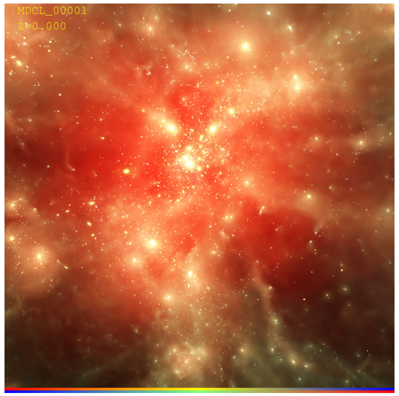
Marenostrum
MUltidark
SImulations
of galaxy
Clusters

The evolution of the Y-M scaling relation in MUSIC



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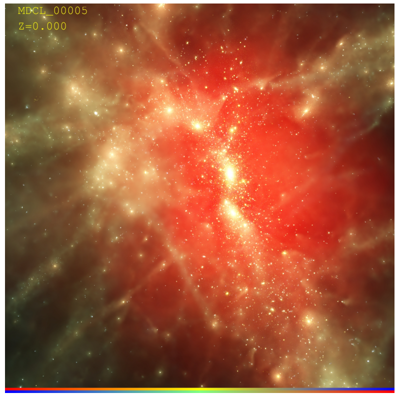

Gustavo Yepes, Marco De Petris, Stefan Gottlöber
Luca Lamagna, Barbara Comis

OUTLINE

- The MUSIC dataset
- Baryon properties of MUSIC clusters
- SZ scaling relations in MUSIC :

    1. testing the self-similar model
    2. impact of the gas fraction on Y-M
    3. cluster evolution in the Y-M scaling relation

- Conclusions

MUSIC

Marenostrum
M**U**ltidark
SImulations
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Clusters

THE MUSIC DATASET

MARENOSTRUM (MUSIC-1) resimulated clusters
•164 (82 relaxed clusters – 82 'bullet-like')
Only few objects with $M > 10^{15}\ h^{-1}M_{SUN}$

} **cooling + SFR resimulations**
(model: Springel & Hernquist, 2003)

MULTIDARK (MUSIC-2) resimulated clusters
•283 lagrangian regions
•> 500 clusters $M > 10^{14}\ h^{-1}M_{SUN}$
•> 2000 objects $M > 10^{13}\ h^{-1}M_{SUN}$

} **cooling + star formation (CSFR) & non radiative (NR)resimulations**

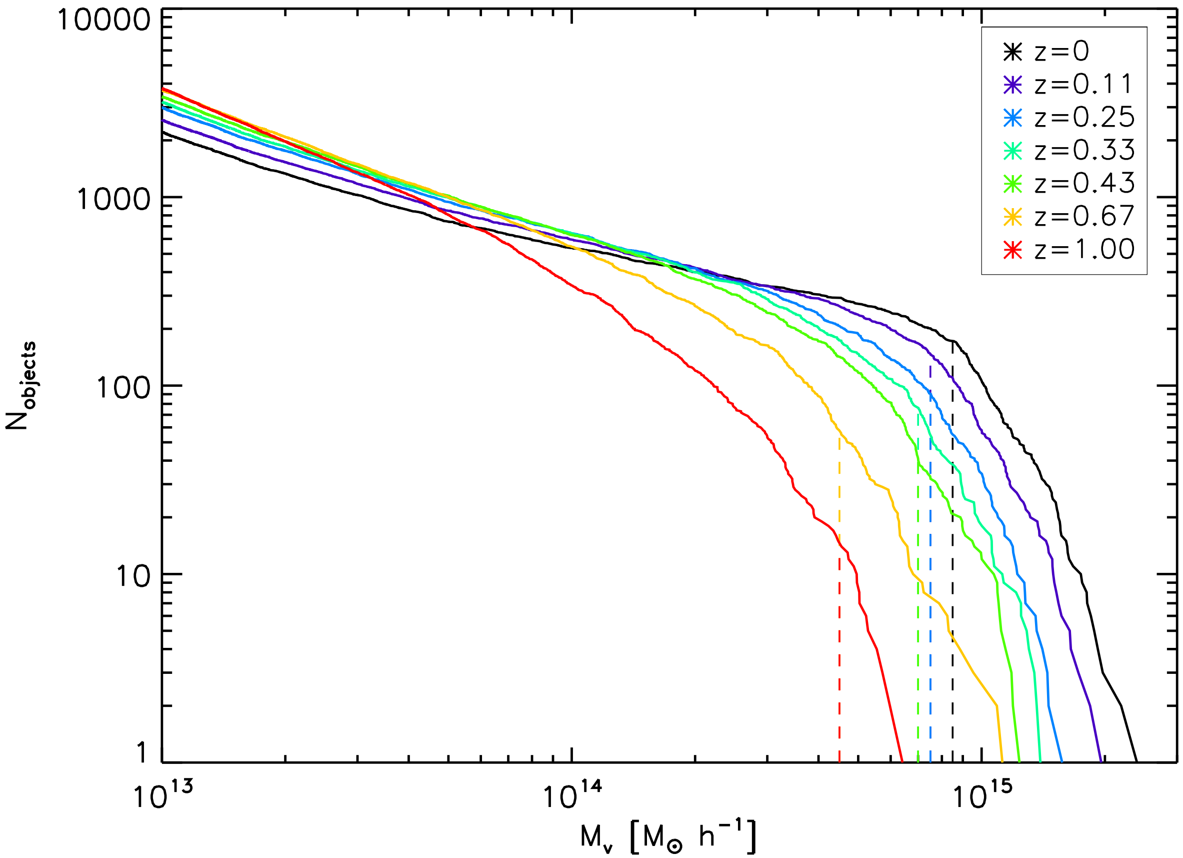
Many objects with $M > 10^{15} h^{-1}\ M_{SUN}$
m_{DM}=9.01 × $10^8 h^{-1}M_{SUN}$ - m_{SPH}=1.9×$10^8 h^{-1}M_{SUN}$
Each cluster described by several millions of particles

700 resimulated clusters with $M > 10^{14}\ h^{-1}M_{SUN}$

⬇

Large statistics to study baryonic properties and calibrate scaling relations

MUSIC-2 is a complete mass-limited volume sample:
all objects beyond a (redshift varying) mass limit formed in the $1h^{-1}$Gpc DM-only simulation have been resimulated

