Neutralino Dark Matter in an SO(10) Model
with Two-step Intermediate Scale Symmetry Breaking

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Work in progress, with M. Drees

Outline

Motivations

- SUSY-SO(10) GUTs
  - Hierarchy problem of Standard Model
  - Existence of Dark Matter
  - Gauge coupling unification
  - $\psi_L = (u_i \quad \nu \quad u_i^c \quad \nu^c \quad d_i \quad e \quad d_i^c \quad e^c)_L^T, \quad i = \{r, g, b\}$
  - Observation of neutrino oscillation
- Low intermediate symmetry breaking scale? ($M_R/M_X \sim 10^{-2}$)
  - $\sqrt{\delta m^2_{atm}} \gtrsim 0.04\text{eV} \Rightarrow M_N \lesssim 10^{14}\text{GeV}$
  - E.g. threshold corrections, nonrenormalizable interactions at M_{Planck}, additional light fields. [Majee.et.al.]

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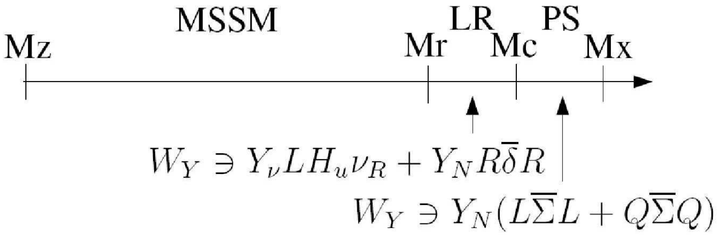
Overview : Two-step Symmetry Breaking



New contributions from Y_ν, Y_N to the RGEs.
$\Rightarrow$ Different SUSY spectra with those of mSUGRA.
$\Rightarrow$ How does it change the regions of the parameter space?

"Survival of the Fittest" [C.S.Aulakh. et.al.]

$\exists$ Light supermultiplets with mass suppressed by the cut-off scale.

Example: The superpotential with U(1) symmetry:
$W_{ren} = m\Phi\overline{\Phi}$.
To break symmetry:

$$W = m\Phi\overline{\Phi} + \frac{(\Phi\overline{\Phi})^2}{2M},$$

with

$$V_D = \frac{g^2}{2}(|\Phi|^2 - |\overline{\Phi}|^2)^2.$$

$$\Rightarrow m_{\Phi-\overline{\Phi}} \sim <\Phi>, \quad m_{\Phi+\overline{\Phi}} \sim \frac{<\Phi>^2}{M}.$$

Model

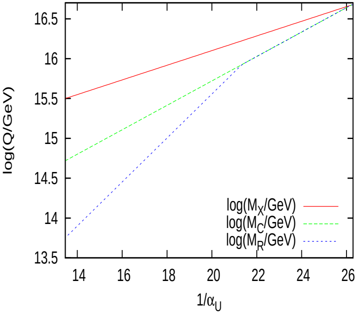
- Higgs representations:
  $S = 54, \quad A = 45, \quad \Sigma = 126, \quad \overline{\Sigma} = \overline{126}$
- Superpotential:
  $$W = \frac{m_S}{2} TrS^2 + \frac{\lambda_S}{3} TrS^3 + \frac{m_A}{2} TrA^2 + \lambda TrA^2 S + m_\Sigma \Sigma\overline{\Sigma} + \eta_S \Sigma^2 S + \overline{\eta}_S \overline{\Sigma}^2 S + \eta_A \Sigma\overline{\Sigma} A$$
- Symmetry breaking :
  $$SO(10) \xrightarrow[M_X]{S} SU(4)_C \times SU(2)_L \times SU(2)_R \times D_P \xrightarrow[M_C]{A} SU(3)_C \times U(1)_{B-L} \times SU(2)_L \times SU(2)_R \xrightarrow[M_R]{\Sigma+\overline{\Sigma}} G_{SM}$$

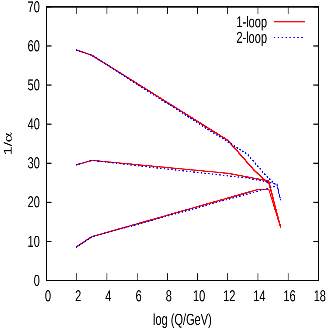
Masses of states that do not belong to the super-Higgs multiplet are suppresed.
$\Rightarrow$ Much lighter than the symmetry breaking scale.

