SYMBOLIC ACCELERATION OF EFTOFLSS AND APPLICATIONS

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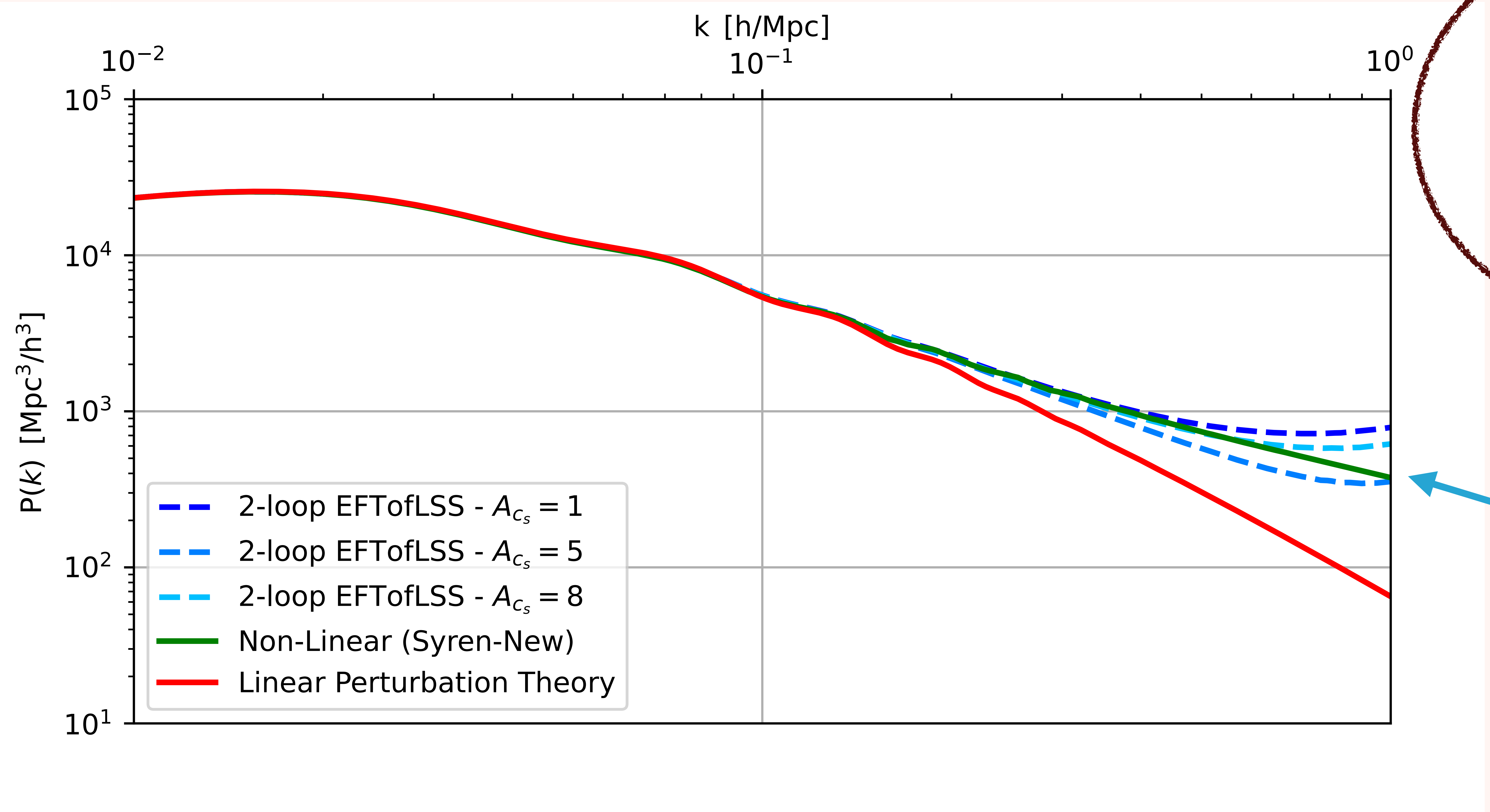
MINISTRY OF EDUCATION YOUTH AND SPORTS

MOTIVATION



Constrain with:

—>Simulations

—>Observations

$c_{s(1)}(z), c_1(z), c_4(z)$

OUTLINE

Goal: ***Constrain EFTofLSS with data***

arXiv:2511.05093

D.F., C. Skordis

Part 1: Accelerating Effective Field Theory of Large Scale Structure

Growth Factor emulators

D.F., D. J. Bartlett C. Skordis

In preparation

Part 2: Constraining the EFTofLSS counterterms

In preparation

D.F., R. Calderon, D. Alonso, C. Skordis

EFT OF LSS

$$P_{1,3}(\vec{k},a)\delta_D(\vec{k}+\vec{k'}) = \int \frac{d^3q_1}{(2\pi)^3}\frac{d^3q_2}{(2\pi)^3}\frac{d^3q_3}{(2\pi)^3}\delta_D^3(\vec{k'}-\vec{q}_1-\vec{q}_2-\vec{q}_3)$$

$\times$ Complicated-Kernel

$$\times < \delta_1(\vec{k},a)\delta_1(\vec{q}_1,a)\delta_1(\vec{q}_2,a)\delta_1(\vec{q}_3,a) >$$

Integrating out

$$\dot{u}_l^i + Hu_l^i + \frac{1}{a}u_l^j(\partial_j u_l^i) + \frac{1}{a}\partial_i\phi_l = -\frac{1}{a\rho_l}\partial_j[\tau^{ij}]_\Lambda$$

Effective stress-energy tensor

- **Short scale physics**

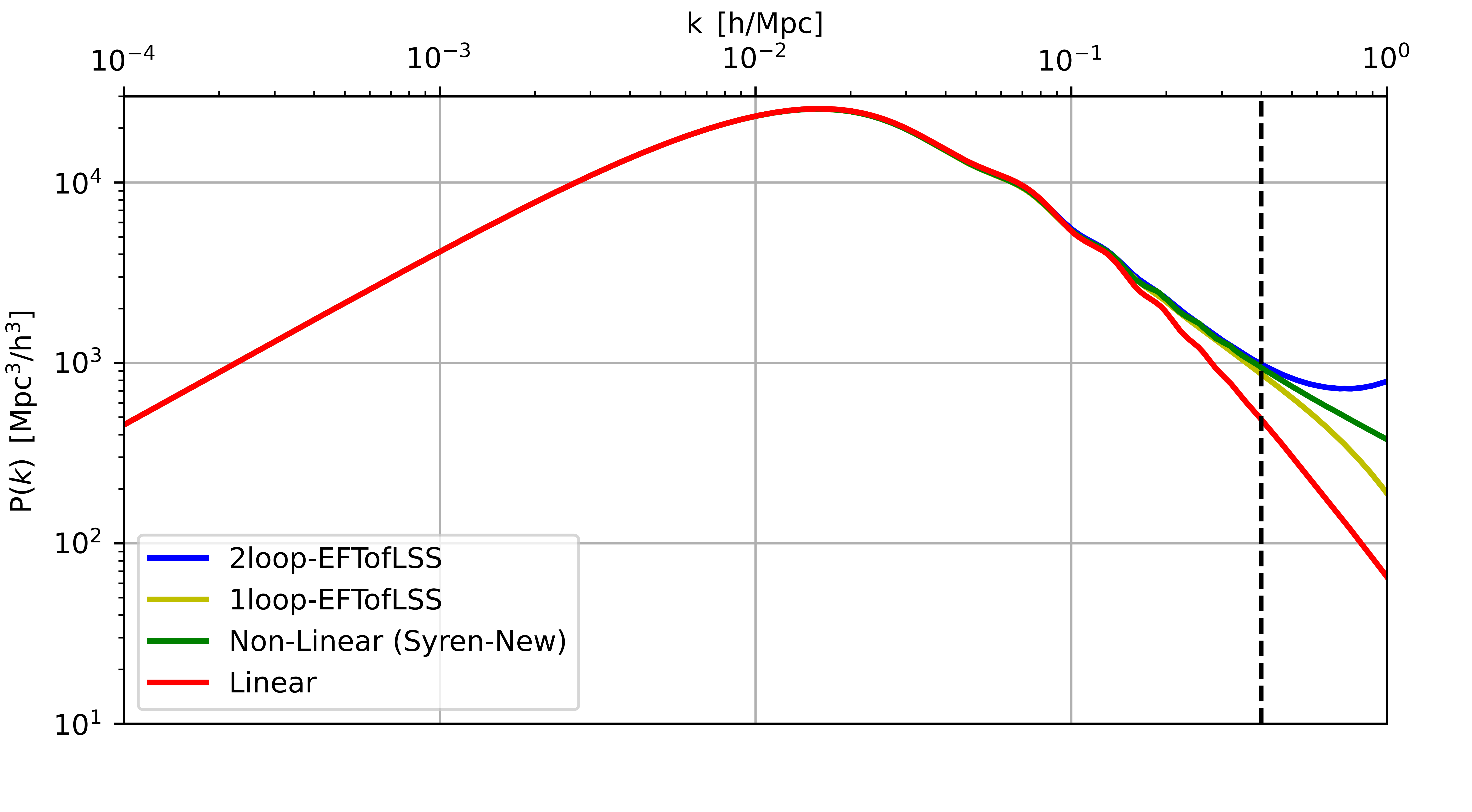
$$P_{\text{2-loop}}^{\text{EFT}}(k,z) = P_{\text{EFT-1-loop}}(k,z) + [D(z)]^6 P_{\text{2-loop}}(k)$$
$$-2(2\pi)c_{s(2)}^2(z)\frac{k^2}{k_{\text{NL}}{}^2}P_{11}(k) + (2\pi)c_{s(1)}^2(z)[D(z)]^4 P_{1-\text{ loop}}^{(c_s)}(k)$$
$$+(2\pi)^2\left(1+\frac{\zeta+\frac{5}{2}}{2\left(\zeta+\frac{5}{4}\right)}\right)\left[c_{s(1)}^2(z)\right]^2[D(z)]^2\frac{k^4}{k_{\text{NL}}{}^4}P_{11}(k)$$
$$+(2\pi)c_1(z)[D(z)]^4 P_{\text{1-loop}}^{(\text{quad, }1)}(k)$$
$$+2(2\pi)^2 c_4(z)[D(z)]^2\frac{k^4}{k_{\text{NL}}{}^4}P_{11}(k)$$

$$P_{1-loop}^{EFT}(k,z) = D(z)^2P_1(k) + D(z)^4P_{1-loop}(k) - 2(2\pi)D(z)^2c_{s(1)}^2(z)\frac{k^2}{k_{NL}^2}P_1(k).$$