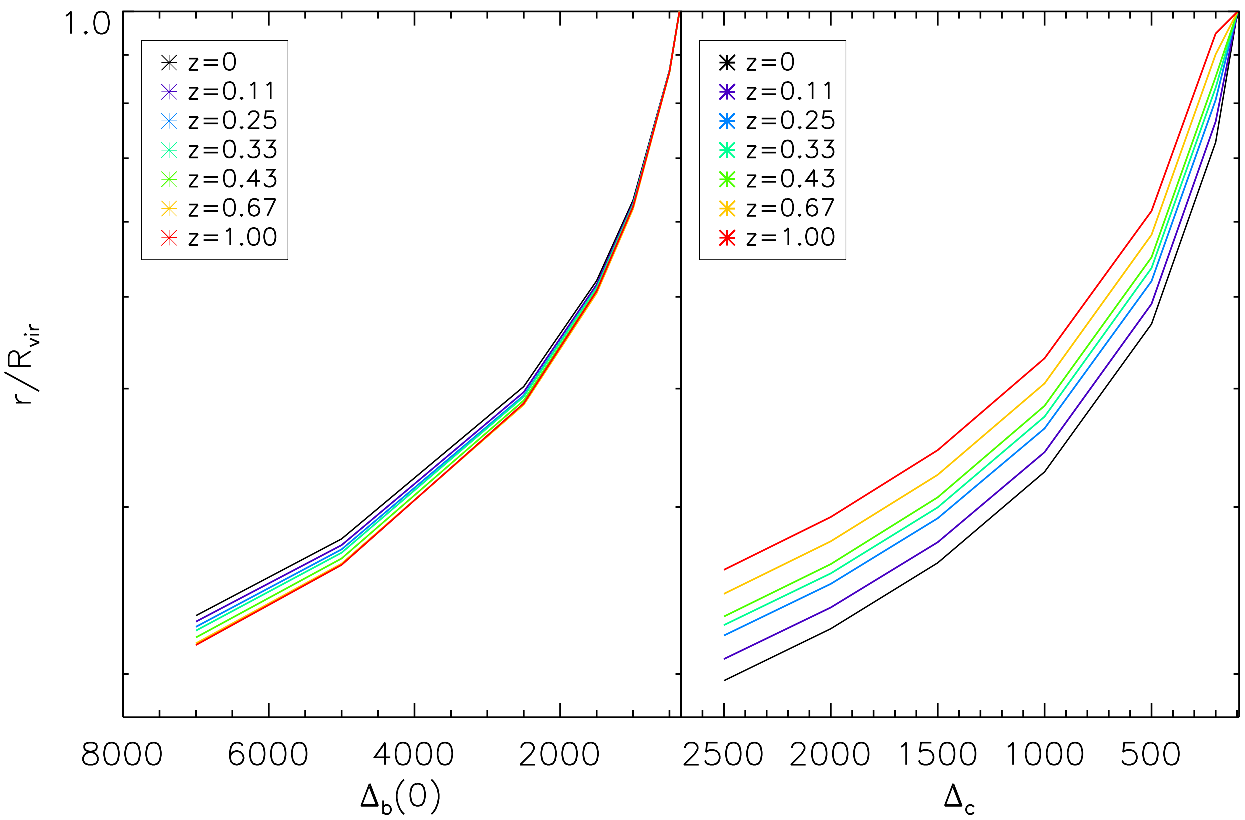


z	M_{compl} [$h^{-1}M_\odot$]	N (M_v > M_{compl})
0.00	8.5×10^{14}	172
0.11	7.5×10^{14}	147
0.25	7.5×10^{14}	90
0.33	7×10^{14}	76
0.43	7×10^{14}	41
0.67	4.5×10^{14}	57
1.00	4.5×10^{14}	14

All MUSIC data (X-rays, SZ,, luminosities..)will be publicly available through the website http://music.ft.uam.es

In this work we analyse all clusters with $M_v > 5\times10^{14}\ h^{-1}M_{SUN}$ at z=0 (271 clusters)

CLUSTER PROPERTIES AT DIFFERENT REDSHIFTS



Two different approaches to define the overdensity radius: a constant critical overdensity Δ_c and a redshift-dependent background overdensity

$$\frac{4}{3}\pi\rho_c(z)\Delta(z)r_\Delta^3 = M_\Delta(z)$$

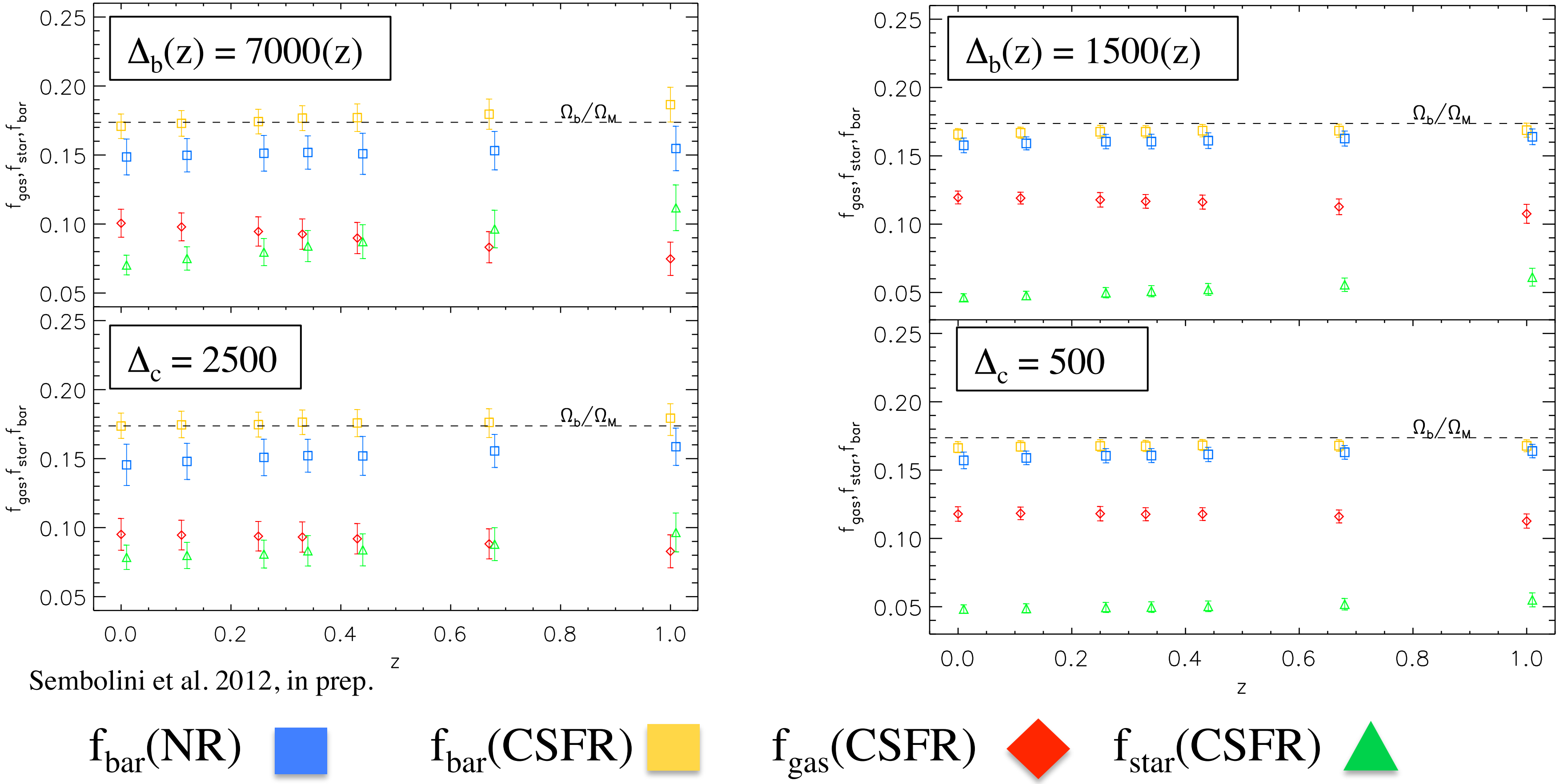
$$\Delta(z) = \Delta(0)\left[\frac{\Delta_v(z)}{\Delta_v(0)}\right]$$

