Cosmology with multiple halo sparsities

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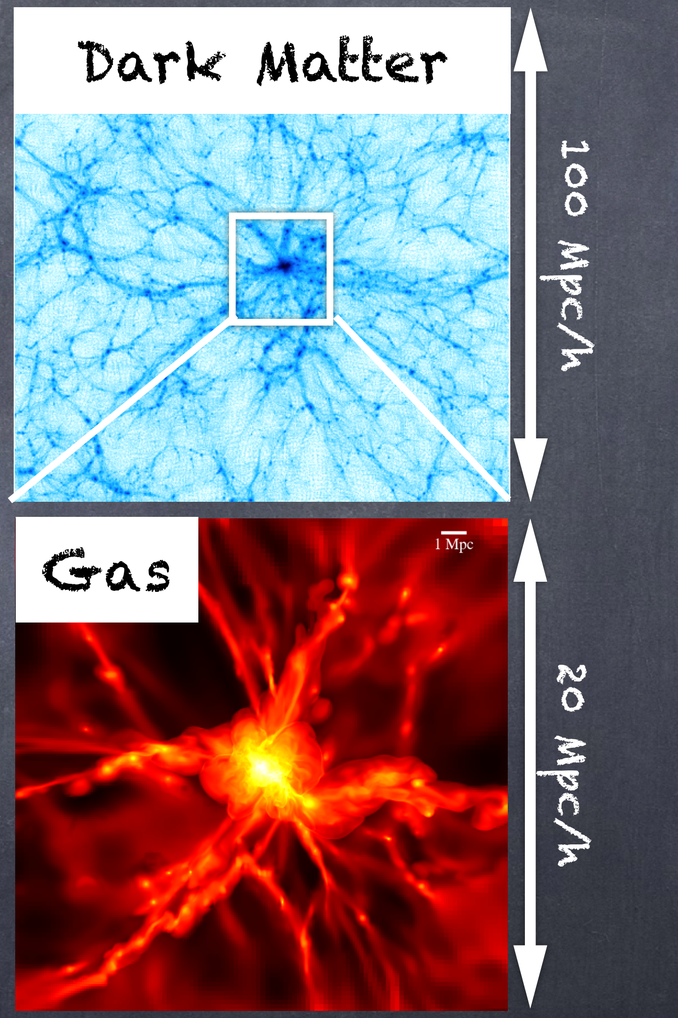
Le Brun et al. 2018

