Higgs-Cosmology Interplay

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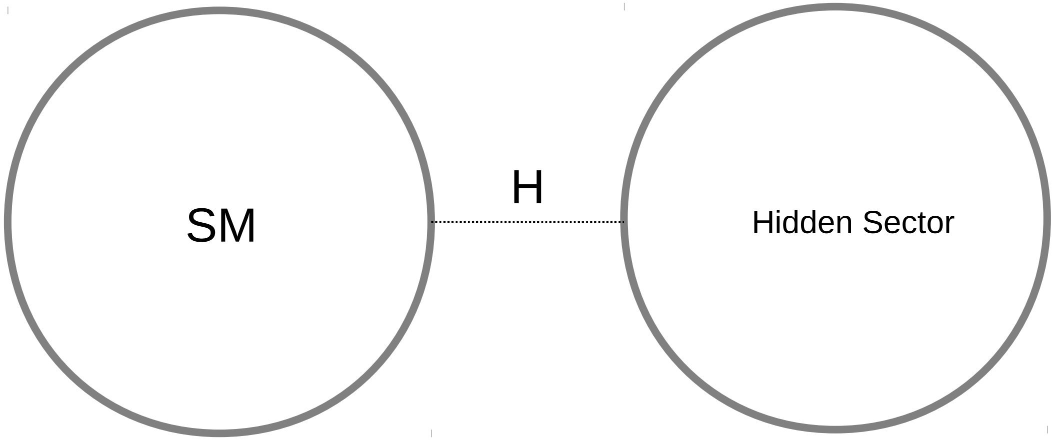
- the Higgs and the hidden sector
- the Higgs and dark matter
- the Higgs and inflation

The Higgs and the hidden sector



Lowest order operators ("Higgs Portal") :

$\bar{H} H\, S^2$ + … (scalar)

$\bar{H} H\, V_\mu V^\mu$ + … (vector)

$\bar{H} H\, \bar{\chi}\, \chi\, / \,\Lambda$ + … (fermion)

"Portal" due to Patt, Wilczek'06 (earlier : Silveira, Zee'85 ; Shabinger, Wells'05 ; ...)

Special role of the Higgs :

Silveira, Zee '85
Veltman, Yndurain '89
...

$|H|^2$ = the only gauge and Lorentz-inv. dim-2 operator

$$L = a\,|H|^2 S^2 + b\,|H|^2 S$$

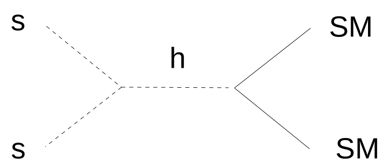
(S = “hidden” scalar)

b=0 (S has hidden charge):

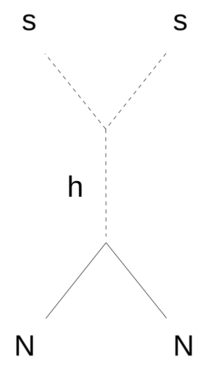
$$L = a\,|H|^2 S^2$$

“S” is stable and couples weakly to SM ⇒ DARK MATTER (?)

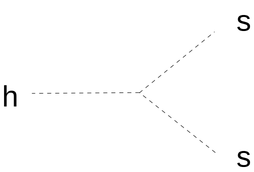
Dark matter:



