Primordial black holes and how to produce them

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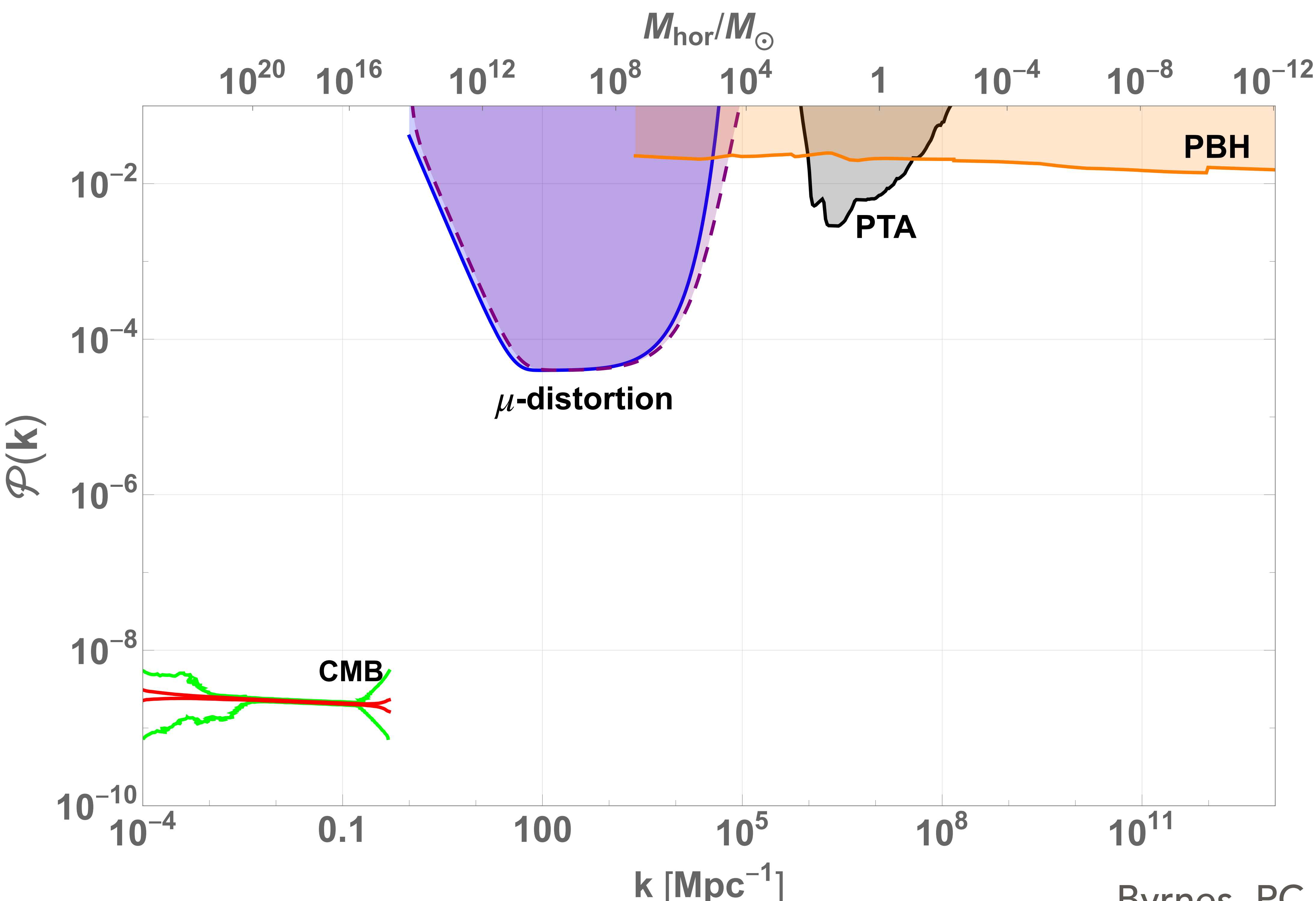
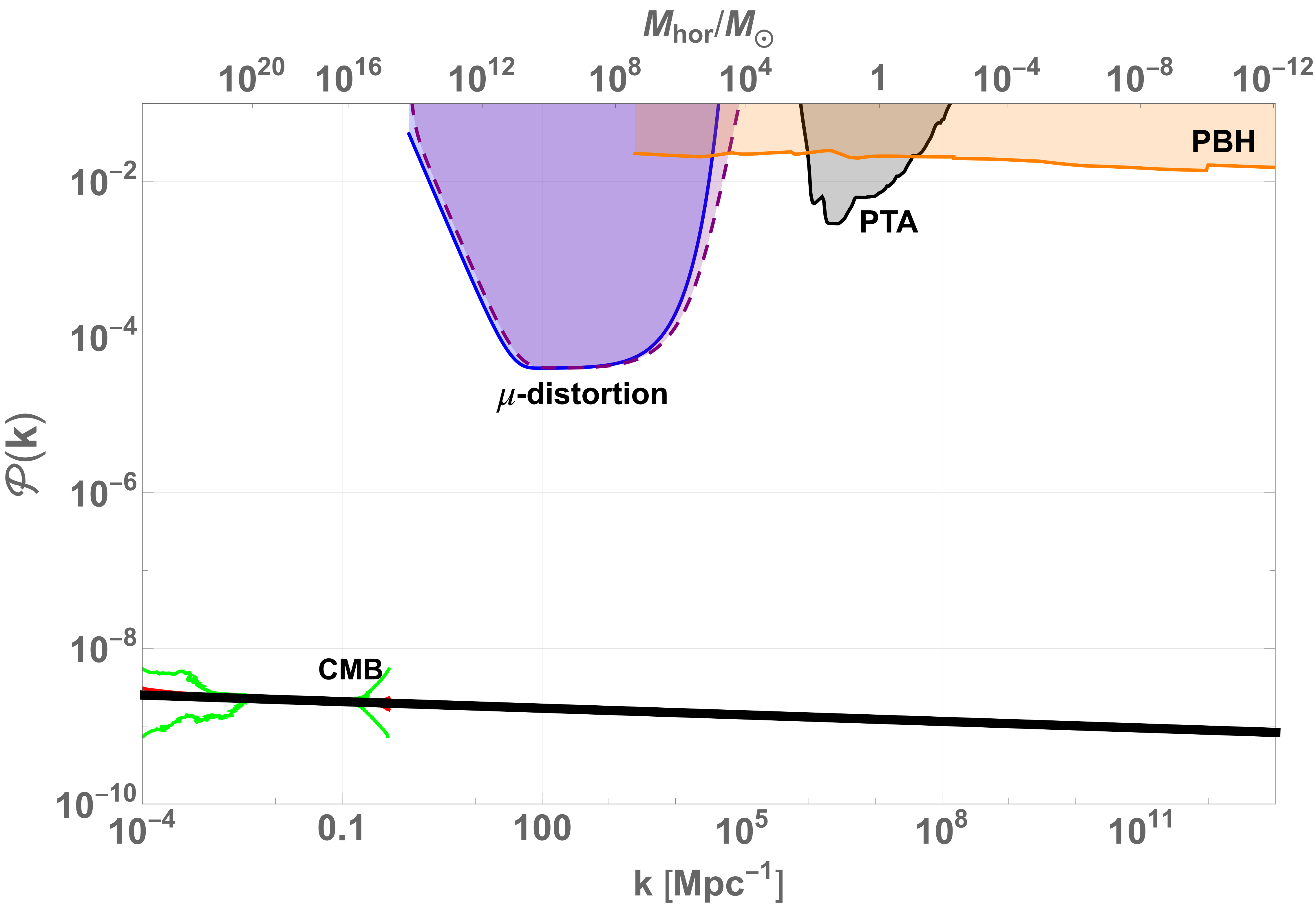
The primordial power spectrum

Measure of how overdense patches of a particular size were at the end of inflation - best 'observable' we have

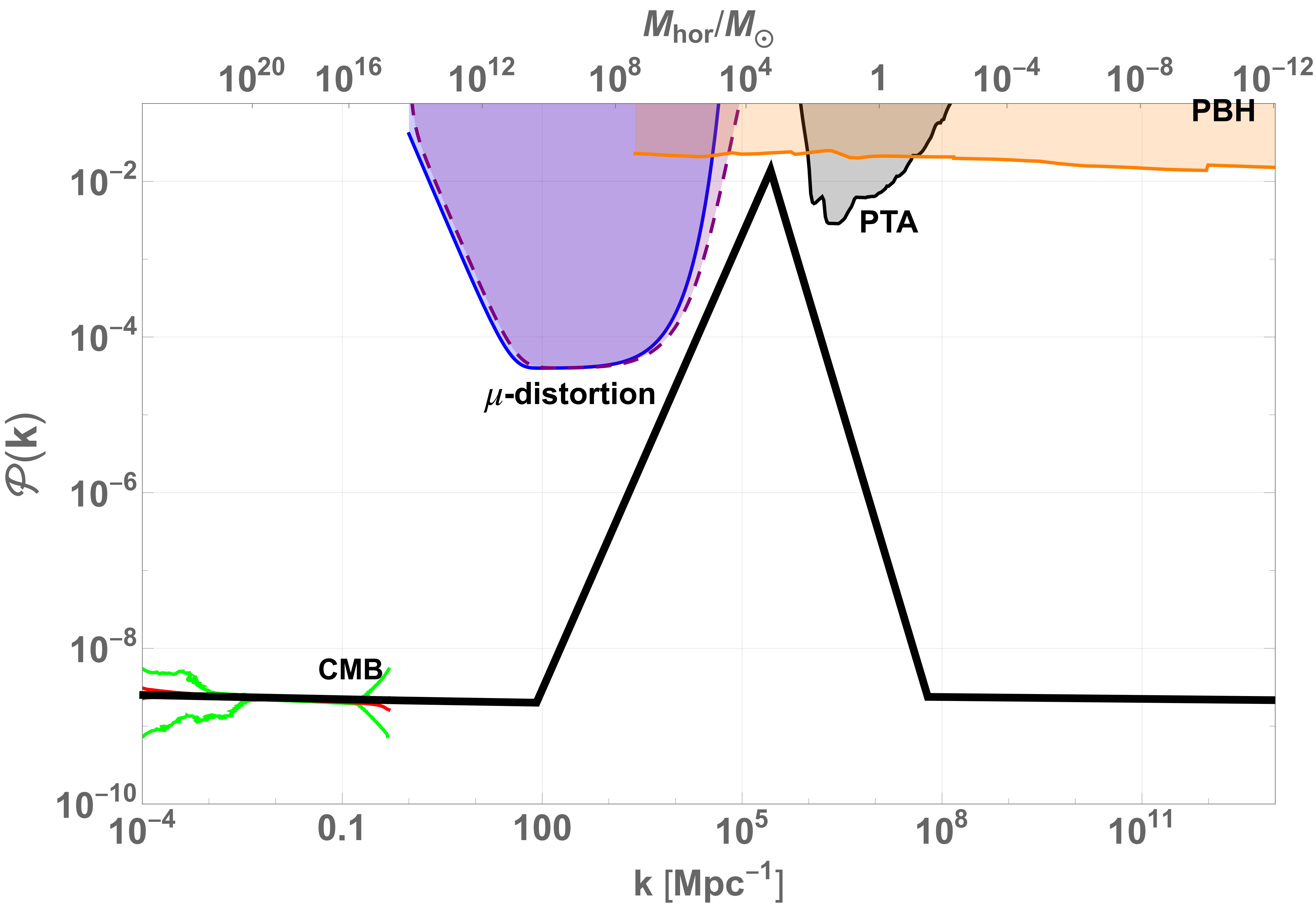


Byrnes, PC, Patil 2018

On CMB scales, the power spectrum is almost scale-invariant with a small amplitude.



