Cosmic Signals from the Hidden Sector

arxiv:0905.3749

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Dark Matter explanation of PAMELA, FERMI and HESS

• Source of $e^+ e^-$
  Broad spectrum extending to $\sim$few TeV
  No new source of $p\bar{p}$

• DM: Annihilation vs. Decay
  – Boost Factor / non-thermal production
    vs. $10^{26}$s lifetime
  – Constraints favour decay

  e.g. Cirelli et.al. 0907.0719
  Profumo & Jeltman 0906.0001
  Meade et.al. 0905.0480
  J.M., Y. Nomura, D. Stolarski & J. Thaler 0901.2926
A Framework for Dark Matter

• Dark matter is composite of new strongly coupled sector at $O(10 - 100 \text{ TeV})$

• Protected by accidental symmetry broken at high scale

• Decay to pseudo–NGB of spontaneously broken global symmetry

Very low scale dynamical SUSY breaking is a natural setting
PAMELA, FERMI, HESS and leptonic final states

• No new source of antiprotons + broad spectrum

⇒ decay through new light state
  - extra step broadens spectrum
  - kinematics prevents baryonic final states

e.g. Cholis et.al. 0802.2922
Arkani-Hamed et.al. 0810.0713
Nomura & Thaler 0810.5397
PAMELA, FERMI, HESS and the WIMP Paradigm

• $e^+ e^-$ excess up to $\sim$few TeV
  $\Rightarrow m_{DM} \sim 10$ TeV

• WIMP paradigm: fix $\frac{g_{DM}^4}{m_{DM}^2}$
  $g_{DM} \sim 1 \Rightarrow m_{DM} \sim$ EW scale

• thermal abundance $\Rightarrow g_{DM} \sim \pi$
  $\Rightarrow$ strongly coupled physics
  composite dark matter

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SUSY Cosmology and Dark Matter

• SUSY breaking $\rightarrow$ massive gravitino

\[ \left( m_3^2 = \frac{F}{M_{Pl}} \right) \]

$\rightarrow$ Cosmological problems

- gravitino over-abundance
- late decays spoil BBN

• Problems disappear if $m_3^2 \lesssim 10$ eV $\iff \sqrt{F} \lesssim 100$ TeV
SUSY Cosmology and Dark Matter

\[ \Lambda \sim 10 - 100 \text{ TeV} \]

\[ m_{\tilde{q}, \tilde{l}} \sim \frac{\alpha}{4\pi} \Lambda \sim 100 \text{ GeV} - \text{TeV} \]

\[ m_{\frac{3}{2}} \sim \frac{\Lambda^2}{M_{Pl}} \lesssim 10 \text{ eV} \]

\text{single scale theory:}
all scales generated by strong dynamics

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SUSY Cosmology and Dark Matter

• Gravitino is LSP ... no neutralino DM!

• Dynamical SUSY breaking $\rightarrow$ strong dynamics
  $\rightarrow$ stable states?

Think of proton stability:
  -elementary: $\mathcal{L} \subset ep$ $\rightarrow$ immediate proton decay
  -composite: $\mathcal{L} \subset LQQQ$ : non-ren.
  $\rightarrow$ accidental $U(1)_B$ $\rightarrow$ proton stable

• Composite states can be naturally stable
  lightest stable state is DM candidate

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**SUSY Cosmology and Dark Matter**

- **Dimension 6 proton decay:** \( \mathcal{L} \supset \frac{LQQQ}{M_{GUT}^2} \)

  \[ \rightarrow \text{proton lifetime} \sim 8\pi \frac{(4\pi)^2 M_{GUT}^4}{m_p^5} \sim 10^{40} \text{s} \]

- **Symmetry protecting DM broken at high scale by dim 6 operator**

  \[ \implies \text{DM lifetime} \sim 8\pi \frac{(4\pi)^2 (10^{17} \text{GeV})^4}{(10 \text{TeV})^5} \sim 10^{26} \text{s} \]

  e.g. Nardi et.al. 0811.4153
  Dimopoulos et.al. 0812.2075

- **10 TeV composite DM with lifetime \( \sim 10^{26} \text{s} \)**

  can appear *naturally* from \( O(10 - 100 \text{ TeV}) \) dynamical SUSY breaking sector
Light Axion-like States

DM decay through light states?

• **Spontaneously break global** $U(1)$ in strong sector
  $\rightarrow$ massless NGB ("axion")

• **Small explicit breaking**
  $\rightarrow$ small mass

• E.g. $U(1)_R +$ supergravity $\longrightarrow m_{\text{axion}} \sim O(1 - 100)$ MeV

  or $U(1)_{\text{PQ}}$ broken by dim 5 operator at $\sim 10^9$ GeV $- M_{\text{Pl}}$
  $\longrightarrow m_{\text{axion}} \sim \text{MeV} \ - \ 10$ GeV
Light Axion-like States

• Higgs charged under $U(1)$
  $\implies$ axion mixes with Higgs

• Axion decays to $\sim$heaviest allowed state

$\begin{align*}
\text{axion mass} : & \quad 2m_e - 2m_\mu & & 2m_\mu - 800 \text{ MeV} & & 800 \text{ MeV} - 2m_p & & 2m_\tau - 2m_b \\
\text{decay channel} : & \quad e^+ e^- & & \mu^+ \mu^- & & \rho^* \pi^0 \to \pi^+ \pi^- \pi^0 & & \tau^+ \tau^-
\end{align*}$
Comparison with PAMELA
Comparison with FERMI and HESS

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Implications: $\gamma$-ray signals?

diffuse gamma ray flux away from the galactic plane

\[ E^2 \Phi_{\gamma} \text{ (GeV cm}^{-2}\text{s}^{-1}\text{sr}^{-1}) \]

- 1 step to $\tau^+\tau^-$
- 1 step to $\pi^+\pi^-\pi^0$
- 2 step to $\mu^+\mu^-$ (FSR)
- background model

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Implications: collider signals?

• Direct axion production from gluons?
  \[ \rightarrow \mu^+ \mu^- + \text{displaced vertex} \]

• Higgs decay to axions?
  axion \[ \rightarrow \mu^+ \mu^- \]

Goh & Ibe 0810.5773
Nomura & Thaler 0810.5397
Lisanti & Wacker 0903.0363
Summary

- Cosmic ray data $\rightarrow$ decaying DM
- $m_{DM} \sim 10$ TeV $\rightarrow$ composite DM
- Natural stability due to accidental symmetry
- Symmetry violation at high scale $\rightarrow$ decay
- Decay to pseudo NGB $\rightarrow$ leptonic final states
natural in context of dynamical SUSY breaking

excellent fit to data

future astrophysical/collider signatures?