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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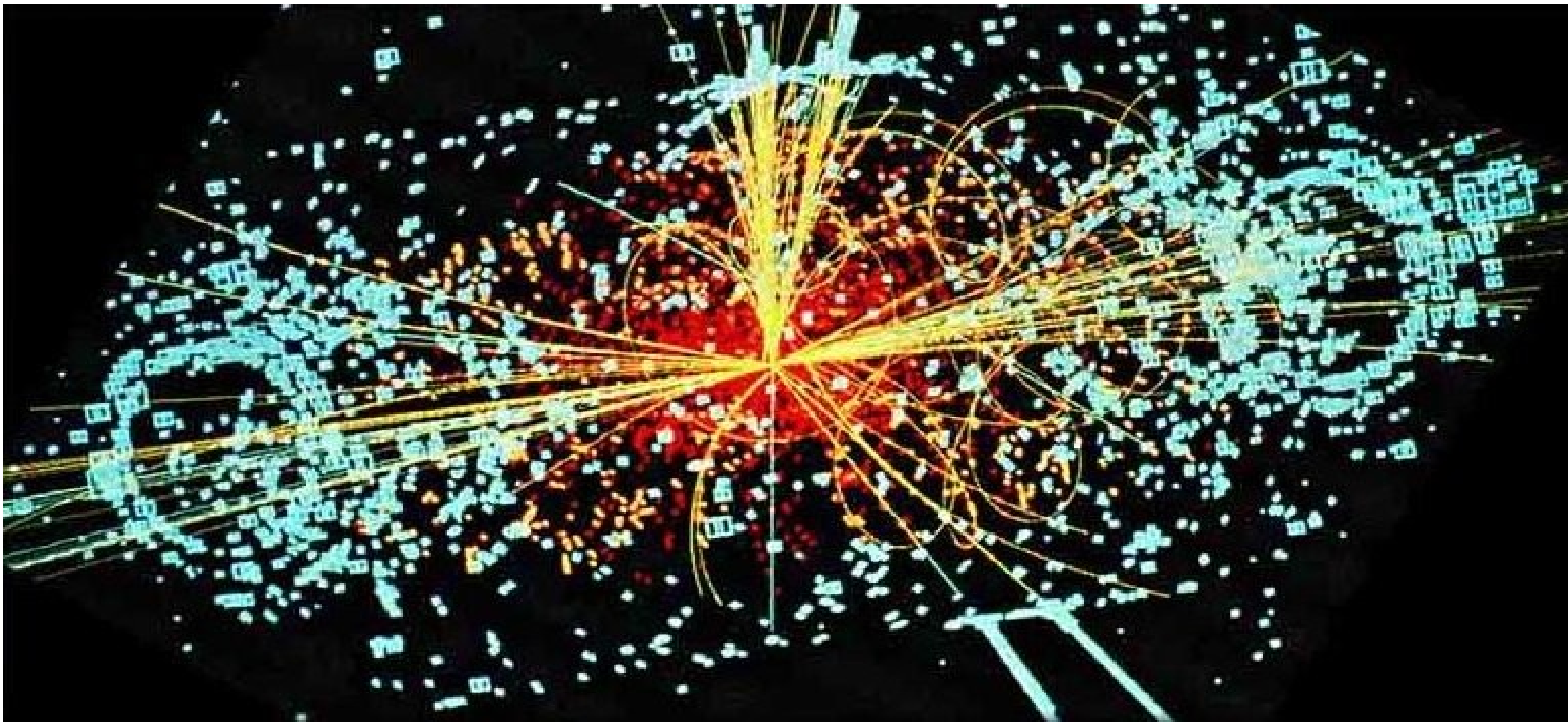
Outline

