Cosmology with multiple halo sparsities

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Universality of dark matter profiles

Navarro et al. 1996

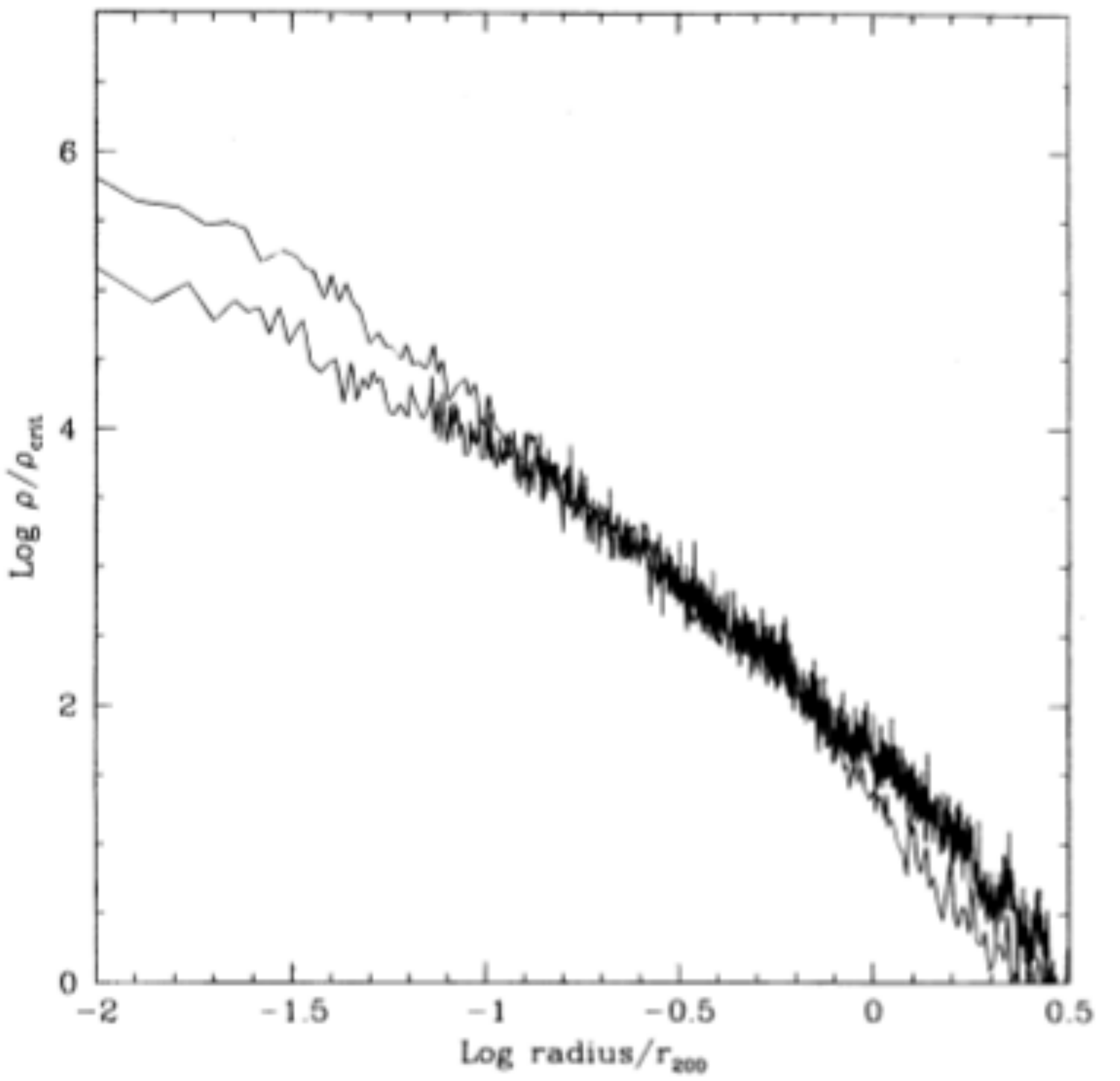
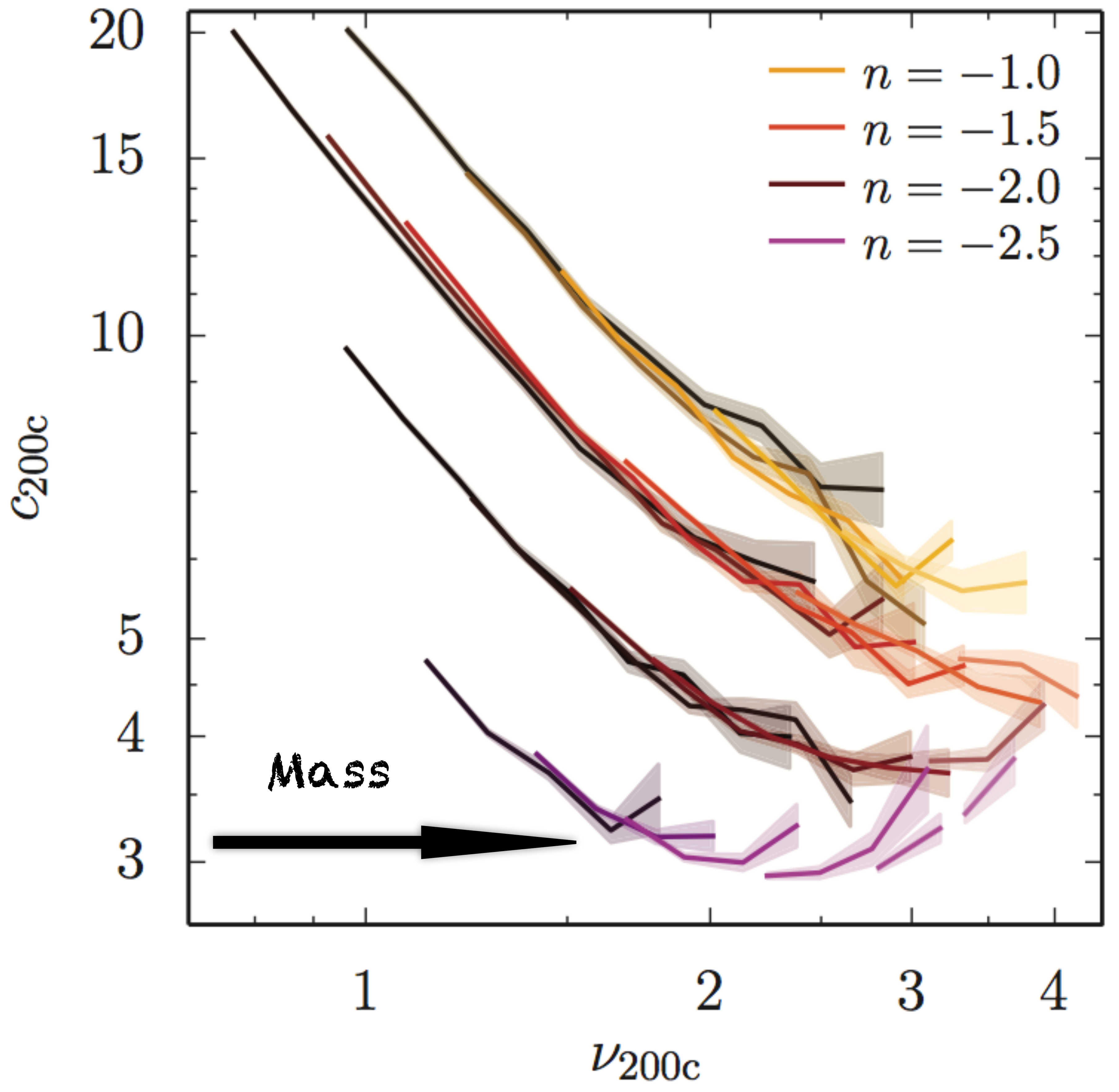


FIG. 4.—Scaled density profiles of the most and least massive halos shown in Fig. 3. The large halo is less centrally concentrated than the less massive system.



