# The outer cluster regions: constraints from simulations X-ray & X+SZ

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with A. Morandi, M. Roncarelli,

K. Dolag, S. Borgani, S. Molendi, L. Moscardini,
G. Murante, P. Tozzi et al.

*The Warm & Hot Universe - New York, 8 May 2008*

## SCIENTIFIC JUSTIFICATION

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

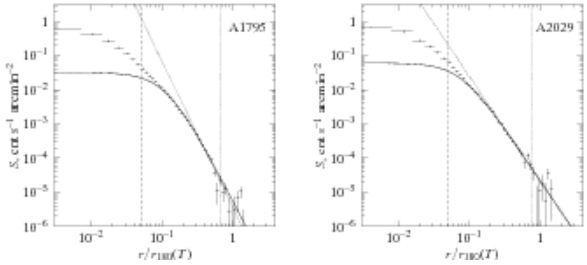
- ✓ Which $n_{gas}$, T and $S_b$ values do we expect at $R_{vir}$ ?
- ✓ Are simulated X-ray clusters consistent with the observed ones in the outskirts ?

## Implications

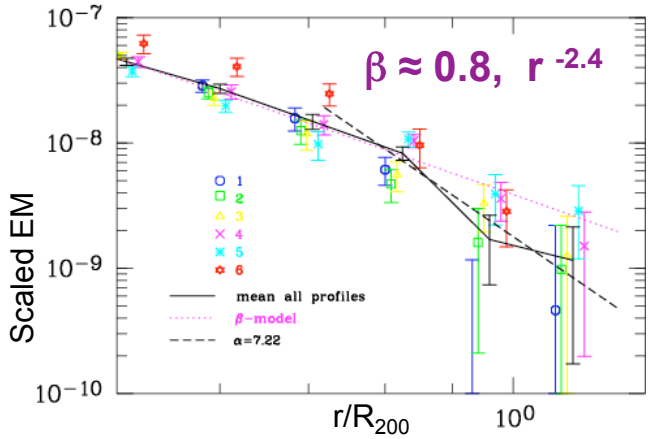
✓ To calibrate the masses (gas and dark matter) in local galaxy clusters to use them as cosmological probes

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

# ICM at $R_{vir}$: *Observed clusters*



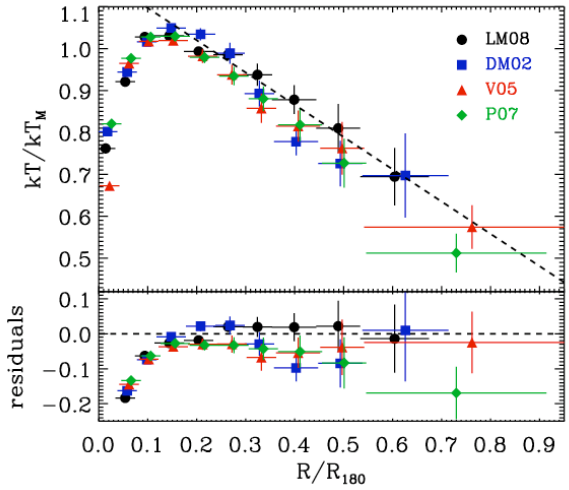

*"Outer regions of the cluster gaseous atmosphere"* Vikhlinin et al. (99): β~0.8 and larger by ~0.05 of the global fit value



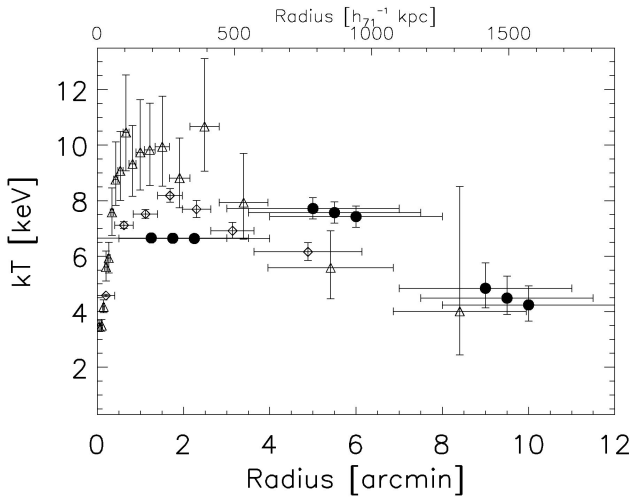

Sample of nearby clusters observed with ROSAT/PSPC (Neumann 2005)