But what if we draw a peak or a feature on the smaller scales?

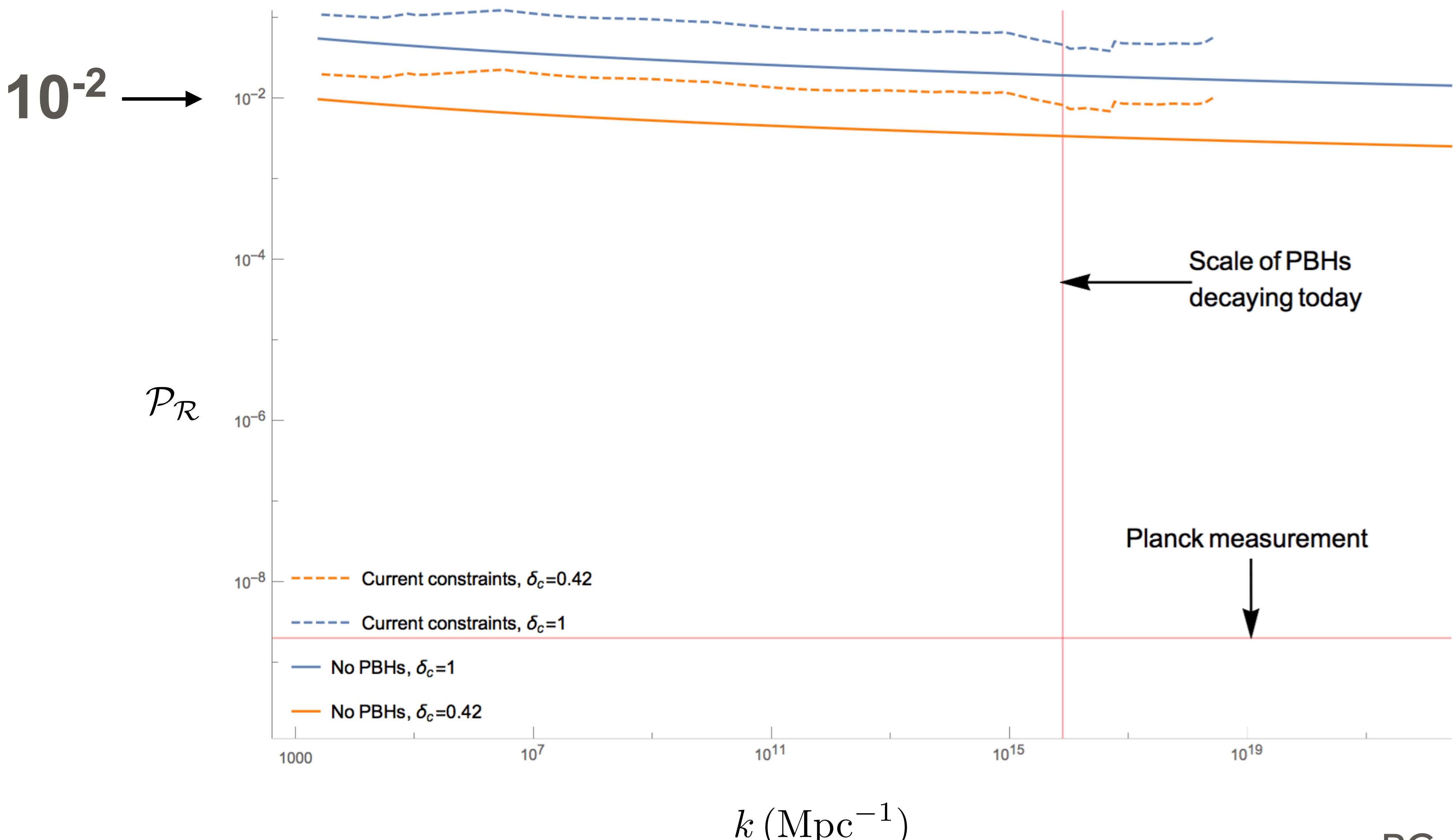


Outline

- Why might we want a peak?
- Why are we interested in PBHs?
- What does the primordial power spectrum tell us about inflation?
- How fast can the power spectrum grow?
- Current and future observational constraints

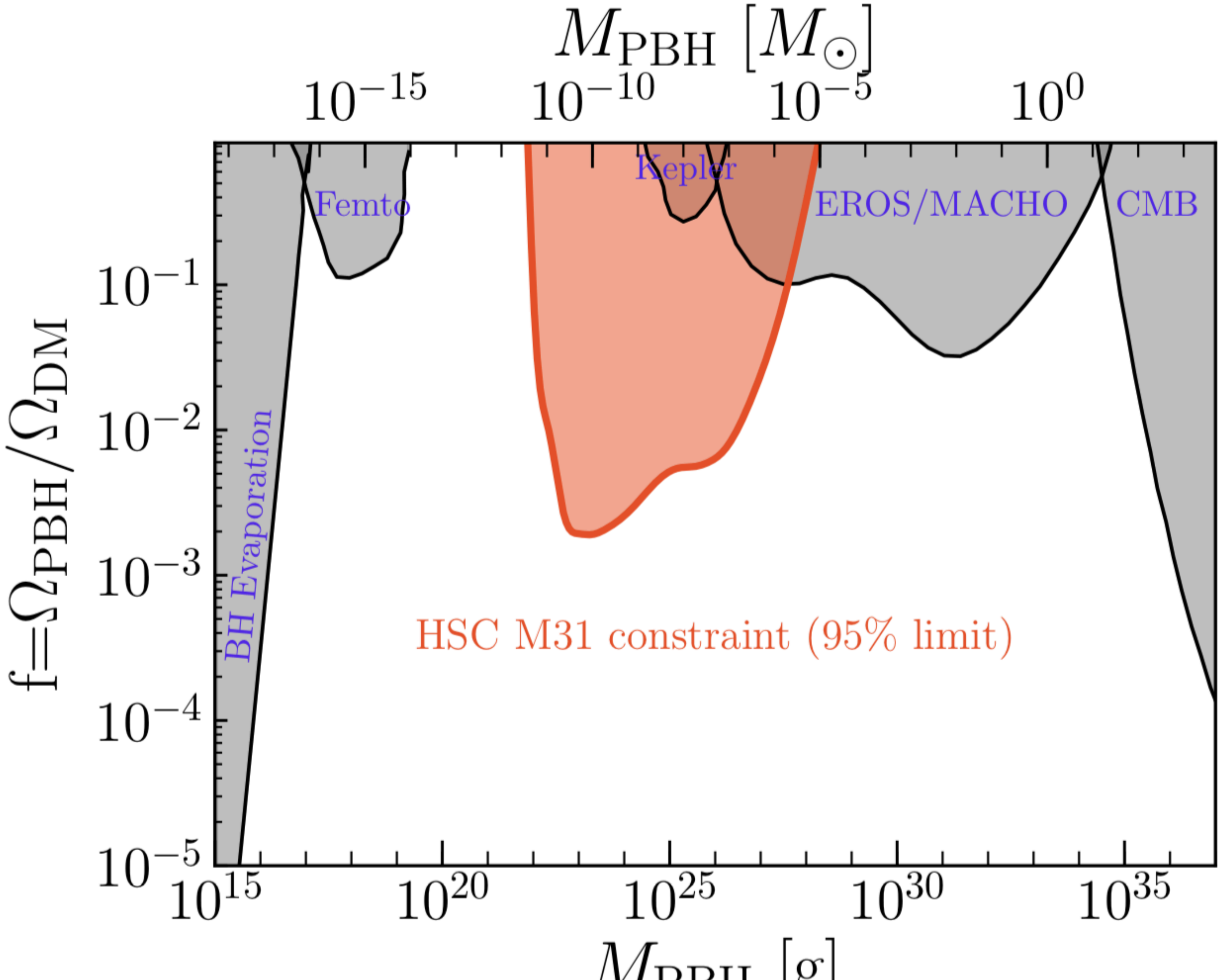
Why might we want a peak?

Primordial black holes can form from large over densities that reenter the horizon after inflation. Assuming Gaussian fluctuations, the power spectrum needs to hit around 10^-2 in order for them to form, so you need a large peak.



PC, Byrnes 2017

Why might we want PBHs?



Niikura et al. 2018 (updated version)

How is inflation related to the power spectrum?

- The primordial power spectrum is related to the inflationary potential:

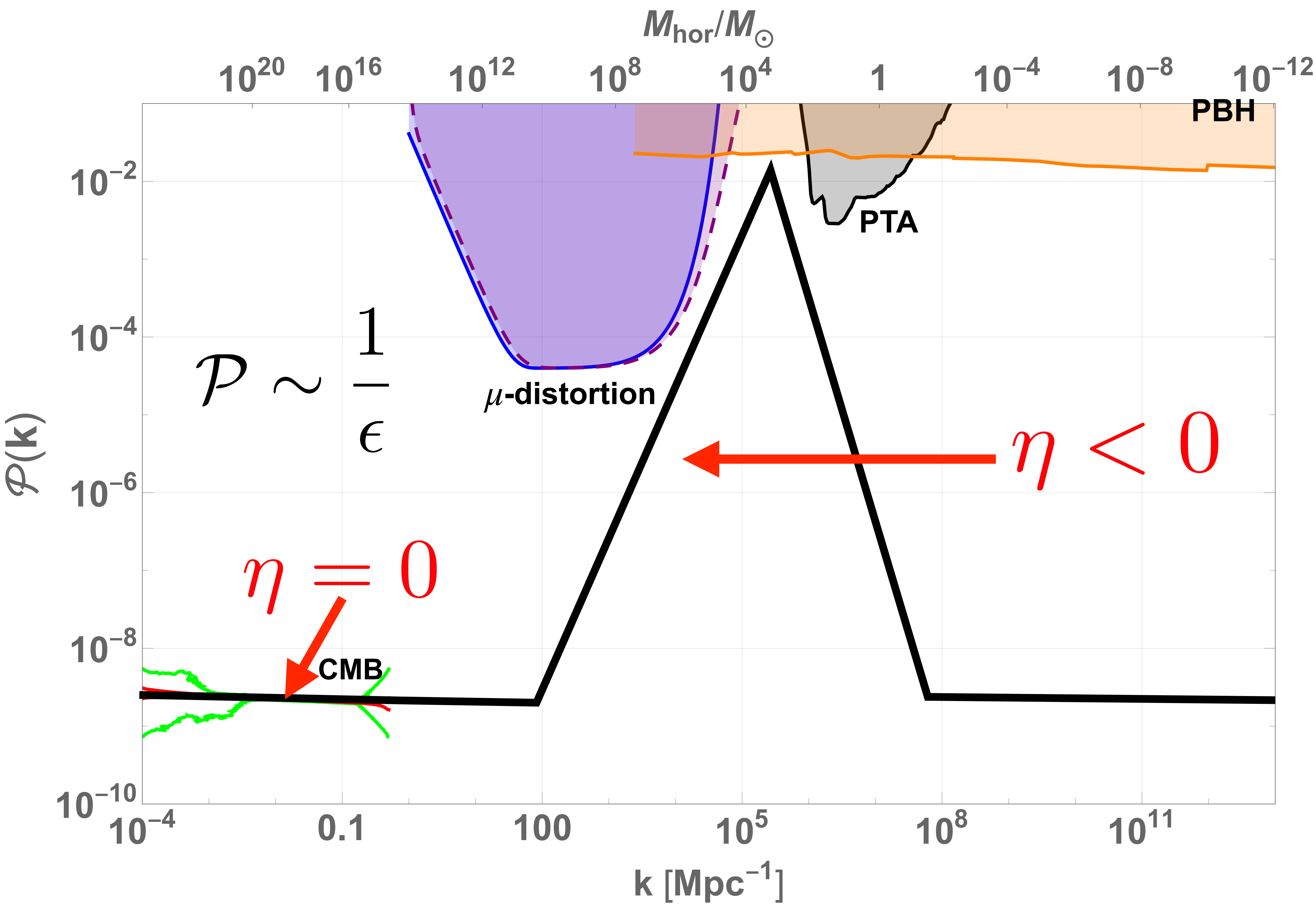
$$\epsilon = -\frac{\dot{H}}{H^2} = \frac{\dot{\phi}^2}{2H^2M_{\rm pl}^2} \qquad \eta = \frac{\dot{\epsilon}}{\epsilon H}$$

