EFT of Quasi-single Field Inflation

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Based on: Xi Tong, Yi Wang, SZ 1708.01709
Aditya Varna Iyer, Shi Pi, Yi Wang, Ziwei Wang, SZ 1710.03054

Quasi-single Field Inflation

Inflaton + massive field m~H

Why is adding massive field interesting?

Non-Gaussianity: Distinct shape

Power Spectrum: Shift on n_s-r diagram

Quasi-single Field Inflation

X. Chen, Y. Wang 0909.0496, 0911.3380, 1205.0160

D. Baumann, D. Green 1109.0292

T. Noumi, M. Yamaguchi, D. Yokoyama 1211.1624

J. Gong, M. Sasaki, S. Pi 1205.0161, 1306.3691

X. Chen, Y. Wang, Xianyu 1604.07841, 1610.06597, 1612.08122, 1703.10166

N. Arkani-Hamed, J. Maldacena 1503.08043

J. Maldacena 1508.01082

R. Flauger, M. Mirbabayi, L. Senatore, E. Silverstein 1606.00513

X. Chen, M. H. Namjoo, Y. Wang 1509.03930, 1601.06228, 1608.01299

J. Liu, C. Sou, Y. Wang 1608.07909

H. Jiang, Y. Wang 1703.04477

X. Tong, Y. Wang, SZ 1708.01709

H. An, M. McAneny, A. K. Ridgway, M. B. Wise 1706.09971, 1711.02667

S. Kumar, R. Sundrum, 1711.03988 … …

Equation of Motion

Lagrangian

$$S[\pi,\sigma]=\int d^3x d\tau \frac{1}{2H^2\tau^2}\left[(\partial_\tau\pi)^2-(\nabla\pi)^2+(\partial_\tau\sigma)^2-(\nabla\sigma)^2-\frac{m^2}{H^2\tau^2}\sigma^2-\frac{2\rho}{H\tau}\sigma\partial_\tau\pi\right]$$

Canonical quantization

$$\pi_{\mathbf{k}}(\tau)=u_k^{(1)}(\tau)a_{\mathbf{k}}^{(1)}+u_k^{(2)}(\tau)a_{\mathbf{k}}^{(2)}+\text{h.c.}$$
$$\sigma_{\mathbf{k}}(\tau)=v_k^{(1)}(\tau)a_{\mathbf{k}}^{(1)}+v_k^{(2)}(\tau)a_{\mathbf{k}}^{(2)}+\text{h.c.}$$

Equation of motion

$$u_k''-\frac{2u_k'}{\tau}+k^2u_k-\frac{\rho}{H}\left(\frac{v_k'}{\tau}-\frac{3v_k}{\tau^2}\right)=0$$
$$v_k''-\frac{2v_k'}{\tau}+\left(k^2+\frac{m^2}{H^2\tau^2}\right)v_k+\frac{\rho}{H}\frac{u_k'}{\tau}=0$$

The two coupled EOM can be used to obtain **numerical result** of QSFI

Effective Action

Integrate out the massive field

$$Z = \int \mathcal{D}\pi \exp\left\{ i \int \frac{d^3x d\tau}{2H^2\tau^2} \left[(\partial_\tau \pi)^2 - (\nabla \pi)^2 + a^{-2}\rho^2 \pi \partial_\tau \left(a^2 \frac{1}{\Box} a^2 \partial_\tau \right) \pi \right] \right\}$$

Neglecting real particle production

$$\frac{1}{\Box} = -\frac{1}{k^2 + (m^2 a^2 - 2a^2 H^2)} + \frac{\partial_\tau^2}{(k^2 + (m^2 a^2 - 2a^2 H^2))^2} + \dots$$

We arrive at the effective action

$$S_{\text{eff}} = \frac{1}{2} \int \frac{d^3k}{(2\pi)^3} d\tau \frac{1}{H^2\tau^2} \left[\left(1 + \frac{\rho^2}{k^2 H^2 \tau^2 + m^2 - 2H^2} \right) \pi'^2 - k^2 \pi^2 \right]$$

Parameter Regime

Parameter regime $m^2 + \rho^2 > 9/4H^2$	Method
Weakly Coupled regime $\rho < m$	In-in formalism
Large Mass Strongly Coupled regime $m < \rho < m^2/H$	
Extremely Strongly Coupled regime $\rho > m^2/H$	Large ρ EFT

