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In this talk, we investigate the relic density and direct detection prospects of rSUGRA, a simple paradigm for supersymmetry breaking that allows for nonuniversal gaugino masses. We present updated plots reflecting the latest cosmological measurements from WMAP.

Dark matter is possibly the first signature of physics beyond the Standard Model. Intriguingly, it appears closely related to the generation of the weak scale. Supersymmetry is possibly the best motivated explanation for the stability of the weak scale. In this talk[a][b], we study the relic density and direct detection prospects of rSUGRA, a simple paradigm for broken supersymmetry designed to allow for nonuniversal gaugino masses[c]. Here we summarize points contained in earlier work[1,2,3] and we also present an updated numerical analysis[d] containing the latest constraints on dark matter from WMAP[8].

One of the simplest extensions of the Standard Model that includes broken supersymmetry is the mSUGRA paradigm. It defines common gaugino masses $m_{1/2}$, scalar masses m_0, and trilinear couplings A_0 at the scale of grand unification, Λ_{GUT}. One must further choose two Higgs sector parameters, $\tan \beta$ and $sgn(\mu)$. Correct generation of the weak scale m_Z determines $|\mu|$. While it is difficult to find such boundary conditions from a more fundamental starting point such as string theory, the appeal of such a paradigm stems from its simplicity.

R-parity, which guarantees the stability of the lightest supersymmetric particle (LSP), is also normally imposed. The LSP oftens turns out to be the lightest neutralino, χ_1^0. The lightest neutralino interacts primarily through weak interactions, so it represents a concrete realization of a WIMP (weakly interacting massive particle), and as such, constitutes one of the most attrac-
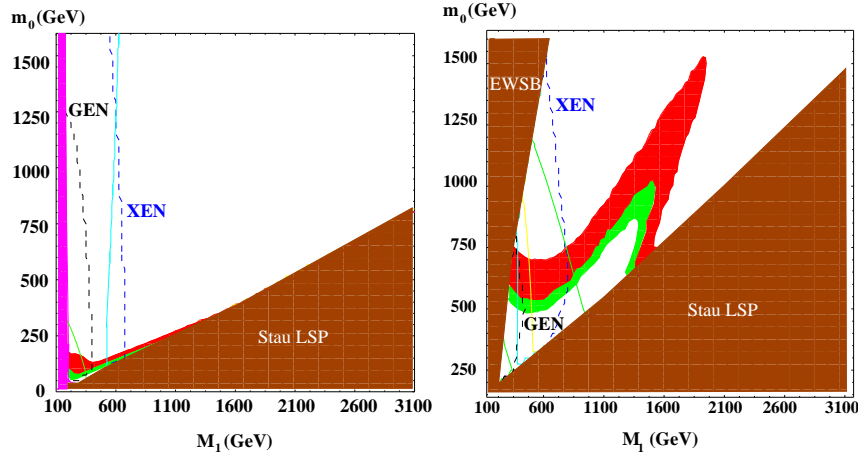
Figure 1. **Preferred Dark Matter Region for mSUGRA with** $\tan\beta = 5$ **(left plot) and** $\tan\beta = 50$ **(right plot)**. The green shaded region fits the latest WMAP data $0.094 \leq \Omega_\chi h^2 \leq 0.129$. The red shaded region used to be allowed by $0.1 \leq \Omega_\chi h^2 \leq 0.3$ but is now ruled out by WMAP. The other shaded regions are ruled out by virtue of having the stau as the LSP (brown, bottom right),violating the chargino mass bound (purple, upper left), and requiring correct electroweak symmetry breaking (upper left). The stau coannihilation tail and A^0 pole regions are clearly discernible.

tive candidates for cold dark matter.

1   Dark Matter in mSUGRA

Some of the viable parameter space is shown in Fig. 1 for values of $\tan\beta = 5$ and 50. We have chosen $\mu > 0$, but results for $\mu < 0$ are not radically different. The power of WMAP for determining the proper relic density can be seen by comparing the cosmologically preferred parameter space before WMAP (red and green areas) with the preferred parameter space available after WMAP (green areas only). At low $\tan\beta$ one can also see the discriminating power of the limit on the lightest Higgs mass, given by the near-vertical magenta line. This eliminates all dark matter parameter space at low $\tan\beta$ except for a small region[9,10] where $\tilde\tau_1$ is nearly degenerate with χ_1^0. In all of the plots, the green solid lines denote the region preferred by the recent measurements of the anomalous magnetic moment of the muon[11]. The yellow line denotes the lower limit on $b \to s\gamma$. Only the region above that line is allowed[12].

