How dark matter cares about topological superstrings

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Dark Matter

Observations of SN CMB and galaxy clusters have provided three stringent constraints on $\Omega_M$ and $\Omega_\Lambda$

Results favor $(\Omega_M, \Omega_\Lambda) \approx (0.3, 0.7)$

Baryonic matter constrained by CMB and BBN

$\Omega_B = 4\% \pm 0.4\% \Rightarrow \Omega_{DM} = 23\% \pm 4\% \quad \Omega_{DM} h^2 = 0.113 \pm 0.003$
Thermal freeze-out abundance of DM can be related to thermally averaged WIMP annihilation cross section

\[ \Omega_{DM} h \sim \frac{10^{-10} \text{ GeV}^{-2}}{\langle \sigma v \rangle} \]

Typical weak cross section is

\[ \langle \sigma v \rangle \sim \frac{\alpha^2}{M_{\text{weak}}^2} \sim 10^{-9} \text{ GeV}^{-2} = 3 \times 10^{-26} \text{ cm}^3\text{s}^{-1} \]

yielding thermal relic density

\[ \Omega_{DM} h \sim 0.1 \]
SUSY Essentials

Rotations ➔ angular momentum operators $L_i$

Boosts ➔ boosts operators $K_i$

Translations ➔ momentum operators $P_\mu$

Spacetime symmetries

SUSY is the symmetry that results when these 10 generators are further supplemented by fermionic operators $Q_\alpha$

$R$ parity is defined by $R_p = (-1)^{3(B-L)+2S}$

All SM particles have $R_p = 1$ and all superpartners have $R_p = -1$

Conservation of $R$-parity implies $\prod R_p = 1$ at each vertex

yielding an elegant way to forbid proton decay in SUSY models
Dark Matter Detection

- Neutralino LSP ($\chi^0$) are prime candidates for dark matter
  
  Goldberg, PRL 50, 1419 (1983)

- Annihilation hindered because of p-wave barrier

- Direct Detection in CDMS, XENON, COUPP, KIMS, etc.

- Indirect Detection:
  excess of $\gamma$, $e^\pm$, $\nu$ from dense astrophysical environments

- ID via monoenergetic gamma-rays from $\chi^0\chi^0 \rightarrow \gamma\gamma, \gamma Z$
  are loop induced in the MSSM and for the bino are small
  
  (BR $\sim 0.1\%$)

  Bern, Gondolo, Perelstein, PLB 411 86, (1997)
\( \chi^0 \chi^0 \) s-wave annihilation into gauge bosons

- s-wave annihilation demands that \( \chi^0 \) have same helicity

Since \( \chi^0 \chi^0 \) is the A term of a chiral superpotential \( WW \) and the two gauge bosons \( \sim F^2 \) are in the F term of the same or different \( WW \) there is a violation of R-symmetry by two units \( \Delta r = 2 \)

- R-charge deficit related to Euler characteristic of the string worldsheet
  \( \chi = 2 - 2g - h \) via \( |\Delta r| \leq -2\chi \) \( \Rightarrow \chi < 0 \)

Therefore require

\[ \chi = -1 \]

\[ g = 1, \ h = 1 \]
Topology

Antoniadis, Narain, Taylor, NPB 7729, 235 (2005)
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R-charge deficit related to Euler characteristic of the string worldsheet \( \chi = 2 - 2g - h \) via \( |\Delta r| \leq -2\chi \Rightarrow \chi < 0 \)

Therefore require

\[ \chi = -1 \]
\[ g = 0, \ h = 3 \]
The topologies $c'$ and $c$ are discussed in the context of neutralino annihilation to monoenergetic gamma rays and low mass superstrings.

Antoniadis, Narain, Taylor, NPB 7729, 235 (2005)

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SM from intersecting D-branes

- Baryonic
- Leptonic

b- Left

c- Right

d- Leptonic

gluon
Stacks, boundaries, and effective interactions

Effective Lagrangian calculable from topology of compactified dimensions if gaugino and gauge boson vertices are attached to two different boundaries.

Additional non-topological contributions if emitted gauge bosons are in same stack as gauginos and vertices are attached to same boundary.

\[
\mathcal{L}_{\text{eff}} = 3g_s^3 N M_s^{-3} \tilde{F}^{(0,3)} (\text{Tr}WW)(\text{Tr}WW)_{\theta\theta} + \text{h.c}
\]

\[
= \frac{3}{8} g_s^3 N M_s^{-3} \tilde{F}^{(0,3)} (\text{Tr}\lambda\lambda)(\text{Tr}FF) + \text{h.c}
\]

\(N = 6 = \) number of stacks traced out in empty boundary.

