Electroweak Symmetry Breaking by a Neutral Sector : Dynamical Relaxation of the Little Hierarchy Problem

Bumseok KYAE
(Pusan Nat'l Univ.)

1806.08451

Sep. 7 (2018) @ Corfu 2018

- The naturalness problem of EW scale and Higgs boson mass has been the most important issue for last four decades.

- The MSSM has been the most promising BSM candidate.

- No evidence of BSM has been observed yet at LHC.

→ Theoretical puzzles raised in the SM still remain UNsolved.

- A barometer of the solution to the naturalness problem is the stop mass .

  The stop mass bound has been already > 1 TeV.

  (The gluino mass bound has exceeded > 2 TeV.)

→ They start threatening the traditional status of SUSY as a solution to the naturalness problem of the EW phase transition.

- ATLAS and CMS have discovered the SM(-like) Higgs with 125 GeV mass, which is too heavy as a SUSY Higgs.

- According to the recent analyses, 10-20 TeV stop mass is necessary for the 125 GeV Higgs mass (without a large stop mixing).

$$\Delta m_{h_u}^2|_{1-\mathrm{loop}} \approx \frac{3|y_t|^2}{8\pi^2}\widetilde{m}_t^2 \log\left(\frac{\widetilde{m}_t^2}{\Lambda^2}\right)\left[1+\frac{1}{2}\frac{A_t^2}{\widetilde{m}_t^2}\right],$$

$$\Delta m_H^2|_{1-\mathrm{loop}} \approx \frac{3m_t^4}{4\pi^2 v_h^2}\left[\log\left(\frac{\widetilde{m}_t^2}{m_t^2}\right)+\frac{A_t^2}{\widetilde{m}_t^2}\left(1-\frac{1}{12}\frac{A_t^2}{\widetilde{m}_t^2}\right)\right],$$

$$\frac{1}{2}m_Z^2 = \frac{m_{h_d}^2 - m_{h_u}^2\tan^2\beta}{\tan^2\beta - 1} - |\mu|^2.$$

- ATLAS and CMS have discovered the SM(-like) Higgs with 125 GeV mass, which is too heavy as a SUSY Higgs.

- According to the recent analyses, 10-20 TeV stop mass is necessary for the 125 GeV Higgs mass (without a large stop mixing).

A fine-tuning of 10^{-3} – 10^{-4}

seems to be unavoidable !! ??

- Recently some new ideas (without SUSY) have been suggested to relax the gauge hierarchy problem.

- For UV completion, however, embedding them in SUSY also have been discussed.

- Recently some new ideas (without SUSY) have been suggested to relax the gauge hierarchy problem.
- For UV completion, however, embedding them in SUSY also have been discussed.

We will attempt to address
the (little) hierarchy problem
in the SUSY framework.

Little Hierarchy Problem

$$|\mu|^2 + \frac{1}{2}M_Z^2 = \frac{m_{h_d}^2 - m_{h_u}^2 \tan^2\beta}{\tan^2\beta - 1}$$

Why is M_Z^2 [$=(g_2^2+g_Y^2)(v_u^2+v_d^2)/2$] so small compared to the soft masses ?

[$v_u^2 + v_d^2 \equiv \langle |H|^2 \rangle = (174\ \mathrm{GeV})^2$]

Problems in SUSY models

Gravity Mediated SUSY Breaking mech.

μ and $B\mu$ terms are O.K.

But Flavor and CP problems would arise.

Gauge Mediated SUSY Breaking mech.

Flavor and CP problems are absent.

But μ and $B\mu$ problems would be serious.

A funny model

$$V = M^2|H|^2 + m^2|\phi|^2 + \lambda^2|H|^2|\phi|^2 + \delta V$$

A funny model

$$V = M^2|H|^2 + m^2|\phi|^2 + \lambda^2|H|^2|\phi|^2 + \delta V$$

$$\left(\lambda^2|H|^2 + m^2\right)\phi + \partial\delta V/\partial\phi^* = 0,$$
$$\left(\lambda^2|\phi|^2 + M^2\right)H + \partial\delta V/\partial H^* = 0.$$