$$r_\Delta \propto \rho_c(z)^{-1/3} \propto E^{-2/3}(z) = (\Omega_M(1+z)^3 + \Omega_\Lambda)^{-1/3}$$

$$r_\Delta \propto \rho_b(z)^{-1/3}\Omega_m(z)^{1/3} \propto (1+z)^{-1}$$

The use of $\Delta_b(z)$ is more efficient to take into account same fractions of virial radius at different redshifts

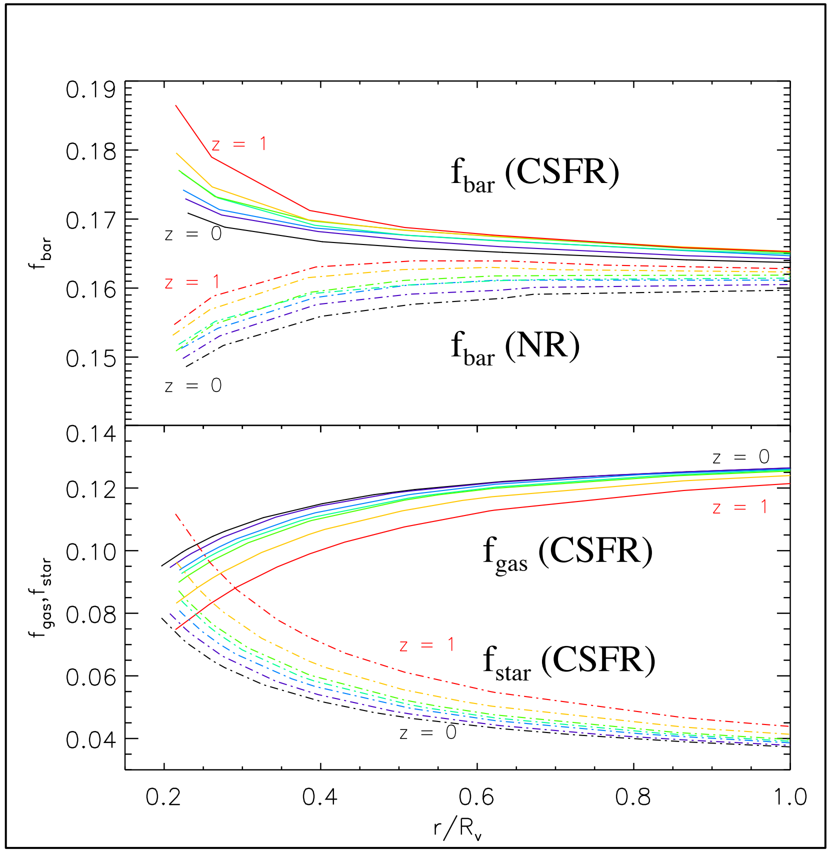
BARYON PROPERTIES



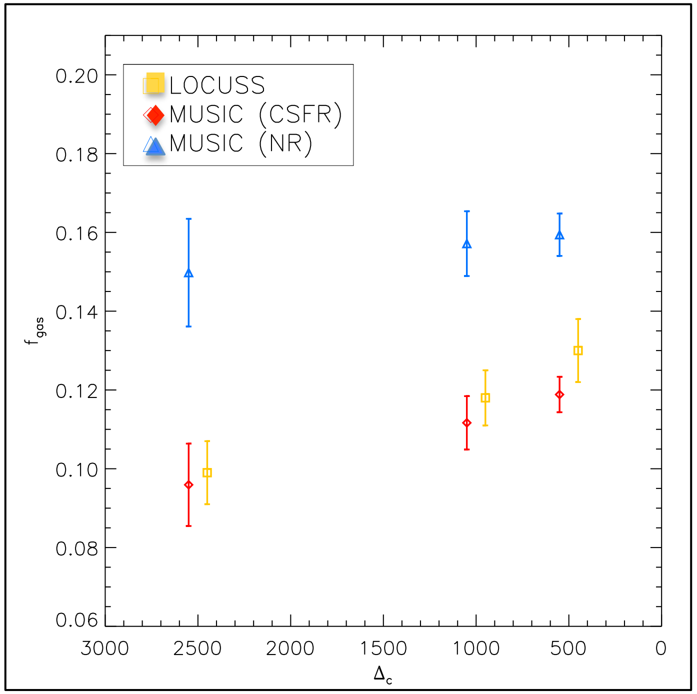
Sembolini et al. 2012, in prep.

- At high overdensities f_{star} increases with z, f_{gas} decreases
- The baryon fraction approaches the cosmic value at Δ_c=500 (f_{bar}(CSFR) > f_{bar}(NR))

f_{gas} PROFILES & COMPARISON WITH OBSERVATIONS



- Evolution with redshift of f_{gas}, f_{star}, f_{bar}
- Inner regions and high redshifts more affected by cold flows (higher f_{star}, f_{bar})
- NR and CSFR clusters both reach $f_{bar} = \Omega_b/\Omega_m$ at R_{vir} (but with different radial profiles)



Sembolini et al. 2012, in prep.

