Exploring the hydrostatic mass bias of the MUSIC clusters of galaxies

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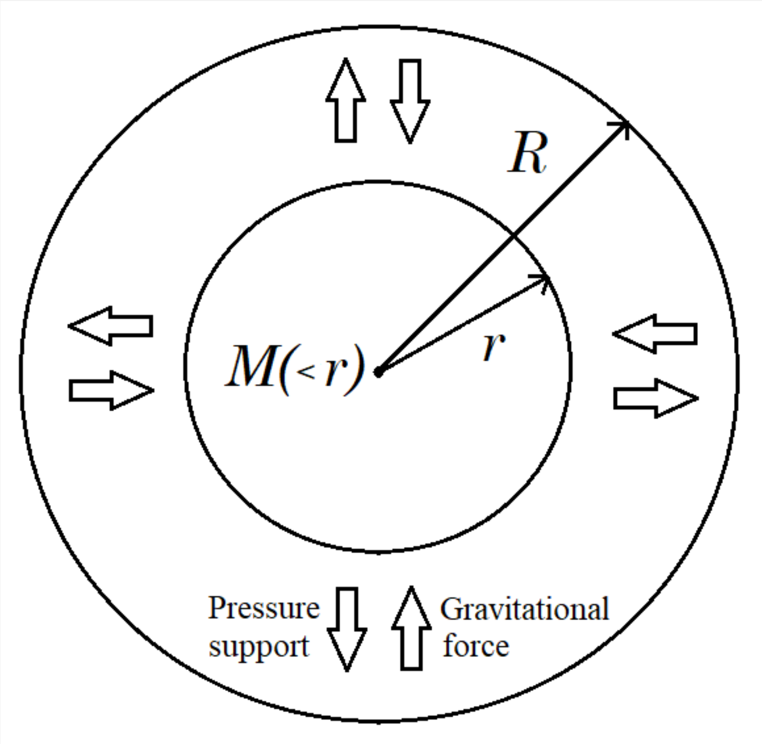
Hydrostatic equilibrium



$$\nabla\varphi(\boldsymbol{x}) = -\frac{\nabla P_{therm}(\boldsymbol{x})}{\mu\, m_p n_e(\boldsymbol{x})}$$

Assuming spherical symmetry:

$$M_{HE,SZ}(< r) = -\frac{r^2}{G\mu\, m_p n_e(r)} \frac{dP_{therm}(r)}{dr}$$

Assuming the gas perfect law:

$$M_{HE,X}(< r) = -\frac{T(r)r}{\mu\, m_p\, G}\left[\frac{d\,\log n_e(r)}{d\,\log r} + \frac{d\,\log\, T(r)}{d\,\log r}\right]$$

$\boldsymbol{x}$: position vector
$\boldsymbol{P_{therm}}$: thermal pressure
$\boldsymbol{\varphi}$: gravitational potential
$\boldsymbol{n_e}$: electron density
μ: mean molecular weight
$\boldsymbol{m_p}$: proton mass
G: gravitational constant
$\boldsymbol{T}$: electron temperature

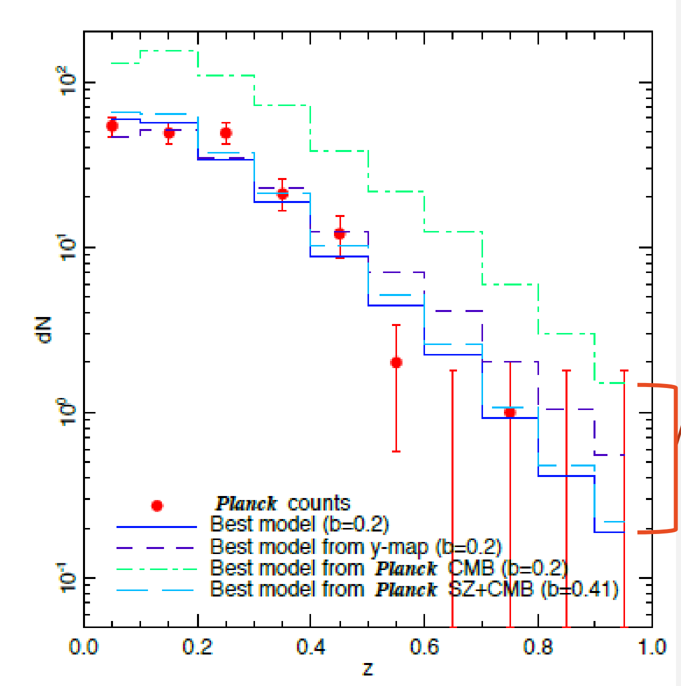
Mass bias defined as:

$$b_{SZ} = \frac{M_{HE,SZ} - M_{true}}{M_{true}}$$

$$b_X = \frac{M_{HE,X} - M_{true}}{M_{true}}$$

Hydrostatic mass bias, state of the art

→ Measure the number of objects, with a certain mass, as a function of the redshift;
→ Compare it with the theoretical prediction;
→ Infer the value of the two cosmological parameters Ω_m e σ_8.

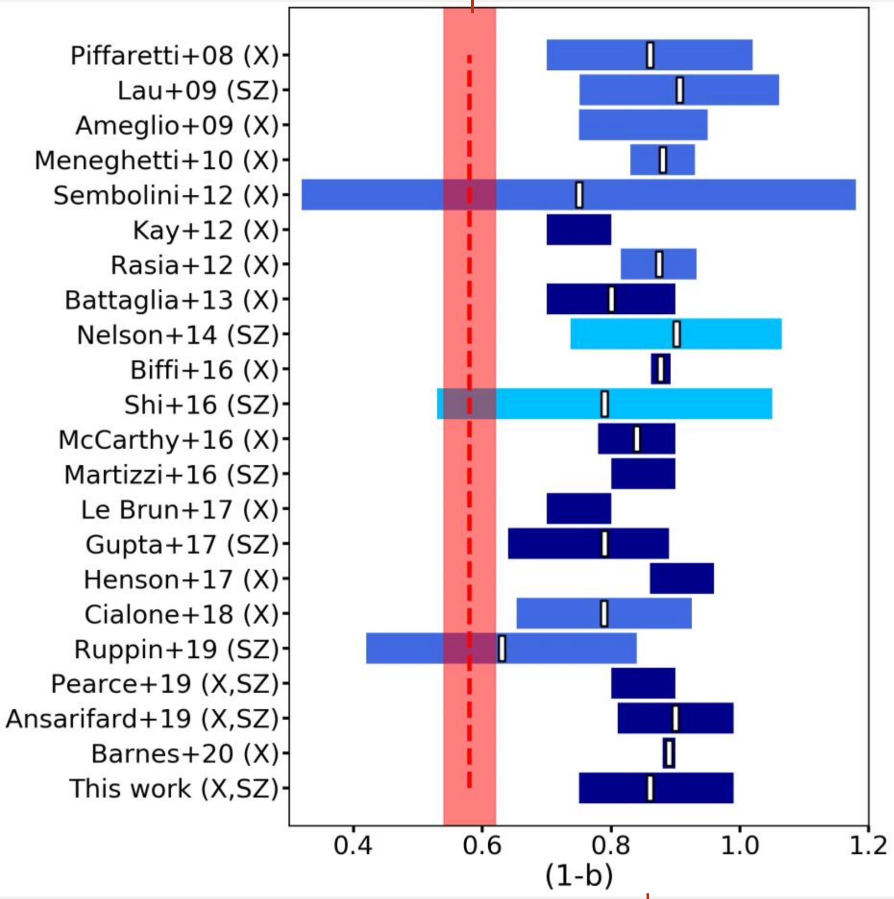


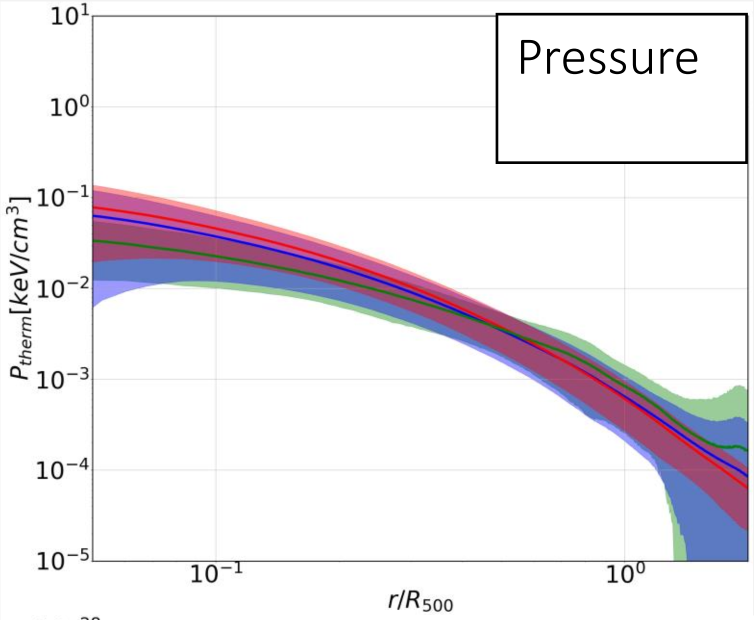
2013 Planck Collaboration paper

(1−*b*) = 0.58±0.04

(1−*b*) ~ 0.8-0.9

@ R_{500} : radius at which the cluster density is 500 times the Universe critical density at that time.

