

Where the wild baryons are

the outskirts of galaxy clusters



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SCIENTIFIC JUSTIFICATION

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

WHY

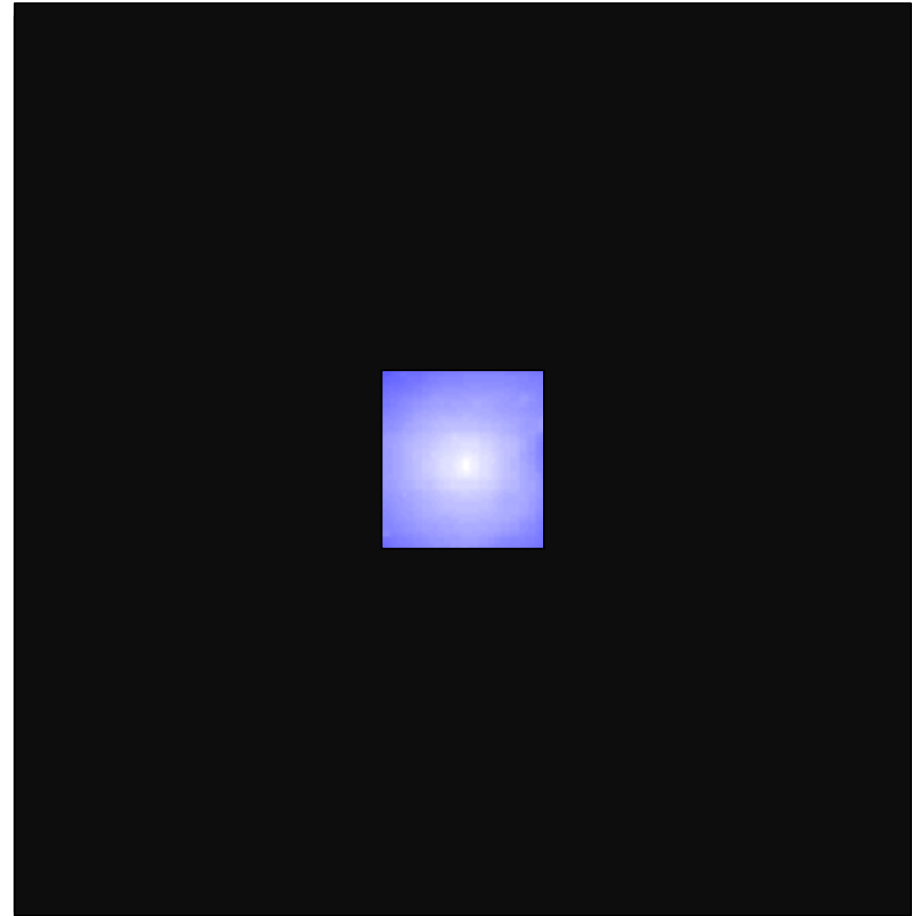
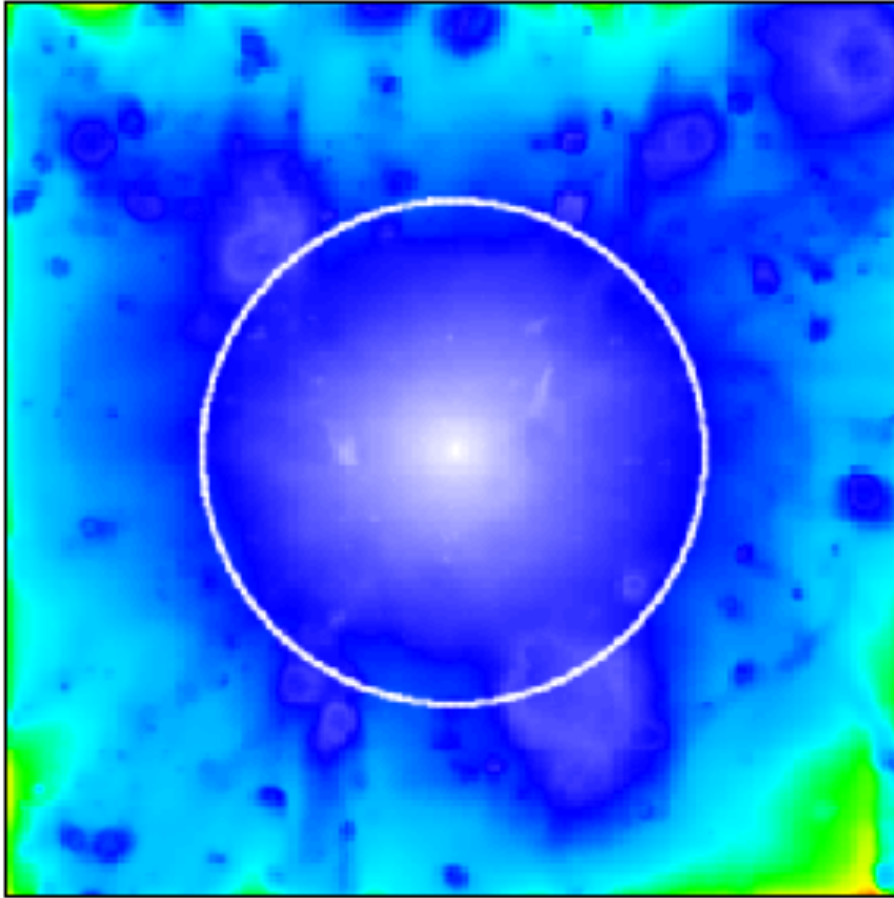
- ✓ To calibrate the masses (gas and dark matter) in local galaxy clusters to use them as cosmological probes

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

Between R_{500} and R_{200} : 70% of cluster volume and ~30% of M_{vir}

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

What limits the observations at R_{200} ?

