Higgs-inflaton coupling from reheating and the metastable Universe

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Particle Physics Day
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Outline

Higgs potential in the SM and EW vacuum metastability

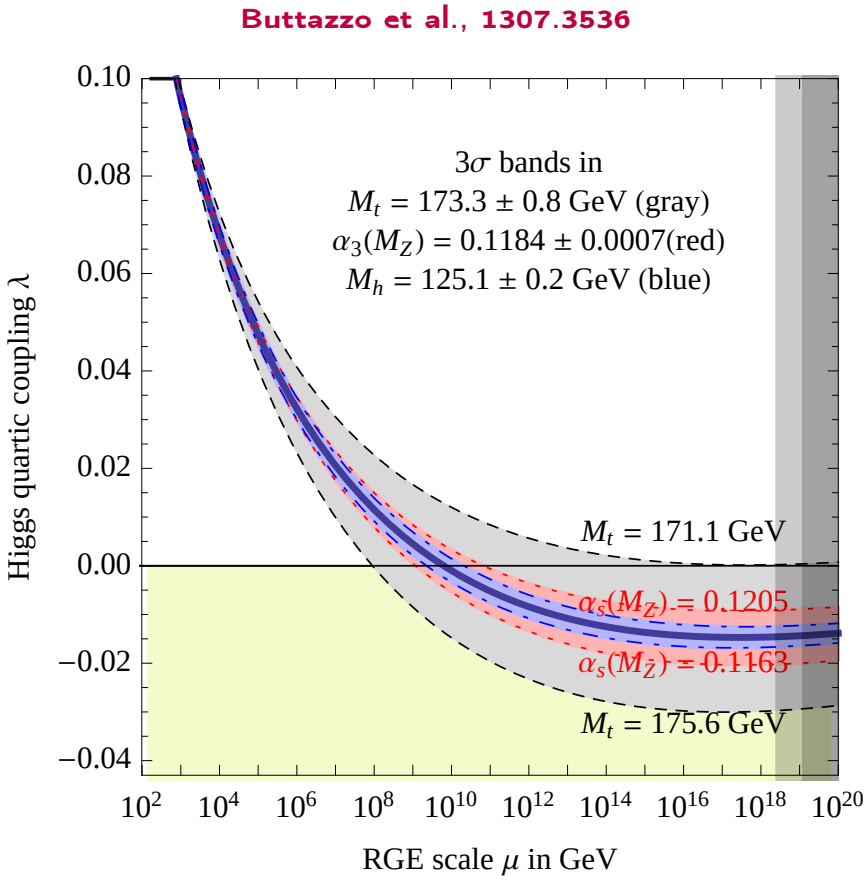
Going beyond the SM: Higgs-inflaton coupling

Higgs-inflaton coupling from reheating

Conclusions

Running of the higgs self-coupling λ

Assuming no new physics enter until $M_{\rm Pl} = 2.4 \times 10^{18}{\rm GeV}$,
we can extrapolate the behaviour of the SM to very high energy



For λ we have

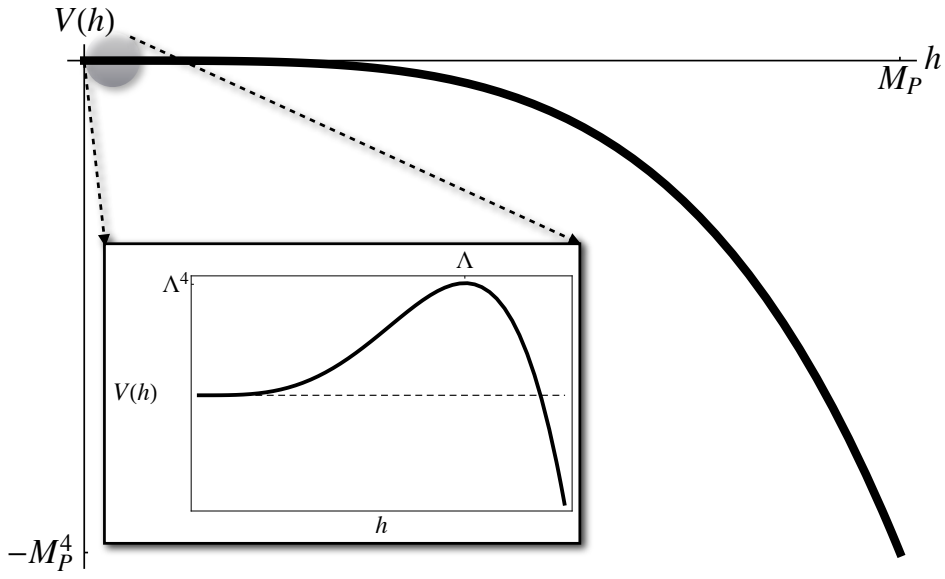
$$\frac{{\rm d}\lambda}{{\rm d}\ln\mu} \propto a\lambda^2 - by_t^4$$
$$\propto \alpha m_H^4 - \beta m_t^4$$