[C.S.Aulakh. et.al., Nucl. Phys. B597 (2001), 89]

Mass spectrum

State	Mass
all of S all of A, except $(15,1,1)_A$ all of Σ and $\overline{\Sigma}$, except $SU(4)_C$ (anti−)decuplets	$\sim M_X$
$(\overline{10},3,1)_\Sigma$ and $(10,3,1)_{\overline{\Sigma}}$ color triplets and sextets of $(10,1,3)_\Sigma$ and $(\overline{10},1,3)_{\overline{\Sigma}}$ color triplets of $(15,1,1)_A$	$\sim M_C$
$(\delta^0 - \overline{\delta}^0)$, δ^+, $\overline{\delta}^-$	$\sim M_R$
color octet and singlet of $(15,1,1)_A$	$\sim M_1 \equiv \max\left[\frac{M_R^2}{M_C}, \frac{M_C^2}{M_X}\right]$
$(\delta^0 + \overline{\delta}^0)$, δ^{++}, $\overline{\delta}^{--}$	$\sim M_2 \equiv M_R^2/M_X$





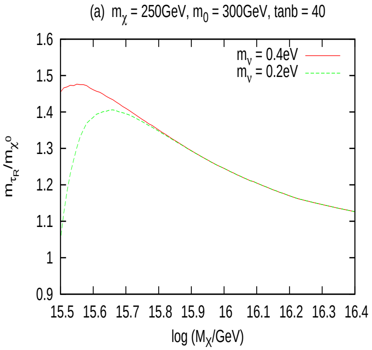
We chose $log(M_X/GeV) = 15.5$,
$log(M_C/GeV) = 14.72$,
$log(M_R/GeV) = 13.75$

