The Higgs-inflaton mixing

Oleg Lebedev

UNIVERSITY OF HELSINKI

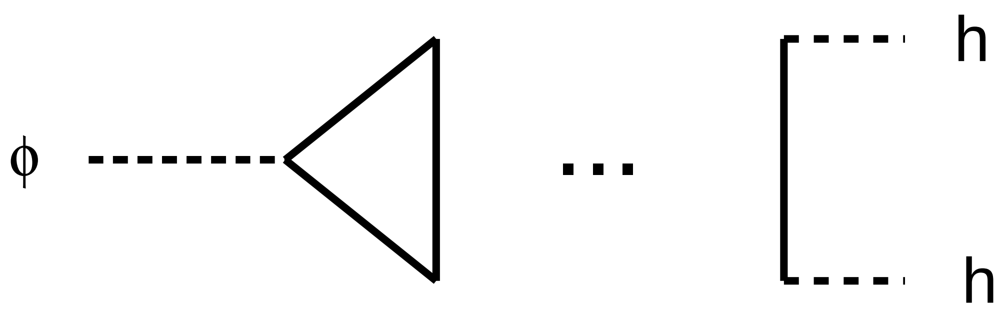
University of Helsinki

Issues:

- Higgs-inflaton mixing in general
- (likely) vacuum metastability
- (de)stabilizing effects during inflation and preheating
- stabilization via Higgs-inflaton mixing

Higgs-inflaton mixing is expected in general *(unless forbidden by symmetry)* :

inflaton decays into SM fields directly or indirectly



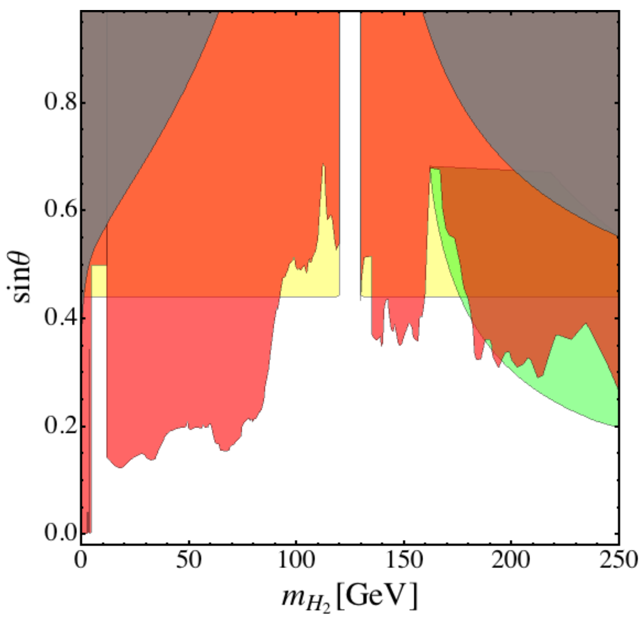
$$\Delta L \sim \phi\, H^{\dagger} H$$

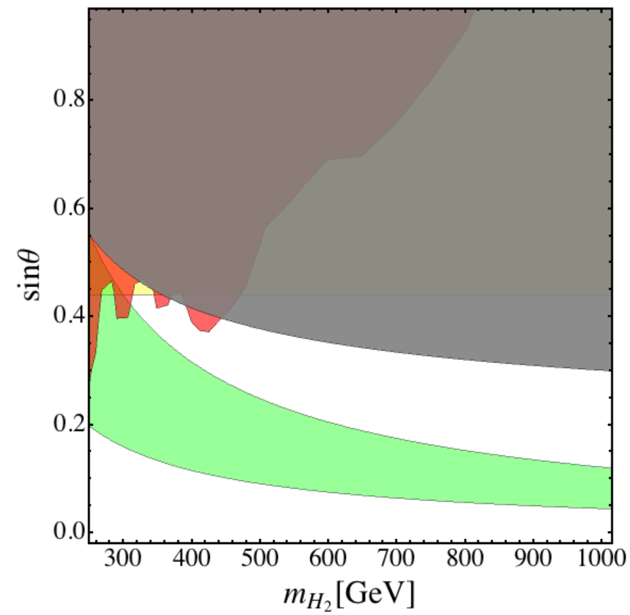
(divergent → counterterm)

