The evolution of physical baryon profiles in galaxy clusters

(Li et al. 2020, 2023)

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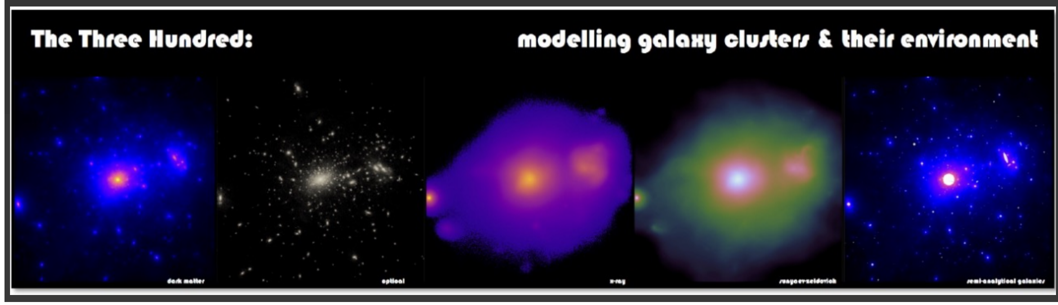

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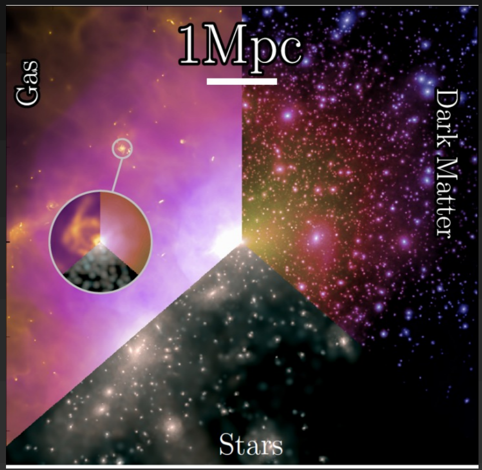
Galaxy clusters

– The large gravitationally bound systems in the Universe

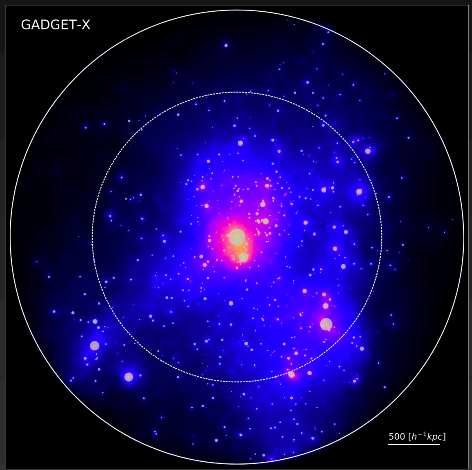
Unique laboratories:
- Galaxy formation
- Cosmology
- Galaxy-halo connection

…

JWST: SMACS 0723 (z = 0.39)



Pakmor et al. 2022 (MillenniumTNG)



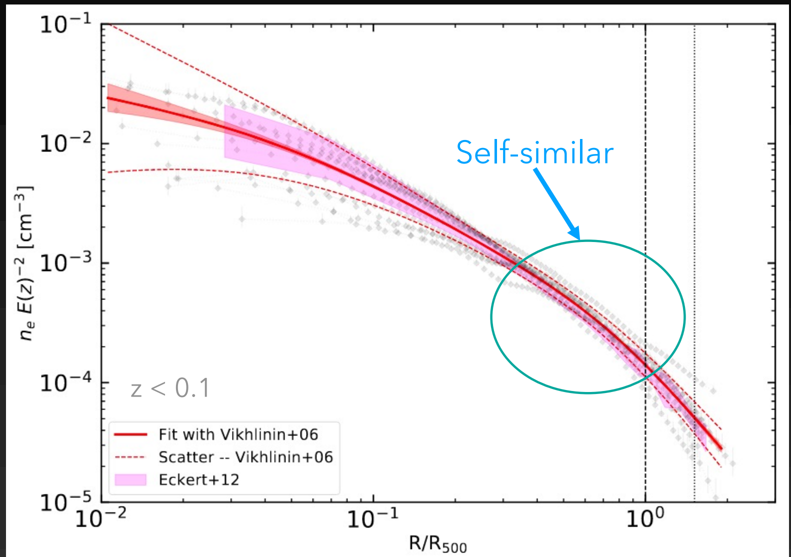
Cui et al. 2018 (Gadget-X)

