

# The Three Hundred

## A large galaxy cluster catalogue for cosmological and astrophysical applications.

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In collaboration with Alexander Knebe, Gustavo Yepes, Frazer Pearce,  
Chris Power, Romeel Dave, Robert Mostoghiu, Yang Wang, etc.

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CAA, Shanghai JiaoTong University, 29 June, 2018

Results are from Cui et al. 2018 (submitted), Mostoghiu et al. in final  
prep. and Wang et al. 2018 in final prep.



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Figure: Join Us!

## Background: Cluster of Galaxies:

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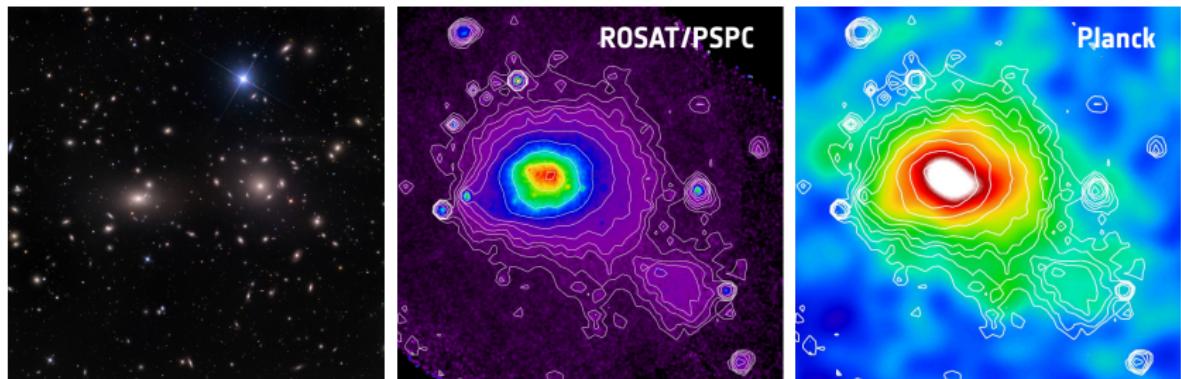


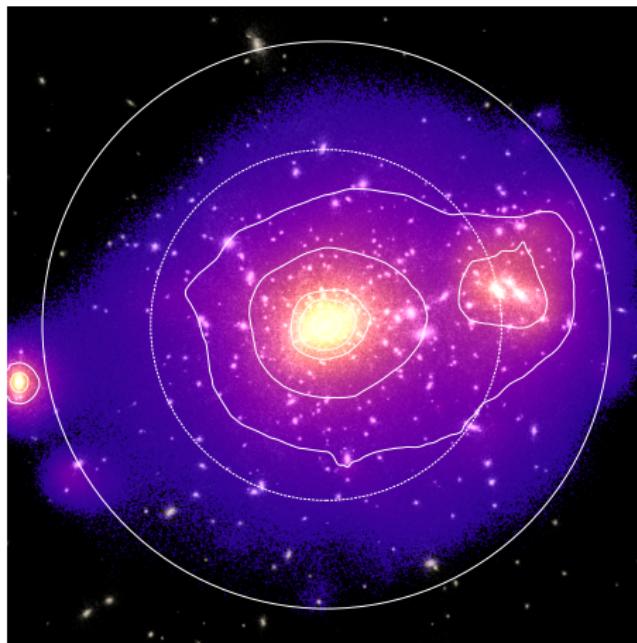
Figure: The Coma cluster.

# Background: Cluster of Galaxies:

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

Simulated Cluster  
17 from the 300  
project

credit: Gustavo  
Yepes.



# The motivation of the Three Hundred: A successor of the NIFTY project

## The NIFTY galaxy cluster comparison project<sup>2</sup>

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, <a href="#">Teyssier (2002)</a>	AMR	Godunov scheme with Riemann solver	N	Y
Moving-mesh	AREPO, <a href="#">Springel (2010)</a>	TreePM	Godunov scheme on moving mesh	Y <sup>a</sup>	Y <sup>b</sup>
Modern SPH	G2-ANARCHY, Dalla Vecchia et al. in prep.	TreePM	SPH kernel: Wendland C2	N	N
	G3-SPHS, <a href="#">Read &amp; Hayfield (2012)</a>	TreePM	Wendland C4	N	N
	G3-MAGNETICUM, Hirschmann et al. (2014)	TreePM	Wendland C6	N	Y
	G3-x, <a href="#">Beck et al. (2016)</a>	TreePM	Wendland C4	N	Y
	G3-PESPH, Huang et al. in prep.	TreePM	HOCTS B-spline	Y	N
Classic SPH	G3-MUSIC, <a href="#">Sembolini et al. (2013)</a>	TreePM	Cubic spline	Y <sup>c</sup>	N
	G3-OWLS, <a href="#">Schaye et al. (2010)</a>	TreePM	Cubic spline	N	Y
	G2-x, <a href="#">Pike et al. (2014)</a>	TreePM	Cubic spline	N	Y
	HYDRA, <a href="#">Couchman et al. (1995)</a>	AP <sup>3</sup> M	Cubic spline	N	N

<sup>2</sup>Ref: Sembolini et al. 2016a,b; Elahi et al. 2016; Cui et al. 2016; Arthur et al. 2017

