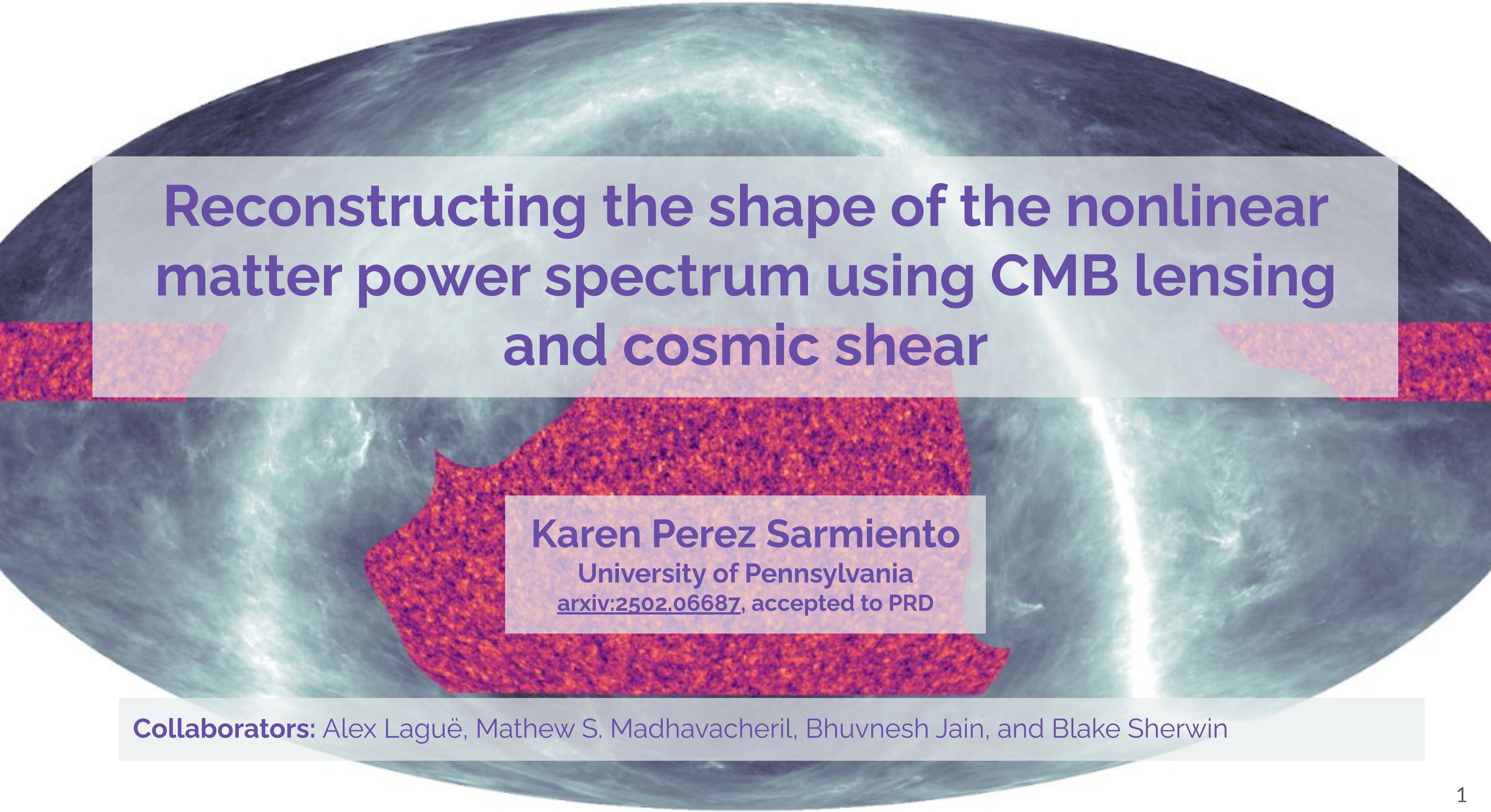


Reconstructing the shape of the nonlinear matter power spectrum using CMB lensing and cosmic shear

