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# The Higgs and Cosmology

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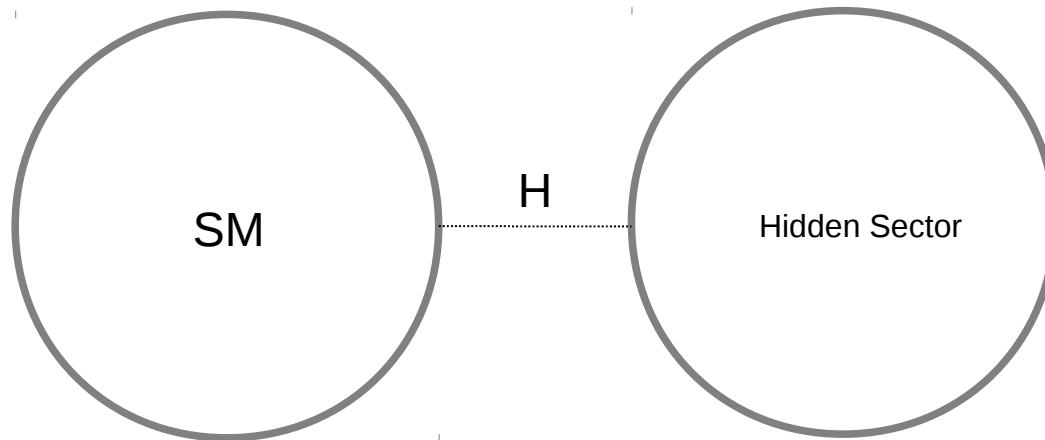
Oleg Lebedev



**University of Helsinki**

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



Lowest order operators (“Higgs Portal”) :

$$\bar{H}H S^2 \quad + \quad \dots \quad (\text{scalar})$$

$$\bar{H}H V_{\mu} V^{\mu} \quad + \quad \dots \quad (\text{vector})$$

$$\bar{H}H \bar{\chi} \chi / \Lambda \quad + \quad \dots \quad (\text{fermion})$$

”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

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

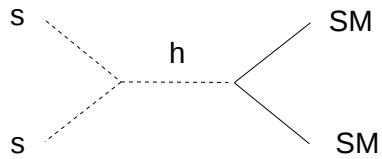
( S = "hidden" scalar )

b=0 (S has hidden charge):

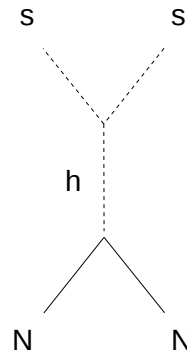
$$L = a |H|^2 S^2$$

"S" is stable and couples weakly to SM  $\Rightarrow$  **DARK MATTER** (?)

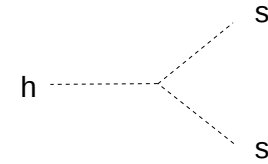
# Dark matter:



