

Gauge Messenger Model

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Introduction

- Supersymmetry is the most promising candidate for the physics beyond the Standard Model.
- There are several good motivations for SUSY.
 - Gauge Coupling Unification with $M_{\text{GUT}} \sim 2 \times 10^{16}$ GeV.
 - Compatible with EW precision data.
 - LSP Dark Matter with weak scale SUSY (with R-parity).
- Most importantly, SUSY addresses **Big (Gauge) Hierarchy Problem**.
- However, MSSM suffers from *Little Hierarchy Problem*.

● Little Hierarchy Problem

- Higgs mass tends to be small in SUSY models and is logarithmically sensitive to the SUSY breaking scale.

$$m_h^2 \approx M_Z^2 \cos^2 2\beta + \frac{3G_F m_t^4}{\sqrt{2}\pi^2} \log \frac{m_{\tilde{t}}^2}{m_t^2}$$

- Current observational bound $m_h \geq 114\text{GeV}$. generically pushes up superpartner masses $m_{\tilde{t}}, m_{H_u}, \dots$ to $\mathcal{O}(\text{TeV})$
 M_Z is determined by soft SUSY breaking parameters.

$$\frac{M_Z^2}{2} \approx -\mu^2(M_Z) - m_{H_u}^2(M_Z)$$

- 0.5 % level fine-tuning → Little Hierarchy Problem

- We suggest a model called a “gauge messenger model” can ameliorate the little hierarchy problem.
- Gauge Messenger Models are a kind of Gauge Mediated SUSY Breaking using GUT superheavy gauge multiplet X, Y as messengers.
- **24 Higgs Σ** breaks SUSY at the same time when it breaks $SU(5)$ GUT gauge group!

$$\langle \Sigma \rangle = M \begin{pmatrix} 2 & & & & \\ & 2 & & & \\ & & 2 & & \\ & & & -3 & \\ & & & & -3 \end{pmatrix} + \theta^2 F \begin{pmatrix} 2 & & & & \\ & 2 & & & \\ & & 2 & & \\ & & & -3 & \\ & & & & -3 \end{pmatrix}$$

$$\rightarrow \int d^4\theta [V, \langle \Sigma \rangle][V, \langle \Sigma \rangle]$$

- Then, SM gauge multiplets and matter multiplets do not feel SUSY breaking at tree level, but X, Y gauge bosons feel SUSY breaking. $\rightarrow$ messengers of SUSY breaking.

- Gauge Messenger Model gives **negative sfermion soft masses!** and large A -term.
- Meta-stable vacuum. good for little hierarchy problem.
- Gauge Messenger Model gives a squeezed spectrum of superparticles.
- distinctive signature with light stop. $\tilde{B}-\tilde{W}-\tilde{h}$ mixed neutralino dark matter.

Gauge Messenger Model

- In SUSY GUT, X, Y gauge bosons $\in SU(5)/G_{321}$ become massive at M_{GUT} by adjoint chiral superfield Σ . We consider the case where F -term of Σ is also induced.

$$SU(5) \xrightarrow{\langle \Sigma \rangle} G_{321} = SU(3) \times SU(2) \times U(1)$$

$$\Sigma = M_{\text{GUT}} \text{diag}(2, 2, 2, -3, -3) + \theta^2 F \text{diag}(2, 2, 2, -3, -3)$$

X, Y and $\lambda_{X,Y}$ are split in mass.

$$M_3 = -4M_{\text{SUSY}}, \quad M_2 = -6M_{\text{SUSY}}, \quad M_1 = -10M_{\text{SUSY}}$$

$$m_Q^2 = (-20 + 3b_G)M_{\text{SUSY}}^2, \quad m_{\bar{u}^c}^2 = (-16 + 4b_G)M_{\text{SUSY}}^2,$$

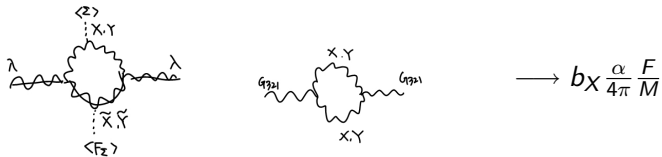
$$m_{d^c}^2 = (-12 + 2b_G)M_{\text{SUSY}}^2, \quad m_L^2 = m_{H_u}^2 = m_{H_d}^2 = (-12 + 3b_G)M_{\text{SUSY}}^2$$

$$m_{\bar{e}^c}^2 = (-12 + 2b_G)M_{\text{SUSY}}^2,$$

$$A_t = 10M_{\text{SUSY}} \text{ where } M_{\text{SUSY}} = \frac{\alpha_{\text{GUT}}}{4\pi} \left| \frac{F}{M} \right|, \quad b_G \text{ is } \beta\text{-func coeff. in } SU(5).$$

$$b_G = 3 \text{ in the minimal case.}$$

- **Gaugino Masses are not universal** and have **opposite** sign to conventional GMSB.