Karen Perez Sarmiento

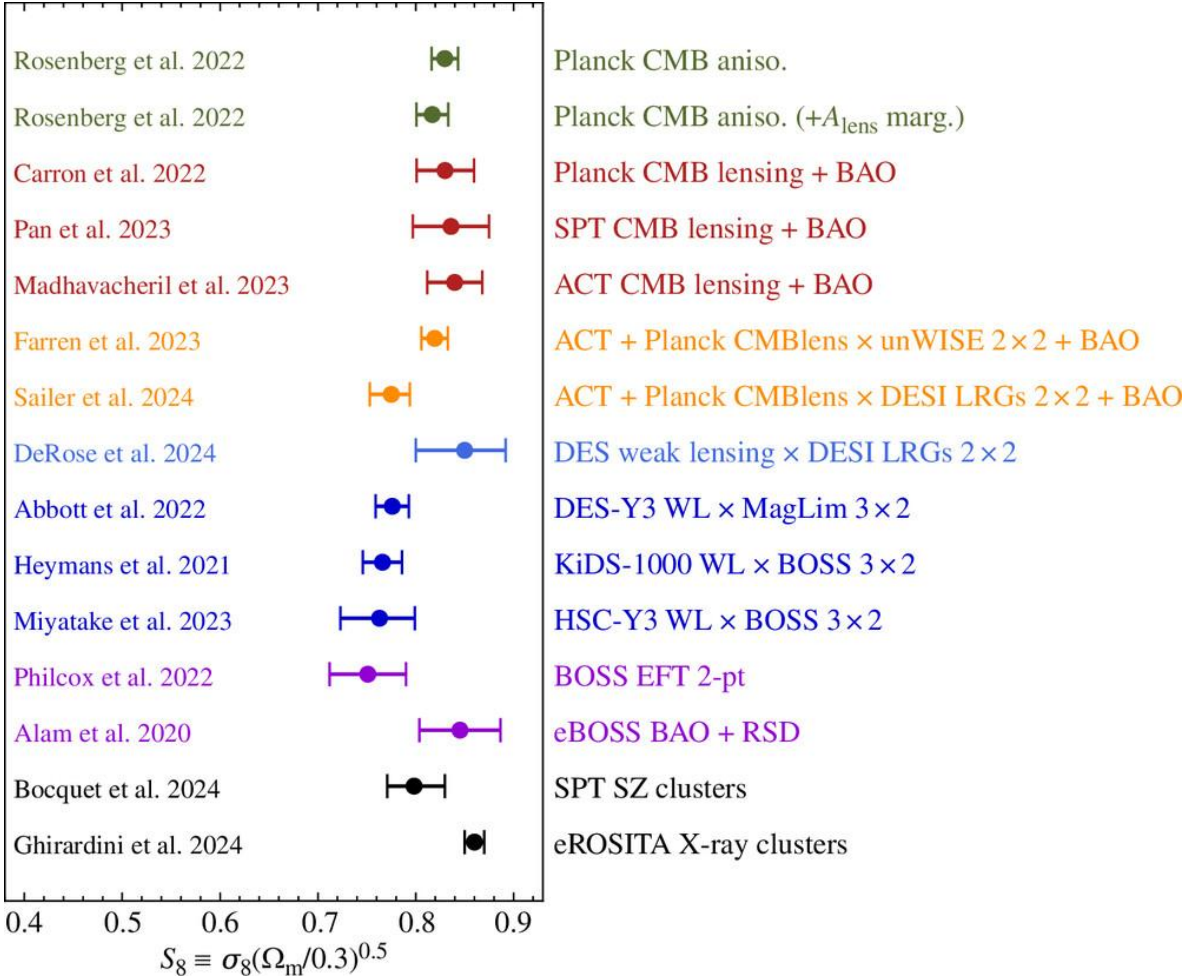
University of Pennsylvania

arxiv:2502.06687, accepted to PRD

Collaborators: Alex Laguë, Mathew S. Madhavacheril, Bhuvnesh Jain, and Blake Sherwin

S_8 tension

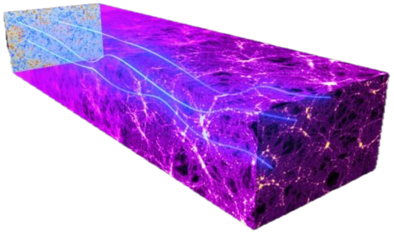
Early-time and late-time measurements of S_8 are in 2-3σ tension with each other!

