CHARACTERIZATION OF THE TEMPERATURE DISTRIBUTION OF GALAXY CLUSTERS

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Elena Rasia (rasia@umich.edu)
University of Michigan

Smooth Particle Hydrodynamics	Adaptive Mesh Refinement
Stefano Borgani; Klaus Dolag; Gian Luigi Granato; Pasquale Mazzotta; Giuseppe Murante; Cinthia Ragone-Figueroa	Erwin Lau; Daisuke Nagai; Camille Avestruz; Kaylea Nelson

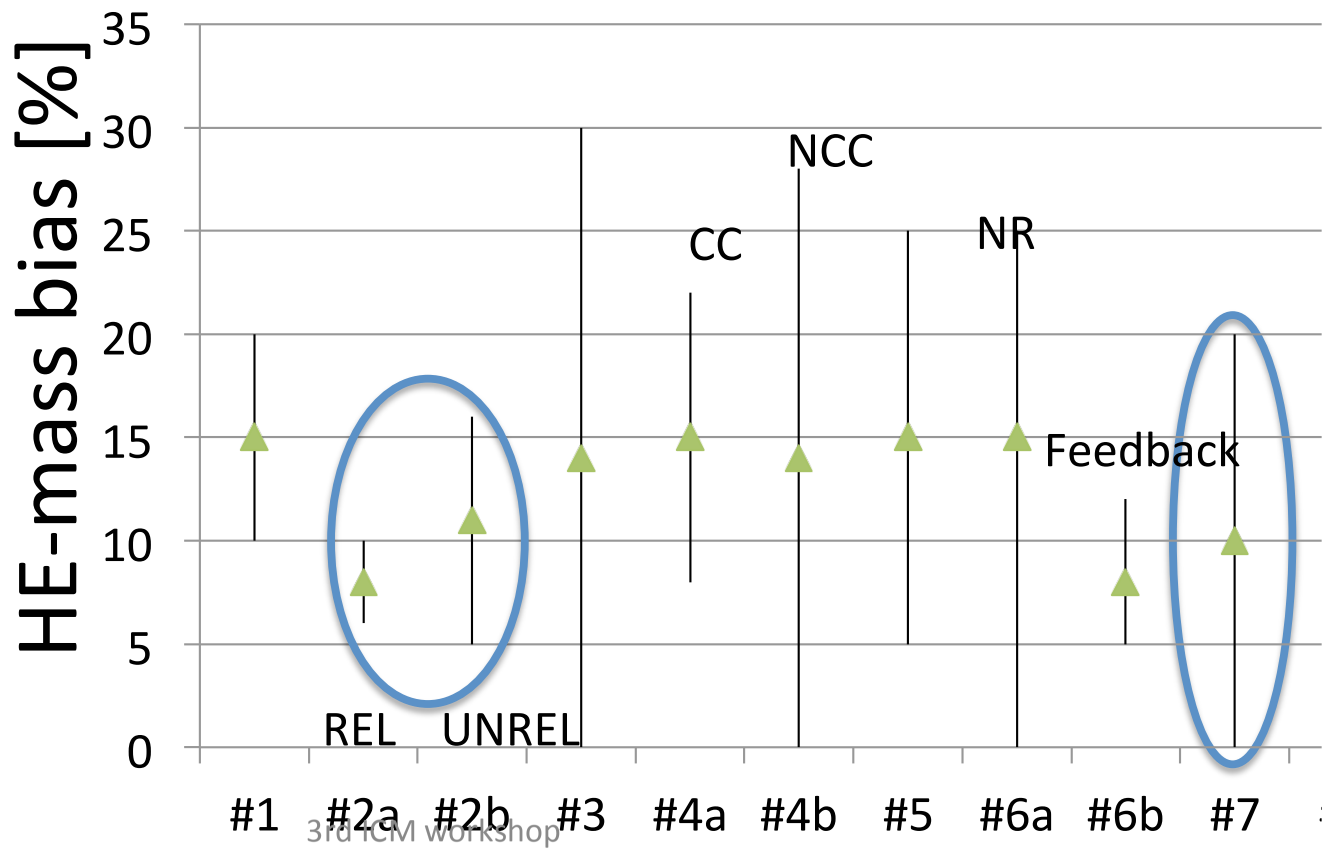
Hydrostatic Equilibrium Mass Bias from simulations

also Kaylea's and Hun's talks

$$M_{HE}(<r) = -\frac{rT(r)}{\mu m_p G}\left[\frac{d\ln\rho_{gas}}{d\ln r} + \frac{d\ln T}{d\ln r}\right]$$

- Computed in 3D: mass-weighted temperature, at $R_{500,TRUE}$
- Bias generates from failure of HE & presence of motion in the gas

1 *Suto et al. 2013*
2a relaxed: *Lau et al 2009*
2b: unrelaxed: *Lau et al 2009*
3: *Piffaretti & Valdarnini 2008*
4a: CC: *Burns et al. 2008, Jeltema et al.08*
4b: NCC: *Burns et al. 2008 Jeltema et al. 08*
5: *Ameglio et al. 2009*
6a: NR *Kay et al. 2004*
6b: feedback *Kay et al. 2004*
7: *Rasia et al. 2004*
+ more (Battaglia et al.; Sembolini et al.)

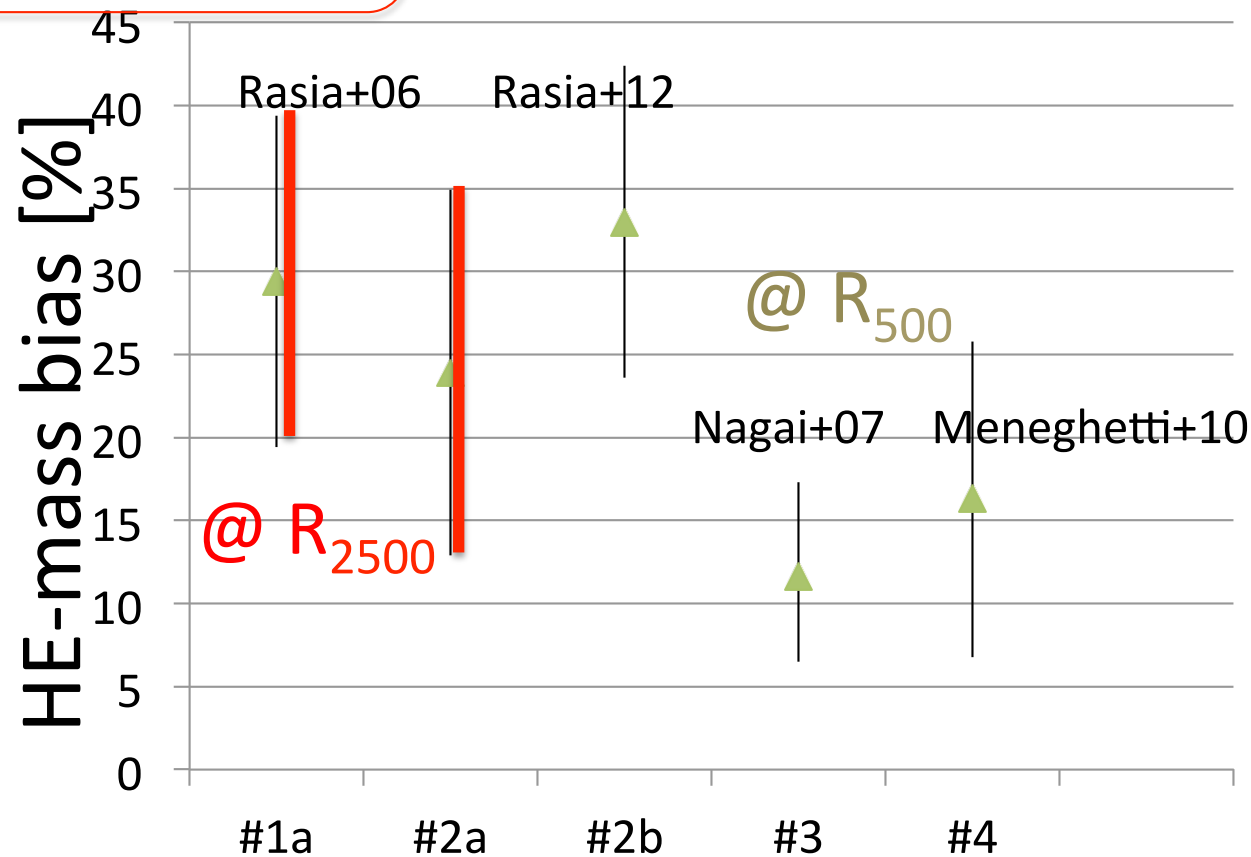


HE MASS BIAS via mock X-ray

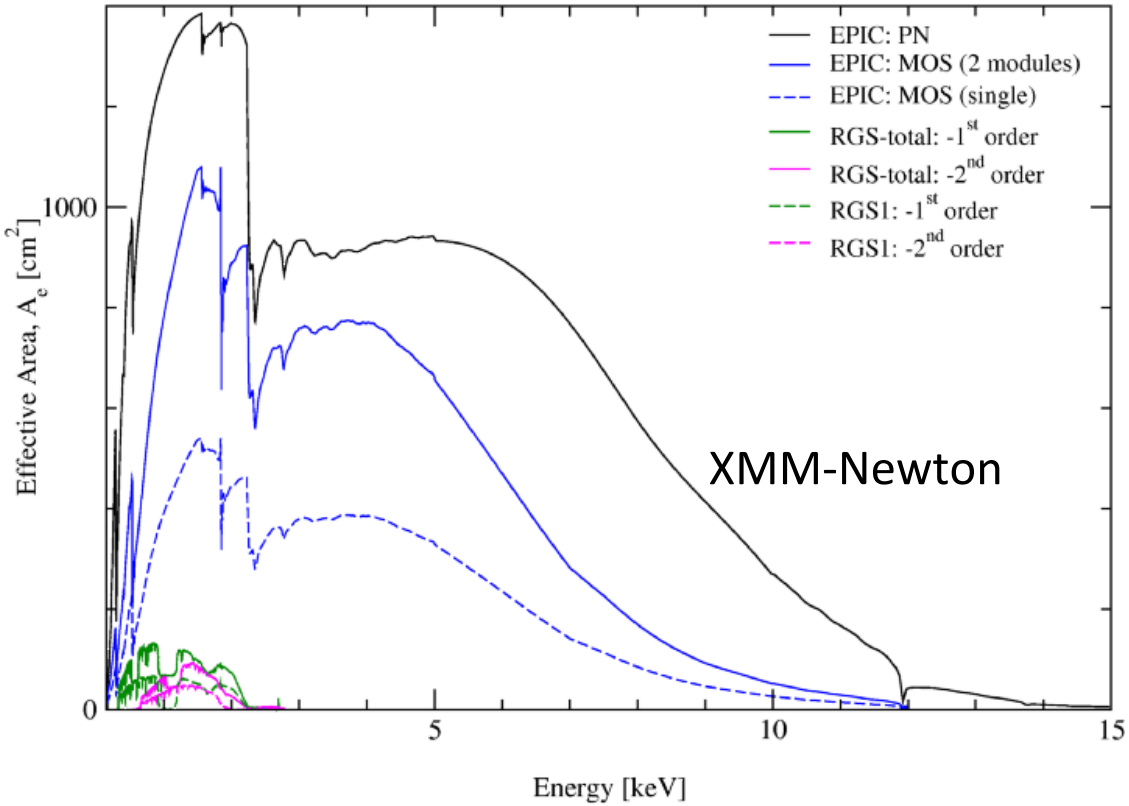
$$M_{HE}(<r) = -\frac{rT(r)}{\mu m_p G}\left[\frac{d\ln\rho_{gas}}{d\ln r} + \frac{d\ln T}{d\ln r}\right]$$

