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"):

\[ \overline{\text{H}} \text{H} S^2 + \ldots \] (scalar)

\[ \overline{\text{H}} \text{H} V_\mu V^{\mu} + \ldots \] (vector)

\[ \overline{\text{H}} \text{H} \overline{\chi} \chi / \Lambda + \ldots \] (fermion)

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

\[ |H|^2 = \text{the only gauge and Lorentz-inv. dim-2 operator} \]

\[ L = a |H|^2 S^2 + b |H|^2 S \]

(\( S = \text{"hidden" scalar} \))

\( b=0 \) (\( S \) 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

white contour = 2 $\sigma$ bound

GAMBIT collaboration

1705.07931
The Higgs and vector dark matter

\[ V \sim \bar{H}H \bar{S}S \quad \rightarrow \quad \text{H-S mixing} \quad \rightarrow \quad h \text{ couples to } G_N \]
Lie groups possess discrete symmetries

gauge fields as dark matter

E.g. \[ \text{U(1)} : A_\mu \rightarrow - A_\mu \]
Minimal $G_N$ breaking implies:

- Vector DM
- Multicomponent DM
- ”Secluded” DM

(à la Pospelov et al. ’07)
Higgs mechanism in the hidden sector:

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

\[ S \rightarrow \text{VEV} \]

SM couplings:
gauge invariance  (+ minimal field content)

\[ Z_2 \]

\[ \downarrow \]

gauge fields are natural DM candidates
Non-abelian case:

But there are 2 $\mathbb{Z}_2$'s:

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

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

$V^a = \text{stable}$
Advantage over the simplest Higgs portal DM:

there exists another hidden sector state which

- can be lighter than DM
- is unstable

\[
\sin \theta \quad \cos \theta
\]

Owing to this, the DM will have the 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)
The Higgs and inflation

SM stability bound:

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

(not settled: Alekhin et al. '12, Bezrukov et al. '12)
$h \gg \Lambda \sim 10^{10} \text{GeV} \quad \Rightarrow \quad V \sim \frac{1}{4} \lambda(h) \ h^4 \quad , \quad \lambda(h) < 0$

\[ \Lambda = 10^{-8} \ M_{\text{Pl}} \quad , \quad \text{barrier} = 10^{-32} \ M_{\text{Pl}}^4 \]
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)

For all initial values of \( h \) up to 0.1 \( M_{pl} \), the \( h \)-potential is convex
(higher \( h \)-values → Planckian density)
Large effective mass term \( \sim \lambda_{h\phi} \phi^2 \) \( \Rightarrow \) \( h(t) \sim h(0) \exp(-3/2Ht) \)

Constraints:

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

Higgs field is driven to zero during inflation!
Higgs/inflaton evolution (in $M_p$):

$\hbar(N_e)$

$\phi(N_e)$

OL, Westphal '12
Higgs vacuum destabilization through preheating

\[ \Delta V = \frac{1}{2} \lambda_{h\phi} h^2 \phi^2 \rightarrow \text{parametric resonance} \]

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

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

\[ \phi \approx \Phi \cos mt \quad \text{with} \quad \Phi \sim \Phi_0 a^{-3/2} \]
Lattice results:

- **t=0**: The graph shows a horizontal line indicating a constant value of h across the lattice.
- **t=15**: Similar to t=0, a horizontal line with a constant value of h.
- **t=27**: The graph displays a series of peaks and troughs, suggesting a time-dependent variation of h.
- **t=30**: The graph also shows variations with maxima and minima, indicating dynamic changes in h over time.
Bounds on the Higgs-inflaton couplings:

quartic:

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

trilinear:

\[ \sigma < 10^{8} \text{ GeV} \]
Conclusion

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