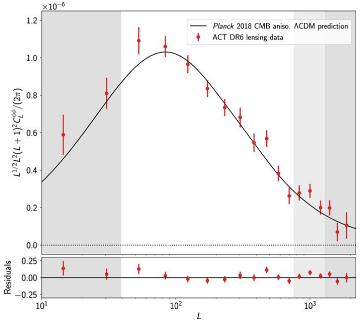


Madhavacheril, 2025

Different probes for the growth of structure

CMB Lensing





Qu et al. 2024

Cosmic shear

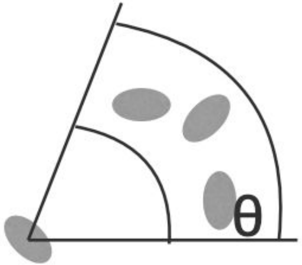
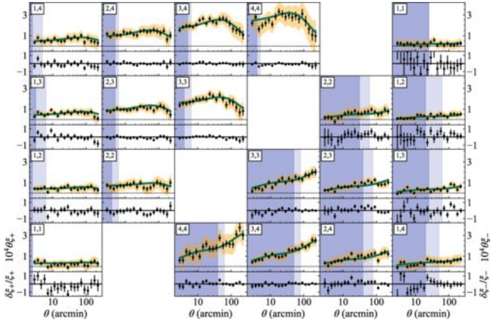
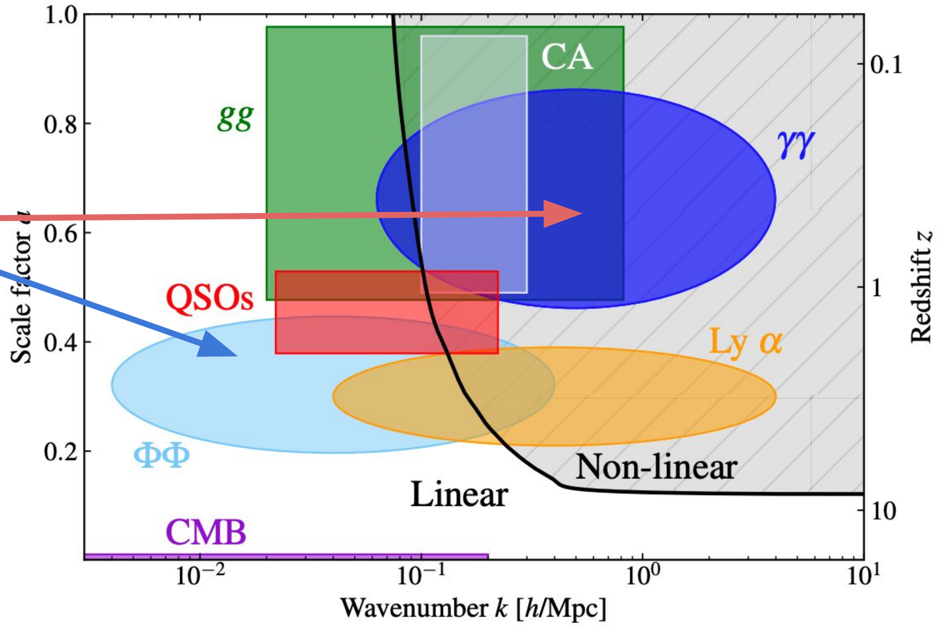


Image credits:
Elizabeth Krause



Amon et al. 2022

CMB lensing and **cosmic shear** are sensitive to different regions of the redshift-scale space for the growth of structure



Broxterman and Kuijken, 2024.

Possible solutions to the S_8 tension

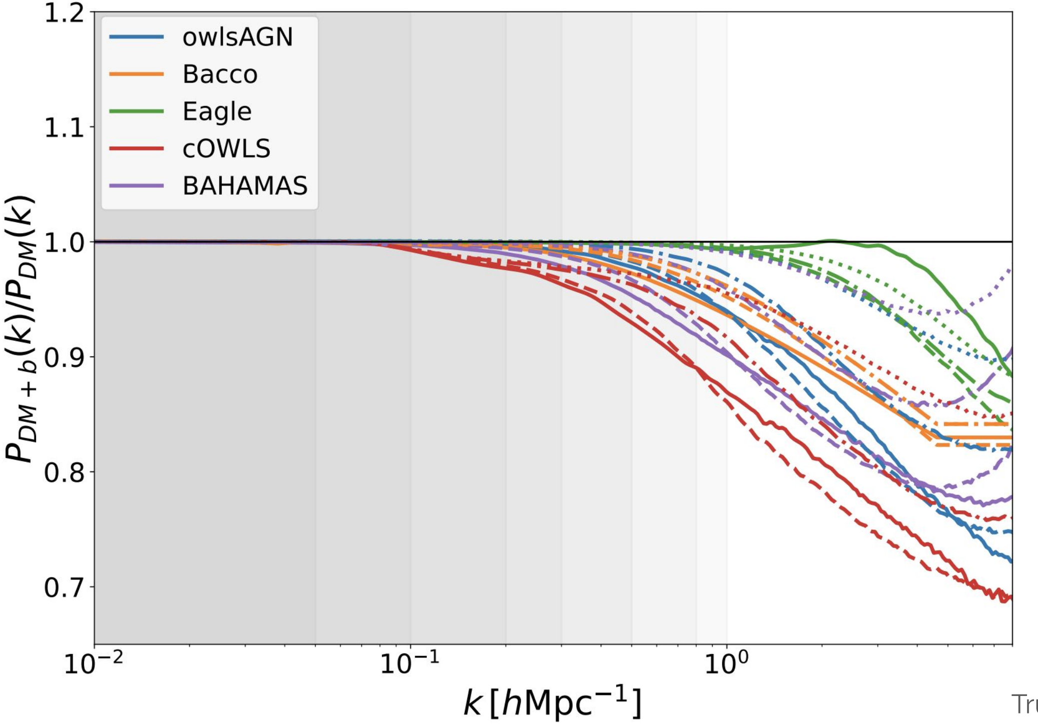
Systematics and uncertainties of measurements

