

Hunting for New Physics in Large Scale Structure of the Universe

Salvatore Bottaro



GGI Symposium, 30th September 2025

The relevance of LSS today...

Parameter	TT+lowE 68% limits	TE+lowE 68% limits	EE+lowE 68% limits	TT,TE,EE+lowE 68% limits	TT,TE,EE+lowE+lensing 68% limits	TT,TE,EE+lowE+lensing+BAO 68% limits
$\Omega_b h^2$	0.02212 ± 0.00022	0.02249 ± 0.00025	0.0240 ± 0.0012	0.02236 ± 0.00015	0.02237 ± 0.00015	0.02242 ± 0.00014
$\Omega_c h^2$	0.1206 ± 0.0021	0.1177 ± 0.0020	0.1158 ± 0.0046	0.1202 ± 0.0014	0.1200 ± 0.0012	0.11933 ± 0.00091
$100\theta_{\text{MC}}$	1.04077 ± 0.00047	1.04139 ± 0.00049	1.03999 ± 0.00089	1.04090 ± 0.00031	1.04092 ± 0.00031	1.04101 ± 0.00029
τ	0.0522 ± 0.0080	0.0496 ± 0.0085	0.0527 ± 0.0090	$0.0544^{+0.0070}_{-0.0081}$	0.0544 ± 0.0073	0.0561 ± 0.0071
$\ln(10^{10} A_s)$	3.040 ± 0.016	$3.018^{+0.020}_{-0.018}$	3.052 ± 0.022	3.045 ± 0.016	3.044 ± 0.014	3.047 ± 0.014
n_s	0.9626 ± 0.0057	0.967 ± 0.011	0.980 ± 0.015	0.9649 ± 0.0044	0.9649 ± 0.0042	0.9665 ± 0.0038
H_0 [km s ⁻¹ Mpc ⁻¹] . .	66.88 ± 0.92	68.44 ± 0.91	69.9 ± 2.7	67.27 ± 0.60	67.36 ± 0.54	67.66 ± 0.42
Ω_Λ	0.679 ± 0.013	0.699 ± 0.012	$0.711^{+0.033}_{-0.026}$	0.6834 ± 0.0084	0.6847 ± 0.0073	0.6889 ± 0.0056
Ω_m	0.321 ± 0.013	0.301 ± 0.012	$0.289^{+0.026}_{-0.033}$	0.3166 ± 0.0084	0.3153 ± 0.0073	0.3111 ± 0.0056

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CMB already measures the cosmological parameters
at the sub percent level

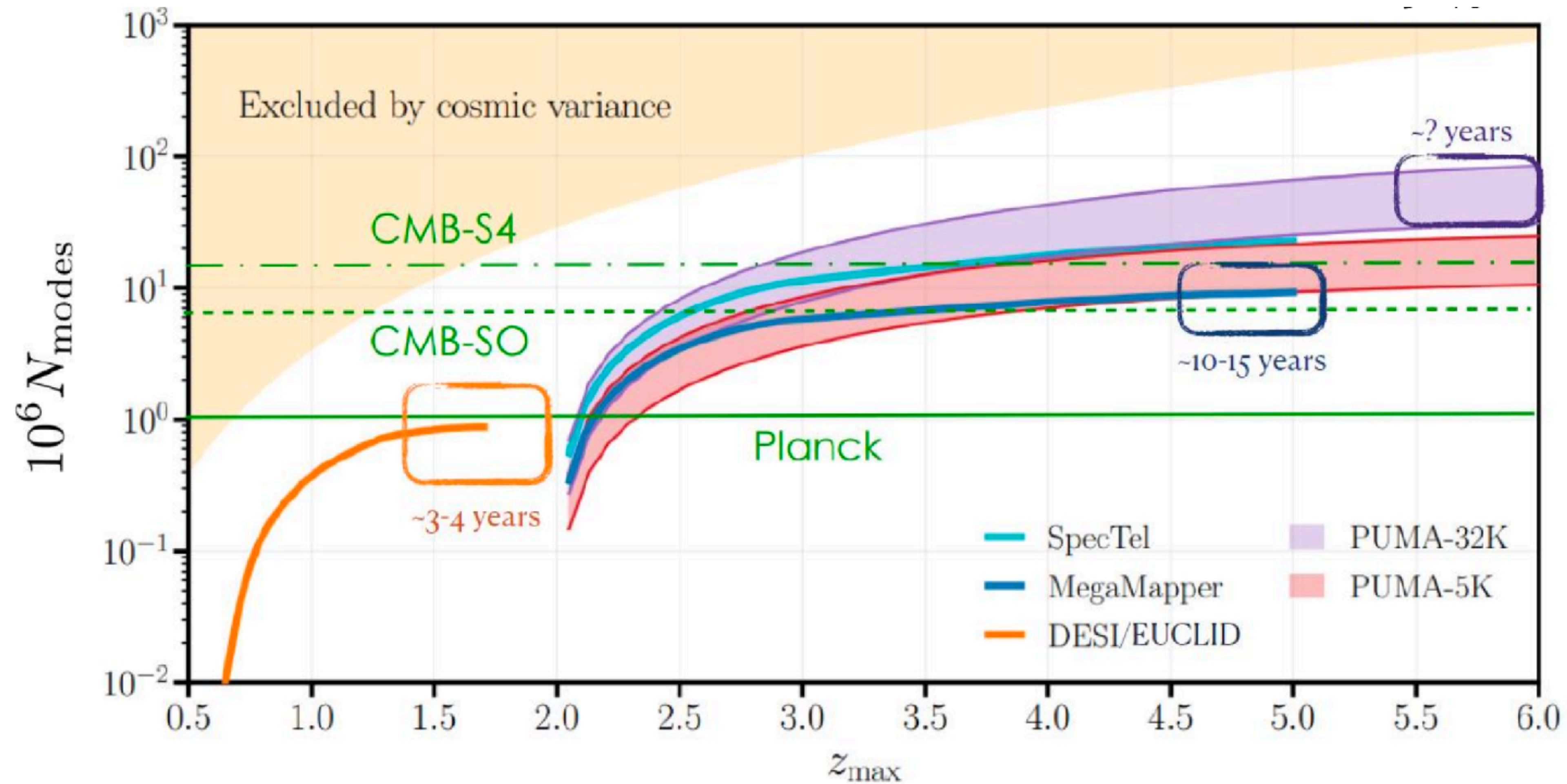
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Information from matter power spectrum
breaks degeneracies

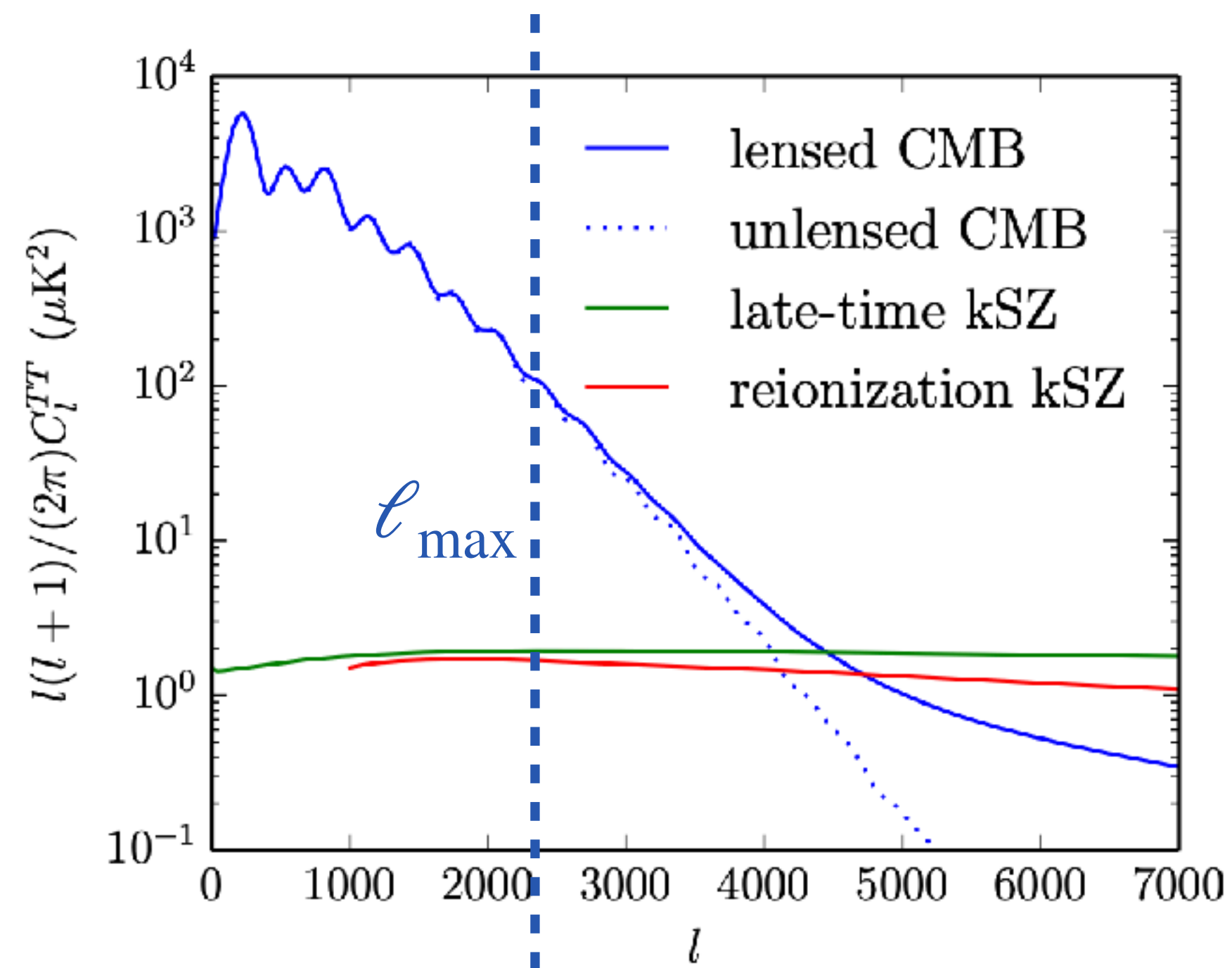
... and in the (very) near future!



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CMB is a 2D surface

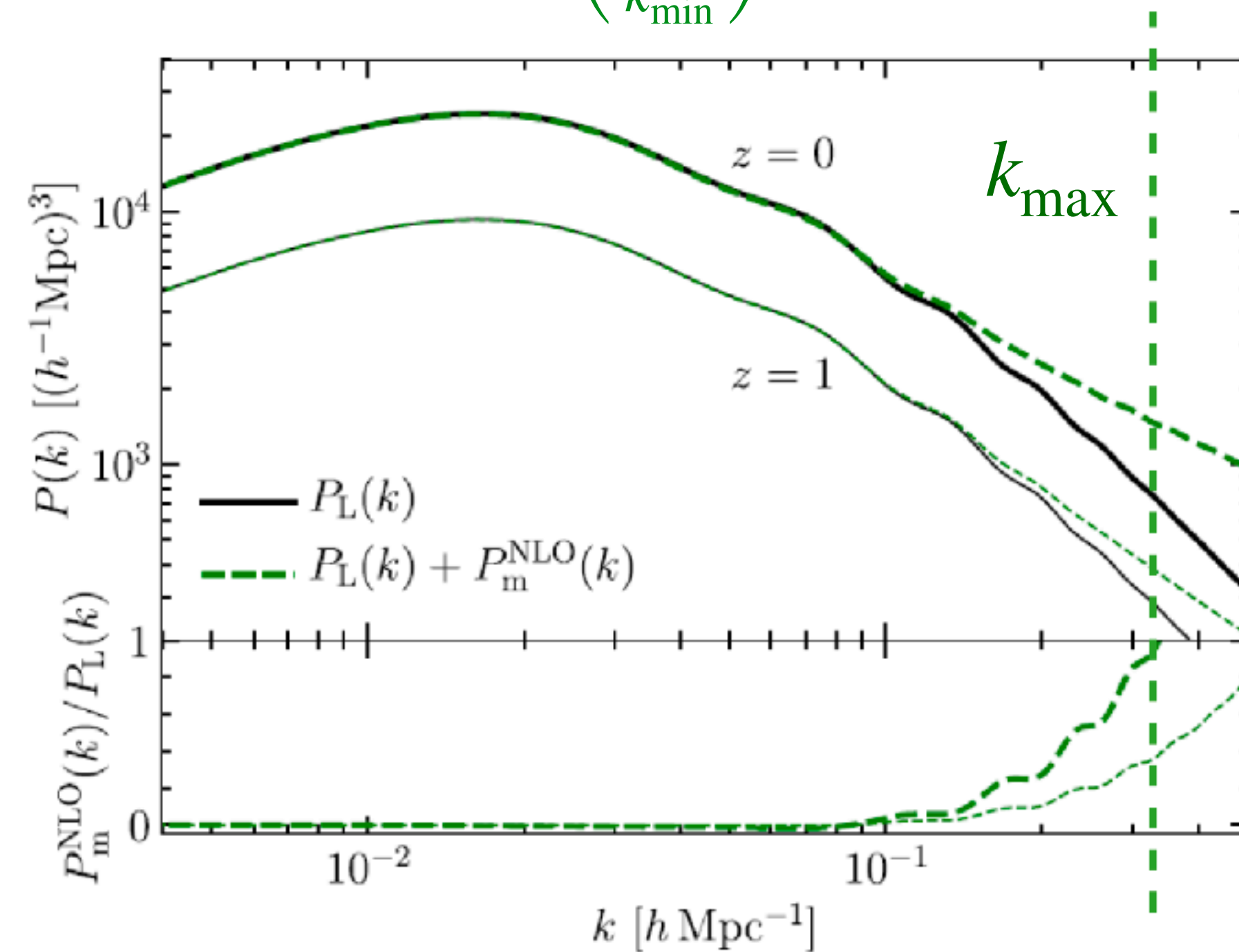
$$N_{\text{modes}}^{\text{CMB}} \approx \ell_{\text{max}}^2 \approx (2200)^2$$



Limited by small-scale
fluctuations

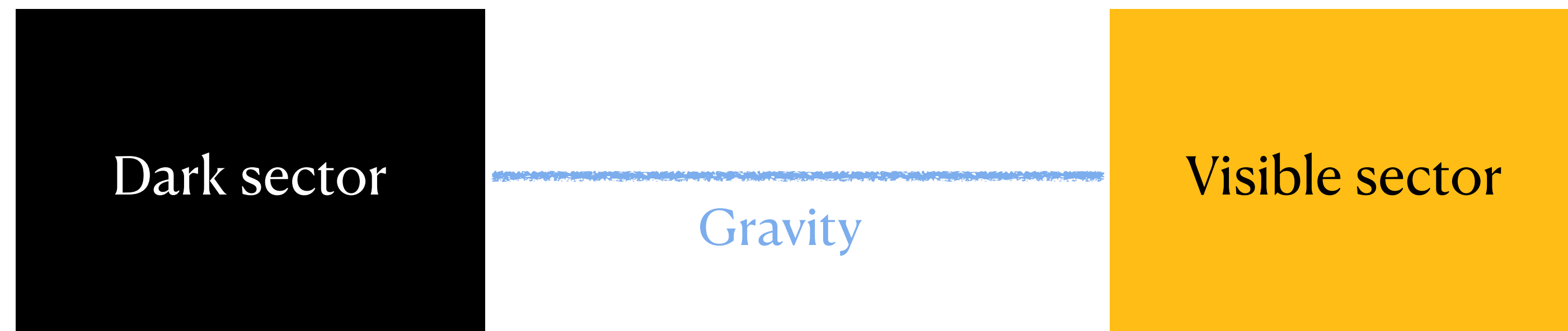
LSS probes a 3D volume

$$N_{\text{modes}}^{\text{LSS}} \approx \left(\frac{k_{\text{max}}}{k_{\text{min}}} \right)^3 \leq 10^9$$