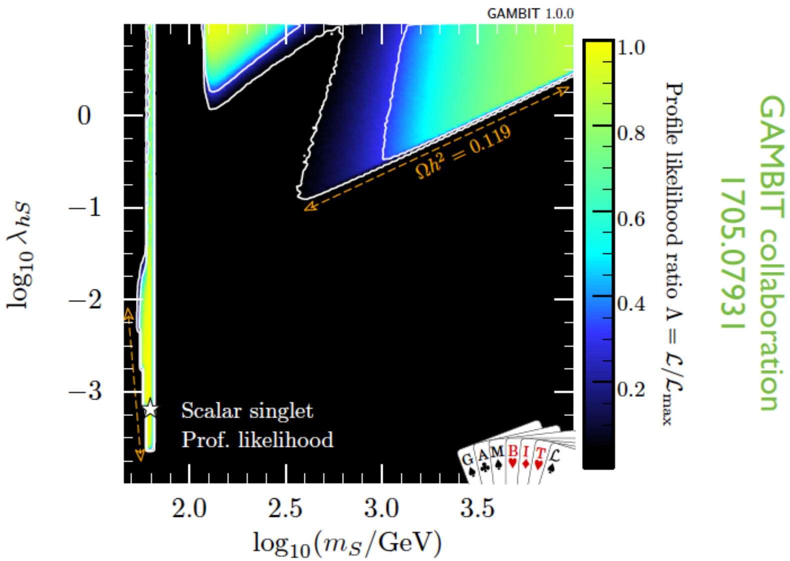
DM annihilation



DM direct detection

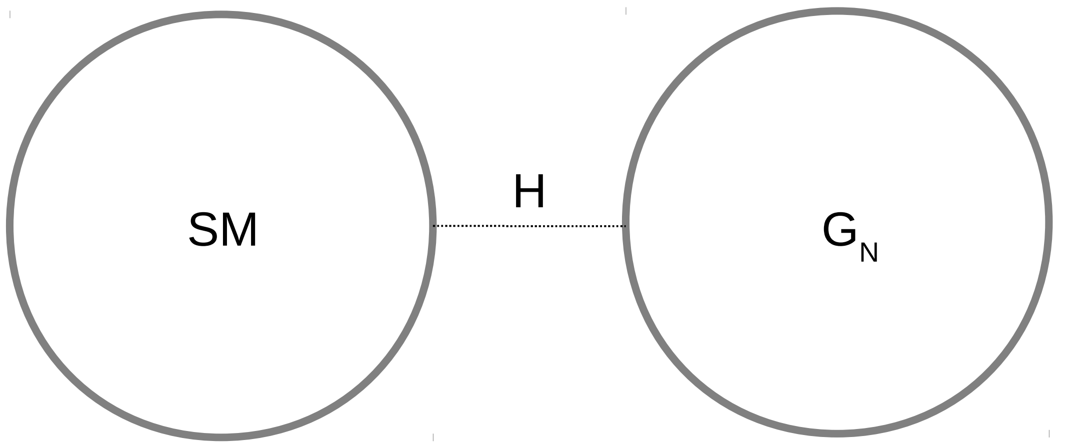


Higgs decay



white contour = 2 σ bound

The Higgs and vector dark matter



$V \sim \bar{H}H\,\bar{S}S$ ⇨ H-S mixing ⇨ **h** **couples to** **G_N**

Lie groups possess discrete symmetries

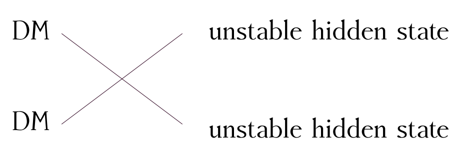
gauge fields as dark matter

E.g. U(1) : $A_\mu \rightarrow -A_\mu$

Gross, OL, Mambrini '15

Minimal G_N breaking implies:

- Vector DM — A_μ
- Multicomponent DM — A_μ , χ
- ”Secluded” DM

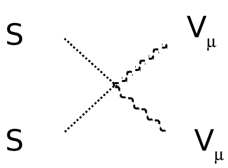


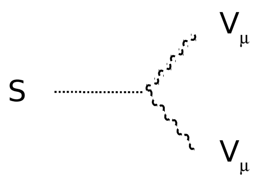
(à la Pospelov et al. ’07)

Higgs mechanism in the hidden sector :

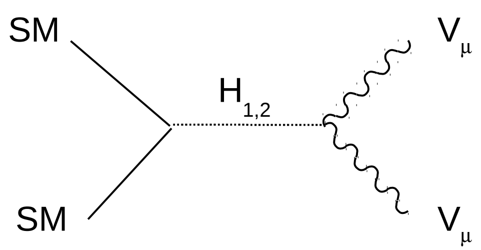
$$L \ = \ -1/4 \ F_{\mu\nu} \ F^{\mu\nu} \ + \ D_\mu S^* \ D^\mu S \ - \ V(S) \ + \ \lambda/4 \ \bar{H} H \ S^* S$$

$$S \longrightarrow \text{VEV}$$





SM couplings:



$\Rightarrow$ Z_2

gauge invariance (+ minimal field content)