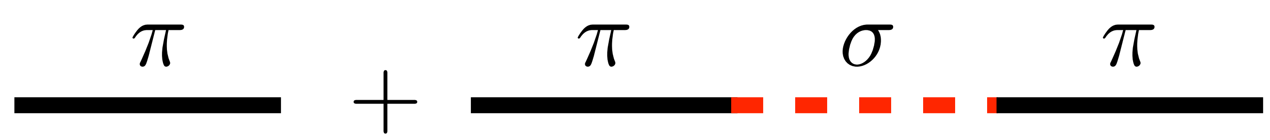
Parameter Regime

Parameter regime $m^2+\rho^2>9/4H^2$	Method
Weakly Coupled regime $\rho<m$	Resummation or Large m EFT
Large Mass Strongly Coupled regime $m<\rho<m^2/H$	
Extremely Strongly Coupled regime $\rho>m^2/H$	Large ρ EFT

Parameter Regime

Parameter regime $m^2+\rho^2>9/4H^2$	Method
Weakly Coupled regime $\rho<m$	Improved EFT
Large Mass Strongly Coupled regime $m<\rho<m^2/H$	
Extremely Strongly Coupled regime $\rho>m^2/H$	

In-in Formalism

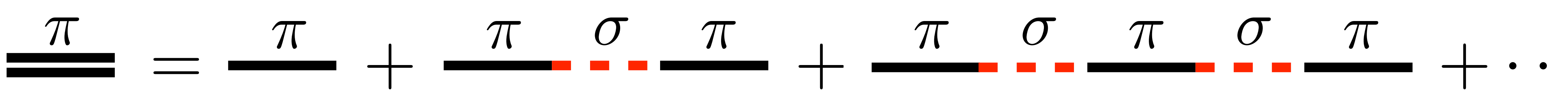


Take into account the first order Feynman Diagram

Local contribution + Non local contribution

Resummation

Feynman Diagram



Take into account the full order Feynman Diagram

Local contribution only

Power Spectrum

$$P_\zeta = P_\zeta^{(0)}(k) c_s^{-1}, \quad c_s = c_s = 1/\sqrt{1 + \frac{\rho^2/H^2}{m^2/H^2 - 9/4}}$$

Large m EFT

Effective Action

$$S_{\rm eff} = \frac{1}{2}\int \frac{d^3k}{(2\pi)^3} d\tau \frac{1}{H^2\tau^2}\left[\left(1+\frac{\rho^2}{k^2 H^2\tau^2 + m^2 - 2H^2}\right)\pi'^2 - k^2\pi^2\right]$$

Mode Function

$$u_k(\tau) = \frac{H}{\sqrt{2c_s k^3}}(1+ic_s k\tau)e^{-ic_s k\tau}, \quad c_s = 1/\sqrt{1+\frac{\rho^2/H^2}{m^2/H^2-2}}$$

Power Spectrum

$$P_\zeta = P_\zeta^{(0)}(k)c_s^{-1}, \quad c_s = 1/\sqrt{1+\frac{\rho^2/H^2}{m^2/H^2-2}}$$

Large ρ EFT

Effective Action

$$S_{\rm eff} = \frac{1}{2}\int \frac{d^3k}{(2\pi)^3} d\tau \frac{1}{H^2\tau^2}\left[\left(1 + \frac{\rho^2}{k^2H^2\tau^2 + m^2 - 2H^2}\right)\pi'^2 - k^2\pi^2\right]$$