Computed through X-ray analysis on synthetic images. X-ray procedure *à la* Vikhlinin et al. 2006

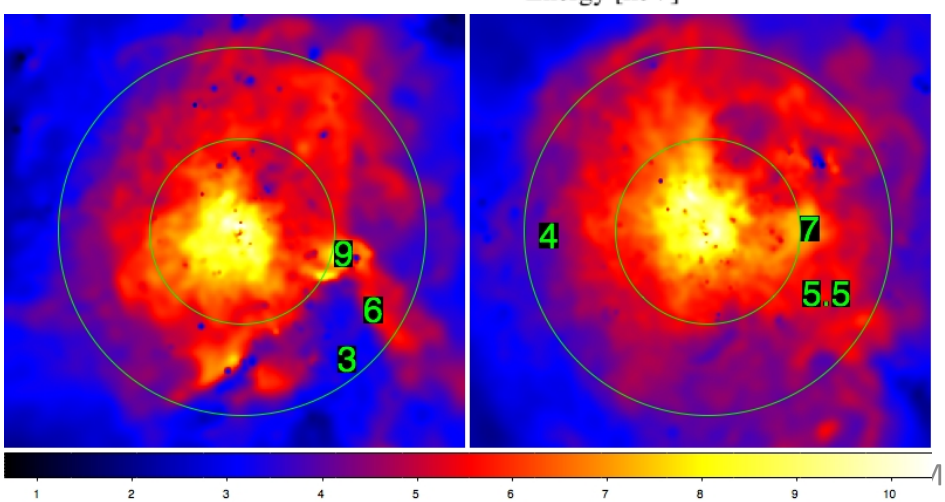
1: *Rasia et al. 2006* (6 objects) R_{2500} M_β Rasia+06
2a: *Rasia et al. 2012* (20 objects) R_{2500} M_{HE} Rasia+12
2a: *Rasia et al. 2012* (20 objects)
3: *Nagai et al 2007* (16 objects) Nagai+07
4: *Meneghetti et al. 2010* (3 objects) Meneghetti+10

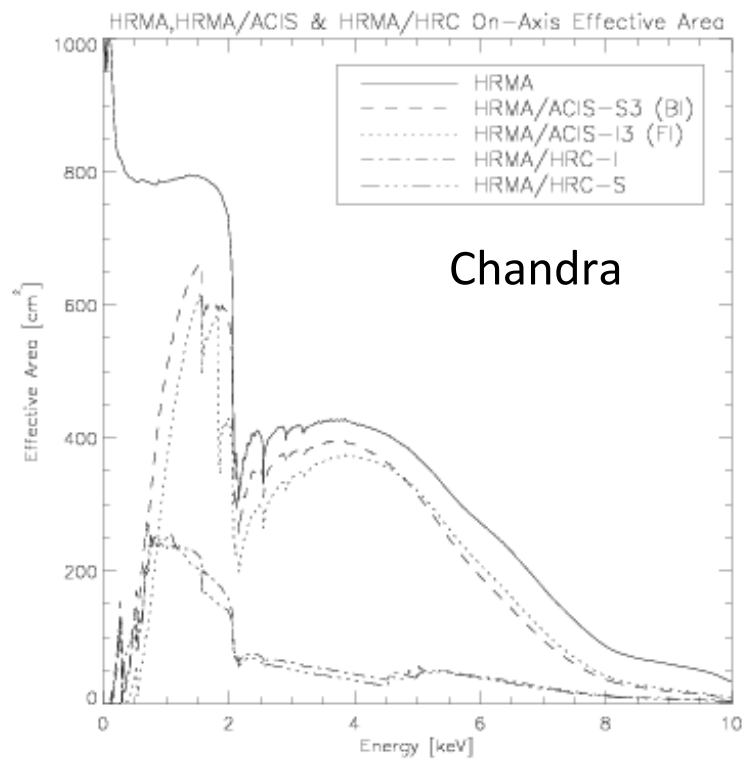


EFFECTIVE AREA

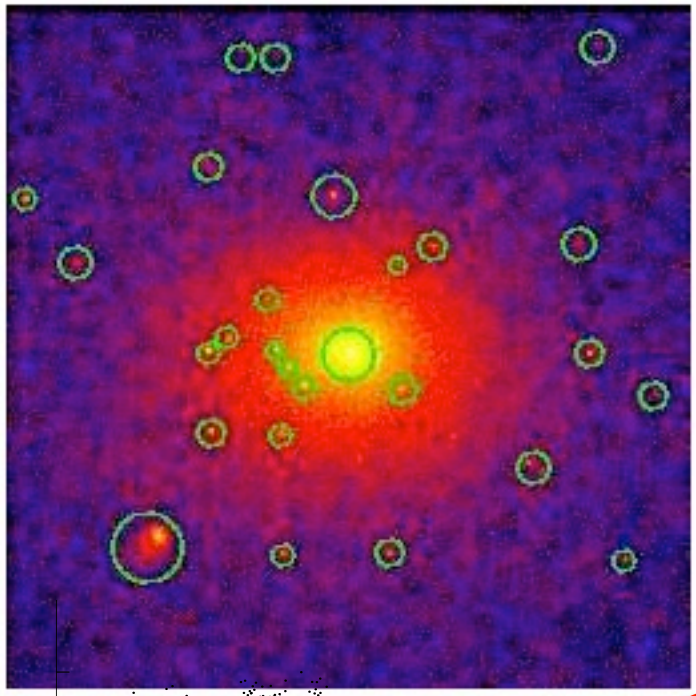


Whenever there are temperature in-homogeneities, the X-ray temperature is biased towards lower values. *Mazzotta et al. 2004, Vikhlinin 2006*