- For the simplest models of inflation:

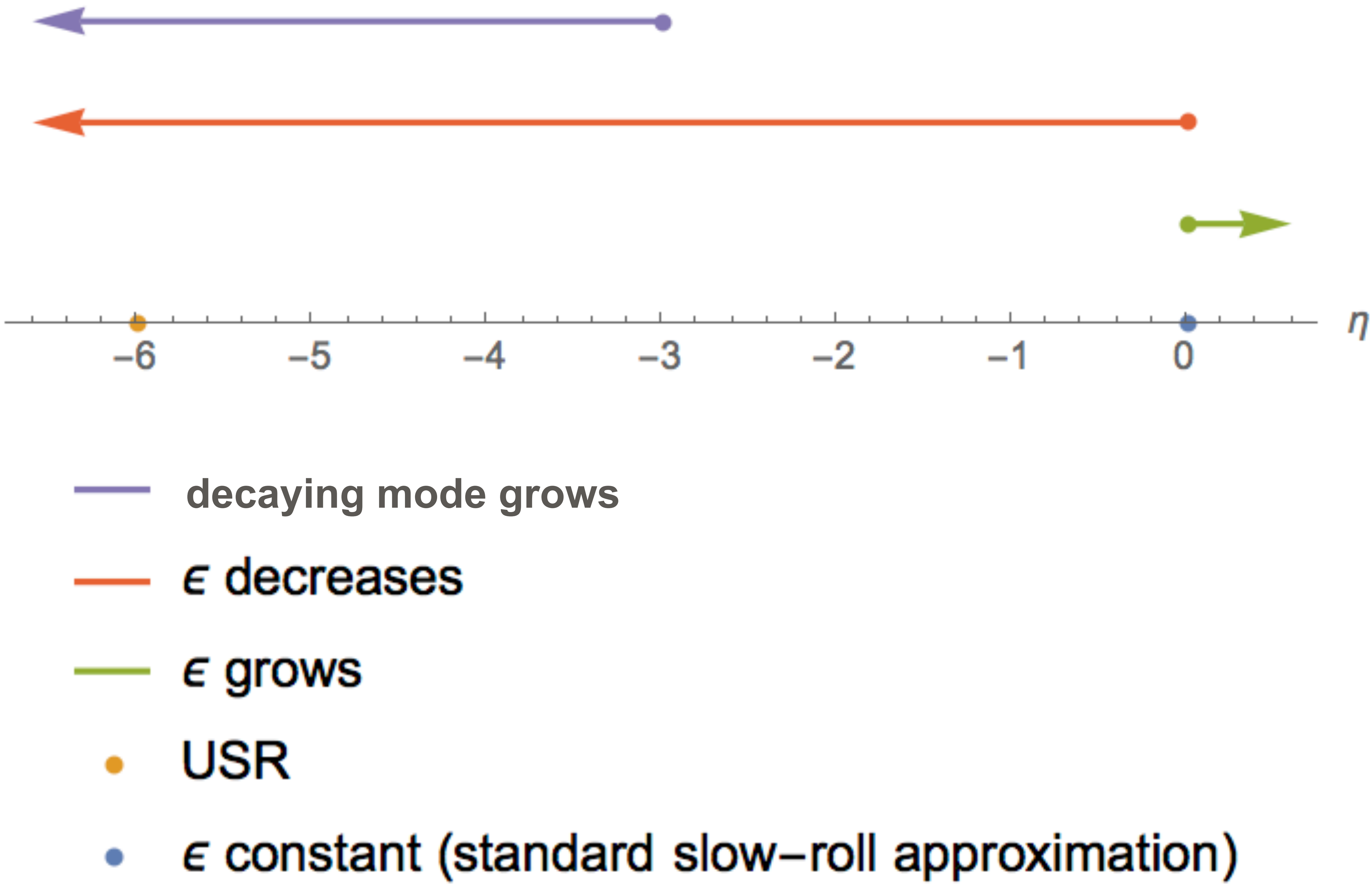
$$\mathcal{P} \sim \frac{1}{\epsilon} \qquad \epsilon_{\rm SR} \sim \left(\frac{V'}{V}\right)^2$$

Slow-roll approximation only valid when ϵ is constant and η ~0

Need to break slow-roll to produce a peak



SR/BSR/USR



−6
−5
−4
−3
−2
−1
0
η
decaying mode grows
ϵ decreases
ϵ grows
USR
ϵ constant (standard slow−roll approximation)

Superhorizon growth

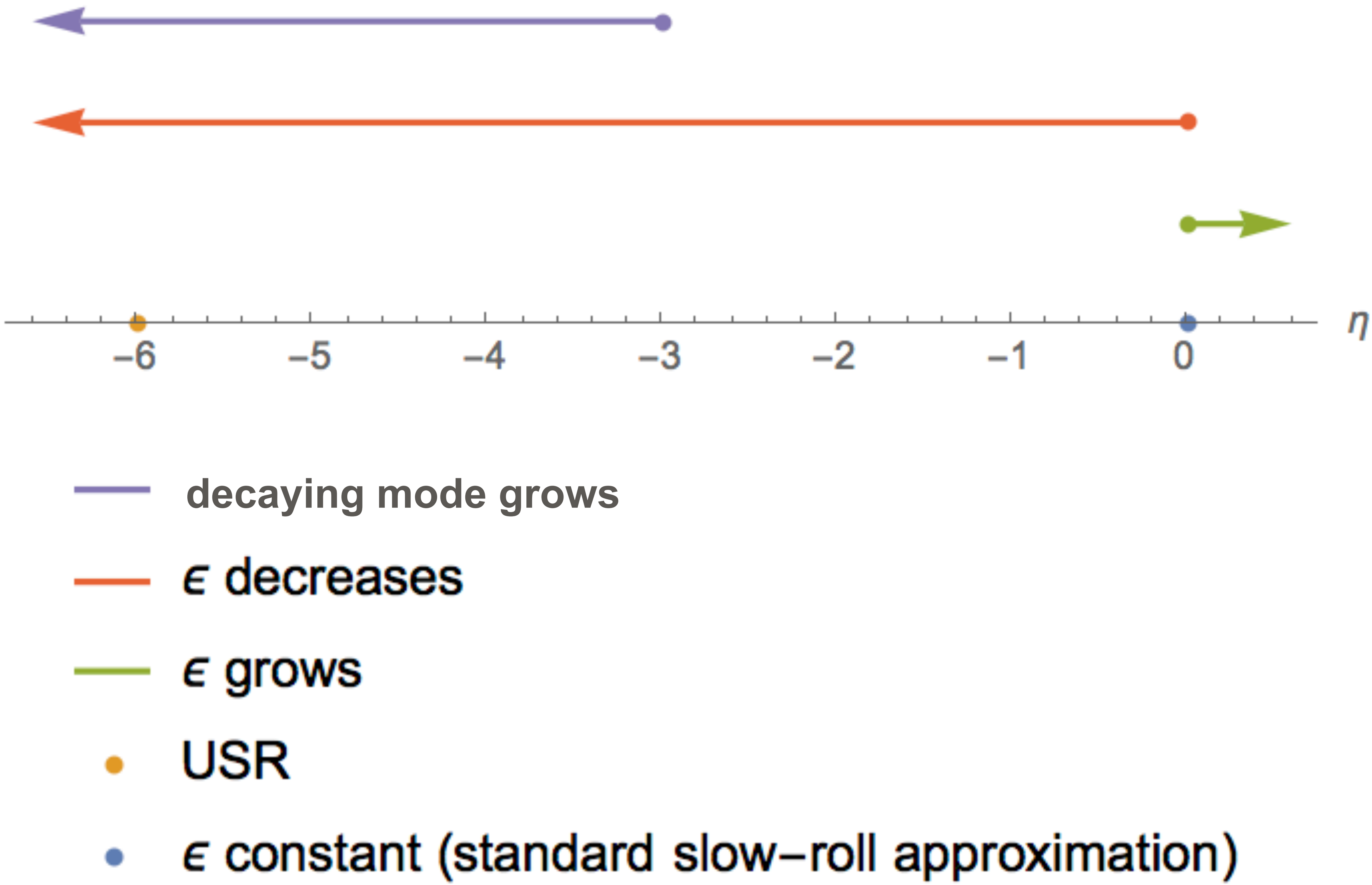
In the slow-roll approximation, everything freezes out after horizon exit. Beyond slow-roll, super horizon growth is possible

Superhorizon growth when ϵ decreases faster than a^3, which is equivalent to $\eta < -3$

