Twin Higgs Portal
Dark Matter

Based on work with David Curtin, SG

2101.11019 [hep-ph]
We extend the Twin Higgs framework to include a singlet scalar particle that acts like dark matter.

We treat the scalar as a thermal relic and compute its expected direct detection cross section.

The pNGB nature of the (SM-like) Higgs suppresses the direct detection cross section, relative to benchmark Higgs portal WIMP models.
We extend the Twin Higgs framework to include a singlet scalar particle that acts like dark matter.

We treat the scalar as a thermal relic and compute its expected direct detection cross section.

The pNGB nature of the (SM-like) Higgs suppresses the direct detection cross section, relative to benchmark Higgs portal WIMP models.

+ extra suppression from asymmetric reheating!
TWIN HIGGS MODELS
Motivation:

Solve the (little) hierarchy problem via color-neutral top partners
Lagrangian:

\[ \mathcal{L} = \mathcal{L}_{SM_A} + \mathcal{L}_{SM_B} \]

- Complete or partial SM copy
- Singlet under SM charges

\[ \mathbb{Z}_2 : A \leftrightarrow B \]

\[ H = (H_A, H_B)^T \]

\[ V = \lambda \left( H^\dagger H - \frac{f_0^2}{2} \right)^2 + \text{breaking terms} \]
Twin Higgs Mechanism

1) \( \langle H \rangle = \frac{1}{\sqrt{2}} f \)

\( SU(4) \rightarrow SU(3) \)

125 GeV Higgs is pNGB of broken \( SU(4) \)
Twin Higgs Mechanism

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\[ SU(4) \rightarrow SU(3) \]

125 GeV Higgs is pNGB of broken SU(4)

2) \[
\begin{align*}
\Delta V &= \frac{3}{8\pi^2} \Lambda^2 \left( \lambda_A^2 H_A^\dagger H_A + \lambda_B^2 H_B^\dagger H_B \right) \\
&= \frac{3\lambda^2}{8\pi^2} \Lambda^2 H^\dagger H
\end{align*}
\]

125 GeV Higgs protected at 1 loop
Introducing:

TWIN HIGGS PORTAL DARK MATTER
Start with Twin Higgs potential:

\[ V = \lambda \left( H_A^\dagger H_A + H_B^\dagger H_B - \frac{f_0^2}{2} \right)^2 + \kappa \left( (H_A^\dagger H_A)^2 + (H_B^\dagger H_B)^2 \right) + \sigma f_0^2 H_A^\dagger H_A \]

- SU(4) symmetric
- explicit breaking terms
\[ V = \lambda \left( H_A^\dagger H_A + H_B^\dagger H_B - \frac{f_0^2}{2} \right)^2 + \kappa \left( \left( H_A^\dagger H_A \right)^2 + \left( H_B^\dagger H_B \right)^2 \right) + \sigma f_0^2 H_A^\dagger H_A \]

\[ + \frac{1}{2} \mu_S^2 S^2 + \frac{1}{2} \lambda_{HS} S^2 \left( H_A^\dagger H_A + H_B^\dagger H_B \right) \]

Add a singlet scalar
\[ V = \lambda \left( H_A^+ H_A + H_B^+ H_B - \frac{f_0^2}{2} \right)^2 + \kappa \left( \left( H_A^+ H_A \right)^2 + \left( H_B^+ H_B \right)^2 \right) + \sigma f_0^2 H_A^+ H_A \]

\[ + \frac{1}{2} \mu S^2 + \frac{1}{2} \lambda_H S^2 \left( H_A^+ H_A + H_B^+ H_B \right) \]

Get **suppressed coupling** to pNGB Higgs

\[ S \xrightarrow{\text{h}} = i \lambda_H \frac{\kappa}{\lambda} v \left( 1 - 2v^2/f^2 \right) \left( 1 - v^2/f^2 \right) + O \left( \frac{\kappa^2}{\lambda^2} \right) \]
\[ V = \lambda \left( H_A^\dagger H_A + H_B^\dagger H_B - \frac{f_0^2}{2} \right)^2 + \kappa \left( (H_A^\dagger H_A)^2 + (H_B^\dagger H_B)^2 \right) + \sigma f_0^2 H_A^\dagger H_A \]

\[ + \frac{1}{2} \mu_S^2 S^2 + \frac{1}{2} \lambda_{HS} S^2 \left( H_A^\dagger H_A + H_B^\dagger H_B \right) \]

Get **suppressed coupling** to pNGB Higgs

\[ S \]

\[ h \]

\[ S \]

\[ i\lambda_{HS} \left( \frac{\kappa}{\lambda} \right) v \left( 1 - 2v^2/f^2 \right) \left( 1 - v^2/f^2 \right) + O \left( \frac{\kappa^2}{\lambda^2} \right) \]

explicit \( SU(4) \) breaking

\( v = f/\sqrt{2} \) in \( Z_2 \) limit

\[ \ldots \text{proportional to explicit breaking parameters.} \]
Get *suppressed coupling* to pNGB Higgs

\[ V = \lambda \left( H_A^\dagger H_A + H_B^\dagger H_B - \frac{f_0^2}{2} \right)^2 + \kappa \left( \left( H_A^\dagger H_A \right)^2 + \left( H_B^\dagger H_B \right)^2 \right) + \sigma f_0^2 H_A^\dagger H_A \]

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... proportional to explicit breaking parameters.
Why does this matter?
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- We treat dark matter as a thermal relic
- pNGB Higgs mediates both freeze out and direct detection
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Low energy ($m_S \ll m_h$):
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Low energy \((m_S \ll m_h)\):

Same small coupling mediates both
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High energy \( (m_S \gtrsim m_h) \):

Excited radial mode

Unsuppressed couplings

(Same small coupling)
Why does this matter?

