(Extra)Ordinary Gaugomaly Mediation

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Contents

1.Introduction

Supersymmetry (SUSY)

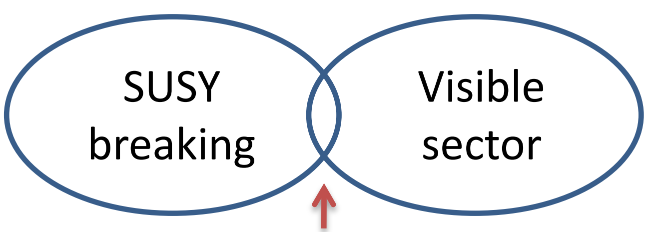
- Hierarchy problem
- Dark Matter (DM)
- GUT
- Inflation…

must be broken

SUSY is broken in a visible (MSSM) sector

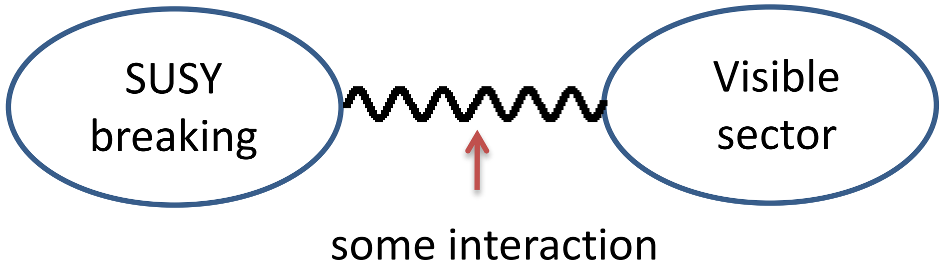
→ Trace formula $\mathrm{Tr}[M^2_{\mathrm{scalars}}] = \mathrm{Tr}[M^2_{\mathrm{fermions}}]$

at tree-level



Tree-level interaction

SUSY must be broken in a Hidden sector !



Gauge mediation ・・・ The Standard Model gauge interaction

Anomaly mediation ・・・ Scale anomaly

Gravity mediation ・・・ Planck suppressed operator

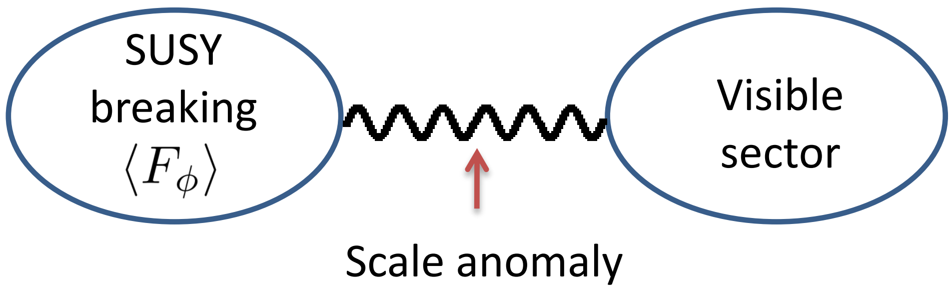
⋮

Several SUSY breaking mechanisms suffer from the flavor problems.

Anomaly mediation

SUSY is broken by a supergravity auxiliary field.

The conformal compensator $\phi = 1 + \theta^2 \langle F_\phi \rangle$ ← SUSY breaking source



The flavor problem is solved.