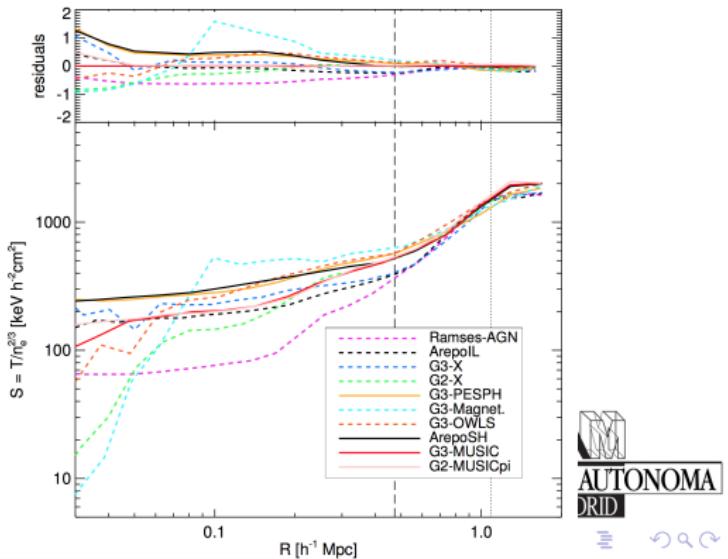
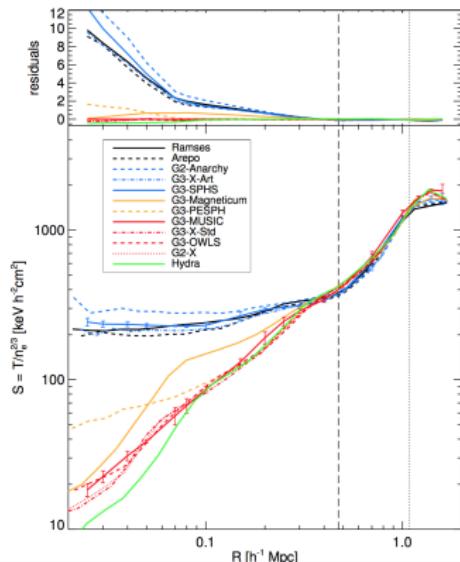
# The motivation of the Three Hundred: A successor of the NIFTY project

## 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 entropy profiles.  
profile.

Ref:  
Sembolini  
et al.  
2016a,b.



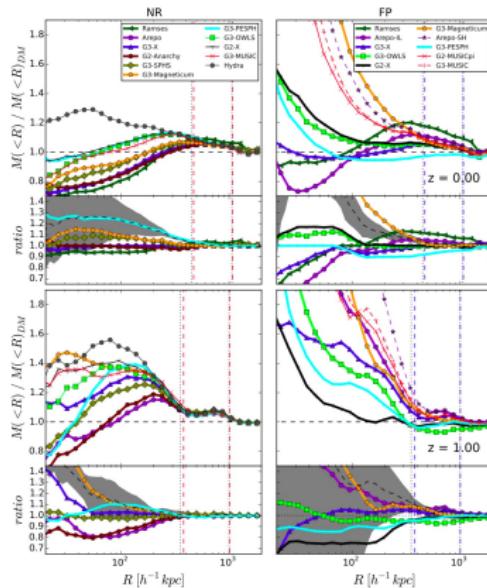
# The motivation of the Three Hundred: A successor of the NIFTY project

## 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



# The motivation of the Three Hundred: A successor of the NIFTY project

## 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.

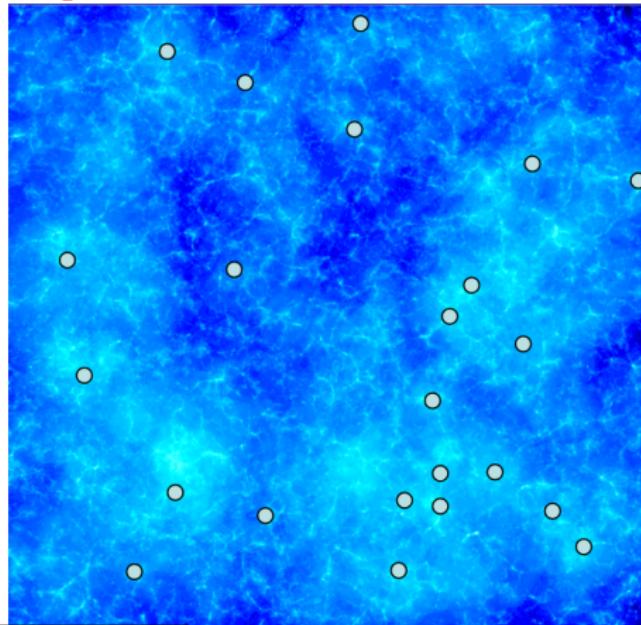
**A large cluster sample!**

# The advantage of the Three Hundred: Basic information

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

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Table: Parameters of the Three Hundred simulations

Parameter	Value	Description
$\Omega_M$	0.307	Total Matter density parameter
$\Omega_B$	0.048	Baryon density parameter
$\Omega_\Lambda$	0.693	Cosmological Constant density parameter
$h$	0.678	Hubble constant in units of 100 km/s/Mpc
$\sigma_8$	0.823	Normalization of Power spectrum
$n_s$	0.96	Power index
$z_{init}$	120	Initial redshift of the simulations
$\epsilon_{phys}$	6.5	Plummer equivalent softening in $h^{-1}$ kpc
Particle mass	2.36 (12.7)	gas (dark matter) particle mass in $[10^8 h^{-1} M_{\odot}]$

<sup>2</sup><https://www.cosmosim.org>

# The advantage of the Three Hundred: theoretical models

## hydrodynamical simulations with baryonic models:

GADGET-**MUSIC**: classic SPH method. Radiative cooling, star formation with both thermal and kinetic Supernova (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:

Three different models

**GALACTICUS**, **SAG** and **SAGE** (see Knebe et al. 2018 for details) are applied on the cosmological MultiDark simulation.

**GALACTICUS**: (Benson 2012) no calibration. only orphan galaxy.

**SAG**: (Cora et al. 2018) calibrated to observation. orphan galaxy + ICL.

**SAGE**: (Croton et al. 2016) no calibration. no orphan galaxy, only ICL.

Notes: We select these catalogues from the same regions as the hydrodynamical simulations.

