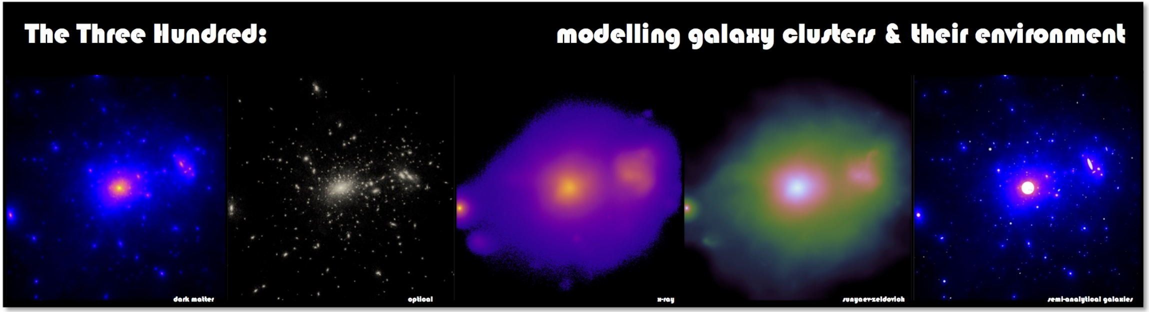

The Three Hundred: The new GIZMO-Simba run

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In collaboration with Romeel Dave, the300 members and **YOU**

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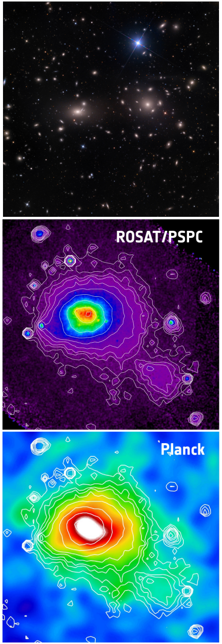
STScI Spring Symposium; https://arxiv.org/abs/2202.14038

29, April 2021

Outline

1. Why
   - Why galaxy clusters
   - Why the300
   - Why SIMBA
2. What
   - What about the baryon evolution
   - What about the satellite galaxy properties
   - What about the BCG properties
   - What about the Gas properties
3. Conclusion and future prospects

The Ultimate Cluster of Galaxies



- Cosmology
- Large-scale structure formation
- Galaxy formation
- IGM physics
- BH
- ....

Why The Three Hundred[3] (The300)

Table: Hydrodynamic simulated cluster. Due to the limitation of the computation power, most current cosmological hydrodynamic simulations can provide limited number of clusters. Most galaxy cluster simulations use the zoomed-in technique to only focus on the galaxy clusters only. Incomplete lists here.

Name	N	mass range	resolution (M_{DM})
MUSIC[1], Sembolini et al. 2013	500	$10^{14} < M_v < 2 \times 10^{15}\ h^{-1}\,\mathrm{M_\odot}$	$1.03 \times 10^9\ h^{-1}\,\mathrm{M_\odot}$
Dianoga, Planelles et al 2013	29	$M_{500} > 2 \times 10^{14}\ h^{-1}\,\mathrm{M_\odot}$	$8.5 \times 10^8\ h^{-1}\,\mathrm{M_\odot}$
Rhapsody-G, Hahn et al. 2017	10	$M_v \sim 10^{15}\ h^{-1}\,\mathrm{M_\odot}$	$8.3 \times 10^8\ h^{-1}\,\mathrm{M_\odot}$
MACSIS, Barnes et al. 2017a	390	$M_{FoF} > 10^{15}\ h^{-1}\,\mathrm{M_\odot}$	$4.4 \times 10^9\ h^{-1}\,\mathrm{M_\odot}$
C-EAGLE, Barnes et al. 2017b	30	$10^{14} < M_{200} < 2.5 \times 10^{15}\ h^{-1}\,\mathrm{M_\odot}$	$10^7\ h^{-1}\,\mathrm{M_\odot}$
Hydrangea[2], Bahe et al. 2017	24	$10^{14} < M_{200} < 2 \times 10^{15}\ h^{-1}\,\mathrm{M_\odot}$	$10^7\ h^{-1}\,\mathrm{M_\odot}$
FABLE, Henden et al. 2018	6	$\sim 10^{13} < M_{halo} <\sim 10^{15}\ h^{-1}\,\mathrm{M_\odot}$	$\sim 5.5 \times 10^7\ h^{-1}\,\mathrm{M_\odot}$

Recent cosmological simulations have much larger volumes, such as BAHAMAS, TNG300, Magneticum, Millennium-TNG, FLAMINGO... see Annalisa Pillepich's talk.

