Observing the ICM in the outskirts: additional cluster science for WFXT

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with S. Molendi et al.

Outline

- **ICM properties in the outskirts**: constraints from observations & simulations on the $\mathbf{n_{gas}}$ & $\mathbf{T_{gas}}$ profiles; *expectations for WFXT*

- **Concentration – M_{tot} relation & f_{gas}**: a new approach to constrain σ_8 & Ω_m

- **CCs at high-z**: evidence for evolution

SCIENTIFIC JUSTIFICATION

from the Executive Summary of the White paper by Giacconni et al. 09

(a) When and how is entropy injected into the inter-galactic medium (IGM)?

(b) What is the history of metal enrichment of the IGM?

(c) What physical mechanisms determine the presence of cool cores in galaxy clusters?

(d) How is the appearance of proto-clusters at z~2 related to the peak of star formation activity and BH accretion?

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(b) What is the history of metal enrichment of the IGM?

A mapping of X-ray emission
back in time &
in the outskirts is required

SCIENTIFIC JUSTIFICATION

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

- ✓ Which n_{gas}, T and S_b values do we expect at R_{200} ?
- ✓ Are simulated X-ray clusters consistent with the observed ones in the outskirts ?

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Implications

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

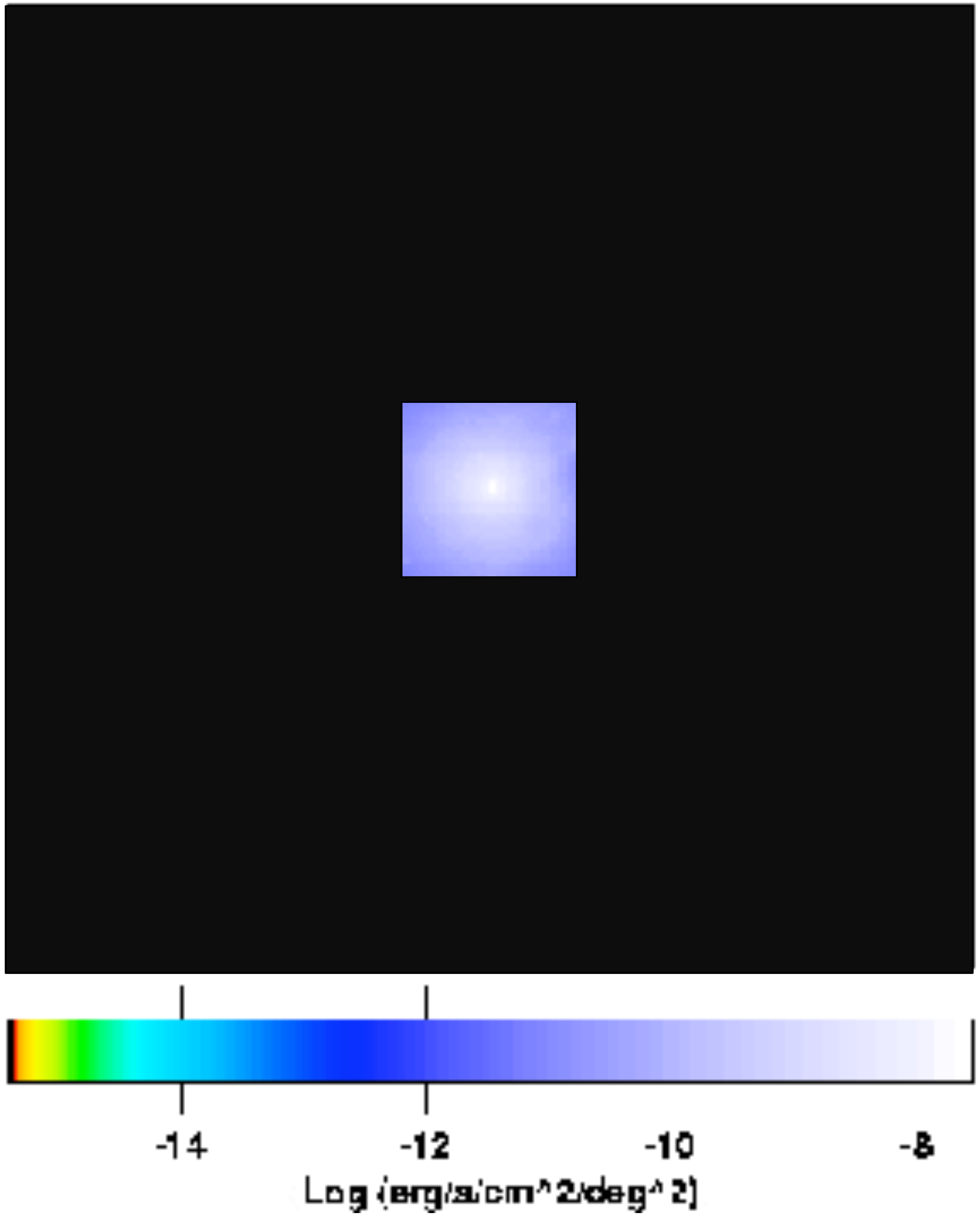
$$M_{tot}(< r) \propto r \times T_{gas}(r) \times (-\alpha_n - \alpha_T)$$

- ✓ To study the accretion of primordial gas in cluster DM halos

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

R_{2500}

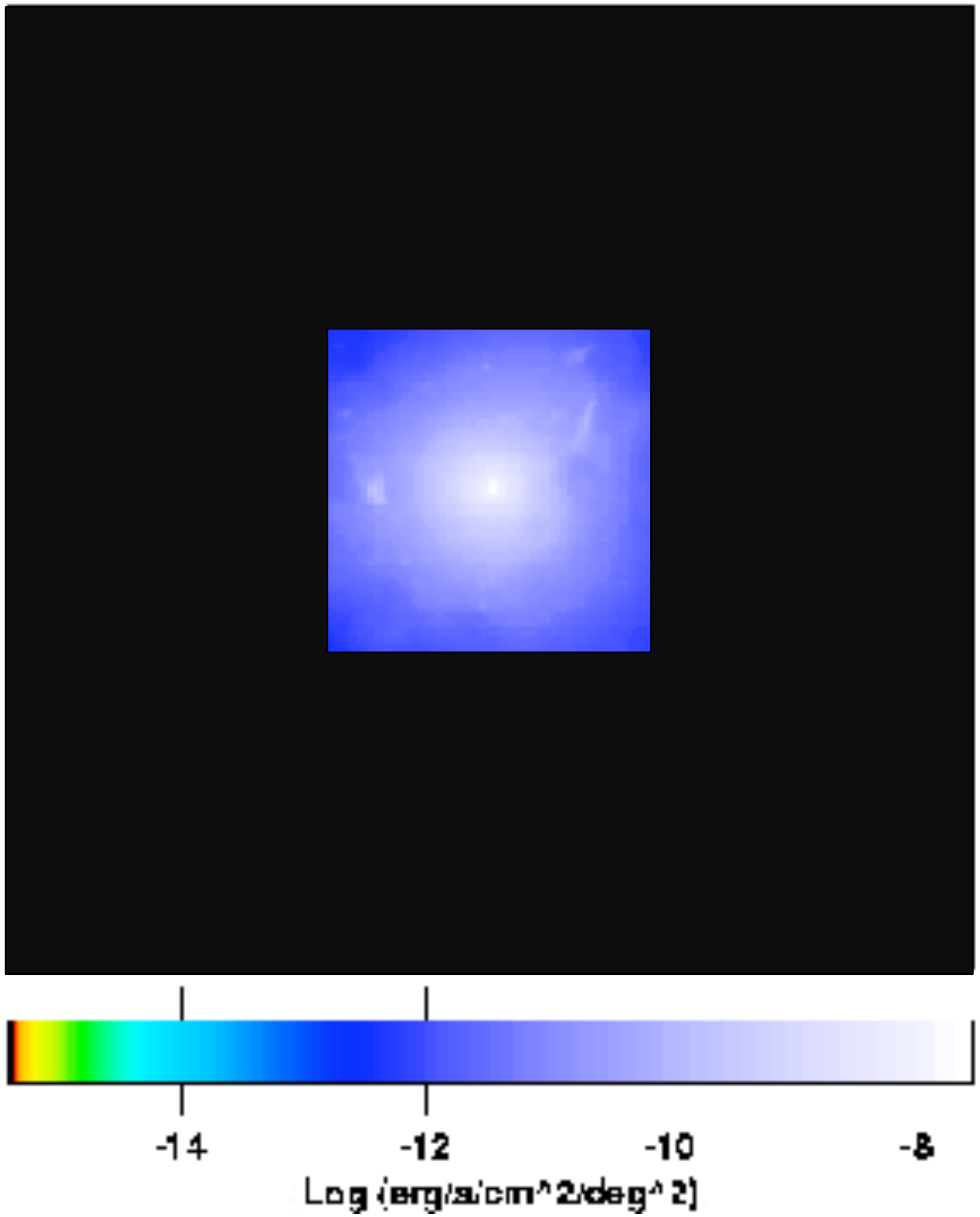
($\sim$0.3 R_{200}
~CXO limit)



