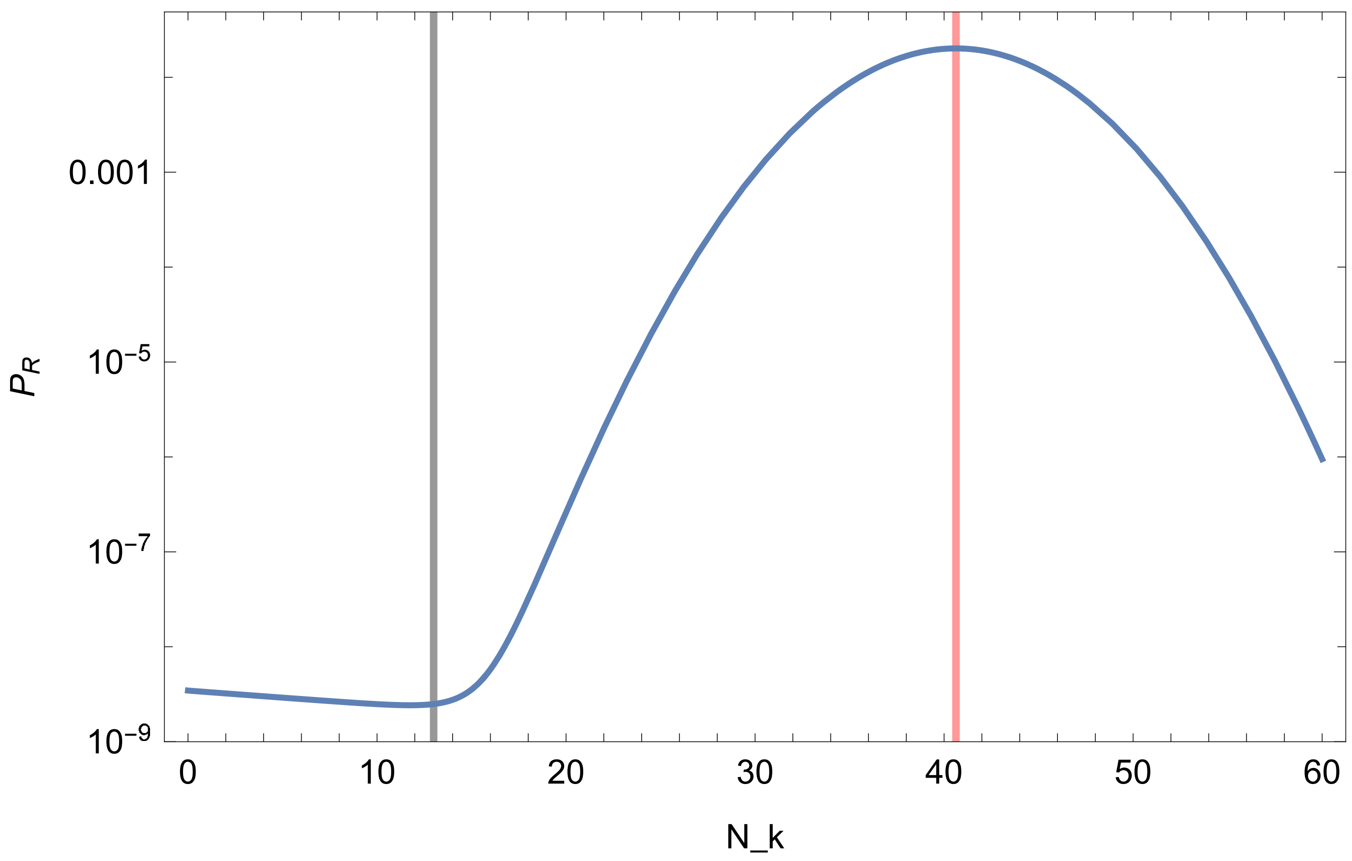
Reconstruction of potentials of hybrid inflation in the light of primordial black hole formation

Rathul Nath Raveendran
Sungkyunkwan university, South Korea

arXiv:2102.02461

Motivation



Nearly scale invariant + peak

Maximum $\approx 10^{-2}$

$$\frac{P(maximum)}{P(CMB)} \approx 10^{7}$$

Single field models: point of inflection (1712.09750), USR (2008.12202)

bump/dip in the potential (1911.00057)

Two field models : with non canonical KE term (2004.08369, 2005.02895)

resonant amplification (2010.03537)

Hybrid inflation (1501.07565)

Motivation

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Massive primordial black holes from hybrid inflation as dark matter and the seeds of galaxies