- Redshift uncertainties
- Biases introduced by intrinsic alignment
- **Baryonic feedback processes**

New Physics

- Dynamical dark energy
- **Non-standard dark matter: axion, self-interacting, warm etc**
- Deviations from GR

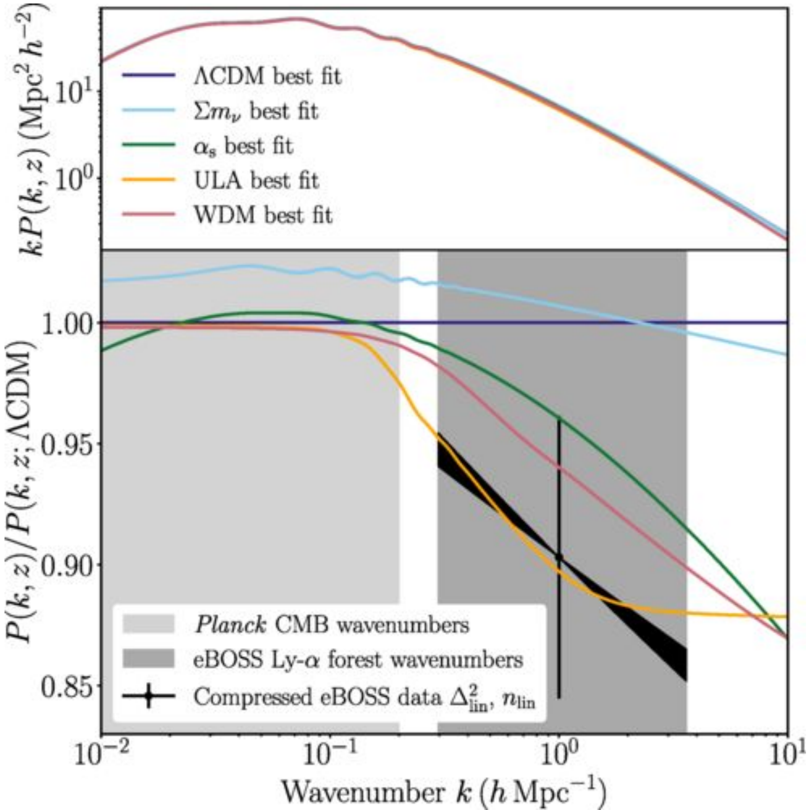
Baryonic feedback and the S_8 tension



Solid lines z=0
Dashed lines z=1
Dashed dotted z =2
Dotted lines z=3

Truttero et al 2025 (2410.18191)

New Physics and the S8 tension



Rogers and Poulin, 2025.

Goal

Measure suppression or enhancement of the observed matter power spectrum with respect to a fiducial matter power spectrum as a function of scale (k).