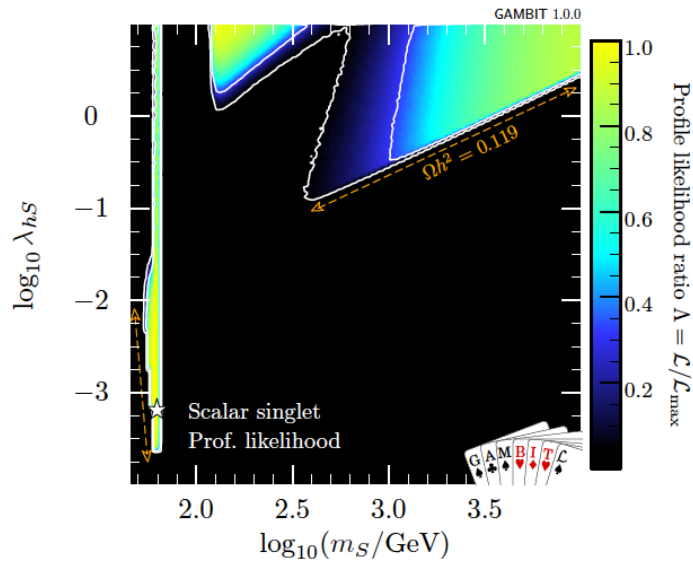
DM annihilation



DM direct detection



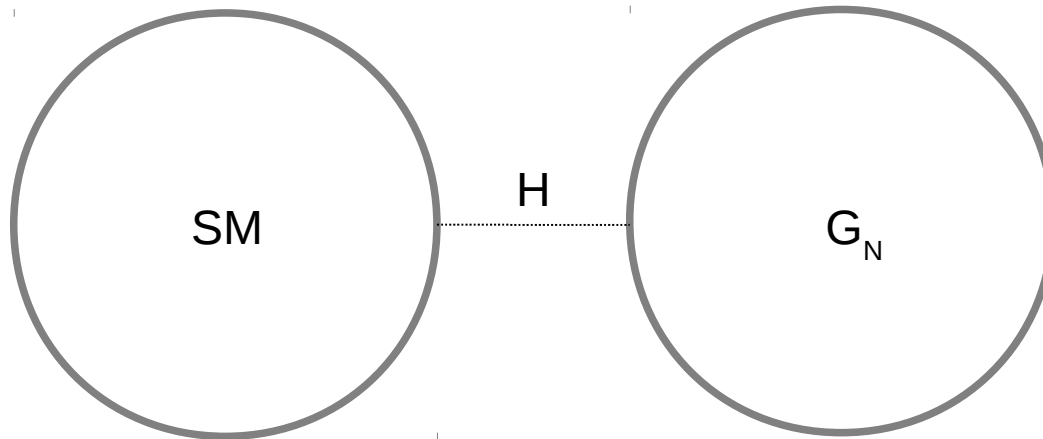
Higgs decay



GAMBIT collaboration  
1705.07931

white contour = 2  $\sigma$  bound

# The Higgs and vector dark matter



$$V \sim \bar{H} H \bar{S} S$$

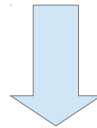


H-S mixing



**h couples to  $G_N$**

Lie groups possess discrete symmetries



gauge fields as dark matter

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

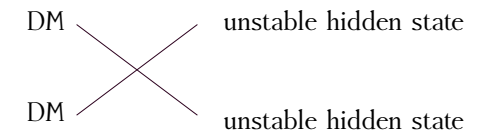


Minimal  $G_N$  breaking implies:

- Vector DM
- Multicomponent DM
- "Secluded" DM

$$A_\mu$$

$$A_\mu, \chi$$



(à la Pospelov et al. '07)

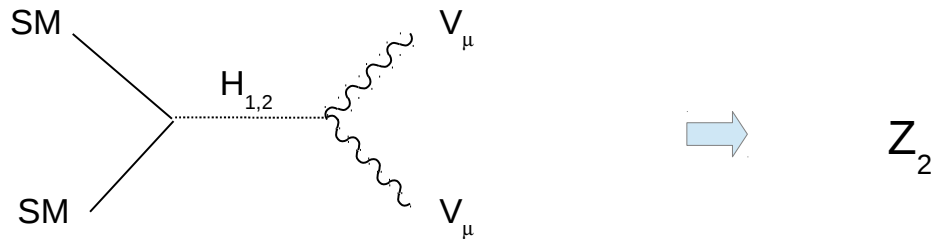
## Higgs mechanism in the hidden sector :

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

$S \longrightarrow \text{VEV}$

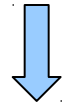


SM couplings:

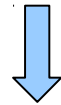


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gauge invariance (+ minimal field content)