The soft masses ~ (loop factor) $\times \langle F_\phi \rangle$

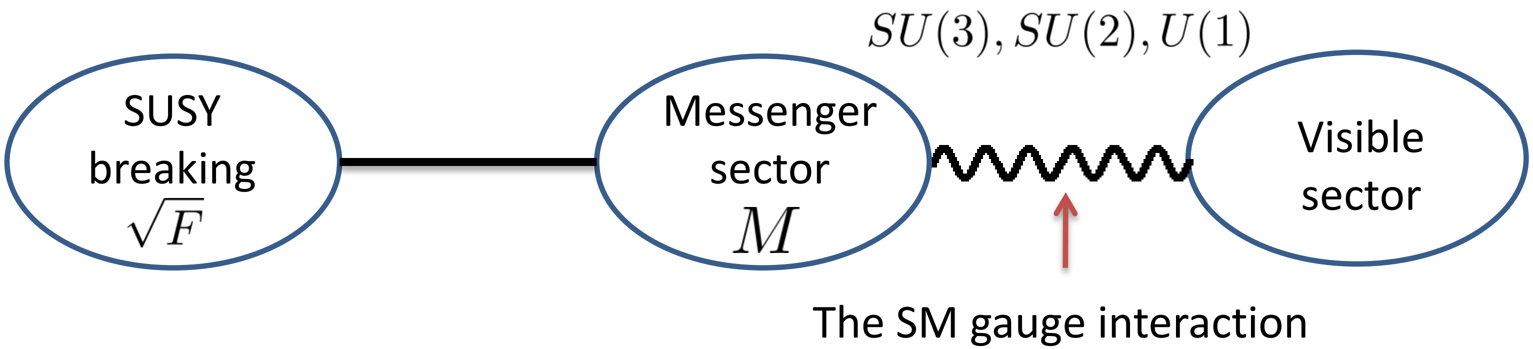
$\langle F_\phi \rangle = \mathcal{O}(10\mathrm{TeV})$ … Gravitino is heavy

The slepton masses become tachyonic in MSSM!

If it is solved

The LSP is a WIMP dark matter candidate.

Gauge mediation



The flavor problem is naturally solved.

The LSP is gravitino.

Cosmological gravitino problems

Gaugino mass is often anomalously small!

Anomaly mediation

Gauge mediation

both attactive mechanisms!

The tachyonic slepton problem

The anomalously small gaugino masses

Mixed

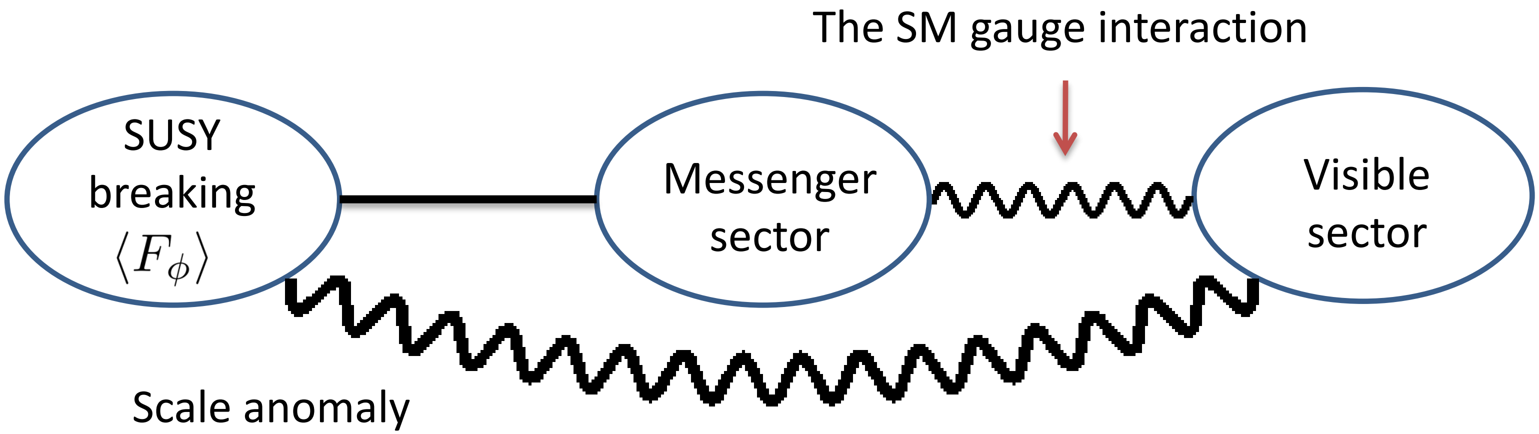
[A. Pomarol and R. Rattazzi ’99]

[A. E. Nelson and N. T. Weiner ‘02]

[K. Hsieh and M. A. Luty ‘06]

Gaugomaly mediation [R. Sundrum '04]

= Gauge mediation + Anomaly mediation



The flavor problem is also solved.

The Messenger scale ~ $\langle F_\phi \rangle$

[A. Pomarol and R. Rattazzi '99]

The tachyonic slepton problem can be cured by the gauge-mediated contribution.

The anomalously small gaugino masses can be enhanced by the anomaly-mediated contribution.