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

Metastability of the EW vacuum and Higgs evolution

This is how the Higgs potential looks like (for large values of h)

$$V_{\text{eff}} \simeq \lambda(h) h^4/4$$



Two problems:

- Huge fine tuning to put the Higgs field in the false vacuum.
- Fluctuations of the Higgs field are proportional to the Hubble scale H during inflation. If $H > \Lambda$, it is likely to end up in the true vacuum.

Extending the SM: modify Higgs' dynamics during inflation

Lebedev&Westphal, 1210.6987

In this talk we assume large field inflation, in particular $m^2\phi^2/2$:

Goal

Make the Higgs potential convex so that the Higgs field evolves to zero during inflation

How-to

Introduce the renormalizable coupling

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

that can induce an effective mass term for h above the Hubble scale

Constraints

- No large radiative corrections to ϕ potential
- Sizable effect to the Higgs evolution

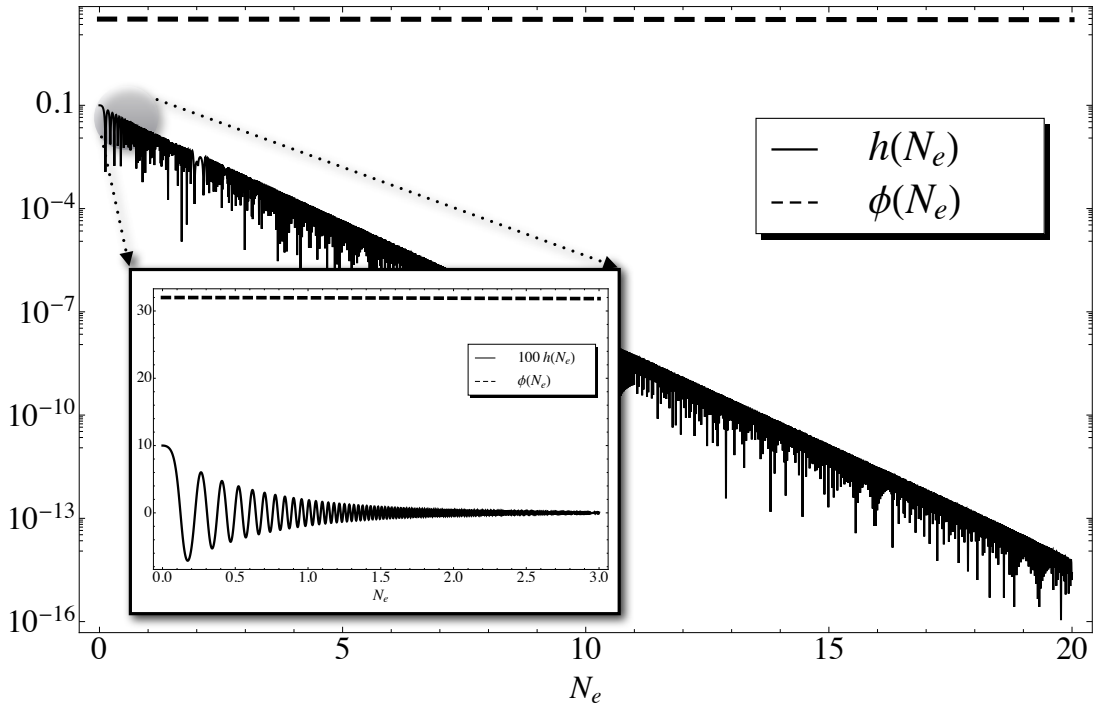
$$10^{-10} < \lambda_{h\phi}/2 < 10^{-6}$$