# ICM at $R_{vir}$: *Observed clusters*




Sample of 60 objects observed with XMM (Leccardi & Molendi 08)




A2204
very preliminary results
with ***Suzaku*** by T.Reiprich

# ICM at $R_{vir}$: *Simulated clusters*

***Simulations***: 4 massive objects
**$M_{vir}$** : 1.9-3.4e15, **$T_{vir}$** : 5.5-9.9 keV

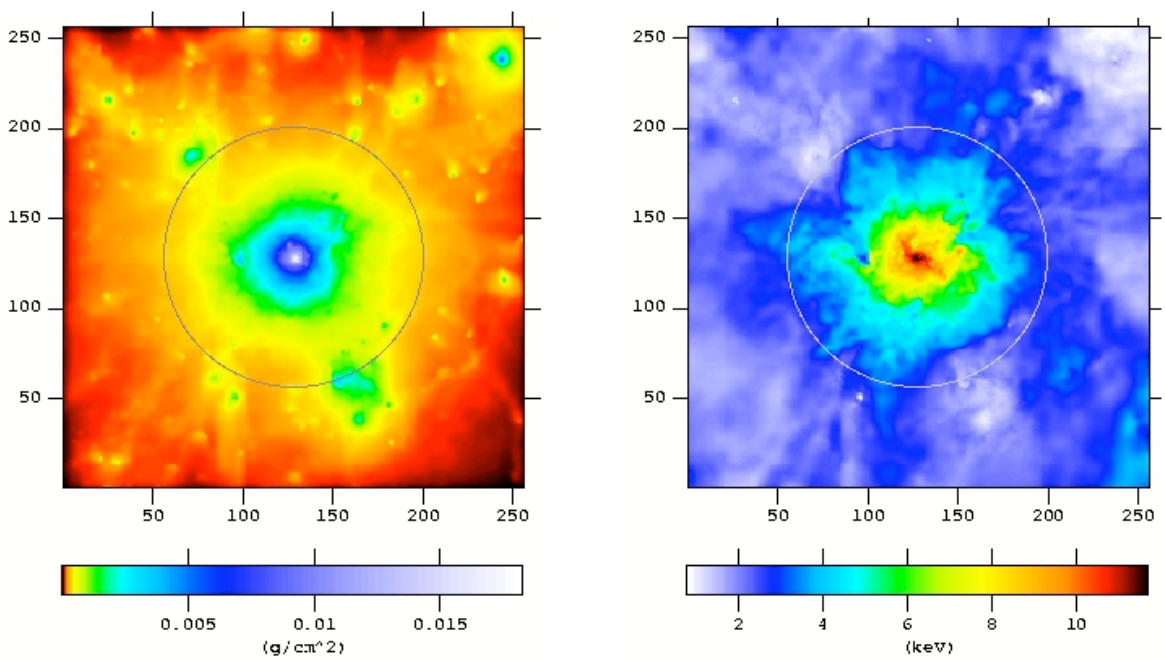
simulated using 4 different physical models:
**gravitational heating** plus *artificial viscosity, cooling, star formation, feedback, thermal conduction*