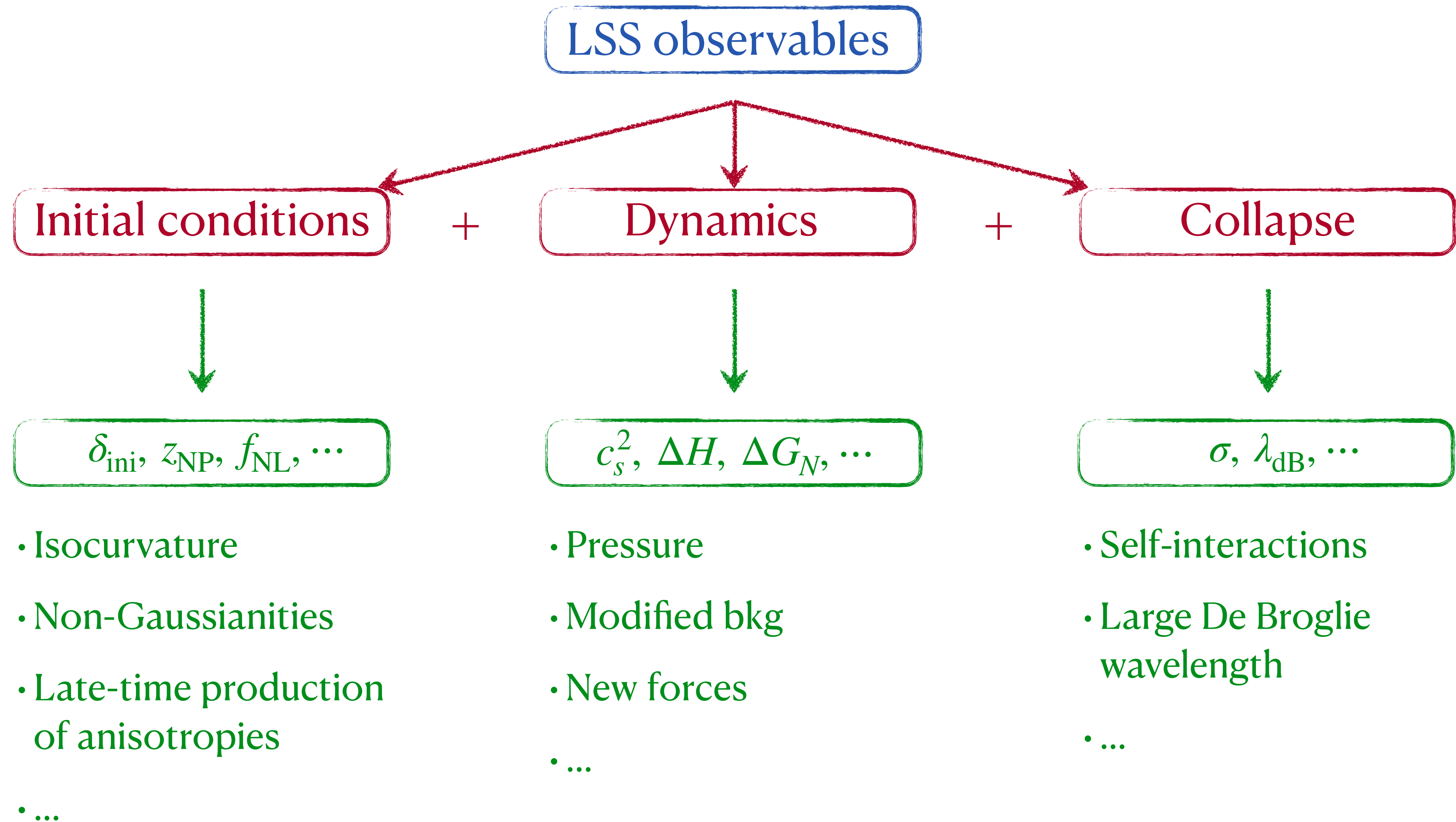
Limited by convergence of
perturbative series

Can we see in the dark?

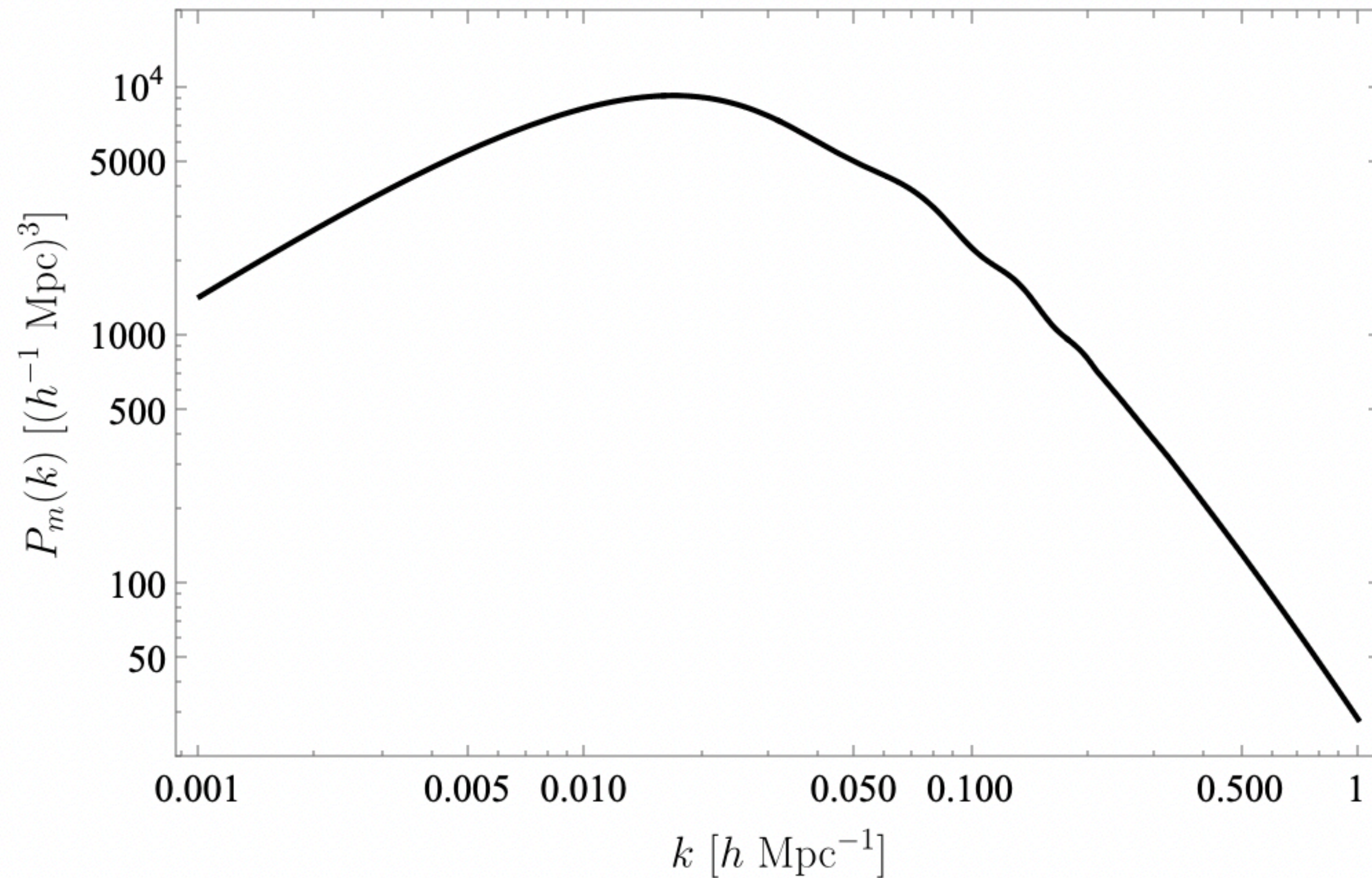


Cosmology is the only way to probe completely secluded dark sectors!

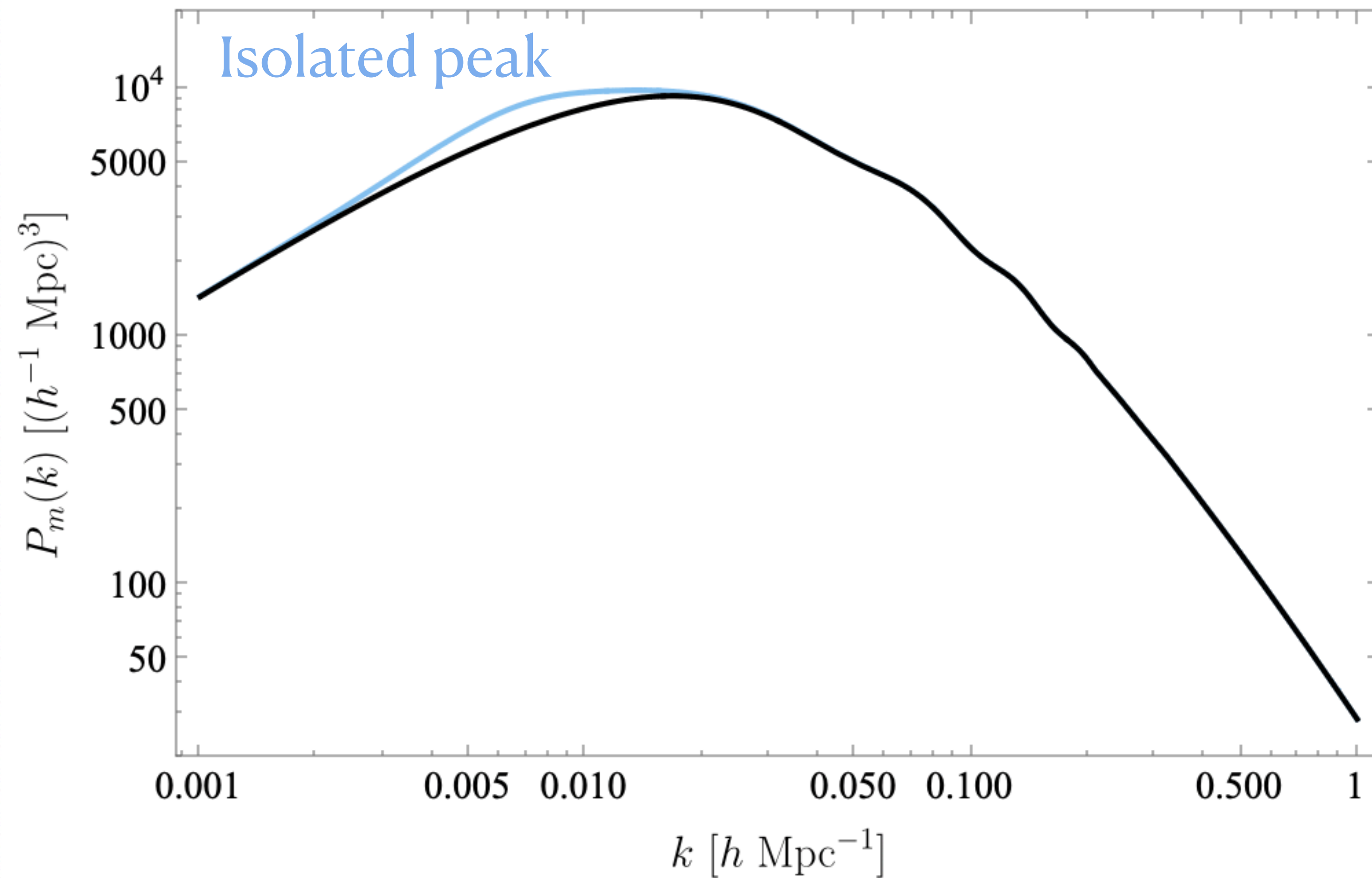
Where can NP hide?



What can we find in the Power Spectrum?



What can we find in the Power Spectrum?