2.The model

We consider the following generalized fermionic mass matrix

$$\mathcal{L}_{mess} = \int d^2\theta\, \phi(\lambda_{ij} X + m_{ij})\psi_i \tilde{\psi}_j + h.c.$$

$\psi_i, \tilde{\psi}_j$: The messenger fields $i, j = 1 \ldots N$

(anti-) fundamental representation under the SU(5) symmetry

$X = \langle X \rangle + \theta^2 \langle F_X \rangle$: A SUSY breaking spurion

λ_{ij}, m_{ij} : constant matrix

$\phi = 1 + \theta^2 \langle F_\phi \rangle$: The superconformal compensator

2.The model

$$\mathcal{L} = \int d^4\theta \, \frac{\phi^\dagger}{\phi} \left(\frac{1}{2} c_S S^2 + c_{Pij} \psi_i \tilde{\psi}_j \right) + \int d^2\theta \left[\frac{\lambda_S}{3!} S^3 + \lambda_{Pij} S \psi_i \tilde{\psi}_j \right] + h.c.$$

S : The singlet field $\psi_i, \tilde{\psi}_j$: The messenger fields

ϕ : The superconformal compensator

c_S, λ_S, c_{Pij} and λ_{Pij} : real coupling constants.

The terms S^2 and $\psi\tilde{\psi}$ can be forbidden by discrete R symmetry.

$$S(\theta) \mapsto -S(i\theta), \psi(\theta) \mapsto -\psi(i\theta), \tilde{\psi}(\theta) \mapsto -\tilde{\psi}(i\theta)$$

Vacuum

Scalar potential

$$V = \left| c_S \langle F_\phi^\dagger \rangle S + \frac{1}{2}\lambda_S S^2 + \lambda_{Pij}\psi_i\tilde{\psi}_j \right|^2$$
$$+ \left| \left(c_{Pij}\langle F_\phi^\dagger \rangle + \lambda_{Pij} S \right) \psi_i \right|^2 + \left| \left(c_{Pij}\langle F_\phi^\dagger \rangle + \lambda_{Pij} S \right) \tilde{\psi}_j \right|^2$$
$$+ |\langle F_\phi \rangle|^2 \left(\frac{1}{2} c_S S^2 + c_{Pij}\psi_i\tilde{\psi}_j \right) + h.c.$$

$\langle \psi \rangle = \langle \tilde{\psi} \rangle = 0$ The SM gauge symmetry is preserved.

$$\langle S \rangle = -\frac{\langle F_\phi \rangle}{2\lambda_S}\left(3c_S + \sqrt{c_S(c_S - 8)} \right)$$
$$\left\langle \frac{F_S}{S} \right\rangle = \frac{\langle F_\phi \rangle}{4}\left(-c_S + \sqrt{c_S(c_S - 8)} \right)$$

$\sim$ order $\langle F_\phi \rangle$

The messenger mass matrix

$$\int d^4\theta \, \frac{\phi^\dagger}{\phi} c_{Pij} \psi_i \tilde{\psi}_j \qquad \int d^2\theta \lambda_{Pij} S \psi_i \tilde{\psi}_j + h.c.$$

$$\langle S \rangle = -\frac{\langle F_\phi \rangle}{2\lambda_S} \left(3c_S + \sqrt{c_S(c_S - 8)} \right)$$

$$\left\langle \frac{F_S}{S} \right\rangle = \frac{\langle F_\phi \rangle}{4} \left(-c_S + \sqrt{c_S(c_S - 8)} \right)$$

$$\mathcal{L}'_{mess} = \int d^2\theta \, \phi \left(M_{ij} + F_{ij}\theta^2 \right) \psi_i \tilde{\psi}_j$$

$$M_{ij} = \langle F_\phi \rangle c_{Pij} + \langle S \rangle \lambda_{Pij}$$

$$F_{ij} = -2\langle F_\phi \rangle M_{ij} + \left(\langle F_\phi \rangle \langle S \rangle + \langle F_S \rangle \right) \lambda_{Pij}$$

$$M_{ij} \not\propto F_{ij}$$

We have the general messenger mass matrix.

