Reviving the Higgs portal WIMP with asymmetrically reheated MTH models

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Based on: work in progress with David Curtin
Part 1: The little hierarchy problem and the Mirror Twin Higgs (MTH)
  • Cosmological issues
  • Asymmetric reheating

Part 2: Higgs portal WIMP DM
  • Direct detection constraints
  • Using asymmetric reheating to extend parameter space
(Little) Hierarchy Problem

• The Higgs mass is highly sensitive to UV physics

• Many popular solutions involve coloured top partners
  
e.g. SUSY, Little Higgs…

• Null experimental results suggest mass scale of top partners above TeV
  
  —> leads to unsatisfactory tuning
  
  —> the Little Hierarchy Problem

• Neutral naturalness:
  
  —> stabilize the Higgs mass using SM-neutral top partners
  
  —> One example: The Mirror Twin Higgs (MTH)
Mirror Twin Higgs model
Mirror Twin Higgs

• Introduce mirror sector related to SM via $\mathbb{Z}_2$ exchange symmetry:

$$\mathcal{L} = \mathcal{L}_{\text{SM}_A} + \mathcal{L}_{\text{SM}_B}$$

$$\mathbb{Z}_2 : A \leftrightarrow B$$

• Higgs sector has approximate global SU(4) symmetry,

$$H = \begin{pmatrix} H_A \\ H_B \end{pmatrix}$$

125 GeV Higgs identified as pNGB of spontaneous SU(4) -> SU(3) breaking

$$h \sim h_A \cos \left( \frac{v}{f} \right) - h_B \sin \left( \frac{v}{f} \right)$$

• Observed Higgs is SM-like, $h \sim h_A$

$\rightarrow$ misalign vevs with soft $\mathbb{Z}_2$ breaking such that $v/f << 1$

$$Br(h \rightarrow \text{inv}) \lesssim .20$$ bounds $v/f$ from above

CMS Collaboration, arXiv:1610.0921

ATLAS Collaboration, arXiv:1508.0786
Mirror Twin Higgs

- $\mathbb{Z}_2$ induces accidental SU(4) symmetry in loop corrections to Higgs mass:

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

since the $\mathbb{Z}_2$ enforces $\lambda_A = \lambda_B \equiv \lambda$

Higgs mass is protected from quadratic divergences up to 5-10 TeV
Mirror Twin Higgs

Problem: Twice the particles means twice the light degrees of freedom during CMB formation

\[ \Delta N_{\text{eff}} \approx 5.6 \]

\[ \Delta N_{\text{eff}} \lesssim 0.6 \]

A few solutions:

**Remove** the light DoFs from mirror spectrum

\[ \rightarrow \text{e.g. Fraternal Twin Higgs (FTH)} \]

**Dilute** the mirror sector before CMB formation

\[ \rightarrow \text{asymmetric reheating} \]

Craig, Katz, Strassler, Sundrum, arXiv:1501.05310

Chacko, Craig, Fox, Harnik, arXiv:1611.07975
Asymmetric Reheating

Introduce new species N that is

- Weakly coupled to the SM
- Heavy
- Long-lived (but unstable)
- Preferential to SM decays

Then:

1) Freezes out while relativistic
2) Redshifts to nonrelativistic, dominates energy density of the universe
3) Decays preferentially to SM, diluting $\Delta N_{\text{eff}}$ to within experimental limits
Asymmetric Reheating

N domination:

$\Delta N_{\text{eff}} \propto \left. \frac{\rho_B}{\rho_A} \right|_{\text{reheat}}$

$\Delta N_{\text{eff}}$ diluted to within experimental bounds

A = visible sector / SM
B = mirror sector

Chacko, Craig, Fox, Harnik, arXiv:1611.07975
Summary so far:

- MTH solves the little hierarchy problem with a pseudo-Goldstone Higgs protected by accidental SU(4) symmetry

- Asymmetric reheating allows the MTH to be cosmologically viable
MTH solves the little hierarchy problem with a pseudo-Goldstone Higgs protected by accidental SU(4) symmetry

Asymmetric reheating allows the MTH to be cosmologically viable

What about dark matter??
Higgs Portal WIMPS
Higgs Portal WIMPs

One of the simplest DM models:

$$V_{\text{scalar}} = \frac{1}{2} m_s^2 S^2 + \frac{1}{4!} \lambda_4 S^4 + \frac{1}{2} \lambda_{HS} S^2 H^\dagger H$$

DM annihilates via Higgs portal in early universe

Freezes out to relic density $\Omega_{\text{DM}}$ when $\Gamma_{\text{int}} < H$
Higgs Portal WIMPs

- Relic density predicts Higgs portal coupling curve (black):

\[ \Omega_{DM} \propto \frac{1}{\langle \sigma v \rangle} \propto \frac{1}{\lambda_{HS}^2} \]

- Direct detection experiments place constraints on size of \( \lambda_{HS} \)

- Current Higgs portal WIMP parameter space nearly closed

- Predictions for \( \lambda_{HS} \) assume standard cosmological history

How does dilution in the MTH change this?
DM is diluted alongside the mirror sector!

Dilution increases the “true” relic density by a factor $D$,

\[ \Omega_{\text{DM}} \rightarrow D \, \Omega_{\text{DM}} \]

Leads to **reduction** in predicted coupling constant

\[ \lambda_{\text{HS}} \rightarrow \frac{\lambda_{\text{HS}}}{D^{1/2}} \]

Parameter space should open up for next generation experiments (e.g. LZ)

LZ Collaboration, arXiv:1509.02910
For: $\Delta N_{\text{eff}} = 0.6, \epsilon = 0.05, T_D = 3 \text{ GeV}, m_{\tilde{h}} = 500 \text{ GeV}$

- Preliminary results (still fixing some issues), but qualitative features seem promising
- Win twice: Parameter space opens up even without dilution due to mirror Dofs!
MTH solves the LHP using a SM-neutral top partner.

Cosmological issues solved by late-time decay of heavy, long-lived, weakly interacting particle.

$\rightarrow$ e.g. right-handed neutrino ($\nu$MTH)

Same cosmology can be utilized to open up parameter space for Higgs portal DM.

MTH parameters also correlate with

$\bullet$ $\text{Br}(h \rightarrow \text{inv})$ at LHC

$\bullet$ $\Delta N_{\text{eff}}$ bounds from CMB data,

and lead to distinctive cosmological signatures.

$\rightarrow$ many complementary searches underway!
Backups
MTH has two processes relevant to direct detection:

\[ \sigma \sim \left( \frac{\lambda_h g_{eff,h}}{m_h^2} + \frac{\lambda_{\hat{h}} g_{eff,\hat{h}}}{m_{\hat{h}}^2} \right)^2 \]

\[ \equiv \frac{\lambda_{\text{eff}}^2 g_{\text{eff}}^2}{m_h^4} \]

- Same form as Higgs portal cross section
- EFT matching