Deflected Mirage Mediation

A Framework for Generalized SUSY Breaking

Based on PRL101:101803(2008) (arXiv:0804.0592),
JHEP 0808:102(2008) (arXiv:0806.2330)

in collaboration with L.Everett, P.Ouyang and K. Zurek

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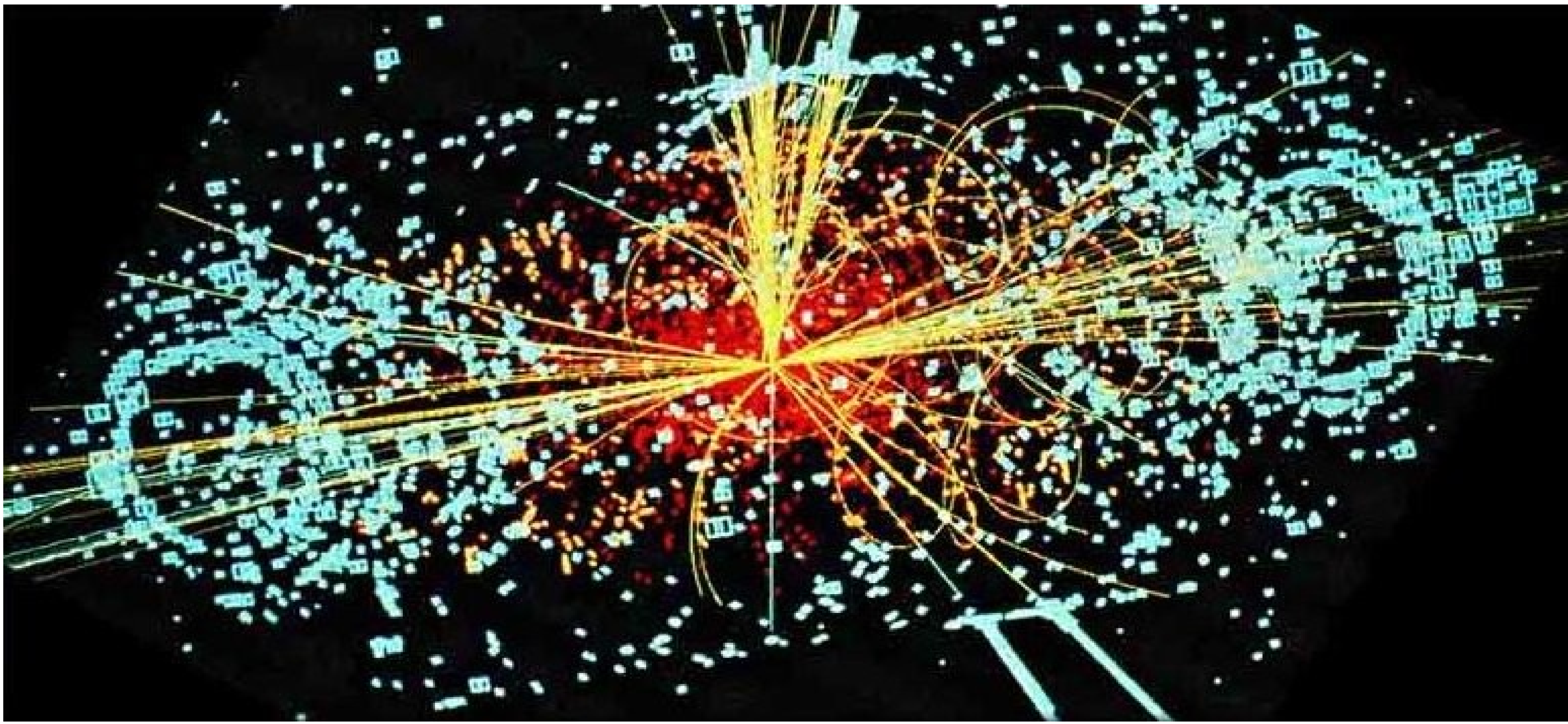
UC Davis, Oct 27, 2008

Outline

- Introduction
- Moduli stabilization and Mixed mediation
- Soft terms in Deflected Mirage Mediation
- Superparticle spectrum and phenomenology
- Conclusion

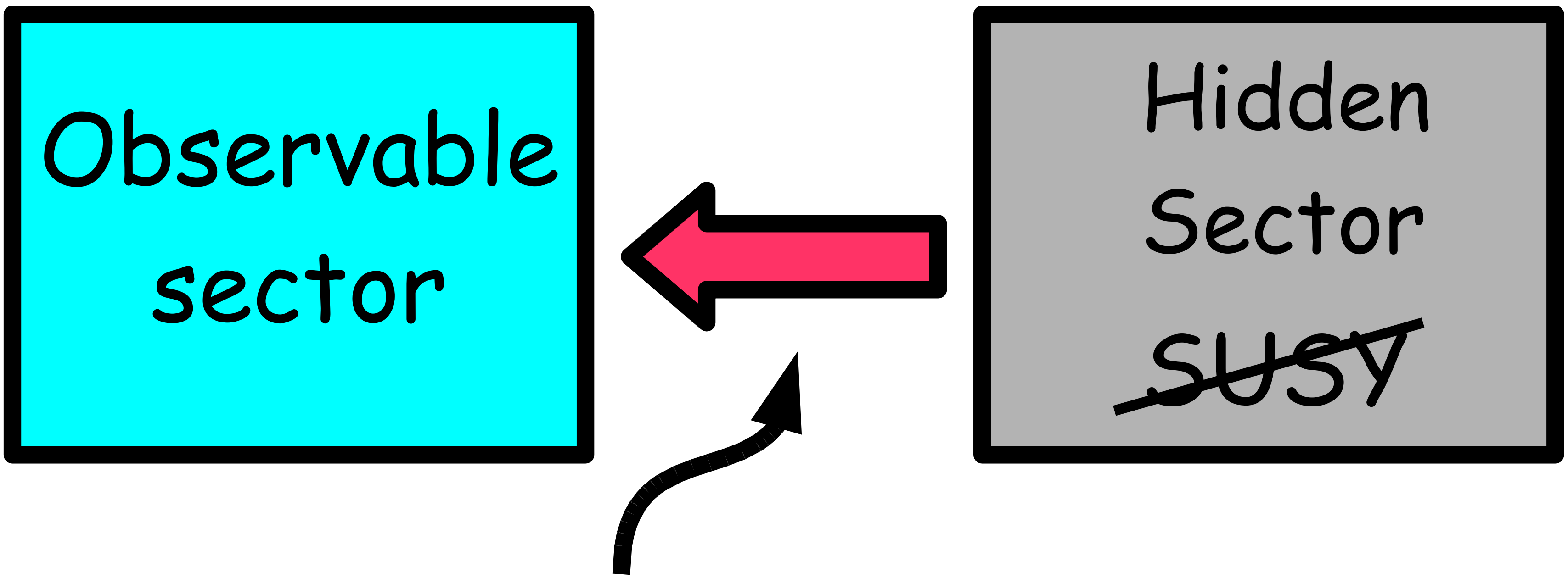
Introduction

At LHC, first collision will be within a year finally!



We may discover SUSY particles and measure their masses.

Paradigm of SUSY

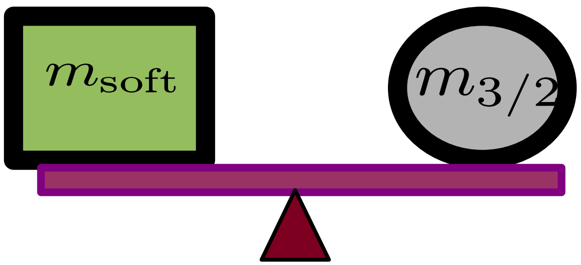


Messengers of ~~SUSY~~ may have information on high-scale dynamics.

Different mediation mechanisms lead to different soft mass pattern:

Gravity Mediation

$$m_{\rm soft} \approx m_{3/2} \approx \frac{F}{M_P}$$

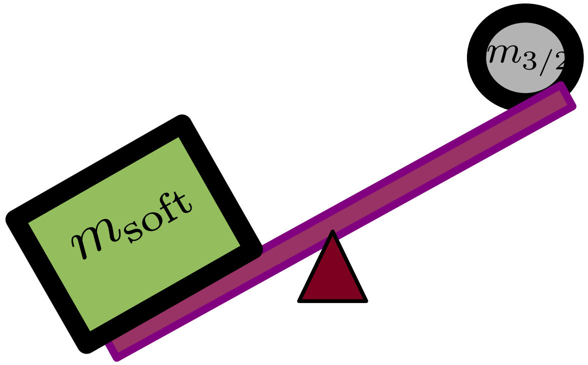


Tree level

Gauge Mediation

$$m_{\rm soft} \approx \frac{g^2}{16\pi^2}\frac{F}{M_{\rm mess}}$$

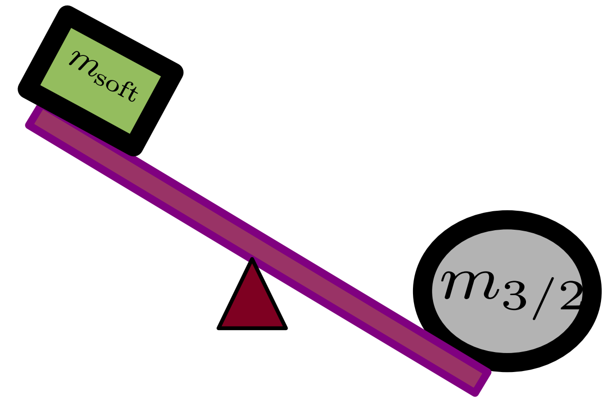
$$\gg m_{3/2} \approx \frac{F}{M_P}$$



One loop level

Anomaly Mediation

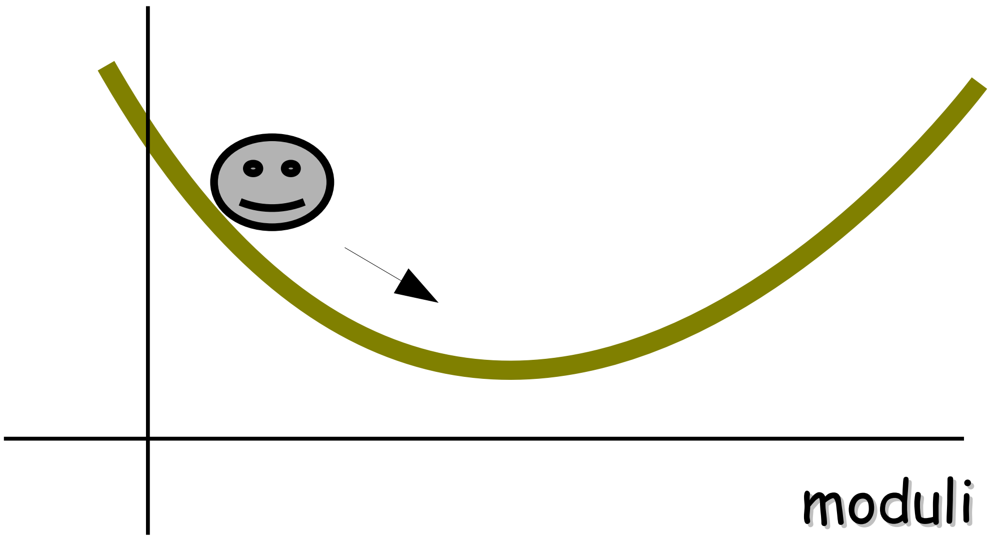
$$m_{\rm soft} \approx \frac{g^2}{16\pi^2} m_{3/2}$$