Can be detected directly

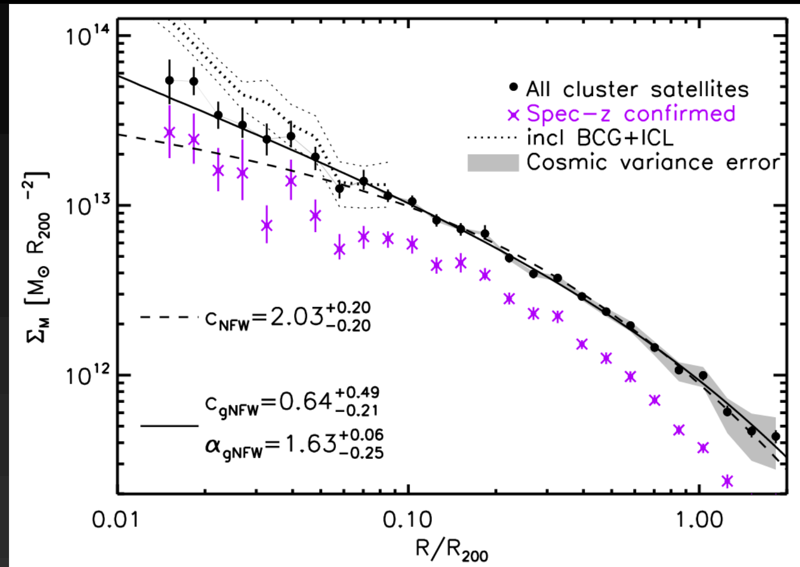
Main components: Stars/Galaxies (~1%), Intracluster medium (~9%), Dark matter (~90%)

Significant ways to understand the properties and history of galaxy clusters!

Baryon distributions from observations



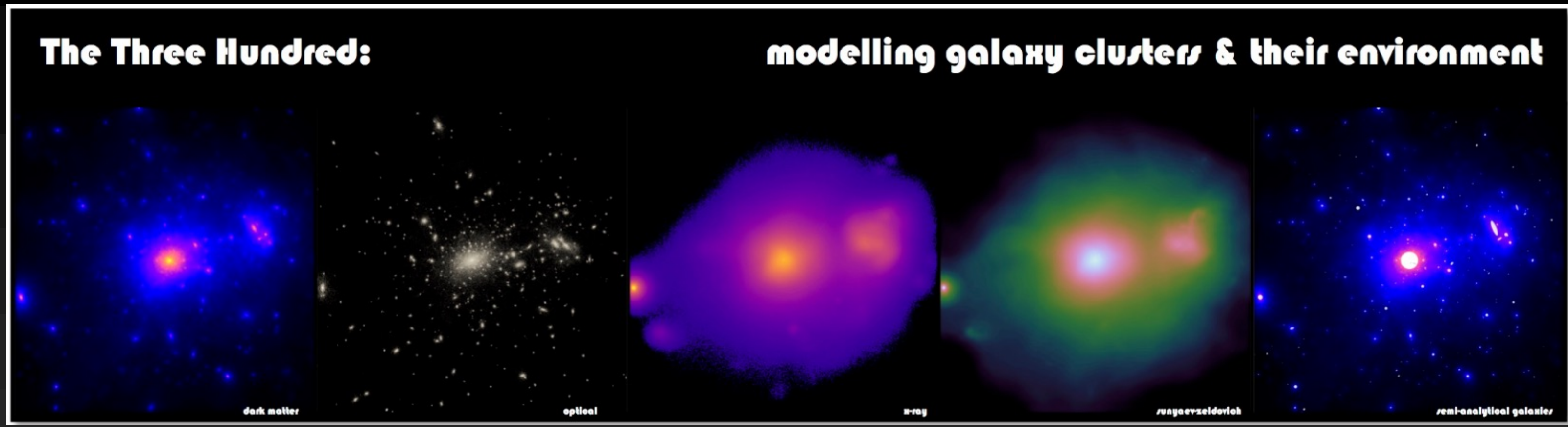
(Ghirardini et al. 2018)



