ray faint Egals have a group-scale gas?

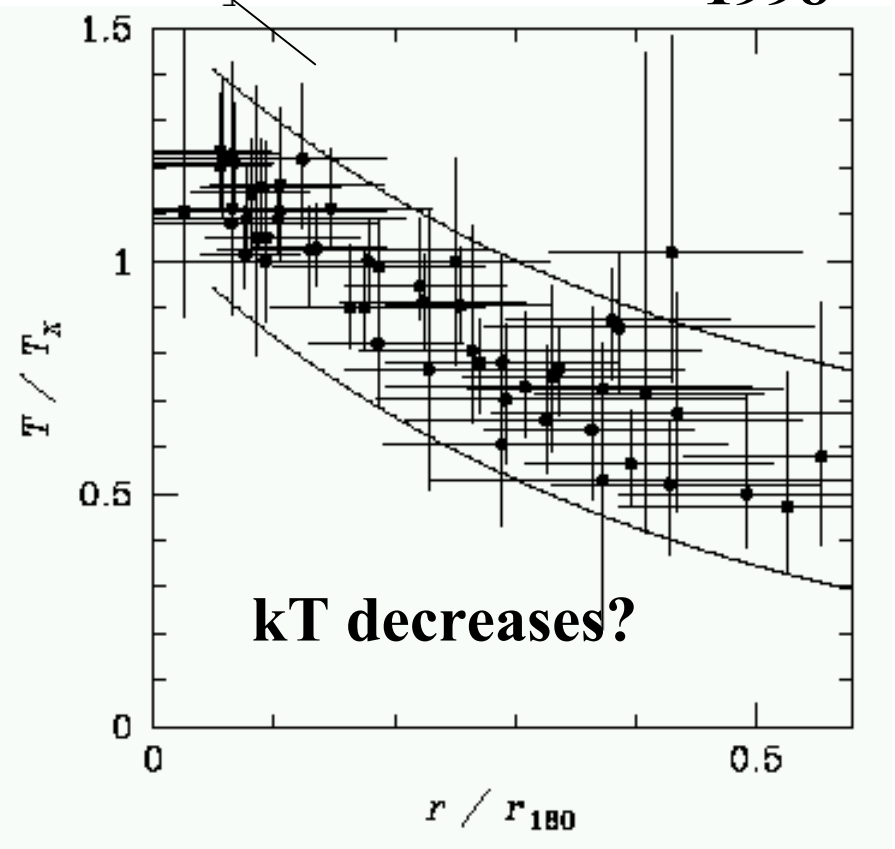
ASCA results