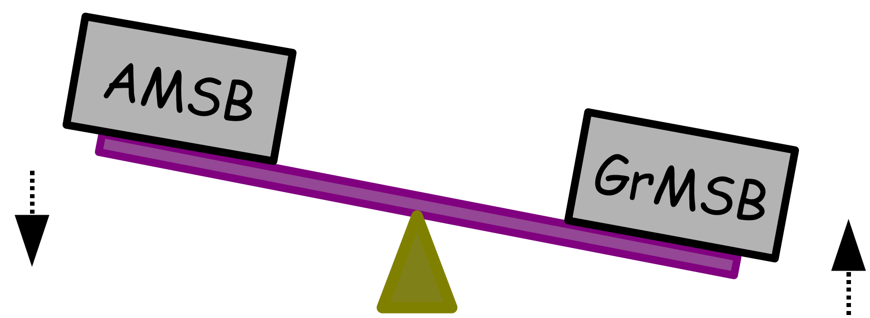


One loop level

Take recent lesson from top-down approach !

Different kinds of ~~SUSY~~ can be comparable with each other when considering stabilization of moduli in hidden sector !



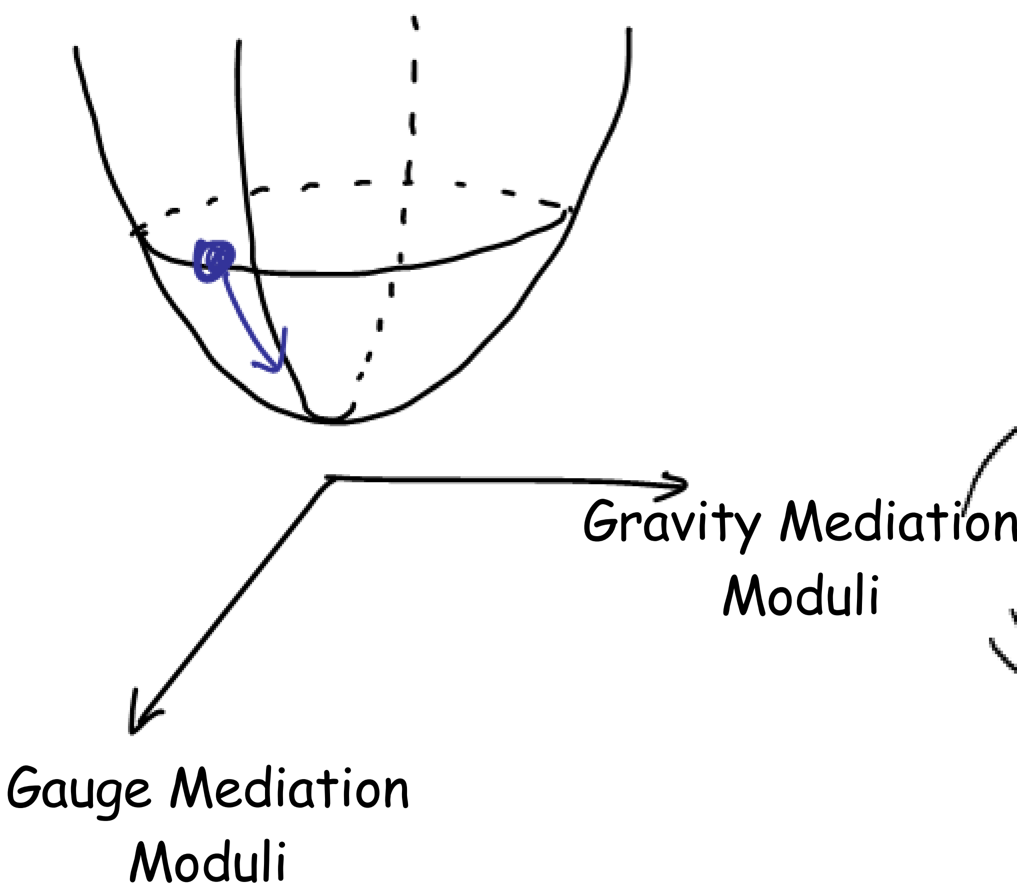


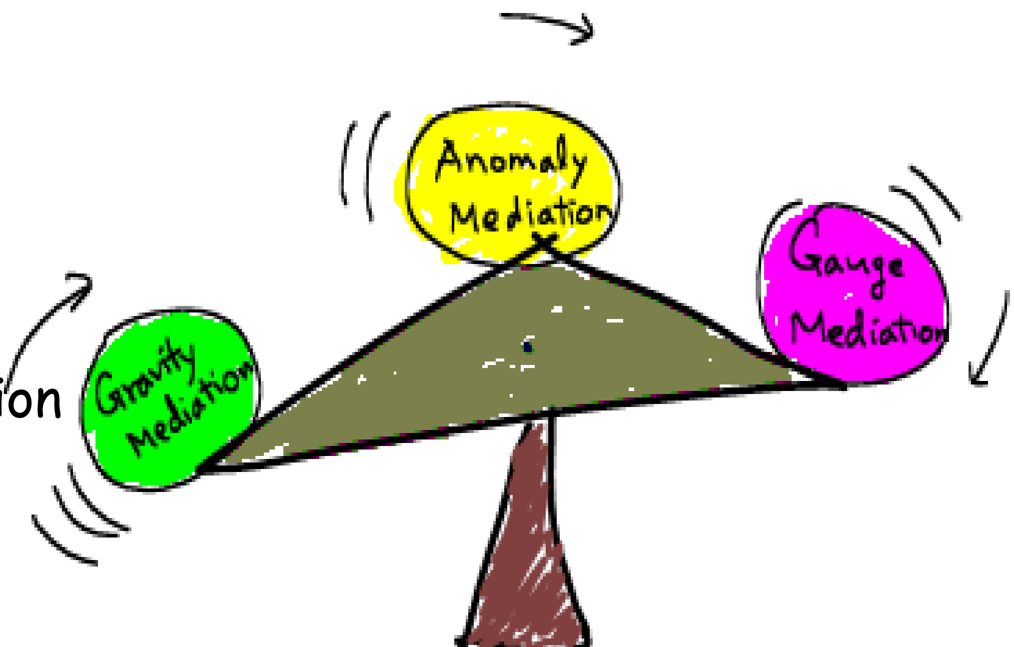
Mixed Modulus-Anomaly Mediation
(Mirage Mediation)

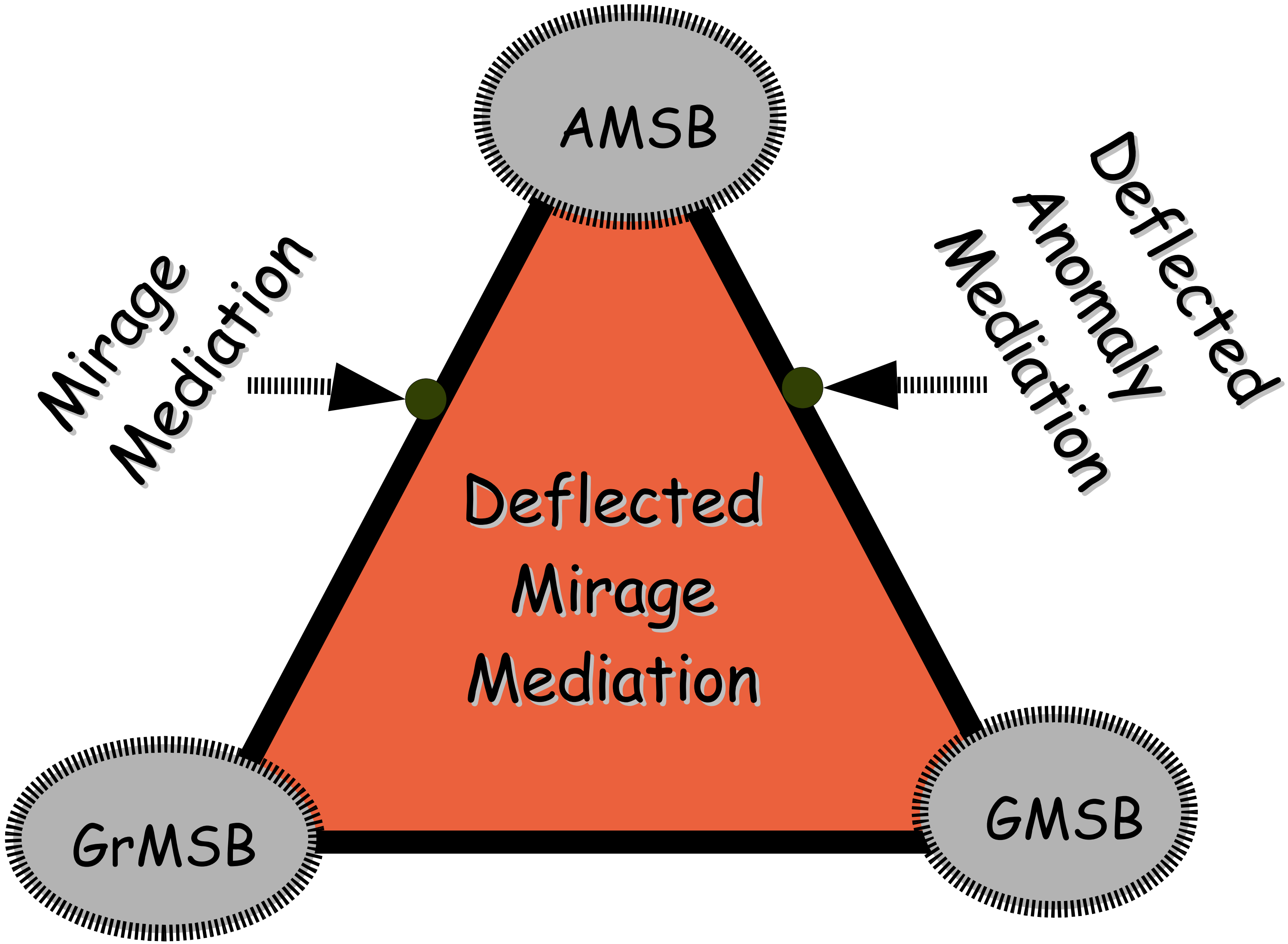
Consider stabilization of gauge mediation moduli X:

⇨ Comparable Anomaly/Gauge/Gravity Mediation

Deflected Mirage Mediation





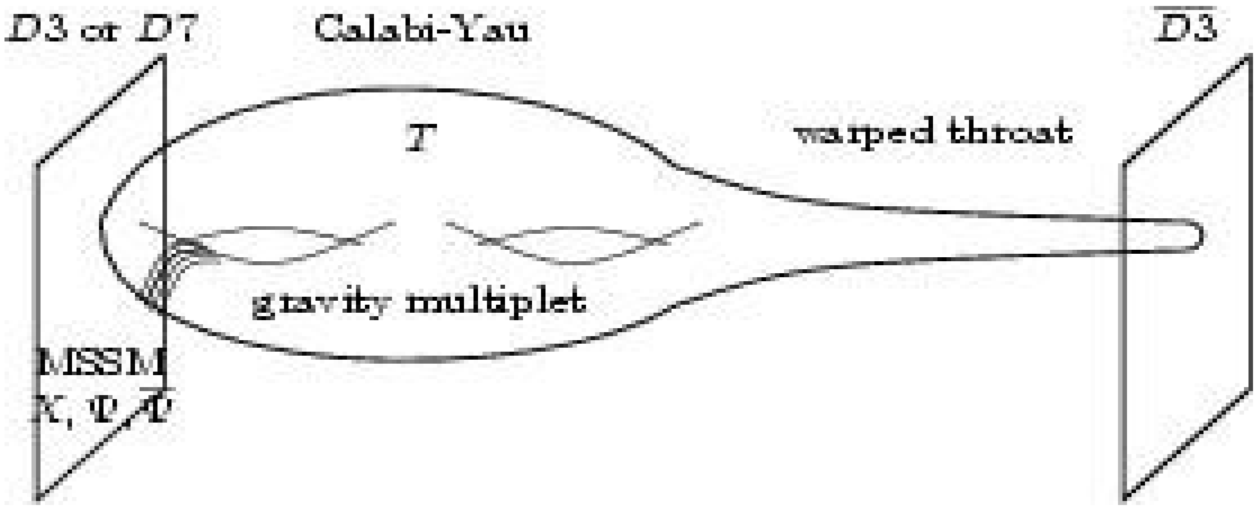


Relative ratios of each contribution in soft masses shows the information of stabilization.

Moduli stabilization and Mixed mediation

KKLT Setup :

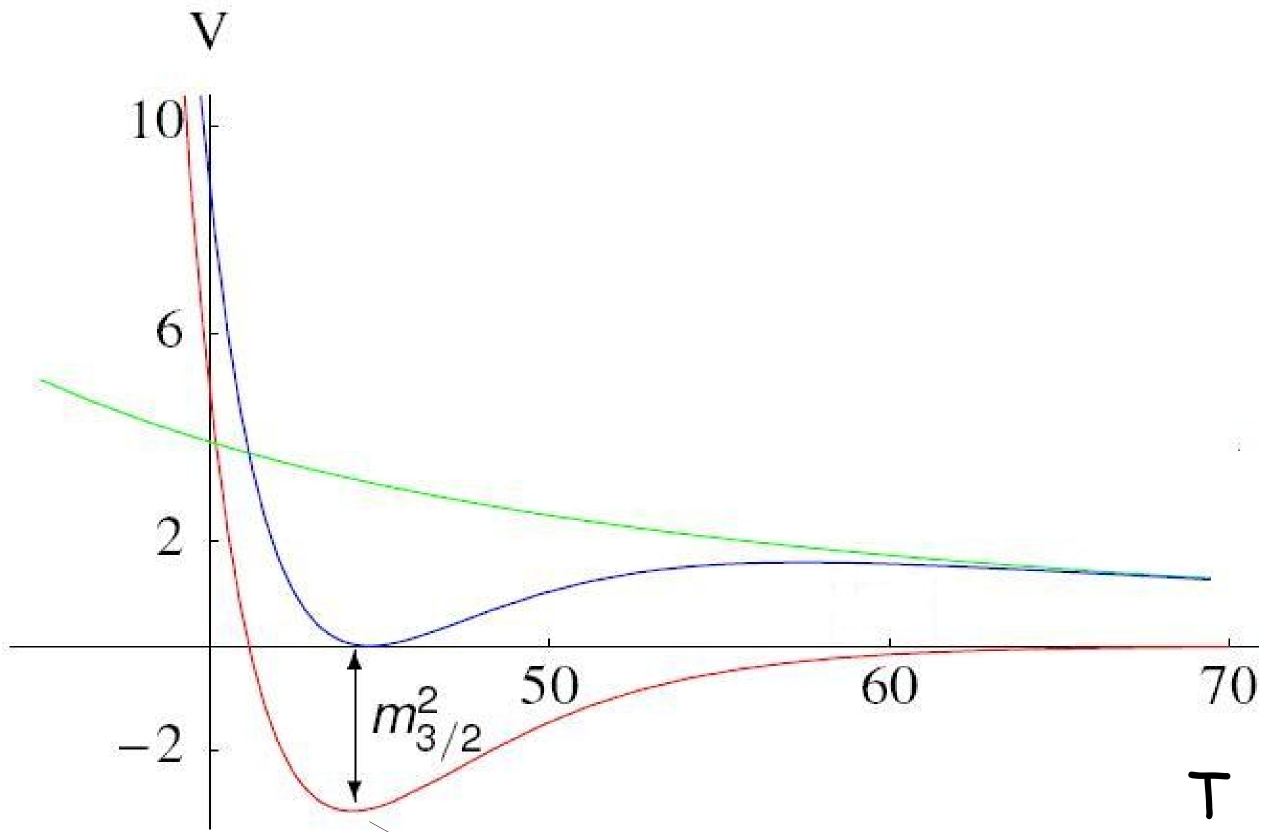
Kachru, Kallosh, Linde, Trivedi (2003)