Sébastien Clesse[1,*] and Juan García-Bellido[2,†]
[1]*Namur Center of Complex Systems (naXys), Department of Mathematics, University of Namur, Rempart de la Vierge 8, 5000 Namur, Belgium*
[2]*Instituto de Física Teórica UAM-CSIC, Universidad Autonóma de Madrid, Cantoblanco, 28049 Madrid, Spain*
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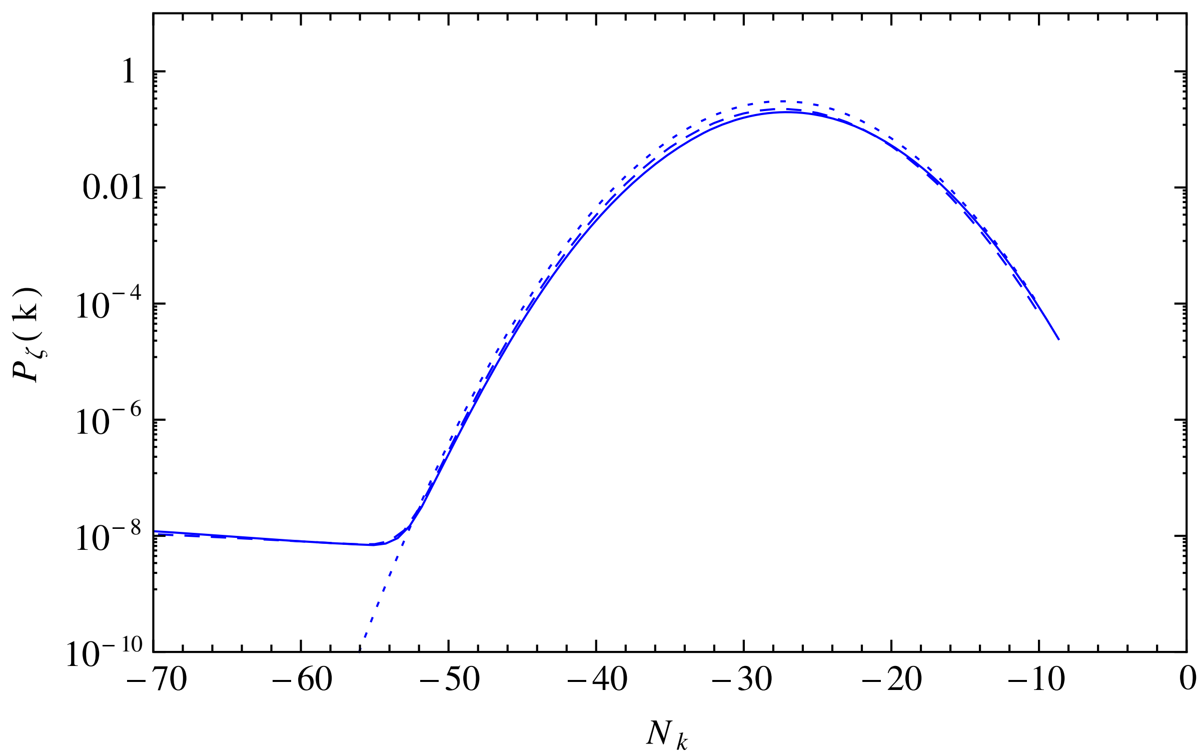
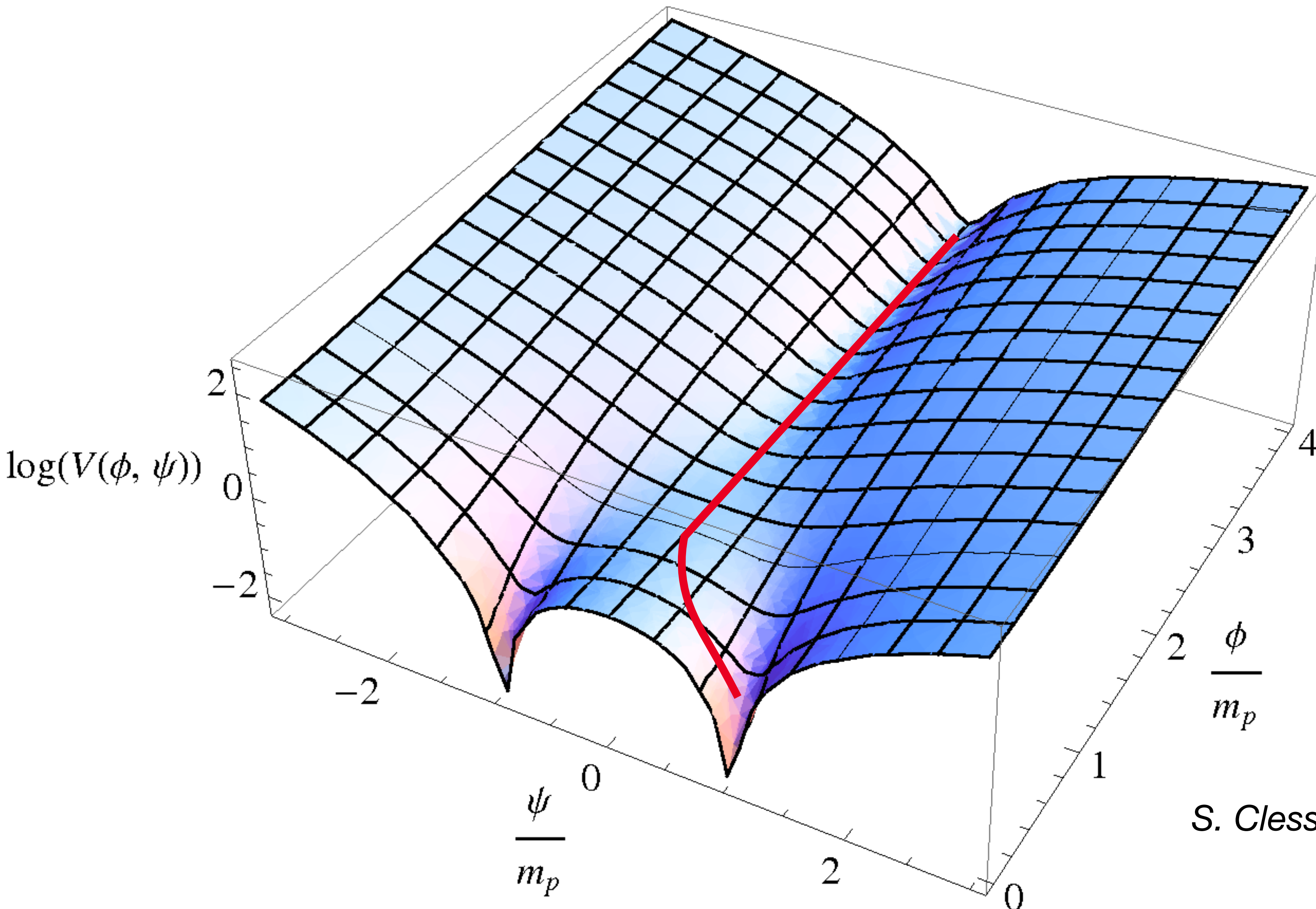
$$V(\phi,\psi) = \Lambda\left[\left(1-\frac{\psi^2}{M^2}\right)^2 + \frac{(\phi-\phi_c)}{\mu_1} - \frac{(\phi-\phi_c)^2}{\mu_2^2} + \frac{2\phi^2\psi^2}{M^2\phi_c^2}\right]$$

$$\mathcal{P}_\zeta(k) \simeq \frac{\Lambda M^2 \mu_1 \phi_c}{192\pi^2 M_P^6 \chi_2 \psi_k^2}$$



