The Higgs Portal

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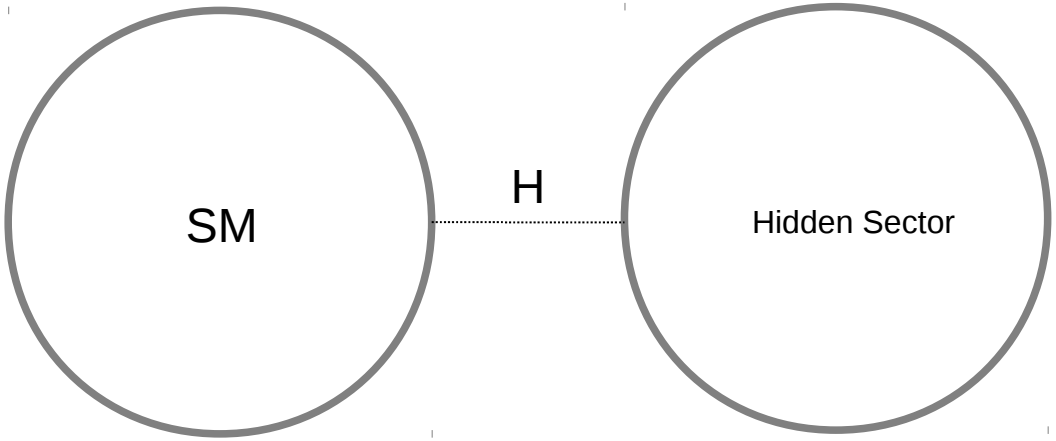
- the Higgs and the hidden sector
- the Higgs and dark matter
- the Higgs and inflation

The Higgs and the hidden sector



Special role of the Higgs :

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

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

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

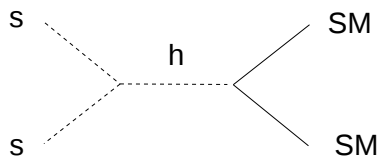
(S = “hidden” scalar)

b=0 (S has hidden charge):

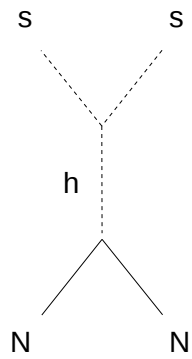
$$L = a\,|H|^2\,S^2$$

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

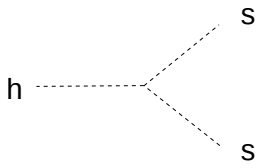
Dark matter:



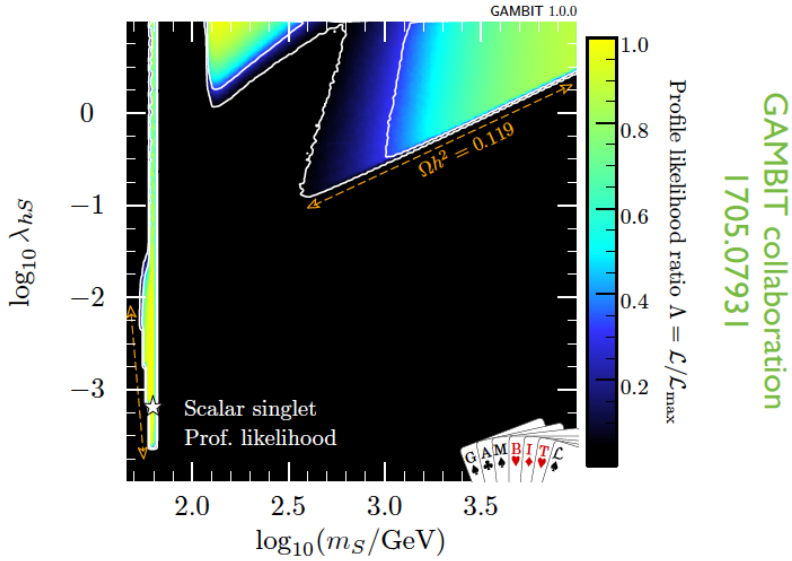
DM annihilation



DM direct detection



Higgs decay



GAMBIT collaboration
1705.07931

white contour = 2 σ bound

The Higgs portal and DD cancellation

Add a complex scalar *S* , require softly broken U(1) symmetry:

$$V = V_0 + V_{\rm soft} \ ,$$
$$V_0 = -\frac{\mu_H^2}{2}\,|H|^2 - \frac{\mu_S^2}{2}\,|S|^2 + \frac{\lambda_H}{2}|H|^4 + \lambda_{HS}|H|^2|S|^2 + \frac{\lambda_S}{2}|S|^4 \ ,$$
$$V_{\rm soft} = -\frac{\mu_S'^2}{4}\,S^2 + {\rm h.c.}$$

