

SUSY-GUTs and Neutralino Dark Matter

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Based on Calibbi, Mambrini, Vempati, JHEP 0709:081 (2007)

Outline

- 1 Introduction
- 2 $SU(5)_{RN}$ and the spectrum
- 3 $SU(5)_{RN}$ and Neutralino DM
- 4 Summary

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Neutralino Dark Matter in Supersymmetric Models

- MSSM with R-parity conservation leads to the lightest Supersymmetric Particle to be stable.
- If LSP is charge neutral and a colour singlet, it would be a perfect candidate to explain Dark Matter relic density.
- In the simplest models of SUSY breaking, like mSUGRA with universal soft masses at the high scale, the LSP is typically a neutralino.

Neutralino Dark Matter in mSUGRA/CMSSM

However, the relic density computed in most of the regions of the parameter space is rather too large or too small.

Need **Critical** relations to be satisfied

In CMSSM/mSUGRA this happens in :

- The *stau* coannihilation region
- The A-pole funnel region
- The focus point/Hyper-bolic branch region

However are they stable ?

Some Diagrams leading to annihilation of neutralinos

In each of these mechanisms leads to a **critical** relation in one particular region of the parameter space.

a)

$\chi_1^0 \bar{f}$ and $\chi_1^0 f$ lines meet at a vertex with a dashed line labeled f connecting to another vertex where \bar{f} and f lines meet.

χ_1^0 and χ_1^0 lines meet at a vertex with a dashed line labeled h, H, A connecting to another vertex where \bar{f} and f lines meet.

χ_1^0 and χ_1^0 lines meet at a vertex with a wavy line labeled Z^* connecting to another vertex where \bar{f} and f lines meet.

$\propto \frac{m_\chi m_f}{m_f^2}$

$\propto \frac{m_\chi^2}{M_A^2} \frac{Z_{11} Z_{13,14}}{m_W} m_f (\tan \beta)^{-2I_f^2}$

$\propto \frac{m_f m_\chi}{m_Z^2} (-|Z_{13}|^2 + |Z_{14}|^2)$

b)

χ_1^0 and χ_1^0 lines meet at a vertex with a wavy line labeled W/Z connecting to another vertex where χ_i and W/Z lines meet.

χ_1^0 and χ_1^0 lines meet at a vertex with a dashed line labeled χ_i connecting to another vertex where Φ_j and Φ_i lines meet.

$\propto \frac{(-Z_{13} V_1^2 + \sqrt{2} Z_{12} V_1^2)^2}{1+m_\chi^2/m_\chi^2 - m_{W/Z}^2/m_\chi^2} / \frac{(-Z_{13} Z_{17}^2 + Z_{14} Z_{17}^2)^2}{1+m_\chi^2/m_\chi^2 - m_{W/Z}^2/m_\chi^2}$

$\propto \frac{i Z_{11,12} Z_{13,14} + Z_{11,12} Z_{13,14}^2}{1+m_\chi^2/m_\chi^2 - m_\phi^2/m_\chi^2}$

Are they stable..?

- The DM relations are not stable under the slightest modifications to the SUSY masses.
- Some of these modifications are **natural** particularly if one wants to consider Grand Unification or seesaw mechanism.

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A $SU(5)$ + **one** RH neutrino example

The superpotential of this framework is given by:

$$W_{SU(5)_{RN}} = \frac{1}{2} h_{ij}^u 10_i 10_j 5_u + h_3^{\nu} \bar{5}_3 1 5_u + h_{ij}^d 10_i \bar{5}_j \bar{5}_d + \frac{1}{2} M_R 11, \quad (1)$$

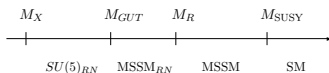


Figure 1: Schematic picture of the energy scales involved in the model.

Implications on the parameter space I

Two main effects due to addition of the GUT + seesaw effects :

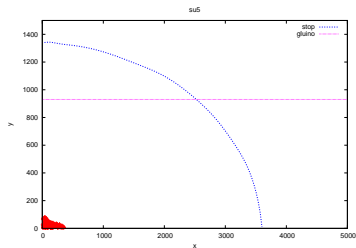
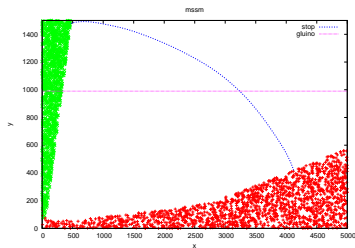
- $\tilde{\tau}_R$ sits in the 10 ; receives full $SU(5)$ gaugino contributions:

$$m_{\tilde{\tau}_R}^2(M_{GUT}) \approx \frac{144}{20\pi} \alpha_5 M_{1/2}^2 \ln\left(\frac{M_X}{M_{GUT}}\right) \approx 0.25 M_{1/2}^2, \quad (2)$$

- The neutrino Yukawa coupling taking part in the see-saw mechanism taken to be as large as the top Yukawa coupling, introduces an additional top-Yukawa like coupling to the up-type Higgs from the scales M_X down to M_R . Efficient REWSB.

Implications on the parameter space - II

The $(M_{1/2} - m_0)$ plane looks like :



Calibbi, Faccia, Masiero, Vempati, PRD 74 (2006) 116002

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For example : $\tan\beta=10$

In the parameter space where LHC is likely to see SUSY.