A funny model

$$V = M^2|H|^2 + m^2|\phi|^2 + \lambda^2|H|^2|\phi|^2 + \delta V$$

$$\left(\lambda^2|H|^2 + m^2\right)\phi + \partial\delta V/\partial\phi^* = 0,$$
$$\left(\lambda^2|\phi|^2 + M^2\right)H + \partial\delta V/\partial H^* = 0.$$

- An interesting extrm. Point: If $\partial\delta V/\partial\phi^*$ is negligible,

$$|H|^2 = -m^2/\lambda^2,\ |\phi|^2 = -M^2/\lambda^2 - g^2m^2/\lambda^4$$

A funny model

ϕ becomes massless, and so
it can get a large VEV.
Φ compensates the large M^2.

$$\left(\lambda^2|H|^2 + m^2\right)\phi + \partial\delta V/\partial\phi^* = 0,$$
$$\left(\lambda^2|\phi|^2 + M^2\right)H + \partial\delta V/\partial H^* = 0.$$

- An interesting extrm. Point: If $\partial\delta V/\partial\phi^*$ is negligible,

$$|H|^2 = -m^2/\lambda^2,\ |\phi|^2 = -M^2/\lambda^2 - g^2m^2/\lambda^4$$

A funny model

ϕ becomes massless, and so
it can get a large VEV.

ϕ compensates the large M^2.

$(\lambda^2|H|^2 + m^2)\phi + \partial\delta V/\partial\phi^* = 0,$

If $m^2 \ll M^2$,

a small m^2 is responsible for the small Higgs VEV.

If

$|H|^2 = -m^2/\lambda^2,\ |\phi|^2 = M^2/\lambda^2 - g^2m^2/\lambda^4$

A funny model

ϕ becomes massless, and so
it can get a large VEV.

ϕ compensates the large M^2.

BUT such a point is a saddle point of V!!

The mixing btw H and ϕ is almost maximal.
One of the mass E.state is tachyonic.

If

λ^4

A funny model

1. Why is $\partial\delta V/\partial\phi^*$ negligible?

$$V = M^2|H|^2 + m^2|\phi|^2 + \lambda^2|H|^2|\phi|^2 + \delta V$$

$$\left(\lambda^2|H|^2 + m^2\right)\phi + \partial\delta V/\partial\phi^* = 0,$$
$$\left(\lambda^2|\phi|^2 + M^2\right)H + \partial\delta V/\partial H^* = 0.$$

- An interesting extrm. Point: If $\partial\delta V/\partial\phi^*$ is negligible,

$$|H|^2 = -m^2/\lambda^2,\ |\phi|^2 = -M^2/\lambda^2 - g^2m^2/\lambda^4$$

A funny model

1. Why is $\partial \delta V / \partial \phi^*$ **negligible ?**

$V = M^2 |H|^2 \ldots |H|^2 |\phi|^2 + \delta V$

2. Why $m^2 \ll M^2$ **?**

How can a relatively small m^2 be generated?

How can the smallness of m^2 be maintained?

$$\left(\lambda^2 |\phi|^2 + M^2\right) H + \partial \delta V / \partial H^* = 0.$$

- An interesting extrm. Point: If $\partial \delta V / \partial \phi^*$ is negligible,

$$|H|^2 = -m^2/\lambda^2 , \; |\phi|^2 = -M^2/\lambda^2 - g^2 m^2/\lambda^4$$

A funny model

1. Why is** $\partial\delta V/\partial \phi^*$ **negligible ?

2. Why** $m^2 \ll M^2$ **?

How can a relatively small m^2 be generated?

How can the smallness of m^2 be maintained?

3. How can the mixing btw H and ϕ be suppressed?

A funny model

1. Why is $\partial \delta V / \partial \phi^*$ negligible ?

Introduce SUSY.

Φ can be a flat direction in the SUSY limit.

How can a relatively small m^2 be generated?

How can the smallness of m^2 be maintained?

$(\lambda^2|\phi|^2 + M^2)H + \partial \delta V / \partial H^* = 0.$

3. How can the mixing btw H and ϕ be suppressed?

A funny model

1. Why is $\partial \delta V / \partial \phi^*$ **negligible ?**

$V = M^2 |H|^2$ … $|H|^2 |\phi|^2 + \delta V$

2. Why $m^2 \ll M^2$ **?**

How can a relatively small m^2 be generated?