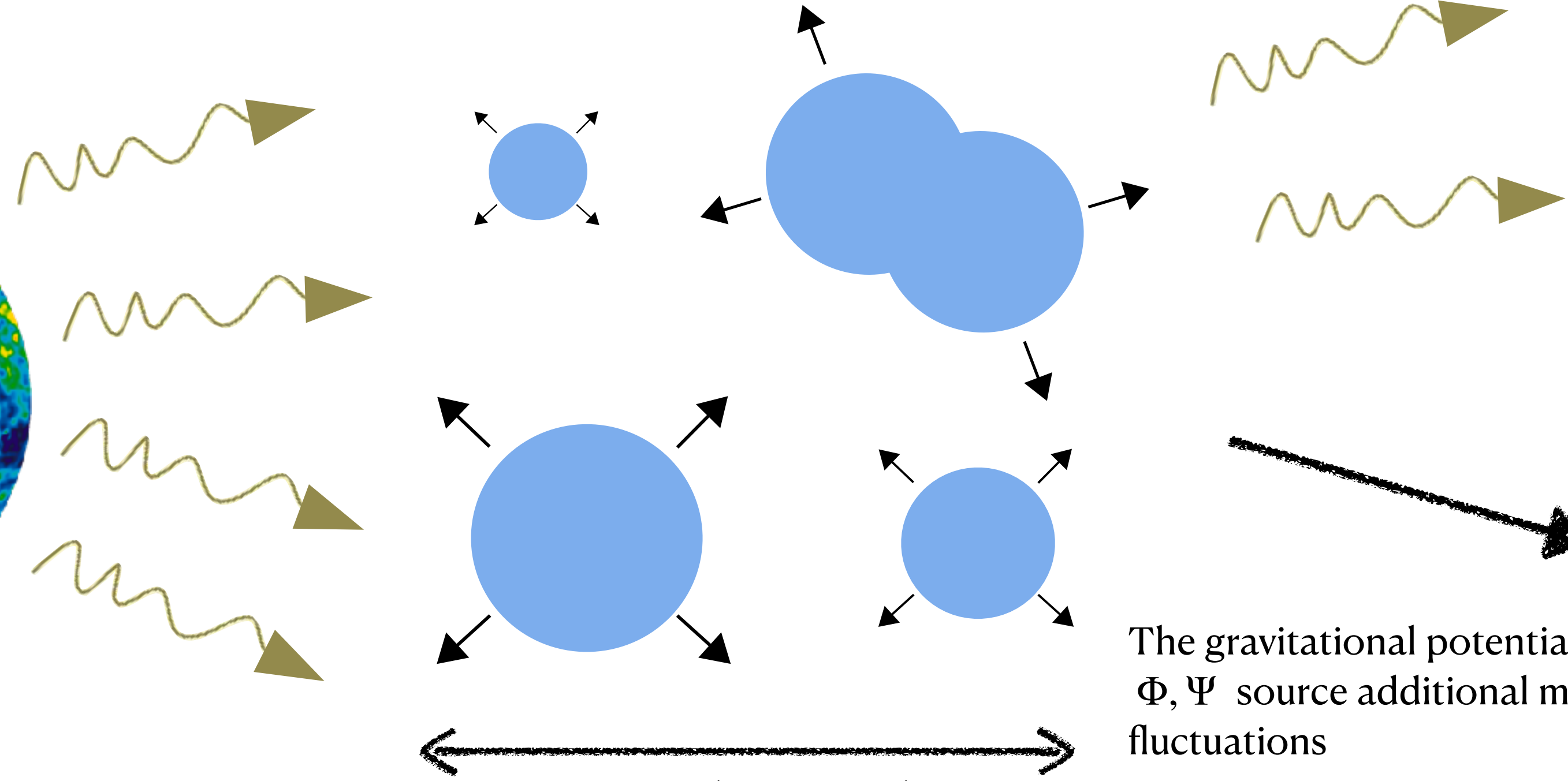
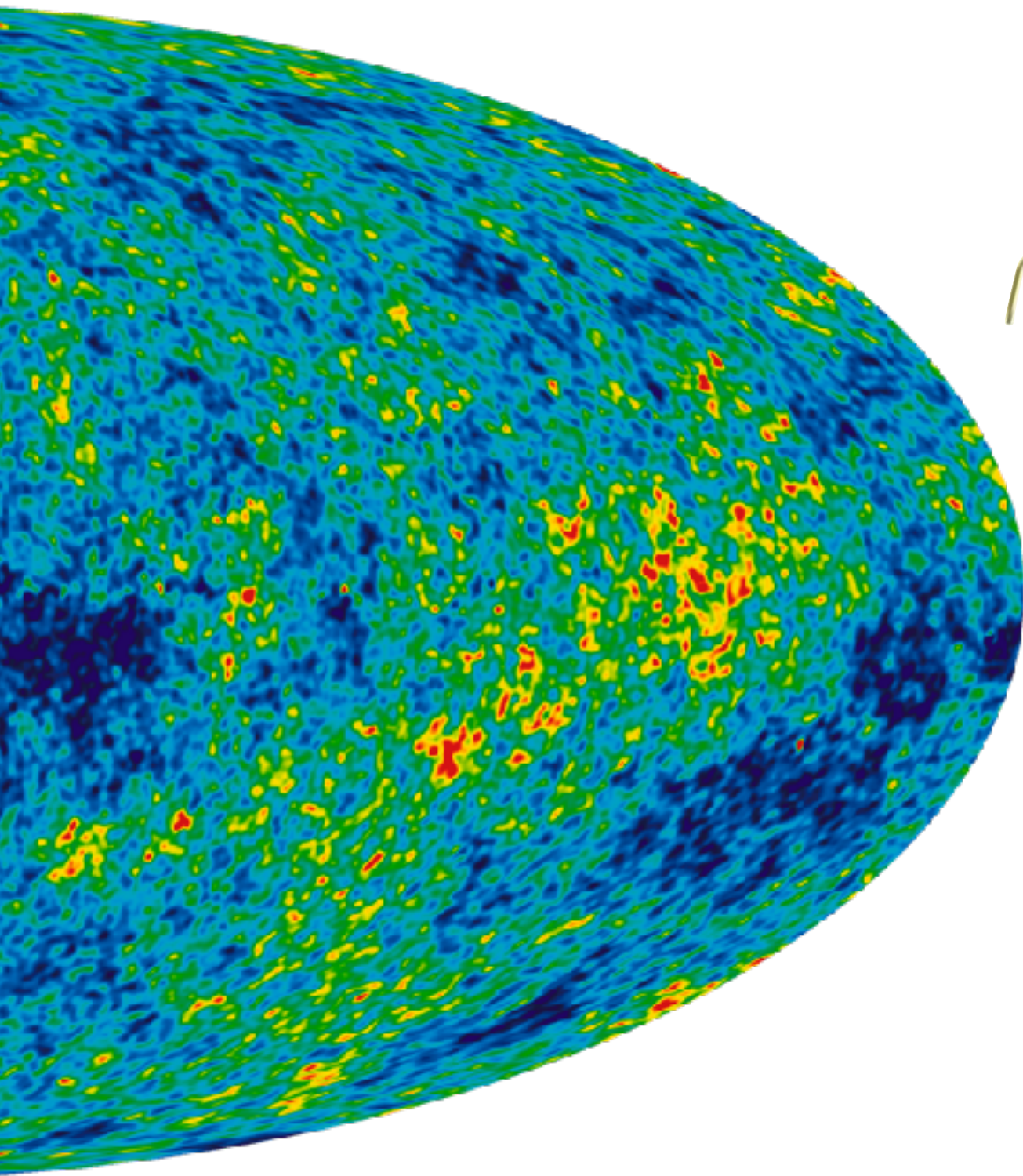
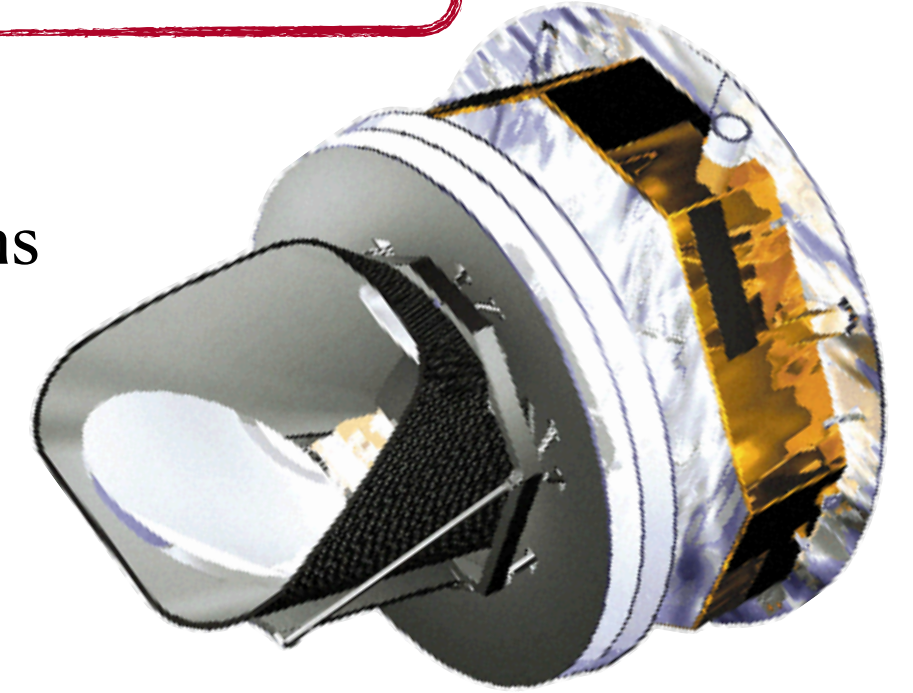


Dynamics of a Late PT

As they collide, bubble release
energy density stored in the false
vacuum $\rho_{\text{vac}} = \Omega_{\text{PT}} \rho_{\text{crit,PT}}$

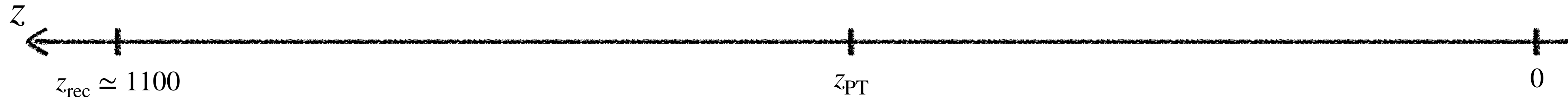
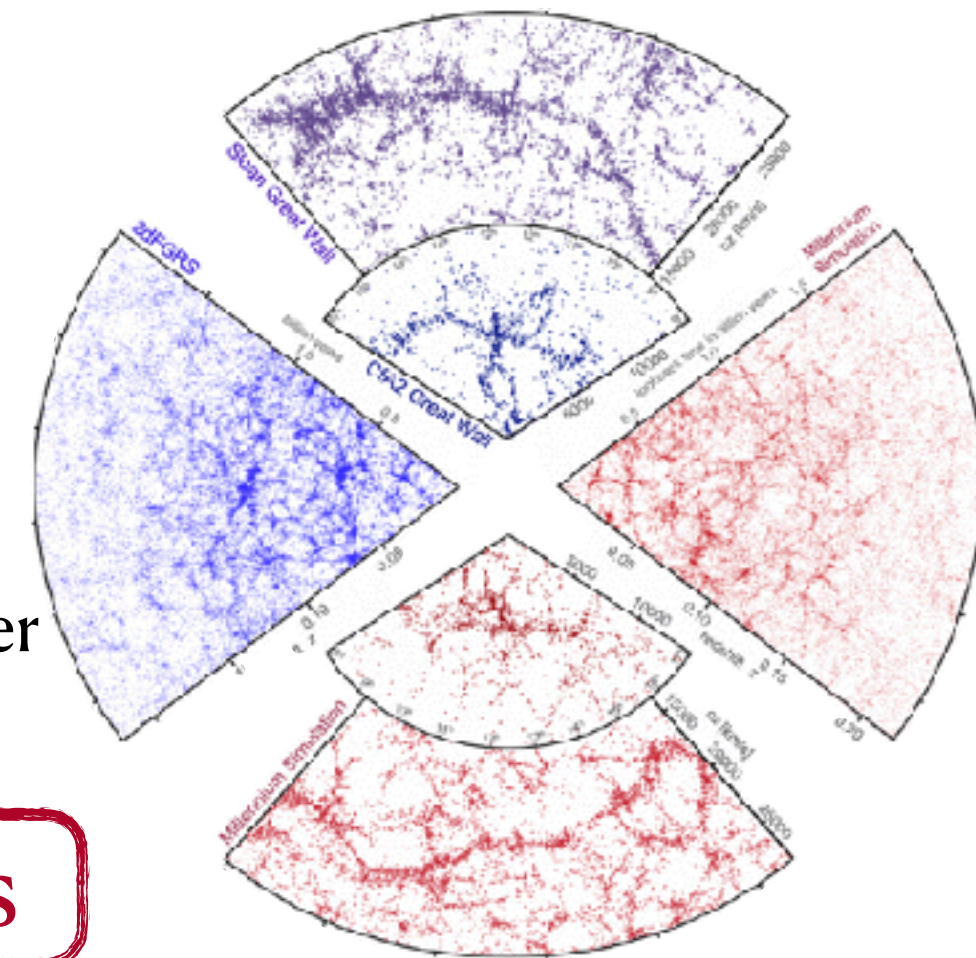
As they expand, bubbles induce
time-dependent metric fluctuations

ISW effect



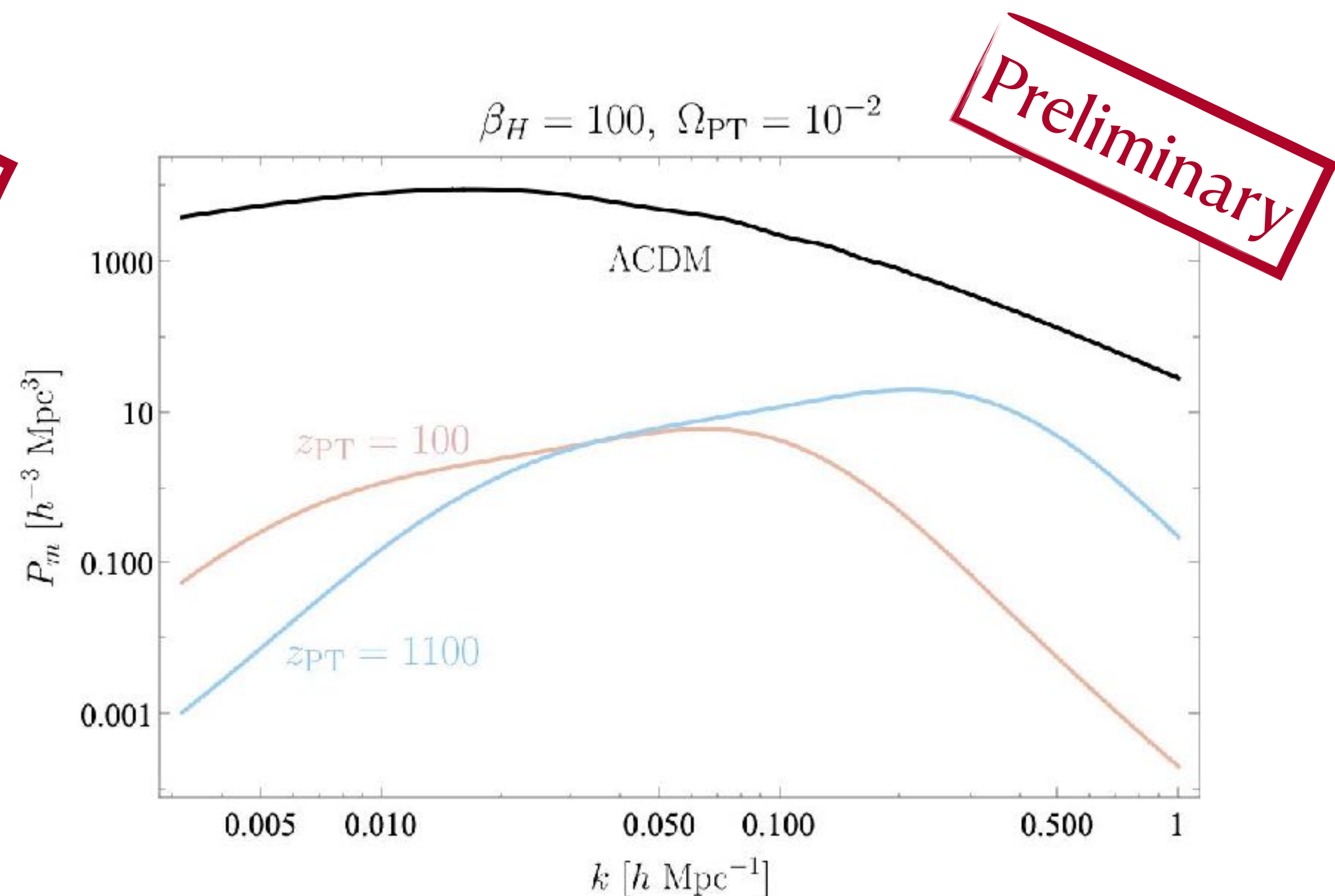
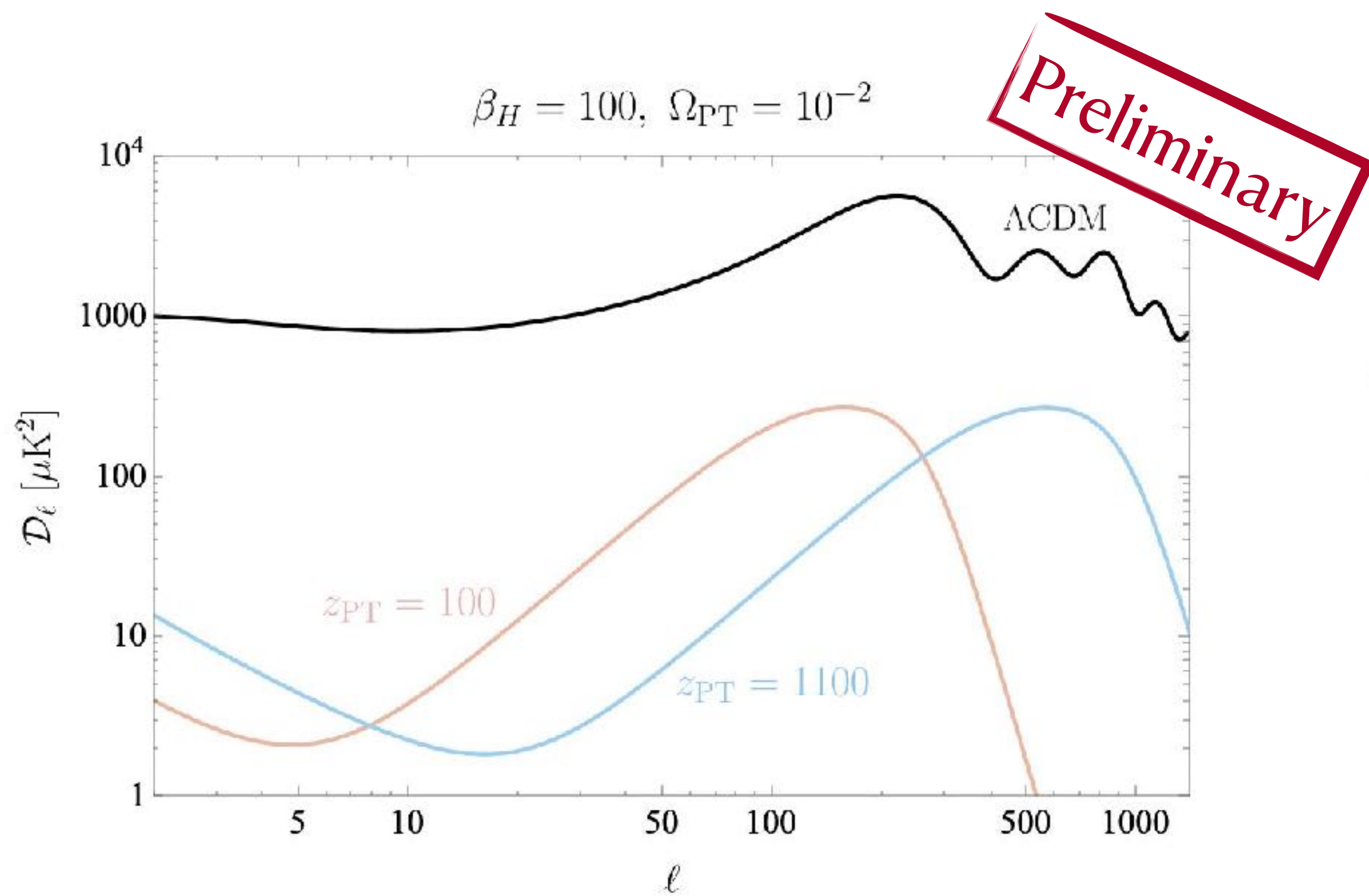
The gravitational potentials Φ, Ψ source additional matter
fluctuations