(van der Burg et al. 2015)

- **Intracluster medium (ICM):** well studied with **X-ray/SZ** data (**z < 1**)
- **Stellar component:** focus on galaxy population

Hydrodynamical simulation: The Three Hundred project



324 theoretically modelled galaxy clusters → Statistic analysis

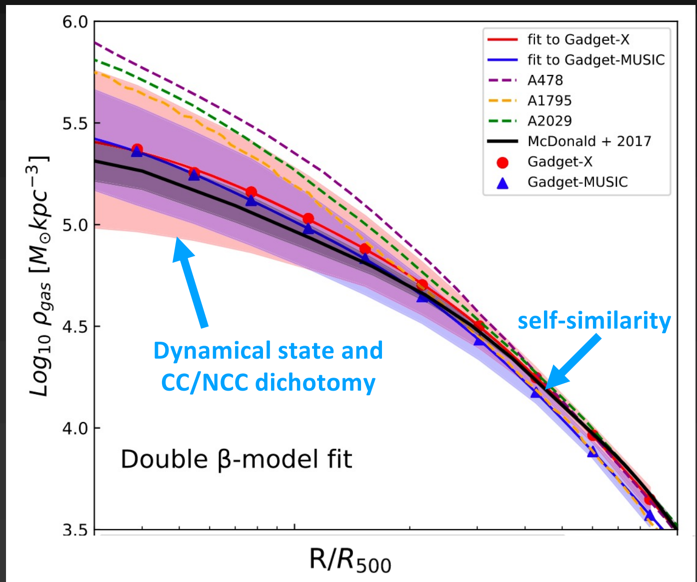
- Zoom-in hydro simulations: Gadget-X, Gadget-MUSIC, GIZMO-SIMBA
- Semi-analytic models: SAG, SAGE, GALACTIC

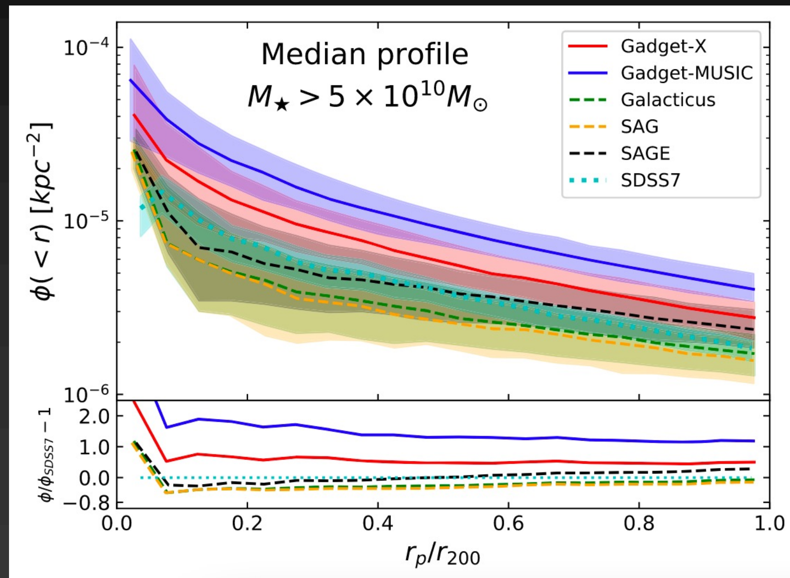
I. The distribution of physical baryon profiles (Li et al. 2020)