How can the smallness of m^2 be maintained?

Introduce both **gravity-** and **gauge-mediated SUSY breaking mech.,**

assuming **gauge mediated effects dominate.**

The **messenger scale** of gauge med. needs to be **low** enough.

A funny model

1. Why is $\partial \delta V / \partial \phi^*$ negligible ?

λ^2 needs **small** enough.

$V = M^2 |H|^2$ ... $|H|^2 |\phi|^2 + \delta V$

2. Why $m^2 \ll M^2$?

How can a relatively small m^2 be generated?

How can the smallness of m^2 be maintained?

Introduce both **gravity** and **gauge mediated SUSY breaking mech.**,

assuming **gauge mediated effects dominate.**

The **messenger scale** of gauge med. needs to be **low** enough.

A funny model

1. Why is $\partial\delta V/\partial\phi^*$ **negligible ?**

2. Why $m^2 \ll M^2$ **?**

How can a relatively small m^2 be generated?

How can the smallness of m^2 be maintained?

$(\lambda^2|\phi|^2 + M^2)\, H + \partial\delta V/\partial H^* = 0.$

3. How can the mixing btw H and ϕ ***be suppressed?***

By **more singlets**

Model

$$W = (\lambda_1 X + \lambda_2 \phi + \mu)\, h_u h_d + M\, XY + (\kappa/2)\, Y\phi^2$$

Model

W = (λ_1X + λ_2ϕ +μ) huhd + M XY + (κ/2) Yϕ^2

$$W_{\rm UV} \supset \Psi \left(y_1 X_1 + y_2 X_2\right) Z + y_3 \Psi^c Z \phi$$
$$+ \left(y_4 X_1 + y_5 X_2\right) h_u h_d + \frac{(\Psi^c)^2}{M_P} \left(y_6 X_1 + y_7 X_2\right) Y + \frac{\kappa}{2} Y \phi^2,$$

Superfields	$X_{1,2}$	Y	Z	ϕ	Ψ	Ψ^c
$\mathrm{U(1)_{PQ}}$	-1	$4/3$	$5/6$	$-2/3$	$1/6$	$-1/6$

Model

W = (λ_1X + λ_2ϕ +μ) huhd + M XY + (κ/2) Yϕ^2

$$V \supset |H|^2|\lambda_1 X + \lambda_2\phi + \mu|^2 + |\lambda_1 h_u h_d + MY|^2 + \left|\frac{\kappa}{2}\phi^2 + MX\right|^2$$
$$+|\lambda_2 h_u h_d + \kappa Y\phi|^2 + m_X^2|X|^2 + m_Y^2|Y|^2 + m_\phi^2|\phi|^2$$
$$+\left\{(\lambda_1 a_1 X + \lambda_2 a_2\phi)h_u h_d + MbXY + \frac{\kappa}{2}aY\phi^2 + \text{h.c.}\right\},$$

where $|H|^2 \equiv |h_u|^2 + |h_d|^2$

Model

$$W = (\lambda_1 X + \lambda_2 \phi + \mu)\, h_u h_d + M\, XY + (\kappa/2)\, Y\phi^2$$

$$\begin{aligned} V \supset\ & |H|^2 |\lambda_1 X + \lambda_2 \phi + \mu|^2 + |\lambda_1 h_u h_d + MY|^2 + \underline{\underline{\left|\frac{\kappa}{2}\phi^2 + MX\right|^2}} \\ & + |\lambda_2 h_u h_d + \kappa Y \phi|^2 + m_X^2 |X|^2 + m_Y^2 |Y|^2 + m_\phi^2 |\phi|^2 \\ & + \left\{ (\lambda_1 a_1 X + \lambda_2 a_2 \phi) h_u h_d + MbXY + \frac{\kappa}{2} a Y \phi^2 + \text{h.c.} \right\}, \end{aligned}$$

where $|H|^2 \equiv |h_u|^2 + |h_d|^2$

Model

$$W = (\lambda_1 X + \lambda_2 \phi + \mu)\, h_u h_d + M\, XY + (\kappa/2)\, Y\phi^2$$

$$V \supset |H|^2 |\lambda_1 X + \lambda_2 \phi + \mu|^2 + |\lambda_1 h_u h_d + MY|^2 + \left|\frac{\kappa}{2}\phi^2 + MX\right|^2$$

