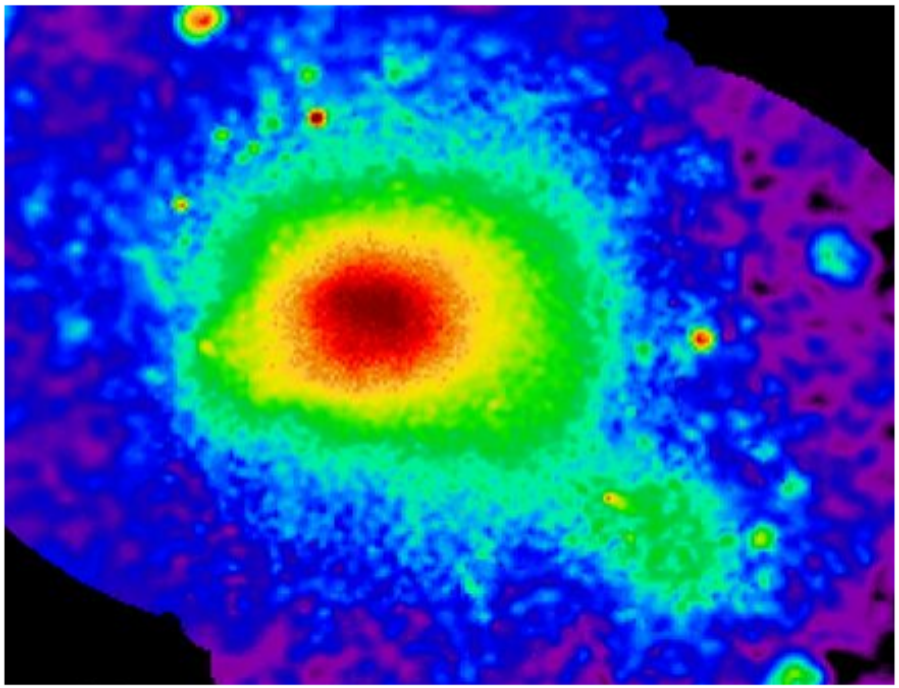
Galaxy clusters outskirts: what, why, how



Stefano Ettori
(INAF-OA Bologna)

SCIENTIFIC JUSTIFICATION

To characterize the thermodynamic of the X-ray emitting plasma at the virial radius

WHY

- ✓ To calibrate the masses (gas and dark matter) in local galaxy clusters to use them as cosmological probes

$$M_{tot}(< r) \propto r \times T_{gas}(r) \times (-\alpha_n - \alpha_T)$$

- ✓ When and how is entropy injected into the Inter-galactic medium (IGM)?
- ✓ What is the history of metal enrichment of the IGM?

SCIENTIFIC JUSTIFICATION

To characterize the thermodynamic of the X-ray emitting plasma at the virial radius

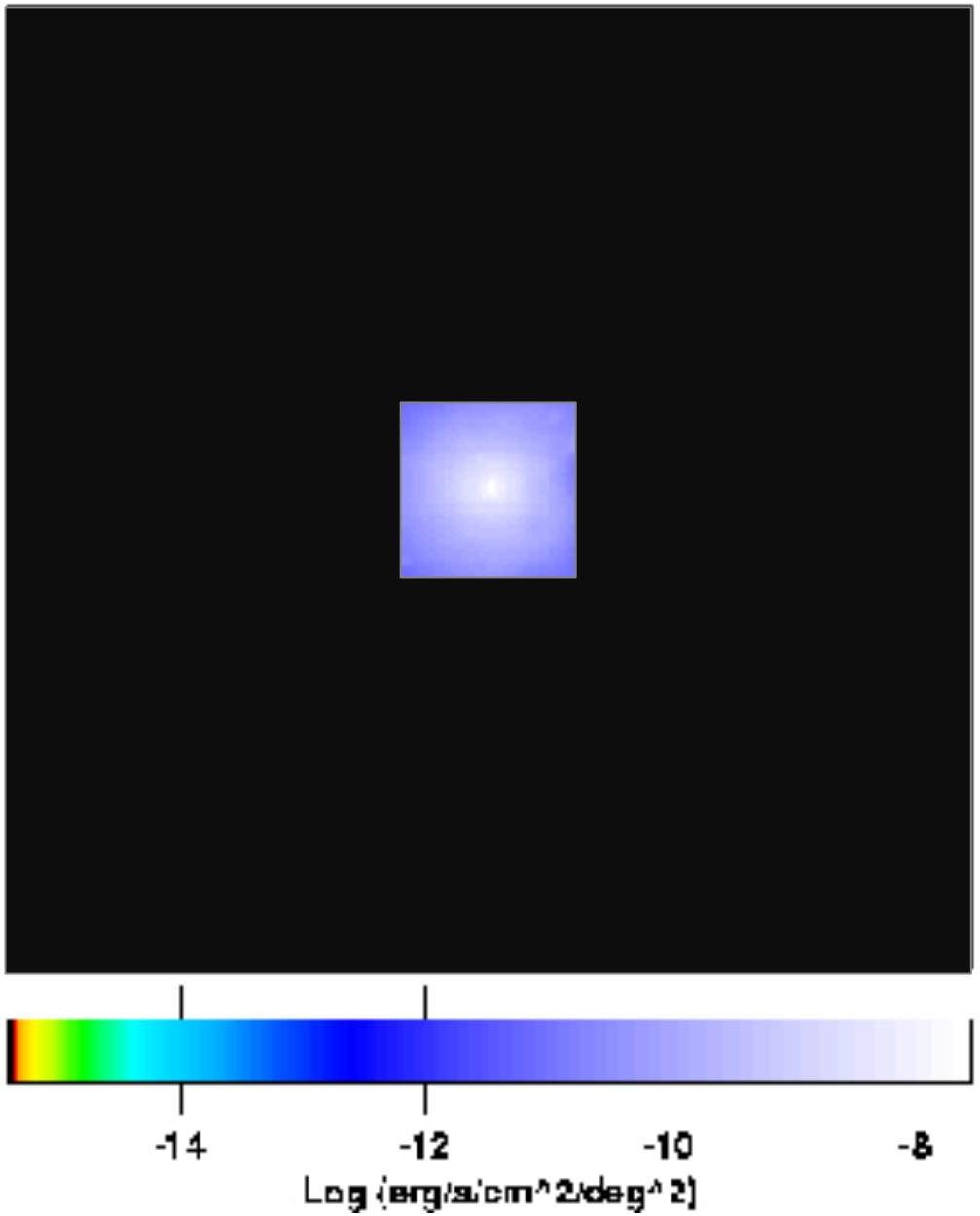
HOW

- ✓ Which $S_{b,}$ n_{gas} and T values do we expect at R_{vir} ?
- ✓ Are simulated X-ray clusters consistent with the observed ones in the outskirts in terms of average values & scatter ?

ICM at R_{200}: *S_b of simulated clusters*

R_{2500}

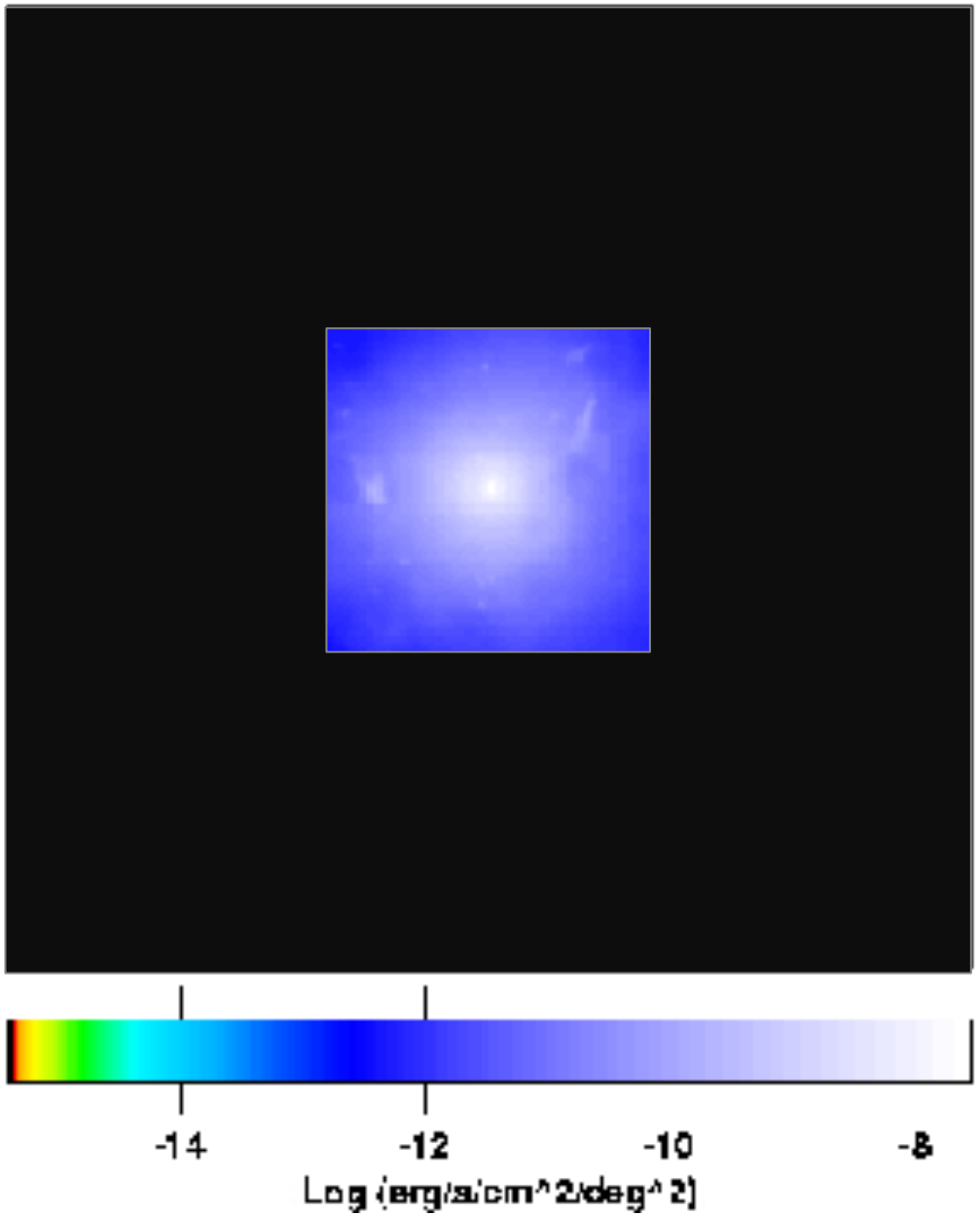
($\sim$0.3 R_{200}
$\sim$CXO limit)