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

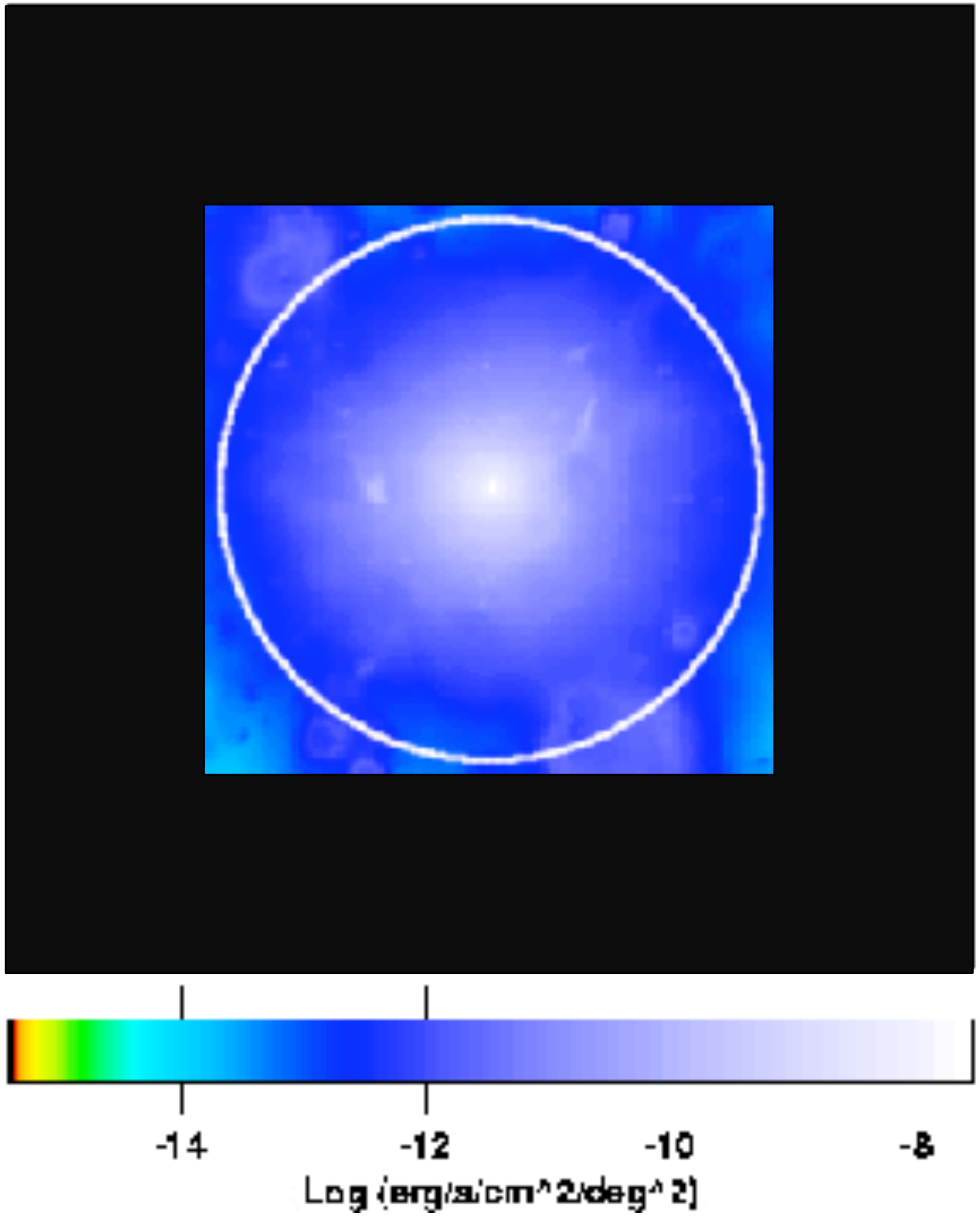
R_{500}

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

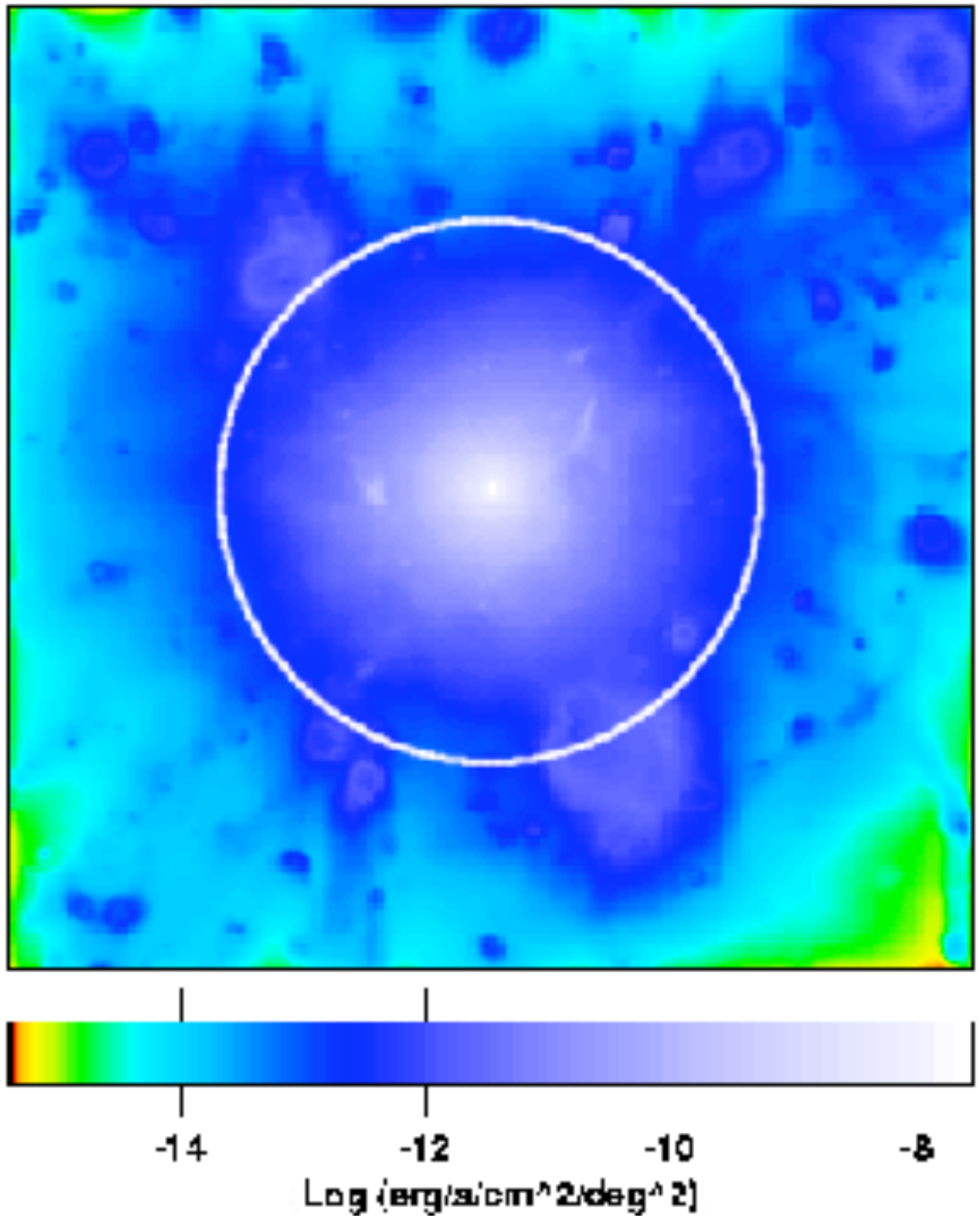


ICM at R_{200}: S_b *of simulated clusters*

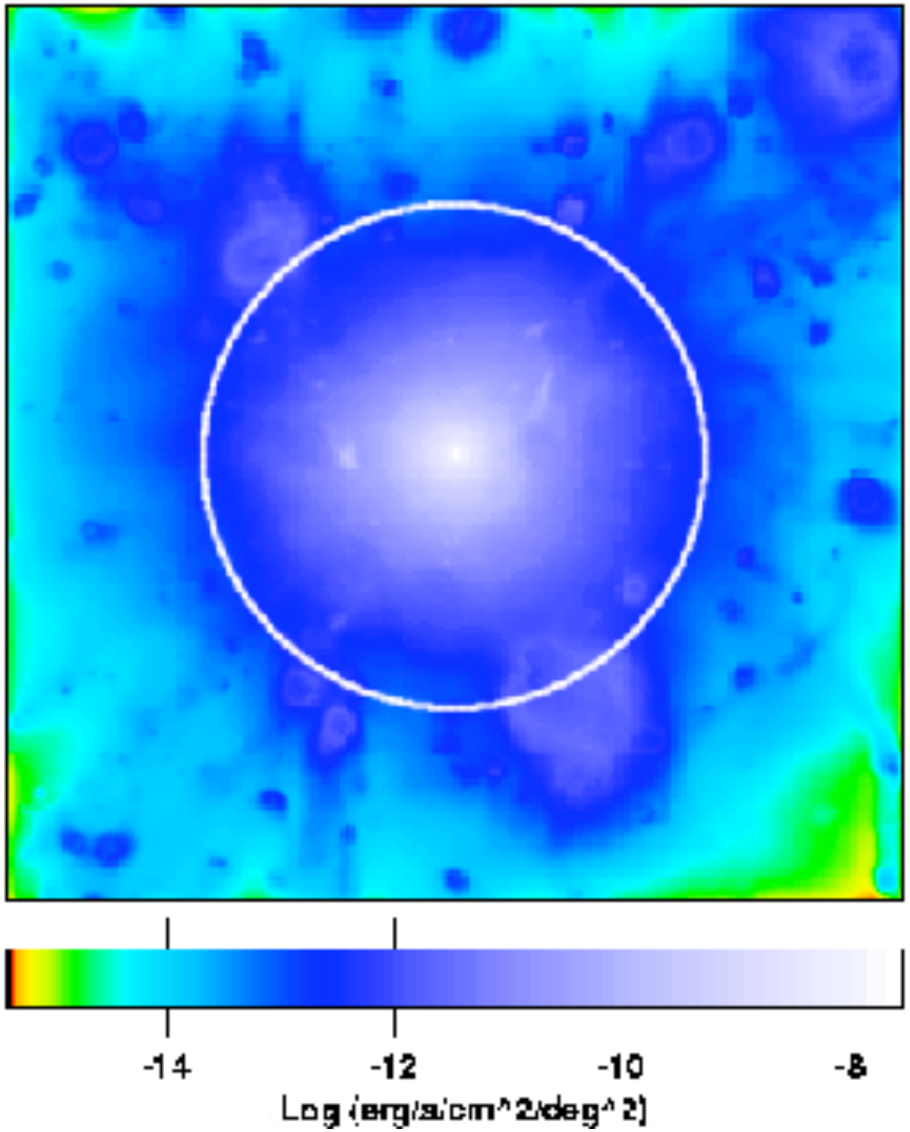
R_{200}

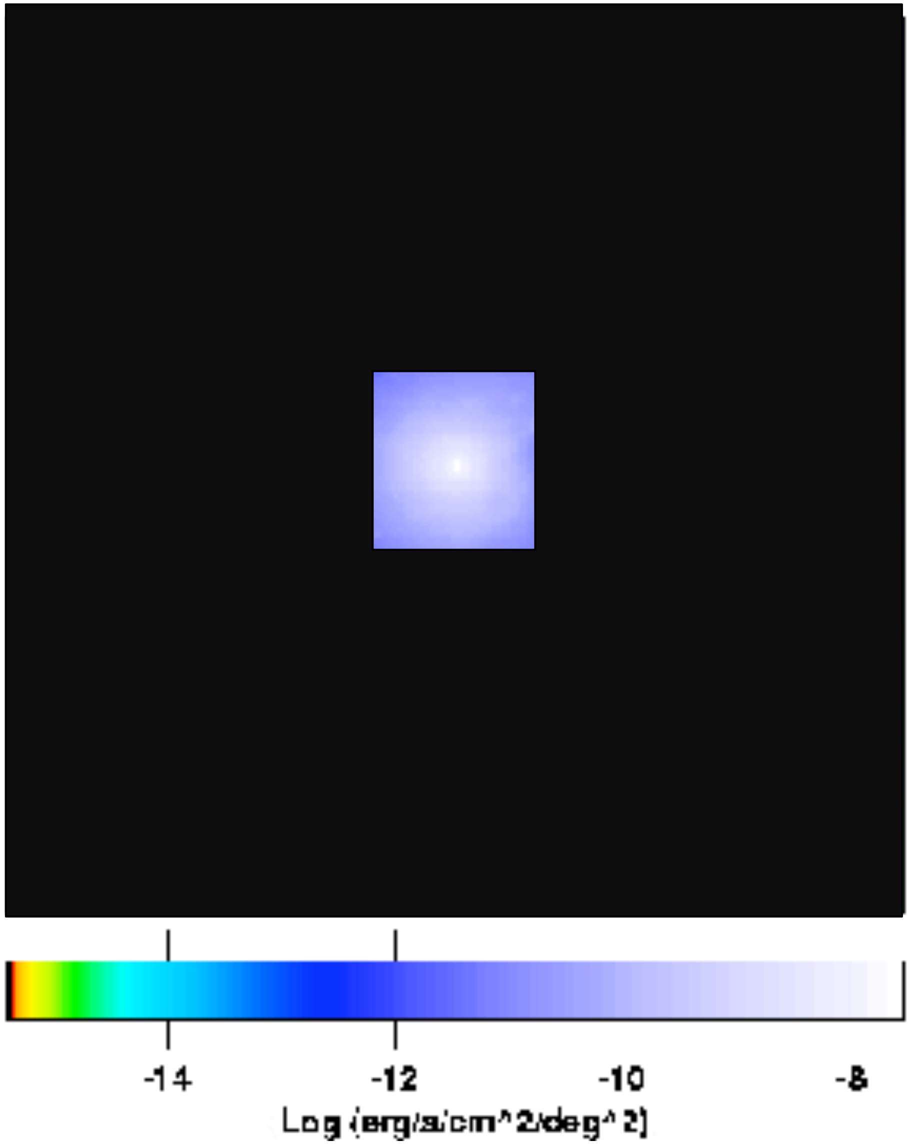


ICM at R_{200}: *S_b of simulated clusters*

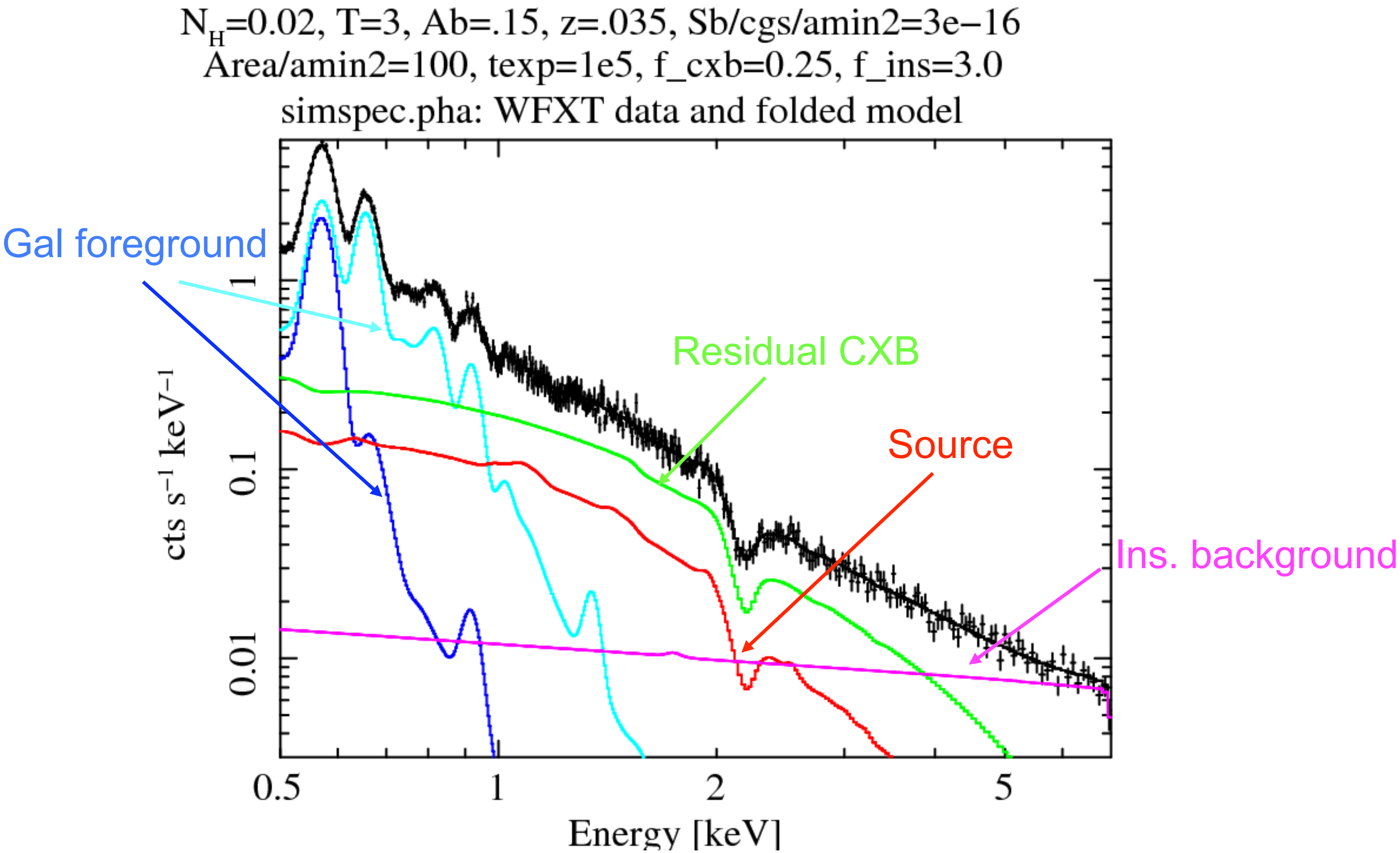


