Higgs instability during and after inflation

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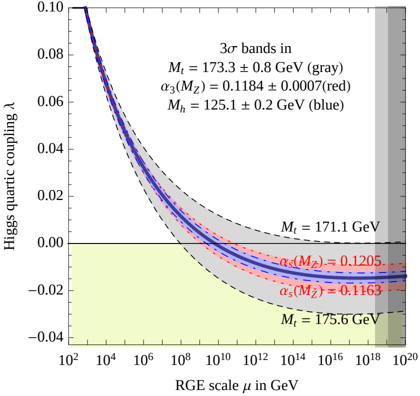
C. Gross, O. Lebedev, MZ, 1506.05106
K. Enqvist, M. Karciauskas, O. Lebedev, S. Rusak, MZ, 1608.08848

Running of the Higgs self coupling

Buttazzo et al., 1307.3536

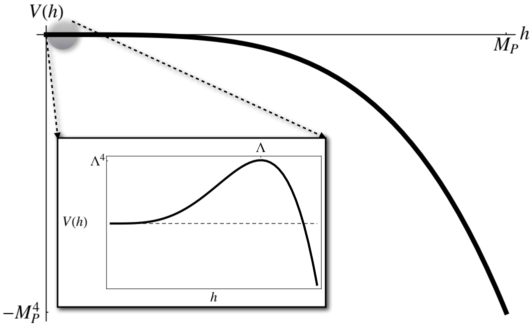


Main contribution at one loop

$$\frac{\mathrm{d}\lambda}{\mathrm{d}\ln\mu} \propto \alpha m_H^4 - \beta m_t^4$$

λ turns negative at $\Lambda \sim 10^{10}\mathrm{GeV}$!

Higgs potential with loop corrections



During inflation $\langle \delta h^2 \rangle \sim H^2$

How the Higgs ended up in the false vacuum?
Why it remained there during inflation?

A possible solution

Lebedev&Westphal, 1210.6987

$$\frac{1}{4}\lambda_{h\phi}h^2\phi^2 \longrightarrow m_h^2 = \lambda_{h\phi}\phi_0^2/2$$

The effective mass makes h roll towards the origin

$$h \sim h(0)e^{-3Ht/2}$$

The mechanism can work if

$$10^{-10} < \lambda_{h\phi} < 10^{-6}$$

Reheating requires the Higgs-inflaton coupling

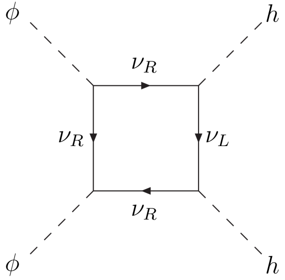
C. Gross,O. Lebedev, MZ, 1506.05106

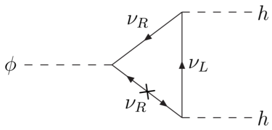
- The coupling $h^2\phi^2$ is required by renormalizability.

Example: right-handed neutrino

$$-\Delta\mathcal{L} = \lambda_\nu \phi \nu_R \nu_R/2 + y_\nu h \bar{\nu}_L \nu_R/\sqrt{2} + M \nu_R \nu_R/2 + \text{h.c.}$$

At one-loop





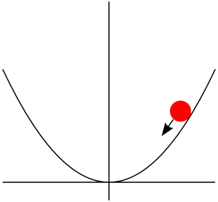
Need to add the counterterms

$$-\Delta\mathcal{L} \supset \frac{\lambda_{h\phi}}{4} h^2 \phi^2 + \frac{\sigma_{h\phi}}{2} h^2 \phi$$

Preheating

Kofman, Linde, Starobinsky '97

After inflation the inflaton oscillates around its minimum



$$V(\phi) = \frac{1}{2} m^2 \phi^2$$

$$\phi \simeq \Phi \cos mt \quad \text{with} \quad \Phi \sim \Phi_0 \, a^{-3/2}$$

- Higgs effective mass periodic in time
- Can lead to resonant production of Higgs particles

$\langle h^2 \rangle \propto$ Number of Higgs quanta

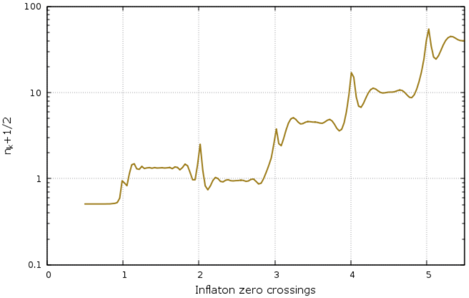
Preheating with quadratic interaction only