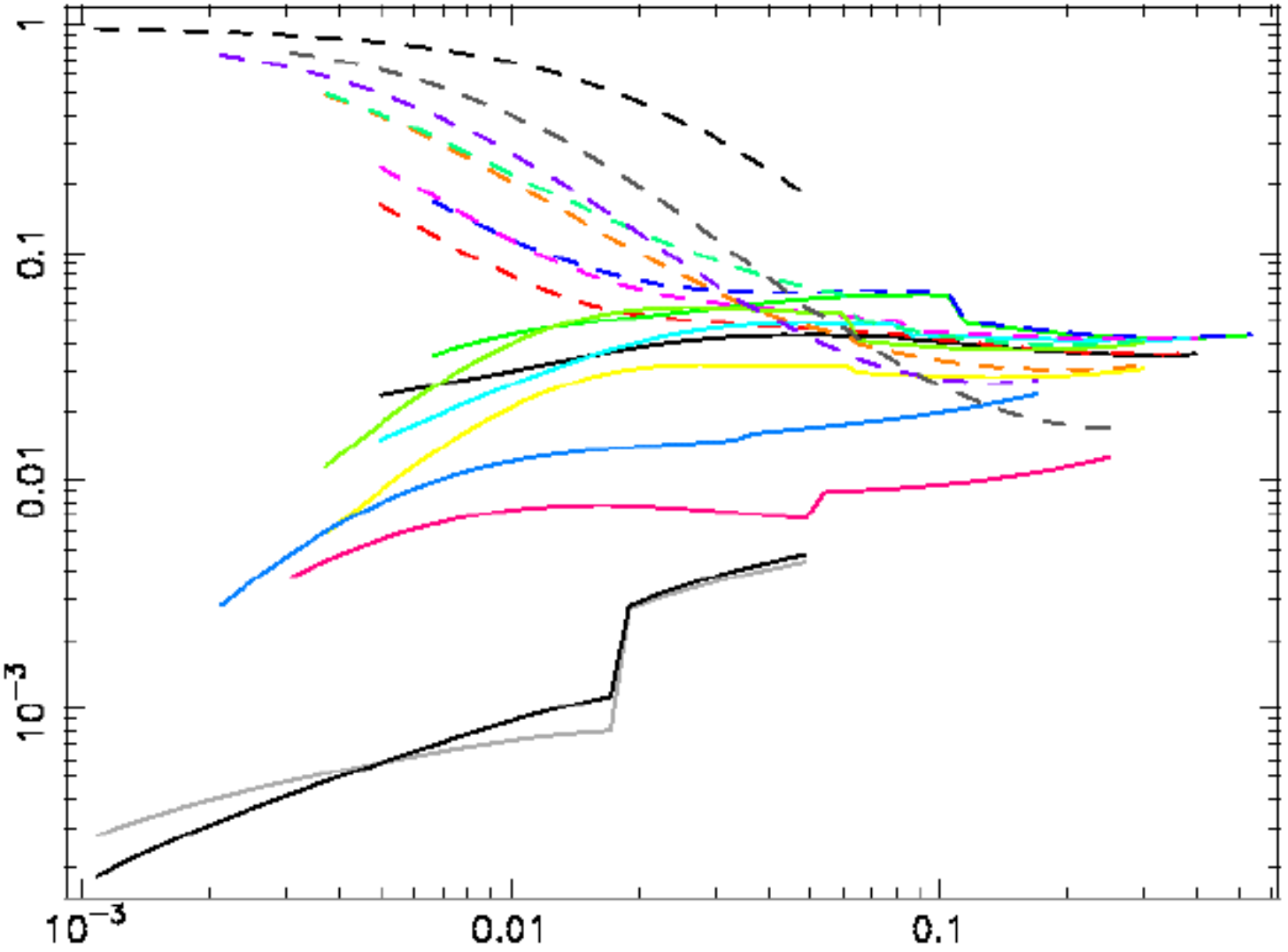
Deprojection technique cannot be applied