Hybrid inflation : Potential



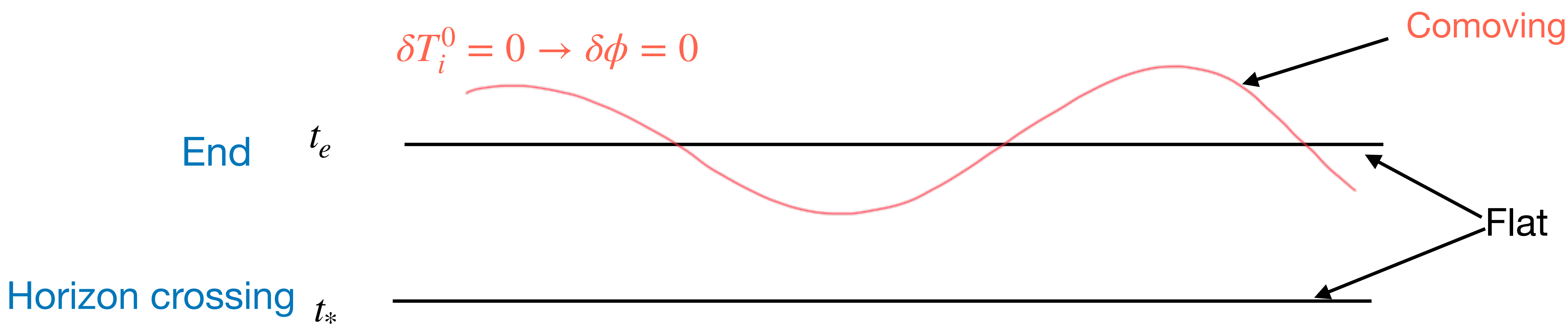
S. Clesse 2011

$$V(\phi,\psi) = \frac{1}{2}m^2\phi^2 + \frac{\lambda}{4}(\psi^2 - L^2)^2 + \frac{\lambda'}{2}\phi^2\psi^2$$

We consider waterfall period $N \approx 20$

δN formalism

Misao Sasaki, Ewan D. Stewart Prog.Theor.Phys.95:71-78,1996



$$N(t_e, t_*, \mathbf{x}) \equiv \int_{t_*}^{t_e} H \, \mathrm{d}t$$

In super-Hubble regime

$$\boxed{\delta N = \mathcal{R} \quad \text{at } t = t_e}$$

$$\delta N \equiv N(\phi, \phi + \delta\phi) - N(\phi)$$

In slow roll approximation

$$\boxed{\delta N = \frac{\partial N}{\partial \phi_*}\delta\phi_* = \mathcal{R}}$$

If we know $N(\phi)$ and $\delta\phi_*$ then we can compute $\mathcal{R}$ at the end of inflation

δN formalism : Two field

Misao Sasaki, Ewan D. Stewart Prog.Theor.Phys.95:71-78,1996

Juan Garcia-Bellido, David Wands, Phys. Rev. D 53, 5437 (1996)

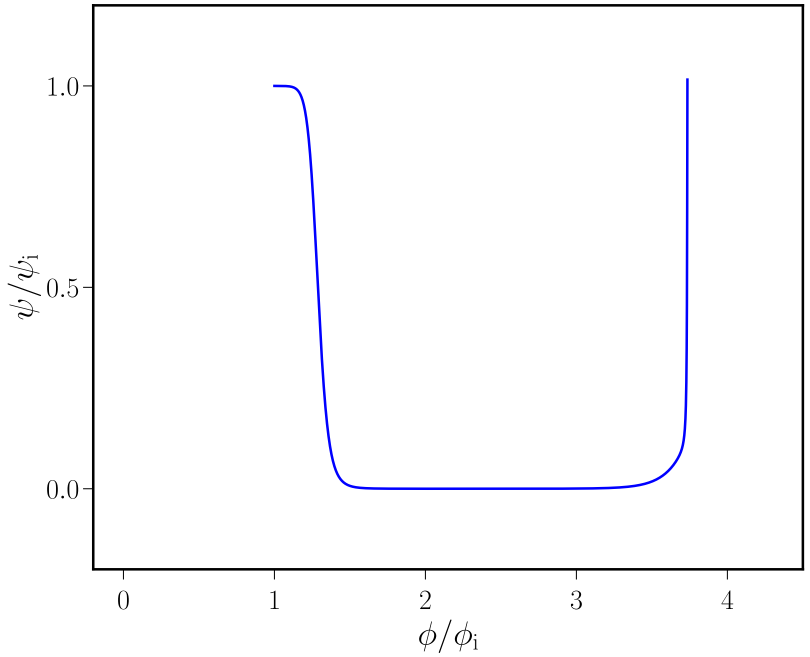
Misao Sasaki, Takahiro Tanaka Prog.Theor.Phys.99:763-782,1998

$$\delta N = \frac{\partial N}{\partial \phi_*}\delta\phi_* + \frac{\partial N}{\partial \psi_*}\delta\psi_*$$

$$\mathcal{P}_{\mathcal{R}} = \frac{H_*^2}{4\pi^2}\left[\left(\frac{\partial N}{\partial \phi_*}\right)^2 + \left(\frac{\partial N}{\partial \psi_*}\right)^2\right]$$