$$\Delta L_{m2} \sim \phi\, h$$

2 mass eigenstates: H_1 = 125 GeV Higgs ; H_2 = extra Higgs ; θ = mixing angle

Falkowski, Gross, OL '15





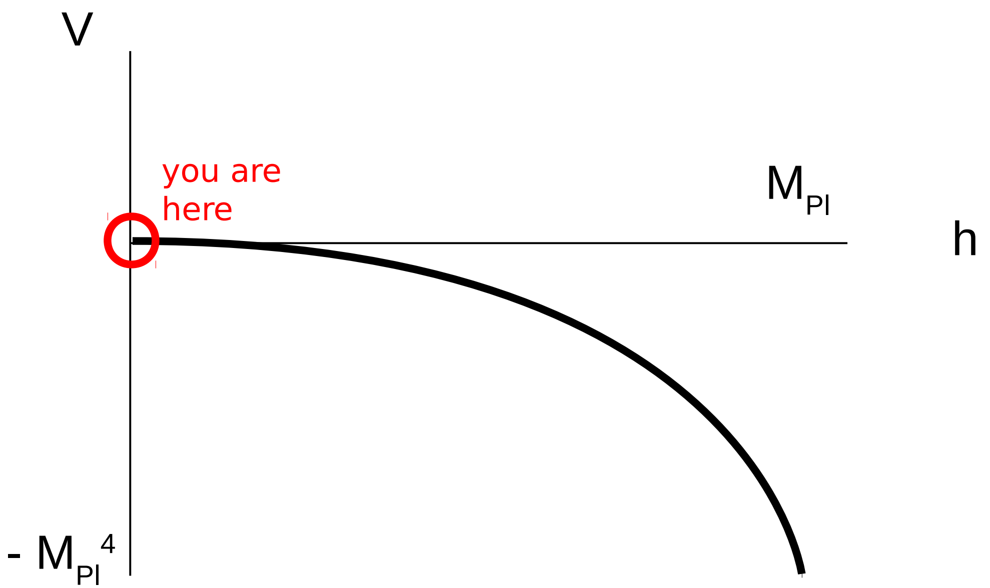
Grey = EW precision data , Yellow = LHC Higgs couplings , Reddish = B-physics, LEP, LHC

Green (optional) = Higgs potential stability/perturbativity up to M_{Pl}

The mixing angle θ as large as 0.3 is allowed!

Vacuum metastability:

$h \gg \Lambda \sim 10^{10}$ GeV $\Rightarrow$ $V \sim \frac{1}{4}\lambda(h)\, h^4$, $\lambda(h) < 0$



$\Lambda = 10^{-8}\, M_{Pl}$, barrier $= 10^{-32}\, M_{Pl}^4$

Problems :

- how did the Universe end up at $h \sim 0$?
- why did it stay there during inflation ?

Solutions :

- modify the Higgs potential during inflation
- just modify the Higgs potential

1. Correct the Higgs potential during inflation only

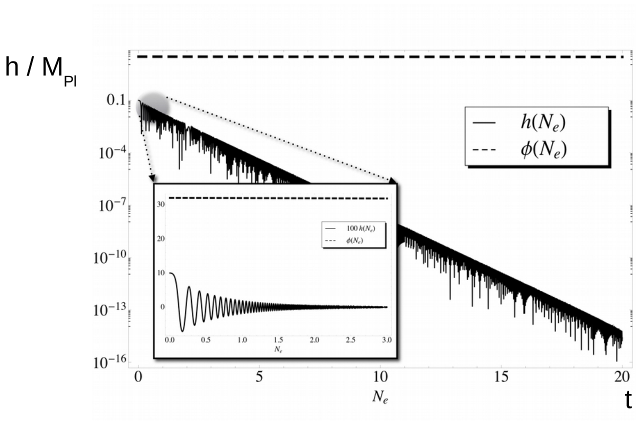
Espinosa, Giudice,Riotto '07
Herranen, Markkanen, Nurmi, Rajantie '14