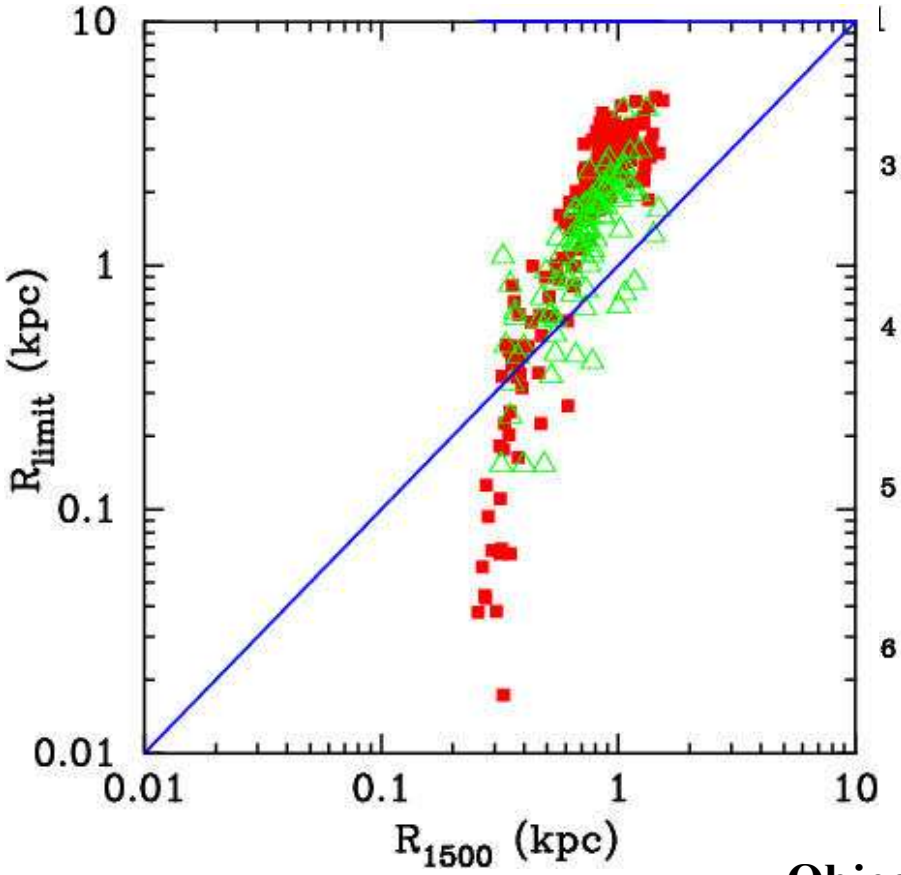


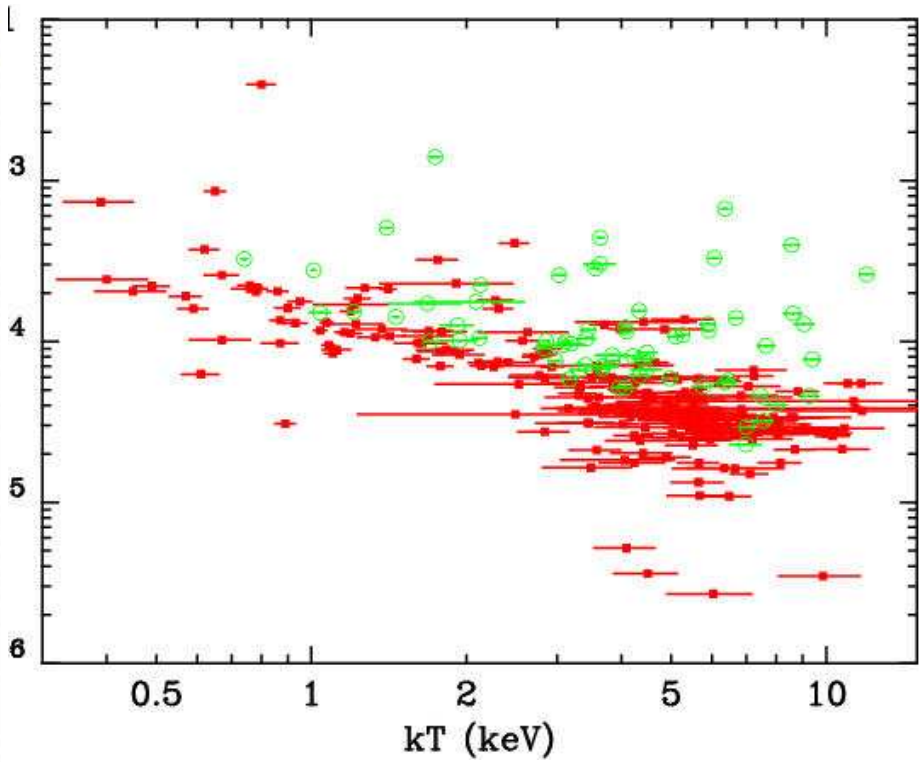
Total mass from
Isothermal beta model fits

