Baryogenesis in Mirror Twin Higgs

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Motivation

- Hierarchy problem, no SUSY found at LHC.
- Mirror Twin Higgs (MTH) evades LHC bounds through a color neutral top partner. A hidden sector is generated through Z_2 symmetry.[1]
- Asymmetric reheating mechanism ensures that ΔN_{eff} bounds are satisfied.[2]
- Baryogenesis in MTH: Z_2 symmetry implies twin baryogenesis.
- Atomic Dark Matter (ADM) has interesting astrophysical implications.[3][4]
- Main question: what does SM baryogenesis imply about mirror sector baryogenesis, and hence atomic dark matter content of universe?

[1] Z. Chacko, H.-S. Goh, and R. Harnik, (2006) arXiv: 0506256
[2] Z. Chacko, N. Craig, P. J. Fox, and R. Harnik (2017) arXiv: 1611.07975
[3] A. Ghalsasi and M. McQuinn (2018) arXiv: 1712.04779
[4] J. Fan, A. Katz, L. Randall, and M. Reece (2013) arXiv: 1303.1521

Mirror Twin Higgs Review

- The hidden sector (denoted B) is a mirror copy of the SM sector (denoted A).

$$SU(3)_A \times SU(2)_A \times U(1)_A \xleftrightarrow{Z_2} SU(3)_B \times SU(2)_B \times U(1)_B$$

- Z_2 symmetry ensures cancellation of quadratic divergences.
- Twin vev higher than SM vev $f > v$, H_B heavier than H_A.
- $3 < f/v < 10$ satisfies Higgs coupling constraints and avoids sub-percent tuning.
- $\Delta N_{\mathrm{eff}} \approx 6 \rightarrow$ need asymmetric reheating or fraternal twin Higgs (hard Z_2 breaking to remove light degrees of freedom)[5]

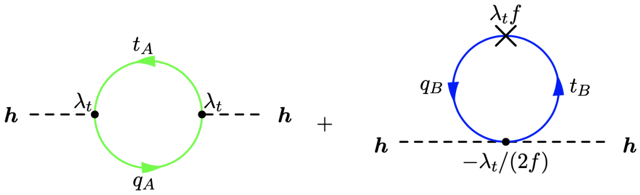
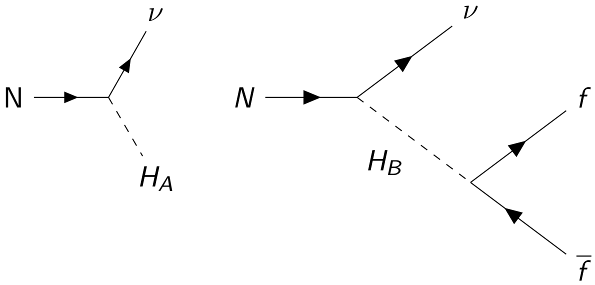


Figure: G. Burdman et al. (2015) arXiv:1411.3310

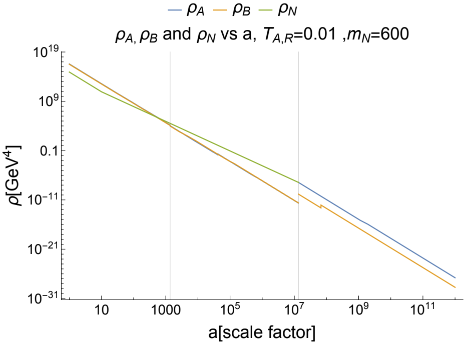
[5] N. Craig, A. Katz, M. Strassler, and R. Sundrum (2015) arXiv: 1501.05310

νMTH

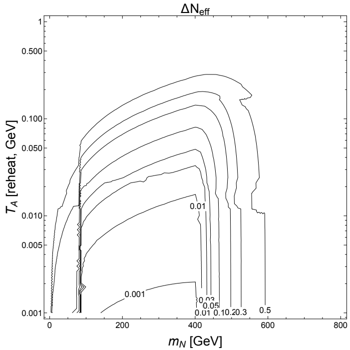
- Introduces right-handed neutrinos N_A and N_B
- Generates active neutrino mass $m_\nu = \frac{y^2 v^2}{m_N^2}$ in both sectors
- N_1 is a long-lived mass eigenstate that freezes out relavistically and leads to an early period of matter domination, decays after two sectors decouple at a few GeV to reheat A more than B
- Branching ratio into B sector $\epsilon = \left(\frac{v}{f}\right)^2$ if all decays are three-body



Asymmetric Reheating (Preliminary)



Energy density history for one-generation reheating.



ΔN_{eff} contours for f/v=5 in the parameter space of reheaton mass and reheating temperature.

- Interesting region $100\mathrm{GeV} < m_N < 400\mathrm{GeV}$: $\epsilon \ll 0.1$ due to additional two-body vs three-body decay (not discussed here but ask me for details).
- $m_N > \mathrm{GeV}$ so will have to generate $m_\nu \ll \mathrm{eV}$ for the lightest active neutrino.