ICM at R_{200}: S_b *of simulated clusters*



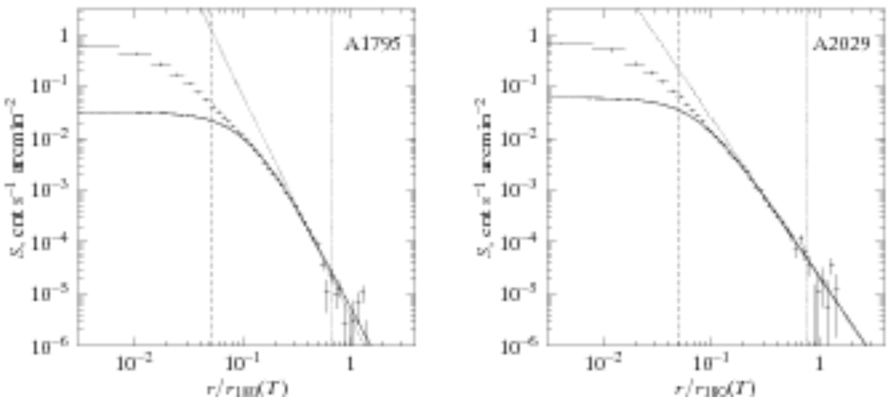


Bkg: dominant in GCs outskirts

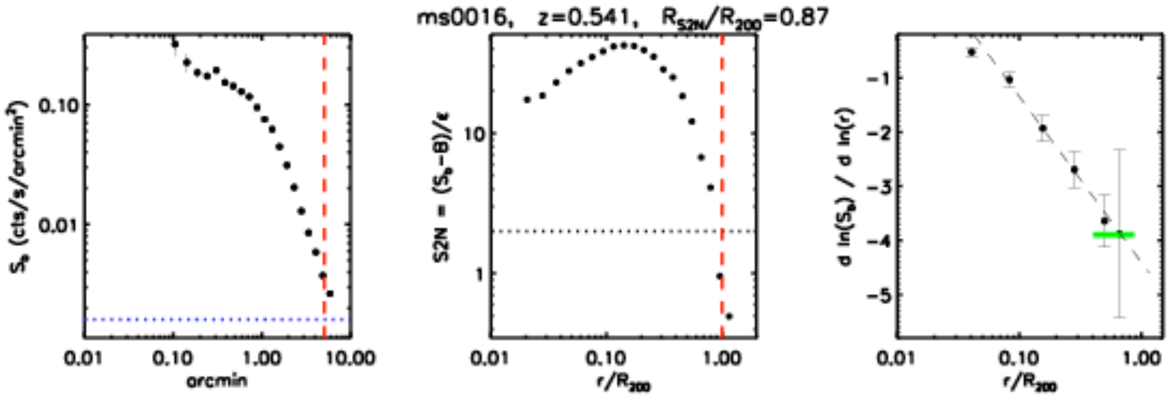


Simulation for 3keV cluster @ R200

S_b at R_{200}: *Observed clusters*



Vikhlinin et al. (99): β~0.8 and larger by ~0.05 of the global fit value; see also Neumann 2005. Both use a sample of nearby clusters observed with ROSAT/PSPC