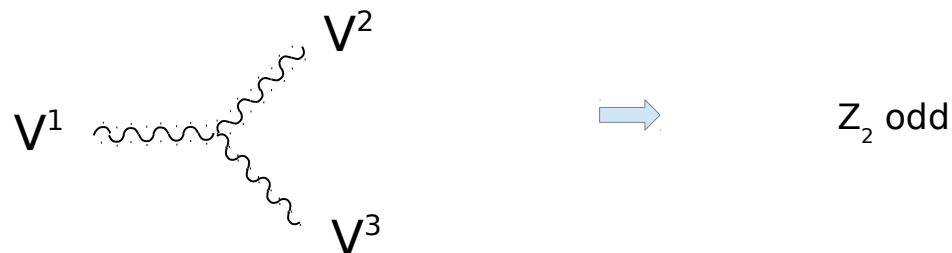
$Z_2$



gauge fields are natural DM candidates

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Non-abelian case:



But there are 2  $Z_2$ 's:

*gauge transform* ↙

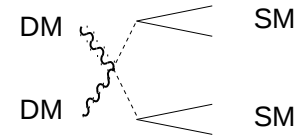
*charge conjugation* ↙

$$\begin{aligned} V^{1,2} &\rightarrow -V^{1,2} & , & & V^3 &\rightarrow V^3 \\ V^{1,3} &\rightarrow -V^{1,3} & , & & V^2 &\rightarrow V^2 \end{aligned} \quad \Rightarrow \quad V^a = \text{stable}$$

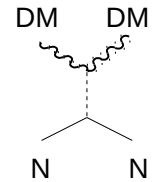
## Advantage over the simplest Higgs portal DM:

there exists another hidden sector state which

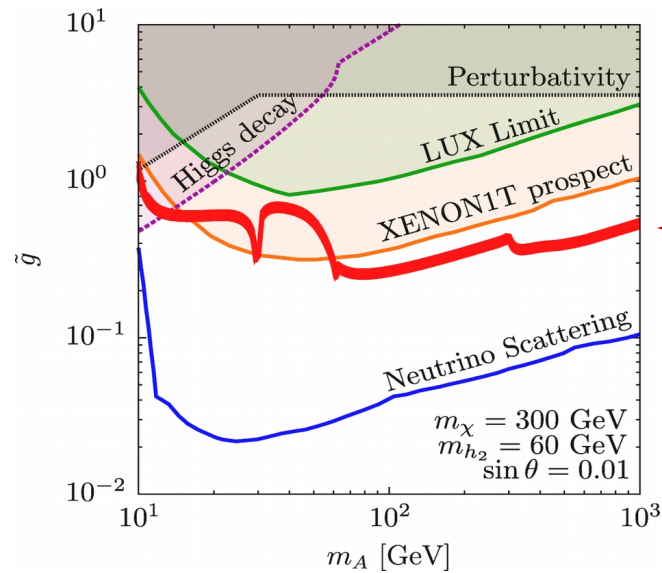
- *can be lighter than DM*
- *is unstable*



$\sim \cos \theta$



$\sim \sin \theta$



correct relic density

- DM annihilation efficient
- Direct detection suppressed



**Higgs portal DM = viable WIMP**

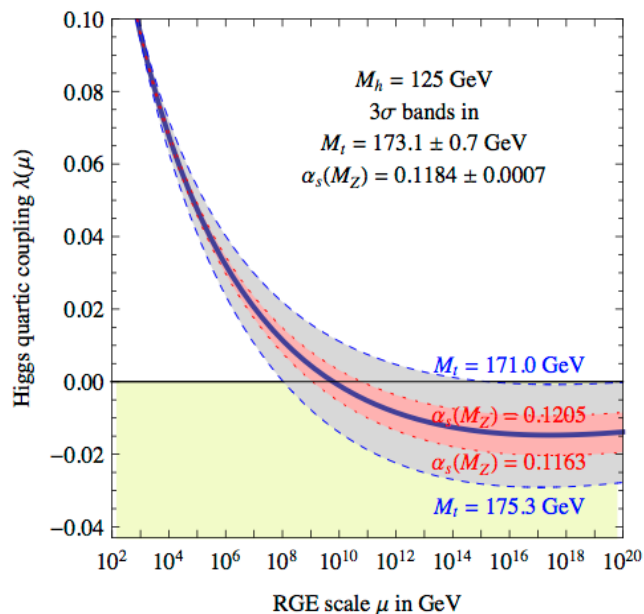
(especially if there's more than one state in the hidden sector )

