Deciphering Baryonic Feedback from tSZ Galaxy Clusters

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Introduction

The next generation of cosmic shear experiments (Roman, Rubin) will probe the structure of our universe to unmatched precision.
In order to extract all the information from these surveys, we need to better model the clustering of matter at smaller scales.
Baryonic effects (e.g. AGN, stellar physics) cause a characteristic suppression in the matter power spectrum at scales below $k \sim 1\,h\,\mathrm{Mpc}^{-1}$ (Fig. 2). Cosmological scale hydrodynamical simulations vary considerably in their predictions of the extent of this suppression due to different implementations of baryonic physics.

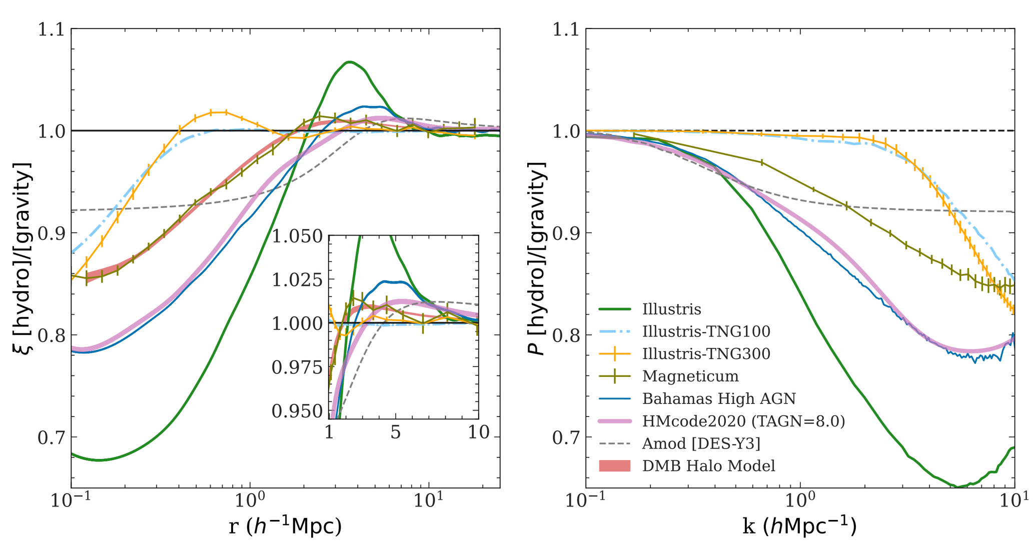


Fig. 1: Left: Baryonic effects in real space cause matter to be pushed out from small scales, and create an excess in clustering at $r \sim 2h^{-1}\mathrm{Mpc}$. Right: Corresponding suppression in the matter power spectrum for a series of commonly used hydrodynamical simulations [3]

The small scale modeling uncertainties lead to scale cuts in cosmic shear, where we throw out any information coming from scales where hydrodynamical simulations disagree with one another. This limits our precision on several cosmological parameters of interest, namely the amplitude of matter density fluctuations S_8 and the matter density in the universe Ω_m.
To make complete use of the information that the Roman HLIS will provide, it is crucial that we find a robust and flexible model for baryonic physics that can further be constrained and tested by other probes.