**$R_{2500}$, $R_{500}$, $R_{200}$ ≈ 0.2, 0.49, 0.74 $R_{vir}$**

$R_{vir}$ … sphere that encloses a mean density of ~100 $\rho_c$

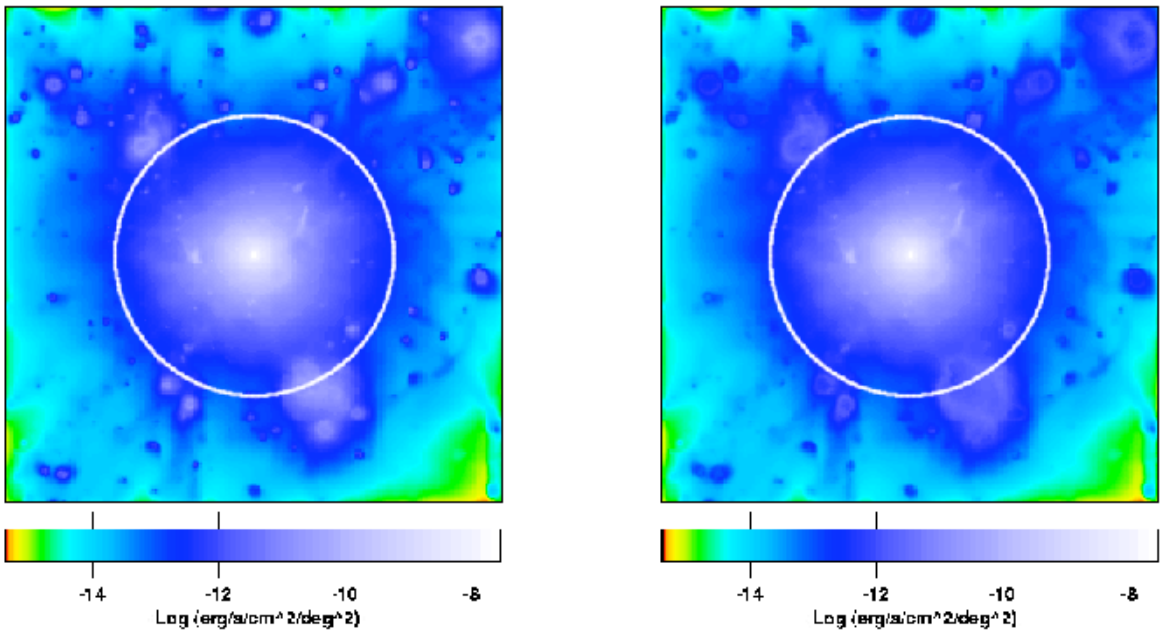
# ICM at $R_{vir}$: *Simulated clusters*

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



# ICM at $R_{vir}$: *Simulated clusters*

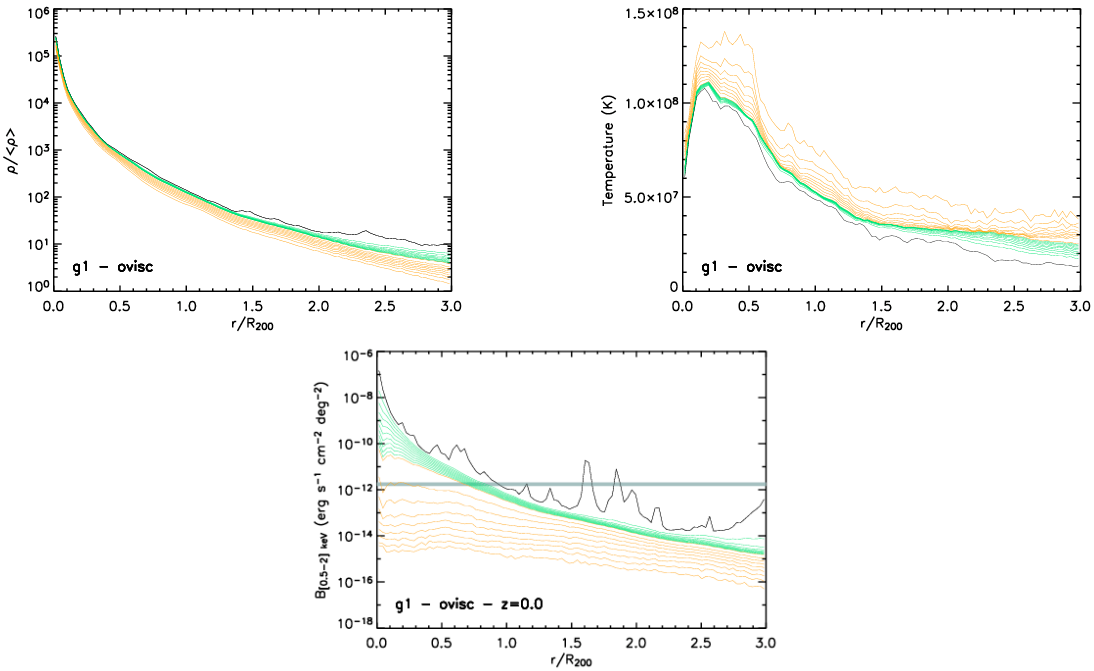
**Soft $S_b$**: 100% & 95% selected volume