# The Higgs and inflation

Buttazzo et al. '13

SM stability bound:

$$m_h > (129.6 \pm 1.5) \text{ GeV}$$

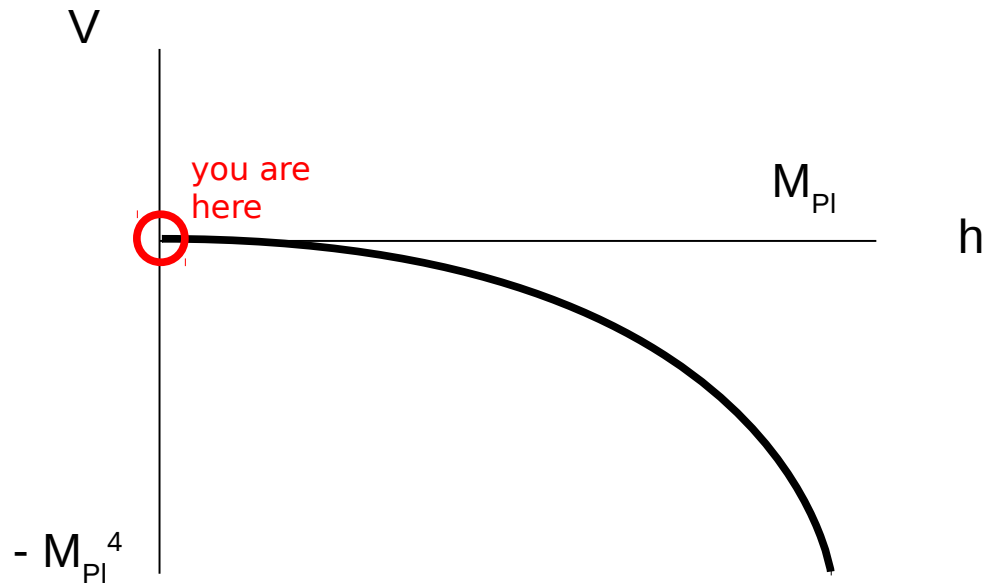


(not settled : Alekhin et al. '12  
Bezrukov et al. '12)

$$h \gg \Lambda \sim 10^{10} \text{ GeV}$$



$$V \sim \frac{1}{4} \lambda(h) h^4, \quad \lambda(h) < 0$$



$$\Lambda = 10^{-8} M_{\text{Pl}}$$

,

$$\text{barrier} = 10^{-32} M_{\text{Pl}}^4$$

Problems :

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

Solutions :

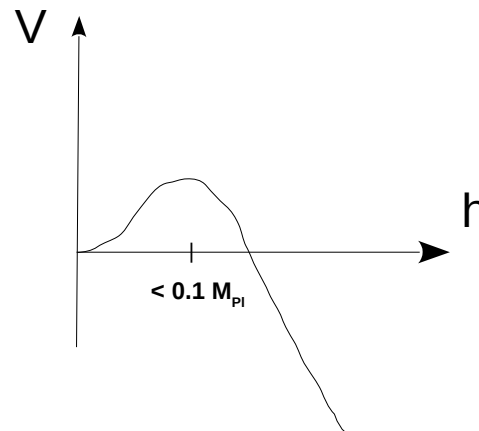
- modify the Higgs potential during inflation
- just modify the Higgs potential

Minimal solution:

Higgs-inflaton coupling:

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

("Higgs portal" coupling)