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

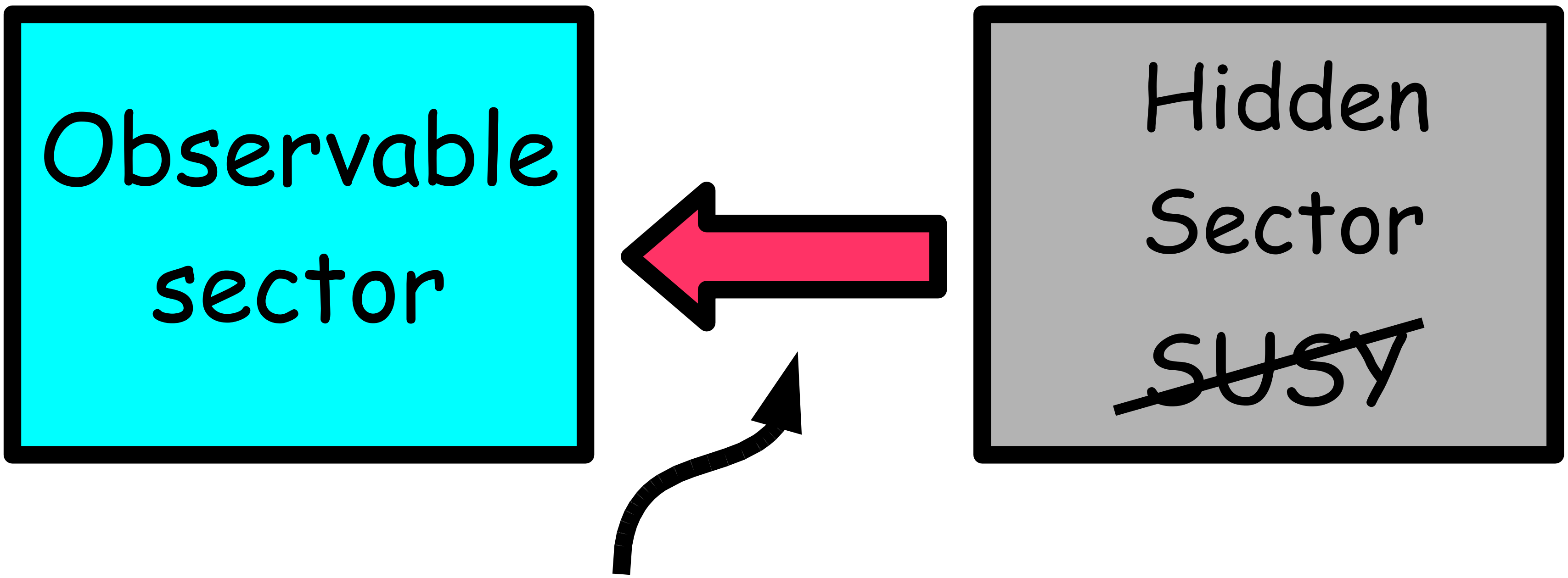
Introduction

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



We may discover SUSY particles and measure their masses.

Paradigm of SUSY

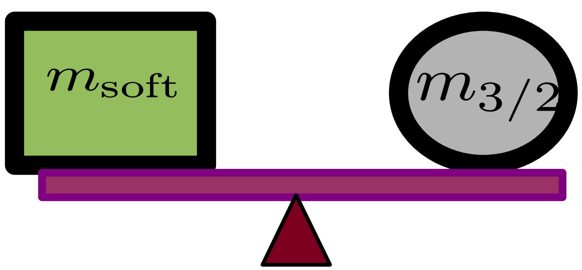


Messengers of ~~SUSY~~ may have information on high-scale dynamics.