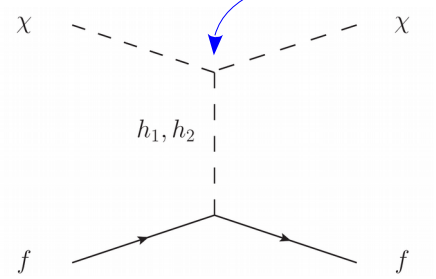
All parameters are real ⇨ <*S*> = real , $S \to S^*$ symmetry

Im *S* = Dark Matter

Gross, OL, Toma (PRL)'17

Direct detection:

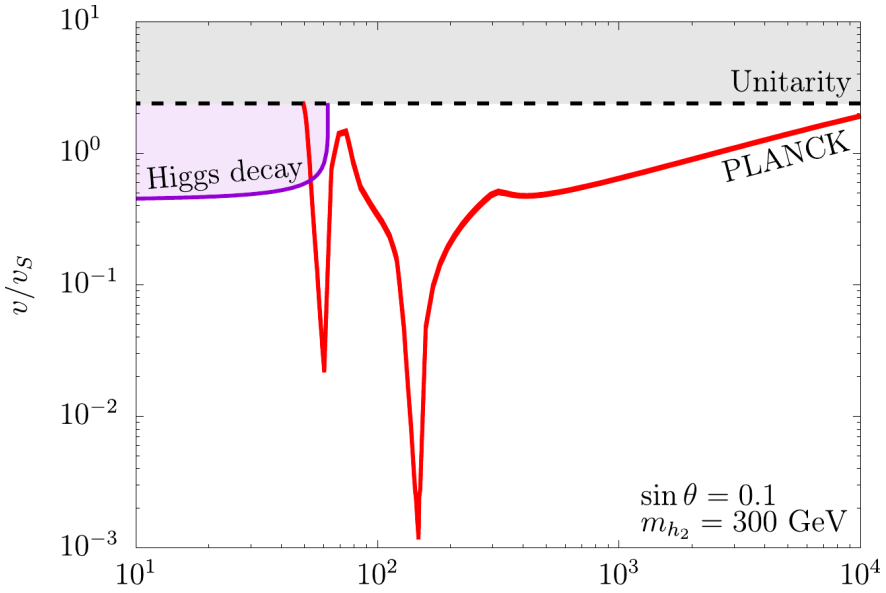
coupling$_i$ ~ m$_i^2$



Tree level:

$$\mathcal{A}_{dd}(t) \propto \sin\theta\cos\theta\left(\frac{m_2^2}{t-m_2^2}-\frac{m_1^2}{t-m_1^2}\right) \longrightarrow 0$$

Perfect cancellation for any parameter choice !



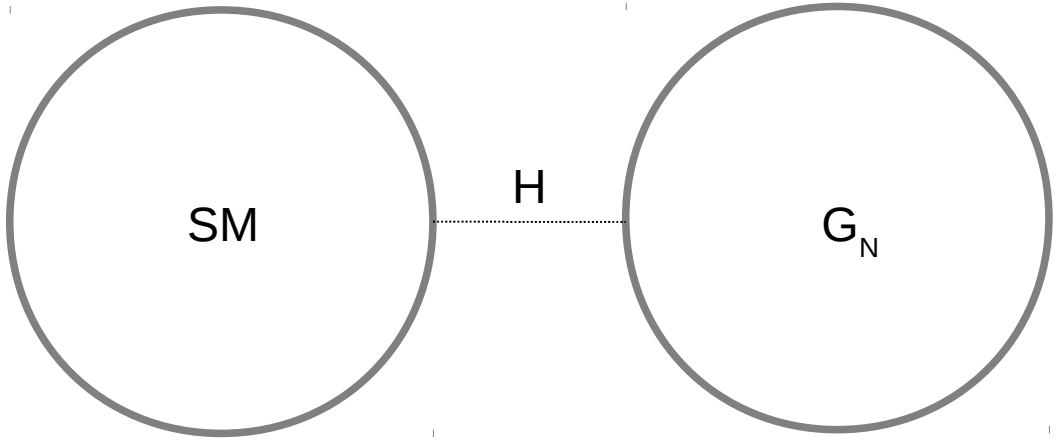
Direct detection = loop-suppressed

Annihilation = unsuppressed

Excellent WIMP

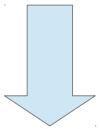
(from 60 GeV to 10 TeV)