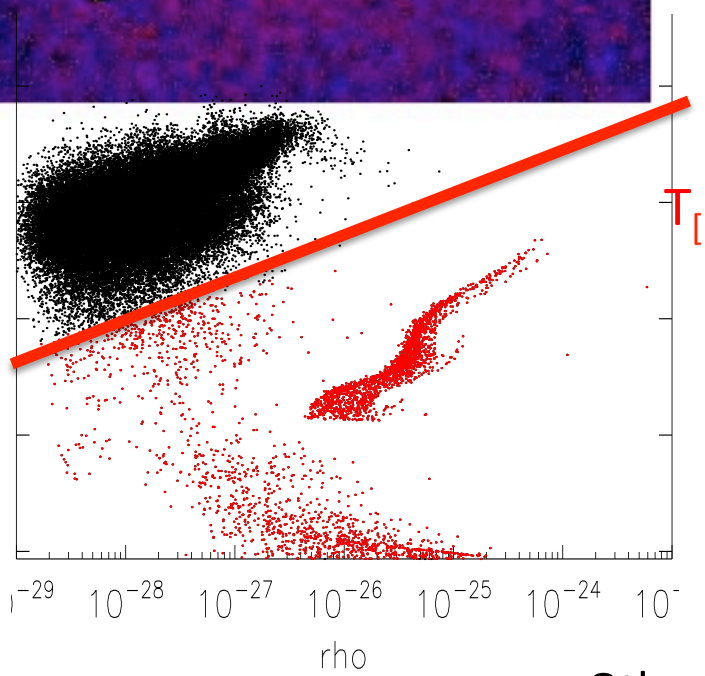


Inhomogeneities are not generated by the overcooled gas



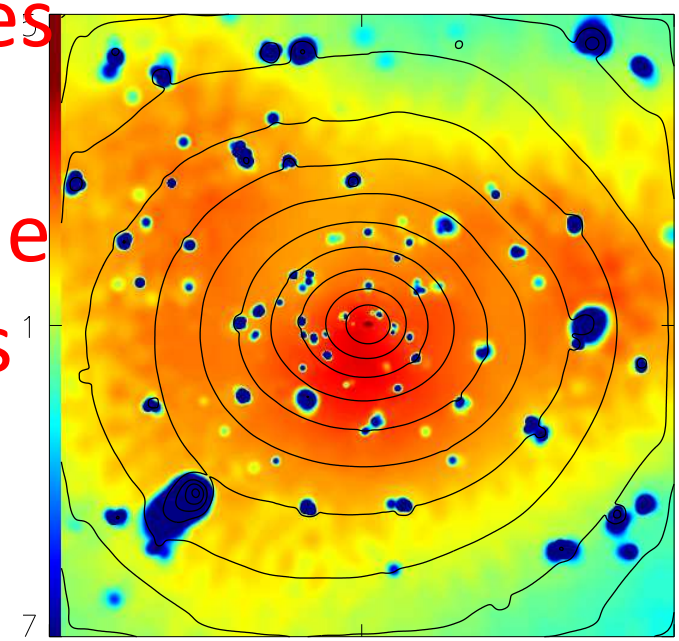
Rasia+06

Mock Chandra image



$T_{[kev]} > 3\ 10^6\ \rho_{[gr/cm3]}^{0.25}$

Rasia+12



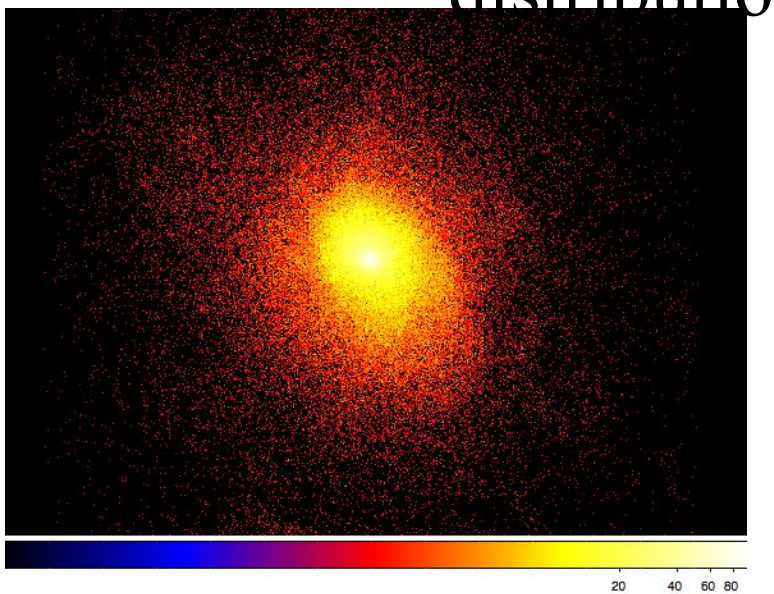
T_{sl} map

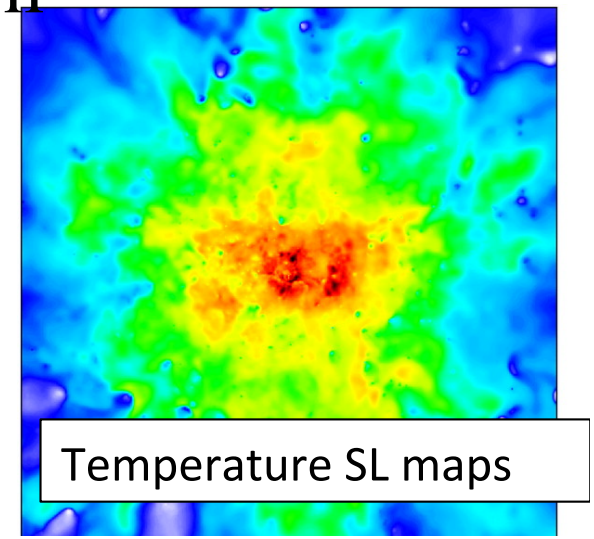
COLD BLOBS problem: not an issue anymore

Other methods: *Roncarelli et al. 2006 and 2013, Vazza et al.13, Zhuravlaeva et al. 13*

Smooth X-ray appearance might hide inhomogenous temperature distribution

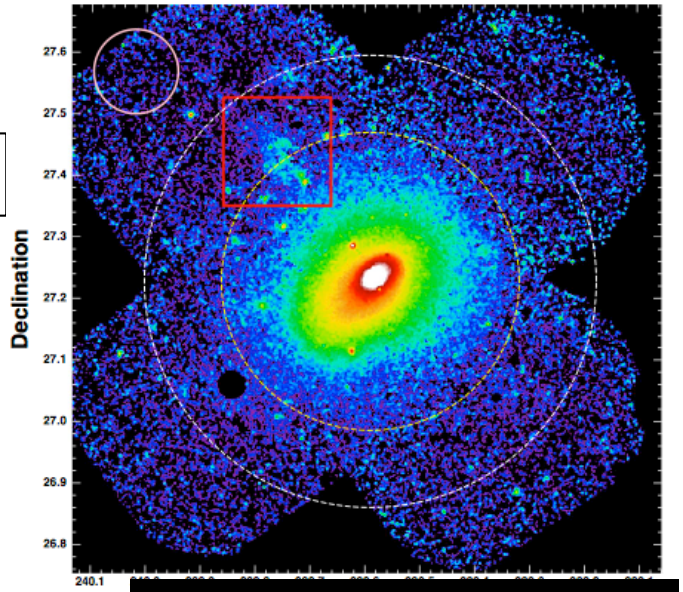
Inhomogeneities:
- Filaments
- clumps
- substructures
- stripped gas



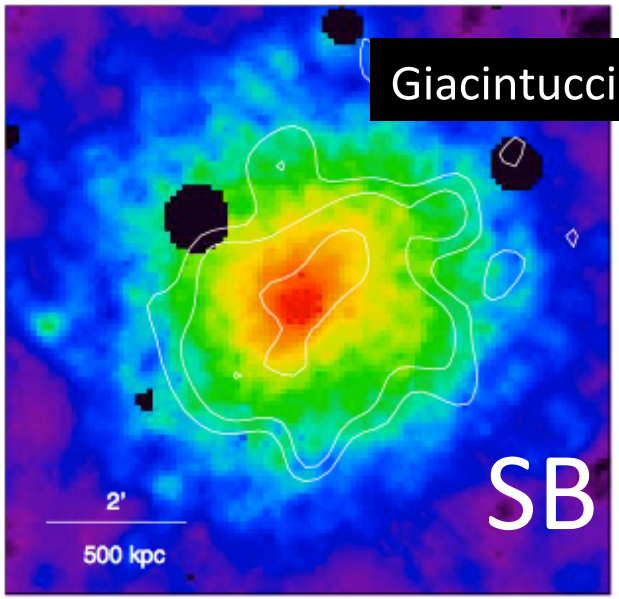


Temperature SL maps

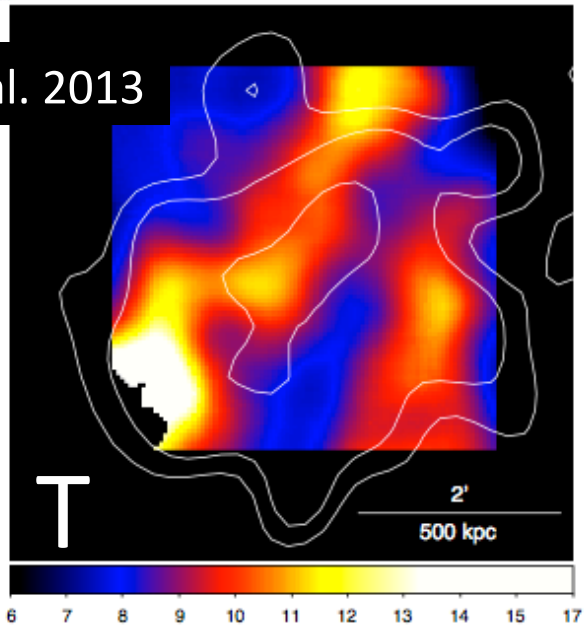
MOCK Chandra soft-band images

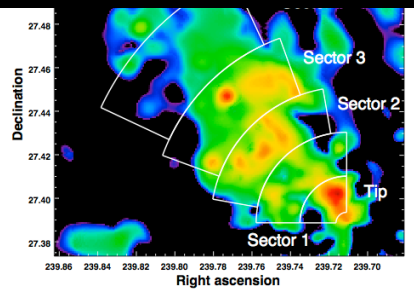


Eckert et al. 2014 A2142



Giacintucci et al. 2013





1st ESTIMATOR:

PROFILE OF TEMPERATURE VARIATION Δ_T (=T_{MW}-T_{SL})

