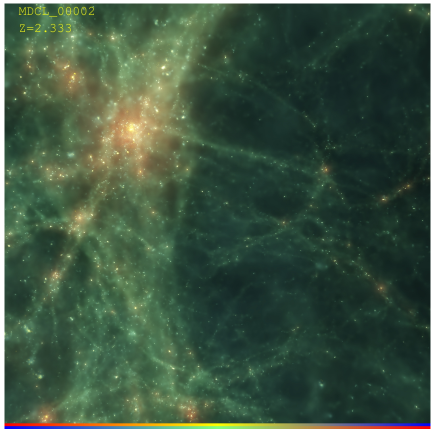
UNIVERSIDAD AUTONOMA DE MADRID

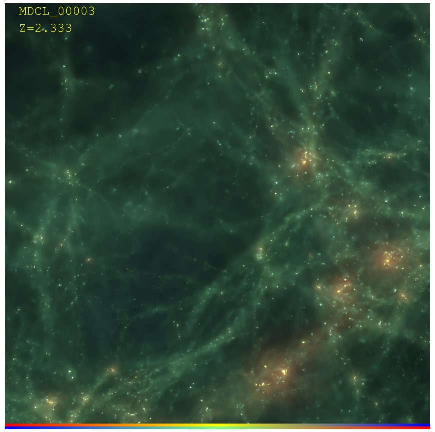
STVDIVM VRBIS

MUSIC
Marenostrum MUltidark SImulations of galaxy Clusters

AIP Leibniz-Institut für Astrophysik Potsdam

Exploring the SZE brightness of MUSIC proto-clusters to calibrate the Y-M scaling law





Federico Sembolini

Universidad Autonoma de Madrid
Sapienza Università di Roma

Gustavo Yepes, Marco De Petris, Emma Foschi
Stefan Gottlöber,Luca Lamagna

OUTLINE

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

  1. mass and angular-size distribution
  2. baryon properties
  3. evolution of the Y-M scaling relation in proto-clusters

- Conclusions

Marenostrum
M**U**ltidark
SImulations
of galaxy
Clusters

THE MUSIC DATASET

(Sembolini et al. 2012, arXiv:1207.4438, submitted to MNRAS)

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 $M > 10^{13}\ h^{-1} M_{SUN}$

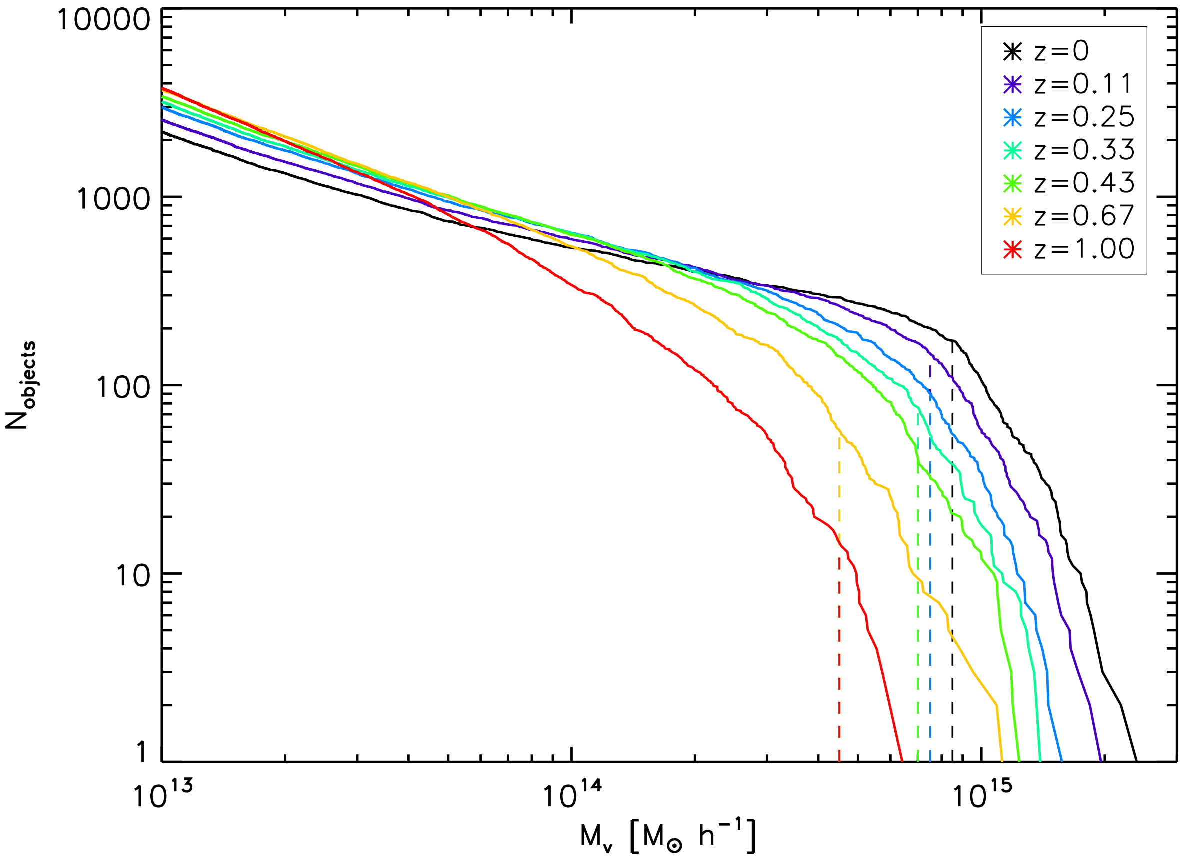
} **cooling + star formation (CSFR) & non radiative (NR)resimulations**

Many objects with $M > 10^{15} h^{-1}\ M_{SUN}$
$m_{DM}=9.01 \times 10^8 h^{-1} M_{SUN}$ - $m_{SPH}=1.9\times10^8 h^{-1} M_{SUN}$
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

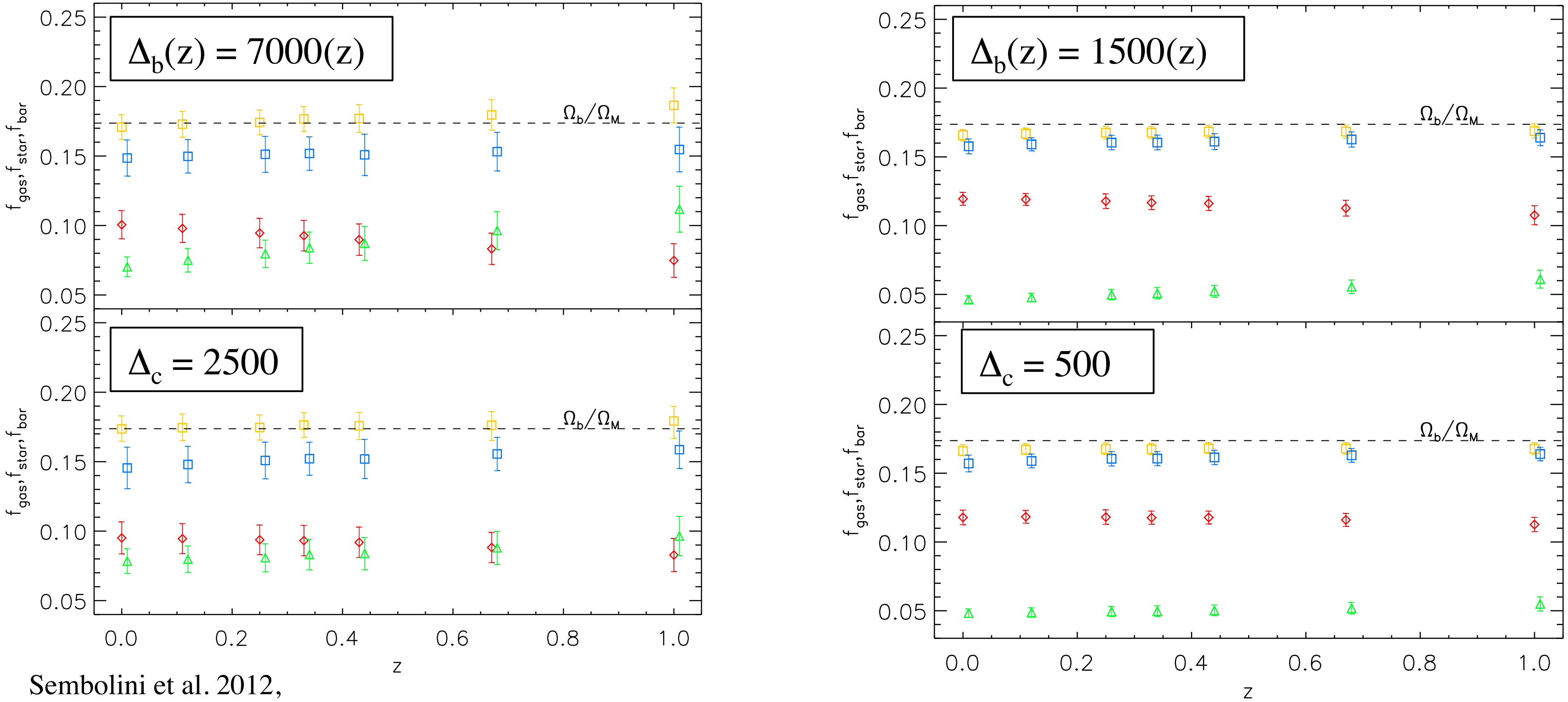
MUSIC-2 is a complete mass-limited volume sample:
all objects beyond a (redshift varying) mass limit formed in the $1h^{-1}$Gpc DM-only simulation have been resimulated