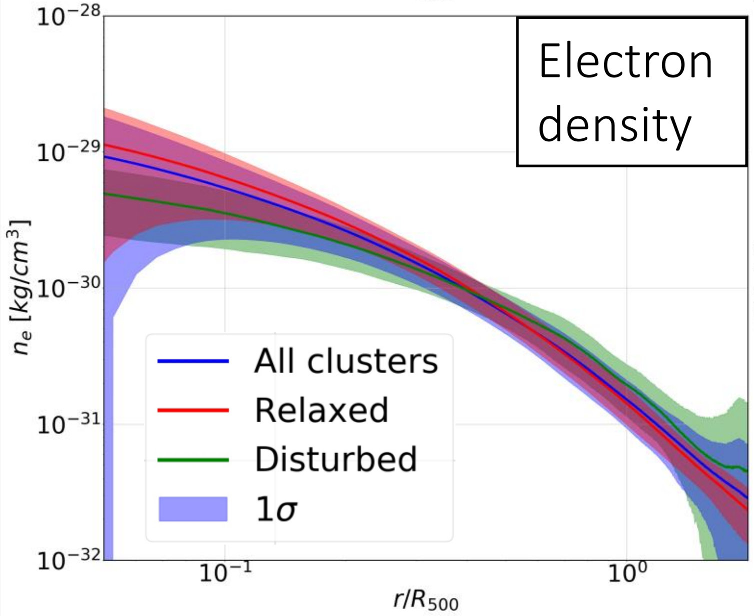


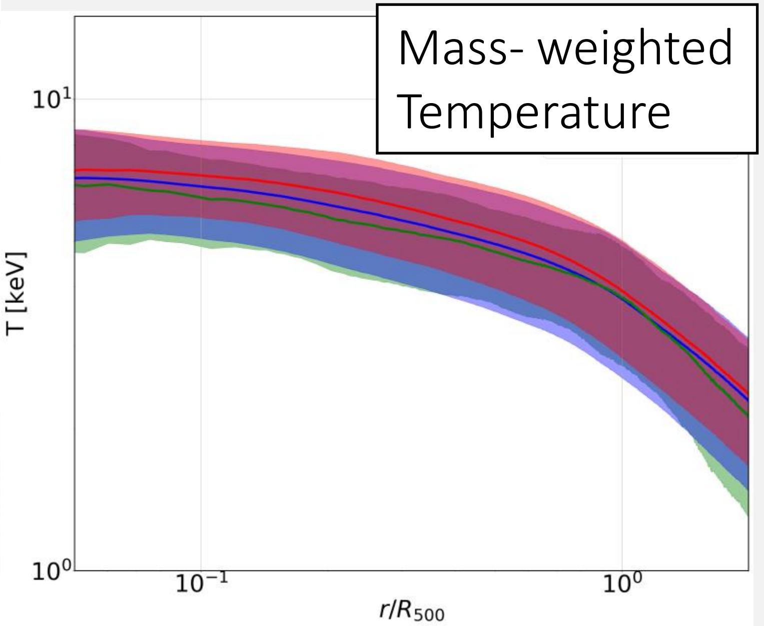


The MUSIC simulations

MUSIC-2: clusters from MultiDark Simulation, Dark-Matter only N-body, in a $1h^{-1}Gpc$ integrating box [*Prada et al. 2012*].

- ○3 physical process models (*flavours*): NR, CSF, and AGN ;
