Supersymmetric Fine-tuning Problem and Little Hierarcy in Mixed Modulus-Anomaly Mediation

Ken-ichi Okumura
Department of Physics, Kyushu University

Discoveries of Higgs and Supersymmetry to Pioneer the particle physics in 21st Century

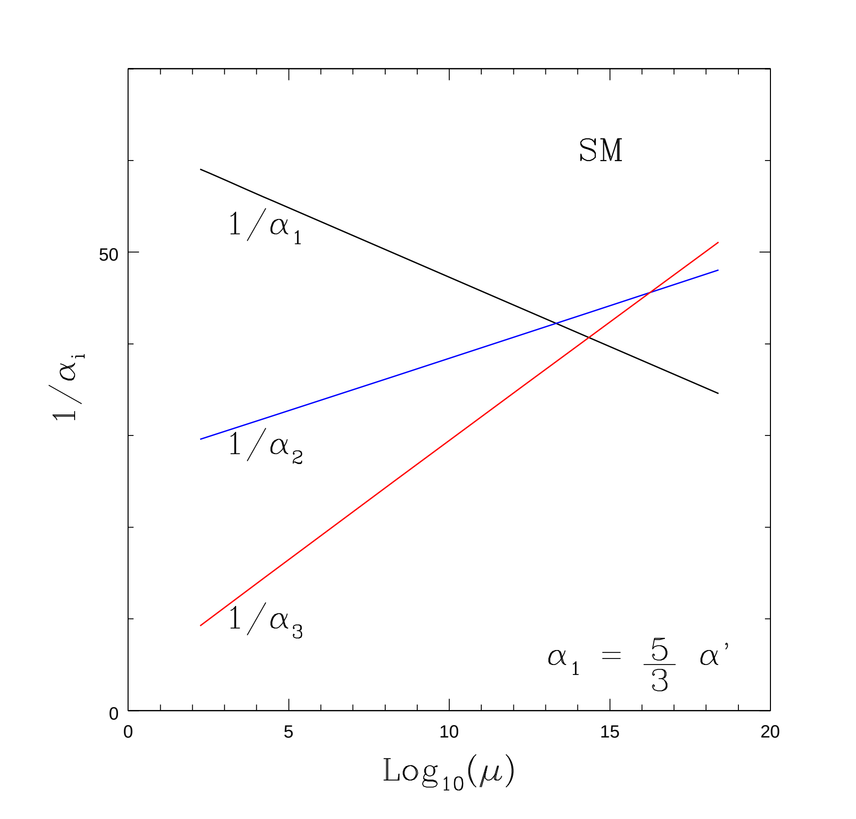
Kiwoon Choi, Kwang-Sik Jeong and K.O. JHEP 0509:039,
Kiwoon Choi, Kwang-Sik Jeong, Tatsuo Kobayashi and K.O. hep-ph/0508029

I. Introduction

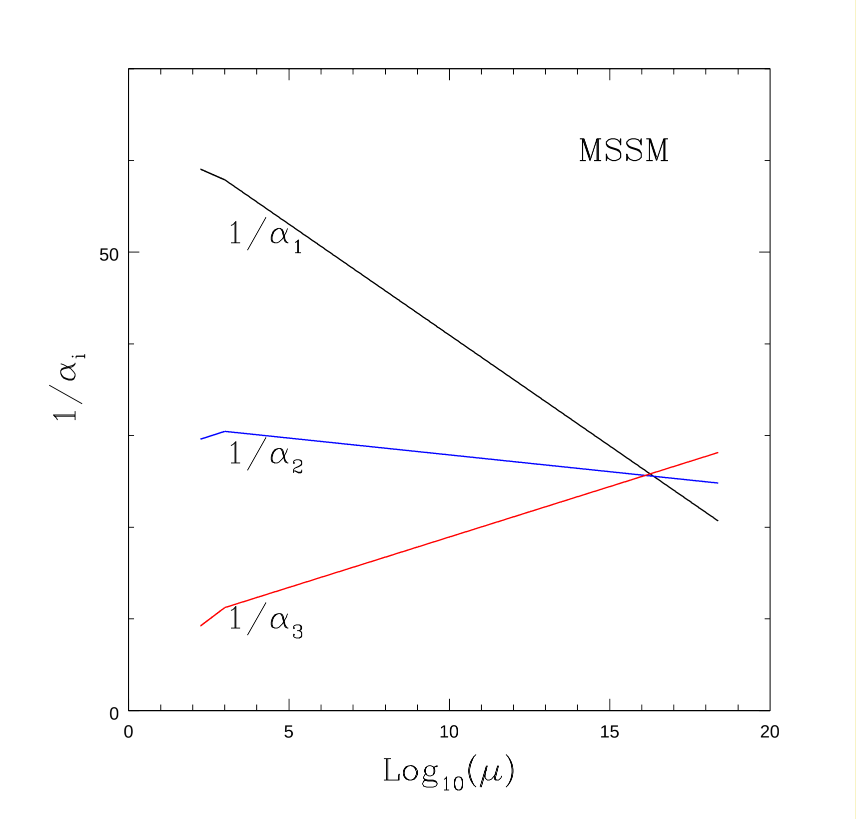
- Supersymmetry (SUSY) is considered to be the first candidate of physics beyond the SM not only as a solution of hierarchy problem but also for many attractive features like gauge coupling unification and natural candidate for cold dark matter.