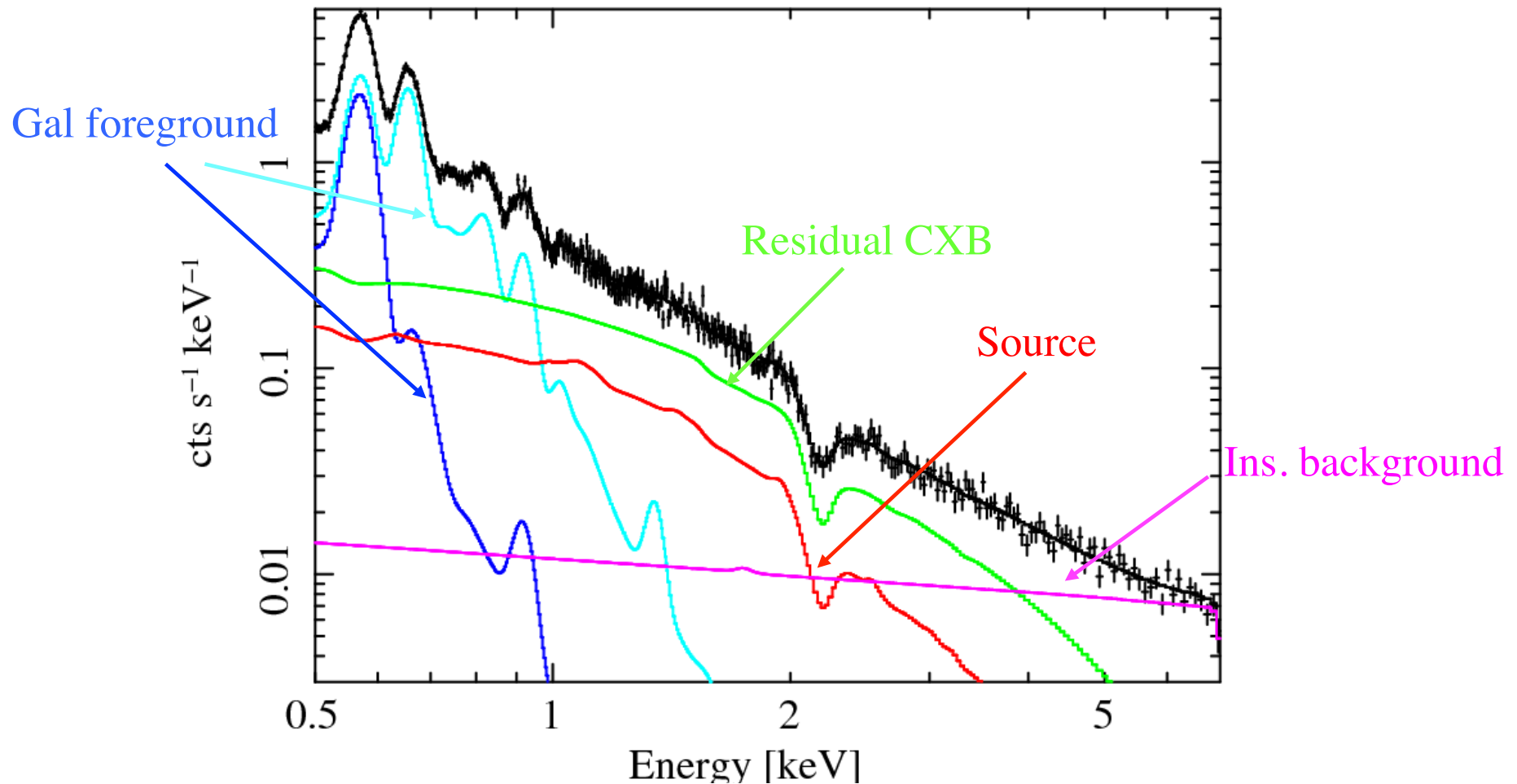


Surface brightness in hydro-simulated clusters
(from Roncarelli, Ettori et al. 2006)

Bkg: dominant in GCs outskirts

$N_H=0.02$, $T=3$, $A_b=.15$, $z=.035$, $S_b/cgs/amin2=3e-16$
 $Area/amin2=100$, $texp=1e5$, $f_cxb=0.25$, $f_ins=3.0$