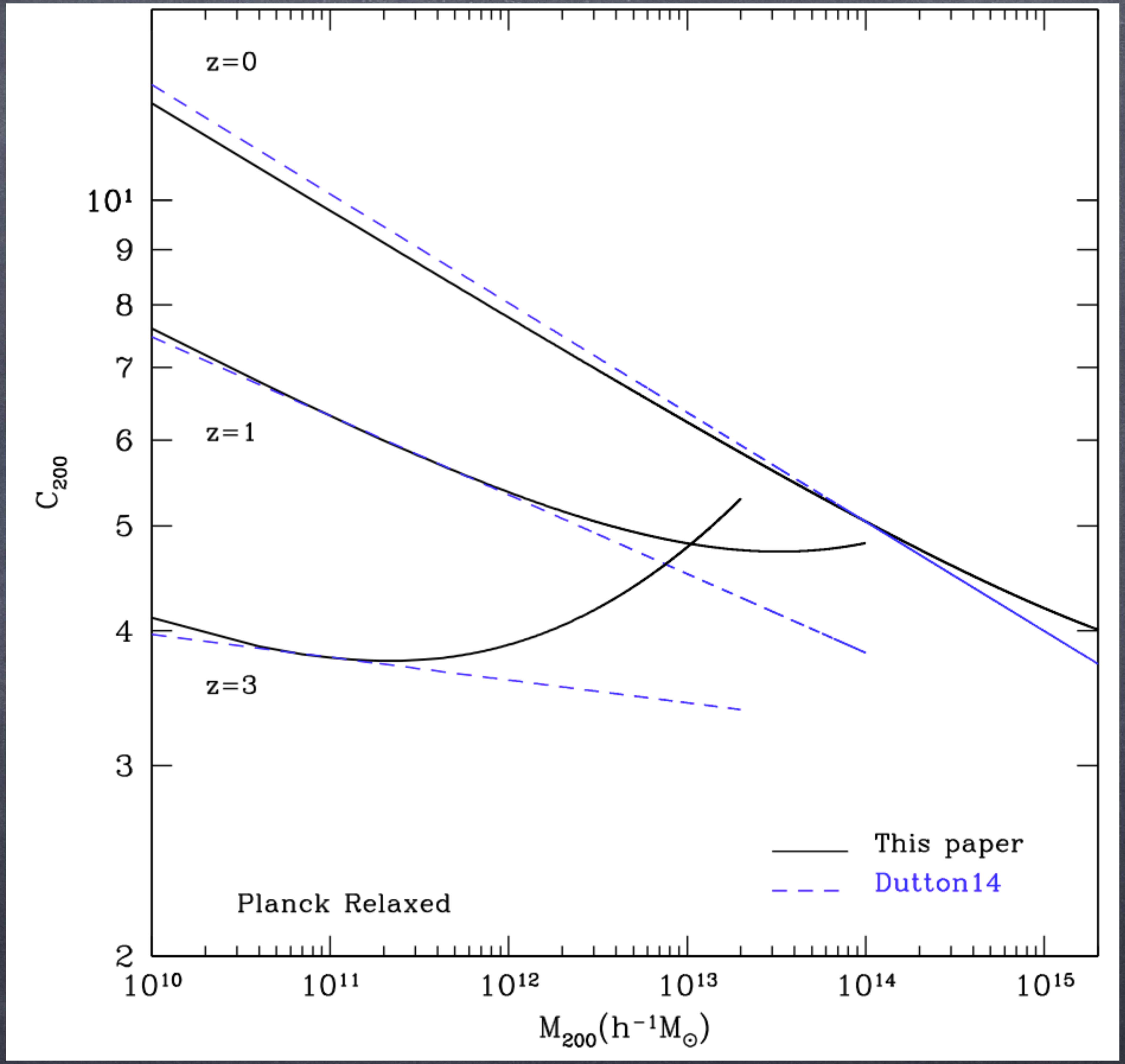
Diemer et al. 2015

See also e.g. Navarro et al. 1997, 2004, 2010, Gao et al. 2008

n: proxy for cosmology

Evolution of dark matter profiles

- Powerful test of ΛCDM.
- Evolution and shape of c-M are controversial especially at high-redshift and masses