arXiv:1507.05326, S. Foreman, H. Perrier, L. Senatore

EFT OF LSS

Valid up to k~0.5 h/Mpc

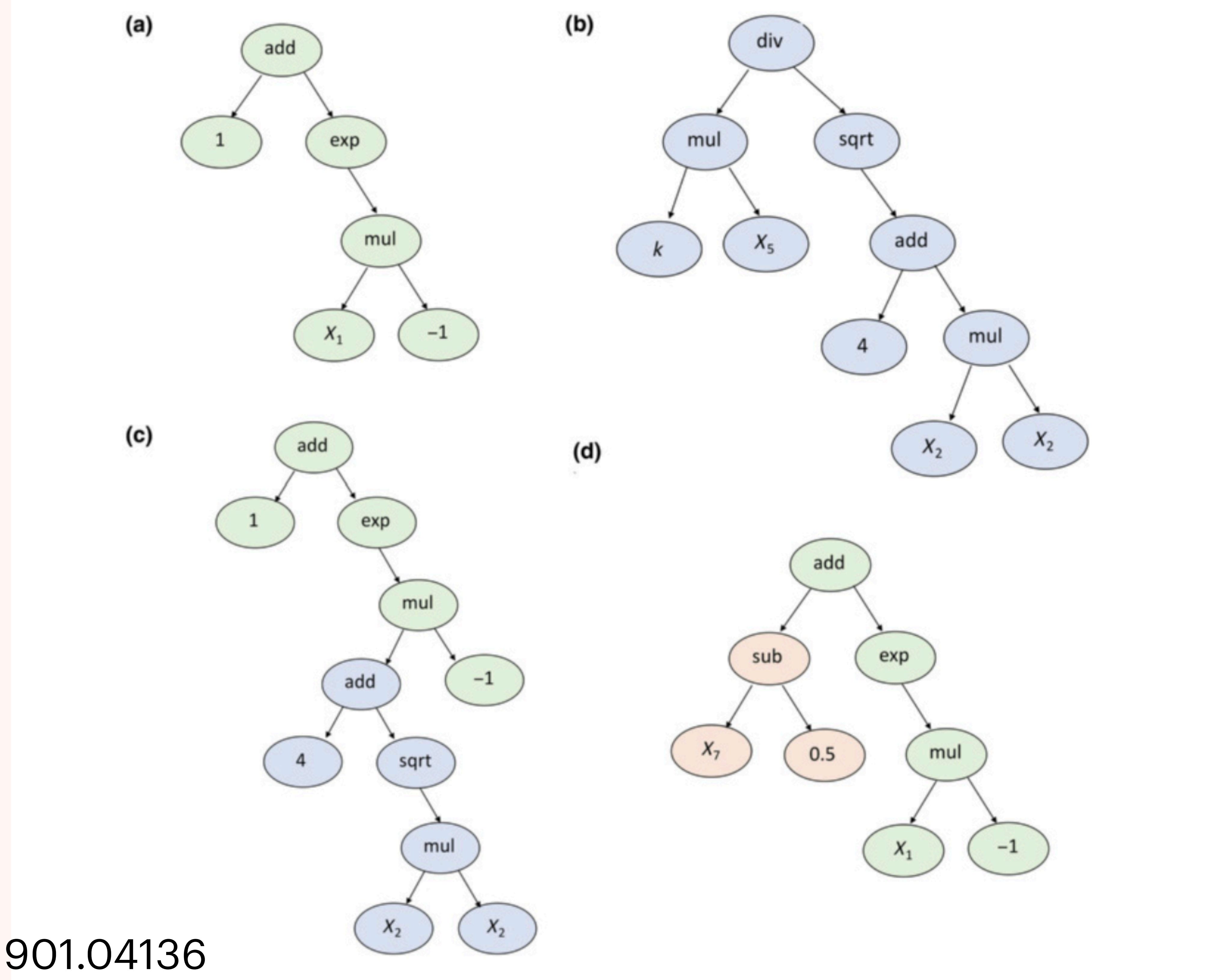


SYM-EFT

Symbolic Regression

https://github.com/heal-research/operon

Genetic programming



arXiv:1901.04136

In Cosmology

$$P^{X-loop}_{complicated-integral}(k, A_s, n_s, \Omega_{CDM}\Omega_b, h)$$

A few seconds to minutes

Regression

Minutes to days

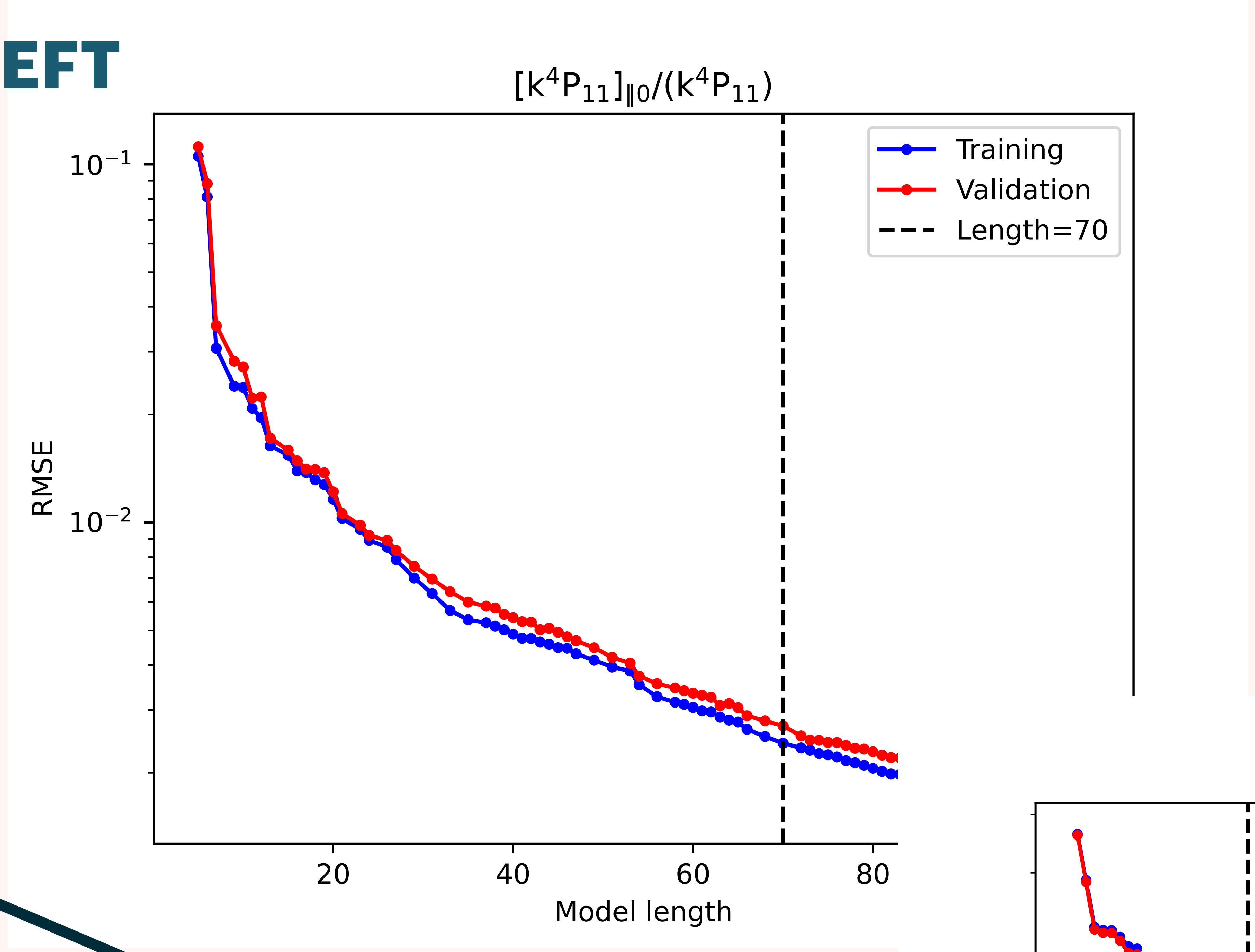
Emulator

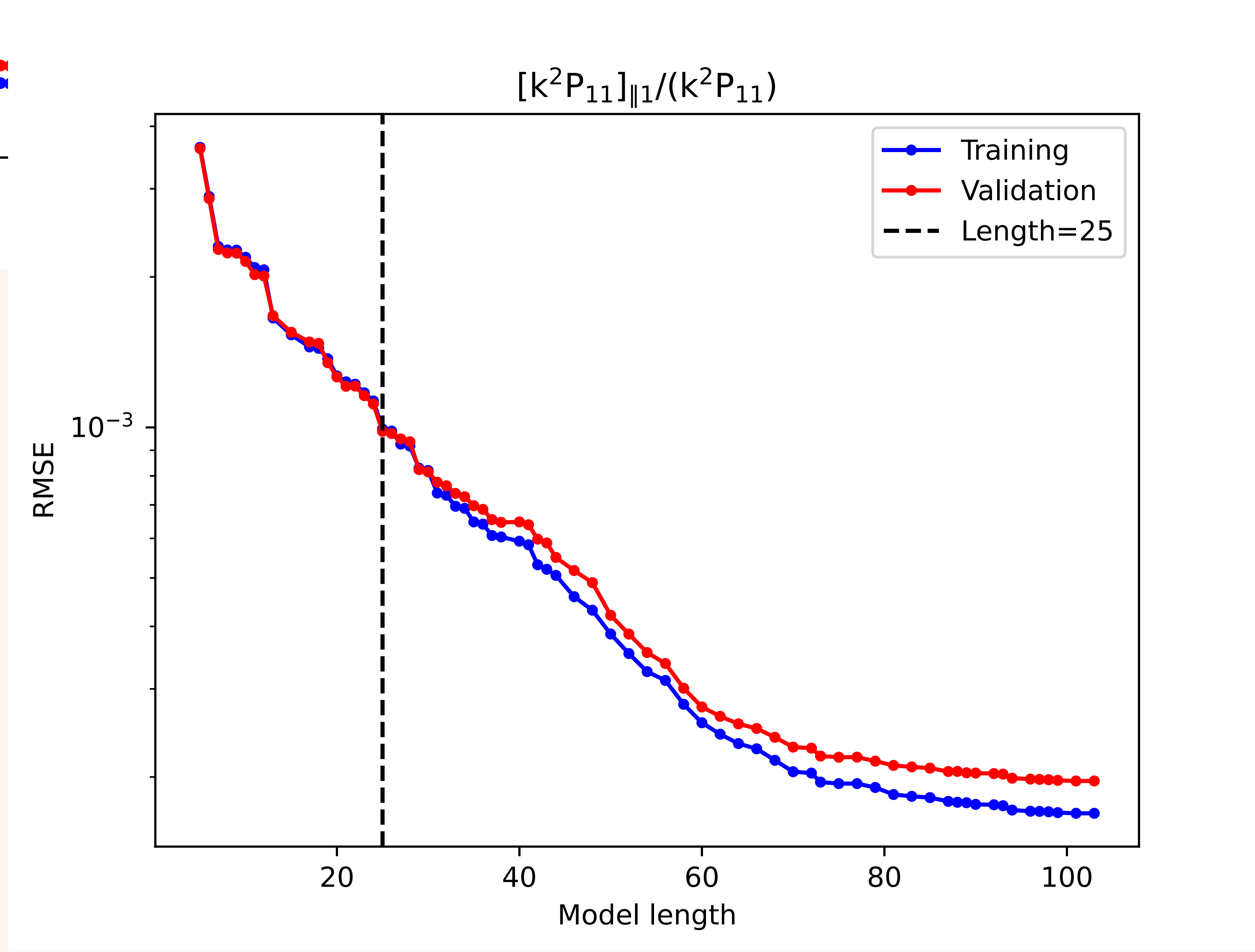
$10^{-4} seconds$

SYM-EFT

Codes used: CosmoEFT and ResumEFT

1-loop	2-loop
$P_{11}(k)_{\parallel 1}$	$P_{11}(k)_{\parallel 2}$
$P_{1\text{-loop}}(k)_{\parallel 0}$	$P_{1\text{-loop}}(k)_{\parallel 1}$
$\left(k^2 P_{11}(k)\right)_{\parallel 0}$	$P_{2\text{-loop}}(k)_{\parallel 0}$
-	$\left(k^4 P_{11}(k)\right)_{\parallel 0}$
-	$\left(k^2 P_{11}(k)\right)_{\parallel 1}$
-	$P^{(\text{quad }1)}_{1\text{-loop}}(k)_{\parallel 0}$
-	$P^{(\text{cs})}_{1\text{-loop}}(k)_{\parallel 0}$

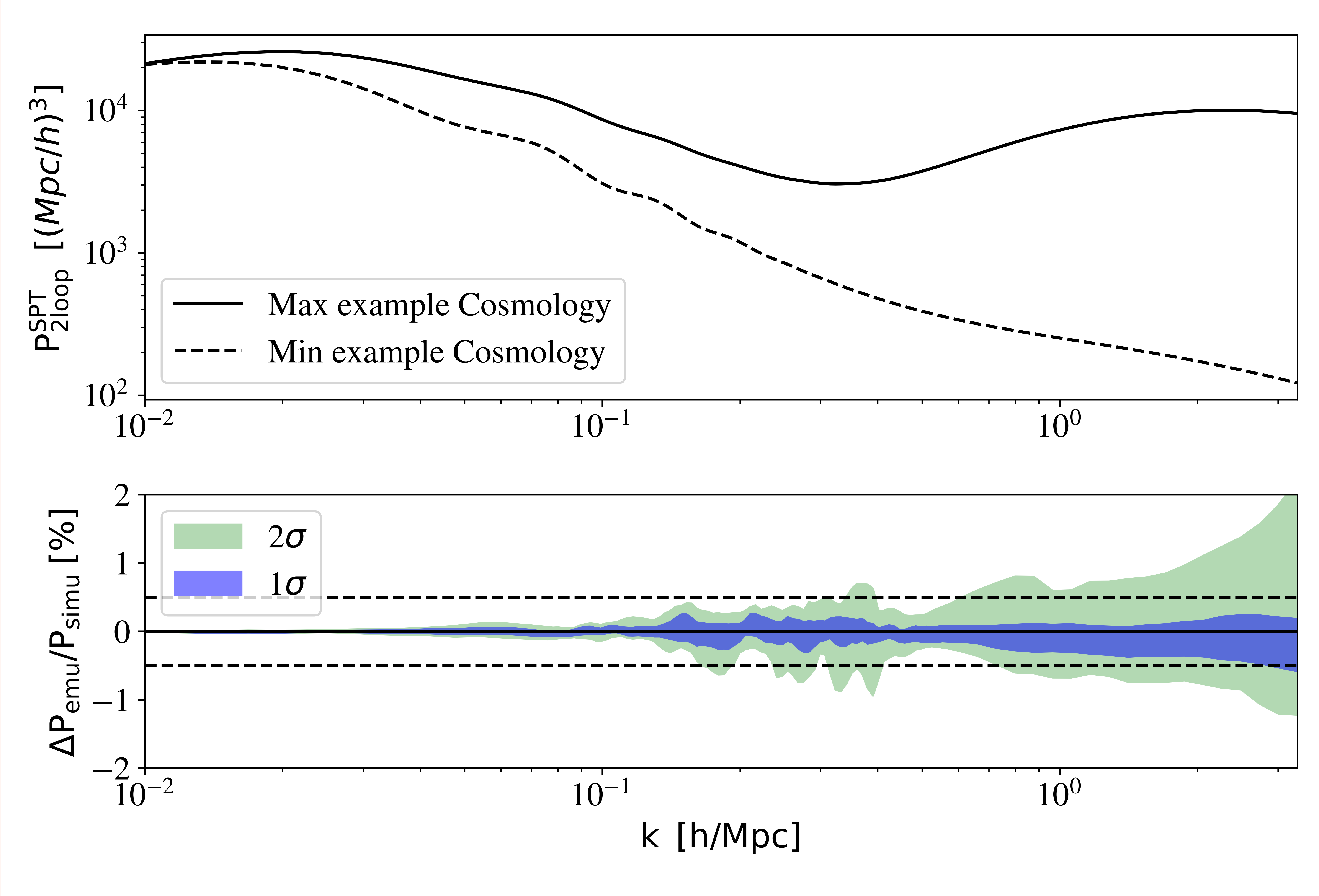




$$\frac{k^2 P_{11\,\parallel 1}}{k^2 P_{lin}} = C_0 + \frac{1}{\sqrt{C_{10} k^{C_{11}} + 1}} \left[C_8 \cos\left(C_9 k\right) - \frac{C_1 \Omega_b \cos\left(C_2 \Omega_m + C_3 \Omega_b - C_4 h - C_5 k\right)}{\sqrt{\frac{C_6}{k^{C_7}} + 1}} \right]$$