Markevitch et al.
1998




1
0.1
0.01
10^{-3}
10^{-3}
0.01
0.1

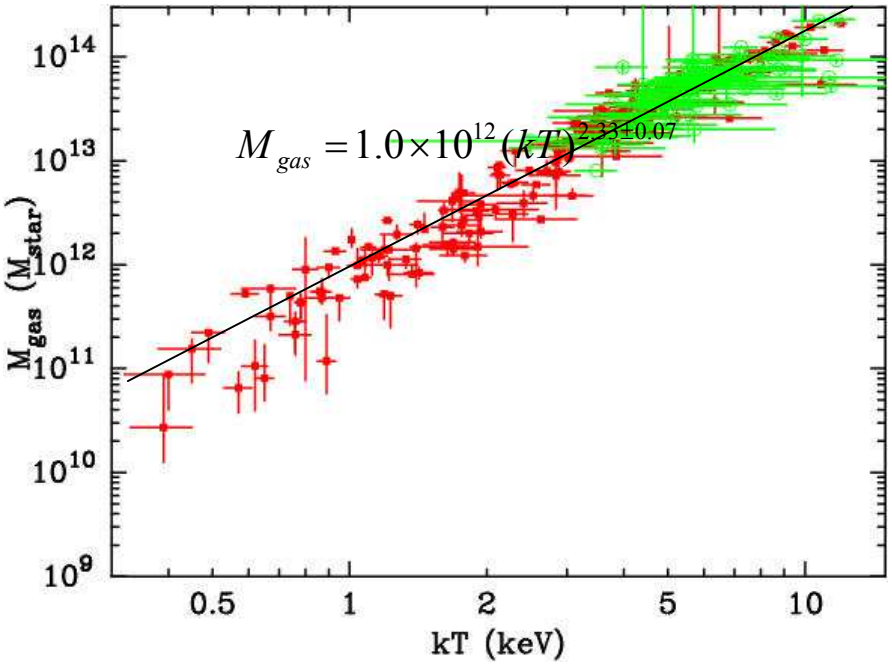




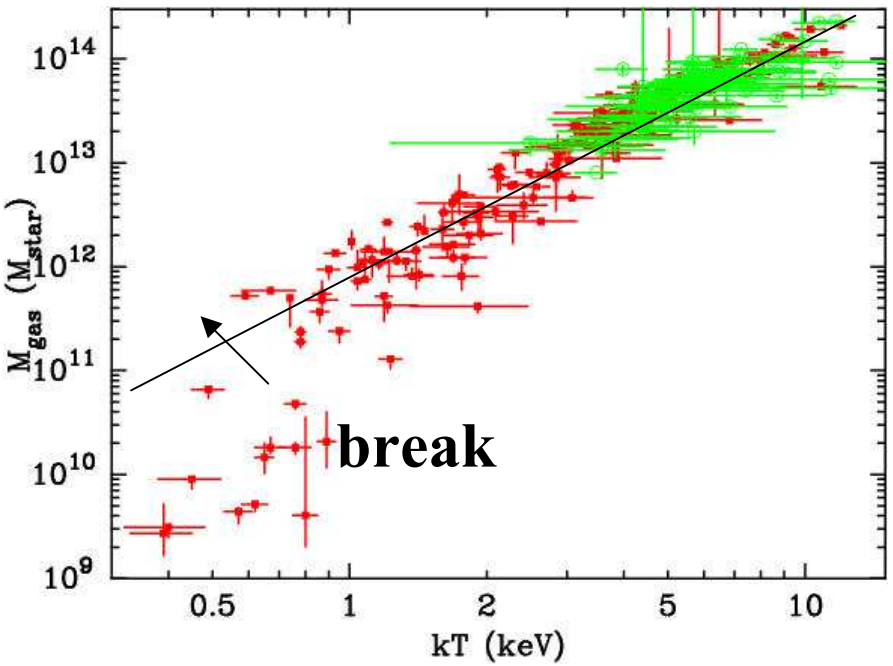
△

Objects whose X-ray emission is beyond the GIS field of view

Gas mass within R_1500 vs kT



Gas mass within Rlimit vs kT

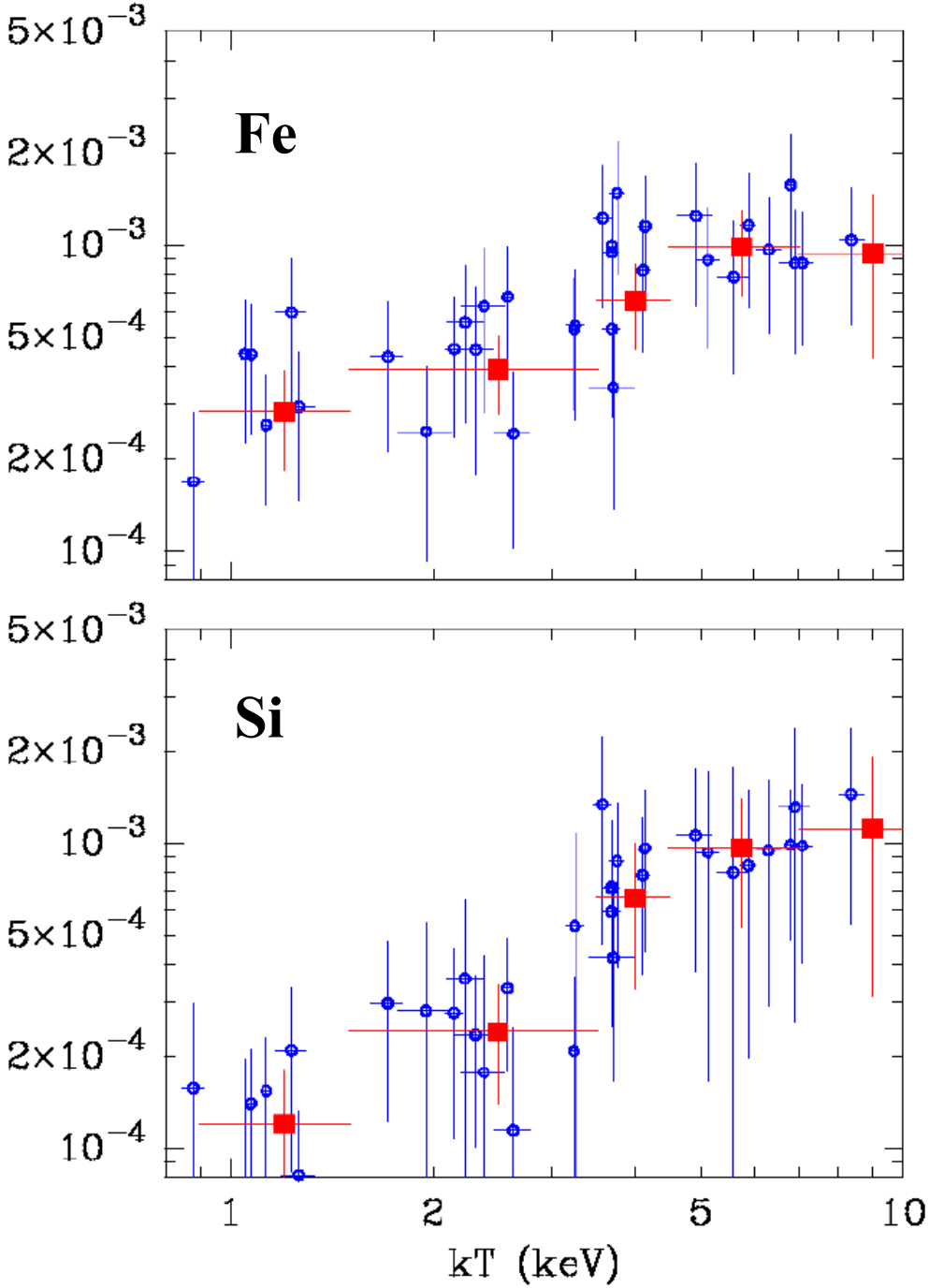