Mode Function

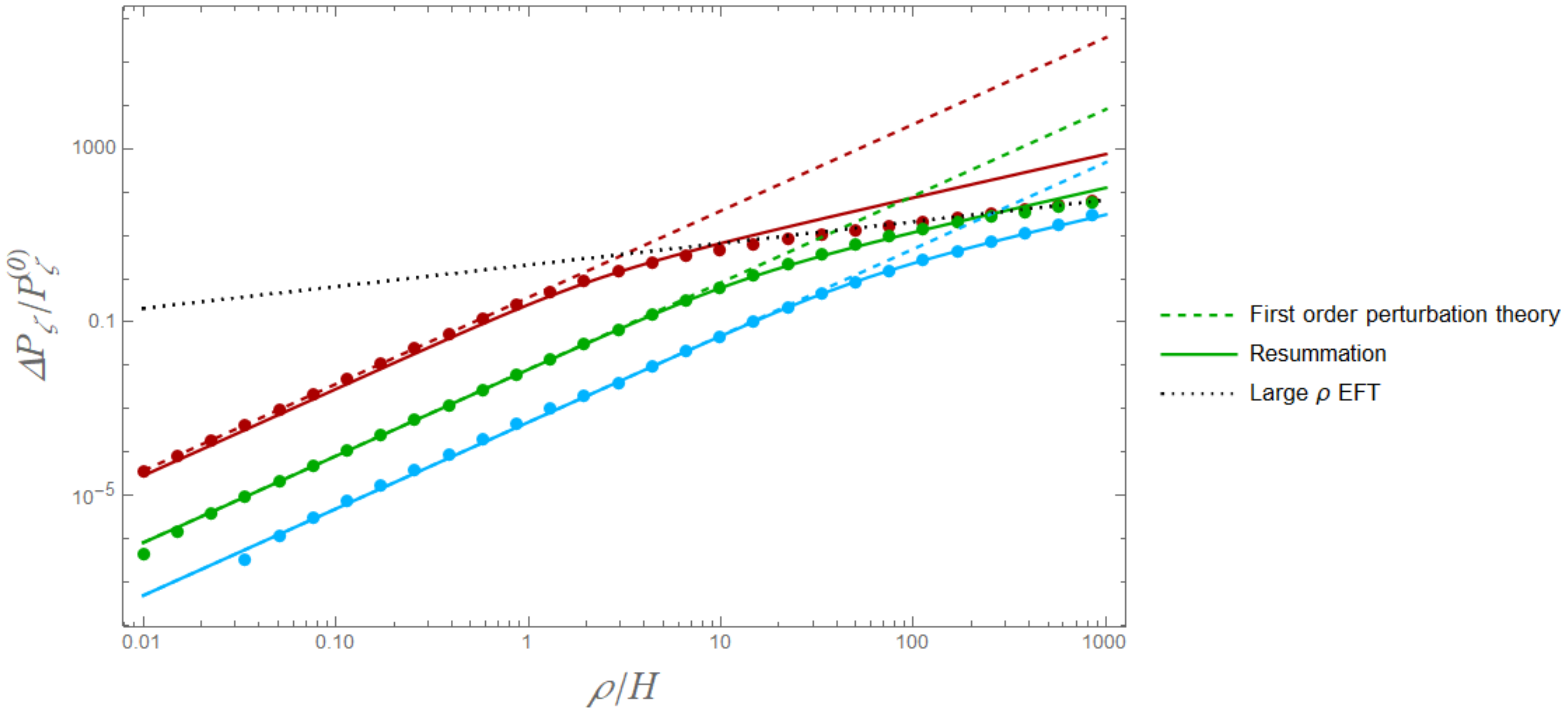
$$u_k(\tau) = \left(\frac{2\pi^2\rho}{H}\right)^{1/4} \frac{H}{\sqrt{2k^3}} \left(\frac{k^2\tau^2 H}{2\rho}\right)^{5/4} H^{(1)}_{5/4}\left(\frac{k^2\tau^2 H}{2\rho}\right)$$

Power Spectrum

$$P_\zeta = P_\zeta^{(0)}(k) c_s^{-1}, \quad c_s^{-1} = \mathcal{C}\left(\frac{\rho}{H}\right)^{1/2}$$

Power Spectrum

Large m EFT gives similar result as resummation



Improved EFT

$$S_{\rm eff} = \frac{1}{2}\int \frac{d^3k}{(2\pi)^3} d\tau \frac{1}{H^2\tau^2}\left[\left(1+\frac{\rho^2}{k^2H^2\tau^2+m^2-2H^2}\right)\pi'^2 - k^2\pi^2\right]$$