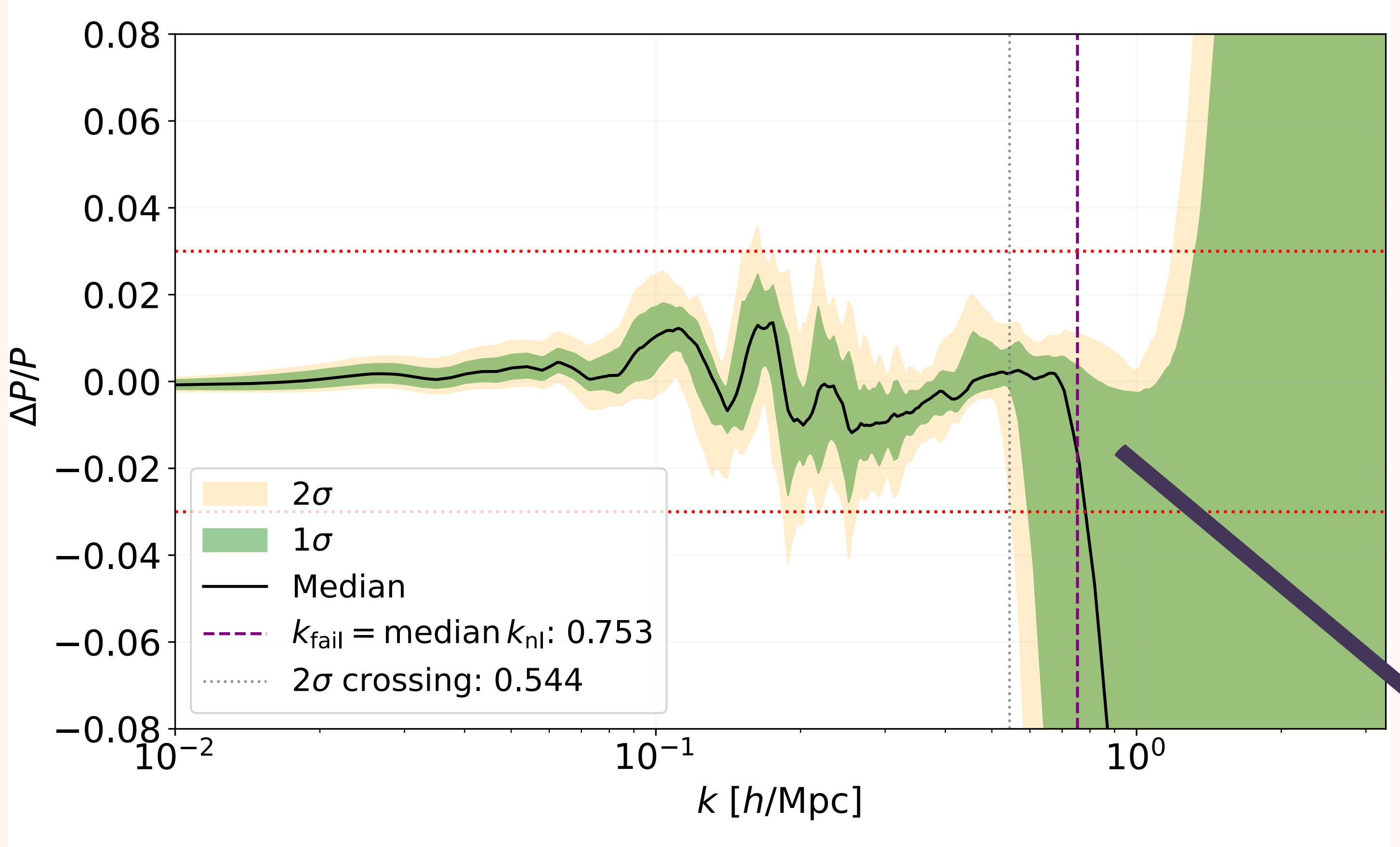
SYM-EFT

1-loop	2-loop
$P_{11}(k)_{\parallel 1}$	$P_{11}(k)_{\parallel 2}$
$P_{1\text{-loop}}(k)_{\parallel 0}$	$P_{1\text{-loop}}(k)_{\parallel 1}$
$\left(k^2 P_{11}(k)\right)_{\parallel 0}$	$P_{2-\text{ loop}}(k)_{\parallel 0}$
-	$\left(k^4 P_{11}(k)\right)_{\parallel 0}$
-	$\left(k^2 P_{11}(k)\right)_{\parallel 1}$
-	$P^{(\text{quad 1})}_{1\text{-loop}}(k)_{\parallel 0}$
-	$P^{(\text{cs})}_{1\text{-loop}}(k)_{\parallel 0}$



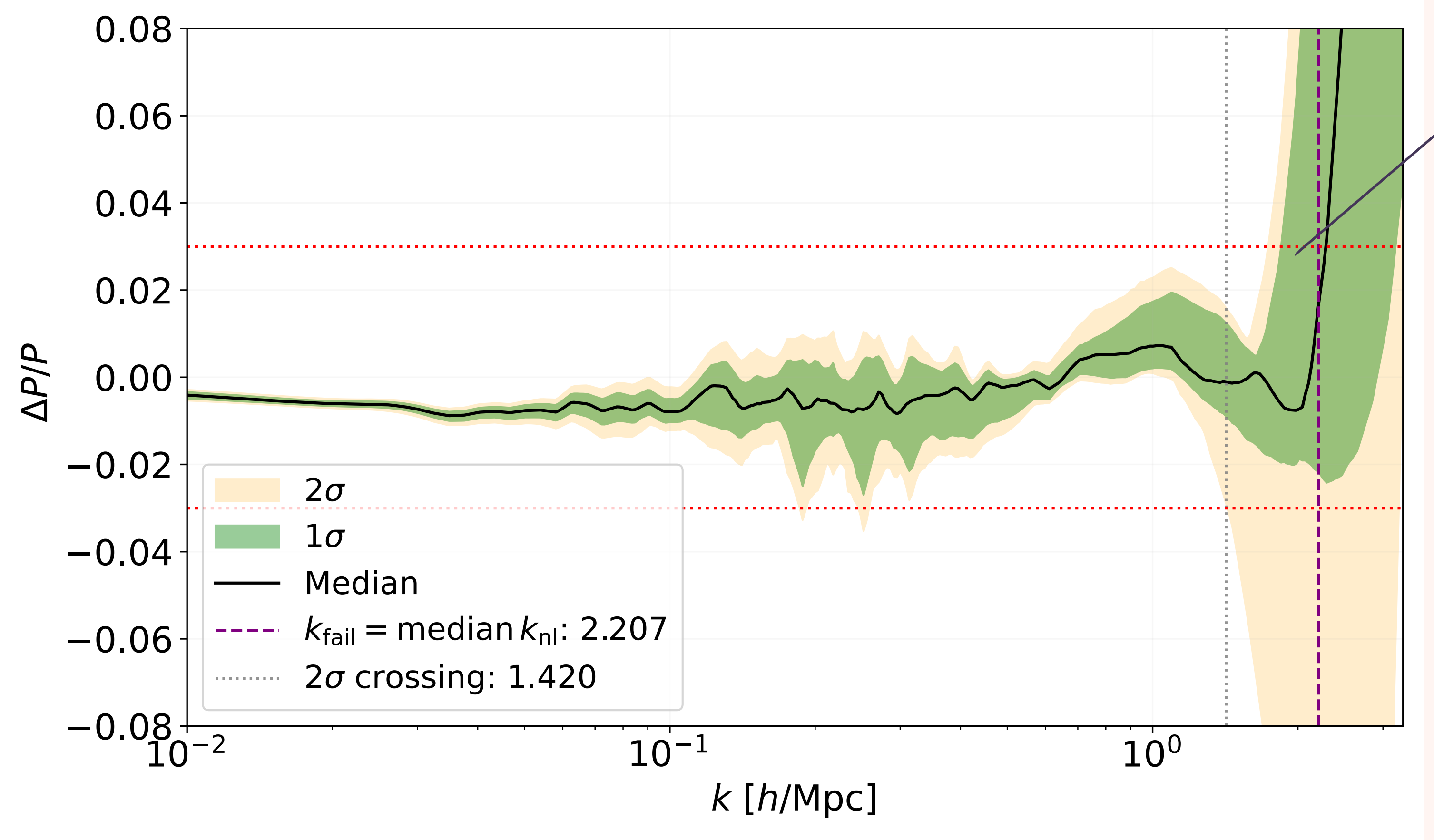
SR emulators :

$$k_{fail}(z, A_s, n_s, \Omega_{CDM}\Omega_b, h)$$

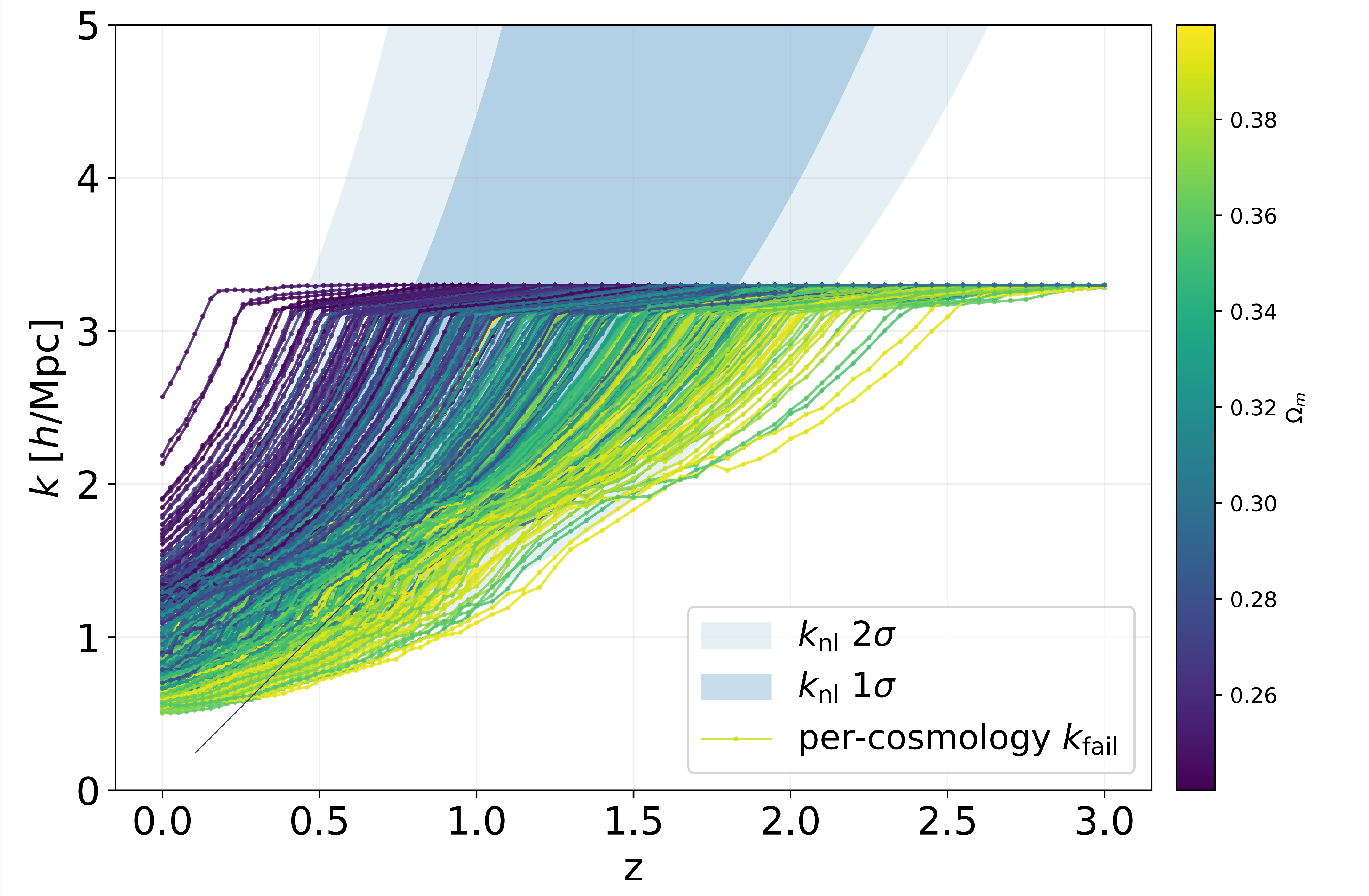


z=0

EFTofLSS fails



z=1



Syren-new, arXiv:2410.14623

Symbol emulator

Part 2: constraining the counterterms

WEAK LENSING

Symbolic EFTofLSS

EFT Counter terms:

- *short scale physics*

Tensions :

- σ_8
- A_{lens}

Can we constrain the EFT counter terms?