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

BARYON PROPERTIES



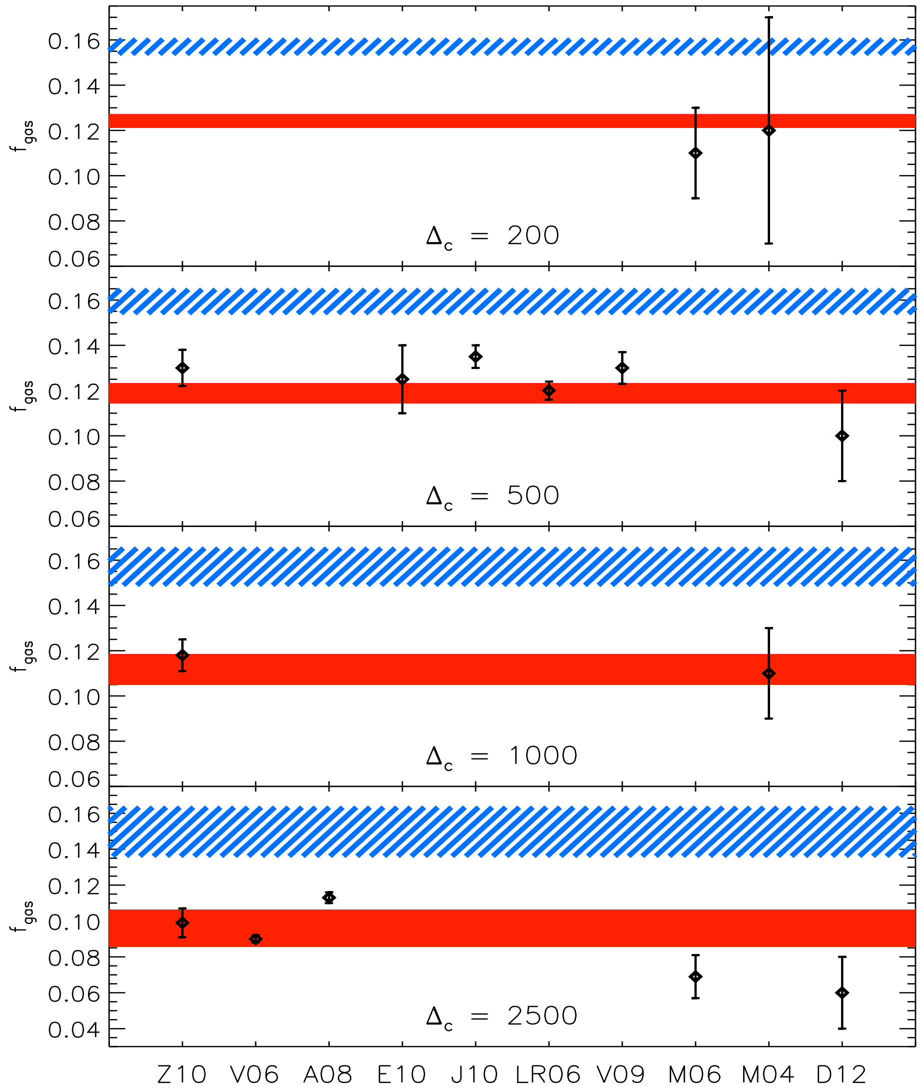
Sembolini et al. 2012,

- 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))

GAS FRACTION : COMPARISON WITH OBSERVATIONS

CSFR clusters:

- Δ_c=500 f_{gas} = (0.118±0.005)
- f_{gas} compatible with observations at all overdensities (LaRoque 2006 (LR06); Maughan 2006 M(06); Vikhlinin 2006 (V06); Ettori 2010 (E10); Zhang 2010 (Z10))



Sembolini et al. 2012

Y – M scaling relation

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

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

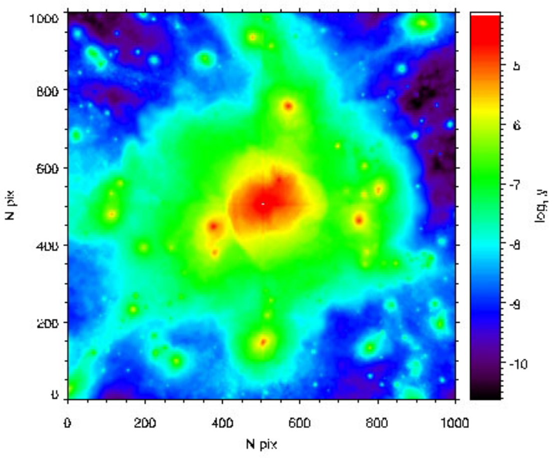
$$Y_S = \frac{\sigma_{TH}}{m_e c^2} \frac{\mu}{\mu_e} \left(\Delta G^2 H_0^2\right)^{1/3} E(z)^{2/3} f_{gas} M_{TOT}^{5/3}$$

A = 1.66

in the self similar scenario

B ≈ -28

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

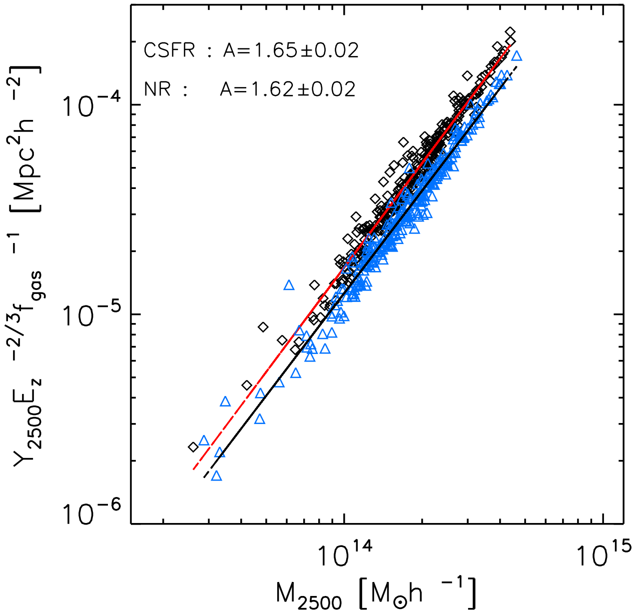


- **Y extracted from simulated maps**

  (ray-tracing)

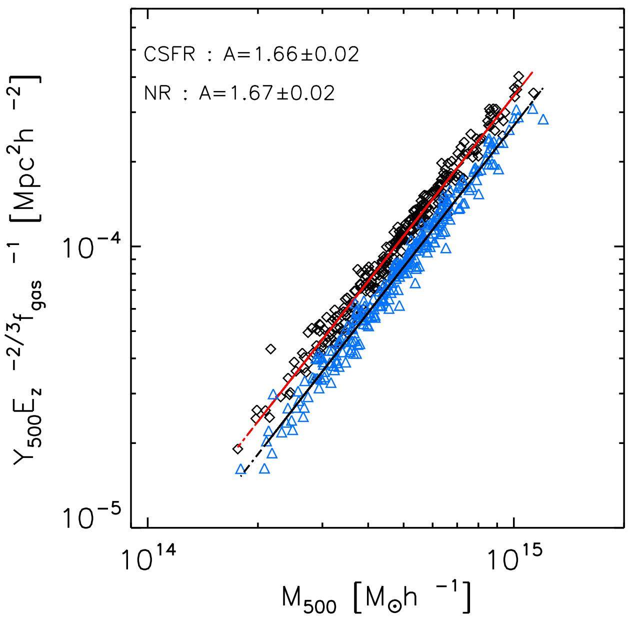
$$y = \int n_e \frac{k_B T_e}{m_e c^2} \sigma_T dl \longrightarrow y_{pix} = \sum_\alpha \sum_i \frac{k_B \sigma_T}{m_e c^2} T_{e,i} n_{e,i} W(r_i, h_i) d\ell_i$$

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



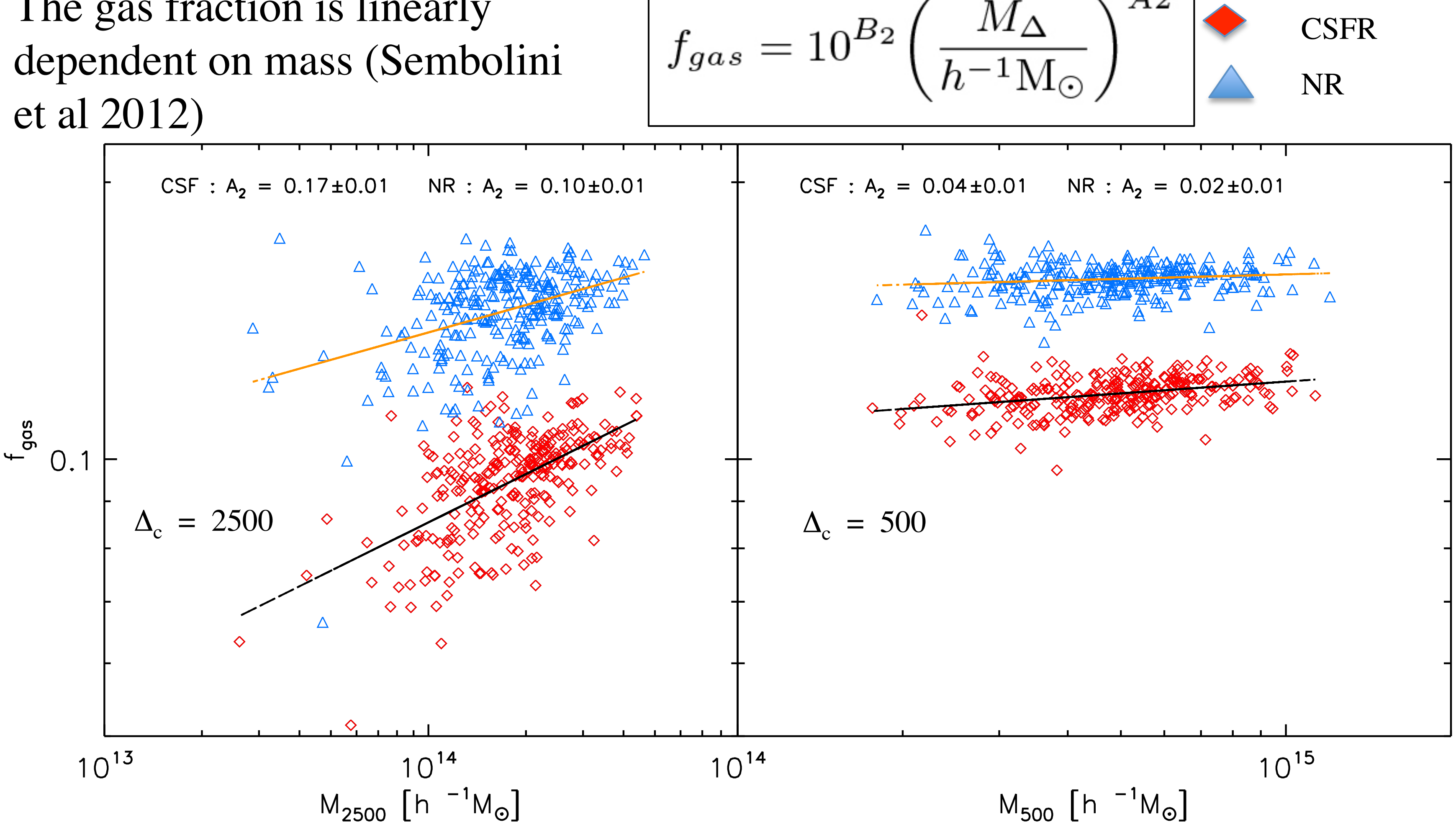
$$Y_{500} = 10^{-28.3\pm0.2} \left(\frac{M_{500}}{h^{-1}\mathrm{M}_\odot} \right)^{1.66\pm0.02} E(z)^{2/3} [h^{-2} Mpc^2]$$

