On Preheating in Higgs Inflation

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Abstract

We consider the preheating in the Higgs inflation.
We argue that the choice of the higher dimensional operator affects the dynamics of the preheating.

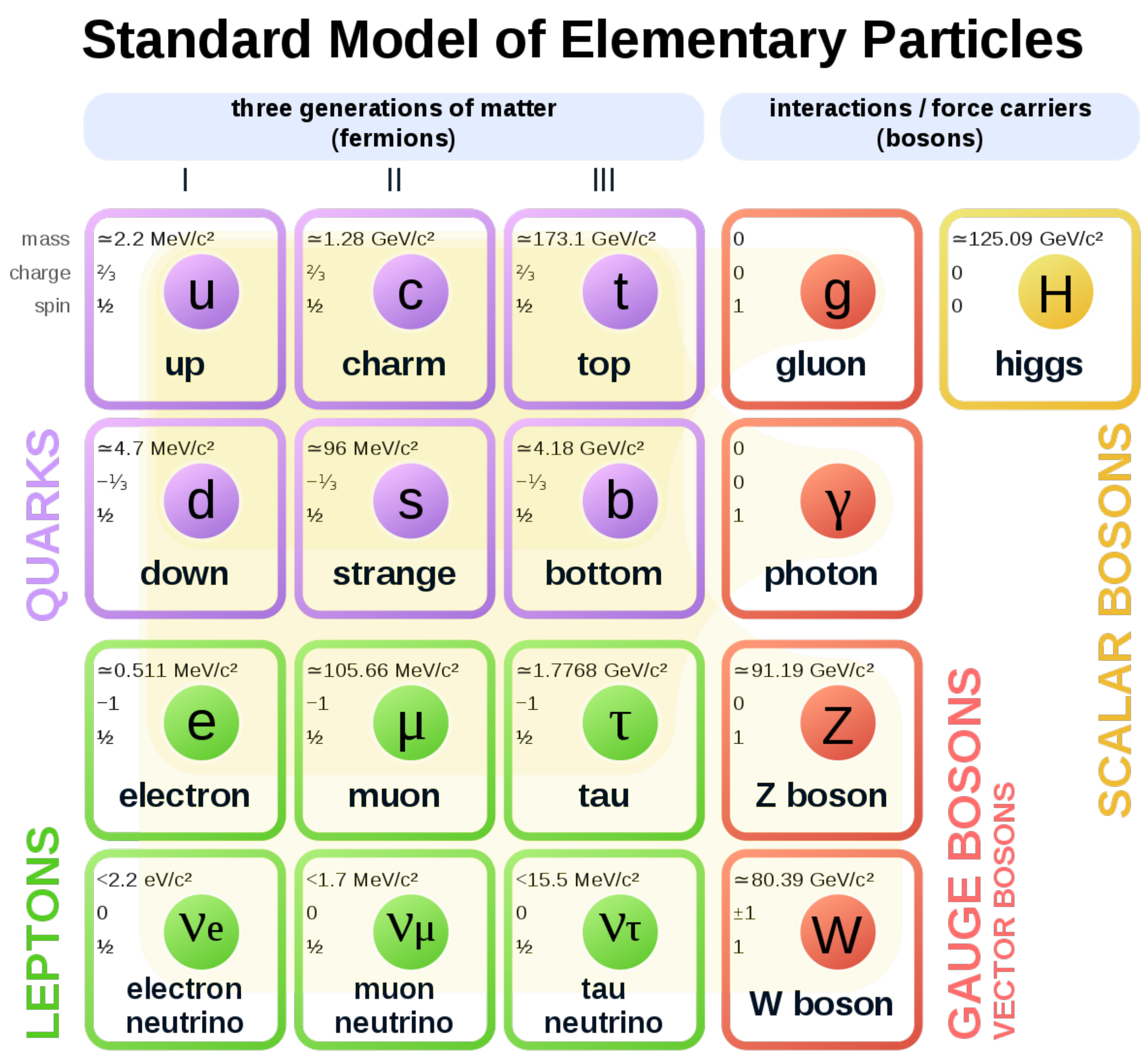
Talk Plan

1. Higgs inflaiton
2. Preheating and higher dim. op.

Standard Model

The Higgs boson is only elementary scalar in the Standard Model.

