The Three Hundred

A large galaxy cluster catalogue for cosmological and astrophysical applications.

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In collaboration with the core team (*Alexander Knebe, Gustavo Yepes* and etc.) of the nIFTy and the Three hundred projects and the participants of the CCC workshop.

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Simulated skies for new-generation spectroscopic surveys workshop at ESA, Madrid, April 24, 2018

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[1] https://weiguangcui.github.io

Background: Cluster of Galaxies:

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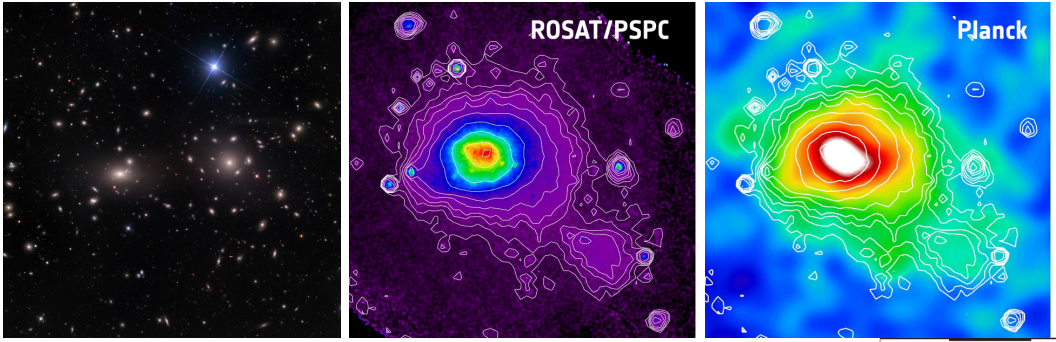

Figure: The Coma cluster.

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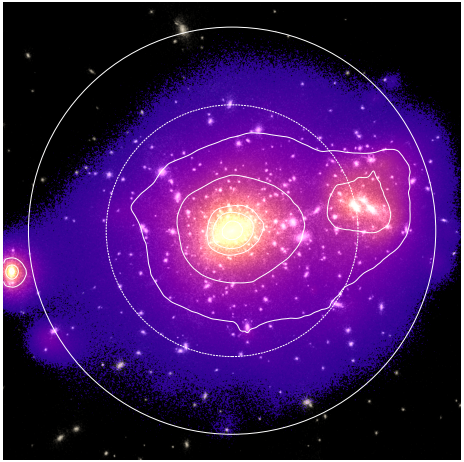
Background: Cluster of Galaxies:

To understand these observational results, especially how they are formed, we need simulations.



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The NIFTY galaxy cluster comparison project[2]

11 different (in both algorithms and baryon models) simulation codes are used to simulate the same galaxy cluster.

Type	Code name, Reference		Baryonic models		
		DM gravity solver	NR gas treatment	FP noAGN	AGN
Grid-based	RAMSES, Teyssier (2002)	AMR	Godunov scheme with Riemann solver	N	Y
Moving-mesh	AREPO, Springel (2010)	TreePM	Godunov scheme on moving mesh	Y[a]	Y[b]
Modern SPH	G2-ANARCHY, Dalla Vecchia et al. in prep.	TreePM	SPH kernel: Wendland C2	N	N
	G3-SPHS, Read & Hayfield (2012)	TreePM	Wendland C4	N	N
	G3-MAGNETICUM, Hirschmann et al. (2014)	TreePM	Wendland C6	N	Y
	G3-X, Beck et al. (2016)	TreePM	Wendland C4	N	Y
	G3-PESPH, Huang et al. in prep.	TreePM	HOCTS B-spline	Y	N
Classic SPH	G3-MUSIC, Sembolini et al. (2013)	TreePM	Cubic spline	Y[c]	N
	G3-OWLS, Schaye et al. (2010)	TreePM	Cubic spline	N	Y
	G2-X, Pike et al. (2014)	TreePM	Cubic spline	N	Y
	HYDRA, Couchman et al. (1995)	AP^{3}M	Cubic spline	N	N

[2] Ref: Sembolini et al. 2016a,b; Elahi et al. 2016; Cui et al. 2016; Arthur et al. 2017