$+|\lambda_2 h$

$$\boxed{(\kappa/2)\phi^2 + MX = 0}$$

***FLAT direction** (= modulus-like)*

in SUSY limit , with $h_u = h_d = Y = 0$

where $|H|^2 = |$

Model

$$W = (\lambda_1 X + \lambda_2 \phi + \mu)\, h_u h_d + M\, XY + (\kappa/2)\, Y\phi^2$$

$$V \supset |H|^2|\lambda_1 X + \lambda_2\phi + \mu|^2 + |\lambda_1 h_u h_d + MY|^2 + \left|\frac{\kappa}{2}\phi^2 + MX\right|^2$$

$+|\lambda$

$+$

Suppose

m_X^2, m_Y^2, m_ϕ^2, a, b, etc.

$\sim O(m^2)$ << MSSM soft para.

where $|H|^2 \equiv |h_u|^2 + |h_d|^2$

Effective mu and Bmu

$$\boxed{\mu_{\text{eff}} = \lambda_1 \langle X \rangle + \lambda_2 \langle \phi \rangle + \mu,}$$

$$\boxed{B\mu_{\text{eff}} = \left(\lambda_1 M^* + \lambda_2 \kappa^* \langle \phi^* \rangle\right) \langle Y^* \rangle + \lambda_1 a_1 \langle X \rangle + \lambda_2 a_2 \langle \phi \rangle + B\mu,}$$

Extreme Conditions

extreme conditions for X, Y, and ϕ

$$\left\{\begin{array}{l} \mathcal{M}_X^2 X + M^* b^* Y^* = -\frac{\kappa}{2} M^* \phi^2 - (\lambda_2 \phi + \mu)\lambda_1^* |H|^2 \\ \qquad\qquad\qquad\qquad -\lambda_1^* a_1^* h_u^* h_d^*, \\ \mathcal{M}_Y^2 Y^* + MbX = -\frac{\kappa}{2} a\phi^2 - (\lambda_1^* M + \lambda_2^* \kappa\phi)\, h_u^* h_d^*, \\ \left(|\kappa Y|^2 + |\lambda_2 H|^2 + m_\phi^2\right)\phi + \left(\frac{\kappa}{2}\phi^2 + MX\right)\kappa^* \phi^* \\ \qquad\qquad + (\lambda_1 X + \mu)\lambda_2^* |H|^2 + \lambda_2^* a_2^* h_u^* h_d^* \\ \qquad\qquad\quad + (\lambda_2 h_u h_d + a^* \phi^*)\kappa^* Y^* = 0. \end{array}\right.$$

Solutions of Extrm. Condi.

$$X \approx \frac{-\kappa\phi^2}{2\mathcal{M}_X^2} M^* \left[1 - \frac{(a-b)b^*}{\mathcal{M}_Y^2} + \frac{2(\lambda_2\phi + \mu)\lambda_1^*|H|^2}{\kappa\phi^2 M^*}\right],$$

$$Y^* \approx \frac{-\kappa\phi^2}{2\mathcal{M}_Y^2}(a-b) - \frac{(\lambda_1^* M + \lambda_2^*\kappa\phi)h_u^* h_d^*}{\mathcal{M}_Y^2}.$$

where $\mathcal{M}_X^2 \equiv |\lambda_1 H|^2 + m_X^2 + |M|^2 \qquad (\approx |M|^2)$

$$\mathcal{M}_Y^2 \equiv |\kappa\phi|^2 + m_Y^2 + |M|^2$$

Extrm. Condi. for Φ

The extremum condition for $\underline{T_\zeta \ (\equiv \kappa\phi/M)}$

$$\boxed{\begin{aligned}&\frac{1}{2}|T_\zeta|^2\left(|\lambda_1 H|^2 + \underline{m_X^2}\right) - T_\zeta^*\left(\lambda_2 + \frac{\mu}{\phi}\right)\lambda_1^*|H|^2 - \frac{1}{2}T_\zeta\lambda_2^*\lambda_1|H|^2\\&+\frac{\mu}{\phi}\lambda_2^*|H|^2 + \left(|\lambda_2 H|^2 + \underline{m_\phi^2}\right) \approx \frac{|T_\zeta|^2(|T_\zeta|^2+2)}{4(|T_\zeta|^2+1)^2}\ \underline{|a-b|^2},\end{aligned}}$$