⇓

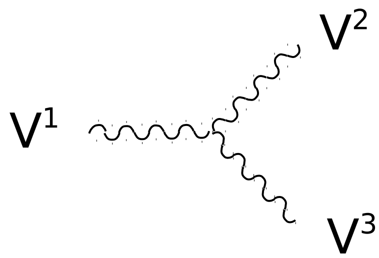
Z_2

⇓

gauge fields are natural DM candidates

Hambye '08
Gross,OL, Mambrini '15

Non-abelian case:



⇒ Z_2 odd

But there are 2 Z_2's:

$V^{1,2} \to -V^{1,2}$, $V^3 \to V^3$

$V^{1,3} \to -V^{1,3}$, $V^2 \to V^2$

⇒ V^a = stable

gauge transform

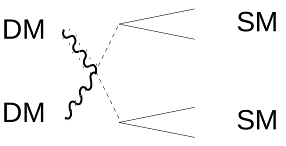
charge conjugation

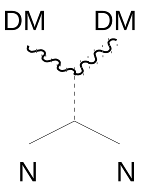
Arcadi, Gross, OL, Pokorski, Toma '16
Hambye '08

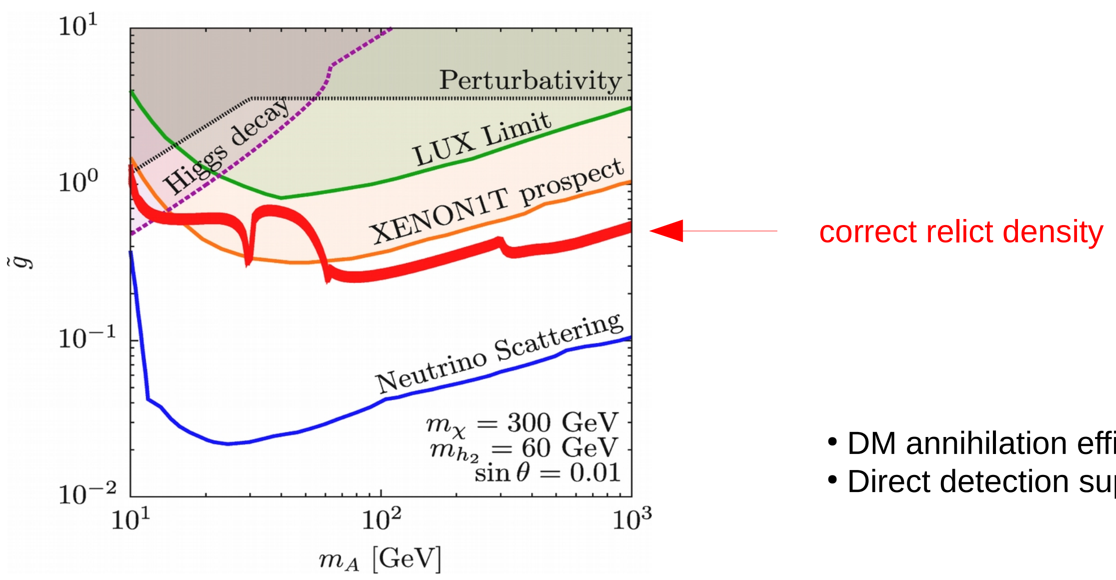
Advantage over the simplest Higgs portal DM:

there exists another hidden sector state which

- ***can be lighter than DM***
- ***is unstable***







- DM annihilation efficient
- Direct detection suppressed

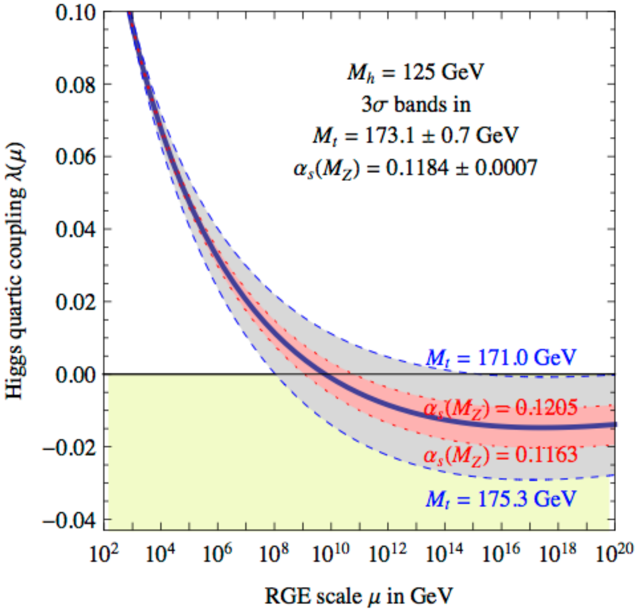
Higgs portal DM = viable WIMP

(especially if there's more than one state in the hidden sector)

The Higgs and inflation

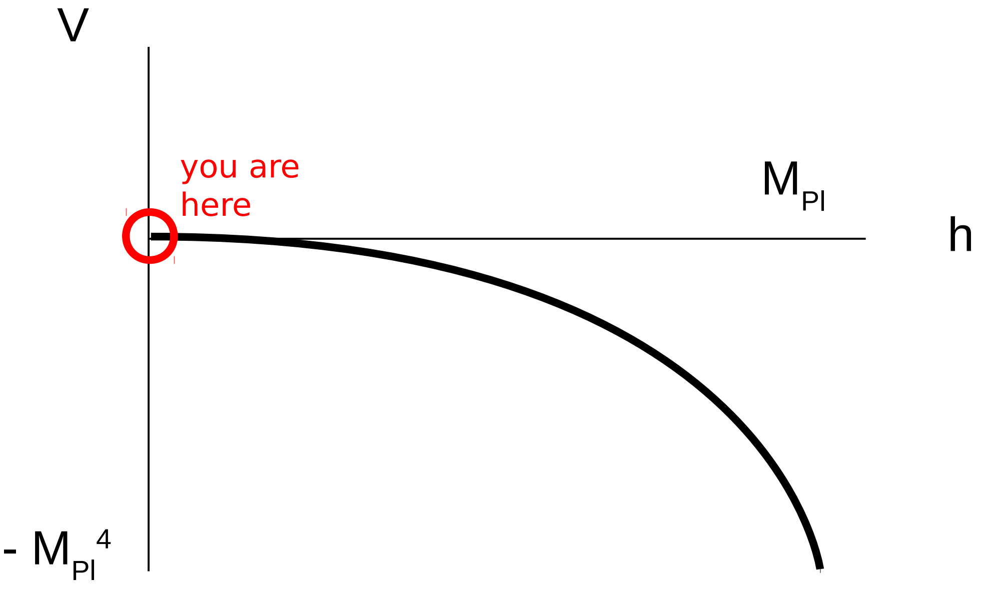
Buttazzo et al.'13

SM stability bound: $m_h > (129.6 \pm 1.5)$ GeV



(not settled : Alekhin et al. '12
Bezrukov et al. '12)

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



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

Problems :

- how did the Universe end up at h ~ 0 ?

- why did it stay there during inflation ?

Solutions :

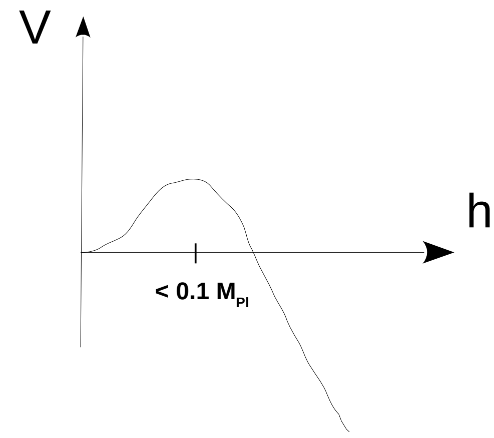
- modify the Higgs potential during inflation

- just modify the Higgs potential

Minimal solution:

Higgs-inflaton coupling: $$\Delta V = \tfrac{1}{2}\, \lambda_{h\phi}\, h^2 \phi^2$$ ("Higgs portal" coupling)

$\Delta V + V_{SM}$:



For all initial values of h up to 0.1 M_{pl} the h-potential is convex
(higher h-values → Planckian density)

Constraints:

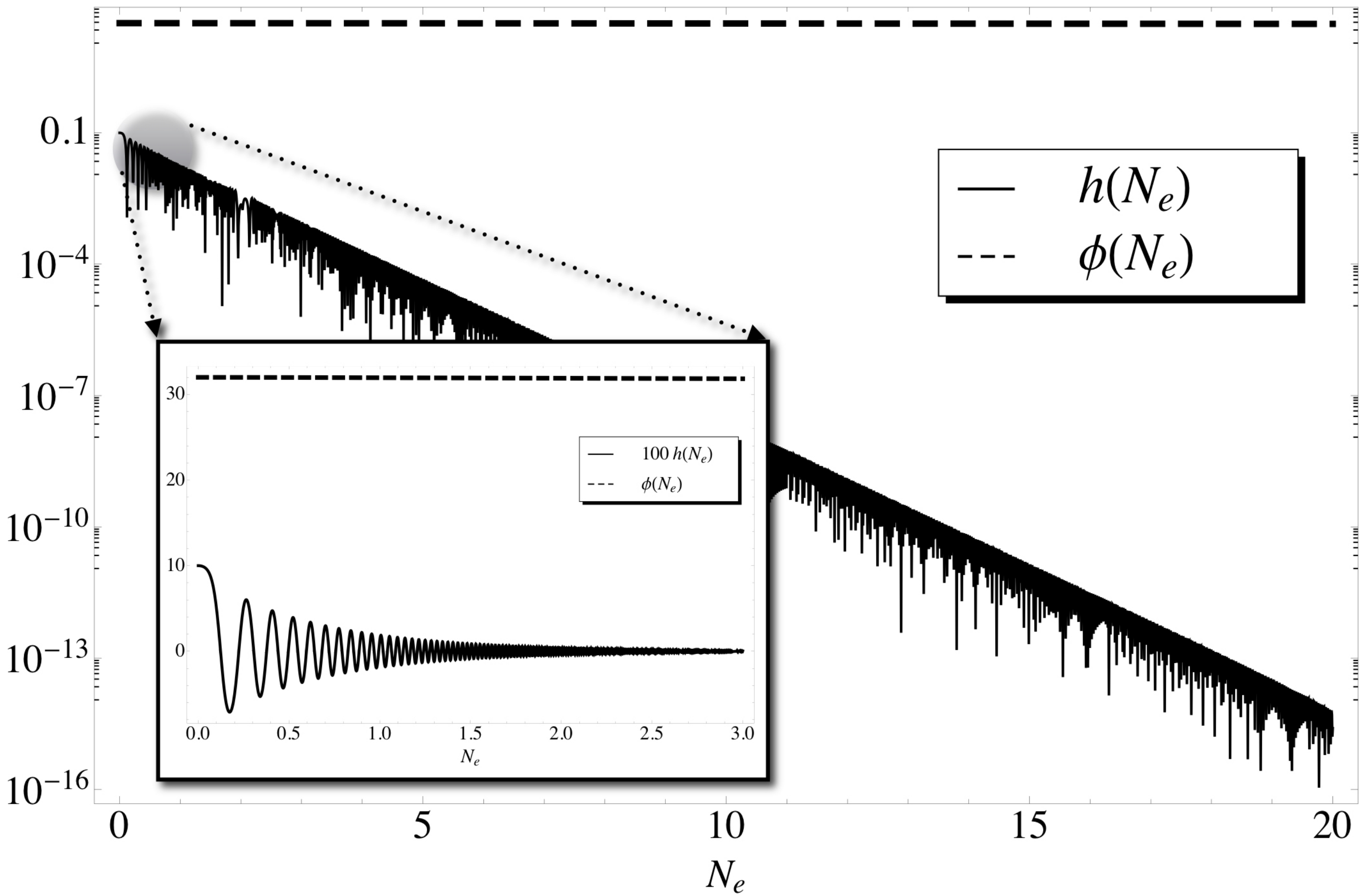
- should not affect V_{infl} → $\lambda_{h\phi} < 10^{-6}$
- $\Delta V + V_{SM} > 0$ → $\phi_0 > 20\ M_{Pl}$

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

Higgs field is driven to zero during inflation !