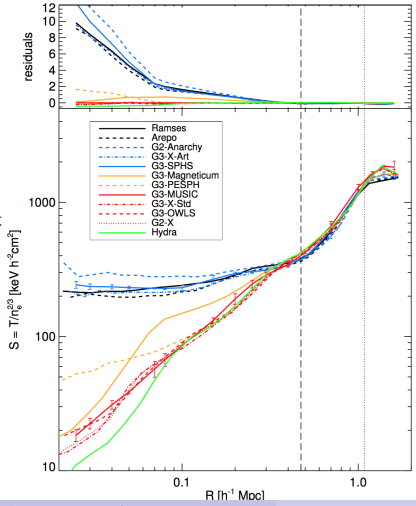
What did we find? I

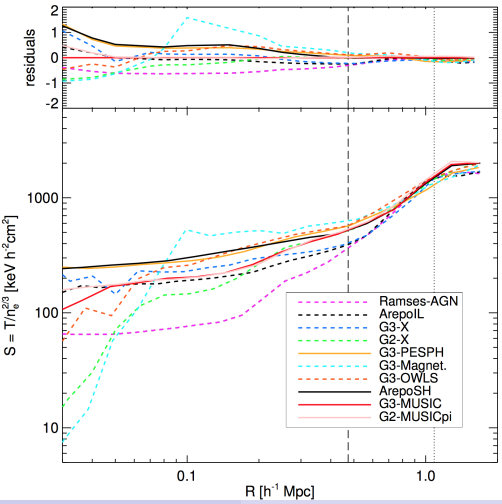
- The modern SPH codes produce correct entropy profiles as AMR, moving mesh.
- The baryon models have larger effects than the fluid simulating techniques by mixing the entropy profiles.

Entropy profile.

Ref:

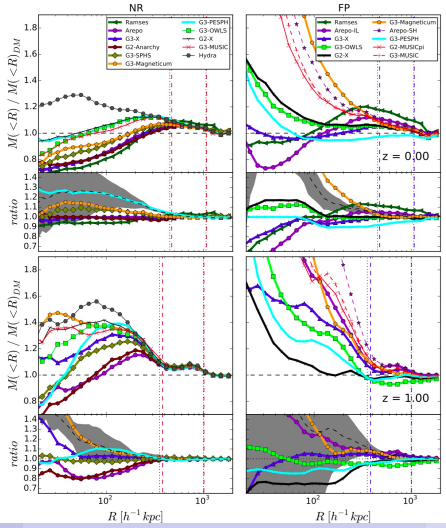
Sembolini et al. 2016a,b.





What did we find? II

- Different baryon models produce similar global properties, large scatter at small scales.



E.g. Baryon effects on density profile.

Ref: Cui et al. 2016

What's next?

Aim: to understand the formation and evolution of galaxy clusters.

- Comparisons between models to understand the theoretical predictions.
- Comparisons between models and observations to constrain the models.

A large cluster sample!

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The Three Hundred: Basic information

- The most massive ($M_{vir} > 8 \times 10^{14}\ h^{-1}\ \mathrm{M}_{\odot}$) 324 clusters are selected from the MultiDark simulation(MDPL2)[2].
- 324 zoomed-in ICs are generated by cutting a spherical region with a radius of $15\ h^{-1}\ \mathrm{Mpc}$ from the cluster center.

Table: Parameters of the Three Hundred simulations

Parameter	Value	Description
Ω_M	0.307	Total Matter density parameter
Ω_B	0.048	Baryon density parameter
Ω_Λ	0.693	Cosmological Constant density parameter
h	0.678	Hubble constant in units of 100 km/s/Mpc
σ_8	0.823	Normalization of Power spectrum
n_s	0.96	Power index
z_{init}	120	Initial redshift of the simulations
ϵ_{phys}	6.5	Plummer equivalent softening in $h^{-1}\ \mathrm{kpc}$
Particle mass	2.36 (12.7)	gas (dark matter) particle mass in $[10^8\ h^{-1}\ \mathrm{M}_{\odot}]$

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[2] https://www.cosmosim.org

The Three Hundred: theoretical models

hydrodynamical simulations with baryonic models:

GADGET-MUSIC: classic SPH method. Radiative cooling, star formation with both thermal and kinetic Supernove (SN) feedback.
GADGET-X: modern SPH with the Wendland C4 kernel. Gas cooling with metal contributions, star formation with chemical enrichment, SN feedback with AGB phase, and AGN feedback.
GIZMO: running.
GADGET-PESPH: running.

