Dark Matter

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CHEP IN-HOUSE
MARCH 10 2012
• Astrophysical evidence
• Cosmological evidence
• Direct Detection
• Indirect Detection
DIRECT EVIDENCE OF DARK MATTER

COLLISION OF BULLET CLUSTER
DIRECT EVIDENCE OF DARK MATTER
COLLISION OF MACS J0025.4-1222
DIRECT EVIDENCE OF DARK MATTER

Saturday 10 March 12
$\Omega_{CDM} h^2 = 0.1109 \pm 0.0056$
particle physics interpretations
Dark matter particle

- colorless, charge-less, (odor-less)
- weak interactions ?
- between weak and electromagnetic
- mass ? (depends on cross section again)
- WIMP : around 100 GeV
- Other candidates : a few eV to a GeV
WIMP Miracle

Relic density roughly of the right order for a 100 GeV WIMP.

THIS HAS BEEN QUESTIONED IN THE RECENT TIMES
SUSY dark matter
SUPERSYMMETRY TRANSFORMS PARTICLES OF DIFFERENT SPIN

ADDS EQUAL NUMBER OF NEW PARTICLES TO STANDARD MODEL
**NEUTRALINO MASS MATRIX**

\[
\mathcal{L} \supset \frac{1}{2} \Psi_N \mathcal{M}_N \Psi_N^T + H.c \quad \quad \Psi_N = \{ \tilde{B}, \tilde{W}^0_1, \tilde{H}^0_1, \tilde{H}^0_2 \}
\]

\[
\mathcal{M}_N = \begin{pmatrix}
M_1 & 0 & -M_Z c\beta s\theta_W & M_Z s\beta s\theta_W \\
0 & M_2 & M_Z c\beta c\theta_W & M_Z s\beta c\theta_W \\
-M_Z c\beta s\theta_W & M_Z c\beta c\theta_W & 0 & -\mu \\
M_Z s\beta s\theta_W & -M_Z s\beta c\theta_W & -\mu & 0
\end{pmatrix}
\]

\[
N^* \cdot M_N \cdot N^\dagger = \text{Diag.}(m_{\chi_1^0}, m_{\chi_2^0}, m_{\chi_3^0}, m_{\chi_4^0})
\]

\[
\chi_1^0 = N_{\tilde{B}_1} \tilde{B} + N_{\tilde{W}_1} \tilde{W}^0 + N_{\tilde{H}_1} \tilde{H}^0_1 + N_{\tilde{H}_2} \tilde{H}^0_2
\]

**LIGHTEST SUSY PARTICLE IS STABLE MIXTURE OF GAUGINOS AND HIGGSINOS**

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\[ m_0 \gg M_{1/2} \]

**FOCUS POINT REGION**

**FUNNEL REGION**

\[ 2m_{\chi_0^1} = m_A \]

**STAU CO-ANNIHILATION REGION**

\[ \tan \beta = 30 \]
\[ A_0 = 0 \]
\[ m_t = 173.2 \text{GeV} \]
GUT/neutrino Effects on Dark Matter

(1) Through flavour violating entries in the slepton mass matrix with and without seesaw (modifies co-annihilation regions)

Choudhury, Garani, Vempati

(2) RG corrections to the Higgs sector especially in the presence of a seesaw (significantly modifies the focus point regions)

(3) Through gauge corrections to the sleptonic fields (as they sit in the same multiplet as squarks) (modifies co-annihilation regions)

Large phenomenological effects from seemingly small corrections

Barger et.al, '08,'10
Calibbi, Mambrini, Vempati et. al, '06, '07, '10
Goto et. al, '07
Gomez et. al, '08, '09, '10
Olive et. al, '08, '09, '10
SuSeFLAV: Supersymmetric Seesaw spectrum and FLAVor Violation Calculator

Debosh Chowdhury, Raghuveer Garani, Sudhir K. Vempati

State of the art computational methods are essential to completely understand Supersymmetry. SuSeFLAV is one such numerical tool which is capable of investigating mSUGRA, GMSB, non universal higgs models and complete non-universal models. The program solves complete MSSM RGEs with complete 3 flavor mixing at 2-loop level + one loop threshold corrections to all MSSM parameters by incorporating radiative electroweak symmetry breaking conditions, using standard model fermion masses and gauge couplings as inputs at the weak scale. The program has a provision to run three right handed neutrinos at user defined scales and mixing. Also, the program computes branching ratios and decay rates for various flavor violating processes such as $\mu \rightarrow e \gamma, \tau \rightarrow e \gamma, \tau \rightarrow \mu \gamma, \mu \rightarrow e e e, \tau \rightarrow \mu \mu \mu, \tau \rightarrow e e e, b \rightarrow s \gamma$ etc. and anomalous magnetic moment of muon.

The first version of SuSeFLAV appeared on the arXiv 1109:3551.

SuSeFLAV is also available at HepForge.

Please cite D. Chowdhury et al. [hep-ph/1109.3551] if you are using SuSeFLAV to write a paper. It will be regularly updated on arXiv and served as user manual.

suseflav at cts.iisc.ernet.in, Raghuveer Garani (rgarani at cts.iisc.ernet.in), Debosh Chowdhury (debosh at cts.iisc.ernet.in) and Sudhir Vempati (vempati at cts.iisc.ernet.in)
Download SuSeFLAV

Tar zipped source file of the latest version (1.1.3) is available here:

- **SuSeFLAV-1.1.3** (Feb 29, 2012)
  - Bug while \( \text{sign}(\mu) = -1 \) is fixed. (Thanks to K. Patel)

Tar zipped source file of the older versions is available here:

- **SuSeFLAV-1.1.2**
  - Bug in writing the output.txt file while scanning is fixed. (Thanks to K. Patel)
  - Corrected the name of mh10 and mh20 in the input file sinputs-nuhm.in. (Thanks to K. Patel)

- **SuSeFLAV-1.1.1**
  - Bug with SLHA format fixed. (Thanks to B. Murakami, C. Phillips and Anonymous R)
  - Updated to SLHA2.
  - Example files improved.

