CDMS II Inspired Neutralino Dark Matter in Flipped SU(5)

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We investigate neutralino dark matter in supersymmetric flipped SU(5), focusing on candidates with masses of order 30 - 150 GeV and spin independent cross sections that are consistent with the most recent CDMS II results. We assume gravity mediated supersymmetry breaking and restrict the magnitude of the soft supersymmetry breaking mass parameters to 1 TeV or less. With non-universal soft gaugino and Higgs masses, and taking flipped SU(5) into account, we identify allowed regions of the parameter space and highlight some benchmark solutions including Higgs and particle spectroscopy.

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In a recently published paper [1] the Cryogenic Dark Matter Search experiment reported two events in the signal region and a combined upper limit, of $3.8 \times 10^{-4} \text{cm}^2$ on the spin independent WIMP-nucleon elastic-scattering cross section for a WIMP of mass 70 GeV. These events may be interpreted as the scattering of the dark matter (DM) from germanium nuclei. The confidence level, however, is too low to claim discovery and the events might turn out to be misidentified background. Nonetheless, if these results are confirmed by other ongoing and in the future by more sensitive direct detection experiments, it would be a huge boost for the lightest supersymmetric particle (LSP) of the minimal supersymmetric standard model (MSSM), which is by far the leading and most compelling DM candidate.

In this paper, partly inspired by the CDMS II experiment, we investigate neutralino LSP dark matter in the context of flipped SU(5) [2], a grand unified theory (GUT) which is closely related to but has some important differences from SU(5). One important advantage flipped SU(5) (FSU(5)) has over other GUTs such as SU(5) and SO(10) is the remarkable ease with which the doublet-triplet splitting problem is resolved [3] within a minimal Higgs framework. Another crucial advantage is the simplicity with which successful minimal supersymmetric hybrid inflation can be implemented in FSU(5) [4]. Motivated in part by these an other important features we have explored the Higgs and particle spectroscopy of MSSM by embedding it within the FSU(5) framework supplemented by $N = 1$ supergravity.

We focus in particular on finding a relatively light particle spectrum and neutralino dark matter which is compatible with the recent CDMS II results. For some other recent attempts in the framework of supersymmetry see [5]. To implement our strategy the magnitudes of the soft supersymmetry breaking mass parameters are kept below a TeV, and comparison is made with the constrained minimal supersymmetric standard model (CMSSM) [6] and non-universal Higgs mass (NUHM2) [7] models after similar restrictions on their soft mass parameters are imposed. With FSU(5) enabled to capture suitable features from both CMSSM and NUHM2, attractive neutralino dark matter candidates with mass $\lesssim 300 \text{ GeV}$ and fully consistent with the CDMS II bounds are obtained.

The supersymmetric FSU(5) model is based on the maximal subgroup $G = SU(5) \times U(1)_X$ of SO(10), and the sixteen chiral superfields per family of SO(10) are arranged under $G$ as: $10_l = (d^c; Q^6)$, $5_3 = (u^c; L)$, $1_5 = (e^c)$. Here the subscripts refer to the respective charges under $U(1)_X$ and we follow the usual notation for the Standard Model (SM) particle content. The MSSM electroweak Higgs doublets $H_u$ and $H_d$ belong to $5_5$ and $5_6$ of SU(5), respectively. We will assume for simplicity that the soft mass terms, induced at $M_{GUT}$ through gravity mediated supersymmetry breaking [8], are equal in magnitude for the scalar squarks and sleptons of the three families. The asymptotic MSSM gaugino masses, on the other hand, can be non-universal. Due to the FSU(5) gauge structure the asymptotic $SU(3)_c$ and $SU(2)_W$ gaugino masses can be different from the $U(1)_Y$ gaugino mass. Assuming SO(10) normalization for $U(1)_X$, the hypercharge generator in FSU(5) is given by $Y = (Y_5;0) = (24X) = 5$, where $Y_5$ and $X$ are the generators of SU(5) and U(1)$_X$ [9]. We then have the following asymptotic relation between the three MSSM gaugino masses:

$$M_1 = \frac{1}{25}M_5 + \frac{24}{25}M_0; \text{ with } M_5 = M_2 = M_3;$$

(1)

where $M_5$ and $M_0$ denote SU(5) and U(1)$_X$ gaugino masses respectively. The supersymmetric FSU(5) model thus has two independent parameters ($M_2 = M_3; M_0$) in the gaugino sector. In other words, in FSU(5), by assuming gaugino non-universality, we increase by one the number of fundamental parameters compared to the CMSSM.