Why not use this as an inflaton?



Inflation

Inflation solves several problems.

- Flatness problem
- Horizon problem

Inflation can generate density perturbation.

- Generated by quantum fluctuation of inflaton.
- Predictive and good agreement with observation

Slow roll inflation

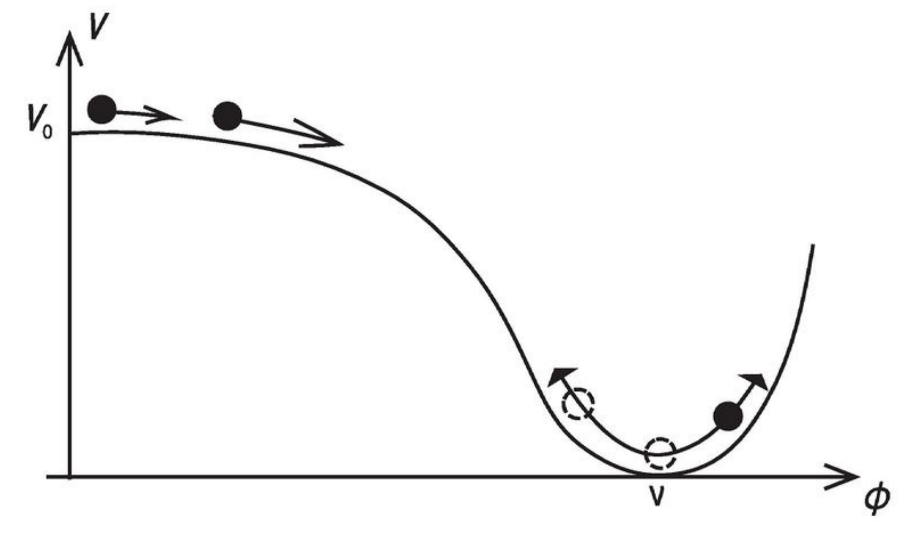
- Flat potential realize exponential expansion.

$$ds^2 = -dt^2 + a^2(dr^2 + r^2 d\theta^2 + r^2 \sin^2\theta d\phi^2)$$

$$H^2 \equiv \left(\frac{\dot{a}}{a}\right)^2 = \frac{1}{3M_{pl}^2}\left(\frac{1}{2}\dot{\varphi}^2 + V\right)$$

- Flatness of potential is characterized by slow roll parameters.

$$\epsilon = \frac{M_{\rm pl}^2 V_\varphi^2}{2V^2} \ll 1 \qquad \eta = \frac{M_{\rm pl}^2 V_{\varphi\varphi}}{V^2} \ll 1$$



Perturbations

scalar perturbation

$$\mathcal{P}_{\mathcal{R}} = A_s \left(\frac{k}{k_0}\right)^{n_s - 1}$$

$$A_s \simeq \frac{V}{24\pi^2 M_{pl}^4 \epsilon}$$

tensor perturbation

$$\mathcal{P}_t = A_t \left(\frac{k}{k_0}\right)^{n_t}$$

$$A_t \simeq \frac{2V}{3\pi^2 M_{pl}^4}$$

spectral index

$$n_s - 1 \simeq 2\eta - 6\epsilon \qquad n_t \simeq -2\epsilon$$

tensor to scalar ratio

$$r \equiv \frac{\mathcal{P}_t}{\mathcal{P}_{\mathcal{R}}} \simeq 16\epsilon$$

observation

$$A_s \sim 10^{-9} \qquad n_s \sim 0.97 \qquad r \lesssim 0.1$$

Higgs inflation

A scenario where SM Higgs boson is inflaton [Bezrukov-Shaposhnikov '08].