- **SuSeFLAV-1.1.0**
  - Bug in the Neutralino tree-level spectrum calculation fixed.

- **SuSeFLAV-1.0.0**

Installation Instructions

NOTE: LAPACK libraries are required to run SuSeFLAV. To download and install LAPACK please visit the website.

To untar the tar-gzipped file, go to the download directory of suselfav_1.x.x.tgz and type the following at the command line:

```
> tar -xvf suselfav_1.x.x.tgz
```

This creates suselfav_1.x.x/ in your directory where it has been downloaded. Now go to the directory suselfav_1.x.x/.

```
> cd suselfav_1.x.x/
```

If you are using SuSeFLAV you will need Fortran 90/95 compiler. SuSeFLAV has been successfully compiled using GNU g95.
FLAVOURED CO-ANNIHILATIONS
CAN GIVE FLAVOUR VIOLATING SIGNALS AT LHC AND STILL GIVE CORRECT RELIC DENSITY
direct detection
SUMMARY OF DIRECT DETECTION RESULTS FROM VARIOUS EXPERIMENTS

The graph above illustrates the observed and expected limits on the spin-independent WIMP-nucleon cross-section for various experiments. The XENON100 experiments, both in 2010 and 2011, are shown with solid lines, while other experiments like CoGeNT and DAMA are indicated with dashed lines. The expected limits for this run are also depicted with shaded bands.

**Summary:**
- **XENON100 (2010)** observed limit (90% CL)
- **XENON100 (2011)**
- **Expected limit of this run:**
  - ± 1 σ expected
  - ± 2 σ expected

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**References:**
A_0 = 0, \tan\beta = 45, \mu > 0, m_t = 172.6 \text{ GeV}

**REACH OF MSUGRA AT LHC**

MISSING ENERGY + N LEPTONS SIGNAL

*Figure 2:* The optimized 5σ SUSY reach of LHC7 in various channels classified by lepton multiplicity: 0ℓ, 1ℓ, SS dilepton, OS dilepton and trilepton for an integrated luminosity of 20 fb⁻¹. Any mSUGRA point will be observable if it falls below the corresponding contour. The fixed mSUGRA parameters are A_0 = 0, \tan\beta = 45 and \mu > 0. Gluino mass contours are shown by the dashed, dark grey curves. The shaded grey area is excluded due to stau LSPs (left side of figure) or no electroweak symmetry breaking (right side of figure), while the shaded grey area marked "LEP excluded" is excluded by non-observation of a sparticle signal from LEP2 searches. All sparticle and background cross sections are normalized to NLO QCD values via k-factors.

Acknowledgments
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References


indirect detection

CHOWDHURY, JOG & VEMPATI, ARXIV 0909.1182
aging potential to considerably strengthen these limits. We include viable dark matter models but also show an appreciably. We leave this for future work, just noting the old would increase the potential for direct detection aperture. The threshold of 2 keV might be optimistically low, our analysis shows this for our data.

This is seen in Fig. 1, where the whole range of the mass spectrum is plotted.

FIG. 1: The results for the spin independent cross section on mass 1. Schedule of the XENON experiment [31].

mSUGRA/mSSM sample
direct and indirect complementarity
light dark matter

GRAVITINO, AXINO, SAXION, STERILE NEUTRINOS, ETC, ETC..
CHANDRA CONSTRAINTS ON AXINO MASSES AND PQ SCALE

FIG. 2: Flux of photons from the Milky Way galactic centre for the Burk profile. The horizontal line is the lower limit of detectability of the flux coming from the Chandra X-ray satellite observations. The shaded region is the window on the axino mass where the axino can act as a warm dark matter candidate.

\[ C = \frac{v^2_h}{4\pi G_N} \]

Similarly for the galactic centre case from Eq.(13):

\[ \int_{r_\odot}^{\infty} \rho_{DM}(r) \, dr = C \left[ \frac{\pi^2}{2} + \tan^{-1} \left( \frac{r_\odot}{r_c} \right) \right] \]

Using Eqs.(17) and (18) one can calculate the flux from the galactic anti-center and galactic center, respectively.

With a reasonable integration time (36 ksec) for observation of a dark matter halo, a line of energy \( E_\gamma = \frac{m_X}{2} \) can be detected at a flux above the value, \( F_{\text{det}} = 10^{-13} \text{erg cm}^{-2} \text{s}^{-1} \).

This determines the region of the parameter space for any theoretical scenario, which can be probed by Chandra.

III. NUMERICAL ANALYSIS

We have taken the value of the neutrino-neutralino mixing parameter \( \xi \) to be \( 3 \times 10^{-6} \), which is the allowed value from neutrino data. In Fig(2), we show the flux...
topics left out

- asymmetric dark matter
- gravitino dark matter - new results on NLSP
- model independent constraints from FERMI
Nature of dark matter is being highly constrained.

In the next few years, one hopes that there will some signal.

Lots of models could get ruled out.