Dark Energy Tracking Modification of Structure Growth and the S8 Tension

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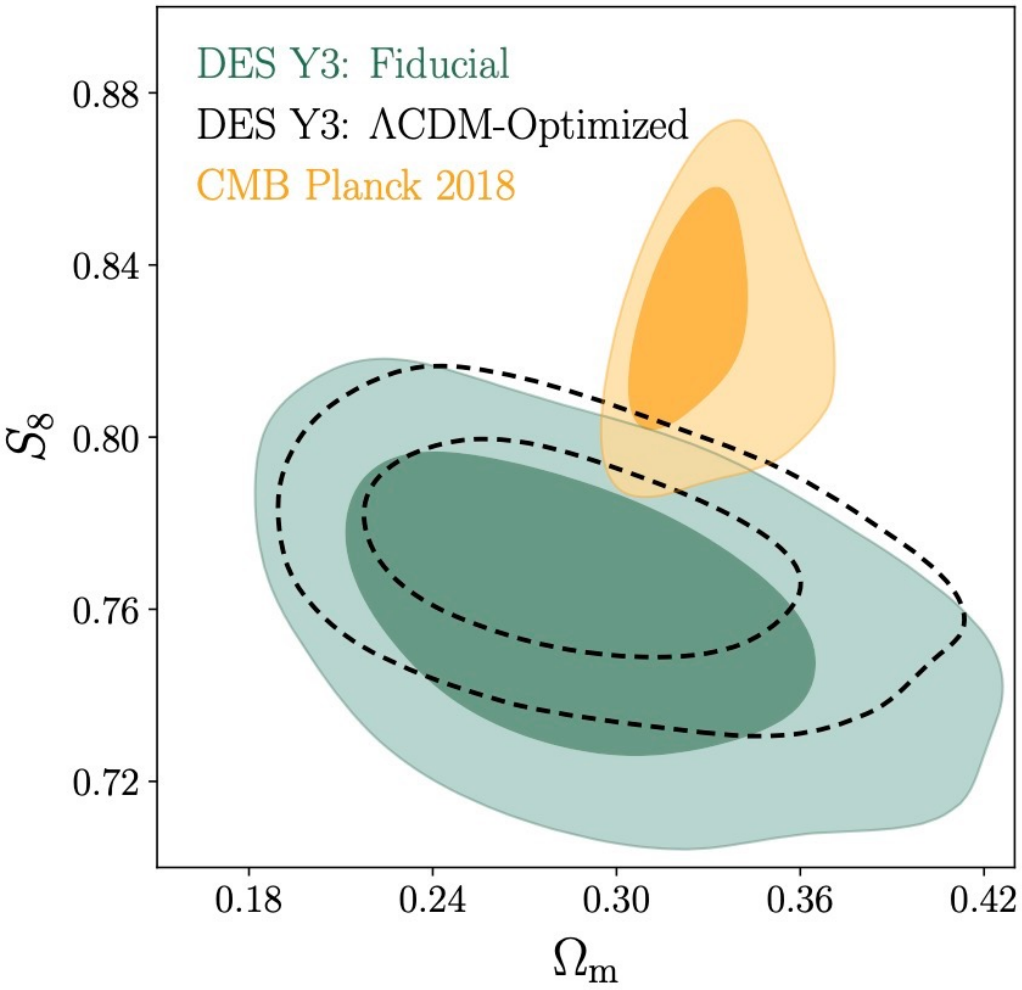
(with Bhuvnesh Jain, Marco Raveri)

Outline

- S8 tension
  - CMB anisotropy vs galaxy survey
  - CMB lensing vs galaxy lensing
- A possible solution: Dark Energy Tracking Growth (DETG):
  - late time modification of structure growth
  - Reconcile CMB lensing and galaxy lensing
  - Potentially to also reconcile CMB anisotropy
- Future

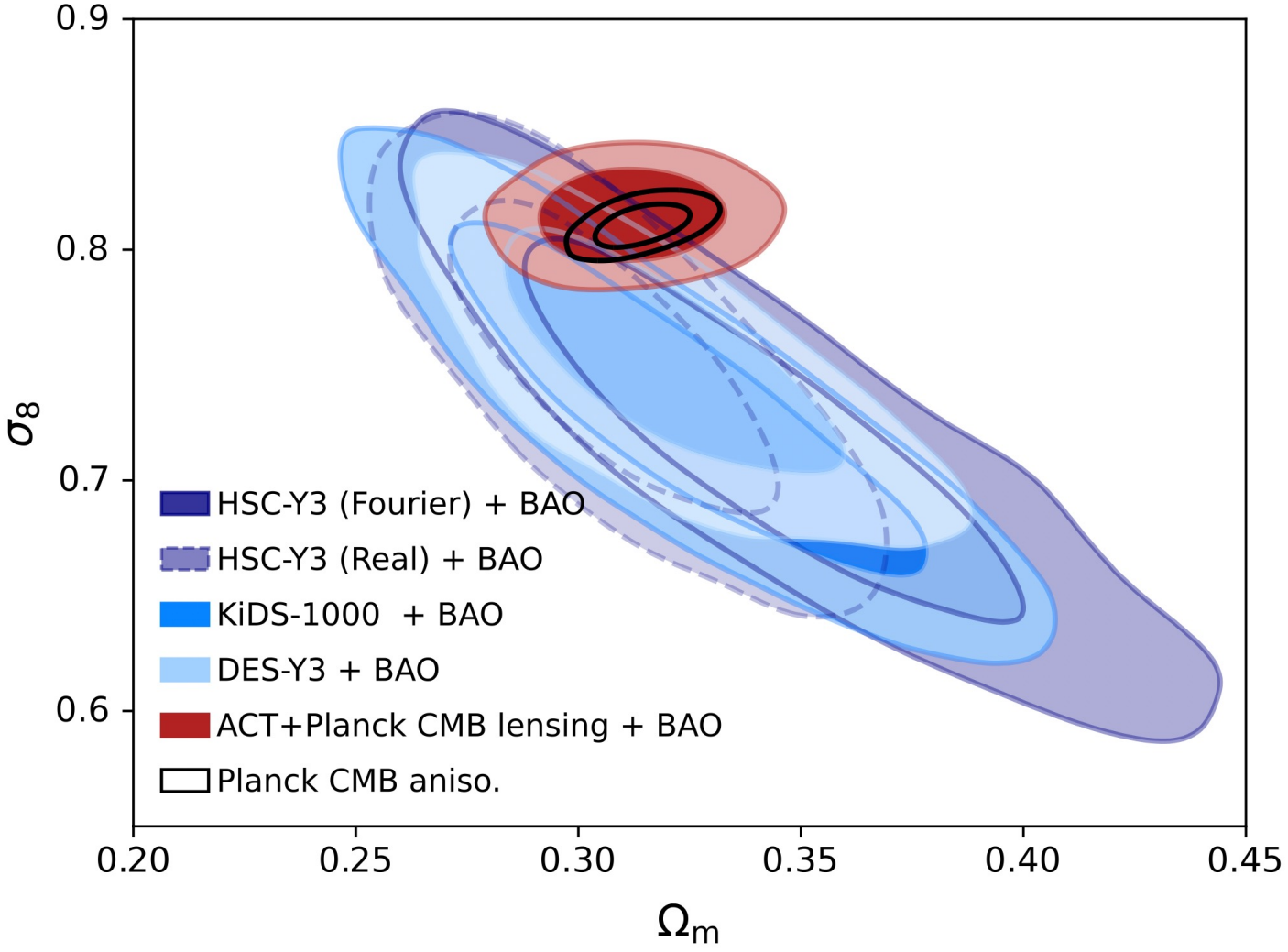
S8 tension



(DES-Y3 results)