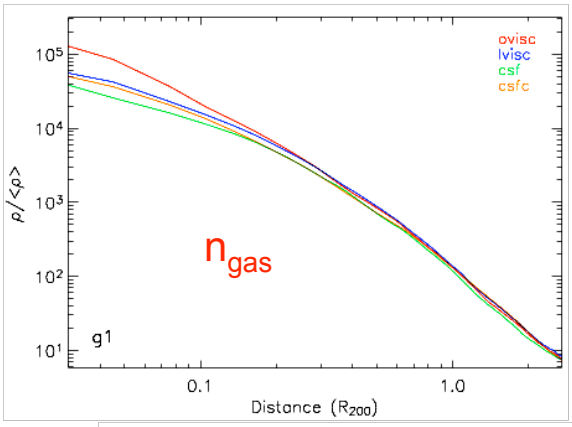


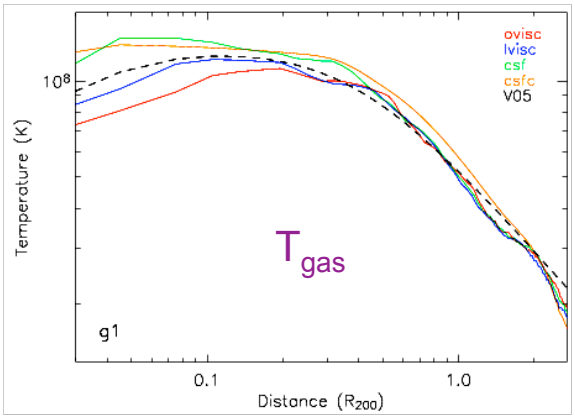

# ICM at $R_{vir}$: *Simulated clusters*

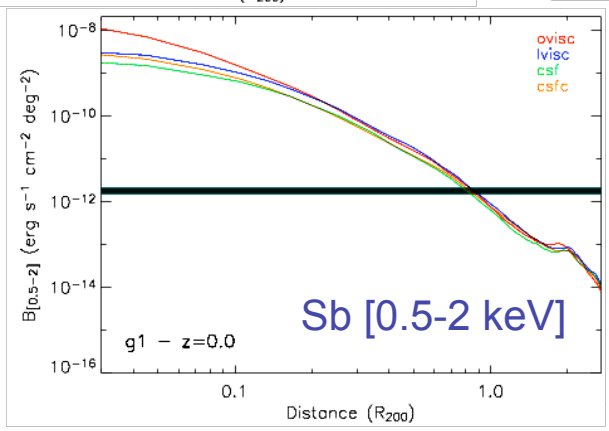
**Volume selection**: from diffuse to denser regions



# ICM at $R_{vir}$: *Simulated clusters*




Unresolved CXB w. CXO
(Hickox & Markevitch 05)

Roncarelli, Ettori et al 06



# ICM at $R_{vir}$: *Simulated clusters*

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

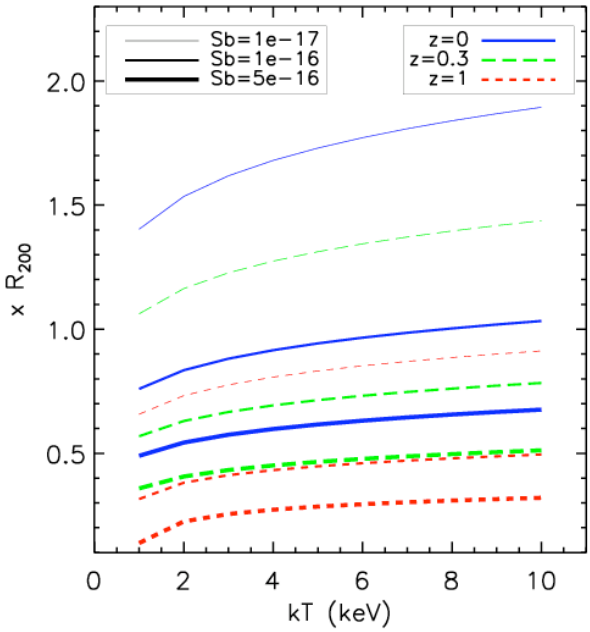
$R_{vir}$ … sphere that encloses a mean density of ~100 $\rho_c$
**$R_{2500}$, $R_{500}$, $R_{200}$ ≈ 0.2, 0.49, 0.74 $R_{vir}$**

| *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**

# Surface brightness at $R_{200}$

**As reference, we can quote** for a T=5 keV obj at z=0,
**a soft X-ray surface brightness of *8e-17*** **erg/s/cm²/arcmin²**