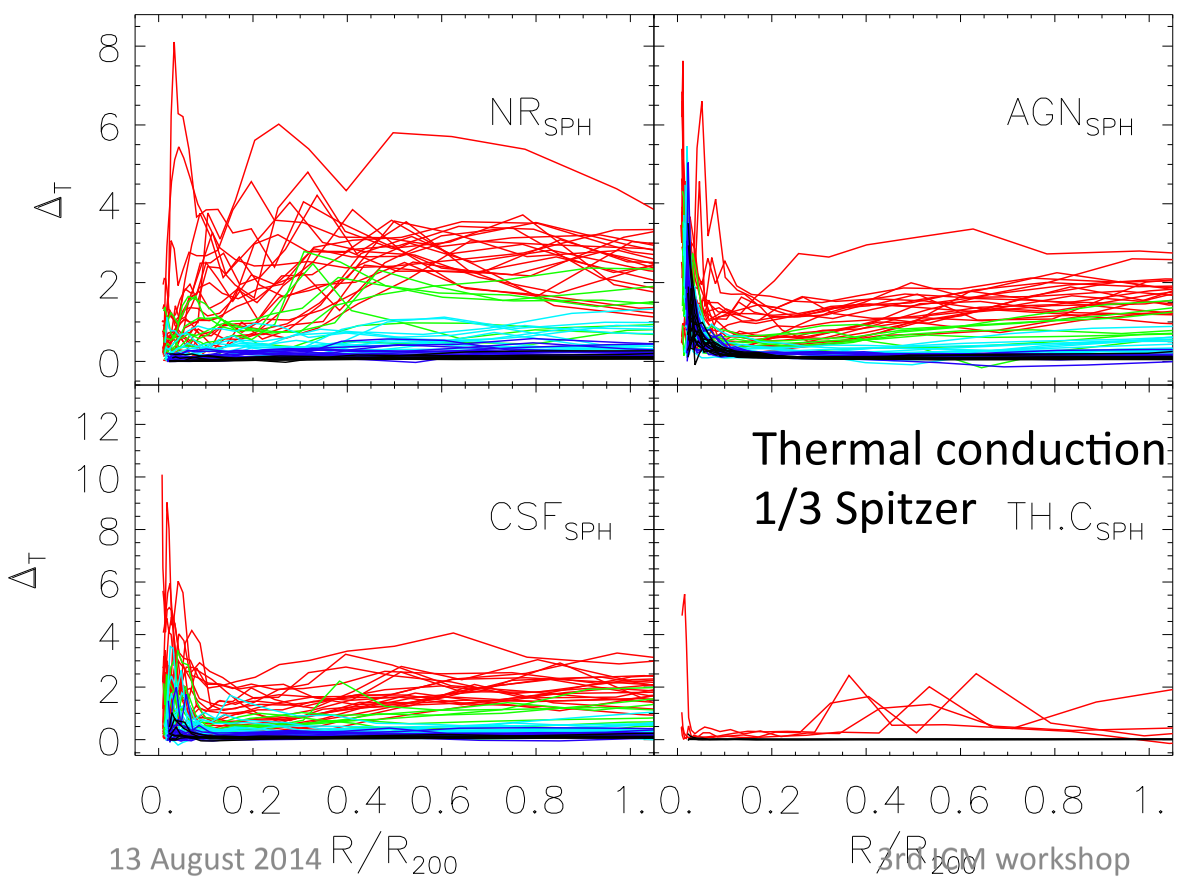
$$T = \Sigma_i W_i T_i / \Sigma_i W_i$$

$$W_{MW} = m$$

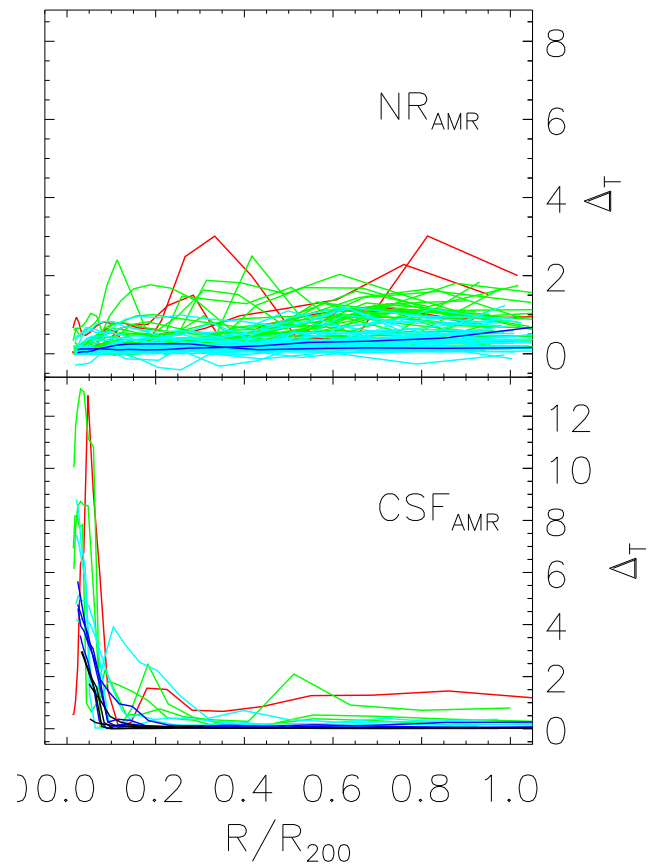
$$W_{SL} = m\rho T^{-0.75}$$

- > 10^{15} h^{-1} M_{sun}
- [5-10] 10^{14} h^{-1} M_{sun}
- [2-5] 10^{14} h^{-1} M_{sun}
- [1-2] 10^{14} h^{-1} M_{sun}

SPH (50 clusters)



AMR (80+16 clusters)



1st ESTIMATOR:

PROFILE OF TEMPERATURE VARIATION Δ_T ($=T_{MW}-T_{SL}$)

- $T_{MW} > T_{SL}$
- Hot systems have larger ΔT
- R12 and N07 have ≠ mass range
- AMR has lower ΔT than SPH

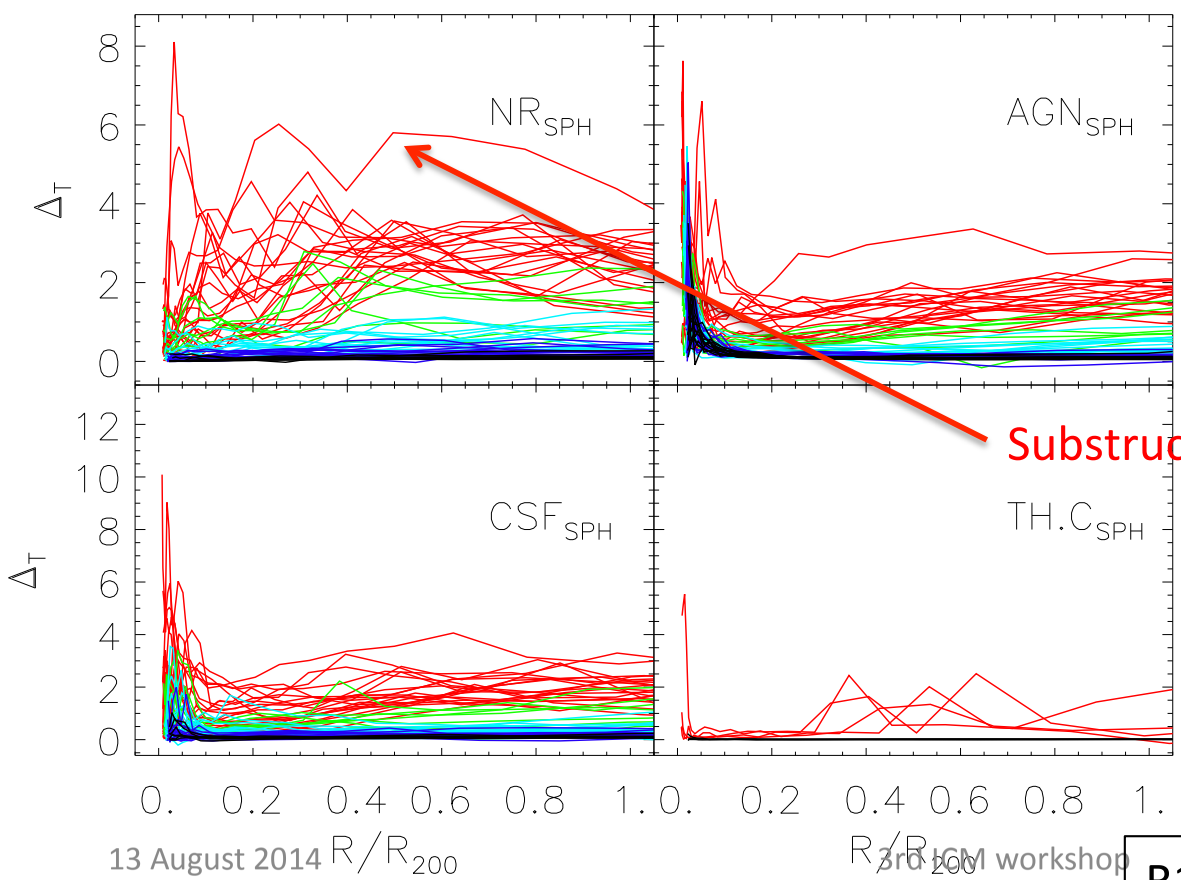
$> 10^{15}\ h^{-1}\ M_{sun}$

$[5\text{-}10]\ 10^{14}\ h^{-1}\ M_{sun}$

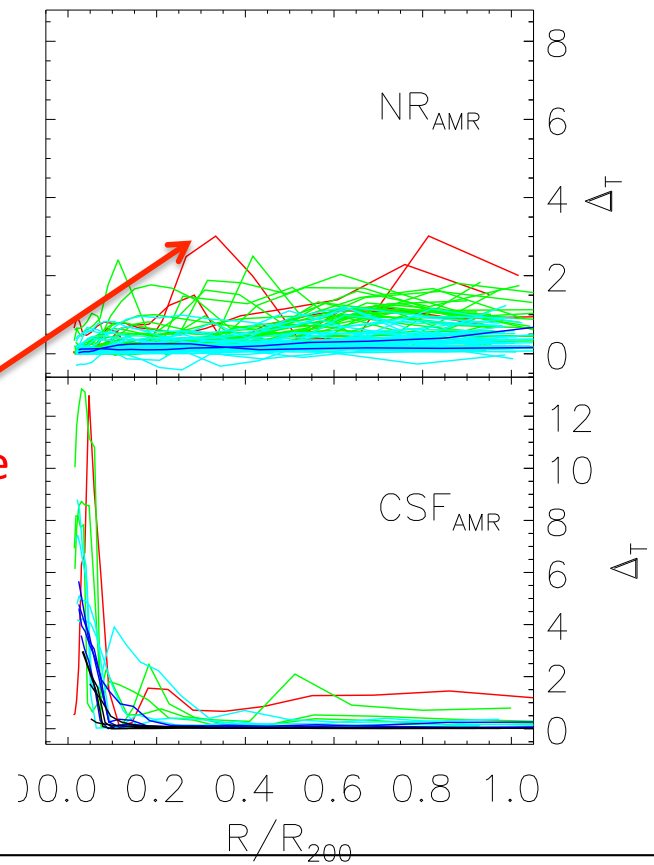
$[2\text{-}5]\ 10^{14}\ h^{-1}\ M_{sun}$

$[1\text{-}2]\ 10^{14}\ h^{-1}\ M_{sun}$

SPH (50 clusters)