# The Three Hundred: the catalogues

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

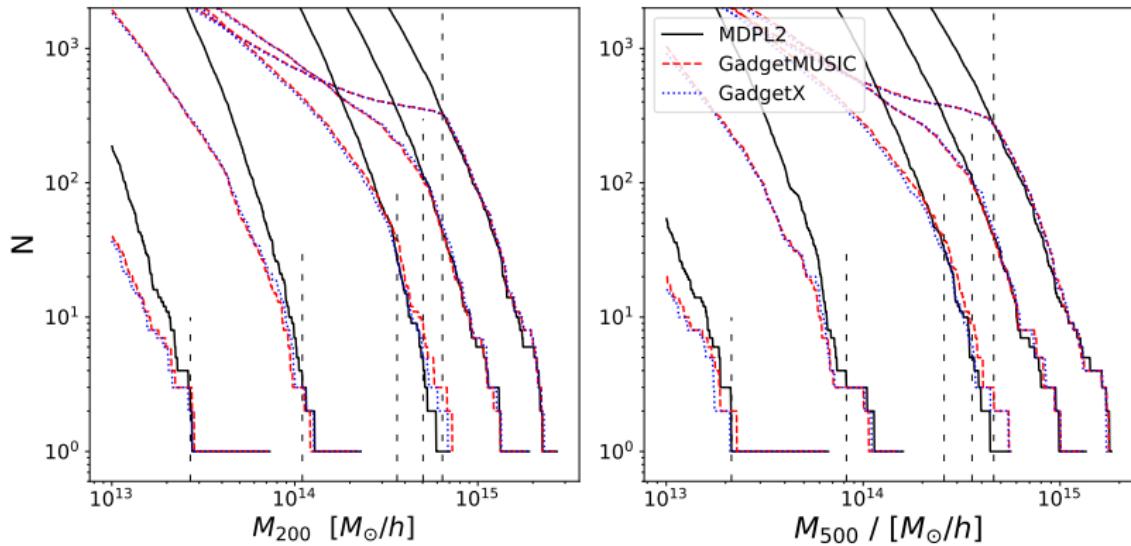


Figure: Cumulative halo mass functions.

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

redshift	$M_{200c}$ [ $10^{14} h^{-1} M_\odot$ ]	$N_{200c}$ MUSIC/X	$M_{500c}$ [ $10^{14} h^{-1} M_\odot$ ]	$N_{500c}$ 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

# The results

# General Properties: Baryon effects on halo mass

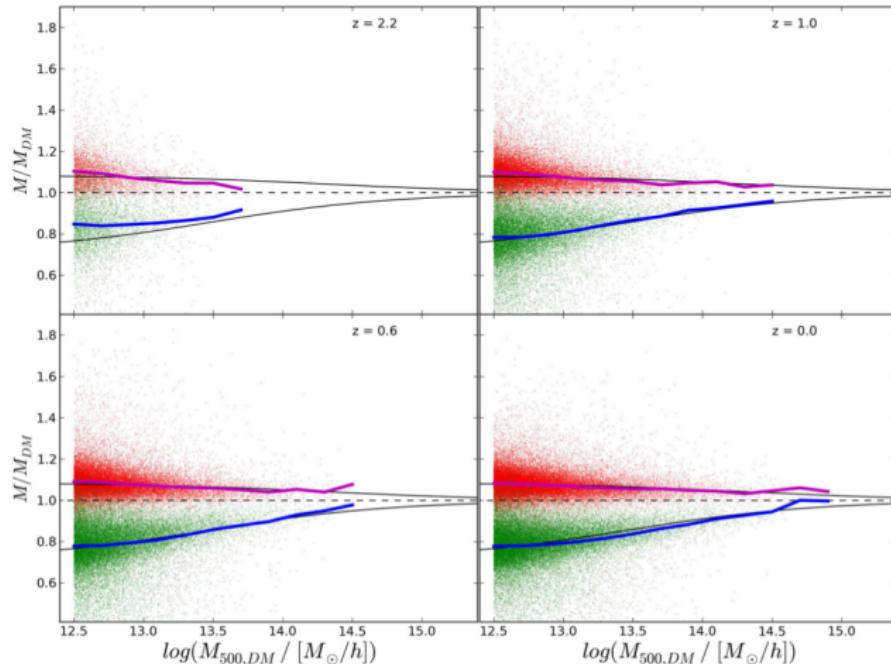


Figure: halo mass ( $M_{500}$ ) difference respected to the DM run. Ref: Cui et al. 2014

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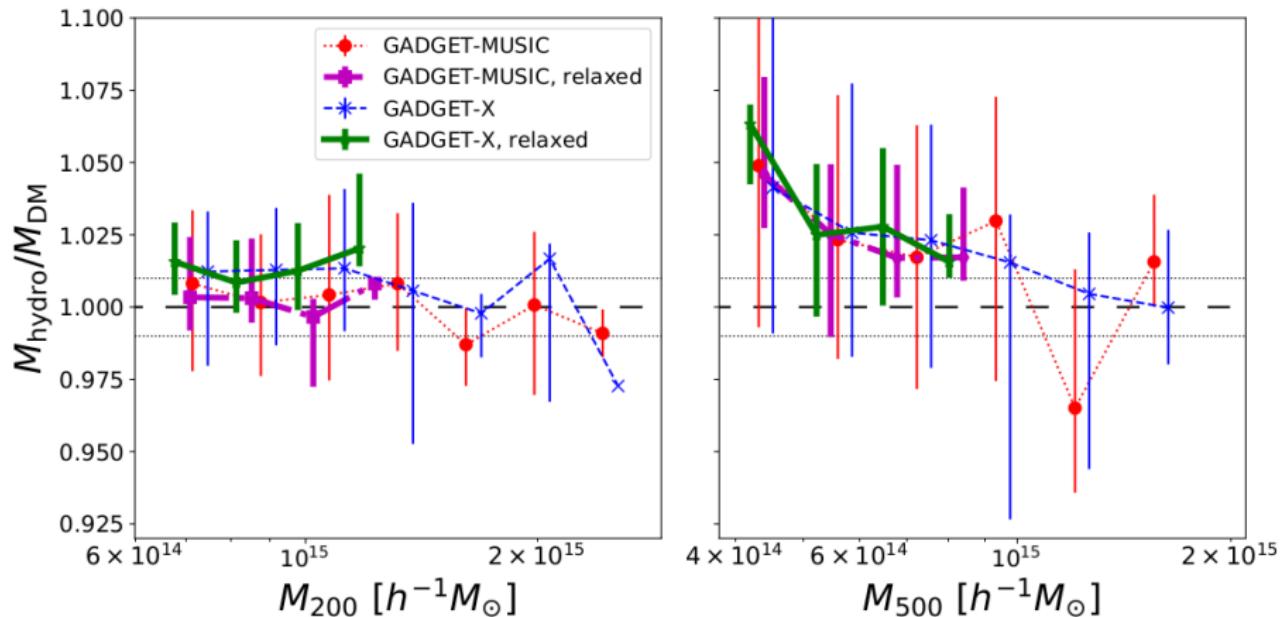


Figure: halo mass difference respected to the DM run.