Superpotential : Flux + Nonperturbative

$$W = w_0 - Ae^{-aT}$$

➡ Stabilize moduli T to SUSY AdS vacuum



SUSY AdS vacuum

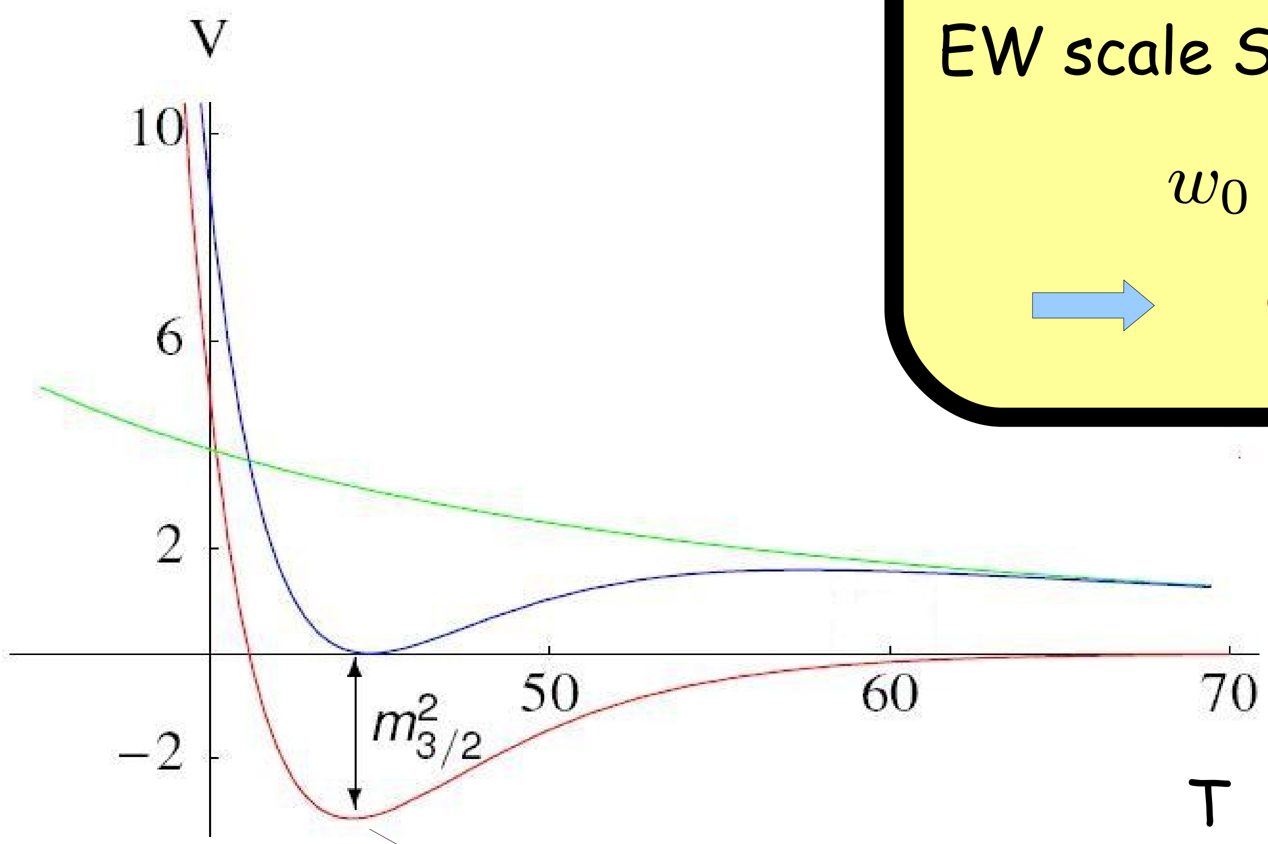
$$m_{3/2} = \frac{w_0}{(2T)^{3/2}}$$

$$W = w_0 - Ae^{-aT}$$

EW scale SUSY requires

$$w_0 \sim 10^{-15}$$

$$\Rightarrow \quad aT \sim \log(M_P/m_{3/2})$$



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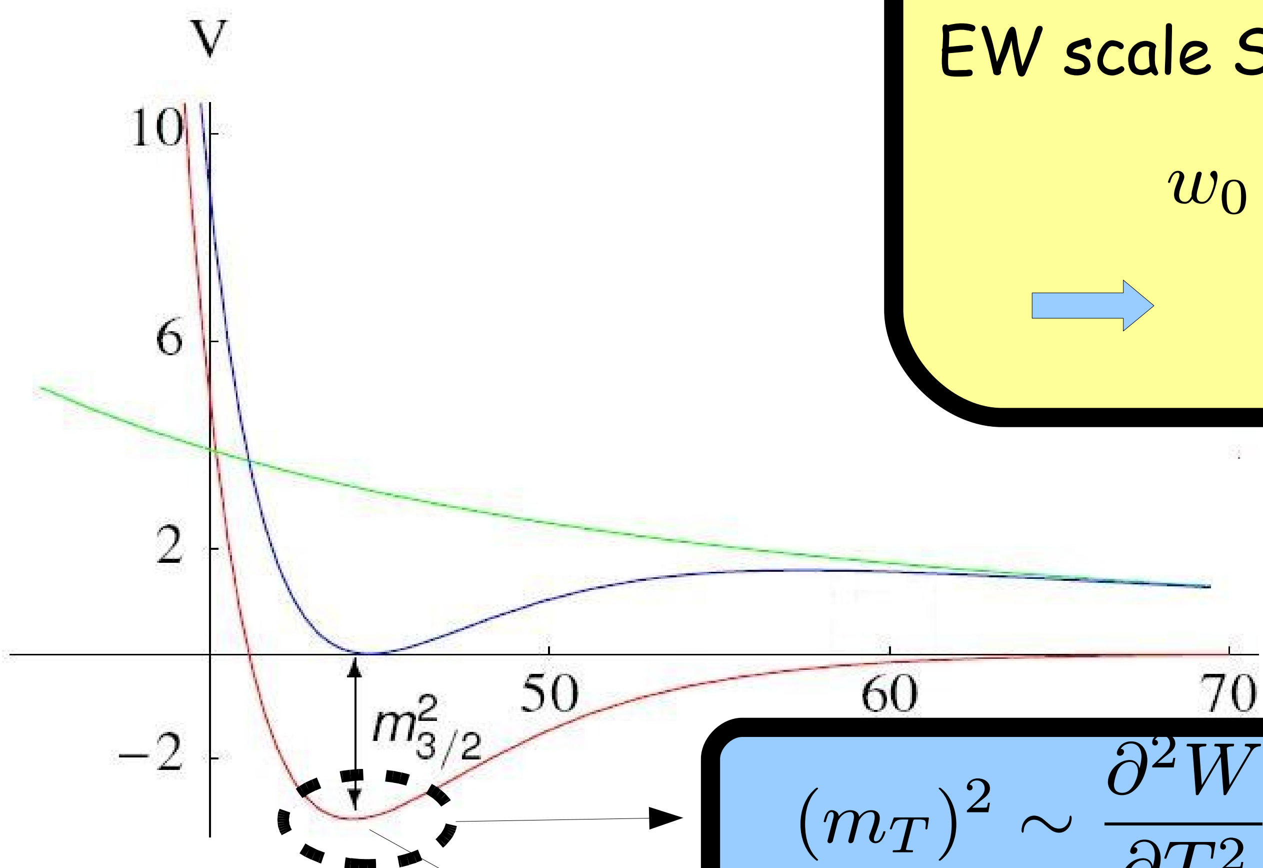
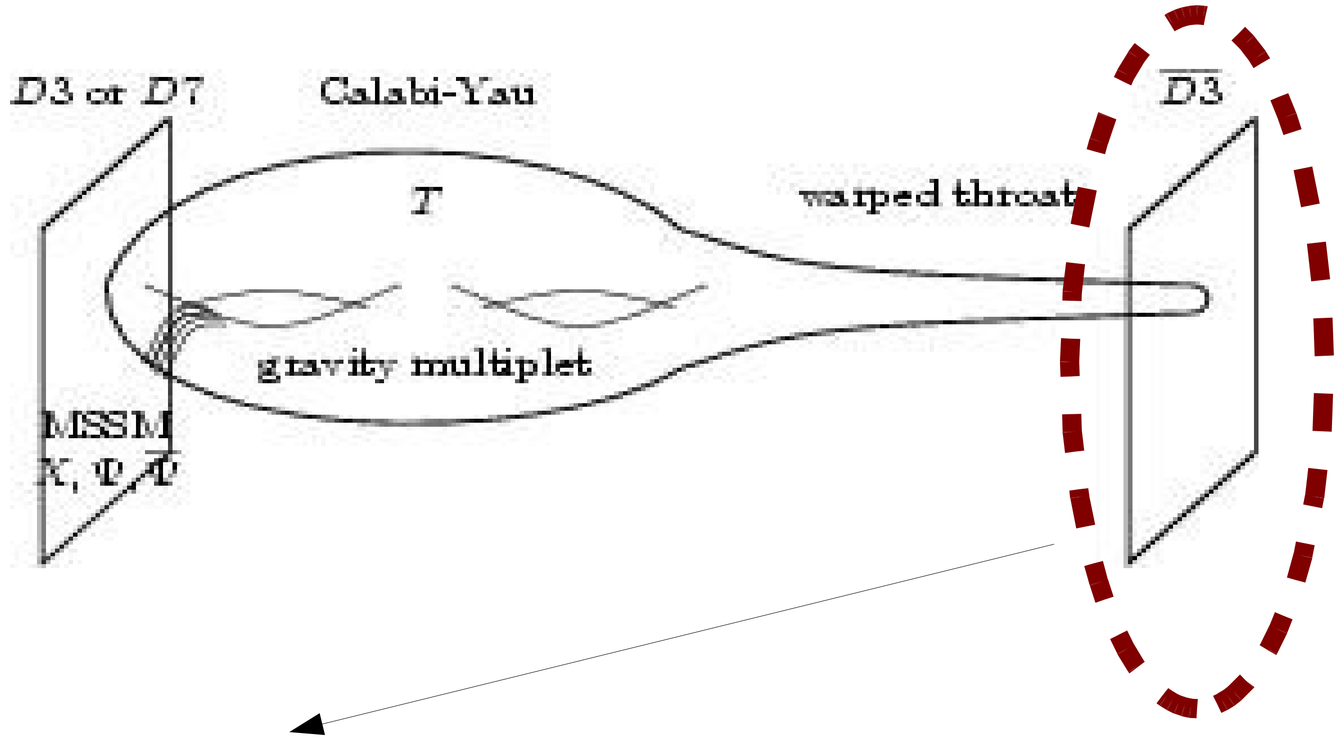


$$(m_T)^2 \sim \frac{\partial^2 W}{\partial T^2} \sim (aT)^2 m_{3/2}^2$$

SUSY AdS vacuum

$$m_{3/2} = \frac{w_0}{(2T)^{3/2}}$$



Anti-D brane : source for ~~SUSY~~

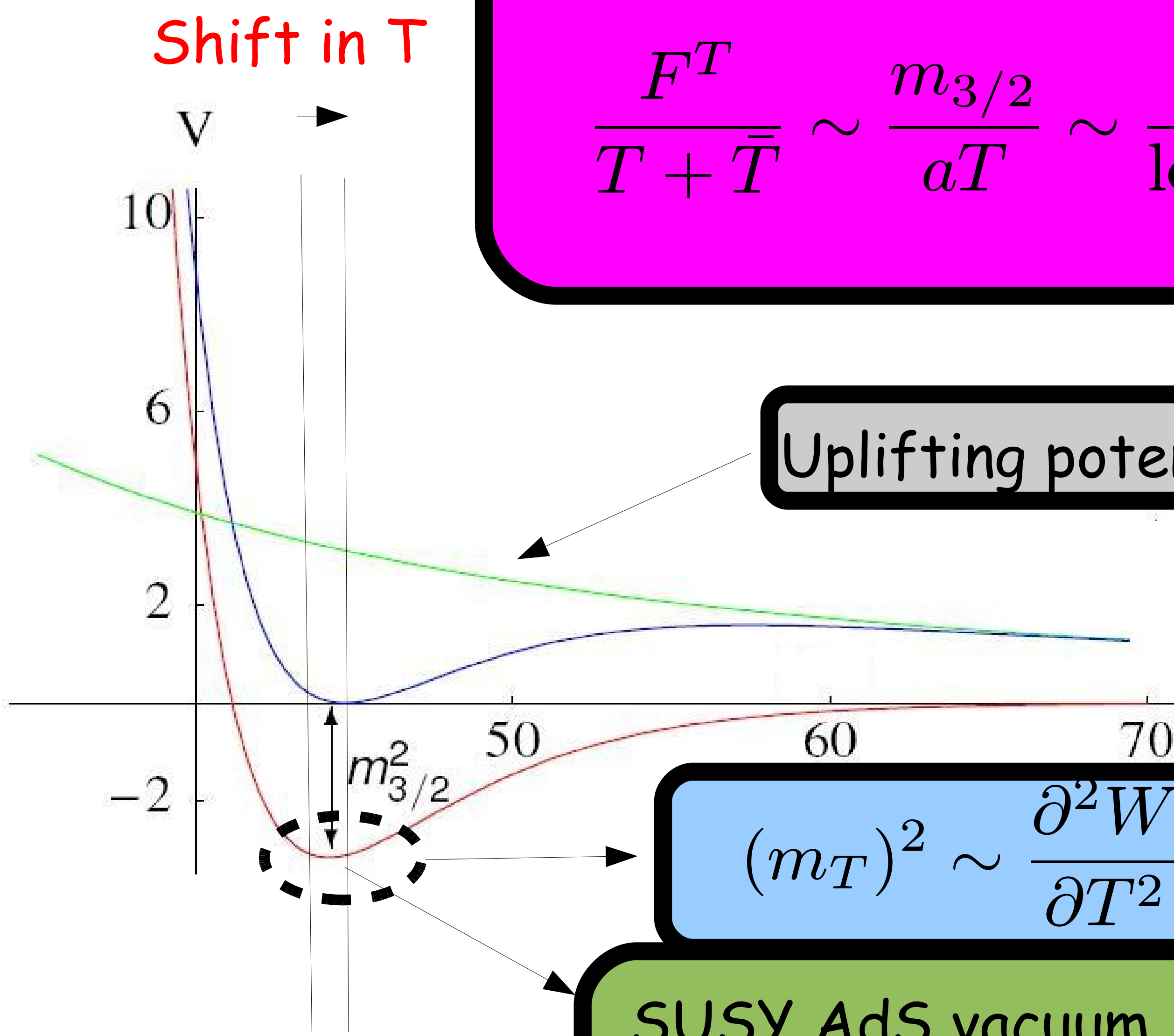
Uplifting scalar potential

$$V \sim \frac{D}{(T+\bar{T})^{2+n}}$$

→ Cancel cosmological constant

ΔT inversely proportional to m_T

$$\frac{F^T}{T+\bar{T}} \sim \frac{m_{3/2}}{aT} \sim \frac{1}{\log(M_P/m_{3/2})}\frac{F^C}{C}$$