For non slow roll $N = N(\phi, \dot{\phi})$

Small field hybrid inflation



$$V = V_0 \left[1 + f(\phi) + g(\phi)h(\psi)\right]$$

ϕ is dominant during inflation- inflation

ψ is responsible for the ending of inflation - waterfall field

Assume slow roll in both directions

$$N = N(\phi_*, \phi_e(\psi_*)) = N(\phi_*, \psi_*) = -\frac{1}{M_\mathrm{P}^2}\int_{\phi_*}^{\phi_e} \frac{V}{V_\phi} d\phi$$

$$\phi_e = \phi_e(\psi_*)$$

$$\mathcal{P}_\zeta(k) = \mathcal{P}_s(k) + \mathcal{P}_p(k)$$

$$\mathcal{P}_s = \frac{H_*^2}{4\pi^2 M_\mathrm{P}^4}\left[\frac{1}{f_{\phi_*}}\left(1 - \frac{g_*}{g_e}\right)\right]^2$$

$$\mathcal{P}_p = \frac{H_*^2}{4\pi^2 M_\mathrm{P}^4}\left[\frac{1}{g_e h_{\psi_*}}\right]^2$$

Reconstruction

$$\mathcal{P}_s(k) \equiv A_s \left(\frac{k}{k_p}\right)^{n_s-1}$$

$$f(\phi) = -\left(\frac{\phi}{\mu}\right)^2$$

↓

$$N_t = N_t(\phi)$$

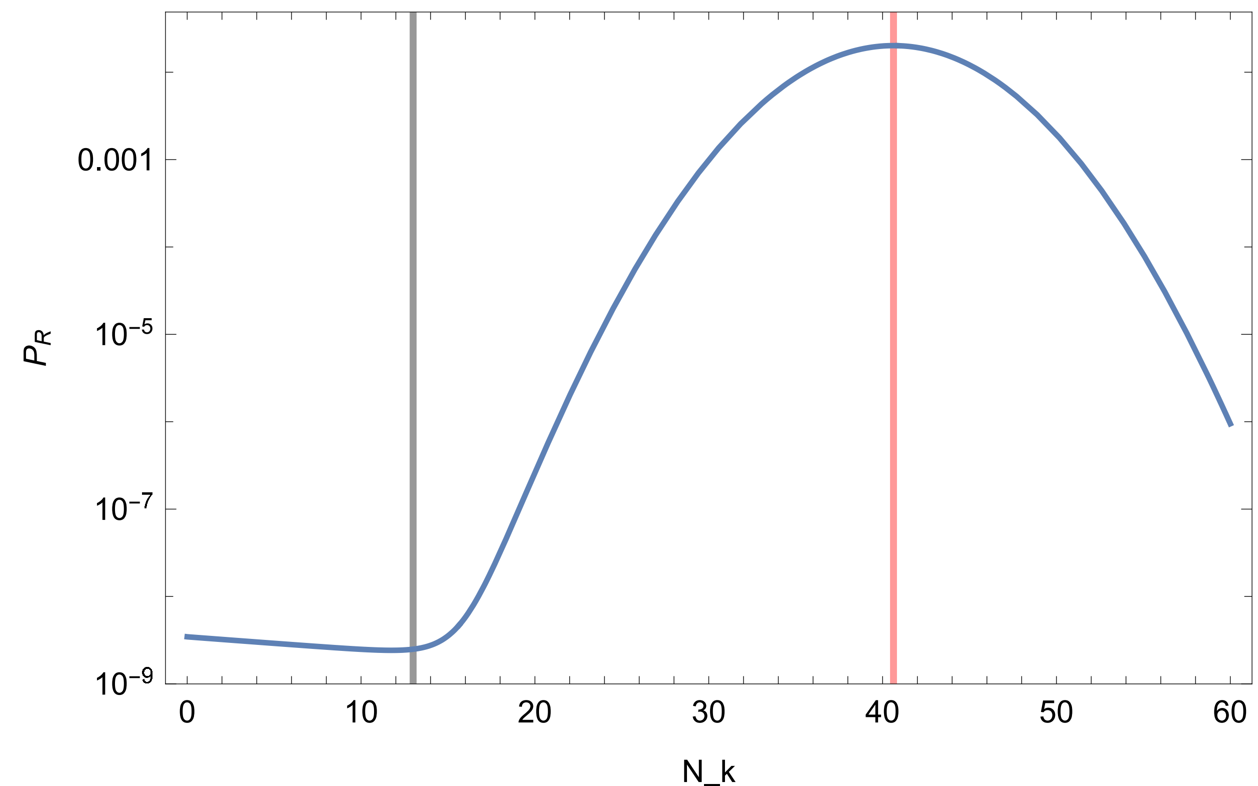
$$\mathcal{P}_p = \frac{H_*^2}{4\pi^2}\left[\delta + \beta e^{-\alpha(N_t - N_{tc})^2} - e^{\lambda(N_t - N_{t1})}\right]^2$$