Extrm. Condi. for Φ

The extremum condition for $\underline{T_\zeta \ (\equiv \kappa\phi/M)}$

$$\frac{1}{2}|T_\zeta|^2\left(|\lambda_1 H|^2+\underline{m_X^2}\right)-T_\zeta^*\left(\lambda_2+\frac{\mu}{\phi}\right)\lambda_1^*|H|^2-\frac{1}{2}T_\zeta\lambda_2^*\lambda_1|H|^2$$

$$\text{or}\quad |H|^2\approx\frac{-m_\phi^2-\frac{1}{2}\left(m_X^2-|a-b|^2\right)|T_\zeta|^2}{\left(\lambda_2-\frac{1}{2}T_\zeta\lambda_1+\frac{\mu}{\phi}\right)\left(\lambda_2^*-T_\zeta^*\lambda_1^*\right)},$$

Extrm. Condi. for Φ

$$|H|^2 \sim -m_{\phi,X}^2 / |\lambda_{2,1}|^2$$

$$\text{or} \quad |H|^2 \approx \frac{-m_\phi^2 - \frac{1}{2}\left(m_X^2 - |a-b|^2\right)|T_\zeta|^2}{\left(\lambda_2 - \frac{1}{2}T_\zeta\lambda_1 + \frac{\mu}{\phi}\right)\left(\lambda_2^* - T_\zeta^*\lambda_1^*\right)},$$

Dynamical Relaxation

$$\boxed{\mu_{\rm eff} = \lambda_1\langle X\rangle + \lambda_2\langle\phi\rangle + \mu,} \quad \boxed{\approx \frac{MT_\zeta}{\kappa}\left(\lambda_2 - \frac{1}{2}\lambda_1 T_\zeta\right) + \mu,}$$

$\mu_{\rm eff}$

$$\boxed{|\mu|^2 + \frac{1}{2}M_Z^2 = \frac{m_{h_d}^2 - m_{h_u}^2\tan^2\beta}{\tan^2\beta - 1}} \; (\approx -m_{h_u}^2)$$

satisfying the conditions for EW symmetry breaking,

$B\mu_{\rm eff}$

$$2B\mu \;<\; (m_{h_u}^2 + |\mu|^2) + (m_{h_d}^2 + |\mu|^2)$$

$$(B\mu)^2 \;>\; (m_{h_u}^2 + |\mu|^2)(m_{h_d}^2 + |\mu|^2)$$

Dynamical Relaxation

$$\boxed{\mu_{\rm eff} = \lambda_1\langle X\rangle + \lambda_2\langle\phi\rangle + \mu,} \quad \boxed{\approx \frac{MT_\zeta}{\kappa}\left(\lambda_2 - \frac{1}{2}\lambda_1 T_\zeta\right) + \mu,}$$

$$\boxed{|\mu|^2 + \frac{1}{2}M_Z^2 = \frac{m_{h_d}^2 - m_{h_u}^2\tan^2\beta}{\tan^2\beta - 1}} \; (\approx -m_{h_u}^2)$$

$\mu_{\rm eff}$

sati

$B\mu_{\rm eff}$

$(B$

For $|\lambda_2 M/\kappa|^2 >> -m_{hu}^2$

$|T_\zeta(1-T_\zeta\lambda_1/2\lambda_2)| << 1$

Little Hierarchy Problem

$$|\mu|^2 + \frac{1}{2}M_Z^2 = \frac{m_{h_d}^2 - m_{h_u}^2 \tan^2\beta}{\tan^2\beta - 1}$$

Why is M_Z^2 [$=(g_2^2+g_Y^2)(v_u^2+v_d^2)/2$] so small compared to the soft masses ?

[$v_u^2 + v_d^2 \equiv \langle |H|^2 \rangle = (174\ \mathrm{GeV})^2$]

Little Hierarchy Problem

It is because m_ϕ, m_χ are so small compared to the MSSM soft masses.

Why is M_Z^2 $[=(g_2^2+g_Y^2)(v_u^2+v_d^2)/2]$ so small compared to the soft masses ?