$$-\mathcal{L}_{hR} = \xi_h H^\dagger H \hat{R}$$

OL, Westphal '12

$$-\mathcal{L}_{h\phi} = \lambda_{h\phi} H^\dagger H \phi^2$$

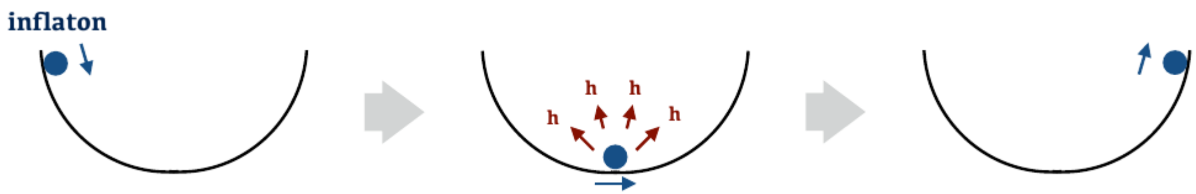
Large effective mass term ~ $\lambda_{h\phi}\ \phi^2$ ⇨ h(t) ~ h(0) exp (- 3/2 Ht)



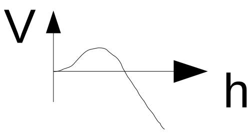
Karciauskas '14
Herranen, Markkanen,Nurmi,Rajantie '15
Ema, Mukaida, Nakayama '16
Enqvist, Karciauskas,OL, Rusak, Zatta '16

However, the same effect may destabilize the Higgs during **preheating**:

Kofman, Linde , Starobinsky '98



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



destabilization

Relatively small window of viable couplings

2. Correct the Higgs potential at all epochs

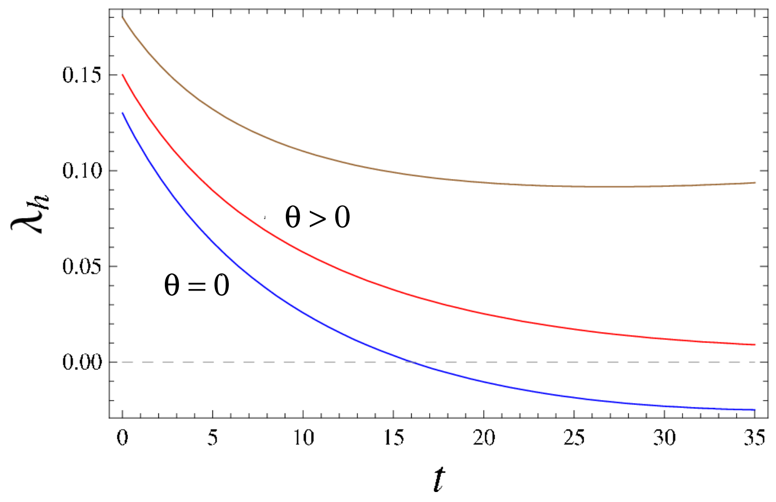
Ema, Karciauskas, OL, Zatta '17

Minimal option: **use inflaton** $\Delta L \sim \phi H^\dagger H$

Two mass eigenstates $h_{1,2}$ with mixing angle θ :

$$2\lambda_h v^2 = m_1^2 \cos^2\theta + m_2^2 \sin^2\theta$$

λ_h increases for $m_2 > m_1$!



$t = \ln(\mu/m_t)$

- Tree level effect
- Affects boundary conditions
- Complete stability

Ema, Karciauskas, OL, Zatta ‘17

The set-up: Higgs (h) + inflaton (ϕ)

Include all dim-4 terms (no symmetry) :

$$S = \int d^4x \sqrt{-\hat{g}} \left[\frac{1}{2}\Omega^2 \hat{R} - \frac{1}{2}\hat{g}^{\mu\nu}\partial_\mu\phi\,\partial_\nu\phi - \frac{1}{2}\hat{g}^{\mu\nu}\partial_\mu h\,\partial_\nu h - V(\phi,h) \right]$$

$$\Omega^2 = 1 + \xi_\phi \phi^2 + \xi_h h^2 \,,$$

$$V(\phi,h) = \frac{\lambda_h}{4}h^4 - \frac{\mu_h^2}{2}h^2 + \frac{\lambda_{h\phi}}{2}h^2\phi^2 + \sigma h^2\phi + \frac{\lambda_\phi}{4}\phi^4 + \frac{b_3}{3}\phi^3 - \frac{\mu_\phi^2}{2}\phi^2 + b_1\phi \,,$$