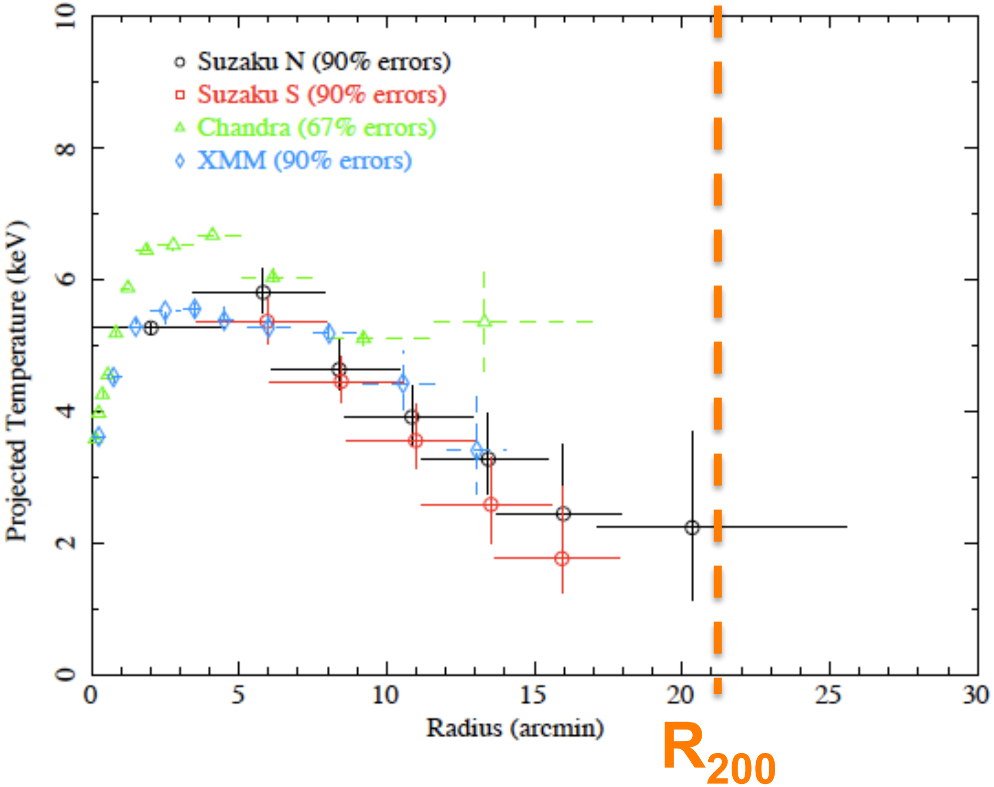
Study of S_b at r >0.7 R_{200} in a sample of high-z (z>0.3) objects with CXO
(Ettori & Balestra 09)

fit of the derivative of ln(Sb)/ln(r):

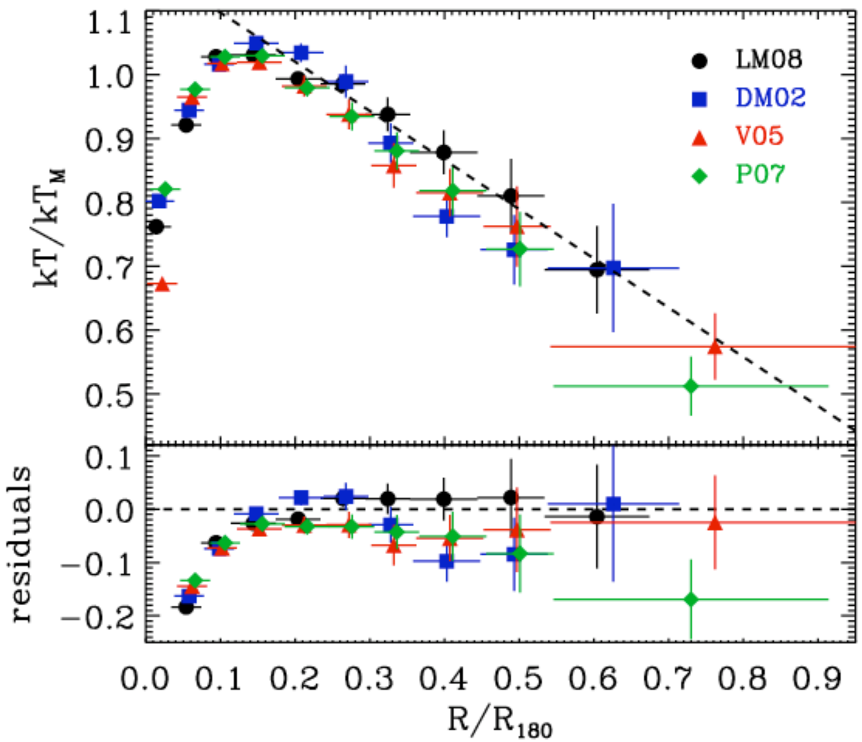
at 0.7 R_{200}: -3.9 ± 0.7,   at R_{200}: -4.3 ± 0.9

Note: $S_b \sim r^{1-6\beta}$ … β=0.8/1.0, slope~-3.8/-5.0

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

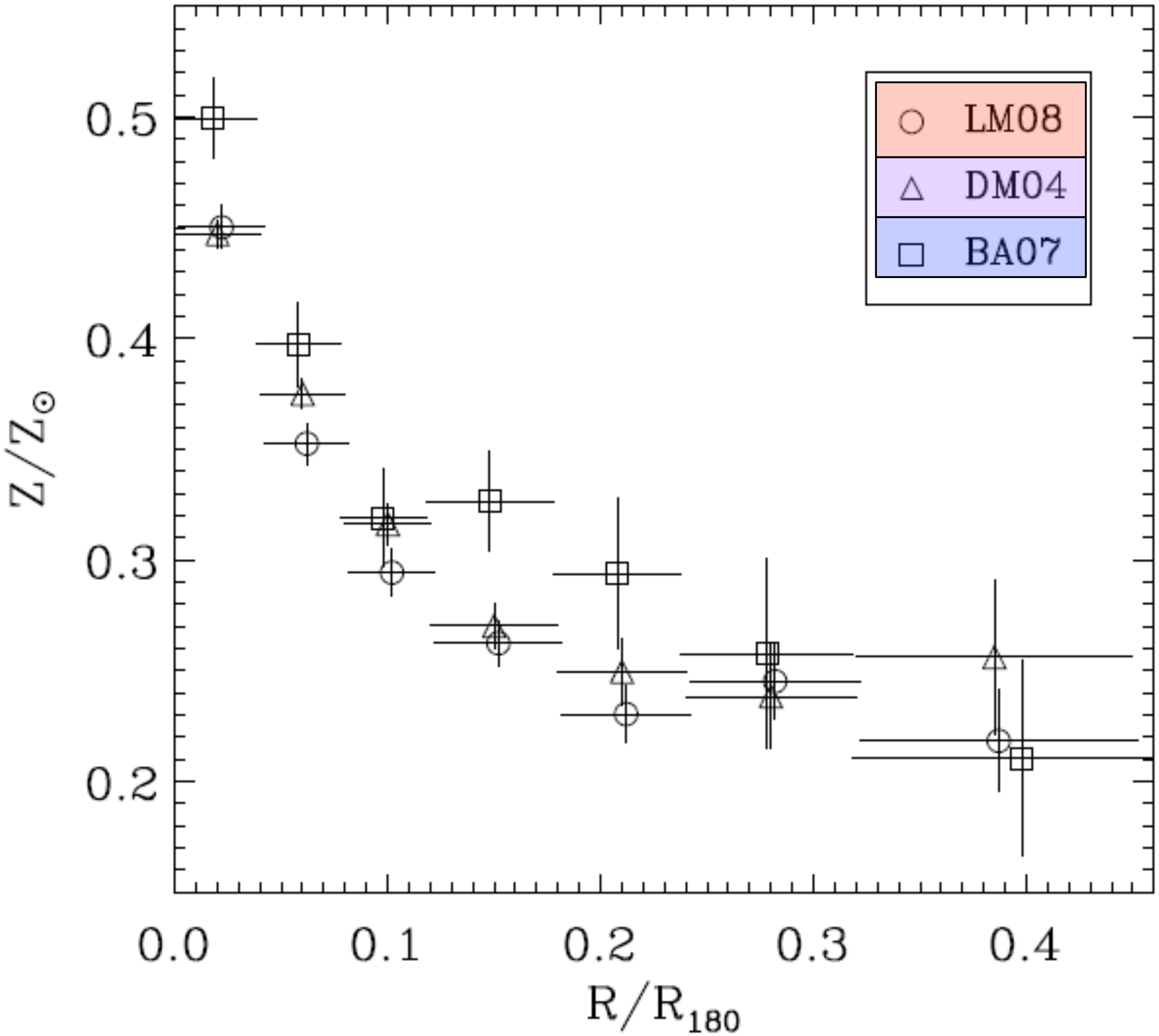


A1795 with ***Suzaku*** by
Bautz et al. (arXiv:0906.3515):
$T \sim r^{-0.9}$, M_{500} ~20-30% < expected



Sample of ~50 objects observed with XMM (Leccardi & Molendi 08)