$$\mathcal{R}_{k\to 0} = C_k + D_k \int \frac{dt}{a^3 \epsilon}$$

this is because the previously decaying mode starts to grow

SR/BSR/USR



−6
−5
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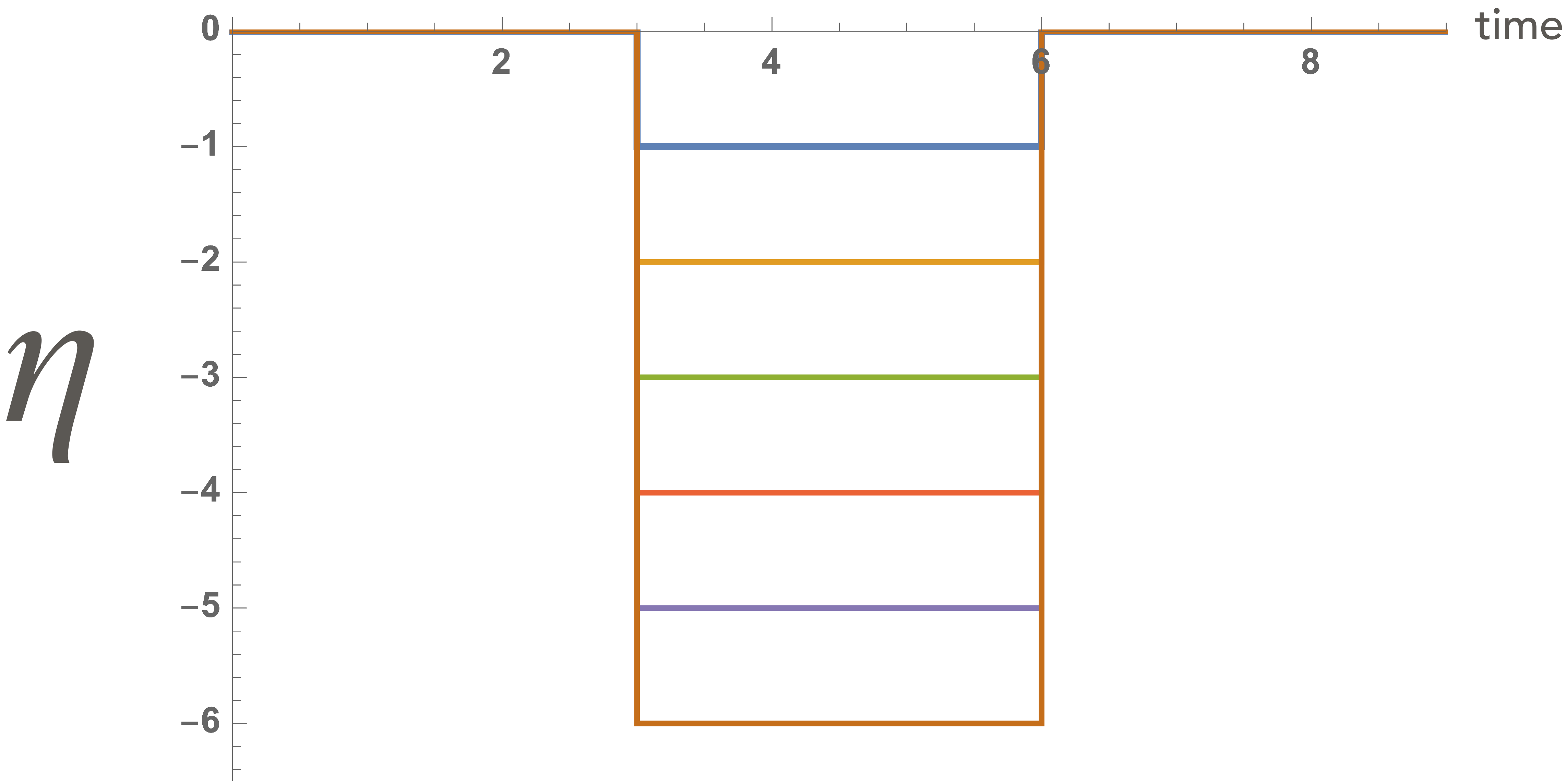
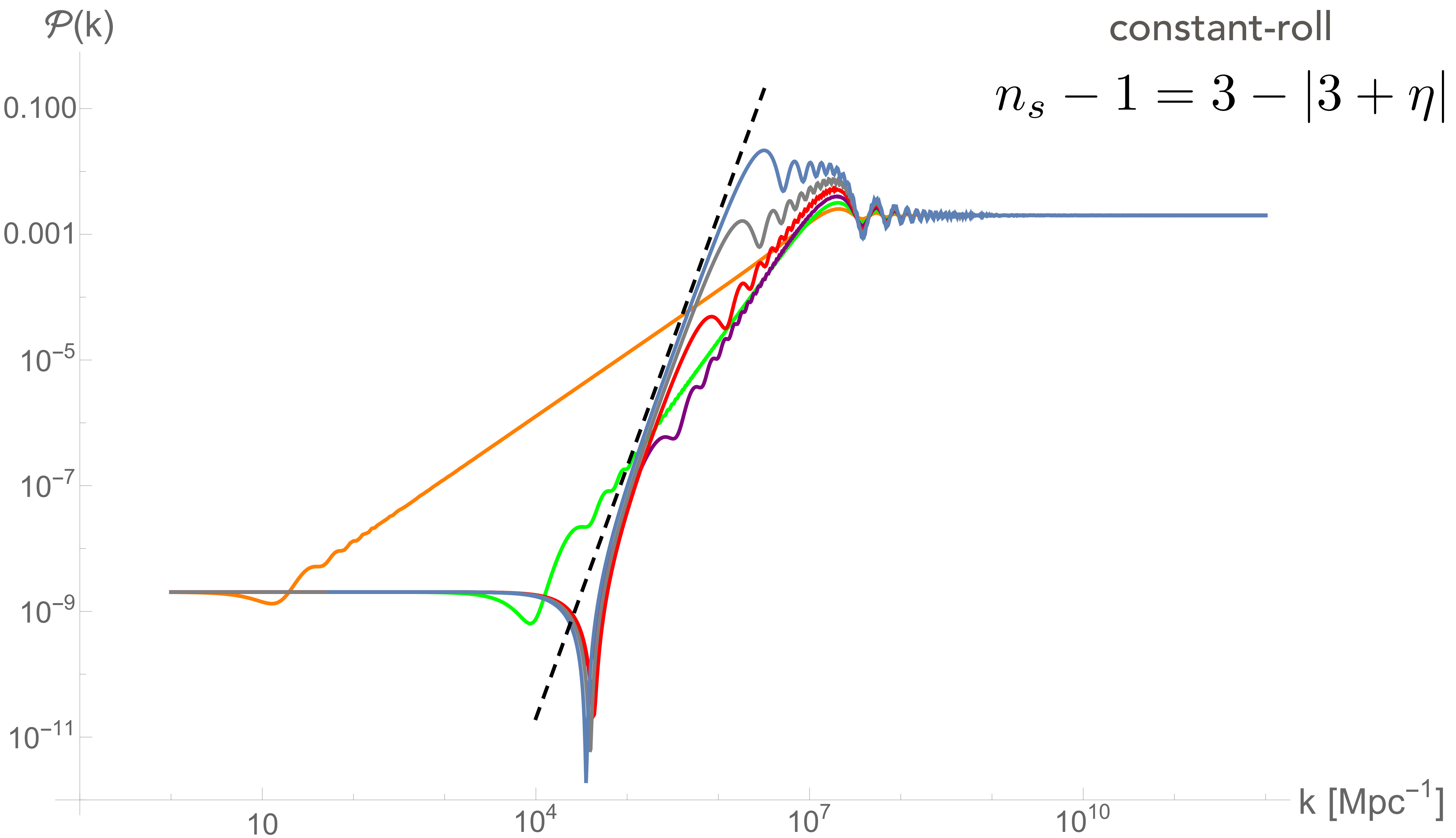
Matching



$$\mathcal{R}_k^1(\tau_i) = \mathcal{R}_k^2(\tau_i) \qquad \mathcal{R}_k'^1(\tau_i) = \mathcal{R}_k'^2(\tau_i)$$

Steepest growth



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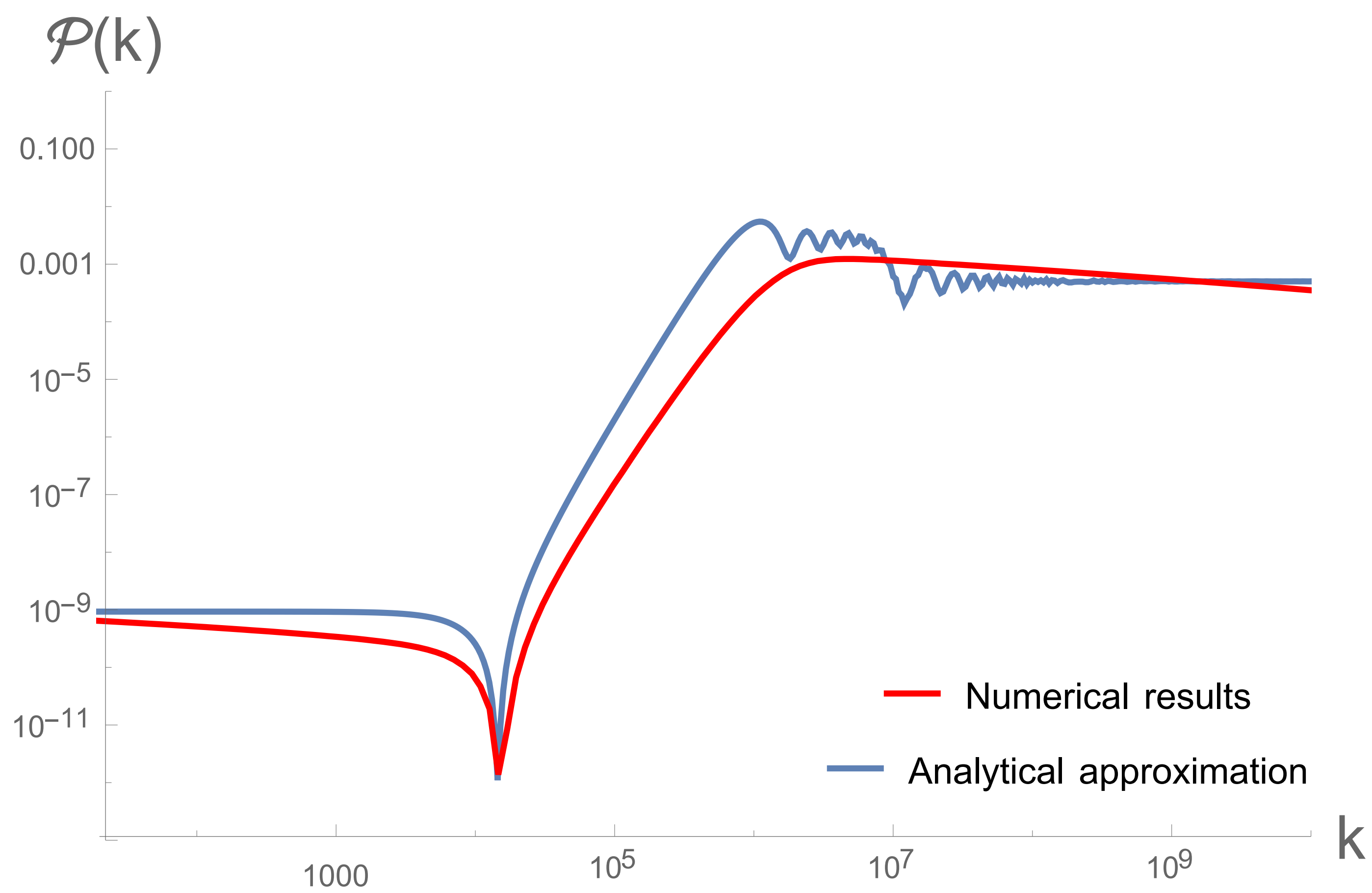
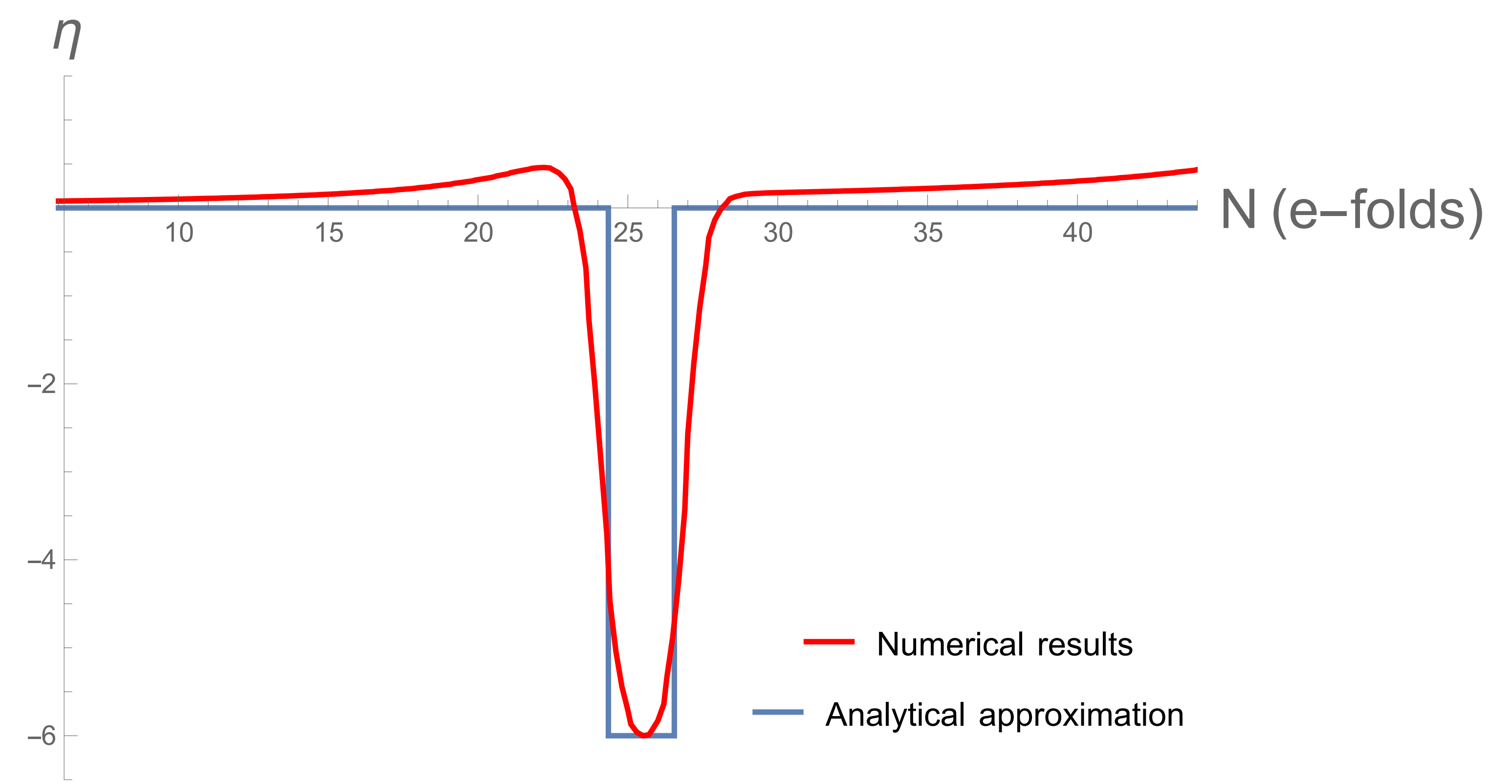
Numerical comparison