LSS observables

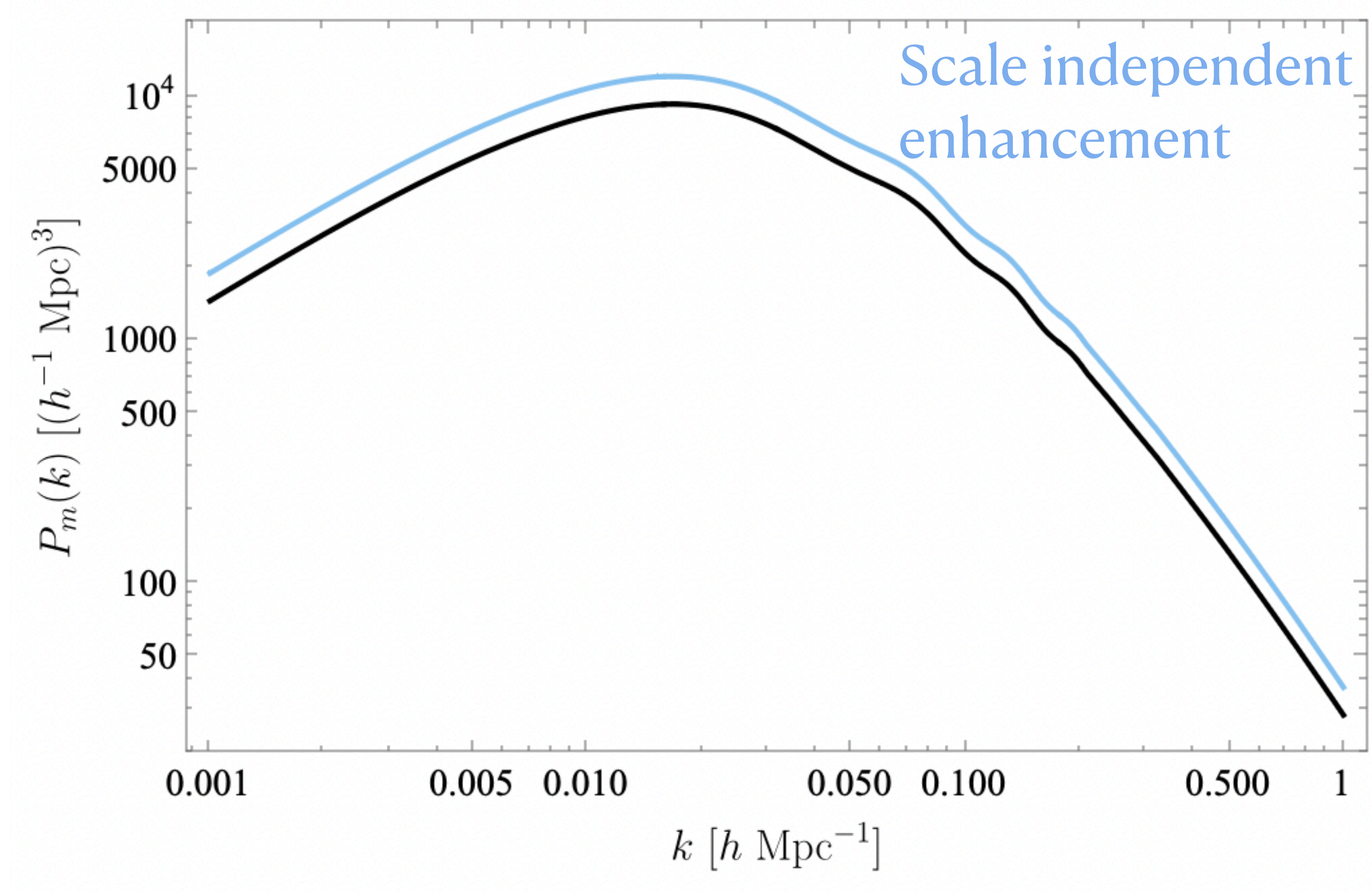


$$\delta t_{\text{PT}} \simeq \frac{1}{\beta_H H_{\text{PT}}} \ll \frac{1}{H_{\text{PT}}}$$

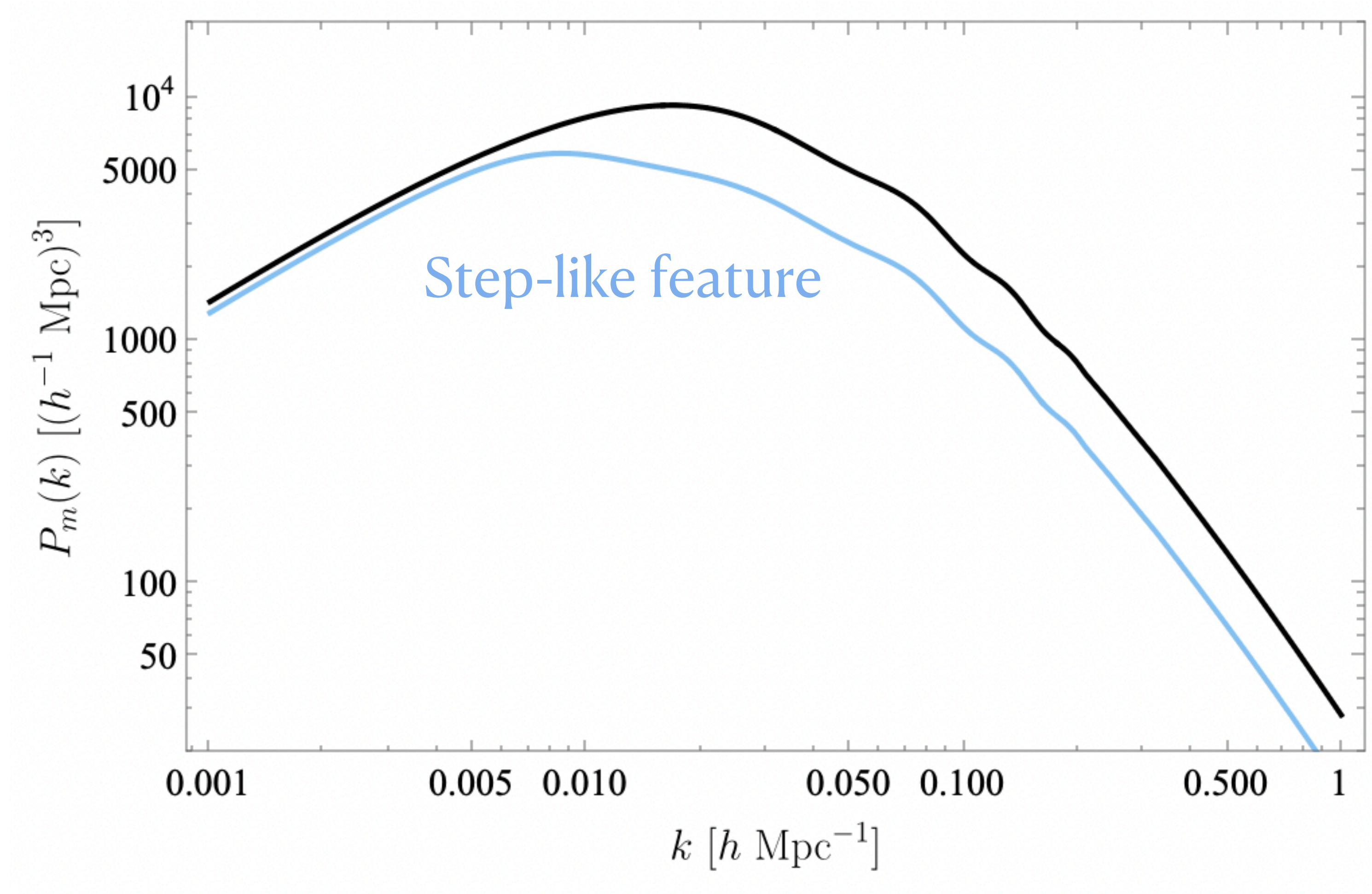
Features of the Signal



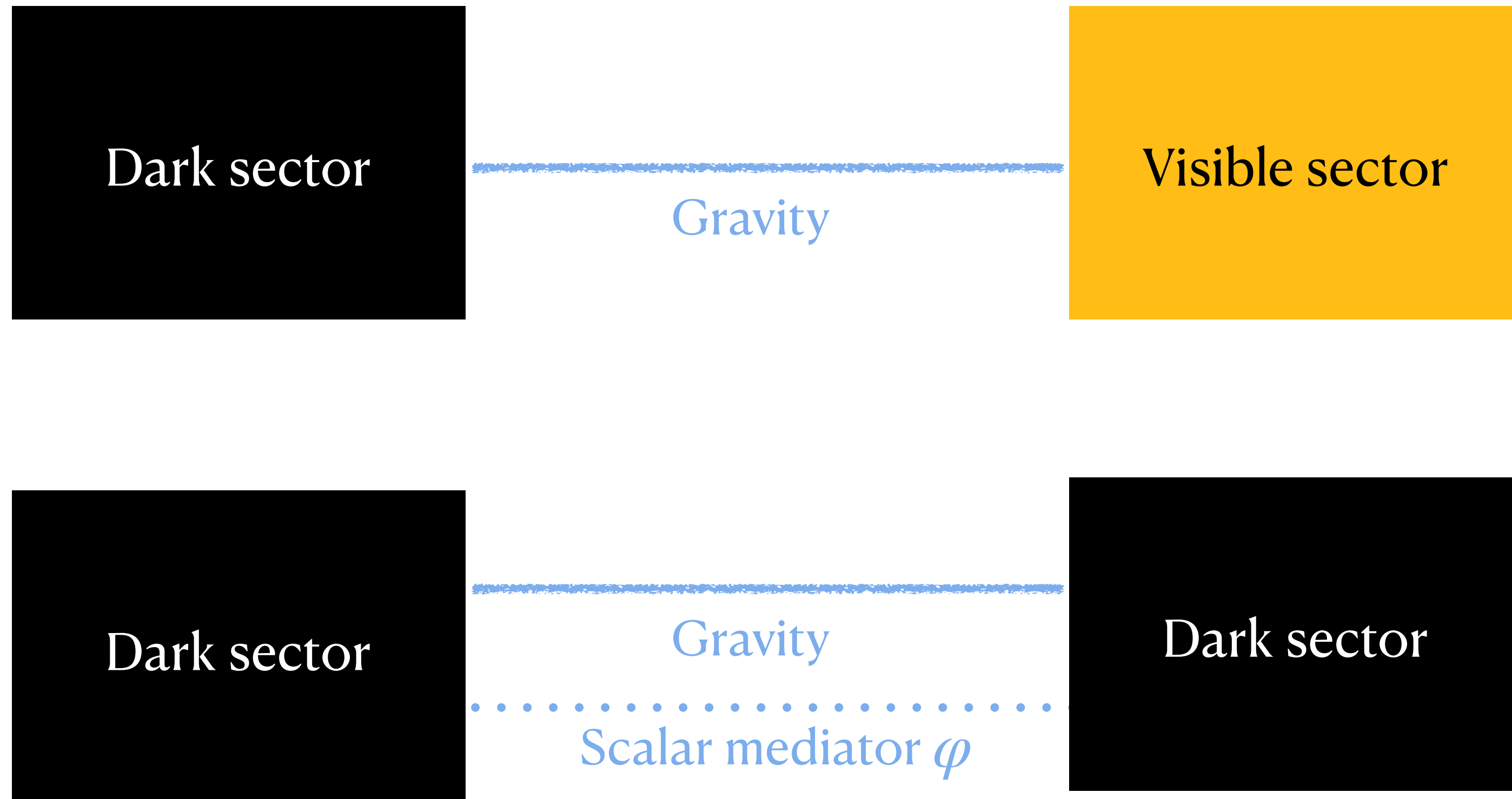
What can we find in the Power Spectrum?