SAMs from MultiDark-Galaxies:

See Alexander's talk for more details of GALACTICUS, SAG (see also sofia's talk) and SAGE (see also Darren's talk).
Notes: We select these catalogues from the same regions as the hydrodynamical simulations.

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The Three Hundred: the catalogues

Halos and subhalos in hydrodynamical simulations are identified with AHF (Ref: Knollmann & Knebe 2009).

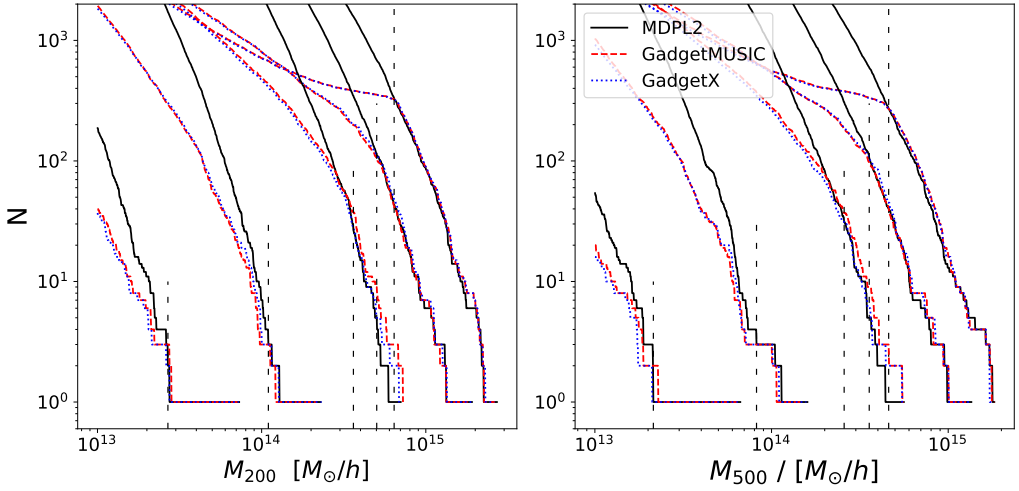

Figure: Cumulative halo mass functions. Cui et al. in prep.

The Three Hundred: the catalogues

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Table: The complete sample of the Three Hundred cluster catalogues at different redshifts.

redshift	M_{200c} $[10^{14}\ h^{-1}\,\mathrm{M}_\odot]$	N_{200c} MUSIC/X	M_{500c} $[10^{14}\ h^{-1}\,\mathrm{M}_\odot]$	N_{500c} MUSIC/X
0.0	6.41	324 / 324	4.60	270 / 270
0.5	5.02	104 / 110	3.57	94 / 103
1.0	3.62	38 / 27	2.57	37 / 31
2.3	1.10	3 / 3	0.82	3 / 3
4.0	0.27	3 / 2	0.21	2 / 1

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The results

The paper will be submitted very soon.

The results are preliminary.

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General Properties: Baryon effects on halo mass

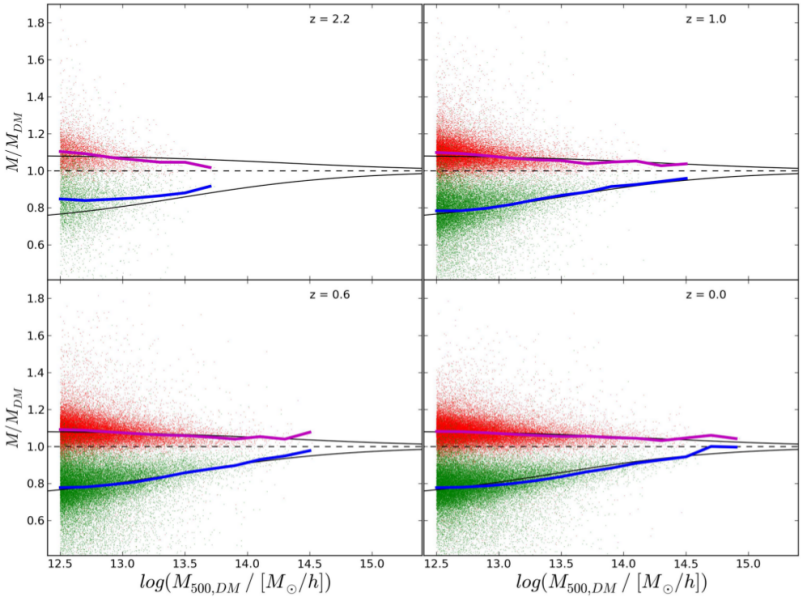

Figure: halo mass (M_{500}) difference respected to the DM run. Ref: Cui et al. 2014