Good approximation of the main features, and dip still there in analytical approximation where epsilon never increases



David Seery's CPPTransport for numerical results

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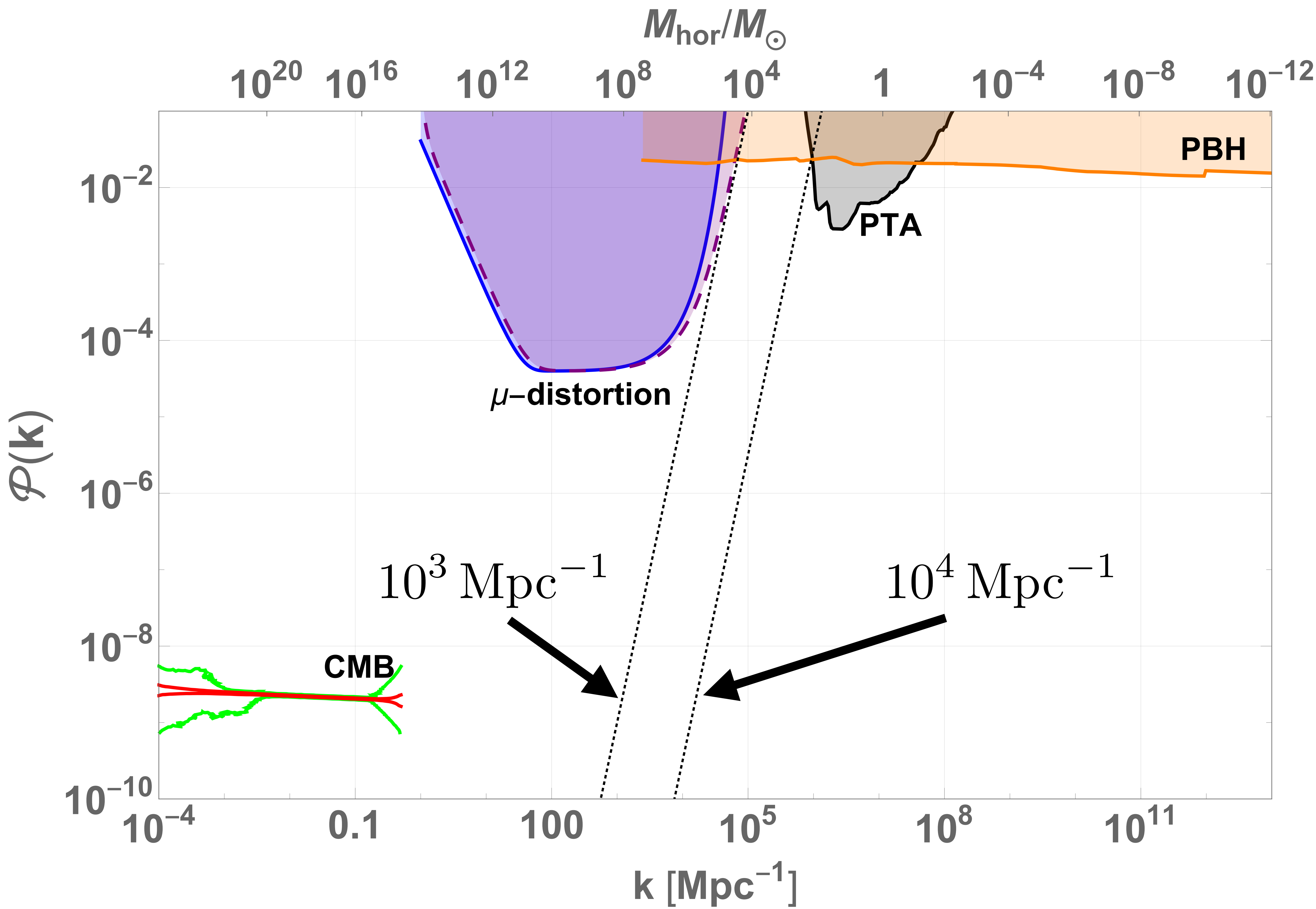
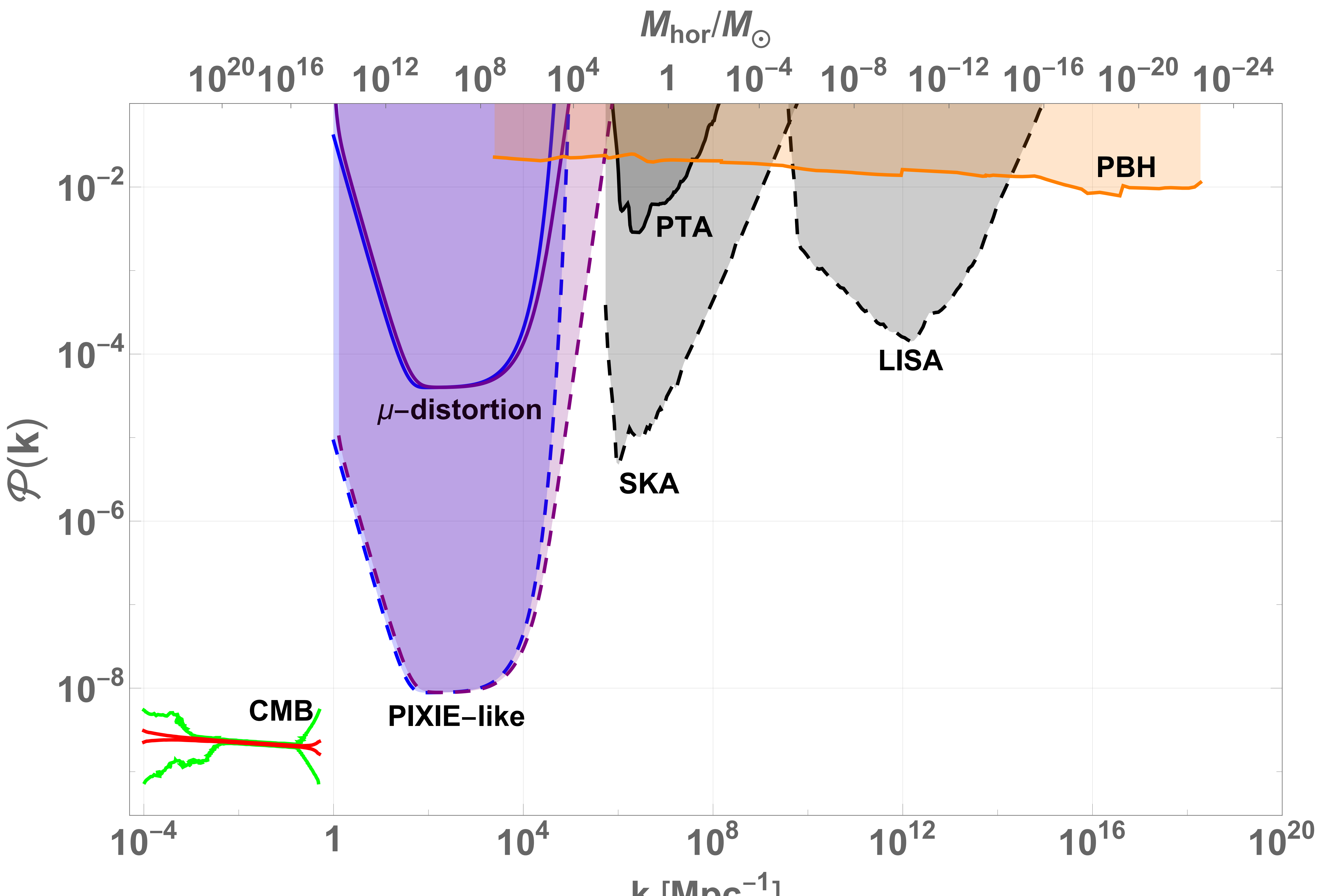
Consequences for observational constraints