3. The soft masses

The gaugino masses

$$M_\lambda = \frac{i}{2\tau}\left(\frac{\partial \tau}{\partial \phi}\bigg|_{\phi=1} F_\phi + \frac{\partial \tau}{\partial X}\bigg|_{X=\langle X\rangle} F_X\right)$$

The holomorphic gauge coupling

$$\tau(\mu) = \tau_0 + i\frac{b'}{2\pi}\log\frac{1}{\Lambda} - \frac{i}{2\pi}\log\det\mathcal{M} + \underline{i\frac{b}{2\pi}\log\frac{\mu}{\phi}}$$

scale anomaly

$$M_\lambda = \frac{\alpha}{4\pi}\left(bF_\phi + \frac{\partial}{\partial X}\log\det\mathcal{M}\bigg|_{X=\langle X\rangle} F_X\right) \qquad \alpha \equiv g^2/4\pi$$

Anomaly mediation

Gauge mediation

The gaugino masses are the sum of the anomaly and gauge mediation.

3. The soft masses

The soft scalar masses

The wavefunction renormlization factor

$$Z = Z\left(\frac{\mu}{\Lambda|\phi|}, \frac{|X|}{\Lambda}\right)$$

$$m_Q^2 = \left[2bC_2\left(\frac{\alpha}{4\pi}\right)^2 + \frac{1}{2}a\frac{y^2}{(4\pi)^2}\left(e\frac{y^2}{(4\pi)^2} - f\frac{\alpha}{4\pi}\right)\right]|F_\phi|^2$$

Anomaly mediation

$$+ 2C_2\left(\frac{\alpha}{4\pi}\right)^2 \sum_i \left(\frac{\partial \log|a_i|}{\partial \log|X|}\right)\left|\frac{F_X}{X}\right|^2$$

Gauge mediation

$$+ 2C_2\left(\frac{\alpha}{4\pi}\right)^2 \frac{\partial}{\partial \log|X|}\log|\det\mathcal{M}|F_\phi\frac{F_X^\dagger}{X^\dagger} + h.c.$$

Mixing term

a_i : The eigenvalue of $\mathcal{M}$

$$\gamma = \frac{1}{16\pi^2}\left(4C_2g^2 - ay^2\right) \quad \beta_g = -\frac{bg^3}{16\pi^2} \quad \beta_y = \frac{y}{16\pi^2}\left(ey^2 - fg^2\right)$$

The doublet and the triplet

$$\mathcal{L}'_{mess} = \int d^2\theta\, \phi \left[\underbrace{(\lambda_{2ij} X + m_{2ij}) \ell_i \tilde{\ell}_j}_{\text{The SU(2) doublet}} + \underbrace{(\lambda_{3ij} X + m_{3ij}) q_i \tilde{q}_j}_{\text{The SU(3) triplet}} \right] + h.c.$$

In (extra) ordinary **gauge** mediation [C. Cheung, A. L. Fitzpatrick and D. Shih '07]

$$\det \mathcal{M} = X^n G(m, \lambda)$$

R-charge

$$n = \frac{1}{R(X)} \sum_{i=1}^{N} (2 - R(\psi_i) - R(\tilde{\psi}_i))$$

$$\Rightarrow \quad M_1 : M_2 : M_3 = \alpha_1 : \alpha_2 : \alpha_3$$

Bino Wino Gluino

Our case

R-symmetry is not imposed any condition on the coupling constants.

We have various gaugino mass ratios!

The soft SUSY breaking Spectrum

Five continuous parameters $F_\phi, \Lambda_g^2, \Lambda_g^3, \Lambda_X^2, \Lambda_X^3$

$$\Lambda_g^{2,3} = \frac{\partial}{\partial X} \log \det \mathcal{M}^{2,3} \Big|_{X=\langle X \rangle} F_X$$

$$(\Lambda_X^{2,3})^2 = \sum_i \left(\frac{\partial \log |a_i^{2,3}|}{\partial \log |X|} \right)^2 \left| \frac{F_X}{X} \right|^2 + \frac{\partial}{\partial \log |X|} \log |\det \mathcal{M}^{2,3}| F_\phi \frac{F_X^\dagger}{X^\dagger} + h.c.$$

The indices 2, 3 represent the doublet and triplet contributions.