ICM at R_{200}: *S_b of simulated clusters*

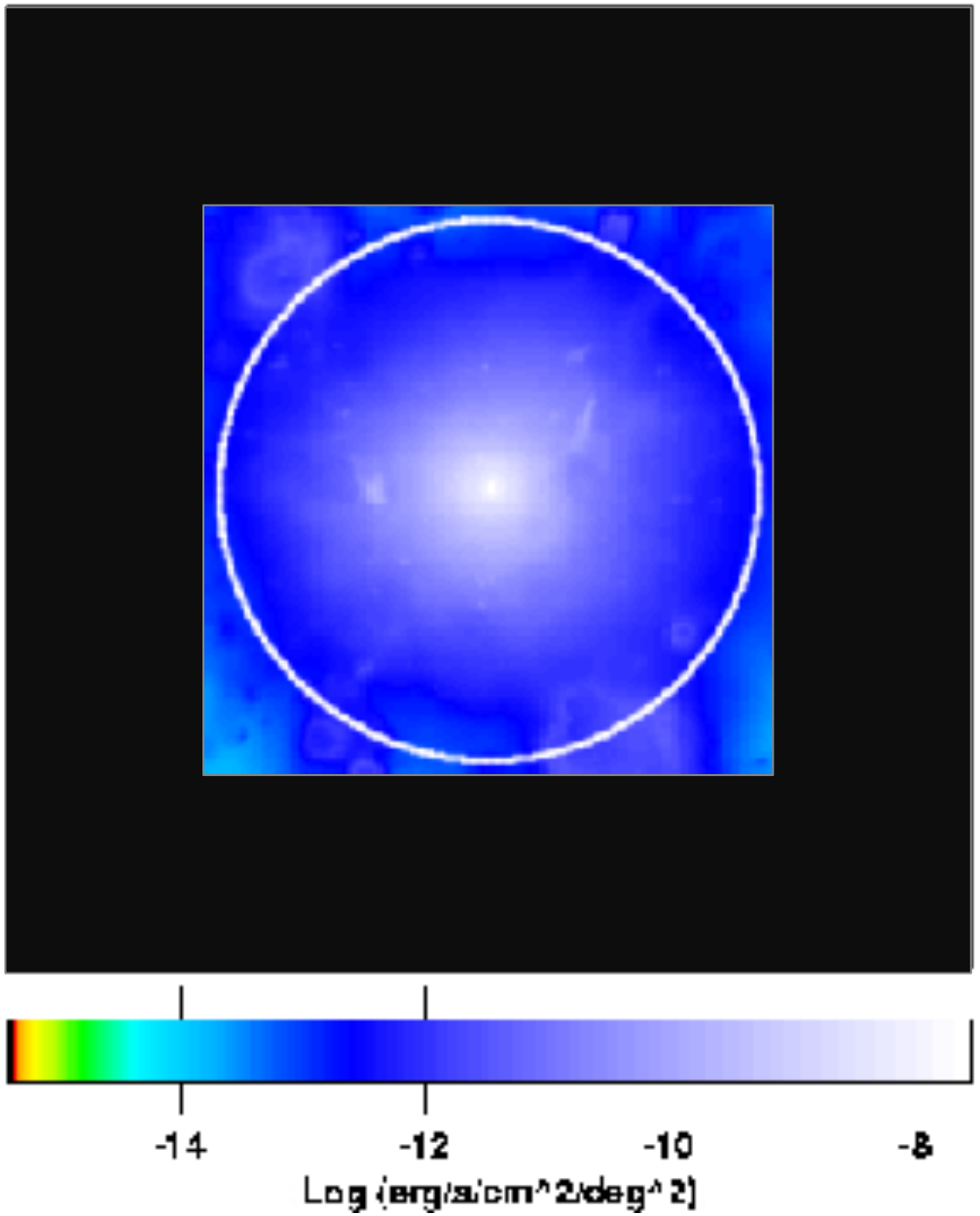
R_{500}

(~0.7 R_{200} ~few best CXO & XMM cases)