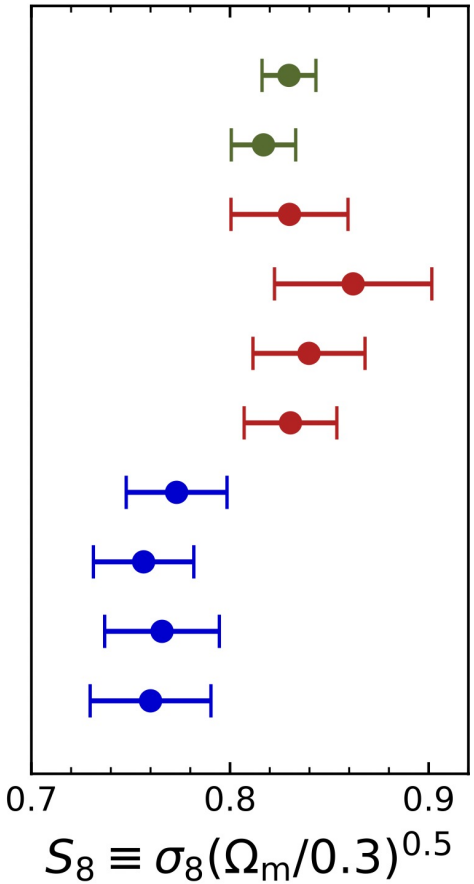
- CMB anisotropy vs galaxy survey
- $S_8 = \sigma_8 \left(\frac{\Omega_m}{0.3}\right)^{0.5}$: the clustering amplitude
- $\sim 2-3\,\sigma$ tension between CMB primary and galaxy survey within LCDM

CMB lensing vs galaxy lensing



(ACT DR6: 2304.05203)

S8 tension



Planck CMB aniso.

Planck CMB aniso. (+A_{lens} marg.)

Planck CMB lensing + BAO

SPT CMB lensing + BAO

ACT CMB lensing + BAO

ACT+Planck CMB lensing + BAO

DES-Y3 galaxy lensing + BAO

KiDS-1000 galaxy lensing + BAO

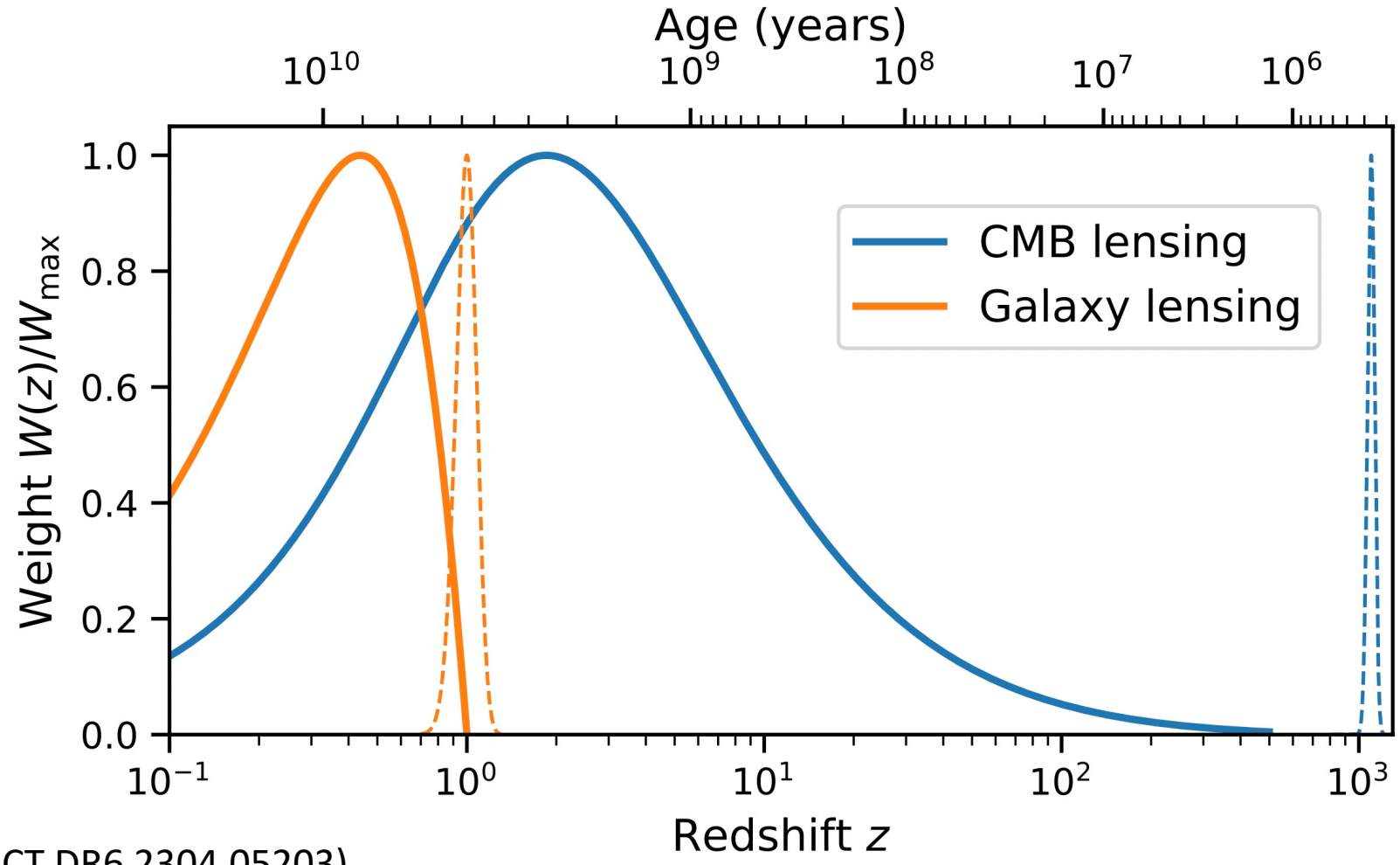
HSC-Y3 galaxy lensing (Fourier) + BAO

HSC-Y3 galaxy lensing (Real) + BAO

(ACT DR6: 2304.05203)

- CMB lensing is consistent with CMB aniso.
- 2-3 σ tension between CMB aniso/lensing and galaxy lensing