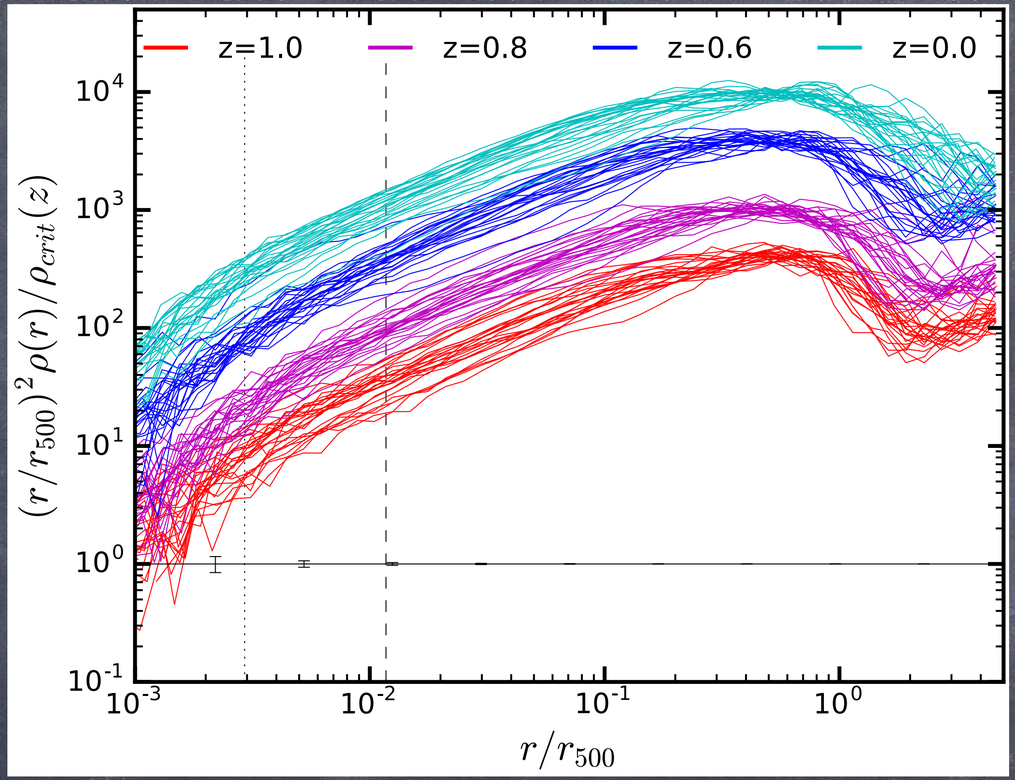
M2Csims Simulations

- 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 $M_{500}>4.49 \times 10^{14}\ M_\odot$: 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