Different mediation mechanisms lead to different soft mass pattern:

Gravity Mediation

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

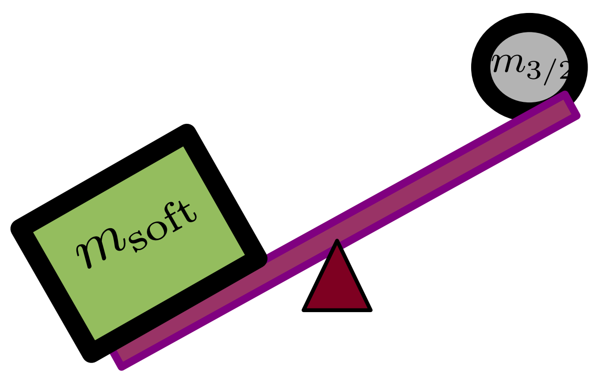


Tree level

Gauge Mediation

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

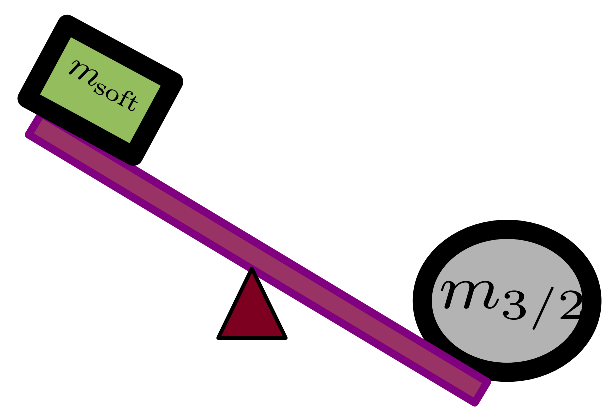
$$\gg m_{3/2} \approx \frac{F}{M_P}$$



One loop level

Anomaly Mediation

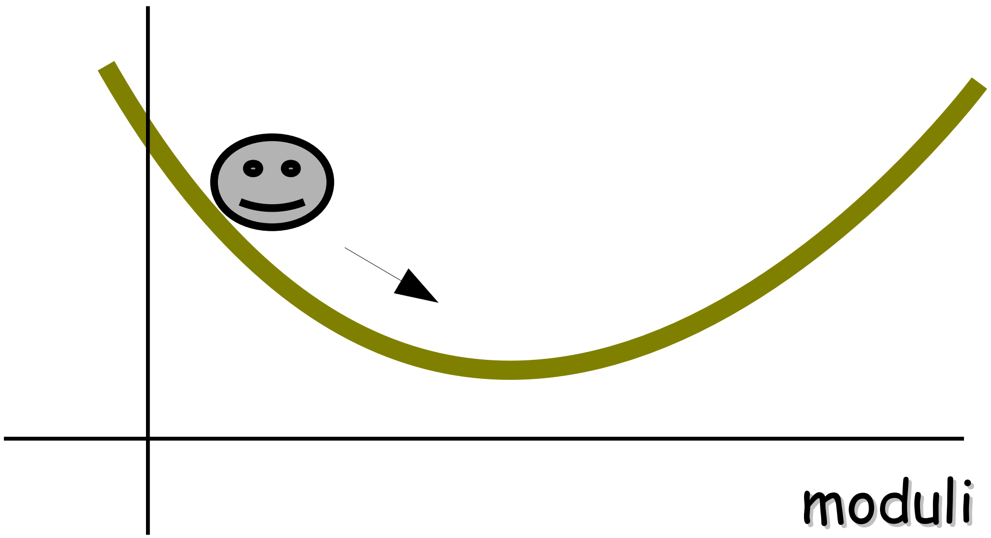
$$m_{\rm soft} \approx \frac{g^2}{16\pi^2} m_{3/2}$$

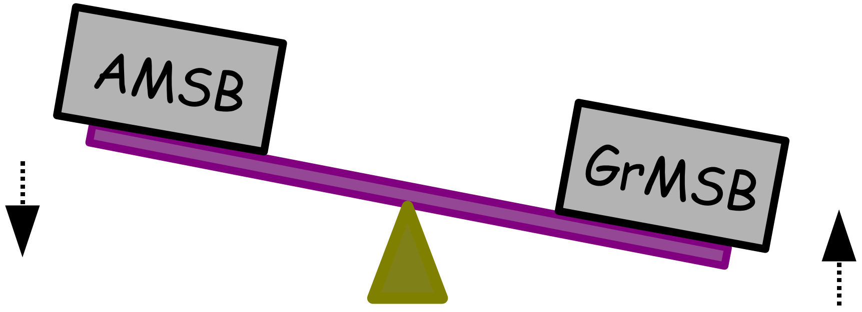


One loop level

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 !