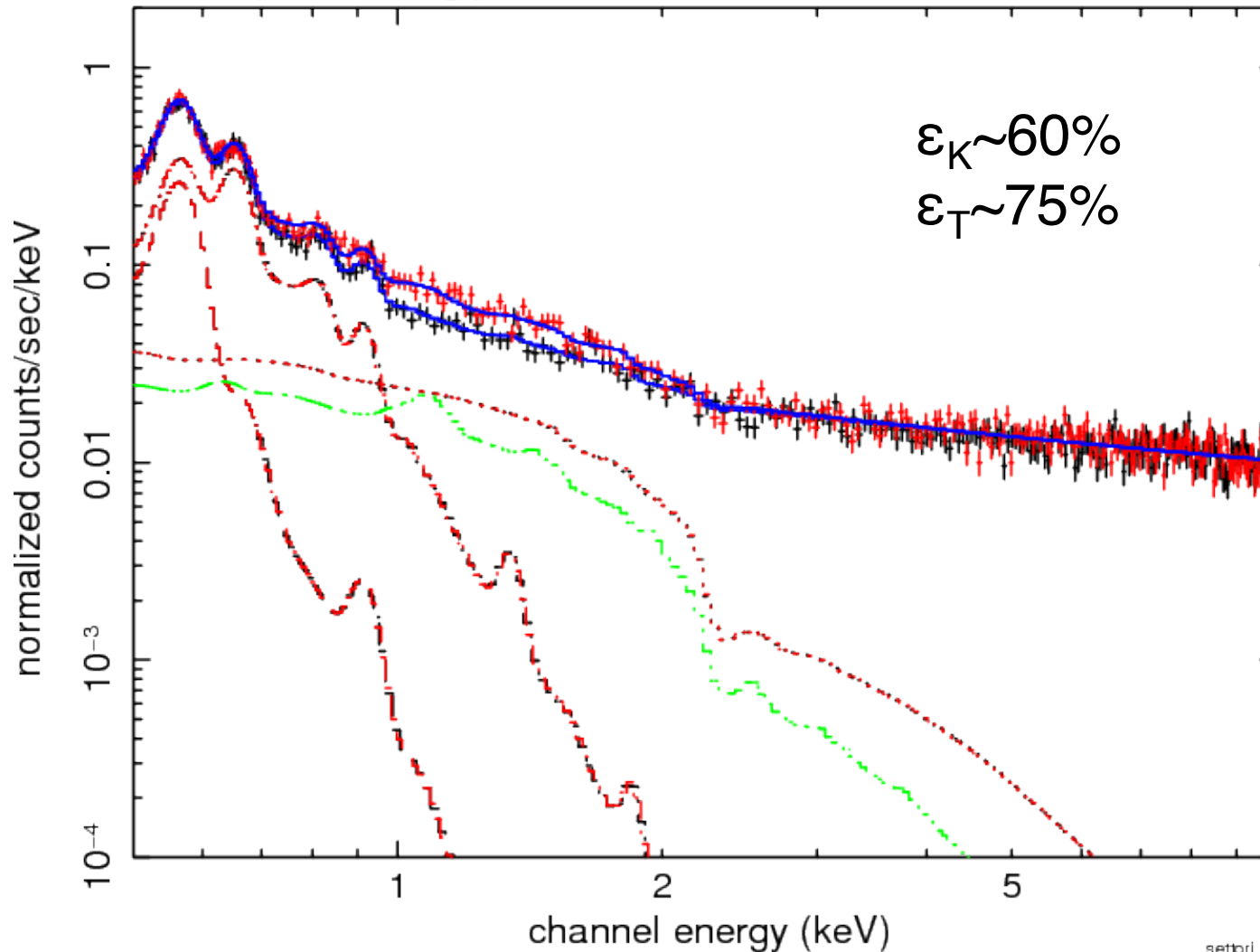
simspec.pha: WFXT data and folded model



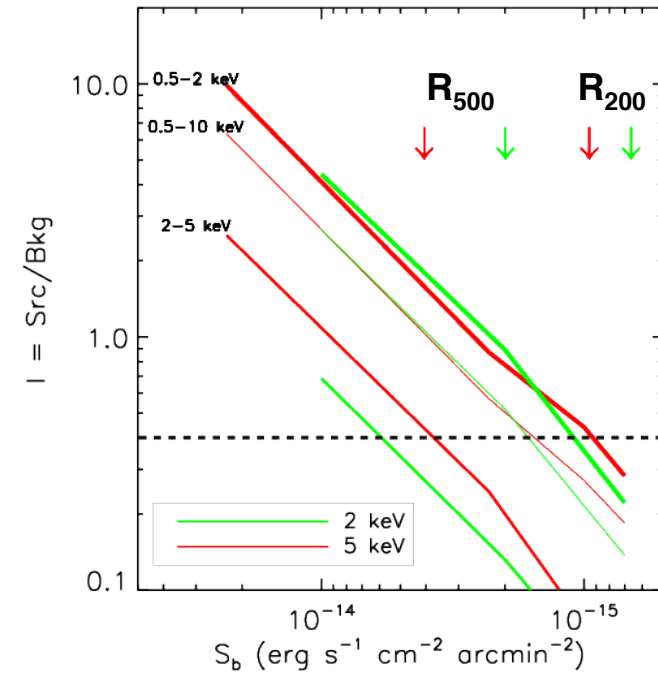
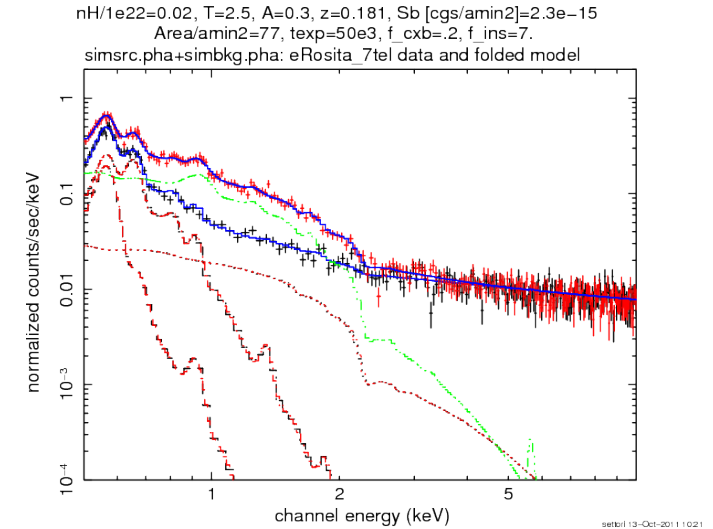
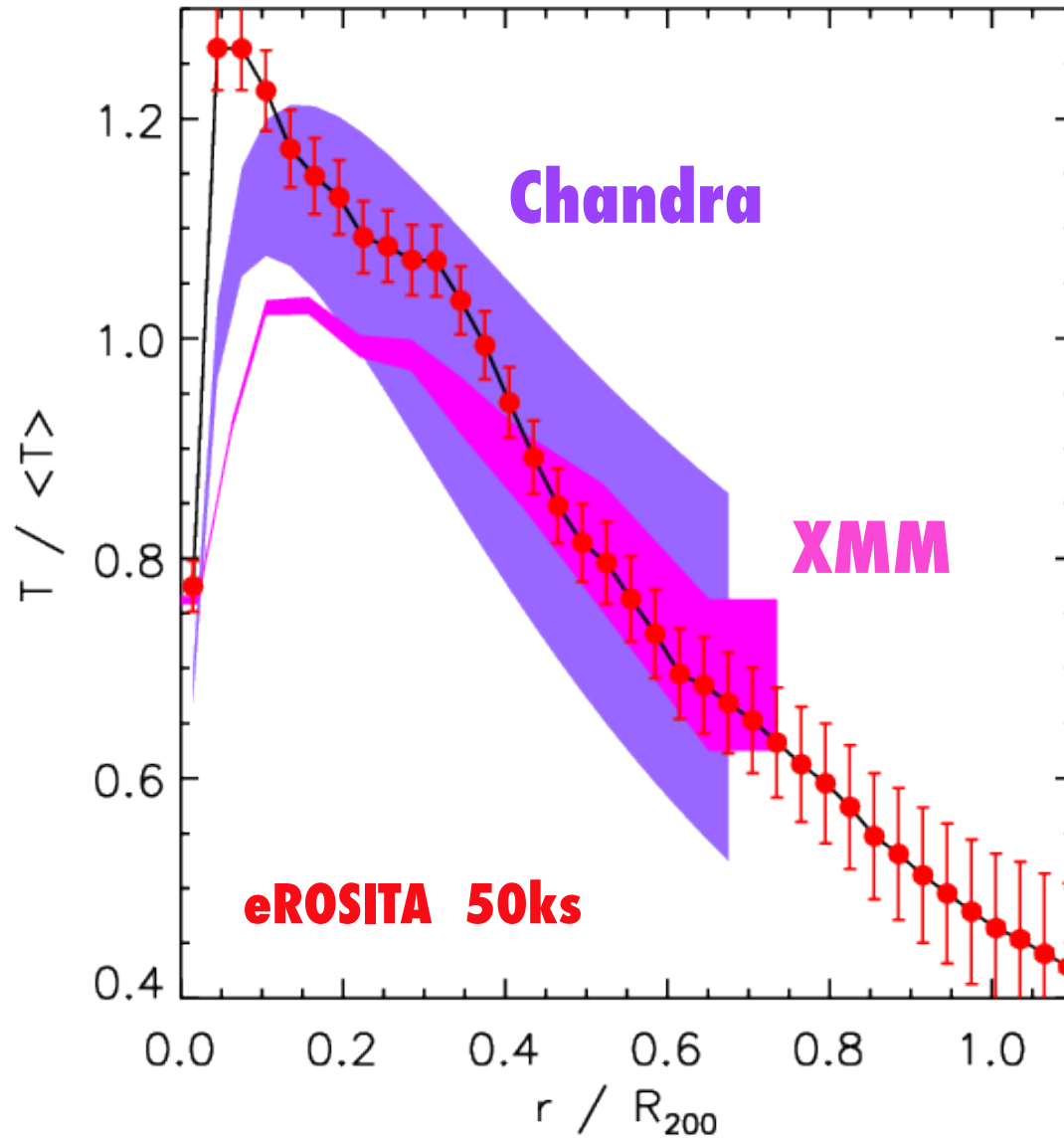
Simulation for 3keV cluster @ R200 (Ettori & Molendi arXiv:1005.0382)