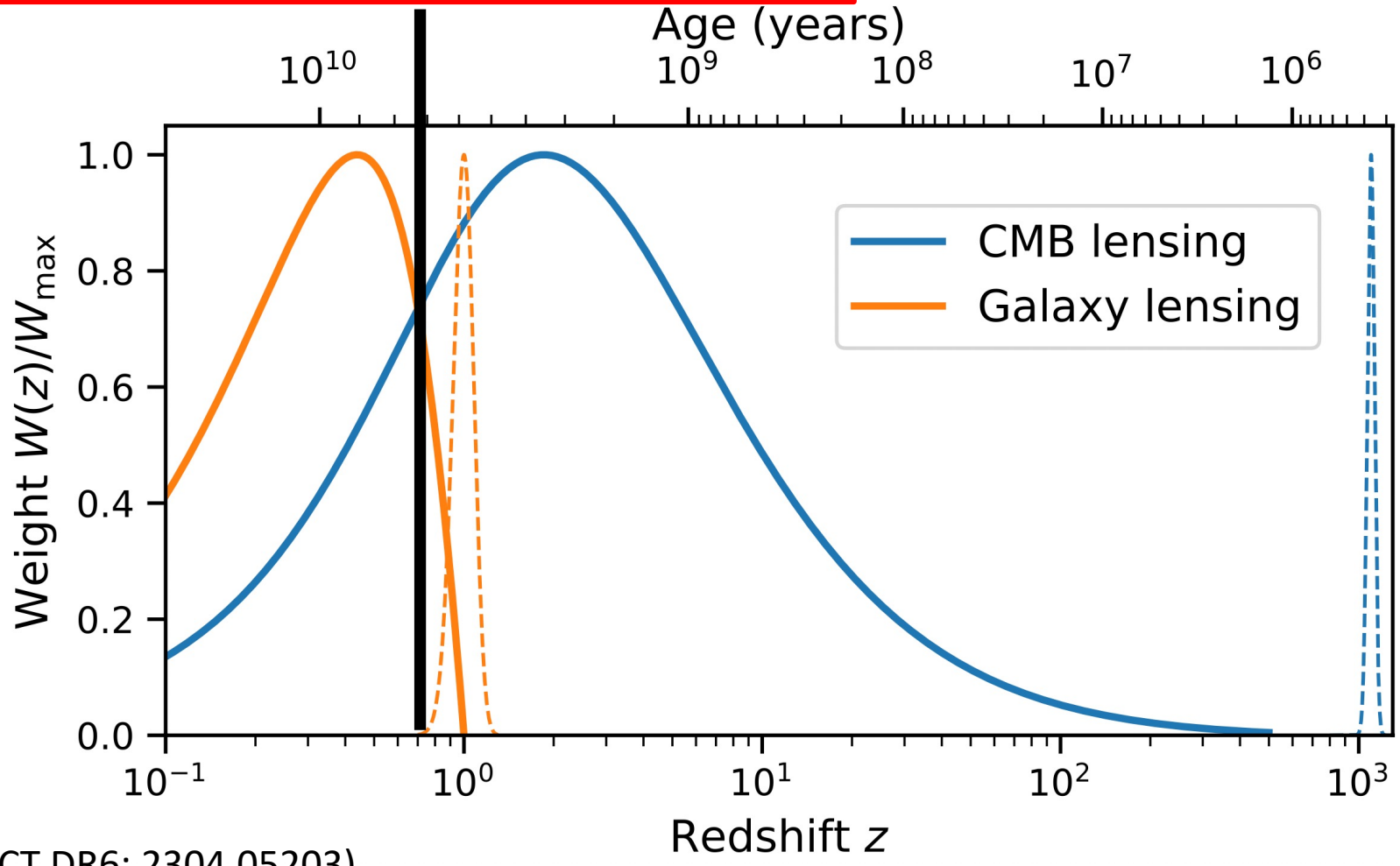
Early time vs Late time



(ACT DR6 2304.05203)

Early time vs Late time

Coincidence with DM-DE equality



(ACT DR6: 2304.05203)

Solution: Basic Idea

- Introduce a time-dependent modification to the structure growth
- Suppress the late-time growth while leave the early-time physics untouched
- Tie this modification to the evolution of dark energy density
- Related ideas: Poulin+ 2209.06217, Nguyen+ 2302.01331, Wen+ 2304.07281

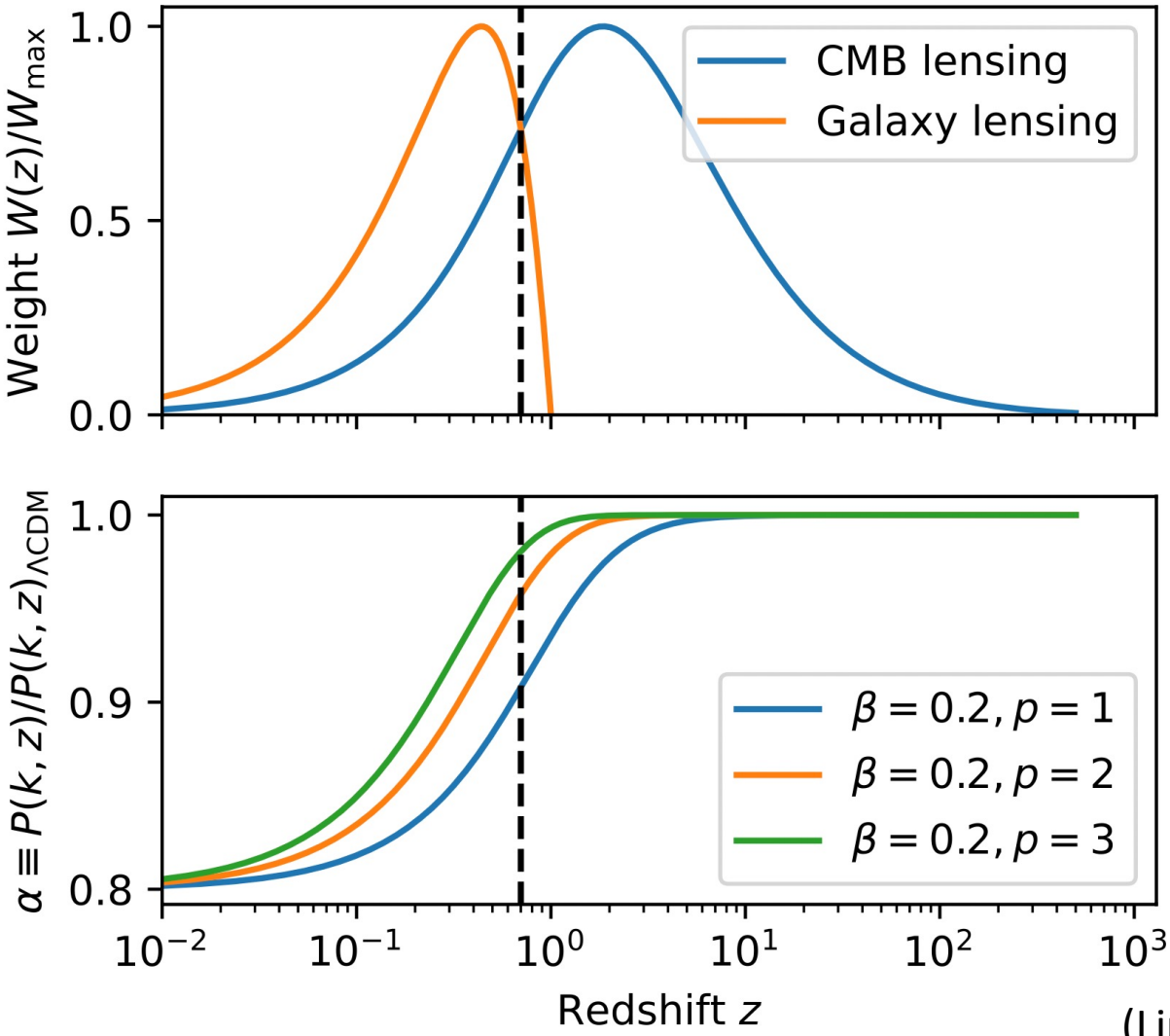
Dark Energy Tracking Growth

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

- $P(k,z)$ is the linear matter power spectrum
- $\Omega_{DE}(z)$ is the fractional dark energy density
- The background is still LCDM
- Use Halofit to compute the non-linear power spectrum
- Only one free parameter β (when p is fixed)