Uplifting potential

$$(m_T)^2 \sim \frac{\partial^2 W}{\partial T^2} \sim (aT)^2 m_{3/2}^2$$

SUSY AdS vacuum

$$m_{3/2} = \frac{w_0}{(2T)^{3/2}}$$

Anomaly mediation and moduli mediation are comparable.

$$\frac{F^T}{T+\bar{T}} \sim \frac{m_{3/2}}{aT} \sim \frac{1}{\log(M_P/m_{3/2})}\frac{F^C}{C}$$

⇒ **Mirage Mediation**

K.Choi, Nilles, Olechowski, Porkorski (2004,2005)
K.Choi, K.S.Jeong, Okumura (2005)
Endo, Yamaguchi, Yoshioka (2005)

Matter Moduli Stabilization and Gauge Mediation

L.Everett, IWK, P. Ouyang and K. Zurek (2008)

In most of string compactification,

1. Vector-like pairs $(\Psi, \overline{\Psi})$ charged under SM gauge symmetry.
2. mass for such vector-like pairs obtained by matter moduli X.

$$W = X\Psi\overline{\Psi}$$

3. X is stabilized due to ~~SUSY~~.

⇒ Anomaly Mediation distributes ~~SUSY~~ to Gauge Mediation.

What happens if condition 3 is not satisfied?

X is stabilized by supersymmetric mechanism at high scale.

F-term stabilization :

$$W = \frac{1}{2} m_X (X - X_0)^2$$

B-term like soft term due to Anomaly Mediation

$$\Delta V \sim m_{3/2} m_X (X - X_0)^2$$

If $m_X \gg m_{3/2}$, no additional ~~SUSY~~

D-term stabilization:

Fayet-Illiopoulos term (gauged U(1) R symmetry or anomalous U(1))

~~$U(1)_A$~~ scale: $\mathcal{O}\left(\frac{M_{\rm st}}{16\pi^2}\right) \gg m_{3/2}$ by Green-Schwarz mechanism

⇒ Moduli dependent FI term.
Shift in T induces ~~SUSY~~ to F^X
However,

$$\frac{F^X}{X} = \mathcal{O}\left(\frac{F^T}{T+\bar{T}}\right)$$

⇒ No dominant ~~SUSY~~ contribution.

K.Choi, K.S.Jeong (2006)

X stabilization by SUSY breaking

F^X is given (roughly) by

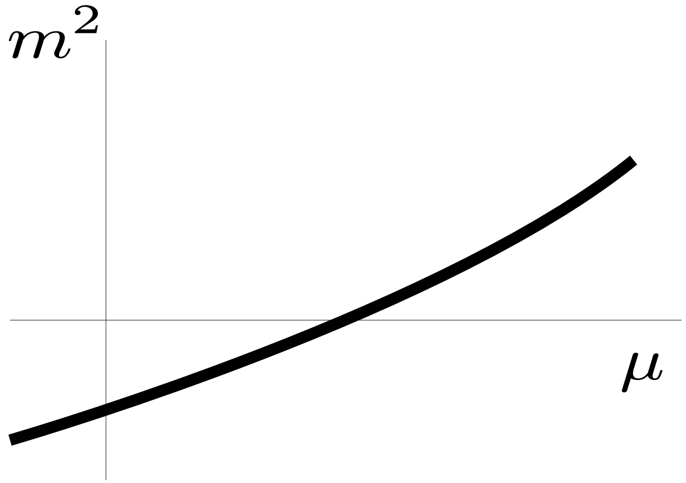
$$F^X = -e^{K/2} K^{X\bar{X}} D_{\bar{X}} \bar{W}$$
$$= \underbrace{-e^{K/2} K^{X\bar{X}} \partial_{\bar{X}} \bar{W}}_{(A)} \underbrace{-e^{K/2} K^{X\bar{X}} K_{\bar{X}} \bar{W}}_{(B)}$$

(A) is from global SUSY. (B) is SUGRA correction.

Because anomaly mediation dominates, (B) becomes important.

Radiative Stabilization

X is stabilized purely by ~~SUSY~~ terms.



Coleman-Weinberg mechanism

$$\partial_X W \ll K_{\bar{X}} W$$

Since $(B) = -e^{K/2} K^{X\bar{X}} K_{\bar{X}} \bar{W} \approx -m_{3/2} X$

$$\frac{F^X}{X} = -m_{3/2} + \mathcal{O}\left(\frac{m_{3/2}}{8\pi^2}, \frac{F^T}{T+\bar{T}}\right)$$

Higher-order stabilization

X is stabilized due to superpotential term

$$W = \frac{X^n}{\Lambda^{n-3}}$$

and ~~SUSY~~ masses, then, $\partial_X W \sim K_X W$ (A) ~ (B).

$$\frac{F^X}{X} \sim m_{3/2}$$

$$\Delta M_{1/2} \sim \frac{\alpha}{4\pi}\frac{F^X}{X}$$

$$\Delta m_0^2 \sim \left(\frac{\alpha}{4\pi}\frac{F^X}{X}\right)^2$$

More precisely, we need to consider the effect of modulus T.

$$\mathcal{L} = \int d^4\theta G + \int d^2\theta W + \mathrm{h.c.}$$

$$G = -3C\bar{C}e^{-K/3} = -pC\bar{C}(T+\bar{T}) + \frac{1}{(T+\bar{T})^{n_X-1}}C\bar{C}X\bar{X}$$

$$W = C^3 W_0(T) + C^3\frac{X^n}{\Lambda^{n-3}}$$

Consider mixing terms between C, T and X

$$F^X = -G^{X\bar{C}}\partial_{\bar{C}}W - G^{X\bar{T}}\partial_{\bar{T}}W - G^{X\bar{X}}\partial_{\bar{X}}W$$

Keeping only the leading order terms

$$V \sim \mathcal{O}(X^{2n-2}) + \mathcal{O}(m_{3/2}X^n) + \mathcal{O}(m_{3/2}^2X^2)$$

We obtain

$$\frac{F^X}{X} = -\frac{2}{n-1}\frac{F^C}{C}$$

independent of T!

$n \geq 3$ (higher order term) $n < 0$ (nonperturbative)

$$-m_{3/2} \leq \frac{F^X}{X} \leq 2m_{3/2}$$

Ratios among anomaly mediation, moduli mediation and gauge mediation contributions are determined by discrete parameters.

Soft terms in Deflected Mirage Mediation

L.Everett, IWK, P.Ouyang, K. Zurek (2008)

We parameterize ~~SUSY~~ by $(m_0, \alpha_m, \alpha_g)$

$$\frac{F^T}{T+\bar{T}} = m_0$$

$$\frac{F^C}{C} = m_{3/2} = \alpha_m \log(M_P/m_{3/2}) m_0$$

$$\frac{F^X}{X} = \alpha_g \frac{F^C}{C}$$

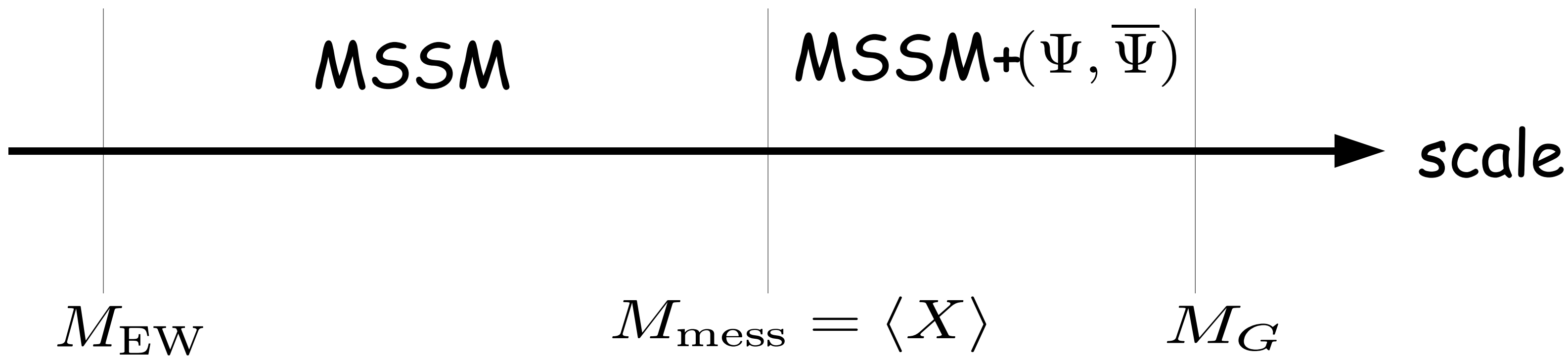
We also have $\tan\beta$ and $M_{\rm mess} \equiv \langle X \rangle$

Discrete parameters:

Modular weights of (Q,U,D,L,E,Hu,Hd)

Number of messenger pairs: N

This scenario has two threshold scales : $M_{\rm G}$ and $M_{\rm mess}$



Soft terms (detailed derivation in arXiv:0806.2330)

Gaugino mass:

$$M_a(M_G) = \frac{F^T}{T + \overline{T}} + \frac{\alpha_G}{4\pi} b'_a \frac{F^C}{C}$$

$$\Delta M_a(M_{\rm mess}) = -N \frac{\alpha_a(M_{\rm mess})}{4\pi} \left(\frac{F^C}{C} + \frac{F^X}{X} \right)$$