- ○$M_{500} > 10^{14}\ M_{\odot}$;
- ○$z = [0.0, 0.11, 0.33, 0.43, 0.54, 0.67, 0.82]$;
- ○Almost 260 clusters for each redshifts.



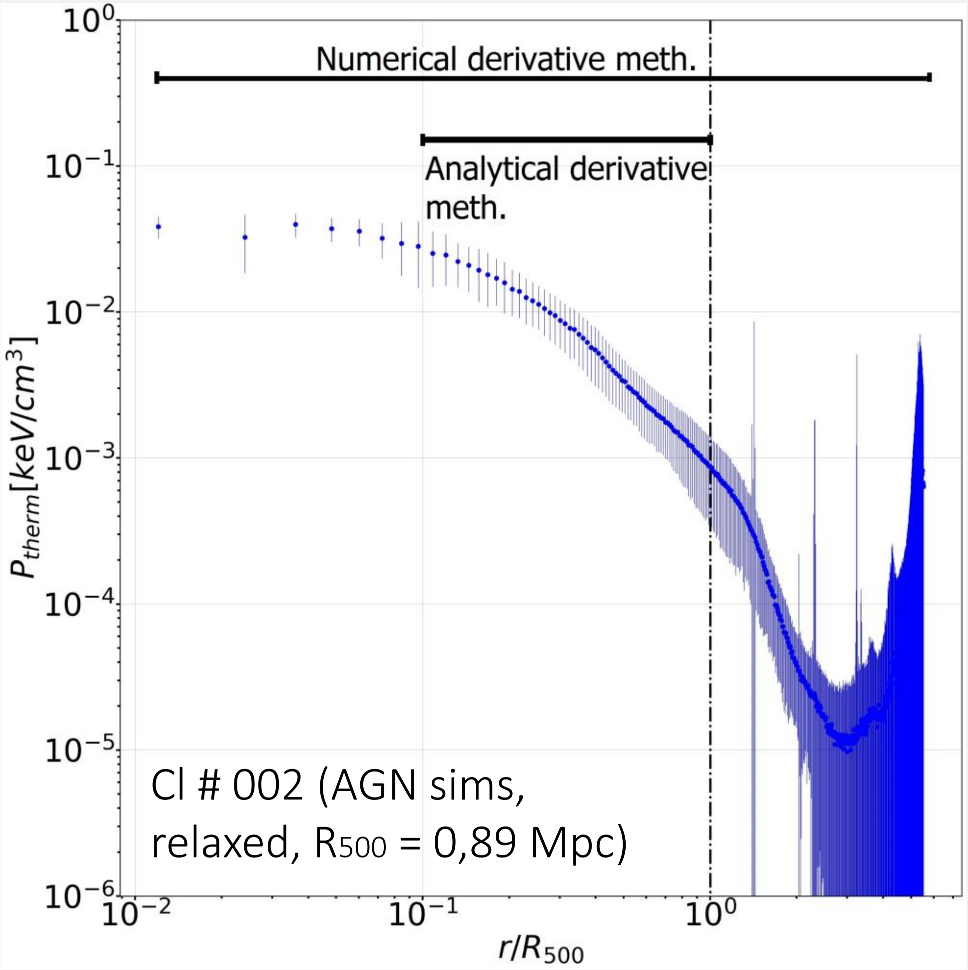


3D profiles:

- Pressure;
- Electron density;
- Mass-weighted temperature;

in spherical shells of 10 kpc thickness.