- **CMB Lensing:** Atacama Cosmology Telescope DR6 lensing power spectrum
- **Cosmic shear:** Dark Energy Survey Y3 cosmic shear data

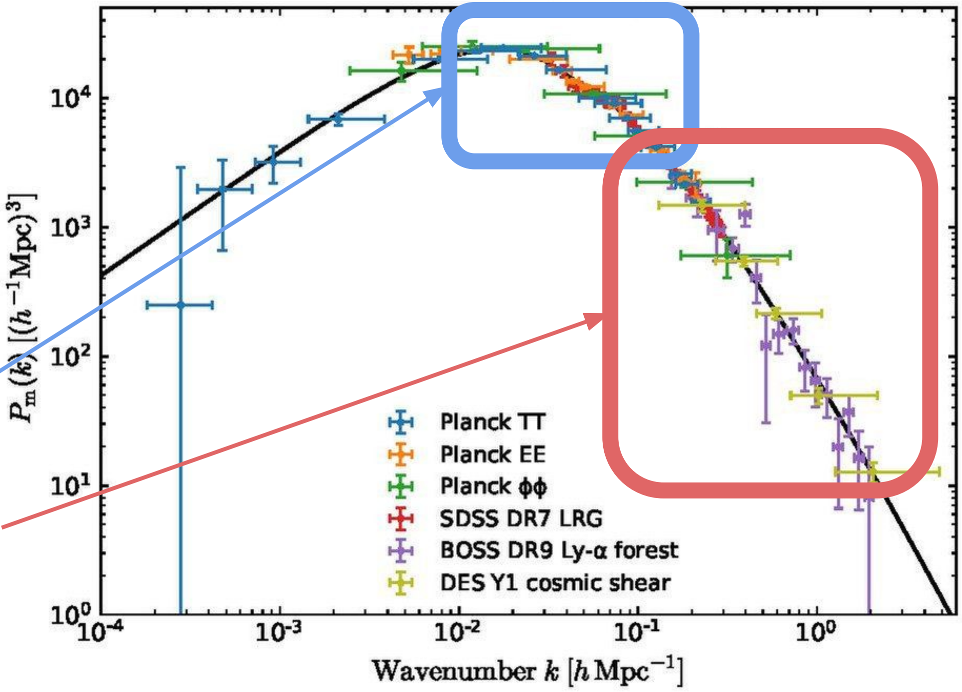


Image credit: ESA and the Planck Collaboration

Model

We propose to modify the matter power spectrum by some parameters α_i over a range of k's

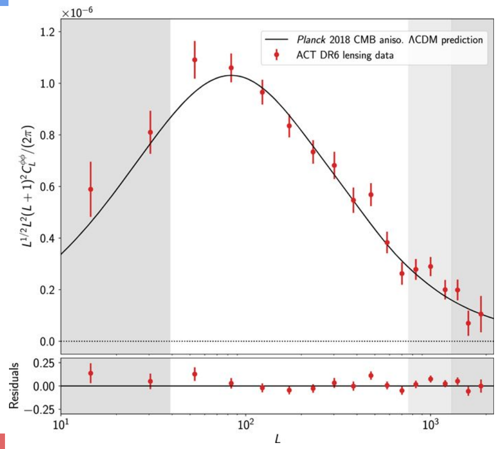
$$P(k, z) = \sum_i^{N_\alpha} \alpha_i \mathbb{B}(k, k_i^l, k_i^h) P^{\text{fid}}(k, z)$$

where:

$$\mathbb{B}(k, k_i^l, k_i^h) = \begin{cases} 1, & \text{if } k_i^l < k \leq k_i^h \\ 0, & \text{otherwise} \end{cases}$$

CMB Lensing

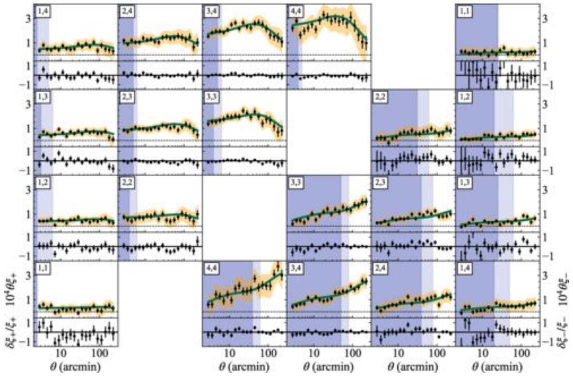
ACT DR6 lensing power spectrum + likelihood



Qu et al. 2024

Cosmic shear

DES Y3 cosmic shear data (no scale cuts) + likelihood (Cocoa)