Le Brun et al. 2018

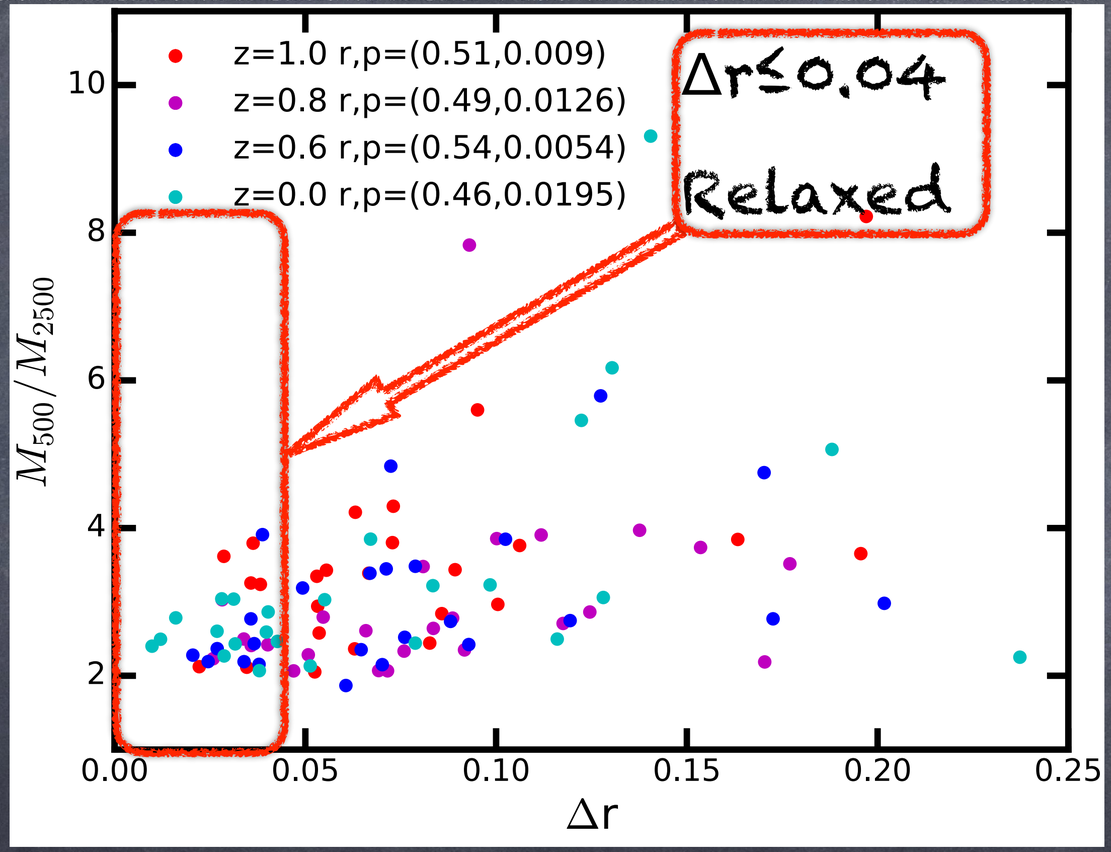


- Zoom ⇒ gain of a factor > 5 in spatial resolution
- Fluctuations are real

Le Brun et al. 2018

Correlation with relaxation state

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

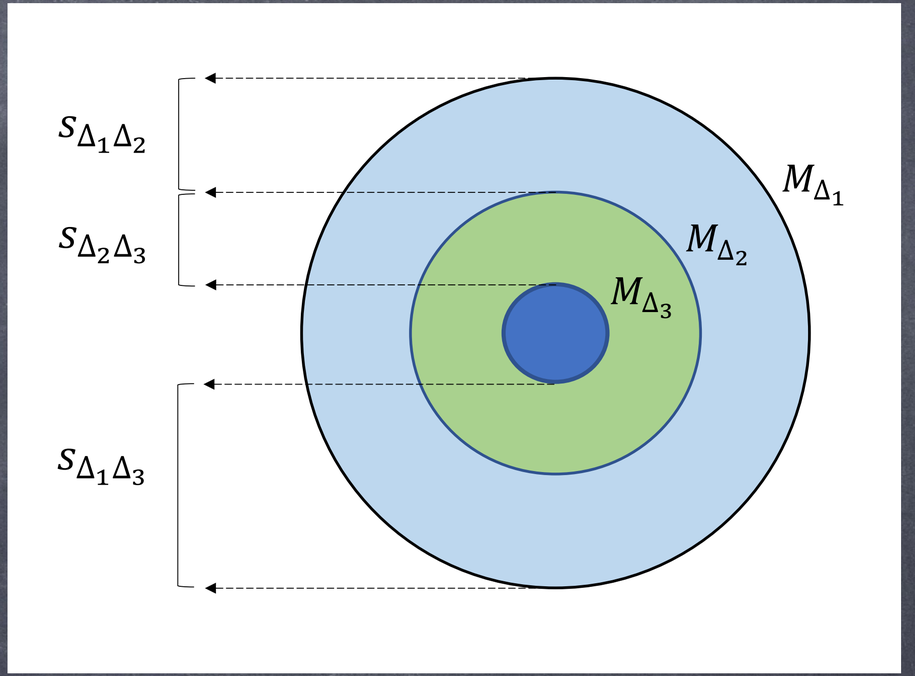


- Most relaxed clusters centrally concentrated
- Unrelaxed ones span larger variety of profile shapes

Halo sparsity

Characterising the mass profile with sparsity $s_{\Delta 1,\Delta 2}=M_{\Delta 1}/M_{\Delta 2}$ ($\Delta_1<\Delta_2$)

- 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 (2204.06582)