Sound speed $$c_s^{-2}(k\tau) = 1+\frac{\rho^2}{k^2H^2\tau^2+m^2-2H^2}$$

Horizon-exit condition $$k\tau = Bc_s^{-1}$$

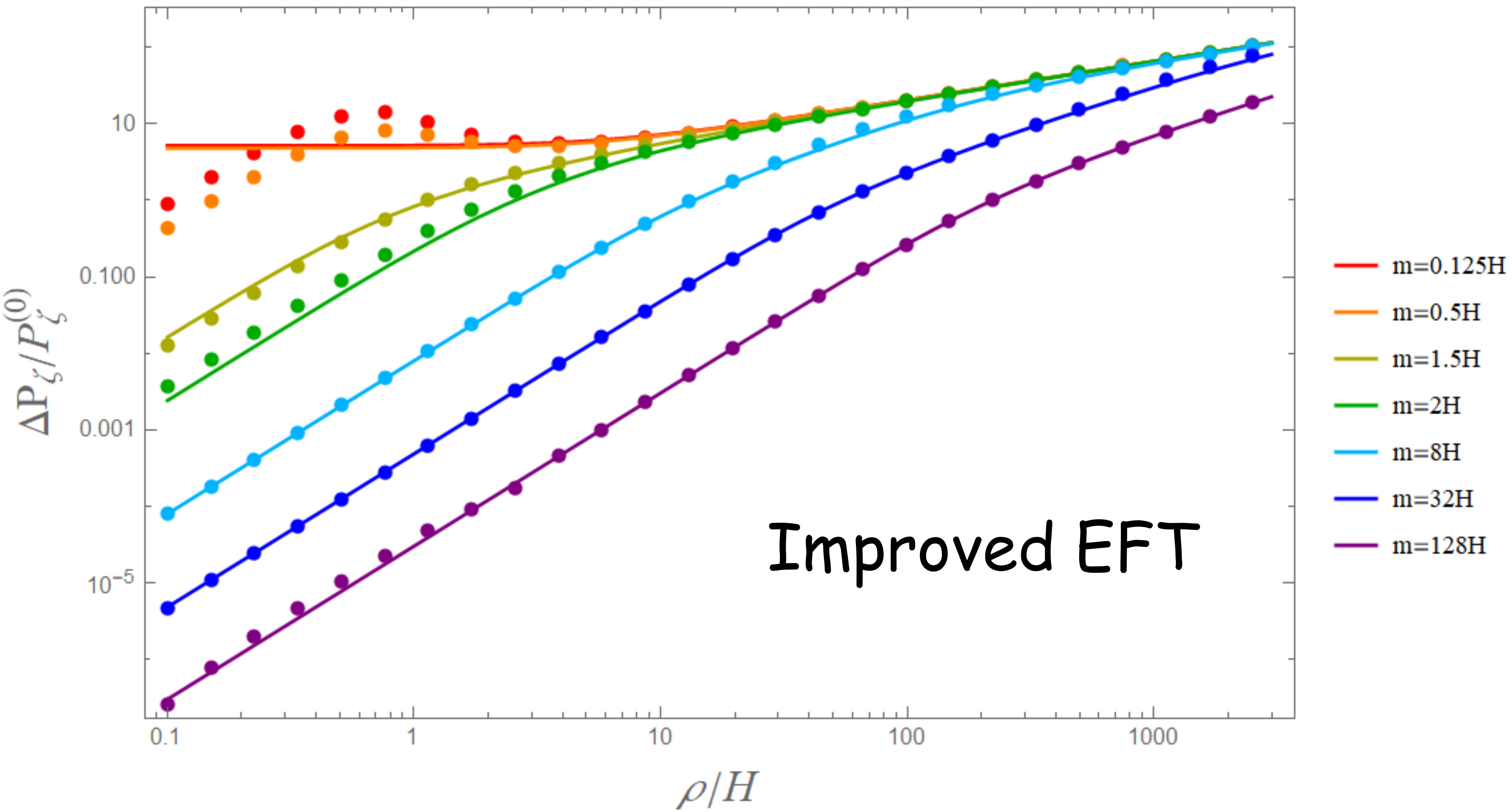
$$c_s^{-2} = 1+\frac{\rho^2}{H^2B^2c_s^{-2}+m^2-2H^2}$$