[1] No AGN

[2] Slightly different to EAGLE in AGN feedback

[3] https://the300-project.org/

Why The300: **1. Multi models**

hydrodynamic simulations with baryonic models:

GADGET-MUSIC (Sembolini et al. 2013): classic SPH method. Radiative cooling, star formation with both thermal and kinetic Supernove (SN) feedback.
GADGET-X (Murante et al. 2010): 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-SIMBA: (Dave, et al 2019, Cui et al. 2022): Advanced BH/AGN models, dust model, 'calibrated' according stellar properties.

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 hydrodynamic simulations.

The most massive 324 clusters are selected from the MultiDark simulation (MDPL2) [4].

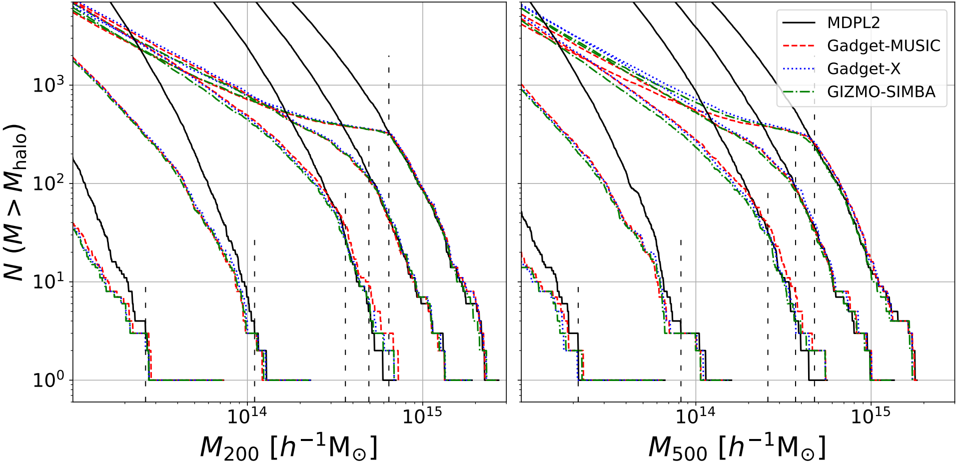
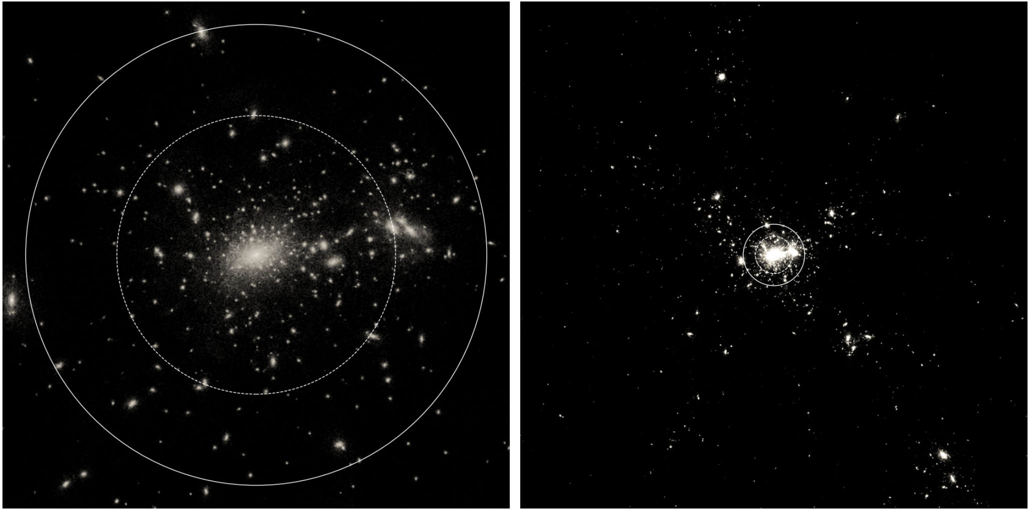


Figure: Cumulative halo mass functions. Cui 2022

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

Why The300: **3. very large high-resolution regions**

The zoomed-in ICs have a radius of 15 h^{-1} Mpc for from the cluster center. The connection between the central cluster with its surrounding environments (filaments) can be studied (see Wang et al. 2018; Kuchner et al. 2020, 2021, 2022; Rost et al. 2021)



