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 $M_{\rm GUT} \sim 2 \times 10^{16}$ 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.

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

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

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

$\rightarrow$ 0.5 % level fine-tuning $\rightarrow$ 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.

$\longrightarrow$ Meta-stable vacuum. good for little hierarchy problem.

- Gauge Messenger Model gives a squeezed spectrum of superparticles.

$\longrightarrow$ 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 $M_{\rm GUT}$ by adjoint chiral superfield Σ. We consider the case where F-term of Σ is also induced.

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

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

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

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

$$m^2_{\tilde Q} = (-20+3b_G)M^2_{\rm SUSY},\qquad m^2_{\tilde u^c} = (-16+4b_G)M^2_{\rm SUSY},$$

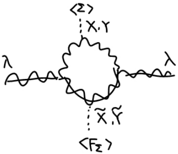
$$m^2_{\tilde d^c} = (-12+2b_G)M^2_{\rm SUSY},\qquad m^2_{\tilde L} = m^2_{H_u} = m^2_{H_d} = (-12+3b_G)M^2_{\rm SUSY}$$

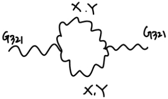
$$m^2_{\tilde e^c} = (-12+2b_G)M^2_{\rm SUSY},$$

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

$b_G = 3$ in the minimal case.

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





$\longrightarrow b_X \frac{\alpha}{4\pi} \frac{F}{M}$

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

> At $M_{\rm GUT}$, $|M_1| : |M_2| : |M_3| = 2.5 : 1.5 : 1$.
> 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 $M_{\rm GUT}$, A_t is sizable ($A_t = -2.5 M_3$).

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

- How can it ameliorate the little hierarchy problem?

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

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

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

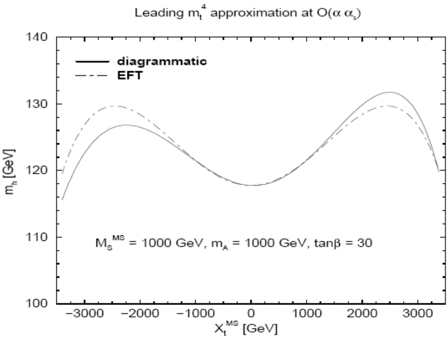
- But Large Mixing between $\tilde{t}_L$ and $\tilde{t}_R$ helps higgs mass lift-up.

$$\mathcal{M}_{\tilde{t}}^2 = \begin{pmatrix} m_{\tilde{Q}3}^2 + m_t^2 + \ldots & -m_{\tilde{u}^c{}_3}(A_t^* + \mu \cot \beta) \\ -(A_t + \mu^* \cot \beta) m_{\tilde{u}^c{}_3}^* & m_{\tilde{u}^c{}_3}^2 + m_t^2 + \ldots \end{pmatrix}$$

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

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

- Physical Higgs Mass vs Stop Mixing



Carena, Haber, Heinemeyer, Hollik, Wagner, Weiglein

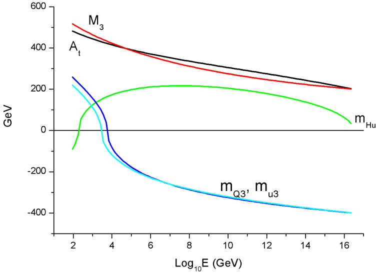
- $\left|\frac{A_t(M_Z)}{m_{\tilde{t}}(M_Z)}\right| \gtrsim 1.5$ is needed.
- So large A_t and small or negative $m_{\tilde{t}}^2$ at M_{GUT} are needed for obtaining the maximal gain from stop mixing.

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

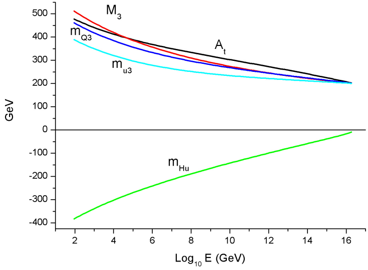
$$\frac{dm^2_{H_u}}{d\log Q} \approx \frac{3y_t^2}{4\pi^2} m^2_{\tilde{t}},$$

