Simple Hidden Sector Dark Matter

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Motivation

- MSSM mitigates fine-tuning to a little hierarchy problem between weak scale and SUSY breaking scale
- DM increasingly bounded
- If SUSY breaking gravity mediated, any hidden sectors will also be $\approx$ weak scale, rendering WIMP miracle easily applicable

M. Tanabashi et al. (Particle Data Group), Phys. Rev. D 98, 030001 (2018)
A supersymmetric hidden sector model will generically have a superpotential

$$\mathcal{W} = \mathcal{W}_{visible} + \mathcal{W}_{HS} + \mathcal{W}_{mix} \quad (1)$$

Where for simplicity we assume $\mathcal{W}_{visible} = \mathcal{W}_{MSSM}$. SUSY version of $\epsilon F_{\mu\nu} F'_{\mu\nu}$ is

$$\mathcal{W}_{mix} = \frac{\epsilon}{2} W_Y W' \quad (3)$$

$$\int d^2 \theta \mathcal{W}_{mix} + \text{h.c.} = \epsilon D_Y D' - \frac{\epsilon}{2} F^\mu_\nu F'^\nu_\mu \quad (4)$$

$$+ i \epsilon \tilde{B} \sigma^\mu \partial_\mu \tilde{B}'^\dagger + i \epsilon \tilde{B}' \sigma^\mu \partial_\mu \tilde{B}^\dagger \quad (5)$$
Model-Portals

MSSM

| \( \tilde{B} \) | \( \tilde{B} \)
|------------------|------------------|
| tuned            | natural          |

SUSY

\( H_u, H_d \)

\( Z'_{\text{inv}} \)

\( \epsilon \)

\( X \)

HS

\( \tilde{B} \)
The Hidden Sector could be arbitrarily complicated, however we analyze essentially the simplest superpotential possible

\[ \mathcal{W}_{HS} = \lambda STH' \] (6)

- \( Q'(H') = +1, \ Q'(T) = -1 \)
- S, T charged under accidental \( \mathbb{Z}_2 \)

HS summary:
- Dirac \( \psi = (S, T^\dagger) \), with dark photon and higgs \( Z', \ H' \) + superpartners \( S_1, \ S_2 \), and neutralinos \( \chi'_1, \ \chi'_2 \)
The dark higgs vev $\langle H \rangle = v'/\sqrt{2}$ gives

$$m_\psi = \lambda v'/\sqrt{2}$$
$$m'_Z = g' v'$$
$$m'_H = g' v' + \text{loops}$$

Neutralinos and scalars depend on other soft masses

$$M_{\chi'} = \begin{pmatrix} m_{\tilde{B}'} & m_{Z'} \\ m_{Z'} & 0 \end{pmatrix},$$

$$m^2_{\text{scalar}} = \begin{pmatrix} \tilde{m}^2_S + m^2_\psi & m^*_\psi A^*_\lambda \\ m_\psi A_\lambda & \tilde{m}^2_T + m^2_\psi - \frac{1}{2} m^2_{Z'} \end{pmatrix}.$$
Thermal History

Two DM candidates - $\psi$, and light scalar partner $S_1$
Two couplings, $\alpha_\lambda = \lambda^2 / 4\pi$, $\alpha' = g'^2 / 4\pi$

What sets the abundance?

**a)** $\psi$ DM abundance

**b)** $S_1$ DM abundance
Dilepton resonances: CMS (orange) [Sirunyan et al. (2019)], CMS (purple) [Collaboration (2019)], ATLAS (red) [Aad et al. (2019)]. Precision electroweak constraints: [Hook et al. (2011)] Hook, Izaguirre, and Wacker (yellow). Direct Detection: XENON1T (blue) [Aprile et al. (2018)], LZ projected (blue dashed) [Akerib et al. (2018)]
Conclusions and Future Work

- Can naturally achieve DM abundance
- Even simplest hidden superpotential can realize a large variety of thermal WIMP scenarios
- Indirect Detection - very promising as it is not limited by the $\epsilon$ suppressed coupling to the SM
- Upcoming Cherenkov Telescope Array (CTA) allows a high energy indirect detection search 20 GeV to 300 TeV
References

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Anson Hook, Eder Izaguirre, and Jay G. Wacker.
Model Independent Bounds on Kinetic Mixing.
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Search for a narrow resonance lighter than 200 GeV decaying to a pair of muons in proton-proton collisions at $\sqrt{s} = 13$ TeV.
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Supplemental Slides I

a) $\psi$ DM $\langle \sigma v \rangle$

b) $S_1$ DM $\langle \sigma v \rangle$