The Higgs and vector dark matter



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

Lie groups possess discrete symmetries



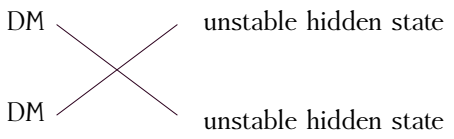
gauge fields as dark matter

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)

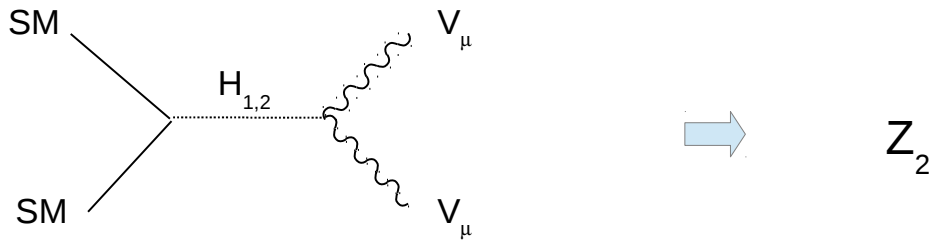
Lee, OL, Mambrini '11

Higgs mechanism in the hidden sector :

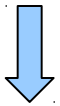
$$L = -1/4\, F_{\mu\nu} F^{\mu\nu} + D_\mu S^* D^\mu S - V(S) + \lambda/4\, \bar{H}H\, S^*S$$

$$S \longrightarrow VEV$$

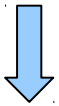
SM couplings:



gauge invariance (+ minimal field content)



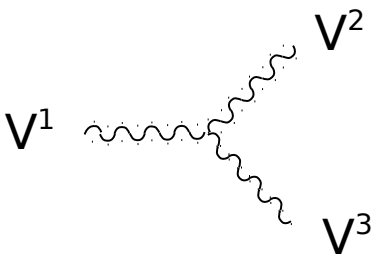
Z_2



gauge fields are natural DM candidates

Hambye '08
Gross,OL, Mambrini '15

Non-abelian case:



$\Rightarrow$ Z_2 odd

But there are 2 Z_2's:

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

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

$\Rightarrow$ V^a = stable

gauge transform

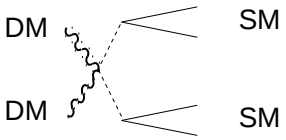
charge conjugation

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

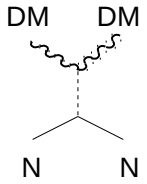
Advantage over the simplest Higgs portal DM:

there exists another hidden sector state which

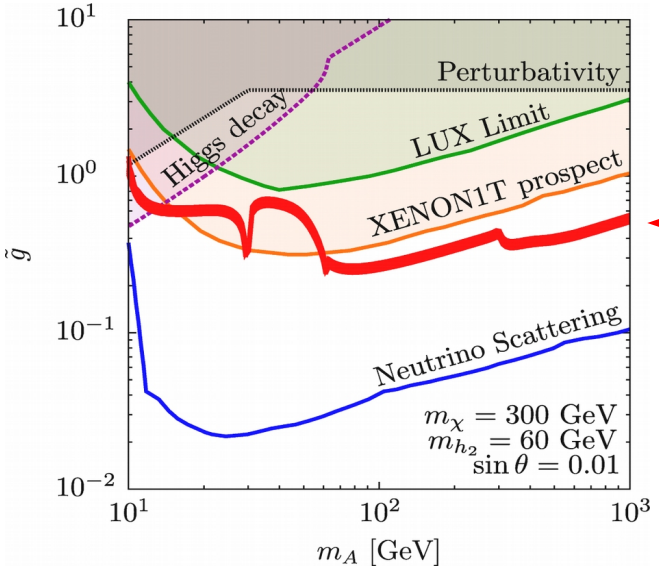
- ***can be lighter than DM***
- ***is unstable***