- However lower bound for m_{h^0} measured in LEPII suggests a direction to heavy $\tilde{t}$ and some degree of fine-tuning in parameters of the MSSM (SUSY fine-tuning problem).

- We propose a new scenario which solves the SUSY fine-tuning problem without any modification of the MSSM based on SUSY braking model inspired from KKLT flux string compactification.



SM
$1/\alpha_1$
$1/\alpha_2$
$1/\alpha_3$
$\alpha_1 = \frac{5}{3} \alpha'$
$1/\alpha_i$
$\mathrm{Log}_{10}(\mu)$
0
50
0
5
10
15
20



MSSM
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$\mathrm{Log}_{10}(\mu)$
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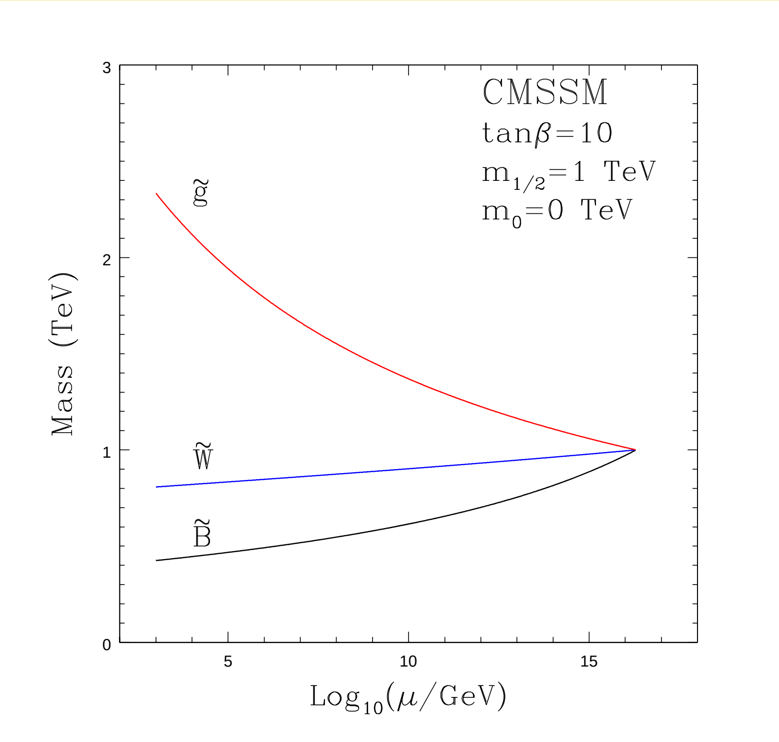
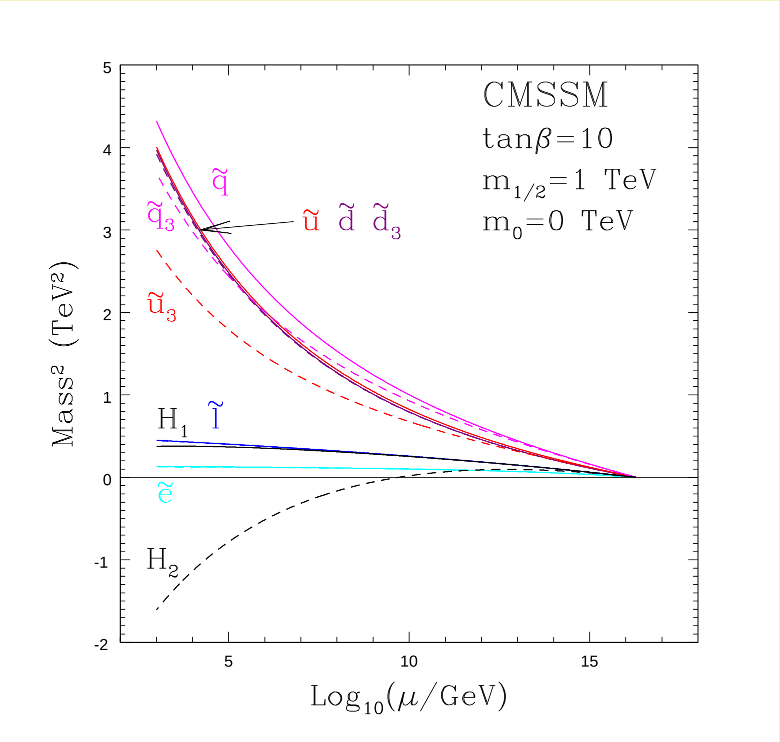
II. Supersymmetric Fine-tuning Problem

Radiative electroweak symmetry breaking





K.Inoue, A.Kakuto, H.Komatsu and S.Takeshita, L.E.Ibanez and G.G.Ross, J.R.Ellis, D.V.Nanopoulos and K.Tamvakis, L.Alvarez-Gaume, J.Polchinski and M.B.Wise

Tuning in the radiative electroweak symmetry breaking

Radiative correction to $m_{H_2}^2$ is order of $m_{\tilde{t}}^2$

$$\Delta m_{H_2}^2 \sim -\frac{3}{4\pi^2} y_t^2 m_{\tilde{t}}^2 \ln\left(\frac{\Lambda}{m_{\tilde{t}}}\right) \approx -2 m_{\tilde{t}}^2$$

$m_Z^2/2$ is given by the difference between $|m_{H_2}^2|$ and $|\mu|^2$.