z>0.2

z<0.2

$M_{メタル}/M_{星}$

システムによらず一定と
考えられる



少なくとも多くのシリコンは
小規模銀河団から逃げて
いる

銀河団形成が先か？
銀河風が吹いたのが先か？

銀河群

cold dark matter

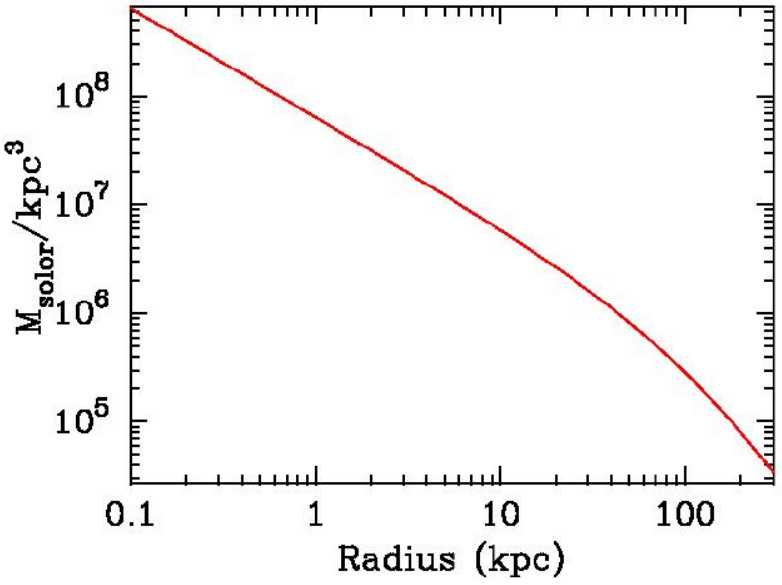
NFWモデル

$$\rho_{NFW} = \frac{\delta_c \rho_{crit}}{(r/r_s)(1+r/r_s)^2}$$

δ_c : 密度パラメーター

r_s : スケール半径

ρ_{crit} : 宇宙の臨界密度