Estimation of the ICM profile gradients



$$\frac{d\,(T, P, n_e)}{dr}$$

- Numerical derivative method

  Study of a large radial range.

- Fit of each thermodynamic quantity with models
- Analytical derivative of the models

Study of local variations.

Fit in [0.1-1] R_{500}
Used models:
- T*: Vikhlinin et al. 2006*
- P*: gNFW, Nagai et al, 2007*
- n_e*: Vikhlinin et al. 2006*

Dynamical state, does it have an impact on the hydrostatic mass bias?

3D indicators:

- Take into account the whole 3D structure of the cluster.

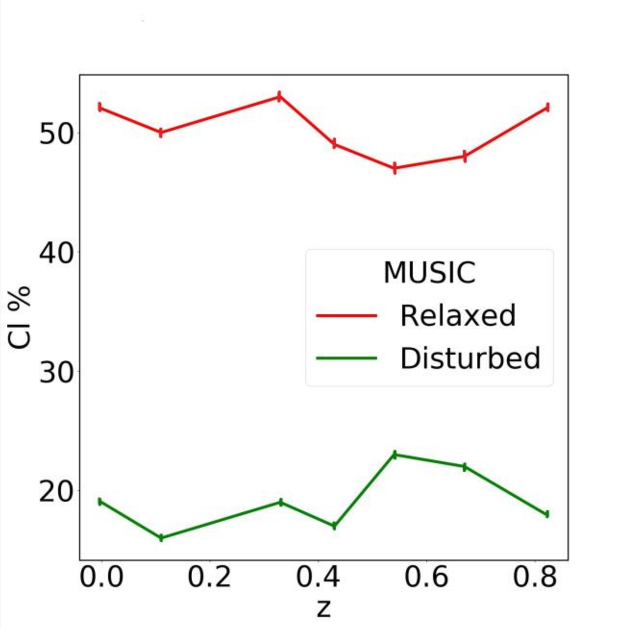
For instance:

The ratio between the mass of the greatest substructure and the cluster mass at R_{500}.

The offset between the density peak r_δ and the center of mass r_{cm}, normalized by R_{500}.

[*Cialone et al. 2018*]