Why The300: **4. multi-wavelength mock observations**

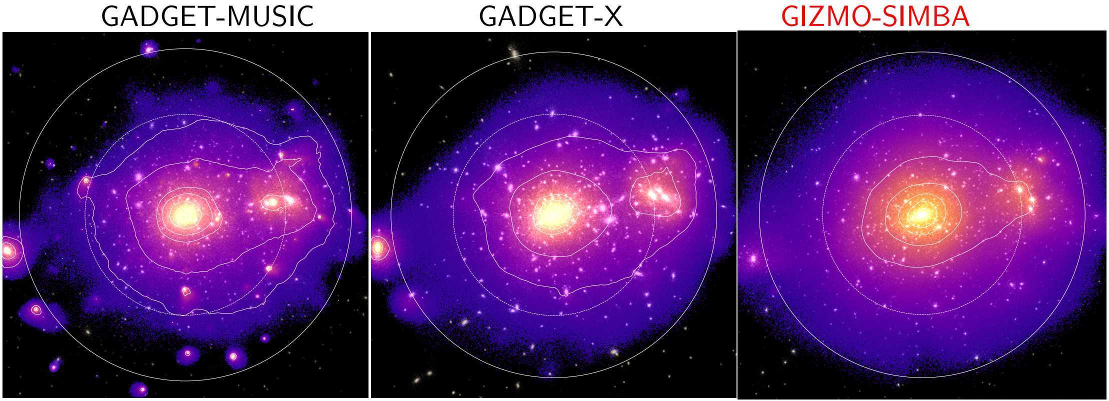
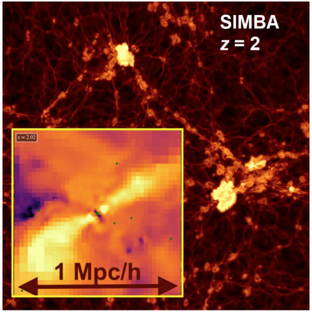


Figure: Mock multi-wavelength observations. From left to right, GADGET-MUSIC, GADGET-X, and GIZMO-SIMBA. Galaxies are shown by combining sdss u, g, r band images; X-ray is presented in colour map and SZ-y signal is highlight in contours. See De Luca et al. 2021 and Daniel de Andres' Talk! We also have lensing maps thanks to Carlo Giocoli. These maps can help to answer Jack Sayers' question and to bridge observation with simulation predictions.

Why SIMBA: *the advanced BH model*

Two types of BH accretion:

- the torque-limited accretion model for cold gas (T<10^5 K, Angles-Alcazar et al. 2015, 2017)
- Bondi-Hoyle-Lyttleton accretion model for hot gas (T>10^5 K)



Christiansen et al. 2020

Three BH feedback models:

- 'Radiative feedback' in high Eddington ratios $f_{Edd} \gtrsim 0.02$ with a wind speed of 1000 km/s.
- Jet feedback (kinetic) in low $f_{Edd} \lesssim 0.02$ ejects the hot gas in collimated jets with a wind speed 15000 km/s (about 2 times higher than the original SIMBA setup).
- X-ray feedback for galaxies in jet-mode with gas fraction f_{gas} <0.2.

Why SIMBA: *the dust model*

- Dust is passively advocated following the gas particles.
- It has the same physical properties with a fixed radius a $=$0.1 μm.
- Dust is produced by condensation of metals from eject of SNe and AGB stars.
- Once dust grains are produced, they can grow by accreting gas phase metals.
- Dust will be destroyed instantaneously in the process of hot winds (for example AGN X-ray heating or jets) and star formation, with all dust mass and metals being returned to the gaseous phase.

See Li et al. 2019 for details.

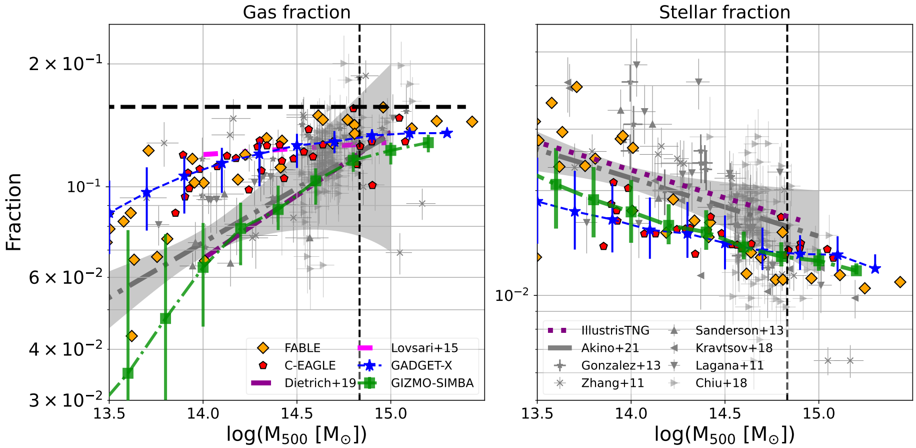
Why SIMBA: *the "calibrated" stellar properties*

The "calibrated" is quoted as we are not calibrating total 324 clusters. We only calibrated one random selected cluster and apply the calibrated parameters to all the other clusters. Calibration is not an easy thing, especially to calibrate three relations together.