CSFR clusters:

- Δ_c=500 f_{gas} = (0.118±0.005)
- f_{gas} compatible with observations at all overdensities (Zhang et al 2010, La Roque 2006)

Y – M scaling relation

$$YD_A^2 \propto f_{gas} M_{TOT}^{5/3} E(z)^{2/3}$$

$$Y = YD_A^2 \cdot E^{-2/3}(z) f_{gas}^{-1}$$

$$X = M_{TOT}$$

$$Y_S = \frac{\sigma_{TH}}{m_e c^2} \frac{\mu}{\mu_e} \left(\Delta G^2 H_0^2\right)^{1/3} E(z)^{2/3} f_{gas} M_{TOT}^{5/3}$$

A = 1.66

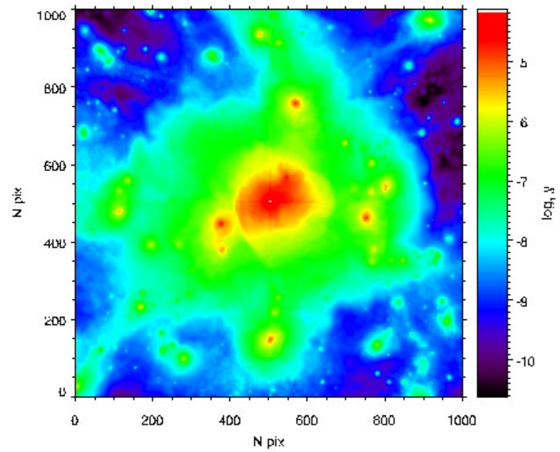
in the self similar scenario

B ≈ -28

(Y in h^{-2}Mpc^2, M in h^{-1}M$_{sun}$)

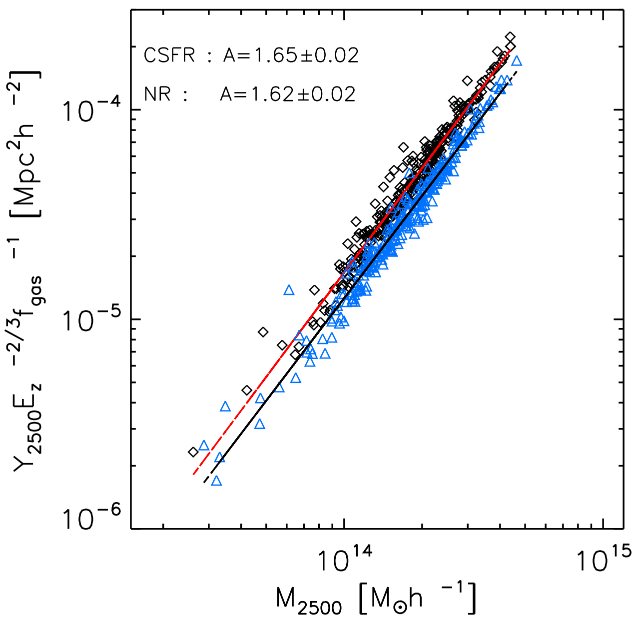
- **Y extracted from simulated maps**

  (ray-tracing)



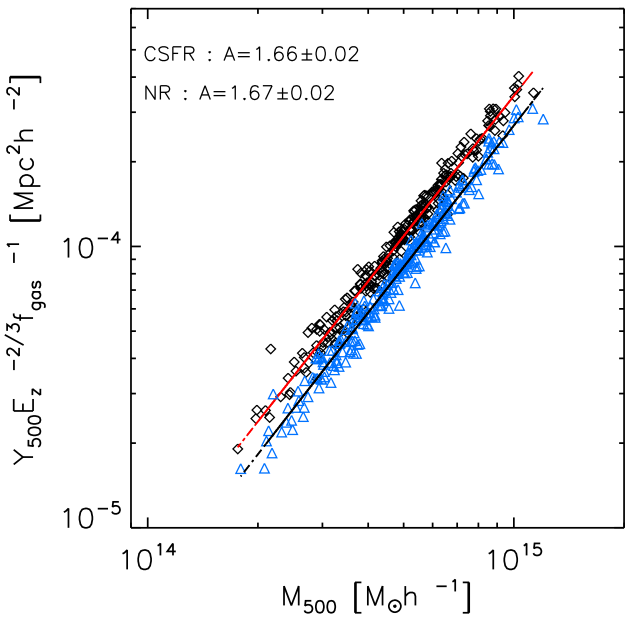
$$y = \int n_e \frac{k_B T_e}{m_e c^2} \sigma_T dl \longrightarrow y_{pix} = \sum_\alpha \sum_i \frac{k_B \sigma_T}{m_e c^2} T_{e,i} n_{e,i} W(r_i, h_i) d\ell_i$$

Y – M scaling relation



$$Y_\Delta = 10^B \left(\frac{M_\Delta}{h^{-1}\mathrm{M}_\odot} \right)^A E(z)^{2/3} [h^{-2} Mpc^2]$$

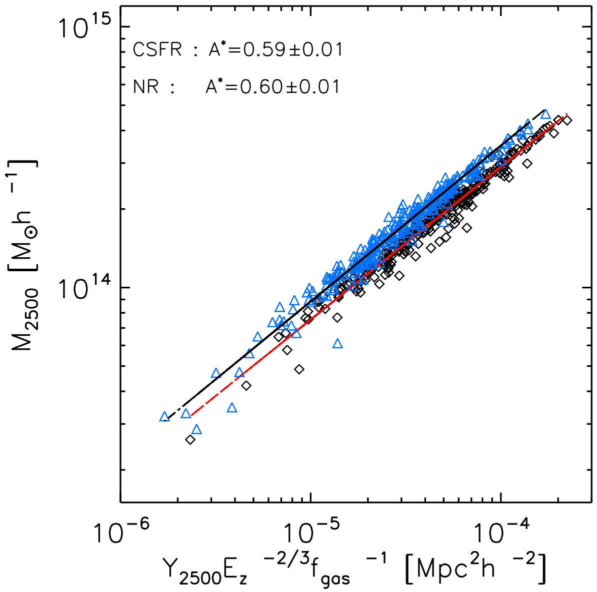
The analysis of MUSIC massive clusters Y-M scaling relation confirms the self-similar scenario