$\longrightarrow$ Bino is the heaviest at M_{GUT} scale.

At M_{GUT} , $|M_1| : |M_2| : |M_3| = 2.5 : 1.5 : 1$.

Due to RG running, at M_Z , $|M_1| : |M_2| : |M_3| \sim 1 : 1 : 2$

universal gaugino at GUT $\rightarrow |M_1| : |M_2| : |M_3| \sim 1 : 2 : 6$ at M_Z

- **Negative soft scalar masses** are generated and **squark masses** are most negative.
- **Large A term** is generated. Easily make $\frac{A_t(M_Z)}{m_{\tilde{t}}(M_Z)}$ large. At M_{GUT} , A_t is sizable ($A_t = -2.5M_3$).

$$A_t = 2(\Delta c_Q + \Delta c_{H_u} + \Delta c_{u^c})M_{\text{SUSY}}$$

- How can it ameliorate the little hierarchy problem?

Higgs mass w/o mixing between $\tilde{t}_L$ and $\tilde{t}_R$,

$$m_h^2 \approx M_Z^2 \cos^2 2\beta + \frac{3G_F m_t^4}{\sqrt{2}\pi^2} \log \frac{m_{\tilde{t}}^2}{m_t^2}$$

→ logarithmically sensitive to $m_{\tilde{t}}^2$. To have $m_h > 114$ GeV,
 $m_{\tilde{t}} \sim \mathcal{O}(\text{TeV})$.

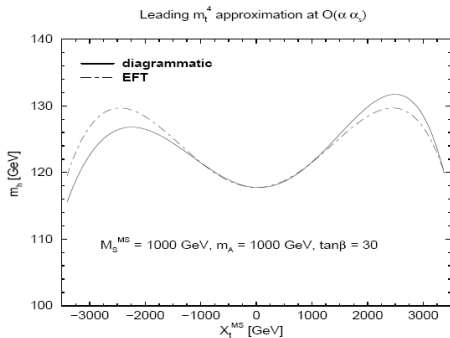
- But Large Mixing between $\tilde{t}_L$ and $\tilde{t}_R$ helps higgs mass lift-up.

$$\mathcal{M}_{\tilde{t}}^2 = \begin{pmatrix} m_{\tilde{Q}3}^2 + m_t^2 + \dots & -m_{\tilde{u}c_3}(A_t^* + \mu \cot \beta) \\ -(A_t + \mu^* \cot \beta)m_{\tilde{u}c_3}^* & m_{\tilde{u}c_3}^2 + m_t^2 + \dots \end{pmatrix}$$

$$m_h^2 \sim M_Z^2 + \frac{3G_F m_t^4}{\sqrt{2}\pi^2} \left\{ \log \frac{m_{\tilde{t}}^2}{m_t^2} + \frac{A_t^2}{m_{\tilde{t}}^2} \left(1 - \frac{A_t^2}{12m_{\tilde{t}}^2} \right) \right\}$$

→ Maximum at $A_t = \pm \sqrt{6} m_{\tilde{t}}$.

Physical Higgs Mass vs Stop Mixing



Carena, Haber, Heinemeyer, Hollik, Wagner, Weiglein

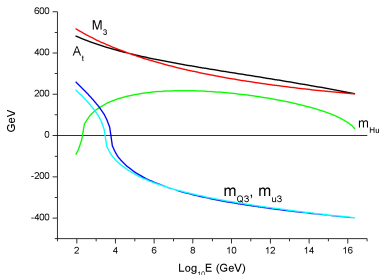
- ▶ $\left| \frac{A_t(M_Z)}{m_{\tilde{t}}(M_Z)} \right| \gtrsim 1.5$ is needed.
- ▶ So large A_t and small or negative $m_{\tilde{t}}^2$ at M_{GUT} are needed for obtaining the maximal gain from stop mixing.