 $\Delta V + V_{SM} :$ 

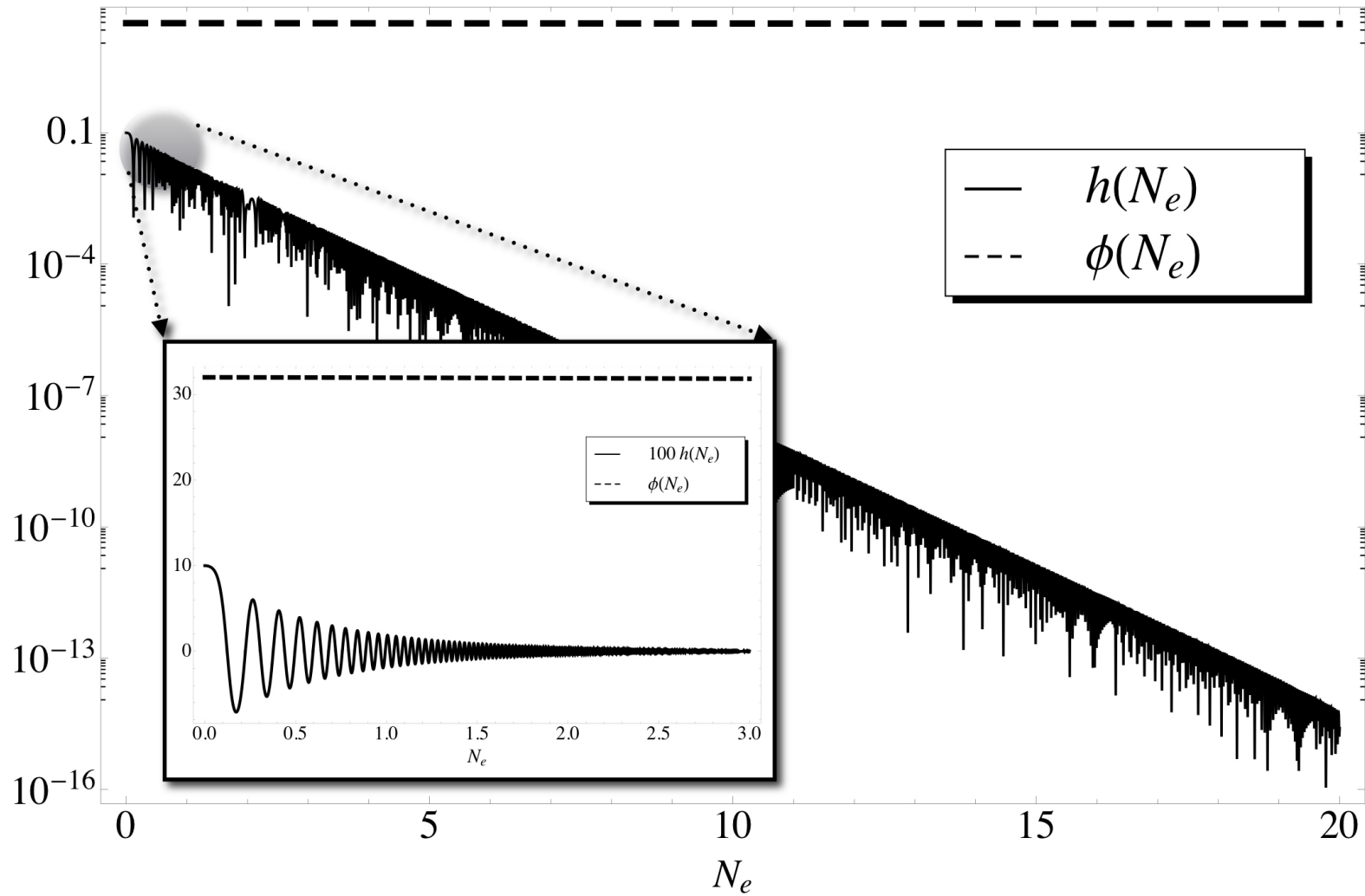
For all initial values of  $h$  up to  $0.1 M_{Pl}$ , the  $h$ -potential is convex  
(higher  $h$ -values  $\rightarrow$  Planckian density)

Constraints:

$$\left\{ \begin{array}{ll} - \text{should not affect } V_{\text{infl}} & \rightarrow \lambda_{h\phi} < 10^{-6} \\ - \Delta V + V_{\text{SM}} > 0 & \rightarrow \phi_0 > 20 M_{\text{Pl}} \end{array} \right.$$