We will also consider both universal ($m_{\tilde{H}^u} = m_{\tilde{H}^d}$) and non-universal ($m_{\tilde{H}^u} \neq m_{\tilde{H}^d}$) soft scalar Higgs masses in FSU(5), which would mean up to three additional parameters compared to the CMSSM. This latter case, with one additional gaugino mass parameter and two soft scalar mass parameters, provides us with some of the most compelling neutralino dark matter candidates for direct detection in the ongoing and fu-
We use the ( \( m_A \) ) parametrization to characterize non-universal soft scalar Higgs masses rather than (\( H_u, H_d \)), where \( m_A \) denotes the coefficient of the supersymmetric bilinear term involving \( m_{H_u} \) and \( m_{H_d} \), and \( m_A \) is the mass of the CP odd scalar boson. The fundamental parameters of our FSU(5) model are:

\[
m_0 M^0, M_2, \tan \beta, \; m_A ;
\]

where \( m_0 \) is the scalar soft mass, \( M^0 \) and \( M_2 \) are the soft gaugino masses discussed above, \( \tan \beta \) is the ratio of the vacuum expectation values (VEVs) of the two Higgs doublets, \( A_0 \) is the universal trilinear soft term, and we will assume that \( \text{sgn} > 0 \). Note that \( m_0 \) and \( m_A \) are specified at the weak scale, whereas the other parameters are specified at \( M_{\text{GUT}} \).

Although not required, we will assume that the gauge coupling unification condition \( g_3 = g_1 = g_2 \) holds at \( M_{\text{GUT}} \) in FSU(5).

We use the ISAJET 7.79 package [10] to perform random scans over the FSU(5) parameter space shown in Eq. (2). ISAJET employs two-loop MSSM renormalization group equations (RGEs) and defines \( M_{\text{GUT}} \) to be the scale at which \( g_1 = g_2 \). This is more than adequate as a few percent deviation from the exact unification condition \( g_3 = g_1 = g_2 \) can be assigned to unknown GUT-scale threshold corrections [11].

We have performed random scans for the following parameter range:

\[
\begin{align*}
0 & \quad m_0 \quad 1 \; \text{TeV}; \\
0 & \quad M^0 \quad 1 \; \text{TeV}; \\
0 & \quad M_2 \quad 1 \; \text{TeV}; \\
0 & \quad m_A \quad 1 \; \text{TeV}; \\
0 & \quad 10 \; \text{TeV}; \\
\tan \beta & = 10;30;50 \\
A_0 & = 0;
\end{align*}
\]

with \( M_2 = 173 \pm 1 \; \text{GeV} \) [12]. The results are not too sensitive to one or two sigma variation in the value of \( M_2 \).

We also collected data for the CMSSM and NUHM2 models as well as for FSU(5) with universal Higgs boundary conditions (FSU(5)-UH) in order to study the impact on the CMSSM predictions if gaugino non-universality subject to Eq. (1) is imposed.