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# General Properties: the dynamical state

Classifying the cluster's dynamical state into 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  $f_s = \sum M_{sub}/M_{200c} < 0.1$ . Cui et al. 2017

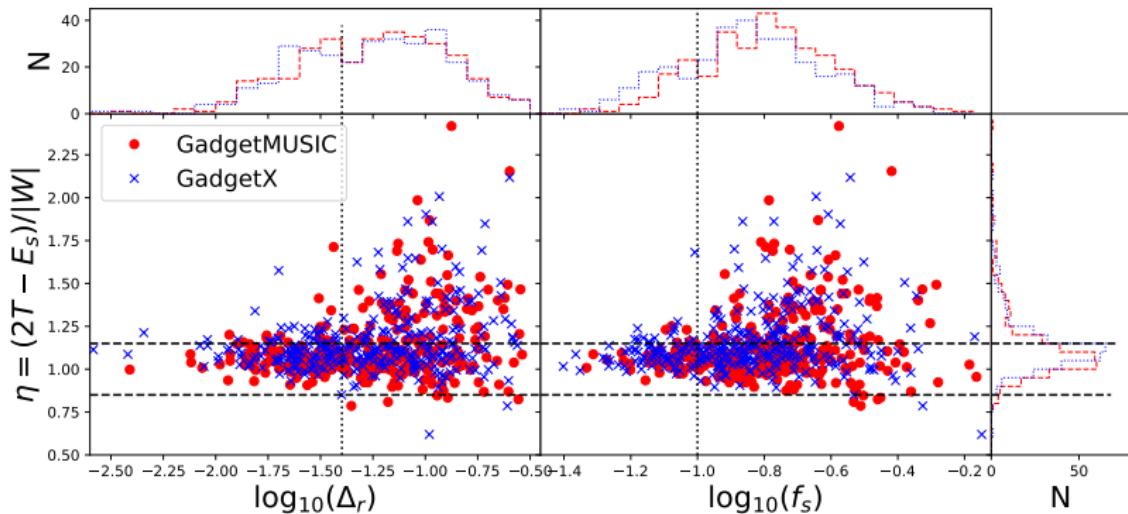


Figure: The relations between the three parameters

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

$M_{200c}$ $10^{14} h^{-1} M_\odot$	$\eta, \Delta_r \& f_s$ MUSIC/X	$\Delta_r \& f_s$ 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

# General Properties: the baryon fractions

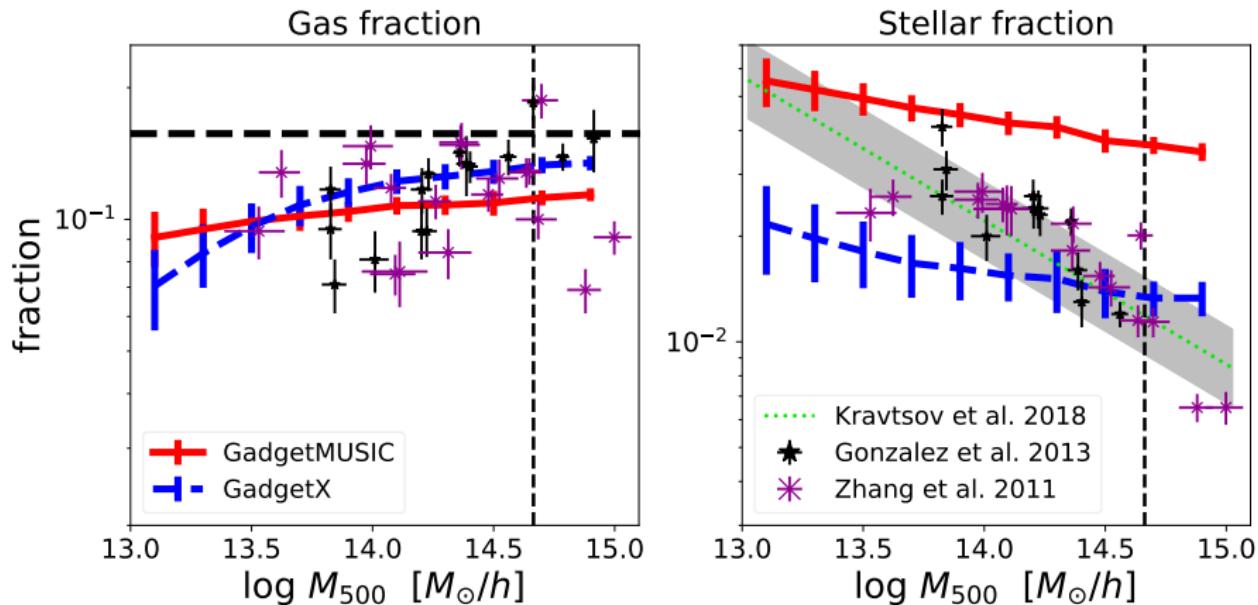


Figure: The baryon fractions.