$$\frac{m_Z^2}{2} = \frac{m_{H_1}^2 - m_{H_2}^2 \tan^2\beta}{\tan^2\beta - 1} - |\mu|^2 \approx -m_{H_2}^2 - |\mu|^2$$

$m_{\tilde{t}} \sim m_{H_2} \approx \mu > 500 GeV$ means $<$ 2% fine-tuning in the measure,

$$\Delta_{\mu^2}^{-1} \equiv \frac{-m_{H_2}^2 - |\mu|^2}{|\mu|^2} \approx \frac{m_Z^2}{2|\mu|^2}$$

Radiative correction in the lightest Higgs boson mass

Theoretical upper bound for m_{h_0} is given by m_Z at tree-level. However, radiative correction from y_t can raise the bound,

H.E.Haber and R.Hempfling, Y.Okada, M.Yamaguchi and T.Yanagida, J.R.Ellis, G.Ridolfi and F.Zwirner

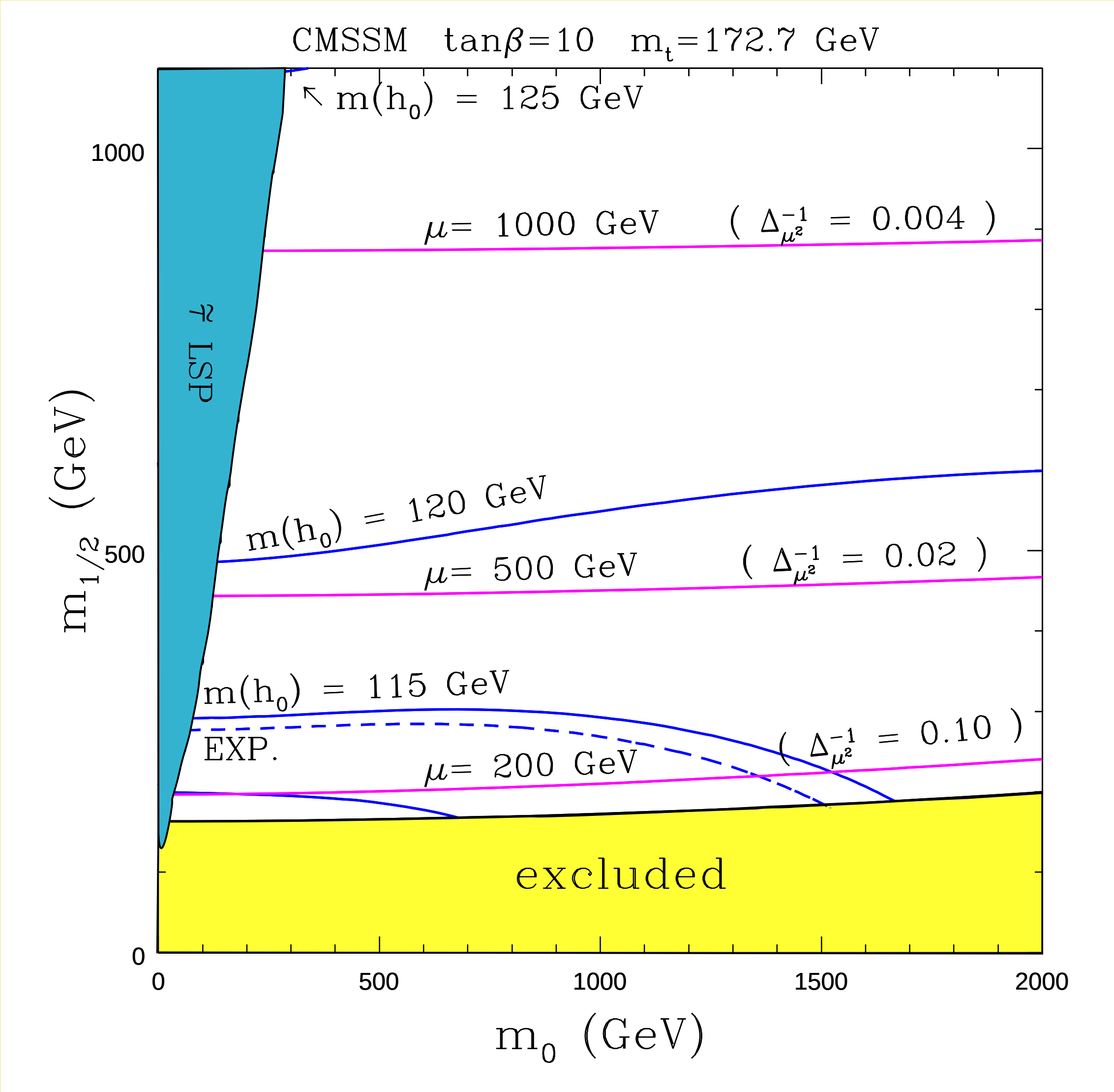
$$m_{h^0}^2 < m_Z^2 + \frac{3g^2 m_t^4}{8\pi^2 m_W^2}\left[\ln\left(\frac{m_{\tilde{t}}^2}{m_t^2}\right) + \frac{X_t^2}{m_{\tilde{t}}^2}\left(1 - \frac{X_t^2}{12 m_{\tilde{t}}^2}\right)\right]$$

where $X_t = A_t - \mu \cot\beta$.

