Minimal model of torsion mediated dark matter

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We propose a minimal model of **Torsion mediated** dark matter annihilations

**Torsion**: Antisymmetric part of the Affine connection in the Einstein-Cartan extension of **General Relativity**

**Observations in DM phenomenology**

- **Particle content**: A SM singlet Dirac fermion $\psi$, SM and Torsion: $\text{DM DM–Torsion–SM SM}$
- The DM is naturally stable without any imposition of ad-hoc symmetry like e.g., $\mathbb{Z}_2$
- **Torsion in phenomenology** $\Rightarrow$ like a massive gauge boson (like $\mathbb{Z}’$) having only **axial coupling**
- The stringent bounds on the SI DM-nucleon direct detection cross-section relaxed due to its axial nature of the torsion.
- Mixings with SM Gauge bosons can be considered to be absent
The covariant derivative of a vector field $A^\nu$ is a tensor $\Rightarrow$
\[ \nabla_\mu A^\nu = \partial_\mu A^\nu + \Gamma^\nu_{\mu\lambda} A_\lambda \ (\Gamma^\nu_{\mu\lambda} \Rightarrow \text{Affine connection}) \]

Affine connection $\Rightarrow$ Christoffel Connection in Einstein \textbf{GR}
\[ \Gamma^\lambda_{\mu\nu} = \frac{1}{2} g^{\lambda\alpha} \left( \partial_\mu g_{\nu\alpha} + \partial_\nu g_{\mu\alpha} - \partial_\alpha g_{\mu\nu} \right) \]

In the Einstein-Cartan extension of \textbf{GR}, the affine connection can have an \textbf{anti-symmetric} part $\tilde{\Gamma}^\lambda_{\mu\nu} = \Gamma^\lambda_{\mu\nu} + C^\lambda_{\mu\nu}$

Useful parametrization (arXiv:hep-th/0103093):
\[ T^\lambda_{\mu\nu} = \tilde{\Gamma}^\lambda_{\mu\nu} - \tilde{\Gamma}^\lambda_{\nu\mu}, \]
\[ T_{\mu\nu\lambda} = \frac{1}{3} \left( T_\nu g_{\mu\lambda} - T_\lambda g_{\mu\nu} \right) - \frac{1}{6} \varepsilon_{\mu\nu\lambda\sigma} S^\sigma + q_{\mu\nu\lambda}, \]

Definitions of the irreducible components:
- $S^\lambda = \varepsilon^{\mu\nu\alpha\lambda} T_{\mu\nu\alpha}$ is axial vector mode
- $q_{\mu\nu\alpha} \Rightarrow$ tensor satisfies $q^\mu_{\nu\mu} = 0$ and $\varepsilon^{\mu\nu\alpha\sigma} q_{\mu\nu\alpha} = 0$. 
- $T\mu = T^\alpha_{\mu\alpha} \Rightarrow$ the vector (trace) mode
Torsion interactions with DM and SM fermions

- For simplicity we consider Torsion characterized by $S_\mu$ only

- Relevant and New parts in Action:
  - $S_\mu$-SM interactions:
    
    \[
    S_D = \int d^4x \left\{ i \bar{f} \gamma^\mu (\partial_\mu - i \eta_1 \gamma^5 S_\mu) f \right\},
    \]

  - $S_\mu$-DM interactions:
    
    \[
    S_{DM} = \int d^4x \left\{ i \bar{\psi} \gamma^\mu (\partial_\mu - i \eta \gamma^5 S_\mu) \psi - m_\psi \bar{\psi} \psi \right\}.
    \]

  - Kinetic terms:
    
    \[
    S_{torsion} = \int d^4x \left\{ - \frac{1}{4} S_{\mu\nu} S^{\mu\nu} + \frac{1}{2} m_s^2 S_\mu S^\mu \right\}
    \]

    $S_{\mu\nu} = \partial_\mu S_\nu - \partial_\nu S_\mu$ and $m_s$ is the torsion mass
Torsion($s_\mu$)-DM($\psi$) phenomenology

Dominant channels (Universal coupling : $\eta_1 = \eta$)

\[
\langle \sigma v \rangle_{ff} \sim \eta^4 \frac{m_f^2}{m_s^4} \left( \frac{\left( m_s^2 - 4m_\psi^2 \right)^2}{\left( m_s^2 - 4m_\psi^2 \right)^2 + \Gamma_s^2 m_s^2} \right) + v^2 \frac{\eta^4 m_\psi^2}{\left( 4m_\psi^2 - m_s^2 \right)^2} \times \cdots
\]

\[
\langle \sigma v \rangle_{ss} \sim \frac{\eta^4}{m_\psi^2} \left( 1 - \frac{m_s^2}{m_\psi^2} \right)^{3/2} \left( 1 - \frac{m_s^2}{2m_\psi^2} \right)^{-2} + \mathcal{O} \left( v^2 \right)
\]
Contributions to relic abundance:

- A resonance at $m_\psi \approx \frac{m_s}{2}$ can be observed.
- For moderate or small $m_s$, (when $\Gamma_s$ can be ignored), the leading order term in the s-channel process may not be sensitive to Breit-Wigner type narrow width resonance.
- The dominant $\nu^2$ contribution carries the resonance effect, specially important in relic density calculation when the DM is lighter than top quark.
- $\text{DM DM} \rightarrow t\bar{t} \sim \frac{m_f^2}{m_s^4}$ for $m_s \sim m_\psi$ can produce significant contributions.
- Similarly, $t$-channel contributions, free from $\nu^2$ suppression, are also important for $m_s \lesssim m_\psi$. 

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Results: relic density and SD cross-section

Universal Coupling scenario ($\eta = \eta_1$):
LHC constraints and Nonuniversal coupling scenario

- \( \sigma(pp \to S_\mu) \times Br(S_\mu \to l^+l^-) \) (\( l \in e, \mu \)) vs. \( m_s \) in the universal and nonuniversal coupling (NU) scenario

- \( \eta \sim 1 \) may lead to \( \Gamma_s/m_s \geq 0.5 \) narrow width approximation breaks down \( \Rightarrow \) LHC constraints relaxed

- NU scenario \( \Rightarrow \) DM phenomenology mostly unchanged

Torsion Portal- GR connection successfully explain DM phenomena
THANK YOU