- The total stellar fractions
- satellite stellar mass function
- BCG-halo mass relation

Why SIMBA: *the "calibrated" stellar properties*

- The total stellar fractions



- satellite stellar mass function
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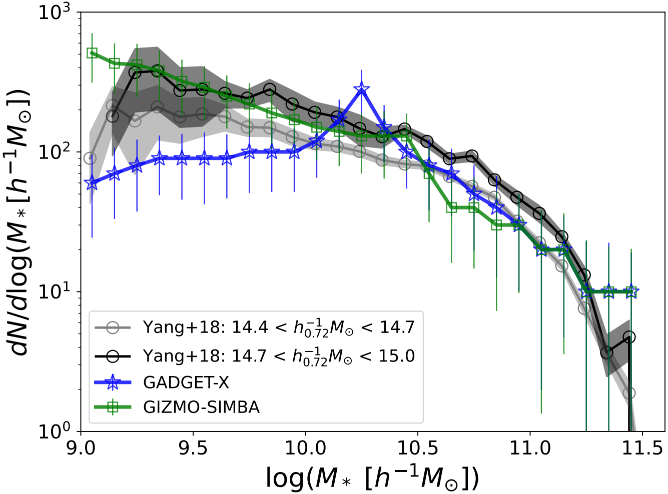
Why SIMBA: *the "calibrated" stellar properties*

- The total stellar fractions
- satellite stellar mass function



- BCG-halo mass relation

Why SIMBA: *the "calibrated" stellar properties*

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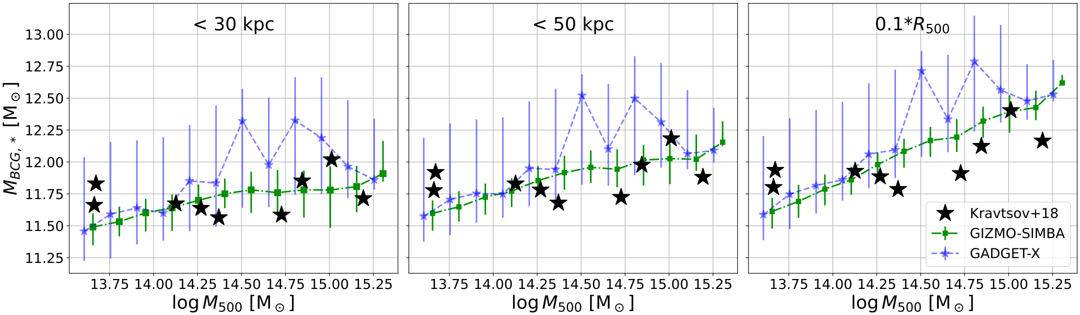


The evolution of the baryon fractions

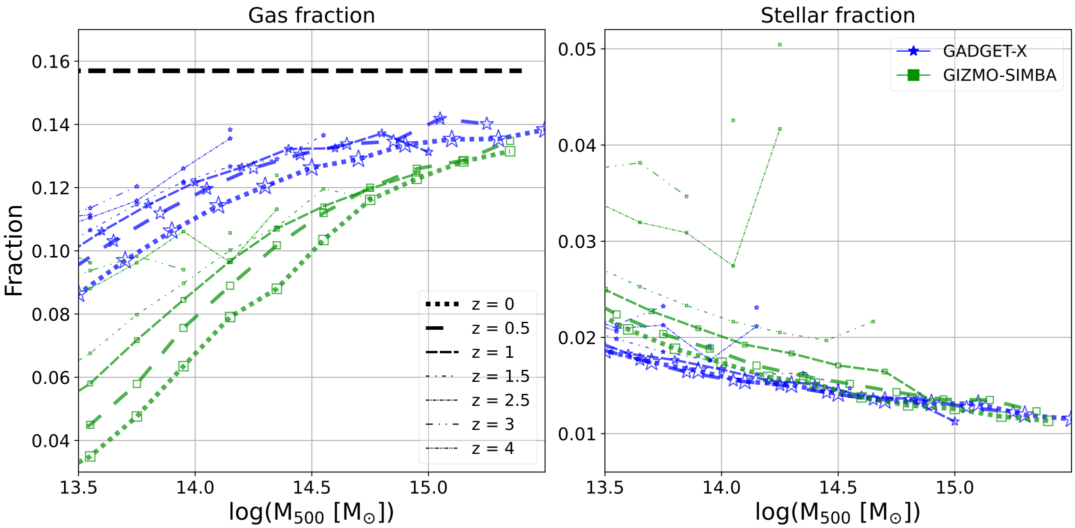


Figure: The gas and stellar fractions evolution at different halo mass range.