Bkg: dominant in GCs outskirts

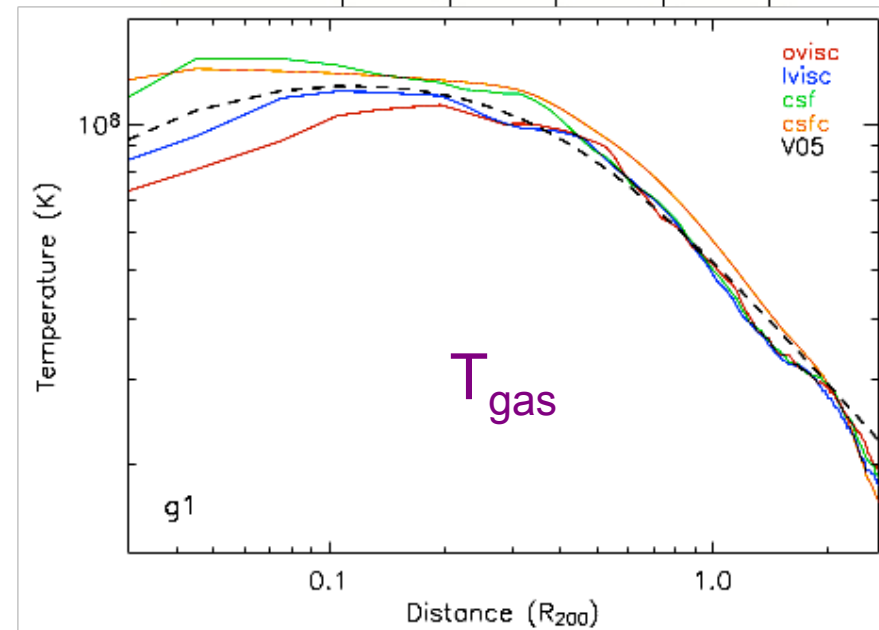
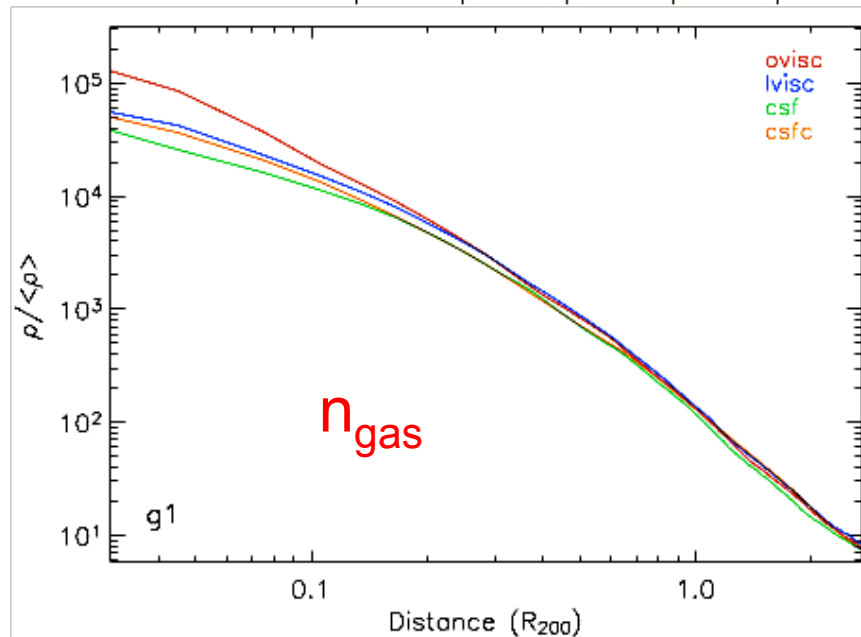
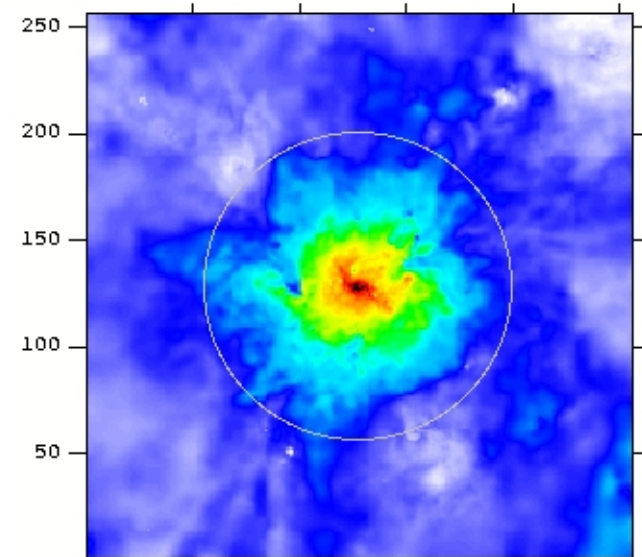
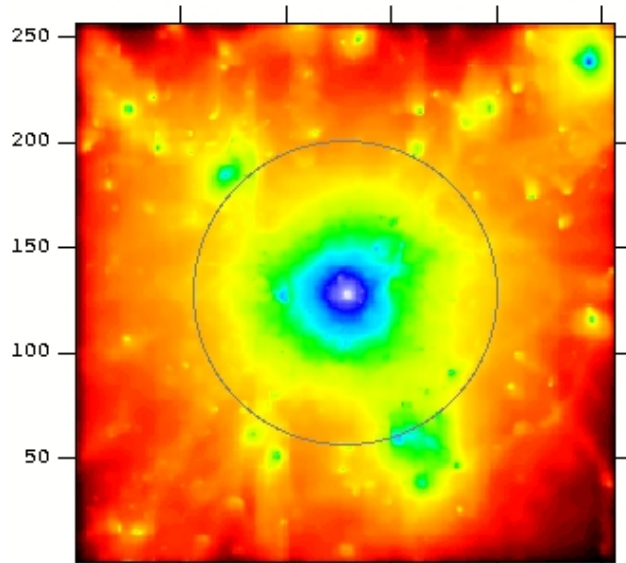
$nH/10^{22}=0.02$, $T=3.$, $A=0.3$, $z=0.035$, S_b [cgs/amin2]= $3e-16$
Area/amin2=100, $t_{exp}=100e3$, $f_{cxb}=.2$, $f_{ins}=7.$
simsrc.pha+simbkg.pha: eRosita_7tel data and folded model



