Principal component analysis and direct projections: what is the recombination epoch telling us?

Model independent constraints using Planck and extending into physical models.

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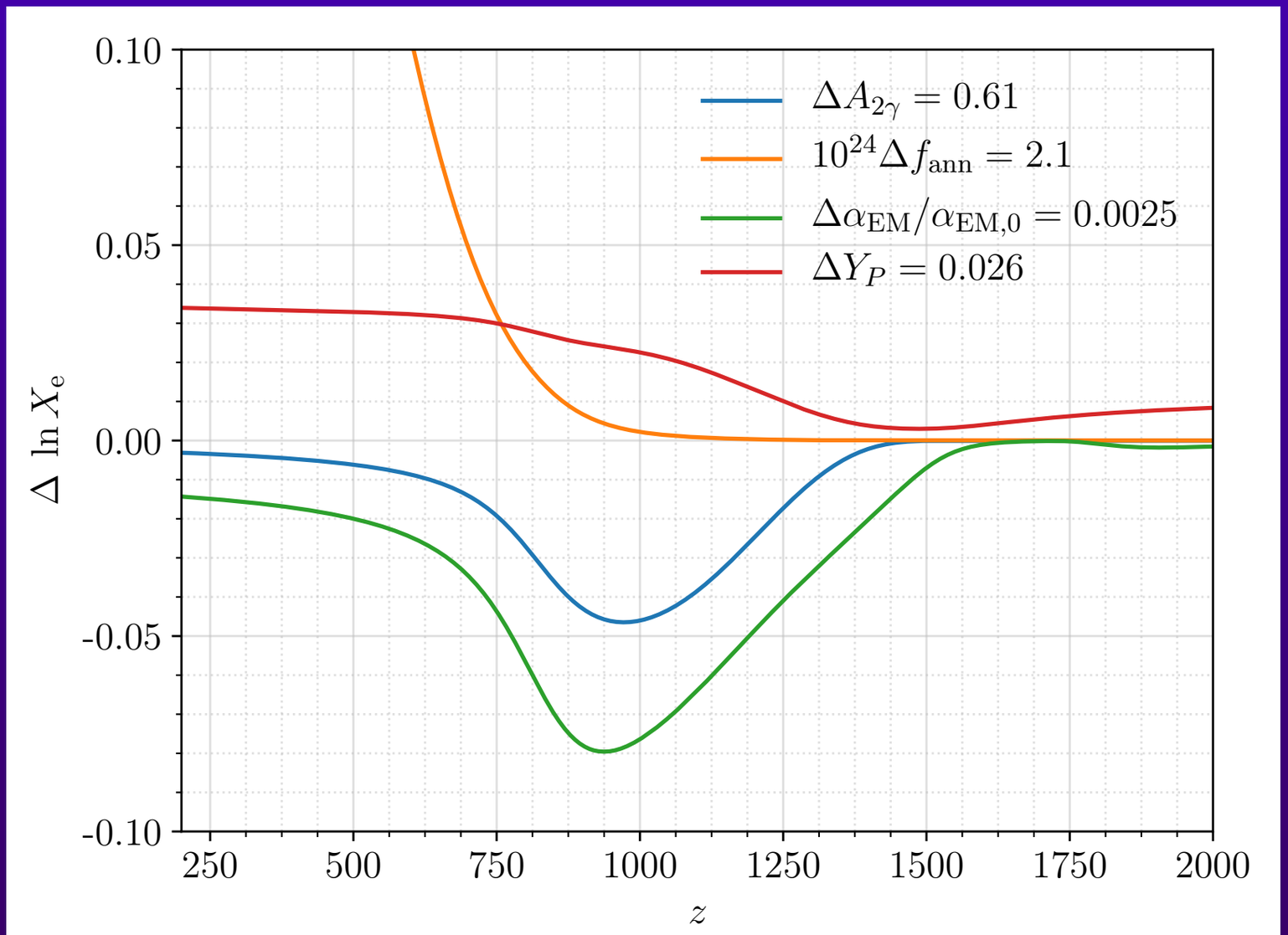
Motivation

(errors are MCMC results: Planck Collaboration [2015], HC[2017])



- Physical variations are model dependent
- Variations sometimes very weakly constrained
- Plan: Let's see what the data favours
- Artefacts of non-standard recombination

Methodology

Orthonormal set of perturbations dX_e (CosmoRec)

Boltzmann code/computation of likelihood (e.g. CAMB, COSMOMC)

Analytical derivatives

Directly sourced likelihood

Construct a matrix representation of data responses (i.e. Fisher)

