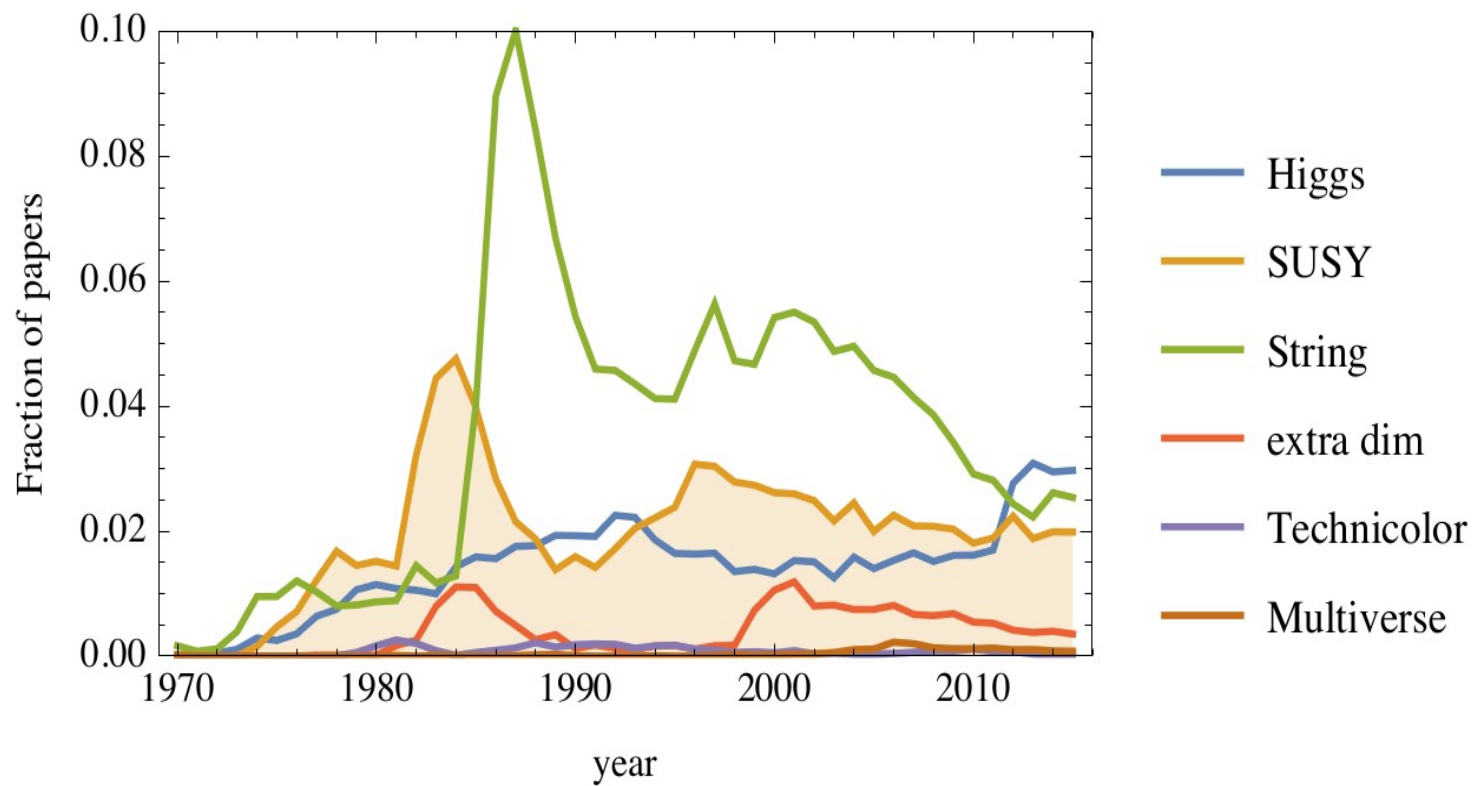

The Higgs and Cosmology

Oleg Lebedev



University of Helsinki



Project "The Higgs Boson and the Cosmos" (U. Helsinki)