For simplicity, we take $\Lambda_g (= \Lambda_g^2 = \Lambda_g^3)$

The soft masses can be written by

$$r_1 \equiv \Lambda_g / \Lambda_X^2 \qquad r_2 \equiv \Lambda_X^2 / F_\phi \qquad r_3 \equiv \Lambda_X^3 / F_\phi$$

in the unit of $\langle F_\phi \rangle$

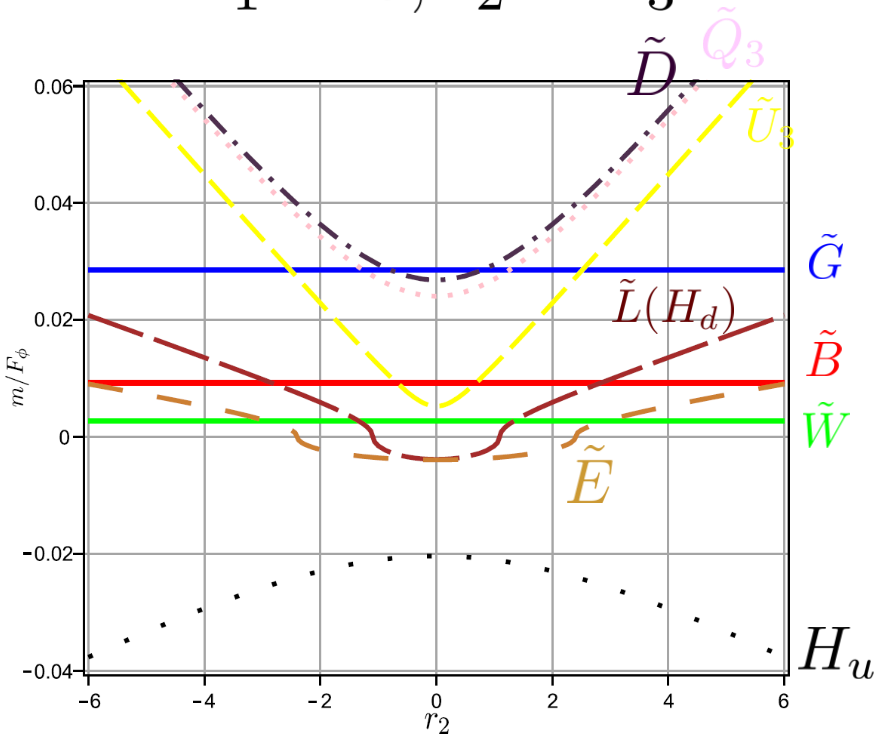
The messenger scale = 10 TeV

The soft masses at the weak scale

The gaugino masses are same as the anomaly mediation.

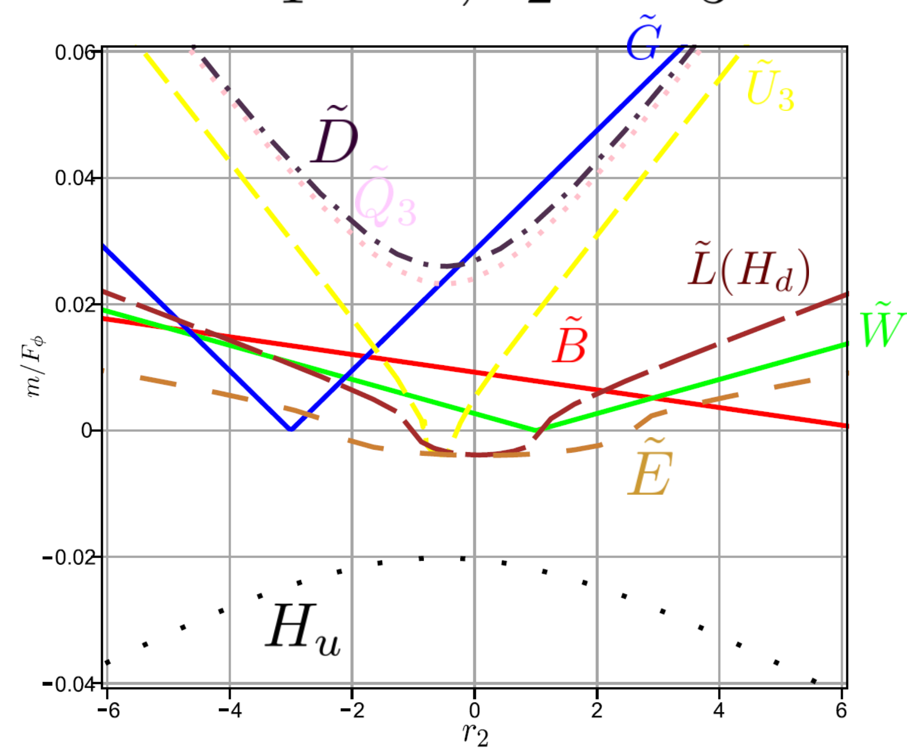
The LSP is the Wino.