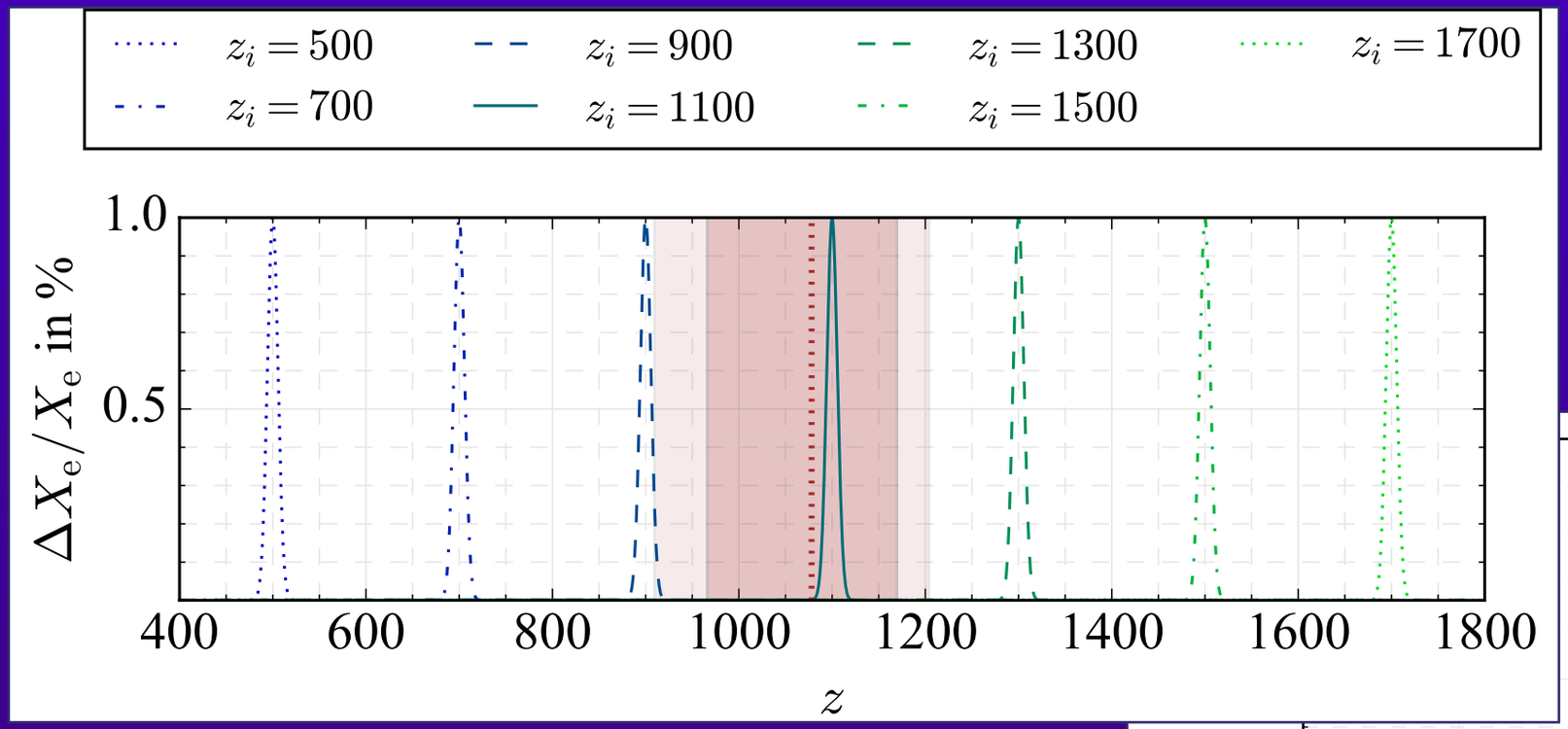
Eigenanalysis

Convert abstract vector back into dX_e (i.e. interpolate)