Helsinki Higgs Forum

14-16 December 2016, Helsinki, Finland

Organizing committee:
Oleg Lebedev (chair)
Katri Huitu (vice chair)
Paula Eerola
Kari Enqvist

Invited speakers include:
Abdelhak Djouadi (Orsay)
Graham Ross (Oxford)
Gustavo Branco (Lisbon)
Stefano Horetti (Southampton)
Marieke Postma (NIKHEF)
Sven-Olaf Moch (Hamburg)
Matti Raidal (Tallinn)
Christophe Grojean (DESY)
Miha Henešek (Ljubljana)
Tilman Plehn (Heidelberg)
Arthur Hebecker (Heidelberg)
Kimmo Kainulainen (Jyväskylä)
Valya Khoze (Durham)
Howard Haber (Santa Cruz)*
Bernd Kniehl (Hamburg)
Per Osland (Bergen)
José Espinosa (Barcelona)
Arttu Rajantie (IC London)

(* = to be confirmed)

Are we on the right track?

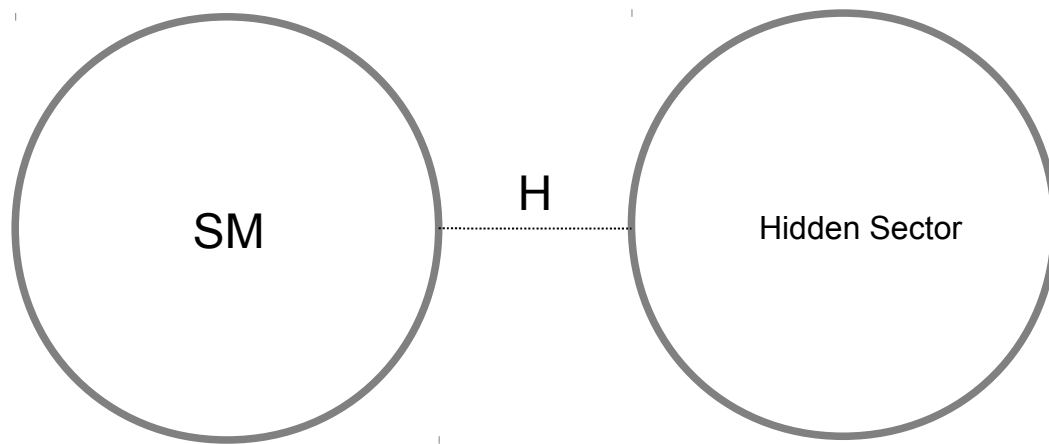
www.hip.fi/nhf

Credit: Sampsa SuLonen



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

The Higgs and the hidden sector



Special role of the Higgs :

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

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

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

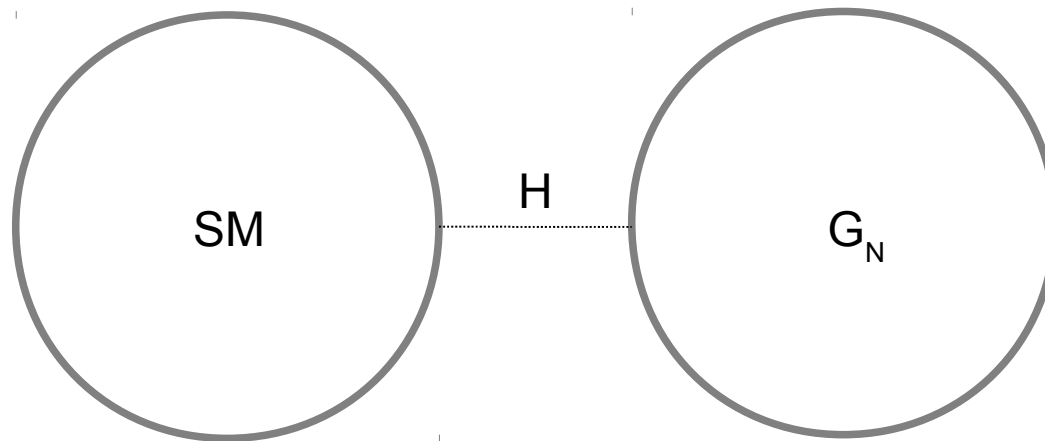
(S = "hidden" scalar)

$b=0$ (S has hidden charge):

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

" S " is stable and couples weakly to SM --> **DARK MATTER** (?)