For instance, the current SM bound is translated into,

$$m_{h^0} > 114.4 \text{ GeV} \rightarrow m_{\tilde{t}} \gtrsim 500 \text{ GeV} \qquad (X_t^2 << m_{\tilde{t}}^2)$$

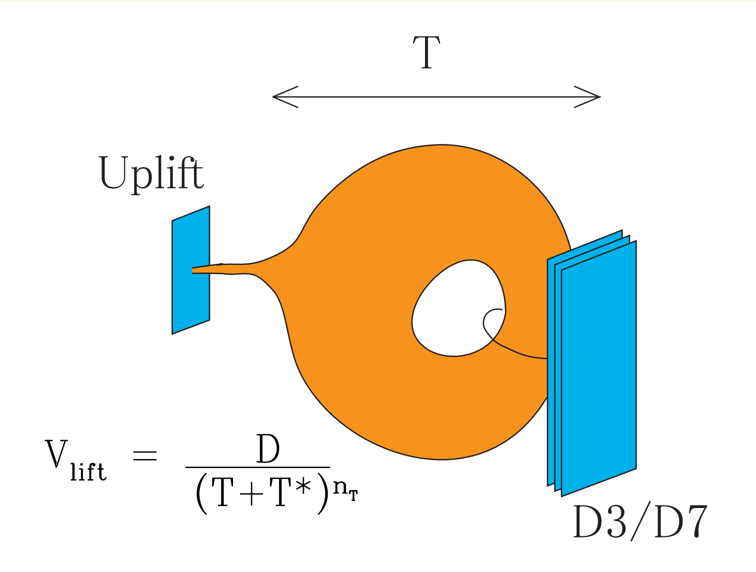
Here we call this tention between the tuning in determination of m_Z and m_{h^0} lower bound as supersymmetric fine-tuning problem.

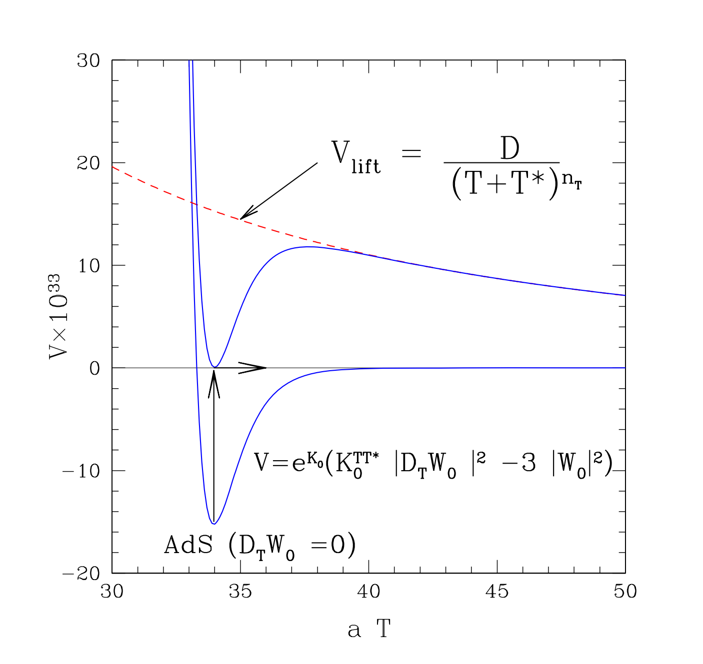

CMSSM tanβ=10 m_t=172.7 GeV
↖ m(h_0) = 125 GeV
μ= 1000 GeV (Δ^{-1}_{μ²} = 0.004)
τ̃ LSP
m(h_0) = 120 GeV
μ= 500 GeV (Δ^{-1}_{μ²} = 0.02)
m(h_0) = 115 GeV
EXP.
μ= 200 GeV (Δ^{-1}_{μ²} = 0.10)
excluded
m_{1/2} (GeV)
m_0 (GeV)
0
500
1000
0
500
1000
1500
2000

III. Mixed Modulus-Anomaly Mediation in KKLT model

Compactified string theory predicts moduli fields (S, T, Z^α) in 4D.
KKLT stabilized all of them with tunable positive cosmological constant.
S, Z^α: flux, $K_0 = -3\ln(T+T^*)$, $W = w_0 - A\exp(-aT)$

Type IIB orientifold





S.Kachru, R.Kallosh, A.Linde and S.P.Trivedi (2003)

Mixed modulus-anomaly mediation

SUSY breaking by uplifting potential is mediated to visible fields on D3/D7 branes via modulus F-term $F^T/(T+T^*)$, which is hierarchically smaller than $m_{3/2}$ ($\approx m_{3/2}/4\pi^2$) $\rightarrow$ anomaly mediation is same order!

K. Choi, A. Falkowski, H.P. Nilles, M. Olechowski and S. Pokorski (2004)

Relative siginificance α is calculable and contorolled by the power of modulus in the upligting potential [$\overline{D3}$ uplifting (KKLT) predicts $\alpha \approx 1 (n_T = 2)$].

$$\alpha \equiv \frac{m_{3/2}}{\ln\left(M_{Pl}/m_{3/2}\right)} \frac{1}{M_0} \approx \frac{2}{n_T}, \qquad M_0 \equiv \frac{F^T}{T+T^*}$$