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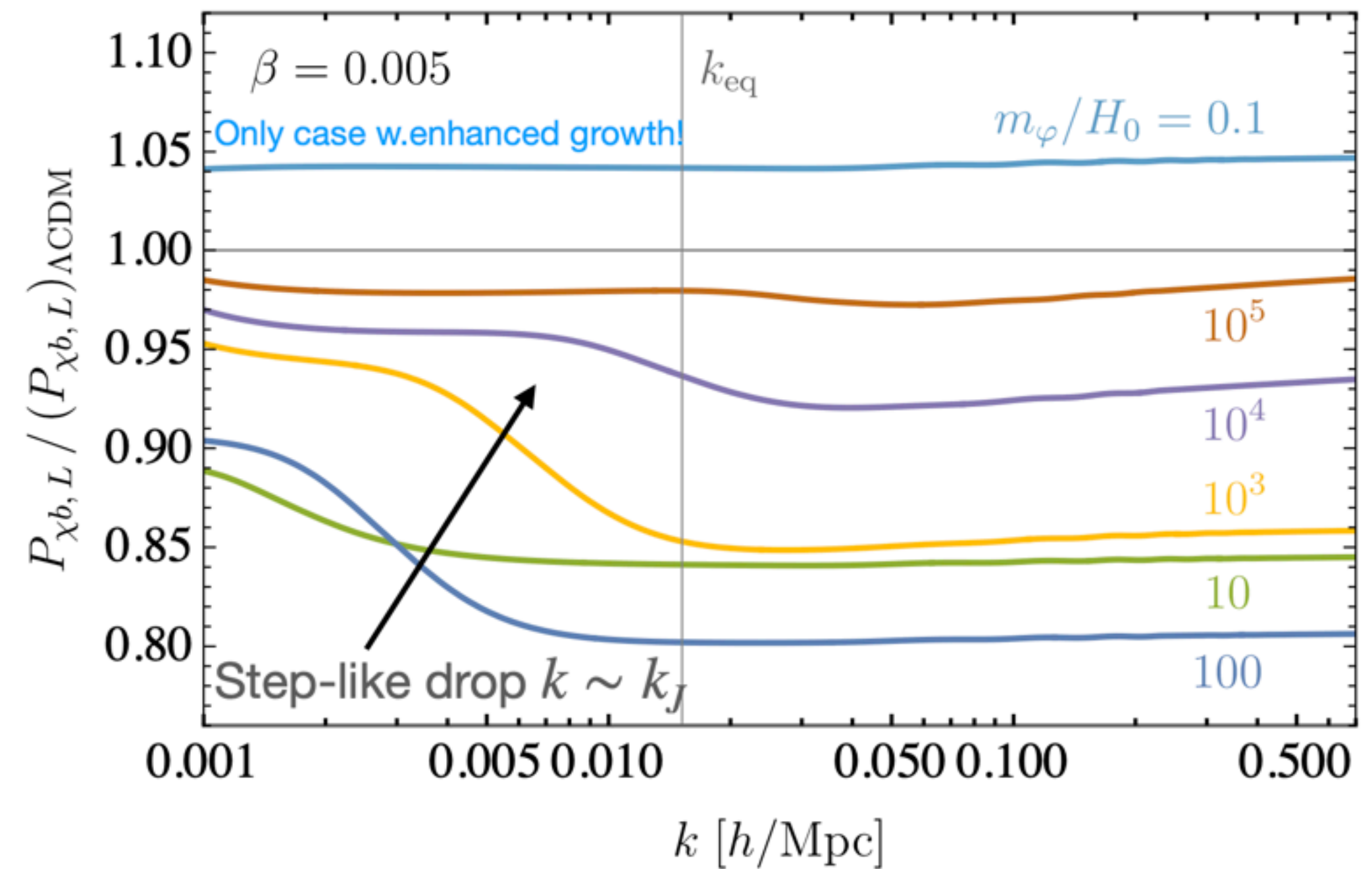
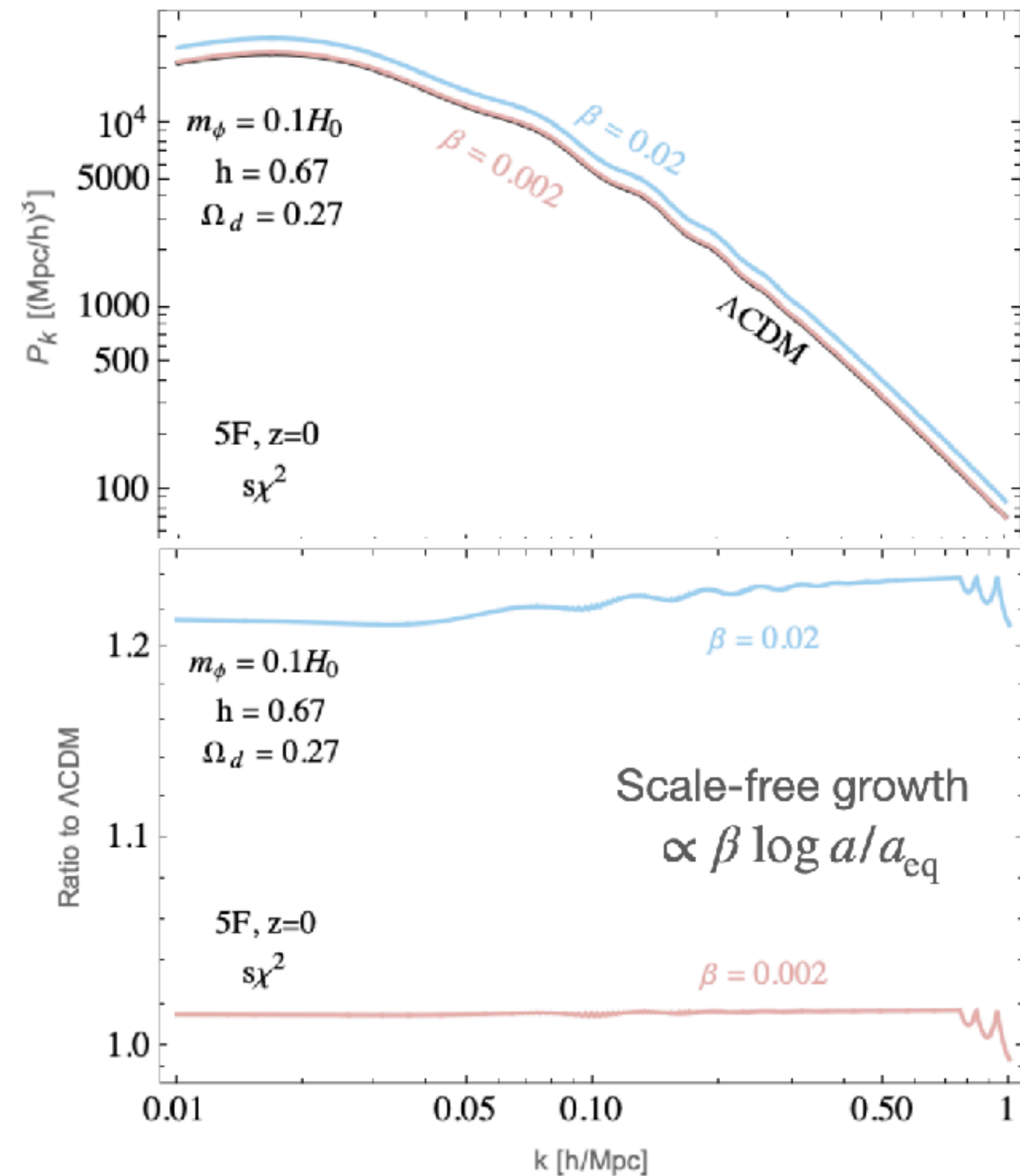


Long-range forces in the DS

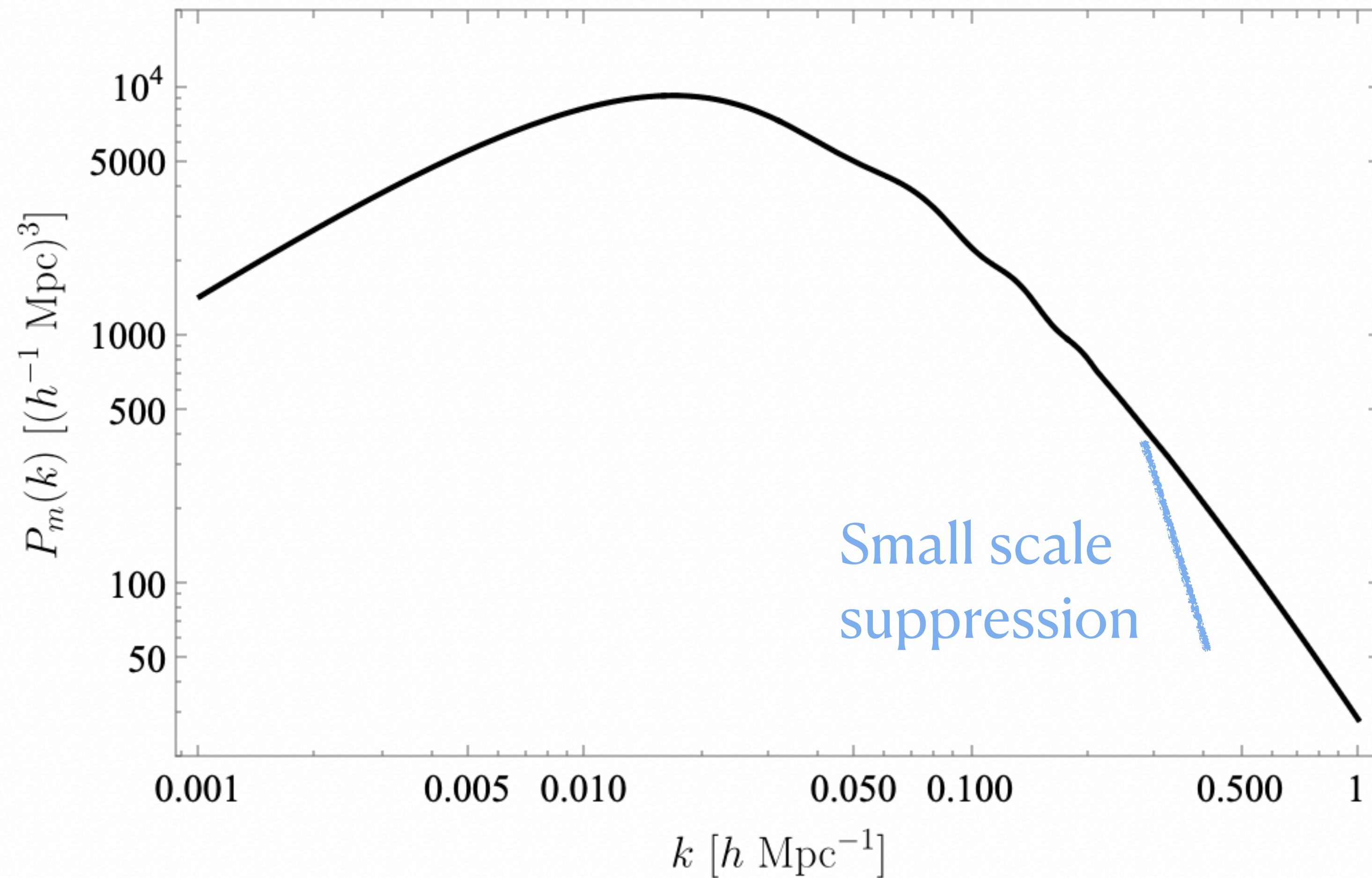


$$\mathcal{L} \supset \frac{1}{2} m_\chi^2 (1 + 2\sqrt{\beta G_N} \varphi) \chi^2$$

Effects on Matter Power Spectrum



What can we find in the Power Spectrum?



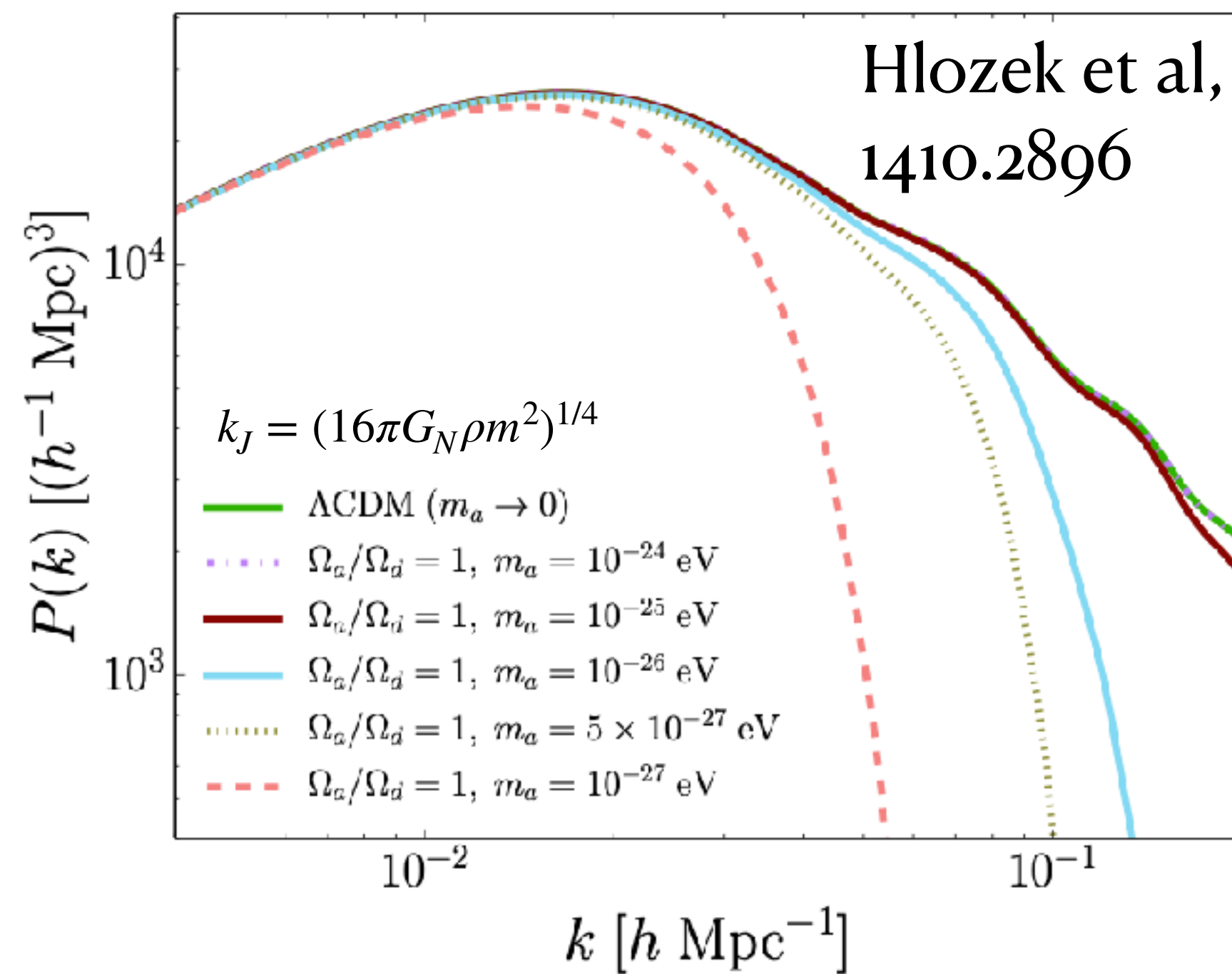
Why so fuzzy?