~ cos θ



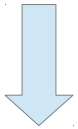
~ sin θ



correct relict density

- DM annihilation efficient
- Direct detection suppressed

à la Pospelov et al.'07



Higgs portal DM = viable WIMP

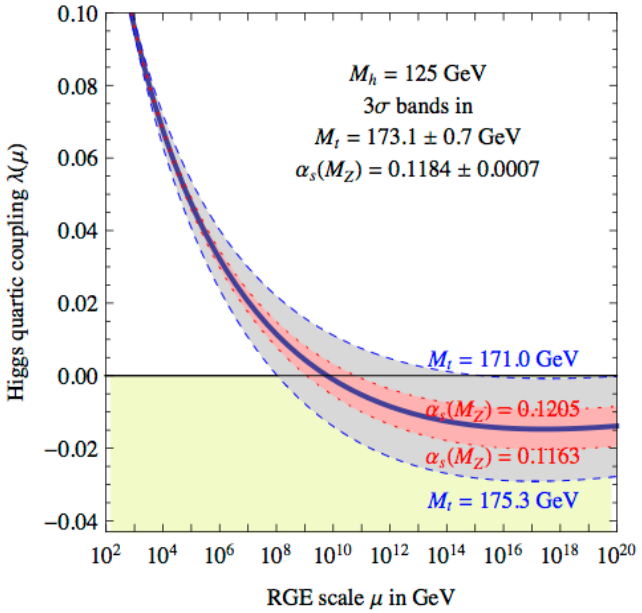
(especially if there's more than one state in the hidden sector)

The Higgs and inflation

Buttazzo et al.'13

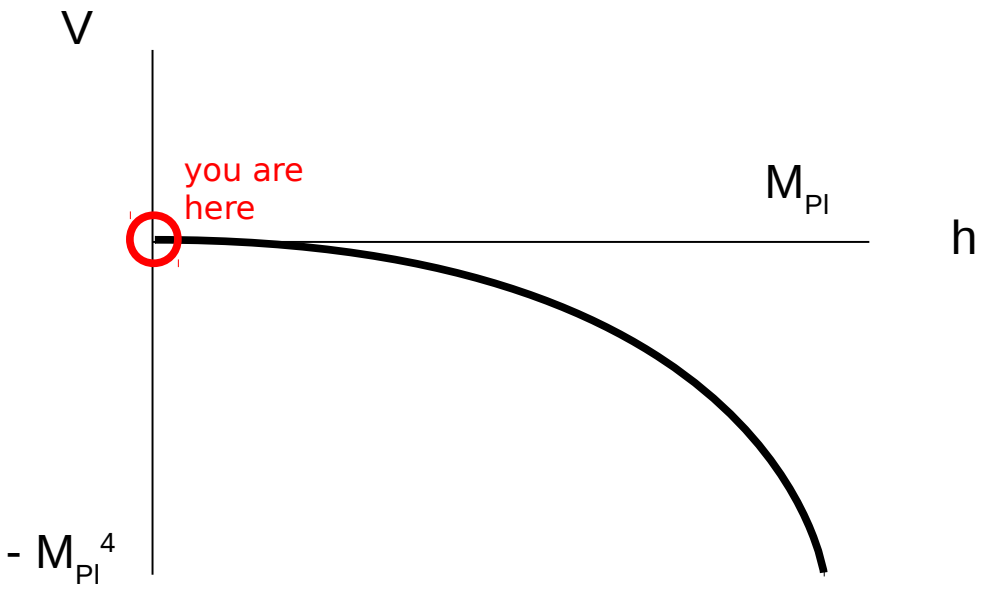
SM stability bound:

$m_h > (129.6 \pm 1.5)$ GeV



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

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



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

Problems :

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

- why did it stay there during inflation ?