As in observational scaling relations, we assume f_{gas} constant (Sembolini et al., 2012)

The f_{gas} -M scaling relation

The gas fraction is linearly dependent on mass (Sembolini et al 2012)

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



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

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

The evolution of the Y-M scaling relation

No redshift evolution at low overdensities

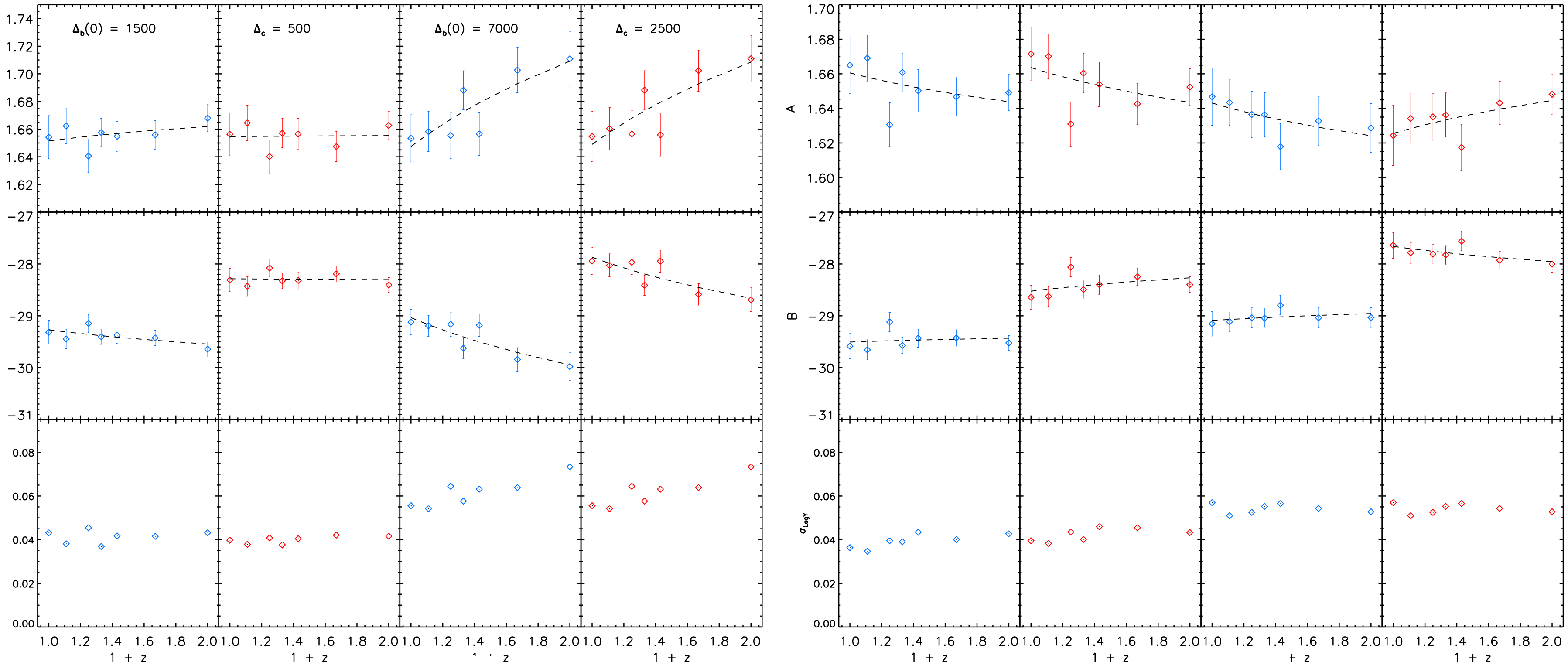
Only at high overdensities and at z>0.5 a small deviation from self-similarity is present

CSFR **NR**

A

B

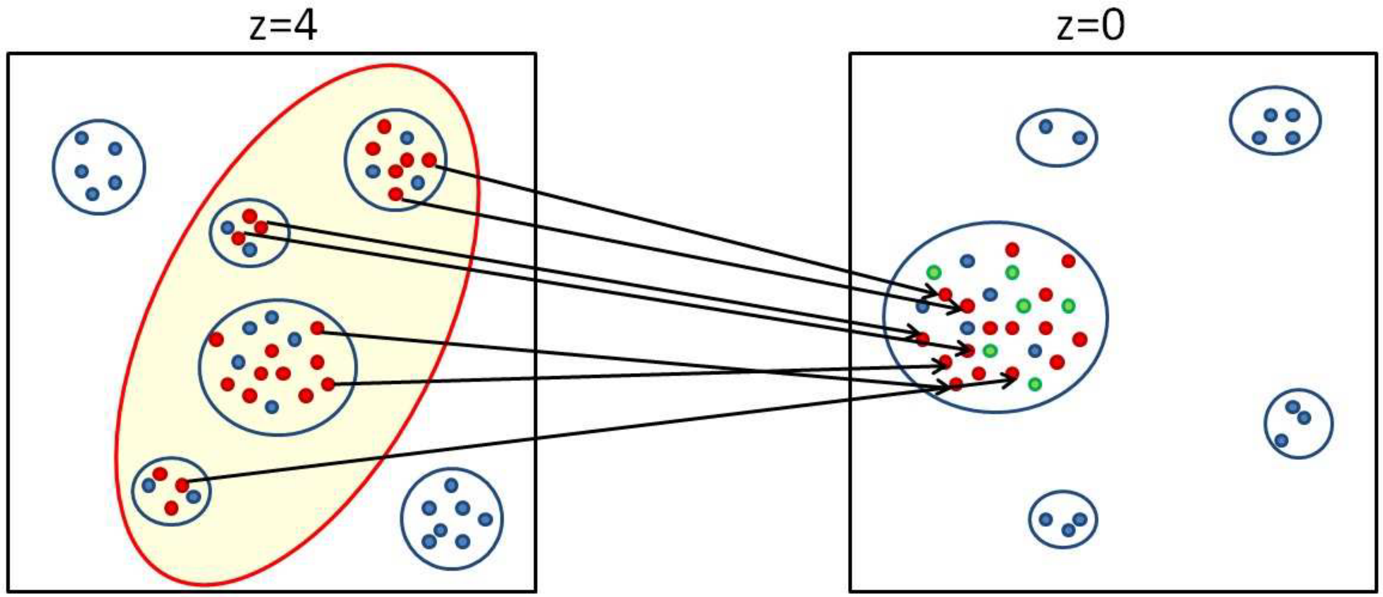
σ



1+z **1+z**

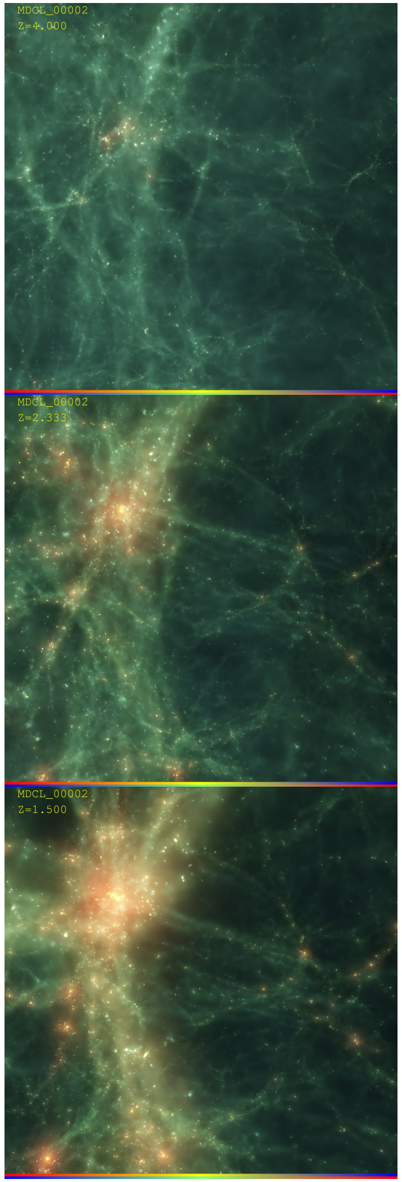
(Sembolini et al. 2012)