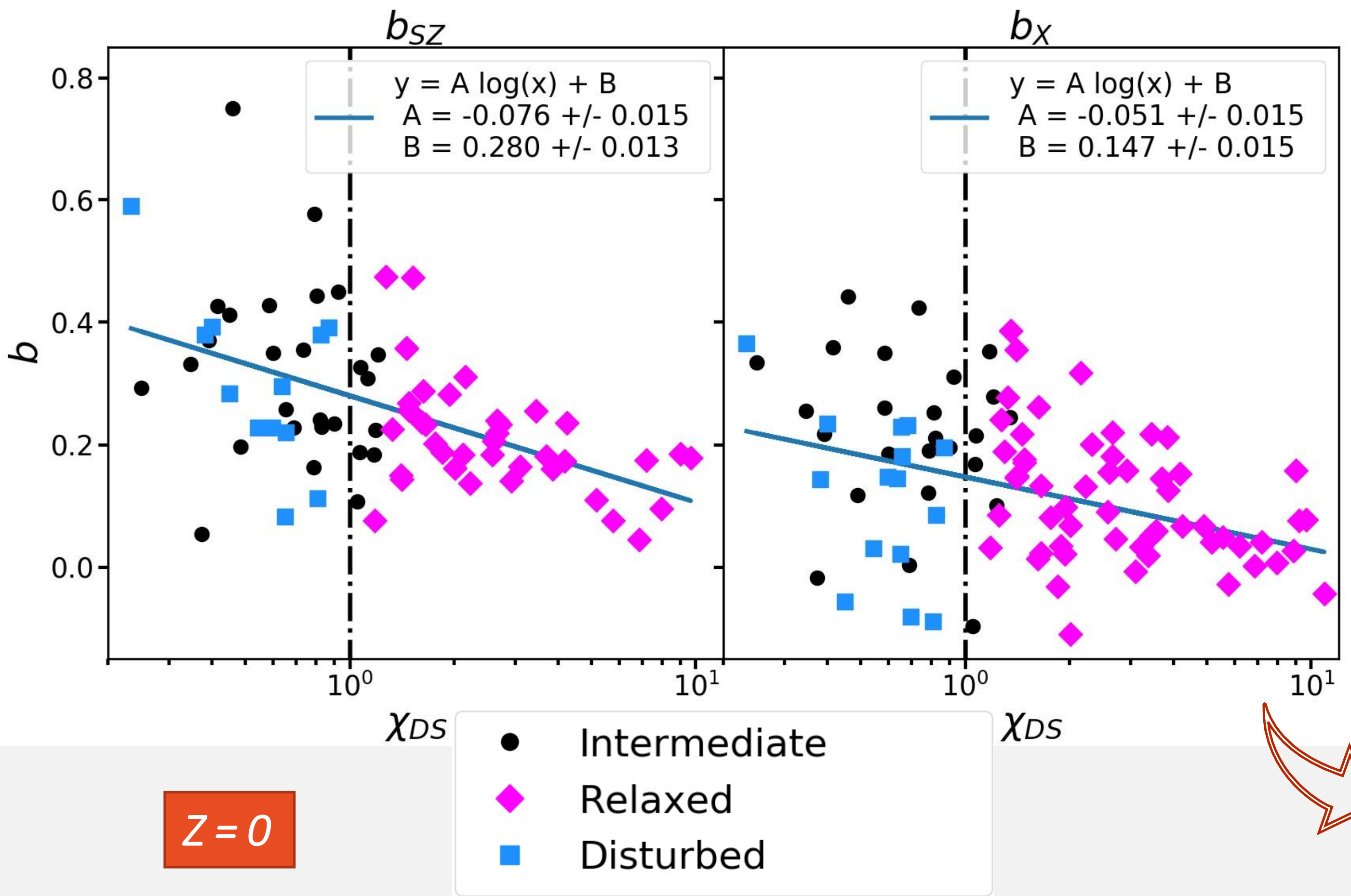
	RELAXED	DISTURBED	HYBRID
$\frac{M_{sub}}{M_{500}}$	< 0.1	> 0.1	*All the other cases*
$\Delta_r = \frac{\lvert r_\delta - r_{cm}\rvert}{R_{500}}$	< 0.1	> 0.1	



«Relaxation» parameter [*Haggar et al., 2020*]

$$\chi_{DS} = \sqrt{\frac{2}{\left(\frac{\Delta_r}{0.1}\right)^2 + \left(\frac{M_{sub}/M_{500}}{0.1}\right)^2}} > 1 \rightarrow \text{dynamically relaxed}$$

Dynamical state, does it have an impact on the hydrostatic mass bias?