T_{gas} at R_{200} : *prospects for eROSITA*



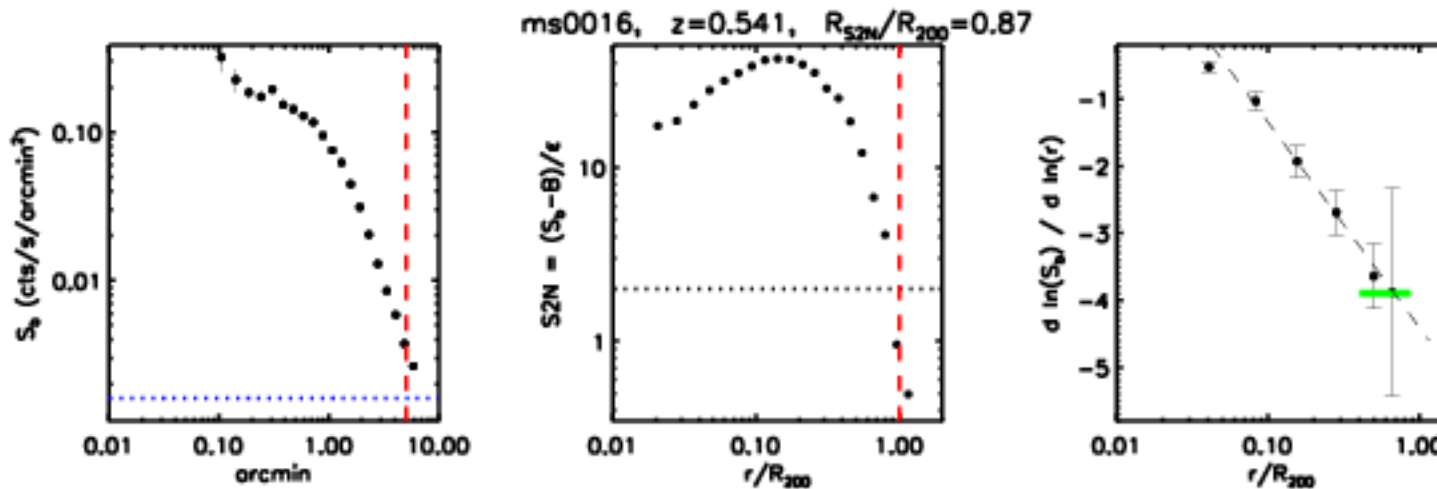
ICM at R_{200} : *Simulated clusters*



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 :

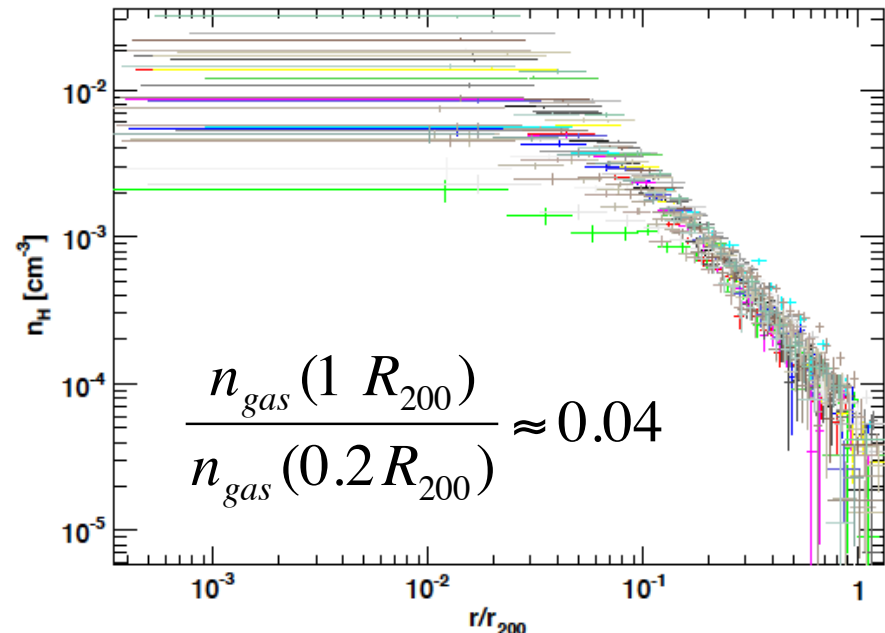
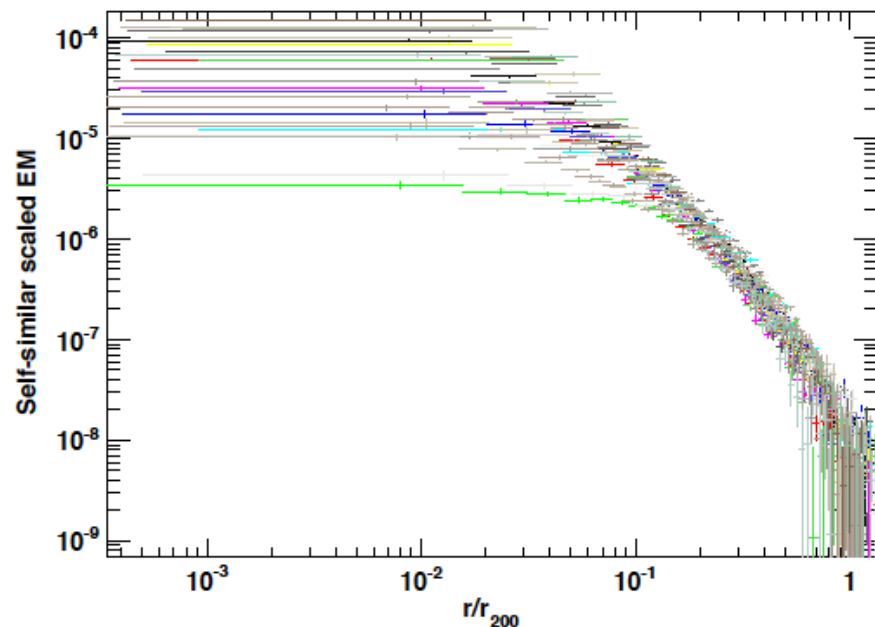
at $0.7 R_{200}$: -3.9 ± 0.7 , at R_{200} : -4.3 ± 0.9