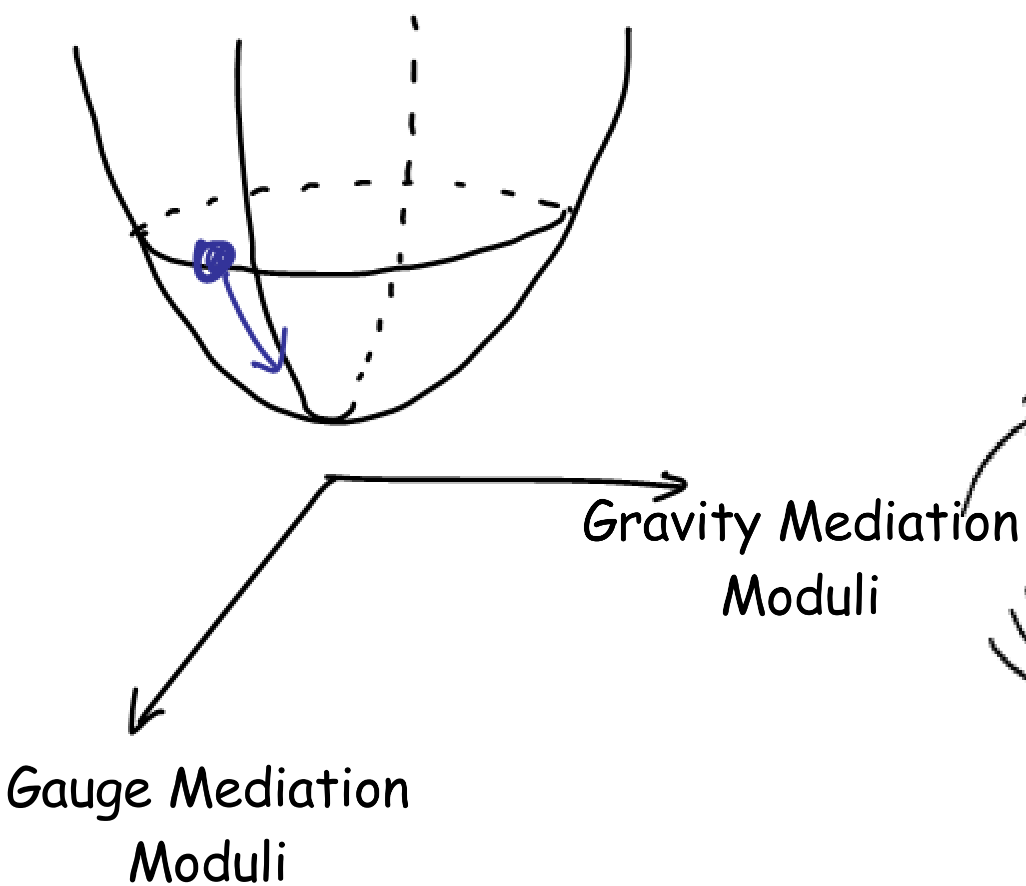


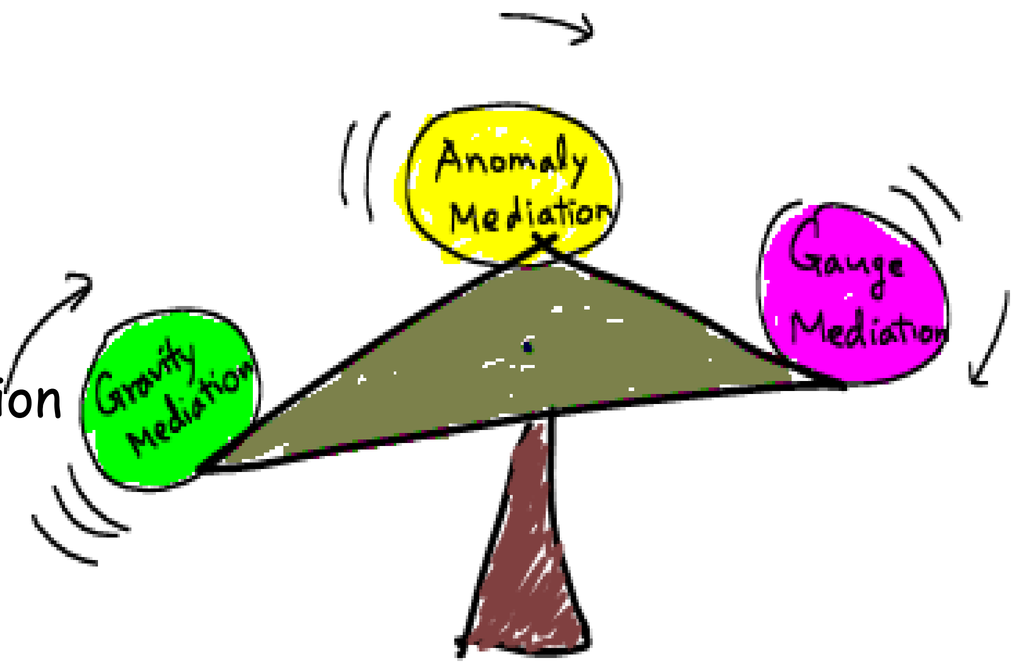
→ Mixed Modulus-Anomaly Mediation