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

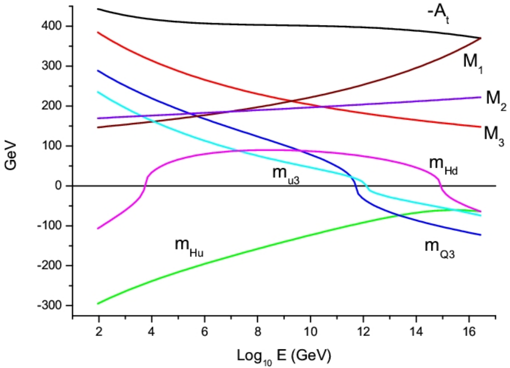
negative $m^2_{\tilde{t}}$



positive $m^2_{\tilde{t}}$

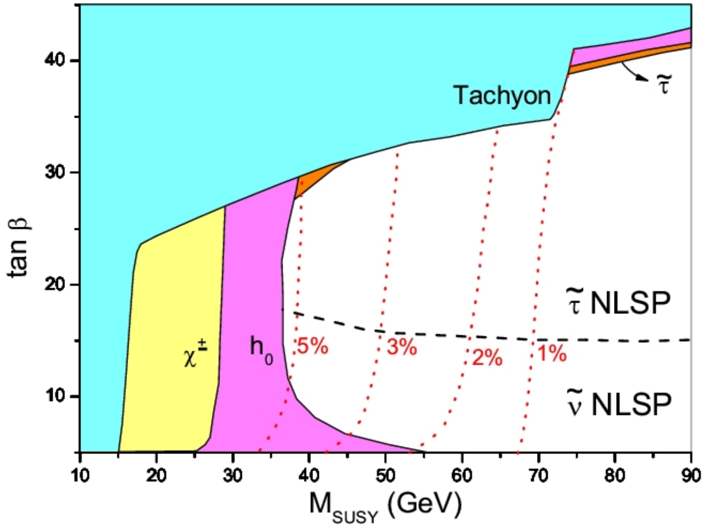


- (Minimal) Gauge Messenger (using SoftSUSY+FeynHiggs)
  - $b_G = 3, M_{\rm SUSY} = 37$ GeV, $\tan\beta = 23$



$$
\begin{aligned}
h_0 &= 114.4 \\
A &= 248 \\
\tilde{t} &= 138 \\
\tilde{b} &= 263 \\
\tilde{\tau} &= 103 \\
\tilde{g} &= 379 \\
\tilde{\chi}_1^{\pm} &= 158 \\
\tilde{\chi}_1^{0} &= 141 \\
\Delta^{-1} &= 5.49\%
\end{aligned}
$$

- Gauge Messenger : Parameter space



Gravity Mediation Contribution

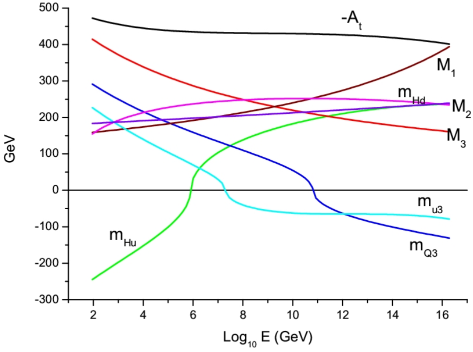
- Gravity Mediation is comparable to Gauge Mediation if $M_{\rm mess} = M_{\rm GUT}$

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

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

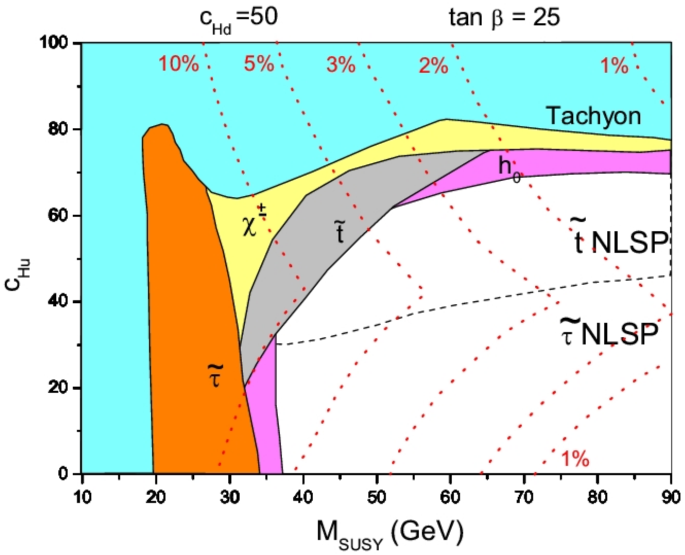
$$\begin{aligned} \Delta m^2_{Q,U,L,D,E} &= c_0 M^2_{\rm SUSY} \\ m^2_{H_u} &= (-12 + 3b_G + c_{H_u}) M^2_{\rm SUSY} \\ m^2_{H_d} &= (-12 + 3b_G + c_{H_d}) M^2_{\rm SUSY} \end{aligned}$$

- Gauge Messenger + Higgs
  - $b_G = 3, M_{\rm SUSY} = 40 GeV$, $\tan\beta = 29$, $c_{H_u} = 38$, $c_{H_d} = 37$



$$
\begin{aligned}
h_0 &= 115.6 \\
A &= 265 \\
\tilde{t} &= 101 \\
\tilde{b} &= 266 \\
\tilde{\tau} &= 88.2 \\
\tilde{g} &= 406 \\
\tilde{\chi}_1^{\pm} &= 152 \\
\tilde{\chi}_1^{0} &= 137 \\
\Delta^{-1} &= 9.01\%
\end{aligned}
$$