Higgs/inflaton evolution (in M_{Pl}):

OL, Westphal ' 12

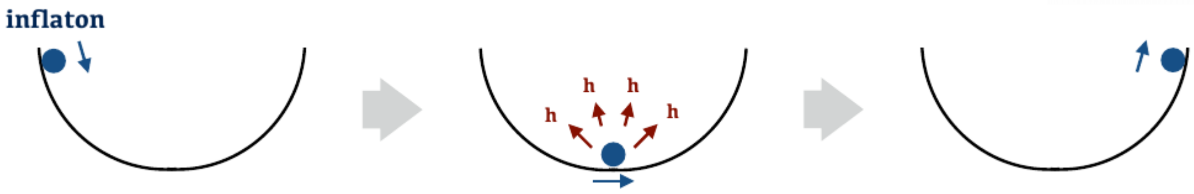


Karciauskas '14
Herranen, Markkanen,Nurmi,Rajantie '15
Ema, Mukaida, Nakayama '16
Enqvist, Karciauskas,OL, Rusak, Zatta '16

Higgs vacuum destabilization through preheating

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

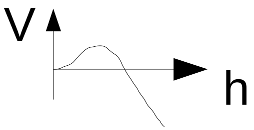
$\phi \simeq \Phi \cos mt$ with $\Phi \sim \Phi_0\, a^{-3/2}$



Kofman, Linde , Starobinsky '98

$\Delta V = \frac{1}{2} \lambda_{h\phi} h^2 \phi^2$ ⇨ parametric resonance

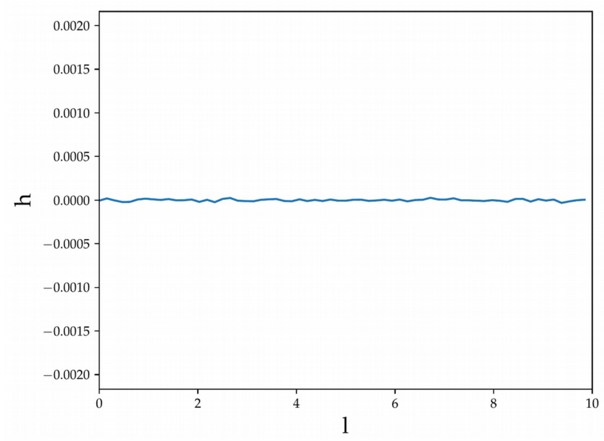
$\langle h^2 \rangle \propto$ Number of Higgs quanta



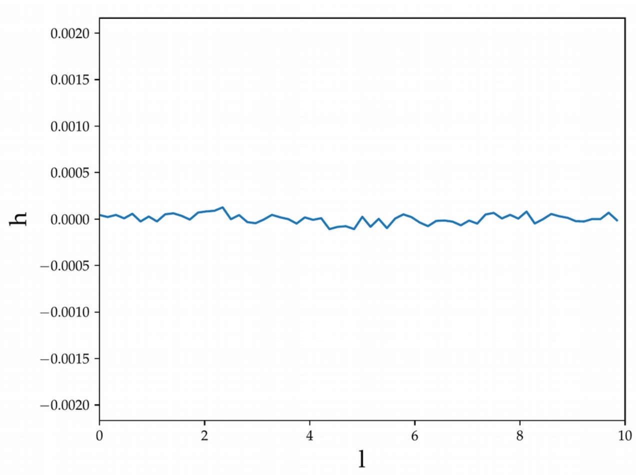
⇨ destabilization

Lattice results:

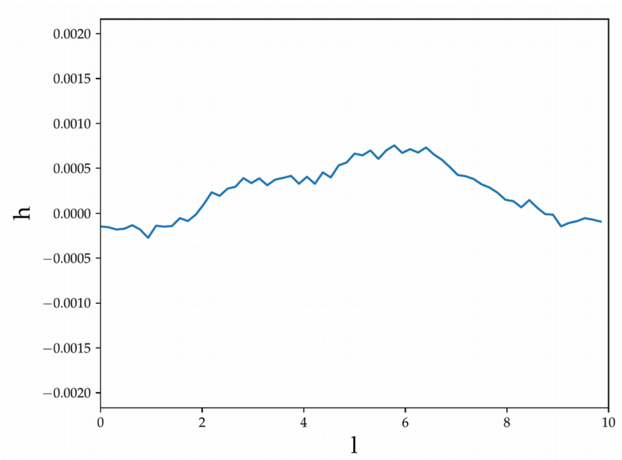
t=0



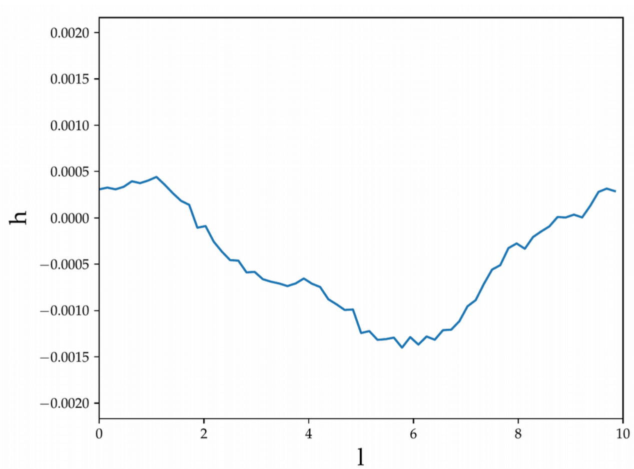
t=15



t=27



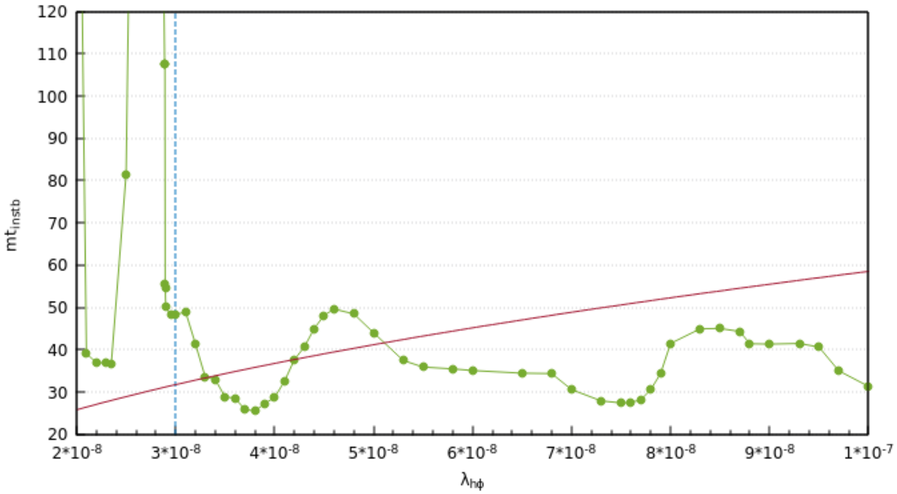
t=30



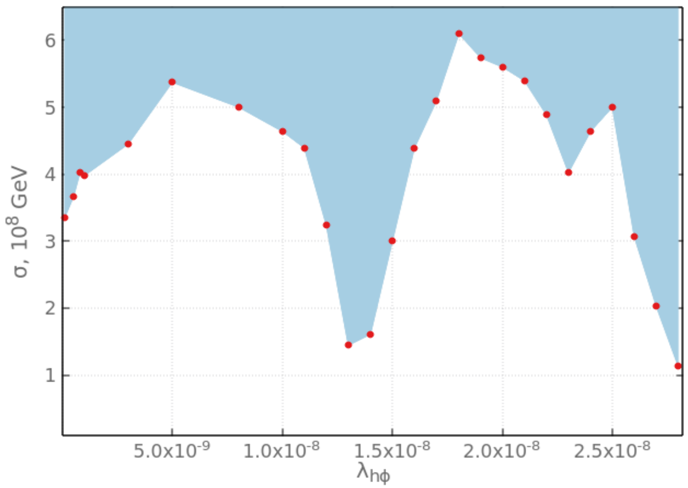
Enqvist, Karciauskas,
OL, Rusak, Zatta '16

Bounds on the Higgs-inflaton couplings :

quartic :



trilinear :



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

$\sigma < 10^{8}$ GeV

Conclusion

- Higgs sector is special
- key to the hidden sector / DM / inflation
- Higgs portal DM viable
- Higgs-inflaton interaction crucial