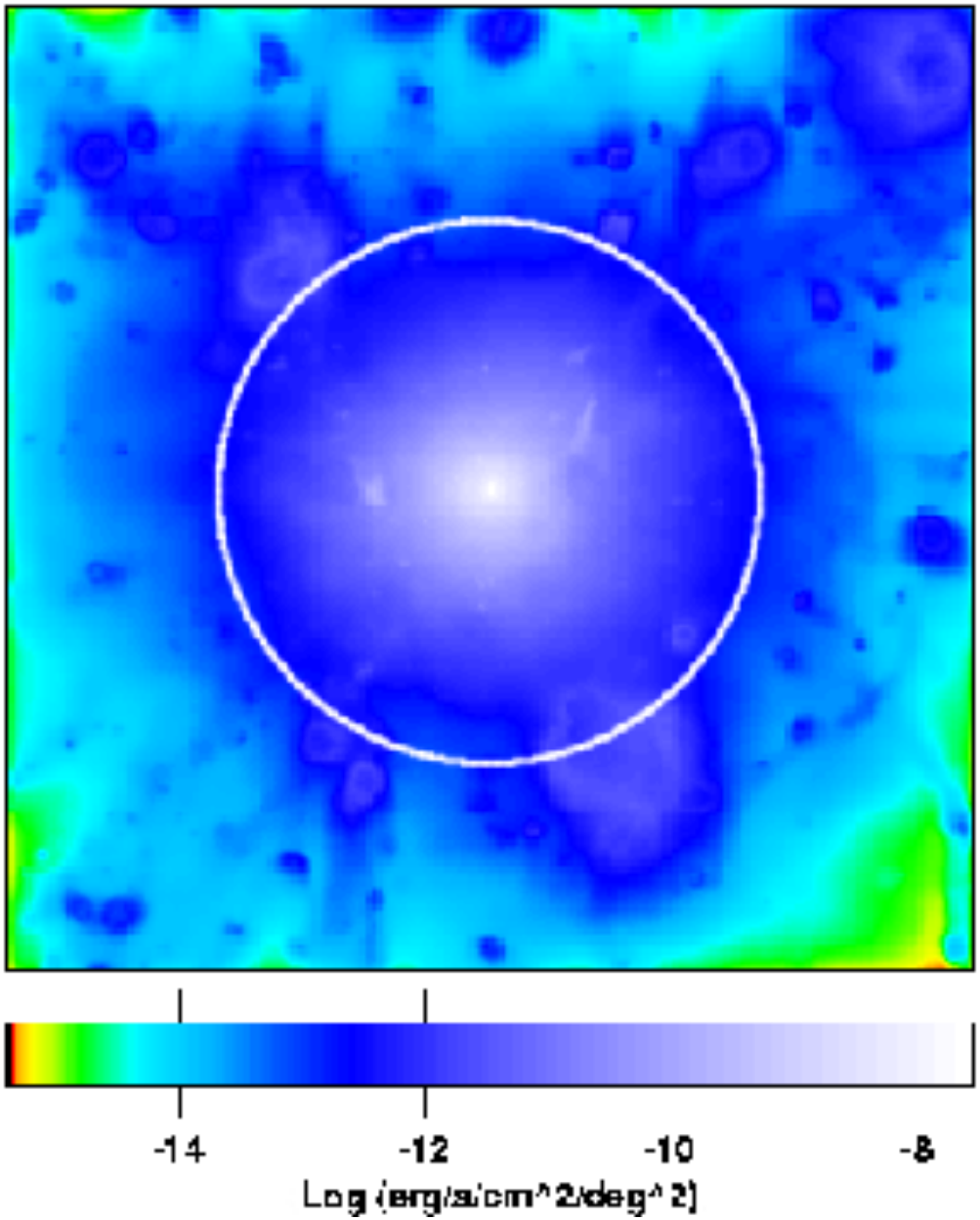


ICM at R_{200}: *S_b of simulated clusters*

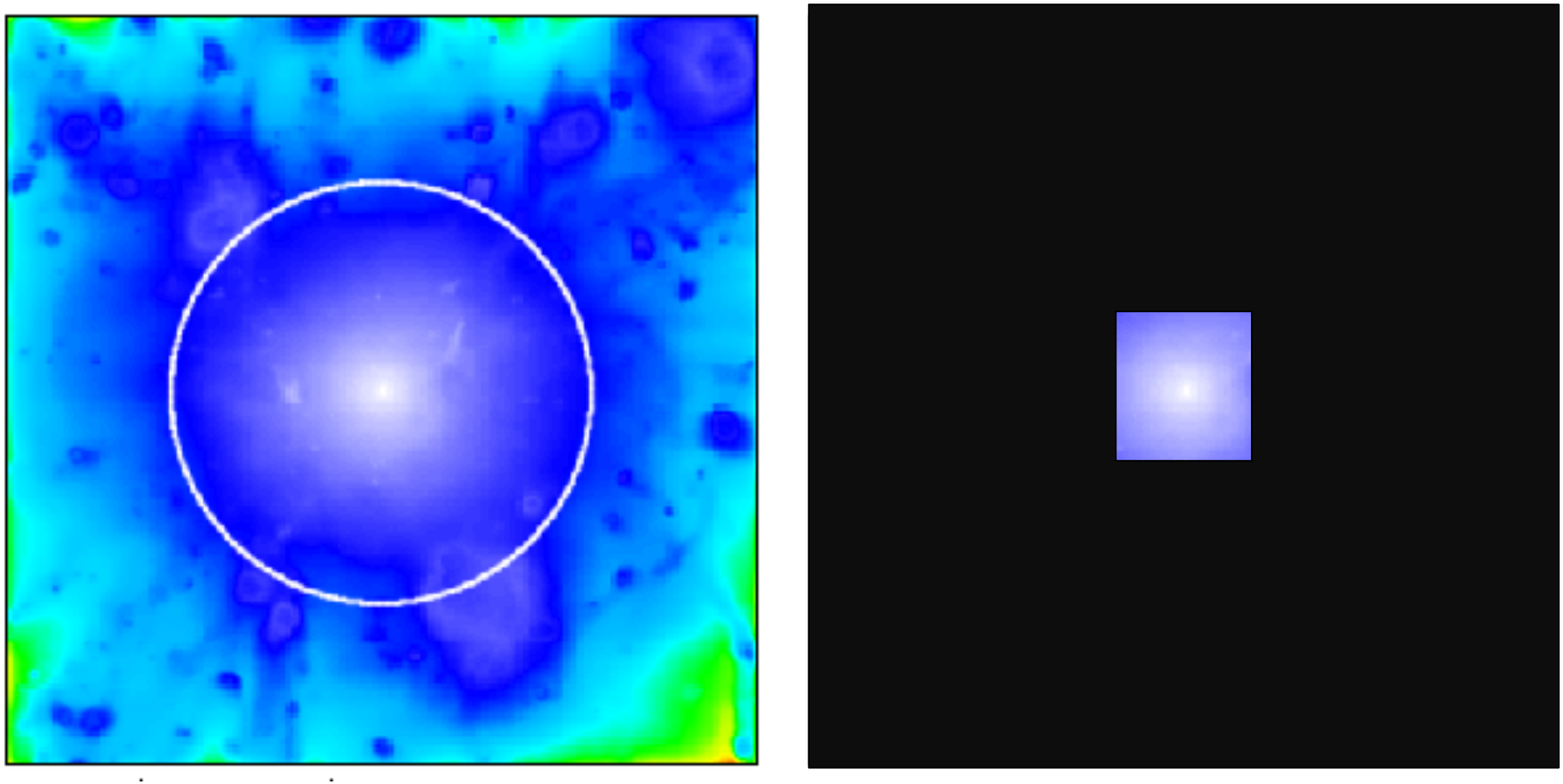
R_{200}



ICM at R_{200}: *S_b of simulated clusters*

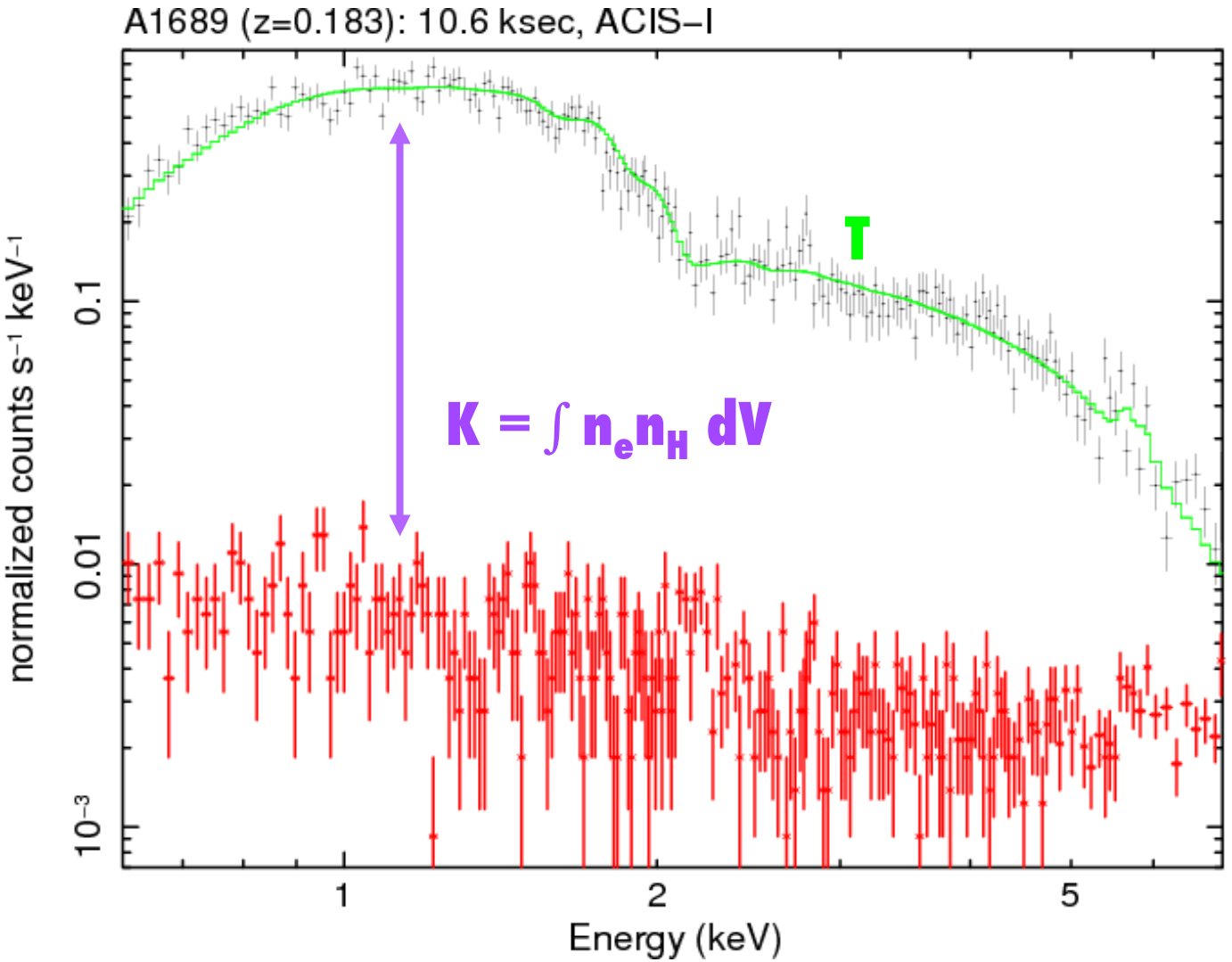


What limits the observations at R_{200}?

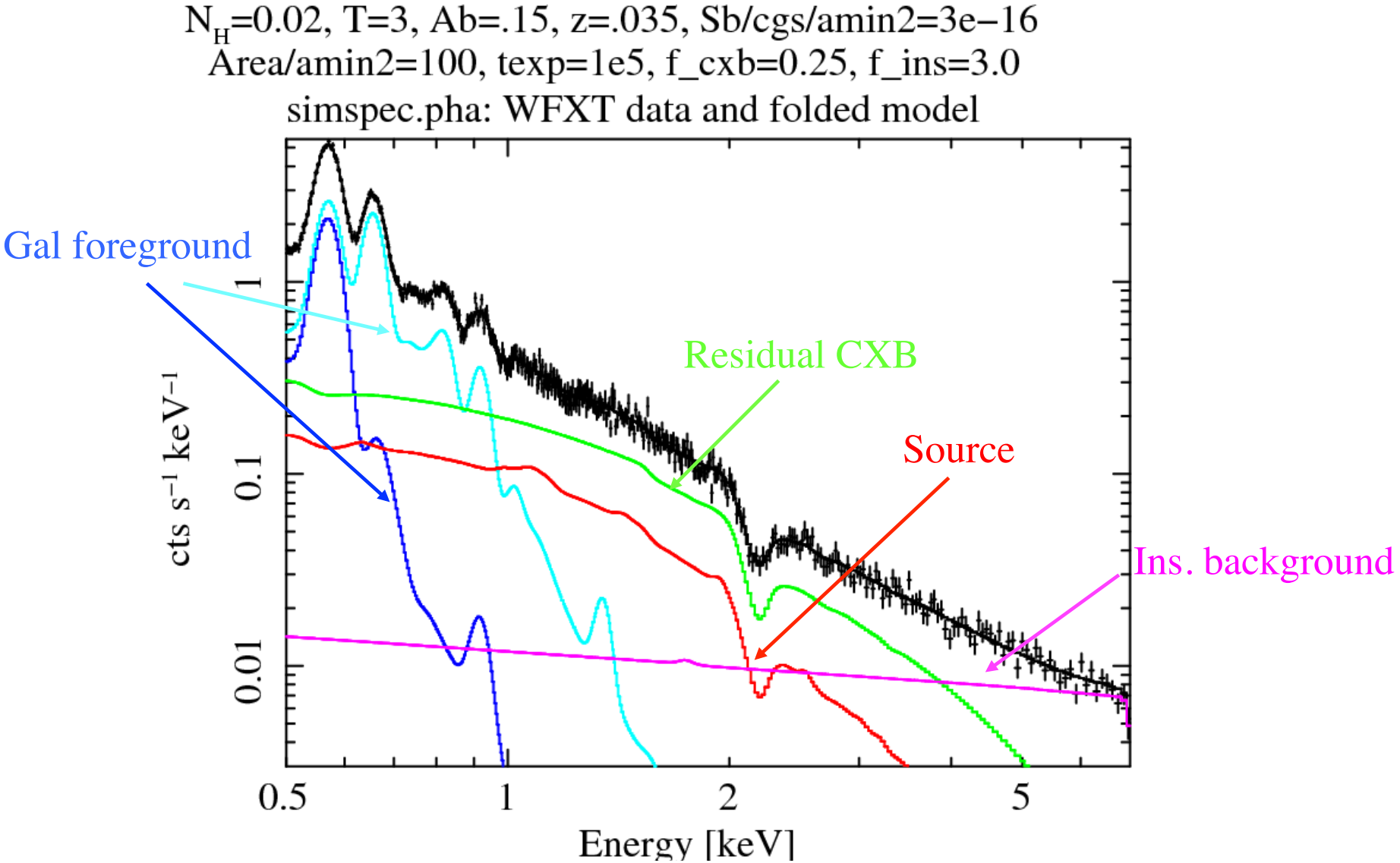


Surface brightness in hydro-simulated clusters
(from Roncarelli, Ettori et al. 2006)