Defining a protocluster in a numerical simulation



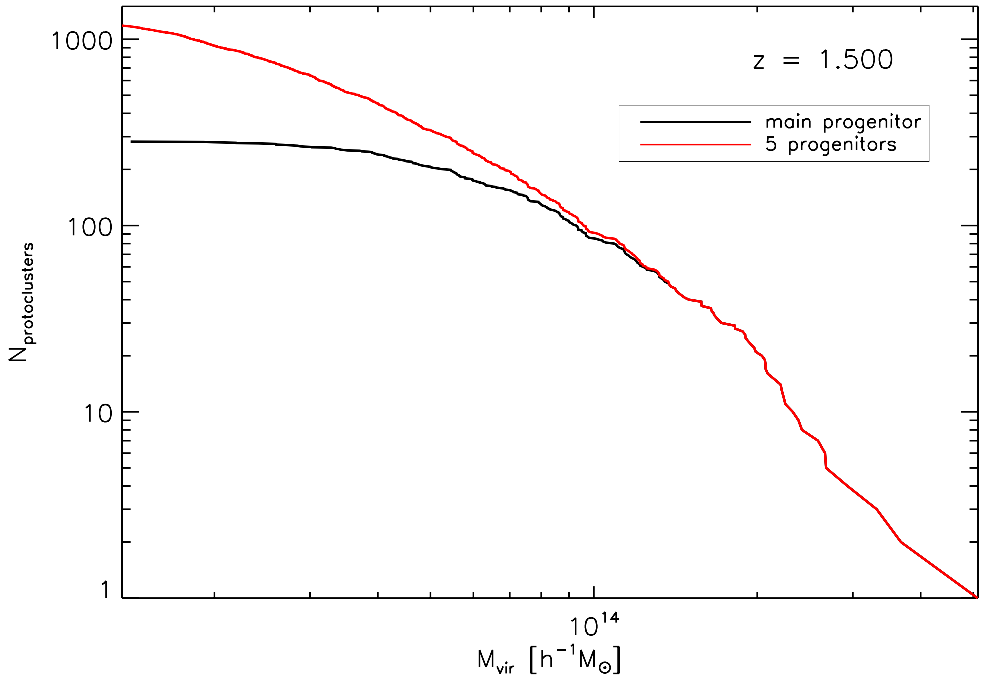
- Using merger-tree, we trace all the objects at high redshift(s) which will end up into a cluster at z = 0
- We define as protocluster the most massive high-redshift object among all the cluster's progenitors

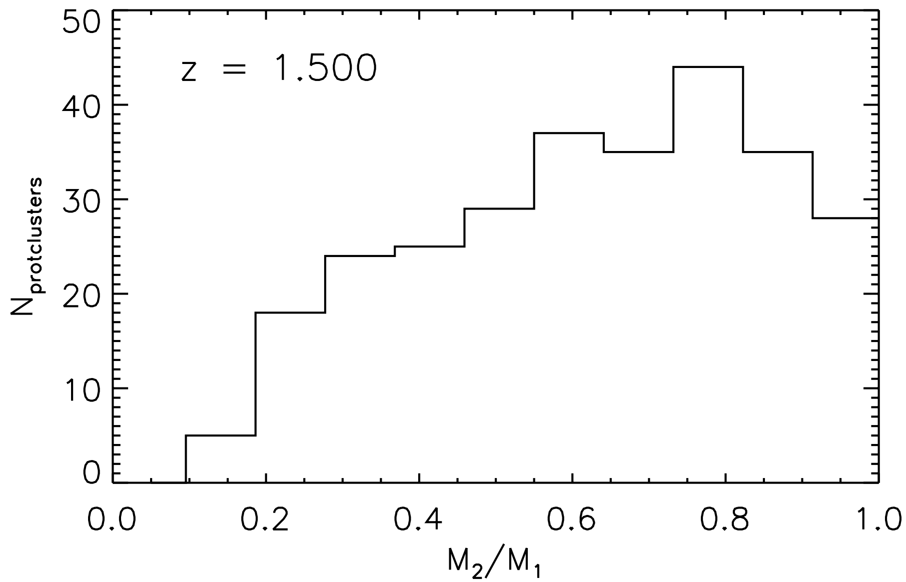
Protoclusters of galaxies in MUSIC simulations



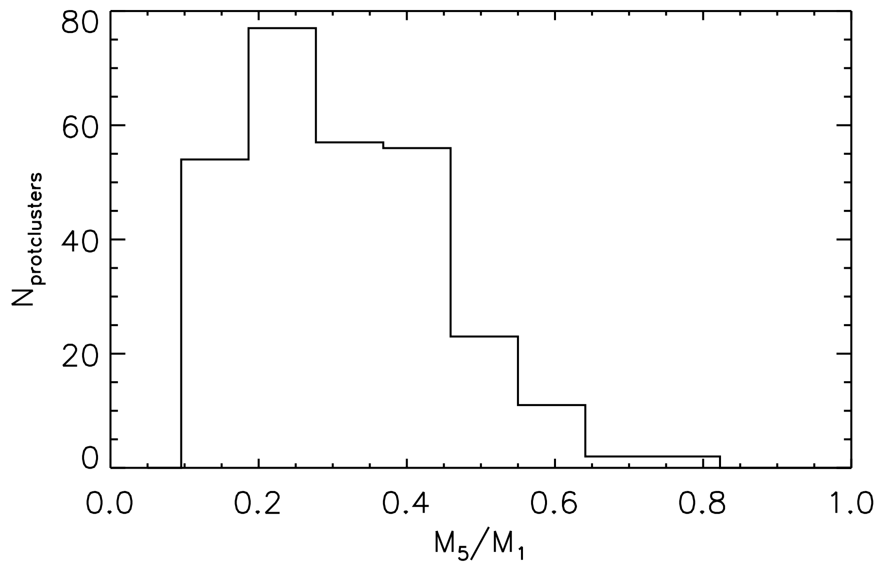
- Only radiative clusters analyzed
- Analysis of protoclusters evolving in the most massive clusters of galaxies -
  $M_v > 5\times10^{14}\ h^{-1}M_{SUN}$ at z=0 (282 clusters):
  - 282 main progenitors (most massive protocluster for each object)
  - 5 most massive protoclusters for each cluster (1410 protoclusters)
- 3 different redshifts analyzed:
  - z = 1.5, 2.3, 4.0
- Properties of protoclusters studied at virial radius
- At z = 4 ~ 70% of most massive objects correspond to the most massive objects at z = 0 (>80% at z = 1.5)

z = 1.5



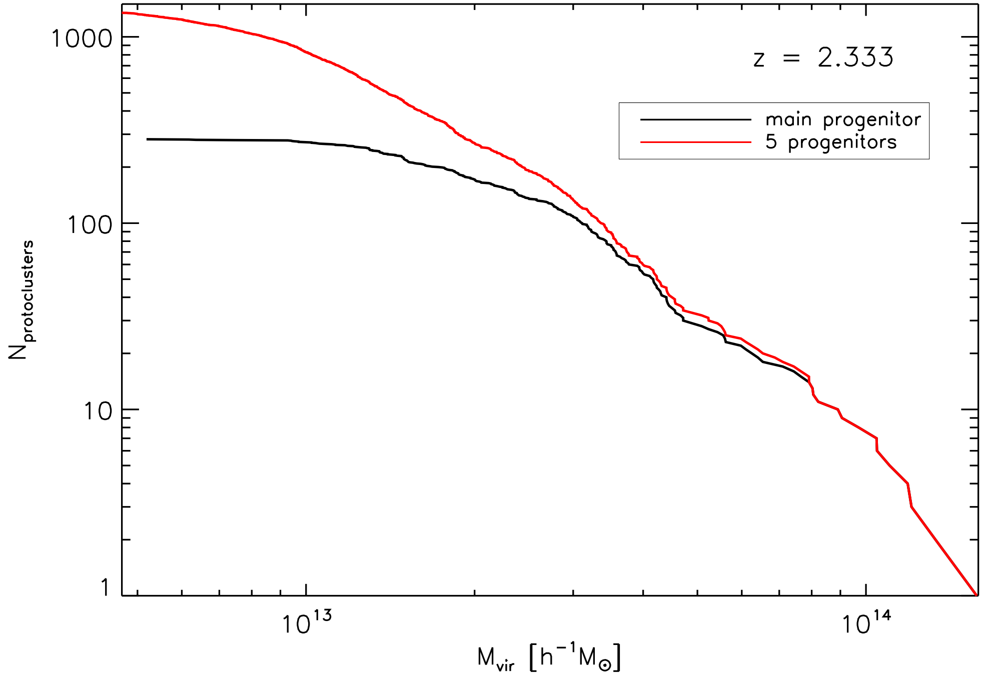


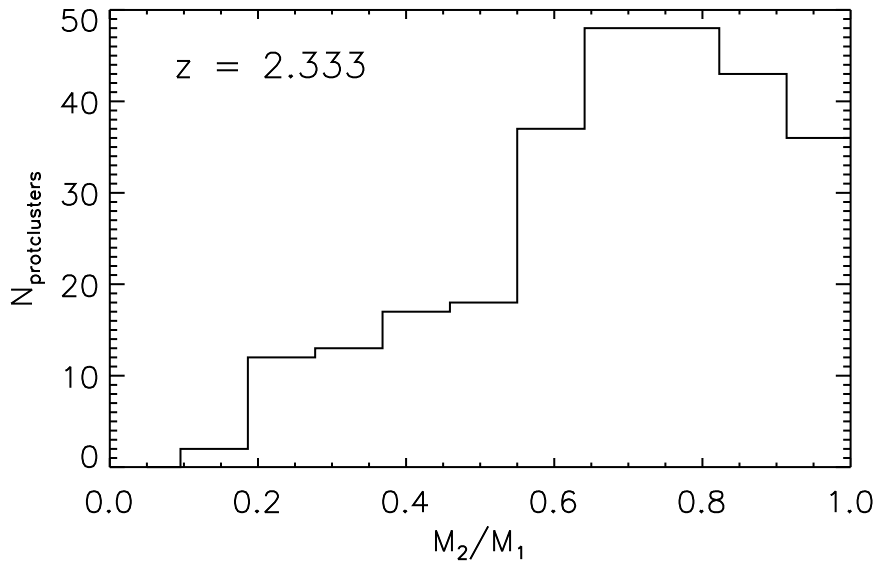
- > 100 objects with M > $10^{14}h^{-1}M_{SUN}$
- <M2/M1> ~ 0.5
- <M5/M1> << 0.5