Note: $S_b \sim r^{1-6\beta}$... $\beta = 0.8/0.9$ (generally 0.67 is assumed)

S_b at R_{200} : Observed clusters

Study of S_b at $r > 0.7 R_{200}$ in a sample of 31 nearby bright clusters observed with ROSAT PSPC

(Eckert, Vazza, SE, et al. 11)



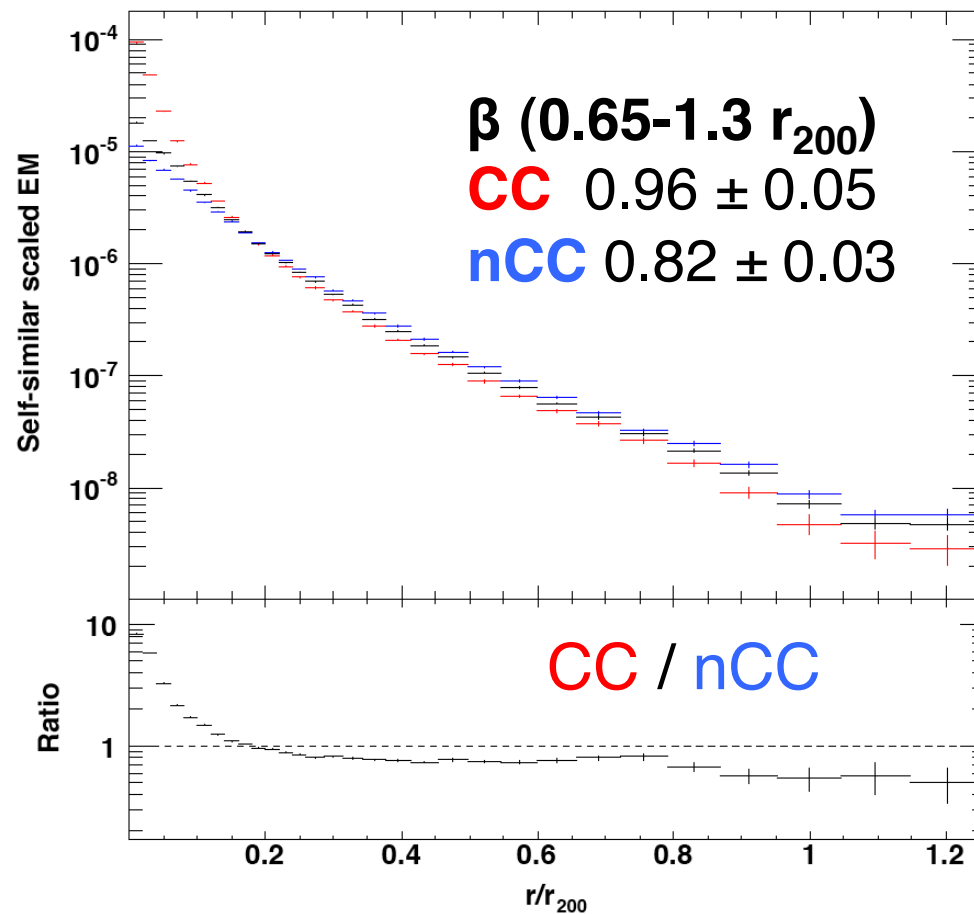
$$f_{gas}(R_{200}) \approx (0.15 \pm 0.01) (T/10 \text{ keV})^{0.48}$$

$$f_{gas}(R_{200}) \approx 0.89 (\Omega_b / \Omega_m)_{WMAP7}$$

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Study of S_b at $r > 0.7 R_{200}$ in a sample of 31 nearby bright clusters observed with ROSAT PSPC