A term:

$$A_{ijk} = A_i + A_j + A_k$$

$$A_i(M_G) = (p - n_i)\frac{F^T}{T + \overline{T}} - \frac{\gamma_i}{16\pi^2}\frac{F^C}{C}$$

$$\Delta A_i(M_{\rm mess}) = 0$$

Soft scalar mass-squared:

$$m_i^2(M_G) = (p/3 - n_i)\left|\frac{F^T}{T + \bar{T}}\right|^2 - \frac{\theta_i'}{32\pi^2}\left(\frac{F^T}{T + \bar{T}}\frac{F^{\bar{C}}}{\bar{C}} + h.c.\right) - \frac{\dot{\gamma}_i'}{(16\pi^2)^2}\left|\frac{F^C}{C}\right|^2$$

$$\Delta m_i^2(M_{\rm mess}) = \sum_a 2c_a N\frac{\alpha_a^2(M_{\rm mess})}{16\pi^2}\left|\frac{F^X}{X} + \frac{F^C}{C}\right|^2$$

$$M_a(M_G) = m_0 \left[1 + \frac{g_0^2}{16\pi^2} b'_a \alpha_m \log \frac{M_P}{m_{3/2}}\right]$$

$$\Delta M_a = -m_0 N \frac{g_a^2(M_{\rm mess})}{16\pi^2} \alpha_m \left(1+\alpha_g\right) \log \frac{M_P}{m_{3/2}}$$

$$A_i(M_G) = m_0 \left[(1-n_i) - \frac{\gamma_i}{16\pi^2} \alpha_m \log \frac{M_P}{m_{3/2}}\right]$$

$$m_i^2(M_{\rm G}) = m_0^2 \left[(1-n_i) - \frac{\theta'_i}{16\pi^2} \alpha_m \log \frac{M_P}{m_{3/2}} - \frac{\dot{\gamma}'_i}{(16\pi^2)^2} \left(\alpha_m \log \frac{M_P}{m_{3/2}}\right)^2\right]$$

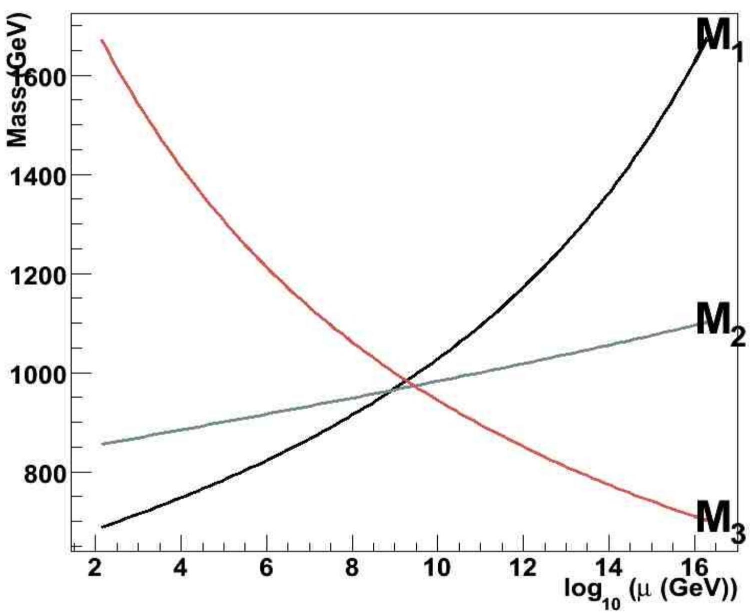
$$\Delta m_i^2 = m_0^2 \sum_a 2 c_a N \frac{g_a^4(M_{\rm mess})}{(16\pi^2)^2} \left[\alpha_m (1+\alpha_g) \log \frac{M_P}{m_{3/2}}\right]^2$$

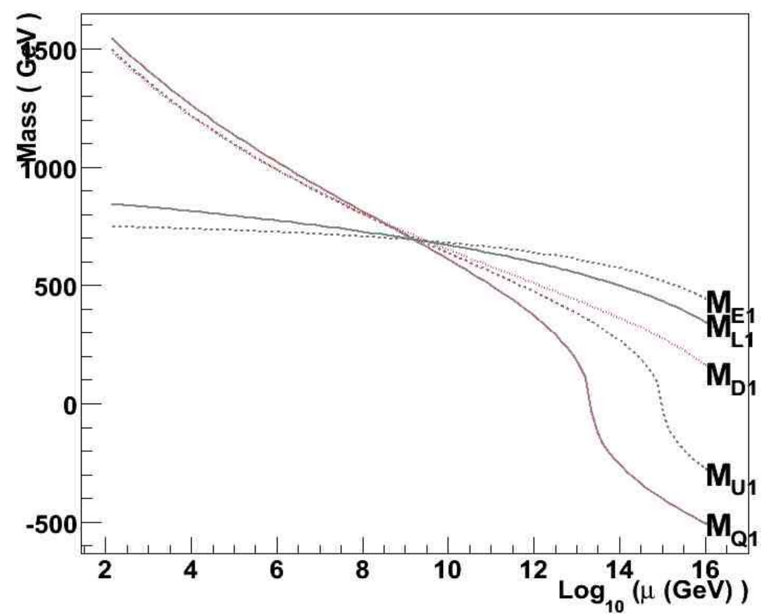
where $\theta_i = 4 \sum_a g_a^2 c_a(\Phi_i) - \sum_{lm} |y_{ilm}|^2 (p - n_i - n_l - n_m)$

Superparticle spectrum and phenomenology

Mirage Unification in Mirage Mediation

K.Choi, K.S.Jeong, Okumura (2005)



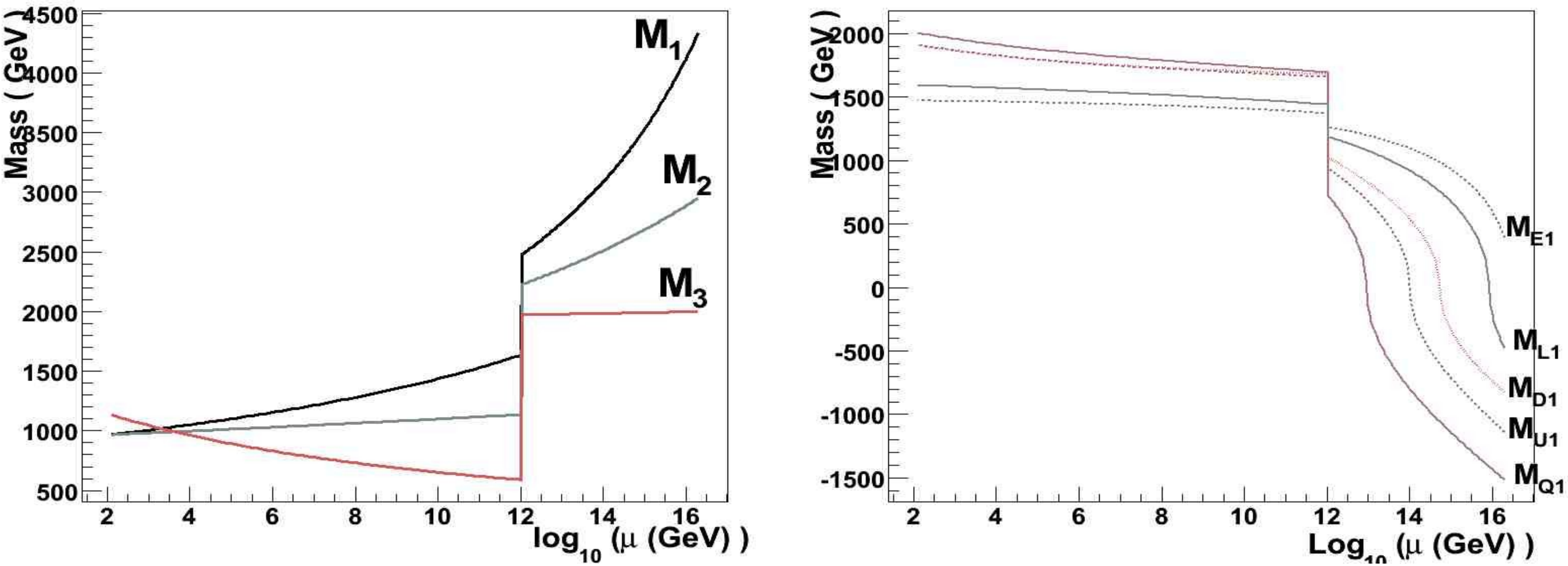


Mirage scale:

$$M_{\rm mirage} = M_G \left(\frac{m_{3/2}}{M_P} \right)^{\alpha_m/2}$$

Deflected Mirage Mediation changes the mirage pattern.

L.Everett, IWK, P.Ouyang, K. Zurek (2008)



$$M_{\rm mirage} = M_{\rm GUT}\left(\frac{m_{3/2}}{M_P}\right)^{\alpha_{\rm m}\rho/2}$$

$$\rho = \frac{1 + \frac{2Ng_0^2}{16\pi^2}\log\frac{M_{\rm GUT}}{M_{\rm mess}}}{1 - \frac{\alpha_{\rm m}\alpha_{\rm g}Ng_0^2}{16\pi^2}\log\frac{M_P}{m_{3/2}}}$$

Mirage unification of gaugino masses leads to

- Light gluino (can be even the lightest.)