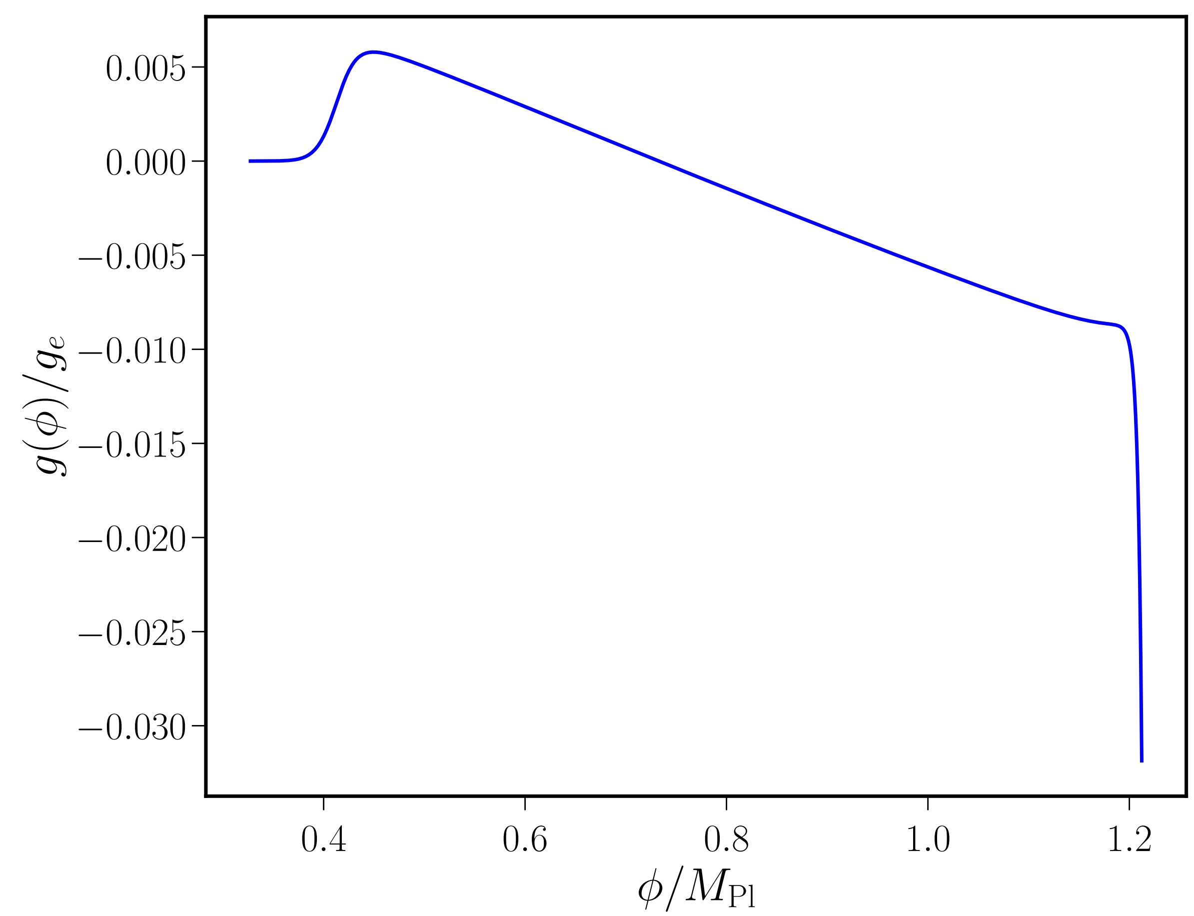
+

Assume $$h(\psi) = \frac{1}{n}\left(\frac{\psi}{\kappa}\right)^n$$

↓

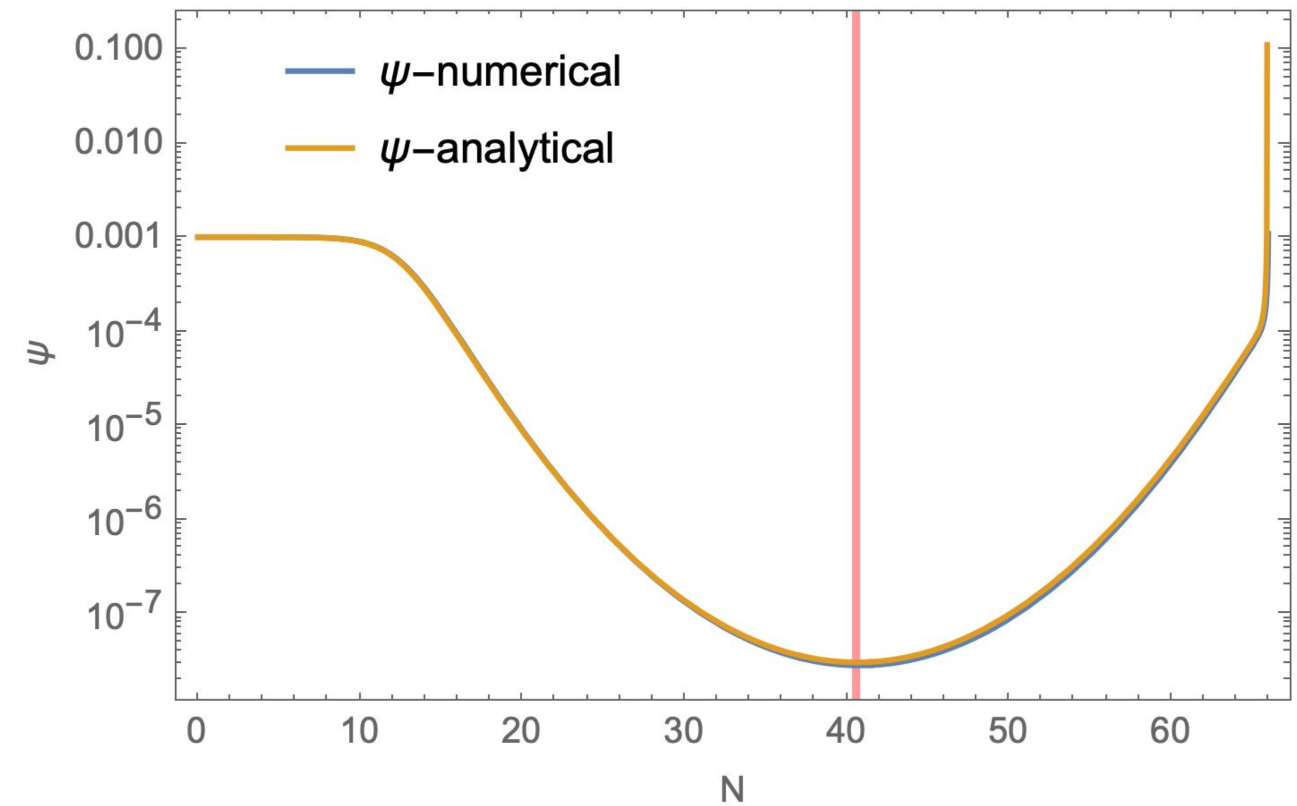
$$g(\phi) = -\frac{H^2}{V_0 h_\psi(N_t)}\left[\frac{d^2\psi}{dN_t^2} + (3-\epsilon_H)\frac{d\psi}{dN_t}\right]$$