COUNTERTERMS

Cosmological pameters $\Omega_{CDM}, \Omega_b, h, A_s, n_s$

Redshift z

$$c_{s(1)}(z) = A_{cs} D(z)^{\alpha_{cs}} + B_{cs} D(z)^{\beta_{cs}}$$

$$c_1(z) = A_1 D(z)^{\alpha_1} + B_1 D(z)^{\beta_1}$$

$$c_4(z) = A_4 D(z)^{\alpha_4} + B_4 D(z)^{\beta_4}$$

— constant

— One power law

—Two power laws

arXiv:1507.05326

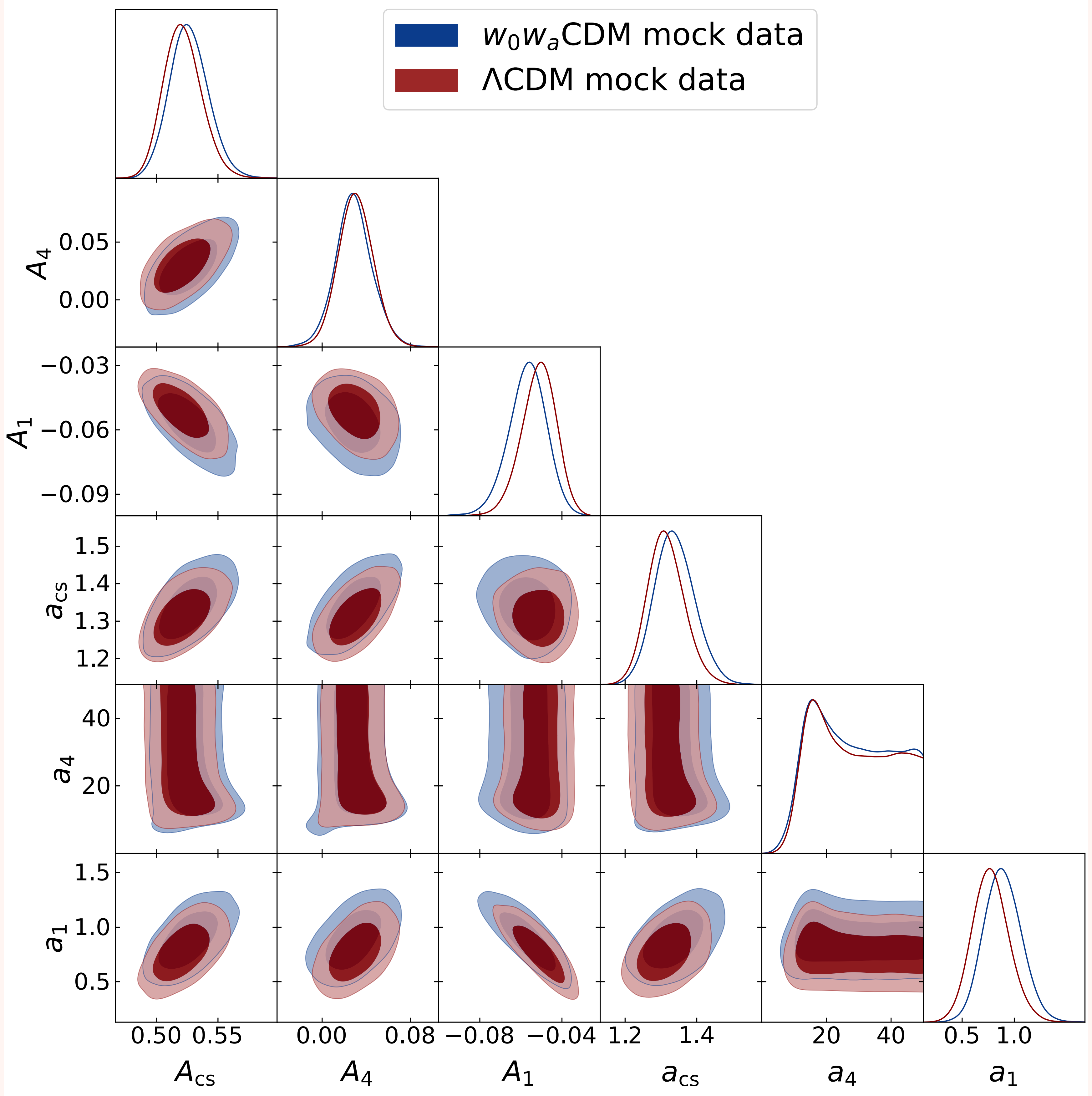
MOCK DATA

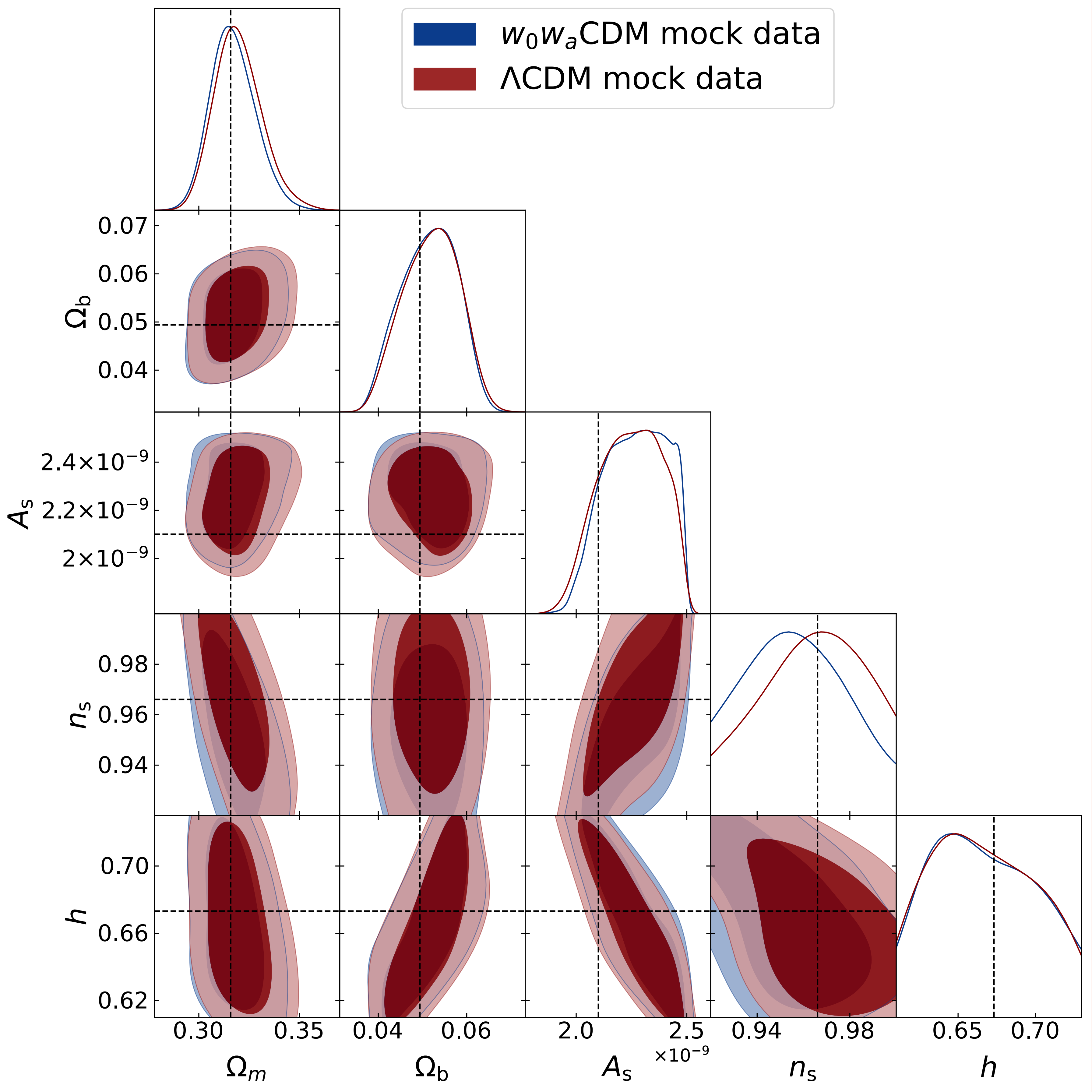
EFTOFLSS

Fit to Non-linear P(k) → ΛCDM → $w_0 w_a CDM$

—> **1 power law** counterterms

—> ΛCDM





MOCK DATA

EFTOFLSS

Fit to Non-linear P(k)

BaccoEmu, arXiv:2011.15018

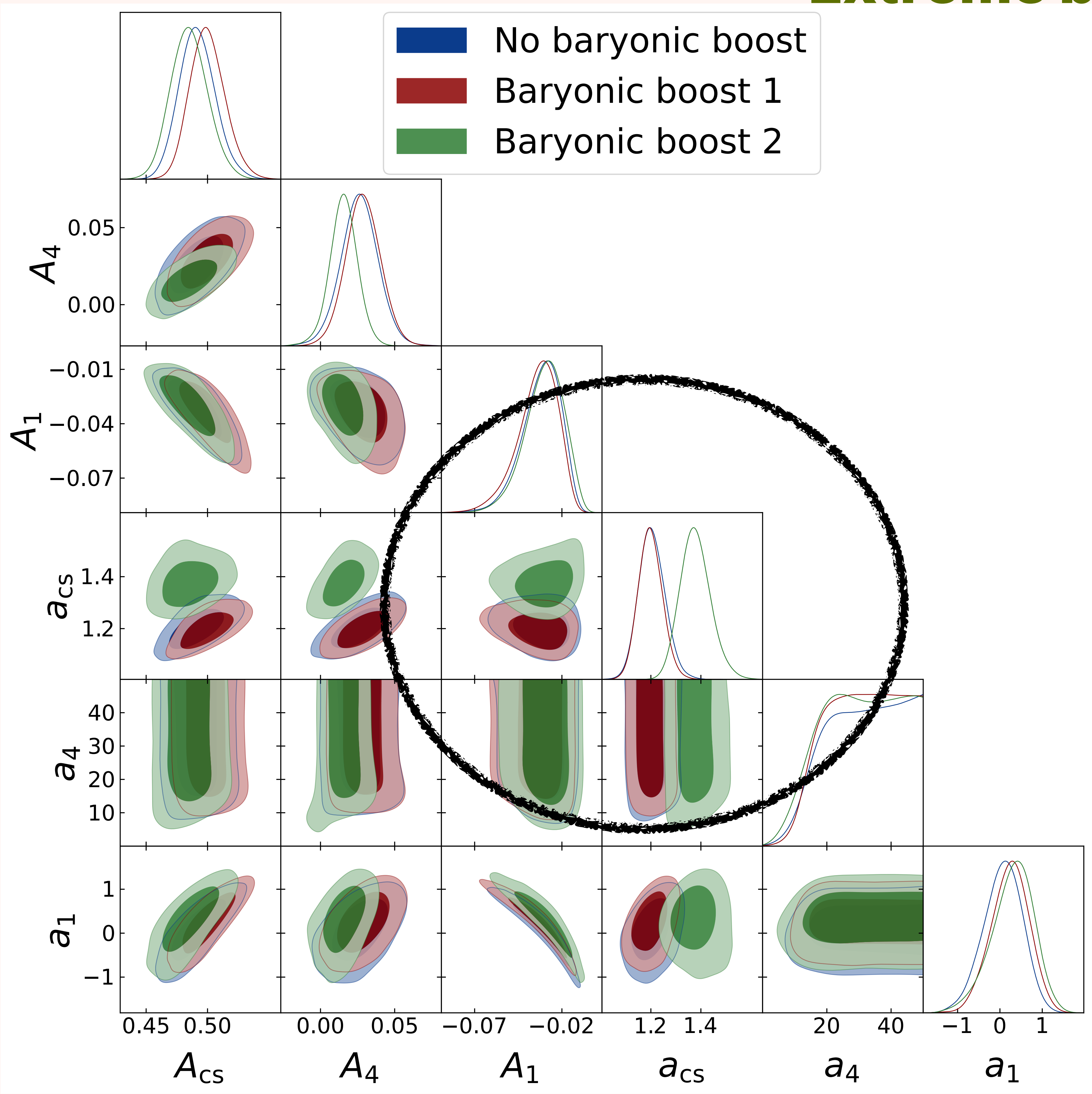
No baryonic boost

Fiducial boost

Extreme boost

—> 1 power law counterterms

—> ΛCDM



MOCK DATA

Fit to Non-linear P(k)