We start from the action

$$S = \int d^4x\sqrt{-g}\left(\frac{1}{2}M_P^2 R + \xi |H|^2 R - |D_\mu H|^2 - \lambda(|H|^2)^2\right).$$

We perform

$$g_{\mu\nu} \to \left(1 + 2\xi\frac{|H|^2}{M_P^2}\right)g_{\mu\nu}$$

The Einstein-frame (coefficient of R is constant) action becomes

$$S = \int d^4x\sqrt{-g}\left(\frac{1}{2}M_P^2 R + \frac{|D_\mu H|^2}{1 + 2\xi|H|^2/M_P^2} - \lambda\frac{(|H|^2)^2}{\left(1 + 2\xi|H|^2/M_P^2\right)^2}\right)$$

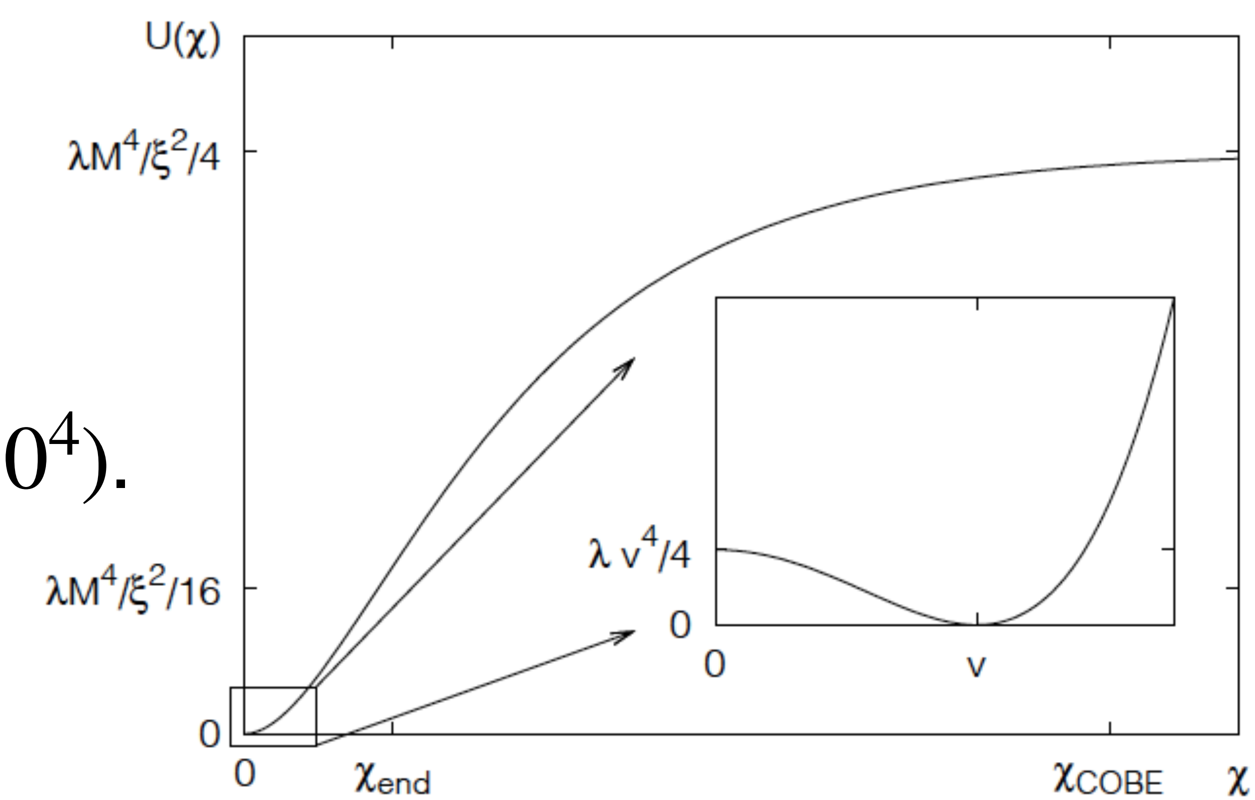
The potential is flat for large field value.