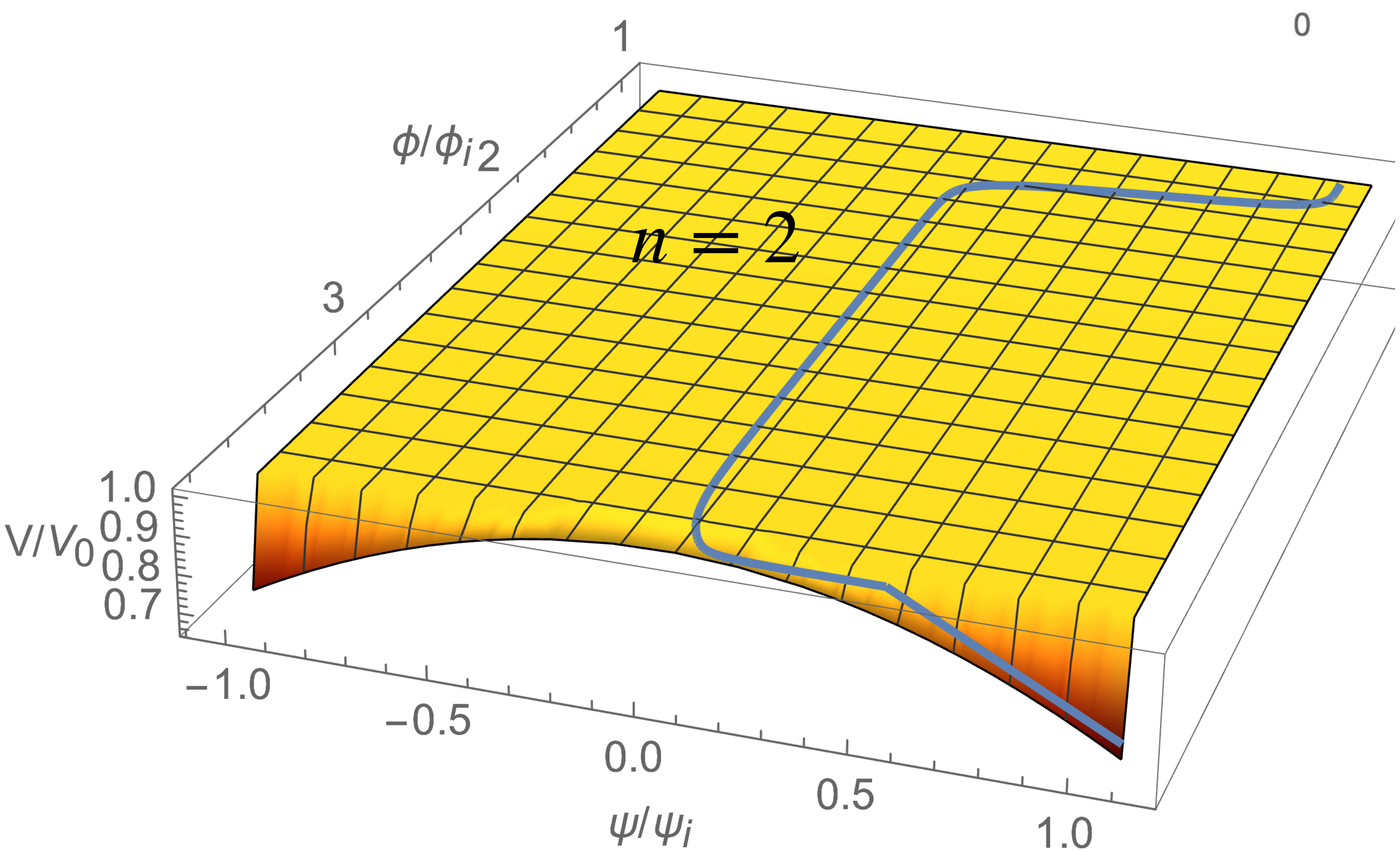


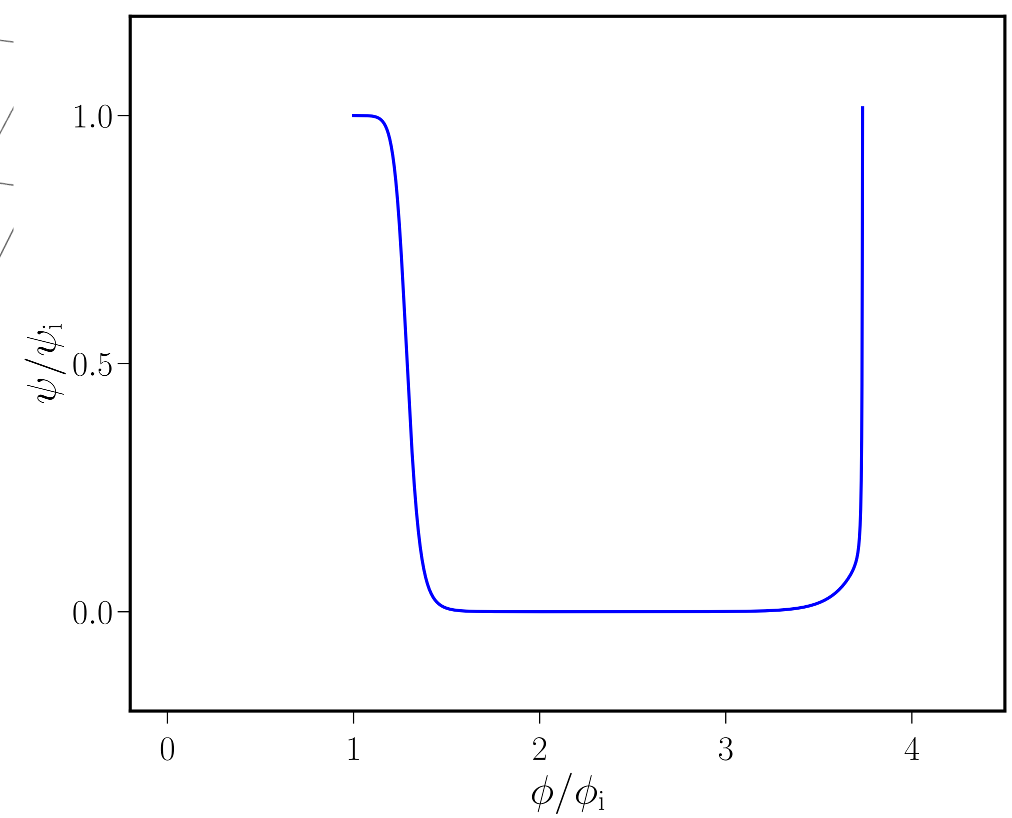


Background

$$\frac{d^2\phi}{dN_t^2} + (3 - \epsilon_H)\ \frac{d\phi}{dN_t} + \frac{V_\phi}{H^2} = 0$$





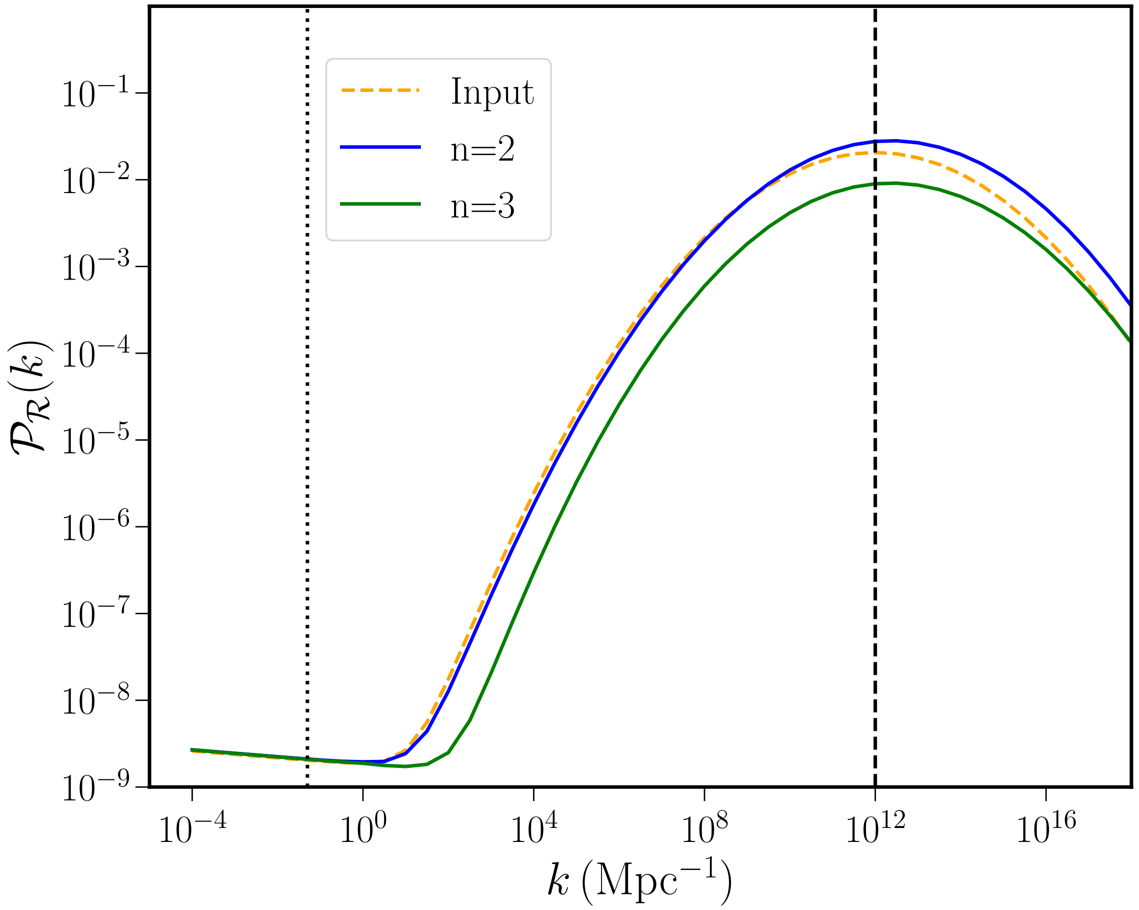


Power spectrum

$$v_\sigma'' + \left(k^2 - \frac{z''}{z}\right) v_\sigma = \frac{2}{z}\left(a\, z\, \dot\theta\, v_s\right)'$$

$$v_s'' + \left(k^2 - \frac{a''}{a} + a^2\,\mu_s^2\right) v_s = -2\, a\, z\, \dot\theta\, \left(\frac{v_\sigma}{z}\right)'$$