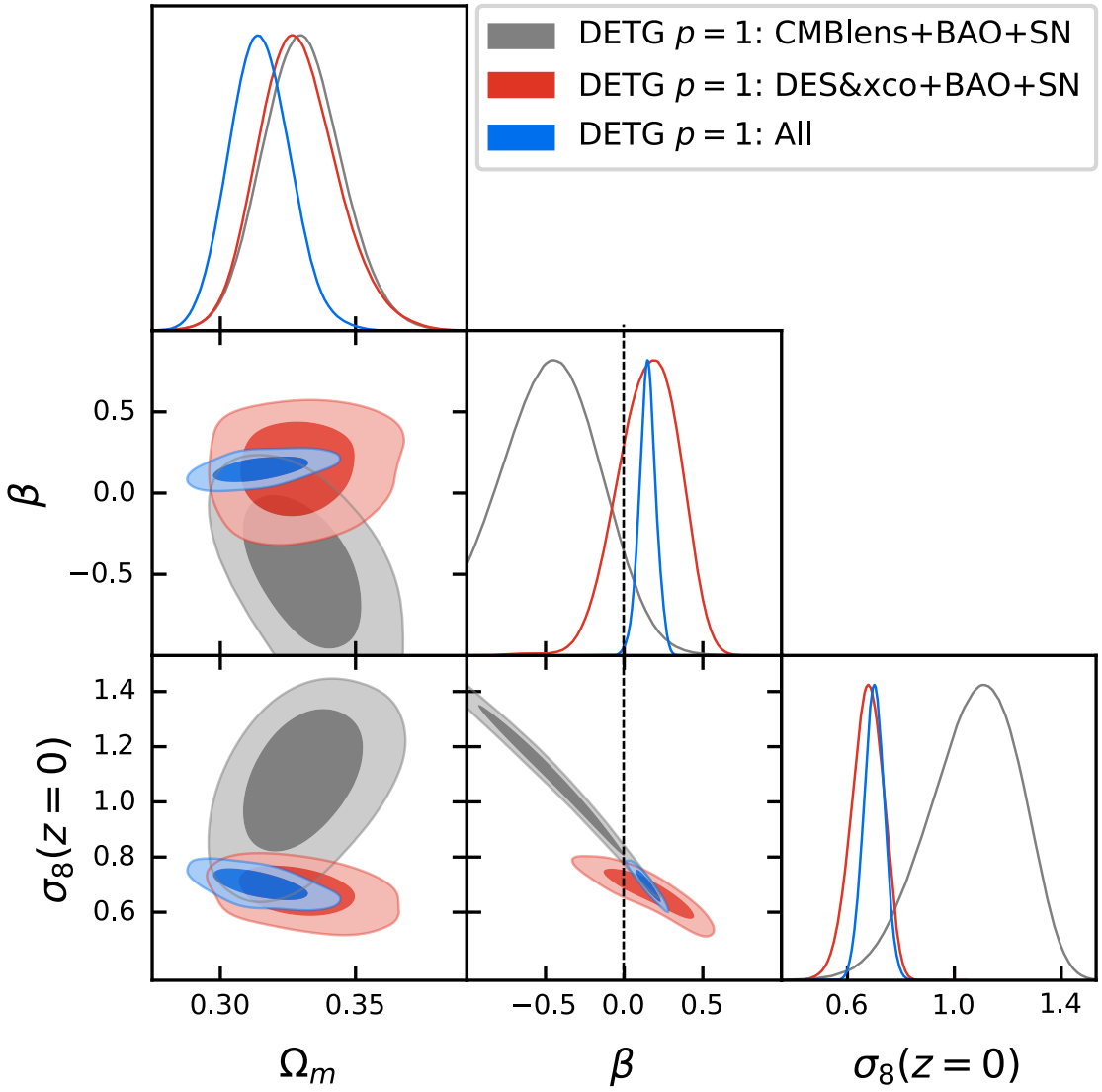
(Lin+ 2308.16183)

Dark Energy Tracking Growth



(Lin+ 2308.16183)

DETG results: the simplest model

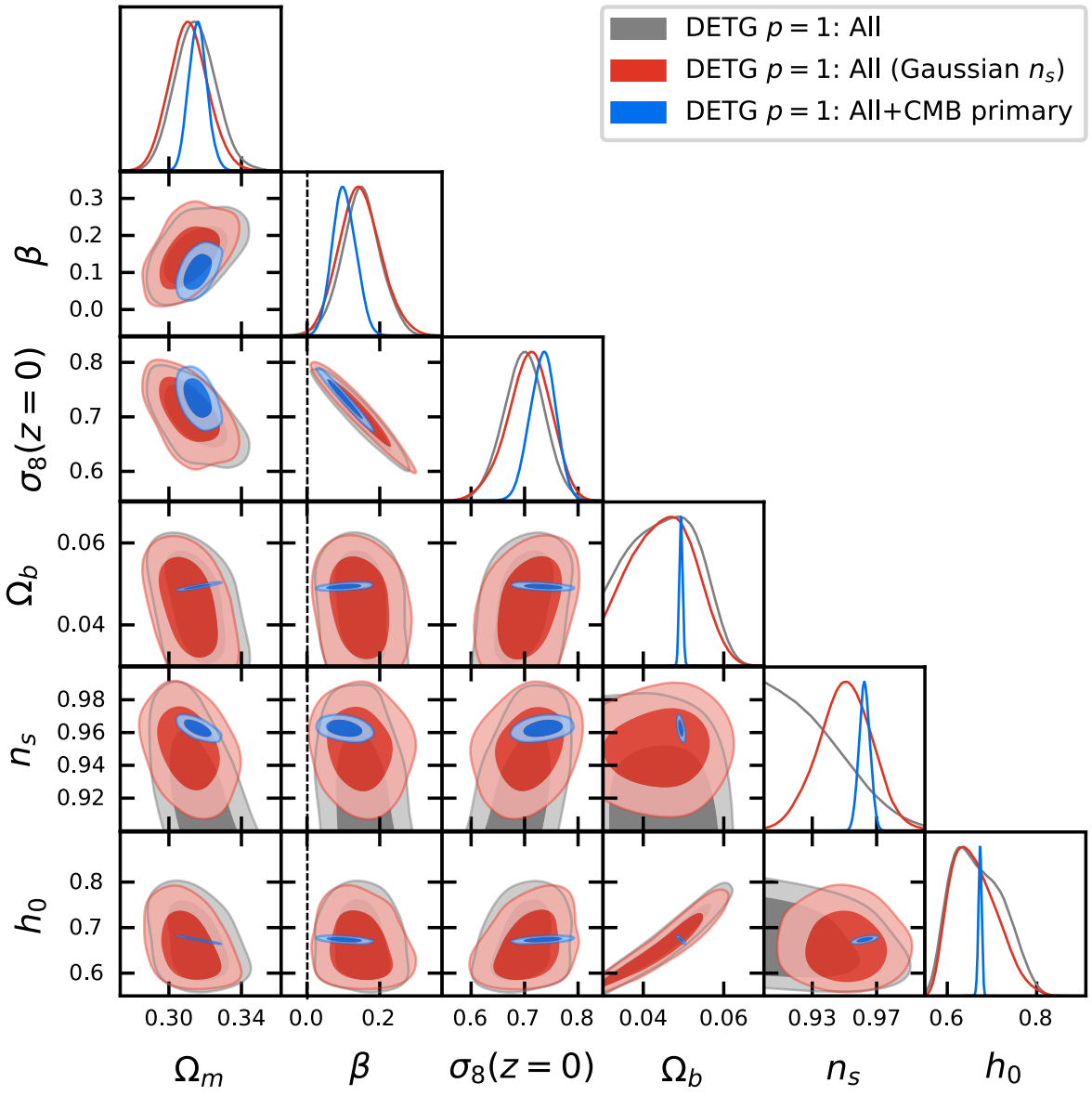


- DES&xco: positive β
- CMBlens: negative β
- All = CMBlens +DES&xco+BAO+SN: positive β, LCDM is excluded at $2.9\ \sigma$
- All p=1 best fit : $\Delta\chi^2 = -7.2$