Extending the SM: system evolution during inflation

$$\ddot{h} + 3H\dot{h} + \partial V/\partial h = 0$$

Two stages

- Initially $3H^2 M_{\rm Pl}^2 = (\dot{h}^2 + m_h^2 h^2)/2 \to h \sim (\cos m_h t)/m_h t$
- After a few Hubble times
  $3H^2 M_{\rm Pl}^2 = m^2\phi^2/2 \to |h(t)| \sim e^{-3Ht/2}|h(0)|$



Reheating models

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Can we infer the size of $\lambda_{h\phi}$ from reheating?

Common feature of reheating models

- Energy density needs to be transferred to SM particles
- This requires a coupling (perhaps indirect) inflaton-SM

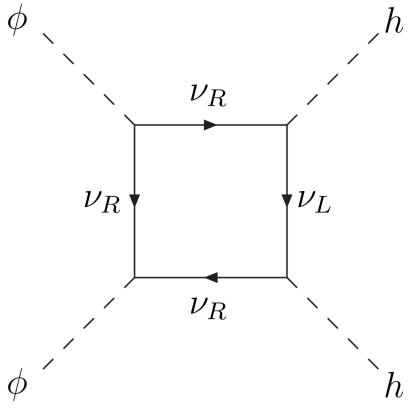
Renormalizability requires the introduction of the coupling $\lambda_{h\phi} h^2 \phi^2$

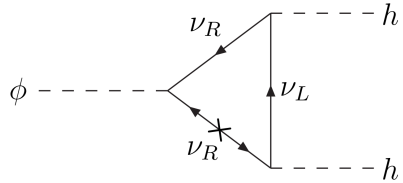
$$V \supset \lambda_{h\phi} h^2 \phi^2/4 + \sigma_{h\phi} h^2 \phi/2 + \lambda_\phi \phi^4/4$$

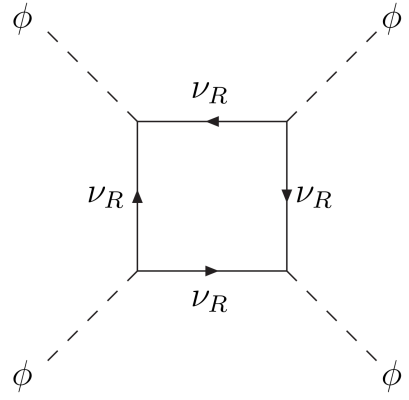
$\lambda_{h\phi}$ runs with the renormalization scale!

Inflaton to RH neutrinos

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







$$\lambda_{h\phi} \simeq \frac{|\lambda_\nu y_\nu|^2}{2\pi^2} \ln \frac{M_{\rm Pl}}{H} \qquad \sigma_{h\phi} \simeq -\frac{M|y_\nu|^2 \mathrm{Re}\lambda_\nu}{2\pi^2} \ln \frac{M_{\rm Pl}}{H} \qquad \lambda_\phi \simeq \frac{|\lambda_\nu|^4}{4\pi^2} \ln \frac{M_{\rm Pl}}{H}$$

- $\lambda_\phi \phi^4$ unimportant with respect to $m^2\phi^2 \longrightarrow \lambda_\nu < 10^{-3}$
- Seesaw and constraints on the mass of active neutrinos$\longrightarrow y_\nu < 0.6$

$$0 < \lambda_{h\phi} < 2 \times 10^{-7}$$

Conclusions

- A small $\phi - h$ coupling can explain why the universe ended in the false vacuum after inflation
- The coupling $\phi - h$ is required for the renormalizability of realistic reheating models
- The induced coupling can be of the right size to affect the Higgs dynamics
- Next: understand the dynamics of reheating and preheating in more detail

Thank you