$$\mu_s^2 = V_{ss} - \dot\theta^2$$



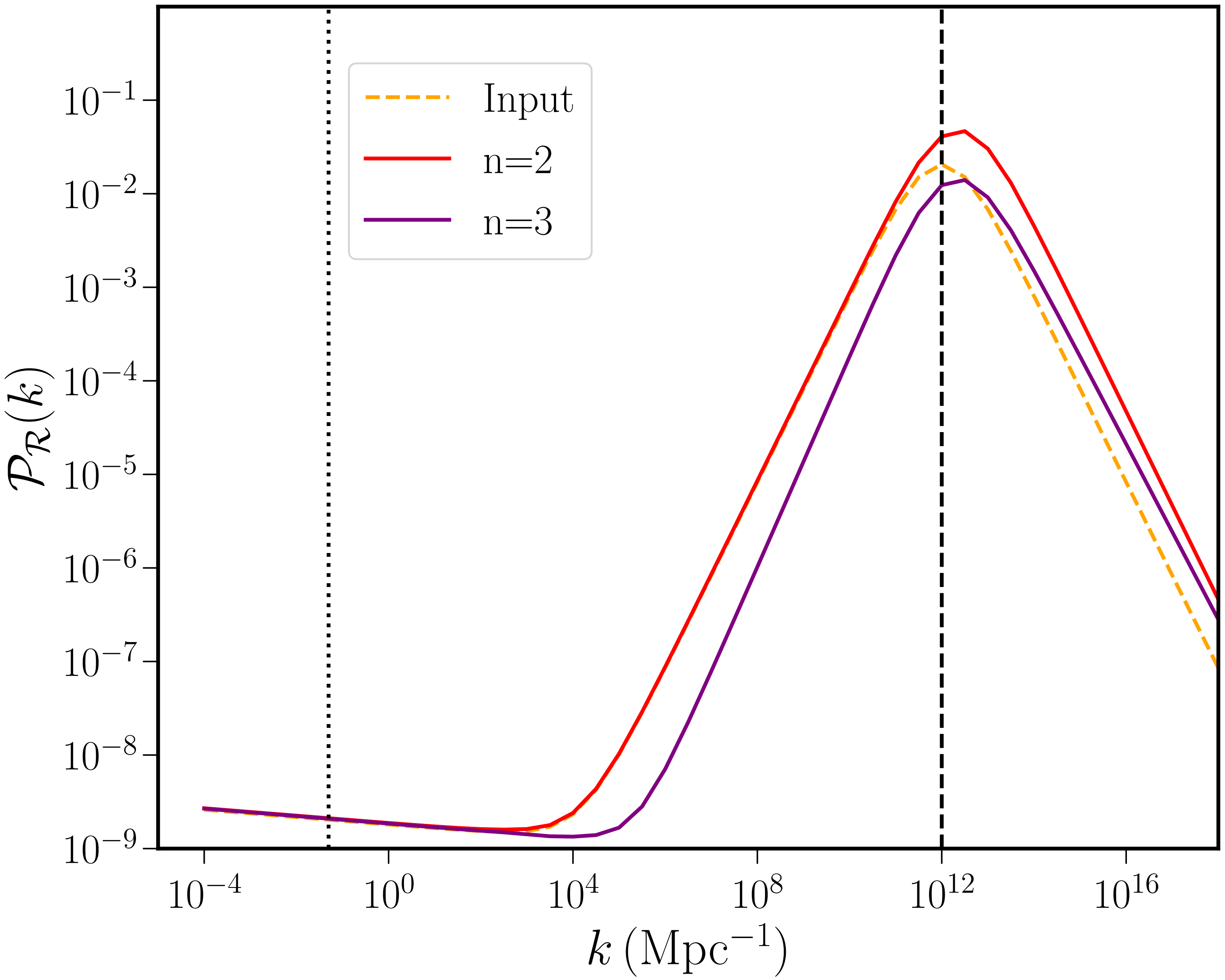
$$\hat v_\sigma = f_\sigma \hat a + f_\sigma^\star \hat a^\dagger + g_\sigma \hat b + g_\sigma^\star \hat b^\dagger$$

$$\hat v_s = f_s \hat a + f_s^\star \hat a^\dagger + g_s \hat b + g_s^\star \hat b^\dagger$$

$$\mathcal{P}_\mathcal{R} = \frac{k^3}{2\pi^2}\frac{|f_\sigma|^2 + |g_\sigma|^2}{z^2}$$

Hyperbolic peak

$$\mathcal{P}_p = \frac{H_*^2}{4\pi^2}\left[\delta + \beta \text{sech}\left[\gamma(N_t - N_{tc})\right] - e^{\lambda(N_t - N_{t1})}\right]^2$$



$$v_s'' + \left(k^2 - \frac{a''}{a} + a^2\,\mu_s^2\right) v_s = -2\,a\,z\,\dot{\theta}\,\left(\frac{v_\sigma}{z}\right)'$$

$$\mu_s^2 = V_{ss} - \dot{\theta}^2$$

In our model $v_{ss} < 0$, isocurvature increases and transfer the power to curvature perturbation at the end

There are model with $\dot{\theta}^2 > V_{ss}$

G. A. Palma, S. Sypsas and C. Zenteno, Phys. Rev. Lett. 125 (2020) no.12, 121301

M. Braglia, D. K. Hazra, F. Finelli, G. F. Smoot, L. Sriramkumar and A. A. Starobinsky, JCAP 08 (2020), 001

J. Fumagalli, S. Renaux-Petel, J. W. Ronayne and L. T. Witkowski, [arXiv:2004.08369 [hep-th]]

On going

- Large field models
- Non canonical kinetic term
- Constructing models for steeper peaks like k^4