DETG results: the simplest model

- Degeneracy between β and $\sigma_8(z=0)$
- How to break the degeneracy:
  - Multiple redshift source bins: DES less degenerate than CMB Lensing
  - Non-linear effect
  - CMB lensing: scale-dependence induced from time-dependence

robustness tests to CMB anisotropy



- CMB primary: Planck 2018 high-l TTTEEE + low-l EE
- we don't model ISW (exclude low-T) and lensing (use Alens)
- The $\sim 3\ \sigma$ evidence over LCDM still holds
- $2.5 - 3\ \sigma$ depends on priors and datasets

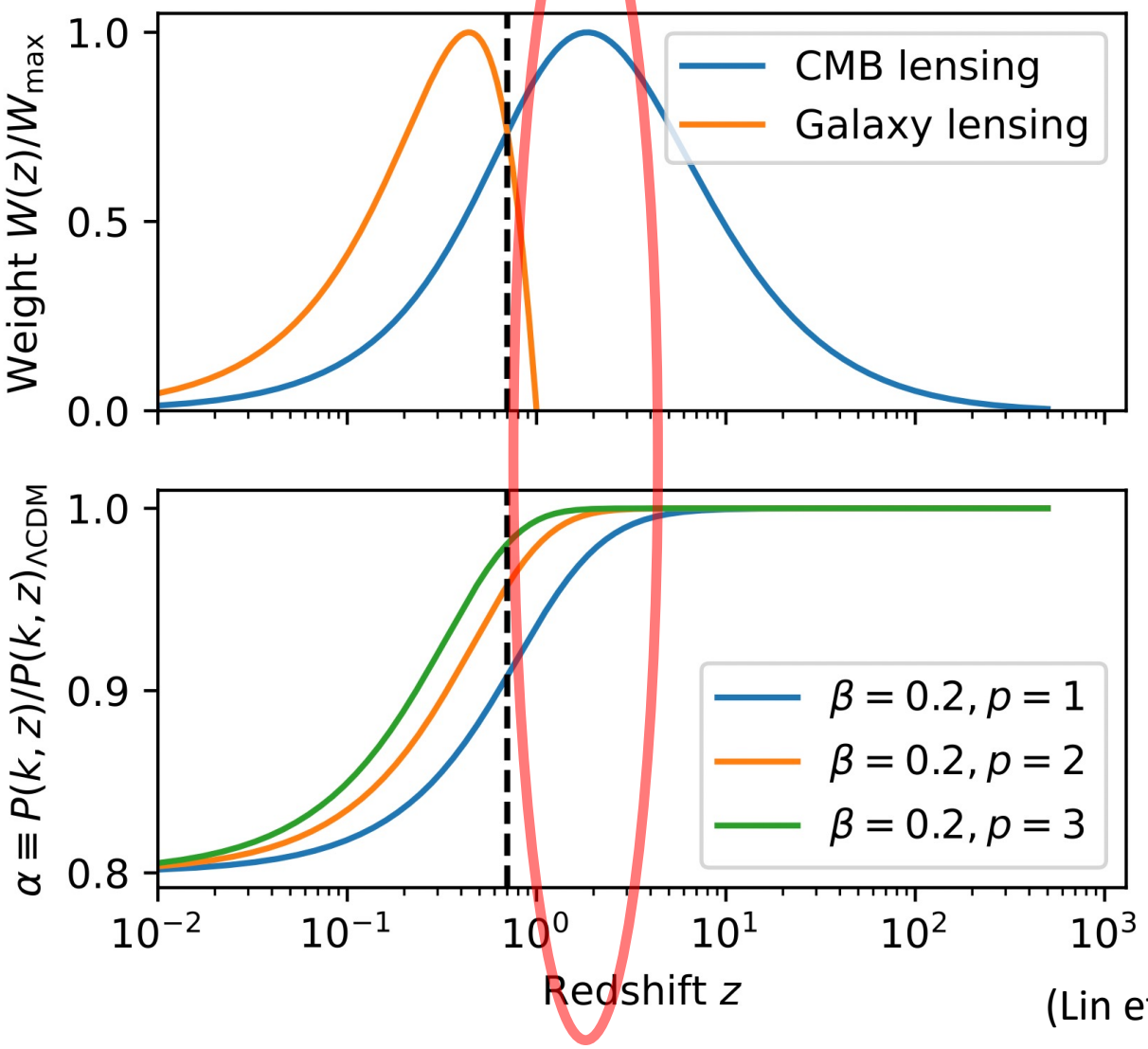
Physical models?

- DETG is a simple phenomenological model
- Some possible physical models
  - Dark energy – dark matter interaction?
  - Modified gravity?
  - Significant dark energy clustering?
  - Some other dark field?

Future

- Higher redshift probes!
- Scale dependence?
- Future data:
  - Galaxy: DES-Y6, DESI, Spec-S5, LSST
  - CMB: ACT, SPT, CMB-S4
  - Particularly: DESI Lyman-alpha

Dark Energy Tracking Growth



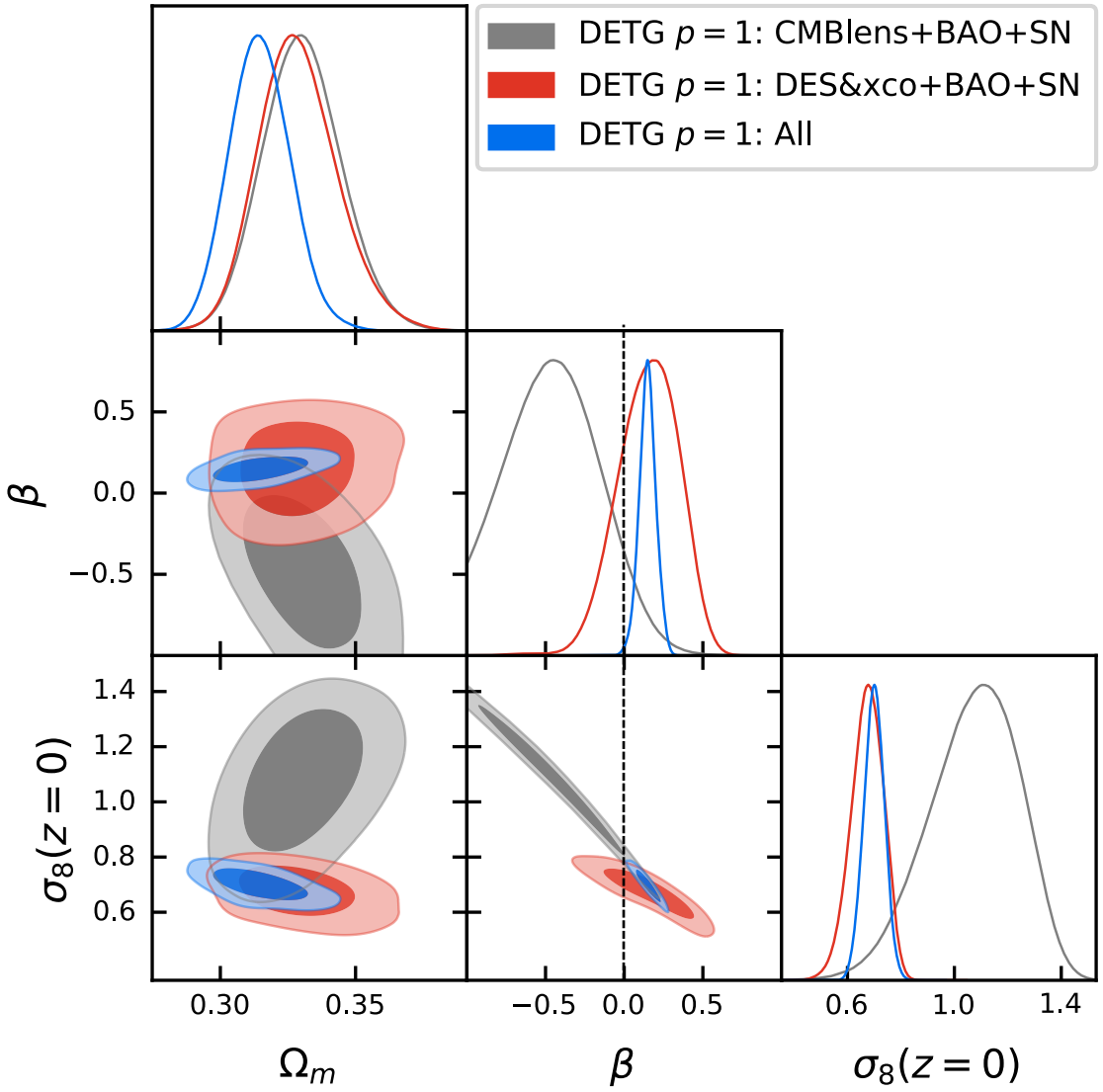
(Lin et al. 2308.16183)