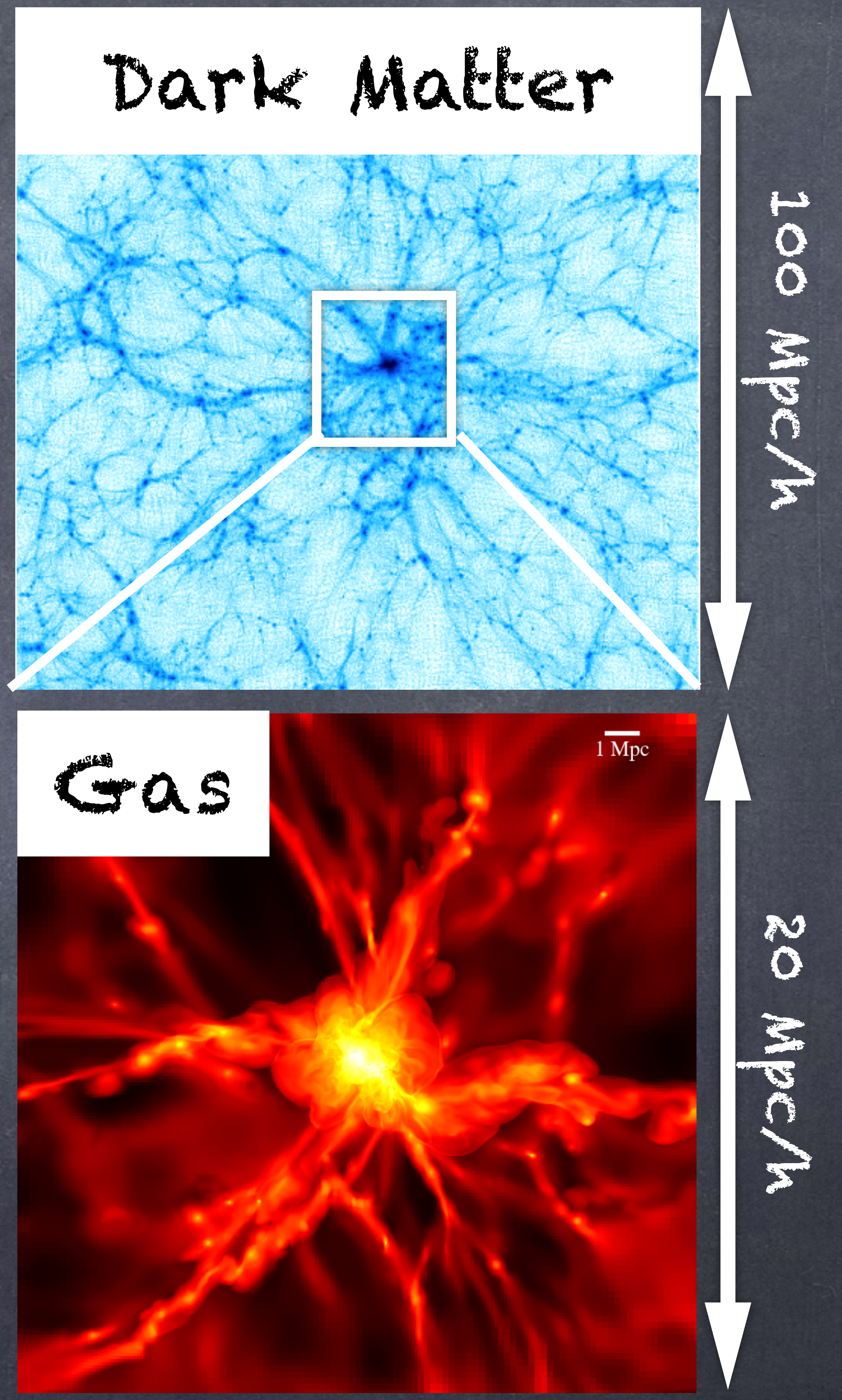


Klypin et al. 2016

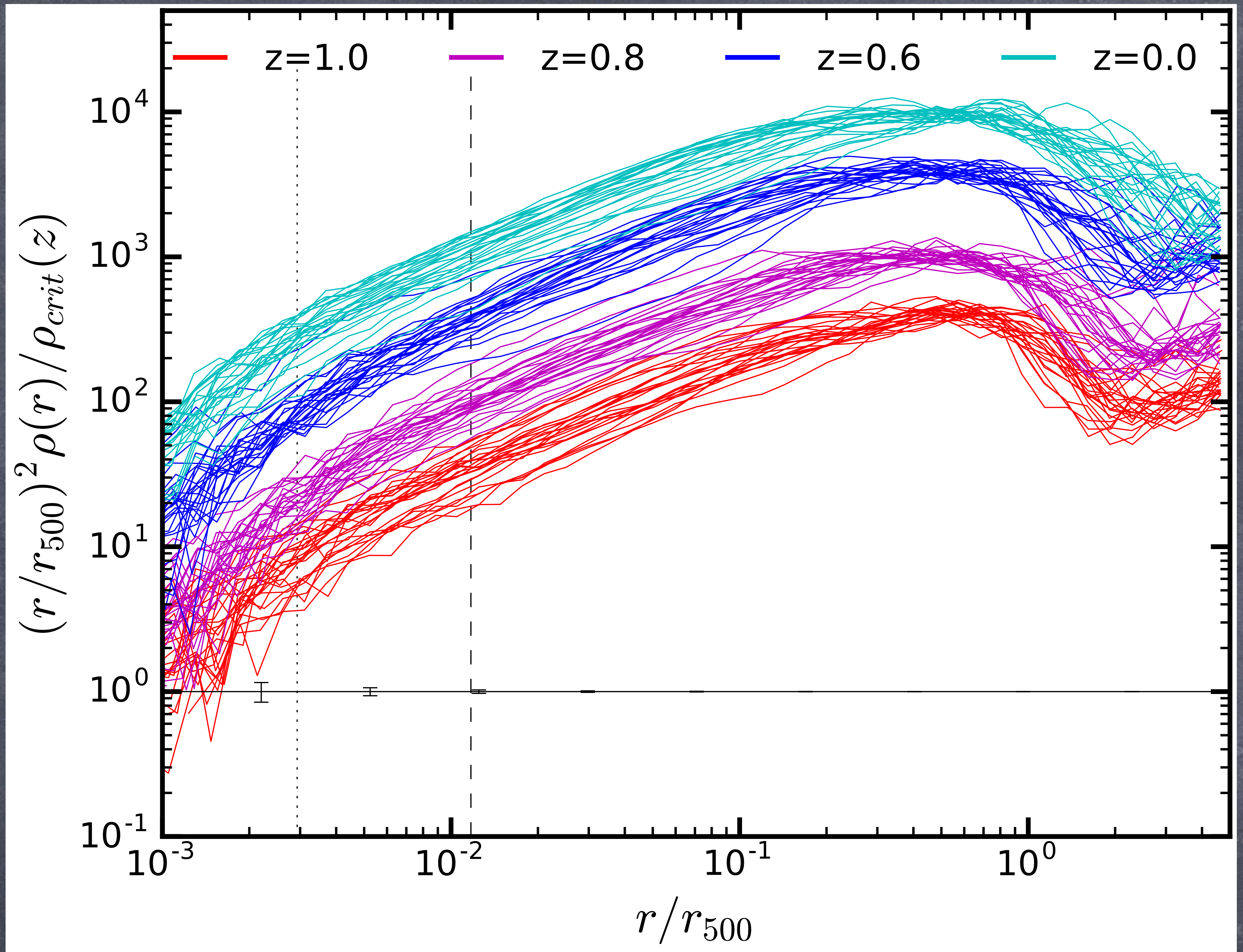
Le Brun et al. 2018

M2Csims Simulations

- AMR code RAMSES (Teyssier 2002)
- >16 million CPU hours (PI Le Brun)
- 3 DMO simulations of 1 (Gpc/h)^3
- >470 few kpc-resolution zooms for selected systems with M_{500}>4.49 x10^{14} $M_\odot$: 50 at z=1, 170 at z=0.8, 181 at z=0.6 and 75 at z=0
- Both DMO and NR runs for each system
- Tailor-made for comparison with Planck clusters