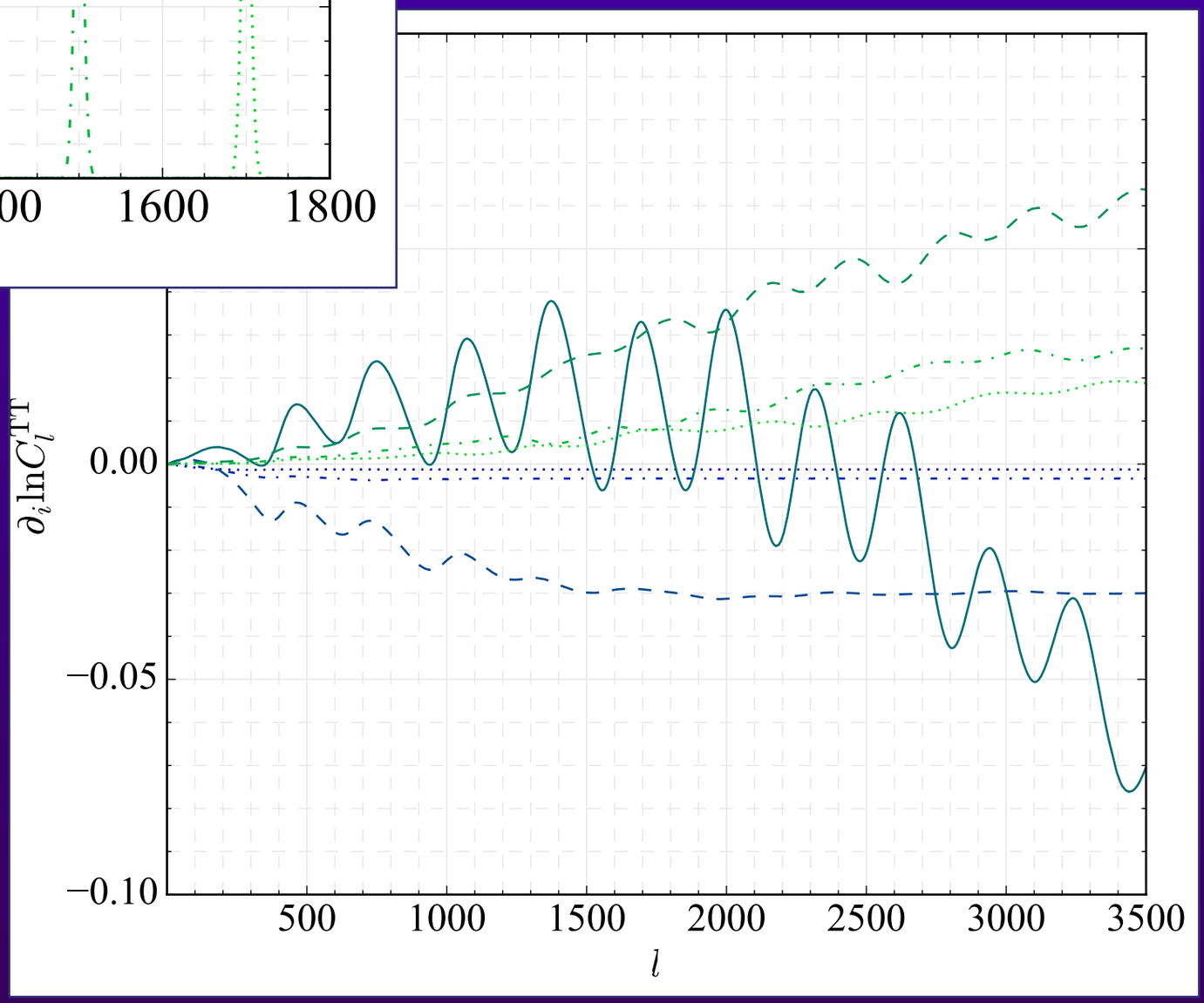
FEARec++

Fisher Eigen Analyser for Recombination

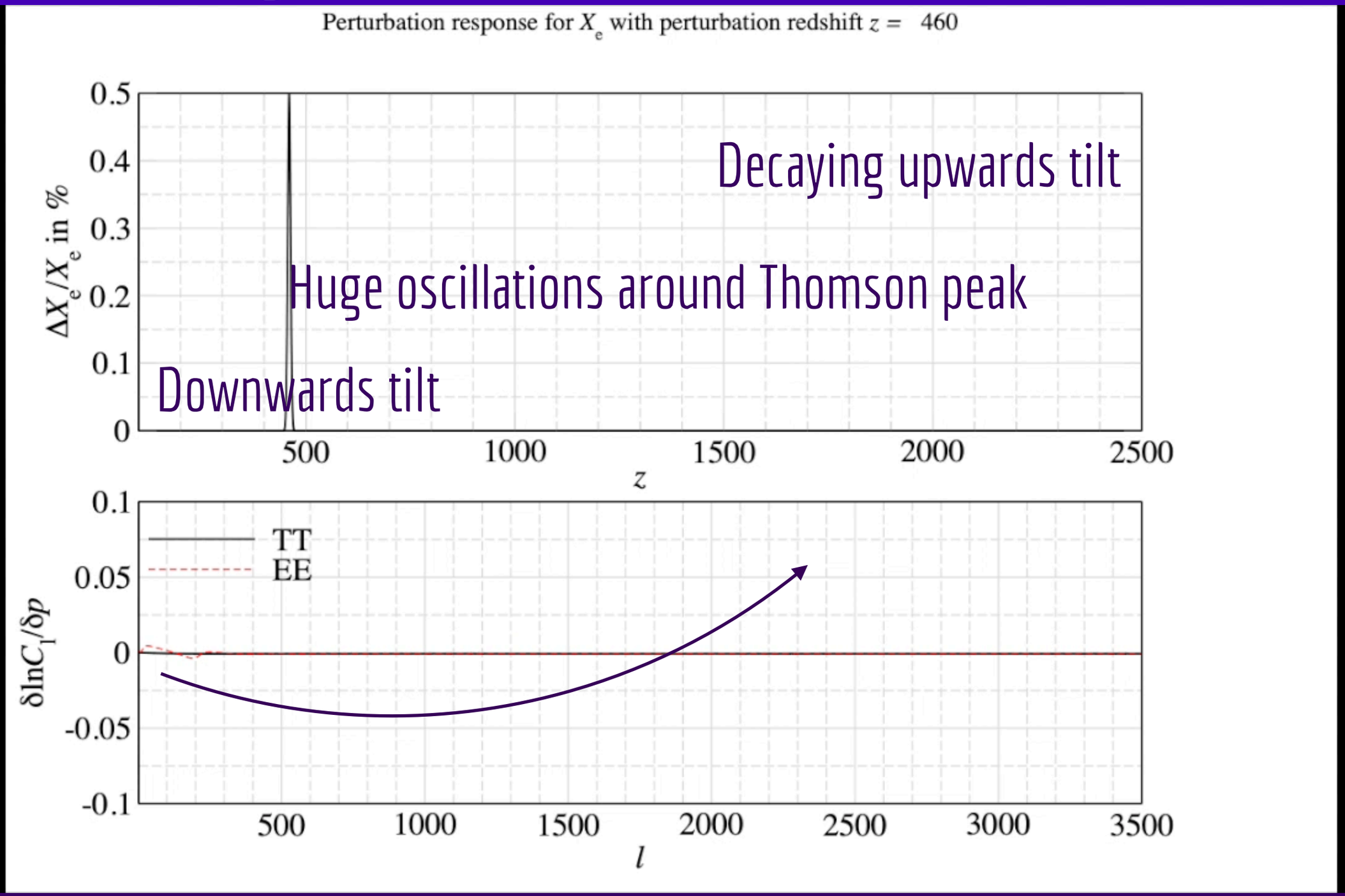
Generalising recombination



- Smooth perturbations in X_e across a redshift grid
- Rescale the recombination history
- Propagate through to the CMB