No baryonic boost

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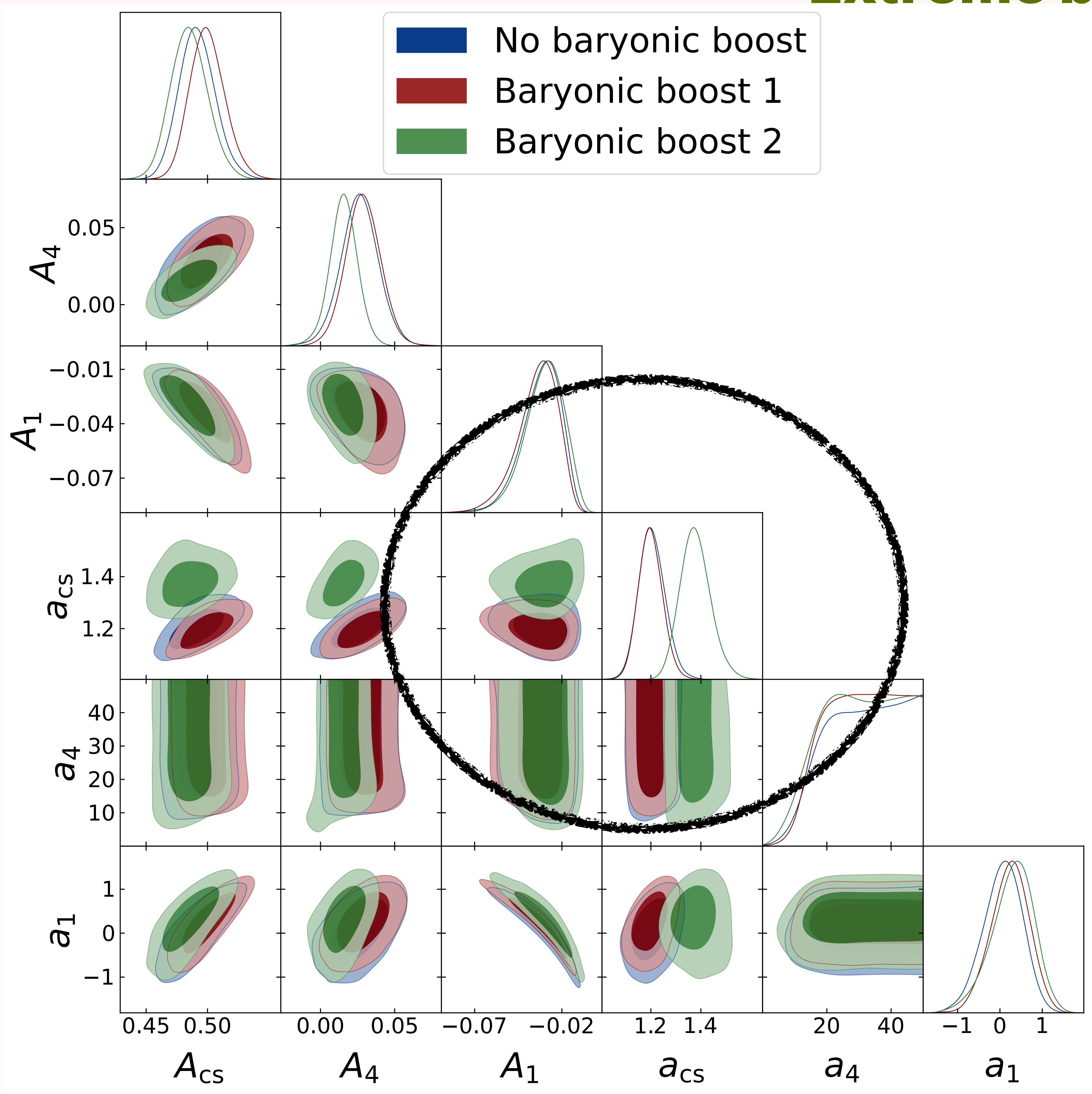
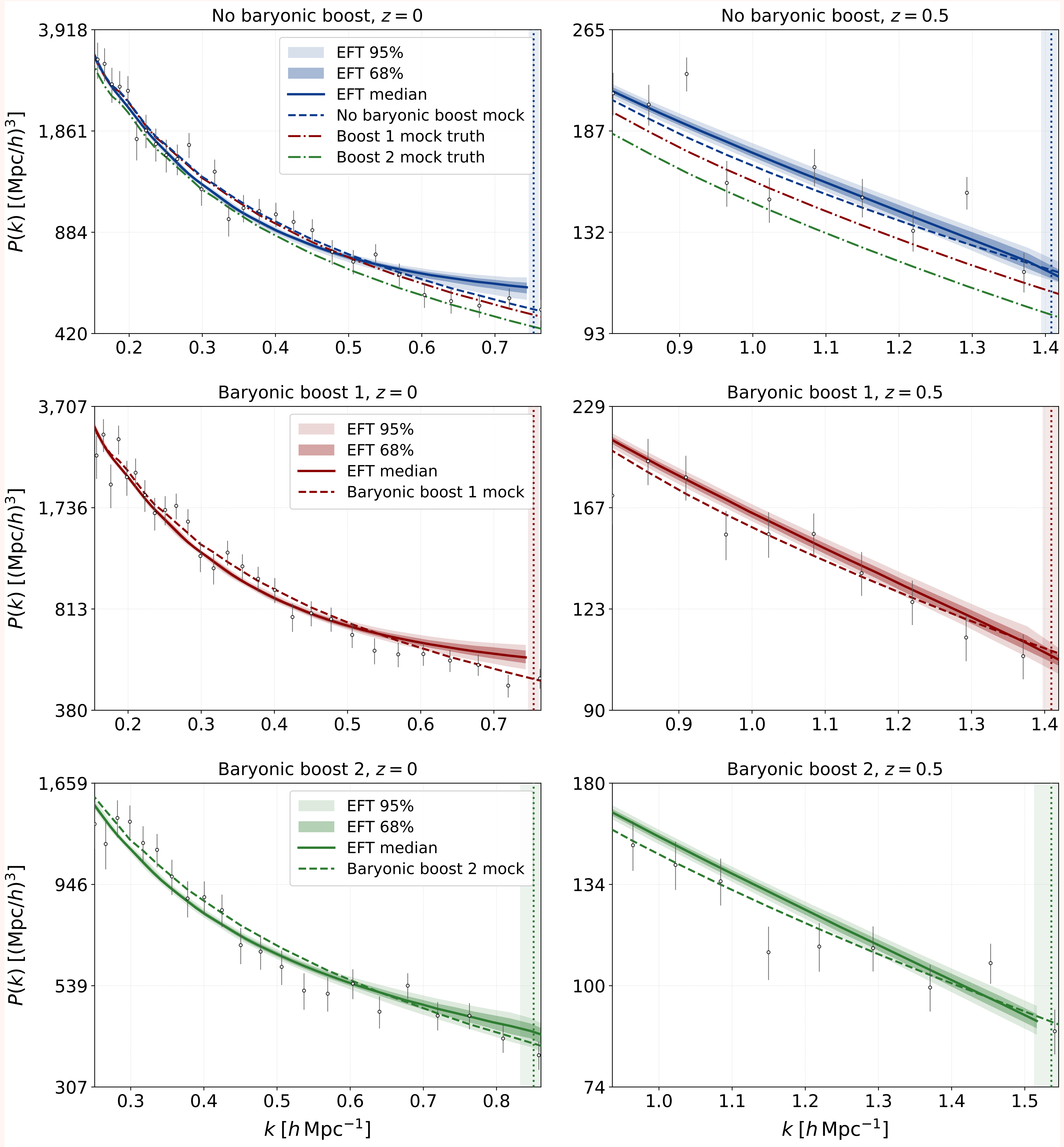
Extreme boost