X-ray total mass: *the observables*



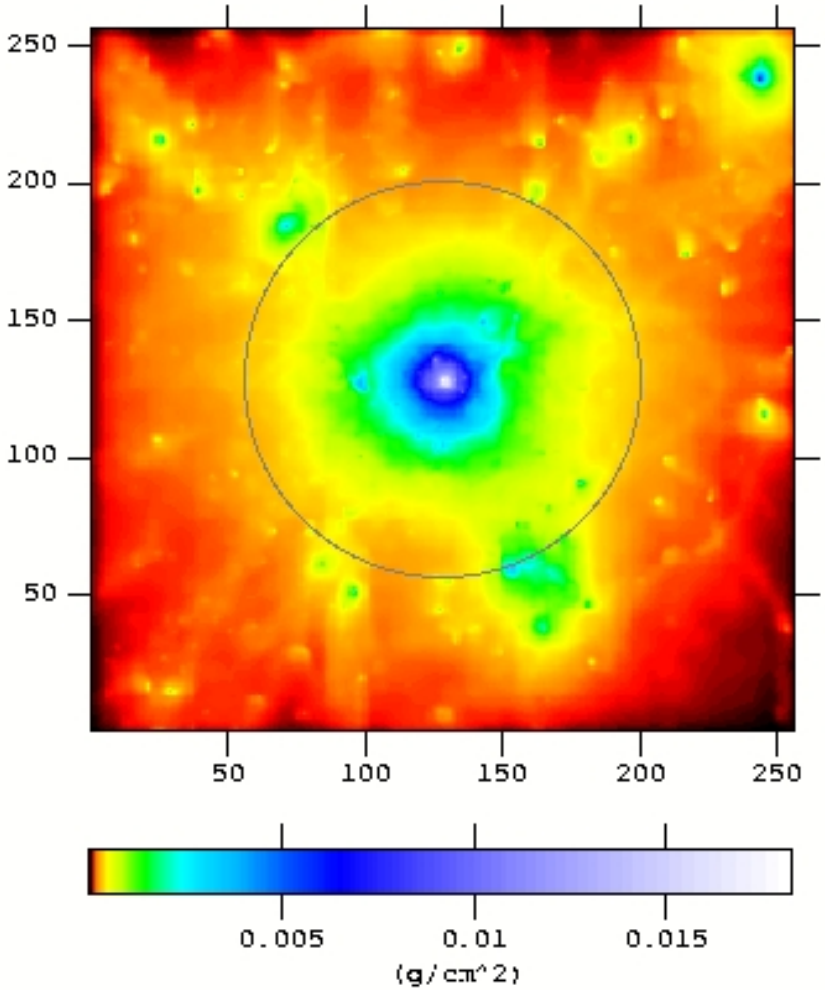
Bkg: dominant in GCs outskirts

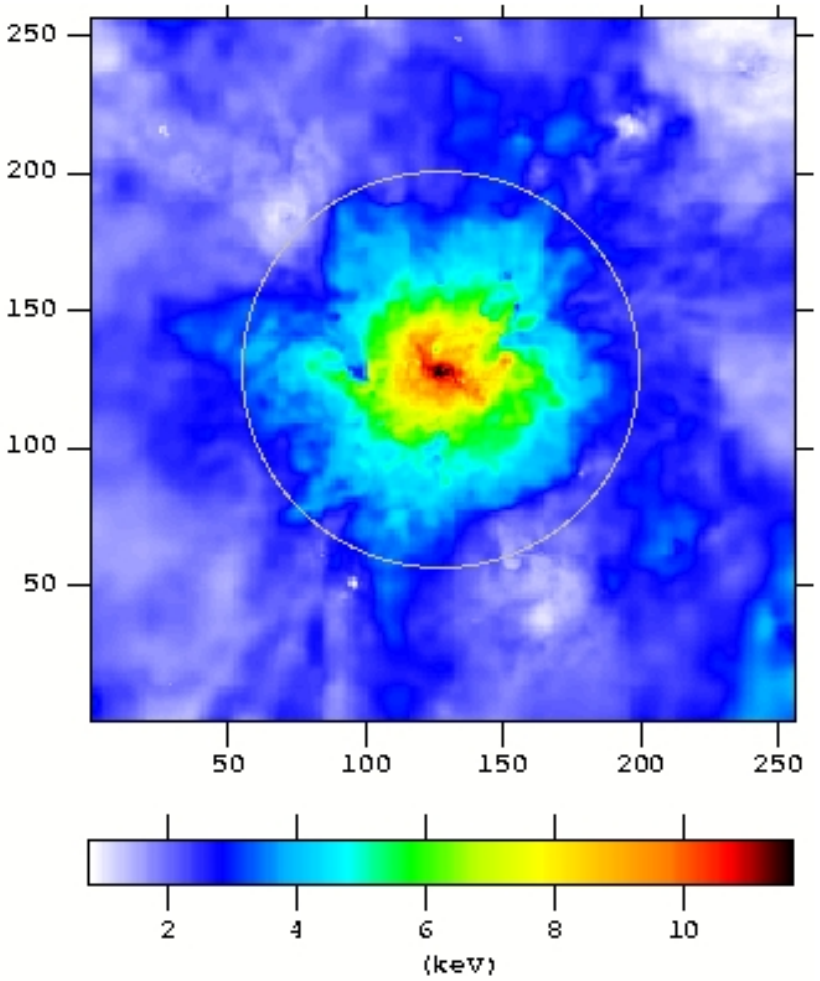


Simulation for 3keV cluster @ R200

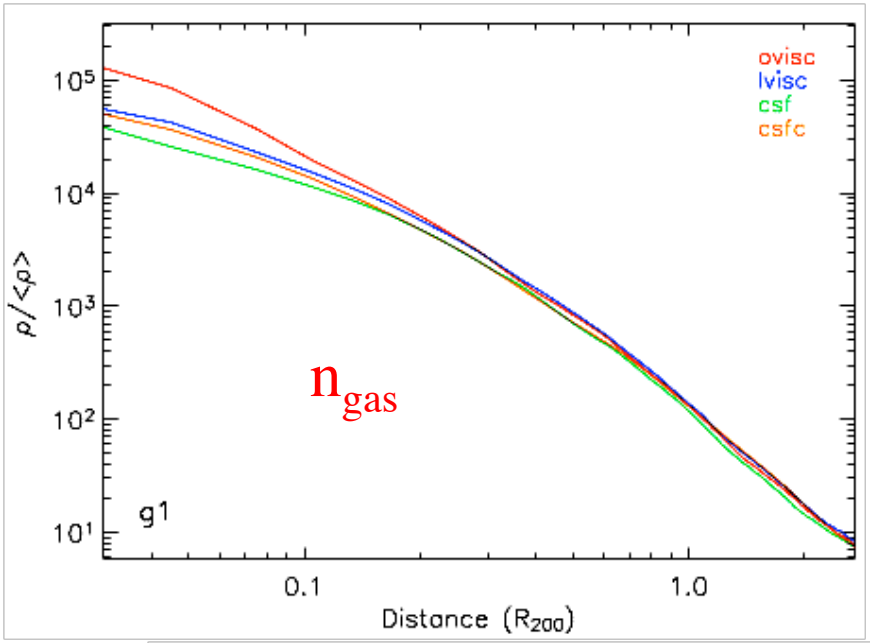
ICM at R_{200}: *Simulated clusters*

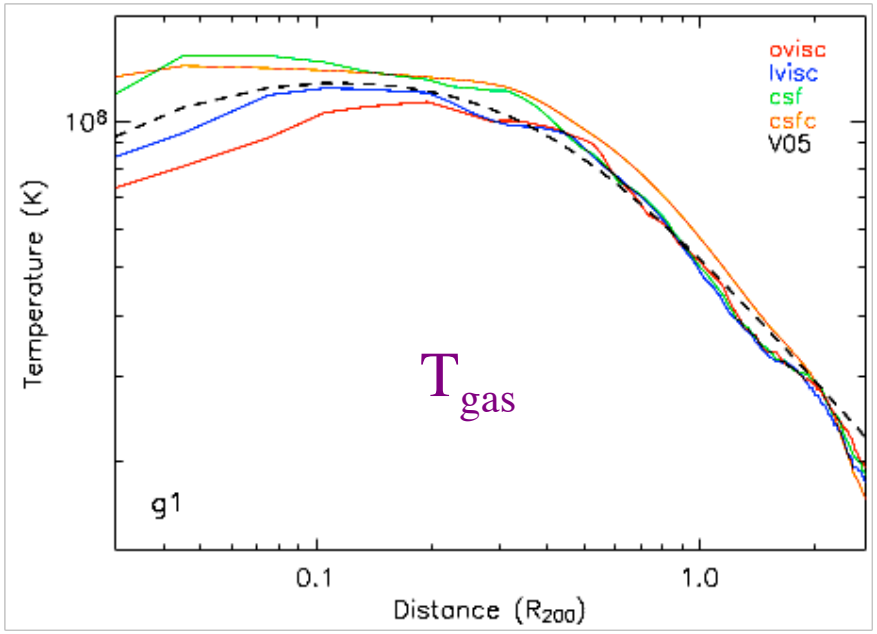
n_{gas} Roncarelli, Ettori et al 06 T_{gas}

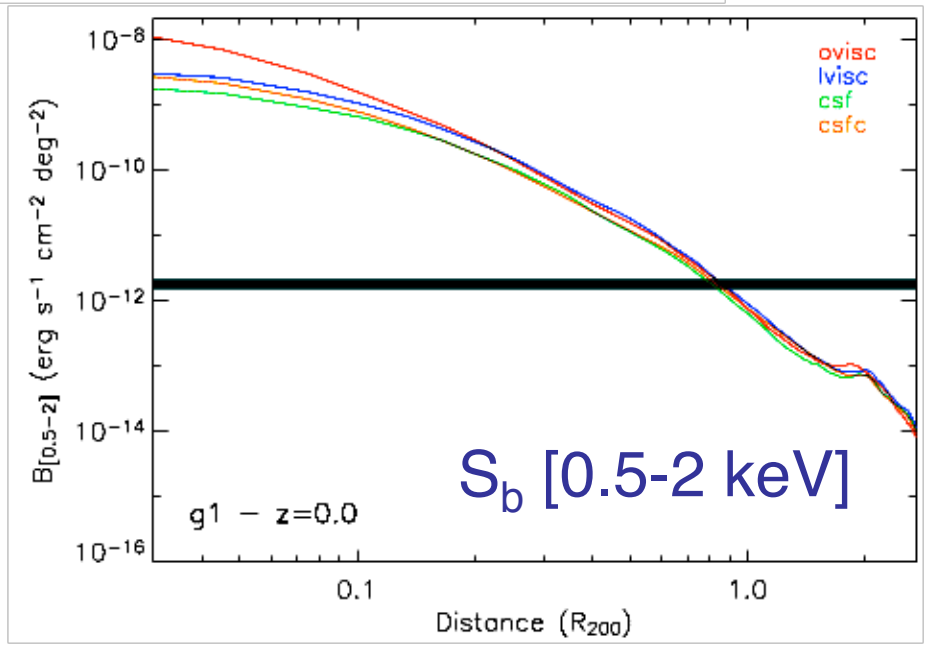




ICM at R_{200}: *Simulated clusters*







Unresolved CXB w. CXO
(Hickox & Markevitch 05)