Future forecasts



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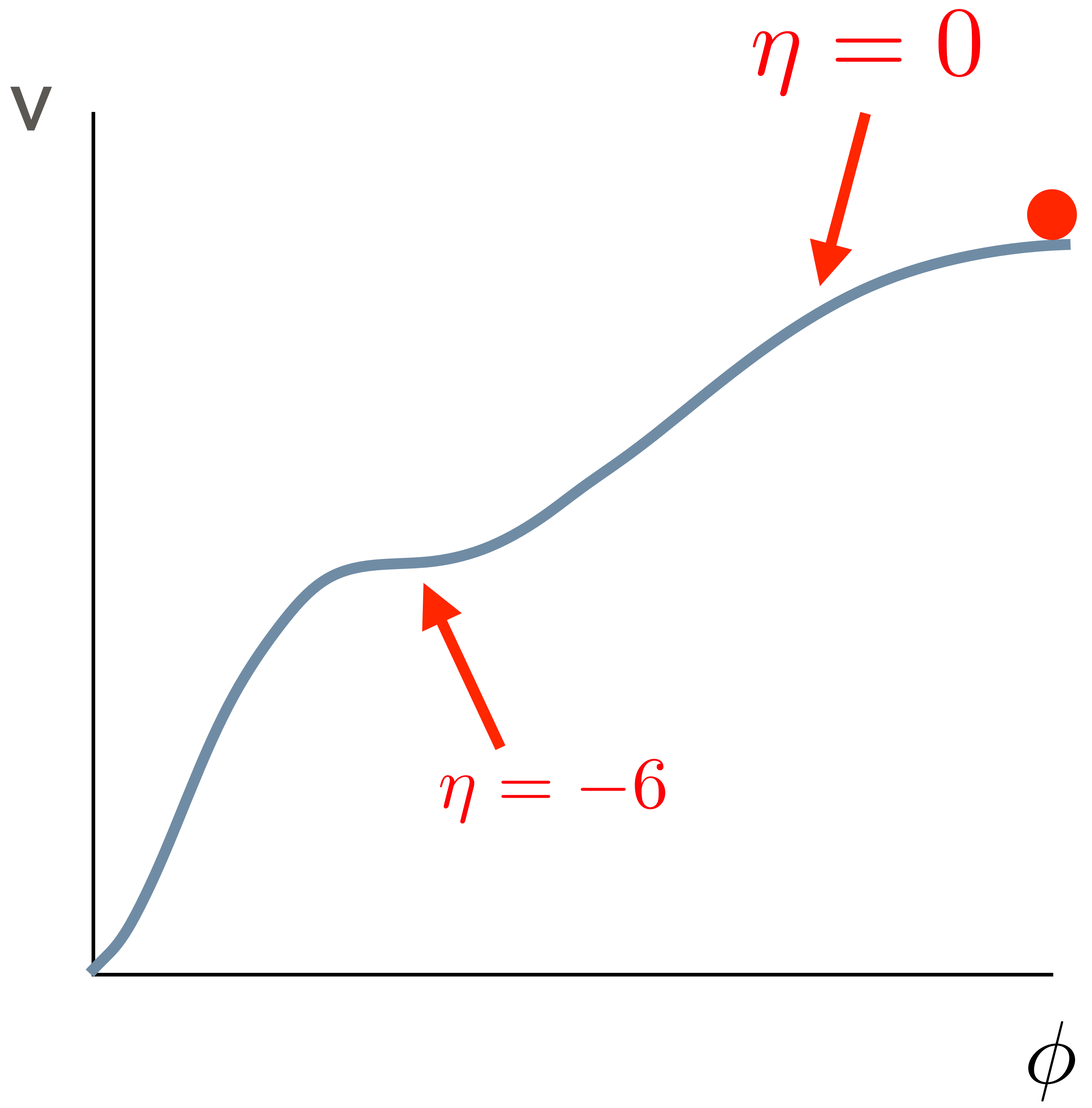
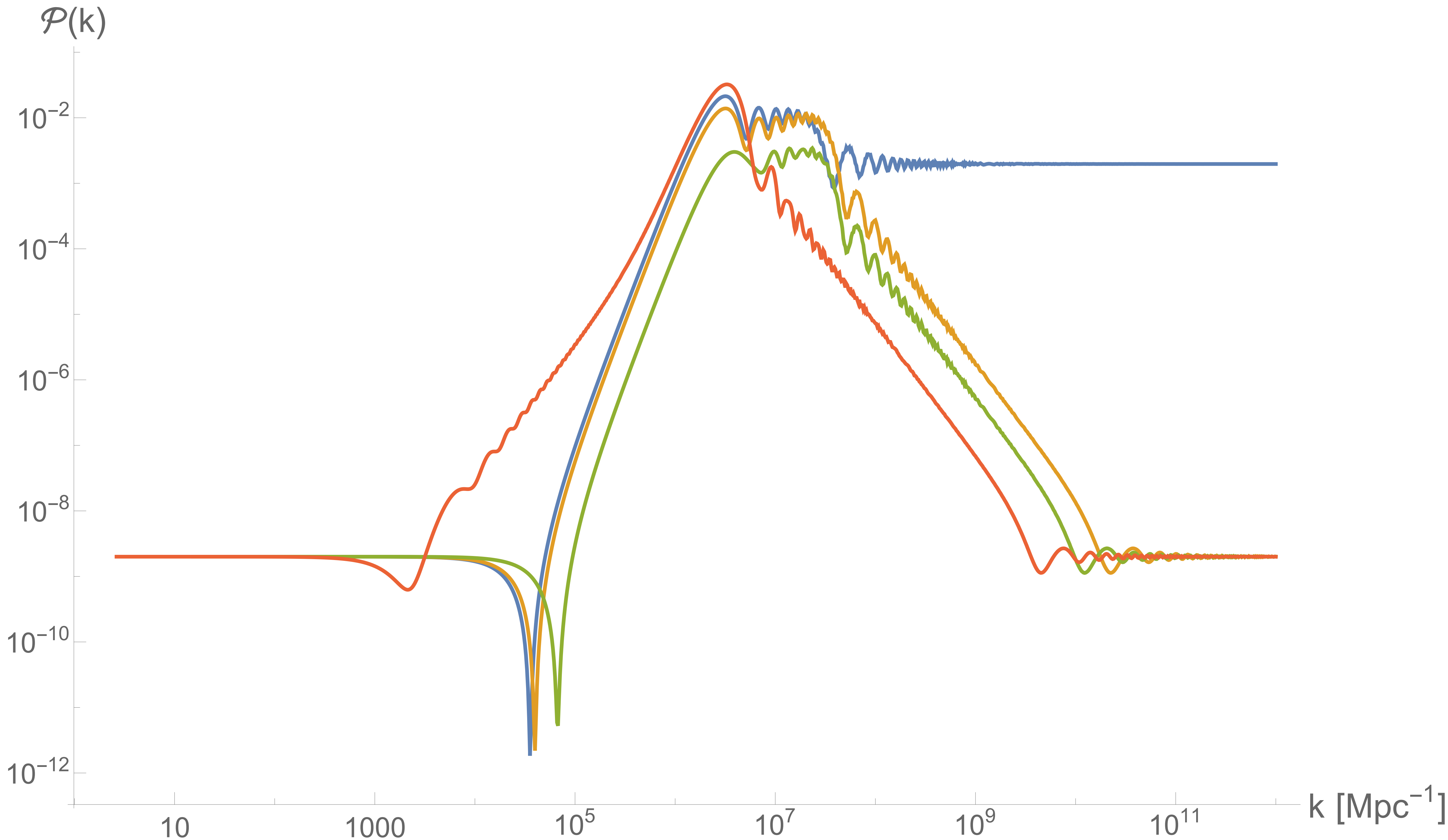
Summary

- You need a large peak in the power spectrum to produce primordial black holes (non-Gaussianity or an early matter dominated phase may help you out)
- Primordial black holes are interesting because they could make up all/part of the dark matter, LIGO has a chance of detecting them, and even one is very prescriptive for describing the inflationary potential
- **The power spectrum can only grow as fast as a spectral index of 4**
- This means that observational constraints on a particular scale actually constrain a wider range because the power spectrum can't jump arbitrarily quickly
- Future forecasts for PIXIE-like experiment and SKA may well shut down the window for solar mass black holes

The inflationary potential



Multi-matching



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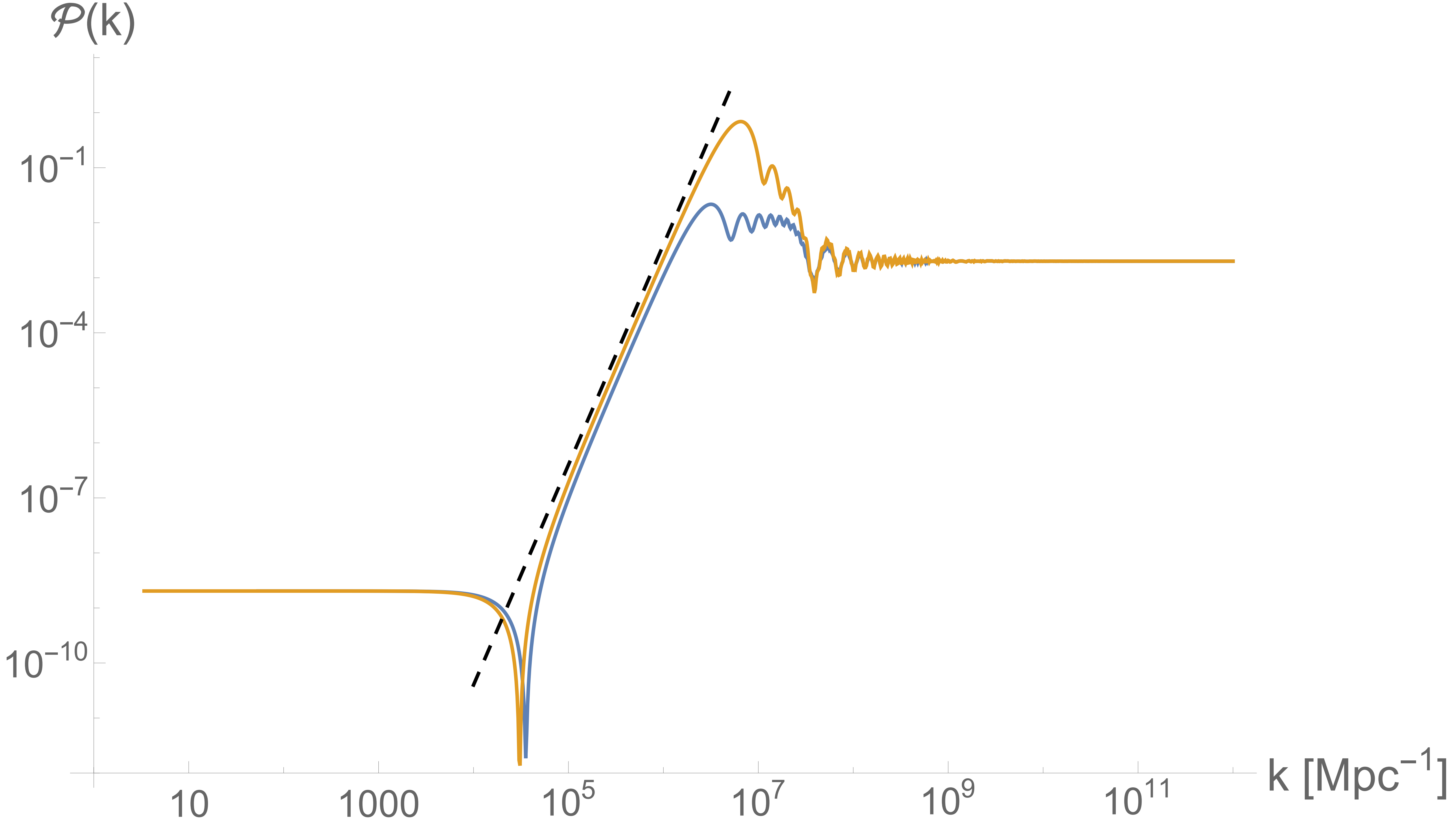
Rolling up hill