Summary

- DETG model introduces a time-dependent modification to the structure growth that tied to the dark energy density evolution
- DETG model can reconcile the difference between CMB lensing and galaxy lensing constraints on S8
- DETG excludes LCDM at 2.5-3 σ with only one free parameter
- DETG is a simple phenomenological model, more physical model is necessary/coming
- Testable with coming soon higher redshift probes

BACKUP

DETG results: the simplest model



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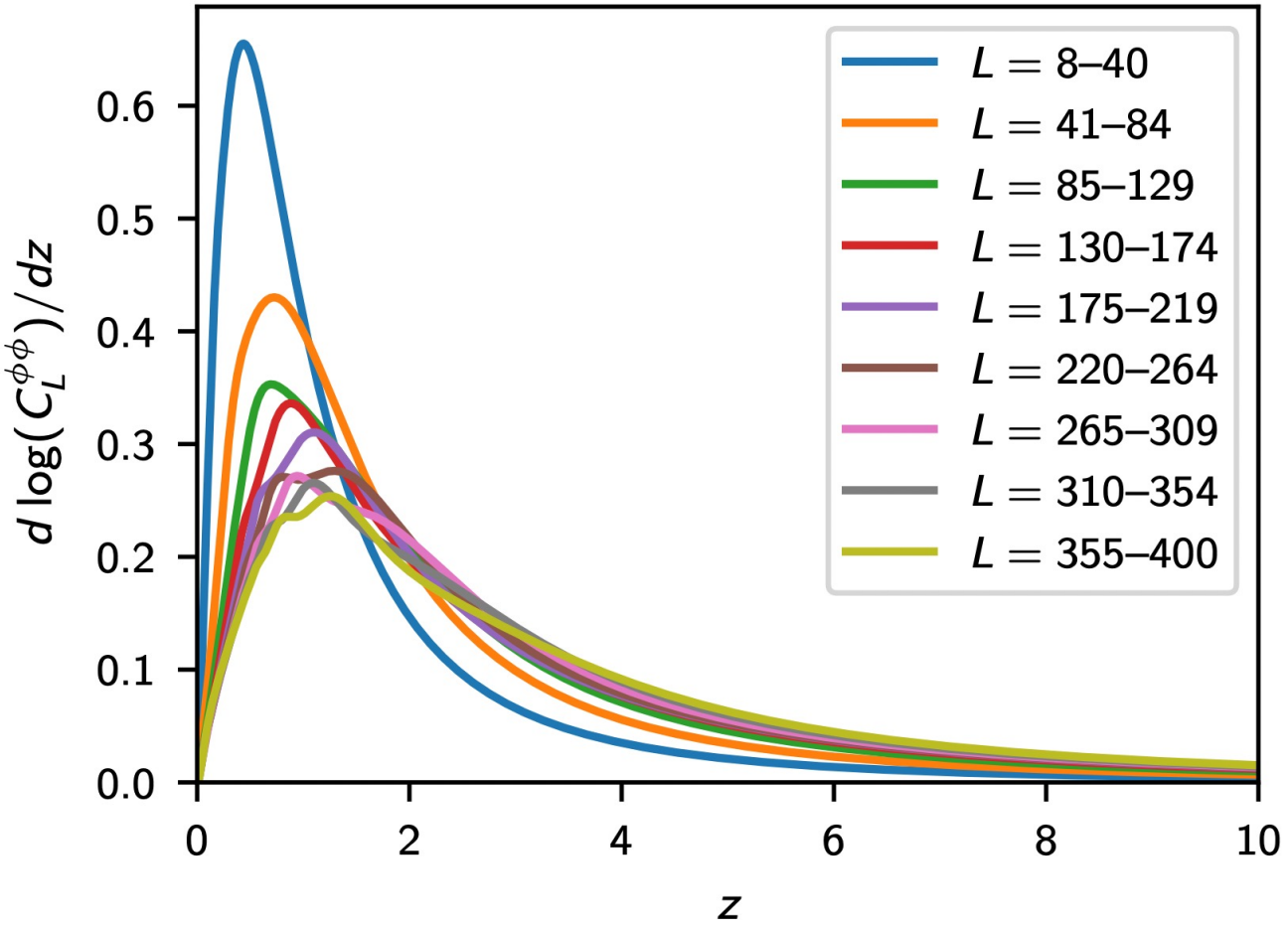
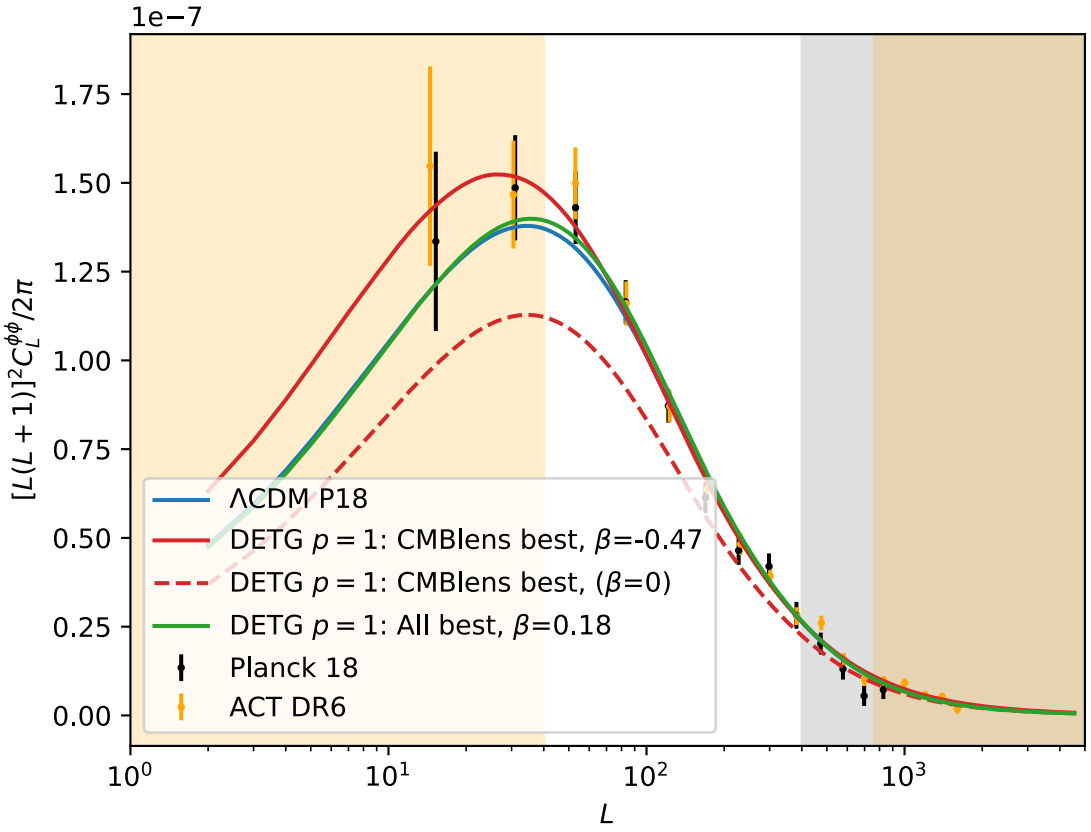
Impact on CMB lensing