(large fluctuations: Espinosa, Guidice, Riotto'07)

Solutions :

- modify the Higgs potential during inflation

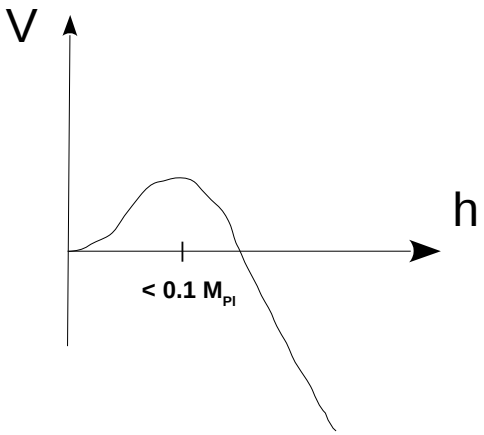
- just modify the Higgs potential

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

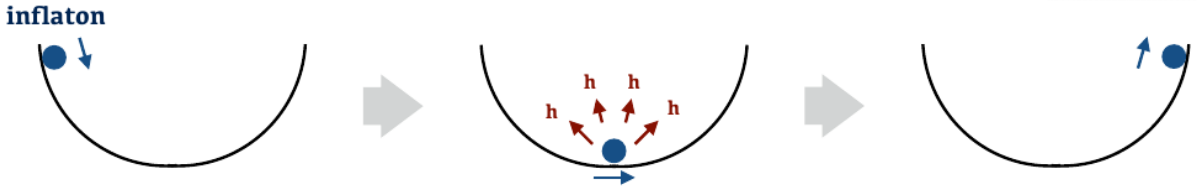
Higgs field is driven to zero during inflation !

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

Higgs vacuum destabilization through preheating

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

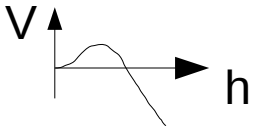
$$\phi \simeq \Phi \cos mt \quad \text{with} \quad \Phi \sim \Phi_0\, a^{-3/2}$$



Kofman, Linde , Starobinsky '98

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

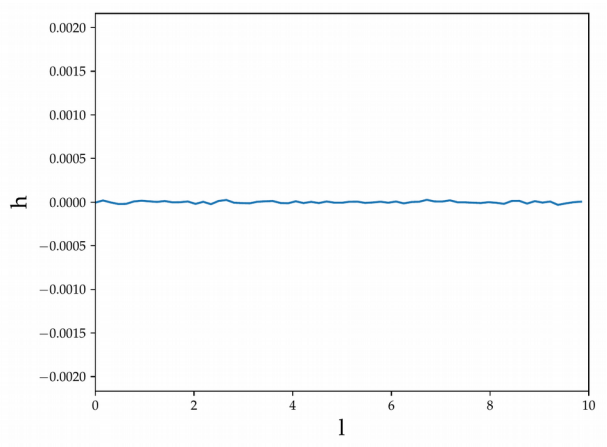
$\langle h^2 \rangle \propto$ Number of Higgs quanta



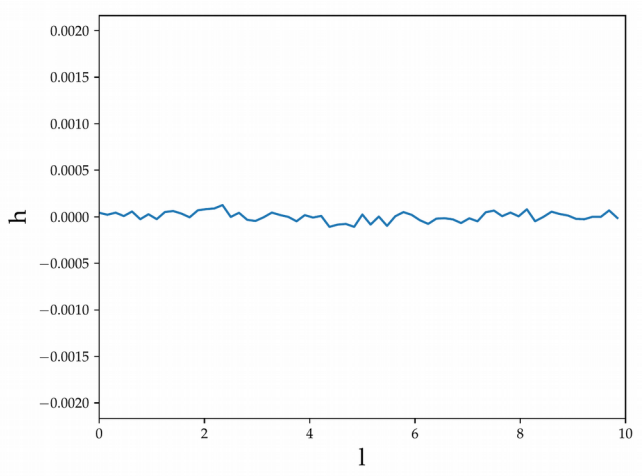
⇨ destabilization

Lattice results:

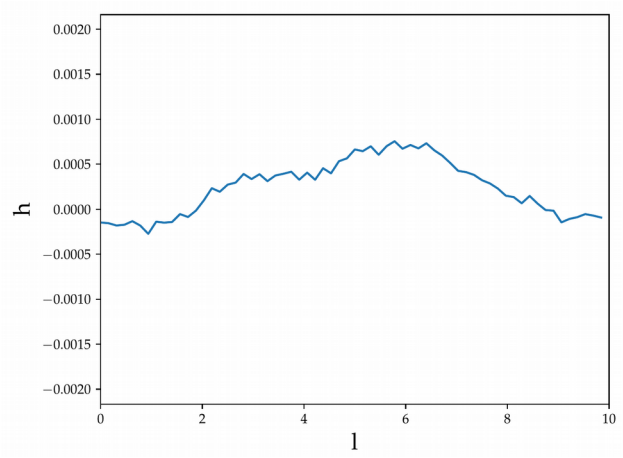
t=0



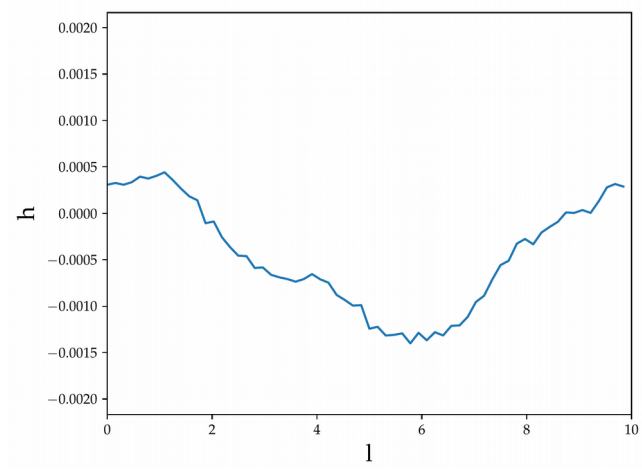
t=15



t=27



t=30



Ema, Karciauskas,OL, Zatta '17

General case: including all relevant operators

$$-\mathcal{L}_{hR} = \xi H^\dagger H \hat{R} \,,$$
$$-\mathcal{L}_{h\phi} = \lambda_{h\phi} H^\dagger H \phi^2 + \sigma H^\dagger H \phi$$

Einstein frame:

$$g^{\mu\nu} = \Omega^{-1} \hat{g}^{\mu\nu} \qquad\qquad \Omega\left(h\right) \equiv 1 - \xi h^2$$

Potential:

$$V\left(\phi, h_{\rm c}\right) = \frac{1}{2} m^2 \phi^2 + \frac{1}{2}\left(\lambda_{h\phi} + 2\xi m^2\right) \phi^2 h_{\rm c}^2 + \frac{1}{2}\sigma\phi h_{\rm c}^2 + \frac{1}{4}\lambda h_{\rm c}^4 + \ldots$$

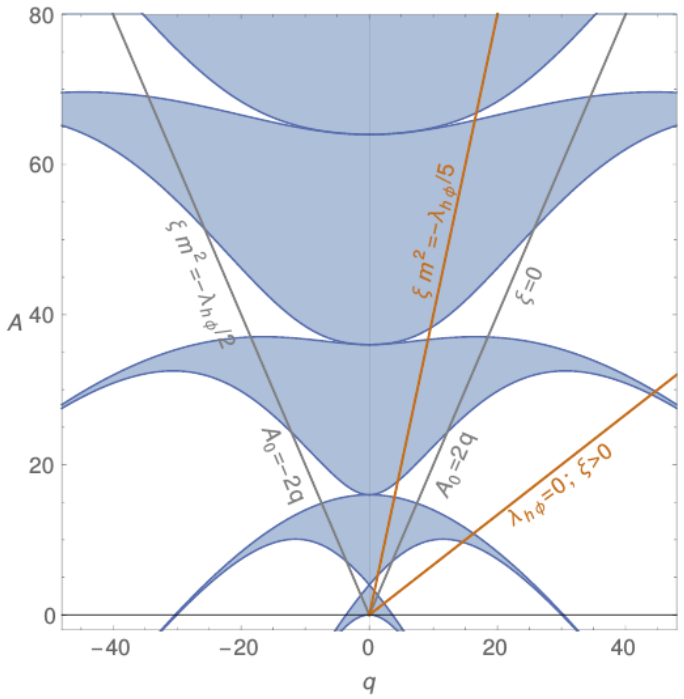
$$h_{\rm c} \simeq h\left[1 + \left(\xi + \frac{1}{6}\right)\xi h^2\right]$$

Mode EOM for the Higgs (simplified):