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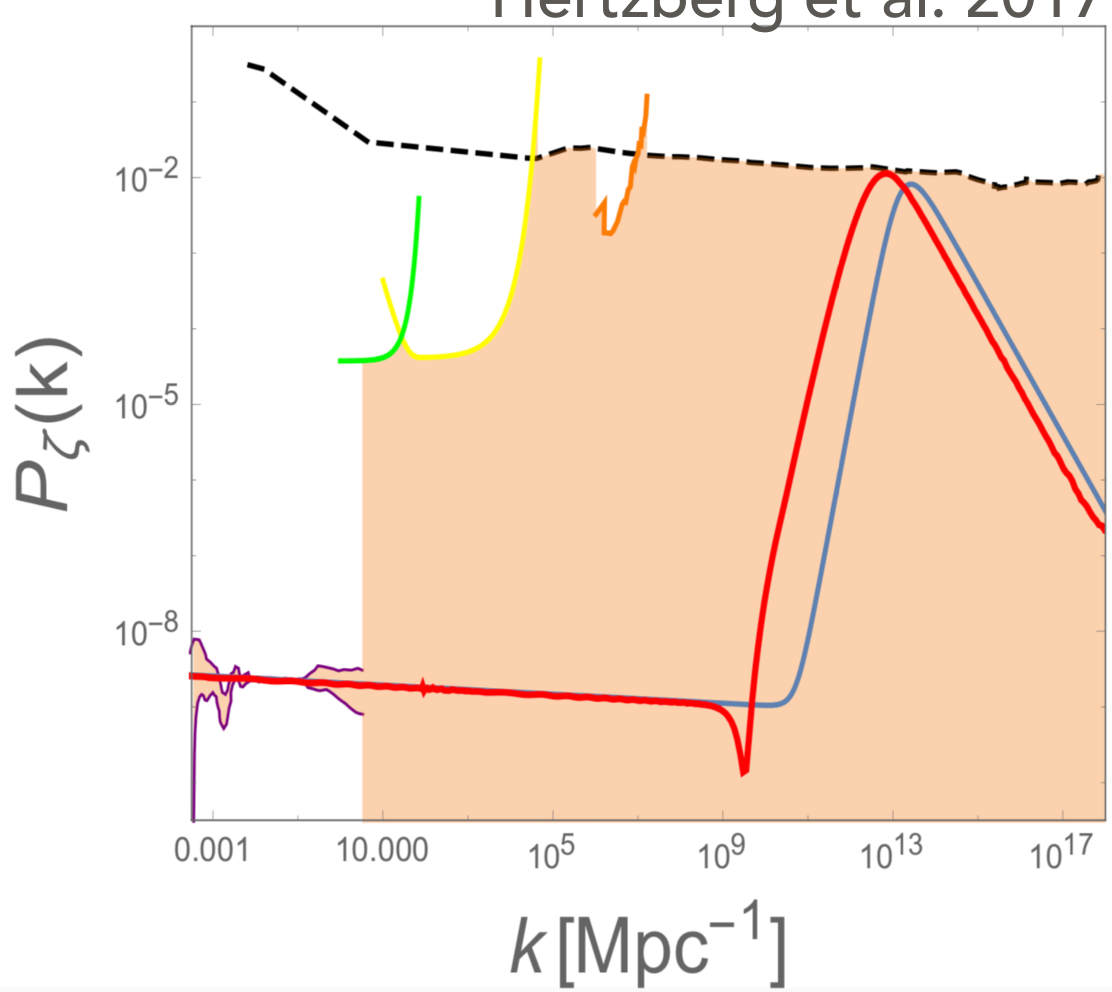
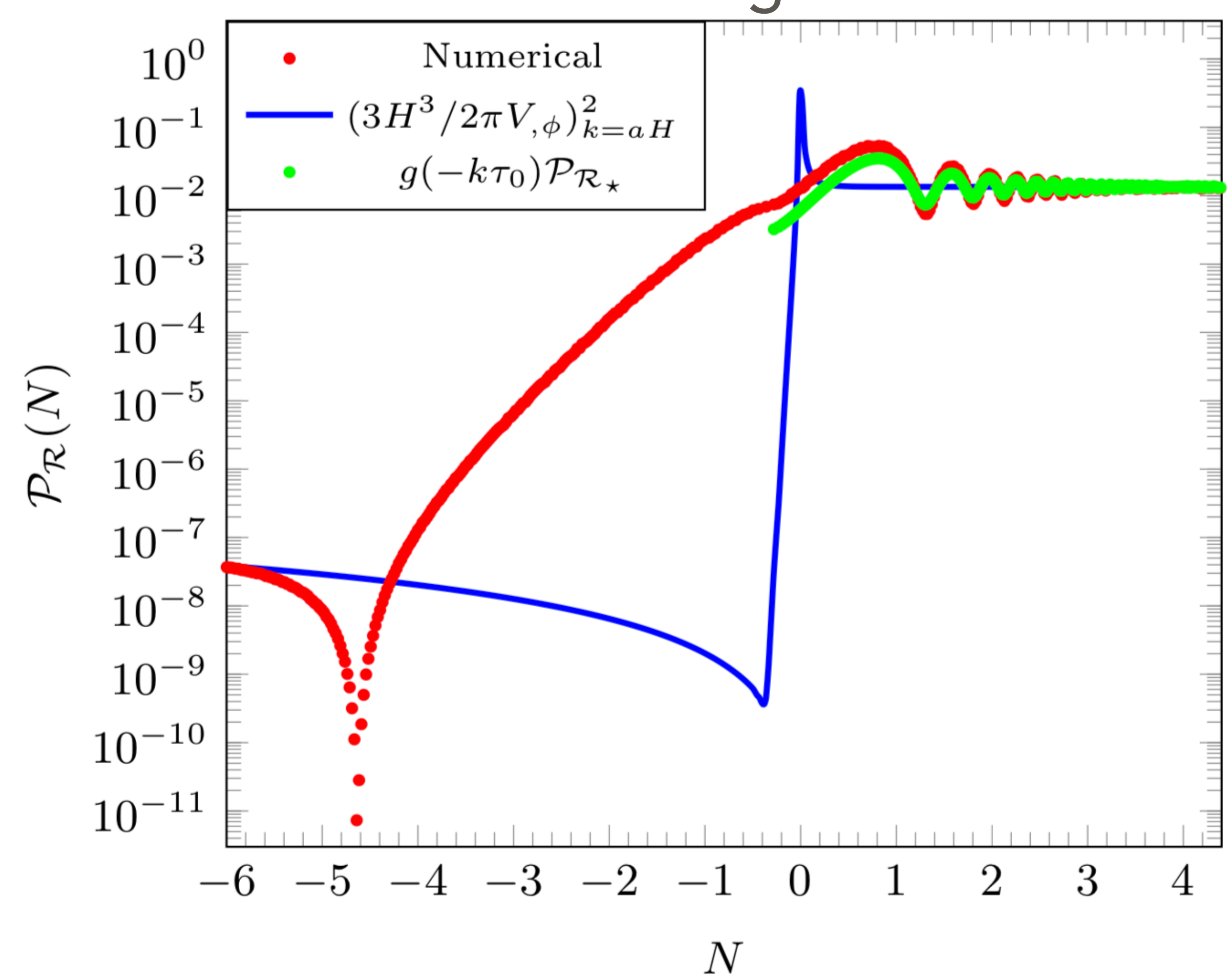
THE DIP

Transient, but always there. Not due to epsilon increasing solely - could something like PIXIE detect it?

Hertzberg et al. 2017

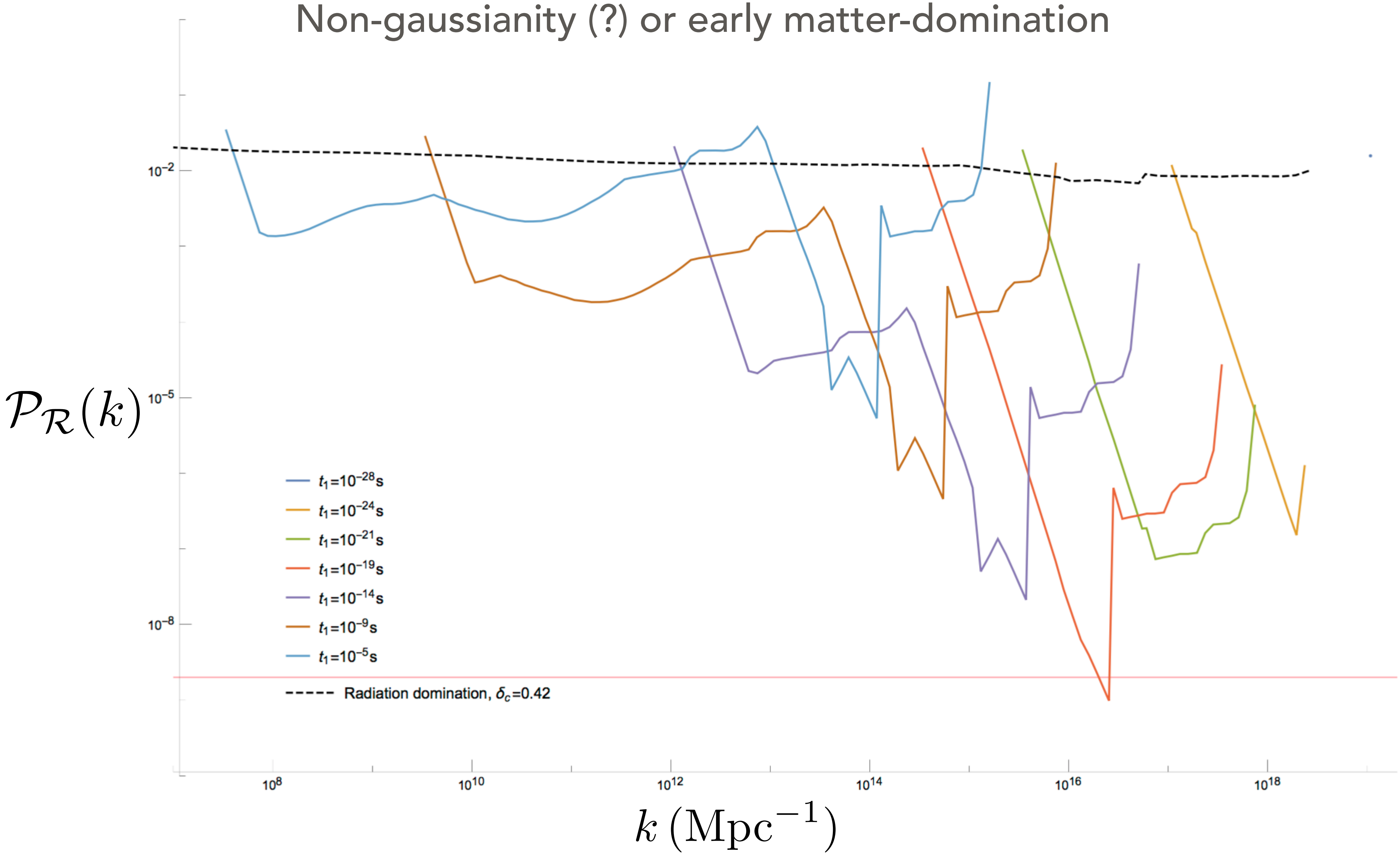


Biagetti et al. 2018



Do you always need a boost in the power spectrum to produce PBHs?