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

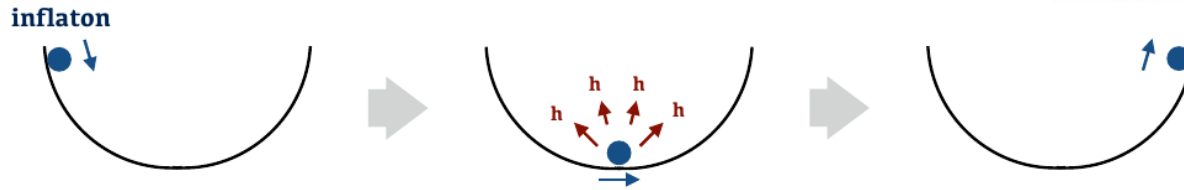
**Higgs field is driven to zero during inflation !**



# Higgs vacuum destabilization through preheating

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

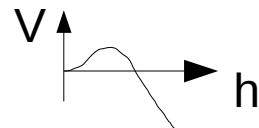
$$\phi \simeq \Phi \cos mt \quad \text{with} \quad \Phi \sim \Phi_0 a^{-3/2}$$



Kofman, Linde, Starobinsky '98

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

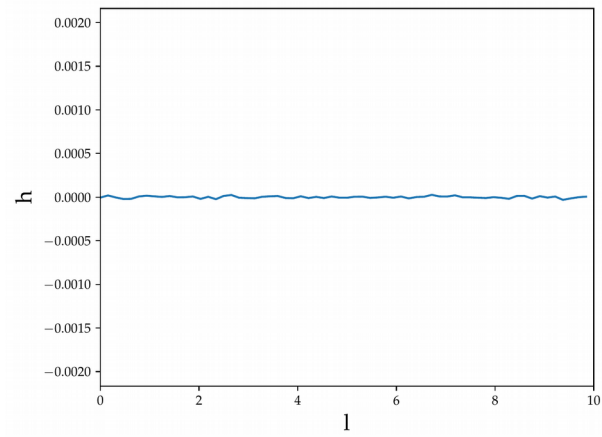
$$\langle h^2 \rangle \propto \text{Number of Higgs quanta}$$