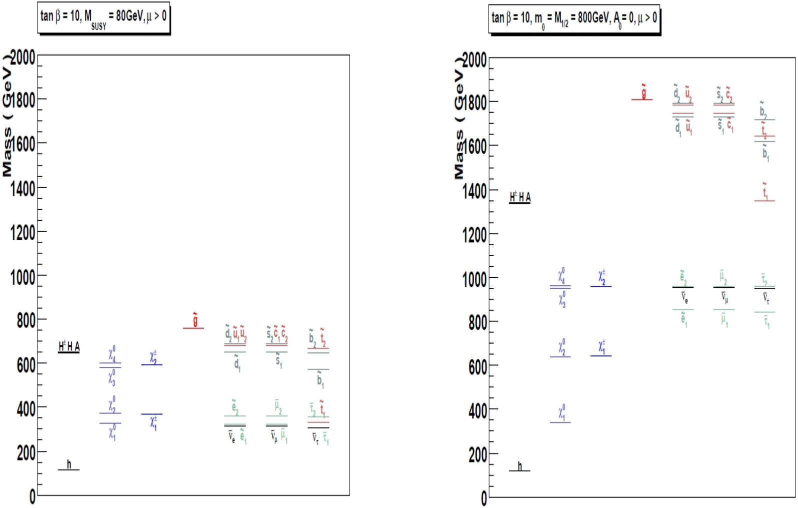
- Gauge Messenger + Higgs : Parameter space



Bino-Wino-Higgsino mixed neutralino Dark Matter

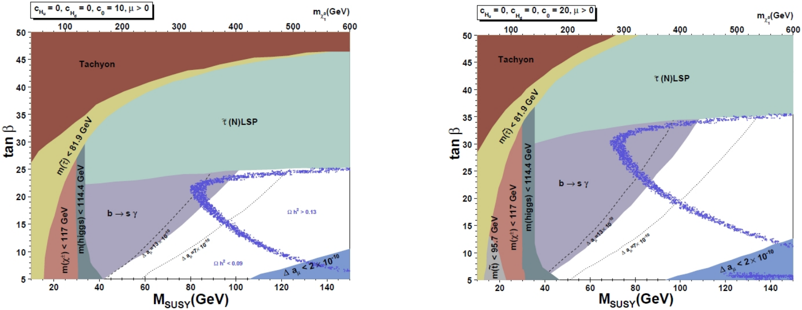
- With small amount of gravity mediation contribution to matter fields, neutralino becomes LSP so that it can be a candidate for the dark matter.
- The lightest neutralino in gauge messenger models is typically mostly bino with a sizable mixture of wino and higgsino. Recall that
  - Bino-like LSP: Too small $\sigma_{an} \longrightarrow$ too large relic density
  - Wino-like or Higgino-like LSP: Too large $\sigma_{an} \longrightarrow$ 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.



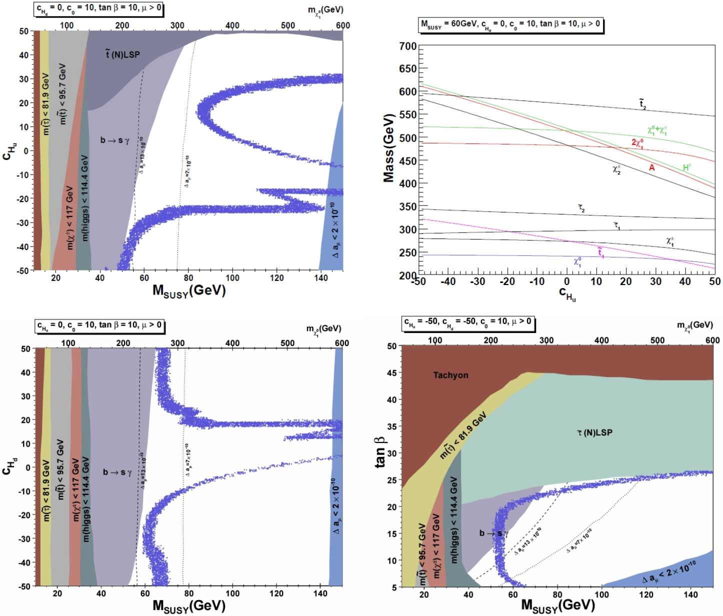
- squeezed spectrum in gauge messenger model! $\longrightarrow$ many particle species can take part in the annihilation process.

- With no additional higgs mass parameters

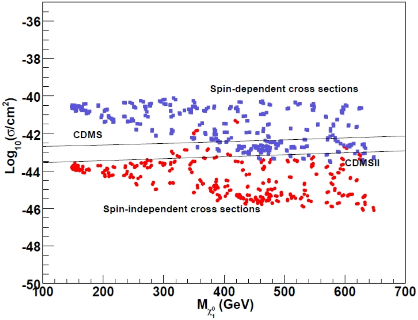


- coannihilation with $\tilde{\tau}$, A-Higgs resonance.

- 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.