Mathieu Equation: $X_k'' + (A_k + 2q\cos 4z)\, X_k = 0 \qquad z = mt/2$

inflaton–induced Higgs mass^2

time



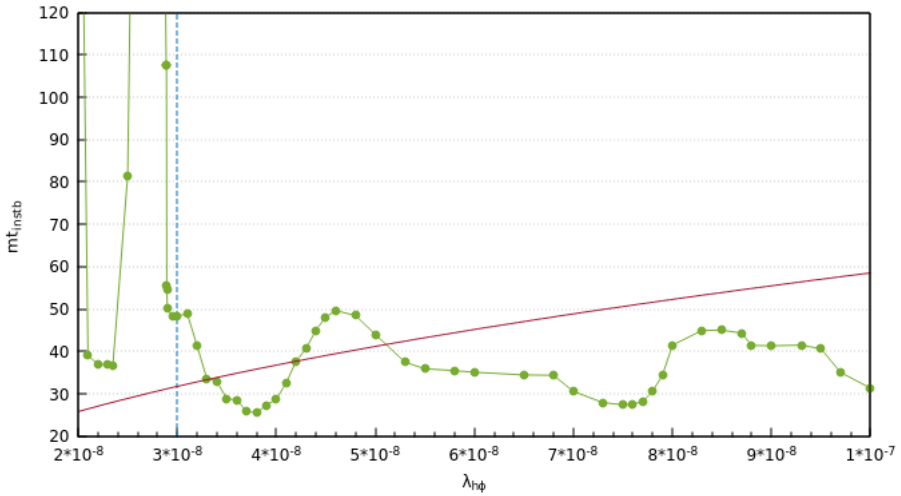
A , q ~ t^{-2}

white = unstable
shaded = stable

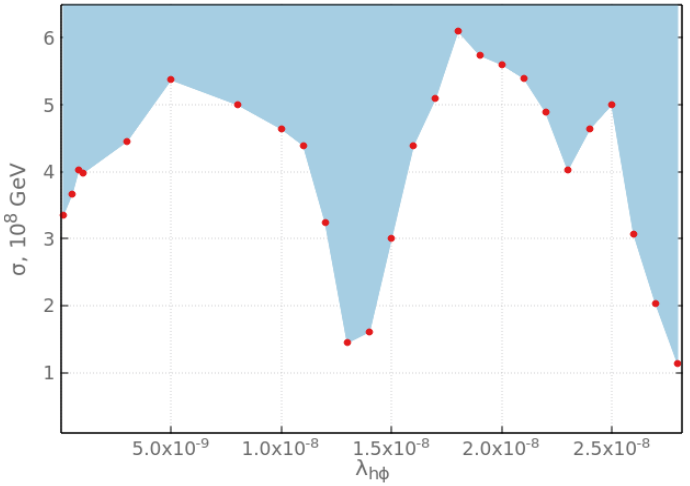
Enqvist, Karciauskas, OL, Rusak, Zatta '16

Bounds on the Higgs-inflaton couplings :

quartic :



trilinear :



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

$\sigma < 10^8$ GeV

Conclusion

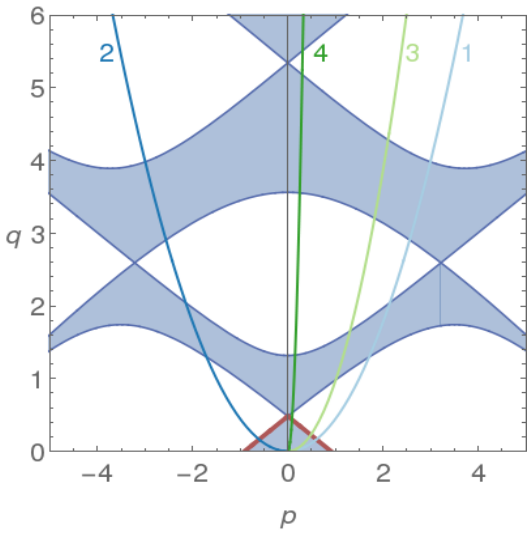
- Higgs sector is special
- key to the hidden sector / DM / inflation
- Higgs portal WIMP DM is viable
- Higgs-inflaton interaction is crucial

Full ''mixed'' resonance:

Whittaker–Hill equation *(no expansion limit)*

$$X'' + 2p\cos(2t)\,X + 2q\cos(4t)\,X = -A\,X$$

time



p , q = effective mass terms
(in inflaton mass units)