- Different L modes are sensitive to different redshifts
- The time - dependence induces a scale-dependence

(Planck 2018: 1807.06209)

Impact on CMB lensing

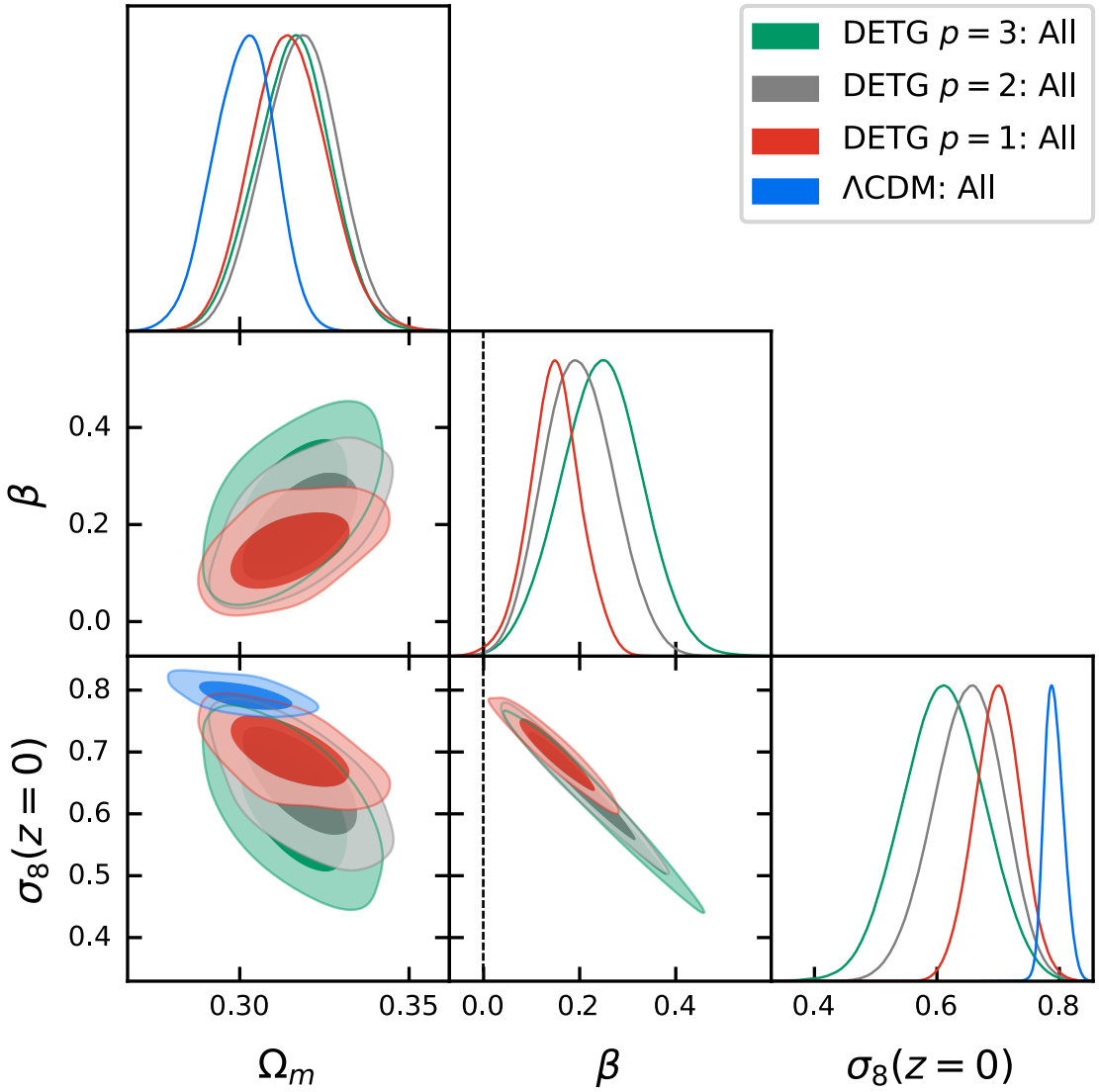


- Late-time modification has larger impact on large scales
- In LCDM, Planck/ACT lensing data have relative higher power in low-l compared to high-l
- CMB lensing has a weak preference for a negative β

