Dark Forces and Dark Matter in a Hidden Sector

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Outline

1 Motivation
2 Hidden Photon
3 Hidden Dark Matter
4 Conclusions
Outline

1 Motivation
   - Hidden Sector
   - GeV-scale Dark Force

2 Hidden Photon

3 Hidden Dark Matter

4 Conclusions
Motivation: Hidden Sector

- String theories usually predict existence of HS
- Various supersymmetric models contain HS
  - HS needed as source of SUSY breaking
- HS not charged under SM gauge groups and v. v.
  - No direct interaction between HS and SM
  - Connection only through messenger particles
- HS can contain gauge fields and matter particles

⇒ Dark Forces and Dark Matter
Motivation: Dark Force and Dark Matter

- breaking of larger gauge groups can yield hidden U(1)s
  - light hidden Photon $\gamma'$
  - couples weakly via kinetic mixing $\chi$

- indirect & direct DM experiments
  - observations by PAMELA, Fermi, DAMA, CoGeNT
  - favor DM models where light messenger particle
    - generates Sommerfeld enhancement,
    - allows leptophilic DM annihilation,
    - mediates scattering on nuclei

$\Rightarrow$ GeV-scale Dark Force
Motivation: GeV-scale Dark Force

Stückelberg mechanism

- simplest mechanism to give mass to abelian gauge boson $\gamma'$
- in certain string compactifications e.g. D7-branes
  mass depends on volume of extra dimension i.e. string-scale
  \[ m_{\gamma'} \gtrsim \frac{M_S^2}{M_{Pl}} \]
- intermediate string-scale: $M_S \sim 10^9 - 10^{10}$ GeV
  gives right regime for axion decay constant and SUSY breaking scales

\[ \Rightarrow m_{\gamma'} \sim \text{GeV-scale} \]
Motivation: GeV-scale Dark Force

Higgs mechanism

- kinetic mixing transfers symmetry breaking from visible sector to HS
- masses in HS roughly suppressed by $\chi$

$$m_{\gamma'} \approx \sqrt{g_Y g_h c_\beta} \sqrt{\chi} v$$

Kinetic mixing $\chi$

- integrating out heavy particles charged under both U(1)s
- kinetic mixing generated at loop level

$$\chi \approx \frac{g_Y g_h}{16\pi^2} \times \kappa \sim 10^{-3} - 10^{-4} \quad (\kappa \sim \mathcal{O}(1))$$

$$\Rightarrow m_{\gamma'} \sim \text{GeV-scale}$$
Outline

1 Motivation

2 Hidden Photon
   - Introduction
   - Constraints

3 Hidden Dark Matter

4 Conclusions
Hidden Photon and Kinetic Mixing

- HS with extra U(1)-symmetry
  \[ \Rightarrow \text{hidden photon } \gamma' \]

- simplest scenario:
  - mass-term for \( \gamma' \)
  - kinetic mixing between \( \gamma \) and \( \gamma' \)

- most general Lagrangian
  \[
  \mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} - \frac{1}{4} X_{\mu\nu} X^{\mu\nu} + \frac{\chi}{2} X_{\mu\nu} F^{\mu\nu} + \frac{m_{\gamma'}^2}{2} X_\mu X^\mu + g_{\gamma} j_{\text{em}}^\mu A_\mu
  \]

- \( \gamma' \) couples and can decay to SM fermions through kinetic mixing
Constraints I: Precision Measurements

Muon & Electron $g-2$ [Pospelov '09]

- 1-loop contribution from $\gamma'$

SM precision measurements [Hook et al. '10]

- deviations from SM measurements
- notably corrections to $Z^0$-mass

BaBar: $\Upsilon(3S)$ decay [Essig et al. '10]

- search for decay into pseudoscalar $a$
  $$e^+ e^- \rightarrow \gamma a \rightarrow \gamma \mu^+ \mu^-$$
- reinterpretation since identical final state
  $$e^+ e^- \rightarrow \gamma' \rightarrow \gamma \mu^+ \mu^-$$
Constraints II: Fixed-target Experiments

- $\gamma'$ Bremsstrahlung off $e^-/p$-beam
- decay $\gamma' \rightarrow e^+e^-$

Past $e^-$-beam dump searches [Bjorken et al. '09]

New and rediscovered experiments

- thin target at **MAMI** [A1 collaboration '11]
- **Serpukhov** $p$-beam dump [Blümlein, Brunner'11]
- $e$-beam dump at **Orsay** [SA, Niebuhr, Jacobsohn, Ringwald, *in prep.*]
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- thin target at MAMI [A1 collaboration '11]
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Sensitivities of future experiments
- JLab: APEX, HPS, DarkLight
- Mainz: MAMI, MESA
- DESY: HIPS at 6 GeV in 2013
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1 Motivation

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3 Hidden Dark Matter
   ■ Toy Model
   ■ More sophisticated Model

4 Conclusions
Toy-Model: Fermionic DM

Additional Dirac fermion $\psi$

- one extra mass parameter $m_\psi$

Relic abundance $\Omega h^2$

- annihilation of $\psi$ through and into $\gamma'$
- resonance for $m_{\gamma'} = 2 m_\psi$

$\Rightarrow \psi$ total DM or subdominant component

[Pospelov et al. '08, Chun et al. '10, Mambrini '10, SA, M. Goodsell, A. Ringwald, work in progress]
Toy-Model: Fermionic DM

Direct Detection

- elastic scattering on nuclei
- mediated by $\gamma'$
- spin-independent vector-like interaction

\[
\psi \xrightarrow{\gamma'} \psi
\]

\[
\mathcal{N} \xrightarrow{\gamma'} \mathcal{N}
\]

Comparison with experiments

- limits on $\sigma_{SI}$ from XENON & CDMS
- potential signature in DAMA & CoGeNT

[SA, M. Goodsell, A. Ringwald, work in progress]
Toy-Model: Fermionic DM

Direct Detection

- elastic scattering on nuclei
- mediated by $\gamma'$
- spin-independent vector-like interaction

\[
\begin{align*}
\psi & \rightarrow \gamma' \rightarrow \psi \\
N & \rightarrow \gamma' \\
N & \rightarrow \gamma' \\
\end{align*}
\]

Comparison with experiments

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[SA, M. Goodsell, A. Ringwald, work in progress]
**SUSY U(1) HS**

- consider MSSM in visible sector
- most simple anomaly-free HS:
  - three chiral superfields
  - superpotential: \( W \supset \lambda S \bar{SH}^+ H^- \)

**Gauge mediation**

- Dirac fermion is DM as in toy-model

**Gravity mediation**

- lightest particle is Majorana fermion
- annihilation through \( \gamma' \Rightarrow \) total or subdominant DM
- axial coupling gives spin-dependent scattering
  - Picasso, COUPP & KIMS constrain \( \sigma_{SD} \)

[SA, M. Goodsell, A. Ringwald, *work in progress*]
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Conclusions

- **HS** motivated by various aspects
  - both from **top-down** (string theory, SUSY) and **bottom-up** (DM)
- potentially rich content: dark forces and dark matter
- weakly coupled but still phenomenologically interesting
- hidden photons as dark force
  - \( \Rightarrow \) constrained by past & further tested in future experiments
- **HS** can contain **viable dark matter candidates**
- many **SUSY & string inspired models** give well motivated HS dark matter
  - \( \Rightarrow \) interesting phenomenology still to be studied