Roncarelli, Ettori et al 06

ICM at R_{200}: *Simulated clusters*

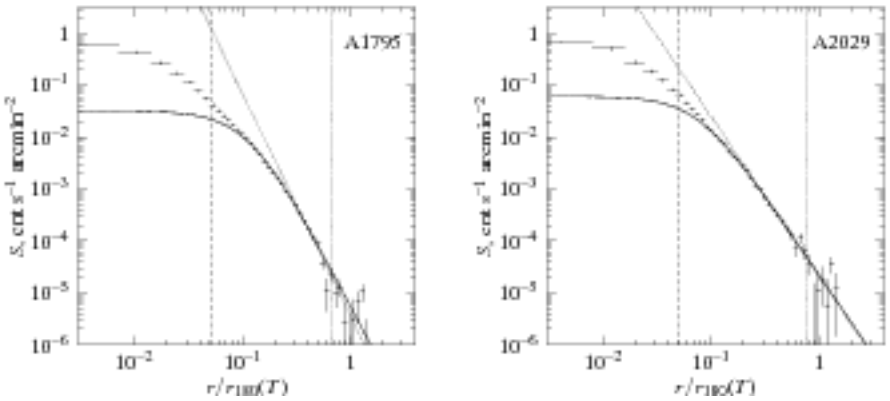
Simulations: 4 massive objects [M_{vir} 1.9-3.4e15, T_{vir} 5.4-9.9 keV]

R_{vir} … sphere that encloses a mean density of ~100 ρ_c
R_{2500}, R_{500}, R_{200} ≈ 0.2, 0.49, 0.74 R_{vir}

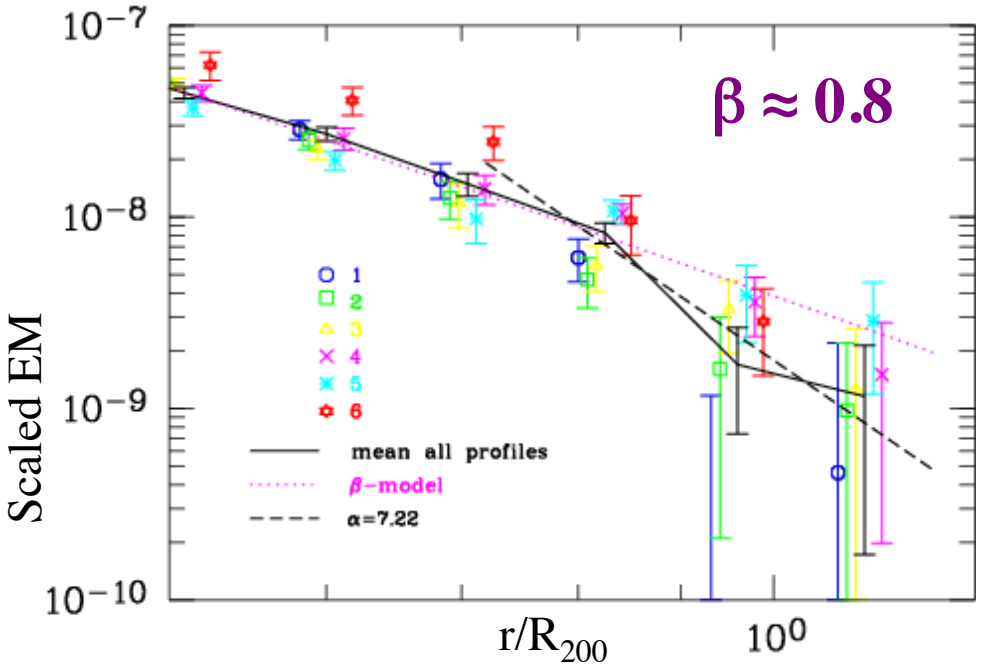
Quant.	**$0.2R_{vir}$**	**$0.5R_{vir}$**	**$0.7R_{vir}$**	**$1.0R_{vir}$**
n_{gas}	1	0.127 (0.004)	0.051 (0.002)	**0.018** (0.002)
T_{gas}	1	0.735 (0.044)	0.613 (0.055)	**0.491** (0.085)

➔ **Independently from the physics, just gravity**

S_b at R_{200}: *Observed clusters*



"Outer regions of the cluster gaseous atmosphere" Vikhlinin et al. (99):
β~0.8 and larger by ~0.05
of the global fit value



Sample of nearby clusters
observed with ROSAT/PSPC
(Neumann 2005)

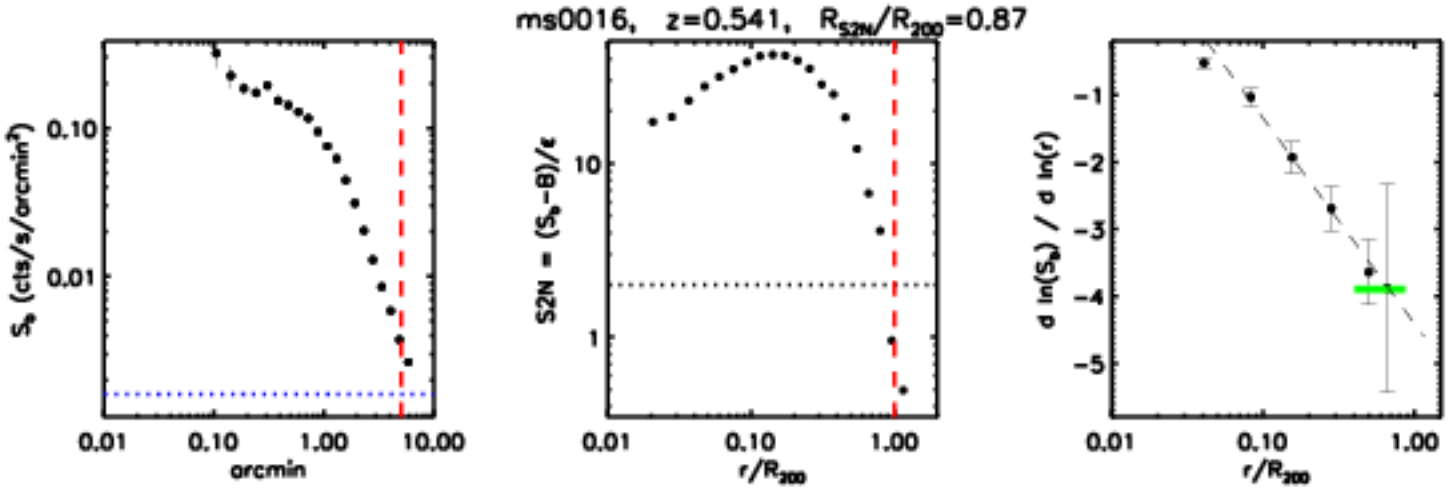
$S_b \sim (1+x^2)^{0.5-3\beta} \sim r^{1-6\beta}$

$n_{gas} \sim (1+x^2)^{-3\beta/2} \sim r^{-3\beta}$

S_b at R_{200}: *Observed clusters*

Study of S_b at r >0.7 R_{200} in a sample of high-z (z>0.3) objects with CXO

(Ettori & Balestra 09)