Potential

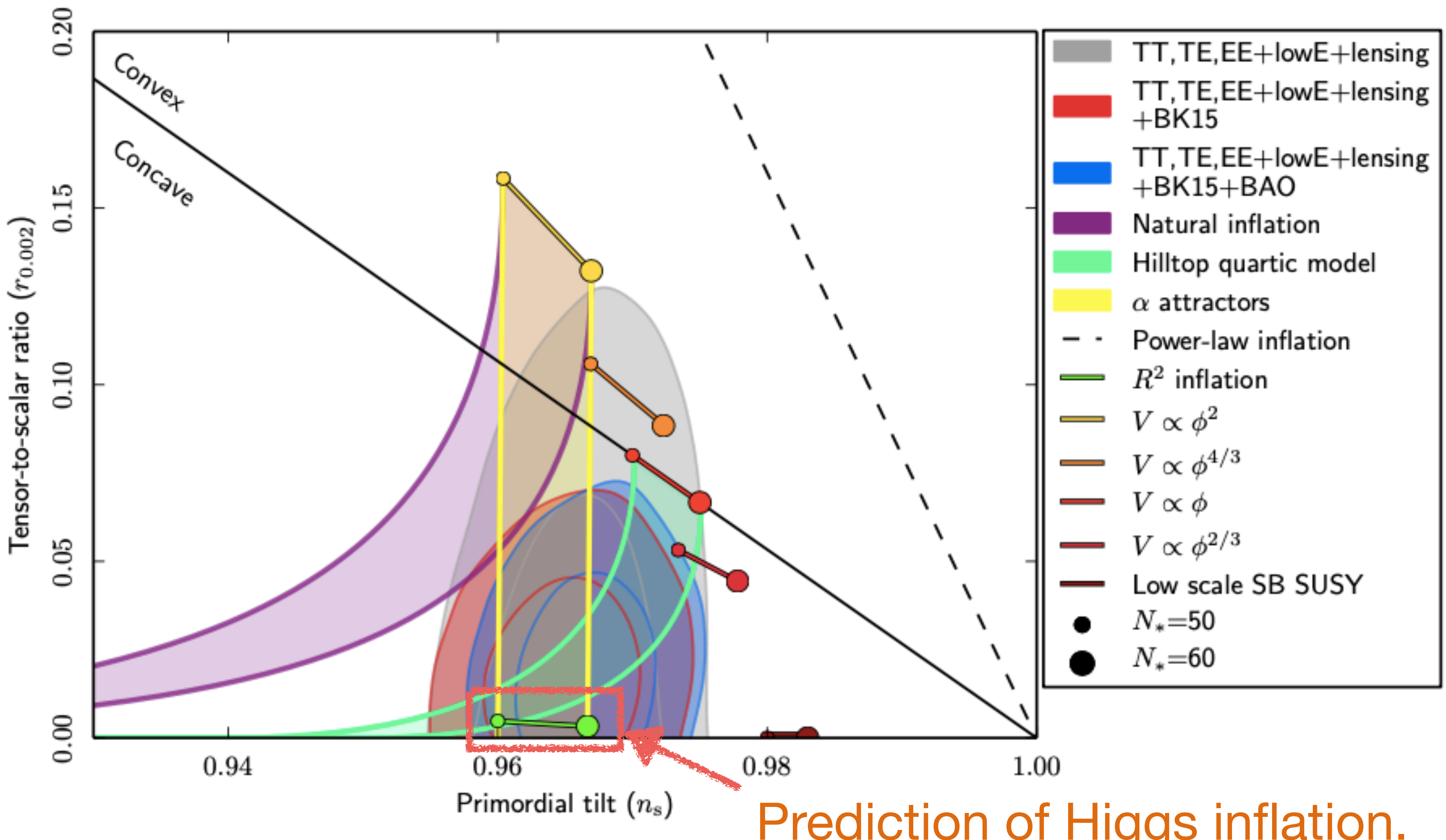
After normalizing the scalar field canonically,
the potential $U(\chi)$ is