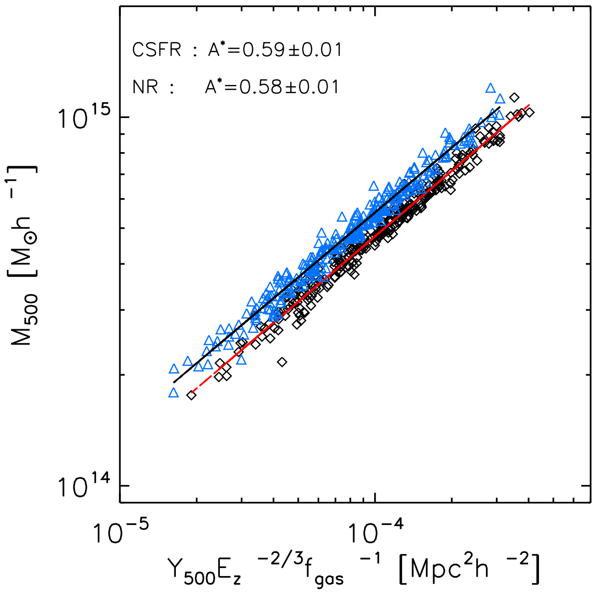


$$Y_{500} = 10^{-28.3\pm0.2} \left(\frac{M_{500}}{h^{-1}\mathrm{M}_\odot} \right)^{1.66\pm0.02} E(z)^{2/3} [h^{-2} Mpc^2]$$

As in observational scaling relations, we assume f_{gas} constant

M-Y scaling relation





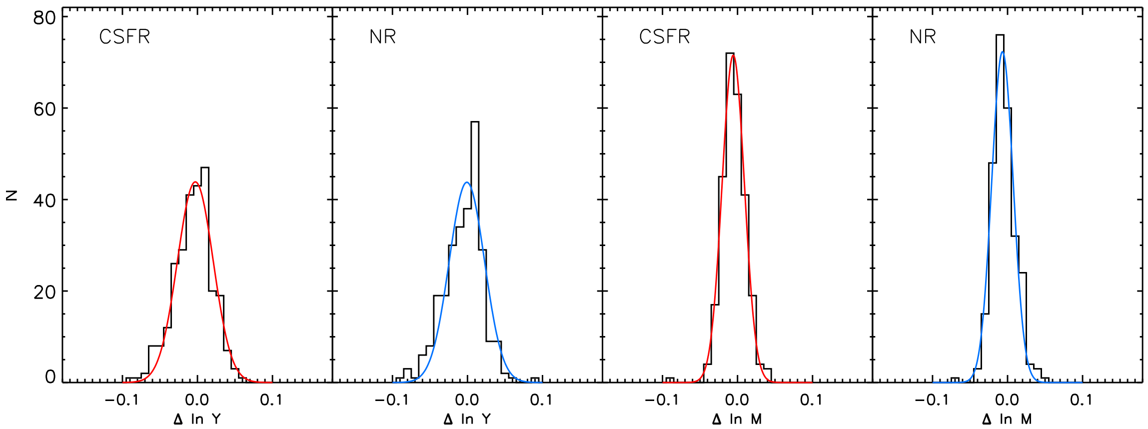
We also study the inverse scaling relation M-Y , more reliable to observational applications

$$M_\Delta = 10^{B*}\left(\frac{Y_\Delta}{h^{-2}Mpc^2}\right)^{A*} E(z)^{-2/5}[h^{-1}\mathrm{M}_\odot]$$

According to the self–similar model, a slope A* = 3/5 is expected

$$M_{500} = 10^{17.0\pm0.1}\left(\frac{Y_{500}}{h^{-2}Mpc^2}\right)^{0.59\pm0.01} E(z)^{-2/5}[h^{-1}\mathrm{M}_\odot]$$

Scatter on SZ scaling relations

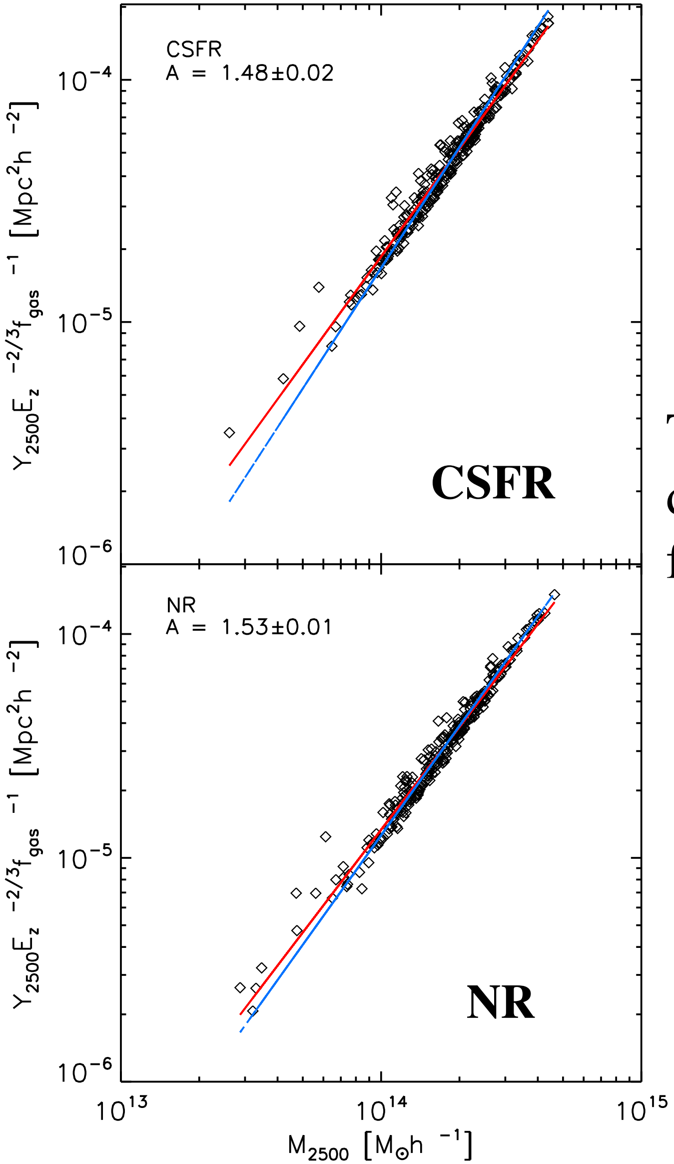


M-Y scaling relation shows lower scatter (σ=0.03) than Y-M (σ=0.05)