Cosmology with sparsity

Corasaniti, Sereno & Ettori 2021

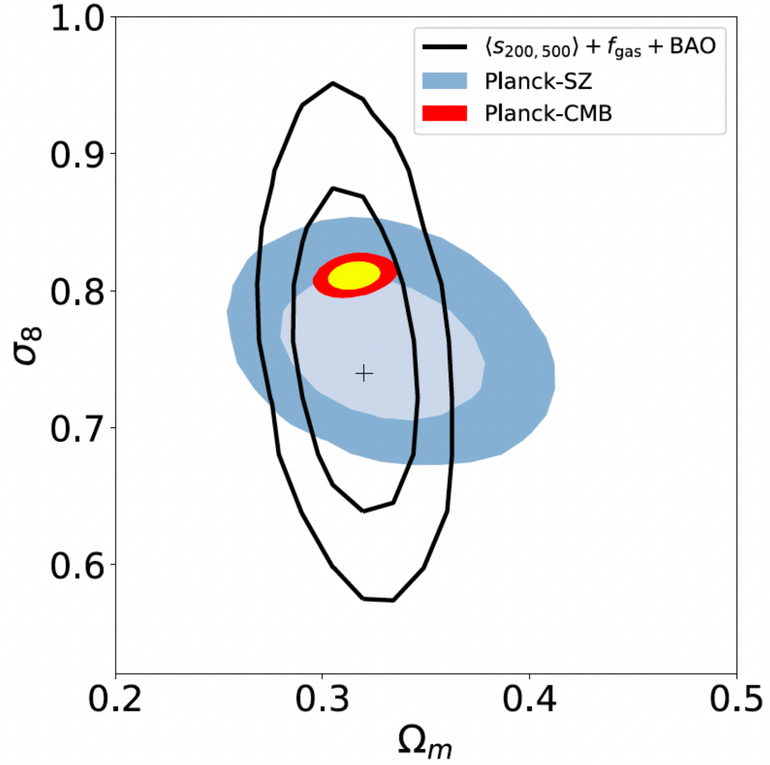
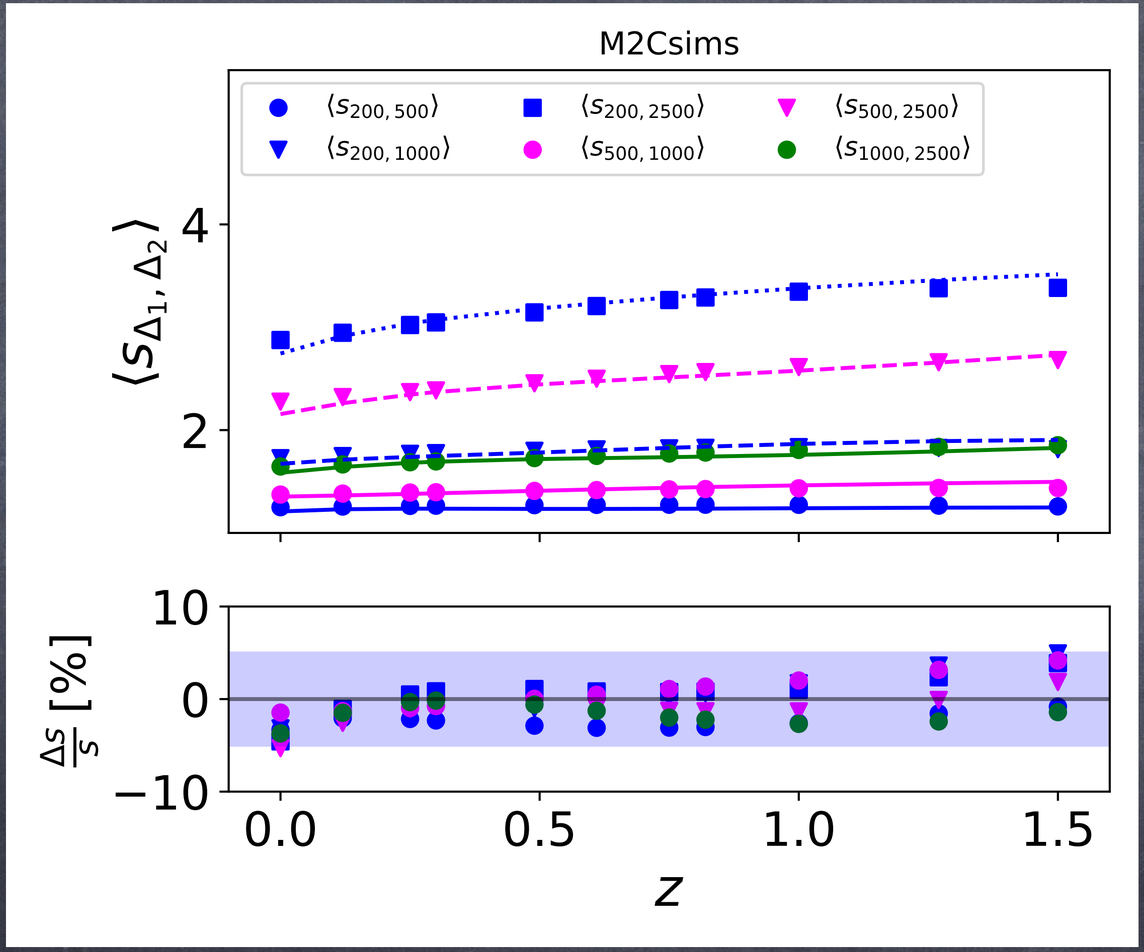