Introduce the Higgs momentum eigenmodes $X_k = a^{3/2} h_k$

$$\ddot{X}_k + \left[(\tfrac{k}{a})^2 + q(t)\cos^2(mt) + 3\lambda_h a^{-3}\langle X^2 \rangle \right] X_k = 0$$

$$\text{with} \quad q(t) = \frac{\lambda_{h\phi}}{2}\left[\Phi(t)\right]^2$$

Occupation number of the mode k: $n_k = \frac{1}{2\omega_k}\left(|\dot{X}_k|^2 + \omega_k^2 |X_k|^2\right) - \frac{1}{2}$



Stability of the Higgs during preheating

Occupation number and Higgs fluctuations are related

$$\langle h^2 \rangle \simeq \int \frac{d^3k}{(2\pi a)^3} \frac{n_k}{\omega_k}$$

We get a bound on $\lambda_{h\phi}$ as follows:

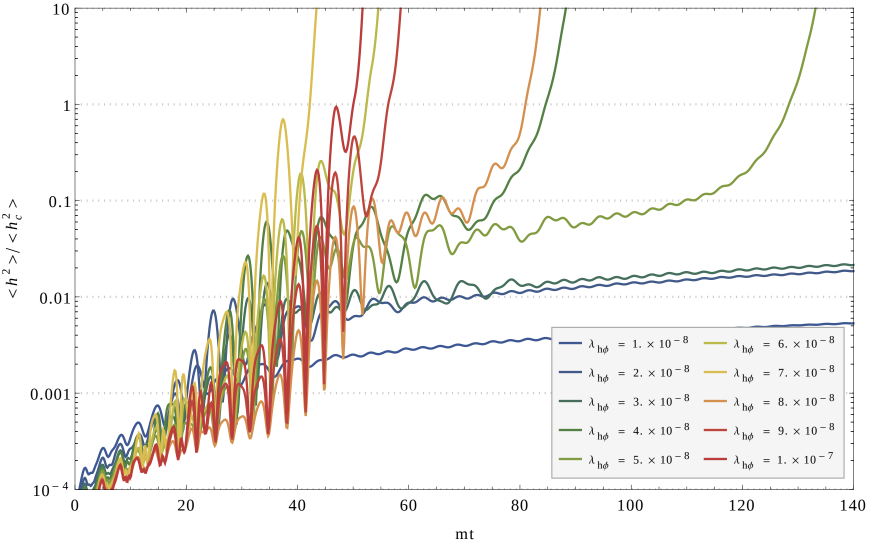
- When $\phi \sim 0$ the effective mass $m_{eff}^2 \sim 3\lambda_h \langle h^2 \rangle < 0$
- Fluctuations grow $\sim \exp(m_{eff}\Delta t)$
- Avoid destabilization if $m_{eff}\Delta t < 1$

$$\lambda_{h\phi} < 3 \times 10^{-8}$$

Ema,Mukaida,Nakayama, 1602.00483

Enqvist,Karciauskas,Lebedev,Rusak,MZ 1608.08848

Stability of the Higgs during preheating II

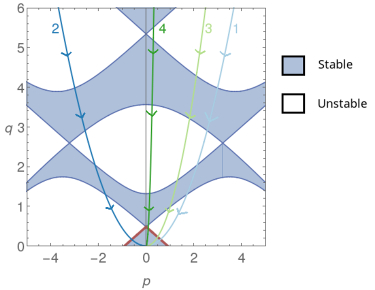


Enqvist, Karciauskas, Lebedev, Rusak, MZ, 1608.08848

Preheating with both couplings

Eigenmodes evolution given by Whittaker-Hill-type equation:

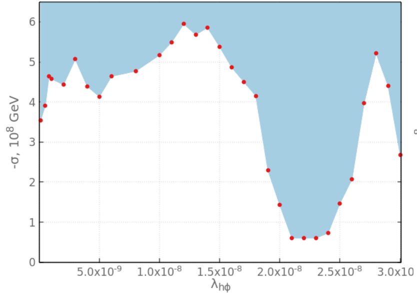
$$\ddot{X}_k + \left[(\tfrac{k}{a})^2 + q\cos^2(mt) + 2p\cos(mt) + 3\lambda_h a^{-3}\langle X^2\rangle \right] X_k = 0$$



Enqvist, Karciauskas, Lebedev, Rusak, MZ, 1608.08848

Stability with both couplings

- Given $\lambda_{h\phi}$ determine $\sigma_{h\phi}$ that destabilizes the vacuum
- White: stable up to the end of preheating



Enqvist, Karciauskas, Lebedev, Rusak, MZ, 1608.08848

Conclusions

Higgs-inflaton couplings:

- can explain why the universe ended up in EW vacuum
- necessary to reheat the universe
- must not destabilize the vacuum during preheating

There exists a favorable range of parameters for which the universe remains in the false vacuum up to the end of preheating

$$10^{-10} < \lambda_{h\phi} < 10^{-8}$$ and $$|\sigma_{h\phi}| < 10^{8}\,\mathrm{GeV}$$

Thank you