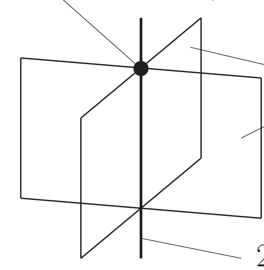
Visible fields on D3/D7 brane ($W = \lambda_{ijk} Q_i Q_j Q_k$),

$$\mathcal{L}_{soft} = -\frac{1}{2} M_a \lambda^a \lambda^a - m_i^2 |\tilde{Q}_i|^2 - \left(\frac{1}{6} A_{ijk} y_{ijk} \tilde{Q}_i \tilde{Q}_j \tilde{Q}_k + \text{h.c.} \right)$$

Moduli mediation:

Gauge k-fn. & Kähler on D3/D7:

$$
\begin{aligned}
f_a &= T^{l_a}, \\
\mathcal{K}_{\rm eff} &= K_0 + Z_i Q_i^* Q_i, \\
& \quad Z_i = 1/(T+T^*)^{n_i}
\end{aligned}
$$



L.E. Ibanez, C. Munoz and R. Rigolin Nucl. Phys. **B553**, 43 (1999)

L.E. Ibanez, hep-ph/0408064; B.C. Allanach, A. Brignole and L.E. Ibanez, hep-ph/0502151

$$
\begin{aligned}
M_a &= F^T \partial_T \ln(Re(f_a)) = l_a M_0, \qquad M_0 \equiv F^T/(T+T^*) \\
A_{ijk} &= -F^T \partial_T \ln\left(\frac{\lambda_{ijk}}{e^{-K_0} Z_i Z_j Z_k}\right) = (3 - n_i - n_j - n_k) M_0, \\
m_i^2 &= \frac{2}{3} V_0 - F^T F^{T*} \partial_T \partial_T^* \ln\left(e^{-K_0/3} Z_i\right) = (1 - n_i)|M_0|^2.
\end{aligned}
$$

* D3 visible gauge/matter fields $\longrightarrow$ no moduli-mediated contribution.

Anomaly-Mediation: Randall and Sundrum (1998), G.F.Giudice, M.A.Luty, H. Murayama and R.Rattazzi (1998)

$$
\begin{aligned}
M_a &= \frac{\beta_a}{g_a} m_{3/2} \\
A_{ijk} &= -\frac{1}{16\pi^2}\left(\gamma_i + \gamma_j + \gamma_k\right) m_{3/2} \\
m^2 &= -\frac{1}{32\pi^2}\frac{d\gamma_i}{d\ln\mu} m_{3/2} \\
&\quad + \frac{1}{8\pi^2}\left\{ T\left(\frac{\partial\gamma_i}{\partial T} M_0 m_{3/2} + \mathrm{H.c.}\right)\right\}
\end{aligned}
$$

where $\frac{\gamma_i}{8\pi^2} = \frac{d\ln Z_i}{d\ln\mu}$.

β_a, $\gamma_i/(8\pi^2) \rightarrow$ 1-loop suppressed, but always exists if $m_{3/2} \neq 0$
Interference term in m_i^2 via modulus dependence of γ_i.

K. Choi, A. Falkowski, H.P. Nilles, M. Olechowski and S. Pokorski (2004)

IV. Mirage Messenger Scale and Little SUSY Hierarchy at TeV

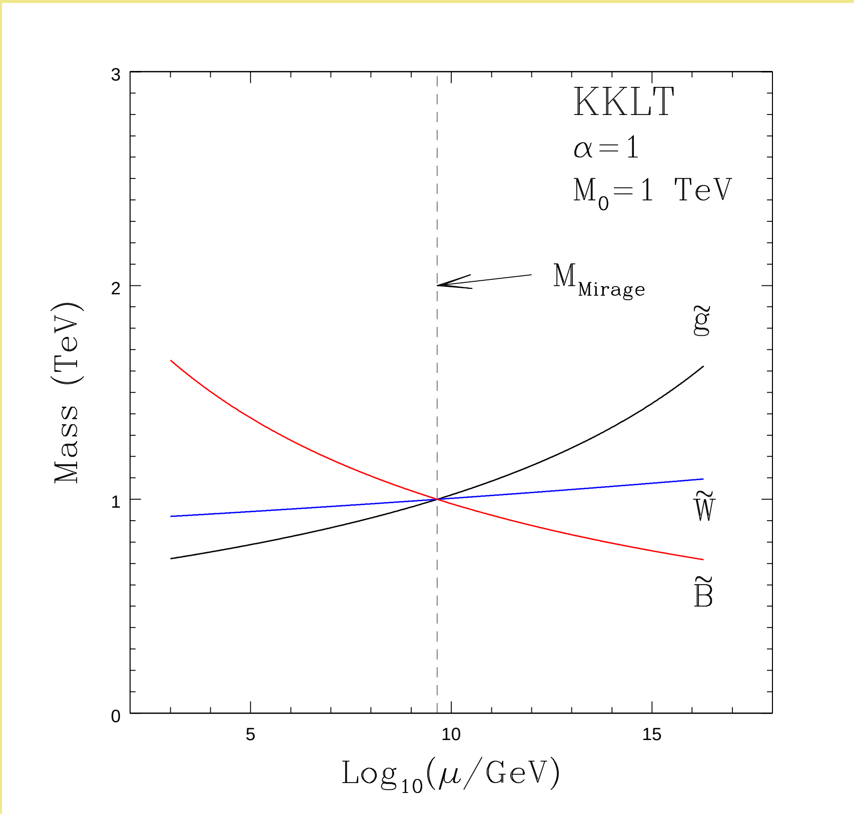
Correlation of R.G. running of modulus mediation with anomaly mediation.