$\mathrm{r}_1 = 0, r_2 = r_3$

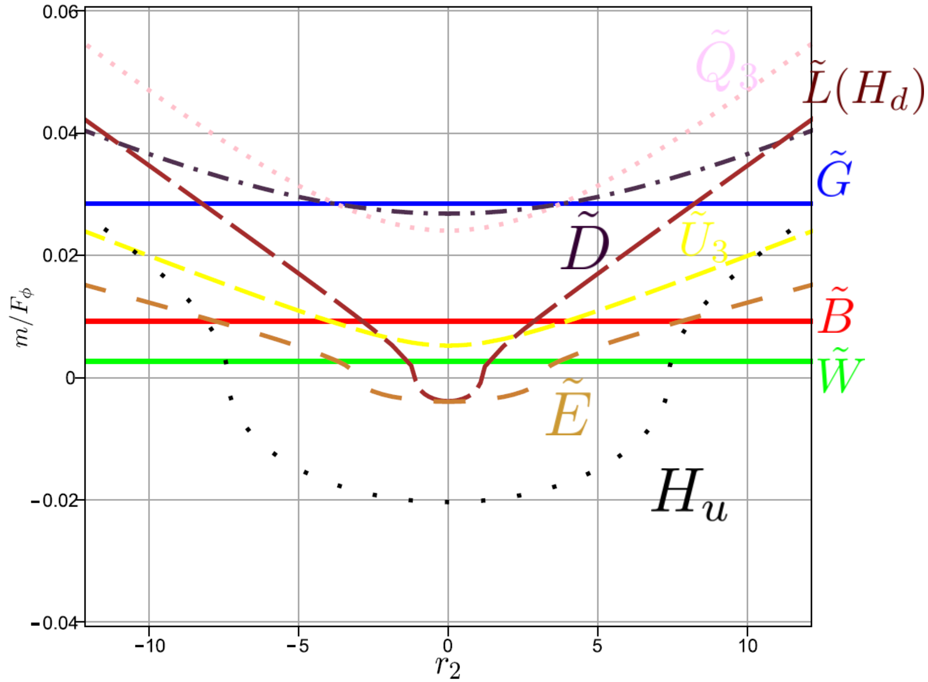


The LSP is the Bino.

