Higgs portal dark matter

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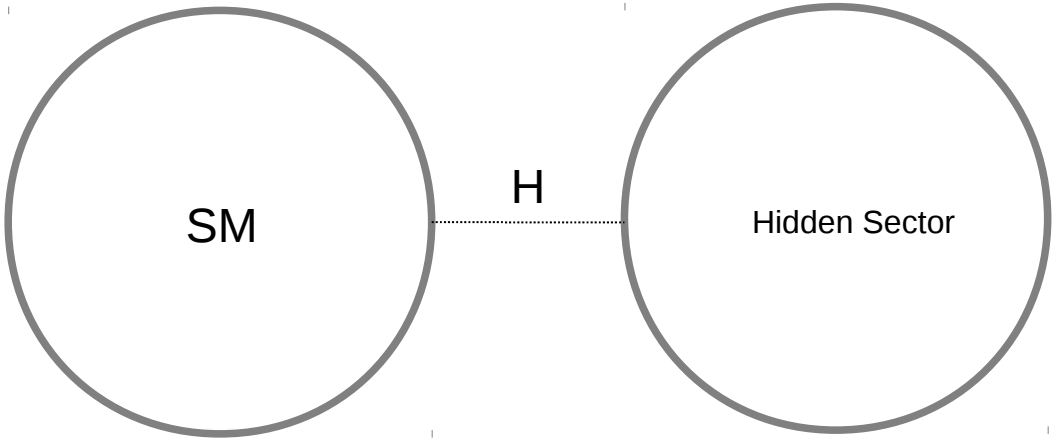
The Higgs and the hidden sector



Lowest order operators ("Higgs Portal") :

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

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

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

"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

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

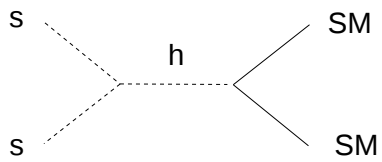
(S = “hidden” scalar)

b=0 (S has hidden charge):

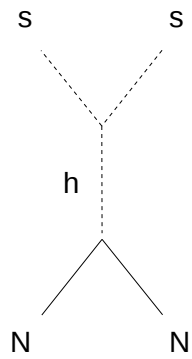
$$L = a\,|H|^2\,S^2$$

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

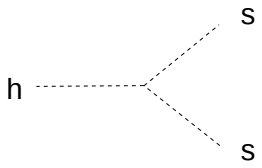
Dark matter:



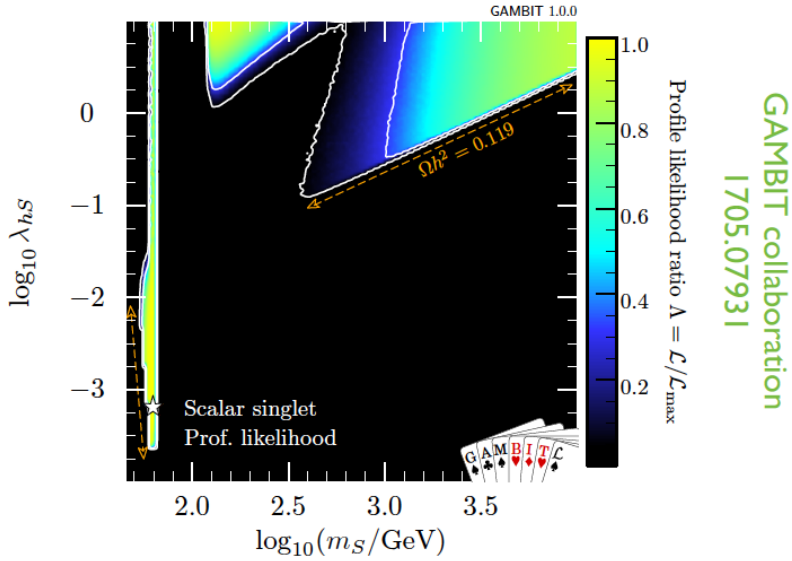
DM annihilation



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:

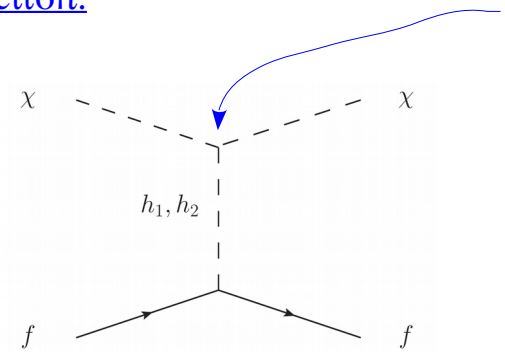
$$V = V_0 + V_{\rm soft} \ ,$$
$$V_0 = -\frac{\mu_H^2}{2}|H|^2 - \frac{\mu_S^2}{2}|S|^2 + \frac{\lambda_H}{2}|H|^4 + \lambda_{HS}|H|^2|S|^2 + \frac{\lambda_S}{2}|S|^4 \ ,$$
$$V_{\rm soft} = -\frac{\mu_S'^2}{4}S^2 + \text{h.c.}$$

All parameters are real ⇨ $\langle S \rangle$ = real , $S \to S^*$ symmetry

Im S = Dark Matter

Gross, OL, Toma '17

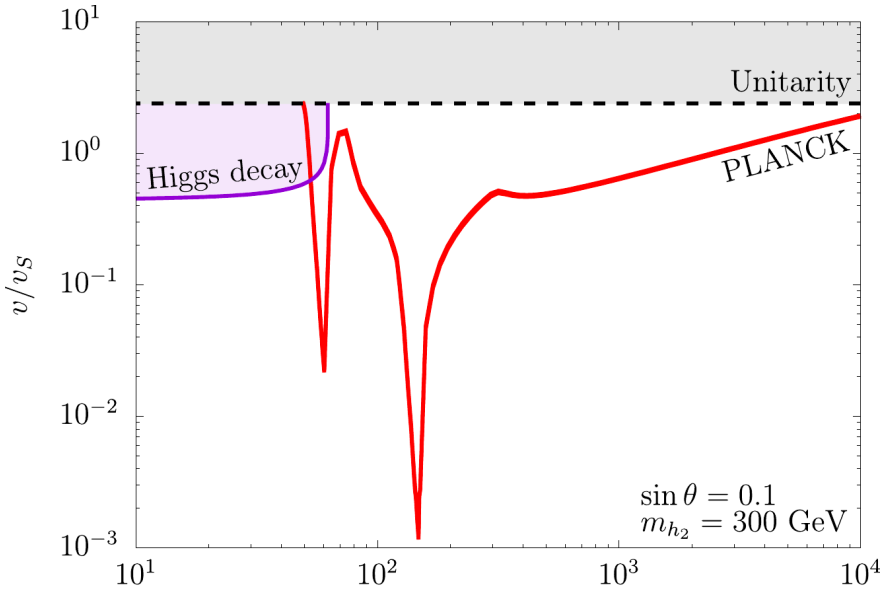
Direct detection:



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 !



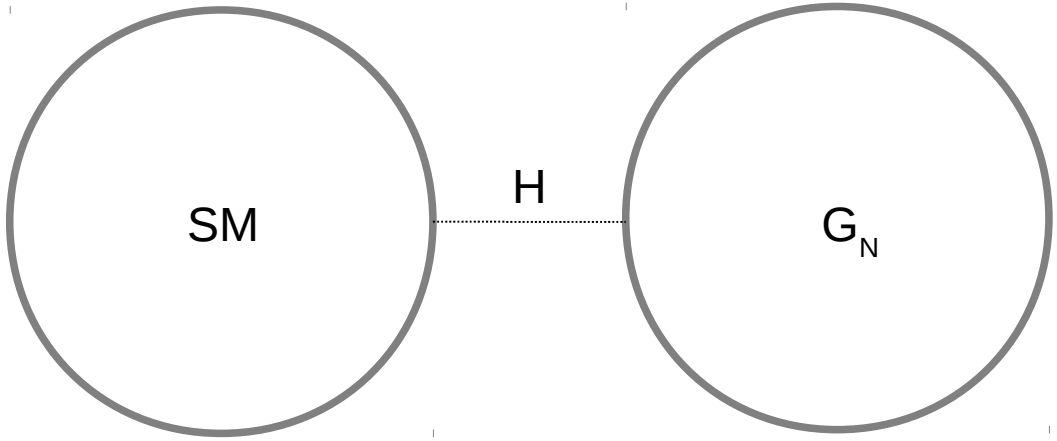
Direct detection = loop-suppressed

Annihilation = unsuppressed

Excellent WIMP

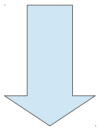
(from 60 GeV to 10 TeV)