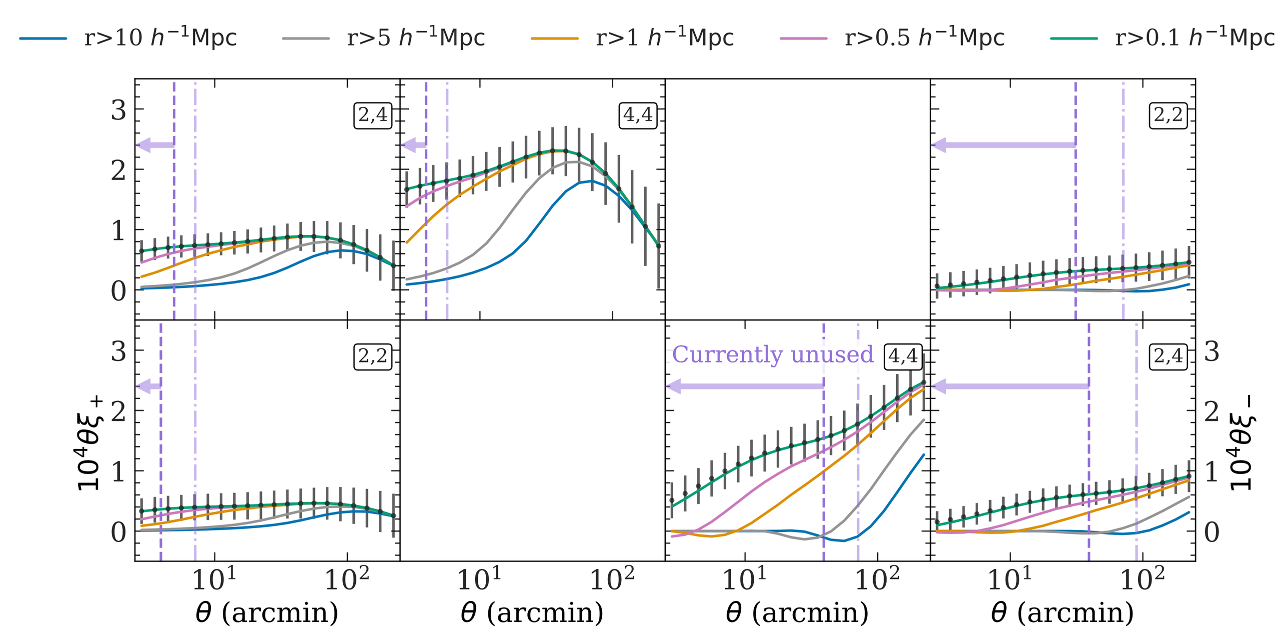


Fig. 2: Scale cuts in Dark Energy Survey Y3 Cosmic Shear Analysis [3]

Detecting Clusters

The **thermal Sunyaev Zeldovich (tSZ)** effect refers to the spectral distortion of CMB signal through inverse compton scattering by high energy electrons in galaxy clusters. The tSZ signal provides a method of selecting galaxy clusters that is free from severe projection effects and difficult-to-model systematics.

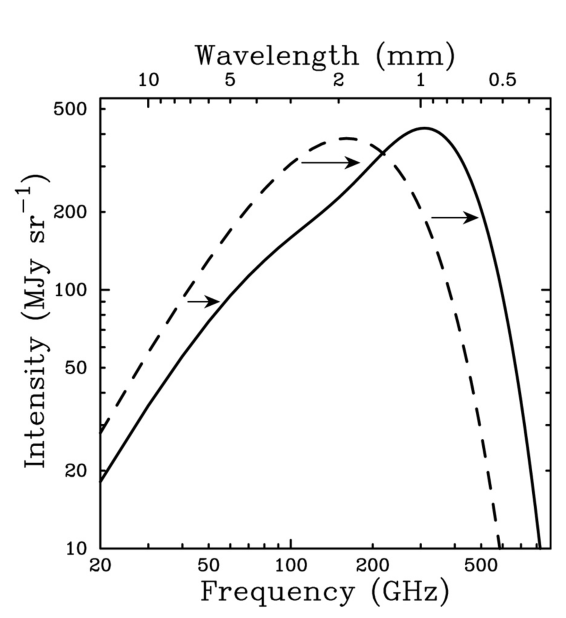


Fig. 3: The SZ Effect Causes a general shift in the blackbody spectrum, as all photons gain energy as they scatter with high energy electrons from a cluster. Depending on the frequency, this may lead to higher or lower intensity in the CMB spectrum [1]

Motivation

The tSZ signal is characterized by the **Compton Y** parameter, which essentially encodes the electron pressure in a cluster. CMB experiments such as the Atacama Cosmology Telescope (ACT) and the South Pole Telescope (SPT) construct mass observable relations with the Compton Y parameter, often using masses calibrated from weak lensing photometric surveys such as the Dark Energy Survey (DES). We can also compute the Y-M relation analytically using a given model for the electron pressure in clusters, and compare this to the observed Y-M relation from a CMB survey.