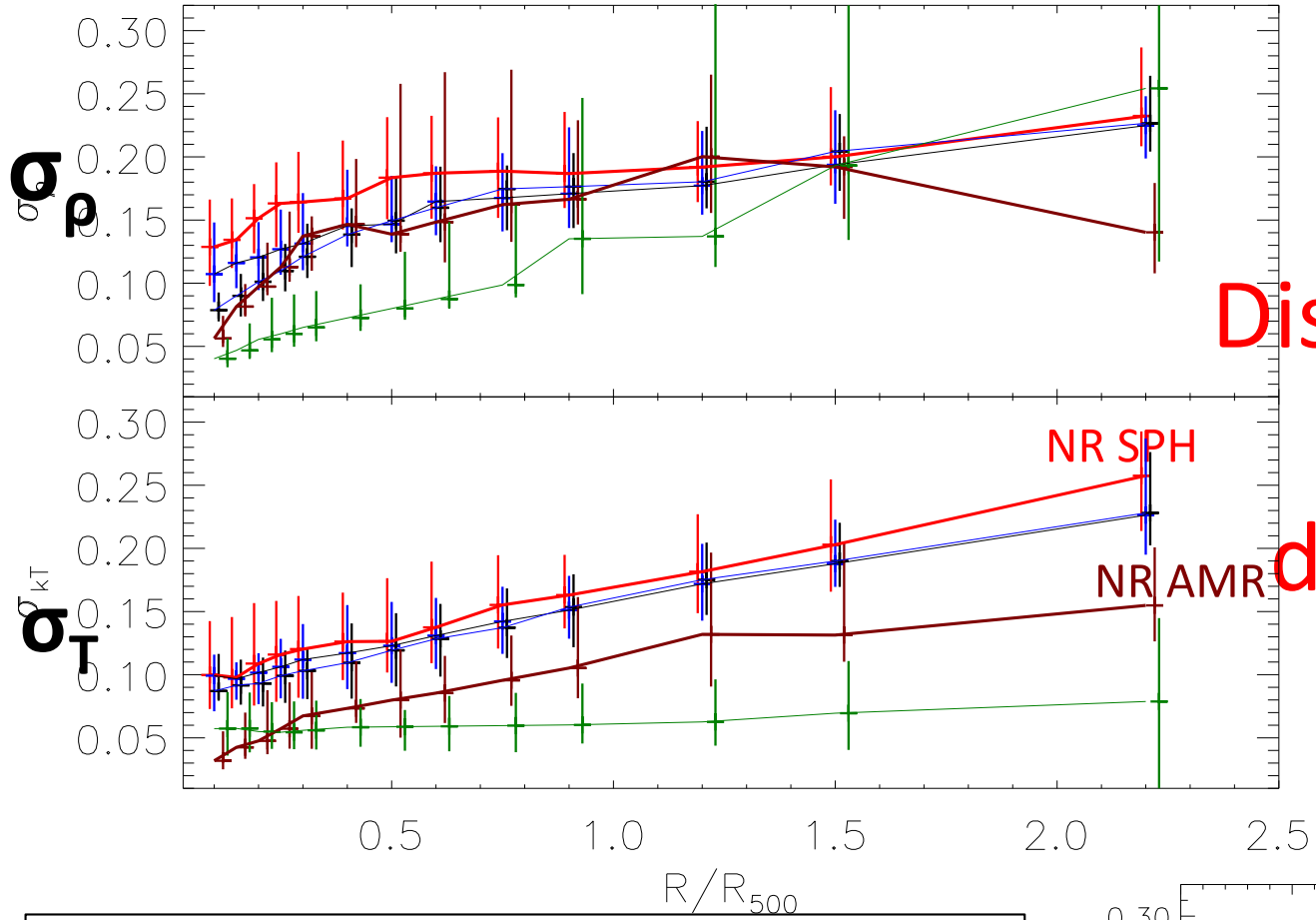


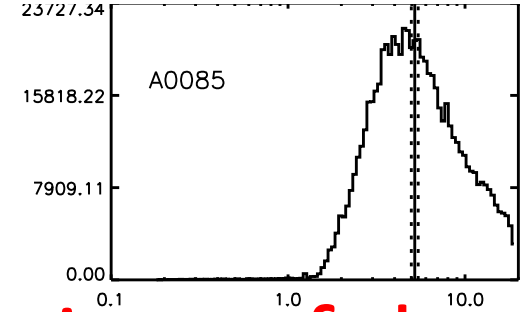
AMR (80+16 clusters)



Substructure

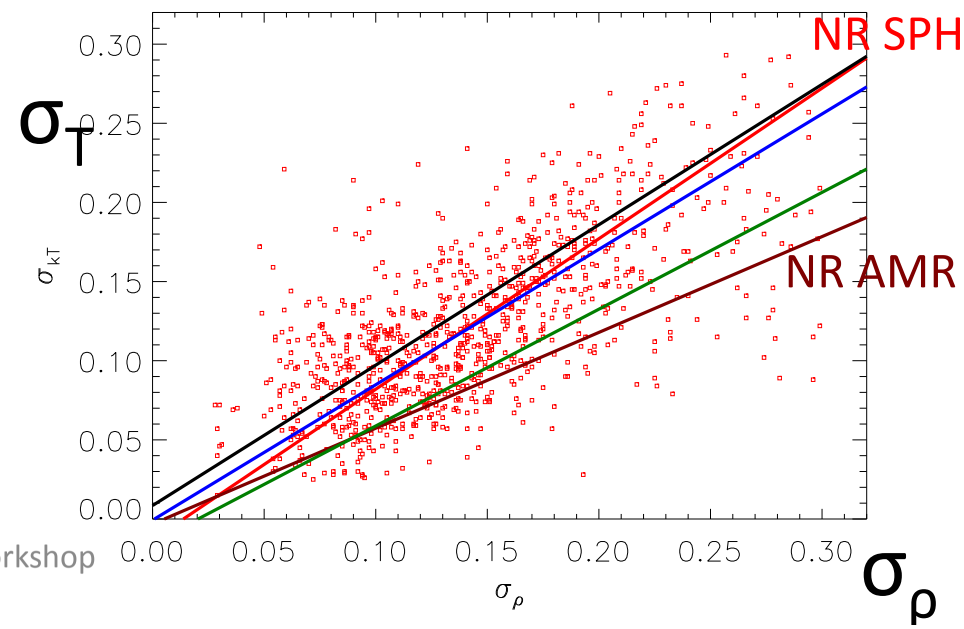
R12 and N07 have different mass range



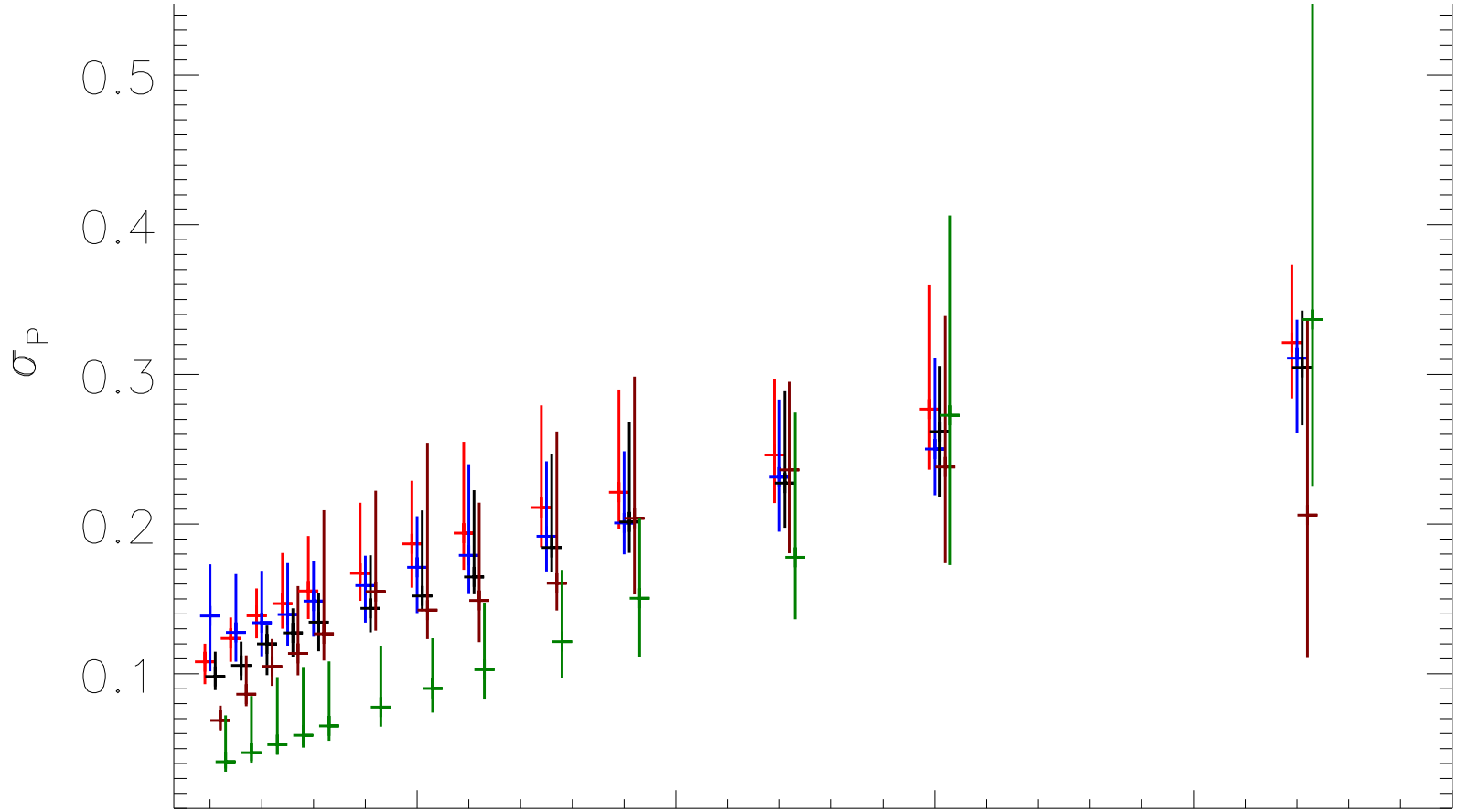


Dispersions of the log-normal distributions of density and temperature

AMR have similar density dispersion but significantly lower temperature dispersion



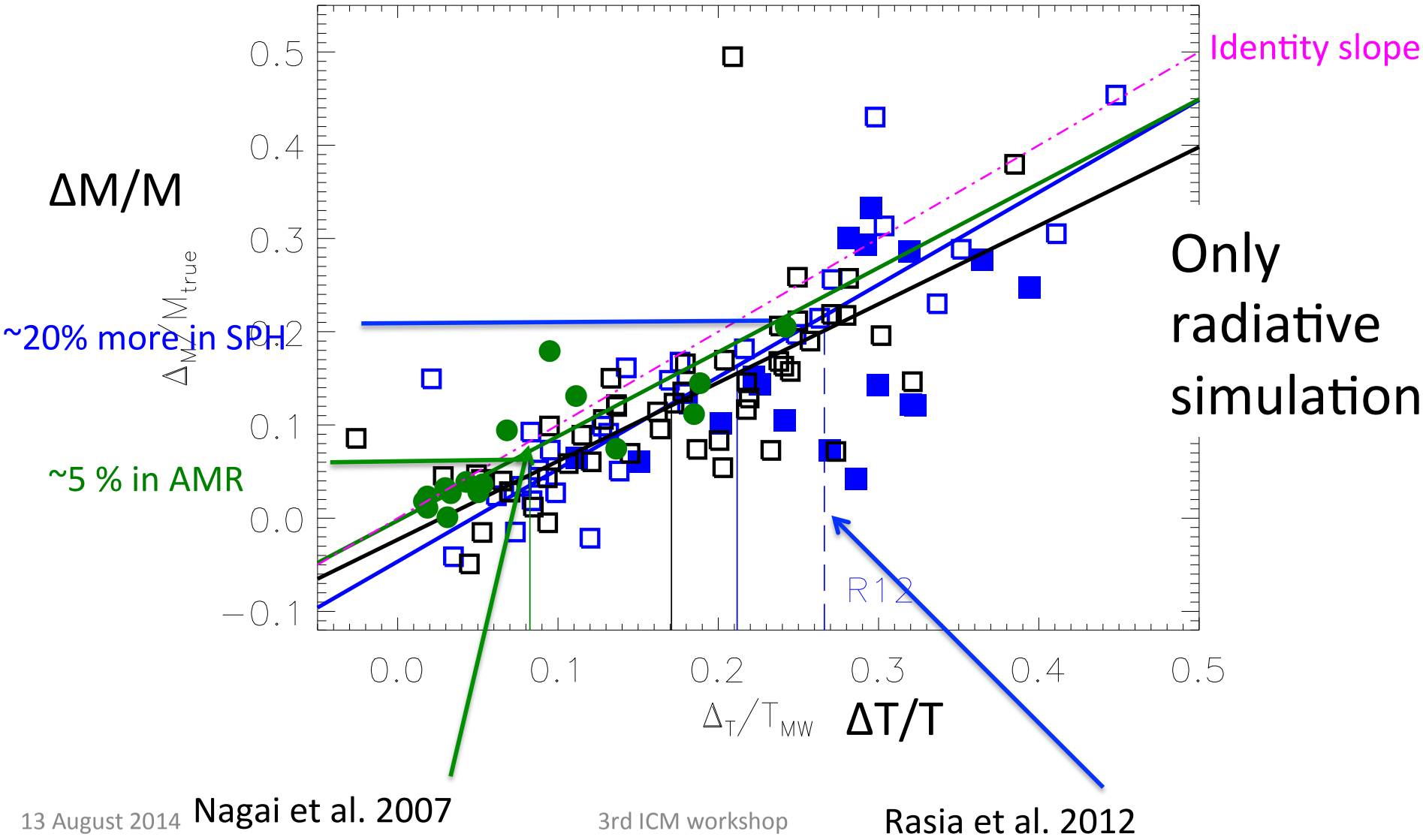
Profile of the dispersions of the pressure log-normal distributions