- **Negative stop mass** also reduces fine-tuning.
 - from the RG running of $m_{H_u}^2$,

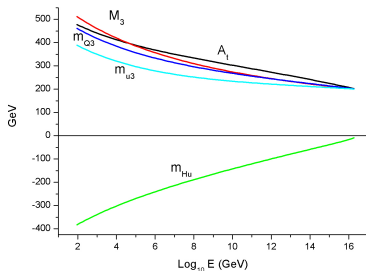
$$\frac{dm_{H_u}^2}{d \log Q} \approx \frac{3y_t^2}{4\pi^2} m_{\tilde{t}}^2,$$

$m_{H_u}^2$ is lifted up by Yukawa loop if $m_{\tilde{t}}^2 < 0$. This enables $m_{H_u}^2$ to stay around M_Z^2 .

negative $m_{\tilde{t}}^2$

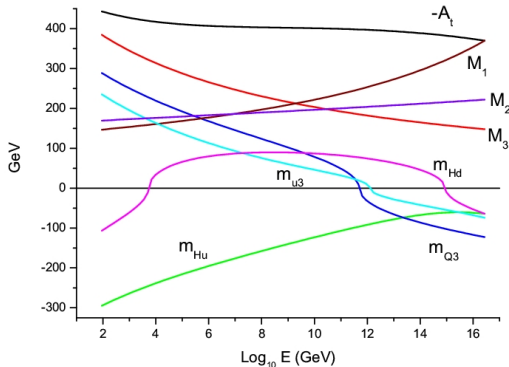


positive $m_{\tilde{t}}^2$



● (Minimal) Gauge Messenger (using SoftSUSY+FeynHiggs)

- $b_G = 3, M_{\text{SUSY}} = 37 \text{ GeV}, \tan \beta = 23$



$$h_0 = 114.4$$

$$A = 248$$

$$\tilde{t} = 138$$

$$\tilde{b} = 263$$

$$\tilde{\tau} = 103$$

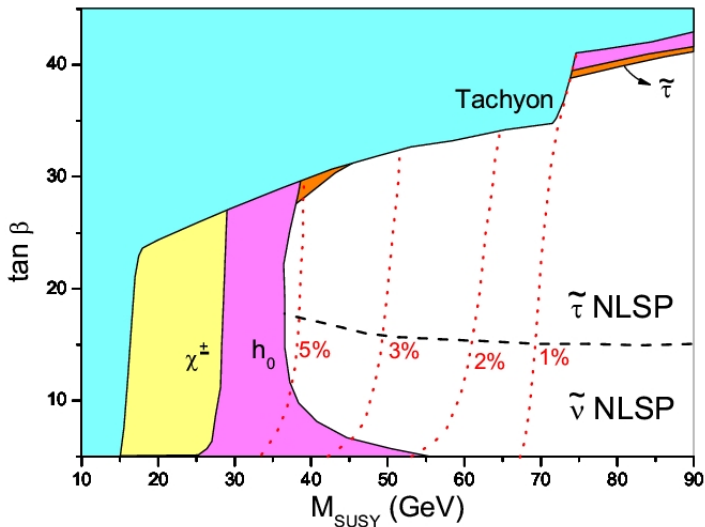
$$\tilde{g} = 379$$

$$\chi_1^{\pm} = 158$$

$$\chi_1^0 = 141$$

$$\Delta^{-1} = 5.49\%$$

- Gauge Messenger : Parameter space



Gravity Mediation Contribution

- Gravity Mediation is comparable to Gauge Mediation if

$$M_{\text{mess}} = M_{\text{GUT}}$$

$$\frac{\alpha}{4\pi} \frac{F}{M} \sim \frac{F}{M_{\text{Pl}}}$$

- We can have comparable gravity mediation contribution. Let us assume such contribution appear in MSSM matter in common.