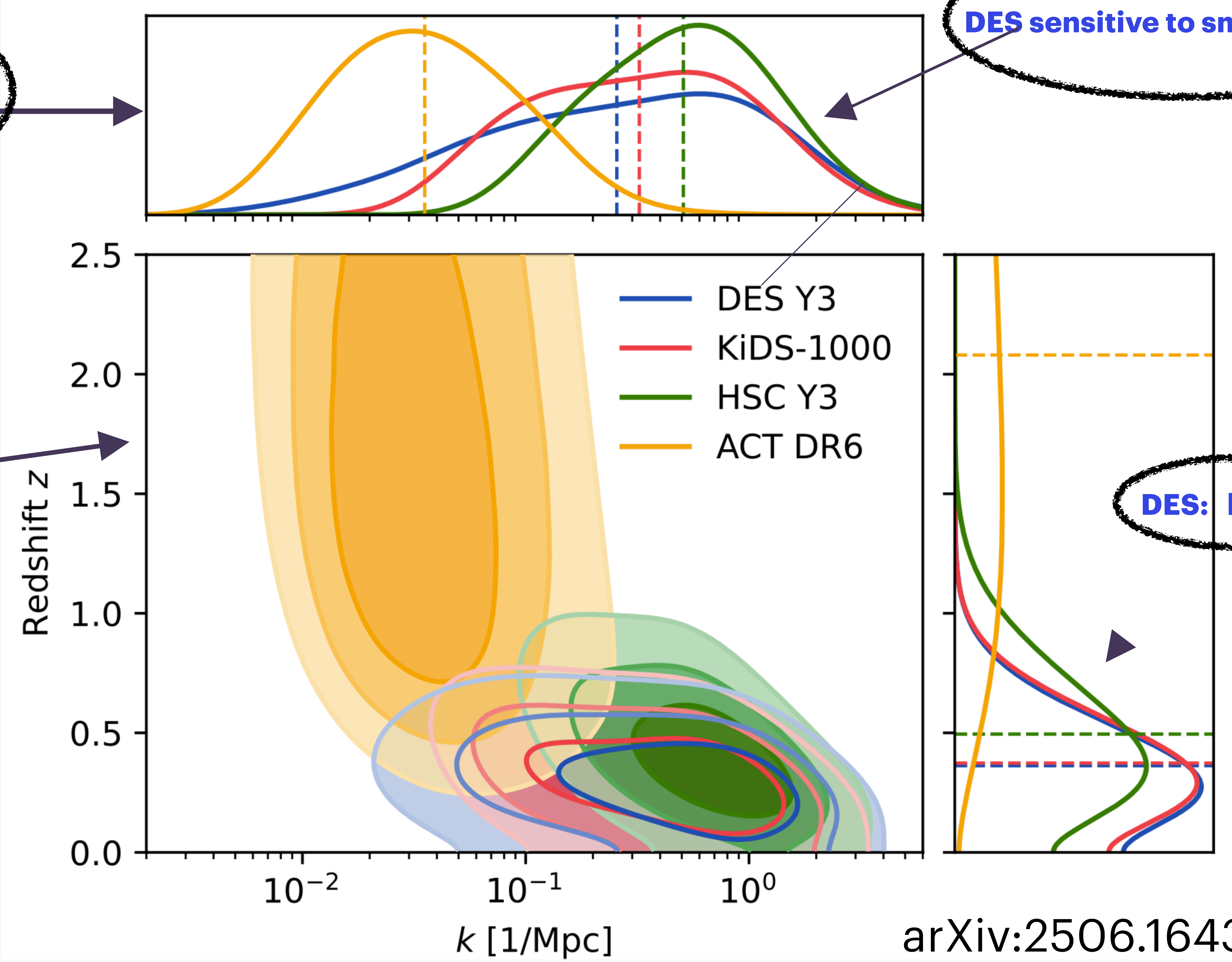
WEAK LENSING

CMB lensing sensitive to large wavelengths

Wide redshift range

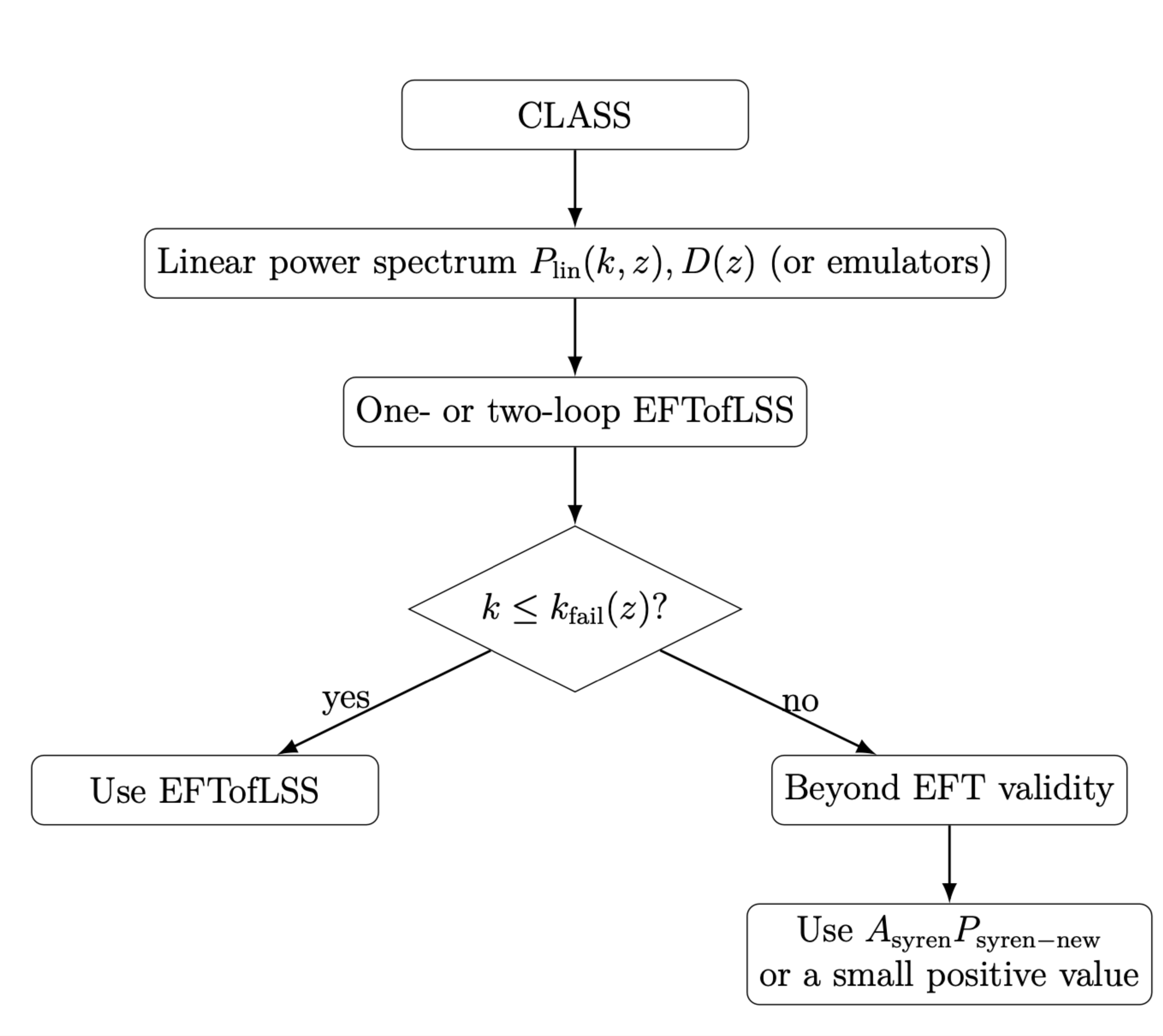
DES sensitive to smaller scales

DES: lower z

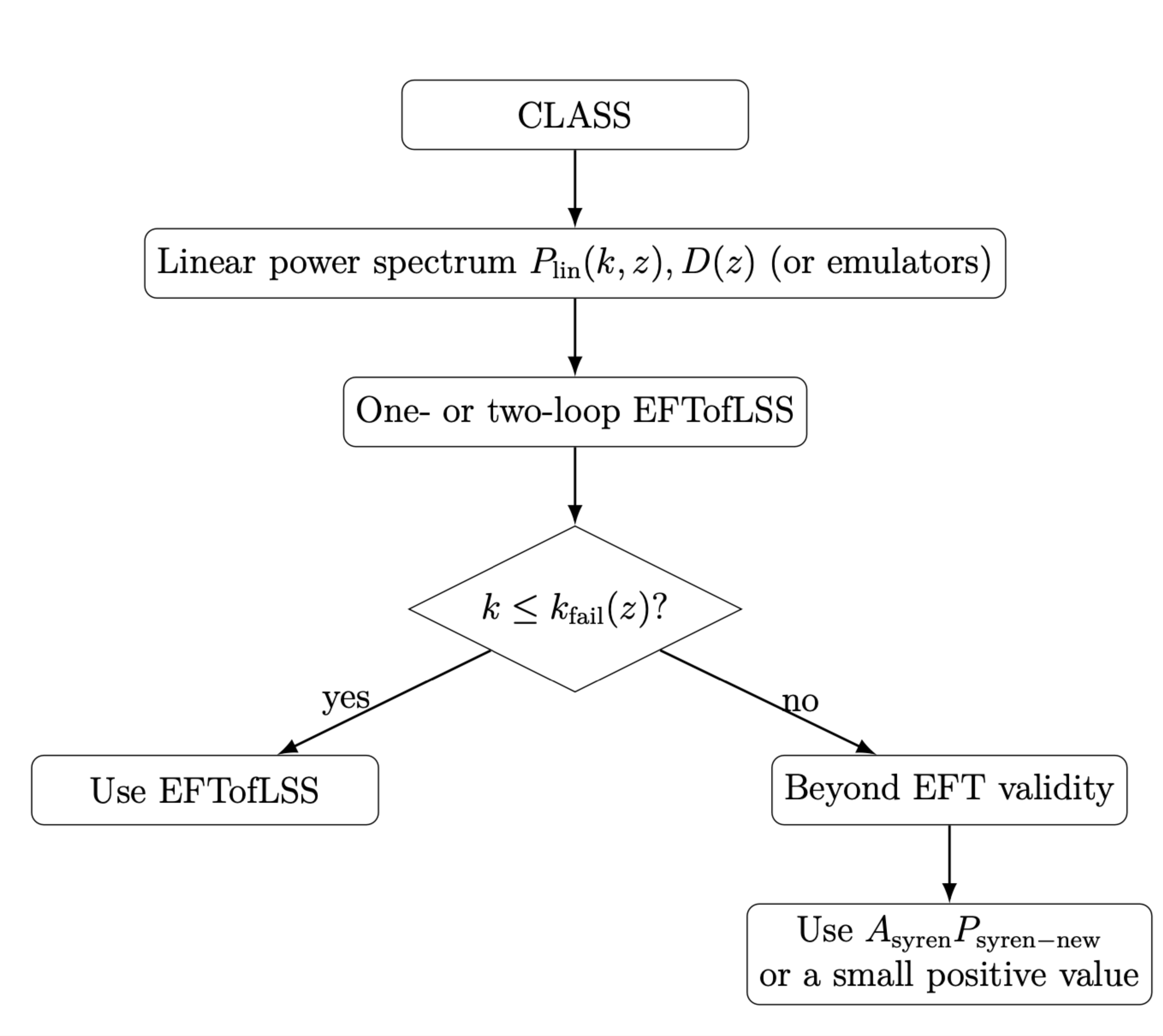


arXiv:2506.16434v1

CMB LENSING


CLASS
Linear power spectrum $P_{\mathrm{lin}}(k, z), D(z)$ (or emulators)
One- or two-loop EFTofLSS
$k \leq k_{\mathrm{fail}}(z)$?
yes
no
Use EFTofLSS
Beyond EFT validity
Use $A_{\mathrm{syren}} P_{\mathrm{syren-new}}$
or a small positive value

CMB LENSING



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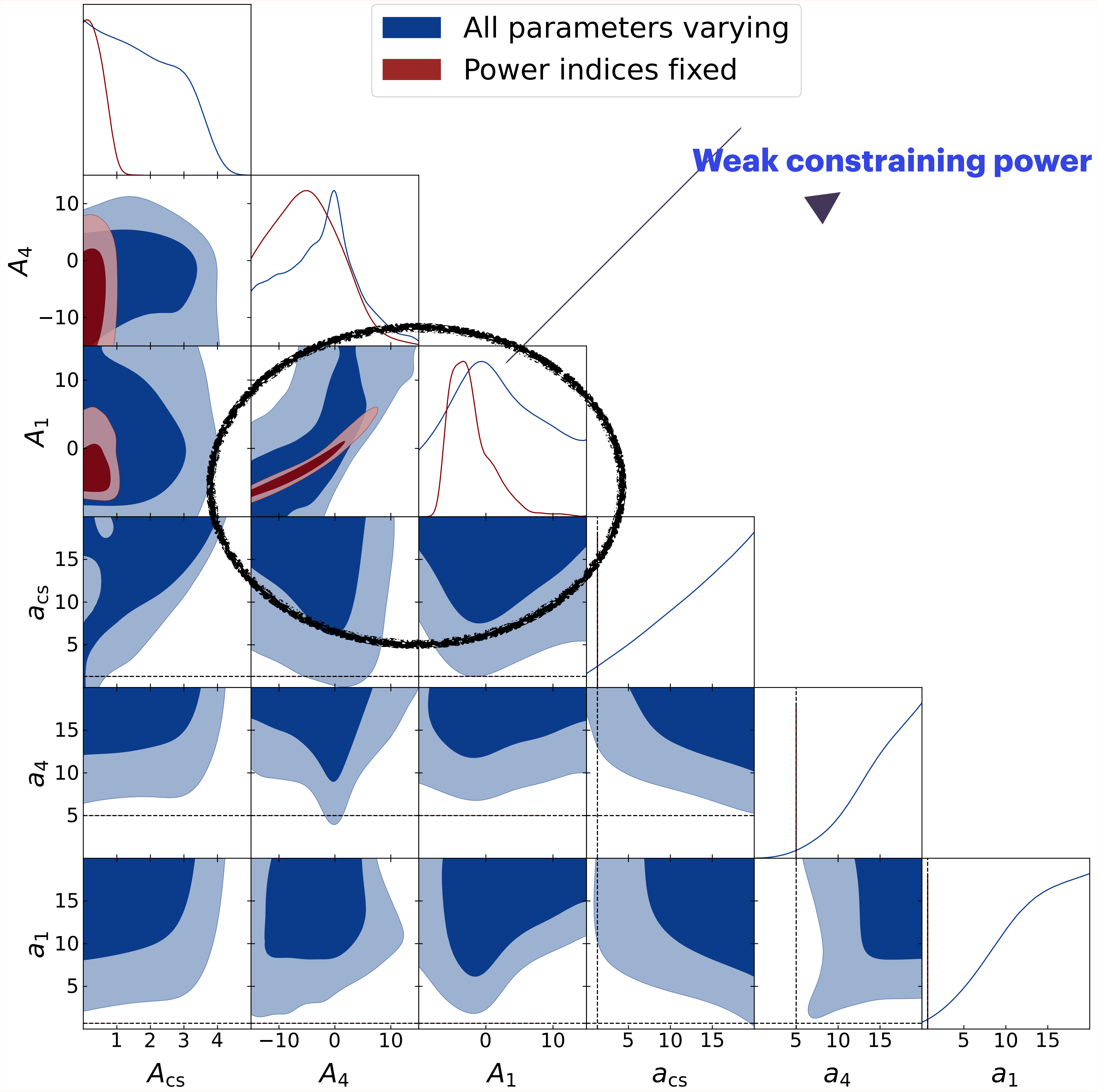
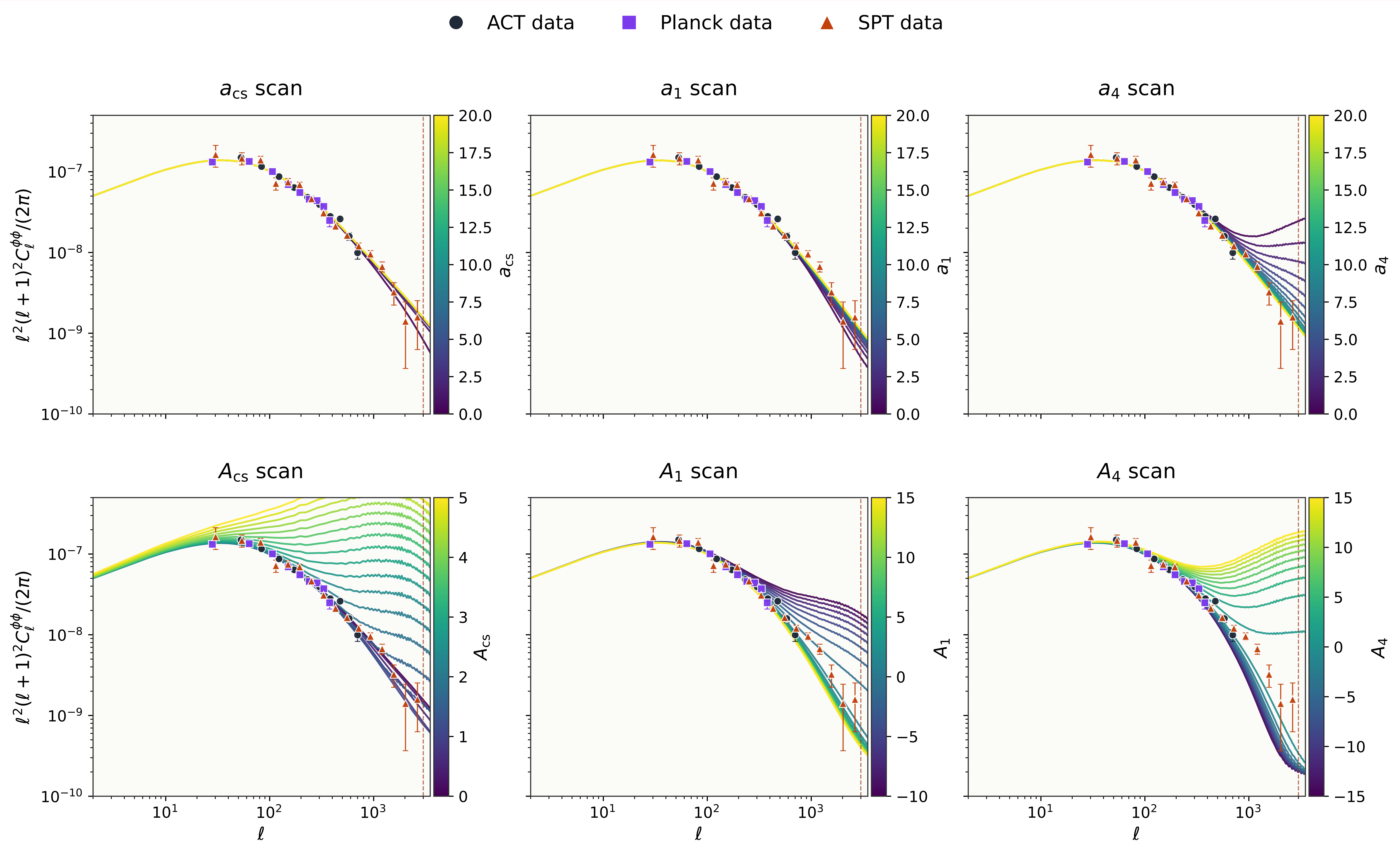


All parameters varying
Power indices fixed
Weak constraining power
A_4
A_1
$a_{\rm cs}$
a_4
a_1
$A_{\rm cs}$