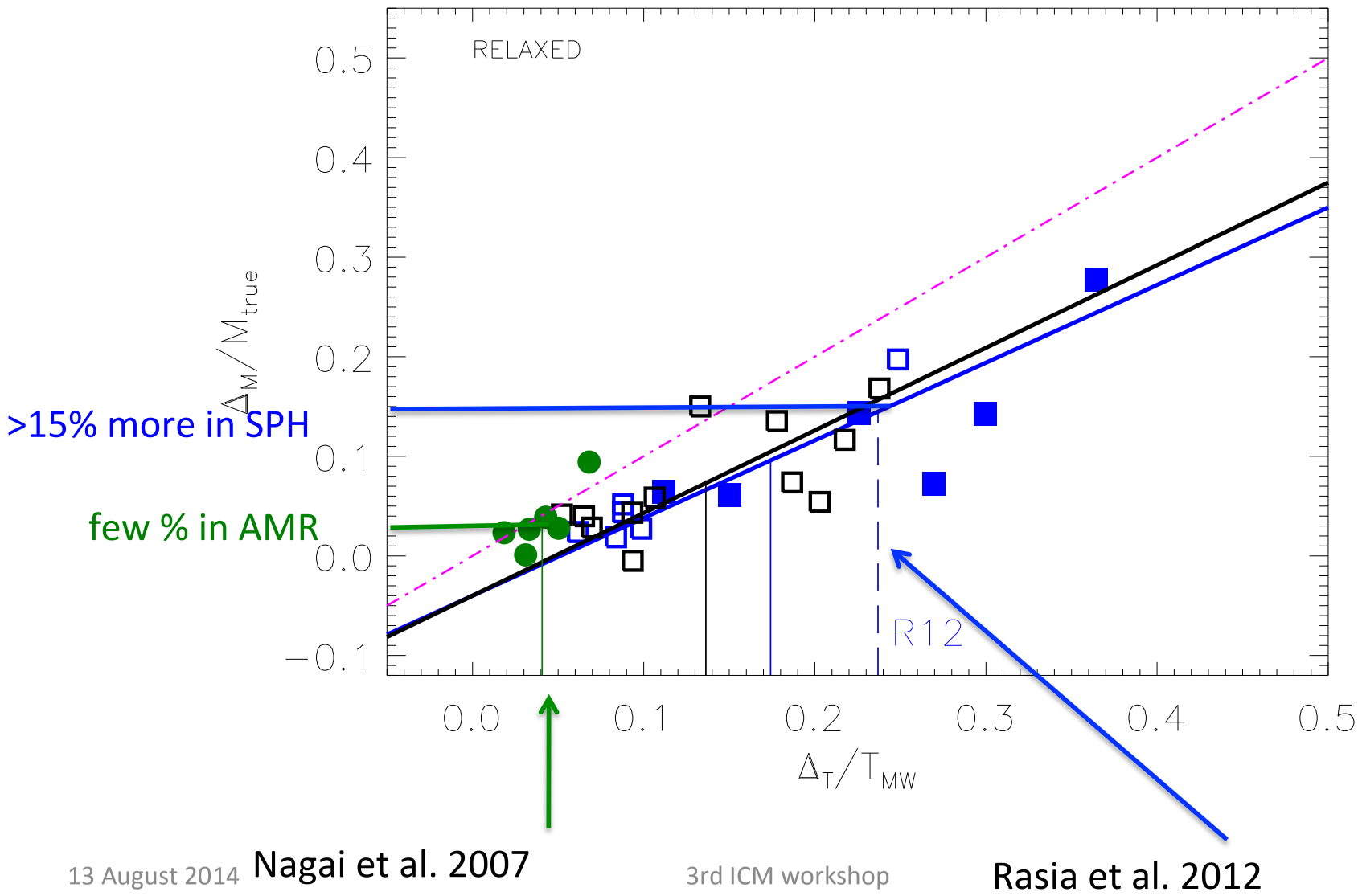
Inhomogeneities are not in pressure equilibrium ($\sigma_P \neq 0$)
Also: restricting to the cold gas: correlation(T_{cold} , ρ_{cold})=0

CONSEQUENCES ON HE MASS BIAS

Δ_T (=T_{MW}-T_{SL}) vs Δ_M (=M_{MW}-M_{SL})