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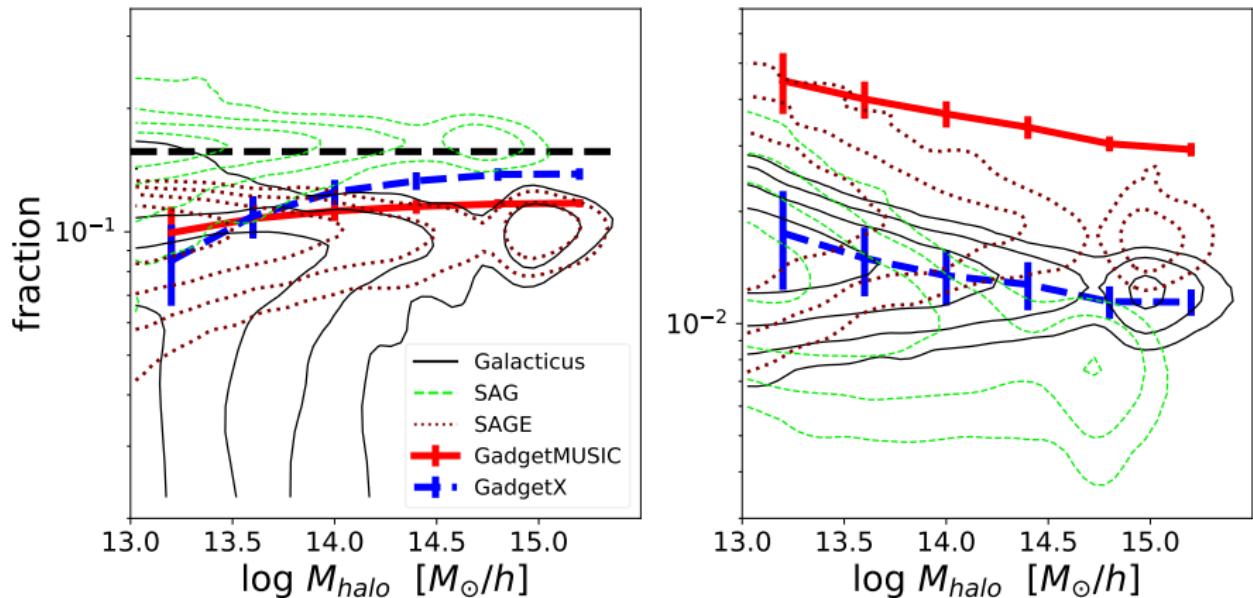
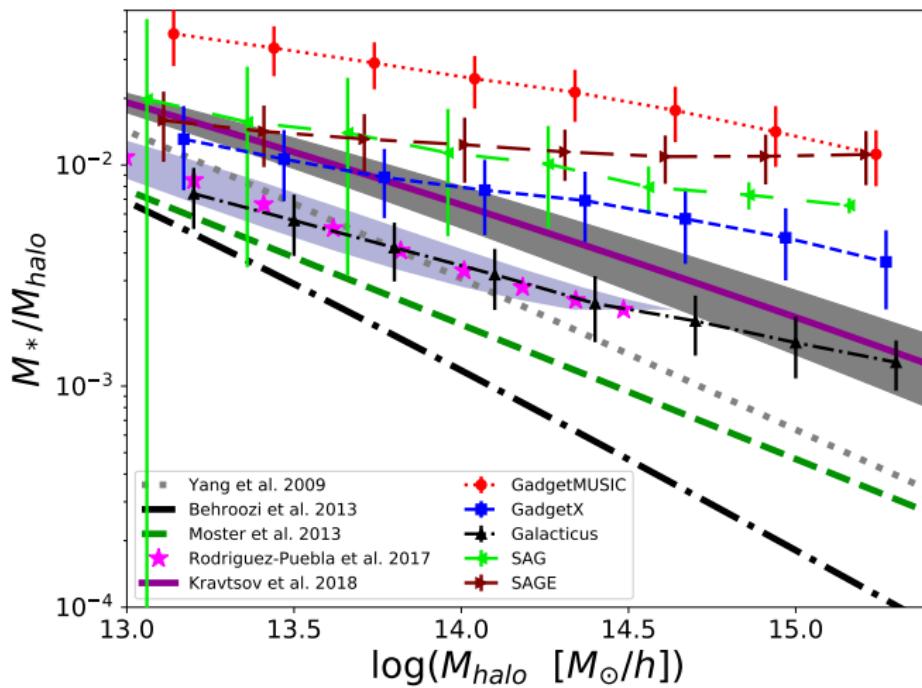


Figure: The baryon fractions.

# Stellar-Halo mass relation



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# Optical relations

The complete sample is used here.

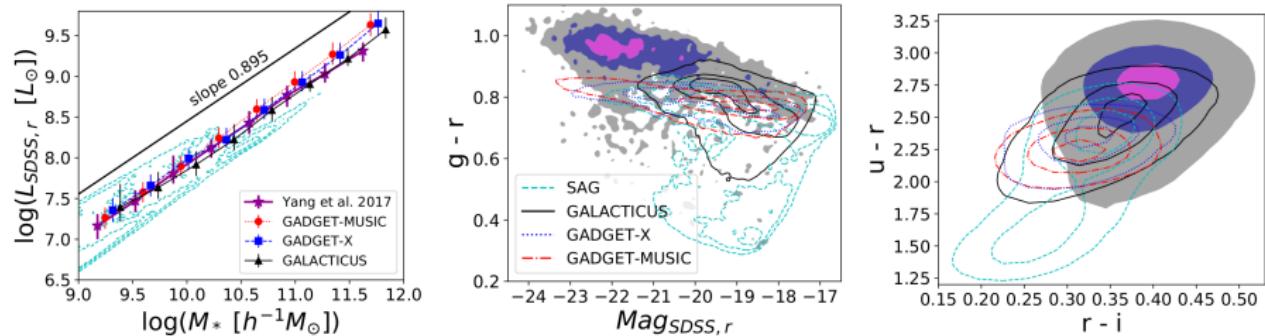


Figure: The optical relations.

# Optical relations: the satellite stellar mass function

The complete sample is used here.

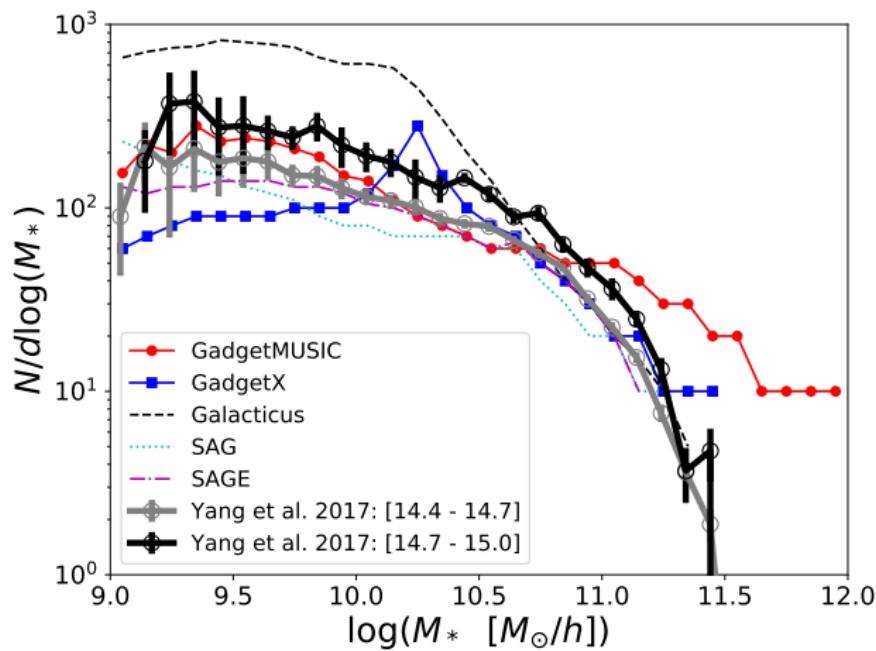


Figure: The satellite stellar mass function.