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

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

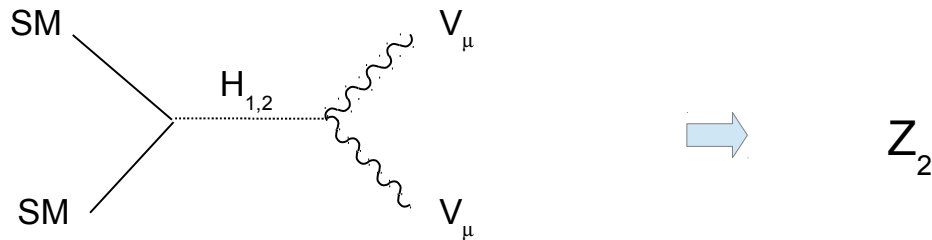
Higgs mechanism in the hidden sector :

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

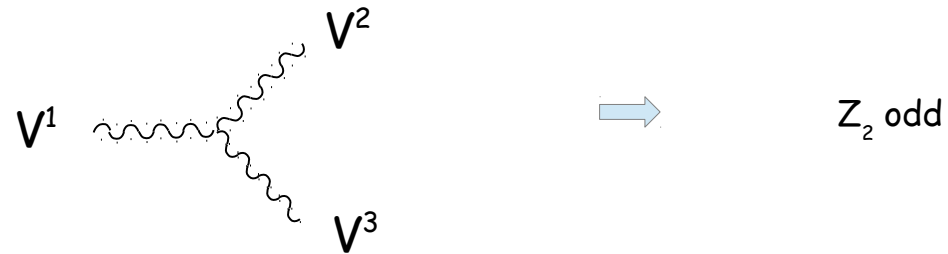
$$S \longrightarrow \text{VEV}$$



SM couplings:



Non-abelian case:



But there are 2 Z_2 's:

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

$$\text{hidden Higgs} = \begin{pmatrix} 0 \\ v \end{pmatrix}$$

$$\sigma_1 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}; \quad \sigma_2 = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}; \quad \sigma_3 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}.$$

Z_2 : reflects real generators

complex (or "charge") conjugation = outer automorphism

Z_2' : reflects off-diagonal generators with non-zero elements in the first row

gauge transformation

SU(N): $Z_2 \times Z_2$



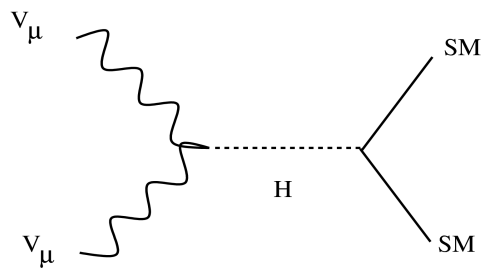
two stable components

E.g. spin1 + spin 0 DM

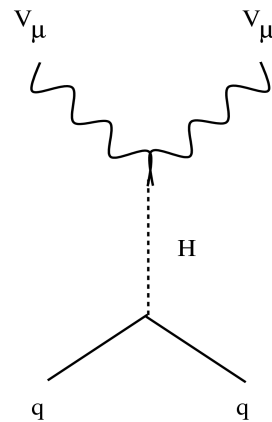
DM phenomenology :