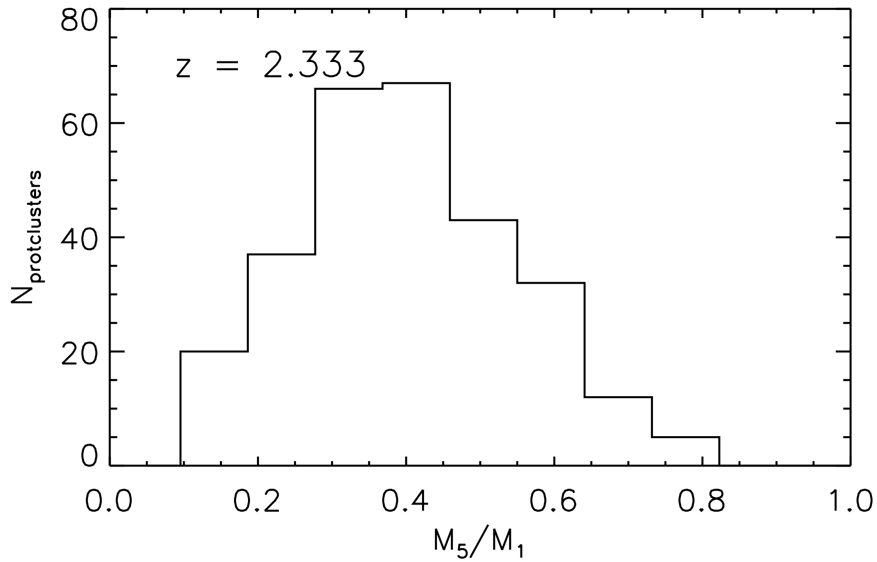
$1.4\times10^{13}h^{-1}M_{SUN} < M < 5.1\times10^{14}h^{-1}M_{SUN}$

z = 2.3



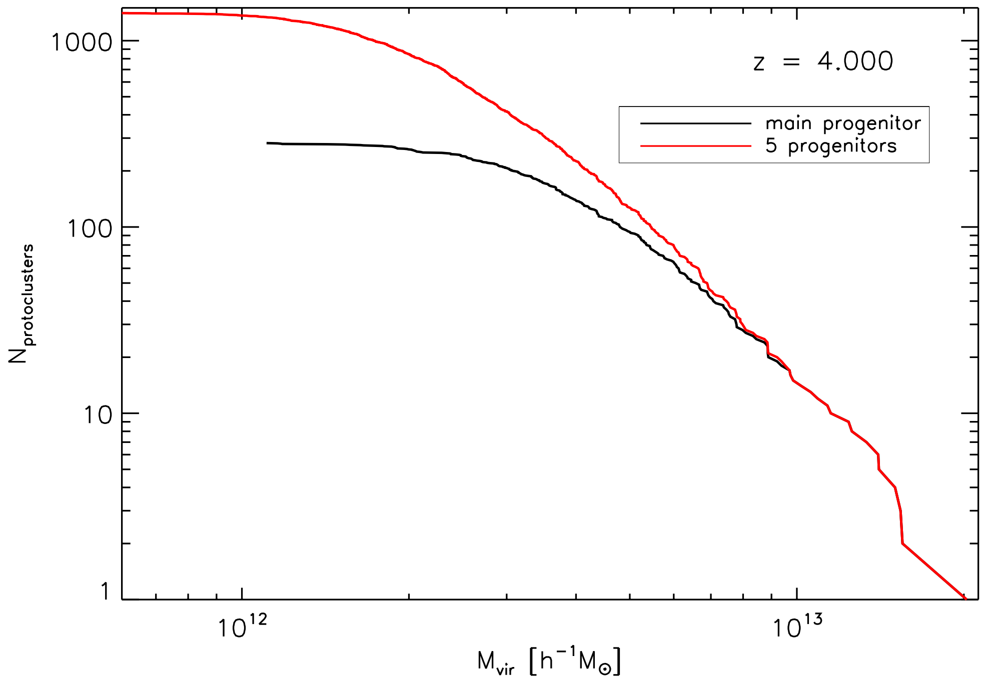


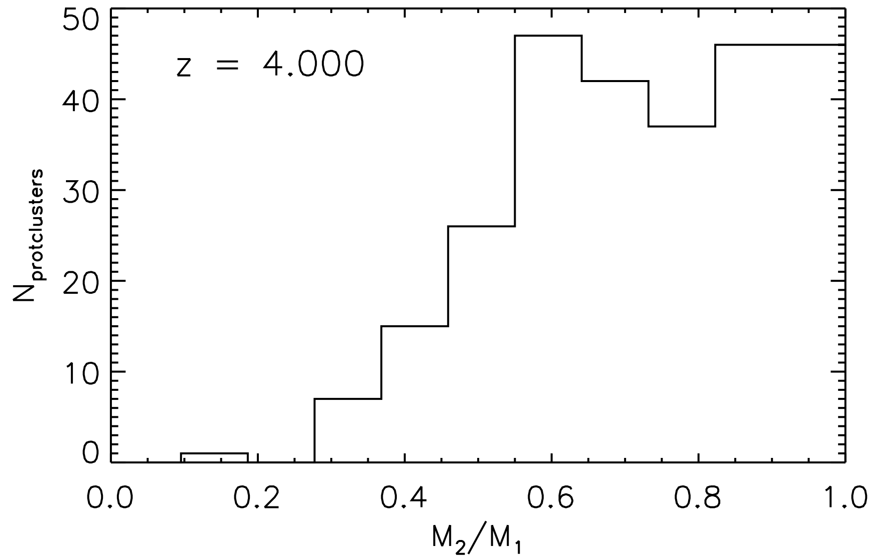
- < 10 objects with M > $10^{14}h^{-1}M_{SUN}$
- <M2/M1> ~ 0.65
- <M5/M1> ~ 0.4

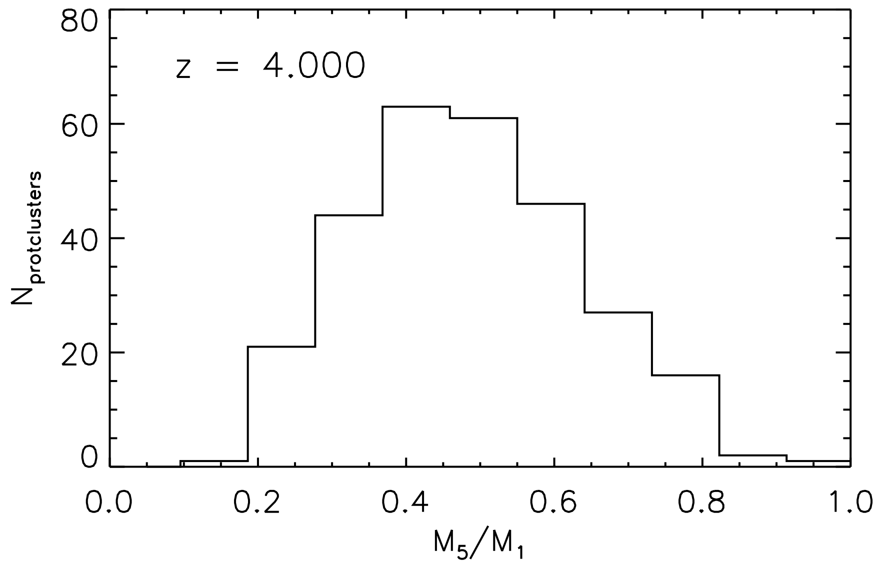


$5.2\times10^{12}h^{-1}M_{SUN} < M < 1.5\times10^{14}h^{-1}M_{SUN}$

z = 4







- ~ 10 objects with $M > 10^{13} h^{-1} M_{SUN}$
- <M2/M1> ~ 0.8
- <M5/M1> ~ 0.5

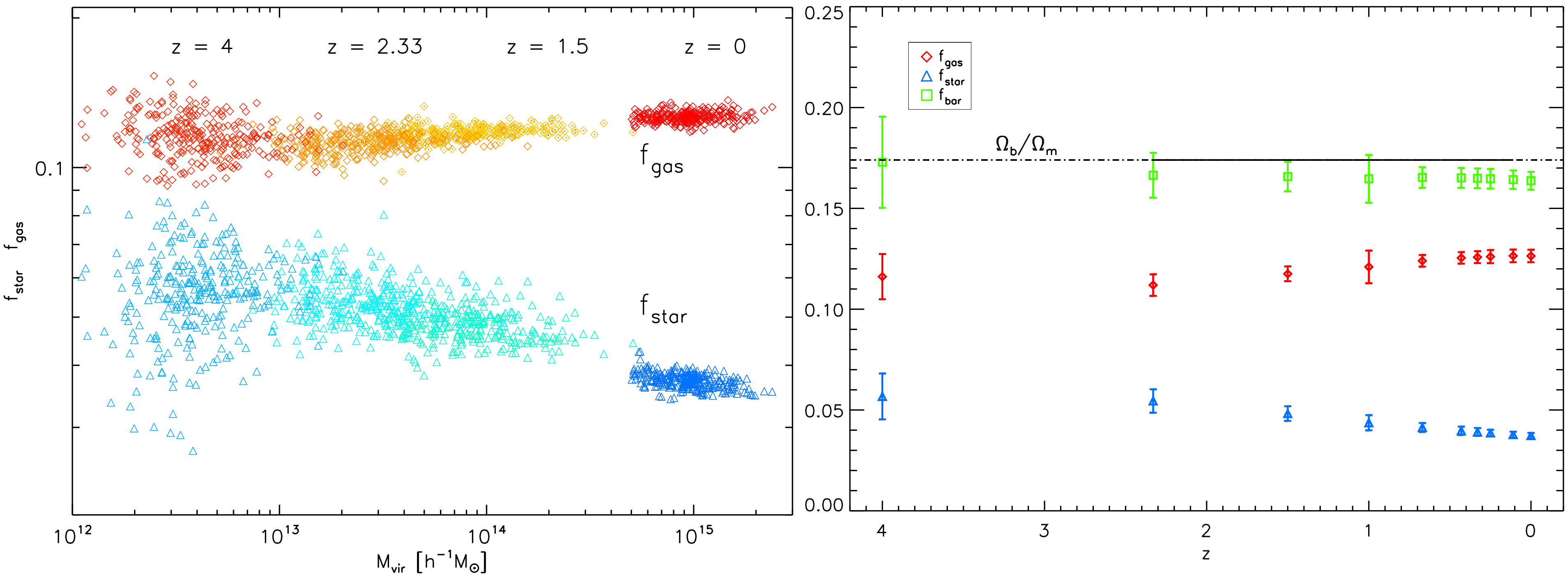
$1.1\times10^{12} h^{-1} M_{SUN} < M < 2.0\times10^{14} h^{-1} M_{SUN}$