$\mathrm{r}_1 = 1, r_2 = r_3$



$$r_1 = 0, r_2 = 5r_3$$



The messenger scale = 10 TeV

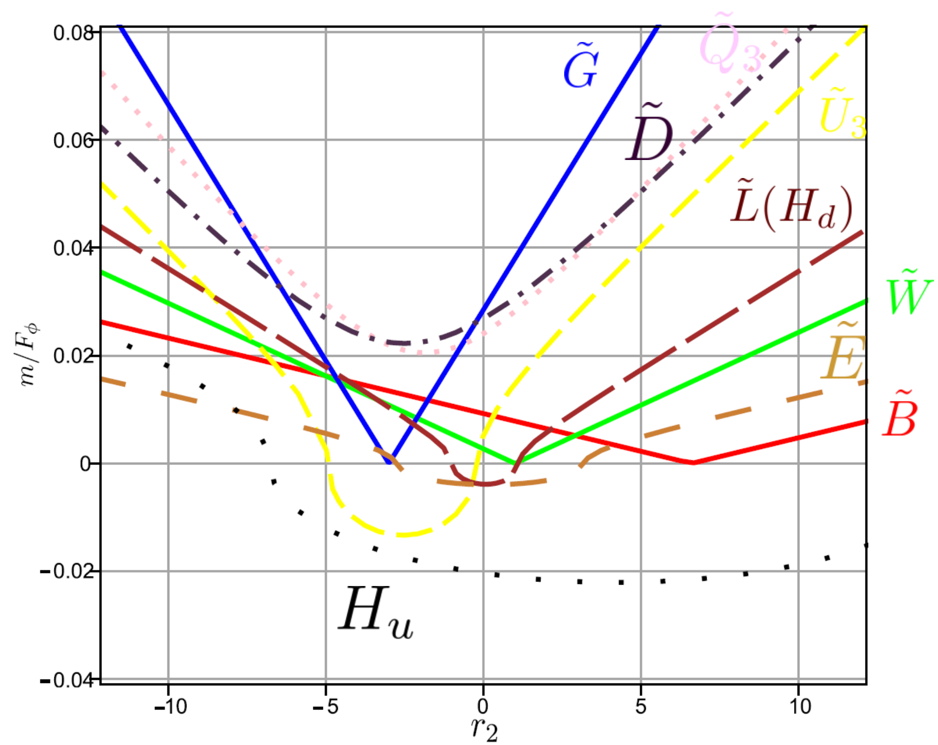
The soft masses at the weak scale

The gaugino masses are same as the anomaly mediation.

The LSP is the Wino.

$$r_1 = 1, r_2 = 5r_3$$

The LSP is the Bino.



4.Summary

We study the model the anomaly mediation
and the gauge mediation are competed.

This model naturally solves the flavor problem.

We have various soft SUSY breaking spectrum.

The LSP is the Bino or the Wino.

a WIMP dark matter candidate

Explicit soft masses

$$
\begin{aligned}
M_1 &= \tilde{\alpha}_1 \left[-\frac{33}{5} F_\phi + \left(\frac{3}{5} \Lambda_g^2 + \frac{2}{5} \Lambda_g^3 \right) \right] , \\
M_2 &= \tilde{\alpha}_2 \left[-F_\phi + \Lambda_g^2 \right] , \\
M_3 &= \tilde{\alpha}_3 \left[3F_\phi + \Lambda_g^3 \right] .
\end{aligned}
$$

$$
\begin{aligned}
m_{\tilde{Q}}^2 = & \left[-\frac{11}{50} \tilde{\alpha}_1^2 - \frac{3}{2} \tilde{\alpha}_2^2 + 8 \tilde{\alpha}_3^2 + Y_t^2 \left(6 Y_t^2 - \frac{13}{15} \tilde{\alpha}_1 - 3 \tilde{\alpha}_2 - \frac{16}{3} \tilde{\alpha}_3 \right) \right] |F_\phi|^2 \\
& + \left[\frac{1}{30} \tilde{\alpha}_1^2 \left(\frac{2}{5} (\Lambda_X^2)^2 + \frac{3}{5} (\Lambda_X^1)^2 \right) + \frac{3}{2} \tilde{\alpha}_2^2 (\Lambda_X^1)^2 + \frac{8}{3} \tilde{\alpha}_3^2 (\Lambda_X^2)^2 \right] , \\
m_{\tilde{U}}^2 = & \left[-\frac{88}{25} \tilde{\alpha}_1^2 + 8 \tilde{\alpha}_3^2 + 2 Y_t^2 \left(6 Y_t^2 - \frac{13}{15} \tilde{\alpha}_1 - 3 \tilde{\alpha}_2 - \frac{16}{3} \tilde{\alpha}_3 \right) \right] |F_\phi|^2 \\
& + \left[\frac{8}{15} \tilde{\alpha}_1^2 \left(\frac{2}{5} (\Lambda_X^2)^2 + \frac{3}{5} (\Lambda_X^1)^2 \right) + \frac{8}{3} \tilde{\alpha}_3^2 (\Lambda_X^2)^2 \right] , \\
m_{\tilde{D}}^2 = & \left[-\frac{22}{25} \tilde{\alpha}_1^2 + 8 \tilde{\alpha}_3^2 \right] |F_\phi|^2 + \left[\frac{2}{15} \tilde{\alpha}_1^2 \left(\frac{2}{5} (\Lambda_X^2)^2 + \frac{3}{5} (\Lambda_X^1)^2 \right) + \frac{8}{3} \tilde{\alpha}_3^2 (\Lambda_X^2)^2 \right] .
\end{aligned}
$$