$[\, v_u^2 + v_d^2 \equiv \langle |H|^2 \rangle = (174\ \mathrm{GeV})^2 \,]$

For small enough $m_{\phi,X}^2$

Introduce Gauge Med. SUSY Breaking
as well as Gravity Med. SUSY breaking

Gauge Med. $\longrightarrow$ Heavy MSSM soft masses
avoiding Exp. Bounds and SUSY flavor and CP problems

Gravity Med. $\longrightarrow$ Small MSSM singlet masses and $B\mu$ term

For small enough $m_{\phi,X}^2$

Introduce Gauge Med. SUSY Breaking

as well as Gravity Med. SUSY breaking

- ***Messenger Scale** of the **Gauge Med.***

  *needs to be **LOW** enough.*

- *λ_2 needs to be **SMALL** enough.*

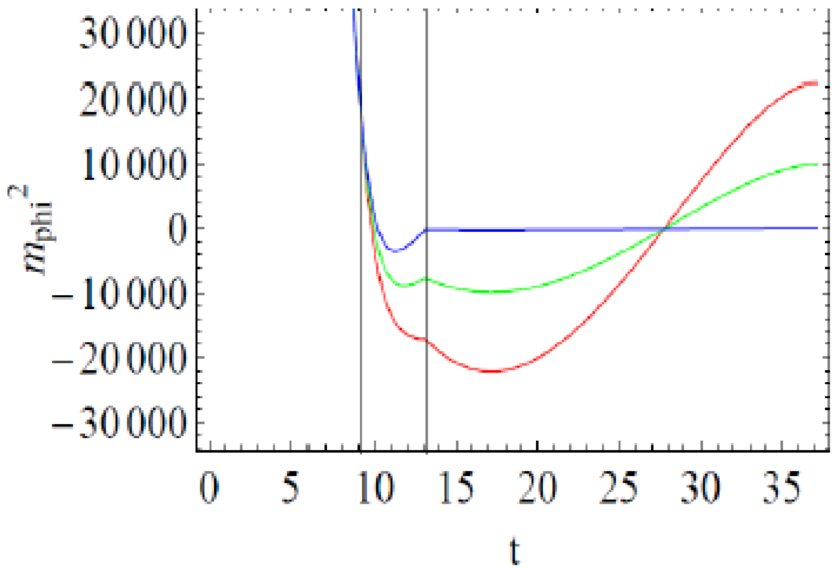
lems

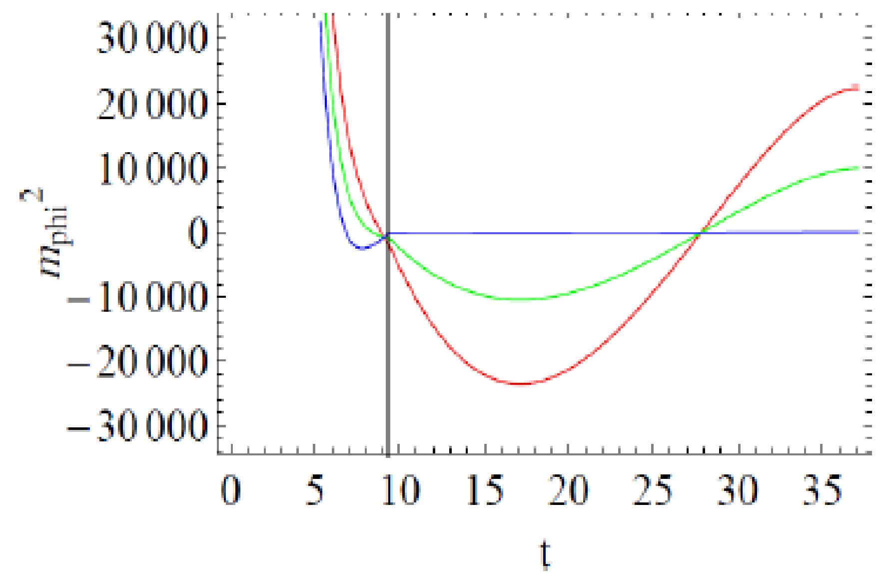
Gravi

term

Focus Point

(λ_1=0.7 ≫ λ_2=0.02)





RG evolutions of m_ϕ^2 under various trial m_0^2s.

the messenger scale = 500 TeV (L) and 12 TeV (R).