Figure 8. Marginalized 1σ and 2σ contours in the Ω_m–σ_8 plane from the combined analysis of the average cluster sparsity, gas mass fraction, and BAO data (black lines). As in Figure 4, we plot marginalized contours from the Planck primary CMB analysis (yellow and red contours) and the Planck-SZ number 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

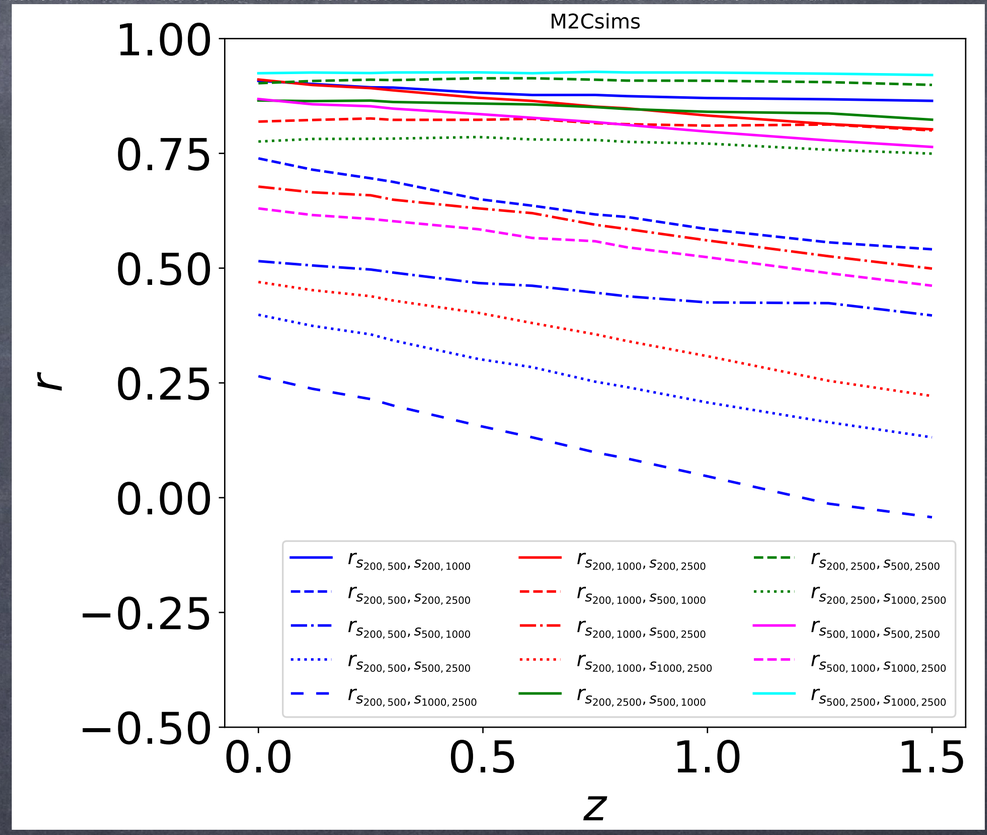


Corasaniti, Le Brun et al. 2022 (2204.06582)

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 (2204.06582)