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



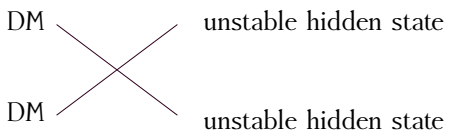
gauge fields as dark matter

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)

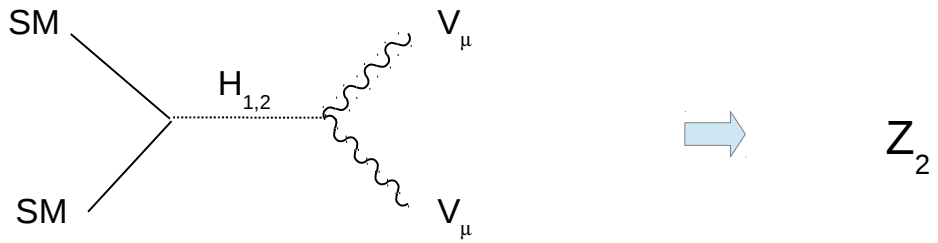
Lee, OL, Mambrini '11

Higgs mechanism in the hidden sector :

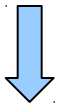
$$L = -1/4\, F_{\mu\nu} F^{\mu\nu} + D_\mu S^* D^\mu S - V(S) + \lambda/4\, \bar{H}H\, S^*S$$

$$S \longrightarrow VEV$$

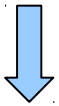
SM couplings:



gauge invariance (+ minimal field content)



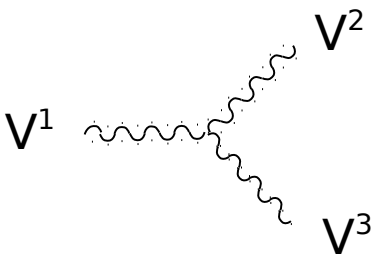
Z_2



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

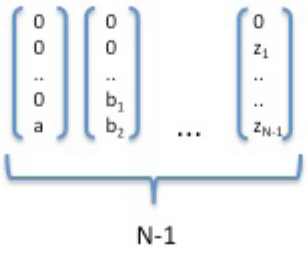
General SU(N) case

$$\left[T^a, T^b\right] = i\, f^{abc}\, T^c$$

Z_2 : reflects real generators

Z_2' : reflects non-Cartan generators with non-zero first row (Pauli-like basis)