In both cases, the stop mass scales = 10 TeV.

Focus Point

Case I $\lambda_2^2 = 5\cdot 10^{-4}$ $\lambda_1^2 = 0.5$	$\tan\beta = 10$ $\tilde{m}_t^2 = (10\,\mathrm{TeV})^2$ $\Lambda_M = 15\,\mathrm{TeV}$	Case II $\lambda_2^2 = 8\cdot 10^{-3}$ $\lambda_1^2 = 0.5$	$\tan\beta = 40$ $\tilde{m}_t^2 = (20\,\mathrm{TeV})^2$ $\Lambda_M = 25\,\mathrm{TeV}$
$\boldsymbol{\Delta}_{\mathrm{m}_0^2}$	19.1	$\boldsymbol{\Delta}_{\mathrm{m}_0^2}$	79.6
$\boldsymbol{\Delta}_{\mathrm{M}_{1/2}}$	83.2	$\boldsymbol{\Delta}_{\mathrm{M}_{1/2}}$	28.6
$\boldsymbol{\Delta}_{\lambda_2^2}$	59.7	$\boldsymbol{\Delta}_{\lambda_2^2}$	56.5
$\boldsymbol{\Delta}_{\mathrm{GM}}$	37.1	$\boldsymbol{\Delta}_{\mathrm{GM}}$	153.5
$\boldsymbol{\Delta}_{\Lambda_{\mathrm{M}}}$	6.0	$\boldsymbol{\Delta}_{\Lambda_{\mathrm{M}}}$	21.3

Focus Point

Case I	$\tan\beta = 10$	Case II	$\tan\beta = 40$
$\lambda_2^2 = 5 \cdot 10^{-4}$	$\tilde{m}_t^2 = (10\,\mathrm{TeV})^2$	$\lambda_2^2 = 8 \cdot 10^{-3}$	$\tilde{m}_t^2 = (20\,\mathrm{TeV})^2$
$\lambda_1^2 = 0.5$	$\Lambda_M = 15\,\mathrm{TeV}$	$\lambda_1^2 = 0.5$	$\Lambda_M = 25\,\mathrm{TeV}$

$F_{gauge}/(16\pi^2\Lambda_M) \equiv GM \approx 5.1\,\mathrm{TeV}$ (I) and $10.5\,\mathrm{TeV}$ (II) ,

$F_{gauge} \ll F_{gravity}$,

$m_{3/2} \approx F_{gravity}/(\sqrt{3}\,M_{Pl}) \approx m_0 = 30.4\,\mathrm{GeV}$ (I) and $124.7\,\mathrm{GeV}$ (II),

We set $M_{1/2} = 125\,m_0$ (I) and $54\,m_0$ (II) at the GUT scale.

Focus Point

Case I	$\tan\beta = 10$	Case II	$\tan\beta = 40$
$\lambda_2^2 = 5\cdot 10^{-4}$	$\tilde{m}_t^2 = (10\,\mathrm{TeV})^2$	$\lambda_2^2 = 8\cdot 10^{-3}$	$\tilde{m}_t^2 = (20\,\mathrm{TeV})^2$
$\lambda_1^2 = 0.5$	$\Lambda_M = 15\,\mathrm{TeV}$	$\lambda_1^2 = 0.5$	$\Lambda_M = 25\,\mathrm{TeV}$

$(M_G\, M_W\, M_B) \approx (12, 5, 3)$ TeV (I) and $(22, 9, 5)$ TeV (II)

$\mu_{eff} \approx 2.5$ TeV (I) and 2.3 TeV (II)

The SUSY particles' masses of the 1st and 2nd generations are much heavier.