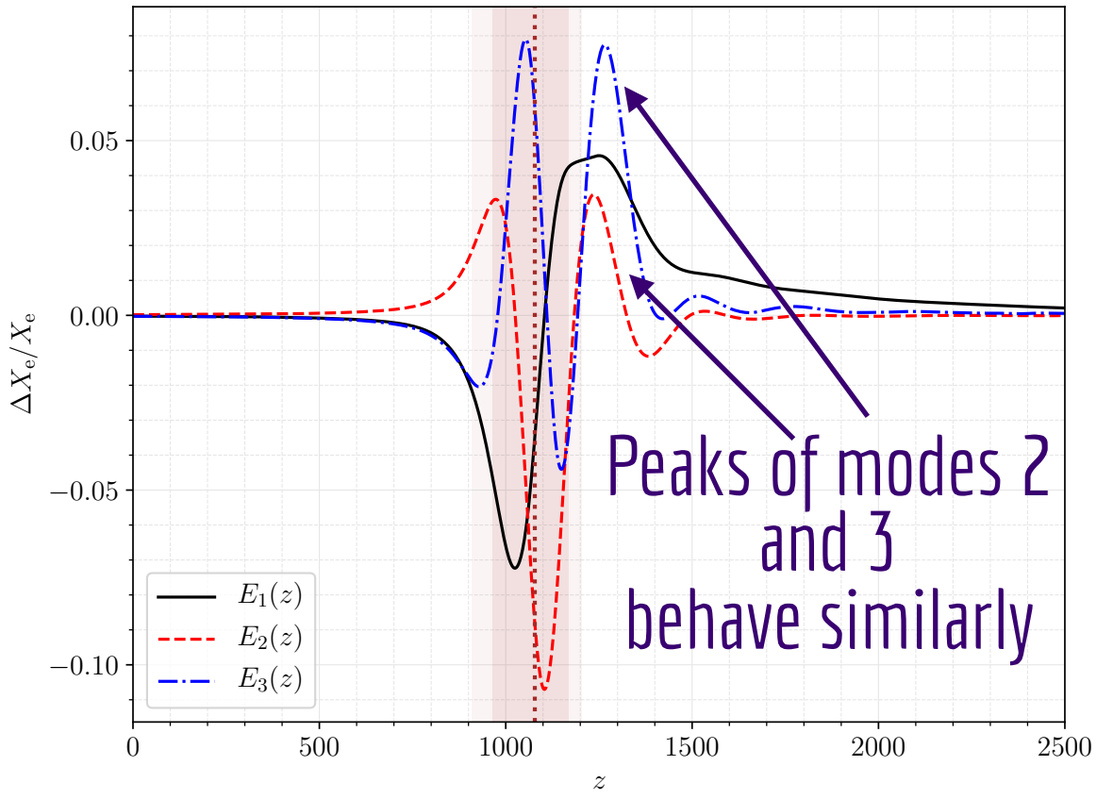


Generalising recombination

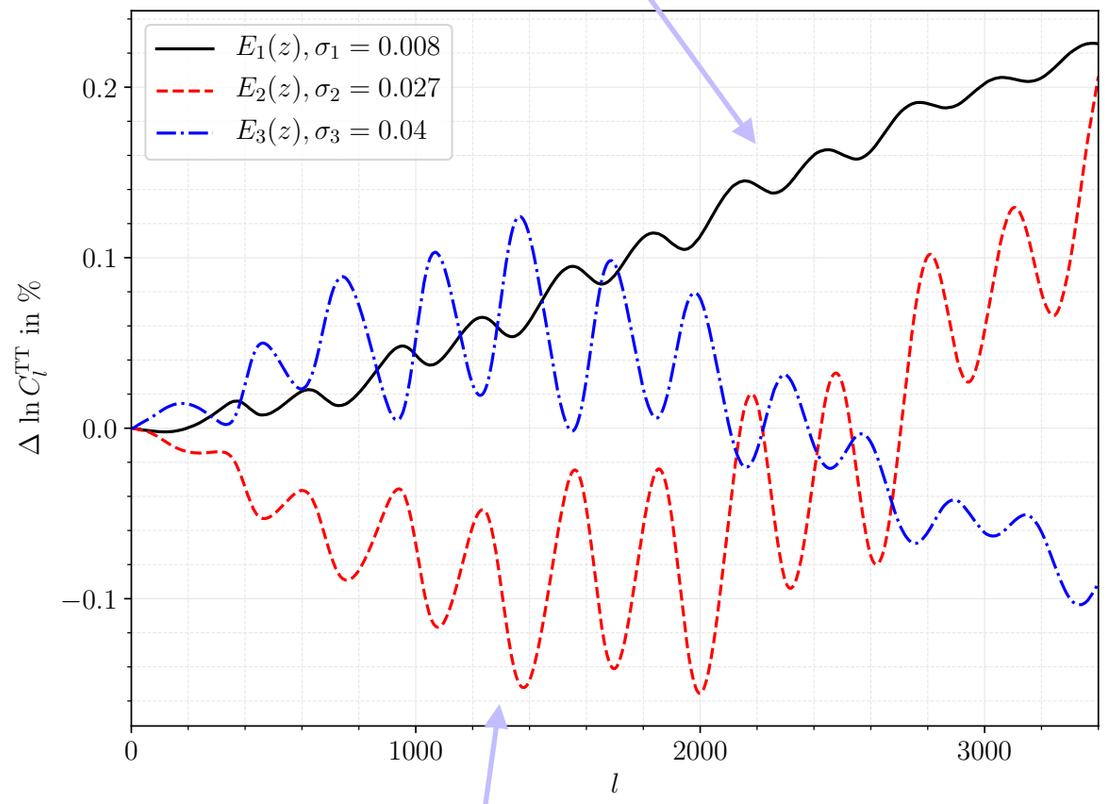


https://sites.google.com/view/pca-recombination/

Analytical method



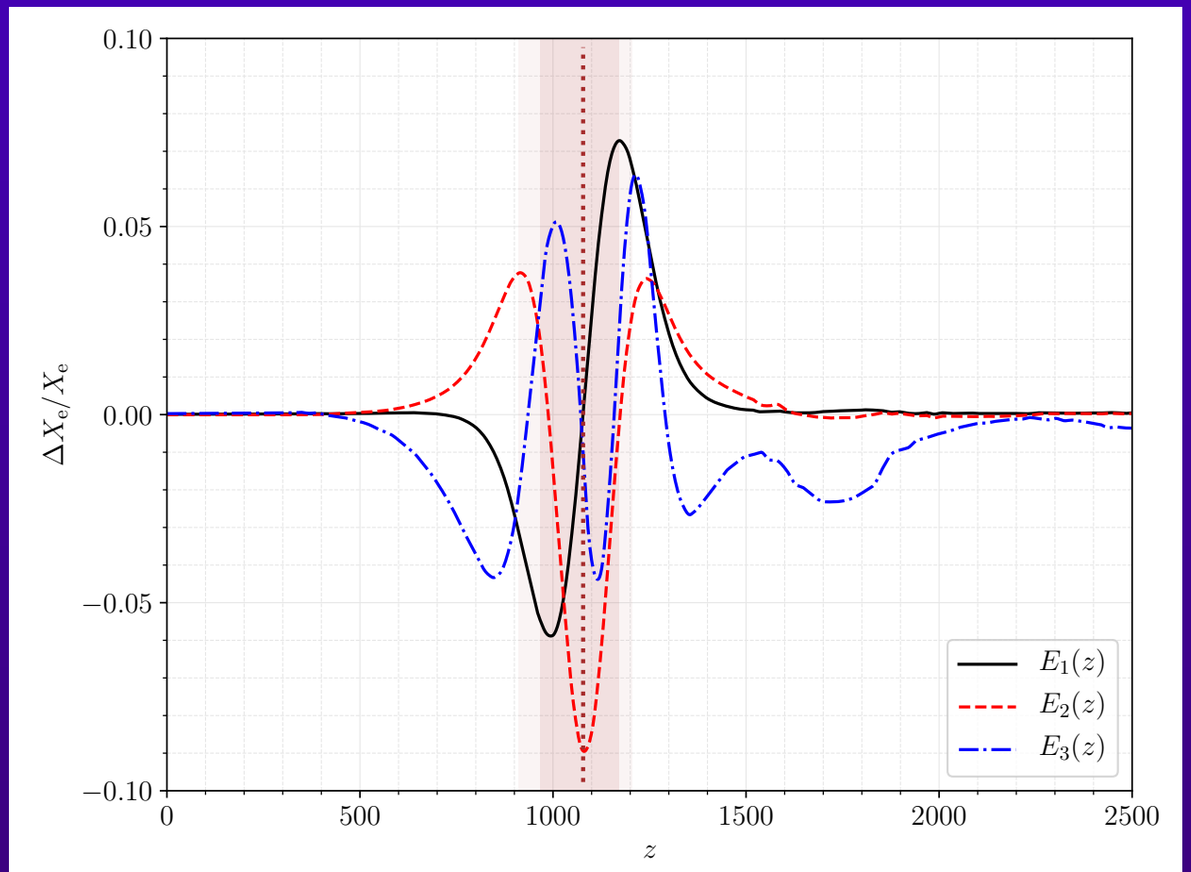
Tilt of the power spectrum

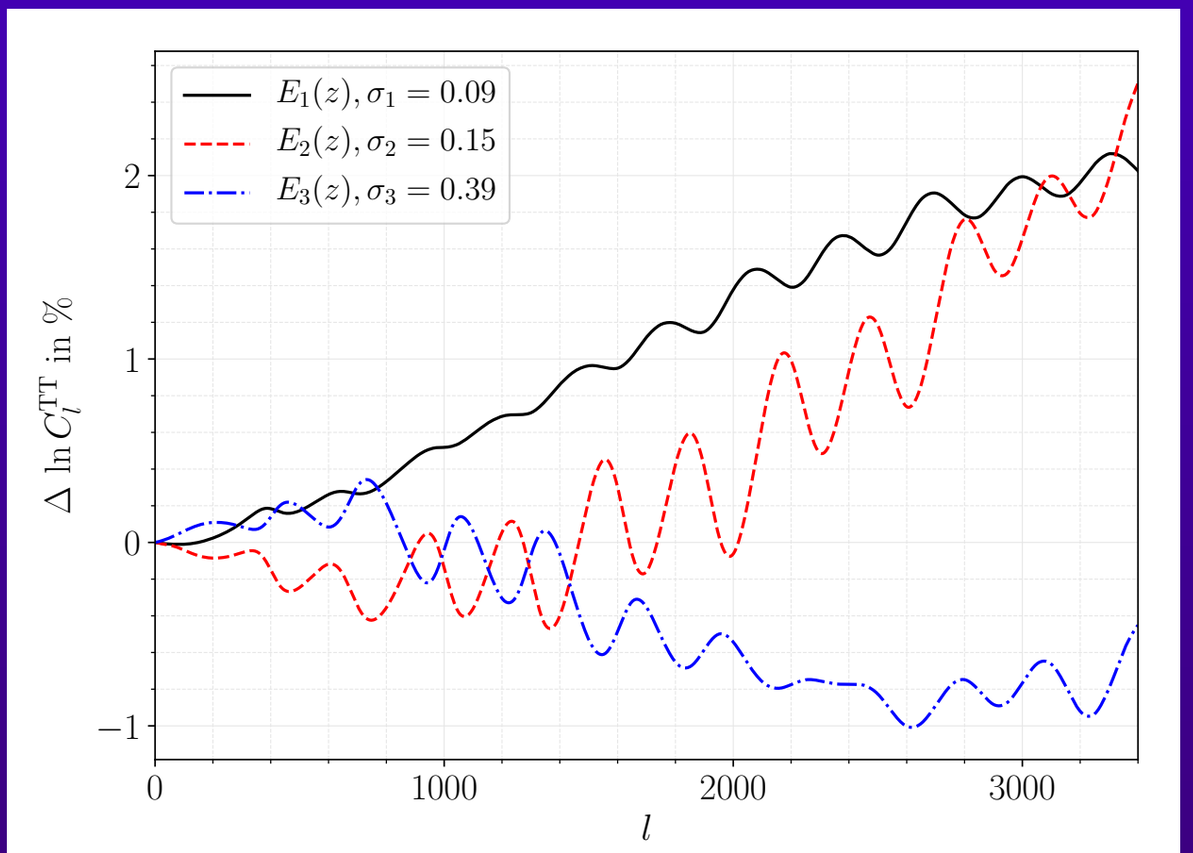


Mirrored in the CMB spectrum

- Consistent with previous study including analytics
- Predominant effect is a tilt of the spectrum
- Secondary effect is oscillations between the modes
- Huge overlaps between second and third principal components

Direct method (Planck)