- We treat dark matter as a thermal relic
- pNGB Higgs mediates *both freeze out and direct detection*

High energy \((m_S \gtrsim m_h)\):

- **Direct detection** suppressed relative to freeze out
- Unsuppressed couplings
- (Same small coupling)

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Reduced direct detection

\[ \Omega_{DM} h^2 = 0.120 \pm 0.001 \]

Planck 2018, astro-ph/1807.06209

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Reduced direct detection

- Freezes out via $\lambda_{SSh}$
- DD proceeds via $\lambda_{SSh}$

Maps on to regular Higgs portal WIMP scenario
Reduced direct detection

• Freezes out via $\lambda_{SSH}$
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Maps on to regular Higgs portal WIMP scenario

• Freezes out through unsuppressed coupling $\lambda_{HS}$
• DD proceeds via $\lambda_{SSH}$

Direct detection suppressed — possibilities for next gen experiments!

Planck 2018, astro-ph/1807.06209

$\Omega_{DM} h^2 = 0.120 \pm .001$
Is there reason to assume we live here?

- Freezes out through unsuppressed coupling $\lambda_{HS}$
- DD proceeds via $\lambda_{SSH}$

Direct detection possible in next generation experiments!
Is there reason to assume we live here?

Yes! Natural mass scale for S is $\mathcal{O}(f)$:

- want natural tree level mass: $m_S^2 = \mu^2 + \lambda_{HS} f^2$
- unsuppressed radial mode coupling generates $\mathcal{O}(f)$ mass corrections at loop level
Is there reason to assume we live here?

Vast majority of unexplored parameter space corresponds to most natural DM mass scale!
Last point:
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Some Twin Higgs models (e.g. MTH) have spectra in tension with $\Delta N_{\text{eff}}$ constraints

This can be solved by diluting the twin radiation through late-time decays to mostly SM final states, known as asymmetric reheating

This dilutes the DM, further reducing the expected coupling:
Last point:

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This can be solved by **diluting** the twin radiation through late-time decays to mostly SM final states, known as **asymmetric reheating**.

This dilutes the DM, further reducing the expected coupling:

$$\Omega \rightarrow \frac{\Omega}{D} \quad \lambda_{HS} \rightarrow \frac{\lambda_{HS}}{\sqrt{D}}$$
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THPDM + AR: cosmologically valid for all twin spectra!
CONCLUSION
We extended the Twin Higgs framework to include a singlet scalar DM candidate
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CONCLUSION

The model is valid for any Twin Higgs spectrum — incorporating asymmetric reheating further suppresses direct detection.
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The pNGB nature of the Higgs leads to suppressed direct detection signals for the most natural DM mass scale.

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The model is valid for any Twin Higgs spectrum — incorporating asymmetric reheating further suppresses direct detection.

Thanks!

hep-ph/2101.11019
EXTRAS
ASYMMETRIC REHEATING
Cosmology issues in Twin Higgs

- DD suppression valid for **all** Twin Higgs models…
- … but some models (e.g. MTH) have spectra in tension with $\Delta N_{\text{eff}}$
- Solve with *asymmetric reheating*:

  nuMTH: Z. Chacko, N. Craig, P. J. Fox, R. Harnik  hep-ph/1611.07975
Cosmology issues in Twin Higgs

- DD suppression valid for all Twin Higgs models…
- … but some models (e.g. MTH) have spectra in tension with $\Delta N_{\text{eff}}$
- Solve with asymmetric reheating:

  - Introduce weakly interacting, massive, long-lived particle with preferential decays to SM
  - Freezes out relativistically, dominates cosmology at late times
  - Decays at late times
  - Dilutes twin sector radiation contribution to $\Delta N_{\text{eff}}$
Cosmology issues in Twin Higgs

• DD suppression valid for all Twin Higgs models…

• … but some models (e.g. MTH) have spectra in tension with $\Delta N_{\text{eff}}$


Diluting twin radiation dilutes DM:

$$\Omega \rightarrow \Omega/D$$

Further reduces DD predictions:

$$\lambda_{HS} \rightarrow \lambda_{HS}/\sqrt{D}$$
ASYMMETRIC REHEATING

\[ m_h = 1500 \text{ GeV}, \quad f/v = 3 \]

\[ \lambda_{HS} \rightarrow \lambda_{HS}/\sqrt{D} \]

\[ \log_{10} \lambda_{\text{eff}} \]

\[ m_s \text{ (GeV)} \]

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ASYMMETRIC REHEATING

Twin Higgs Portal DM + asymmetric reheating

Model of DM that is cosmologically valid for any twin spectrum

$\lambda_{HS} \rightarrow \lambda_{HS}/\sqrt{D}$