Investigate the scatter and self-similarity of physical profiles

Gas: density, temperature, metallicity

Stars/Galaxies: mass density, number density, age, SFR/sSFR, metallicity





z = 0

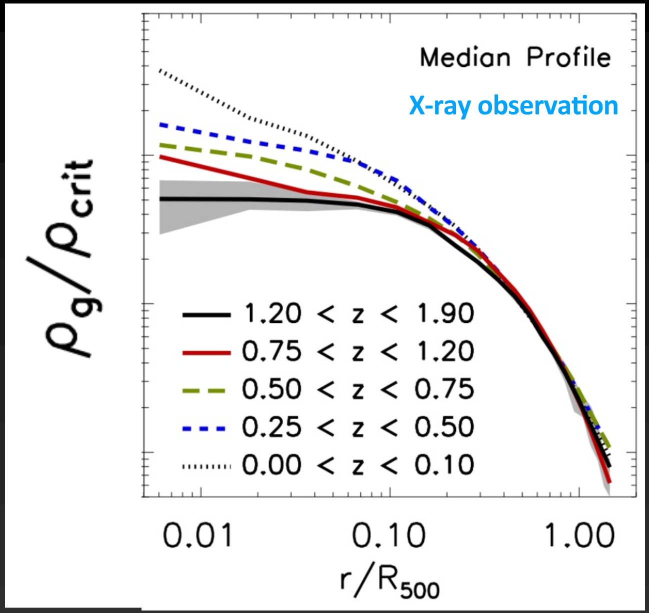
Do not find any clear radial dependence of stellar age, metallicity and (s)SFR

How about the baryon distribution at high redshifts?

II. The evolution of physical baryon profiles (Li et al. 2023)

- Observations
  - Individual clusters at high redshifts (**z ≲ 2**)
  - Self-similarity in the outskirts

High-redshift clusters are not necessarily the progenitors of low-redshift clusters.



(McDonald et al. 2017)

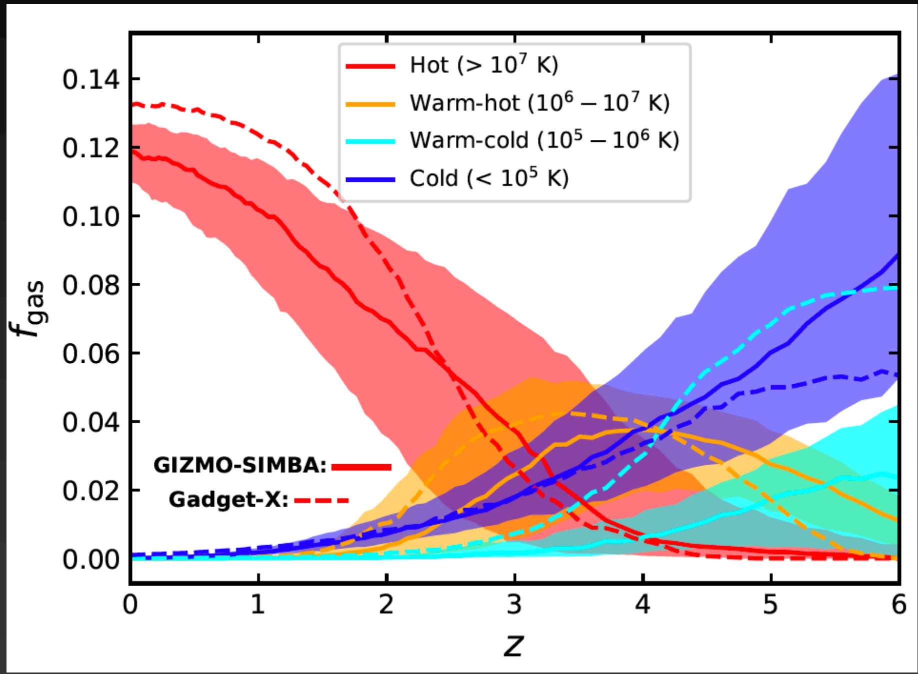
- Simulations (our work)
  - True progenitors → 1. Avoid sample selection
  - An extended redshift range (from z = 4 to z = 0) → 2. Explore self-similarity at high redshift
  - Effects of baryon models : Gadget-X (G3X) and GIZMO-SIMBA (GIZ) → 3. Understand effects of different baryon models
  - Multi physical properties → 4. Understand baryon distribution from different views

Global heating history for gas in halos

- Cold and warm-cold gas:
  - Dominated at high redshifts (z > 4)
- Warm-hot gas: gravitational shock
- Hot gas: AGN feedback and accretion shock
  - Increase after z ~ 4
  - Overtake the other fractions at z ~ 3

Gas selection

Gas mass fraction



(Li et al. 2023)

Similar gas evolution but subtle fraction differences!