$$\sigma = \sqrt{\frac{\sum_i (\log Y_i - A \log X_i - B)^2}{N-2}}$$

CSFR	A	B	σ_Y	A*	B*	σ_M
2500	1.65 ± 0.02	-27.9 ± 0.3	5%	0.59± 0.01	16.8 ± 0.03	3%
2000	1.65 ± 0.02	-28.0 ± 0.2	5%	0.59± 0.01	16.8 ± 0.02	3%
1500	1.66 ± 0.02	-28.2 ± 0.2	5%	0.59± 0.01	16.9 ± 0.02	3%
1000	1.67 ± 0.02	-28.4 ± 0.2	4%	0.59± 0.01	16.9 ± 0.02	3%
500	1.66 ± 0.02	-28.3 ± 0.2	4%	0.59± 0.01	17.0 ± 0.02	2%
200	1.64 ± 0.02	-28.3 ± 0.2	4%	0.59± 0.01	17.1 ± 0.02	3%
98v	1.64 ± 0.02	-28.3 ± 0.3	5%	0.59± 0.01	17.2 ± 0.03	3%
NR						
2500	1.62 ± 0.02	-27.6 ± 0.2	6%	0.60± 0.01	16.9 ± 0.03	3%
2000	1.65 ± 0.02	-28.0 ± 0.2	5%	0.59± 0.01	16.9 ± 0.02	3%
1500	1.67 ± 0.02	-28.3 ± 0.2	4%	0.59± 0.01	17.0 ± 0.02	3%
1000	1.68 ± 0.02	-28.6 ± 0.2	4%	0.59± 0.01	17.0 ± 0.02	2%
500	1.67 ± 0.02	-28.6 ± 0.2	4%	0.59± 0.01	17.1 ± 0.02	2%
200	1.66 ± 0.02	-28.3 ± 0.2	4%	0.59± 0.01	17.2 ± 0.02	2%
98v	1.65 ± 0.02	-28.5 ± 0.3	5%	0.58± 0.01	17.2 ± 0.03	3%

The impact of f_{gas} on Y-M scaling relaton



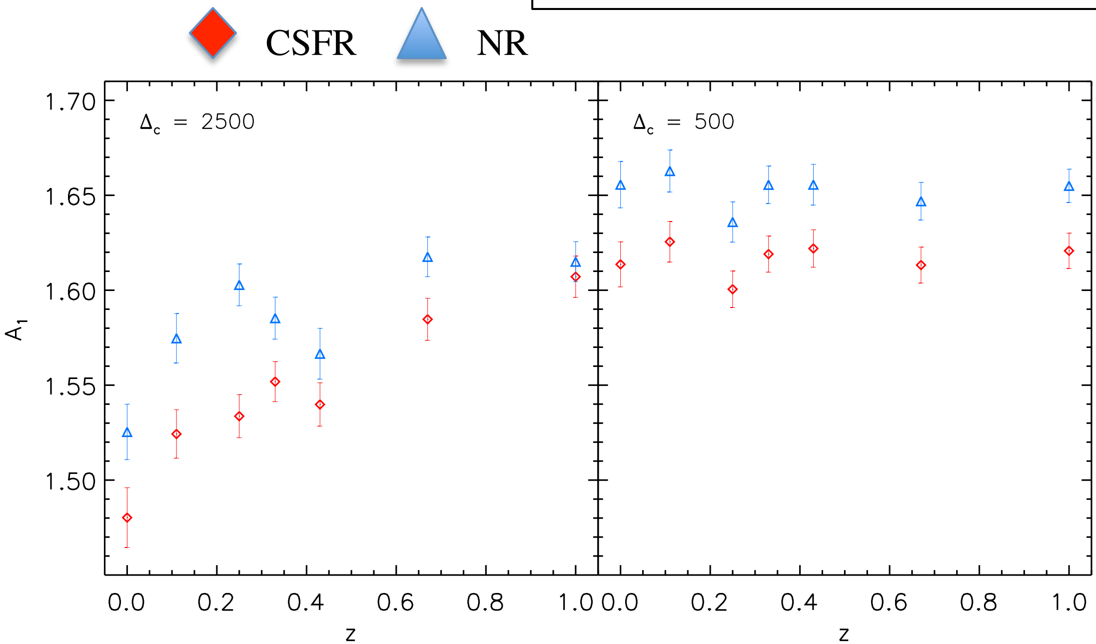
Sembolini et al. 2012, in prep.

We study the Y-M relation assigning to each cluster its value of f_{gas} → This corresponds to study the Y-M_{gas} relation

$$Y_\Delta f_{gas}^{-1} = 10^{B1}\left(\frac{M_\Delta}{h^{-1}M_\odot}\right)^{A1} E(z)^{2/3}[h^{-2}Mpc^2]$$

The introduction of f_{gas} deviates the Y-M relations from self-similarity

$$A_1 = 1.64 - 0.65 \times \left(\frac{\Delta_c}{10^4}\right)$$



The f_{gas} -M scaling relation

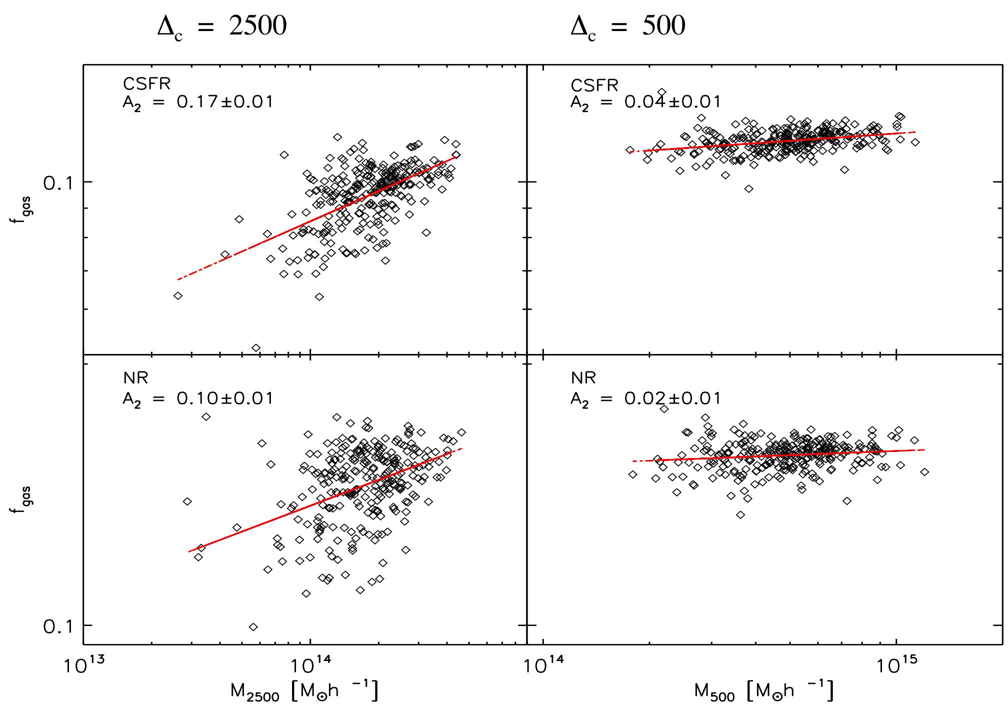
The gas fraction is linearly dependent on mass