Λ CDM issues

Missing satellites



Macroscopic Jeans scale

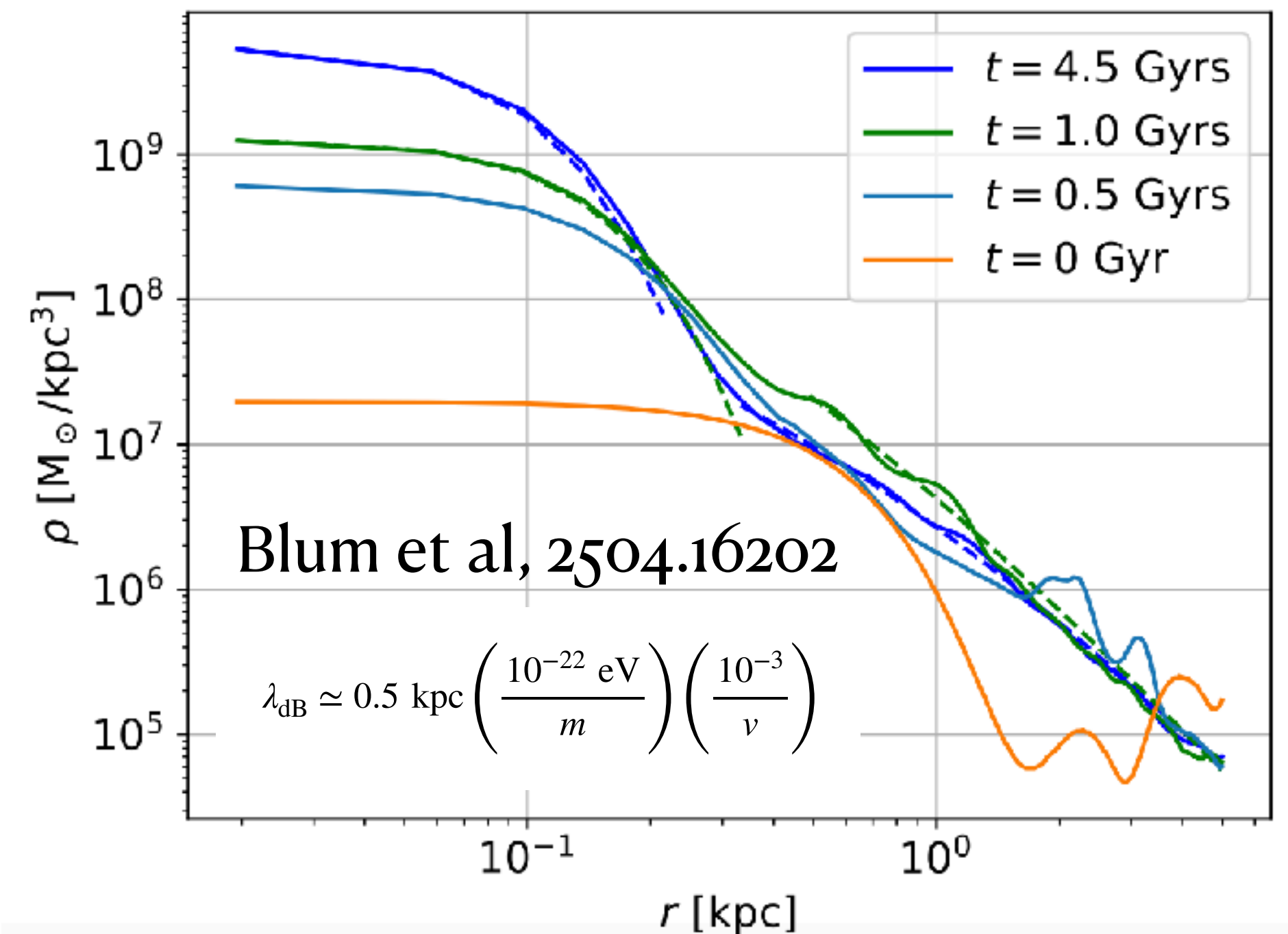


FDM solution:
Ultralight DM

Core vs cusp

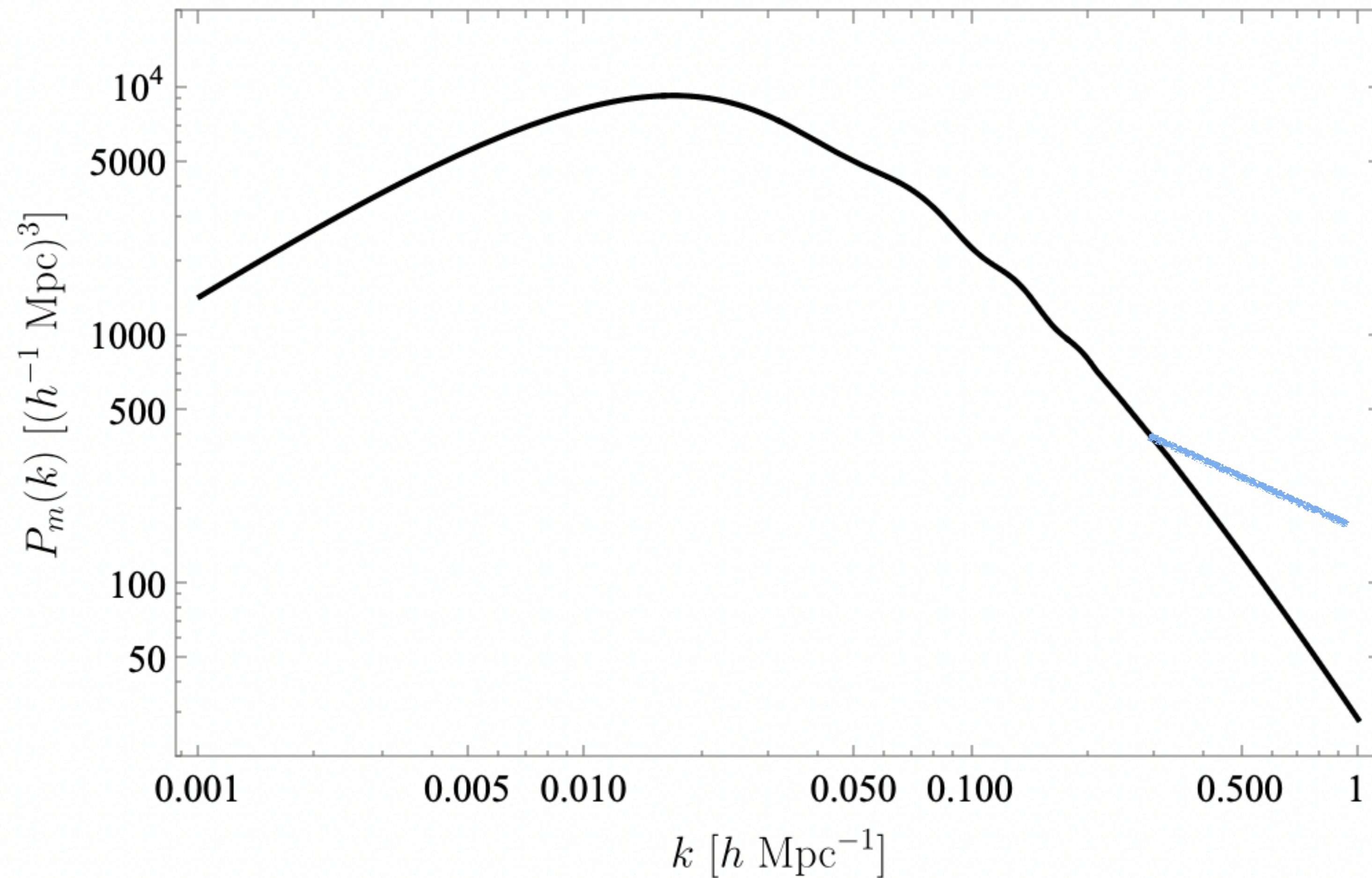


Macroscopic dB wavelength



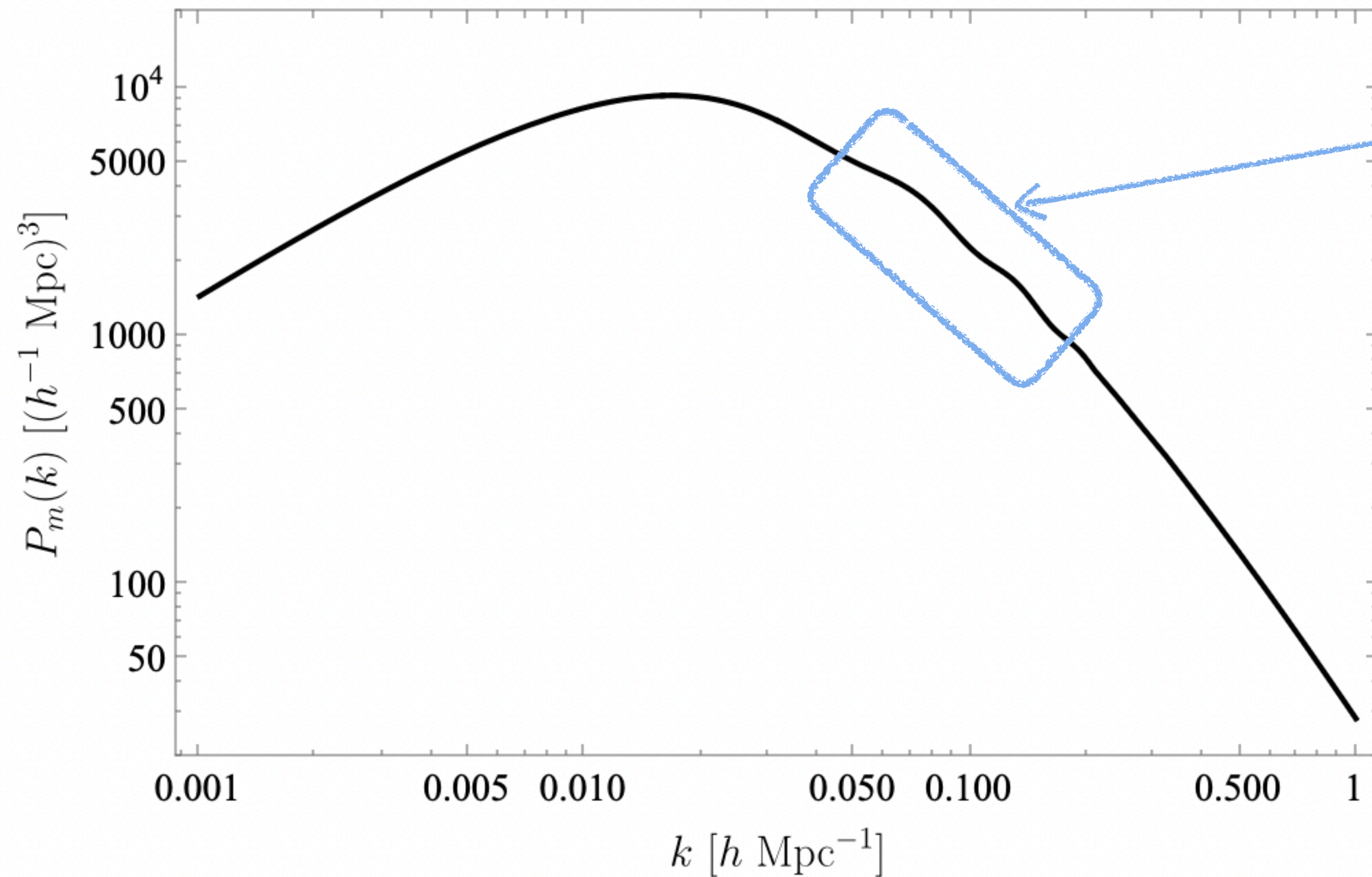
How do these features affect structures formation?

What can we find in the Power Spectrum?



Small scale enhancement:
- Isocurvature
- Can we get anything from dynamics?

What can we find in the Power Spectrum?

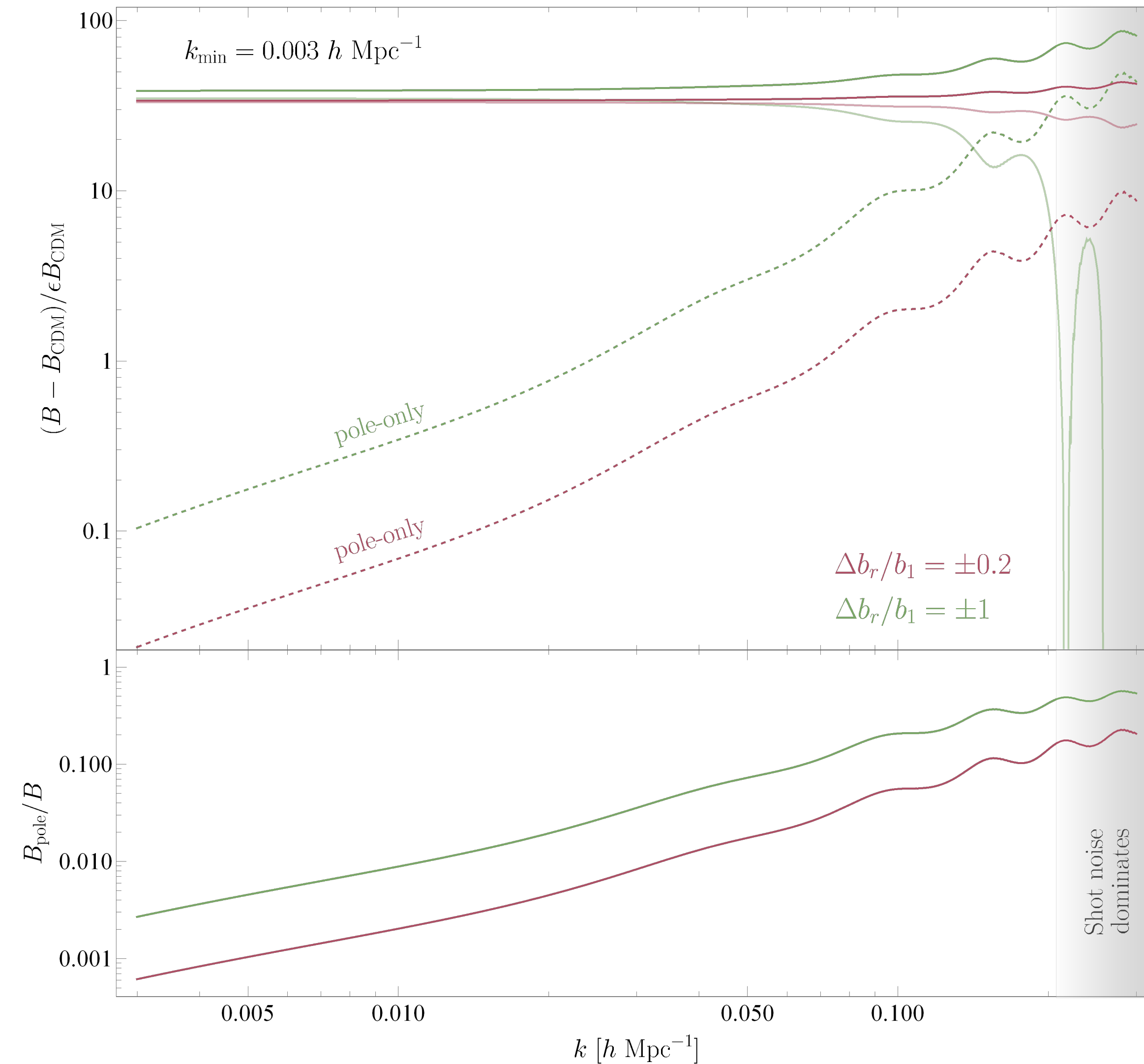


Modified BAO shape:

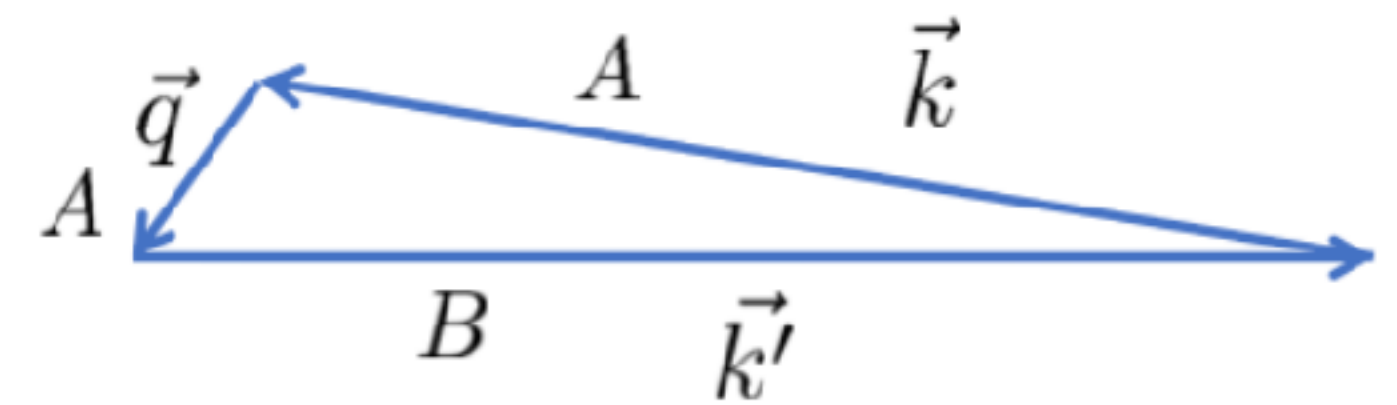
- DAO?

- Shift in the phase?

Look for new observables



Example: pole of the bispectrum



$$\lim_{q \rightarrow 0} \Delta B(q, k, k') \propto \Delta_{AB} \frac{\vec{q} \cdot \vec{k}}{q^2} P^{\text{lin}}(k) P^{\text{lin}}(q)$$

$$\Delta_{AB} = b_1^A (b_1^A b_r^B - b_1^B b_r^A)$$

Conclusions

Hunting for NP with LSS

Opportunity

Necessity

Tons of new data

Secluded DS

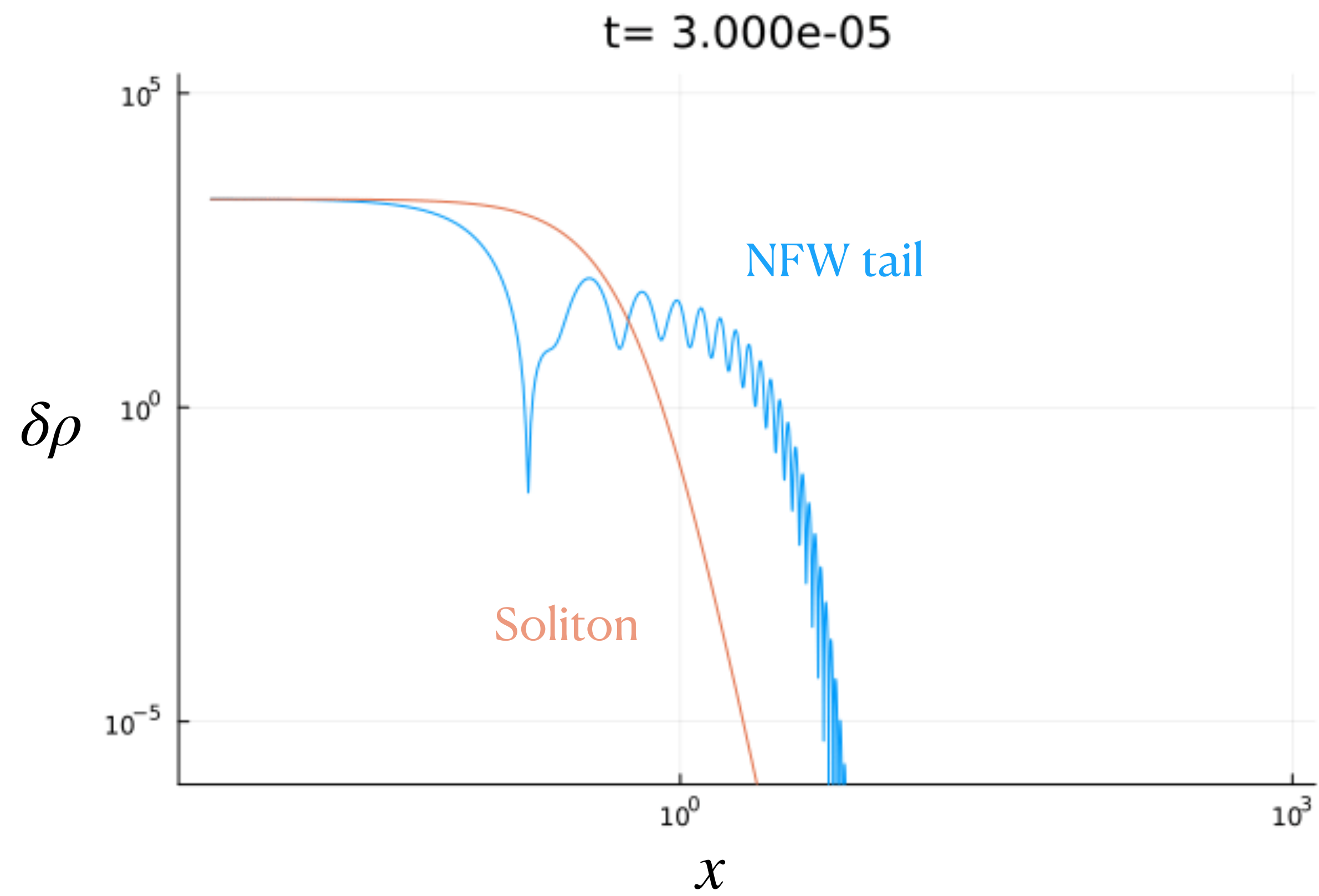
Unprecedented
sensitivity. Feature-
sensitive observables?