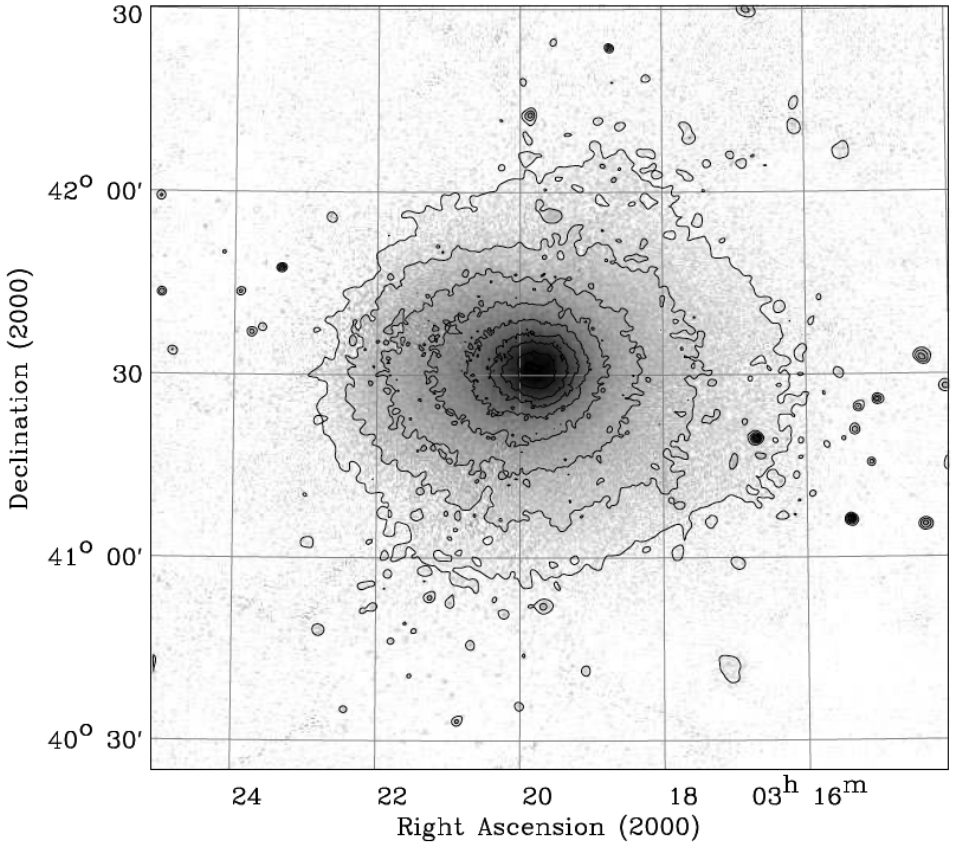


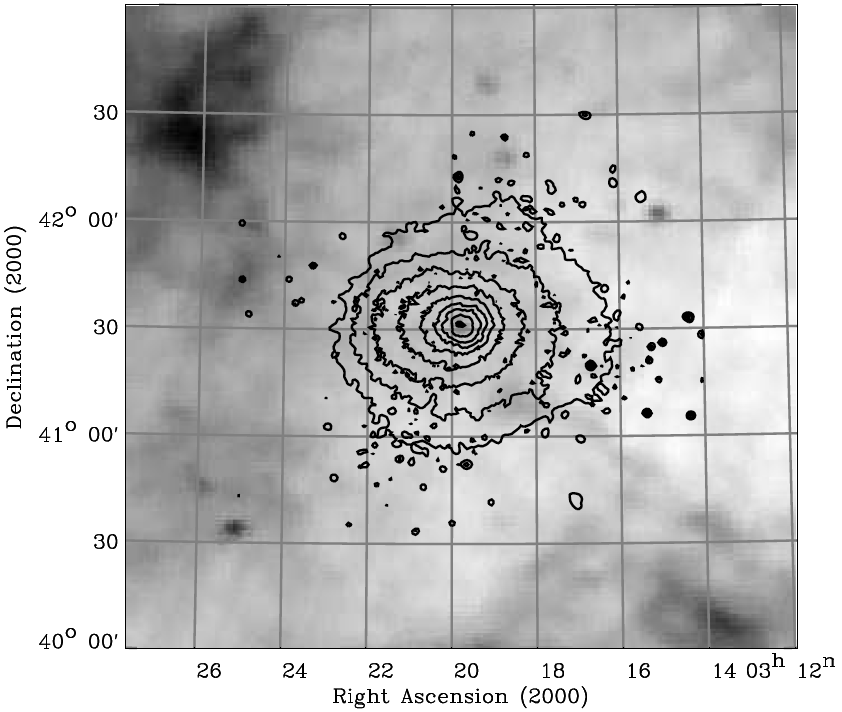
Slope of S_b:

at 0.7 R_{200}: -3.9 ± 0.7, at R_{200}: -4.3 ± 0.9

Note: $S_b \sim r^{1-6\beta}$ … β=0.8/0.9

S_b at R_{200}: *Perseus cluster*

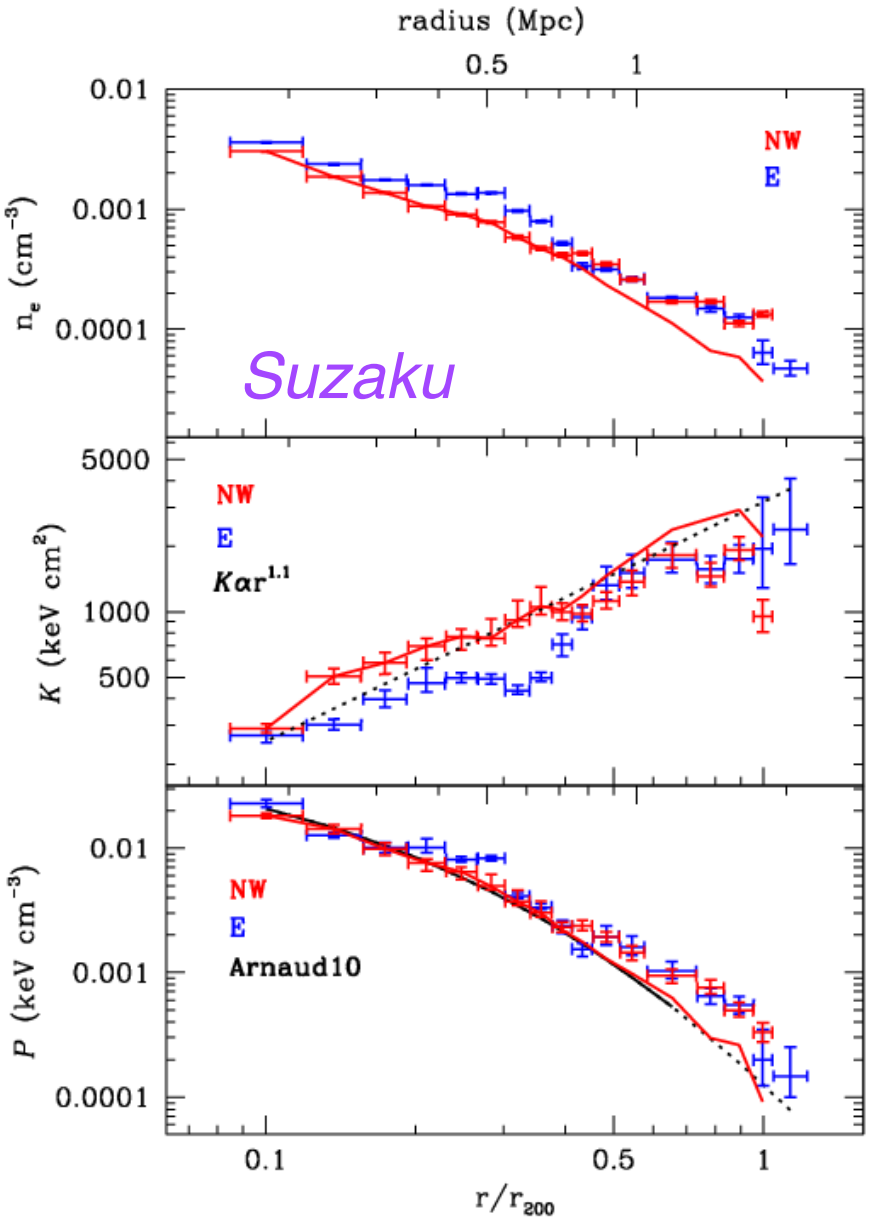


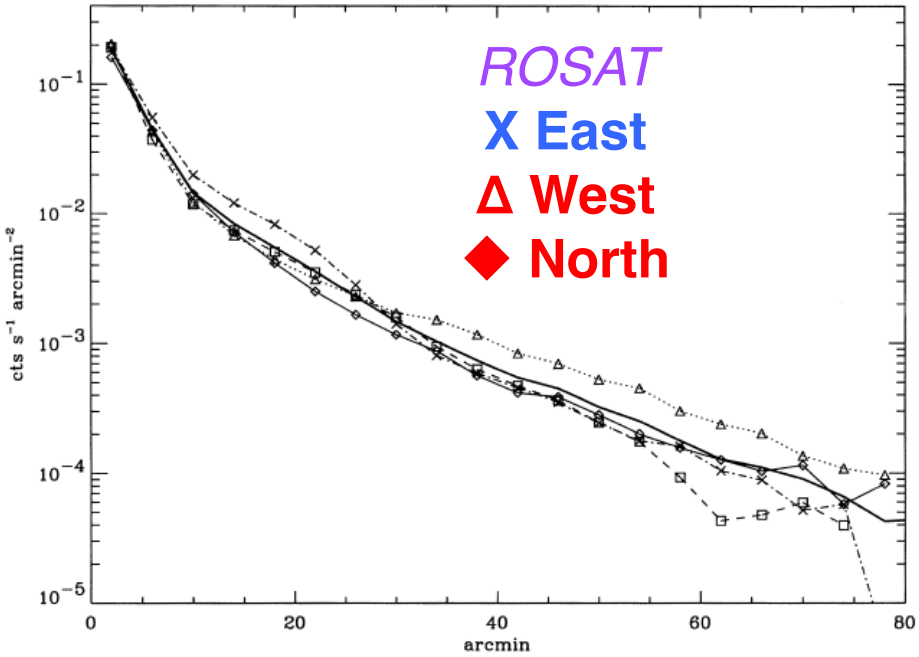


4 exposures with ROSAT PSPC

(Ettori et al. 98)