Best fit to All dataset All=CMBlens+DESY3+BAO+SN

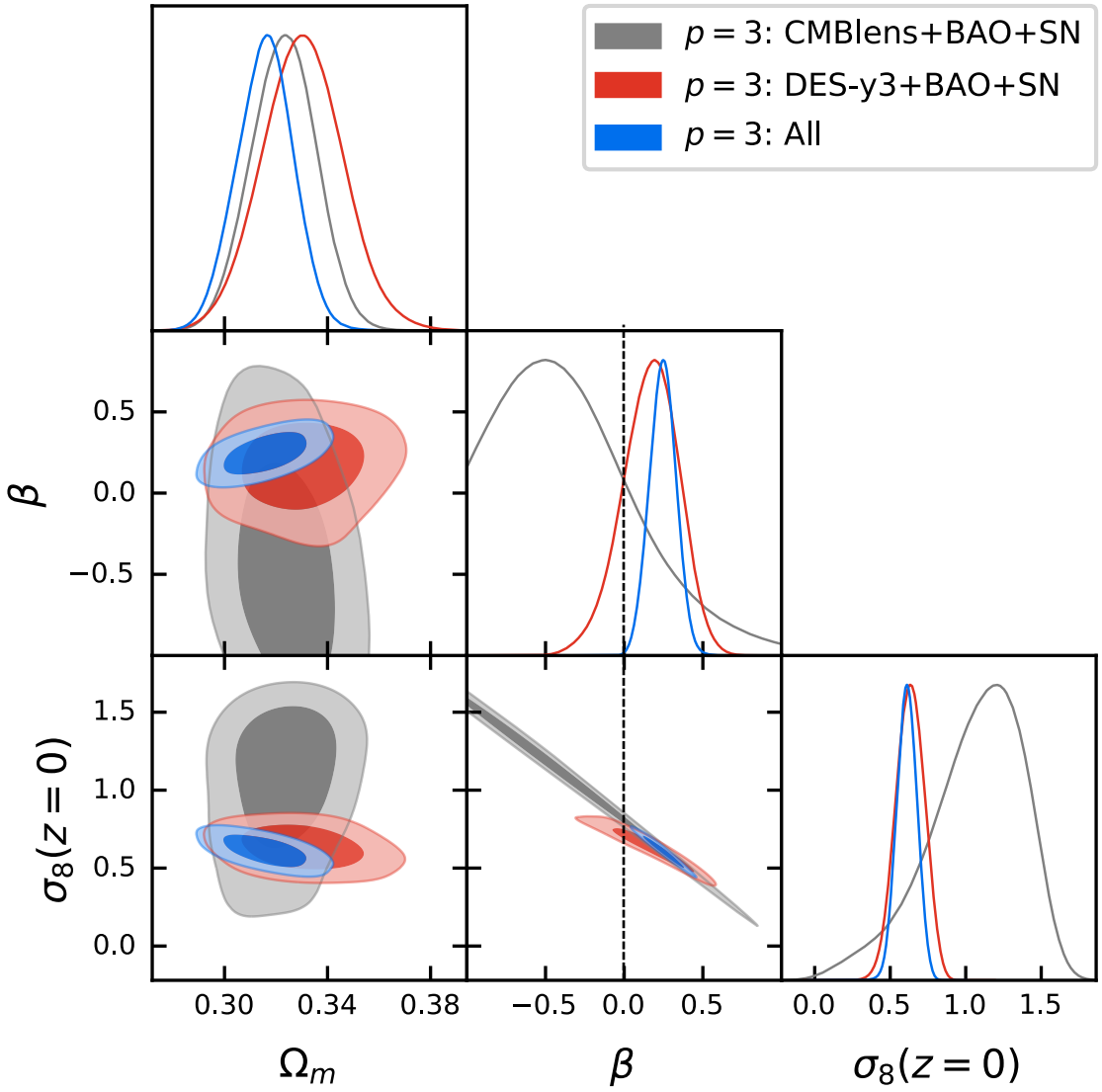
model	ΛCDM	DETG $p=1$
Ω_m	0.300 (0.301±0.009)	0.321 (0.315±0.011)
H_0	72.64 (68.68±6.59)	66.85 (66.98±6.13)
Ω_b	0.0528 (0.0484±0.0093)	0.0464 (0.0452±0.0090)
n_s	0.907 (0.937±0.027)	0.909 (0.932±0.023)
$\sigma_8(z=0)$	0.788 (0.792±0.015)	0.673 (0.699±0.038)
β	0	0.182 (0.149±0.052)
$\Delta\chi^2_{\rm DES-Y3}$	0	-2.9
$\Delta\chi^2_{\rm CMBlens}$	0	0.2
$\Delta\chi^2_{\rm BAO}$	0	-1.1
$\Delta\chi^2_{\rm SN}$	0	-3.3
$\Delta\chi^2_{\rm prior}$	0	-0.2
$\Delta\chi^2_{\rm tot}$	0	-7.2

DETG results: impact of p

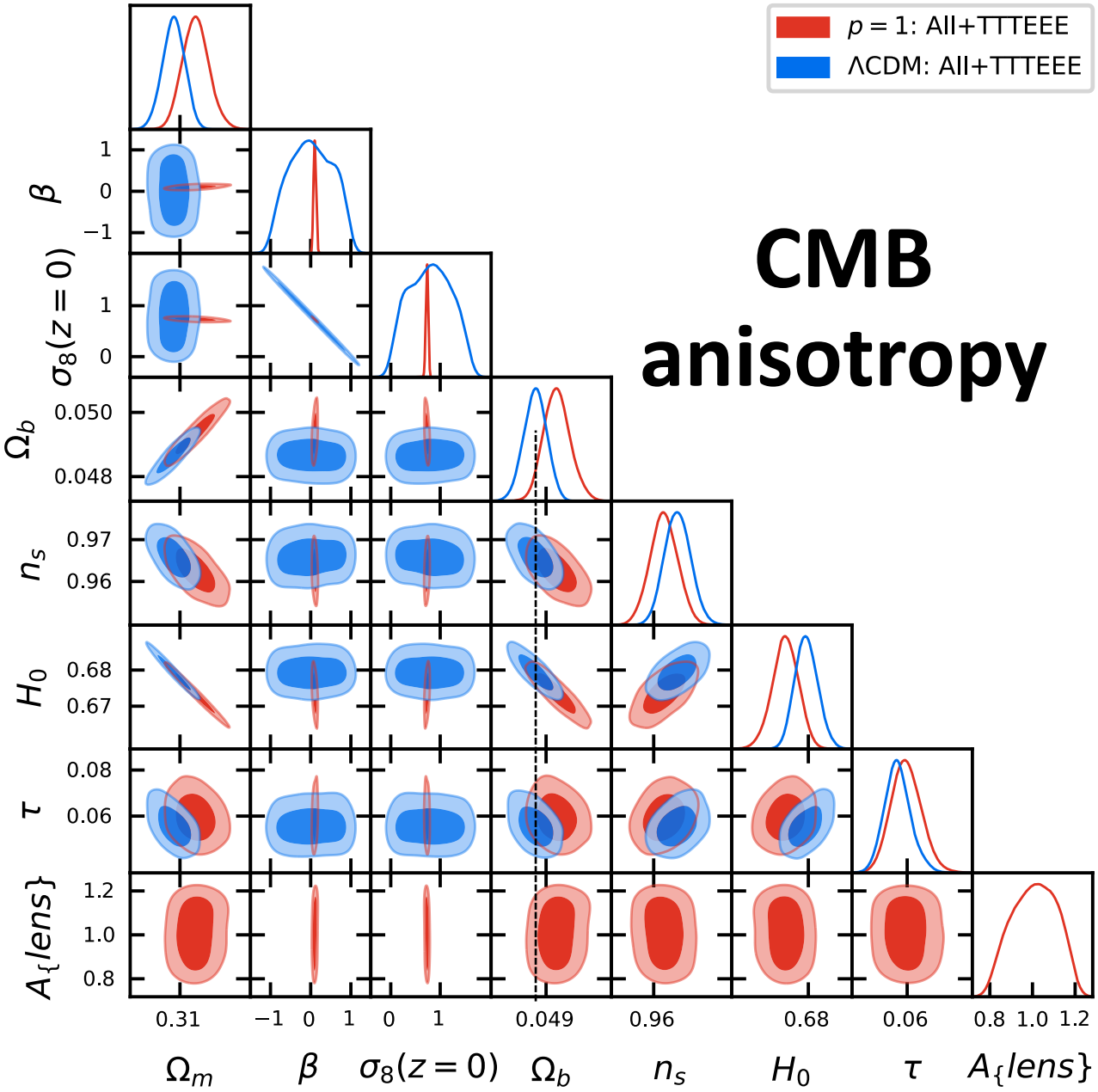


- A larger p means the modification happens at a later time
- Hence less constrain from CMB lensing
- Higher evidence for non-zero β

DETG results: p=3 model



- more consistent between galaxy lensing and CMB lensing


p = 1: All+TTTEEE
ΛCDM: All+TTTEEE
CMB anisotropy
β
σ8(z = 0)
Ωb
ns
H0
τ
A{lens}
Ωm
0.31
0.049
0.96
0.68
0.06
0.8 1.0 1.2

Related to H0 tension?

- Phenomenologically can be combined with any early-time H0 solutions, e.g. Early Dark Energy
- Still two separate solutions to two tensions