Correlations: the NFW case

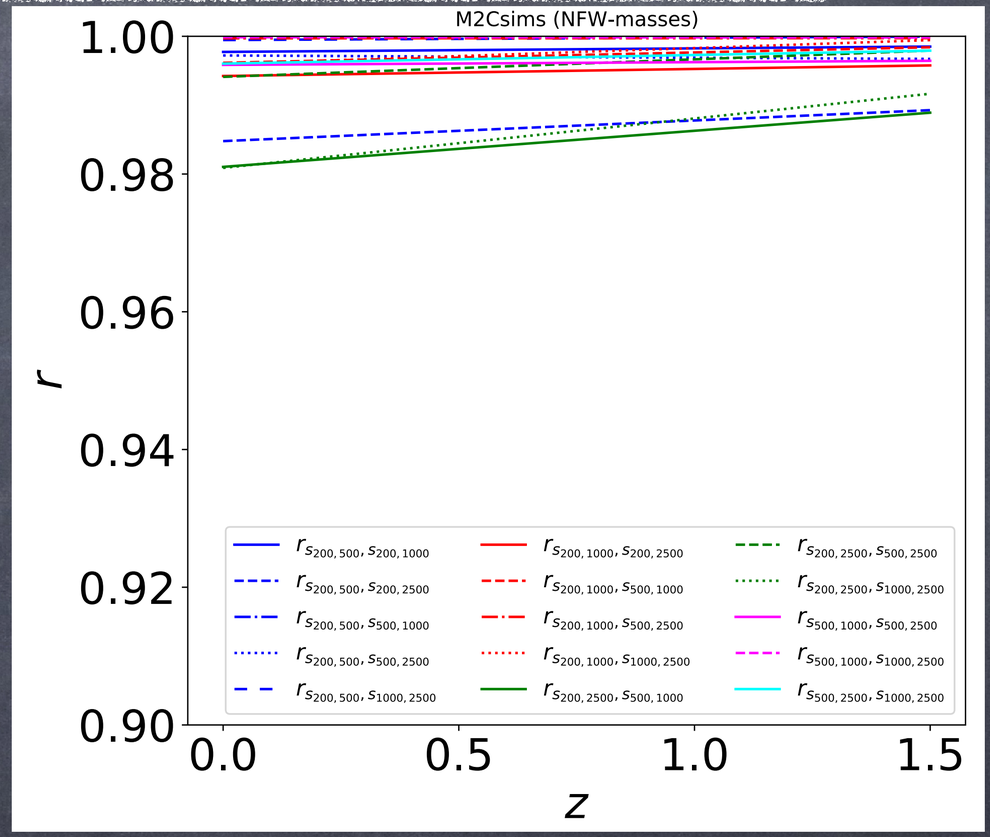
- If density profiles follow NFW exactly

➡ 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 (2204.06582)