Plenty of new features
imprinted in LSS
observables

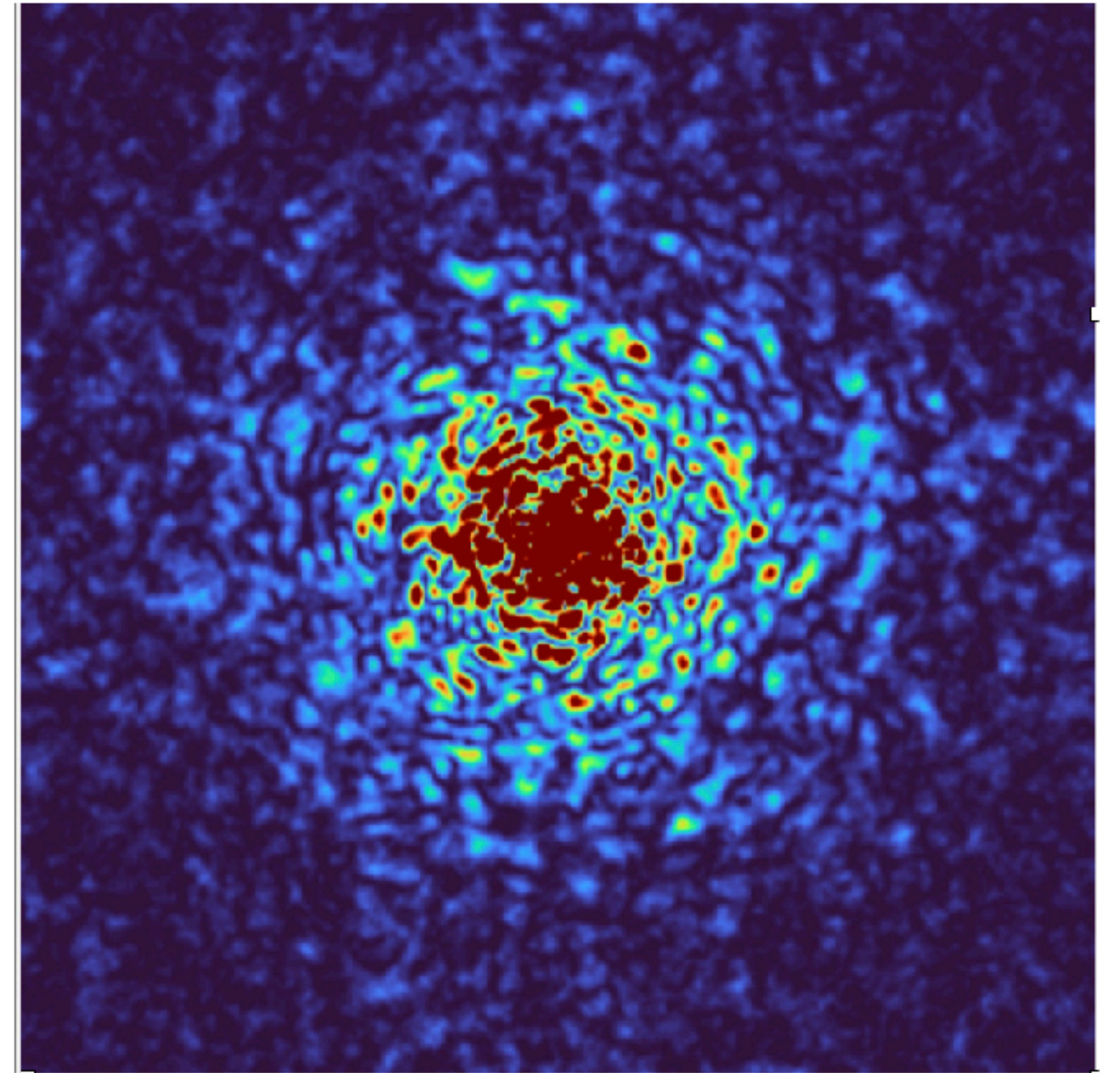
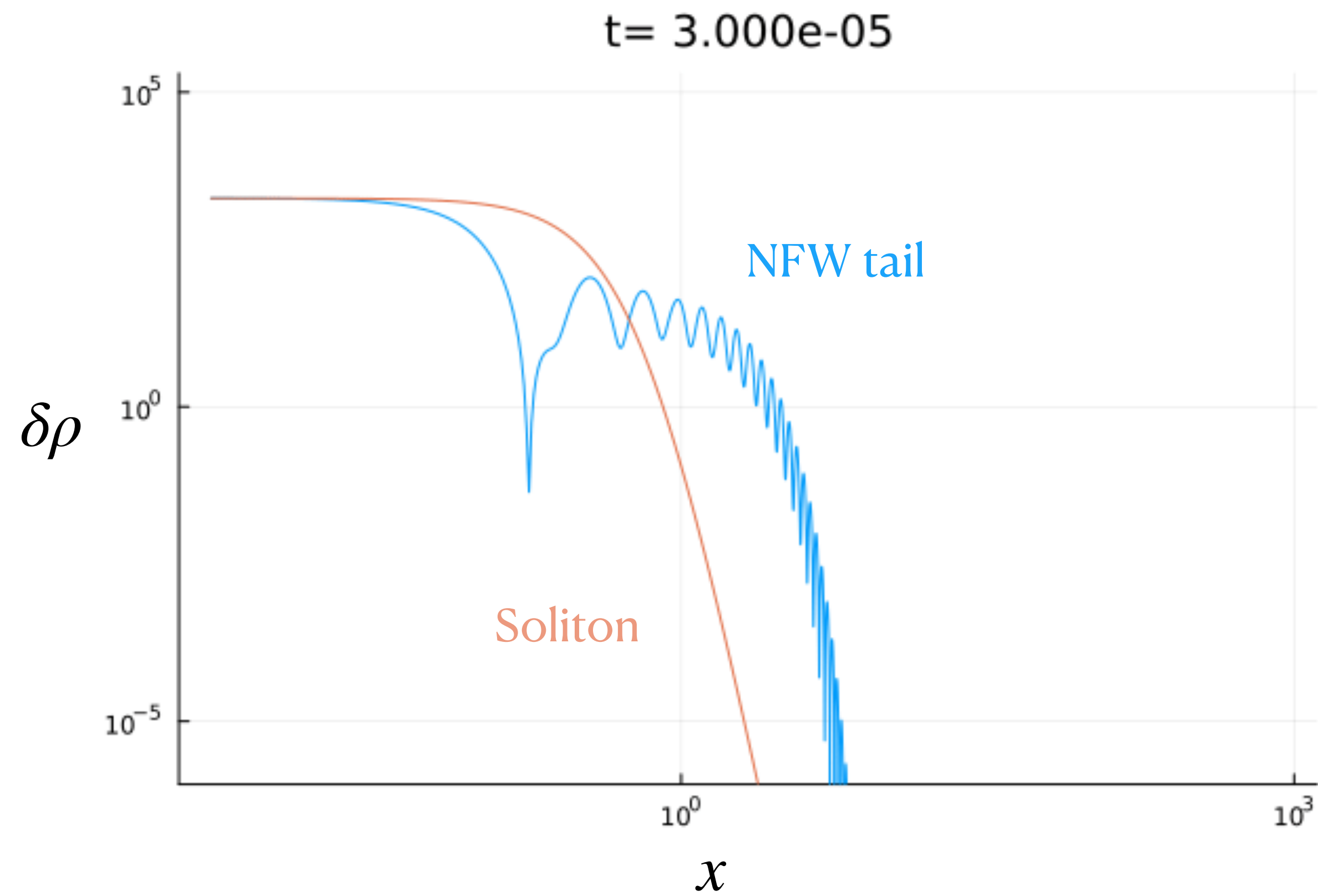
Future can be bright even if completely dark!

Thanks!

Modified dynamics of collapse

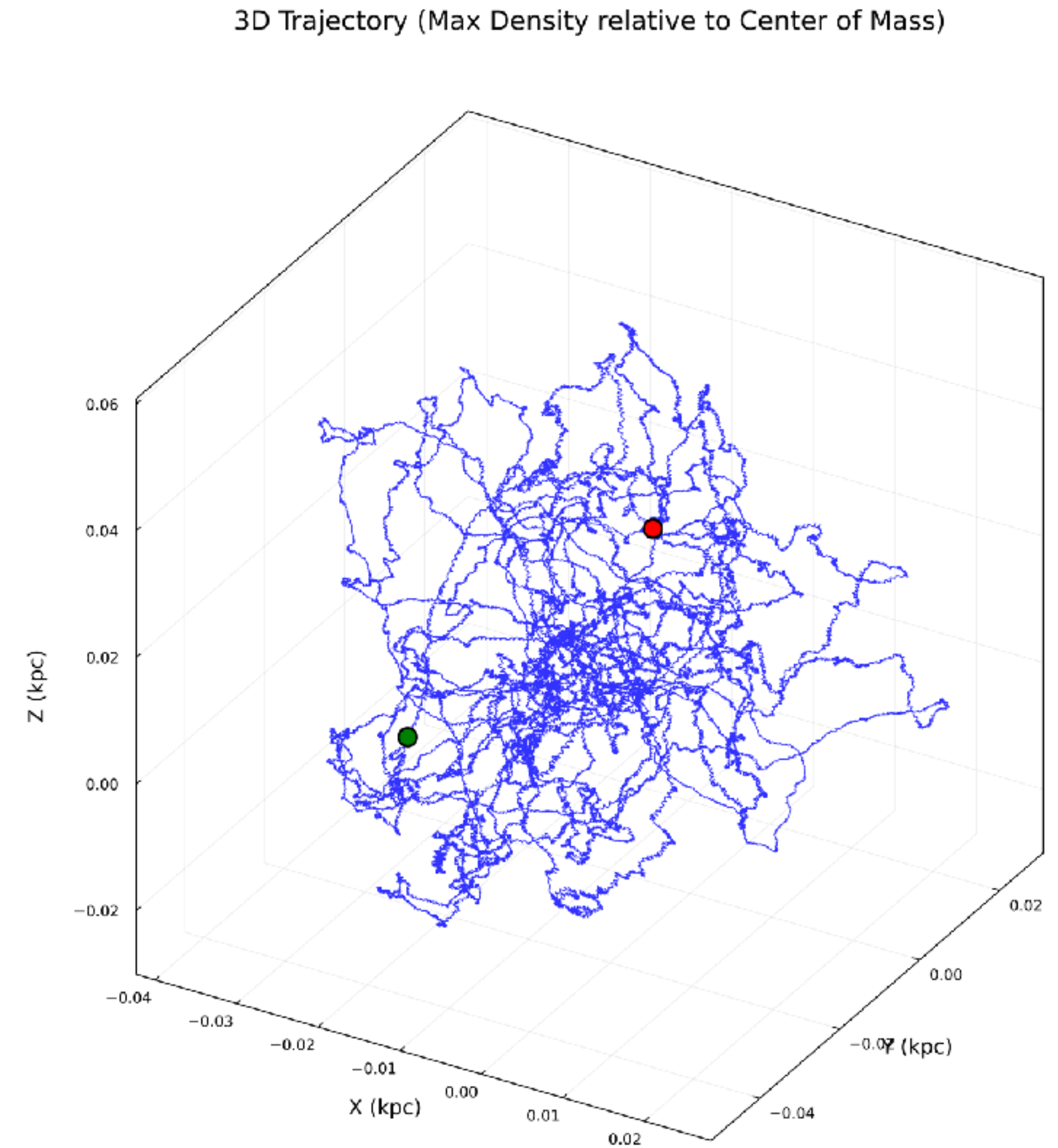
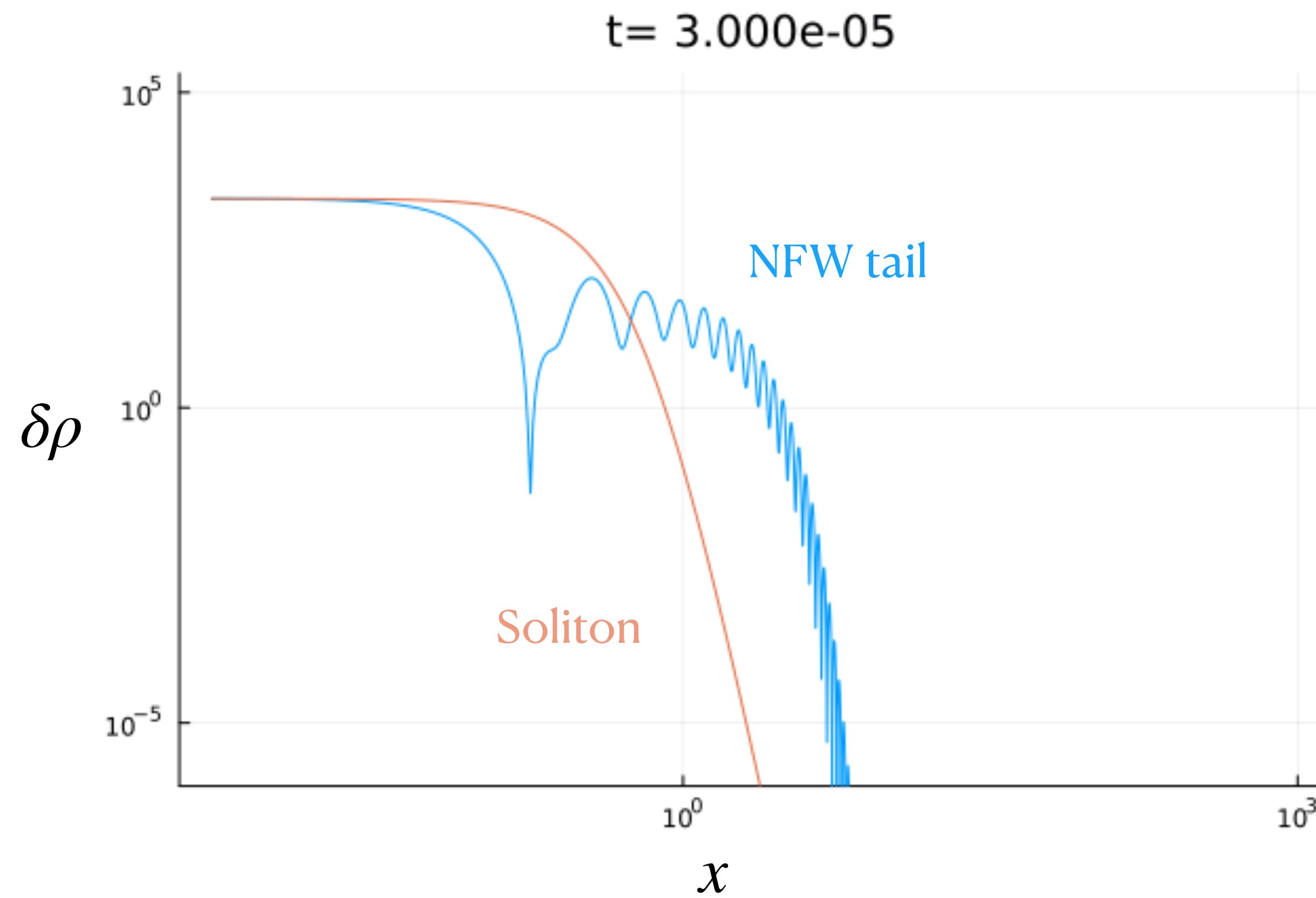