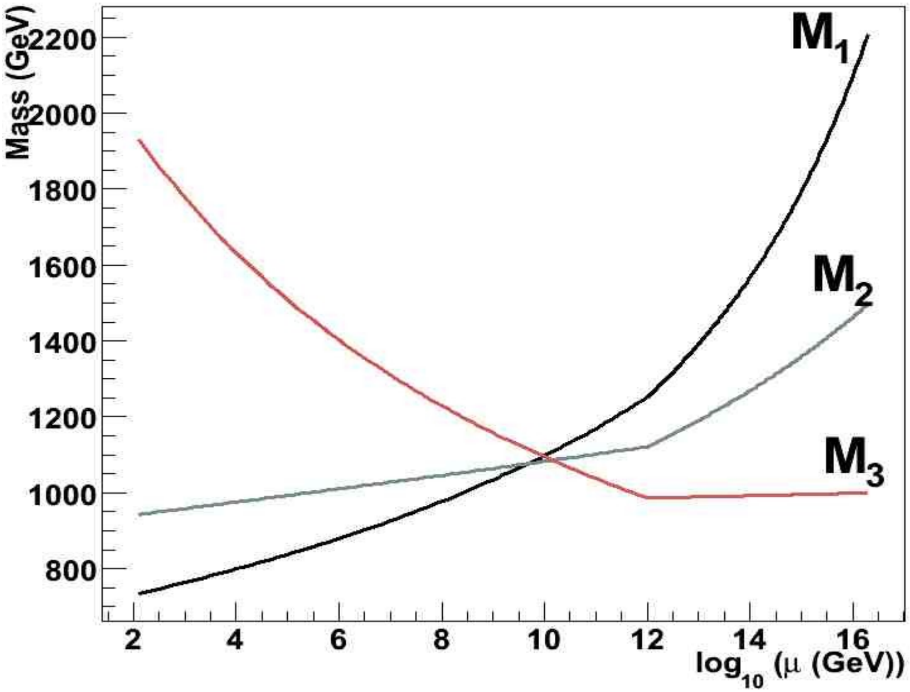
- Sizable mixing between bino and wino

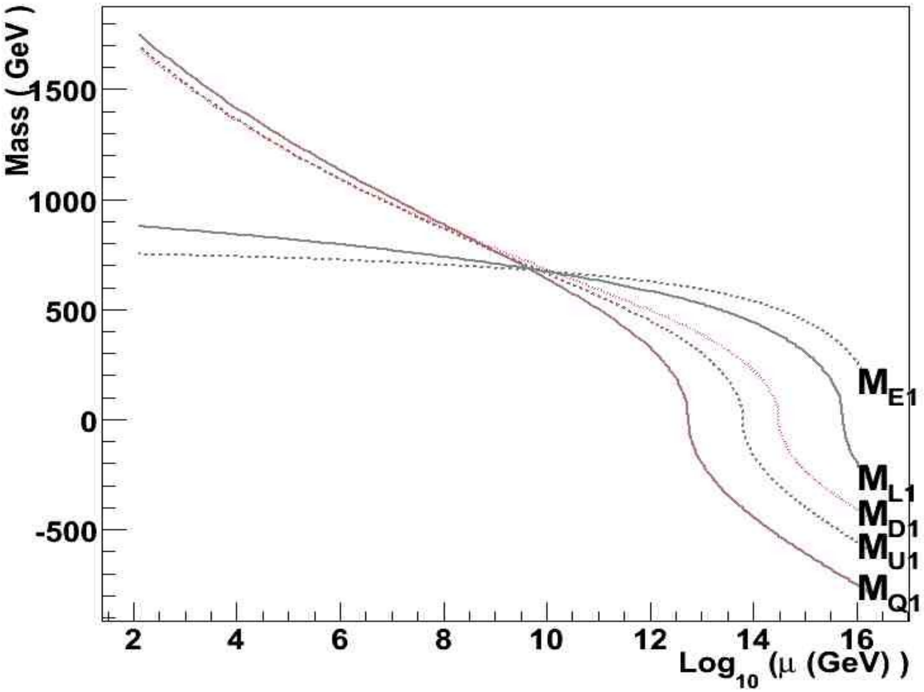
  → Well-tempered neutralino

- Relatively less severe fine-tuning due to light gluino, negative stop mass square and large A-term

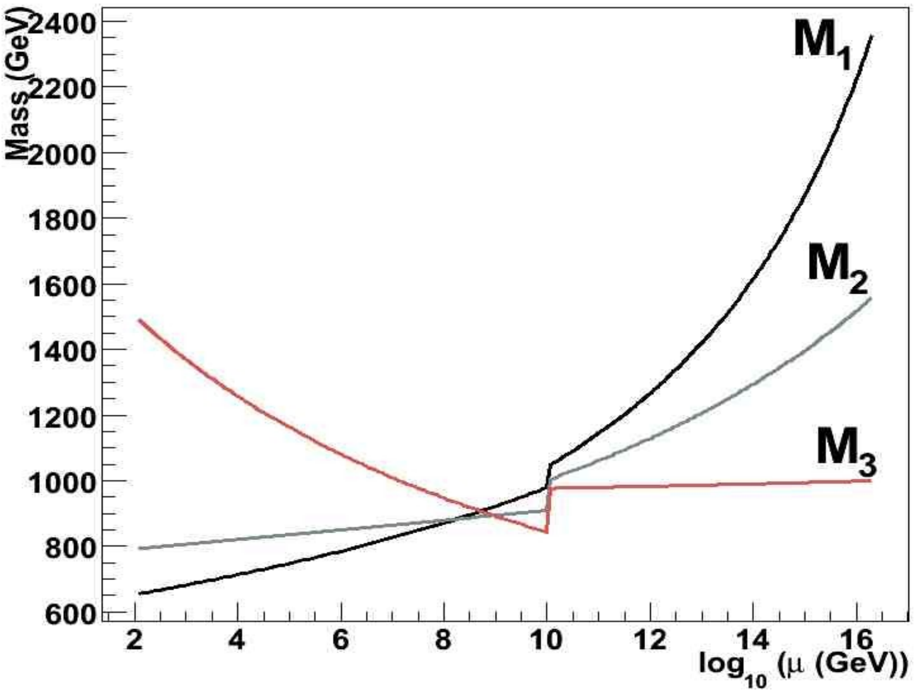
RG evolution pattern

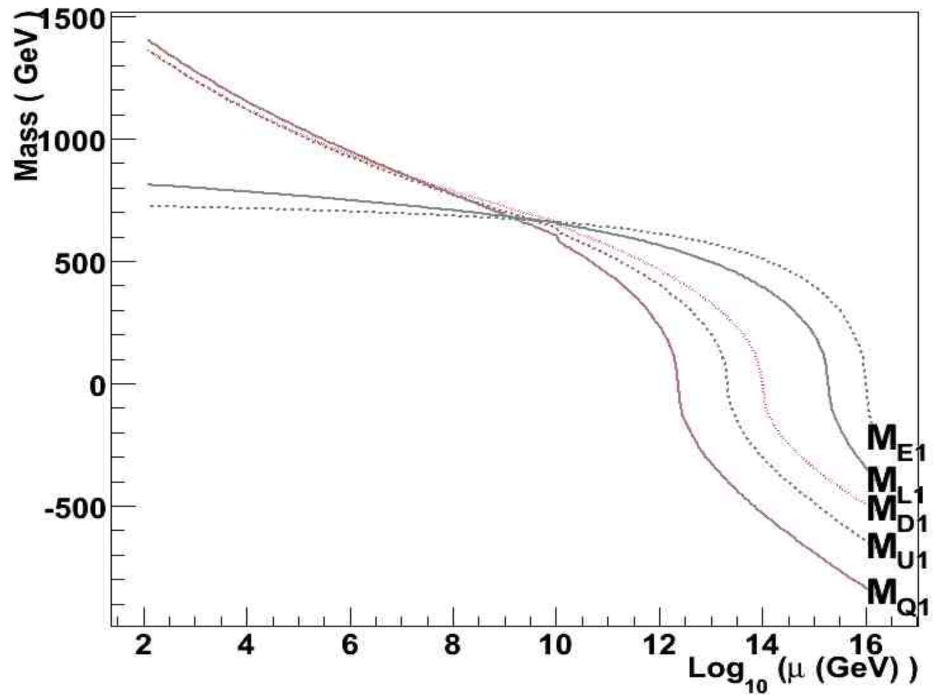
Coleman-Weinberg stabilization (W=0)





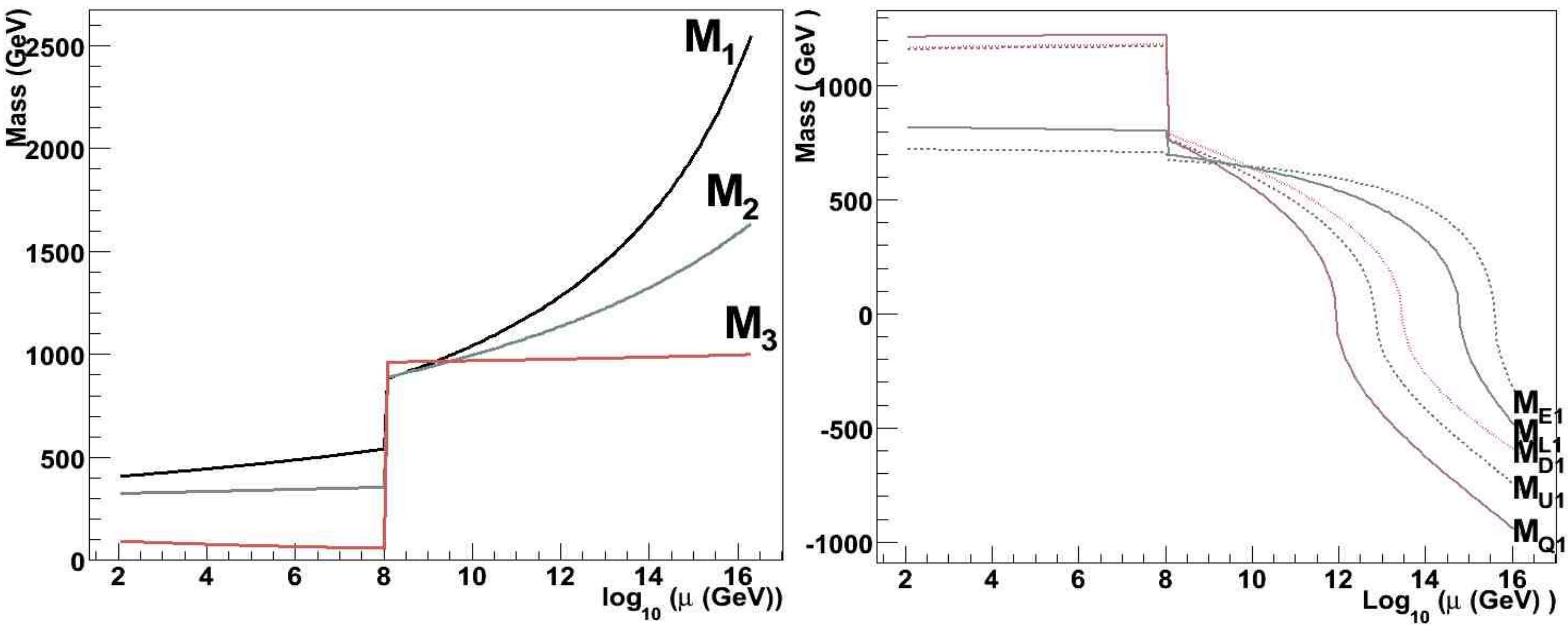
Stabilization by nonrenormalizable op. $$W(X) = \frac{X^4}{M_P}$$