Baryogenesis in νMTH

- Main idea: N decays to generate baryon number violation (similar to leptogenesis and WIMP baryogenesis).
- The reheaton may or may not be the generaton.
- The generaton has to be coupled to quarks and a colored scalar ϕ near m_{gen}.
- $m_{gen} > m_\phi > 500\mathrm{GeV}$ from LHC bound for colored scalar. [6]

[6] except for the case of resonant baryogenesis

Model

- Introduce following interactions in the Lagrangian

$$\mathcal{L} \supset -y_A \tilde{H}_A \bar{L}_A N_A - \lambda_A \bar{N}_A \phi_A U_A - \lambda'_A D_A D_A \phi_A^\dagger$$
$$-y_B \tilde{H}_B \bar{L}_B N_B - \lambda_B \bar{N}_B \phi_B U_B - \lambda'_B D_B D_B \phi_B^\dagger$$

- We add particle content

Multiplet	$SU(3)_A$	$SU(2)_A$	$U(1)_A$	$SU(3)_B$	$SU(2)$	$U(1)_B$
ϕ_A	3	1	-2/3	1	1	0
ϕ_B	1	1	0	3	1	-2/3
N_A	1	1	0	1	1	0
N_B	1	1	0	1	1	0

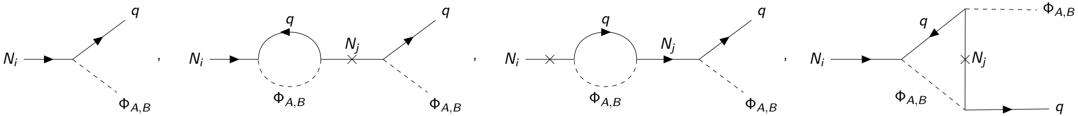
- Mass eigenstates and eigenvalues

$$N = \frac{1}{\sqrt{2}}(N_A \pm N_B), \;\; M = m_N \pm m_{AB}$$

Cases we study

CASE 1:reheaton = generaton = N_1

- N_2 interferes, need $m_{N_2} <= m_{N_1}$
- If $m_{\phi_A} > m_{\phi_B}$, SM baryogenesis suppresed unless $m_{N_1} \sim m_{N_2}$ (further study ongoing for the resonant baryonesis limit)
- If $m_{\phi_A} < m_{N_1} < m_{\phi_B}$, SM baryogenesis unsuppressed, twin baryogenesis suppressed
- If $m_{\phi_A}, m_{\phi_B} < m_{N_1}$, both unsuppressed.



Cases we study

CASE 2: reheaton $\neq$ generaton

- The generaton N_1 and the colored scalar ϕ need to be heavier than 500GeV, but now N_1 generates eV neutrino, so coupling $y = \frac{\sqrt{m_\nu m_N}}{v}$ is large enough for early out of equilibrium decay, leaving the reheating process undisturbed.
- The reheaton N_2 can be arbitrary mass. For $m_N > \mathrm{GeV}$, we get $m_\nu \ll \mathrm{eV}$.
- If $m_{N_2} \sim 100\mathrm{GeV}$, we can now have $\epsilon \ll 0.1$.
- Further studies in progress for this case.

Preliminary Results

- SM baryogenesis fixes coupling combinations.
- We can predict the ADM density:

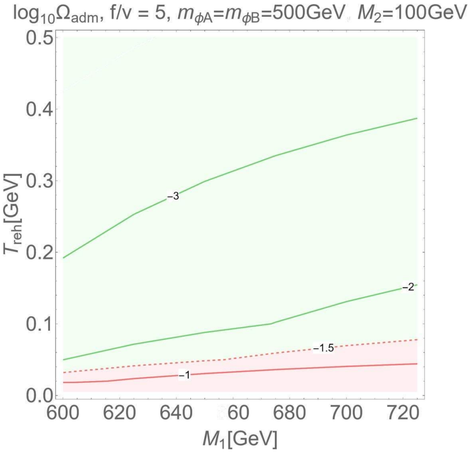
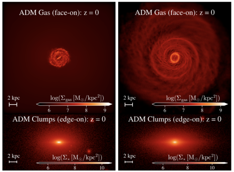


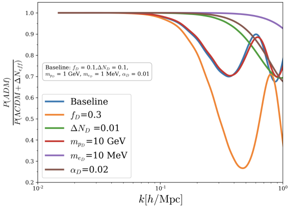
Figure: ADM prediction in the case of reheaton=generaton.

Conclusion

- MTH solves the hierarchy problem without being constrained by LHC bounds.
- MTH generates a hidden sector through a Z2 symmetry. If we assume the hidden sector to be stable, it leads to nontrivial cosmology violation.
- Asymmetric reheating fixes the problem of cosmology violation and gives active neutrino masses via right-handed neutrinos.
- Right-handed neutrino decay can generate baryon asymmetry in both SM and twin sectors, naturally set $\Omega_{ADM}/\Omega_{DM} \sim 10^{-3} - 10^{-1}$.
- Baryogenesis might re-introduce colored state close to collider limit (except for the case of resonant baryogenesis). Is our baryogenesis picture completely general?
- **Motivates ADM searches in cosmology and astrophysics:**



Roy, S. et al. (2023) arx:2304.09878



S. Bansal et al. (2012) arx:2212.02487