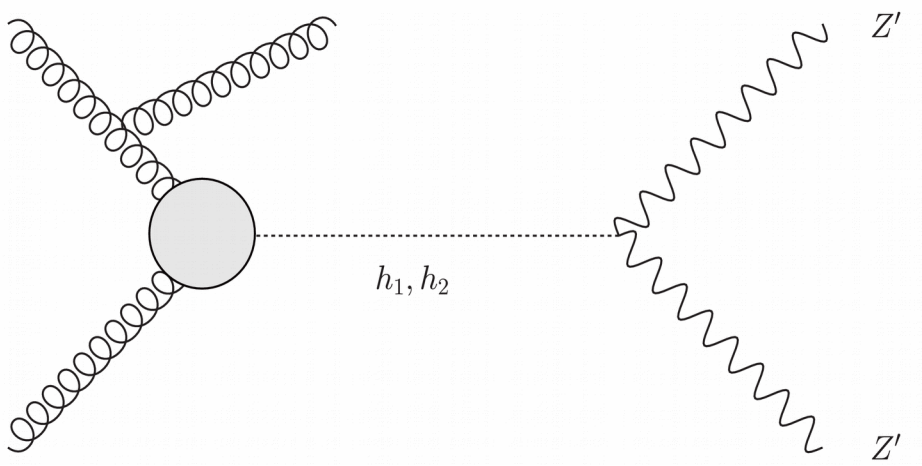
stability region

instability region

Kim, OL ,Schmeier '15

Higgsophilic gauge bosons at the LHC:

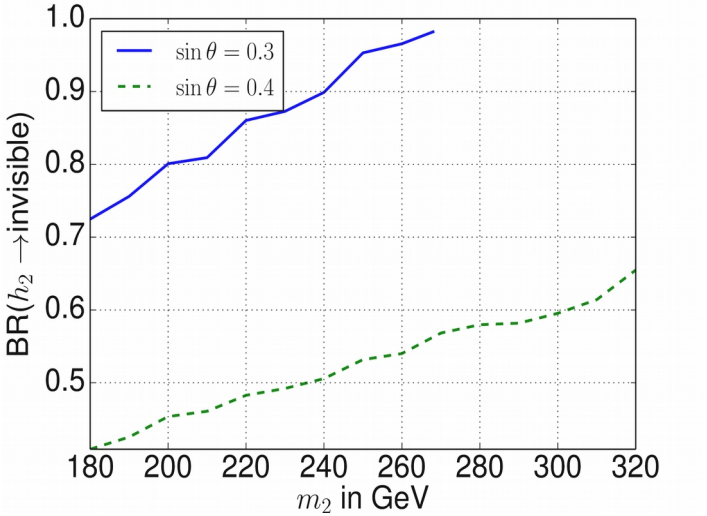
monojets (or VBF) + missing E_T

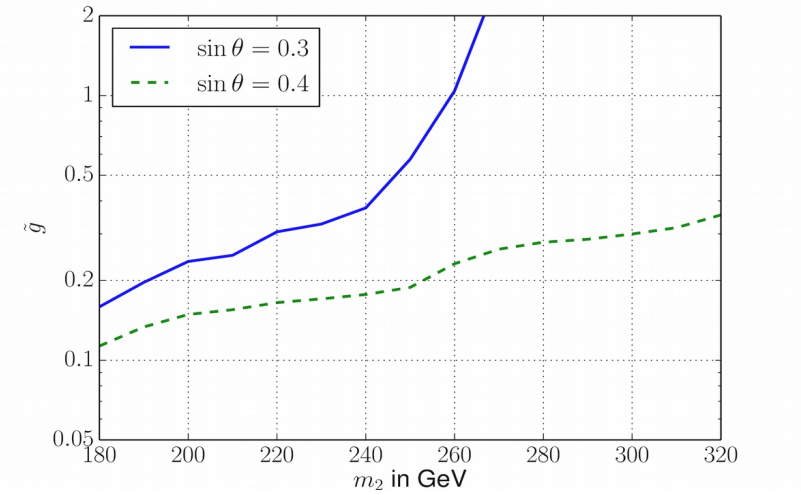


efficient for $m_2 > 2\, m_{Z'}$

Kim, OL ,Schmeier '15

Monojet results with 600 fb^{-1} :





+ similar results for VBF with already 300 fb^{-1}