$$M_{gas}(R) = \int_0^R 4\pi R'^2 \, \mu m_p n_{gas} dR'$$

球対称　静水圧平衡

$$\nabla P_{gas} = -\rho_{gas} \nabla \phi$$

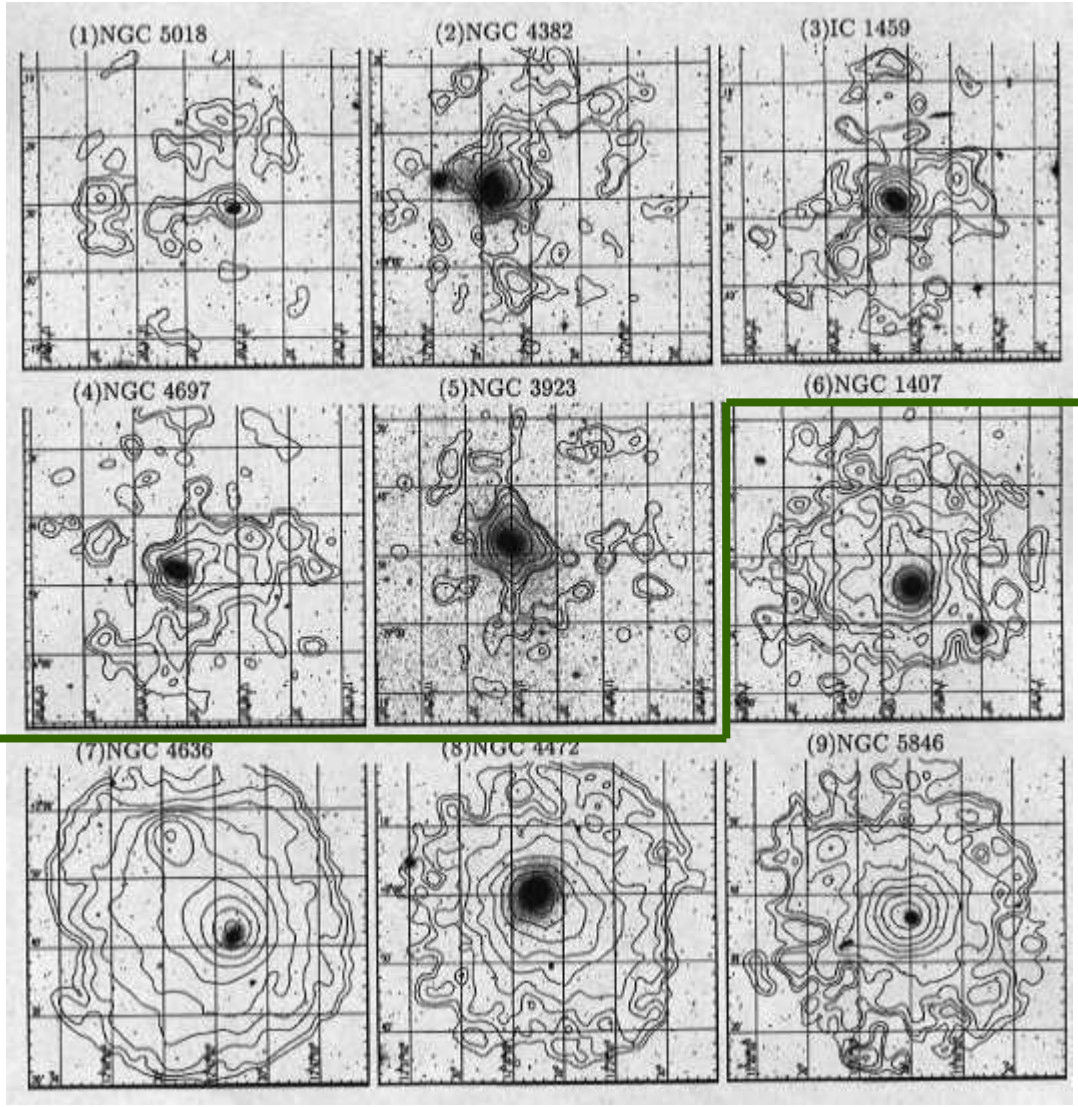
$$M_{tot}(R) = -\frac{kT(R)R}{\mu m_p G}\left(\frac{d \log n_{gas}(R)}{d \log R} + \frac{d \log T(R)}{d \log R} \right)$$

楕円銀河(Egal)

ASCA image(Matsushita D)