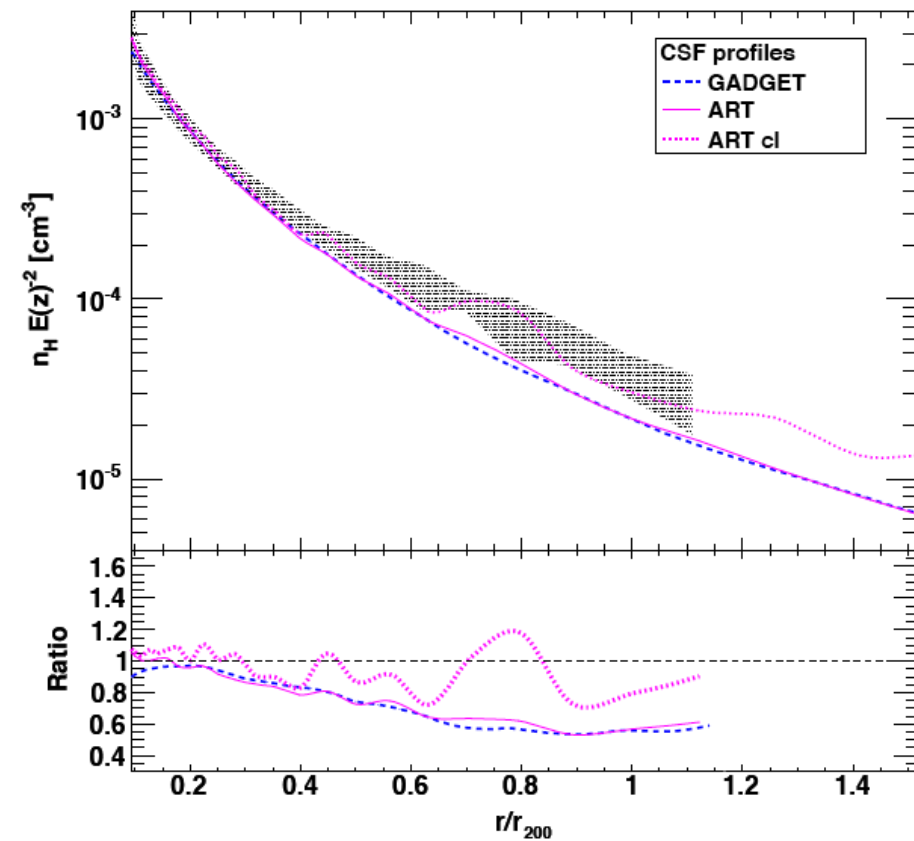
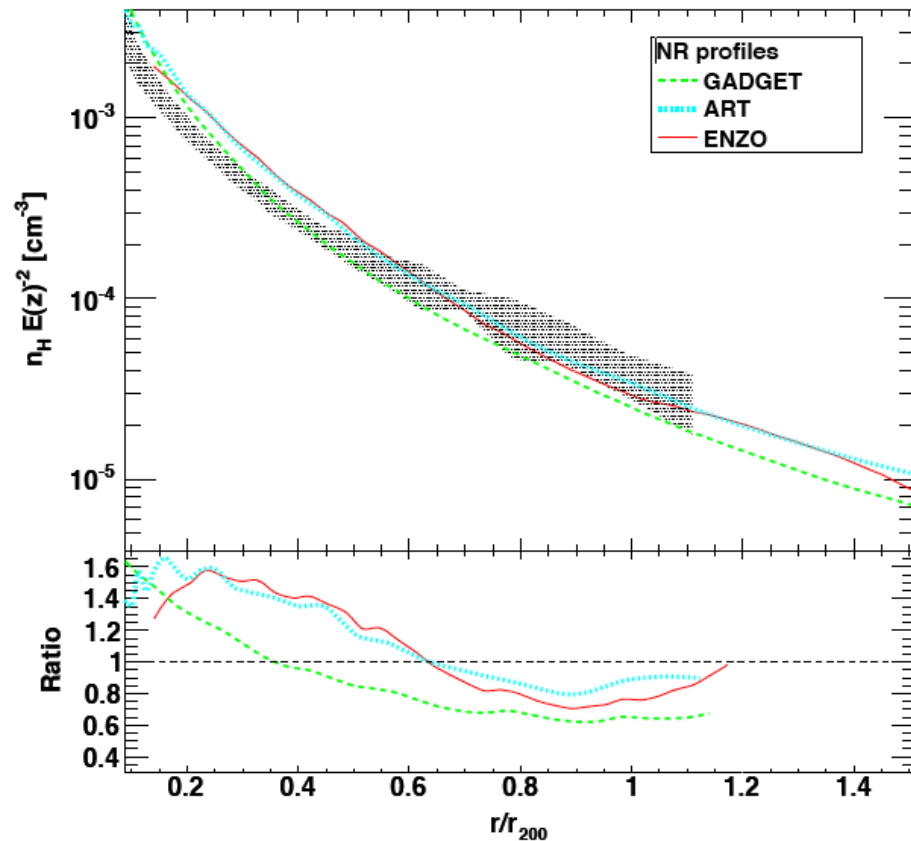
(Eckert, Vazza, SE, et al. 11)



