Indirect detection of light dark matter

Francesc Ferrer

Case Western Reserve University

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Outline

1 Introduction
   - The nature of the Dark Matter
   - The MSSM neutralino

2 Light dark matter in the NMSSM
   - The \( \mu \) problem of the MSSM
   - Neutralinos with a singlet component

3 Indirect detection
   - \( \chi \)s in the Earth and the Sun
   - Antimatter and \( \gamma \)-ray fluxes
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The nature of the Dark Matter

ΛCDM cosmology
- We can describe the composition of the Universe
- The nature of the dark sector is still unknown
1/4th is made of Cold Dark Matter

Cold Dark Matter

- Structure formation requires the Dark Matter to be non-relativistic
- A neutral particle with mass and interaction rates at the electroweak scale is a good candidate
Other possibilities

- Modify gravity?
Other possibilities

- Modify gravity?
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The MSSM neutralino

Input from Particle Physics

- **SUSY** is a symmetry between bosons and fermions that, if present not far above the electroweak scale, can explain the hierarchy problem of the Standard Model of PP.
- As a bonus, the LSP is stable in R-Parity conserving models and, if neutral, is an example of WIMP.
- The neutralino LSP can be detected using both direct and indirect detection methods.
Dark Matter
The NMSSM neutralino
Indirect detection
Summary

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The $\mu$ problem of the MSSM

Fine-tuning in the MSSM

- The MSSM lagrangian has an unprotected dimensionful parameter:
  \[ \mathcal{L} \sim \mu^2 H_1 H_2 \]

- The LEP lower bound on $h$ pushes the scale of SUSY breaking above the electroweak scale.

- Electroweak Baryogenesis, $n_b/n_\gamma \sim 10^{-10}$, is not possible in the MSSM.
Singlet extensions of the MSSM

The Next-to-MSSM
- Introduce a singlet superfield with a $\mathbb{Z}_3$ invariance:

$$\lambda \hat{S} \hat{H}_u \hat{H}_d + \frac{\kappa}{3} \hat{S}^3$$

Natural solution
- Effective $\mu_{\text{eff}} = \langle S \rangle$.
- Extra decay channels: $h \rightarrow aa$.
- Stronger electroweak phase transition.
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Neutralinos with a singlet component

NMSSM neutralinos

- They can be as light as $\sim 100$ MeV.
- In the $\sim 100$ MeV mass range they could explain the SPI data.
- If in the $\sim 10$ GeV range, they could account for the discrepancy between DAMA and CDMS.
Neutralinos with a singlet component

Light neutralinos
- Direct detection experiments are optimized for neutralinos heavier than $\sim 50$ GeV
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Indirect detection

Focus on the few GeV mass range

- (Some) Direct detection experiments are not sensitive to $m_\chi \lesssim 50$ GeV.
- A weakly interacting particle can annihilate to Standard Model final states:
  \[ \chi\chi \rightarrow f\bar{f}, W^+W^-, ZZ, \ldots \]
- Indirect detection rates increase as $1/m_\chi^2$. 

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The NMSSM neutralino

**Indirect detection**

- **νs from the Earth or the Sun**

  - **Trapped neutralinos**
    - $\chi$ can be trapped via elastic scattering and settle in the Earth/Sun core.
    - We can monitor $\nu$s from annihilations.

  - Indirect detection of light dark matter
Solar dynamics

- Energy transport by neutralinos could reduce the central Sun temperature.
- The mean free path of the neutralinos in the Sun is much larger than $r_\chi \lesssim 0.13R_\odot \sqrt{1 \text{ GeV}/m_\chi}$, and energy is transported in a non-local manner.
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PAMELA is measuring $e^+$ and $\bar{p}$ fluxes. The forthcoming AMS-02 will improve the precision on the $e^+$ flux.

The proposed balloon-borne GAPS experiment will search for antideuterons in the background-free interval $0.1 \leq E \leq 0.25$ GeV.
Neutralino annihilations yield a two component flux of gamma rays.

The estimates of the flux depend on the dark matter halo profile and on the evaluation of the background.
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