Gas mass density

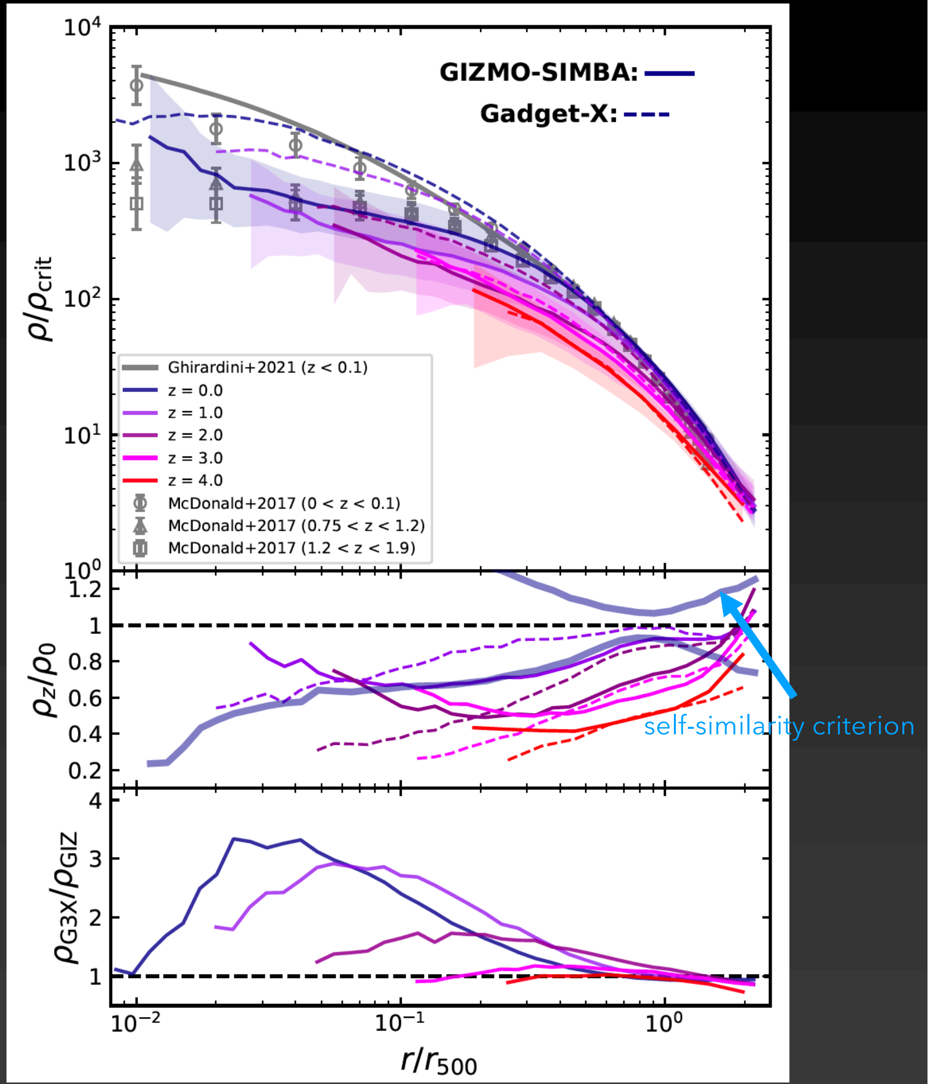
– A direct and fundamental reflection of gas amount and distribution

- **Core region** (r $\lesssim 0.1 r_{500}$)
  - Differences due to AGN feedback model

    GIZ: kinetic scheme (more efficient)

    G3X: thermal scheme

- **Outer region** (r $\gtrsim 0.3 r_{500}$)
  - A deviation from self-similarity since z = 2



(Li et al. 2023)