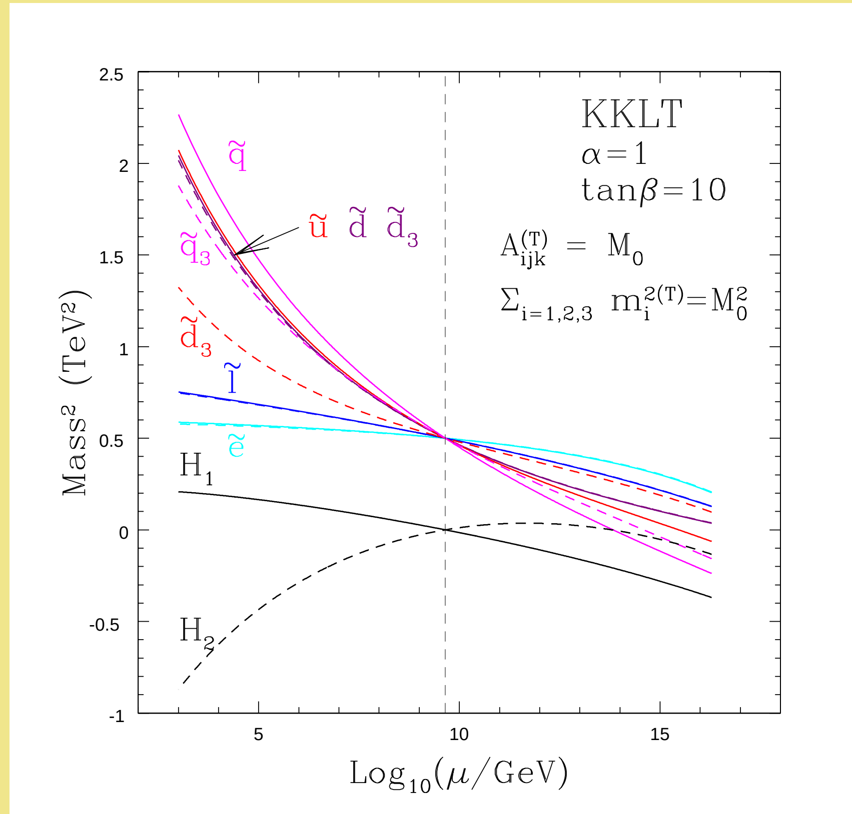
$$\text{Modulus}: \; M_a(\mu) = \frac{g_a^2(\mu)}{g_a^2(\Lambda)} M_0 = \; M_0 - \frac{\beta_a}{g_a} \ln\left(\frac{\Lambda}{\mu}\right)^2 M_0$$

$$\text{Anomaly}: \; M_a(\mu) = \frac{\beta_a}{g_a} m_{3/2}$$

They cancel at $\mu = \Lambda \exp\left(-\frac{m_{3/2}}{2M_0}\right) \approx \Lambda\left(\frac{m_{3/2}}{\Lambda}\right)^{\alpha/2}$.

$\overline{D3}$ uplifting (KKLT) predicts $\mu = \sqrt{\Lambda m_{3/2}}$.