S_b at R_{200}: *Perseus cluster*

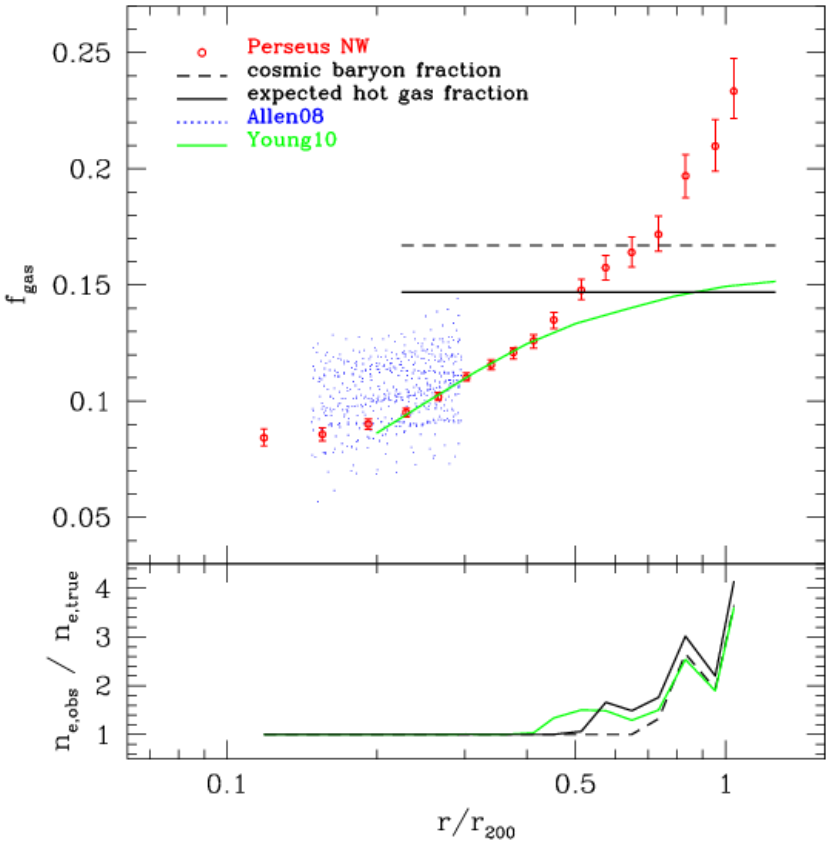


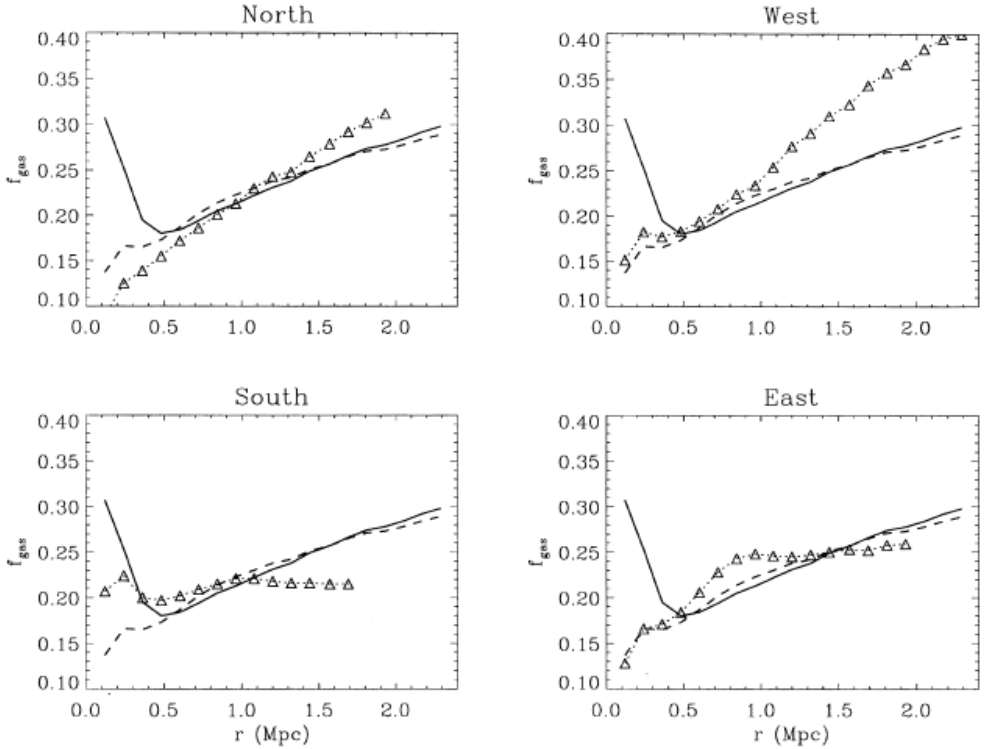


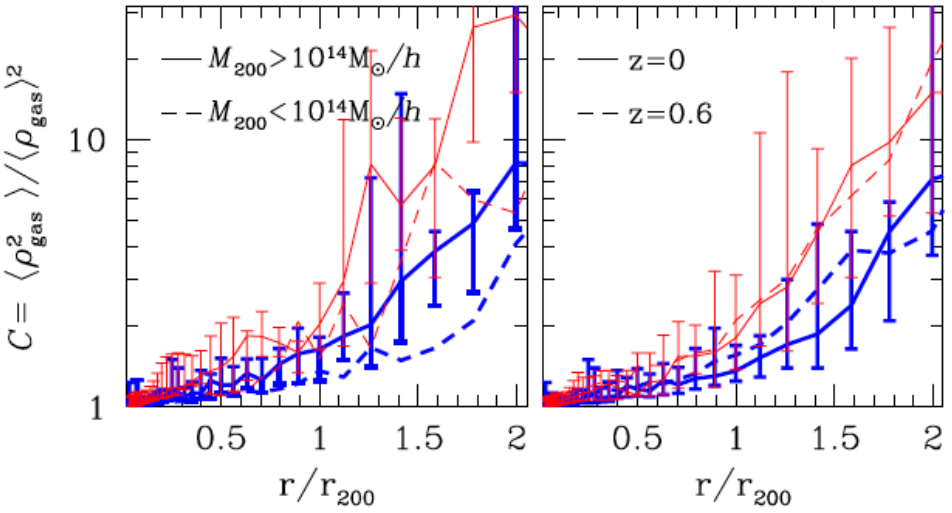
80'~1.78 Mpc~R_{200}

S_b at R_{200}: *Perseus cluster*

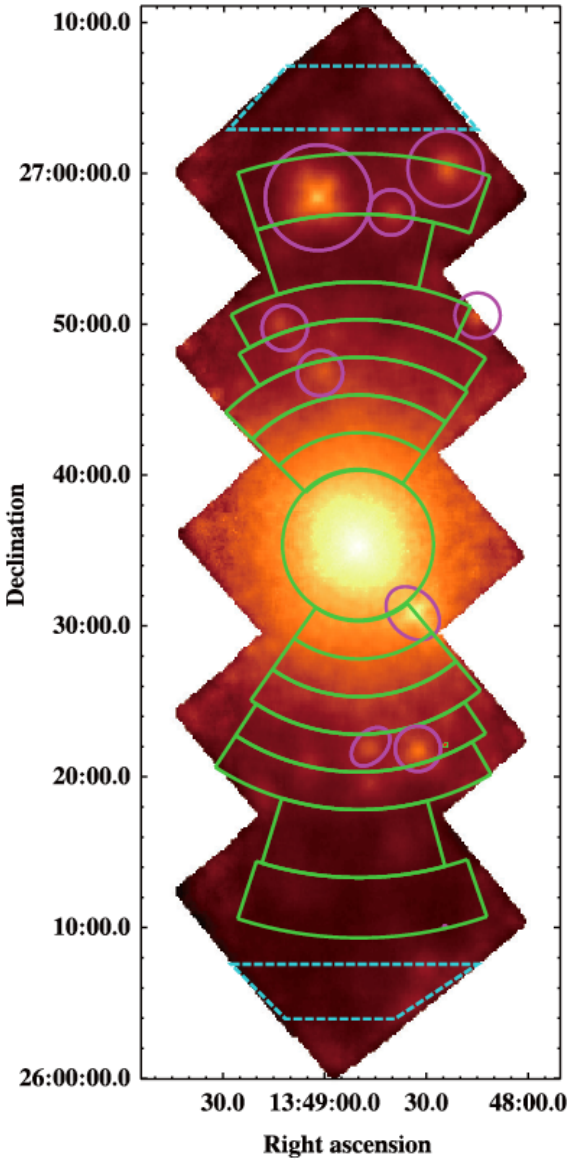
Suzaku (Simionescu et al. 11)