CMB LENSING

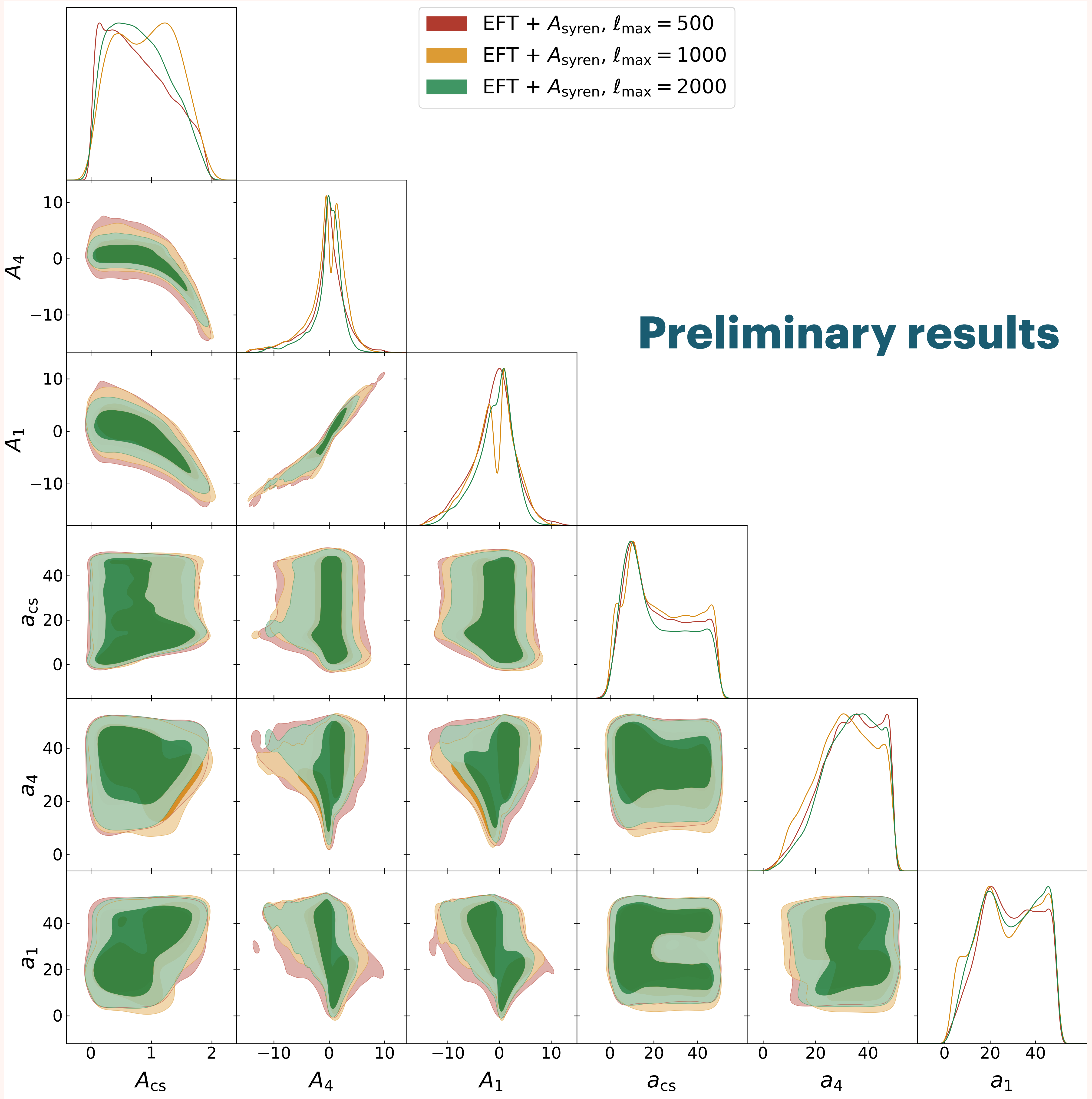


ACT data
Planck data
SPT data
a_{cs} scan
a_1 scan
a_4 scan
A_{cs} scan
A_1 scan
A_4 scan
$\ell^2(\ell+1)^2 C_\ell^{\phi\phi}/(2\pi)$
ℓ
a_{cs}
a_1
a_4
A_{cs}
A_1
A_4

DES Y3 COSMIC SHEAR

Tighter constraints on the EFTofLSS amplitudes

Time evolution parameters remain less constrained



Preliminary results

SUMMARY

Part 1: Accelerating Effective Field Theory of Large Scale Structure

Symbolic emulator for EFTofLSS up to 2 loops

SymEFT : CLASS, python, JAX

Part 2: Constraining counterterms

Simulations: ΛCDM

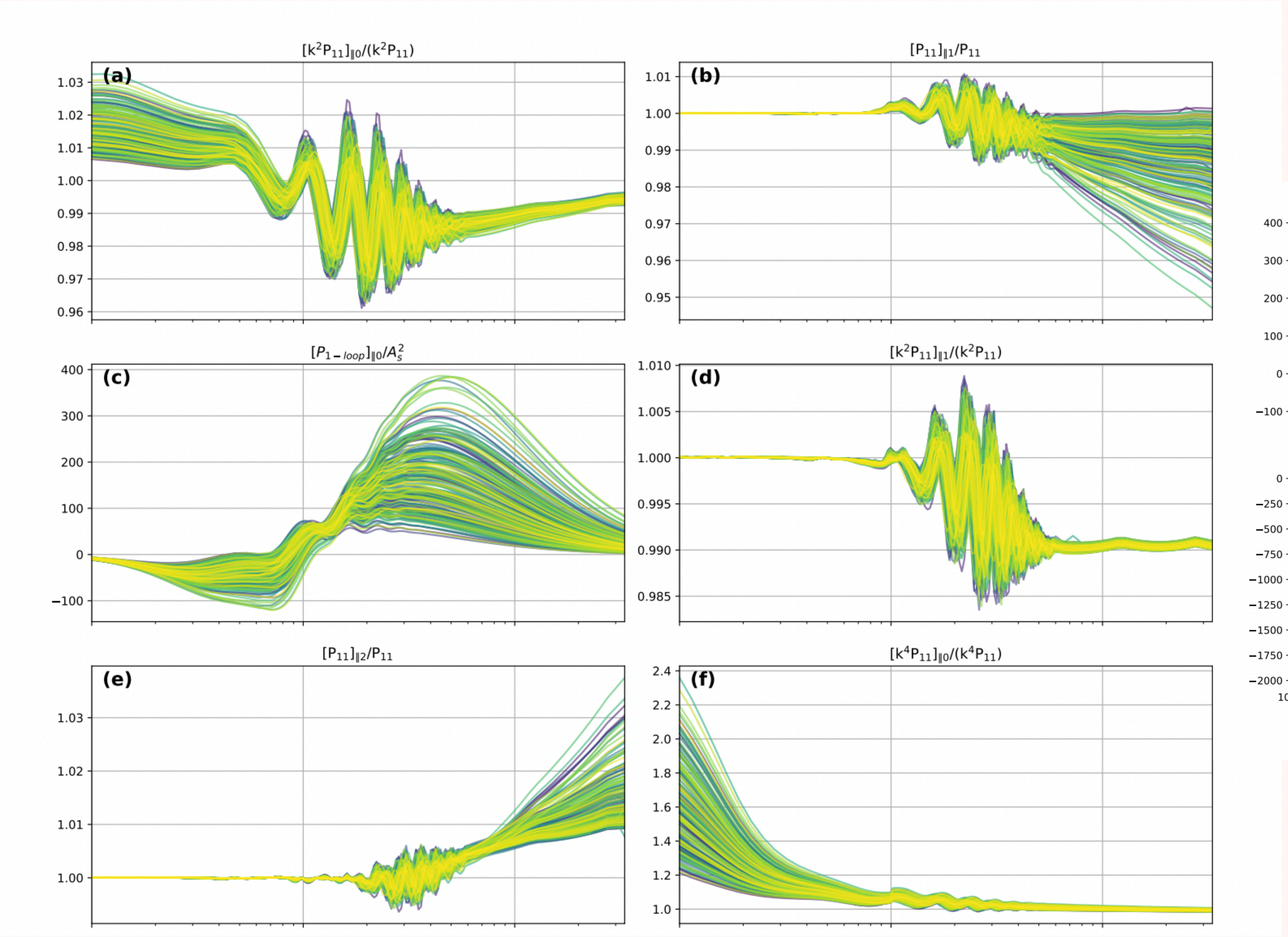
$w_0 w_a CDM$

baryonic boost models

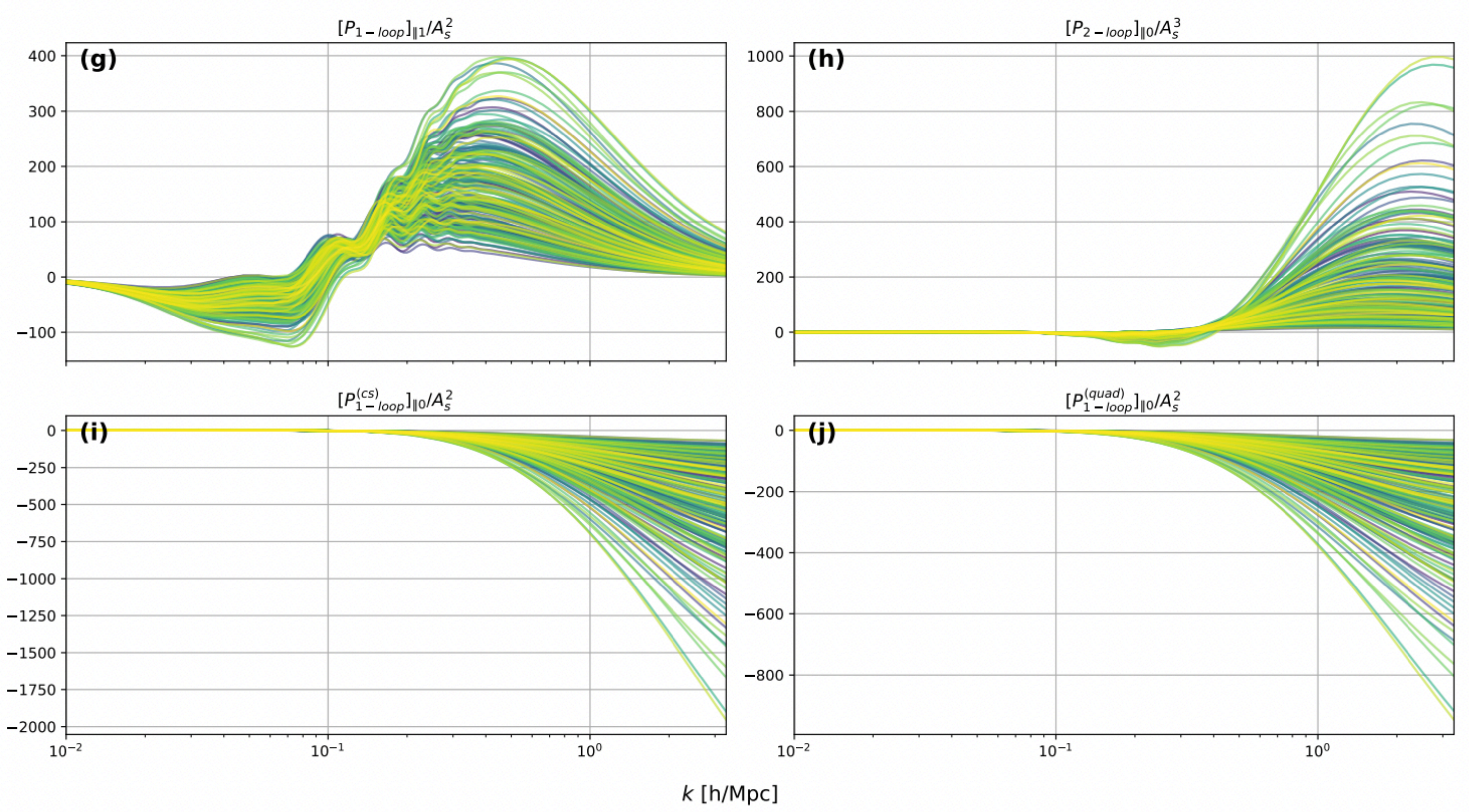
Observations: CMB, DES ⌛ ⌛

Happy to answer questions!

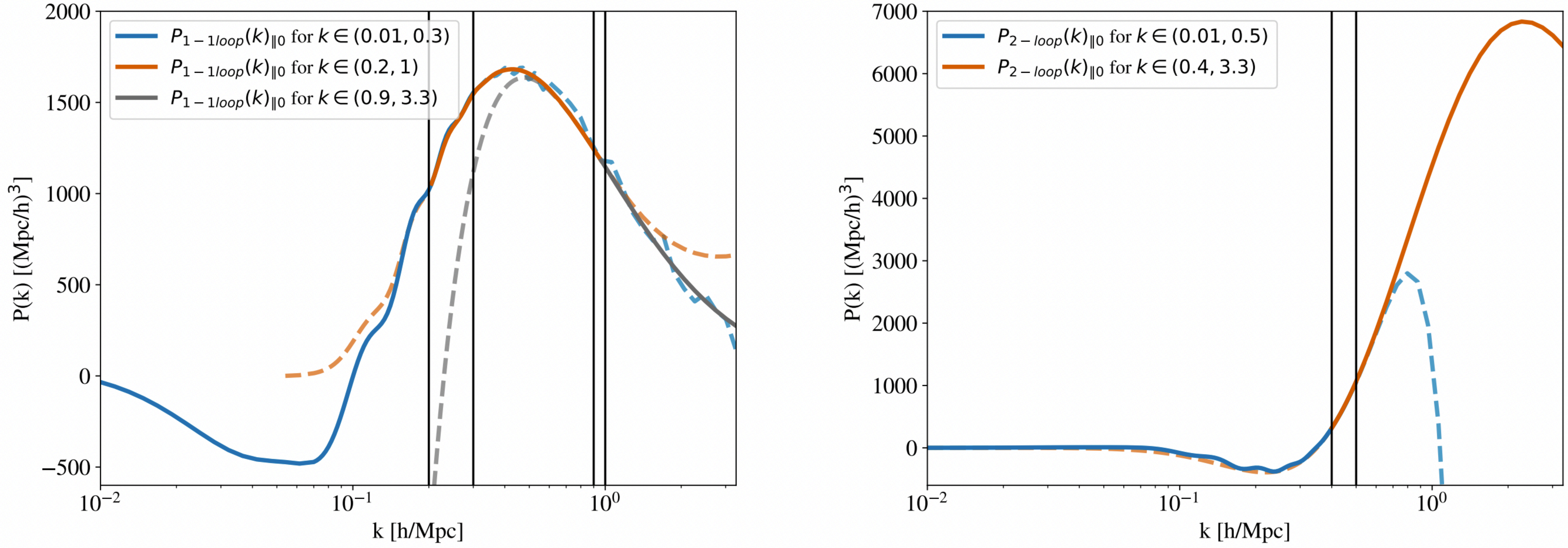
Backup slides



$[k^2P_{11}]_{\|0}/(k^2P_{11})$
(a)
$[P_{11}]_{\|1}/P_{11}$
(b)
$[P_{1-loop}]_{\|0}/A_s^2$
(c)
$[k^2P_{11}]_{\|1}/(k^2P_{11})$
(d)
$[P_{11}]_{\|2}/P_{11}$
(e)
$[k^4P_{11}]_{\|0}/(k^4P_{11})$
(f)