X線で暗いものは、
X-ray Compact

X線で明るいものは、
X-ray Extended



ASCA GISのデータ

銀河団、銀河群、楕円銀河　　約200個（z<0.2）

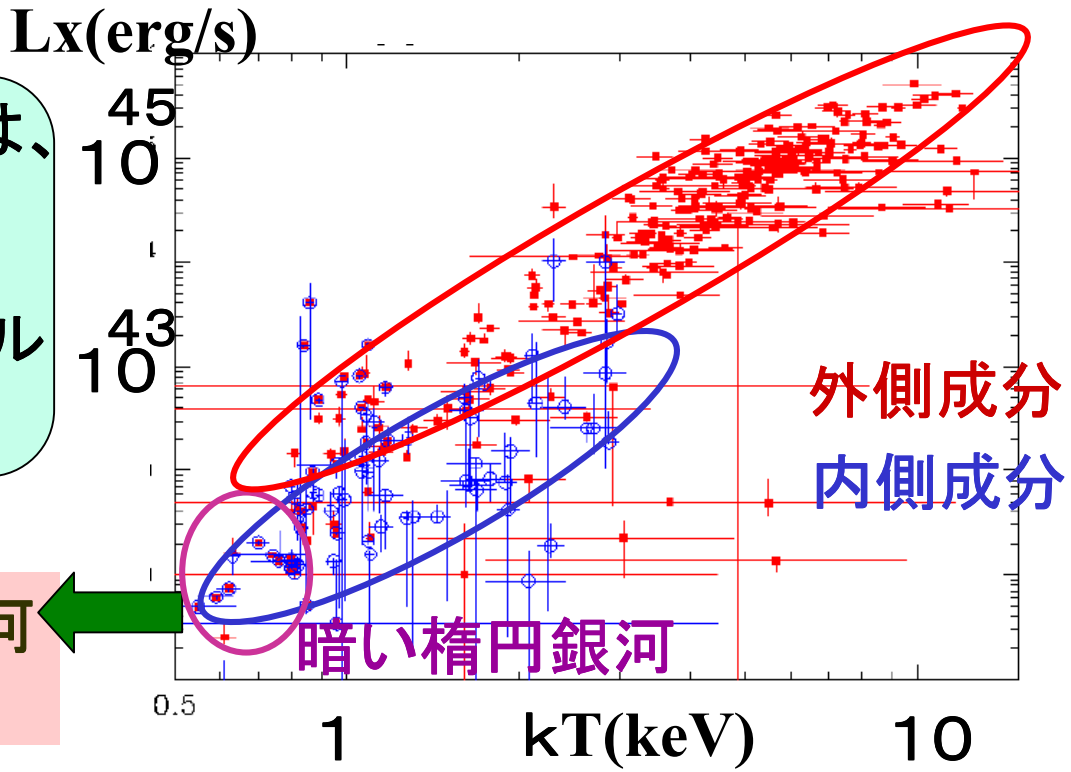
同一手法で統一的に解析

解析手法や検出器によるシステマティックな違いなし

１βか２βモデルでフィット（２βの場合、内側成分は、
β=0.7, コア半径=10kpc固定）

２βが必要とされるときは、
そのパラメータを採用

中心部を除いたスペクトル
から、温度決定



内側成分は、暗い楕円銀河
の延長上にある。

ASCA GISの銀河団、銀河群、楕円銀河の約200個の
データを系統的に解析

多くの銀河群は2βモデルで表される

内側成分（中心銀河付随）は、
暗い楕円銀河の延長上

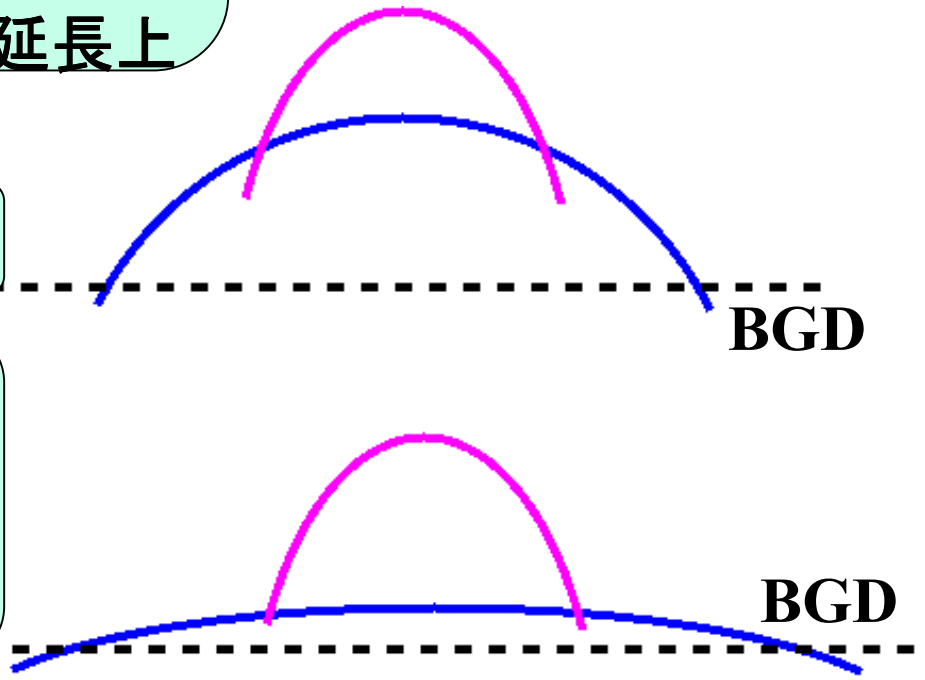
外側成分（銀河群スケール）は
銀河団の延長上

銀河群のX線光度のばらつきは、外側までガスが見えていないものがあるため

明るい楕円銀河＝銀河群

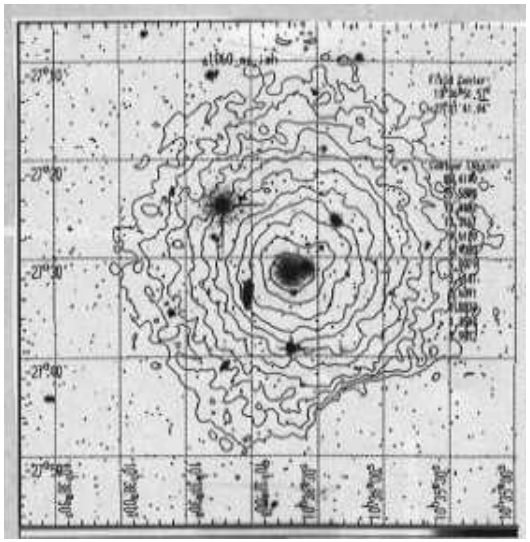