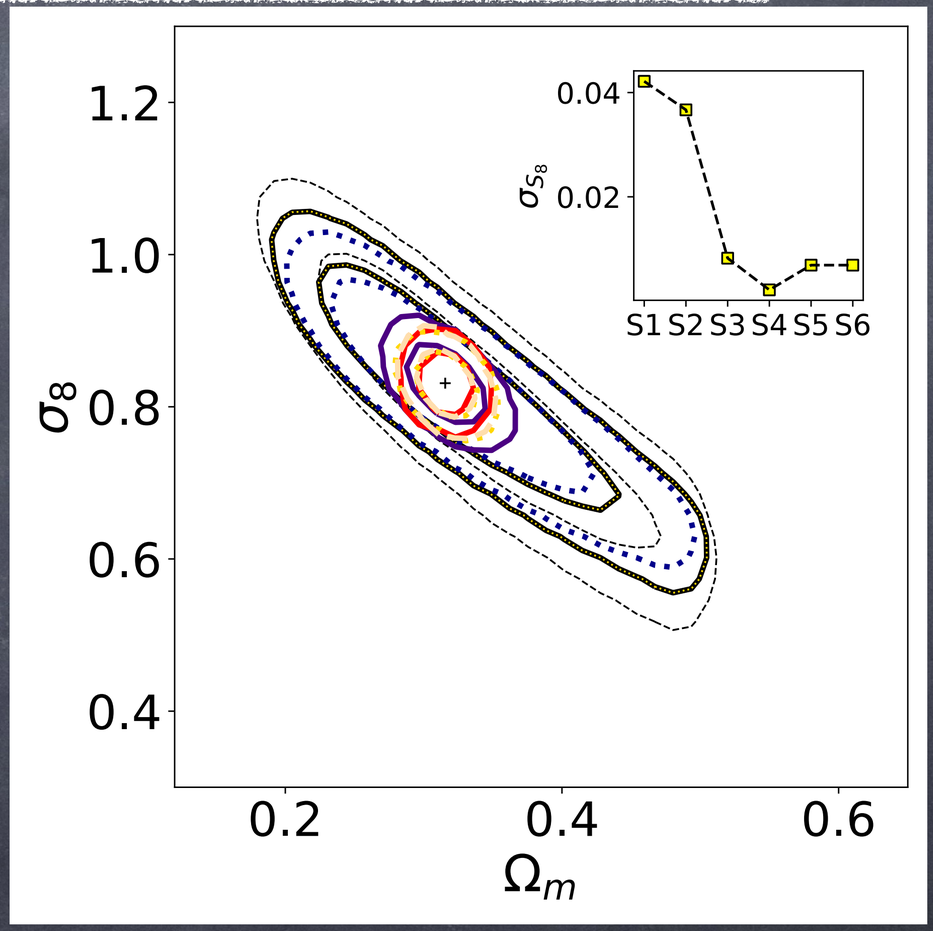
Cosmology with multiple sparsities

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

➡ N_s=6 sparsities

- Account for correlations
- MCMC analysis

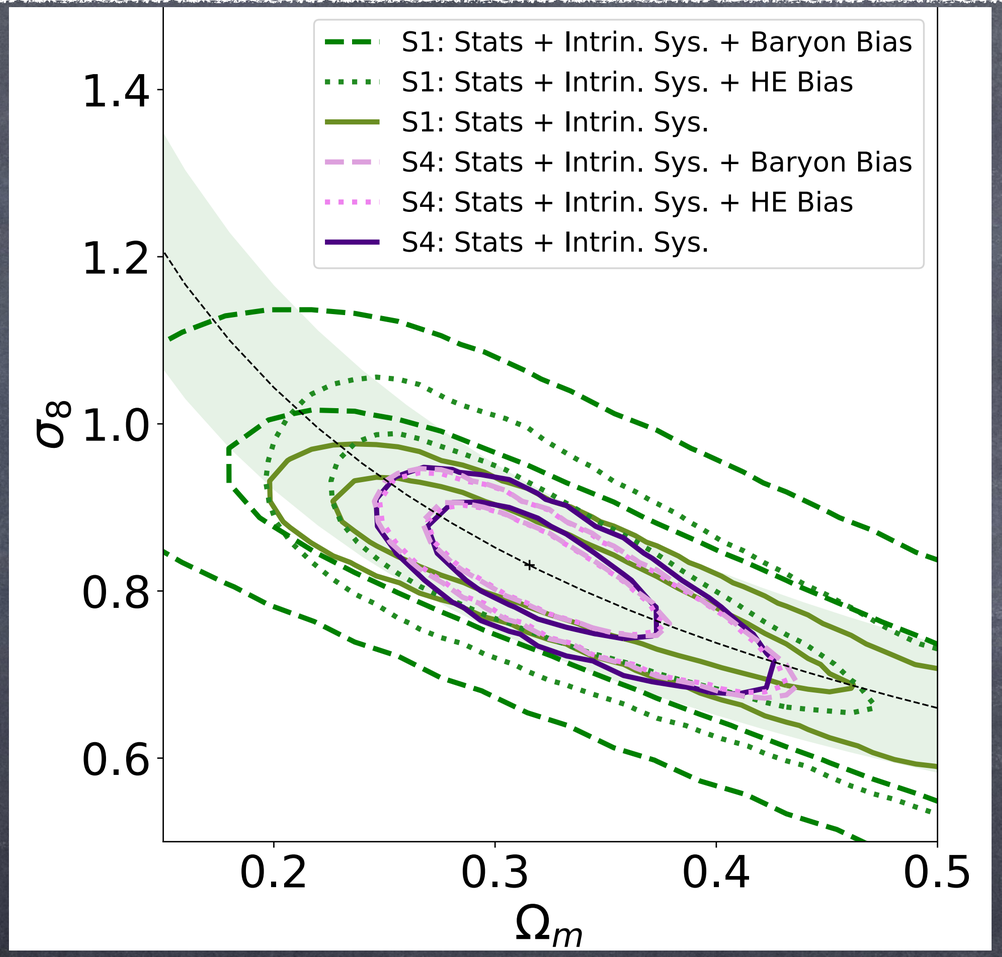
➡ Constraints saturate at N_s=4



Corasaniti, Le Brun et al. 2022 (2204.06582)

Forecast for CHEX-MATE

Corasaniti, Le Brun et al. 2022 (2204.06582)



Additional sparsities break 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!