# Higgs instability during and after inflation

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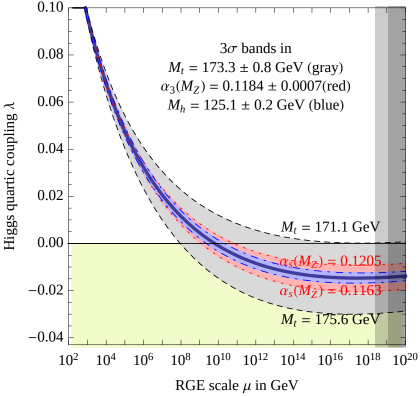
C. Gross, O. Lebedev, MZ, 1506.05106
K. Enqvist, M. Karciauskas, O. Lebedev, S. Rusak, MZ, 1608.08848

# Running of the Higgs self coupling

Buttazzo et al., 1307.3536

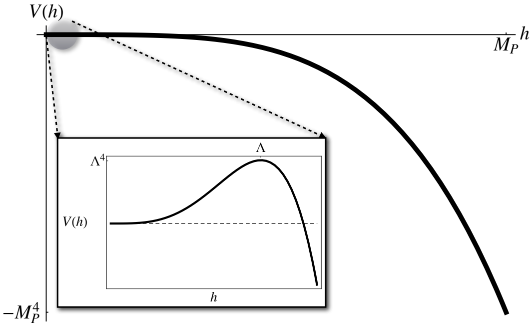



Main contribution at one loop

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

$\lambda$ 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 implies the Higgs-inflaton coupling

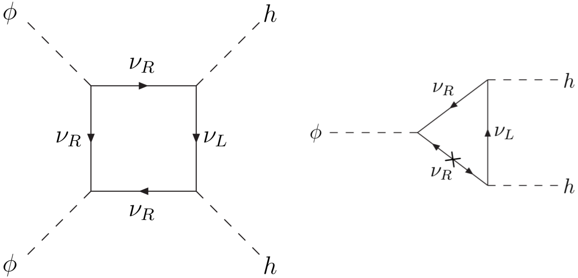
C. Gross,O. Lebedev, MZ, 1506.05106


- Higgs-inflaton couplings are generated from loops
- 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

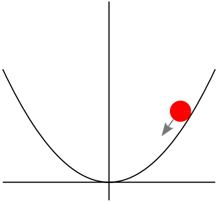



Need to add the counterterms

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

# Preheating

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

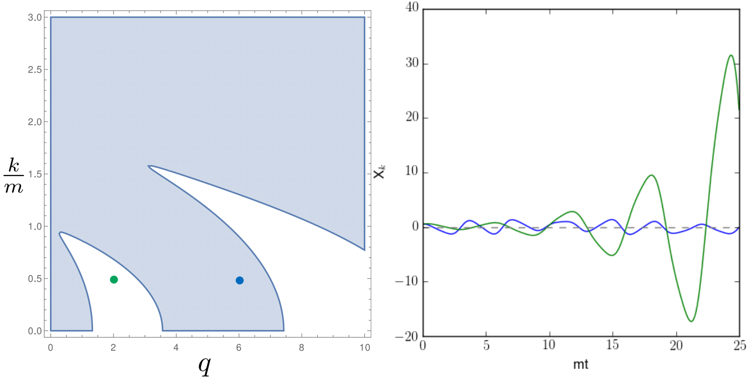
# Preheating with quartic interaction only

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

$$\ddot{X}_k + \left[ (\tfrac{k}{a})^2 + m^2 q \cos^2(mt) + \delta m^2_{\text{self}} \right] X_k = 0$$

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

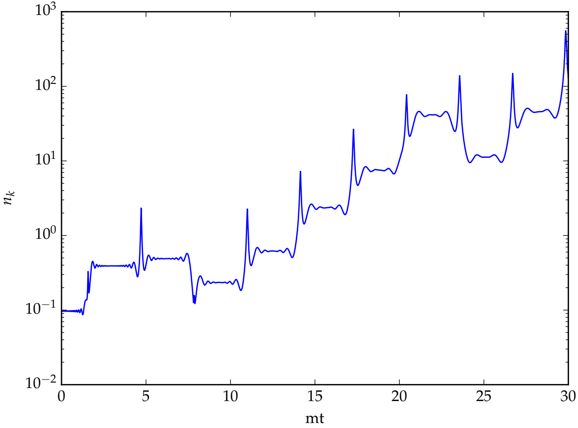
Kofman, Linde, Starobinsky '97



# Preheating with quartic interaction only II

Occupation number of the mode $k$:

$$n_k = \frac{1}{2\omega_k}\left(|\dot{X}_k|^2 + \omega_k^2|X_k|^2\right) - \frac{1}{2}$$