暗い楕円銀河は？

外側の銀河群スケールの
成分のガス密度が低すぎて
見えないだけの可能性



A1060 → 重力ポテンシャルを調べやすい

中心は複雑でない
温度一定

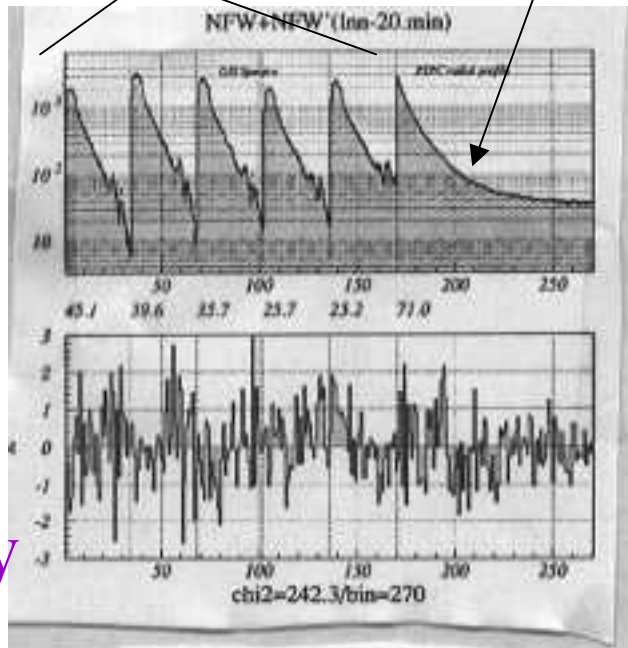


2つを同時フィット

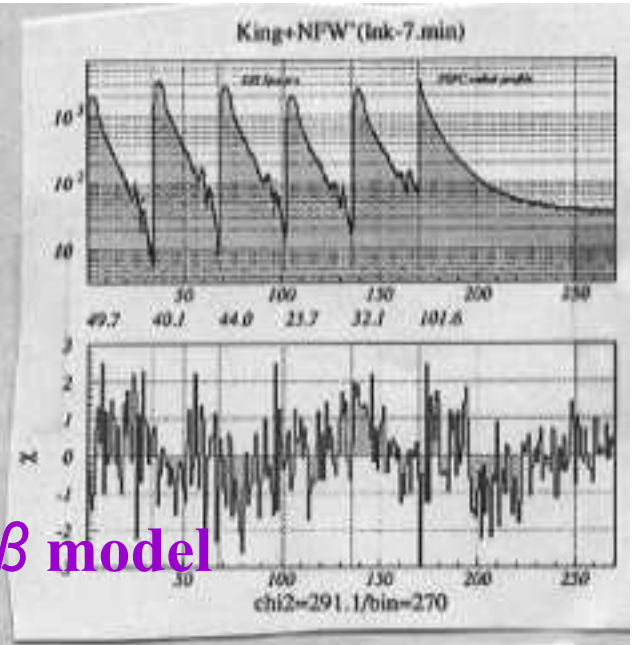
「あすか」の各半径のスペクトル

ROSATの輝度分布

田村D



NFW



β model

Table 5.7: Model parameters of mass calculations.

model	r_s^{tot} or r_{rms} (arcmin.)	η	r_s^{gas} (arcmin.)	B	n	χ^2/ν
$NFW + NFW'$	14′.6	1.0(fix)	35′.6	10.2	0.97	242/262
$NFW' + NFW'$	100′(fix)	1.53	35′.1	10.1	0.97	248/262
$King + NFW'$	5′.86	–	36′.1	10.4	0.97	291/262

NFW is prefered