

Higgs Dynamics During And After Inflation

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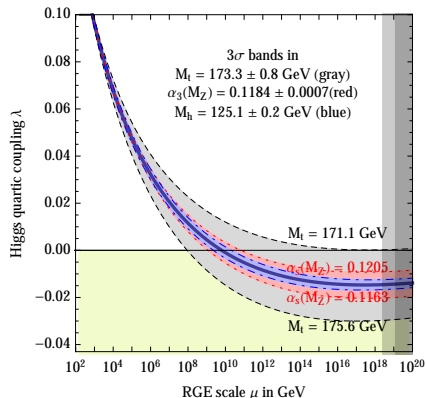
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Running of the Higgs self coupling

Buttazzo et al., 1307.3536

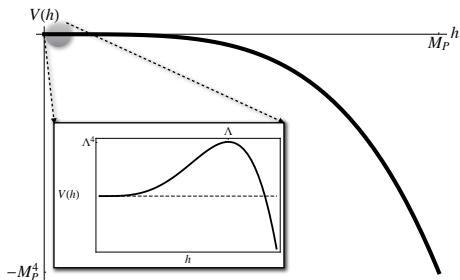


Main contribution at one loop

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

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

The SM Higgs potential



Cosmological puzzles:

- ▶ Who/what put the Higgs in the EW vacuum?
- ▶ Why/How it remained there during inflation?

Possible solutions

Introduce the couplings

- ▶ $\frac{1}{2}\lambda_{h\phi}h^2\phi^2$
- ▶ $\frac{1}{2}\xi h^2 R$

Lebedev & Westphal, 1210.6987

Espinosa, Giudice, Riotto, 1210.6987

Can give a mass for the Higgs that makes it roll towards the origin

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

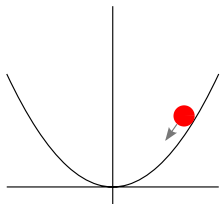
- ▶ Both couplings are generated through divergent loops

For $h \gg v$ the full Higgs potential takes the form

$$V = \lambda h^4 + \frac{1}{2}\xi R h^2 + \frac{1}{2}\lambda_{h\phi}\phi^2 h^2 + \sigma\phi h^2$$

Preheating

After inflation the inflaton oscillates around its minimum



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

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

- ▶ Can lead to resonant production of Higgs particles

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

Preheating with non-zero $\lambda_{h\phi}$ and ξ

$$\text{Mathieu Equation: } X_k'' + (A_k + 2q \cos 4z) X_k = 0 \quad z = mt/2$$

with

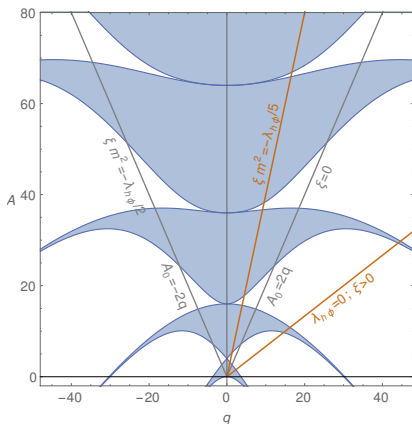
$$A_k = \left(\frac{k}{ma}\right)^2 + 2(\lambda_{h\phi} + \xi m^2) \frac{\Phi^2}{m^2}$$

$$q = (\lambda_{h\phi} + 3\xi m^2) \frac{\Phi^2}{m^2}$$

Strength of the resonance:

- ▶ Angle of the line
- ▶ Speed of the crossing

Ema, Karciauskas, Lebedev, MZ, 1703.04681

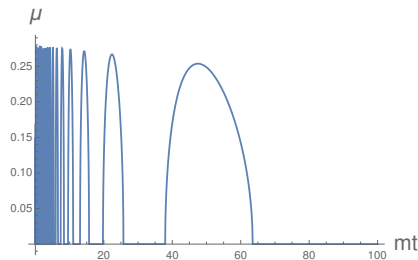


Preheating with non-zero $\lambda_{h\phi}$ and ξ

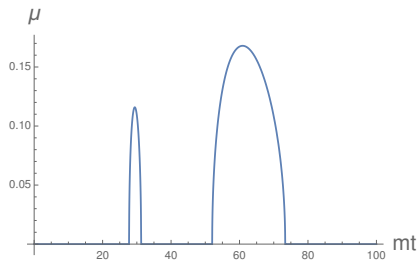
When the mode k is in the white region its amplitude grows as

$$X_k \propto e^{\mu \Delta mt}$$

$$A_0 = 2q$$



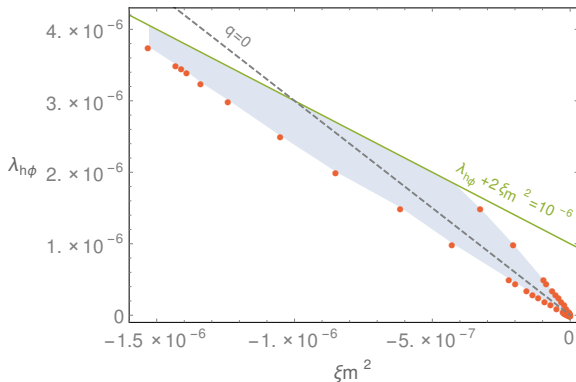
$$A_0 = 3q$$



Ema, Karciauskas, Lebedev, MZ, 1703.04681

Lattice results

Parameter space for stability up to the end of preheating:



Ema, Karciauskas, Lebedev, MZ, 1703.04681

Adding the trilinear coupling σ

Eigenmodes evolve according to the Whittaker-Hill equation

$$X_k'' + (A_k + 2p \cos 2z + 2q \cos 4z) X_k = 0$$

where $p = 2\sigma\Phi/m^2$

- ▶ Two different frequencies
- ▶ Higgs tachyonic during part of the oscillation

Only possibility is to get an upper bound on σ :

$$\sigma < 10^9 \text{ GeV}$$

Conclusions

The couplings ξ and $\lambda_{h\phi}$:

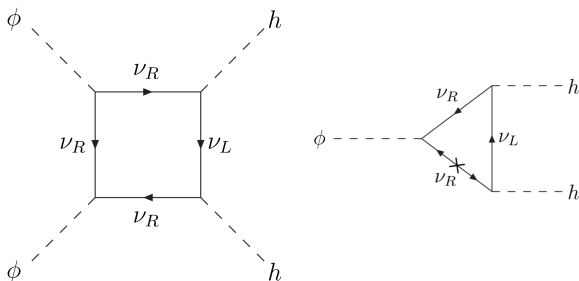
- ▶ can explain how the universe ended up in the EW vacuum
- ▶ are generated by quantum effects
- ▶ must not destabilize the vacuum during preheating

THANK YOU

Example: right-handed neutrino

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

At one-loop

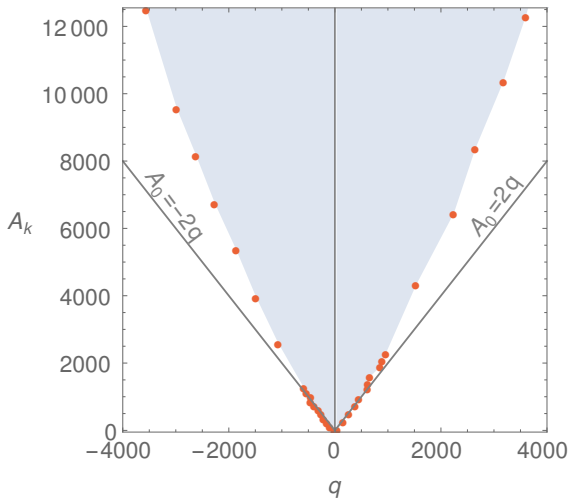


Need to add the counterterms

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

Lattice results II

Stable region obtained via classical lattice simulations



Ema, Karciauskas, Lebedev, MZ, 1703.04681