GAS FRACTION AND STELLAR FRACTION IN PROTOCLUSTERS

@R_{vir}

(main progenitors)

- **z = 1.5** **f_{gas} = 0.115±0.004** **f_{star} = 0.048±0.003** **f_{bar} = 0.166±0.007**
- **z = 2.3** **f_{gas} = 0.112±0.005** **f_{star} = 0.054±0.006** **f_{bar} = 0.167±0.011**
- **z = 4.0** **f_{gas} = 0.122±0.014** **f_{star} = 0.057±0.011** **f_{bar} = 0.173±0.022**

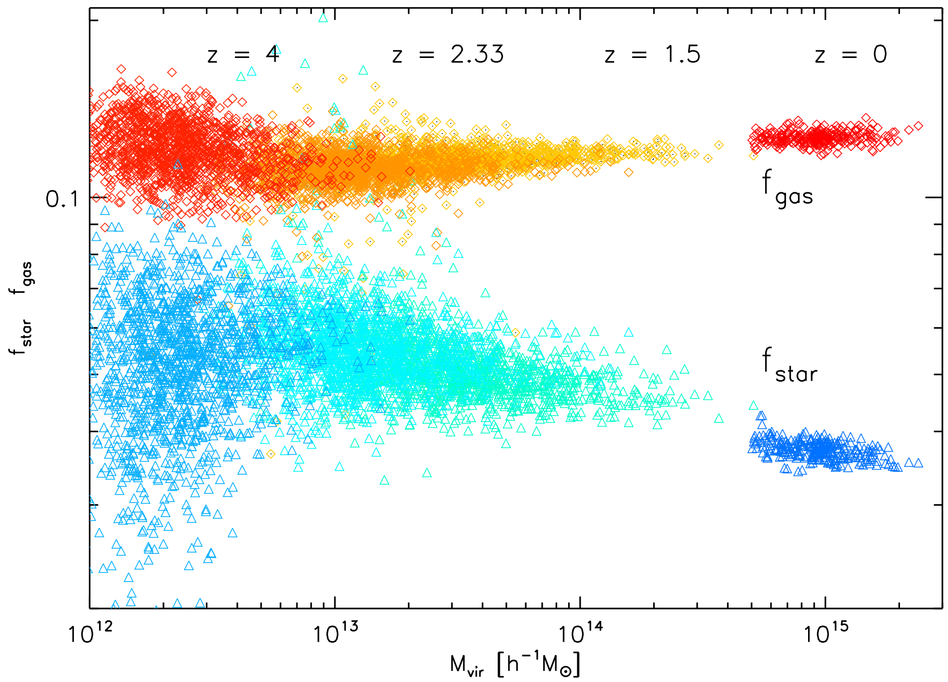


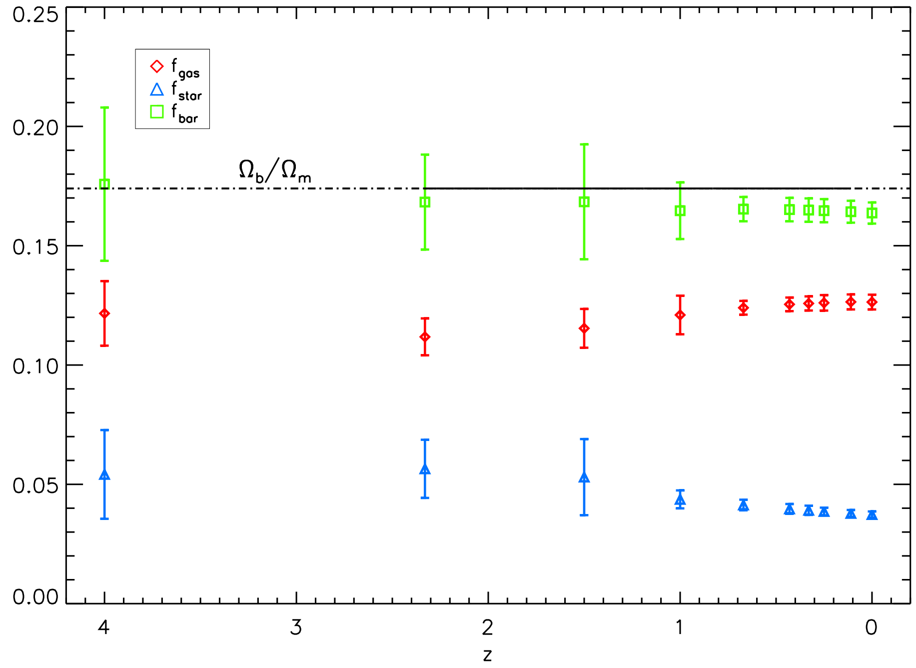
- Mean values of star and gas fraction compatible with z≤1 - baryon fraction compatible with Ωb/Ωm=0.174 – gas and star fraction linear dependent from total mass

GAS FRACTION AND STELLAR FRACTION IN PROTOCLUSTERS (2)

@R_{vir}

(5 most massive progenitors)

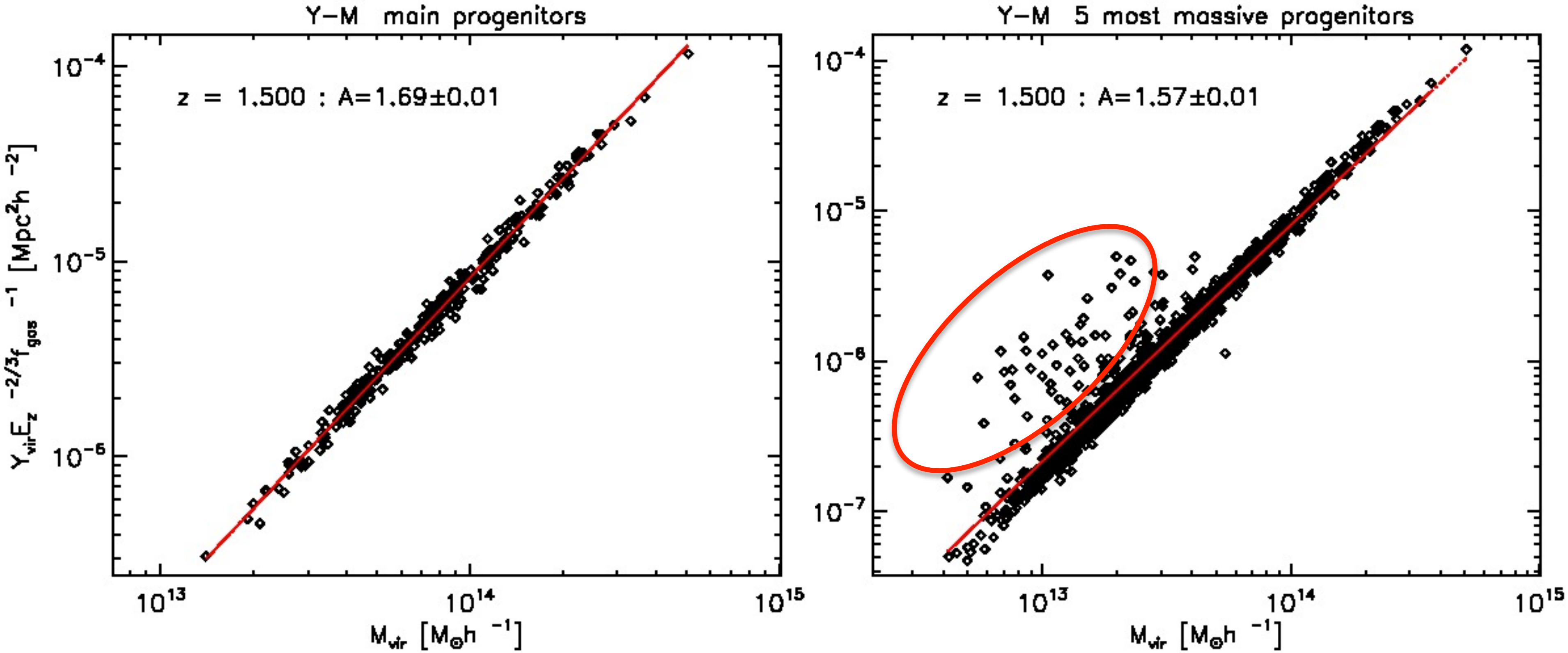




Higher dispersion than when considering only the one single progenitor, but same mean values of gas, star and baryon fraction