Density profiles

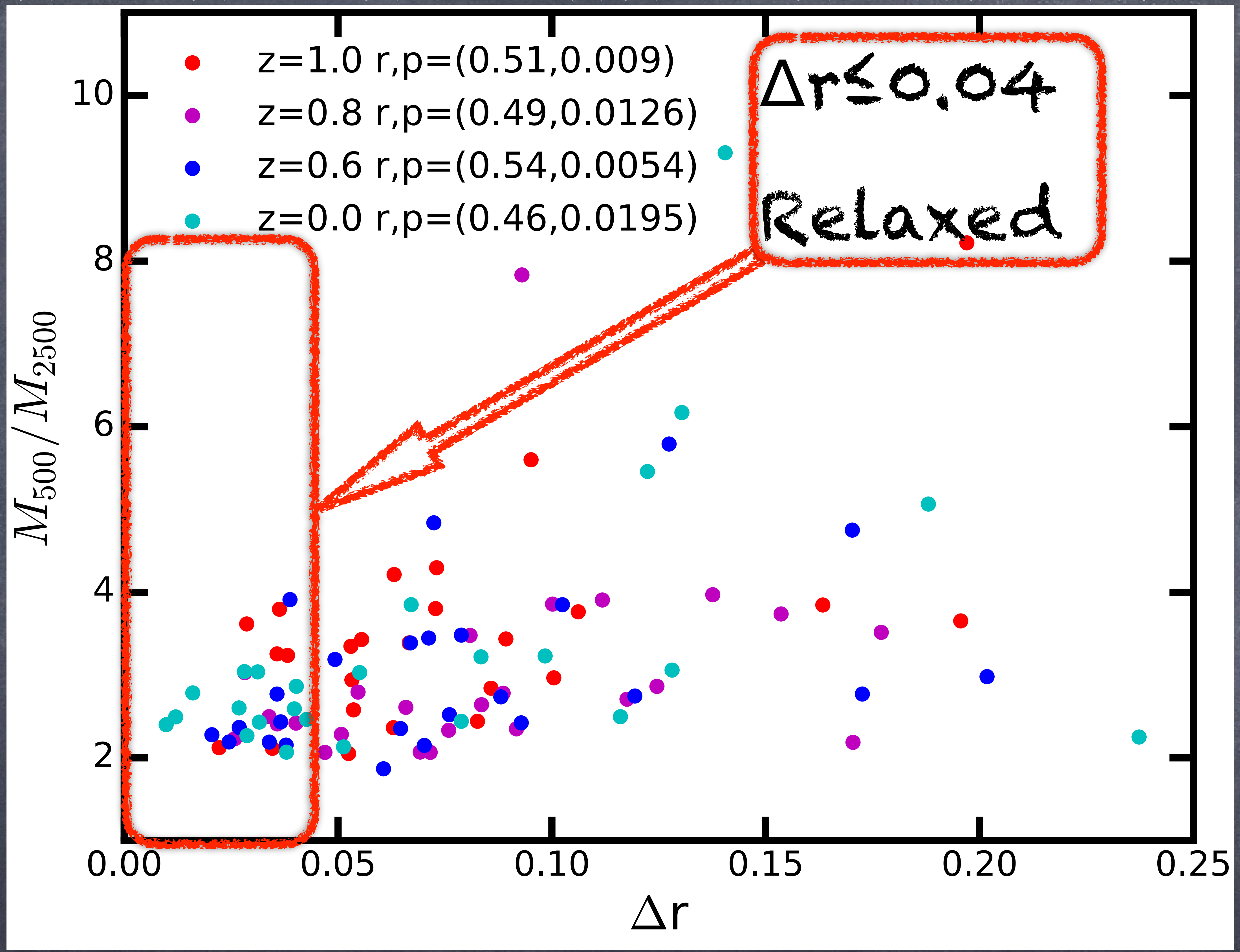


- Zoom ⇒ gain of a factor > 5 in spatial resolution
- Fluctuations are real

Le Brun et al. 2018

Correlation with relaxation state

For a practical application to merger timings, see Richardson & Corasaniti 2022

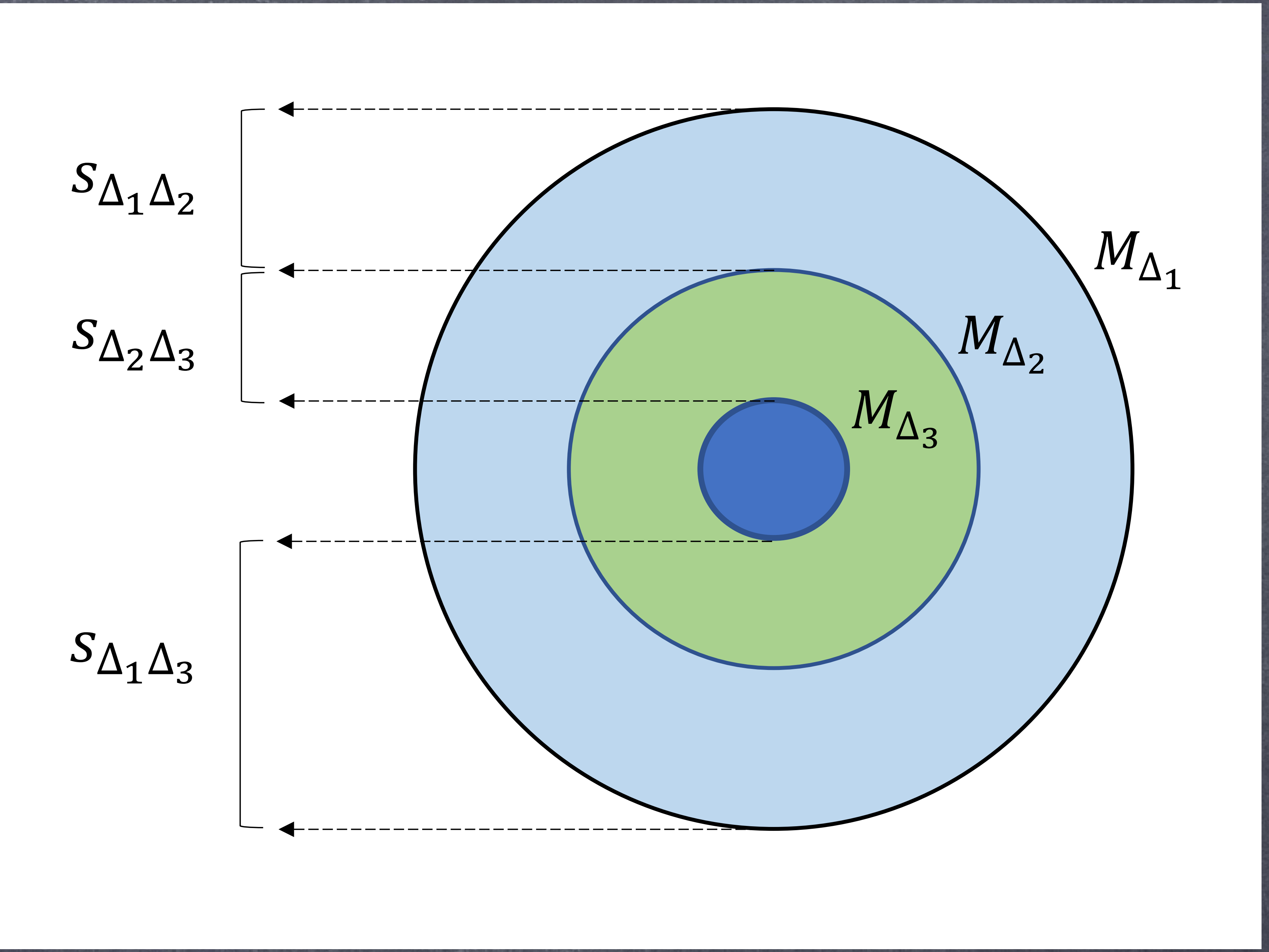


- Most relaxed clusters centrally concentrated
- Unrelaxed ones span larger variety of profile shapes

Halo sparsity

Characterising the mass profile with sparsity $s_{\Delta1,\Delta2}=M_{\Delta1}/M_{\Delta2}$ ($\Delta_1<\Delta_2$)

- Quantifies shape
- Nearly independent of halo mass
- Cosmology dependent
- Astrophysics dependent
- Sample mean prediction using HMF



Balmès et al. 2014, Corasiniti et al. 2018, Corasaniti & Rasera 2019, Corasaniti et al. 2021, Corasaniti, Le Brun et al. 2022