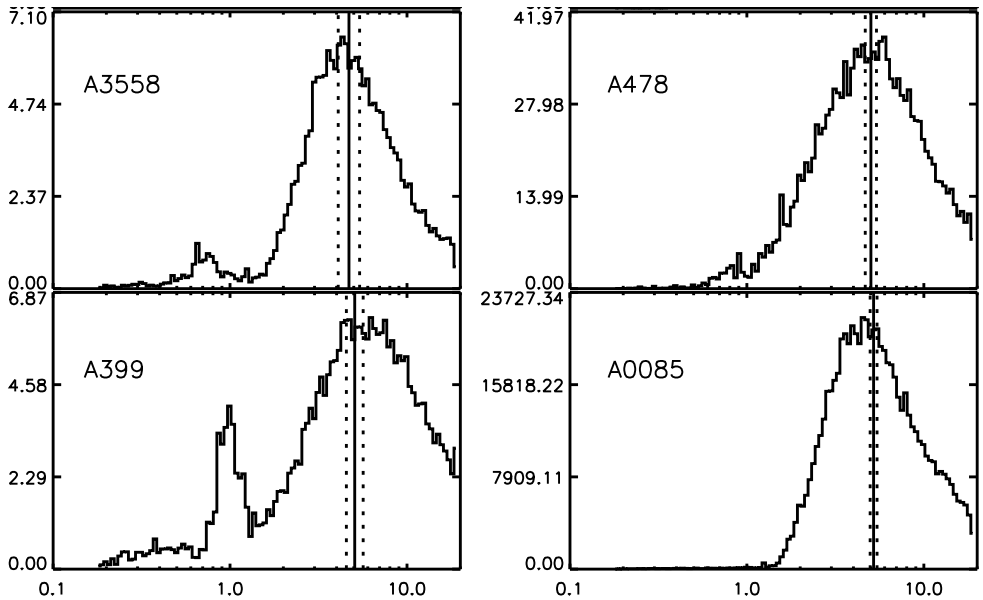


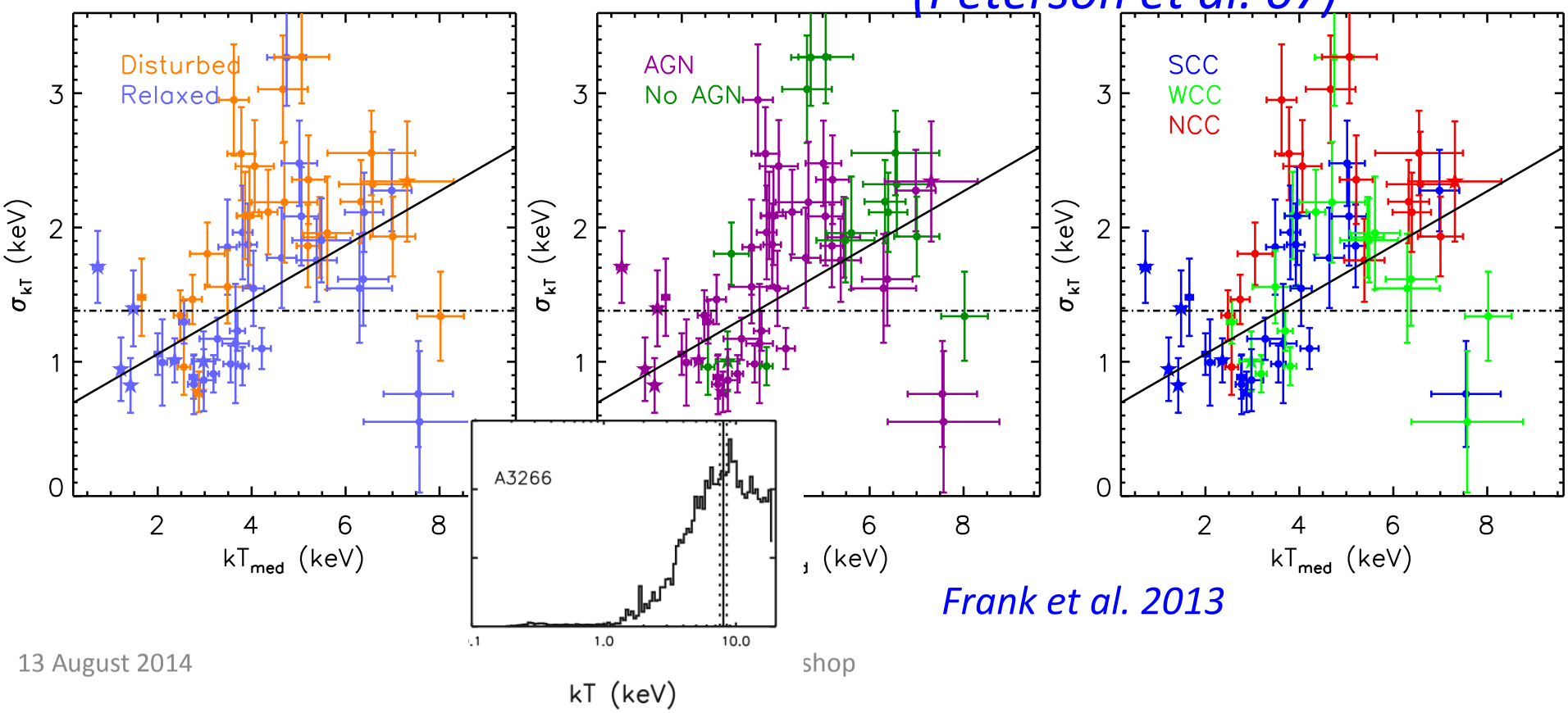
X-ray REGULAR CLUSTERS: Δ_T vs Δ_M



2nd estimator: σ_{kT}-kT_{med} relation

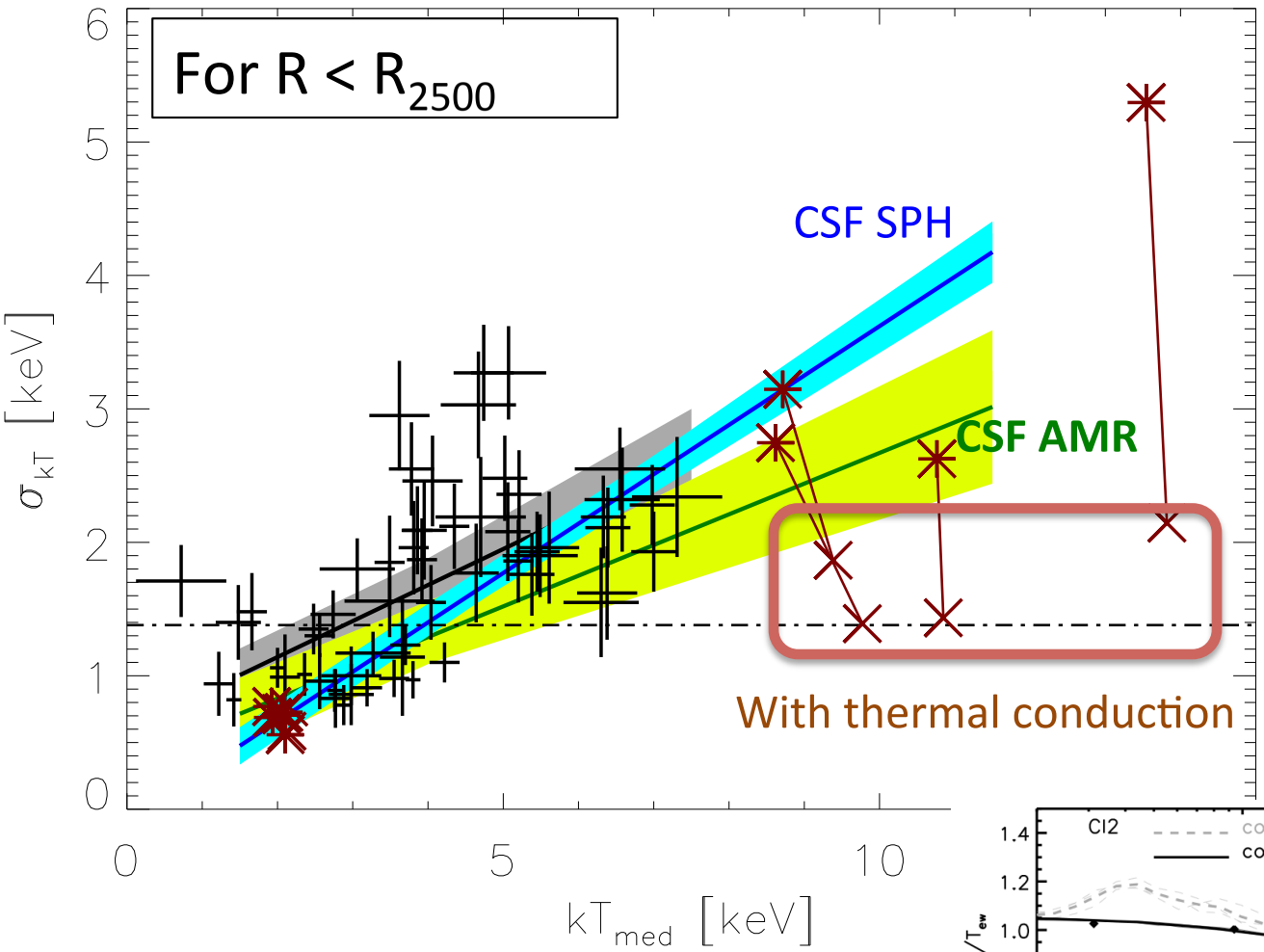
60 objects from HIFLUGCS
Smoothed Particle Inference Technique
(Peterson et al. 07)



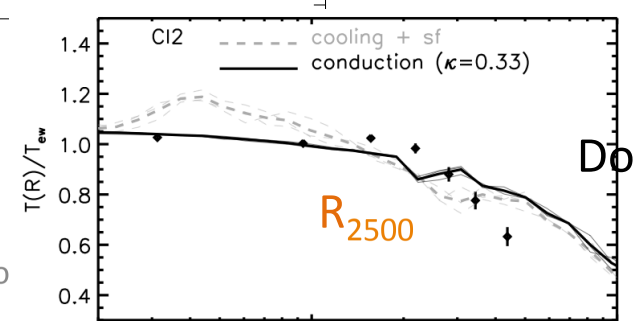


Frank et al. 2013

COMPARISON w. DATA IS NOT CONCLUSIVE!

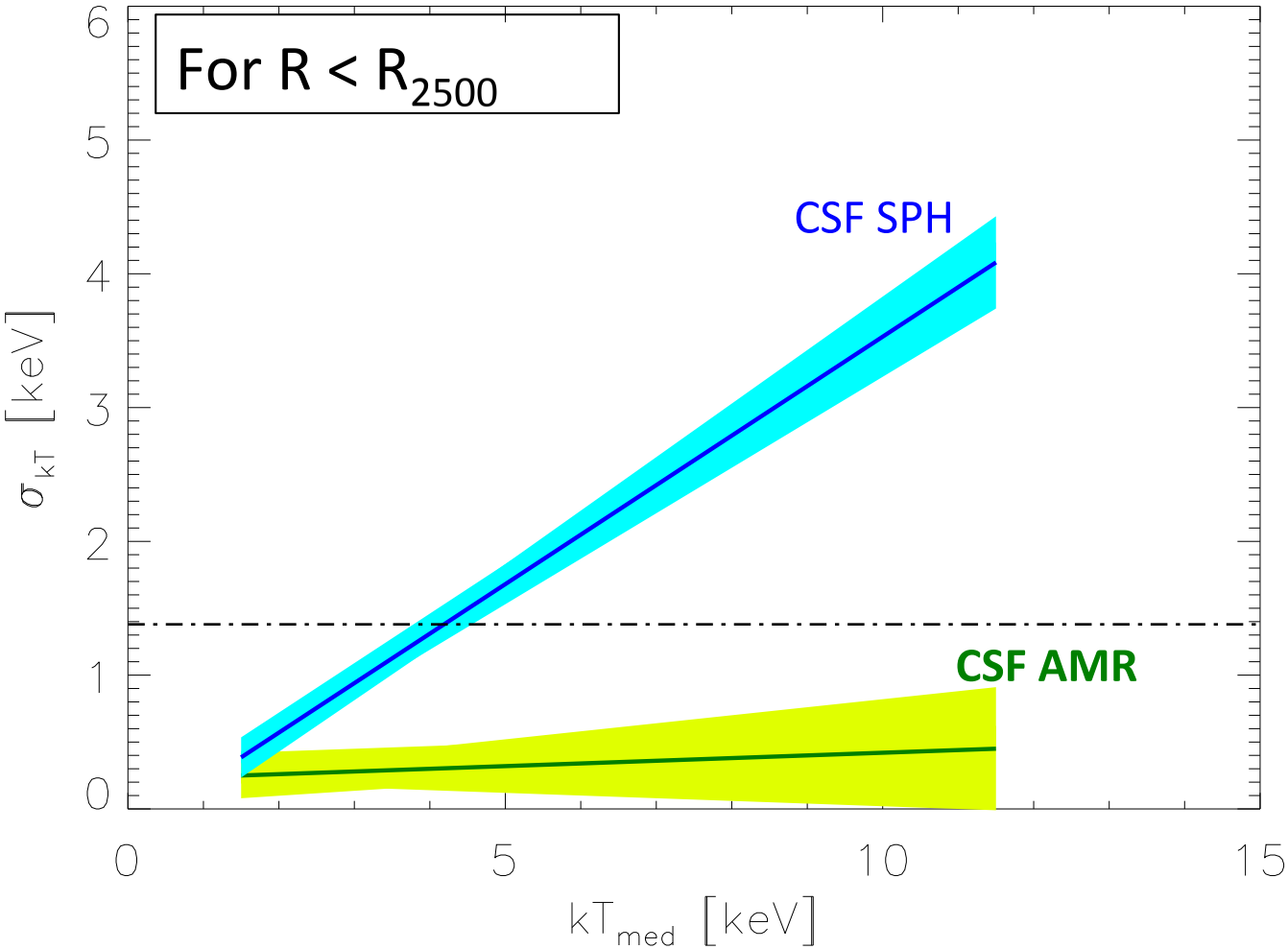


- Thermal conduction might be constrained by observing high-T clusters
- Radiative simulations of both codes agree with the data but for different reasons