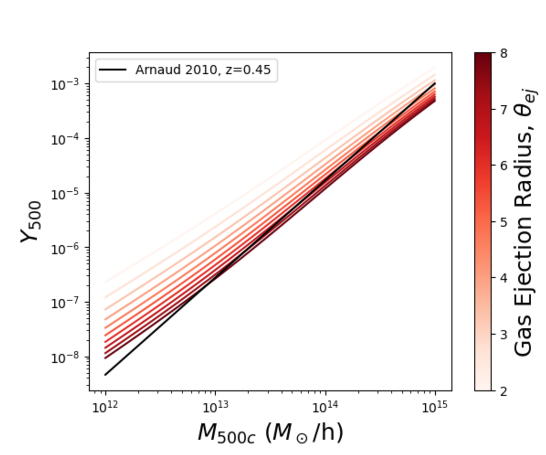


Fig. 4: The Compton Y-M relation exhibits a strong dependence on the gas ejection radius parameter θ_ej

Model

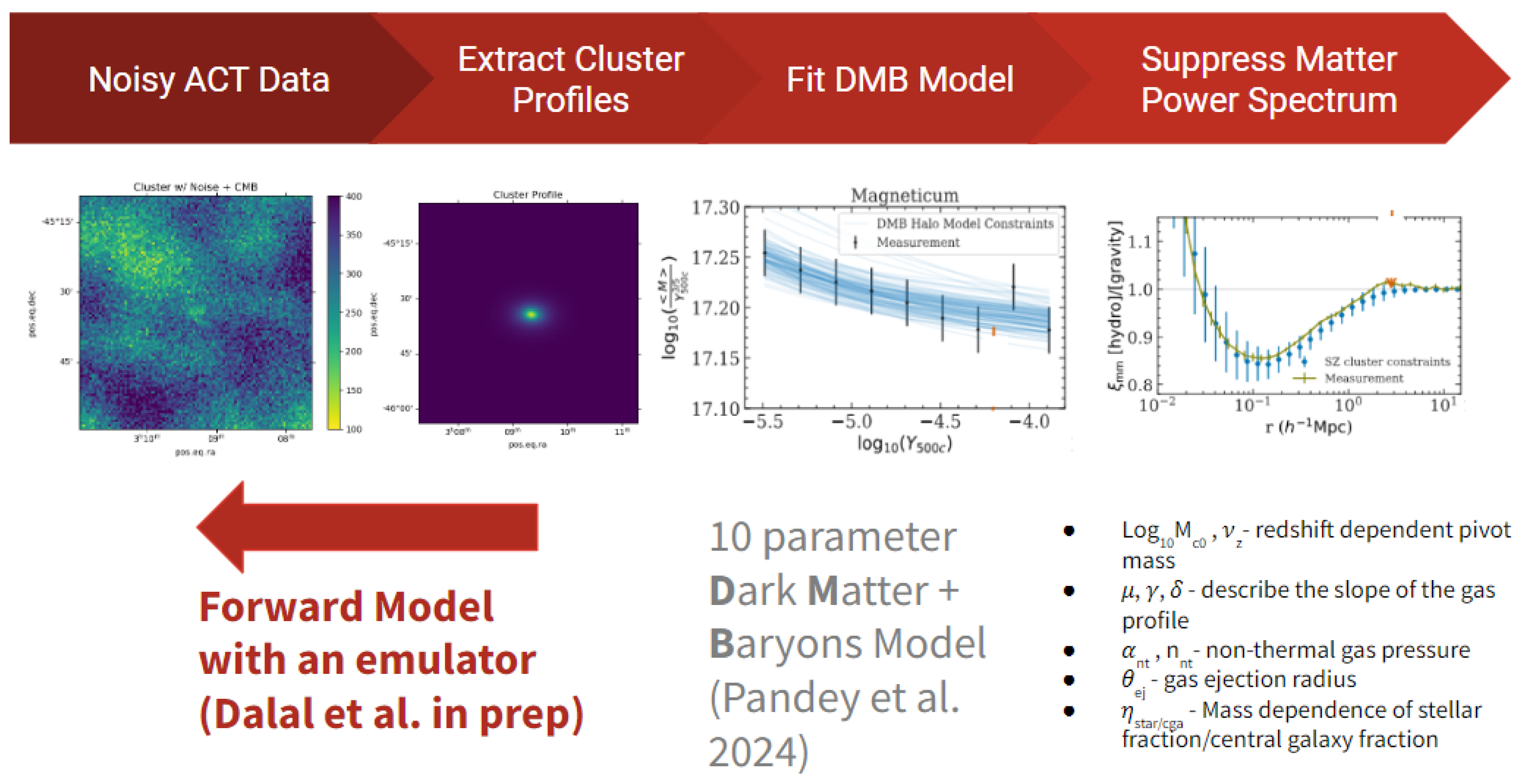
We analytically model the baryon-corrected dark matter profile following [2] by breaking the halo into three components:

$$\rho_\mathrm{dmb} = \rho_\mathrm{clm} + \rho_\mathrm{gas} + \rho_\mathrm{stellar} \quad (1)$$

Assuming hydrostatic equilibrium, we can compute an electron pressure profile from ρ_gas and a Compton Y_{500c} corresponding to the tSZ signal.

$$P_e = \frac{4-2Y}{8-5Y} P_\mathrm{thermal}, \quad Y = 0.24 \quad (2)$$

$$Y_{500c} = \frac{\sigma_T}{m_e c^2} \int_0^{R_{500c}} P_e(r) 4\pi r^2 \, dr \quad (3)$$



Forecasts

We perform Fisher forecasts to quantify the systematic biases and increased uncertainties in the $S_8 = \sigma_8(\Omega_\mathrm{m}/0.3)^{1/2}$ parameter due to DMB misspecifications and DMB parameter uncertainties.
The analyses assume a ΛCDM cosmological model, and marginalize over observational and astrophysical systematics. To make the most conservative estimates, we chose to fix the DMB model parameters when performing the forecasts rather than using a joint fit technique.
The systematic biases are quantified via a Fisher bias formalism to transform the DMB parameter misspecification into a bias on S_8.

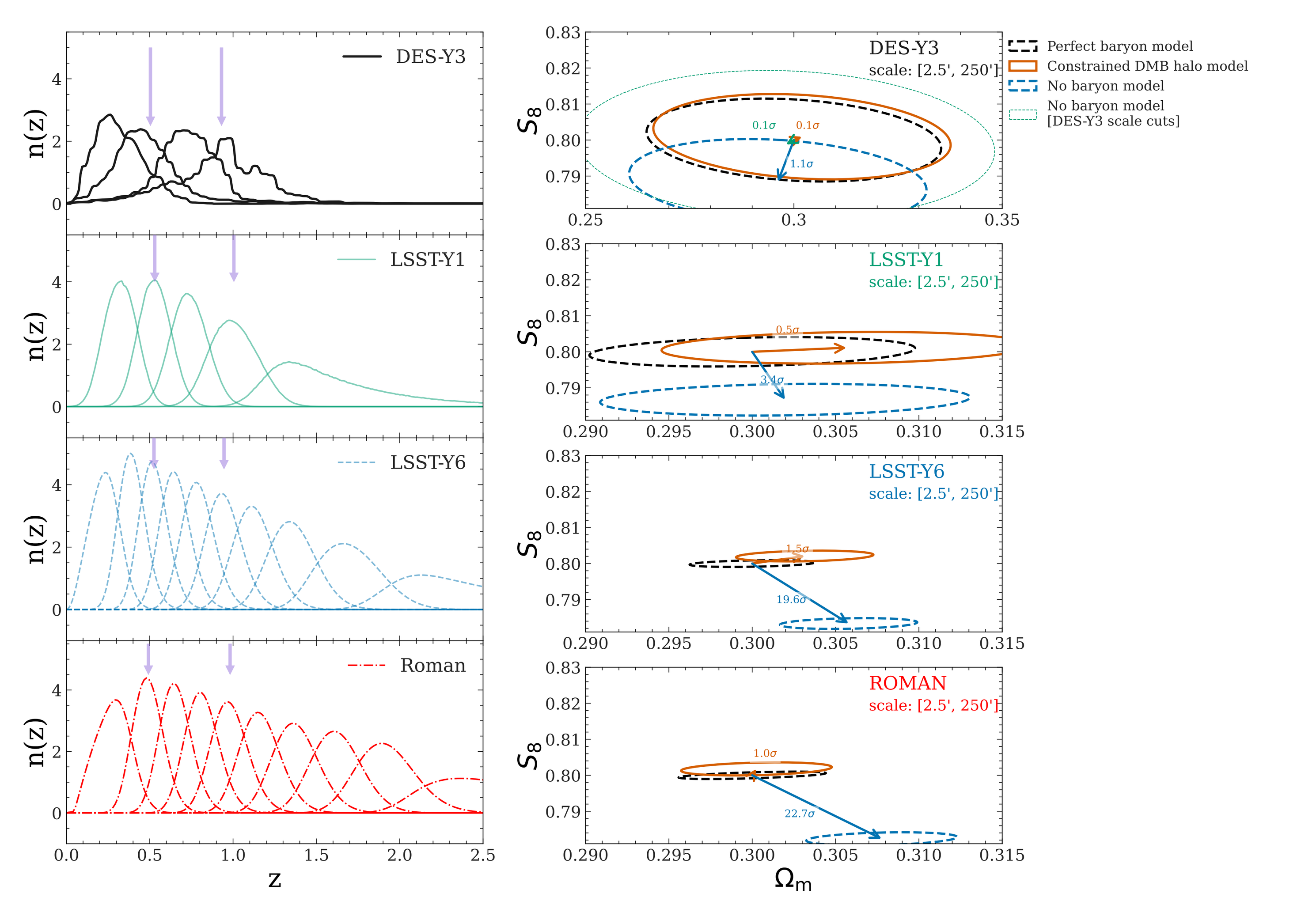


Fig. 6: Left: Simulated redshift distributions of LSST and Roman soruce galaxies + DES source bins. Right: Forecasted cosmic shear constraints on S_8 and Ω_m. Contours show the 1σ confidence region. Black contours assume perfect baryon model, orange contours correspond to our DMB model, and blue lines correspond to a gravity only model. [3]

Conclusions & Future Work

- Baryonic effects will play a crucial role in the precision and accuracy of our cosmological constraints in the upcoming decade.
- We will constrain the DMB model using ACT and DES data
- We will test how constraints differ when using a joint fit method
- We plan to incorporate the DMB model into the Roman Cosmology Pipeline

Acknowledgements

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References

[1] John E. Carlstrom et al. "Cosmology with the Sunyaev-Zel'dovich Effect". In: 40.1 (Sept. 2002), pp. 643–680.

[2] Shivam Pandey et al. *GODMAX: Modeling gas thermodynamics and matter distribution using JAX.* 2024. arXiv: 2401.18072.

[3] Chun-Hao To et al. *Deciphering baryonic feedback with galaxy clusters.* 2024. arXiv: 2402.00110.