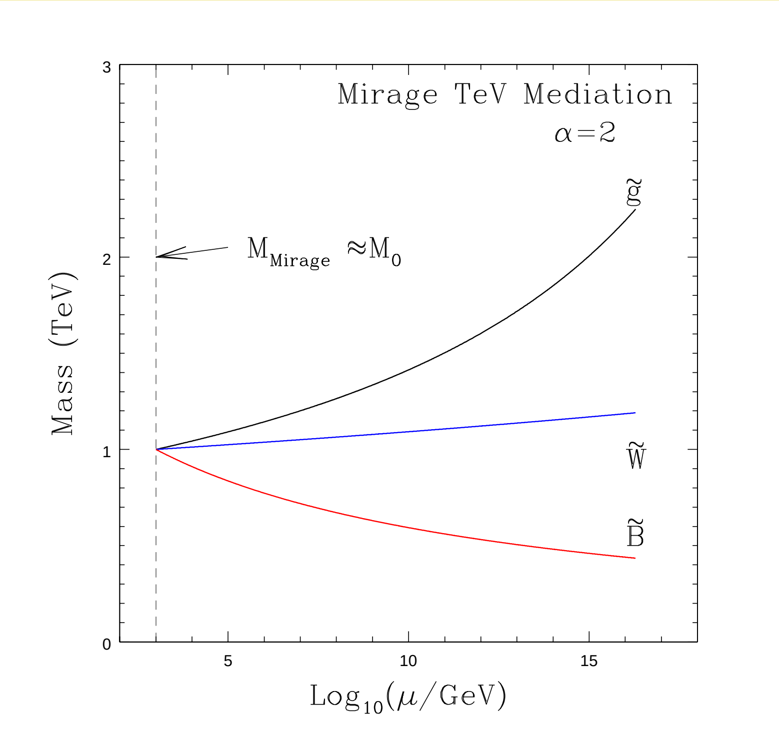


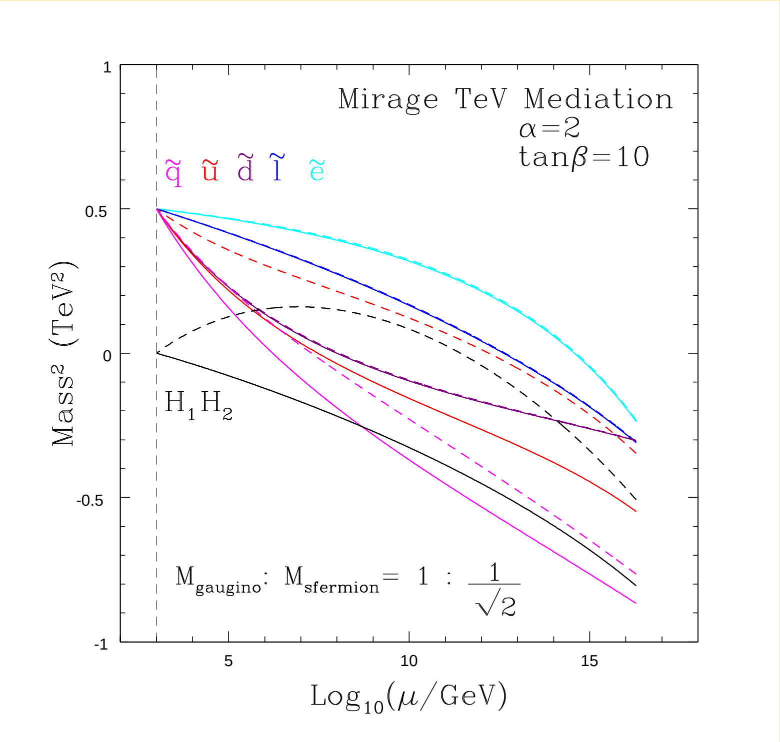


Anomaly mediation effectively shifts the messenger scale.
(mirage messenger scale : $M_{\rm Mirage}$) K. Choi, K-S. Jeong, K.O. (2005)

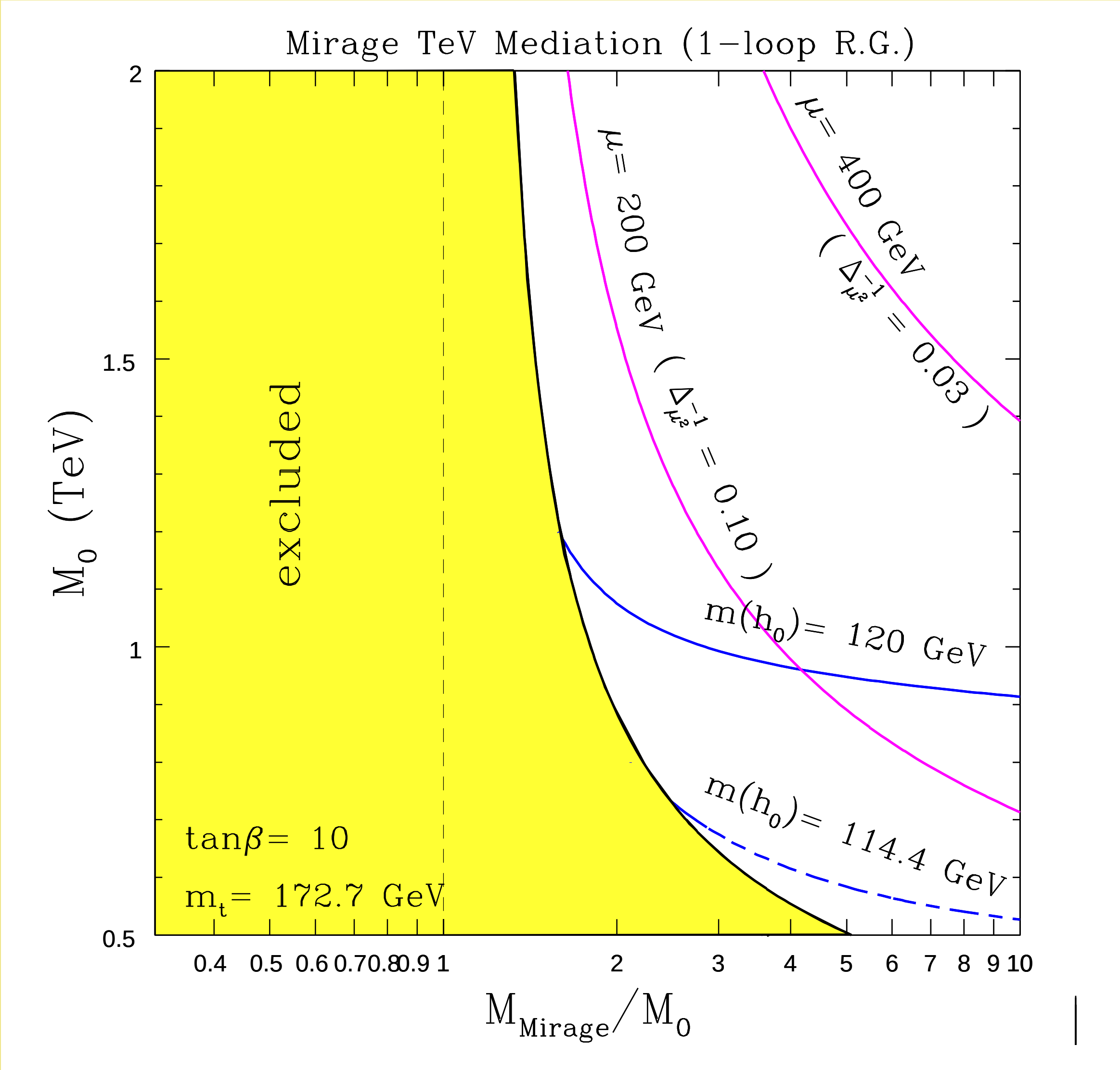
V. Solving SUSY Fine-tuning by Mirage TeV Hierarchy