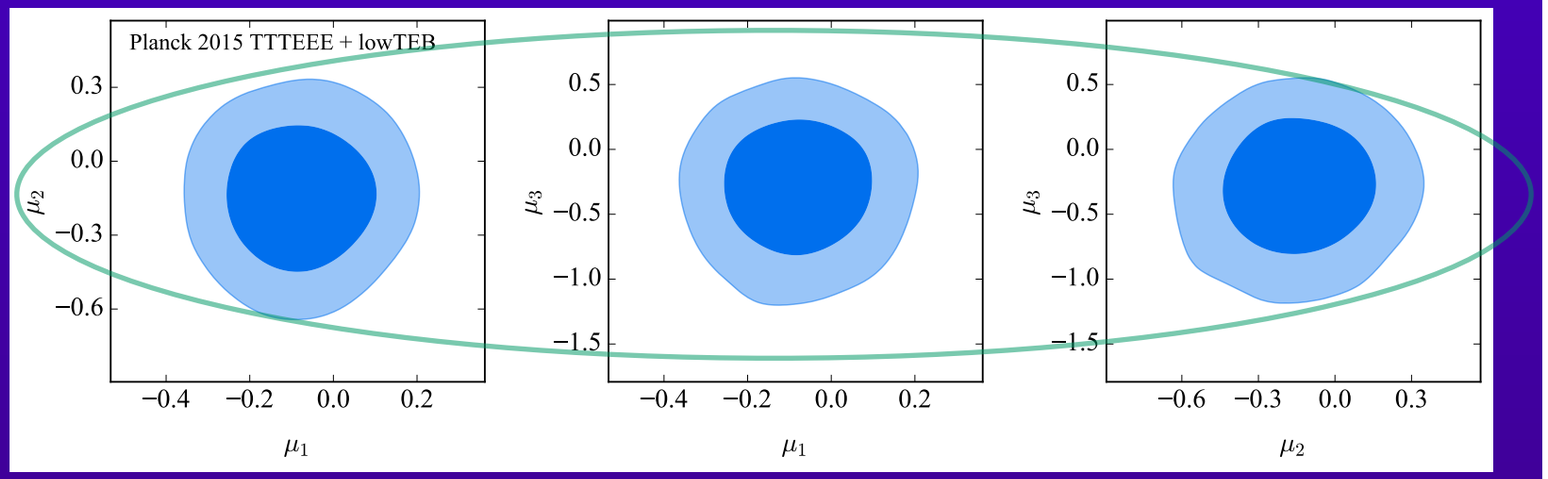


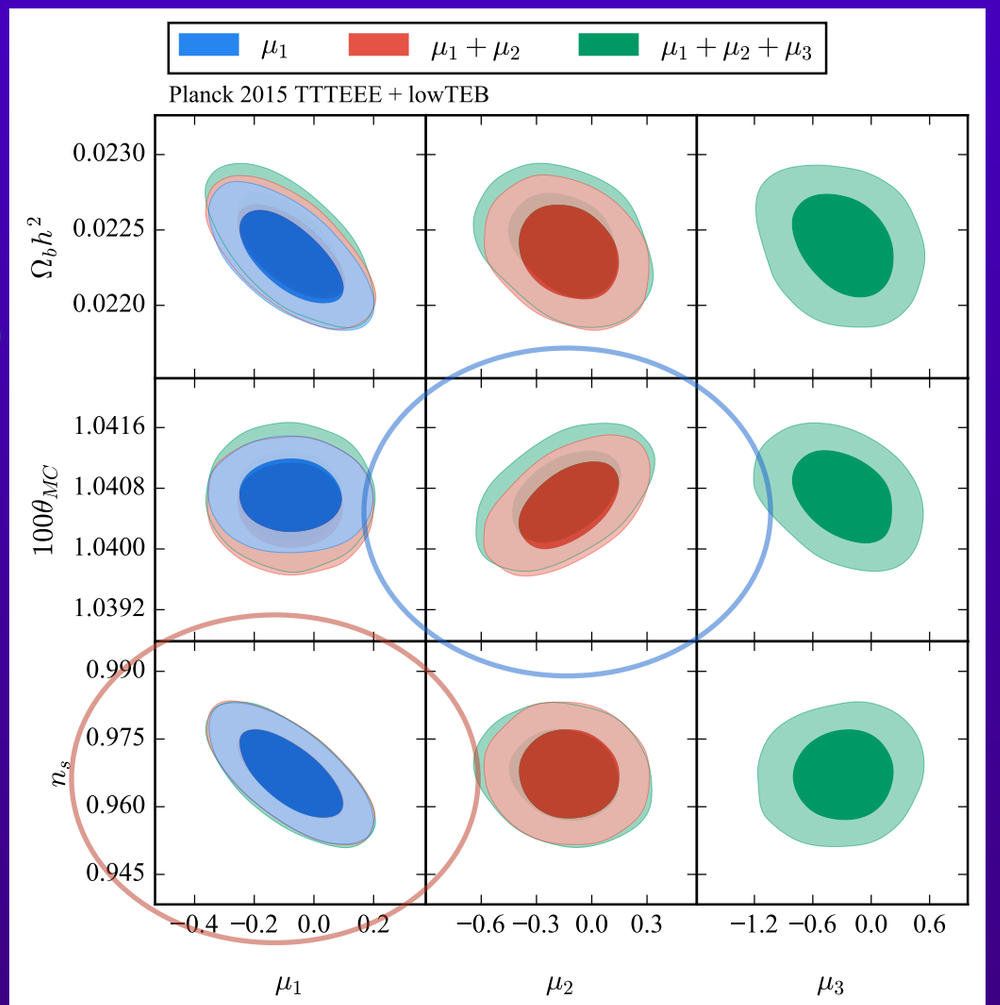


- Smearing of the tilt in mode 1
- Smoothing of the peaks in mode 2
- Decoupling of modes 2 and 3, with the third mode developing high redshift features
- Convergence, marginalisation: all tested

Correlation	Planck 2015	HC 2019
ξ_{21}	-0.05	2×10^{-6}
ξ_{31}	-0.09	1×10^{-4}
ξ_{32}	-0.07	4×10^{-5}