The evolution of the baryon fractions

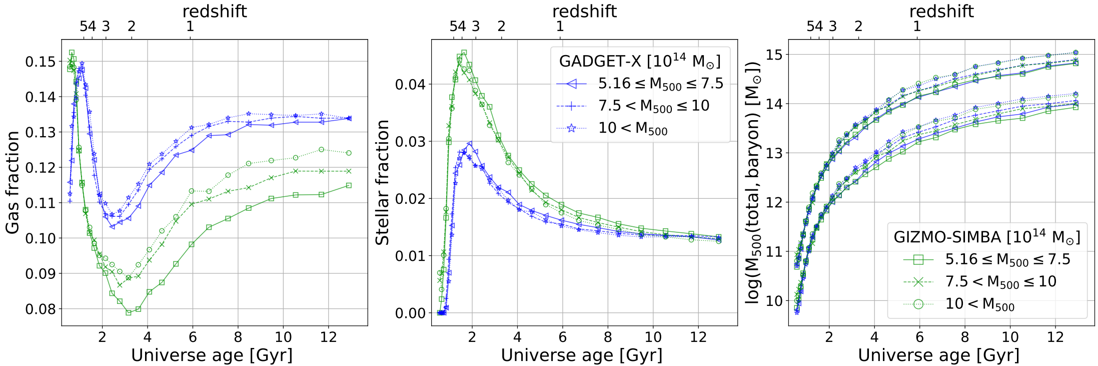
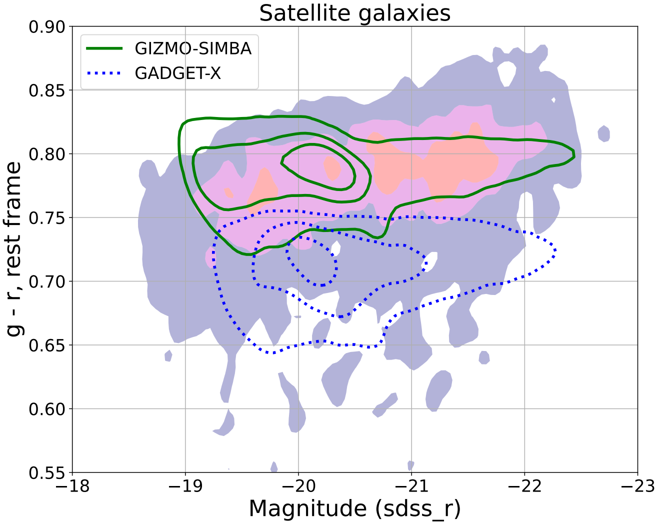
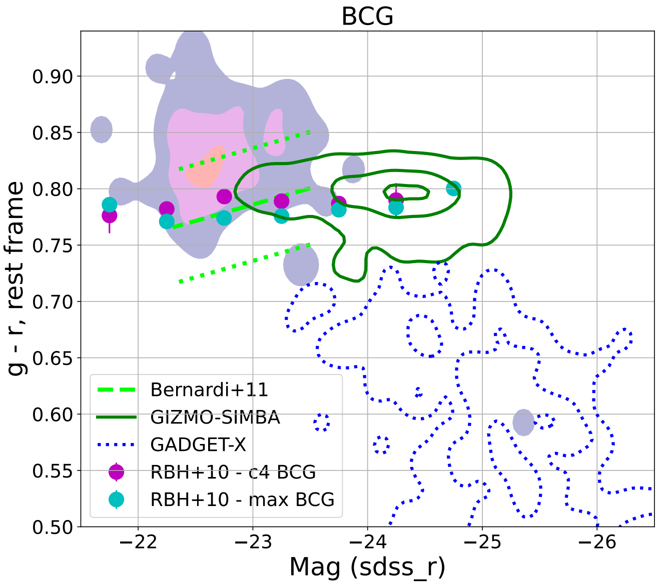


Figure: The gas and stellar fractions and masses evolution by tracking the central clusters separated into 3 mass bins.

The color-magnitude diagram for satellite galaxies



The satellite galaxy colour-magnitude diagram at rest frame.
SDSS satellite galaxy distribution is shown in the colour map. The same percentiles (16th-50th-84th) are used for GIZMO-SIMBA and GADGET-X contours. The same stellar mass cut $M_* > 10^{10} M_\odot$ is applied.



The BCG colour-magnitude diagram at rest frame. Everything is the same as the colour-magnitude diagram for satellite galaxies, but shown the BCG instead here. Note that the Bernardi et al. 2011 results show the massive red sequence galaxies.