# Surface brightness at $R_{200}$

*simulations vs observations*

In the [0.5-2] keV band, ***slope*** of $S_b = - d \ln(S_b) / d \ln(r)$

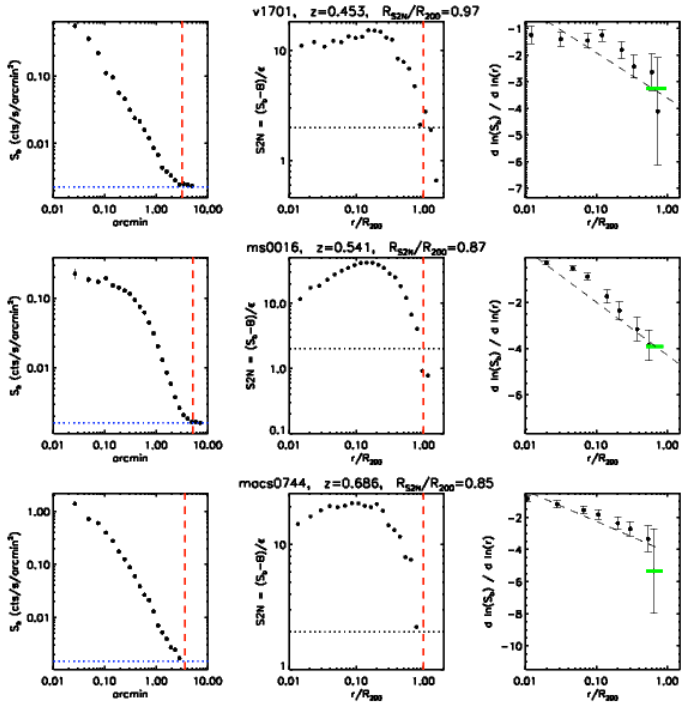
**0.3-1.2 $R_{200}$** Simulations: 3.79-4.05
Observations: 3.79 ± 0.38 (Neumann 05)

**0.7-1.2 $R_{200}$** Simulations: 4.29-4.54
Observations: 5.7 ± 1.3 (Neumann 05)

**>1.2 $R_{200}$** Simulations: 4.90-5.67
… 40% higher than observed values at $R_{200}$

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

# Surface brightness at $R_{200}$




**High-z** (z>0.3) **objects with CXO** (Ettori et al in prep.):

*fit of the derivative of ln(Sb)/ln( r) extrapolated at $R_{200}$ -4.7 ± 1.0*



# Slopes: given $n_{gas}\sim r^a$, $T_{gas}\sim r^b$, $\rho_{DM}\sim r^c$

$S_b \sim r^{2a+1+0.4b}$; $0<b/a<2/3$;

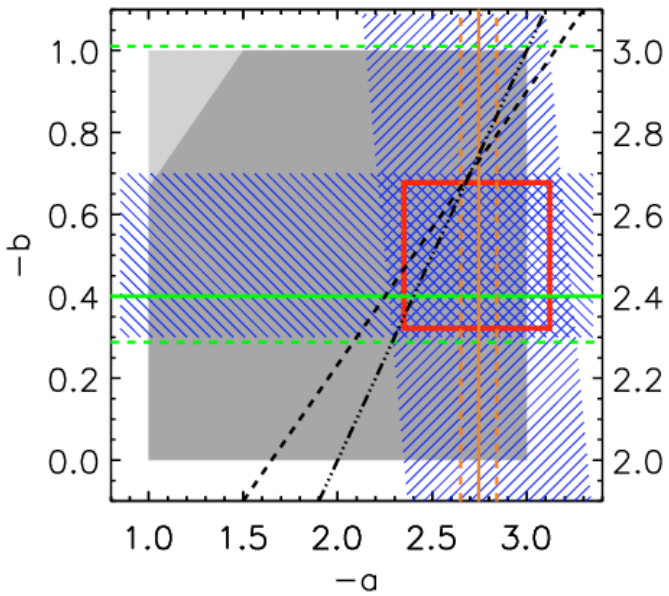
$M_{gas}>0$, $a+3>0$; $M_{DM}\sim r^{3+c} \sim M_{hyd}\sim r^{b+1}$

$S_b$ from CXO & from simulations

$T_{gas}$: [Markevitch98, Vikhlinin05]

$K\sim r^{b-2a/3}\sim r^{1.1}$

$f_{gas}\sim r^0$




$\rho_{DM}\sim r^{-2.5(0.2)}$ Navarro05

# X+SZ *(in progress… A.Morandi)*

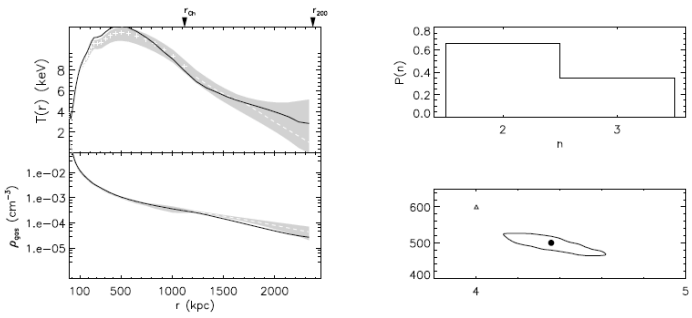
✓ **Within 0.5 $R_{200}$**, ~95% of X-ray counts are present, but just 60% of the total energy