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# Gas scaling relations

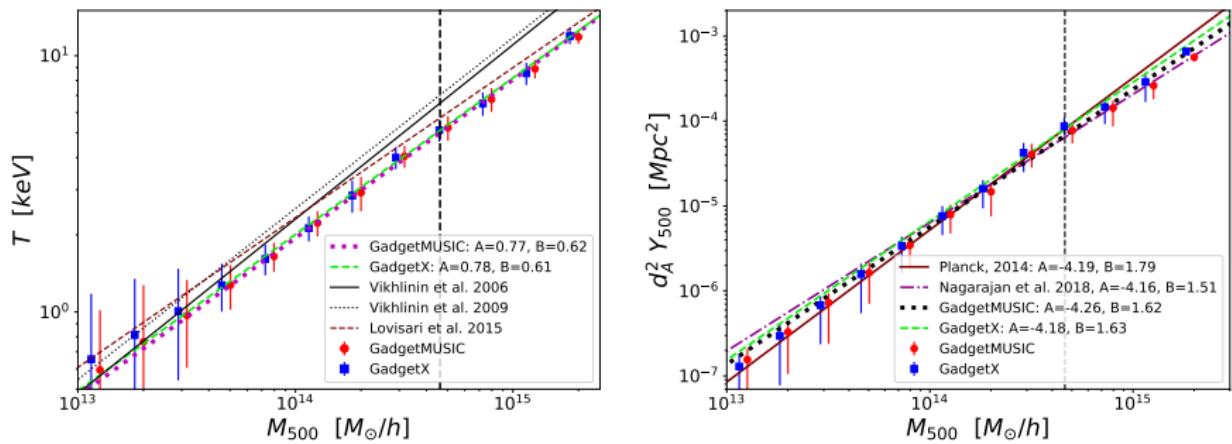


Figure: The gas relations.

# The cluster density profiles: Mostoghiu et al. in prep.

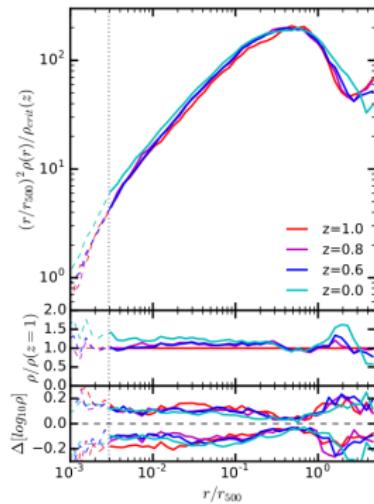


Figure: Density profiles.  
Le Brun et al. 2018

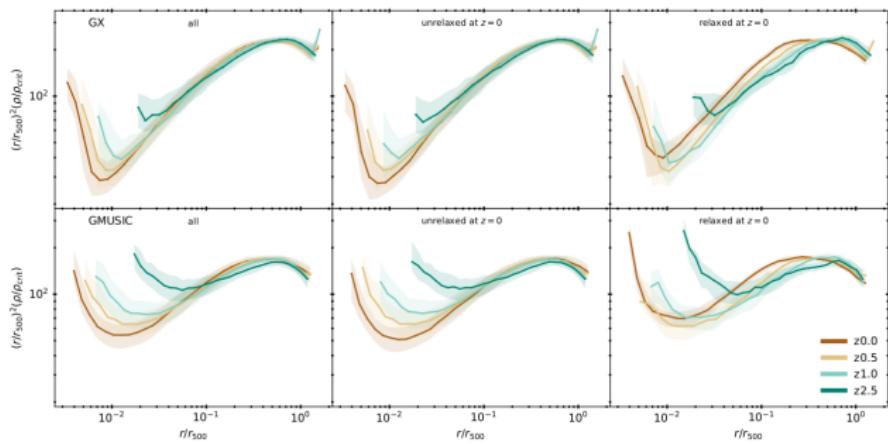


Figure: Density profiles from the mass-complete sample.  
credit: Robert Mostoghiu