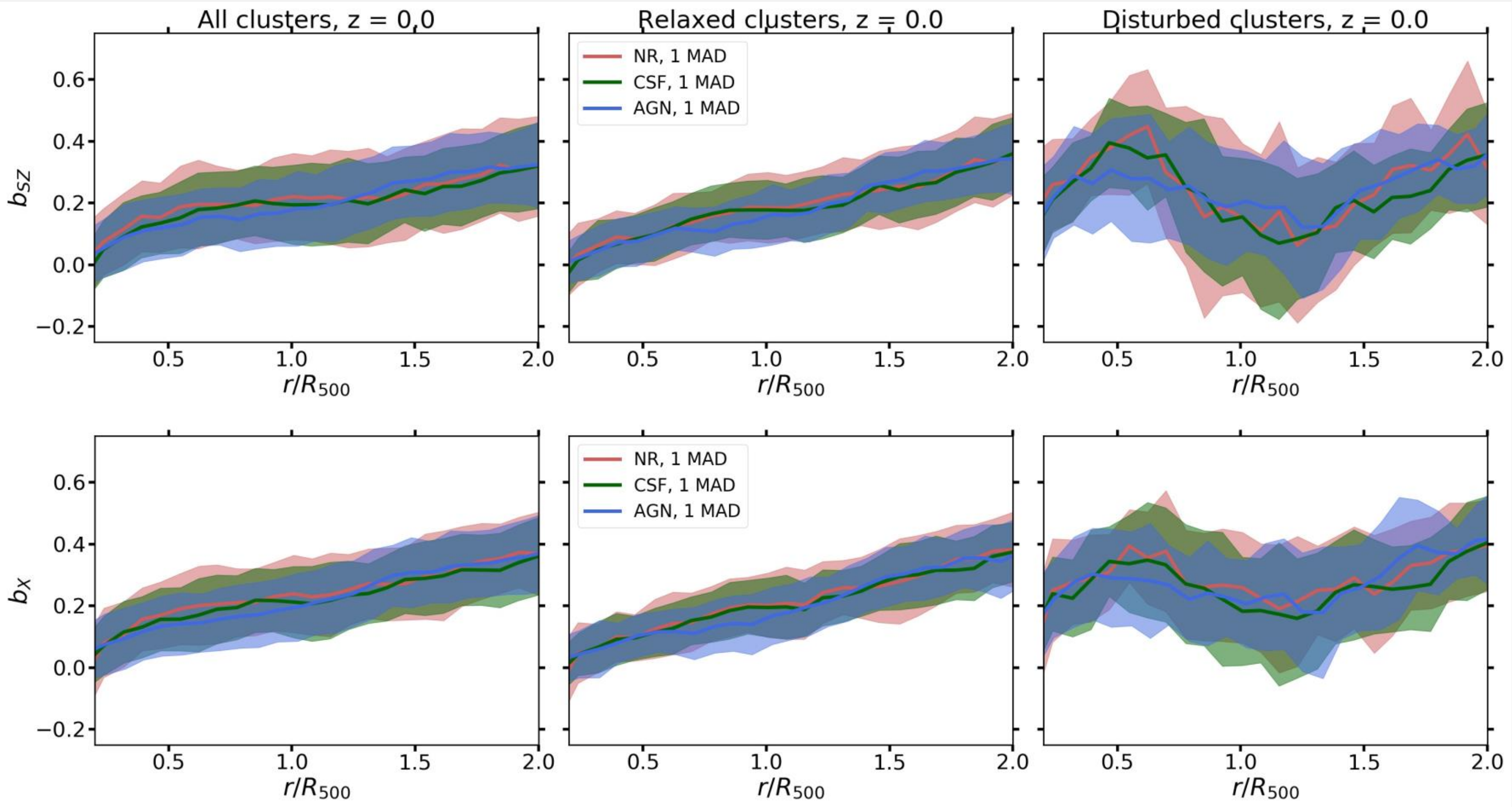


Z = 0

- **YES**
  Dependence of the bias on the relaxation status.
- The relaxed clusters present a lower scatter;

The more a cluster is relaxed → The lower is the bias → The better is the HE mass estimate.

Bias dependence on radial profile



Numerical derivative method: powerful to explore the hydrostatic mass bias in the large radial range.

Disturbed clusters:
- many variations
- a dip between R_{500} and 1.5 R_{500}
- large scatter

Outskirts: greater non-thermal contributions to the cluster mass.

Conclusions

Using synthetic clusters from the MUSIC simulations we find that:

- The HE mass biases are in agreement with the results from other simulations;
- The scatter in the bias is larger for disturbed clusters;
- The more a cluster is relaxed, the smaller is the bias and the better will be the HE mass estimate.
- The more we go toward the outskirts of the clusters, the higher the non-thermal pressure contribution will be.

THANK YOU