Improved EFT

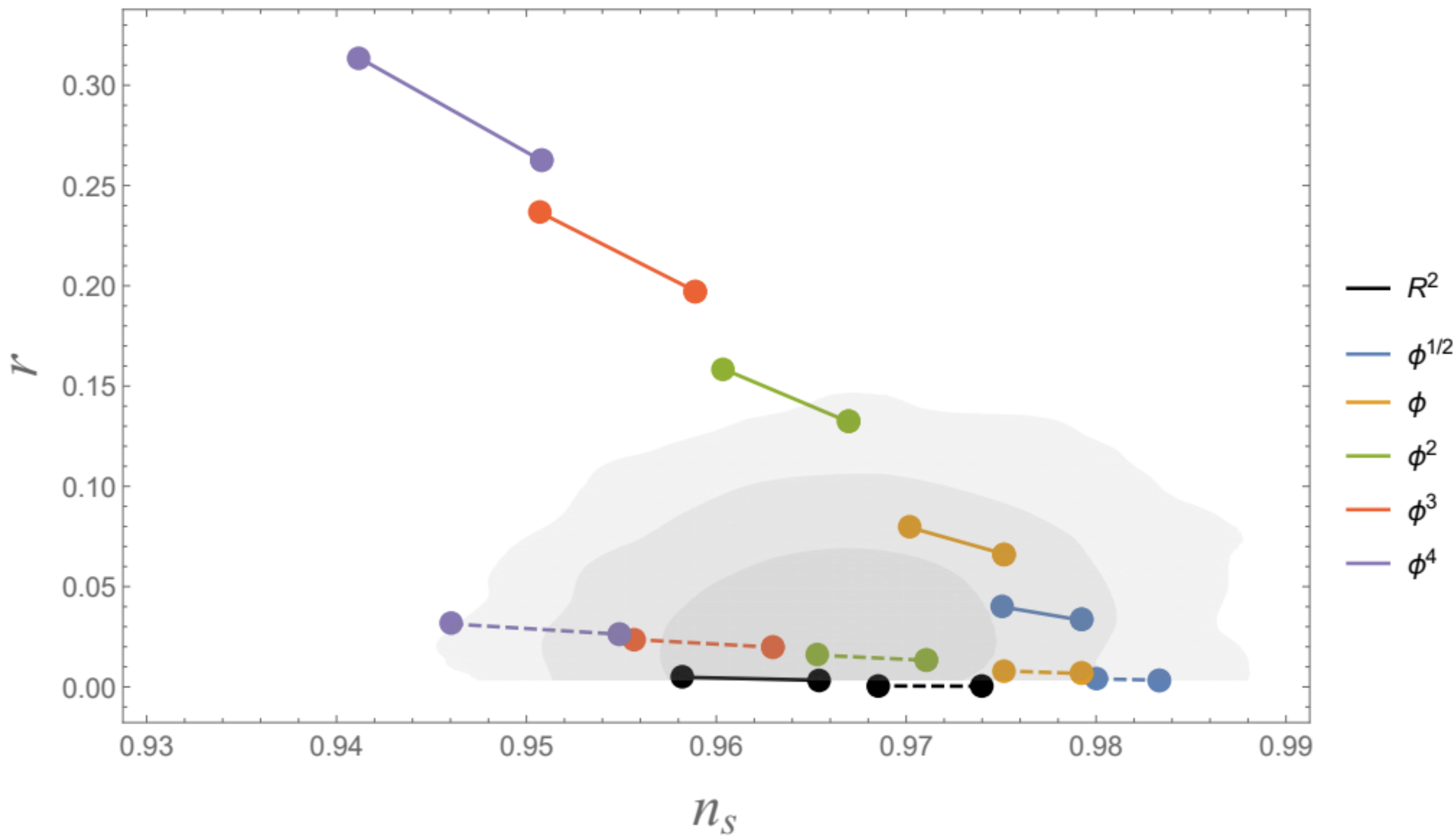
Solve the previous equation and match with large ρ EFT, we obtain the power spectrum

$$P_\zeta = P_\zeta^{(0)} c_s^{-1}, \quad c_s^{-1} = \sqrt{\frac{2\left(m^2 - 2H^2 + \rho^2\right)}{m^2 - 2H^2 - \frac{H^2}{C^4} + \sqrt{\left(m^2 - 2H^2 + \frac{H^2}{C^4}\right)^2 + \frac{4H^2\rho^2}{C^4}}}}$$

Power Spectrum



Shift on ns-r



0.30
0.25
0.20
0.15
0.10
0.05
0.00
r
0.93
0.94
0.95
0.96
0.97
0.98
0.99
n_s
R^2
$\phi^{1/2}$
ϕ
ϕ^2
ϕ^3
ϕ^4

Thank You