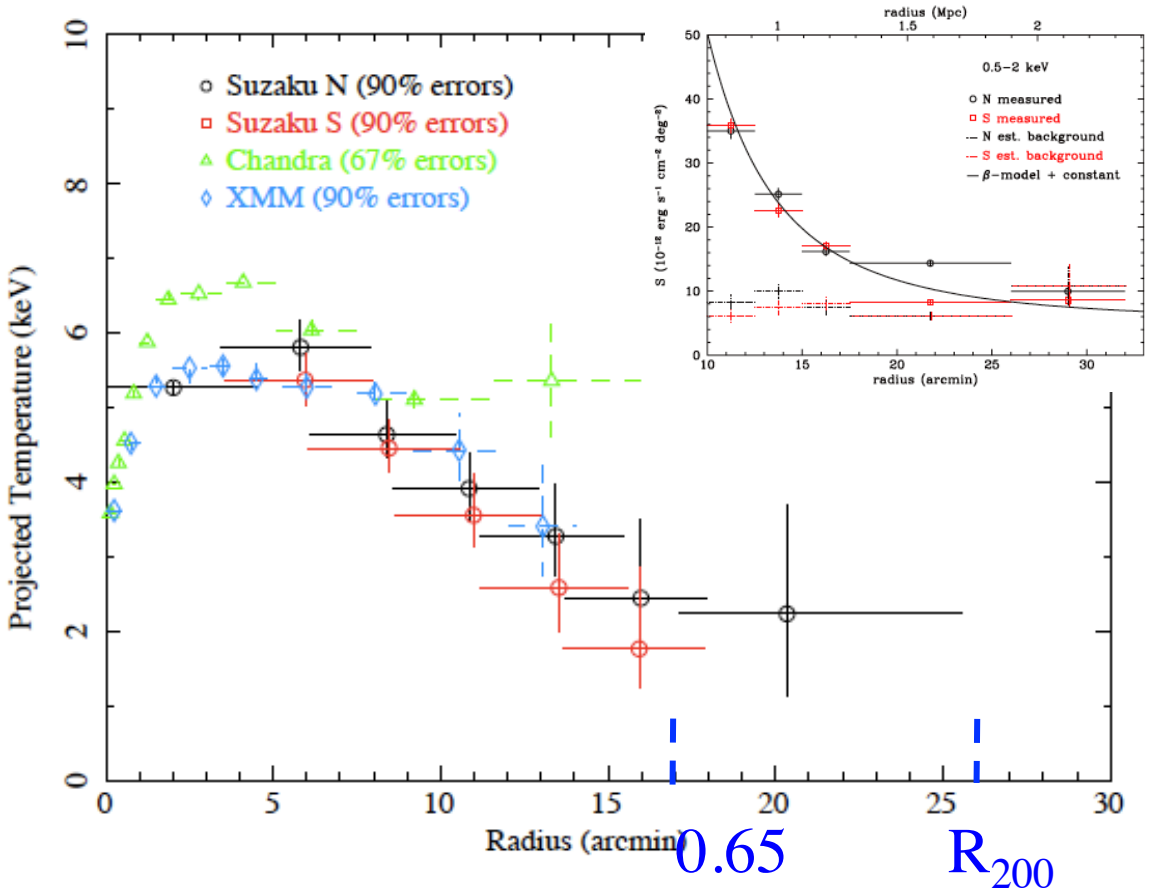




T_{gas} at R_{200}: *Observed clusters*

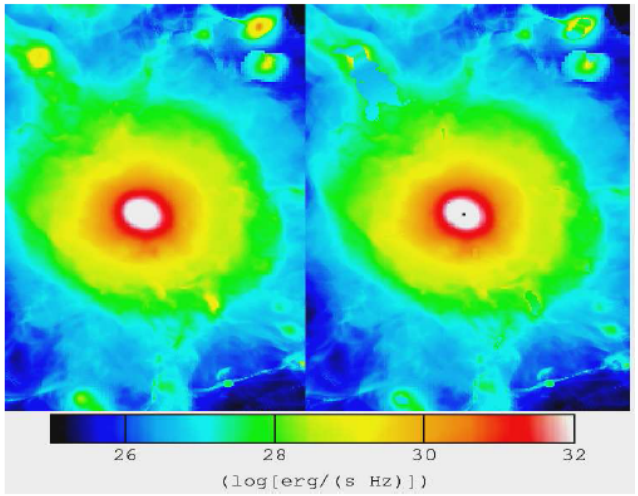


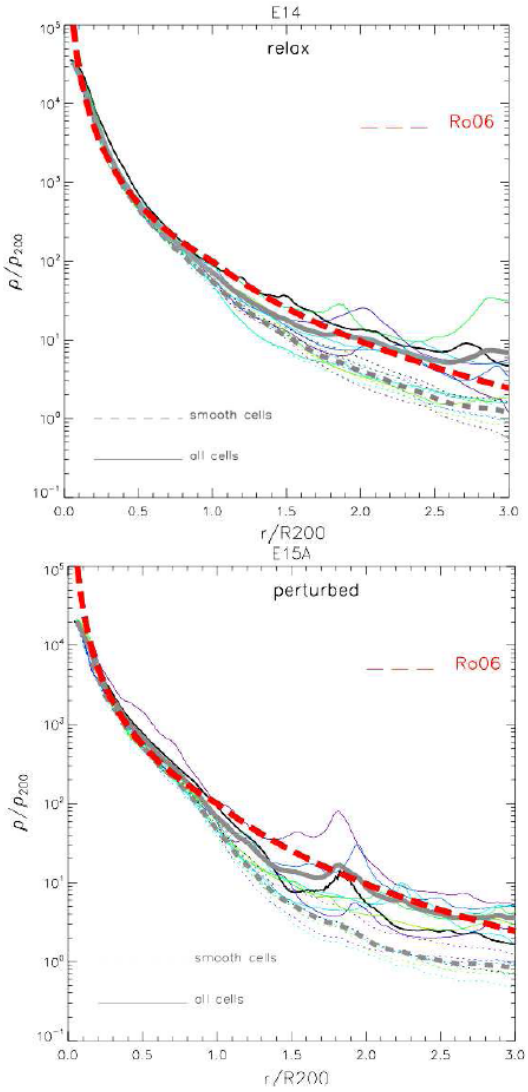
A1795 with ***Suzaku*** by
Bautz et al. (arXiv:0906.3515):
$T \sim r^{-0.9}$, M_{500} ~20-30% < expected

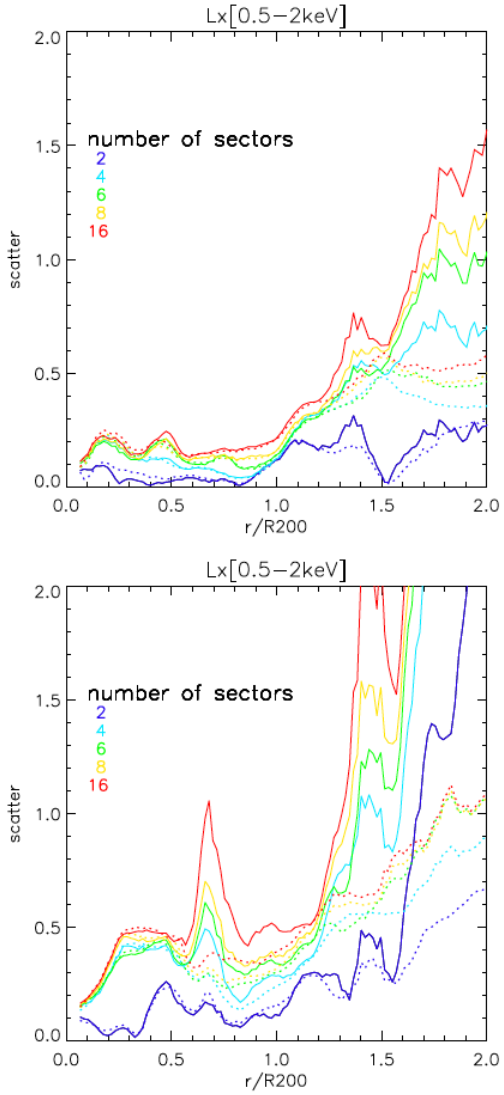


ICM at R_{200}: *the scatter*

(Vazza, Roncarelli, Ettori, Dolag 2011)

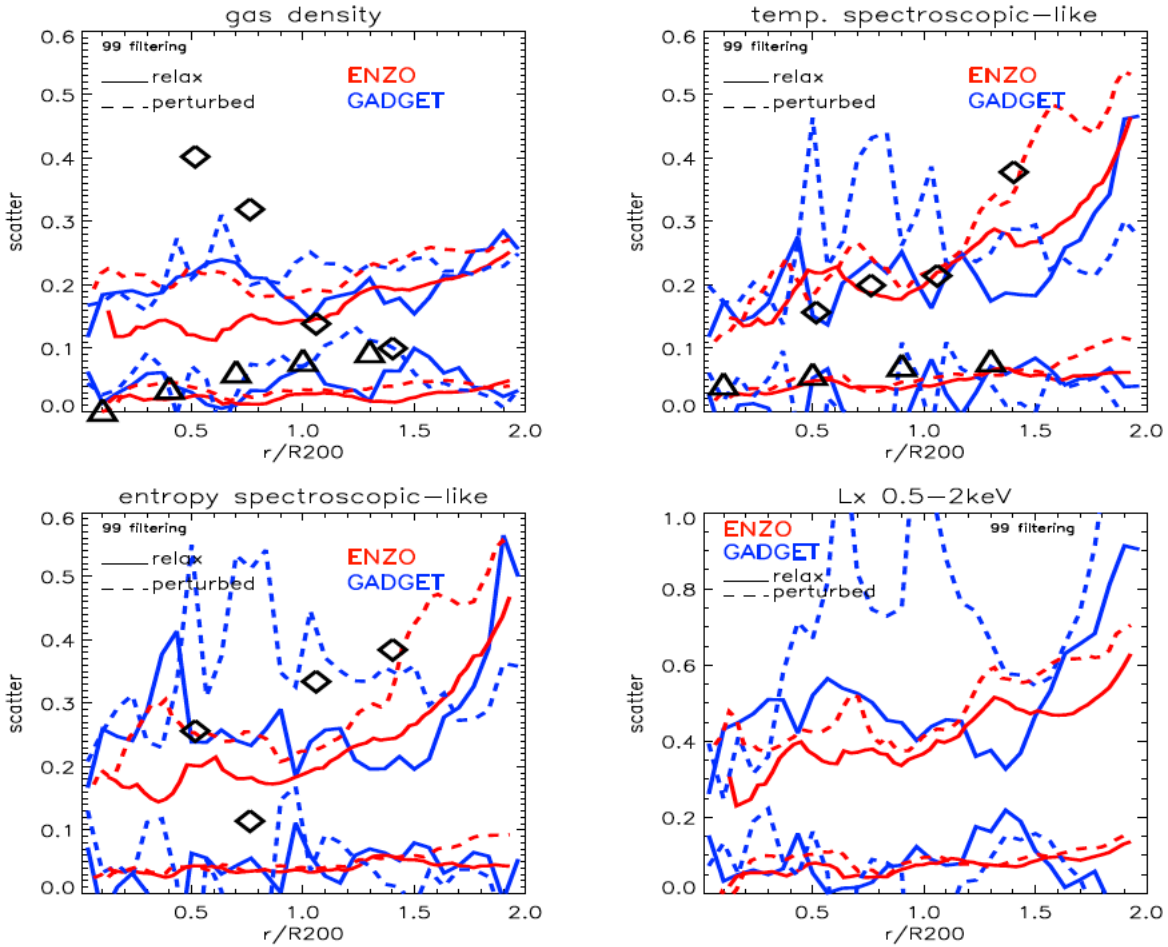






ICM at R_{200}: *the scatter*

(Vazza, Roncarelli, Ettori, Dolag 2011)



◆ PKS0745 (George et al.09)

Δ A1795 (Bautz et al. 09)

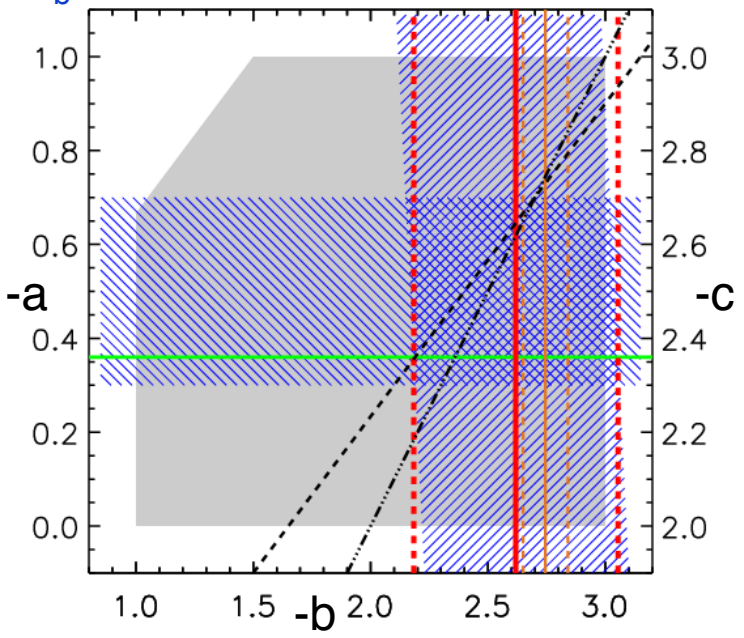
(**Suzaku**)

Thickest lines: after filtering the 1% most dense particles

CONCLUSIONS on the ICM in the outskirts

We know what we'd observe at R_{200} (T_{gas}, S_b):
X-ray observations & simulations provide a consistent picture

S_b from CXO & from simulations



$n_{gas} \sim r^{-b} \sim r^{-2.6}$ $T_{gas} \sim r^{-a} \sim r^{-0.5}$

$S_{b\ (0.5\text{-}2\ keV)} \sim$ 2e-12 erg/s/cm^2/deg^2

…but we can have also some surprises (K_{gas}, M_{HE})…

CONCLUSIONS on the ICM in the outskirts

- The entropy profiles is observed to be flatter than predicted *($T_e \neq T_i$?)*; M_{HE} lower/uncertain by 20-30%

- The scatter can provide insight on the physics acting in the outskirts *(is the physics in the hydro/grid-based simulations correct ? how much the present estimates at R_{200} are representative ?)*