Amon et al. 2022

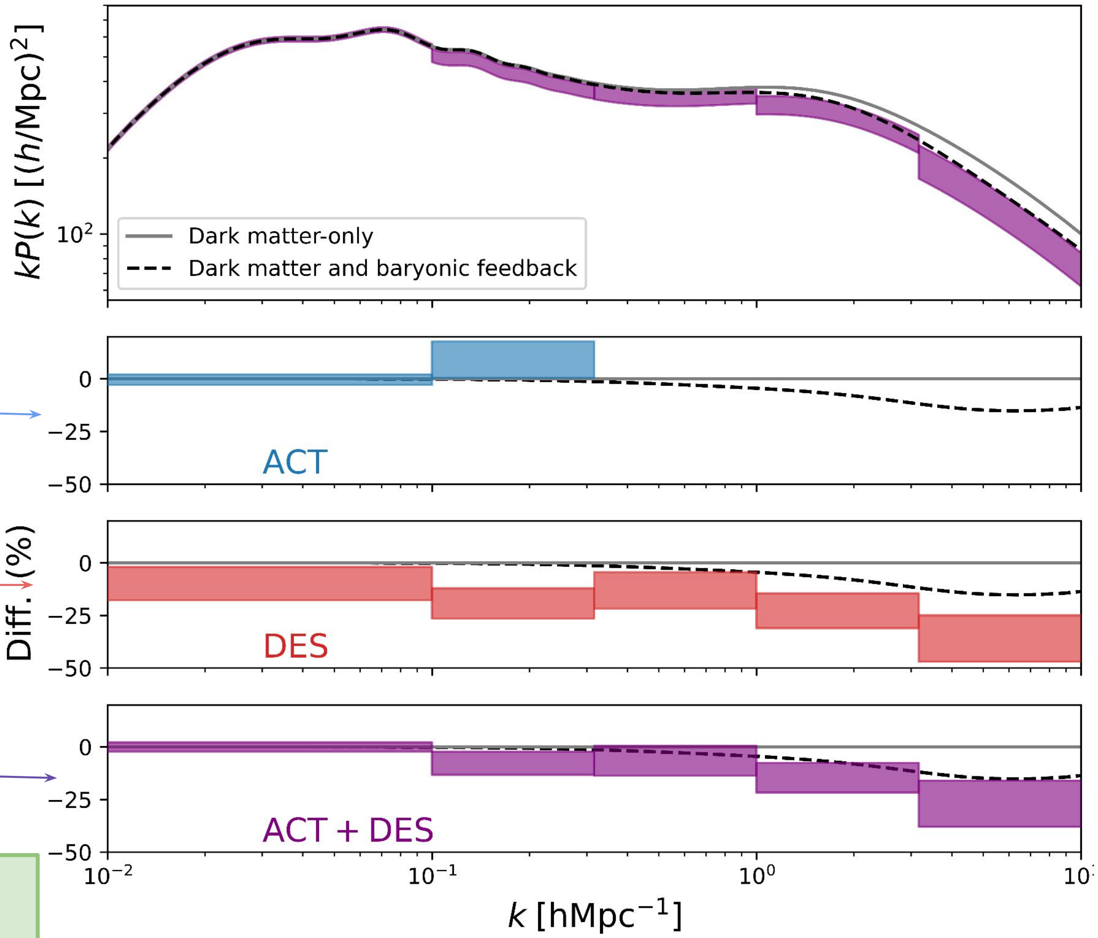
- We kept **cosmology fixed.**
- We used MCMC to fit for the **α parameters as well as the DES nuisance** parameters.
- We did **not enforce any scale cuts** on the DES Y3 cosmic shear data.
- We ran different cases:
  - **ACT-only**
  - **DES-only**
  - **ACT+DES**
- We used the Halofit mead2020 model to **compute ONLY the dark matter contributions to the nonlinear P(k).**