For the use of individual haloes, see Richardson & Corasaniti 2023

Cosmology with sparsity

Corasaniti, Sereno & Ettori 2021

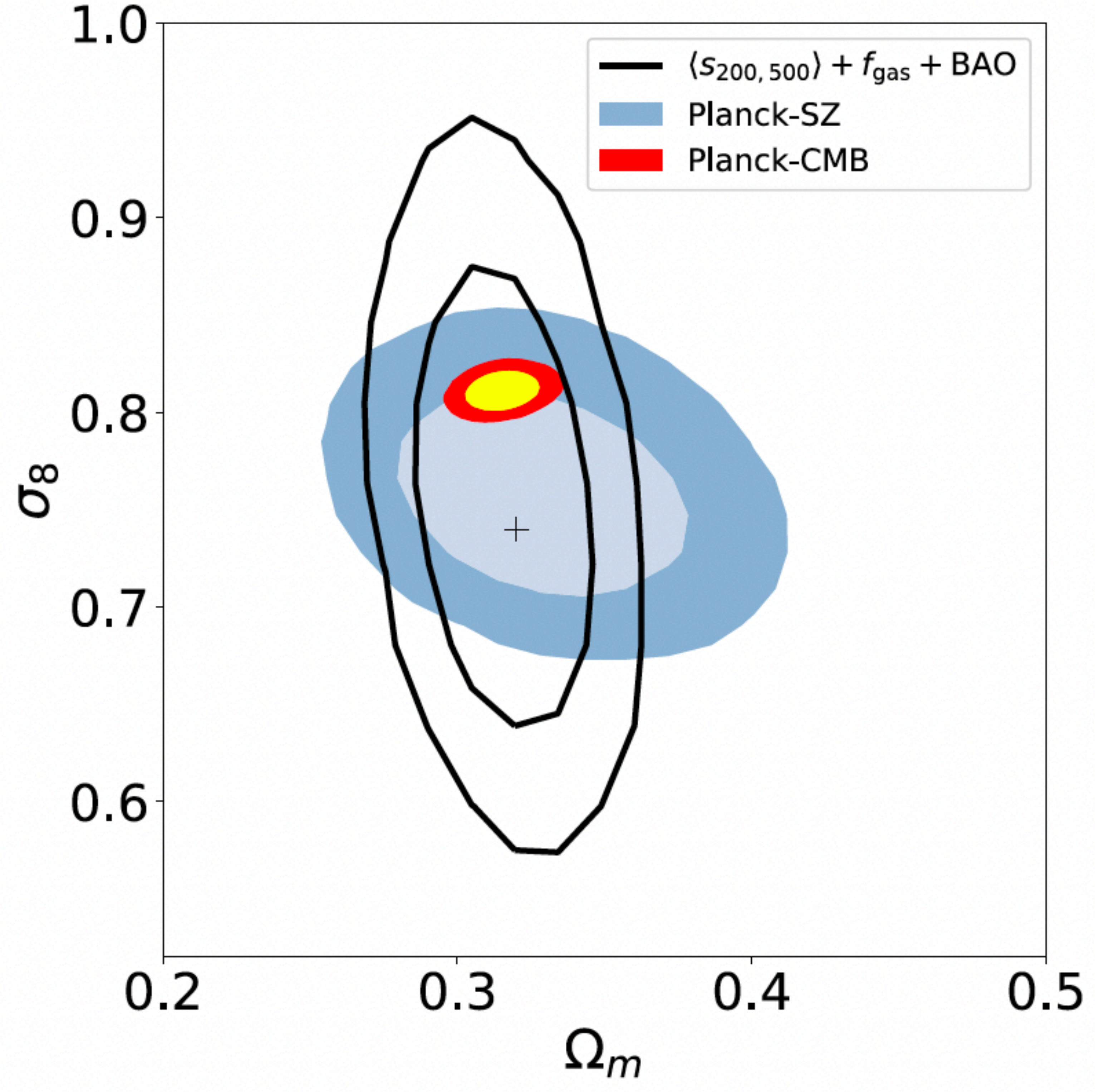
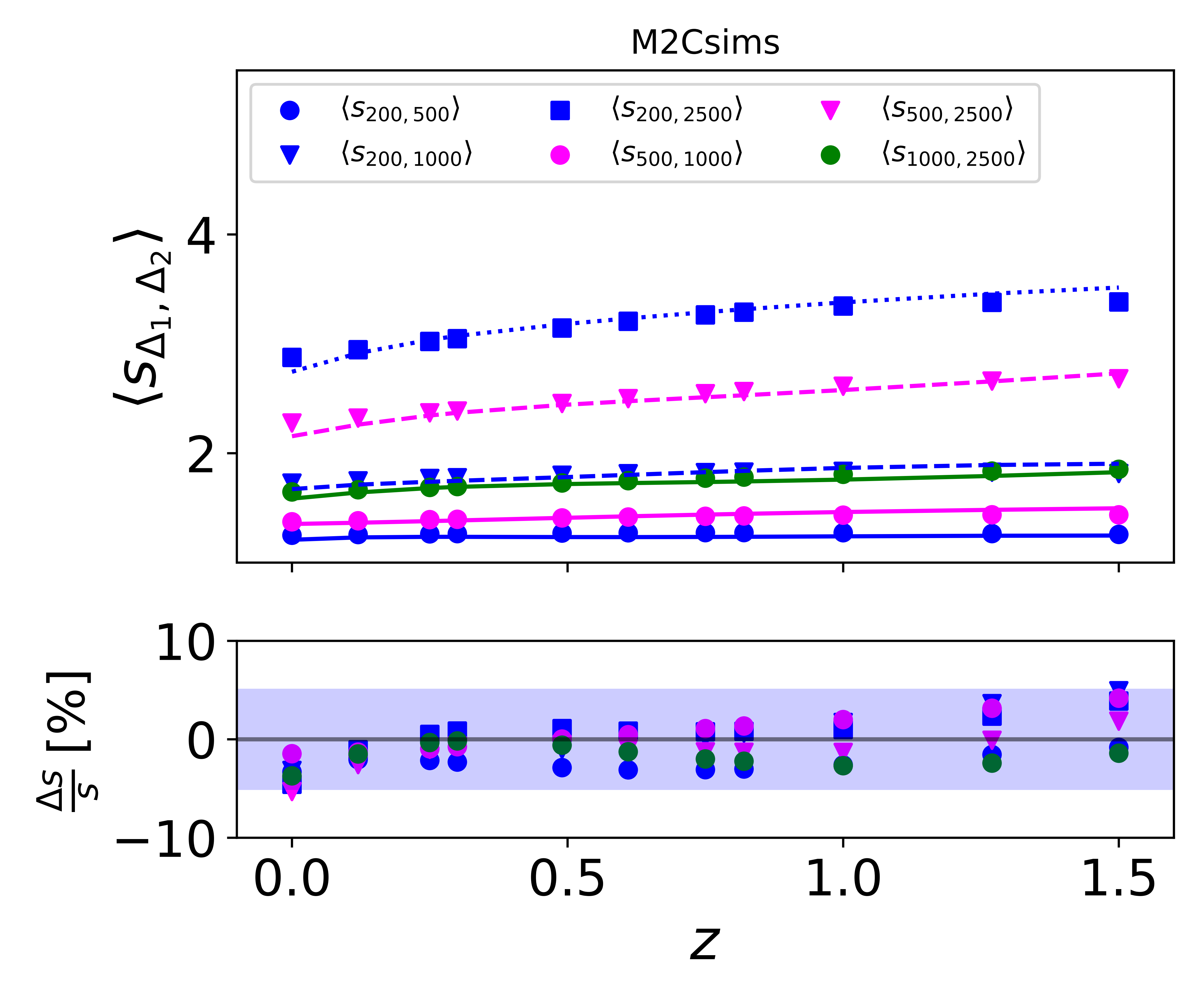


Figure 8. Marginalized 1σ and 2σ contours in the Ω_m–σ_8 plane from the combined analysis of the average cluster sparsity, gas mass fraction, and BAO data (black lines). As in Figure 4, we plot marginalized contours from the Planck primary CMB analysis (yellow and red contours) and the Planck-SZ number counts (dark and light blue contours). The plus sign corresponds to the best-fit ΛCDM model with parameter values $\hat{\Omega}_m = 0.320$ and $\hat{\sigma}_8 = 0.738$ (and $\hat{h} = 0.690$).