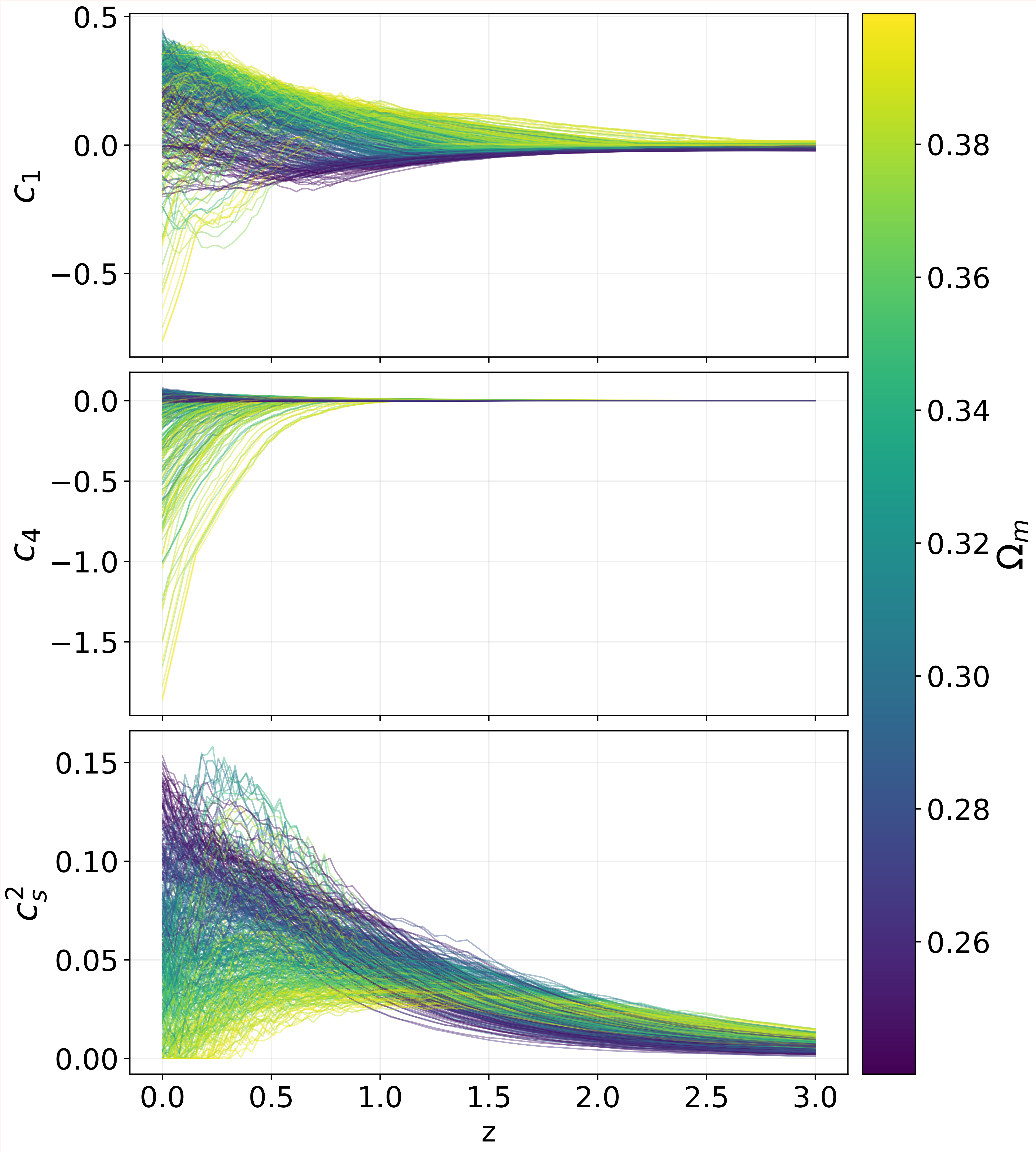


$[P_{1-loop}]_{\|1}/A_s^2$
(g)
$[P_{2-loop}]_{\|0}/A_s^3$
(h)
$[P^{(cs)}_{1-loop}]_{\|0}/A_s^2$
(i)
$[P^{(quad)}_{1-loop}]_{\|0}/A_s^2$
(j)
10^{-2} 10^{-1} 10^{0}
k [h/Mpc]

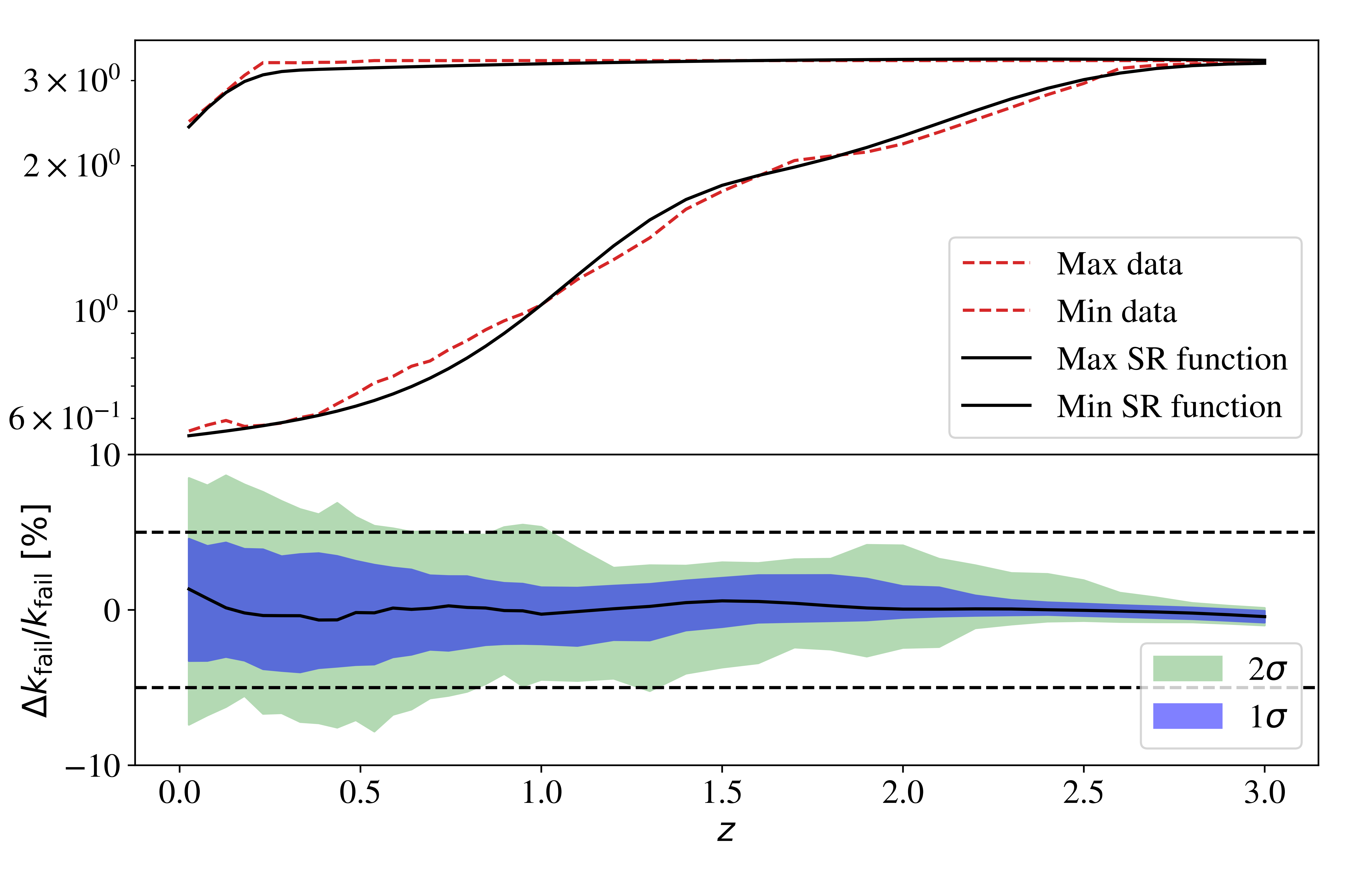


$P_{1-1loop}(k)_{\|0}$ for $k \in (0.01, 0.3)$
$P_{1-1loop}(k)_{\|0}$ for $k \in (0.2, 1)$
$P_{1-1loop}(k)_{\|0}$ for $k \in (0.9, 3.3)$
P(k) [(Mpc/h)^3]
k [h/Mpc]
2000
1500
1000
500
0
−500
10^{-2}
10^{-1}
10^{0}
$P_{2-loop}(k)_{\|0}$ for $k \in (0.01, 0.5)$
$P_{2-loop}(k)_{\|0}$ for $k \in (0.4, 3.3)$
P(k) [(Mpc/h)^3]
k [h/Mpc]
7000
6000
5000
4000
3000
2000
1000
0
10^{-2}
10^{-1}
10^{0}

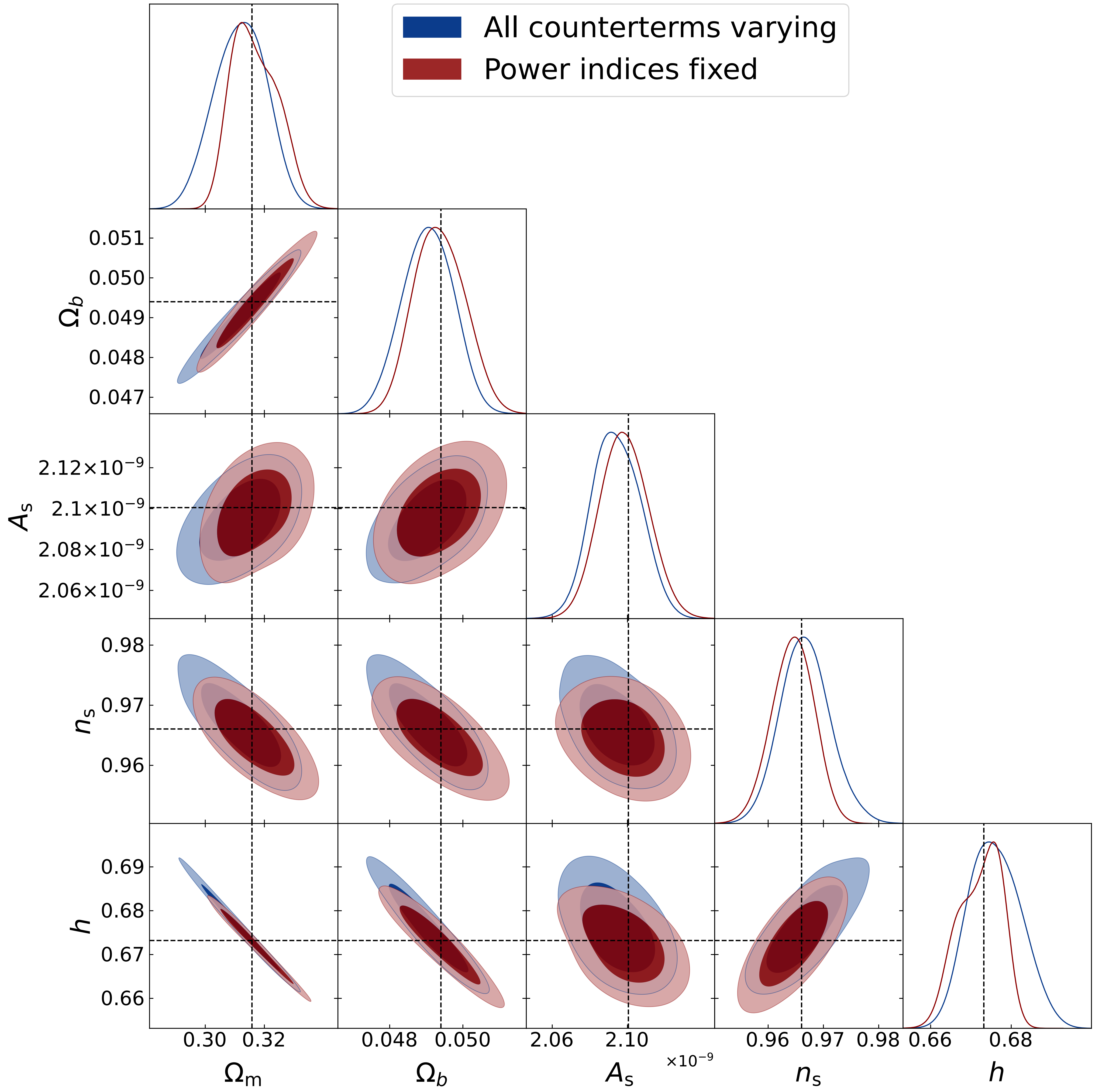
Counterterms:



SR emulators : $k_{fail}(z, A_s, n_s, \Omega_{CDM}\Omega_b, h)$



CMB TTTEEE+LENSING



MOCK DATA

EFTOFLSS

Fit to Non-linear P(k)

→ ΛCDM

→ $w_0 w_a CDM$

—> **constant** counterterms

—> ΛCDM