Gas: Entropy

$$K = \frac{k_B T}{n_e^{2/3}}$$

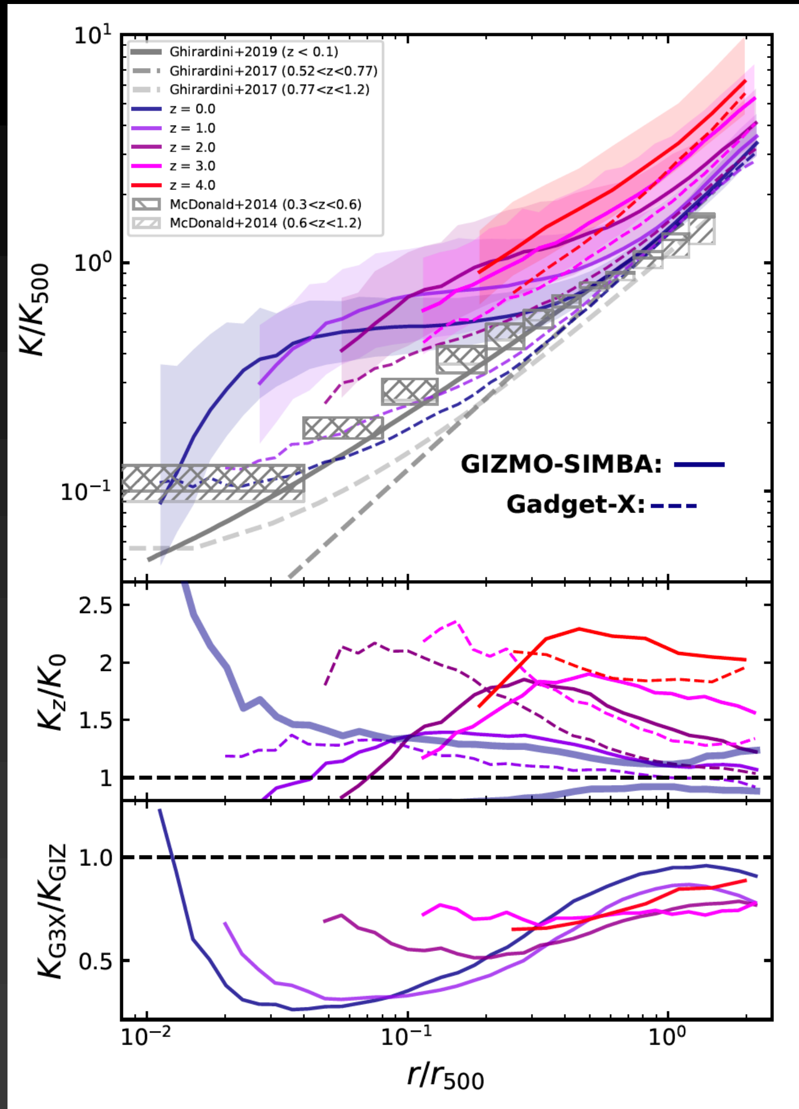
– A unique view of thermal history

- A power-law profile in the outskirts

- Core region
  - GX: follow a power law slope in line with observation
  - GIZ: an excess accompanied by a flatter profile

High fraction of non-cool-core clusters in GIZMO-SIMBA

The mechanism to dominate central entropy is in debate.



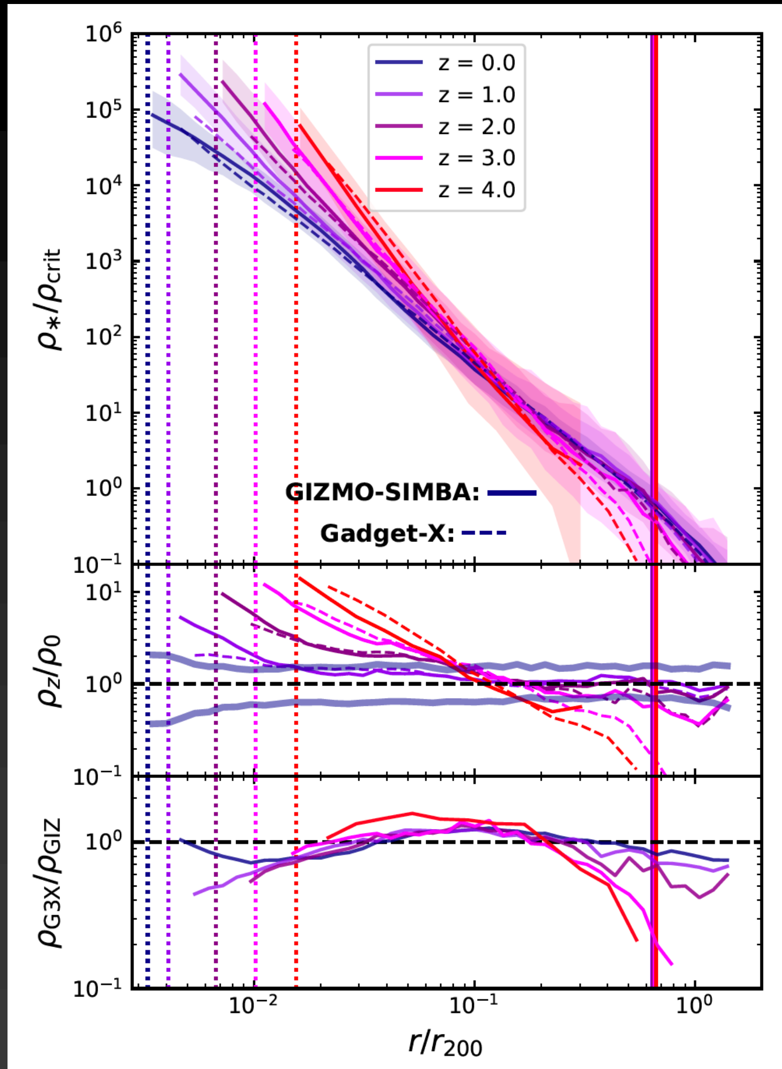
(Li et al. 2023)