Markov chain results

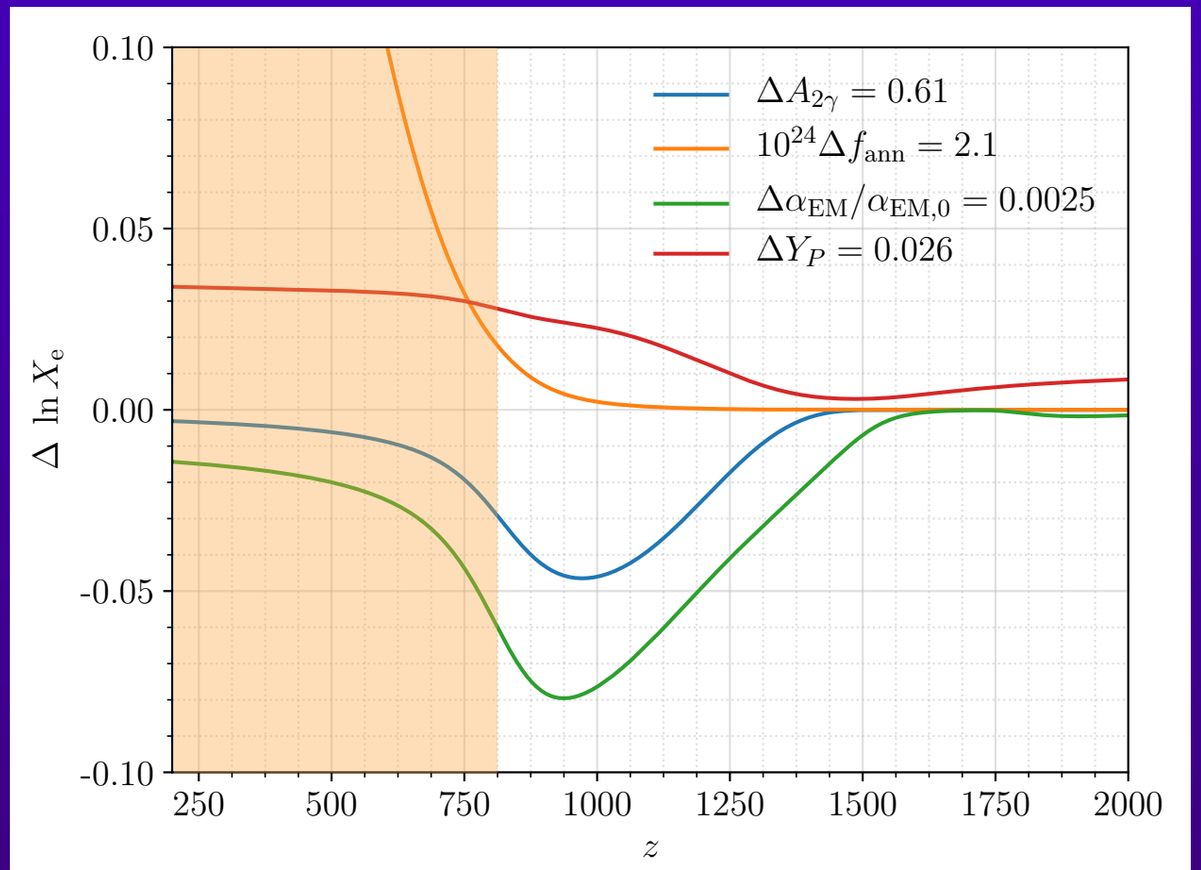


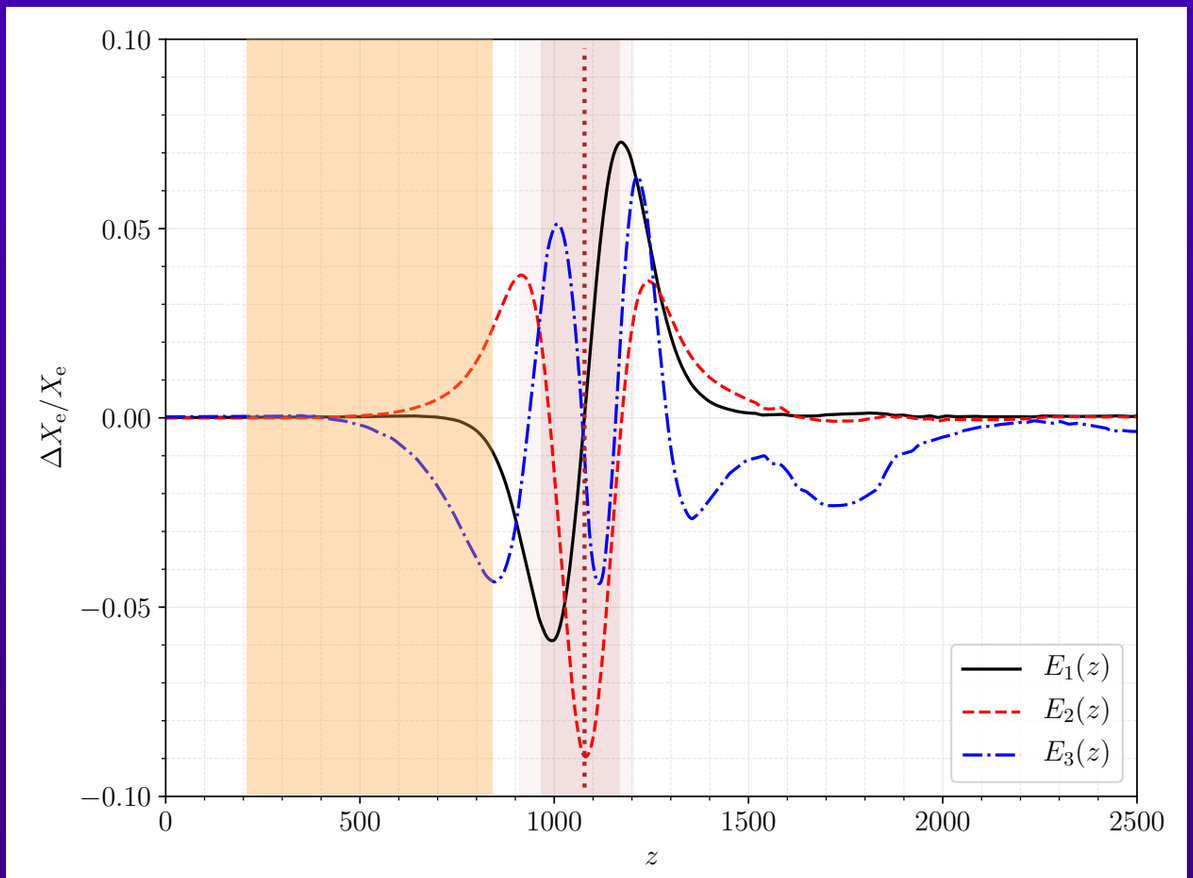


- Consistent with standard
- Tilt in spectrum of first mode similar to n_s
- Last scattering surface resonant with mode 2
- Orthogonality strides forward (0.1% after MCMC)

Parameter	Planck15	+ 1 mode	+ 2 modes	+ 3 modes
$\Omega_b h^2$	0.02224 ± 0.00016	0.02232 ± 0.00020	0.02235 ± 0.00021	0.02240 ± 0.00022
$100\theta_{MC}$	1.04073 ± 0.00033	1.04071 ± 0.00032	1.04058 ± 0.00038	1.04070 ± 0.00040
n_s	0.9652 ± 0.0048	0.9671 ± 0.0064	0.9672 ± 0.0065	0.9672 ± 0.0067
μ_1	$--$	-0.08 ± 0.11	-0.08 ± 0.12	-0.08 ± 0.12
μ_2	$--$	$--$	-0.13 ± 0.18	-0.14 ± 0.19
μ_3	$--$	$--$	$--$	-0.30 ± 0.35
H_0	67.25 ± 0.65	67.35 ± 0.68	67.45 ± 0.71	67.54 ± 0.74