Mass Matrix (fermion)

$$\begin{pmatrix} \kappa Y & \kappa\phi & 0 & \lambda_2 h_u & \lambda_2 h_d \\ \kappa\phi & 0 & M & 0 & 0 \\ 0 & M & 0 & \lambda_1 h_u & \lambda_1 h_d \\ \lambda_2 h_u & 0 & \lambda_1 h_u & 0 & \mu_{\rm eff} \\ \lambda_2 h_d & 0 & \lambda_1 h_d & \mu_{\rm eff} & 0 \end{pmatrix}$$

in the basis of $\{\phi, Y, X, h_d, h_u\}$

Mass Matrix (fermion)

$$
\left(\begin{array}{ccc|cc}
\kappa Y & \kappa\phi & 0 & \lambda_2 h_u & \lambda_2 h_d \\
\kappa\phi & 0 & M & 0 & 0 \\
0 & M & 0 & \lambda_1 h_u & \lambda_1 h_d \\
\hline
\lambda_2 h_u & 0 & \lambda_1 h_u & 0 & \mu_{\rm eff} \\
\lambda_2 h_d & 0 & \lambda_1 h_d & \mu_{\rm eff} & 0
\end{array}\right)
$$

in the basis of $\{\phi, Y, X, h_d, h_u\}$

Mass Matrix (fermion)

$$\left(\begin{array}{ccc|cc} \kappa Y & \kappa\phi & 0 & \lambda_2 h_u & \lambda_2 h_d \\ \kappa\phi & 0 & M & 0 & 0 \\ 0 & M & 0 & \lambda_1 h_u & \lambda_1 h_d \\ \hline \lambda_2 h_u & 0 & \lambda_1 h_u & & \\ \lambda_2 h_d & 0 & \lambda_1 h & & \end{array}\right)$$

$$\frac{\kappa\langle Y\rangle}{1+T_\zeta^2} \approx \frac{1}{2}\, T_\zeta^2\ (b^* - a^*)$$

<u>**The smallest mass E. value**</u>

≈ sub GeV or lighter,

The lightest E. state plays the role of DM.

Mass Matrix (scalar)

$$\begin{pmatrix} m_H^2 & \lambda_2 H \mu_{\text{eff}}^* & \lambda_1 H \mu_{\text{eff}}^* \\ \lambda_2^* H^* \mu_{\text{eff}} & m_\phi^2 + |\lambda_2 H|^2 + |\kappa\phi|^2 & \lambda_2^* \lambda_1 |H|^2 + \kappa^* \phi^* M \\ \lambda_1^* H^* \mu_{\text{eff}} & \lambda_1^* \lambda_2 |H|^2 + \kappa\phi M^* & m_X^2 + |\lambda_1 H|^2 + |M|^2 \end{pmatrix}$$

in the basis of $\{H, \phi, X\}$

Mass Matrix (scalar)

- In the limit of $\lambda_2/\lambda_1 = \kappa\phi/M$ $(=T_\zeta)$,

The mixing angle btw the Higgs and singlets are suppressed.

We assume $(\lambda_2/\lambda_1 - \kappa\phi/M)/\,(\lambda_2/\lambda_1) \sim 0.1$.

- We can consider one more flat direction to easily get ALL positive E. values:

$$W \supset m XY' + (\kappa/2)Y'\phi'^2 ,$$

which leaves almost intact the above results, except adding a small SUSY mass to X.

Mass Matrix (scalar)

We can fulfill the constraints e.g. with

- $\lambda_1 \approx$ **0.7**, $|\lambda_2/\lambda_1| = 0.03\ (0.12)$, $T_\zeta < 0.027\ (0.11)$,
- $M_3 \sim$ **1** $-$ 10 GeV , $M_2 \sim$ **5 TeV** ,
- $\boldsymbol{\varepsilon} \sim \mathbf{10^{-1} - 10^{-2}}$, $|\tan\theta| > 10^{+1}$.

The mixing btw H and the singlets can be suppressed enough.

The mixing btw ϕ and X is almost the maximal.

Conclusion

- The MSSM μ term is dynamically adjusted by singlets such that the min. cond. of the Higgs is fulfilled.
  A ***FLAT DIRECTION*** compensates m_{hu}^2, while the ***SM Higgs*** does m_{ϕ}^2.

- A relatively small soft mass of a singlet (m_{ϕ}^2 or m_{χ}^2) is responsible for the small <H> (or small M_Z). Possible by Small Gravity Medi. Effects!

- The MSSM SUSY ptl.s are heavy enough to avoid Exp. Bounds and FCNC. Possible by Large Gauge Medi. Effects!

- A sub-GeV fermionic DM is predicted, while the Higgsino is quite heavy.

- The Mixings btw the Higgs and singlets can be suppressed enough by introducing several singlets.

Thank You !!