While scanning the parameter space, we employ the Metropolis-Hastings algorithm as described in [13]. All of the collected data points satisfy the requirement of radiative electroweak symmetry breaking (REWSB) with the neutralino in each case being the LSP. Furthermore, all of these points satisfy the constraint \( \Delta M^2_{\text{CDM}} > 10 \). This is done so as to collect more points with a WMAP compatible value of cold dark matter (CDM) relic abundance. For the Metropolis-Hastings algorithm, we only use the value of \( \Delta M^2_{\text{CDM}} \) to bias our search. Our purpose in using the Metropolis-Hastings algorithm is to be able to search around regions of acceptable \( \Delta M^2_{\text{CDM}} \) more fully. After collecting the data, we impose the mass bounds on all the particles [14] and use the IsaTools package [15] to implement the following phenomenological constraints:

\[
\begin{align*}
& m_h \quad (\text{lightest Higgs mass}) \quad 114.4 \pm 1 \; \text{GeV} \quad [16] \\
& \Delta M^2_{\text{CDM}} \quad \text{1D} \quad [17] \\
& \Delta M^2_{\text{CDM}} \quad \text{2D} \quad [18] \\
& \Delta M^2_{\text{CDM}} \quad \text{5D} \quad [19] \\
& \Delta M^2_{\text{CDM}} \quad \text{10D} \quad [20]
\end{align*}
\]

In Fig. 1 we present the results for the FSU(5) model in the \( M \) plane for \( m_0, M_2, M_1, m_0, \) and \( m_A \) planes for \( \tan \beta = 30 \). Points consistent with REWSB and \( \Delta M^2_{\text{CDM}} > 10 \) are shown in gray. Light blue points satisfy the WMAP bounds on \( \Delta M^2_{\text{CDM}} \) dark matter abundance and particle mass bounds, except the bound on the lightest Higgs mass. Orange points form a subset of light blue points that satisfies constraints from \( \Delta M^2_{\text{CDM}} \) dark matter abundance and particle mass bounds, except the bound on the lightest Higgs mass. Green points form a subset of brown points that satisfies all constraints including \( \Delta M^2_{\text{CDM}} \).
renormalizes by a factor 2 larger than $M_2$. This possibility can be seen in the $M_2 - M_1$ plane in Fig. 1. The line $M_2 = M_1$ corresponds to the NUHM2 model, and off-diagonal allowed regions are a manifestation of non-universality in the gaugino sector. The region $M_2 = M_1$ is disfavored because of the lower bound on dark matter relic abundance and in this region the wino, which has a large annihilation cross section, becomes a significant component of the neutralino. The white region in the upper left corner of this $M_2 - M_1$ plane occurs because we only allow $M^2 > 0$, so that an artificial lower bound of $M_1 = M_2 = 25$ is imposed.

The $m_0$ plane of Fig. 1 shows the very interesting possibility of a very low value of 100 GeV for $m_0 < 300$ GeV. In the $m_A$ - $M_1$ plane one can see the somewhat sharp bound $m_A = 180$ GeV. This, as well as the lower bound on $M_1$, is caused primarily by a contribution to $BR(B_L \leftrightarrow B_R)$ or $BR(B_s \leftrightarrow B_s)$ which is too high because of a relatively light spectrum.

In Fig. 2 we present plots of $\frac{-\gamma}{\mu}$-nucleon spin-independent cross-section ($\sigma_I$) versus $m_{\tilde{\nu}_1}$ for the CMSSM, FSU(5)-UH, NUHM2 and FSU(5) models for $\tan\beta = 30$. It is clear that for the choice of parameters in Eq. (3), only the FSU(5) model can provide a suitable dark matter candidate at or near the upper bound on $\sigma_I$ set by CDMS II (solid black line in Fig. 2). The CMSSM can provide a suitable $\frac{-\gamma}{\mu}$, and it does so in the focus point region where $m_0$ is large (> 1 TeV), and $\frac{-\gamma}{\mu}$ acquires a significant higgsino component because of small $m_A$. The FSU(5)-UH model, with $M_1$ as a free parameter, does slightly better than the CMSSM by allowing lighter neutralinos to achieve a relatively higher $\frac{-\gamma}{\mu}$. However, both the CMSSM and FSU(5)-UH models suffer from a $BR(b \leftrightarrow s)$ which is too large. This problem is cured in the NUHM2 and FSU(5) models by allowing $\frac{-\gamma}{\mu}$ to be a free parameter, thereby allowing for the possibility to suppress or cancel the contributions to $BR(b \leftrightarrow s)$. The NUHM2 model, however, is disfavored for our choice of parameters and for $m_{\tilde{\nu}_1} > 130$ GeV because of the LEP bound on the mass of the lightest Higgs boson. The FSU(5) model cures this problem by decoupling $M_3$ from $M_1$ and, therefore, allowing for a heavier gluino than in the NUHM2 case for the same neutralino mass. The contributions to the squark masses from the gluino loops are responsible for heavier squark masses in the FSU(5) model which, in turn, provide for a relatively heavier Higgs mass. We can see in Fig. 2 that, from the point of view of CDMS II, FSU(5) provides a satisfactory dark matter candidate, consistent with all the constraints for $m_{\tilde{\nu}_1} < 30$ GeV. The results for $\tan\beta = 10, 50$ are similar. Also shown in Fig. 2 are the current bounds on $\sigma_I$ from XENON10 (dashed black line) and the projected reach of SuperCDMS (solid red) and XENON100 (dashed red). Note that both axes are logarithmic.