Inflation is driven by ϕ with $\xi_\phi \gg 1$ (à la Bezrukov-Shaposhnikov) :

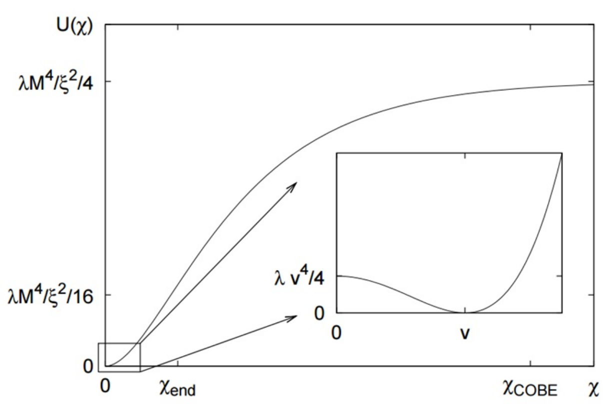


Fig. 1. Effective potential in the Einstein frame.

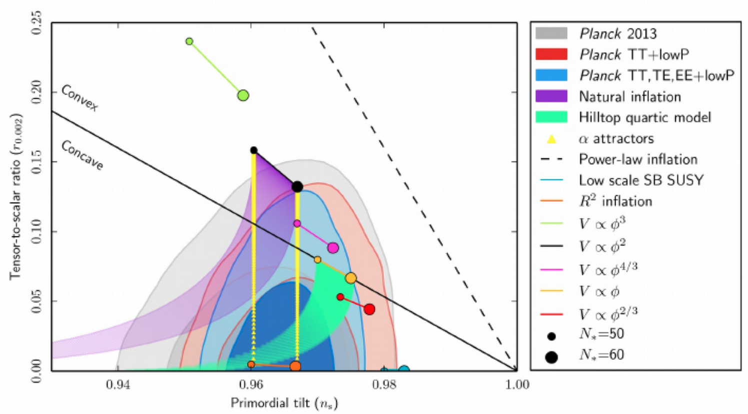


Fig. 12. Marginalized joint 68 % and 95 % CL regions for n_s and $r_{0.002}$ from *Planck* in combination with other data sets, compared to the theoretical predictions of selected inflationary models.

High energy constraints :

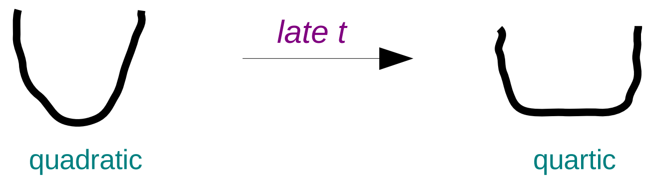
$\lambda_\phi < 10^{-5}$ ➡ no unitarity issues

$\lambda_{h\phi} < 10^{-2}$ ➡ no large rad. corrections

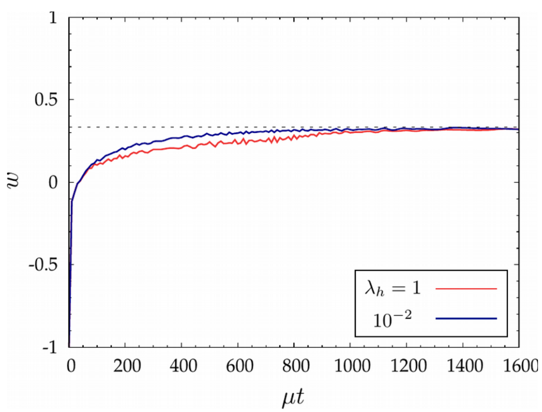
(also assume a single scale ➡ TeV dimensionful parameters)

Preheating :