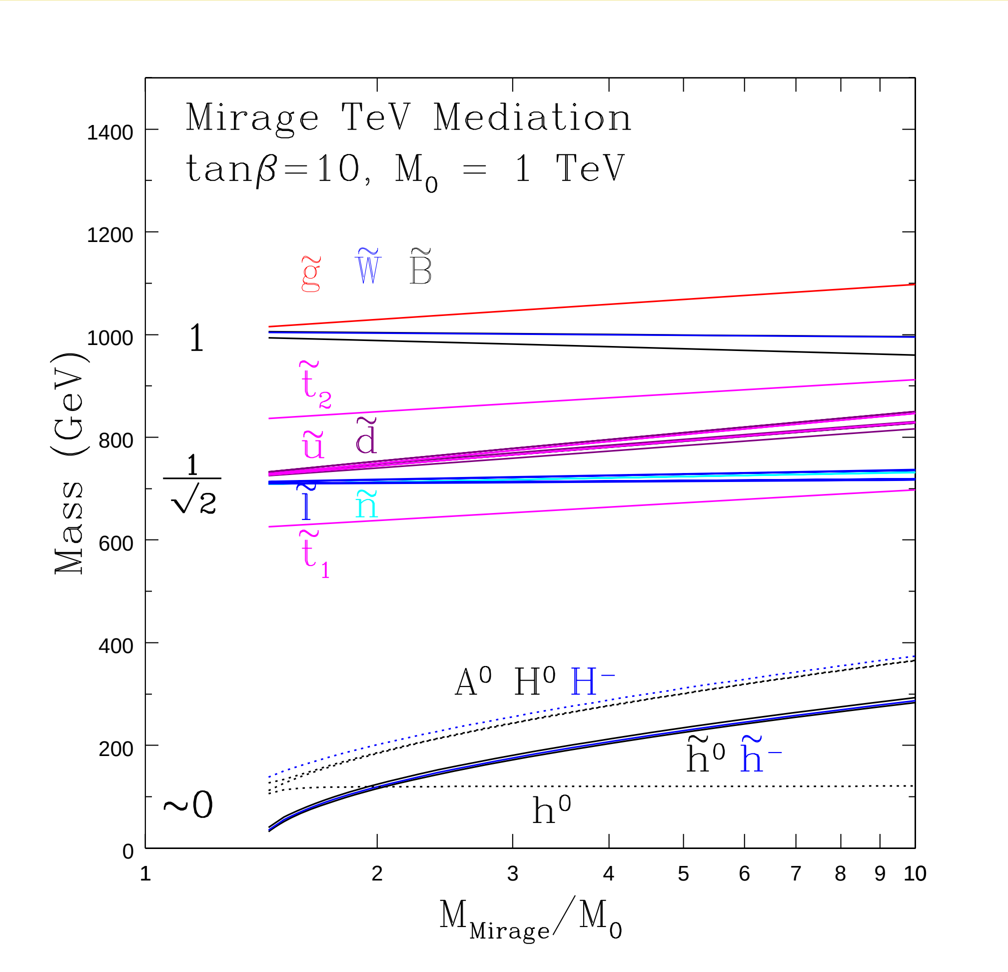
If we have uplifting of $n_T = 1$, $M_{\rm Mirage} \approx M_0$ (Mirage TeV Mediation)





We can realize the little hierarchy by setting $m_{H_1,H_2} = 0$ at $\approx M_0$.


Mirage TeV Mediation (1−loop R.G.)
2
1.5
1
0.5
M0 (TeV)
0.4 0.5 0.6 0.7 0.8 0.9 1 2 3 4 5 6 7 8 9 10
MMirage/M0
excluded
μ= 200 GeV ($\Delta^{-1}_{\mu^2}$ = 0.10)
μ= 400 GeV ($\Delta^{-1}_{\mu^2}$ = 0.03)
m(h0)= 120 GeV
m(h0)= 114.4 GeV
tanβ= 10
mt= 172.7 GeV


Mirage TeV Mediation
tanβ=10, M0 = 1 TeV
Mass (GeV)
1400
1200
1000
800
600
400
200
0
1
1/√2
~0
g̃ W̃ B̃
t̃2
ũ d̃
l̃ ñ
t̃1
A0 H0 H−
h̃0 h̃−
h0
1 2 3 4 5 6 7 8 9 10
MMirage/M0

VI. Conclusion

- Raising lower bound for m_{h^0} favors heavy $\tilde{t}$ and m_{H_2} in general which leads to fine-tuning in the electroweak symmetry breaking of the MSSM.

- We proposed a new scenario where the little hierarchy between Higgs and SUSY particles is realized by mirage messenger scale in mixed modulus-anomaly mediation without any modification of the MSSM.

- Tuning parameter $\Delta_{\mu^2}^{-1}$ can be naturally above 10% and m_{h^0} easily exceeds 120 GeV.

- The scenario favors light SUSY particles $\lesssim 1$ TeV and predics distinctive relation among the gaugino and sfermion masses.

- Heavy Higgs bosons and higgsinos are predicted around 100 $\sim$ 200 GeV and LSP is pure higgsino.