$$m_{\tilde{L}}^2 = \left[-\frac{99}{50}\tilde{\alpha}_1^2 + \frac{3}{2}\tilde{\alpha}_2^2\right]|F_\phi|^2 + \left[\frac{3}{10}\tilde{\alpha}_1^2\left(\frac{2}{5}(\Lambda_X^2)^2 + \frac{3}{5}(\Lambda_X^1)^2\right) + \frac{3}{2}\tilde{\alpha}_2^2(\Lambda_X^1)^2\right],$$
$$m_{\tilde{E}}^2 = \left[-\frac{198}{25}\tilde{\alpha}_1^2\right]|F_\phi|^2 + \left[\frac{6}{5}\tilde{\alpha}_1^2\left(\frac{2}{5}(\Lambda_X^2)^2 + \frac{3}{5}(\Lambda_X^1)^2\right)\right].$$

$$1.5r_2^2 + r_3^2 \gtrsim 19$$

$$m_{H_1}^2 = m_{\tilde{L}}^2$$
$$m_{H_2}^2 = \left[-\frac{99}{50}\tilde{\alpha}_1^2 - \frac{3}{2}\tilde{\alpha}_2^2 + 3Y_t^2\left(6Y_t^2 - \frac{13}{15}\tilde{\alpha}_1 - 3\tilde{\alpha}_2 - \frac{16}{3}\tilde{\alpha}_3\right)\right]|F_\phi|^2$$
$$+ \left[\frac{3}{10}\tilde{\alpha}_1^2\left(\frac{2}{5}(\Lambda_X^2)^2 + \frac{3}{5}(\Lambda_X^1)^2\right) + \frac{3}{2}\tilde{\alpha}_2^2(\Lambda_X^1)^2\right].$$

$$\tilde{\alpha}_i = \left(\frac{g_i}{4\pi}\right)^2, Y_t = \left(\frac{y_t}{4\pi}\right)^2$$

Various representation points (at weak scale)

	Point 1	Point 2	Point 3	Point 4	Point 5
r_1	0	0	0	0	0
r_2	3.5	4.0	4.0	7.35	2.5
r_3	3.5	2.0	0.8	1.47	5.0
$m_{3/2}$	50TeV	50TeV	50TeV	50TeV	50TeV
$m_{\tilde{B}}$	462	462	462	462	462
$m_{\tilde{W}}$	135	135	135	135	135
$m_{\tilde{G}}$	1430	1430	1430	1430	1430
$m_{\tilde{Q}_3}$	2450	1800	1450	1910	3200
$m_{\tilde{U}_3}$	1970	1130	465	753	2810
$m_{\tilde{Q}_{1,2}}$	2590	1940	1580	2040	3370
$m_{\tilde{U}_{1,2}}$	2302	1480	970	1260	3180
$m_{\tilde{D}}$	2530	1820	1430	1624	3340
$m_{\tilde{L}}(m_{H_1})$	586	163	671	1268	412
$m_{\tilde{E}}$	209	192	166	431	232
m_{H_2}	1375	1020	856	88.7	1790
A_t	1300	1300	1300	1300	1300

The messenger scale = 10 TeV

All masses are in GeV.

	Point 6	Point 7	Point 8	Point 9	Point 10
r_1	1	1	1	1	1
r_2	4.0	4.5	4.5	2.5	3.5
r_3	4.0	2.25	0.9	5.0	7.0
$m_{3/2}$	15TeV	20TeV	20TeV	25TeV	15TeV
$m_{\tilde{B}}$	54.6	58.8	58.8	144	65.1
$m_{\tilde{W}}$	122	189	189	101	101
$m_{\tilde{G}}$	998	1430	1425	1306	926
$m_{\tilde{Q}_3}$	961	1070	954	1713	1376
$m_{\tilde{U}_3}$	835	875	743	1527	1260
$m_{\tilde{Q}_{1,2}}$	1010	870	1000	1800	1440
$m_{\tilde{U}_{1,2}}$	936	994	856	1710	1400
$m_{\tilde{D}}$	987	1080	954	1788	1430
$m_{\tilde{L}}(m_{H_1})$	207	310	671	207	185
$m_{\tilde{E}}$	76.1	91.0	80.2	112	112
m_{H_2}	487	507	441	932	716
A_t	590	819	819	858	564