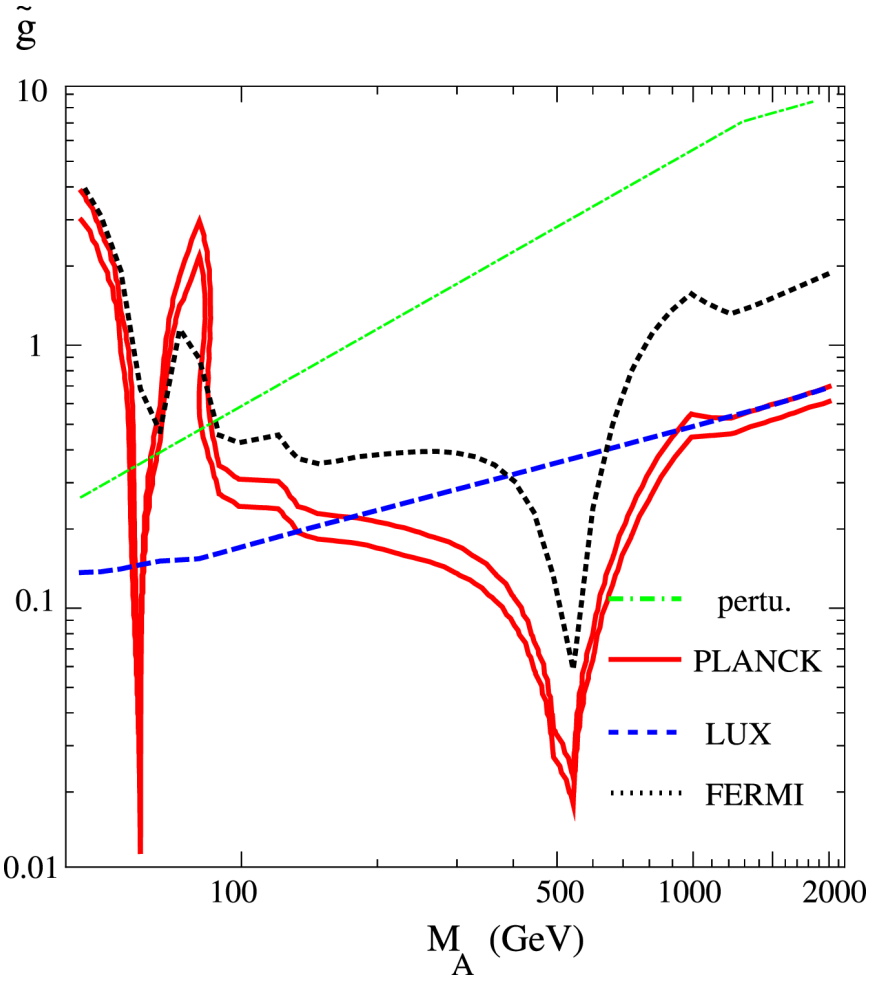
Higgsing:



$Z_2 \times Z_2'$ preserved if CP is conserved

(in fact generalizes to $Z_2 \times U(1)$)

Gross,OL, Mambrini '15



U(1)

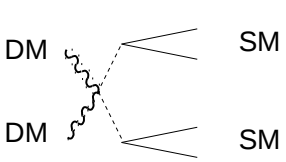
sin θ = 0.3

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

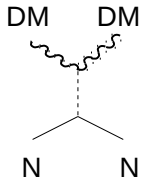
Advantage over the simplest Higgs portal DM:

there exists another hidden sector state which

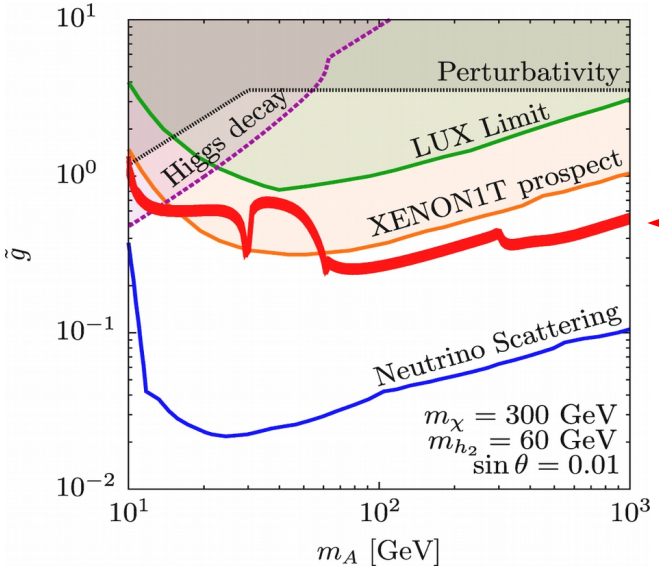
- ***can be lighter than DM***
- ***is unstable***



~ cos θ

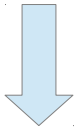


~ sin θ



correct relict density

- DM annihilation efficient
- Direct detection suppressed



Higgs portal DM = viable WIMP

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

Conclusion

- Higgs portal WIMP is alive
- Interesting options :
  - DD cancellations via symmetry
  - “secluded” dark matter
  - (broad) resonant annihilation
  - TeV dark matter