General Properties: Baryon effects on halo mass

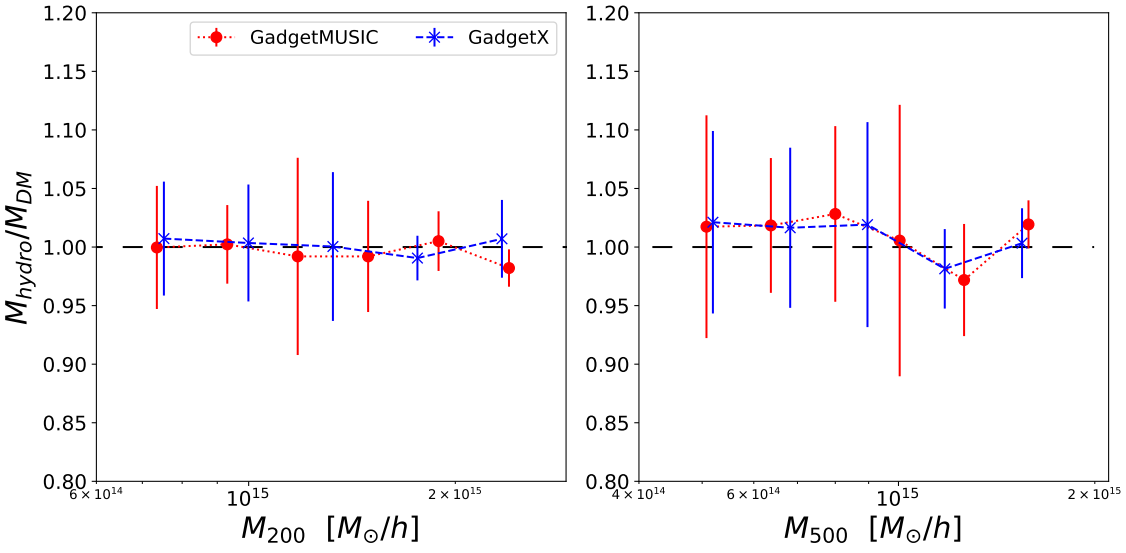

Figure: halo mass difference respected to the DM run. Cui et al. in prep.

General Properties: the dynamical state

We applied 3 criteria to classify the cluster's dynamical state to relaxed and un-relaxed: the virial ratio $\eta = (2T - E_s)/|W|$ with $0.85 < \eta < 1.15$, center-of-mass offset $\Delta_r = |R_{cm} - R_c|/R_{200c} < 0.04$ and subhalo mass fraction $f_s = \sum M_{sub}/M_{200c} < 0.1$.

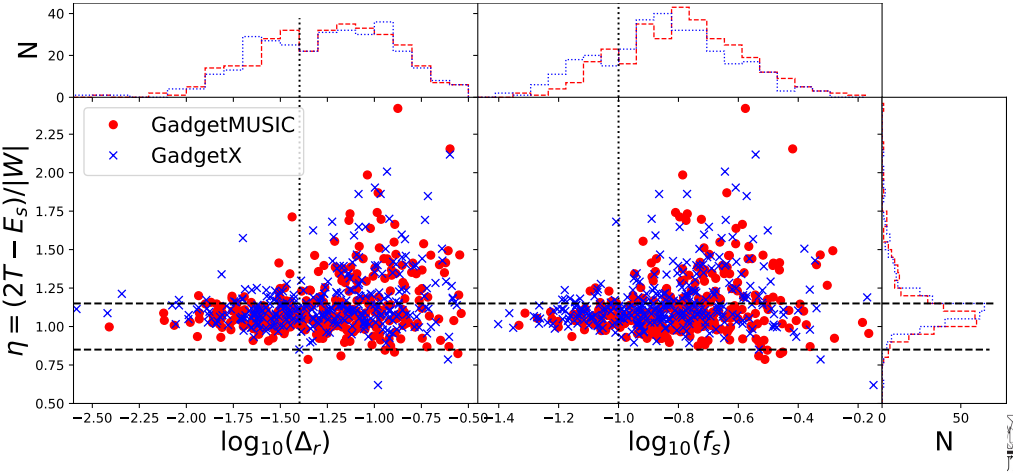

Figure: The relations between the three parameters. Cui et al. in prep.