Kofman, Linde, Starobinsky '97

# Stability of the Higgs during preheating

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

When $\phi \sim 0$ the effective mass $m_{eff}^2 \sim 3\lambda_h \langle h^2 \rangle$ is tachyonic

Two effects:

- $\langle h^2 \rangle$ grows due to preheating
- $\langle h^2 \rangle$ grows due to the tachyonic mass term

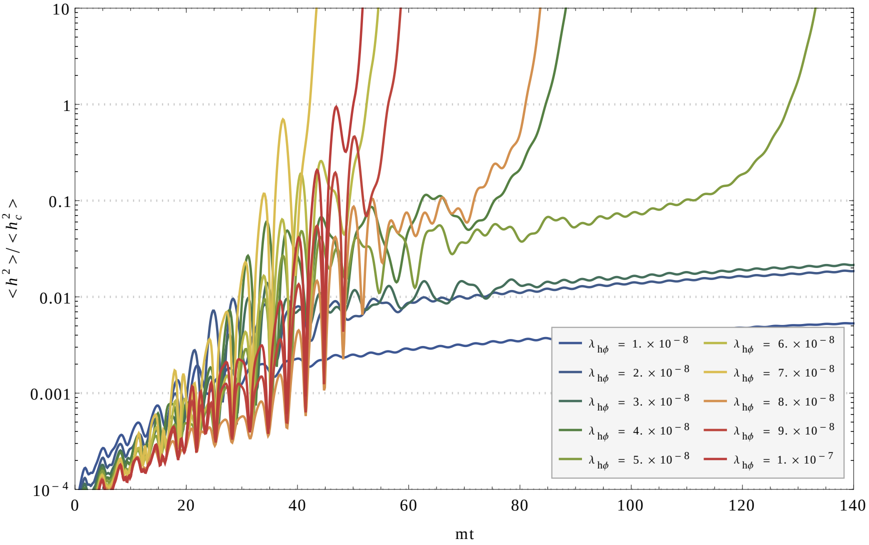
$\langle h^2 \rangle$ isn't left over the instability barrier at the end of preheating if

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

Ema,Mukaida,Nakayama, 1602.00483

Enqvist,Karciauskas,Lebedev,Rusak,MZ 1608.08848

# Numerical simulation




Enqvist, Karciauskas, Lebedev, Rusak, MZ, 1608.08848

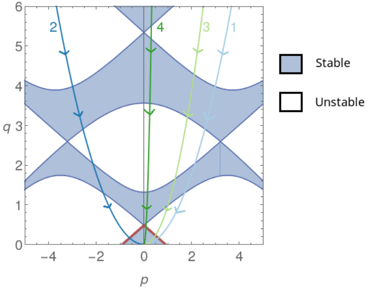
# Preheating with both couplings

Eigenmodes evolution given by Whittaker-Hill-type equation:

$$\ddot{X}_k + \left[ (\tfrac{k}{a})^2 + m^2 q \cos^2(mt) + 2m^2 p \cos(mt) + \delta m^2_{\text{self}} \right] X_k = 0$$

$$q = \frac{\lambda_{h\phi}\Phi^2}{2m^2}$$

$$p = 2\frac{\sigma_{h\phi}\Phi}{m^2}$$

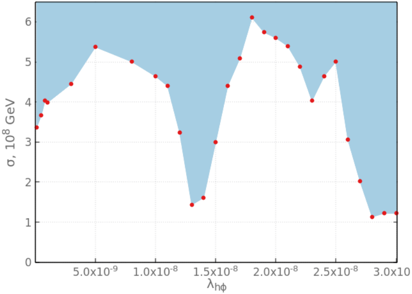



Enqvist, Karciauskas, Lebedev, Rusak, MZ, 1608.08848

# Stability with both couplings

For $\lambda_{h\phi}$ that stabilizes EW vacuum up to the end of preheating

- Determine smallest $\sigma_{h\phi}$ that destabilizes the EW vacuum




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

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

# Thank you