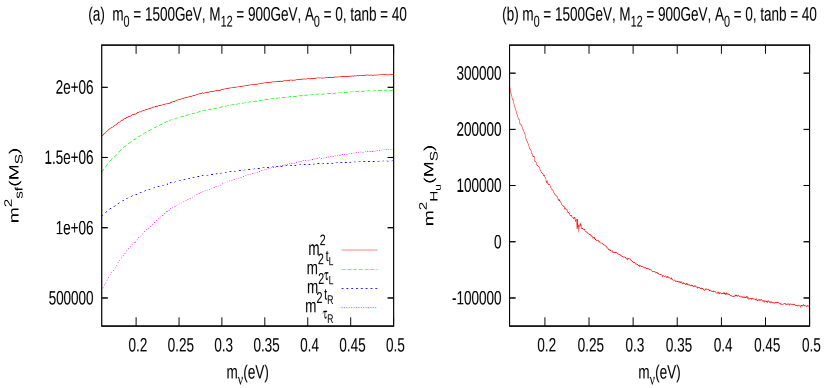
Yukawa Structure

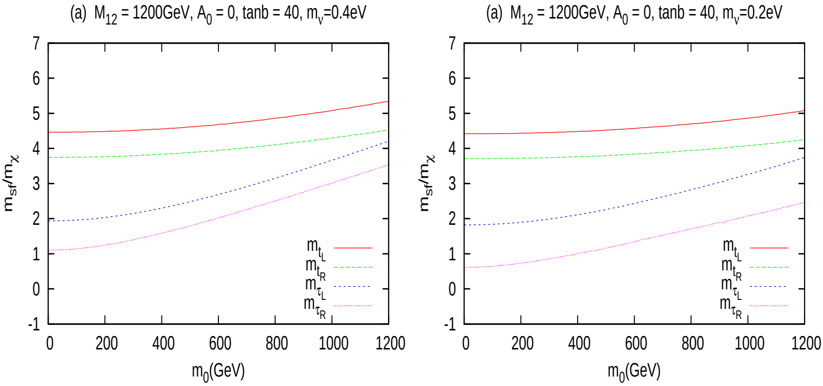
- $Q < M_2$
  $W_{\mathrm{Y,MSSM}} = Y_u U^c Q H_u + Y_d D^c Q H_d + Y_e E^c L H_d$
- $M_2 < Q < M_R$
  $W_{\mathrm{Y,gen}} = \sum_{i=1}^{2} \left(Y_{u,i} U^c Q H_{u,i} + Y_{d,i} D^c Q H_{d,i} + Y_{e,i} E^c L H_{d,i} \right)$
  $+ \frac{1}{2} Y_N E^c \bar{\delta}^{--} E^c,$
  where
  $H_{u/d} = \cos\varphi_{u/d} H_{u/d,1} + \sin\varphi_{u/d} H_{u/d,2}$
- $M_R < Q < M_C$
  $W_{\mathrm{Y,3122}} = \sum_{i=1}^{2} \left(Y_{q,i} Q^c Q \Phi_i + Y_{l,i} L^c L \Phi_i \right) + \frac{1}{2} Y_N L^c \bar{\delta} L^c$
- $M_C < Q < M_X$
  $W_{\mathrm{Y,422}} = \sum_{i=1}^{2} Y_i F^c F \Phi_i + \frac{1}{2} Y_N \left(F^c \overline{\Sigma}_R F^c + F \overline{\Sigma}_L F \right)$

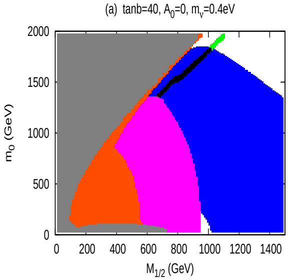
Phenomenology

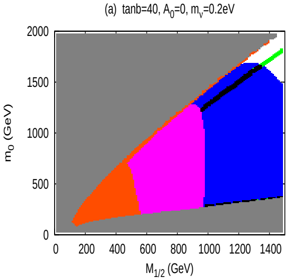
- $M_i(M_{SUSY}) = c_i M_{1/2}$
  $c_1 \simeq 0.23; \quad c_2 \simeq 0.46; \quad c_3 \simeq 1.4$
- $\frac{m_{\tilde{e}_R}(1TeV)}{|M_1(1TeV)|} \geq 1.7$

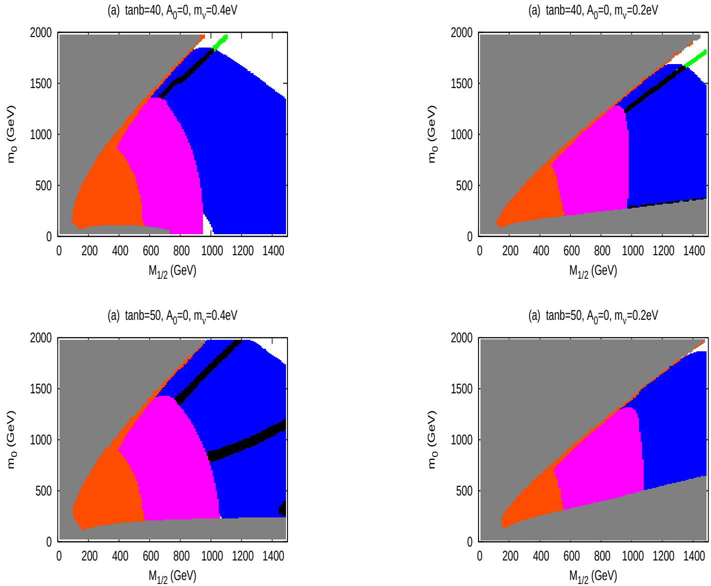



(a) m0 = 1500GeV, M12 = 900GeV, A0 = 0, tanb = 40
(b) m0 = 1500GeV, M12 = 900GeV, A0 = 0, tanb = 40
m2sf(MS)
m2Hu(MS)
2e+06
1.5e+06
1e+06
500000
300000
200000
100000
0
-100000
0.2
0.25
0.3
0.35
0.4
0.45
0.5
mν(eV)
m2tL
m2τL
m2tR
m2τR