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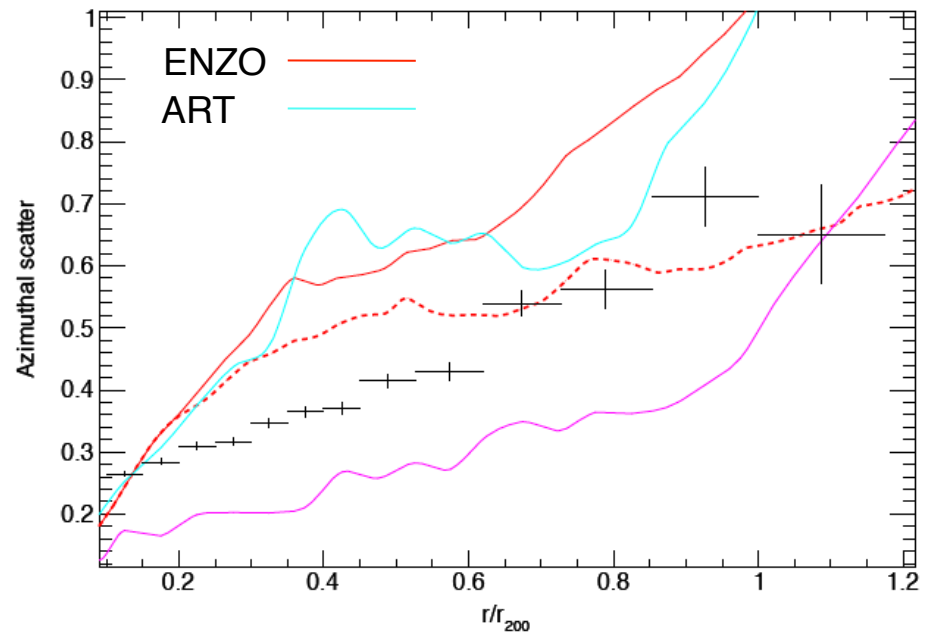
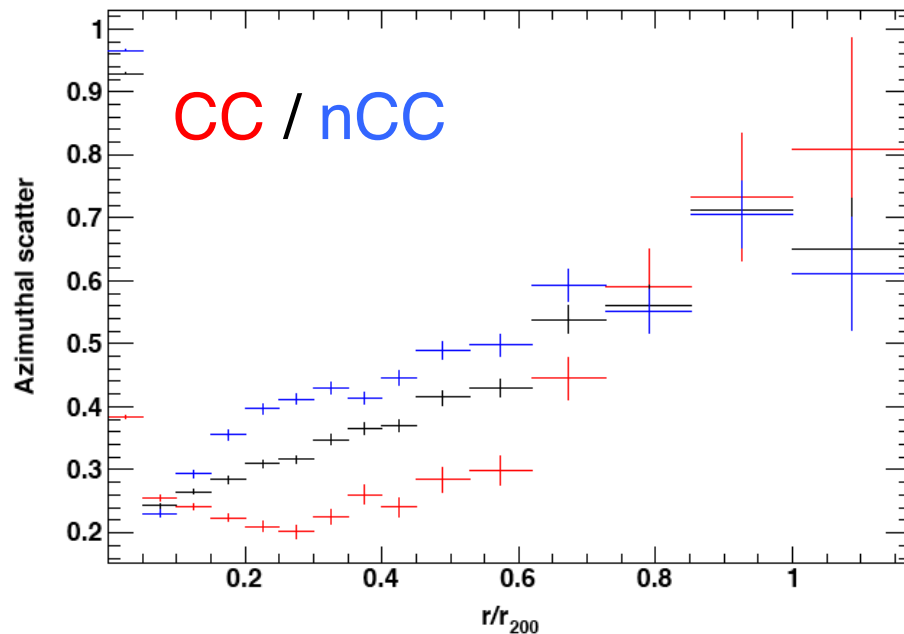
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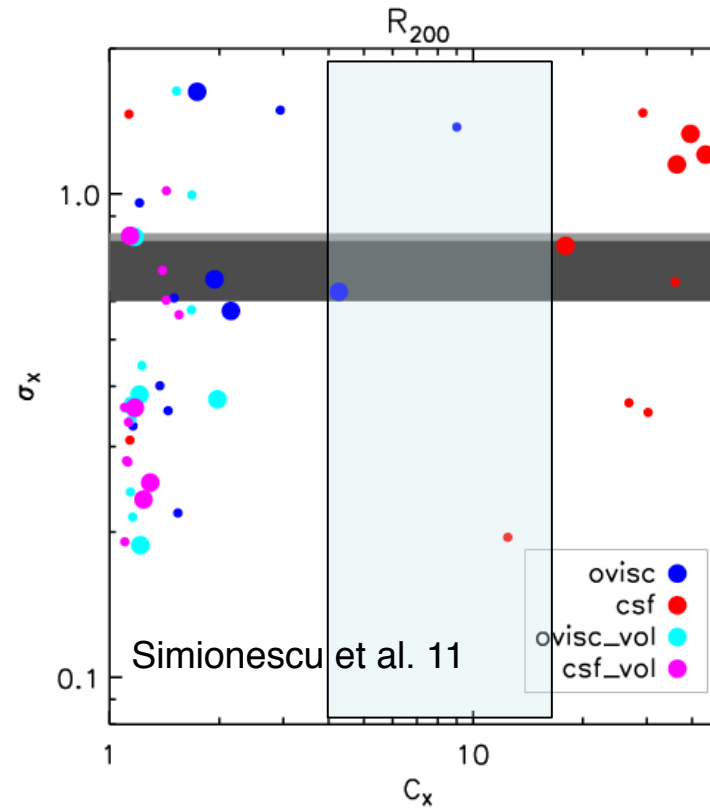
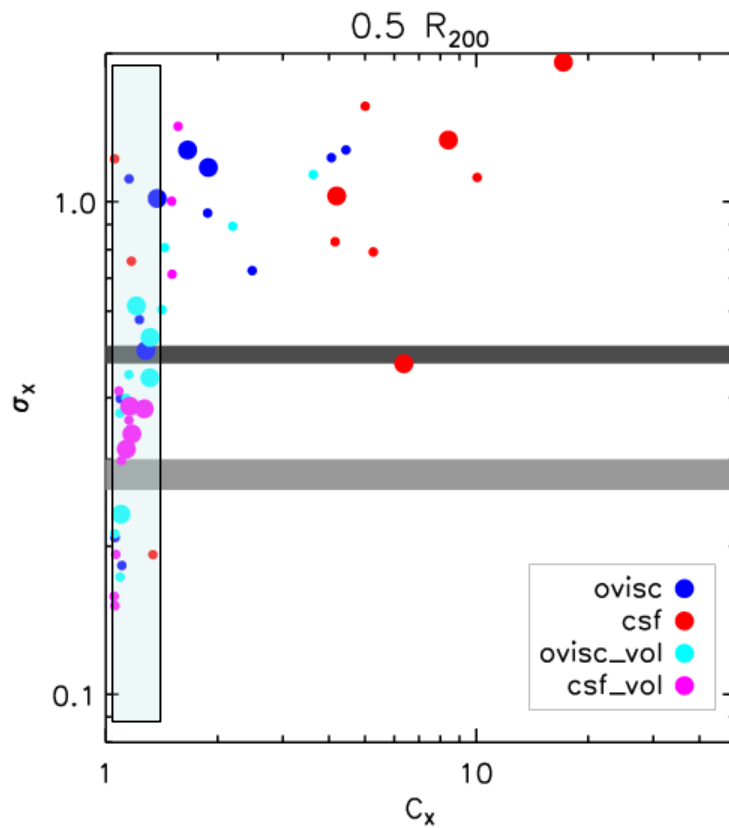


(see Vazza, Roncarelli, Ettori, Dolag 11)

ICM at R_{200} : *scatter & clumpiness*

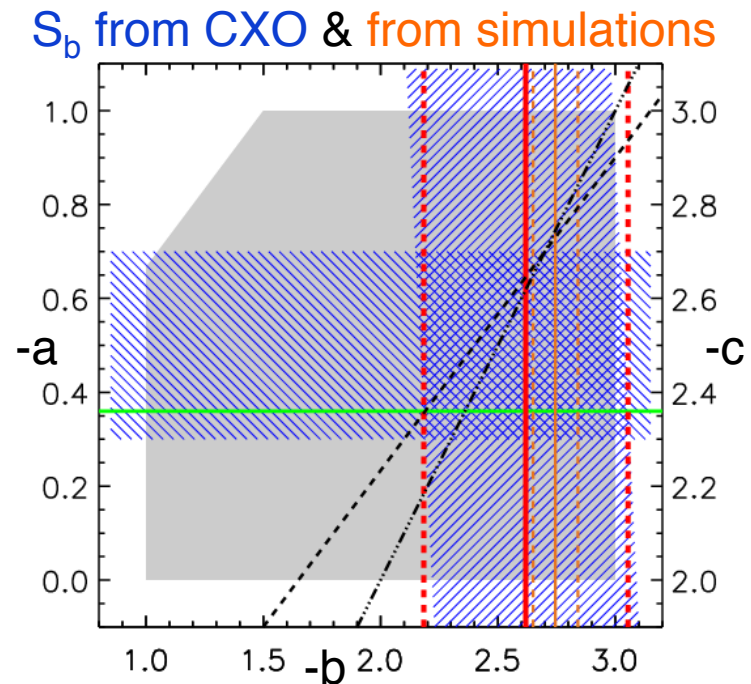
(Ettori, Roncarelli et al. 2011)

Correlation σ_x - C_x is very significant ($3e-11/ 3e-5$)



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



$$n_{\text{gas}} \sim r^{-b} \sim r^{-2.6}$$

$$T_{\text{gas}} \sim r^{-a} \sim r^{-0.5}$$

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

...but we can have also some surprises ($K_{\text{gas}}, M_{\text{HE}}$)...

CONCLUSIONS on the ICM in the outskirts

- The scatter provides an observational probe of the physics acting in the outskirts
 - ✓ *Is the physics in the hydro/grid-based simulations correct ?*
 - ✓ *how much are the present estimates at R_{200} representative ?*
 - ✓ *how does the clumpiness affect the estimated ICM properties ?*