At high $\tan\beta$ the presence of a light pseudoscalar Higgs, A^0, creates more viable parameter space. Here the parameter space is also increased because the mass limit on the lightest Higgs, h^0, is relatively unconstraining. Even so, Nature still must either choose extreme degeneracy between χ_1^0 and $\tilde\tau_1$ or an extremely large value for $\tan\beta$. However, it is also possible that
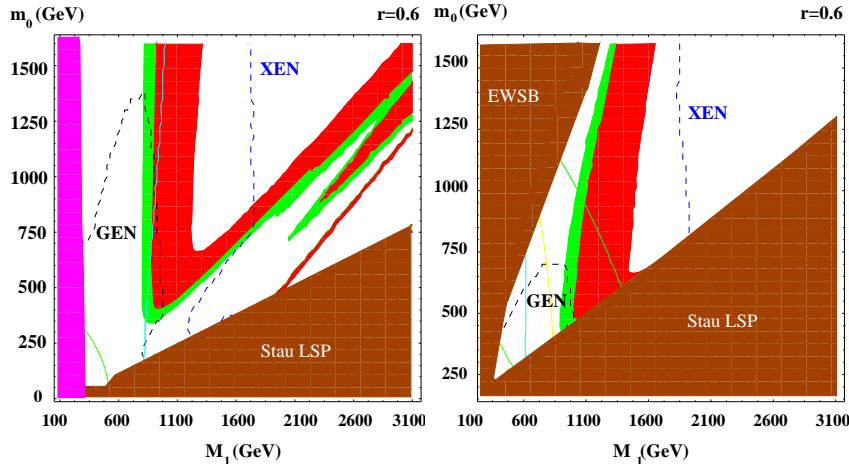
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Figure 2. **Relic Density Contours for rSUGRA with** $\tan\beta = 5$ **(left plot),** $\tan\beta = 50$ **(right plot) and** $r = 0.6$. Contours are the same as before.

Nature has not chosen mSUGRA at all. If one abandons the simple mSUGRA paradigm and takes suggestions from a higher theory, many different new possible directions present themselves. We choose to take our suggestion from string theories, which frequently give nonuniversal gaugino masses[13]. A more phenomenological motivation for choosing nonuniversal gaugino masses comes from realizing that the bino and wino masses, M_1 and M_2, have primary importance in determining the mass and annihilation properties of χ_1^0 through their presence in the 4×4 neutralino mass matrix.

2 Dark Matter in rSUGRA

We define rSUGRA by starting with mSUGRA and adding gaugino mass nonuniversality through the parameter $r = M_2/M_1$. The gaugino mass parameters are defined at the high boundary scale, $\Lambda_{UV} \simeq \Lambda_{GUT}$. Thus, one must only define one additional parameter, r, to extend mSUGRA to rSUGRA[e].

We have displayed some of the available rSUGRA parameter space in Fig. 2 for the same values of $\tan\beta$ as in Section 1. Here we fix $r = 0.6$. There is a smooth yet rapid transition from mSUGRA behavior at $r = 1$ to this behavior at $r = 0.6$[3]. It is apparent that choosing $r = 0.6$ significantly increases the amount of preferred dark matter parameter space for low $\tan\beta$.