(a) M12 = 1200GeV, A0 = 0, tanb = 40, mν=0.4eV
msf/mχ
m0(GeV)
mtL
mtR
mτL
mτR
0
200
400
600
800
1000
1200
-1
0
1
2
3
4
5
6
7
(a) M12 = 1200GeV, A0 = 0, tanb = 40, mν=0.2eV
msf/mχ
m0(GeV)
mtL
mtR
mτL
mτR


(a) tanb=40, A0=0, mν=0.4eV
m0 (GeV)
M1/2 (GeV)
2000
1500
1000
500
0
0
200
400
600
800
1000
1200
1400


(a) tanb=40, A0=0, mν=0.2eV
m0 (GeV)
M1/2 (GeV)
2000
1500
1000
500
0
0
200
400
600
800
1000
1200
1400


(a) tanb=40, A_0=0, m_ν=0.4eV
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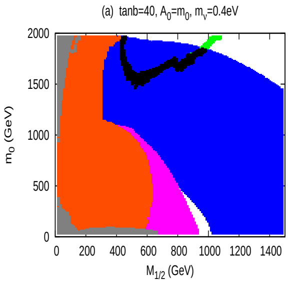
(a) tanb=50, A_0=0, m_ν=0.4eV
(a) tanb=50, A_0=0, m_ν=0.2eV
m_0 (GeV)
$M_{1/2}$ (GeV)
0 500 1000 1500 2000
0 200 400 600 800 1000 1200 1400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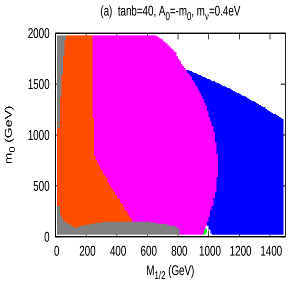
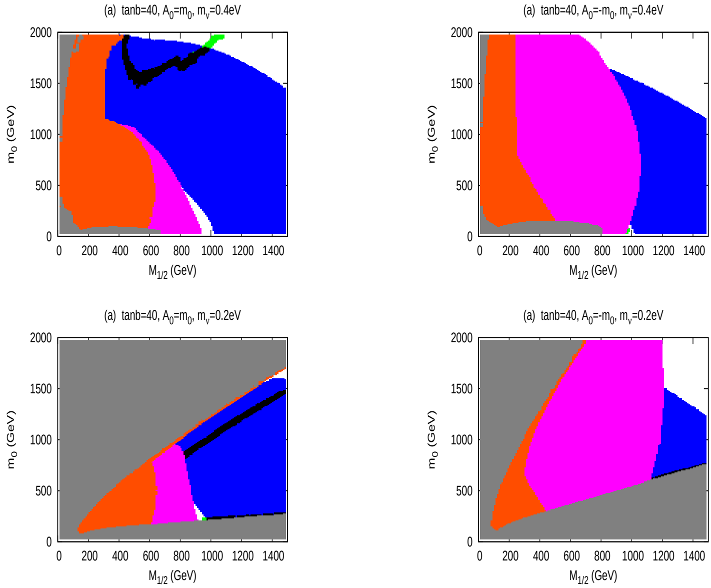
M1/2 (GeV)


(a) tanb=40, A0=-m0, mν=0.4eV
2000
1500
1000
500
0
m0 (GeV)
0 200 400 600 800 1000 1200 1400
M1/2 (GeV)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Summary

- Discrepancy between seesaw scale and GUT scale can be explained with the enhanced symmetry (breaking).
- The thermal $\tilde{\chi}_1^0$ Dark Matter remains viable, for different regions of parameter space with mSUGRA.
- The effects of implying the intermediate scale are:
  - Smaller gaugino masses due to the enhanced gauge symmetries and the large dimensional Higgs used to break them.
    $\Rightarrow$ Focus point region for the large $M_{1/2}$.
  - Lighter sfermions because of the Dirac and Majonara Yukawa coupling.
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