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Table: The fractions of relaxed clusters with different combinations of criteria.

M_{200c} $10^{14}\ h^{-1}\,\mathrm{M}_\odot$	η, Δ_r & f_s MUSIC/X	Δ_r & f_s MUSIC/X	f_s MUSIC/X
$0.10 - 0.50$	0.44 / 0.36	0.56 / 0.48	0.70 / 0.65
$0.50 - 1.00$	0.36 / 0.34	0.45 / 0.46	0.56 / 0.57
$1.00 - 6.41$	0.27 / 0.29	0.30 / 0.35	0.43 / 0.48
$6.41 - 10$	0.18 / 0.21	0.20 / 0.24	0.21 / 0.26
> 10	0.06 / 0.08	0.07 / 0.13	0.07 / 0.14

Table: The Cool Core cluster fraction (two methods: Rosetti et al. 2011 and central entropy) in the complete sample: $f_{CC} = \frac{N_{CC}}{N_{total}}$, the CC fraction in dynamically relaxed clusters $f_{CC/dr} = \frac{N_{CC,relaxed}}{N_{relaxed}}$ and the relaxation fraction in CC $f_{dr/CC} = \frac{N_{CC,relaxed}}{N_{CC}}$.

Simulation	f_{CC}	$f_{CC/dr}$	$f_{dr/CC}$
MUSIC	0.09	0.04	0.07
X	0.26	0.33	0.21

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General Properties: the baryon fractions

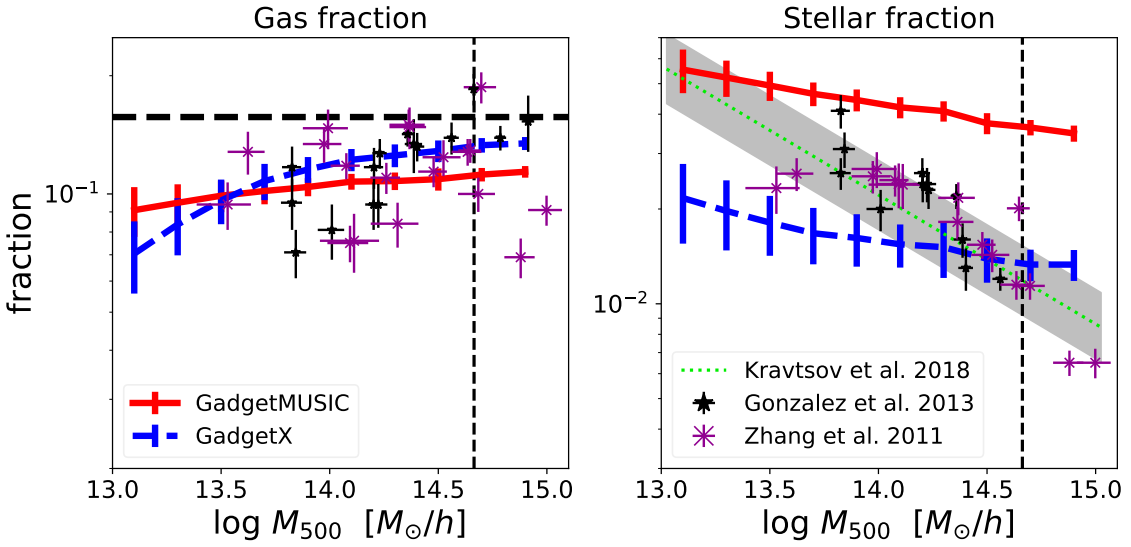


Figure: The baryon fractions. Cui et al. in prep.

Optical relations

The complete sample is used here.