Results

CMB Lensing

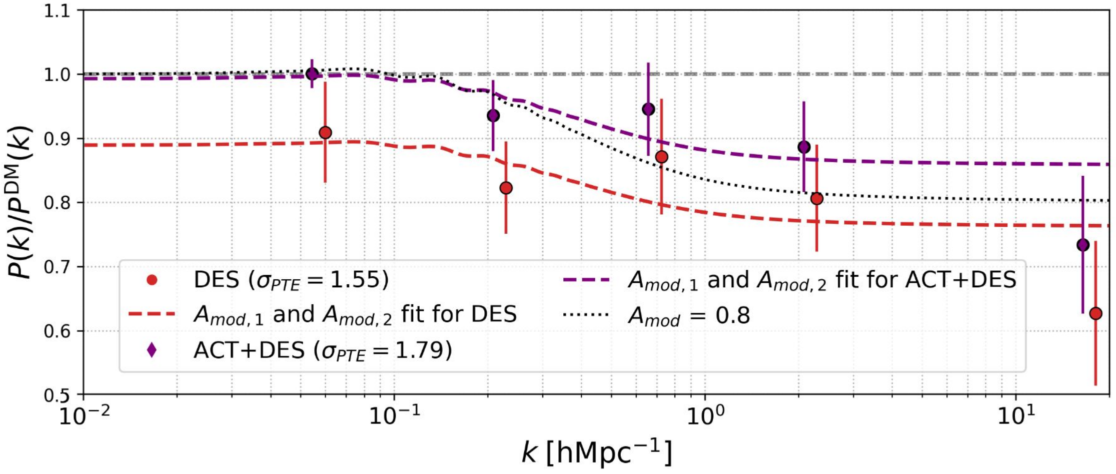
Cosmic shear

CMB Lensing + Cosmic Shear



Perez Sarmiento et al. 2025
arxiv:2502.06687, accepted to PRD

Quantifying scale-dependence



Mild indication for scale dependence (σ=1.8) found only for the **joint fit with ACT+DES** using Halofit ***mead2020*** (DM only).

We see an scale-independent offset with just DES data.

This means we need data from probes like CMB lensing to fix the linear scales.

Other works that aimed to reconstruct P(k)

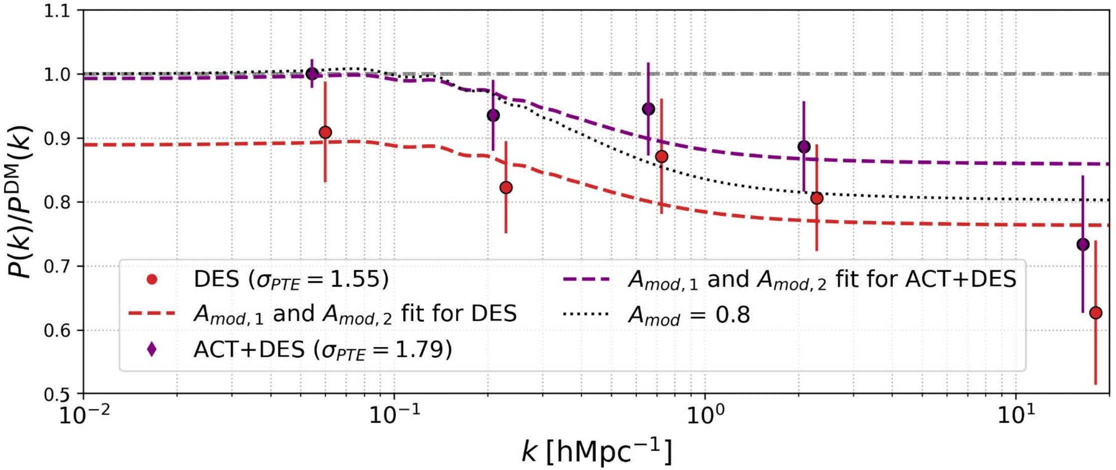
Amon and Efstathiou (2022) and Preston et al (2023) introduced a simple phenomenological model to reconstruct P(k).

$$P_m(k,z) = P_m^L(k,z) + A_{mod}[P_m^{NL}(k,z) - P_m^L(k,z)]$$

We fit our α parameters to a variation of this model that frees up the amplitude of the linear matter power spectrum:

$$P_m(k,z) = \boxed{A_{\mathrm{mod},1}} P_m^L(k,z) + A_{\mathrm{mod},2}[P_m^{\mathrm{NL}}(k,z) - P_m^L(k,z)]$$

Comparison to Amon et al. 2023 model.



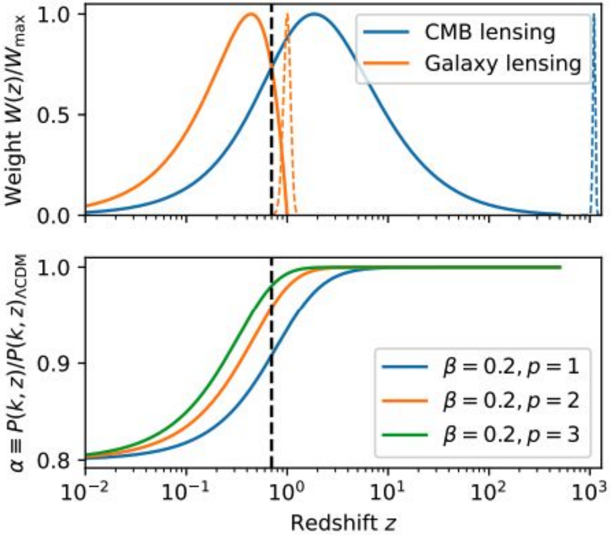
ACT+DES joint fit agrees with the Amon+ and Preston+ papers.