$$U(\chi) = \frac{\lambda}{4}\frac{M_P^4}{\xi^2}\left(1 - e^{-\sqrt{\frac{2}{3}}\frac{\chi}{M_P}}\right)^2.$$

where χ :canonical Higgs field.
To fit the amplitude of
the scalar perturbation, $\xi = \mathcal{O}(10^4)$.



CMB


Tensor-to-scalar ratio ($r_{0.002}$)
0.00
0.05
0.10
0.15
0.20
0.94
0.96
0.98
1.00
Primordial tilt (n_s)
Convex
Concave
TT,TE,EE+lowE+lensing
TT,TE,EE+lowE+lensing +BK15
TT,TE,EE+lowE+lensing +BK15+BAO
Natural inflation
Hilltop quartic model
α attractors
Power-law inflation
R^2 inflation
$V \propto \phi^2$
$V \propto \phi^{4/3}$
$V \propto \phi$
$V \propto \phi^{2/3}$
Low scale SB SUSY
N_*=50
N_*=60
Prediction of Higgs inflation.

Talk Plan

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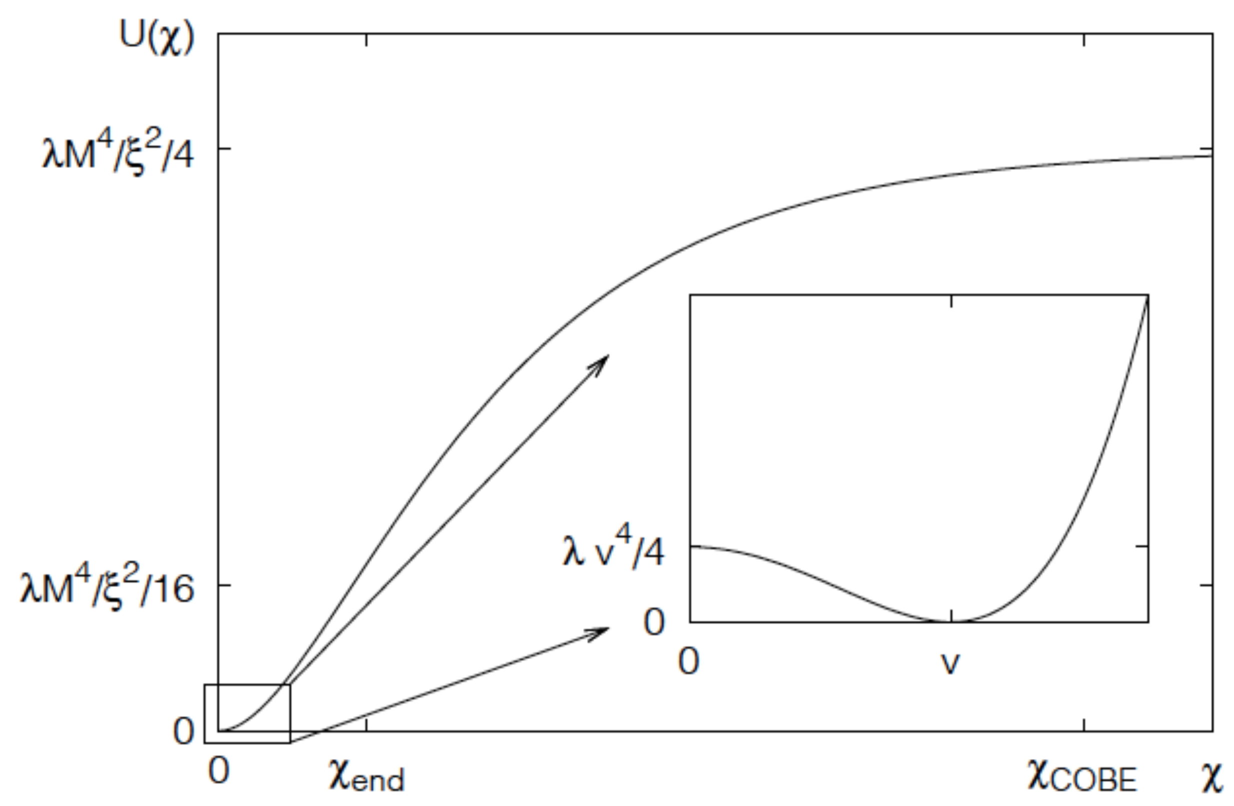
After inflation