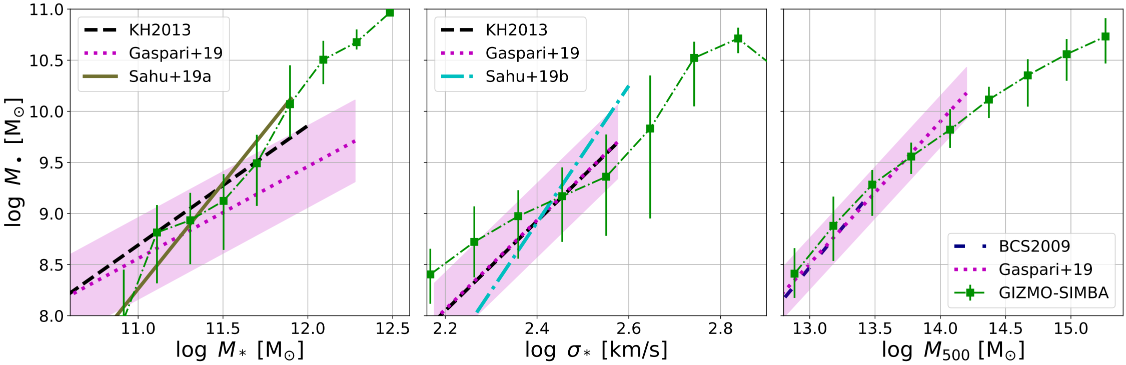
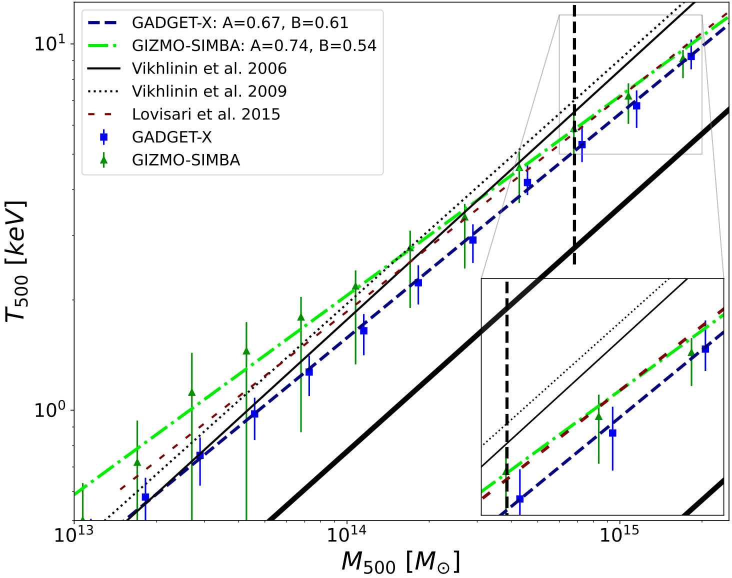
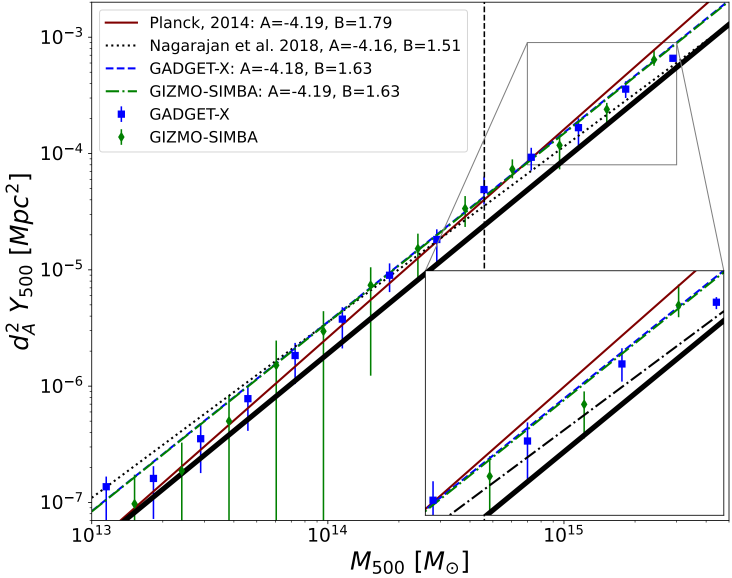


Figure: The $M_\bullet$ - M_* (left), $M_\bullet$ - σ_* (middle) and $M_\bullet$ - M_{halo} (right) relations. GIZMO-SIMBA is in good agreement with observational results at lower masses. It predicts a slight deviation from the interpolations: A higher ($\sim$ 2 times) BH mass in $M_* \gtrsim 10^{12} M_\odot$; A flatter trend in $M_\bullet$ - σ_* (middle) and $M_\bullet$ - M_{halo} (right) relations.

The Gas properties



The mass-weighted temperature - halo mass relation.
GIZMO-SIMBA seems to have slightly higher temperature compared to GADGET-X, especially at lower halo mass range.



The Y_{500} - M_{500} relation. Note, mass-weighted fitting based on their completeness fraction is adopted for all three simulation models.