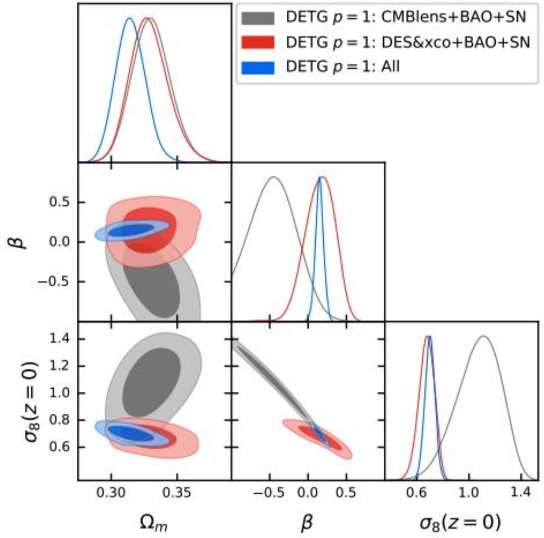
DES-only fit prefers a $A_{mod,1} \neq 1$

Lin et al. 2023 - Late Time Modification of Structure Growth and the S8 tension (arxiv:2308.16183).

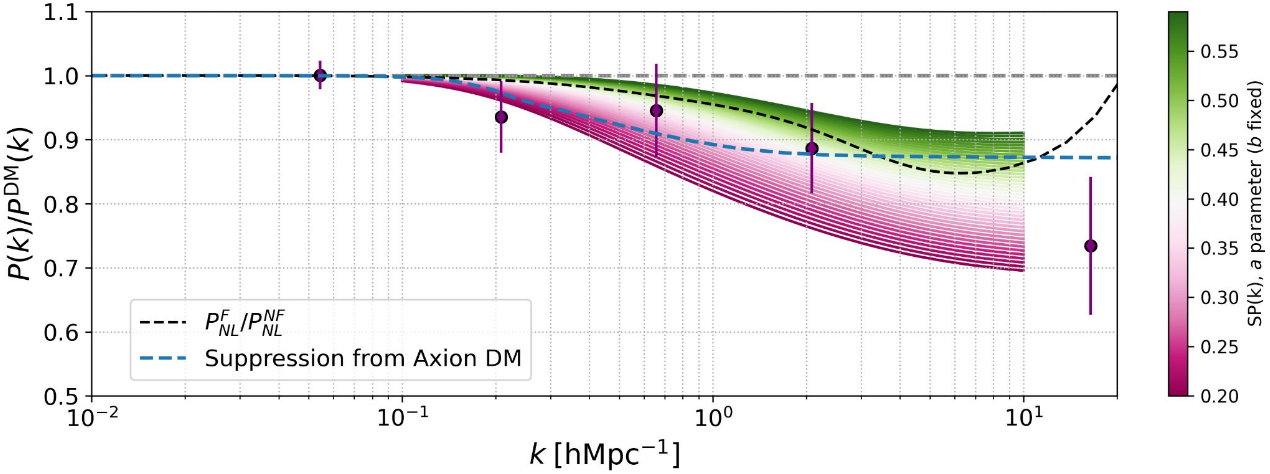
Evolving Dark Energy at late times

$$\alpha(z) = \frac{P_L(k,z)}{P_L(k,z)_{\Lambda\mathrm{CDM}}} = 1 - \beta\left(\frac{\Omega_{\mathrm{DE}}(z)}{\Omega^0_{\mathrm{DE}}}\right)^p$$





Comparison to baryonic feedback and DM models



Shape of suppression in agreement with **SP(k) hydrodynamical model** from Salcido et al. 2023 and with **ultralight axion dark matter** model from Rogers and Poulin, 2025.

Conclusions

- We find **mild indication for a scale-dependent** matter power spectrum **suppression** at non-linear scales with the **joint fit (ACT+DES),** and a scale-independent offset with DES: we need both data sets to reconstruct P(k) across this wide range of scales.
- The **model from Amon and Efstathiou with A_{mod} = 0.8** roughly describes the shape and scale of suppression **for the joint fit (ACT+DES).**
- The **SP(k) model for baryonic feedback** and the **ultralight axion dark matter model** adequately describe the shape and scale of suppression. But **impossible to distinguish between the two** effects. **We need more accurate baryonic feedback models!**
- **Redshift-dependent suppressions** can manifest as scale-dependent suppressions (Limber integral).