Direct projections



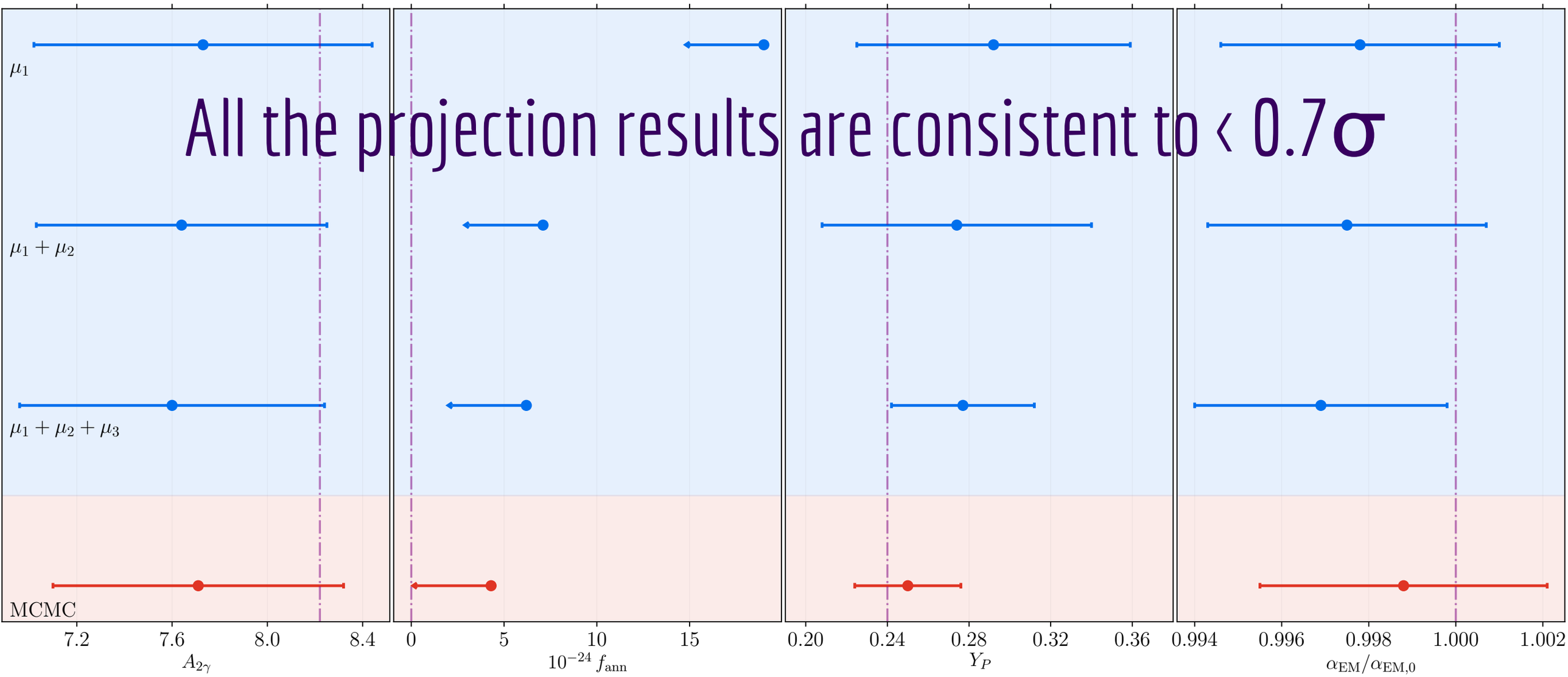


Low redshift variations

- Cast physical variations onto principal components
- Check which modes project best

Projections and amplitudes —› χ^2 —› minimise

Results of the projections



All the projection results are consistent to $< 0.7\sigma$

Two photon decay

Most information in modes 1 and 2

Dark matter annihilation

Larger variations from higher modes (extreme redshift behaviour)

Primordial helium

Strong drive from the third mode, similar story

Fine structure constant

Consistent value to within 0.1σ

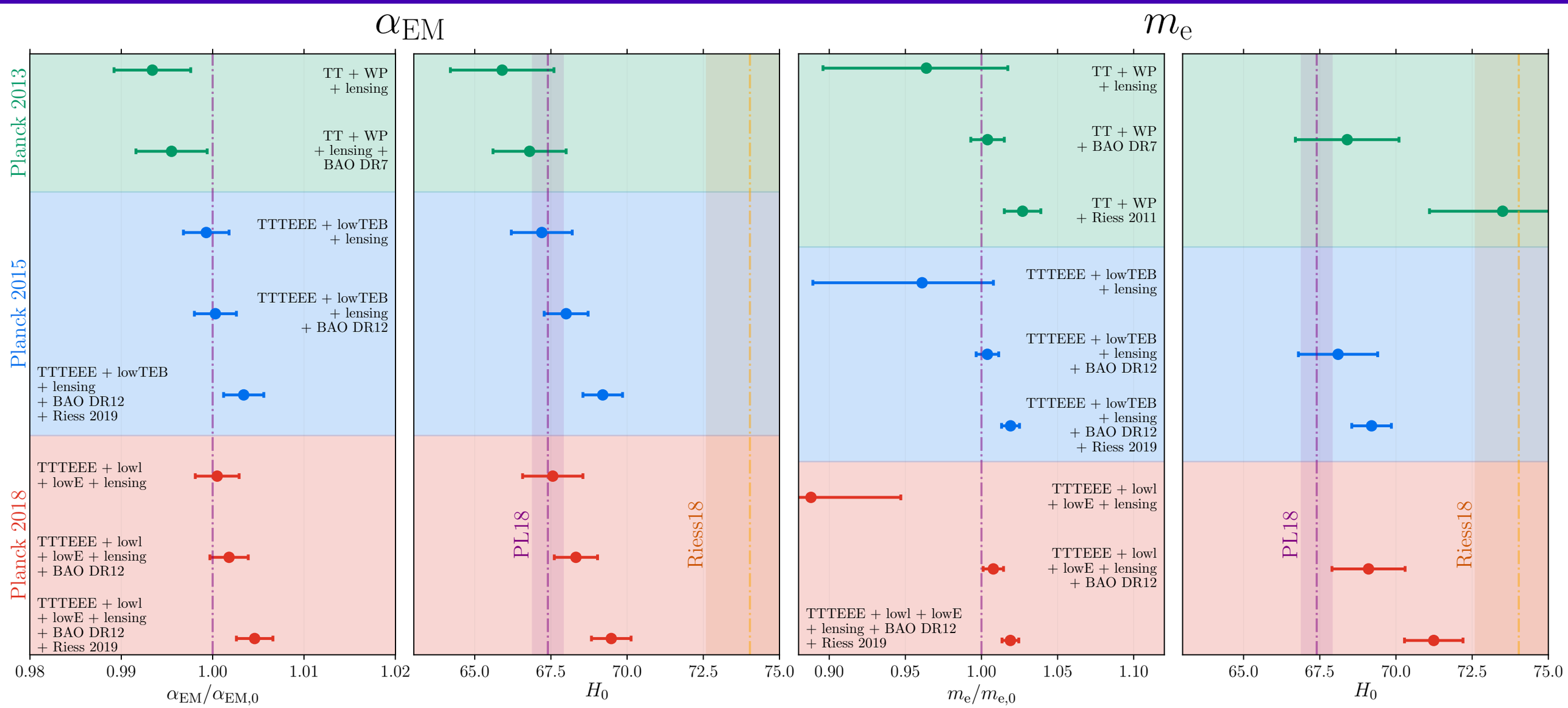
Conclusions

*coming soon: https:/github.com/hulktear/FEARec

- New machinery in FEARec++* —› 2.5 x improvements in the eigenmodes errors
- More orthogonal, de-correlated modes —› projections
- Time dependent variations in α_{EM} and m_e: now applicable with this machinery (LH, Chluba 2017) and Planck 2018 likelihood.
- also...

‘Updated fundamental constant constraints from Planck 2018 data…’

Hart and Chluba (2019, submitted to MNRAS, arXiV on Tuesday)



Questions or comments: luke.hart@manchester.ac.uk

Around all week: please come and chat!

Thank you!

Troubleshooting the likelihood

Low-l likelihood, some noise we don't know about?

Numerical instabilities around fiducial.

All okay around our eigenmodes.