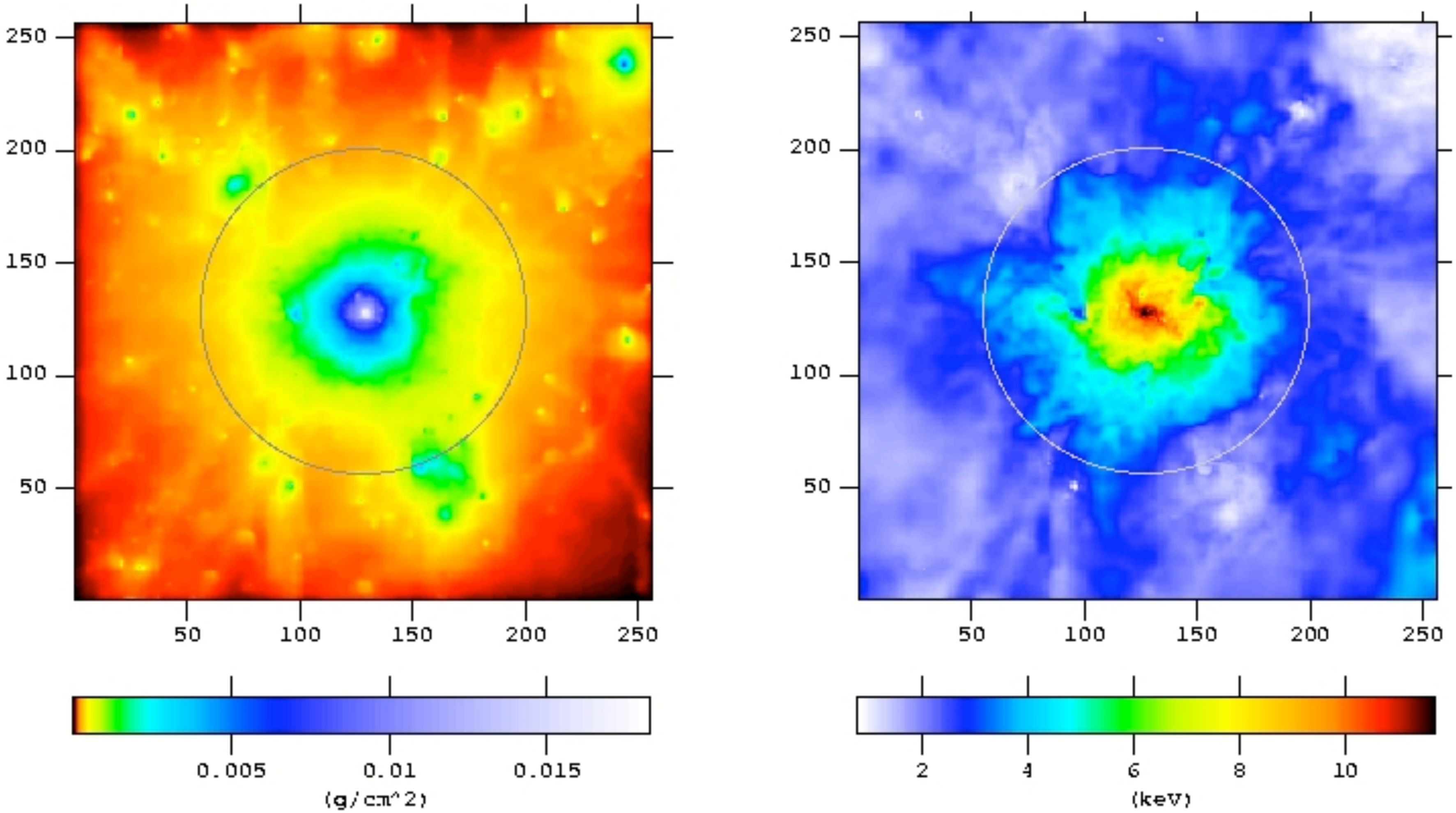
Z_{gas} at R_{200}: *Observed clusters*



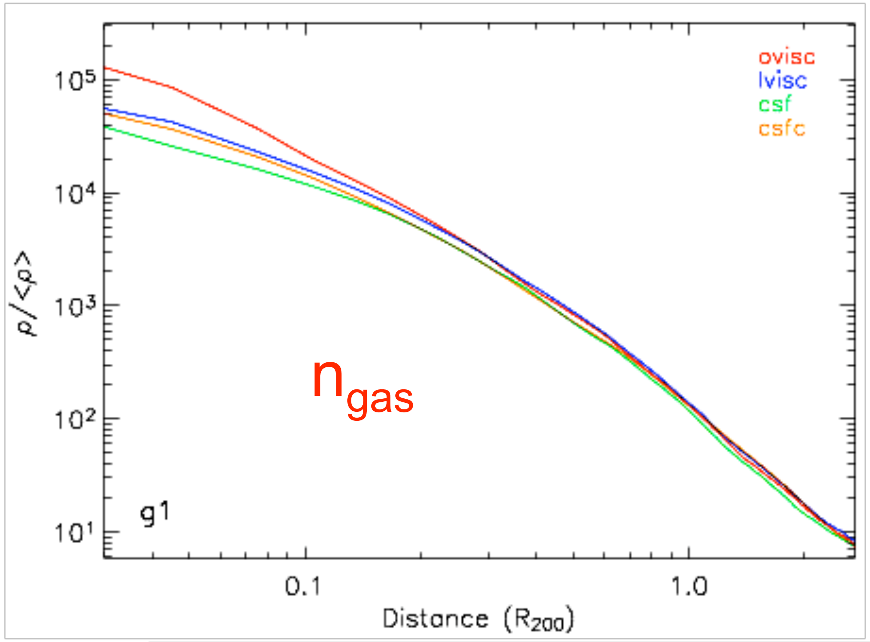
XMM
BeppoSAX
CXO

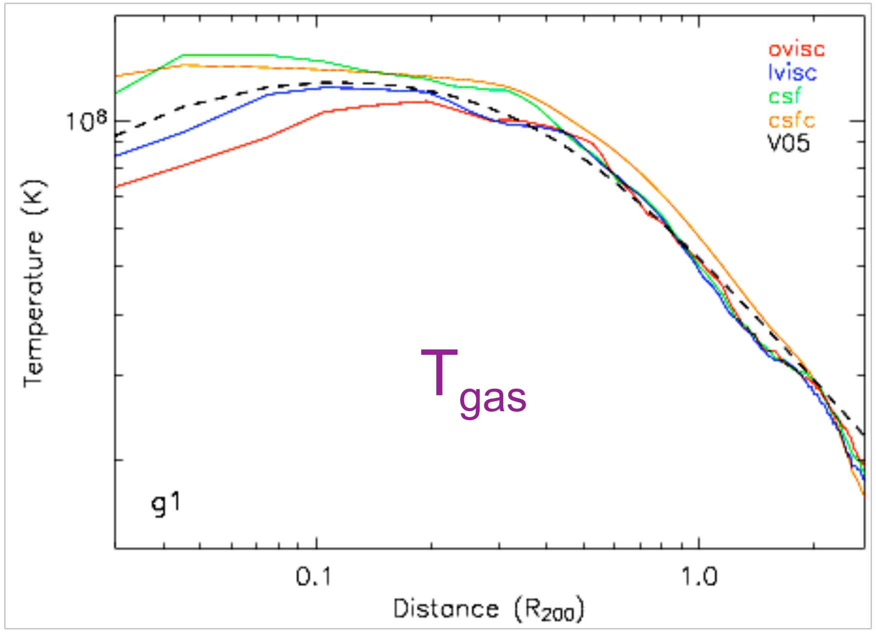
ICM at R_{200}: *Simulated clusters*

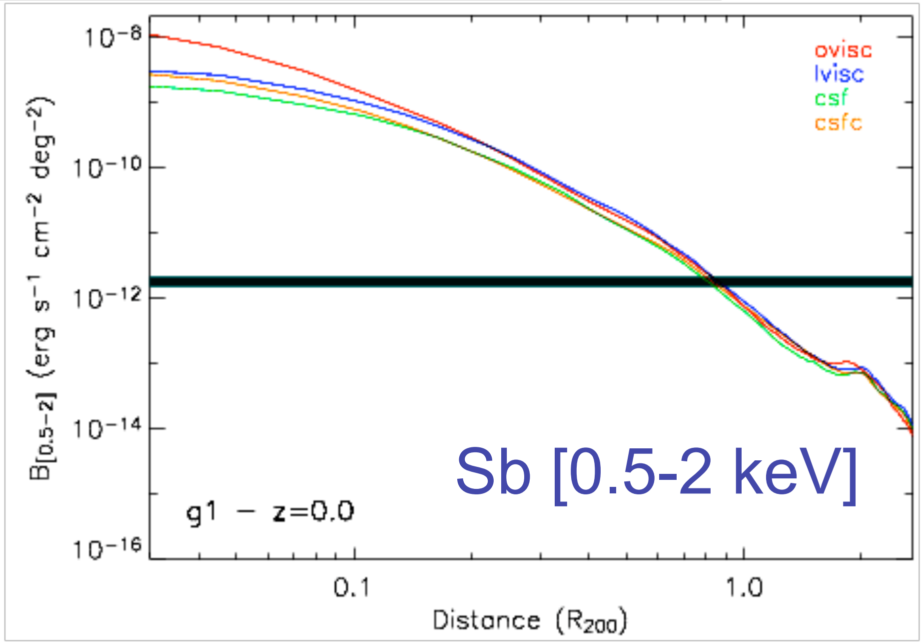
n_{gas} Roncarelli, Ettori et al 06 T_{gas}



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}

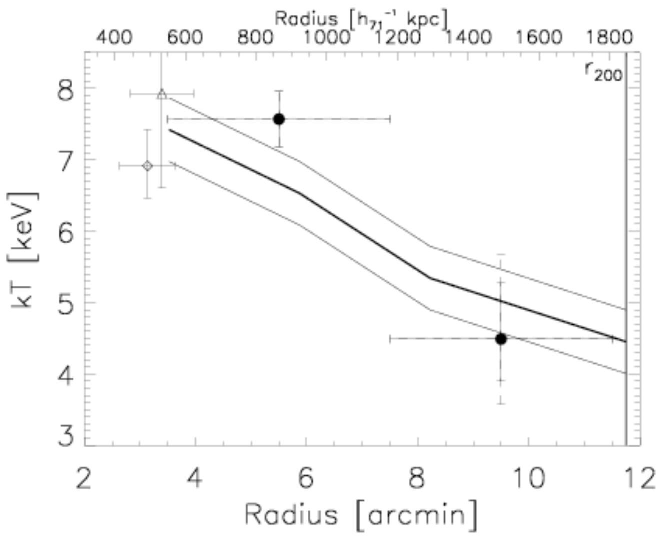
Quant.	**$0.2R_{vir}$**	**$0.5R_{vir}$**	**$0.7R_{vir}$**	**$1.0R_{vir}$**
n_{gas}	1	0.127 (0.004)	0.051 (0.002)	**0.018** (0.002)
T_{gas}	1	0.735 (0.044)	0.613 (0.055)	**0.491** (0.085)

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

CONCLUSIONS on the ICM in the outskirts

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

- $S_{b\ (0.5\text{-}2\ keV)} \sim$ 2e-12 erg/s/cm^2/deg^2
- $n_{gas} \sim r^{-2.6}$
- $T_{gas} \sim r^{-0.5}$



A2204
(***Suzaku***; Reiprich et al 09)

SAMPLE SELECTION

To address issues under different cluster conditions, we define a matrix of exposures accordingly to the following properties:
[**CC/nCC**, **Regular / Merging-Complex / Turbolent**]

(**CC/nCC**) Objects that present, or not, a CC with measured T drop in the centre;

(**Regular**) Objects with round isophotes that do not show evidence of substructures;
(**Merging-Complex**) Objects with evidence of major merging and/or multiple clumps;
(**Turbolent**) Objects with weak evidence of major mergers from imaging analysis but that show indications of no-relaxed ICM from spectral analysis (e.g. measured bulk motions) and/or combination of spectral and spatial analysis (reconstructed pressure map).