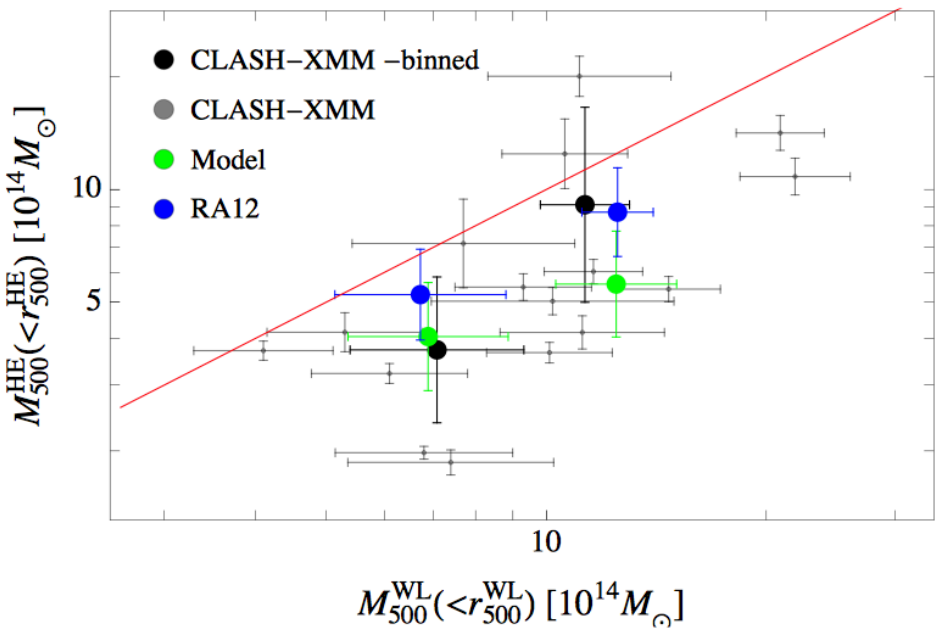
Dolag et al. 04

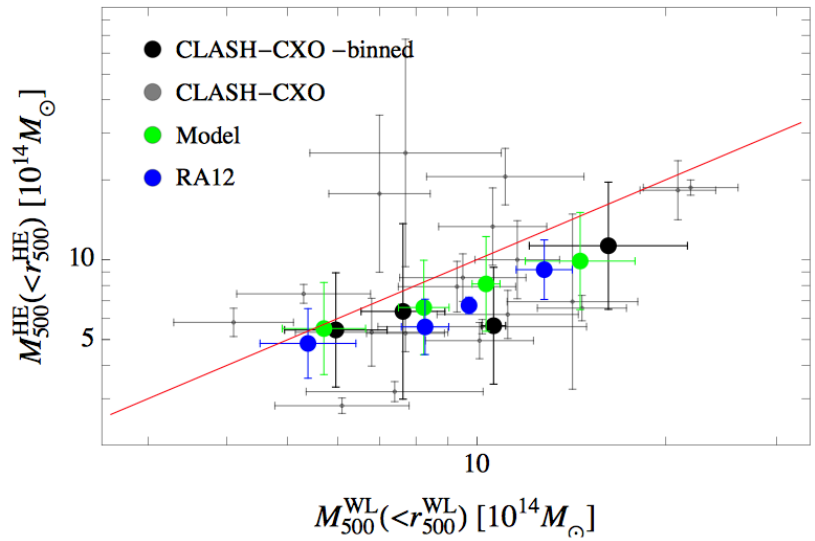
COMPARISON SIMULATIONS – DATA … NOT CONCLUSIVE!



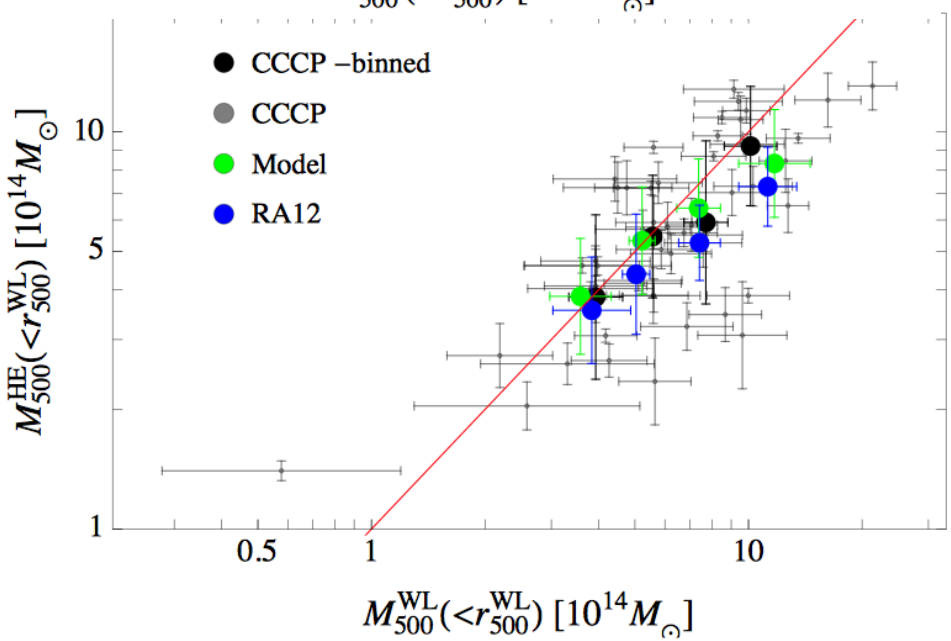
0.15 R_{500} excised

M_{HE} vs M_{WL} (Sereno & Ettori 2014)





(Donahue+14, Merten+14)



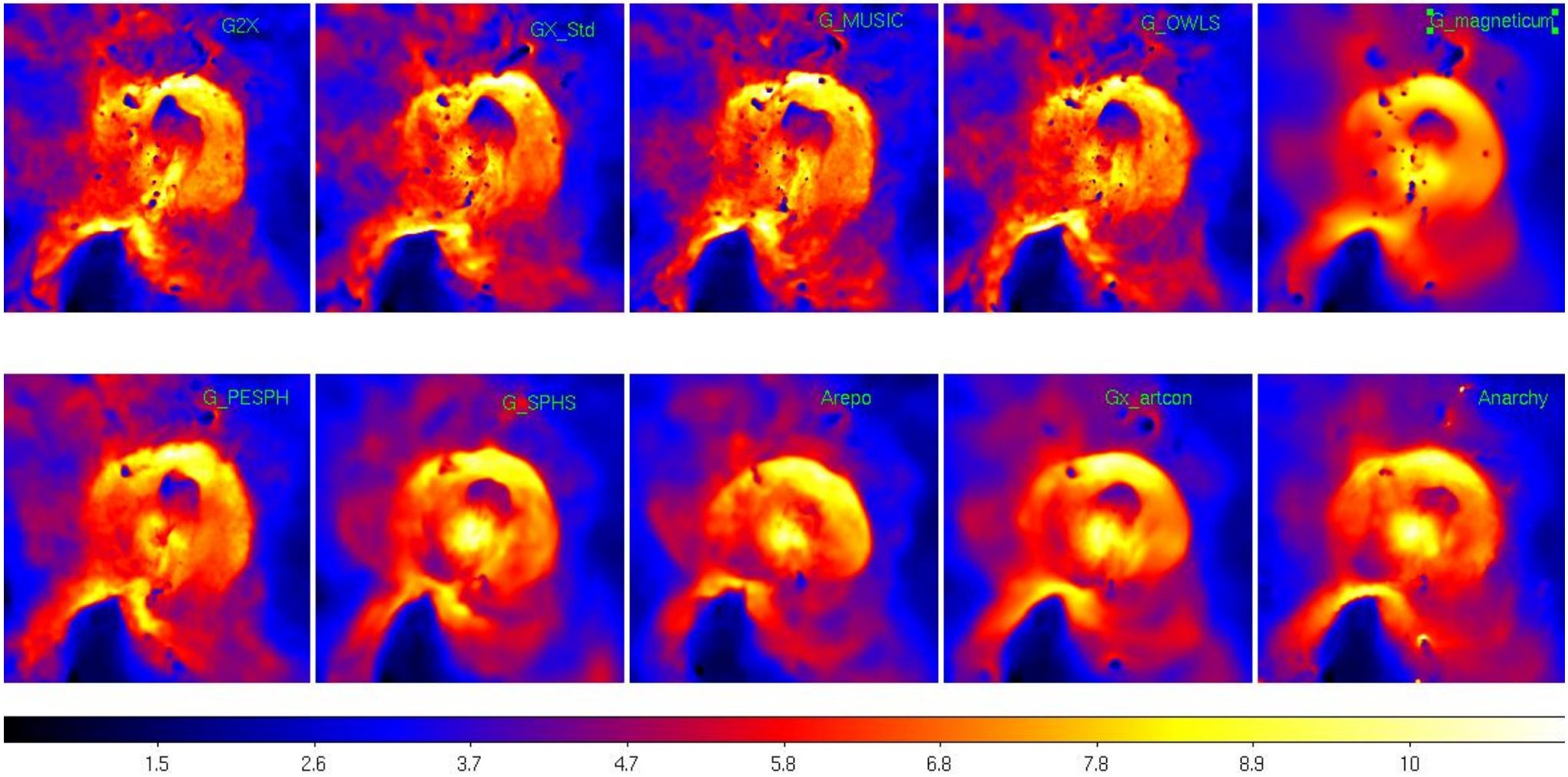
(Madhavi+13, Hoekstra+12)

NIFTY COSMOLOGY

Gadget 2X (Kay/Newton)	Gadget 3 Standard Viscosity (Murante/ Borgani)	Gadget 2 MUSIC (Yepes/ Sembolini)	Gadget OWLS (McCarthy)	Gadget Magneticum (physical thermal conduction) (Saro/ Dolag)
Gadget PESPH (February/ Dave)	Gadget SPHS (Power/Read/ Hobbs)	Arepo (Puchwein/ Springel)	Gadget 3 Artificial Conduction (Murante/ Borgani/Becker)	Gadget-Anarchy (Della Vecchia)

Art (Nelson/Nagai) ; Hydra (Thacker)

NIFTY COSMOLOGY



TMW maps

CONCLUSIONS

- AMR simulations predict a lower degree of ICM temperature inhomogeneities (efficient mixing destroys substructures and quickly heats the stripped gas).
- The codes have similar consequences on the X-ray mass. However, since ΔT is smaller in AMR simulations, N07 mass bias can be a factor of 2 lower (N07 has smaller mass range).
- more insights on the ICM processes might be provided by:
  - Masking the core
  - measure temperature variation at distances larger than R2500
  - for high– temperature clusters.