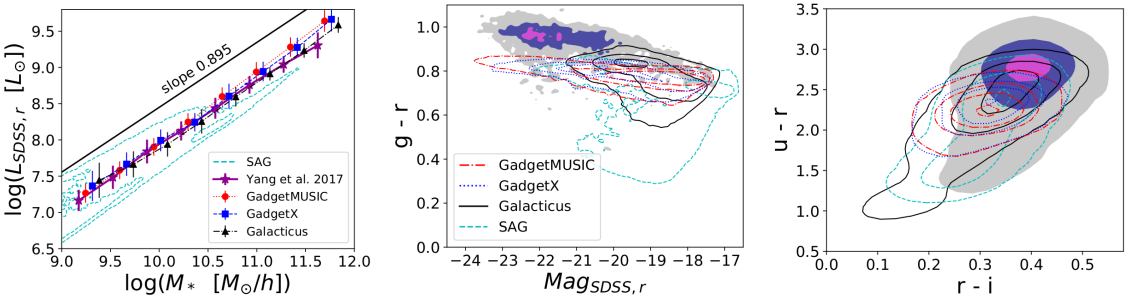
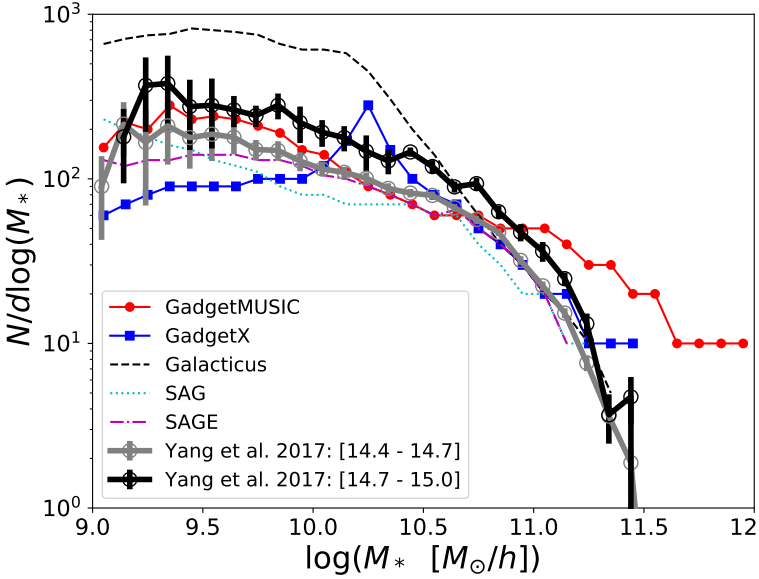


Figure: The optical relations. Cui et al. in prep.

Optical relations: the satellite stellar mass function

The complete sample is used here.



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Gas scaling relations

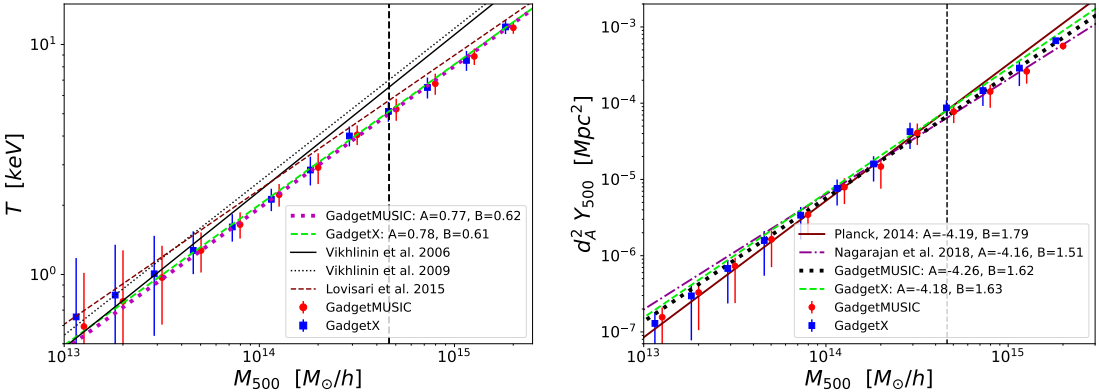

Figure: The gas relations. Cui et al. in prep.

Conclusion

- The baryons have a negligible impact on the halo mass for both M_{200} and M_{500}.
- $\sim$ 20% of the complete sample is relaxed clusters, 26% (9%) of the sample is CC for GadgetX (MUSIC).
- The baryon fractions are in agreement with the observations at massive halo masses for GadgetX.
- The optical relations are in agreement with the observations but the galaxies from more models seem to be a little blue.
- The gas relations are in agreement with observations.

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Future works

- The density profiles, Mostoghiu et al. in prep.
- The environment effects, Wang et al. in prep.
- The mock images in optical, X-ray and SZ (lower images). And more...