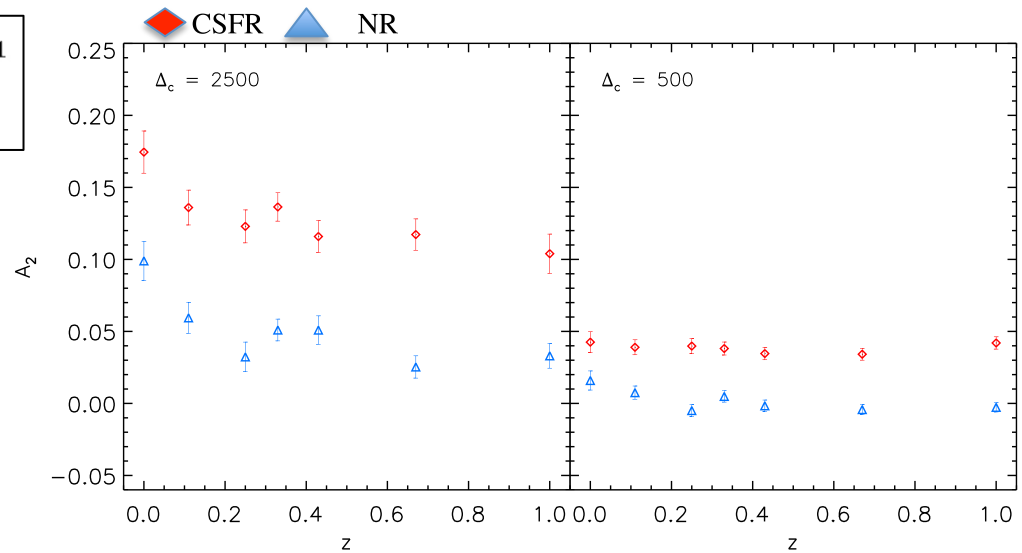
$$f_{gas} = 10^{B_2} \left(\frac{M_\Delta}{h^{-1} M_\odot} \right)^{A2}$$

This effect is bigger at high overdensities and affects both NR and CSFR clusters

$$f_{gas}(\Delta_c = 2500) = 10^{-3.5\pm0.2} \left(\frac{M_{2500}}{h^{-1} M_\odot} \right)^{0.17\pm0.01}$$

$$A_2 = 0.002 - 0.7 \times \left(\frac{\Delta_c}{10^4} \right)$$





The evolution of the Y-M scaling relation

1. Fitting the evolution of A and B parameters with redshift in the form:

$$\log A(z) = \log A_0 + \alpha_1 \log(1+z) \qquad \log B(z) = \log B_0 + \alpha_2 \log(1+z)$$

2 .Generating a sample of cluster at different redshifts, looking for a possible dependence from redshift in the form

$$Y f_{gas} E^{2/3} \propto M^{5/3} (1+z)^{\beta}$$

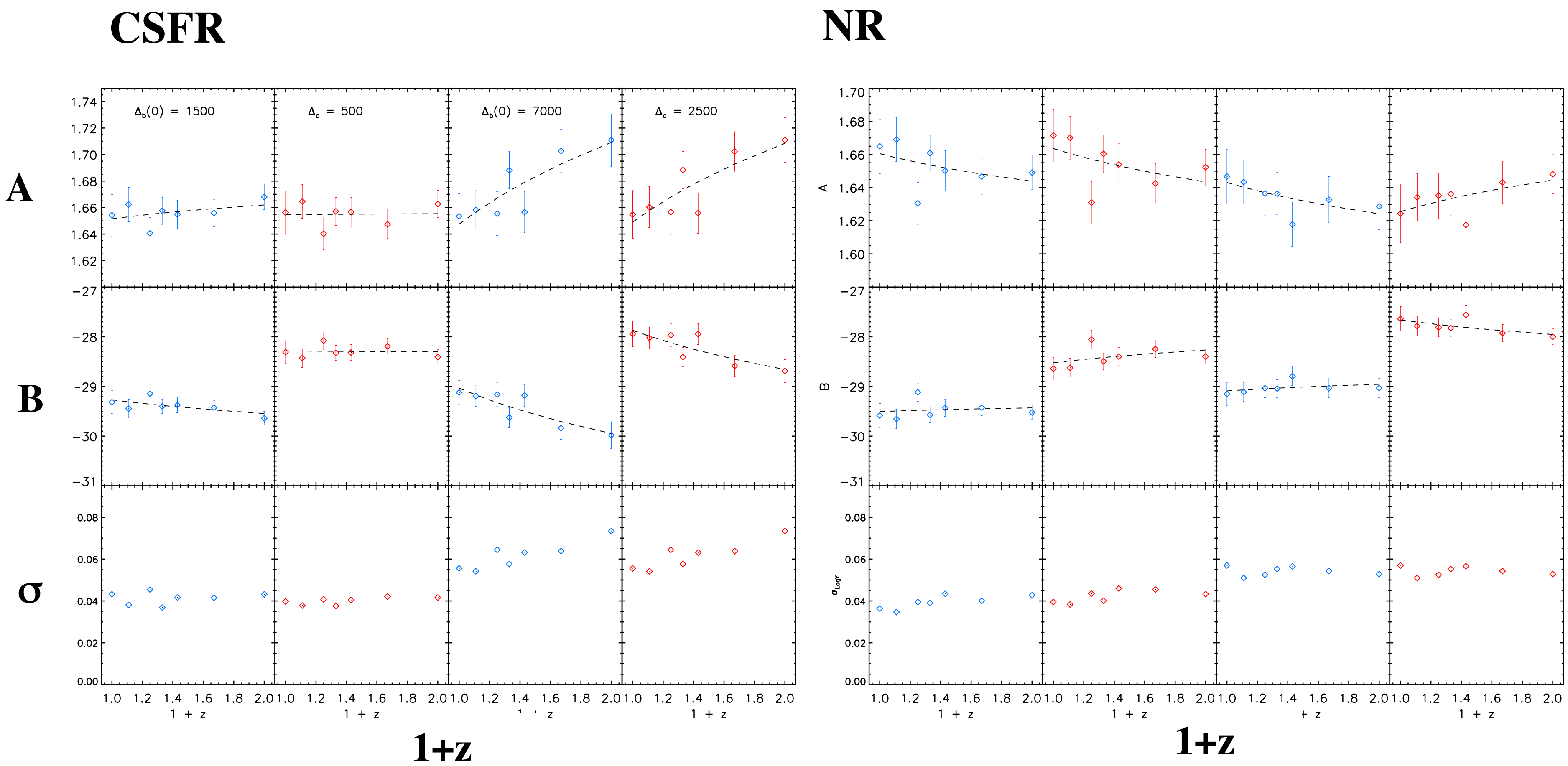
Each cluster appears in the sample only at one redshift and that the subset is populated according to the cluster abundances observed in MUSIC as a function of z