Halo sparsity prediction from HMF

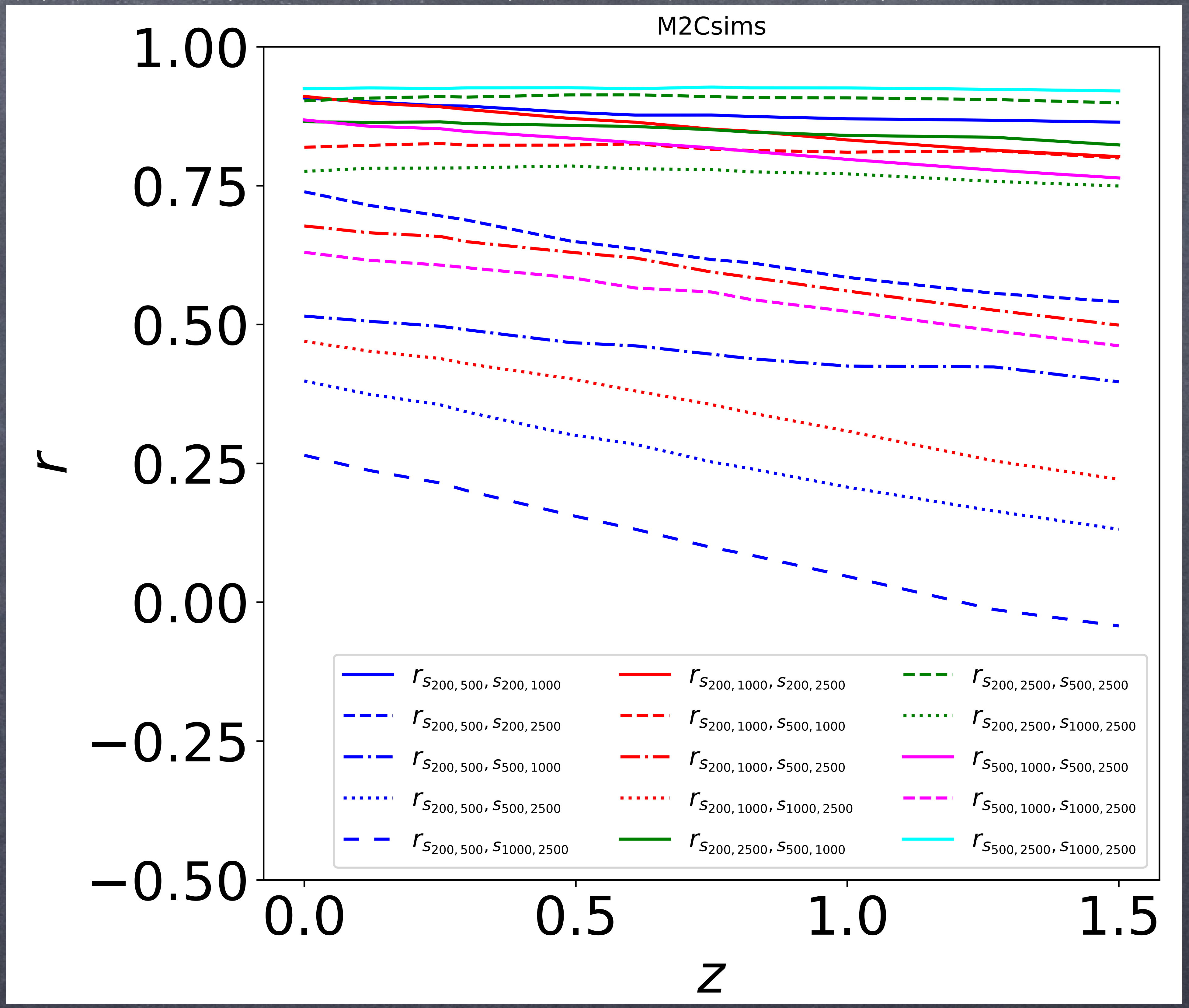
Corasaniti, Le Brun et al. 2022



Differences are well within 5% level

Correlations

- **All** correlations **increase** with **decreasing redshift**
- A **direct consequence** of halo mass assembly process (**inside-out growth**)
- **Smaller correlations** for sparsities sampling mass profile within mass shells at **larger separations**
- **Redshift evolution** of coefficients **well approximated** by linear regression



Corasaniti, Le Brun et al. 2022

Correlations: the NFW case

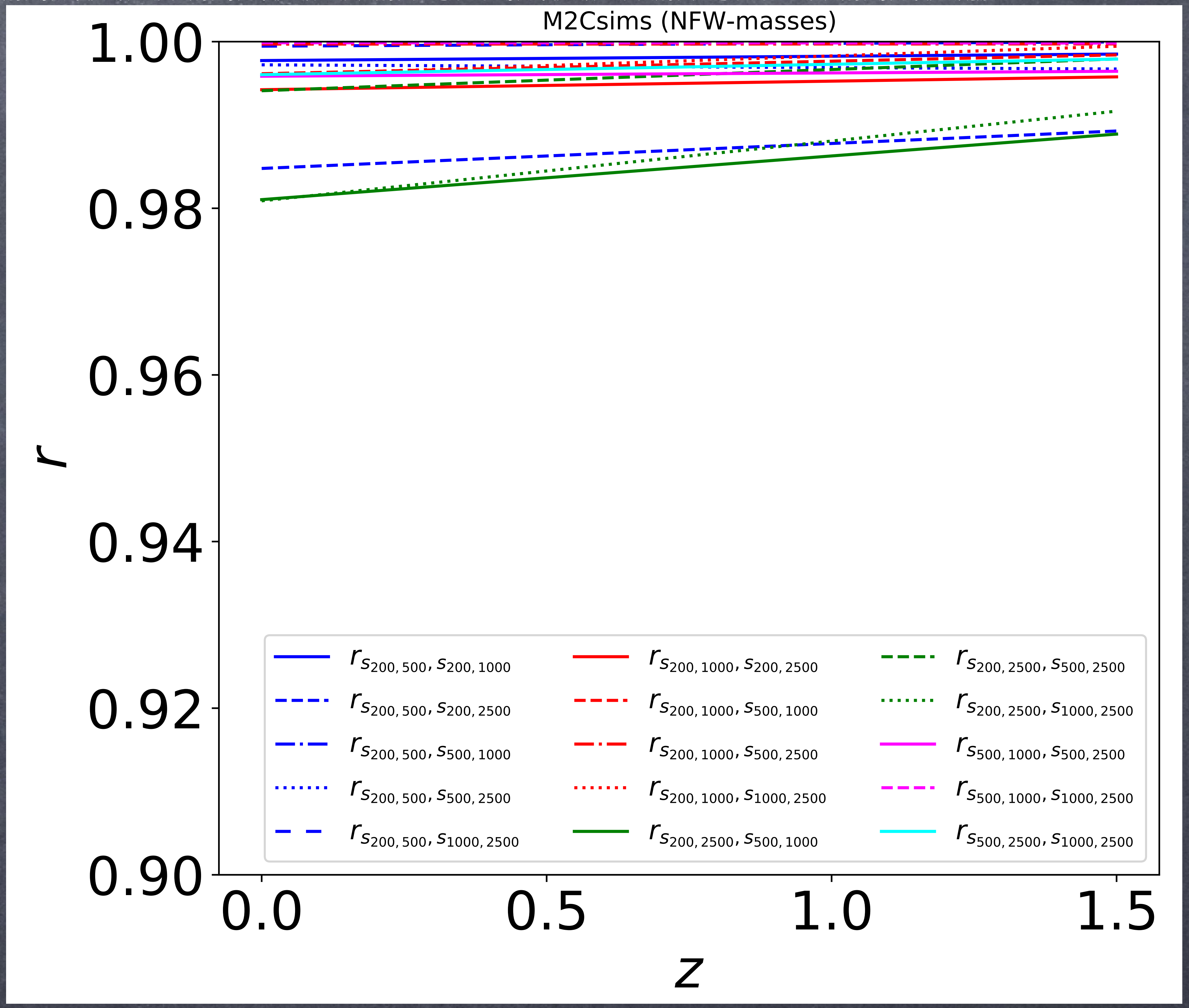
- If density profiles follow NFW exactly

➡ all information on mass profile fully encoded in values of overall halo mass and concentration parameter

- Due to one-to-one relation between halo sparsity and concentration for NFW haloes (Balmès et al. 2014)