STRATEGY

By applying **the criterion R_{200} < R_{WF} = 30'**, we select 23 / 45 objects present in the flux-limited sample of the brightest clusters in Mohr et al. (1999).
We add also clusters like Perseus and Coma.

status	CC	nCC
REGULAR	**PKS0745** [A13], **A1795** [A13] **A2597** [A13*c*], **Sersic159-03** [A13*c*] **A133** [B1], **A478** [B13]	**A1413** [A1]
MERGING-COMPLEX	**A2142** [A12], **A3667** [A2] **Shapley SC** [A12], **A399-401** [A12] **2A0335** [A13*c*]	**A1689** [A1], **A754** [A2]
TURBOLENT	**Perseus** [A3]	**Coma** [A2]

FEASIBILITY

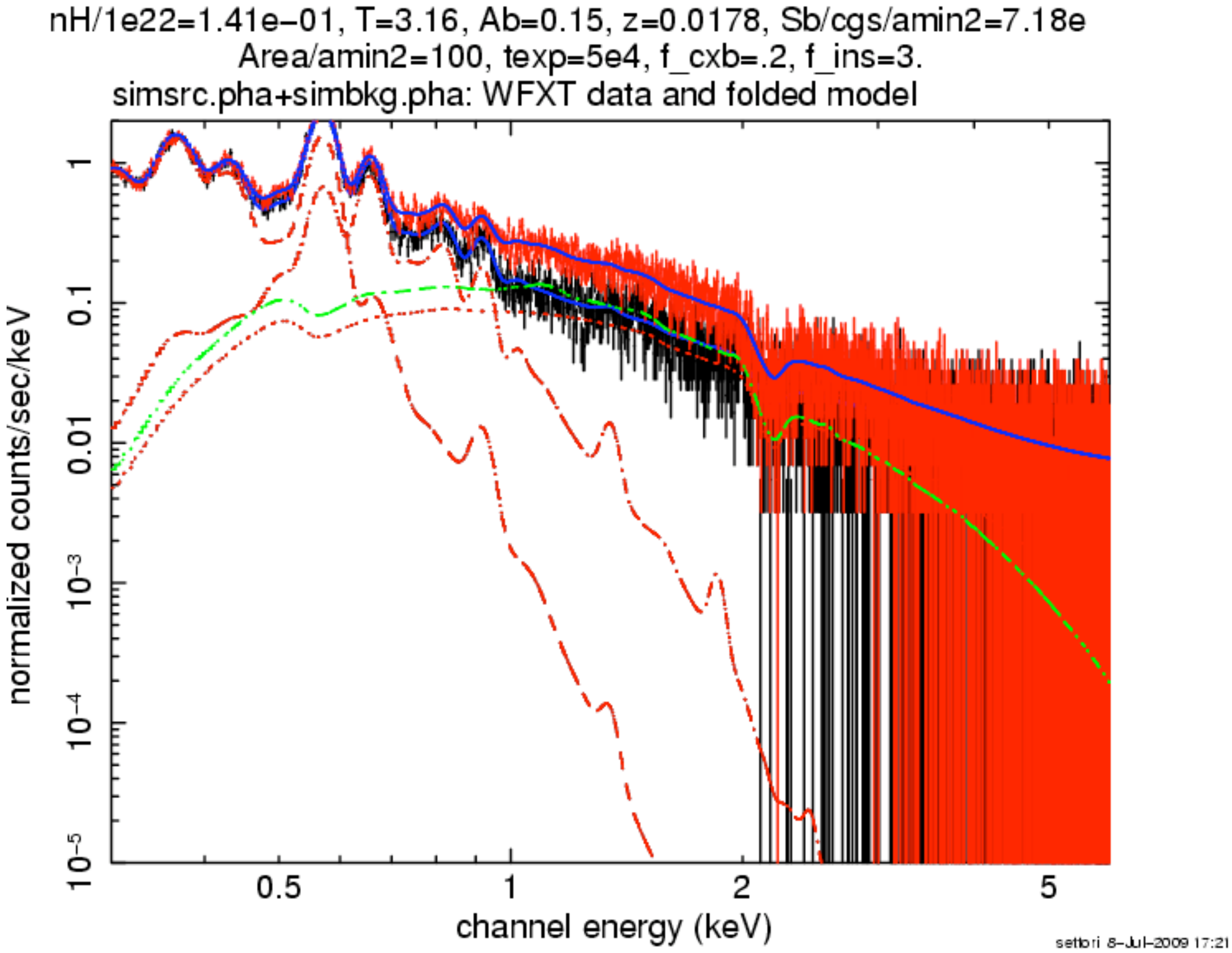
- We use **simback.sh** with WF matrices

- We include **random fluctuation** in the src+bkg spectra integrated over 100 arcmin^2 :
at **1%** level in **nH** value & **normalization** of the instrumental background;
at **5%** level in **normalization & temperature values of the two local background component**, **normalization & photon-index of the CXB**.

- The **resolved fraction of the CXB** is 80% in WF spectra

- **Input values**:
Sb in (0.5-2) keV from Mohr et al. (1999);
we also increase β by 20%
Z = 0.15 Zsun
T = 0.5 T_{mean} (see Roncarelli et al. 2006) & between 1 and 2 keV