Y-M relation of MUSIC PROTOCLUSTERS

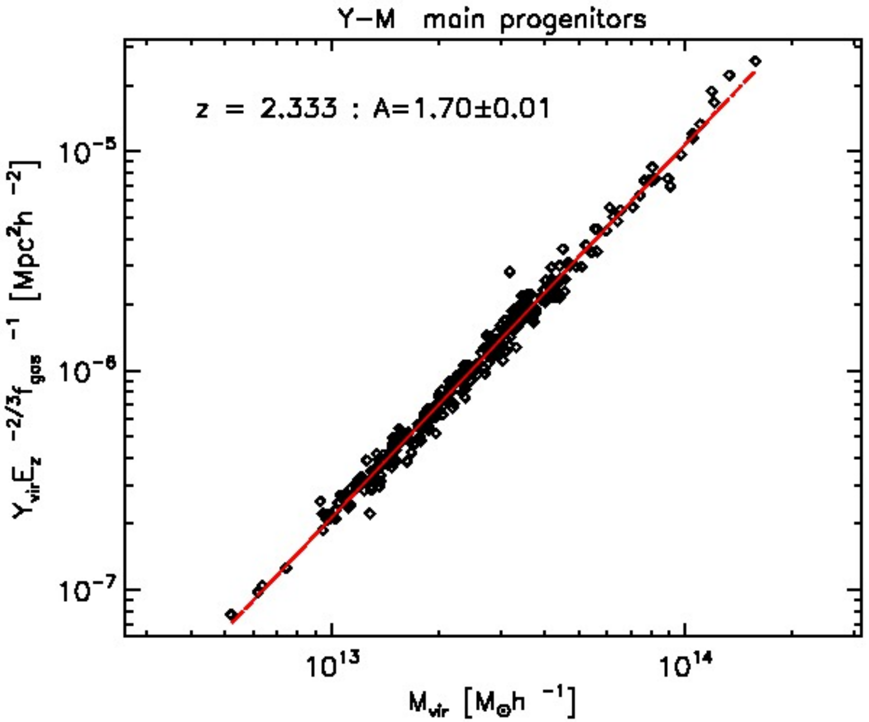
z = 1.5

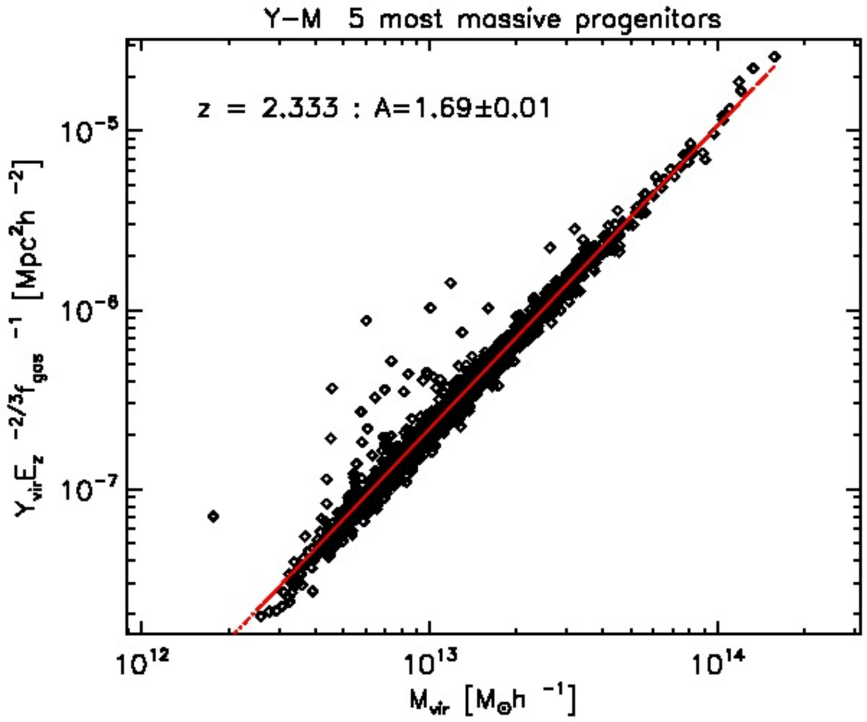


- Similar results than at z = 1 (low deviation from self-similarity)
- When considering 5 progenitors, the effect of smallest non-virialized objects introduces a deviation from self-similarity

Y-M relation of MUSIC PROTOCLUSTERS (2)

z = 2.3

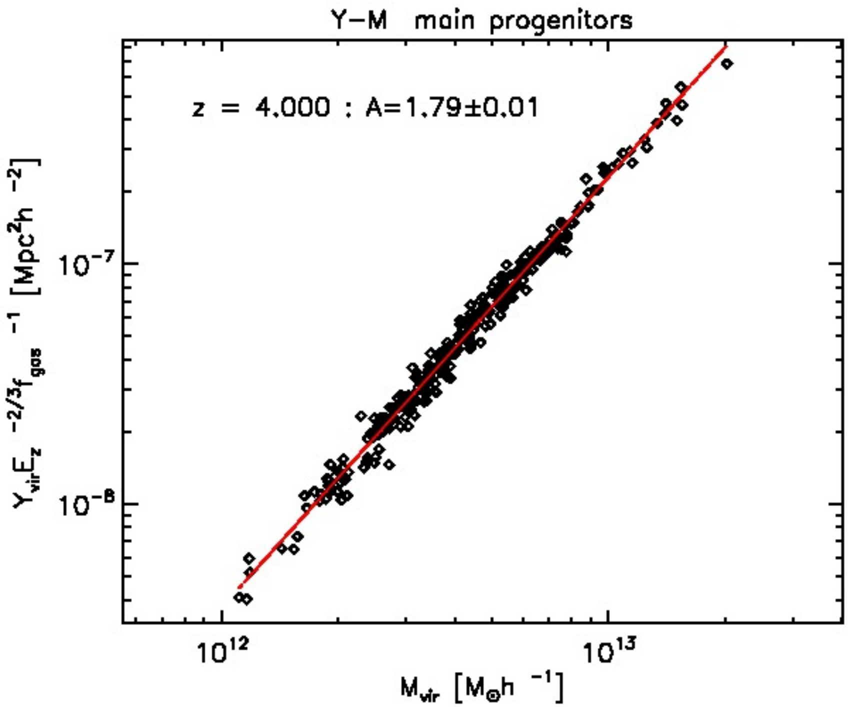


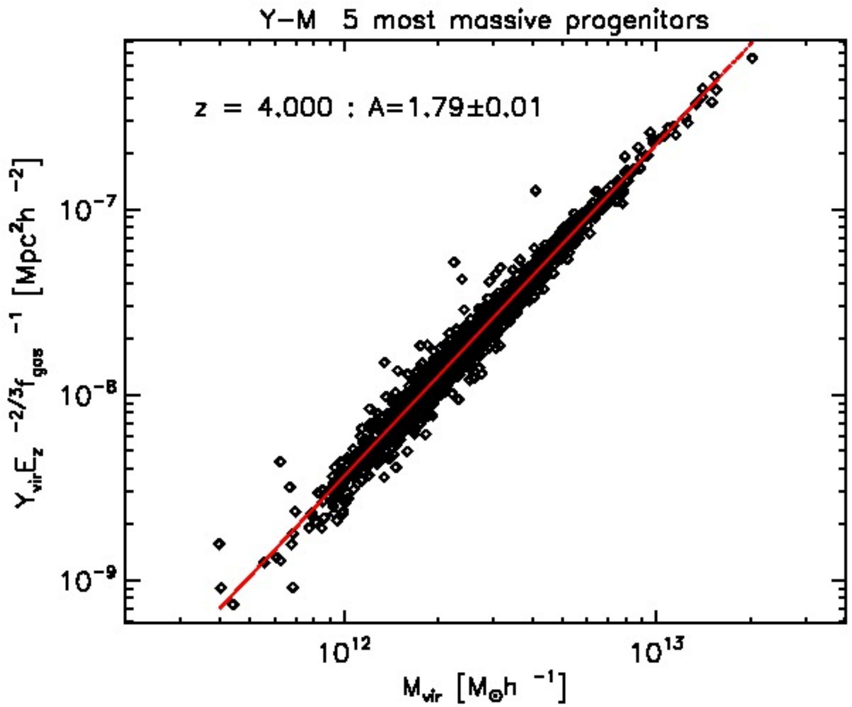


- Deviation from self-similarity slightly bigger than @z=1.5
- Same behaviour when considering one or five progenitors

Y-M relation of MUSIC PROTOCLUSTERS (3)

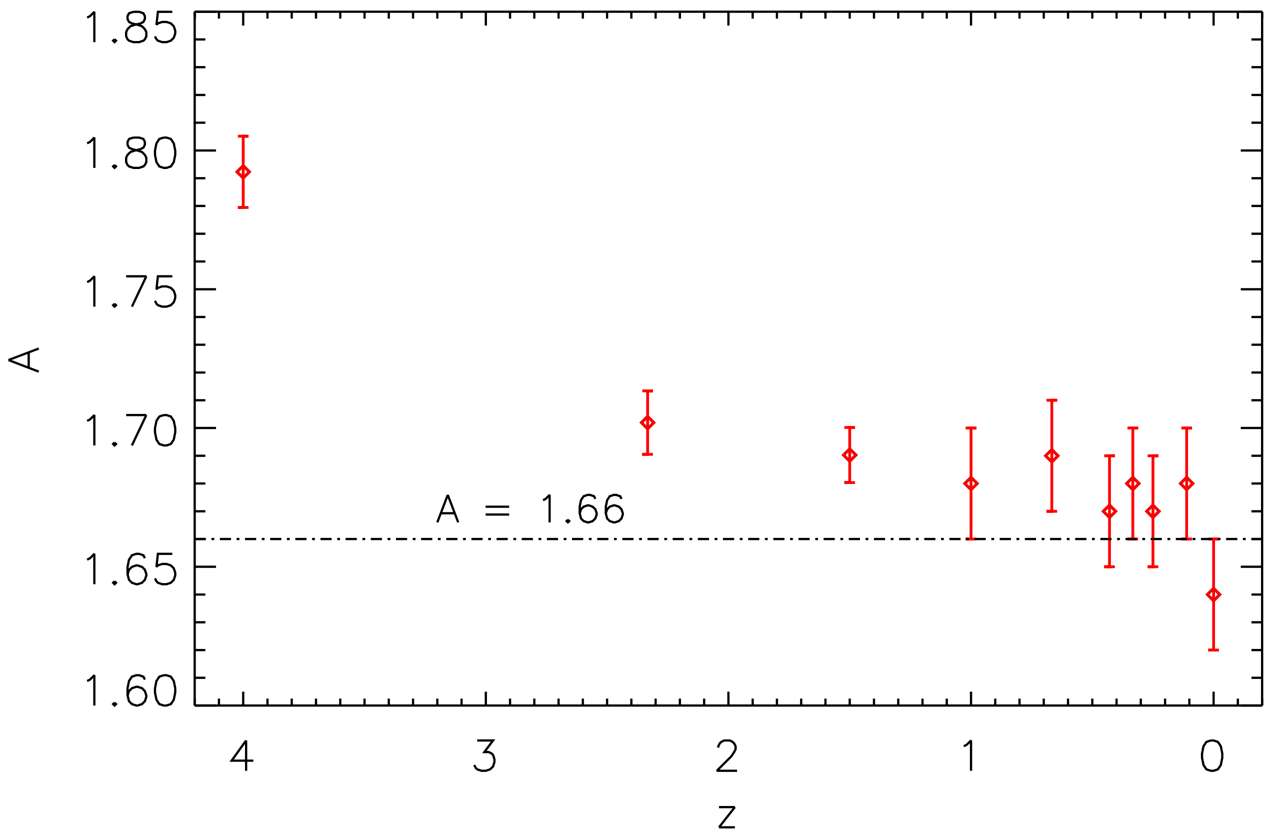
z = 4.0





- Strong deviation from self-similarity : A >> 1.66
- Same behaviour when considering one or five progenitors