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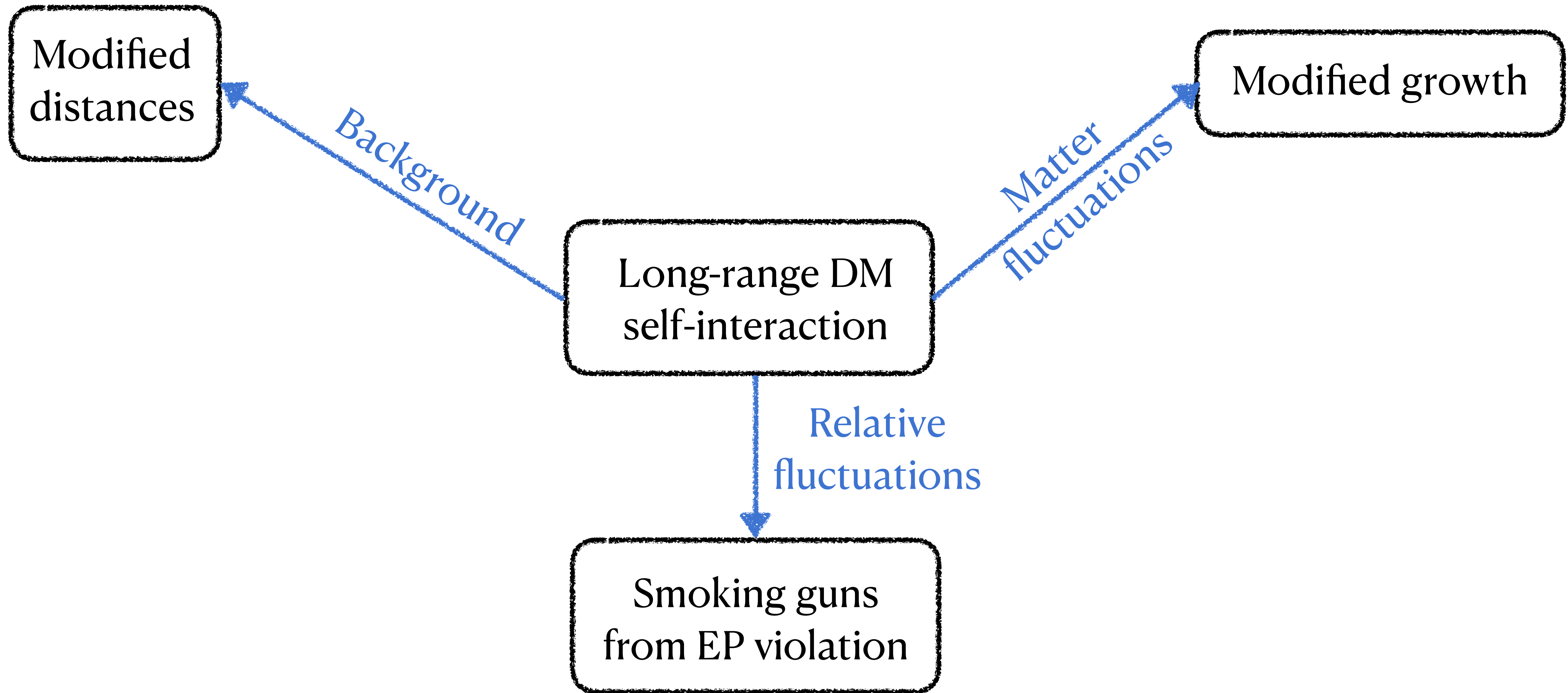
Credits: Giuseppe Rossi

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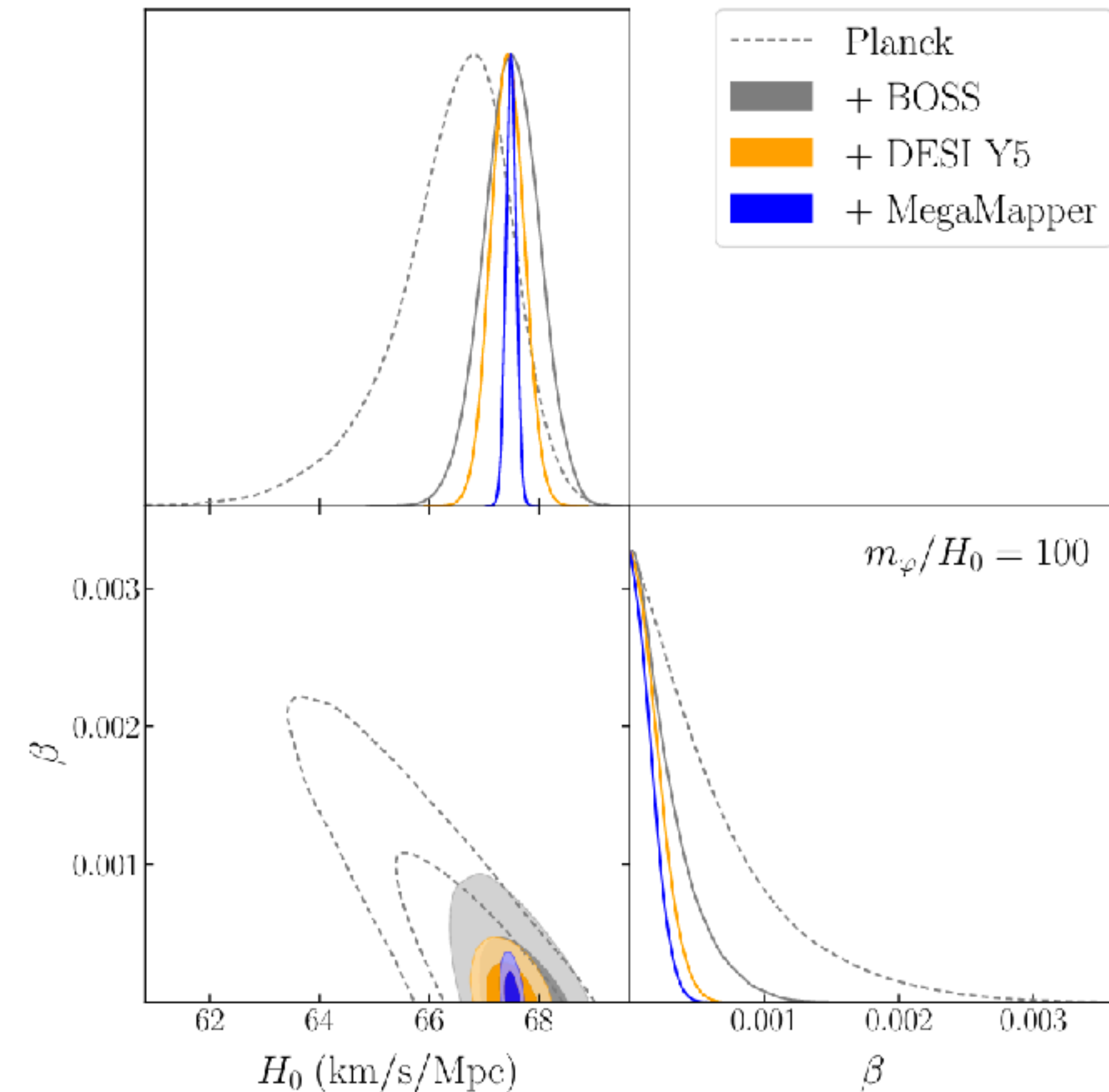
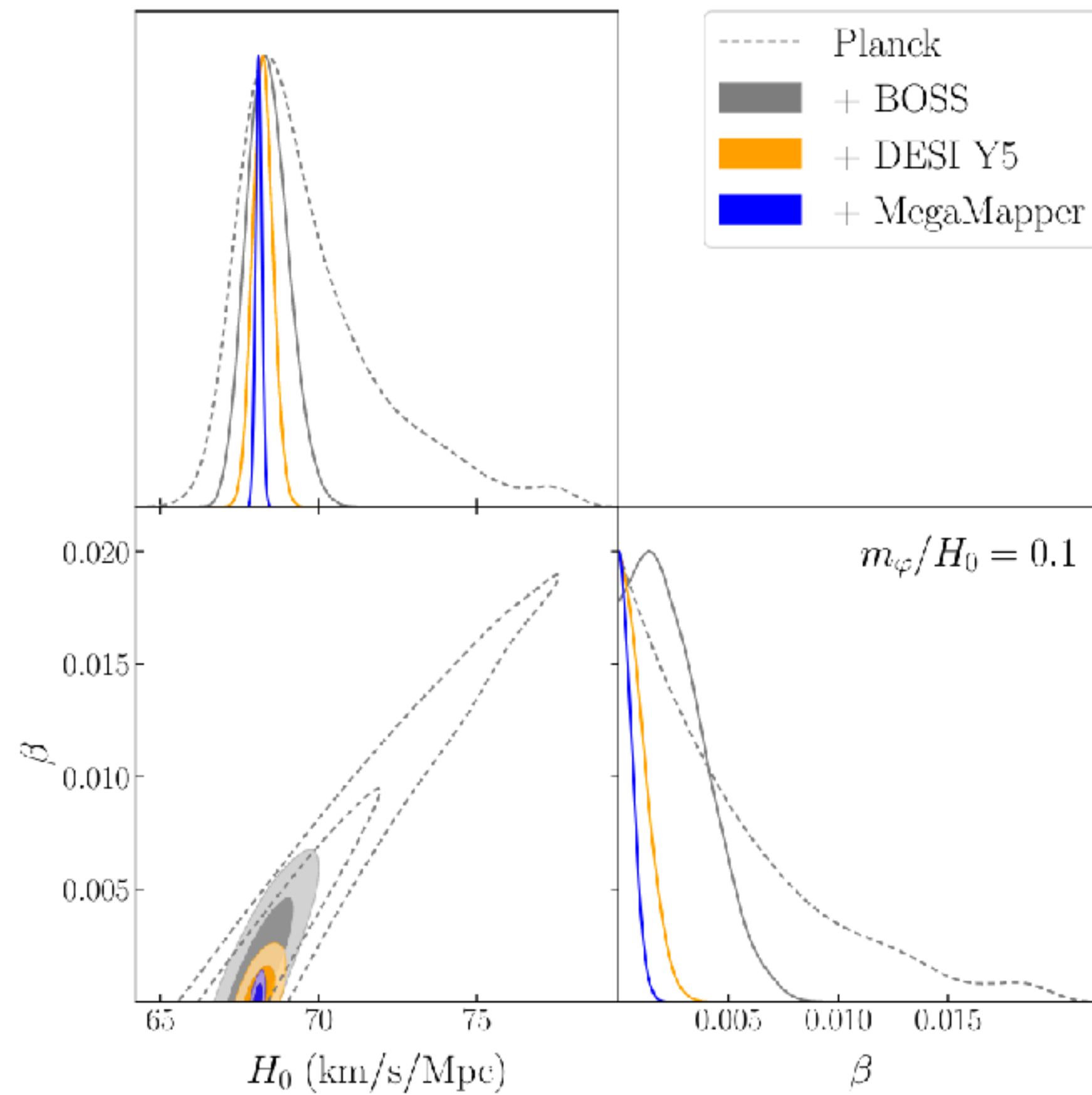


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Dark force dynamics

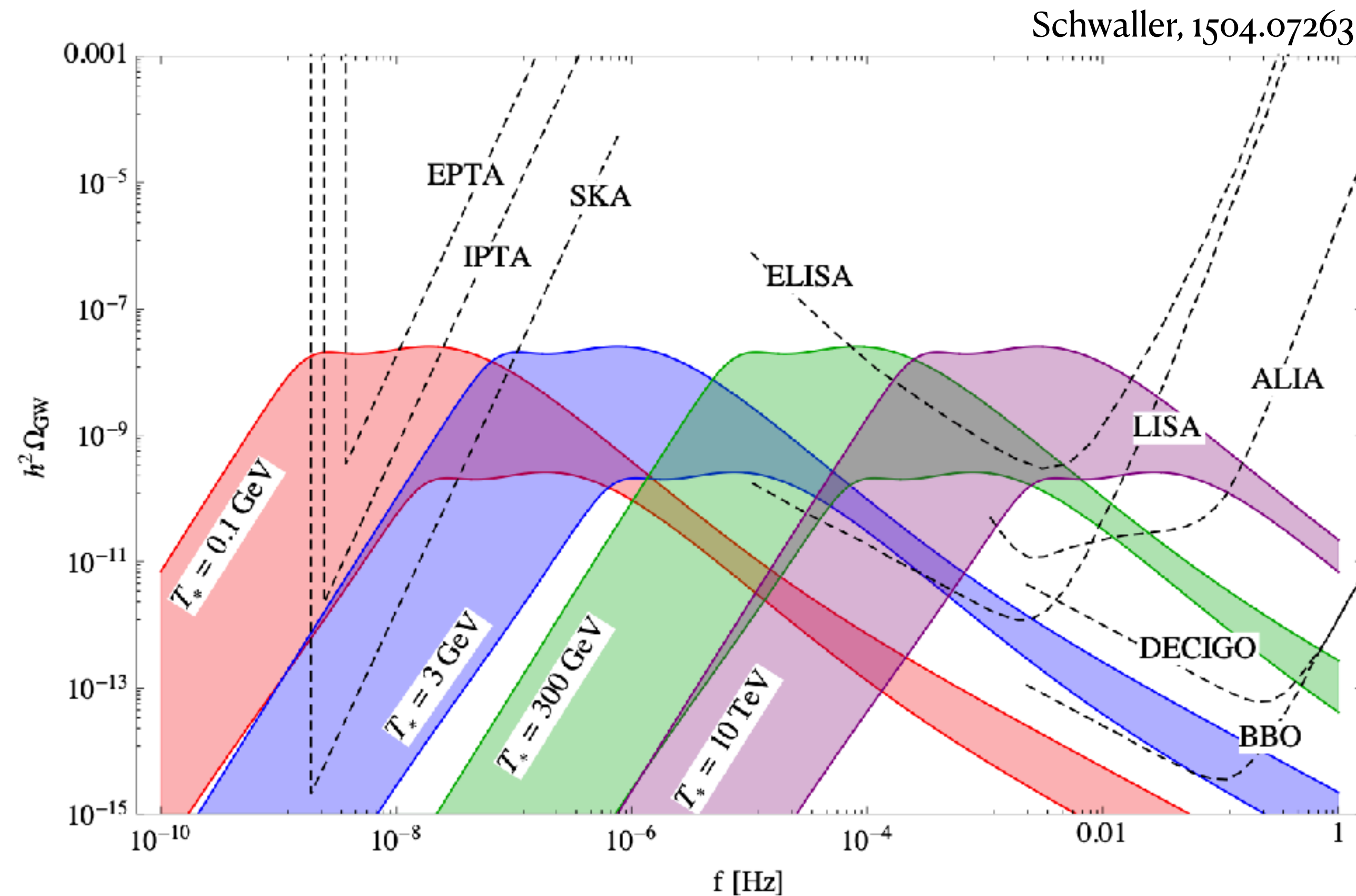


Bounds



Can we test late-time PT?

PT happening at $T \gtrsim 1$ eV produce GWs in the sensitivity range of future interferometers



What about later PT? Imprints left on cosmological observables!

Features of the Signal