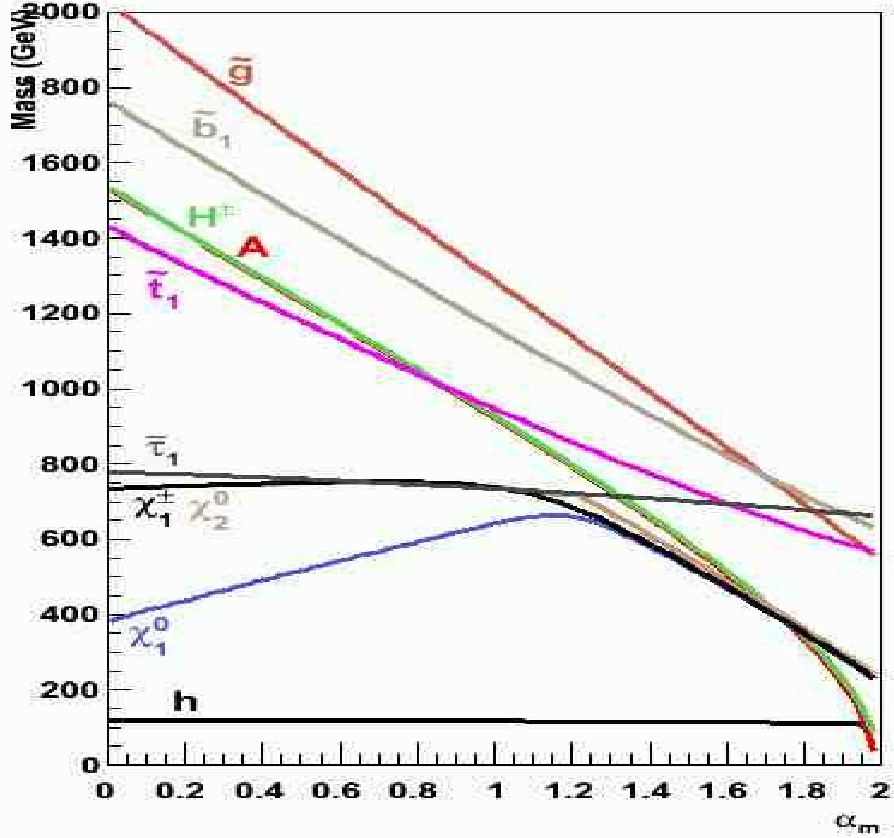
Stabilization by nonpertubative potential

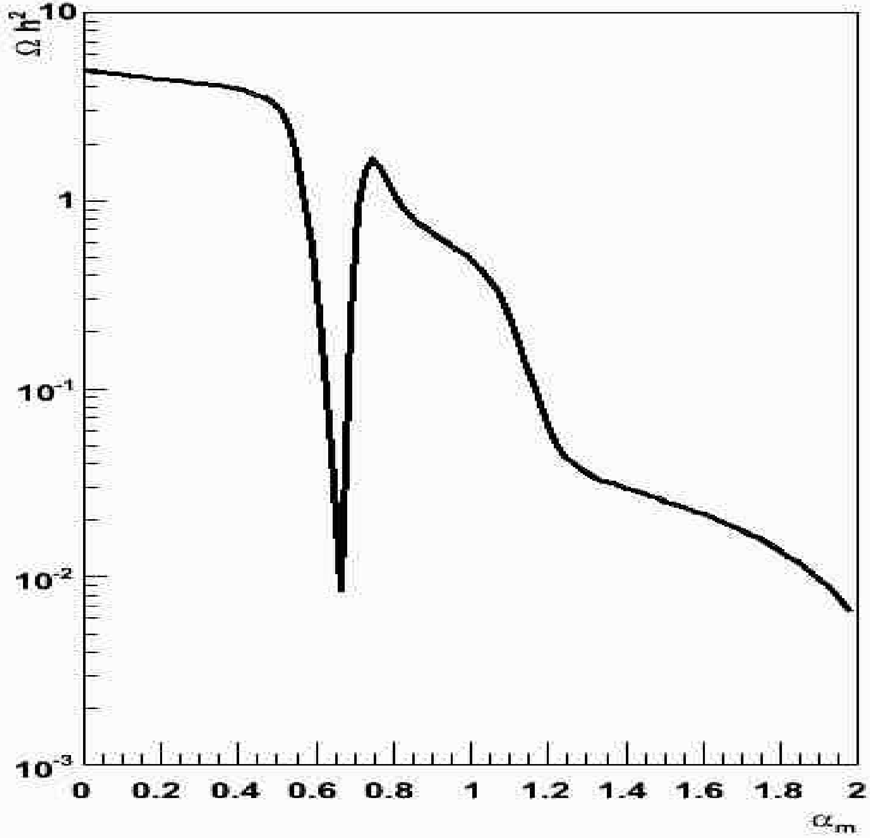
$$W(X) = \frac{\Lambda^4}{X} \qquad \Lambda \sim 10^7 \text{ GeV}$$



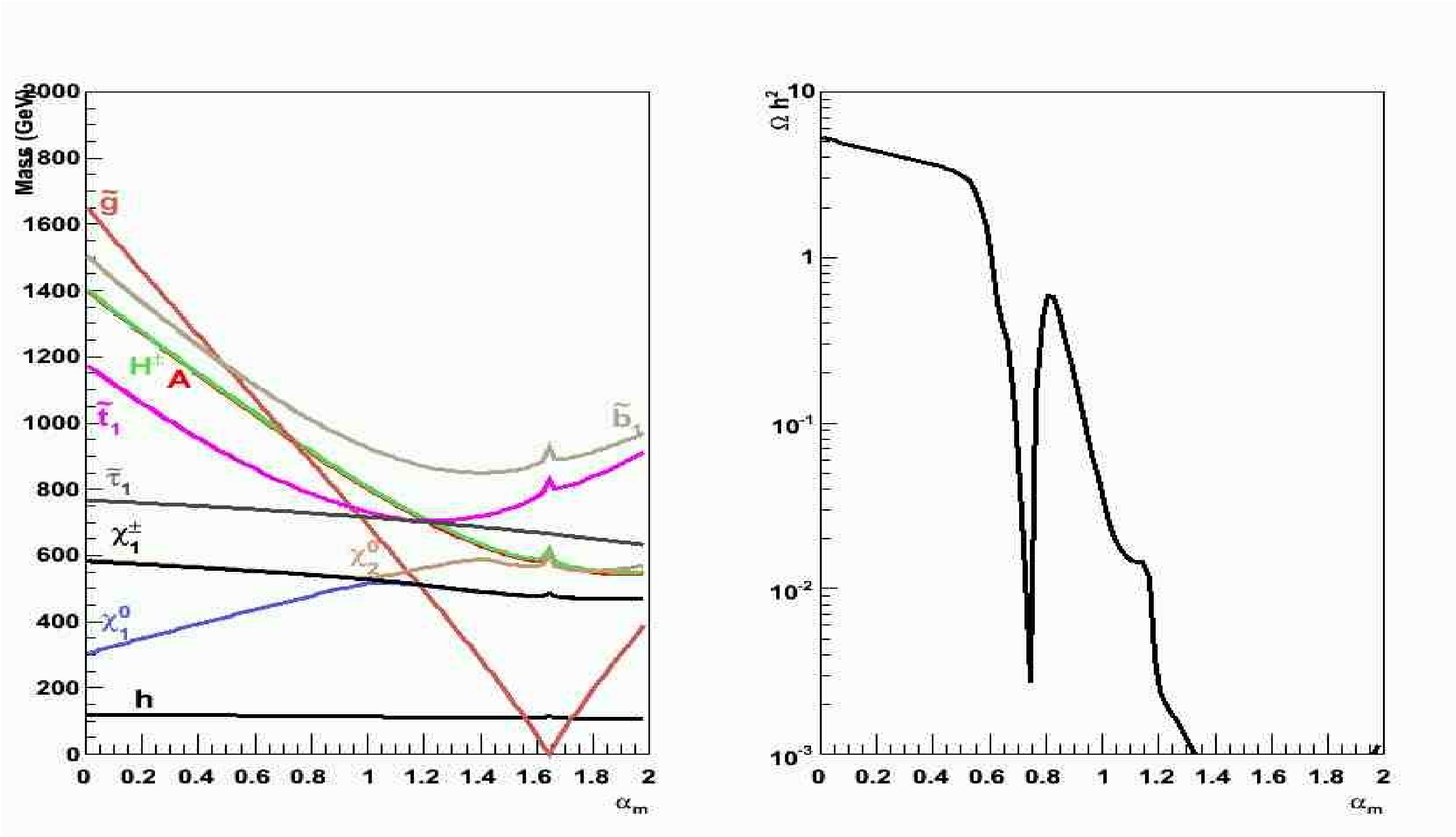
Sparticle Spectrum and neutralino relic density

work in progress, L.Everett, IWK, K.Zurek





$$m_0 = 1 \text{ TeV}, N = 1, \alpha_g = 0.5$$



$$m_0 = 1 \text{ TeV}, N = 3, \alpha_g = 0.5$$

Conclusion

- In the top-down approach, considering moduli stabilization can lead to mixed SUSY breaking scenarios.
- Relative ratios of ~~SUSY~~ terms can encode information regarding high scale dynamics.
- Deflected Mirage Mediation: a generalized framework for mixed SUSY scenarios which includes the three standard mechanisms of anomaly mediation, gauge mediation, gravity/modulus mediation.
- Mirage unification of gaugino masses remains, but generically at a deflected scale.
- Patterns of soft terms at low energy distinctive, and should be testable at LHC

$\mu/B\mu$ Problem and Axionic Mirage mediation

Nakamura, Okumura, Yamaguchi (2008)

For $\mu/B\mu$ Problem, perhaps hint at the fact that we are exploring this idea in context of full deflected mirage mediation framework.

$$\int d^4\theta C\bar{C}(H_u\bar{H}_u + H_d\bar{H}_d) + \left\{ \int d^2\theta C^3 \mu H_u H_d + \text{h.c.} \right\}$$

$\mu/B\mu$ problem : When anomaly mediation dominates

$$B \sim \frac{F^C}{C} \sim \mathcal{O}\left(m_{3/2}\right)$$

Must forbid tree-level mass term ⇒ PQ symmetry

Use matter moduli X as a PQ symmetry breaking field.

Model

	H_u	H_d	X	Y	T
PQ Charge	-2	-2	-2	-2	4

$$W = y_1 T H_u H_d + y_2 XYT$$

$$-3\exp(-K/3) = |X|^2 + |Y|^2 + |T|^2 + \kappa \overline{X} Y + \text{h.c.}$$

Stabilize X by Coleman-Weinberg mechanism :

$\langle X \rangle$ intermediate ~~PQ~~ scale $\frac{F^X}{X} \approx -\frac{F^C}{C}$

Y and T get massive. Integrate out T

$$Y \approx -\frac{y_1}{y_2}\frac{H_u H_d}{X}$$

Generate μ term and B term $\sim \left(\frac{F^C}{C} + \frac{F^X}{X} \right)$

$$\Delta \mathcal{L} = -\kappa \frac{y_1}{y_2} \int d^4\theta \frac{\overline{CX}}{CX} (CH_u)(CH_d)$$

$$\frac{F^C}{C} + \frac{F^X}{X} \approx \mathcal{O}\left(\frac{F^T}{T + \bar{T}} + \frac{1}{16\pi^2} m_{3/2} \right)$$