Bkg: dominant in GCs outskirts

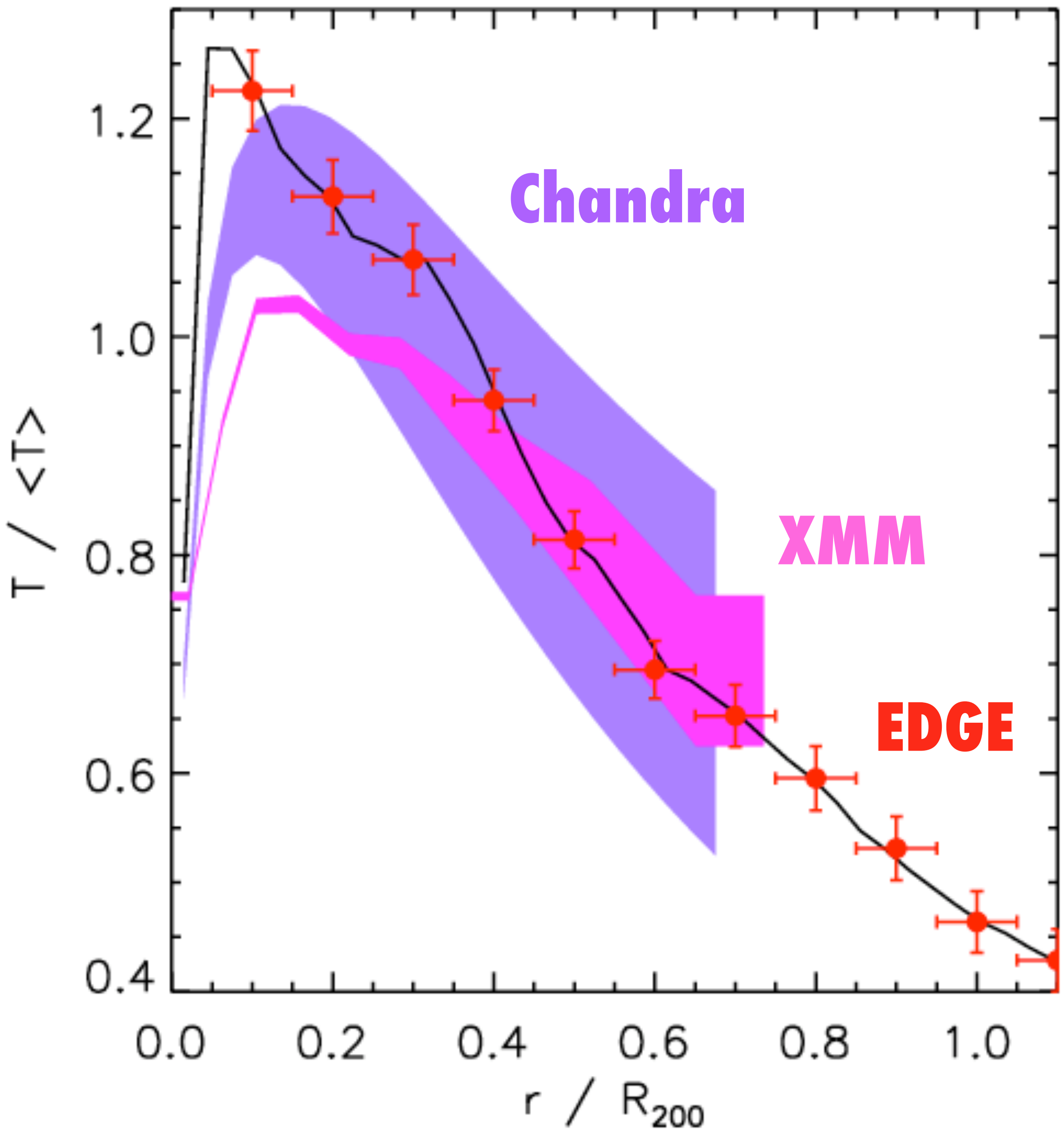


FEASIBILITY

Relative error in % at 90% c.l. **Exposure time = 50 ksec**

status	K	T fixed Z	K	T	Z
REGULAR/CC: A1795					
$T = 2, Z = 0.15$	8	11 (-1.5σ)	15	12 (-0.8σ)	42
TURBOLENT/CC: Perseus					
$T = 3.16, Z = 0.15$	8	12 (-2.9σ)	14	18 (-0.9σ)	62
$T = 2, Z = 0.15$	-	-	15	12 (-1.0σ)	53
$\beta_{20}, T = 3.16, Z = 0.15$	32	64 (0.1σ)	>100	>100	>100
$\beta_{20}, T = 2, Z = 0.15$	-	-	65	34 (-2.5σ)	-
MERGING/nCC: A1689					
$T = 5.05, Z = 0.15$	8	30 (-0.4σ)	16	25 (-0.4σ)	>100
$T = 2, Z = 0.15$	-	-	15	7 (-5.2σ)	41
$\beta_{20}, T = 5.05, Z = 0.15$	43	54 (-2.7σ)	>100	>100	>100
$\beta_{20}, T = 2, Z = 0.15$	-	-	>100	>100	>100

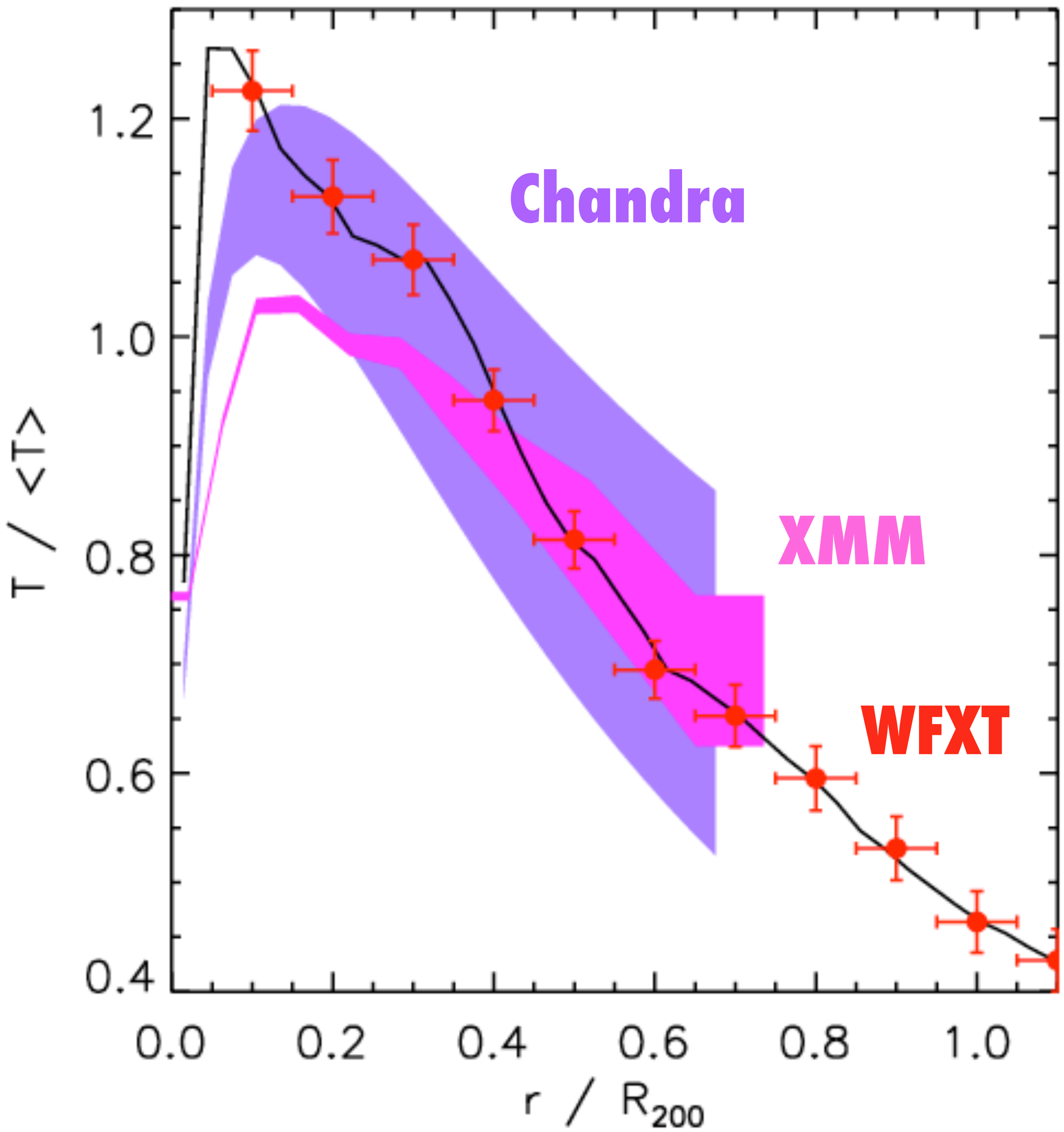
T_{gas} at R_{200}: *expectations*



1Msec

arXiv:0707.4103

T_{gas} at R_{200}: *expectations*



50ksec

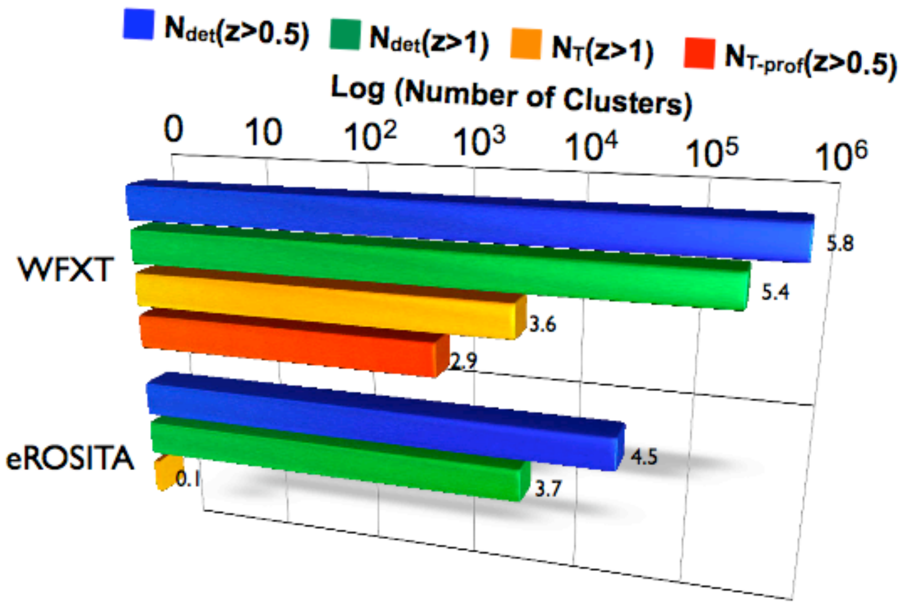
CONCLUSIONS on a cluster sample at R_{200} for WFXT

- **K** & T measured with **ε~10-30%** (90% c.l.) over 100 $arcmin^2$ with 50 ks

- **Z** can be constrained with **ε~40%** if the nominal T_{gas} is lower than predicted from numerical simulations (better in the range 1-2 keV).

- Steeper Sb in the outskirts (lower by a mean factor of 7) reduces significantly the level of accuracy: marginal constraints on K &T, no constraints on Z