| m_0 | Point 1 | Point 2 | Point 3 | Point 4 | Point 5 |
|-----|---------|---------|---------|---------|---------|
|     | 399     | 704     | 247     | 496     | 937     |
| m_1 | 110     | 147     | 186     | 312     | 373     |
| m_2 | 893     | 708     | 484     | 714     | 780     |
| $\tan\beta$ | 30 | 30 | 30 | 10 | 50 |
| $A_0$ | 0 | 0 | 0 | 0 | 0 |
| $m_A$ | 451 | 351 | 183 | 597 | 433 |
| $m_{h_1}$ | 119 | 117 | 115 | 116 | 118 |
| $m_{h_0}$ | 454 | 354 | 184 | 601 | 435 |
| $m_{h_2}$ | 462 | 363 | 202 | 606 | 445 |
| $m_{h_1}$ | 31,112 | 53,186 | 73,378 | 105,162 | 150,295 |
| $m_{h_0}$ | 113,726 | 194,582 | 665,675 | 172,586 | 303,646 |
| $m_{h_2}$ | 105,717 | 187,574 | 379,676 | 155,578 | 298,637 |
| $m_{h_3}$ | 1960 | 1600 | 1110 | 1600 | 1760 |
| $m_{h_4}$ | 1840,1770 | 1610,1570 | 1050,1020 | 1540,1500 | 1840,1790 |
| $m_{h_5}$ | 1300,1630 | 1110,1410 | 814,1000 | 1070,1390 | 1260,1510 |
| $m_{h_6}$ | 1840,1750 | 1610,1550 | 1050,1010 | 1540,1480 | 1840,1780 |
| $m_{h_7}$ | 1600,1670 | 1380,1470 | 943,995 | 1370,1470 | 1480,1510 |
| $m_{h_8}$ | 719 | 853 | 406 | 695 | 1060 |
| $m_{h_9}$ | 698 | 829 | 410 | 690 | 929 |
| $m_{h_{10}}$ | 726,292 | 858,658 | 415,218 | 701,447 | 1070,933 |
| $m_{h_{11}}$ | 204,706 | 599,834 | 219,431 | 444,698 | 574,933 |

TABLE I: Particle and Higgs masses (in GeV units), with $m_t = 173.2$ GeV. These five points, with $\tan\beta$ from 10 to 50, satisfy all the constraints and have a $\frac{-\gamma}{\mu}$ that is slightly below the CDMS II bound in each case.
Motivated by the newly released CDMS II upper bounds on spin independent WIMP-nucleon cross sections, and with new experiments of even greater sensitivity expected to go online in the near future, we have examined the soft supersymmetry breaking parameter space of MSSM embedded in flipped SU(5) to identify realistic neutralino dark matter candidates. We have identified regions of the parameter space containing perfectly viable neutralino dark matter candidates ranging in mass from around 30 to more than 100 GeV. The corresponding sparticle and Higgs mass spectra is also presented with several new particles likely to be accessible at the LHC.

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