After the inflation, the Higgs field starts to oscillate around the origin.
Large ξ induces the violation of the perturbative unitarity at this stage [Ema-Jinno-Mukaida-Nakayama '16].

Problem arises by coupling

$$\frac{1}{\left(1+2\xi|H|^2/M_P^2\right)^4}\frac{\xi^2}{M_P^2}\left(\partial_\mu|H|^2\right)^2$$

in Einstein frame.



Large coupling

The problem is obvious by seeing the strength of the coupling among fluctuations.

By defining

$$H = \frac{1}{\sqrt{2}} \begin{pmatrix} \phi_1 + i\phi_2 \\ \phi_3 + i\phi_4 \end{pmatrix}$$

where ϕ_1 is oscillating. This leads to the four point couplings whose coupling constants are the order of

$$\text{(Coupling constants)} = \mathcal{O}(\lambda\, \xi^2)$$

Typically, this is much larger than 4π.

(but there are exceptions e.g. critical Higgs inflation where ξ is small

[YH-Kawai-Oda-Park ’14 ×2, Bezrukov-Shaposhnikov ‘14])

A way out

The previous argument highly depends on the choice of the higher dimensional operator. Since we have the term

$$\frac{1}{\left(1+2\xi|H|^2/M_P^2\right)^4}\frac{\xi^2}{M_P^2}\left(\partial_\mu|H|^2\right)^2,$$

we expect the other operators like

$$\frac{1}{\left(1+2\xi|H|^2/M_P^2\right)^8}\frac{\xi^4}{M_P^4}\left(|\partial_\mu H|^2\right)^2,$$

A way out

If the coupling

$$\frac{1}{\left(1+2\xi|H|^2/M_P^2\right)^8}\frac{\xi^4}{M_P^4}\left(|\partial_\mu H|^2\right)^2$$

exists, this leads to the large kinetic term

$$\frac{\xi^4}{M_P^4}\dot{\phi}_1^2\left(\partial_\mu\phi_j\right)^2=\mathcal{O}(\lambda\xi^2)\left(\partial_\mu\phi_j\right)^2, \quad \text{where } H=\frac{1}{\sqrt{2}}\begin{pmatrix}\phi_1+i\phi_2\\ \phi_3+i\phi_4\end{pmatrix}$$

when ϕ_1 crosses the origin. Canonical rescaling $\phi_j \to \phi_j/\sqrt{\lambda\xi^2}$ reduces the coupling constants.

In this way, unitary violation during the preheating is avoided if we add an appropriate higher dimensional term.

The above expectation can be checked by computing the particle production numerically. [YH-Kawana-Scherlis '20]

Summary

We consider the preheating in the Higgs inflation.
The perturbative unitarity is violated due to the large non-minimal coupling between the scalar curvature and Higgs.

The unitary violation during the preheating is avoided if we add an appropriate higher dimensional term.