Conclusion

The new GIZMO-SIMBA run which is completely different baryon model (also hydrodynamics), by designed, have a different constrains (mostly focusing on galaxy/stellar properties) to highlight the agreement/disagreement between these models.

- I hope that I have convinced you that GIZMO-SIMBA provide a more realistic galaxy/stellar properties.
- There is clear much more differences between GIZMO-SIMBA and GADGET-X at high redshift and at lower halo mass. Furthermore, more differences are in details (agreed with Arif!), such as profiles.
- The SZ $Y - M$ relation is generally in line with each other and with observations at z=0, however, for slightly different contributions.
- GIZMO-SIMBA also predicts that the BH scaling relations can be different at the most massive objects.

Planned/proposed simulations

- High-resolution (HD) runs, 8X more high-resolution particles with $M_{DM} \sim 10^7\ h^{-1}\,\mathrm{M}_{\odot}$. 30 (10%) selected clusters with ultra-high resolution ($10^6\ h^{-1}\,\mathrm{M}_{\odot}$) to resolve dwarf galaxies in clusters.
- Protocluster runs focusing on the protocluster regions with extra-high resolution at high redshift.
- Alternative cosmology/SIDM model runs.

How to join us

We are for the minimum requirement to join: (1) agree to our policy (for fair play) and (2) a short description on what you are going to do (for avoiding conflicts and also for collaboration)

In return, you will access to our data server (free use!!) which stores all simulation data/catalogues/mock maps.

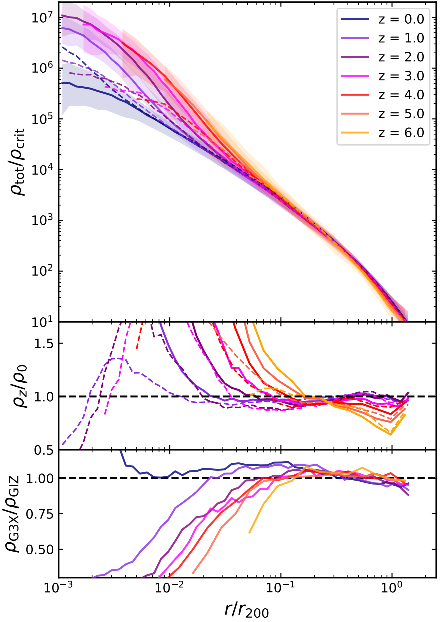
We also have plans to release the data, possibly in about 1 year's time if you prefer to wait.

Supplement materials

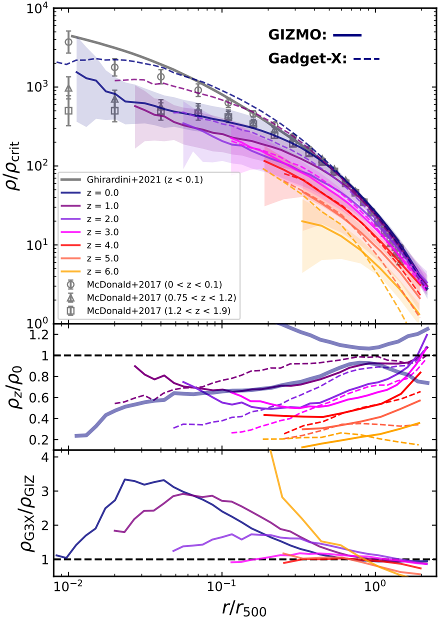
The GIZMO-Simba run of the 300 clusters: basic information

- This GIZMO-Simba version of the 300 cluster is based on the success of the Simba simulation (Dave et al. 2019).
- The simulation code is based on GIZMO (Hopkins 2015, 2017), MUFASA model (Dave et al. 2016) with a new advanced BH model (Angles-Alcazar et al. 2017) and a dust model (Li et al. 2019). See next slide for details.
- Other input physics: GRACKLE-3 for gas radiative cooling and photoionization heating, Haardt & Madau (2012) ionizing background with self-shielding, an H_2-based star formation rate, 11 elements are tracked with chemical enrichment from Type II supernovae (SNe), Type Ia SNe, and Asymptotic Giant Branch (AGB) stars, stellar feedback with mass loading factor follows Angles-Alcazar et al. (2017b).