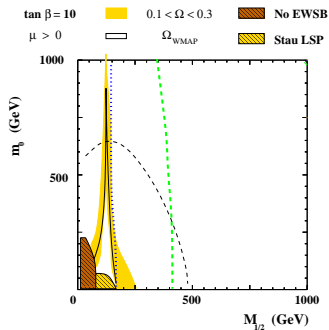


Figure 1: The $(m_0, M_{1/2})$ plane with all the low-energy constraints on the parameter space. While the color code is explained above, the green dashed line indicates the Higgs mass bound from the LEP, while the dark dashed line represents the $b \rightarrow s + \gamma$ limit.

Is there any region..?

Infact, if one scans the entire parameter space

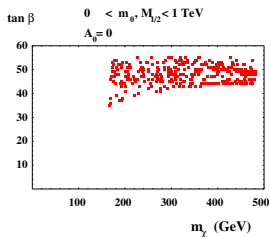
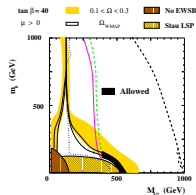
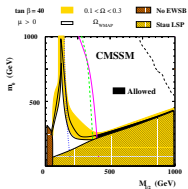


Figure 1: Points allowed by experimental and theoretical constraints after a scan on $(0 < m_0, M_{1/2} < 1 \text{ TeV})$ and $(20 < \tan \beta < 55)$

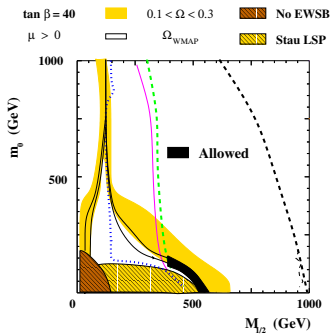
A comparison between mSUGRA and SUSY-SU(5)

The coannihilation region for $\tan \beta=40$ for the case of CMSSM and $SU(5)_{RN}$.



Zooming...the trunk region

Upper bound on neutralino mass ($\tan \beta$ dependent).



Why ??...

At the weak scale, roughly the stau mass matrix is now given by:

$$\mathcal{M}_{\tilde{\tau}}^2 = \begin{pmatrix} m_{\tilde{\tau}_{LL}}^2 & m_{\tilde{\tau}_{LR}}^2 \\ m_{\tilde{\tau}_{LR}}^2 & m_{\tilde{\tau}_{RR}}^2 \end{pmatrix}, \quad (3)$$

where, including the pre-GUT effects,

$$m_{\tilde{\tau}_{RR}}^2 \simeq (1 - \rho) m_0^2 + 0.3 M_{1/2}^2 \quad (4)$$

ρ is a positive coefficient dependent on $\tan \beta$. and

$$\begin{aligned} m_{\tilde{\tau}_{LR}}^2 &= m_{\tau} (A_{\tau} - \mu \tan \beta) \\ &\approx -m_{\tau} \mu \tan \beta \end{aligned} \quad (5)$$

Why ?? Contd...

In first approximation the lightest eigenvalue of Eq. (3) is given by:

$$\begin{aligned}
 m_{\tilde{\tau}_1}^2 &\simeq m_{\tilde{\tau}_{RR}}^2 - m_\tau \mu \tan \beta \\
 &\simeq (1 - \rho) m_0^2 + 0.3 M_{1/2}^2 - m_\tau \mu \tan \beta \quad (6)
 \end{aligned}$$

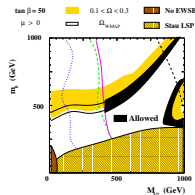
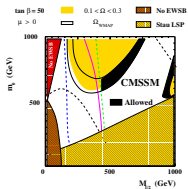
coannihilation condition

$$m_{\tilde{\tau}_1} \approx M_1 \approx 0.47 M_{1/2}.$$

$\tan \beta \approx (1 - \rho)(msusy/m_\tau)$, which leads to a lower limit on $\tan \beta < 27$,

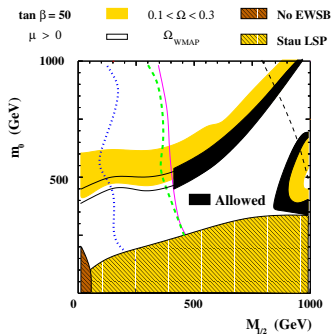
A comparison between mSUGRA and SUSY-SU(5)

We show the coannihilation region for $\tan \beta=50$ for the case of CMSSM and $SU(5)_{RN}$.



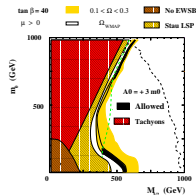
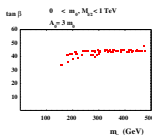
Zooming...

A large area opens up..corresponding to funnel region.



A-terms

$A_0 = 3 m_0$ case. Left panel: points allowed by experimental and theoretical constraints after a scan on ($0 < m_0, M_{1/2} < 1$ TeV) and ($20 < \tan \beta < 55$). Right panel: the $(m_0, M_{1/2})$ plane plot for $\tan \beta = 40$; the two branches of the stau coannihilation region.



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Summary and Future Directions

- GUT effects destabilize the **critical** relations required for viable neutralino DM. This specifically holds true for (stau) co-annihilation regions and Focus point/ Hyperbolic branch regions.
- For Simple $SU(5)$ + seesaw model, we found (a) a bound on $\tan\beta > 35$ and (b) co-annihilation region leads to an **upperbound** on neutralino mass (c) Focus point region disappears (d) A-pole funnel survives.
- Dark matter can play an very important role in distinguishing models at colliders. **arXiv:0710.0726**
- GUT effects at other models of SUSY breaking and implications to Dark matter are worth exploring.