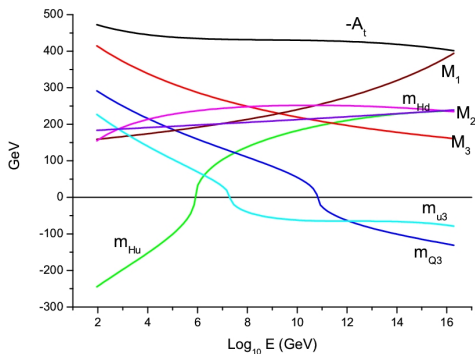
$$\Delta m_{Q,U,L,D,E}^2 = c_0 M_{\text{SUSY}}^2$$

$$m_{H_u}^2 = (-12 + 3b_G + c_{H_u}) M_{\text{SUSY}}^2$$

$$m_{H_d}^2 = (-12 + 3b_G + c_{H_d}) M_{\text{SUSY}}^2$$

● Gauge Messenger + Higgs

- $b_G = 3, M_{\text{SUSY}} = 40\text{GeV}, \tan\beta = 29, c_{H_u} = 38, c_{H_d} = 37$



$$h_0 = 115.6$$

$$A = 265$$

$$\tilde{t} = 101$$

$$\tilde{b} = 266$$

$$\tilde{\tau} = 88.2$$

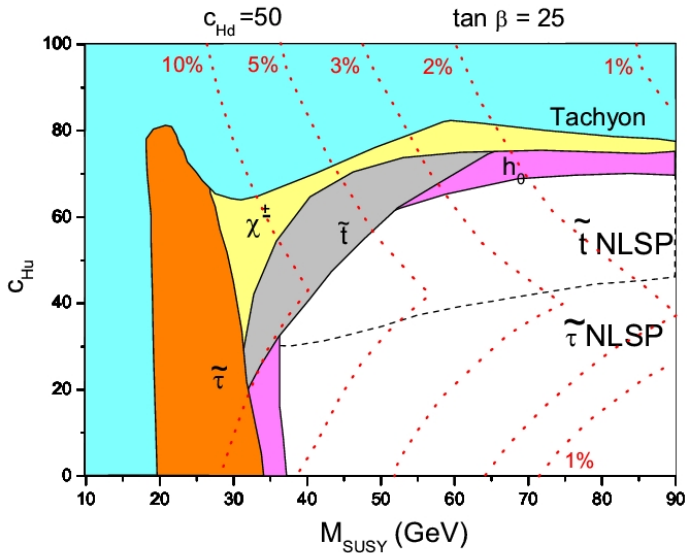
$$\tilde{g} = 406$$

$$\chi_1^{\pm} = 152$$

$$\chi_1^0 = 137$$

$$\Delta^{-1} = 9.01\%$$

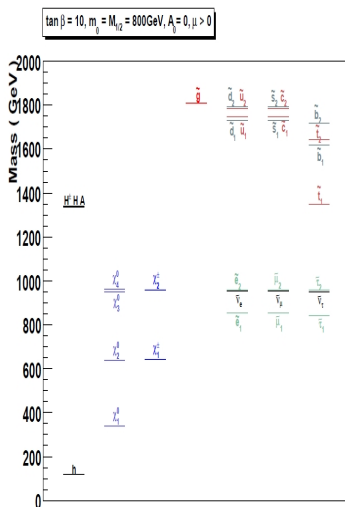
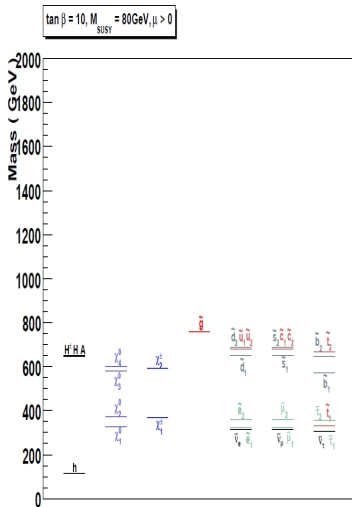
- Gauge Messenger + Higgs : Parameter space



Bino-Wino-Higgsino mixed neutralino Dark Matter

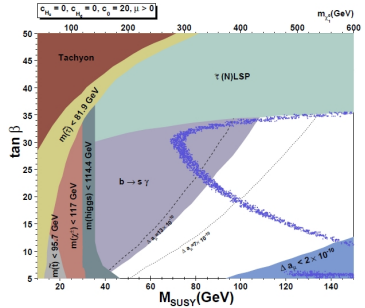
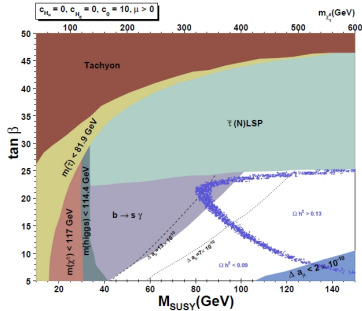
- With small amount of gravity mediation contribution to matter fields, neutralino becomes LSP so that it can be a candidate for the dark matter.
- The lightest neutralino in gauge messenger models is typically mostly bino with a sizable mixture of wino and higgsino. Recall that
 - Bino-like LSP: Too small $\sigma_{an} \rightarrow$ too large relic density
 - Wino-like or Higgsino-like LSP: Too large $\sigma_{an} \rightarrow$ too small relic density or too heavy LSP.
- Universal gaugino masses at the GUT scale lead to bino:wino:gluino = 1 : 2: 6 $\rightarrow$ bino-like.
- The gauge messenger model has 1 : 1.1: 2. Sizable mixing between bino and wino is possible. Since this model has natural parameters where $\mu \sim M_Z$, higgsino component also mixes with bino and wino in LSP.