DM-nucleon scattering

annihilation

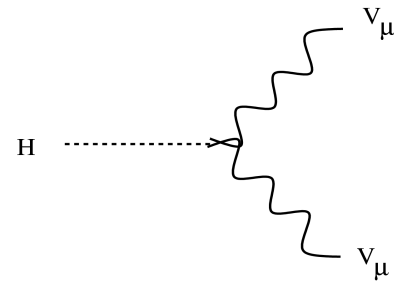


$$\langle \sigma v \rangle$$

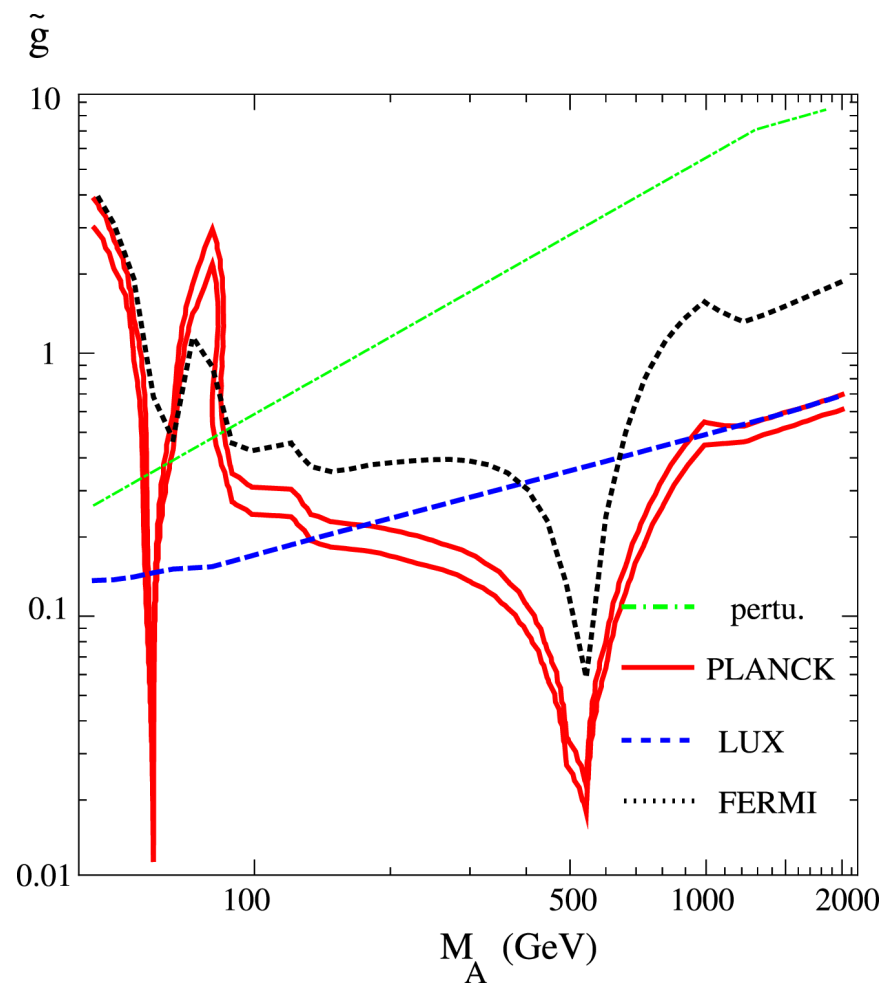


$$\sigma_{S-P}^{\text{SI}}$$

invisible Higgs decay



$$\Gamma_H^{\text{inv}}$$

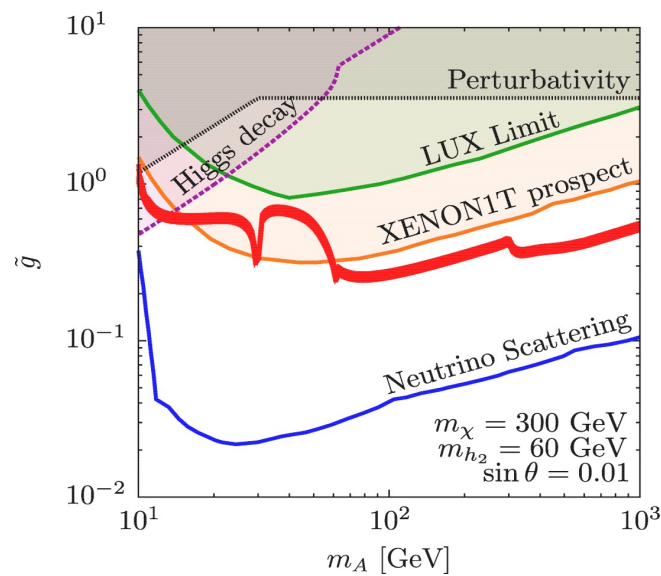


U(1)
 $\sin \theta = 0.3$

Secluded DM:

DM unstable

DM unstable



Arcadi, Gross, OL,
Pokorski, Toma '16

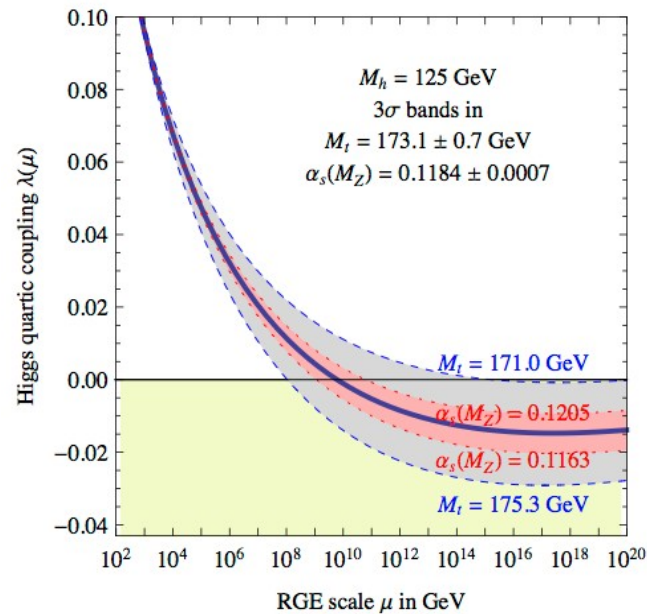
$AA \longrightarrow h_2 h_2$

The Higgs and inflation

Buttazzo et al. '13

SM stability bound:

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

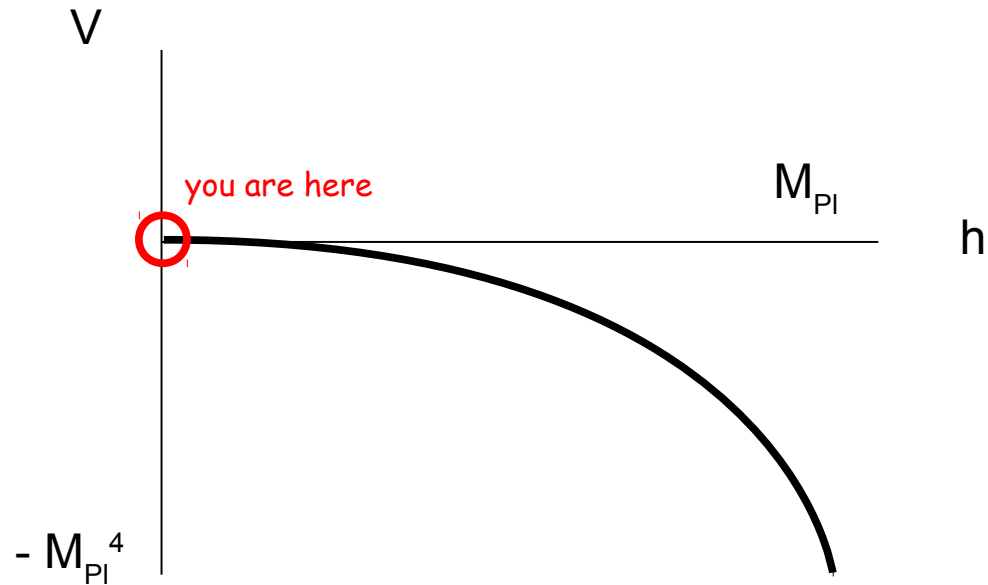


(not settled : Alekhin et al. '12
Bezrukov et al. '12)

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



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



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

,

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

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
-

Solution 1:

Higgs-inflaton coupling

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

("Higgs portal" coupling)

$$\Delta V + V_{\text{Higgs}} > 0$$



$$\phi_0 \sim 20 M_{\text{Pl}} , \quad \lambda_{h\phi} \sim 10^{-6}$$

Large effective mass term

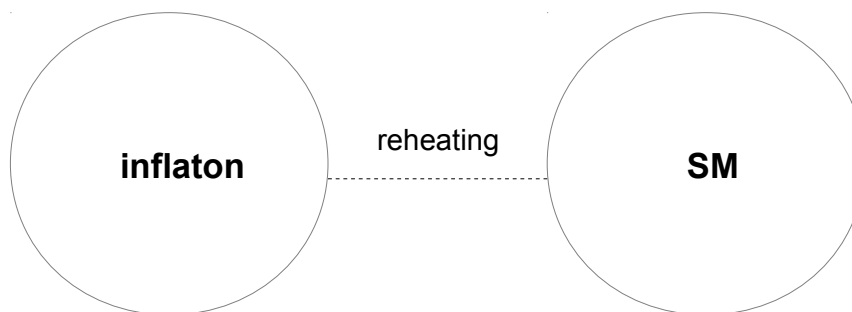


$$h(t) \sim h(0) \exp(-3/2 H t)$$

Higgs field is driven to zero during inflation !

The Higgs-inflaton coupling is

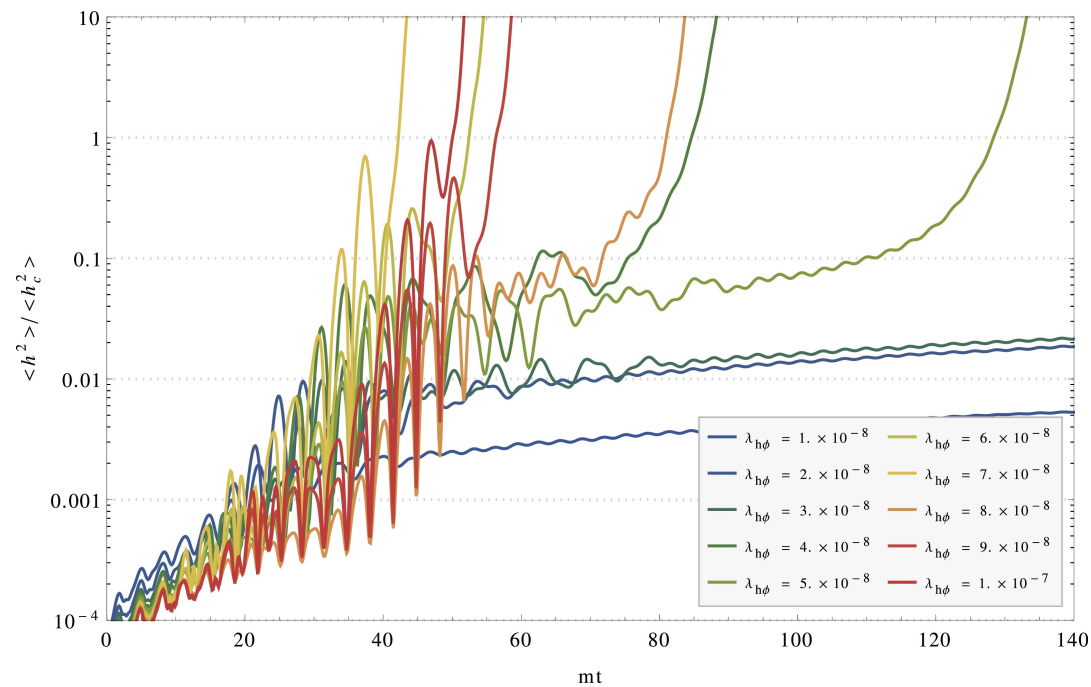
- generated radiatively
- required by renormalizability
- important if greater than 10^{-10}



Further constraints:

instability can be triggered by a resonance during preheating

Enqvist, Karciauskas, OL, Rusak, Zatta' 16



Conclusion

- Higgs sector is special
- key to the hidden sector / DM / inflation
- need precise Higgs data