\(F^{(0,3)} = 3N \tilde{F}^{(0,3)} \equiv \) genus zero topological partition function on a worldsheet with \(h = 3\) boundaries.
Constraint from relic abundance

To generate measured relic density \( \Omega_{\text{DM}} h^2 = 0.113 \pm 0.003 \), requires annihilation rate

\[
\left\langle \sigma v \right\rangle_{\text{eff}} = \sigma v |_{WW} + \sigma v |_{gg} + \sigma v |_{BB} \\
\approx 3 \times 10^{-26} \text{ cm}^3/\text{s}
\]

for each gluon or W pair

\[
\sigma v |_{W^i W^i} = \sigma v |_{g^i g^i} \\
= \frac{c}{4\pi} \left( 3g_s^3 N \tilde{F}^{(0,3)} \right)^2 \frac{1}{M_s^2} \left( \frac{m_{\chi^0}}{M_s} \right)^4
\]

To account non-topological contributions to \( \chi^0 \chi^0 \rightarrow BB \) define

\[
\zeta = \frac{\mathcal{M}(BB)}{\mathcal{M}(W^3 W^3)}
\]

Relic constraint is

\[
[1 + 0.083(\zeta^2 - 1)] \left( \frac{\tilde{F}^{(0,3)}}{2.8} \right)^2 \left( \frac{g_s}{0.2} \right)^6 \left( \frac{m_{\chi^0}/M_s}{0.5} \right)^4 \left( \frac{2 \text{ TeV}}{M_s} \right)^2 \approx 1
\]
Smoking Gun

Rewrite cross sections in terms of $\gamma$, $Z$, $W^\pm$, $g$

\[
\sigma v|_{\gamma\gamma} = \sigma v|_{W^3W^3} (\sin^2 \theta_W + \zeta \cos^2 \theta_W)^2
\]

\[
\sigma v|_{ZZ} = \sigma v|_{W^3W^3} (\cos^2 \theta_W + \zeta \sin^2 \theta_W)^2
\]

\[
\sigma v|_{\gamma Z} = \sigma v|_{W^3W^3} 2 \cos^2 \theta_W \sin^2 \theta_W (1 - \zeta)^2
\]

\[
\sigma v|_{W^+W^-} = 2 \sigma v|_{W^3W^3}
\]

\[
\sigma v|_{gg} = 8 \sigma v|_{W^3W^3}
\]

For $\zeta \simeq 1$ obtain nearly 10% branching into $\gamma\gamma$ large number of gamma rays with energy $\sim m_{\chi^0}$
H.E.S.S. and Galactic Center

Gamma-ray Flux from annihilation in GC

\[ \phi_{\gamma}^\prime (\psi, E_\gamma) = \int \bar{J} \frac{1}{2} \frac{D_\odot}{4\pi} \frac{\rho_\odot^2}{m_\chi^2} \sum_f \langle \sigma v \rangle_f \frac{dN_f}{dE_\gamma} d\Omega \]

\[ \bar{J} = \frac{1}{\Delta \Omega} \int_{\Delta \Omega} J(\psi) \, d\Omega \]

\[ J(\psi) = (D_\odot \rho_\odot^2)^{-1} \int_{\ell=0}^{\infty} \rho_\odot^2 [r(\ell, \psi)] d\ell \]

\[ r^2 = \ell^2 + D_\odot^2 - 2\ell D_\odot \cos \psi \]

\[ \frac{dN_f}{dE_\gamma} \] normalized photon spectrum per annihilation via channel \( f \)

\[ \rho(\vec{x}) \] dark matter density at generic location \( \vec{x} \) wrt to GC
Neutralino annihilation to monoenergetic gamma rays and low mass superstrings

**Direct Detection**

- The (dimension 7) interaction operator relevant for DD is
  \[ L_{\text{eff}} = \frac{\alpha_s}{\Lambda^3} \bar{\chi} \chi G_{\mu\nu}^a G^{\mu\nu a} \]

The spin independent elastic scattering cross section is

\[ \sigma = \frac{4}{\pi} m_p^2 f_p^2 = \frac{4}{\pi} m_p^2 \left( \frac{8\pi}{9} \frac{m_p}{\Lambda^3} f_{TG} \right)^2 = \frac{256}{81} \pi \frac{m_p^4}{\Lambda^6} f_{TG}^2 \]

reflects the gluon content of the nucleus and is measured to be \( \sim 0.83 \)

Jungman, Kamionkowski, Griest, PR 267, 195 (1996)

- For \( M_s = 2 \) TeV \( \Rightarrow \Lambda = 2.5 \) TeV \[ \Rightarrow \sigma \approx 10^{-47} \text{ cm}^2 \]

well below current limits \( \sigma < 2 \times 10^{-43} \text{ cm}^2 @90\%CL \)

CDMS Collaboration arXiv:0912.3592
Remarks and Conclusions

We constructed a model that generates a supersymmetric R-symmetry violating effective Lagrangian which allows for s-wave annihilation of neutralinos (once gauginos acquire mass via an unspecified mechanism).

The model allows for a neutralino relic abundance consistent with the measured dark matter density.

The branching fraction to monochromatic gamma rays is orders of magnitude larger than in the MSSM.

A very bright and distinctive gamma-ray line that may lie within the reach of current or next-generation gamma-ray telescopes is predicted.