- For comparison, we show the typical spectrum of gauge messenger model and mSUGRA.



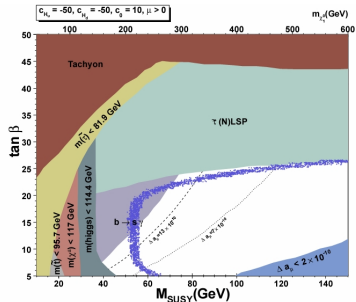
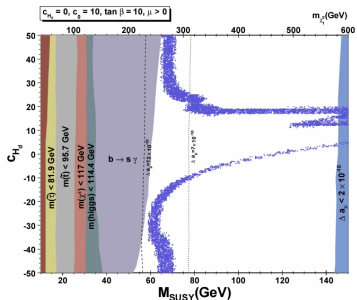
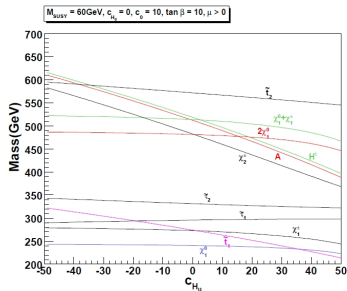
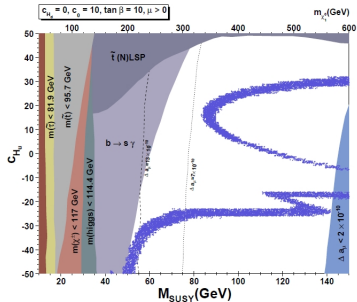
- squeezed spectrum in gauge messenger model! $\rightarrow$ many particle species can take part in the annihilation process.

- With no additional higgs mass parameters

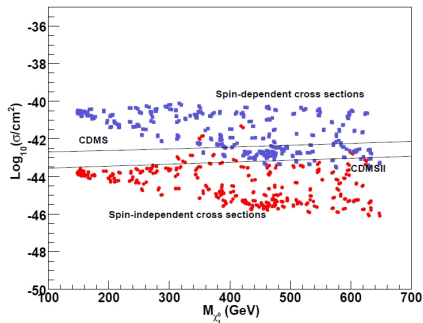


- coannihilation with $\tilde{\tau}$, A-Higgs resonance.

• With higgs mass parameters



- Direct detection cross section



- It could be detected in near future experiment.

Conclusion

- SUSY suffers from the little hierarchy problem. This can be cured by **negative stop mass** which can reduce quantum correction to soft mass for Higgs and large $A_t/M_{\tilde{t}}$ which mitigates lightest Higgs mass bound $\rightarrow$ Our universe is now at a **meta-stable** vacuum!
- **Gauge messenger model** gives new interesting type of SUSY mass spectrum. Nonuniversal gaugino mass, negative squark mass at GUT scale and large A term. All of these properties lead to **smaller fine-tuning** than conventional SUSY breaking scenarios.
- We obtain **squeezed spectrum at the EW scale** Gluino and Bino/Wino ($< 500 \sim 600$ GeV) and squarks and sleptons also have similar masses. **Gauge messenger model** is one of the first concrete models having all these features.

Conclusion

- Fine Tuning is improved up to 10 %
Almost factor 10 or 20 times improvement compared to CMSSM which needs a fine tuning of 0.5 % to 1 %.
- This model has Bino-Wino-Higgsino mixing neutralino as a good dark matter candidate. We don't have to rely on fine-tuned coannihilation region or resonance funnel region for explaining WMAP relic density. Mixing effect remains relatively large bulk region for it.
- Dark matter detection of gauge messenger model can be achieved in near future.