# The cluster density profiles: Mostoghiu et al. in prep.

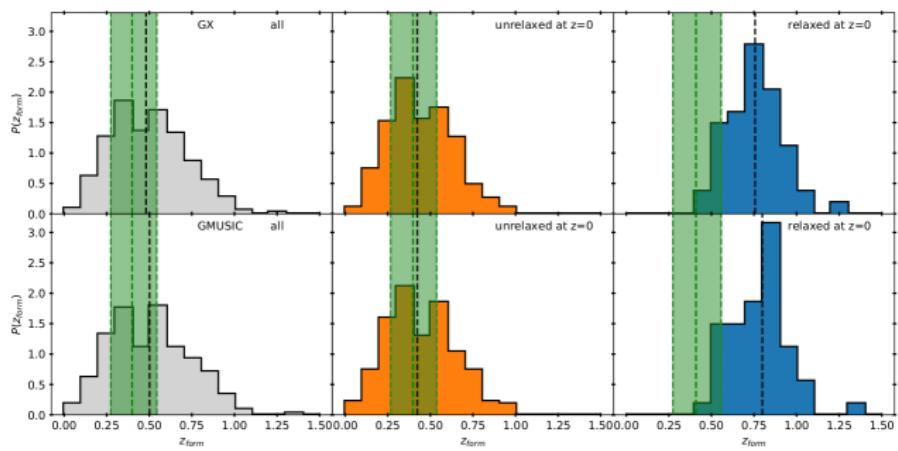
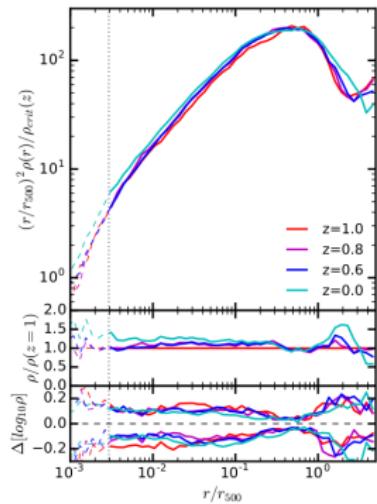
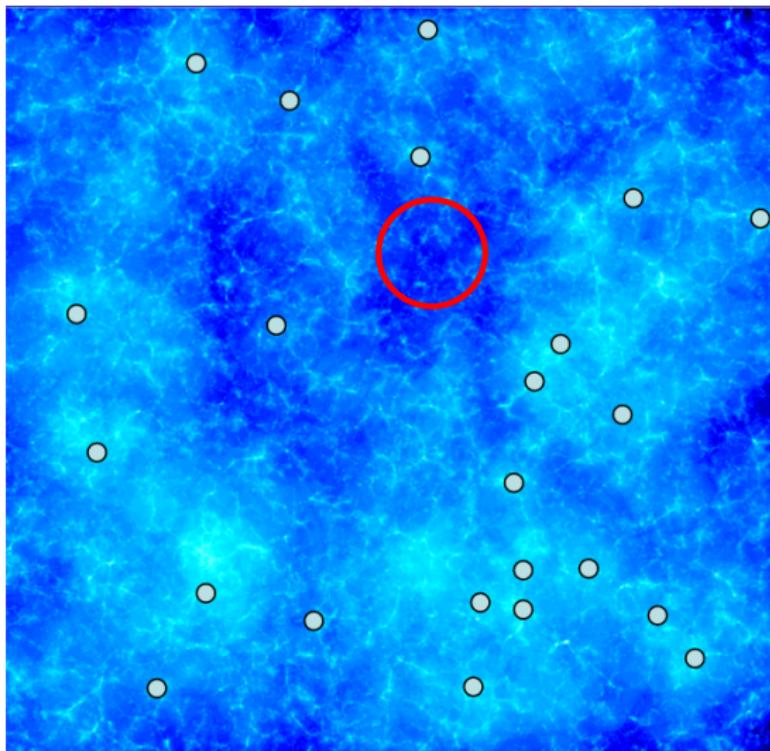


Figure: Formation time. credit: Robert Mostoghiu

Figure: Density profiles.  
Le Brun et al. 2018

# The environmental effects: Wang et al. in prep.



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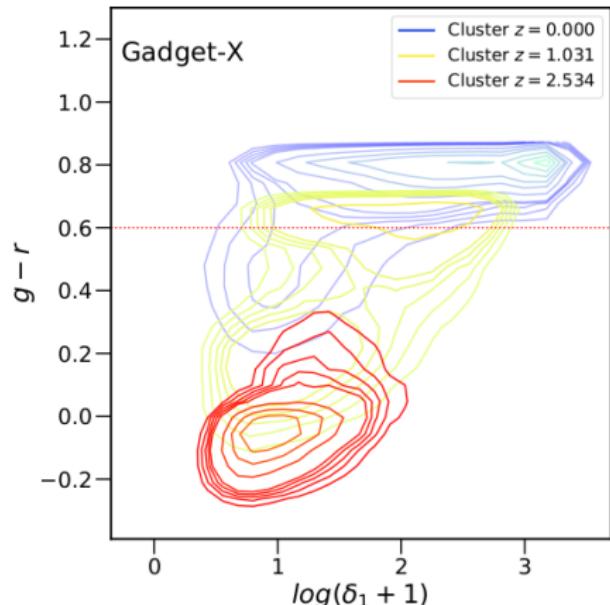
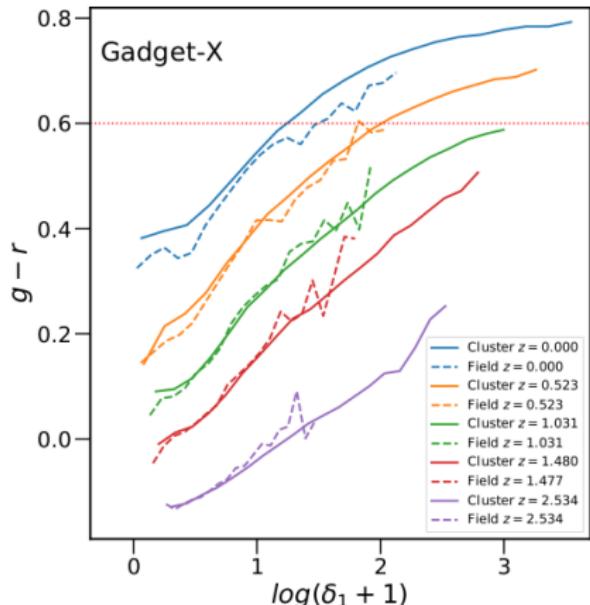