Stellar: mass density

–A major observable

- Higher stellar density in GIZ than that in G3X
  - ➢ Early time of consuming gas into stars in GIZ

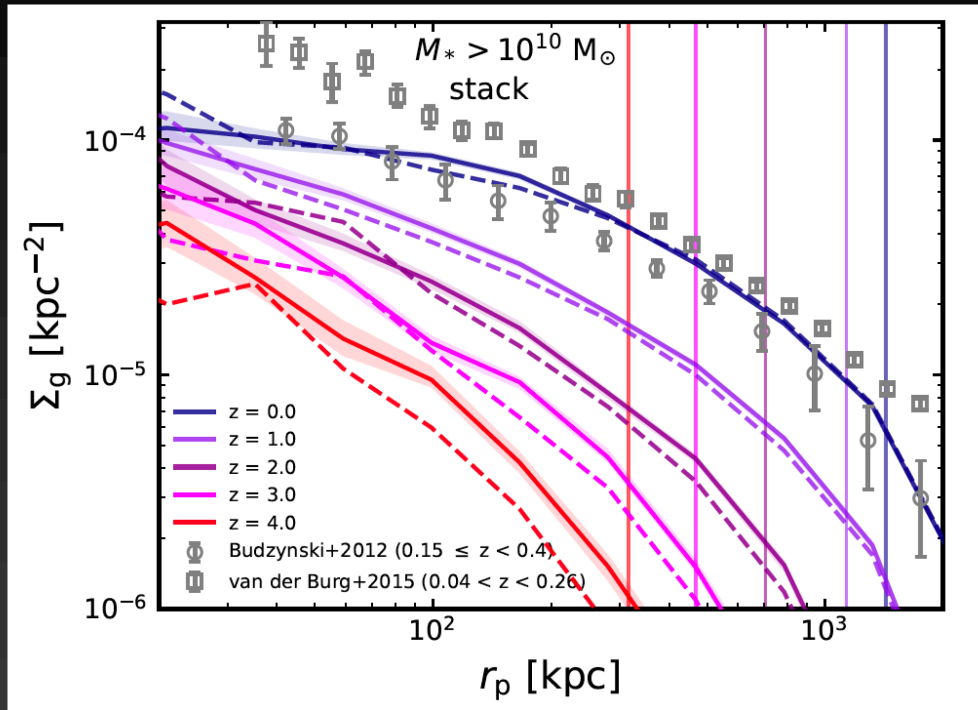
- Highly constrained at r ~ $0.1r_{200}$
  - ➢ Less affected by the gravitational and non-gravitational processes



(Li et al. 2023)

Stellar: satellite galaxy number density

- Simulations reasonably match well with low-redshift observations
- A faster drop at the outer radius than at the inner region.
  - ➢ Reflect an early assembled time in the center



(Li et al. 2023)

Summary

We theoretically provide a general picture of the evolution of baryon distributions:

- **In outer radii**:
  - Agreements between the two runs and observation and hold the self-similarity assumption. (At low redshifts)
    - ✓ To distinguish large differences at high-redshift -> Deep observations
- **In core regions:**
  - Differences in simulations (AGN feedback model?)
    - ✓ Understand which model is mostly responsible -> Turn on and off each baryon model