Relic Neutralinos and Dark Matter

(A. Bottino)

- Neutralino ($\chi$) as
  the Lightest Supersymmetric Particle
  (Relic abundance)

- Searches for relic neutralinos
  1) direct detection
  2) signals from $\chi-\chi$ annihilation
     in Earth and Sun
  3) exotic $\bar{p}$'s in cosmic rays

- Interplay among these searches & with
  measurements at accelerators

1-2) A.B., F. Donato, N. Fornengo, S. Scopel
3) A.B., F. Donato, N. Fornengo, P. Salati
Supersymmetry theories with conserved $R$-parity imply that the Lightest Susy Particle is stable.

Different schemes for mechanism of Susy entail LSP of different nature.

1. Susy (at scale $\sim 10^{10}-10^{11}$ GeV) communicated from hidden sector to visible one by gravity
   \[ \Rightarrow \text{LSP} \equiv \text{neutralino} \ (\chi) \]

2. Susy (at scale $\sim 10-100$ TeV) communicated by SM gauge interactions
   \[ \Rightarrow \text{LSP} \equiv \text{gravitino} \ , \text{NLSP} \equiv \text{neutralino} \]
   (DM candidates also occur in the hidden and messenger sectors, Dimopoulos, Giudice, Pomarol)

We consider here only case ①
Neutralino is a good candidate as a Weakly Interacting Massive Particle

* would have decoupled from primeval plasma at a temperature $T \sim \frac{1}{20} m$ (cold relic)

$\Rightarrow$ could contribute sizeably to $\Omega_m$

$\Rightarrow$ could be detectable either directly or indirectly in searches for relic particles

Definition: linear combination

$\chi = a_1 \tilde{B} + a_2 \tilde{W}^{(3)} + a_3 \tilde{H}^0 + a_4 \tilde{H}^0$

\text{gaugino} \quad \text{higgsino}

of lowest mass $m_\chi$.

gaugino fractional weight: $P = a_1^2 + a_2^2$
Susy scheme adopted here:

Minimal Supersymmetric extension of Standard Model

at the electroweak scale, implemented by some assumptions to reduce drastically the number of Susy parameters (to six).

Δ The ranges of Susy parameters are very loosely constrained

(by experimental bounds & theoretical arguments)

⇒ this implies large dispersions in the values for \( \mathcal{O}_\chi \) and

for detection rates
The relic abundance of a cold relic particle is given by

\[ \Omega h^2 \approx \frac{10^{-37} \text{ cm}^2}{\langle \sigma \text{ann} \nu \rangle} \]

In the supersymmetric parameter space there are neutralino configurations with a relic abundance in the cosmologically interesting range

\[ 0.03 \leq \Omega h^2 \leq 0.3 \]
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Searches for relic neutralinos

- direct search: elastic scattering of $\chi$ off nuclei
  \[ \chi + N \rightarrow \chi + N \]

- indirect searches:
  * signals due to $\chi-\chi$ annihilations taking place in celestial bodies (where $\chi$'s have been accumulated) $\rightarrow \gamma$'s $\rightarrow$ up-going $\mu$'s
    (Earth, Sun)
  * signals due to $\chi-\chi$ annihilations taking place in the halo
    \[ \chi + \chi \rightarrow \bar{p} + \bar{p}, \ldots \]

  - keep directionality, detectable if omitted by regions of high $\chi$ density
  - gamma line (2$\gamma$)

  - searched for as rare components in cosmic rays
Direct detection

\[ \frac{dS}{dE_{\text{recoil}}} \Rightarrow \frac{p_x}{p_{\text{scalar}}} \]  

\( = \frac{p_x}{p_{\text{scalar}}} \)  

S/B discrimination by annual modulation

\[ S(t) = S(v_{\text{av}}) + S_m \cos \left[ \omega (t-t_0) \right] \]  

\[ \uparrow \text{U.E. Orb} \]  

\[ \Rightarrow \]  

\[ S \]  

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\[
\left( \frac{p_x}{0.5 \text{ GeV} \cdot \text{cm}^{-2}} \right) \sigma_{\text{nucleon}} \text{ scalar} \quad \text{vs} \quad m_x
\]

upper bound (90\%) from DAMA/NaI and Ge/Gotthard

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$\chi-\chi$ annihilation in celestial bodies

(Sun, Earth)

emission of $\nu$'s $\rightarrow$

$\rightarrow$ up-going $\mu$'s in neutrino telescopes

$\Phi_\mu$ vs $m_\chi$
--- Baksan upper bound (90\% C.L.)
--- MACRO upper bound (90\% C.L.)

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Figure 1
the primary flux is calculated here
with a $\chi$-configuration: $m_\chi = 60 \text{ GeV}$, $P = 0.98$
$\Omega_\chi h^2 = 0.11$

Here the dark halo is taken spherical
(for a flattening factor $= 0.5$, the primary
flux is enhanced by a factor 2.3)
Propagation of $\bar{\nu}$'s in the Galaxy

The relevant terms in the $\bar{\nu}$ transport equation are:

- **Source terms**
- **Diffusion term**
- **Convection term**
- **Energy losses & gains terms**
- **Particle losses terms**

Here our Galaxy is modelled by:

1) a **thin disk** of atomic and molecular hydrogen
2) an **extended region** of diffusion containing irregular magnetic fields
3) a **spheroidal halo** of dark matter

$P(R,\pi) = \frac{a^2 + R^2}{a^2 + R^2 + \pi^2/q^2}$

$q = \text{flattening parameter}$

$0.3 \leq q \leq 1$

possible clumpiness

diffusion region for cosmic rays

![Diagram of Galaxy model](image)
Comparison with BESS95 data

- Data are consistent with secondary $\bar{p}$'s
- However, primaries due to $\chi$-$\chi$ annihilation improve the best fit to data sizeably
- Therefore, the spectrum in the low-energy range $0.1 \text{ GeV} \leq T_\bar{p} \leq 1 \text{ GeV}$ may reveal new physics
- We select Suyy configurations that provide a best fit at 95\% c.l. and examine their explorability by
  * experiments of direct search for WIMPs
  * search at accelerators
Figure 12 (a)
\[
\left( \frac{p_X}{0.4 \text{ GeV cm}^{-2}} \right) \sigma_{\text{scalar}}^{\text{nucleon}} \quad \text{vs} \quad m_X
\]

Figure 6.1 (a)
Figure 6.2
For a recent analysis on how LEP data may constrain SUSY parameter space, see J. Ellis, Falk, Gaisser, Olive & Schmitt

hep-ph/9801448
Conclusions

- For
  * direct detection
  * high-energy ν's from Earth & Sun
  * exotic F's in cosmic rays

  present / near-future experimental sensitivities able to provide exploration of interesting regions of the Susy parameter space

- some of these regions are in common (good in view of difficulties in S/B discrimination) and are explorable with present accelerators