Auxiliary cluster science



[PRESENT] **Clusters with M_{tot} from T(r)**

Allen et al. (08; T>5 keV): **42 obj 0.06<z<1.06**, 4 @z>0.8

Vikhlinin et al. (09; T>3-5 keV): **36-9 obj 0.35<z<0.9**; 2-2 @z>0.8

Gas mass fraction

To constrain the cosmological model

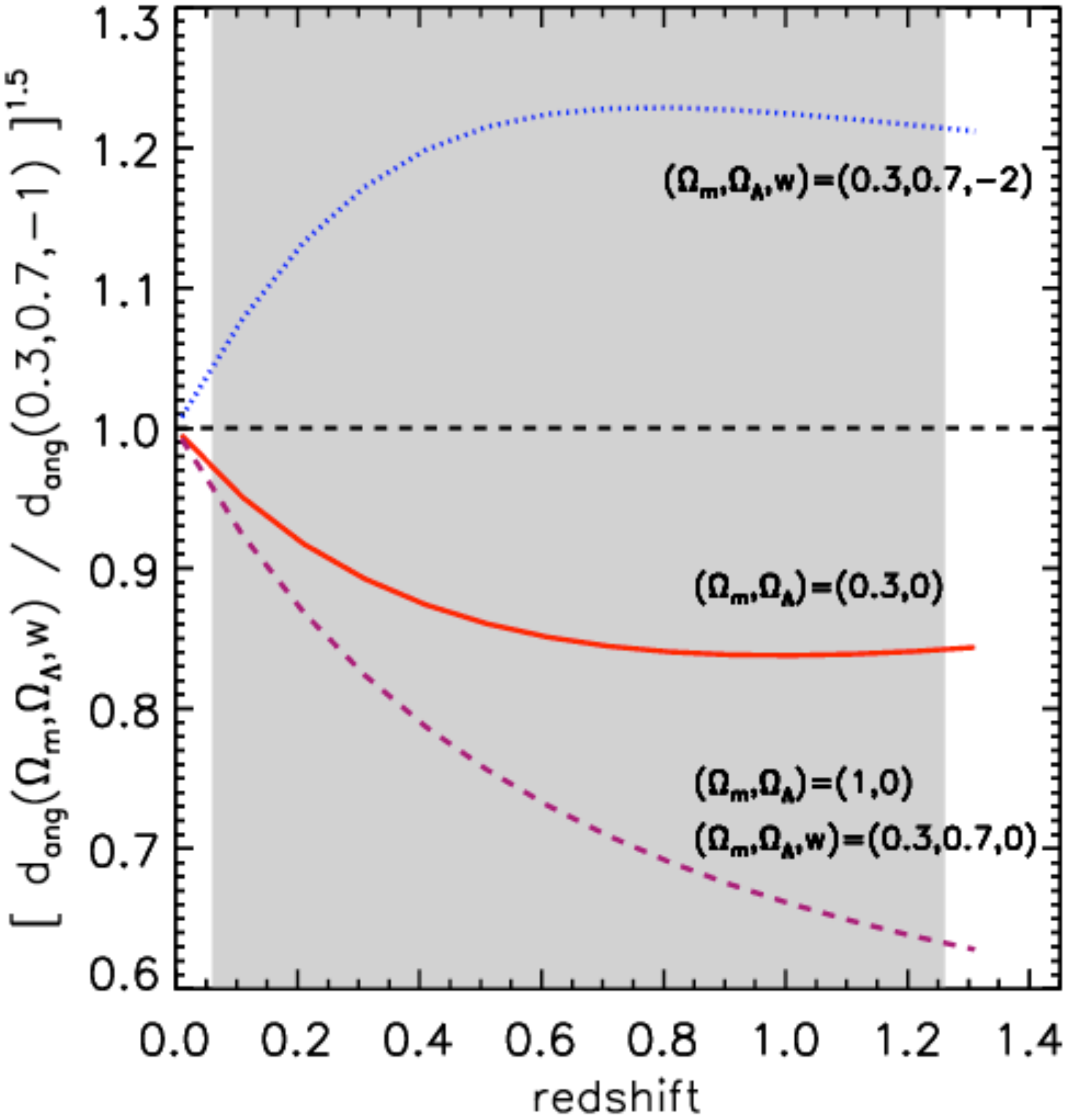
$$\Omega_m + \Omega_\Lambda + \Omega_k = 1$$

We combine a **dynamical** and a **geometrical** method

(see also Allen et al, Blanchard et al., Ettori et al, Mohr et al) :

1. baryonic content of galaxy clusters is representative of the cosmic baryon fraction Ω_b / Ω_m (White et al. 93)
2. f_{gas} is assumed constant in cosmic time in very massive systems (Sasaki 96, Pen 97)

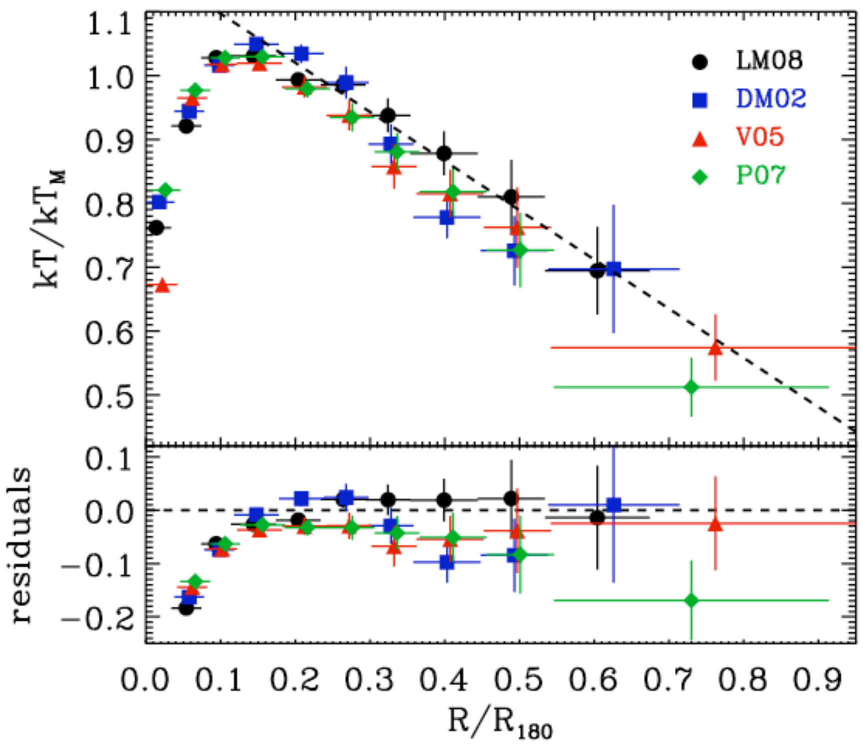
The cosmological dependence



500 relaxed hot (T>5 keV) obj with f_{gas} estimate precise at 5% level provides a FoM_{DETF} ~15-40 (Rapetti et al. 08), comparable to:

ground-based SNIa … 8-22
Space-based SNIa … 19-27
Ground-based BAO … 5-55
Space-based BAO … 20-42
Space-based clusters cts … 6-39

The c-M_{tot} relation



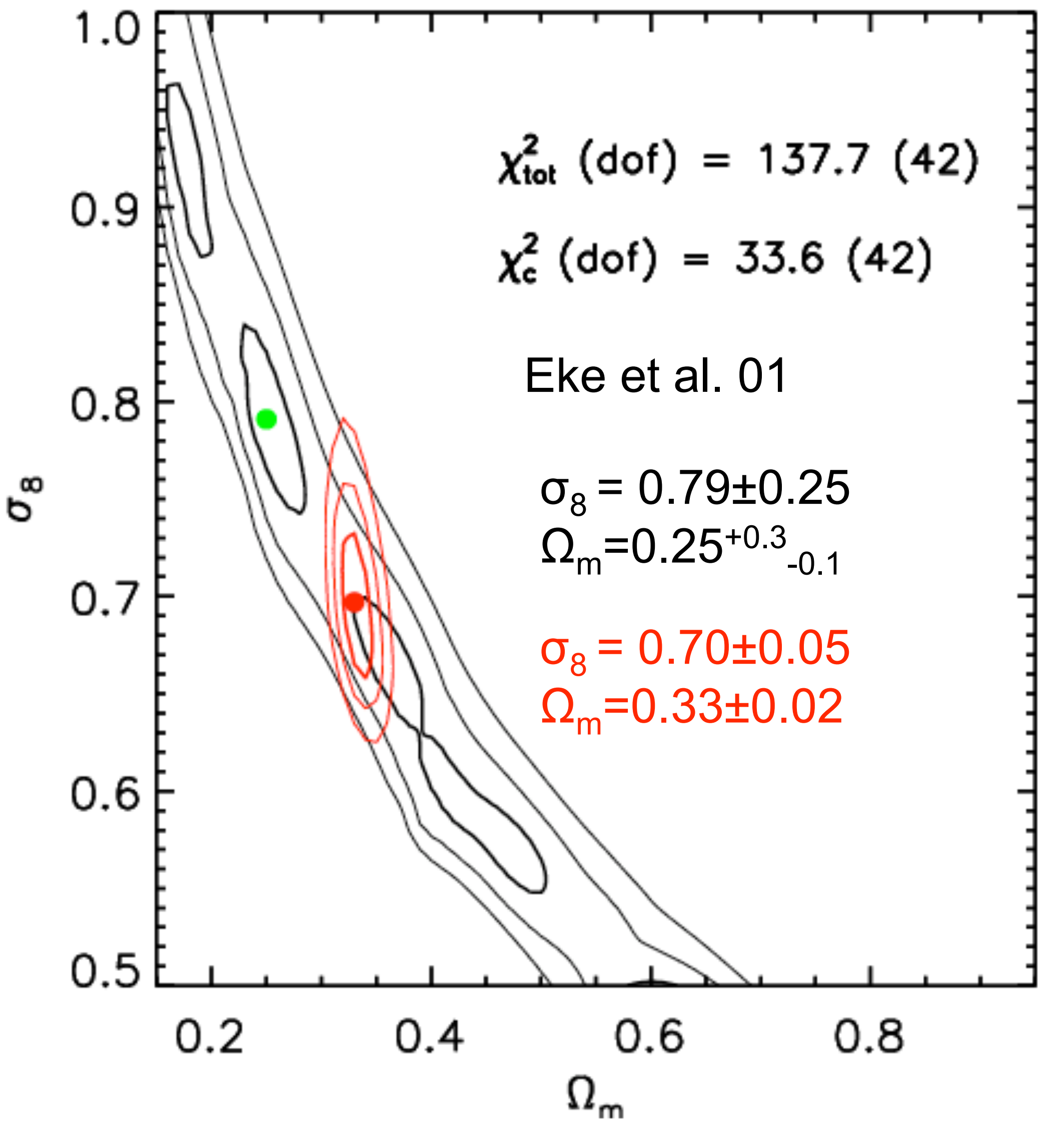
We (*Ettori et al. 09* in prep) recover M_{gas} & M_{tot} from 44 X-ray luminous galaxy clusters observed with XMM-Newton in the z-range 0.1-0.3 (from *Leccardi & Molendi 2008*) to constrain (σ_8, Ω_m).

The c-M_{tot} relation: σ_8–Ω_m

• We constrain (σ_8, Ω_m) by comparing our estimates of (c_{200}, M_{200}) to the predictions tuned from CDM simulations (*black contours*)

• We consider both **systematics** (e.g. different T profiles; fitted n_{gas}; no-limits on r_s; two methods: ~10%) in our measurements & **scatter** from numerical predictions (~20%, e.g. Neto et al. 07)

• We add constraints from f_{bar} (*red contours*).



CONCLUSIONS on c-M_{tot}-f_{gas} & WFXT

- X-ray techniques provide M_{gas} & M_{tot} with a good control of both statistical & systematic uncertainties

- **WFXT**: selection of a sample of relaxed, massive objects *over a large z-range* to constrain some cosmological params (σ_8, $\Omega_{m,}$ Ω_Λ) through estimates in the c-M_{tot}-f_{gas} plane

- CAVEAT: N-body community 'd realize an adequate sets of cosmological simulations over a large box to properly predict the expected concentration associated to the massive (>10^{14} Msun) DM halos as function of (σ_8, Ω_m; z)