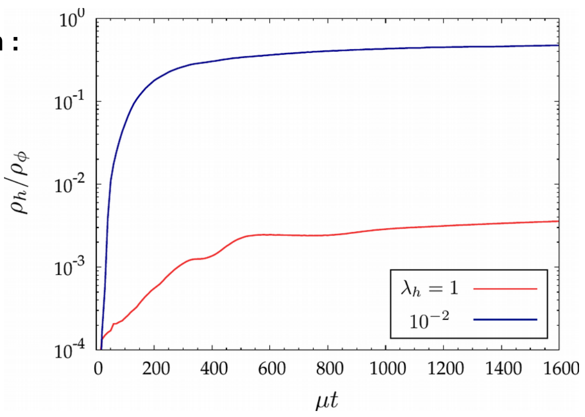
V_{inflaton} :



Equation of state:



Higgs production :

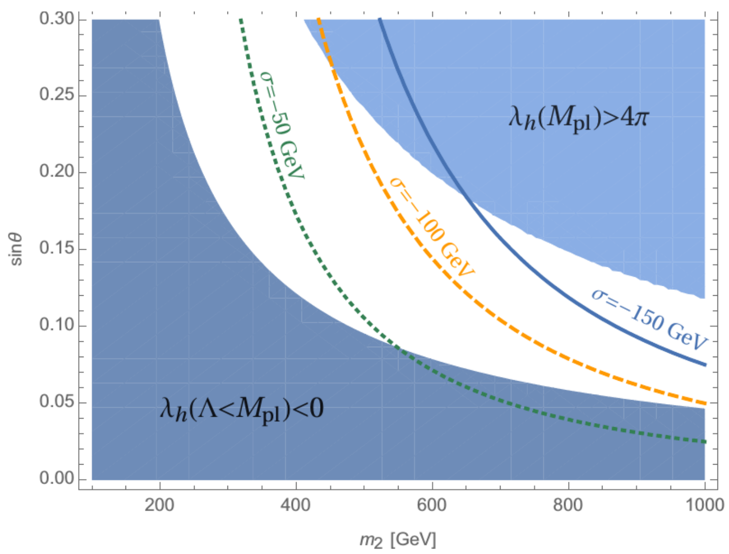


Reheating :

$\phi + \phi \rightarrow h + h$ ➡ $T_{reh} > 10^{12}$ GeV

ϕ freezes-out and decays $\phi \rightarrow h + h$

Vacuum stability :



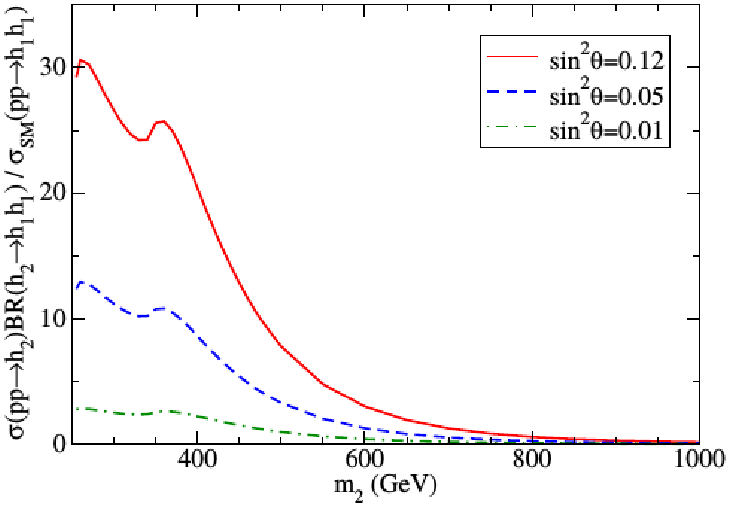
$$\sigma' v = \frac{\sin 2\theta}{4}\left(m_1^2 - m_2^2\right)$$

the trilinear interaction is crucial for the mixing

Inflaton search at LHC :

- Universal Higgs coupling reduction
- Heavy Higgs–like resonance
- Resonant decay $h_2 \to h_1 h_1$

Lewis, Sullivan '17



CONCLUSION

– Higgs-inflaton mixing generally expected

– naturally generated by $\phi H^\dagger H$

– can fully stabilize the EW vacuum

– healthy inflation/reheating

– single mass scale (TeV) $\rightarrow$ second "Higgs" at the LHC