Total density

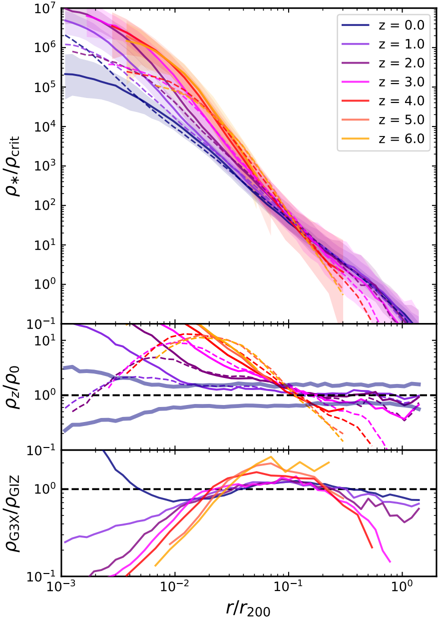


Gas density

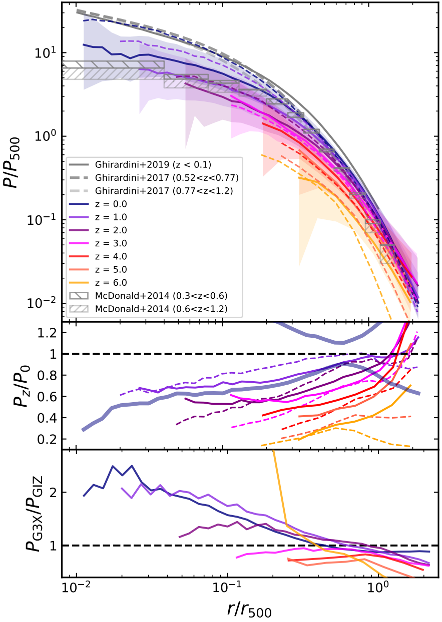


GIZMO:
Gadget-X:
Ghirardini+2021 (z < 0.1)
z = 0.0
z = 1.0
z = 2.0
z = 3.0
z = 4.0
z = 5.0
z = 6.0
McDonald+2017 (0 < z < 0.1)
McDonald+2017 (0.75 < z < 1.2)
McDonald+2017 (1.2 < z < 1.9)
$\rho/\rho_{\rm crit}$
ρ_z/ρ_0
$\rho_{\rm G3X}/\rho_{\rm GIZ}$
r/r_{500}

Stellar density

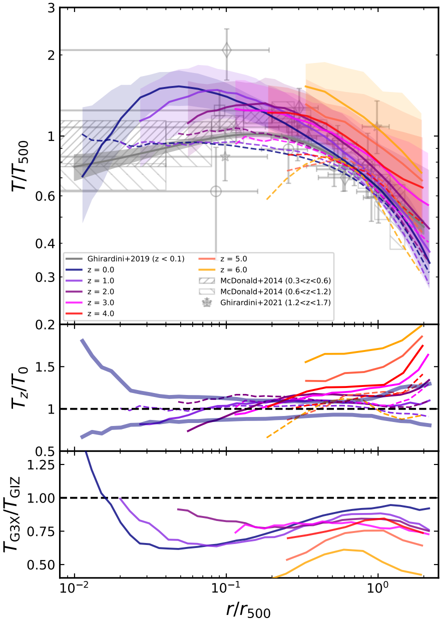


Pressure

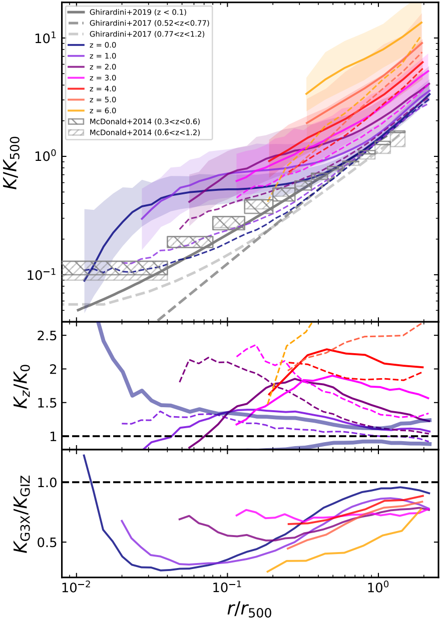


Ghirardini+2019 (z < 0.1)
Ghirardini+2017 (0.52<z<0.77)
Ghirardini+2017 (0.77<z<1.2)
z = 0.0
z = 1.0
z = 2.0
z = 3.0
z = 4.0
z = 5.0
z = 6.0
McDonald+2014 (0.3<z<0.6)
McDonald+2014 (0.6<z<1.2)
P/P_{500}
P_z/P_0
P_{G3X}/P_{GIZ}
r/r_{500}

Temperature



Entropy



Ghirardini+2019 (z < 0.1)
Ghirardini+2017 (0.52<z<0.77)
Ghirardini+2017 (0.77<z<1.2)
z = 0.0
z = 1.0
z = 2.0
z = 3.0
z = 4.0
z = 5.0
z = 6.0
McDonald+2014 (0.3<z<0.6)
McDonald+2014 (0.6<z<1.2)
K/K_{500}
K_z/K_0
K_{G3X}/K_{GIZ}
r/r_{500}