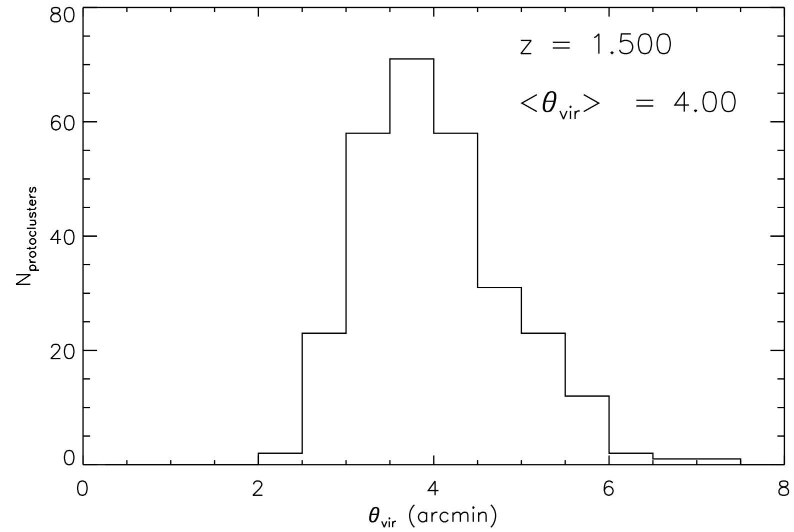
Evolution of the Y-M relation in PROTOCLUSTERS



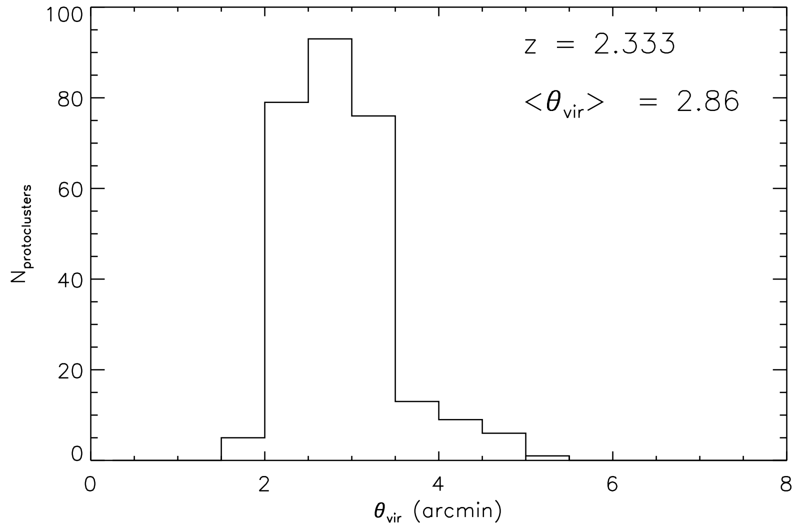
- Y-M scaling relation deviates from self-similarity at z > 0.5 (Sembolini et al. 2012)
- Deviation from self-similarity becomes stronger at z >2

Angular size distribution of protoclusters

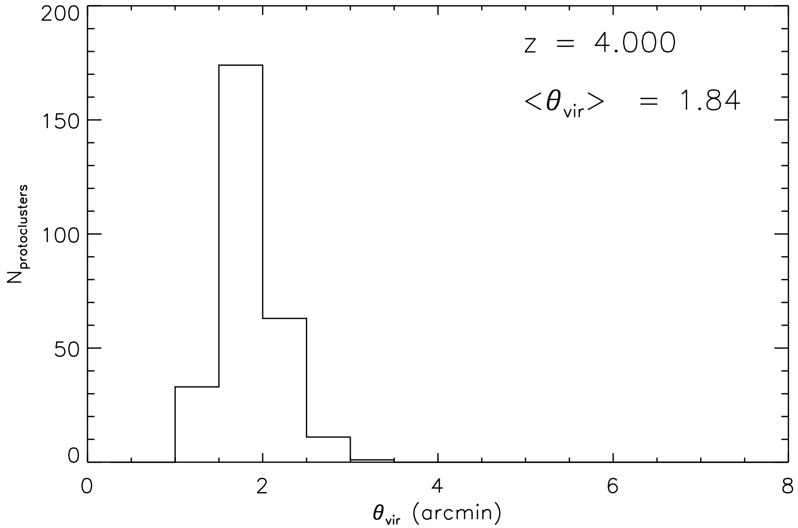
$3.6\times10^{-8} < Y < 1.4\times10^{-5}$ [h^{-1}Mpc^2]



$8.7\times10^{-9} < Y < 2.9\times10^{-6}$ [h^{-1}Mpc^2]



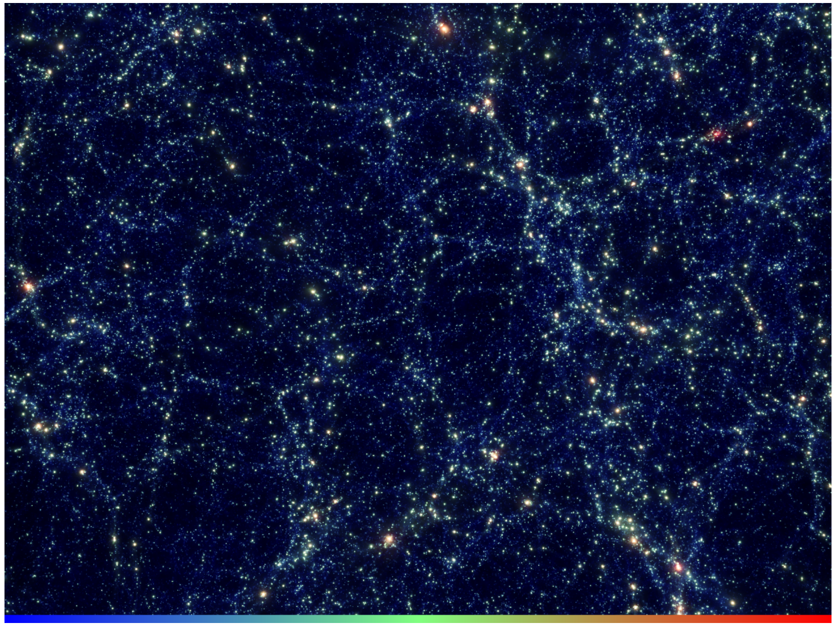
$4.7\times10^{-10} < Y < 7.9\times10^{-8}$ [h^{-1}Mpc^2]

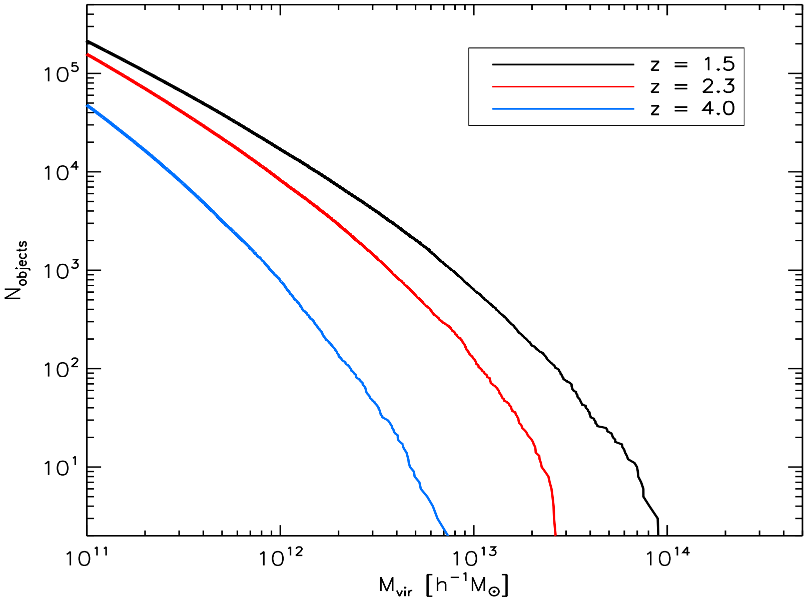


$$\theta_{vir} = \frac{2R_{vir}}{D_A} \approx \frac{10r_c}{D_A} = 10\theta_c$$

$$\theta_c \ll 1\ arcmin$$

Next coming analysis : the Curie simulation





200h^{-1} Mpc box, same cosmology as MUSIC done in multiple mass resolutions:

- Gas+ Cooling+SF (S&H model) 2×1024^3 (280 snapshots stored.)
- $M_{DM}=4.6\times10^8 h^{-1}$ M_{SUN} ;
  $M_{gas}=9.7\times10^7 h^{-1}$ M_{SUN}
- Full AHF analyses + Merger trees available for half of snapshots

Analysis of ALL protoclusters forming in a 200h^{-1} Mpc box (not only the progenitors of most massive clusters)

http://curiehz.ft.uam.es

CONCLUSIONS

- Analysis of 1410 MUSIC protoclusters at z = 1.5, 2.3, 4 : the most massive progenitors of MUSIC most massive clusters
- At z = 1.5 many clusters have already been formed (M > $10^{14}h^{-1}M_{SUN}$)
- At z > 2 many progenitors of the same cluster(s) show similar masses
- The mean values of gas, star and baryon fraction of protoclusters are very similar to the mean values of clusters – gas and star fraction depends on total mass
- The Y-M scaling relation of protoclusters shows a deviation from self-similarty – A>>1.66 at z > 2