Figure: color–environment relation. credit: Yang Wang



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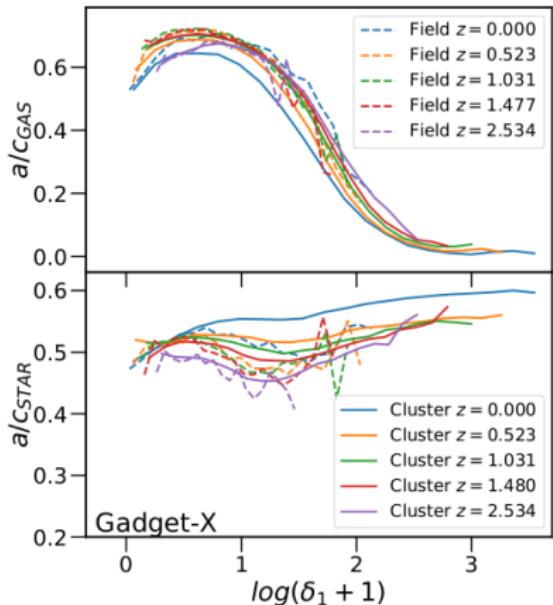
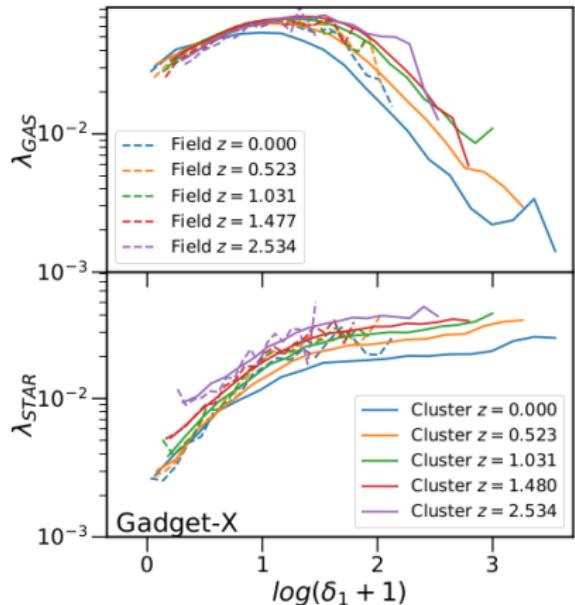


Figure: Spin/shape – environment relation. credit: Yang Wang 

# 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).
- Compare with observations (Agreement): The baryon fractions for cluster mass range, optical relations and gas scaling relations are generally in agreement with the observations.
- Compare with observations (Disagreement): stellar-halo mass relation (A problem of ICL), galaxy color in clusters seems a little blue.
- Relaxed clusters show a weak redshift evolution of the density profile, which is due to their earlier formation time.
- There is a weak environmental effects.

# Future works

## Glenfiddling Projects (2018):

Please free to add/remove your name to projects and edit the titles to be more accurate.

Project	Lead	Participants	Comments	Infrastructure	Status
1 Evolution of cluster density profiles	Robert	Alexander, Weiguang	To be submitted during week 11-15 June		Advanced draft
2 Influence of environment	Yang	Frazer, Alexander	To be submitted before end of June		Draft
3 Mock observations (optical)	Robert	Meghan, Lilián, Weiguang, Alexander, Romeo	plan to use Profound ( <a href="https://arxiv.org/pdf/1602.00937.pdf">https://arxiv.org/pdf/1602.00937.pdf</a> ) and get Aaron Robotham onboard. Note (CP): Can you let me know exactly what you want done and I can help with this? > AR: check project page for very brief description :-)		
			To be finalized during Robert's visit to ICRAR spring 2019		
			Romeo might supply improved optical maps until then		
4 HI and large scale structure	Katerina	Sofia, Romeo	Using Disperse.		
5 Metallicity/radial temperature/SFR profiles	Weiguang	Gengqiang	To understand the baryonic processes/different baryonic modes through these profiles		
6 Gas environments & tracking haloes	Jake		Combine gas environments / disperse / hessian. Statistical analysis of halo environment. How many haloes are arriving in filaments? Link to Ulian & Pascual evolution tables.		
7 Backsplash	Jake, Alexander	Lynnday	How does backsplash contamination depend on cluster properties? Are different clusters more contaminated? Apart from kinematics, are backsplash halo properties different to infalling population? Can machine learning algorithms tell them apart? Paper to be finalized during Jake's visit to UAM Oct/Nov 2018		To be finished Oct/Nov 2018
8 Radiative transfer in gizmo	Margherita	Romeo	Long ways off. Needs RT code inserting into Gizmo and new runs.		
9 Evolution of halo properties wrt orbits.	Lilián, Pascal	Chris, Adam, Sofia, Jake	Emphasis on gas fractions and stripping. Tracking with VELLOCATOR trees. (Ulian continuing to work on gas fractions, Pascal updating trees/catalogs) Ulian: focus on hotcold gas fractions during infall and perhaps SFR (worry about resolution) Pascal: where does this stripped gas go, does it stay as whirs or dispers cold/hot rich gas, looking at synchrotron/x-ray emitting.		
10 (Radial) alignment of substructures	Alexander	Kat, Charlotte, Rodrigo	Kat will pick this up again in autumn 2018		
11 X-ray scaling relations and profiles in Gizmo	Dylan	Weiguang, Romeo	Scaling relation plots ready to go for Gizmo; just need the actual runs (see Infrastructure).		
12 Environmental quenching timescale. Role of mass.	Tomas	Sofia	Hydro vs SAM		
			To be pushed forward during Tomas' visit to Nottingham June/July 2019		
13 Dynamical state vs wavelength	Lynnday	Meghan, Weiguang, Ian, Gustavo, Marcos, Silvia, D. de Luca (Spainish)	(this is the same project as the Crystal Ciser one below...)		
14 Lensing	Jesus Vega	Gustavo	Possible applications: lensing efficiency -> clusters, comparison with HFF, Magnification of z>5 galaxies.		
15 Machine Learning applications	Gustavo	Federico Demboini	Use of ML methods to learn from SZ and X-ray maps from 3000 and apply them to clusters size halos in Large scale DM only sims.		ongoing
16 UCD formation and evolution	Julian	Frazer, Alfonso Aragón Salamanca	Track stripped and early forming DM halos and compare galaxies within them to properties of observed UCDs. Contrast formation scenarios.		ongoing
17 Supporting WEAVE survey preparation	Meghan	Jake, Frazer, Ulrike Kuchner, Alfonso Aragón-Salamanca	Create a "truth table" for galaxy environments and create observational galaxy quantities tuned to the JPPLUS photometric survey. In order to plan/test/refine the targeting strategy for the WEAVE cluster infall spectroscopic survey		ongoing
18 Phase space	Jake	Lilián, Pascal, Meghan	Phase space plane over 300 clusters. Gas fractions (stripping regions), binning cluster properties. Projection effects. Few interesting clusters. Looking for preprocessing.		

Figure: Tasks from GlenFiddling workshop.

# Future works



Figure: Be one of us!

Contact me [cuiweiguang@gmail.com](mailto:cuiweiguang@gmail.com) or Alexander  
[alexander.knebe@uam.es](mailto:alexander.knebe@uam.es)