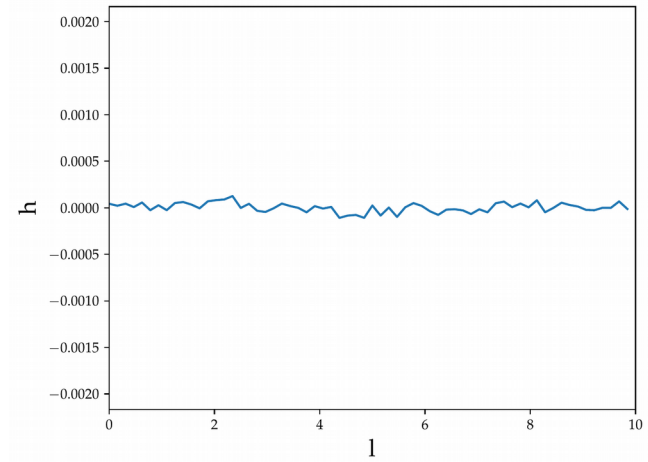
$\Rightarrow$  destabilization

## Lattice results:

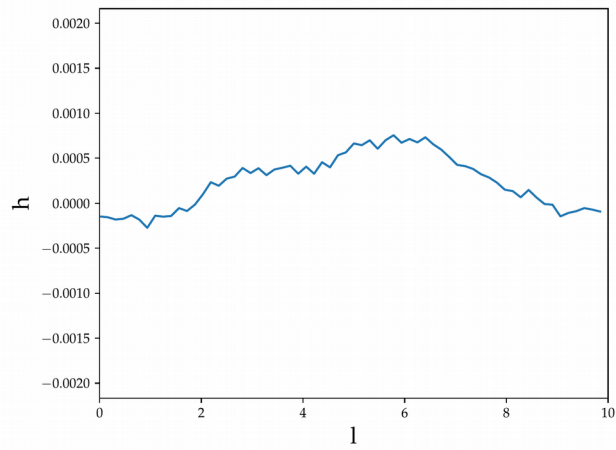
t=0



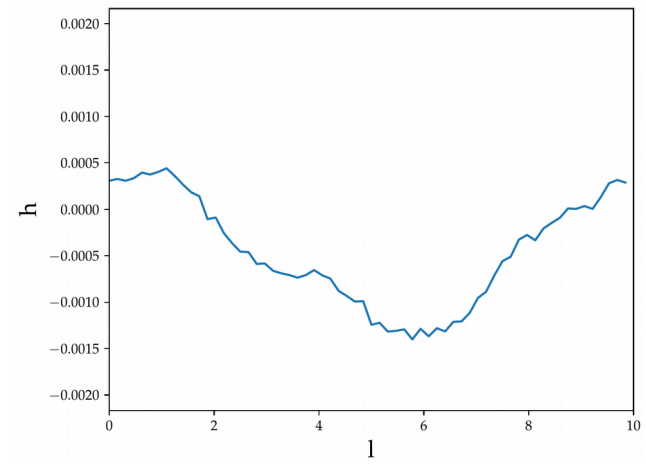
t=15



t=27

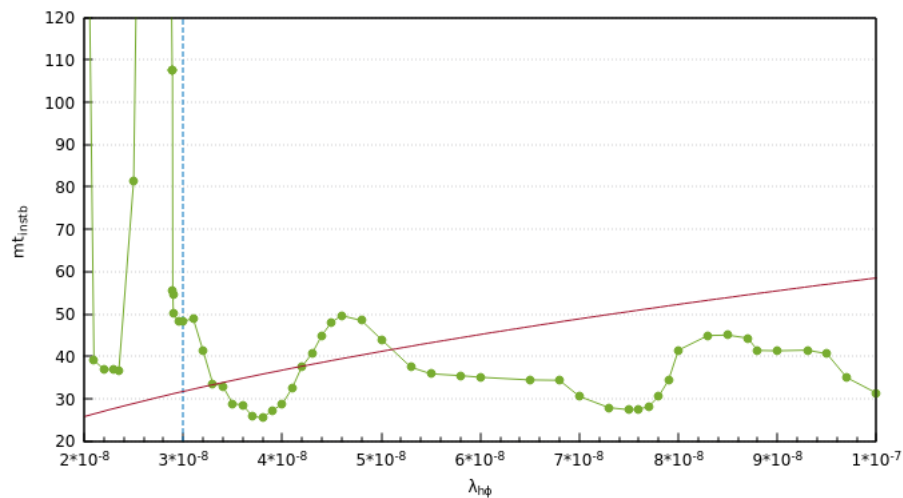


t=30



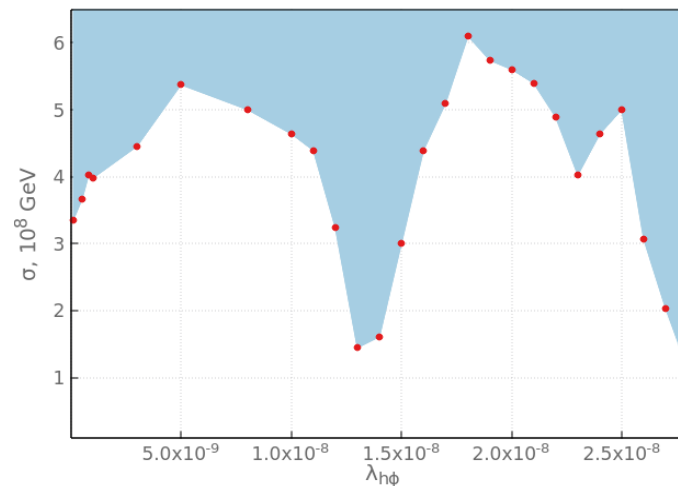
Bounds on the Higgs-inflaton couplings :

quartic :



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

trilinear :



$$\sigma < 10^8 \text{ GeV}$$

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# Conclusion

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