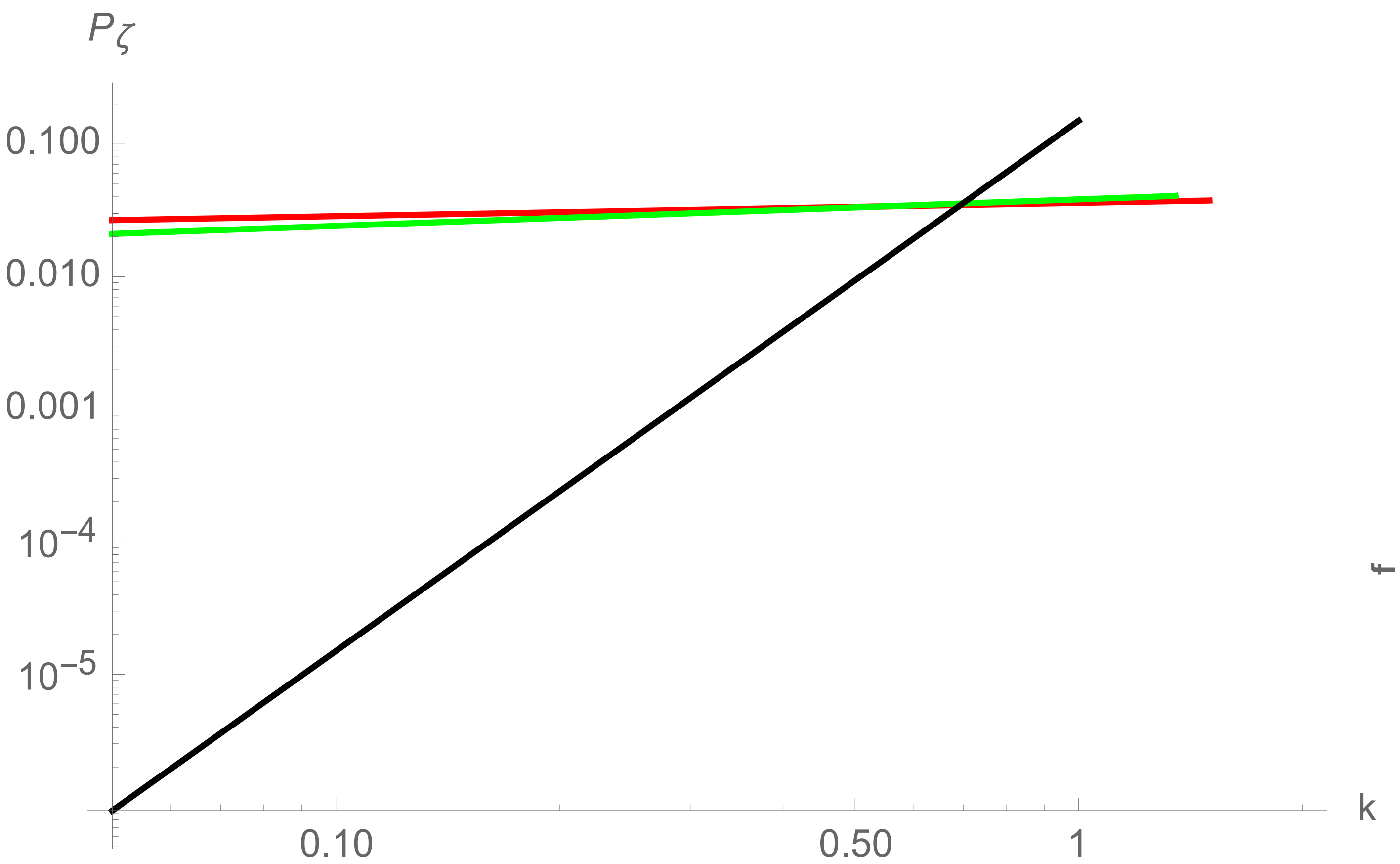
Non-gaussianity (?) or early matter-domination

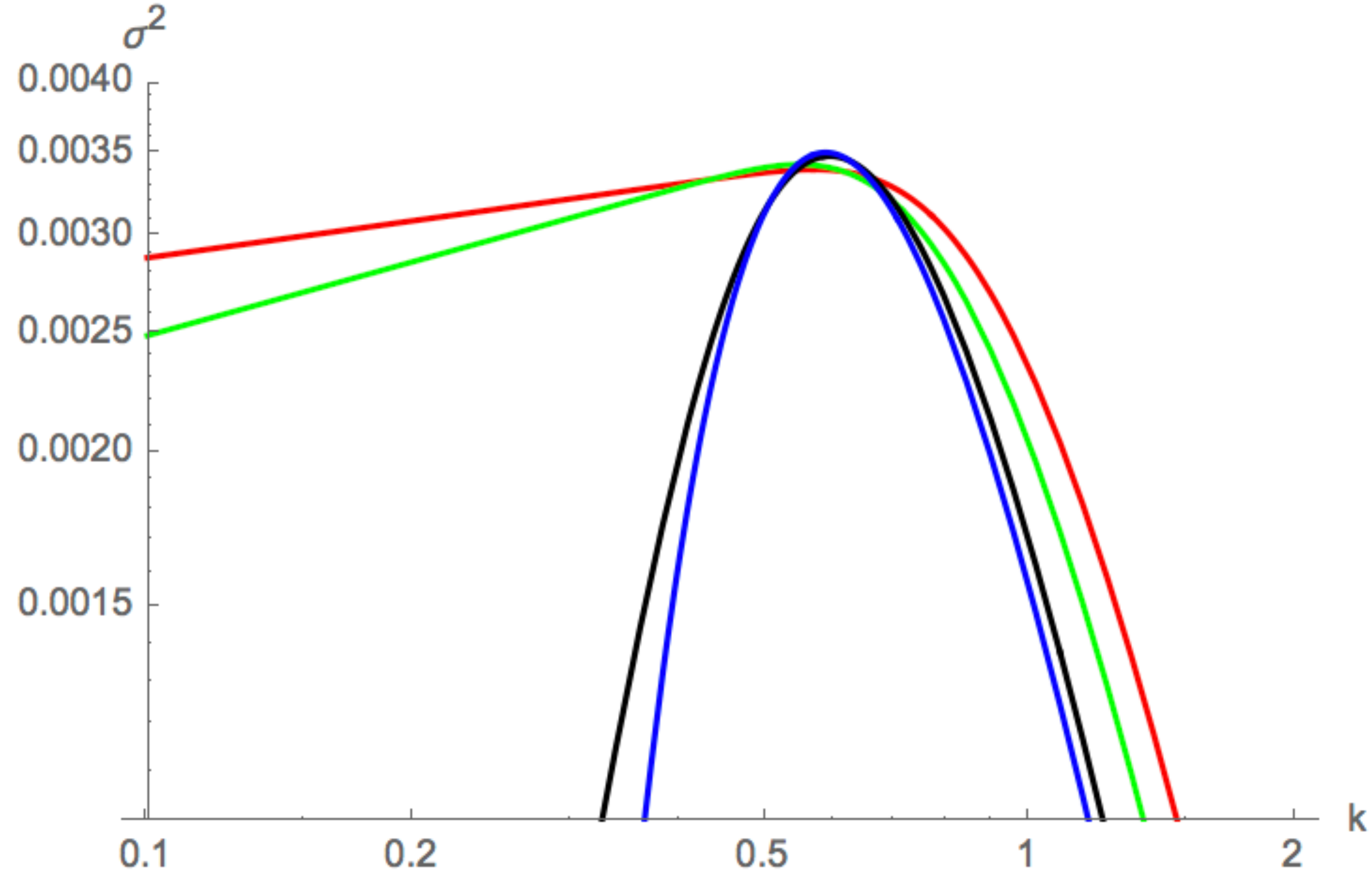


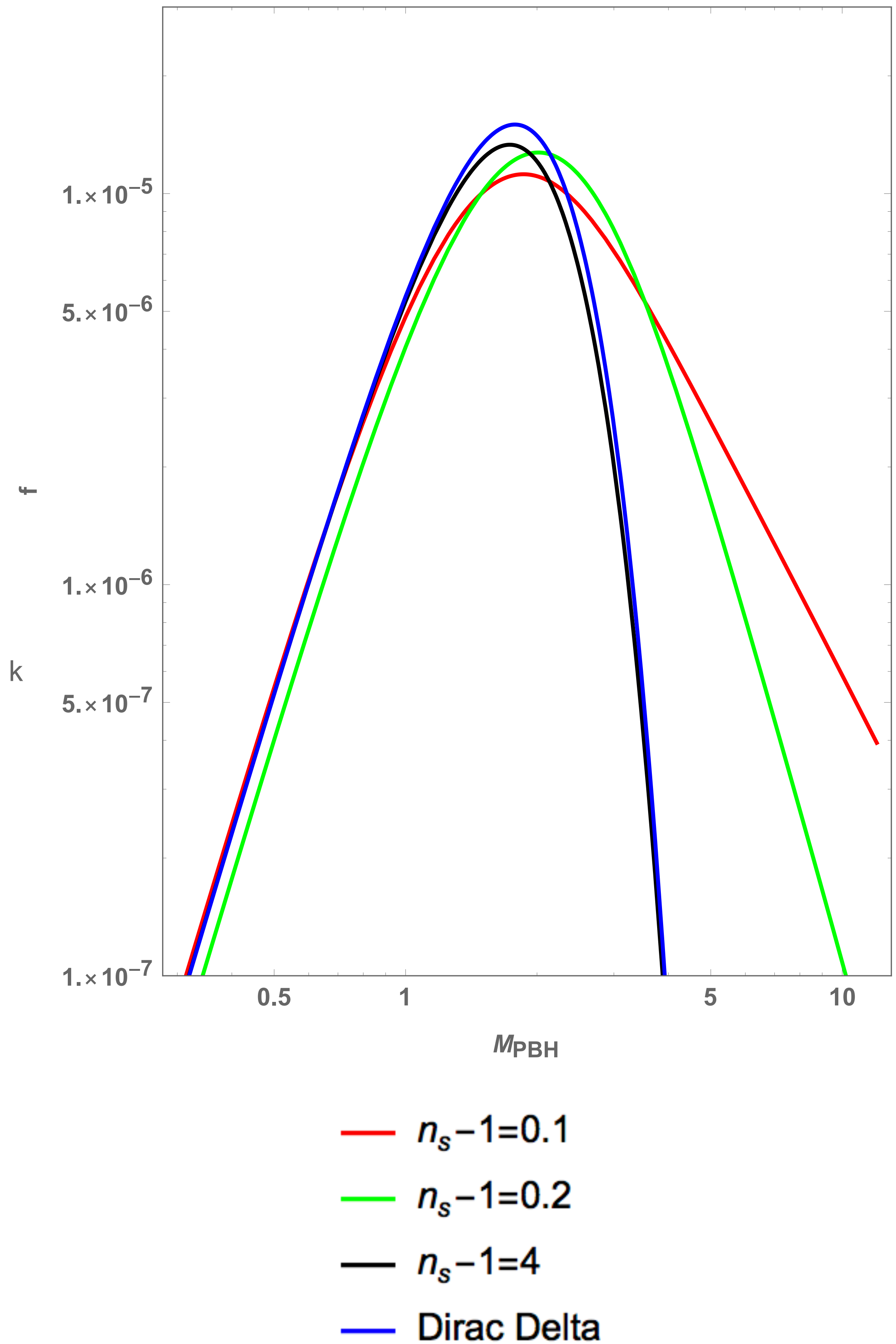
PC, Byrnes 2017

see also Carr, Tenkanen and Vaskonen 2017

Mass function dependence







Assumptions

- Gaussian fluctuations
- Mass of horizon ~ mass of black hole
- Degrees of freedom piecewise
- Gaussian window function
- Delta critical constant for radiation domination
- Monochromatic constraints in some cases
- Quantum diffusion