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[e]In this talk, we take $M_3 = M_2$, but in our paper[3] we have also analyzed the other simple choice, $M_3 = M_1$. We make this choice because string theory seems to have a preference for gluino-wino equality over gluino-bino equality[13].
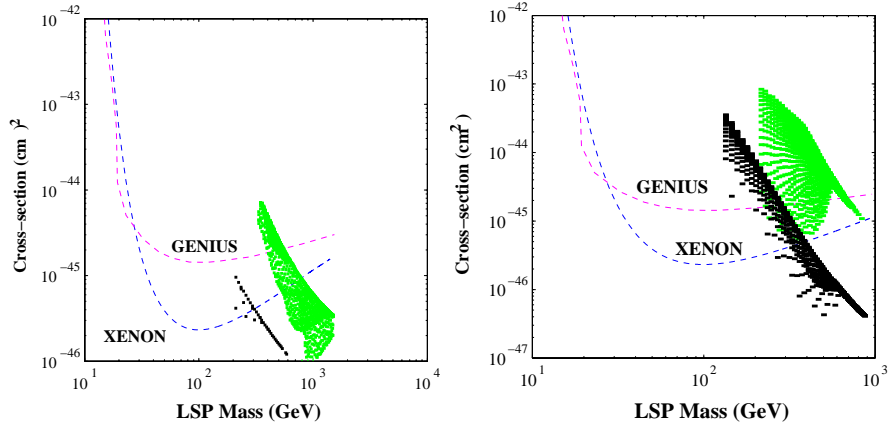
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Figure 3. **Direct Detection Expected Reaches for rSUGRA with** $\tan\beta = 5$ **(left plot) and** $\tan\beta = 50$ **(right plot).** $r = 0.6$ and 0.65 parameter space is green while mSUGRA (rSUGRA with $r = 1$) parameter space is black.

This is primarily due to increased degeneracy between χ_1^0, χ_2^0 and $\chi_1^{\pm}$ and also the RGE running effects on the mass spectrum from the smaller high-scale value of M_3. The large nearly-vertical plumes at both $\tan\beta = 5$ and $\tan\beta = 50$ around $M_1 = 800$ GeV are due solely to gaugino coannihilation as a result of the three-fold $(\chi_1^0, \chi_2^0, \chi_1^{\pm})$ degeneracy. Perhaps even more interesting, the features at high M_1 for $\tan\beta = 5$ result from two new Higgs poles. These are altogether unique and distinct from the A^0 pole visible at $\tan\beta = 50$ in mSUGRA. The upper pole region[3,14] results from resonant coannihilation of χ_1^0 and χ_2^0 through the pseudoscalar Higgs, A^0, and the heavy scalar Higgs, H^0. The lower pole region[3] comes from resonant coannihilation of χ_1^0 and $\chi_1^{\pm}$ through the charged Higgs, $H^{\pm}$. These two new poles result from an interplay between coannihilation effects and the RGE running effects of M_3. The lower value of M_3 allows the heavier Higgs states to take relatively small values at $\tan\beta = 5$ due to the effects of M_3 on μ. These lower values of M_3 also help alleviate finetuning issues.

3 Direct Detection Prospects

In Fig. 3 we present the direct detection prospects of rSUGRA for several values or r. We denote points with $r = 1$ (mSUGRA) by black, and points with $r = 0.6$ and 0.65 by green. We present these results in the $m_{\chi_1^0}$ vs. spin-independent neutralino-nucleon scattering cross section plane. We include expected detection capabilites for the proposed GENIUS [15] and XENON [16] detectors. We have also shown the expected detection contours for GENIUS and XENON earlier in Figs. 1 and 2. Again the benefits of the rSUGRA

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paradigm are clear. There is little hope in mSUGRA for direct detection of dark matter in GENIUS except for $\tan\beta \sim 50$. However, for $r = 0.6$ and 0.65, significant portions of the preferred parameter space at $\tan\beta = 5$ can be seen by GENIUS and all of the parameter space at $\tan\beta = 50$ can be seen by XENON. This improvement compared to mSUGRA results from the effect of a small M_3. A reduced value for M_3, as stated earlier, reduces the masses of the Higgs particles. Additionally, a low M_3 also results in smaller masses for the squarks. Both Higgs bosons and squarks mediate spin-independent neutralino-nucleon scattering interactions, so if one lowers these masses, one would intuitively expect to increase the direct detection rates. Finally, the increased detectability at $\tan\beta = 50$ compared to $\tan\beta = 5$ is also due to smaller masses for the Higgs bosons.

In summary, we presented the relic density and direct detection prospects of the rSUGRA paradigm. We show that allowing for nonuniversal gaugino masses significantly increases both preferred dark matter parameter space, and detectability in future direct detection experiments.

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