z	N($M_v > 5 \times 10^{14} h^{-1} M_\odot$)
0.00	271
0.11	237
0.25	187
0.33	147
0.43	117
0.67	44
1.00	8

The evolution of the Y-M scaling relation (1)

No redshift evolution at low overdensities

Only at high overdensities and at z>0.5 a small deviation from self-similarity is present



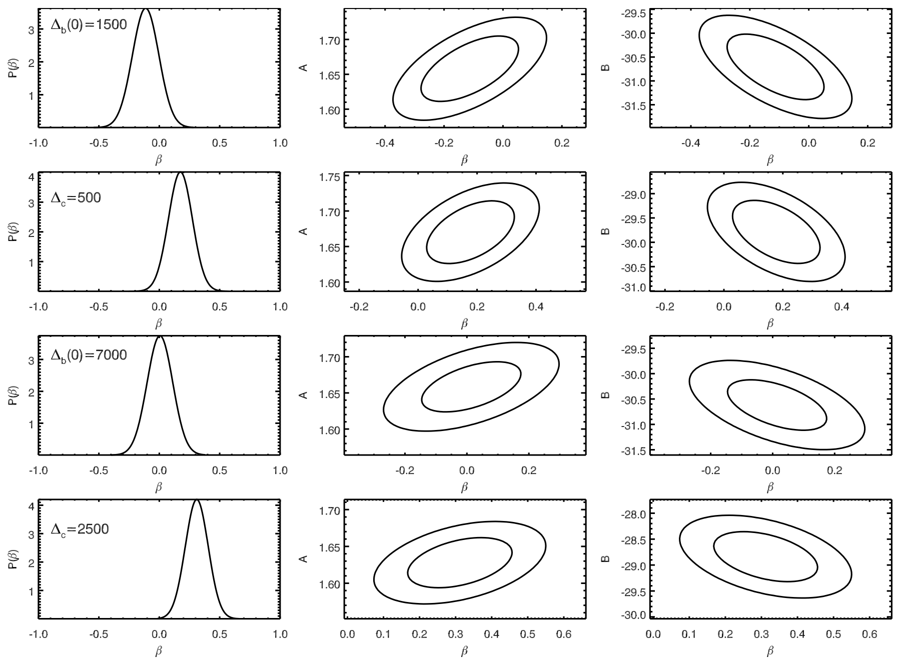
Sembolini et al. 2012, in prep.

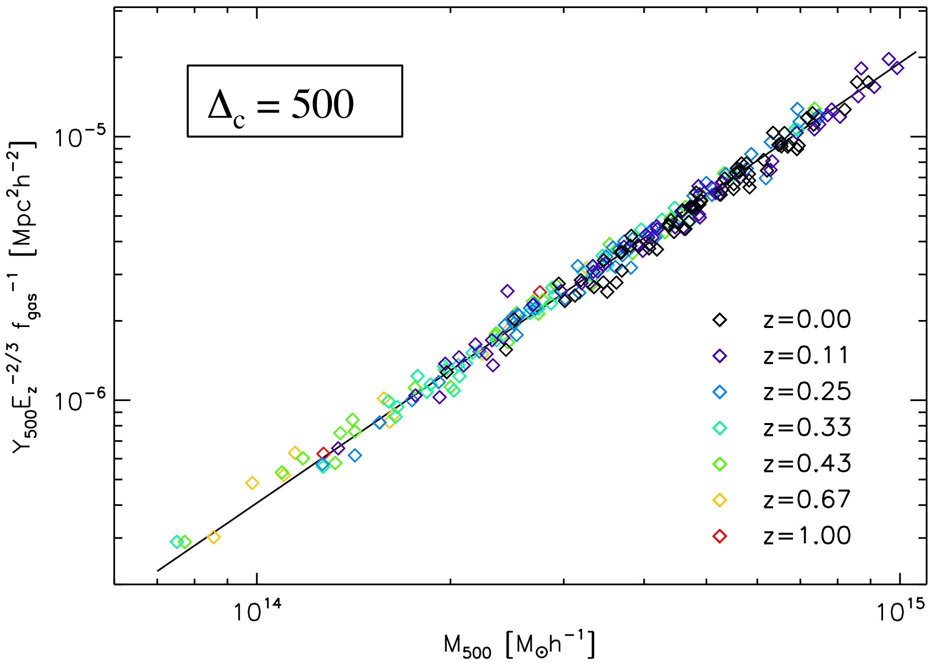
The evolution of the Y-M scaling relation (2)

[h]

	Δ_c =500	Δ_c =2500	$\Delta_b(z)$ = 1500(z)	$\Delta_b(z)$ = 7000(z)
A	1.672± 0.028	1.627 ± 0.022	1.652± 0.028	1.656 ± 0.023
B	-29.77± 0.42	-28.85± 0.32	-30.65±0.42	-30.61± 0.33
β	0.17 ± 0.10	0.31± 0.14	-0.12± 0.11	0.00± 0.11

The fit results are still fairly consistent with self similarity and no additional redshift in the Y-M scaling relation





CONCLUSIONS

- The MUSIC dataset is a large sample of clusters simulated with radiative (and non-radiative physics) and high mass resolution

  - MUSIC-2 constitutes a complete mass limited volume sample
- SZ scaling relations of massive MUSIC clusters confirm the predictions of the self-similar model
- The gas fraction depends on mass and deviates the Y-M from self-similarity at high overdensities
- The Y-M scaling relation of massive clusters is rather insensitive to redshfit evolution up to z ~1