➡ single sparsity estimate would carry all information on mass profile

- r<1 due to scatter in mass-concentration relation



Corasaniti, Le Brun et al. 2022

Cosmology with multiple sparsities

- Non-parametric cluster mass estimates at Δ=200c, 500c, 1000c and 2500c

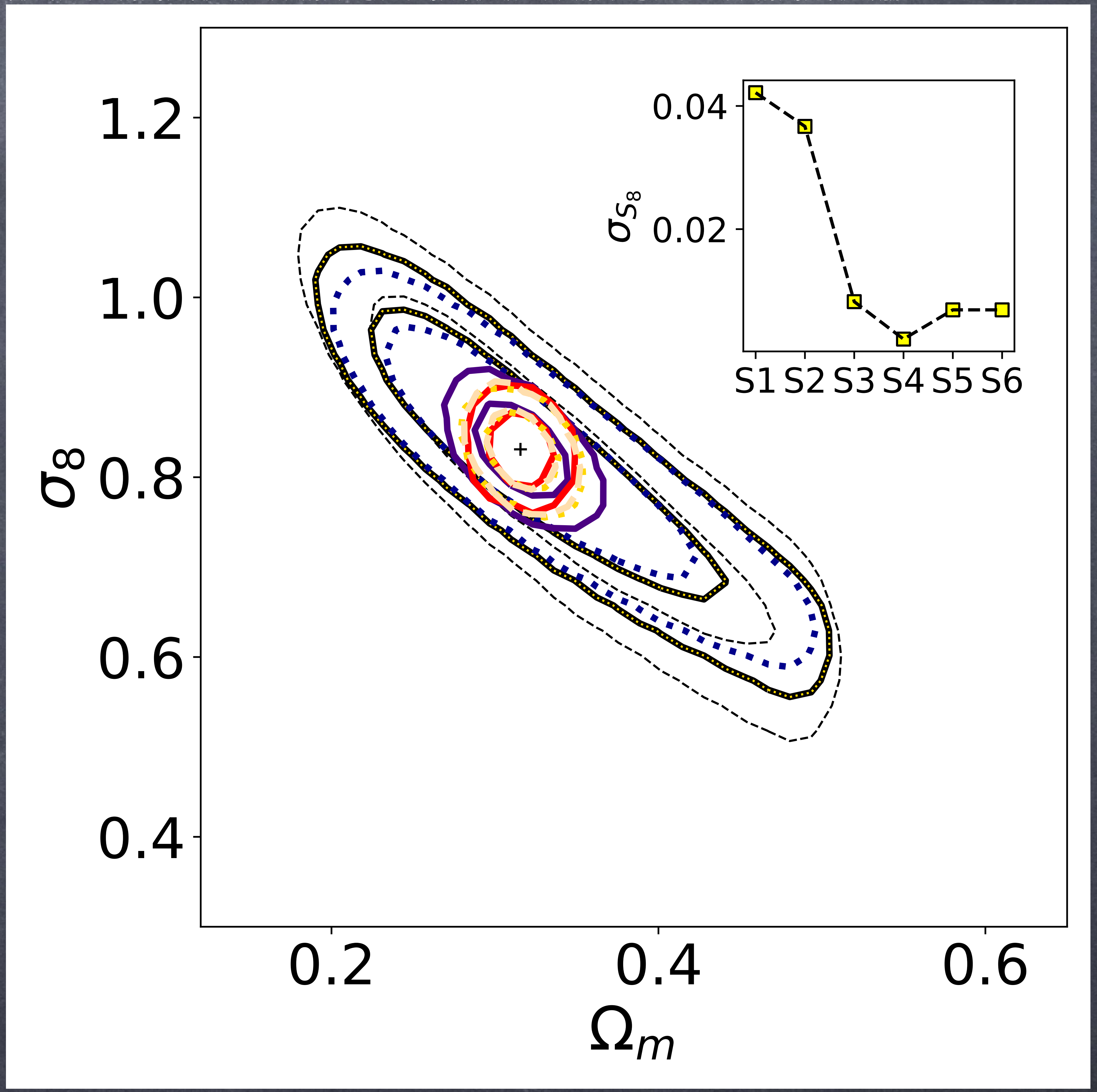
➡ N_s=6 sparsities

- Account for correlations

- MCMC analysis

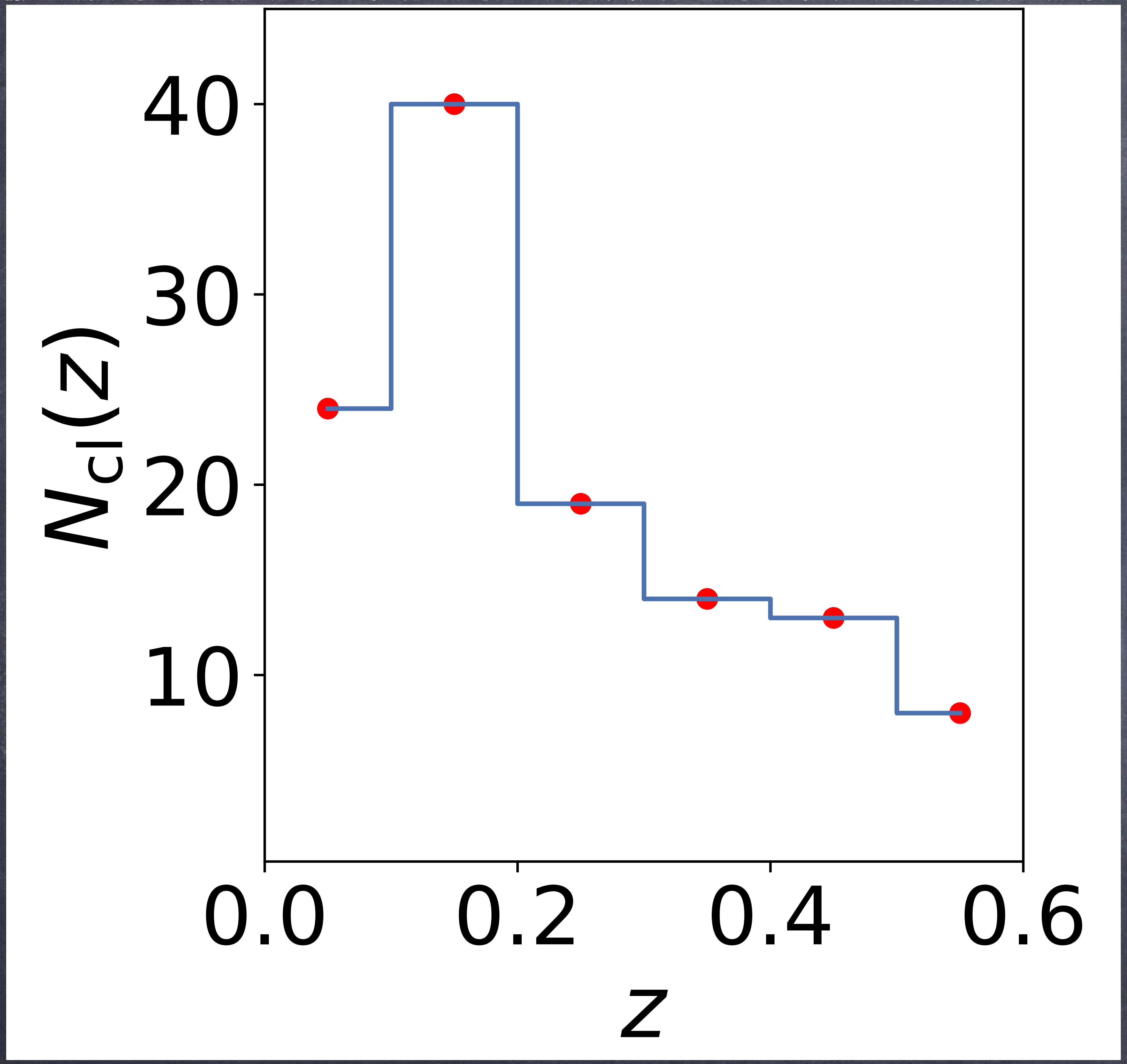
➡ Constraints saturate at N_s=4

➡ Additional sparsities break the S_8 degeneracy



Corasaniti, Le Brun et al. 2022

Forecast for CHEX-MATE I



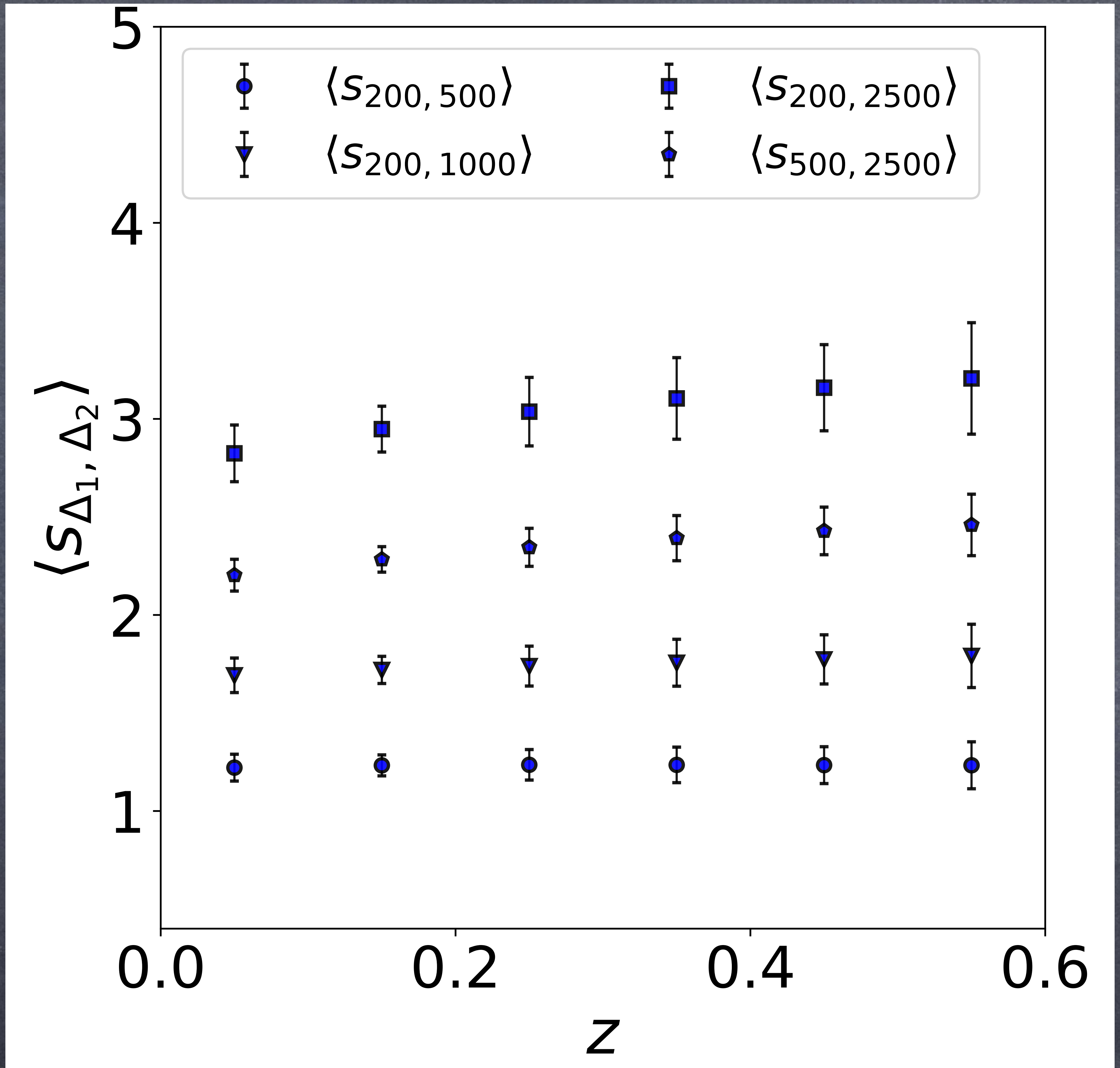
Data from CHEX-MATE project (CHEX-MATE Collaboration et al. 2021, incl. Le Brun)

	$\Delta b_{200,500}$	$\Delta b_{200,1000}$	$\Delta b_{200,2500}$	$\Delta b_{500,2500}$
HE mass bias	0.03	0.02	0.03	0.04
Baryon mass bias	0.04	0.10	0.15	0.10

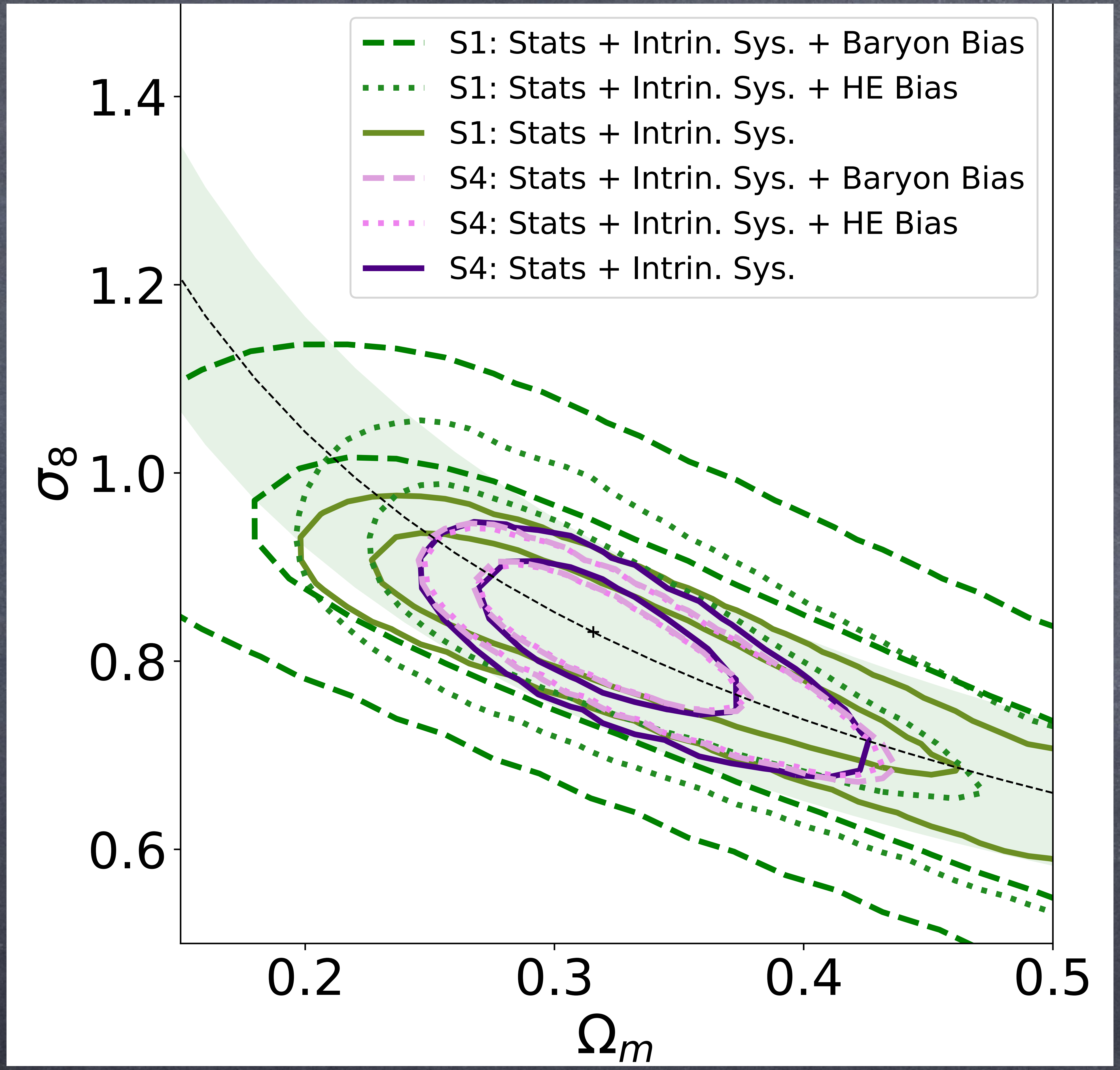
Corasaniti, Le Brun et al. 2022

Forecast for CHEX-MATE II

Corasaniti, Le Brun et al. 2022



Forecast for CHEX-MATE III



Corasaniti, Le Brun et al. 2022

Additional sparsities break some of the S_8 degeneracy

Take-home messages

- Sparsities associated with mass distribution in distinct spherical halo shells not highly correlated

➡ Additional cosmological information encoded in average halo mass profile. Can be exploited through multiple sparsity measurements

- Sparsities obtained using mass estimates derived from NFW best-fitting density profile result in correlations close to unity and significantly different from those inferred from analysis of halo masses

➡ Suggests that imposing NFW profile to haloes performs strong compression that misses cosmological information imprinted on different regions of halo mass profile.

- Constraints improvement saturates beyond four sparsities
- Strongly encourage development of methodologies capable of providing independent mass estimates at different overdensities free of profile shape assumptions

Thank you!