✓ Other biases affect X-ray analysis: cosmological dimming, subclumps, background

✓ **With SZ data** (e.g. CBI interferometer on large FOV), we can try to recover the gas properties at $R_{200}$: no dependence on z, linear dependence on clumps density, background just from thermal noise



# X+SZ *(in progress… A.Morandi)*

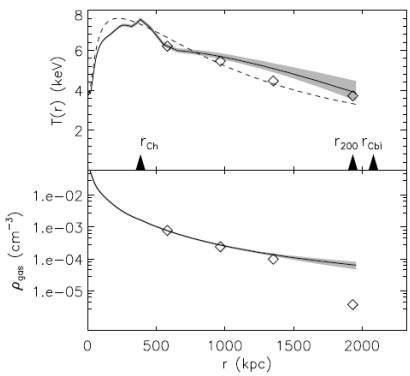



Joint fit of the observed X-ray T profile and SZ visibility + hydrostatic equilibrium

➔ Constraints on T, $n_{gas}$, DM profile

(***upper panels***)
mock data of A2204

(***right***)
best-fit of A478

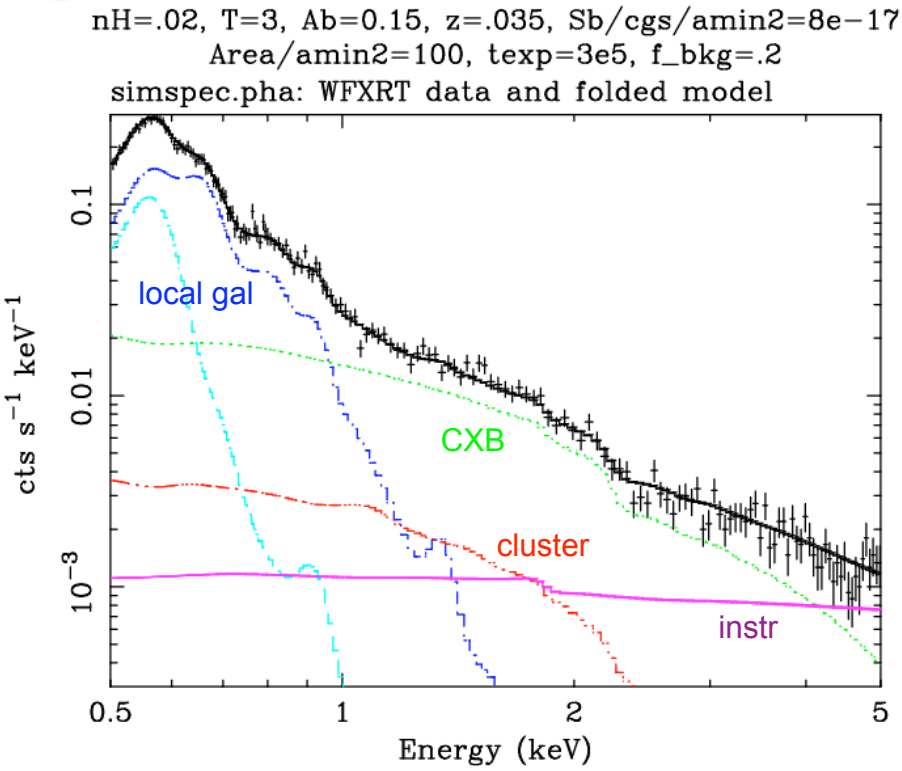


# CONCLUSIONS: summary

- We know what we'd observe at $R_{200}$ ($T_{gas}$, Sb): X-ray observations & simulations provide a consistent picture with $n_{gas}$~$r^{-2.6}$ & $T_{gas}$~$r^{-0.4}$ & $S_b$~1e-16erg/s/cm$^2$/arcmin$^2$

- SZ data are complementary to X-ray data: a joint X+SZ analysis is a powerful tool to investigate the cluster outskirts

- With an $t_{exp}$= 1 Msec and random fluctuations of 5% on the bkg components, we can reach typical uncertainties (90% c.l.) **<10%** on **K** & **T** of MEKAL with WF/TES independently



# Bkg: dominant in GCs outskirts