(Mirage Mediation)

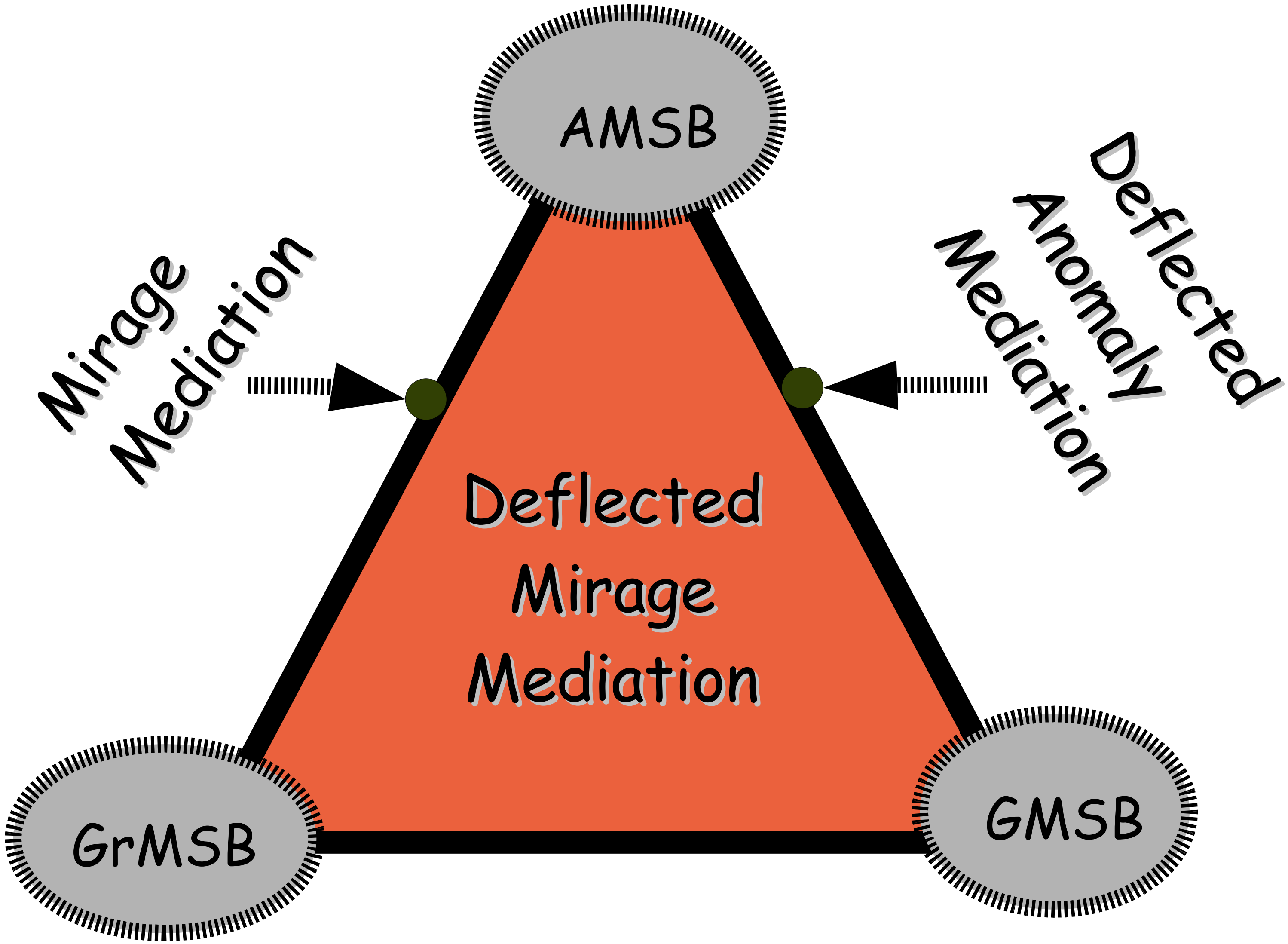
Consider stabilization of gauge mediation moduli X:

⇨ Comparable Anomaly/Gauge/Gravity Mediation

Deflected Mirage Mediation





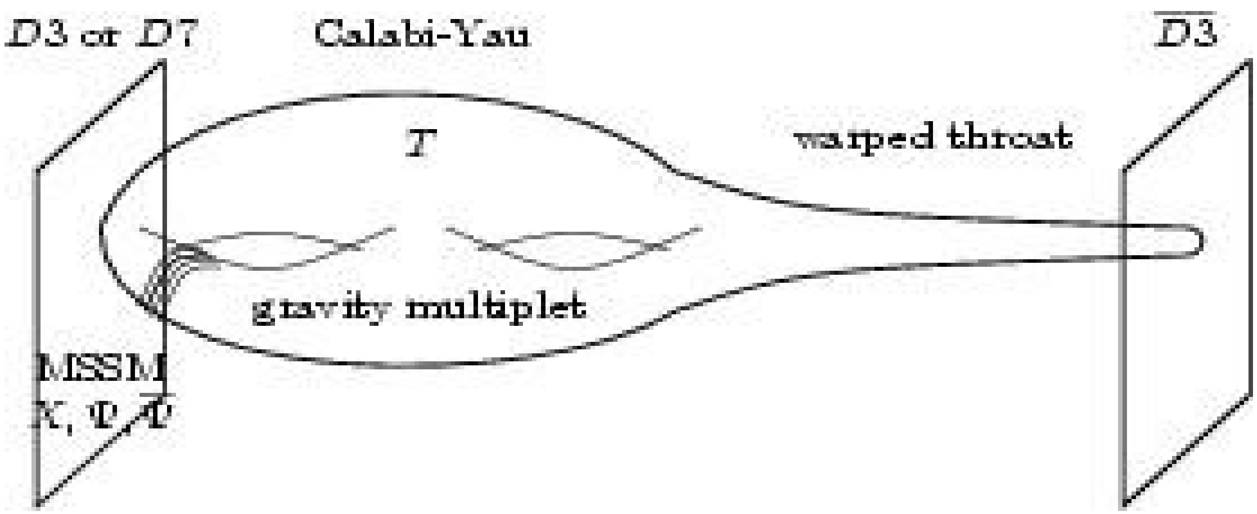


Relative ratios of each contribution in soft masses shows the information of stabilization.

Moduli stabilization and Mixed mediation

KKLT Setup :

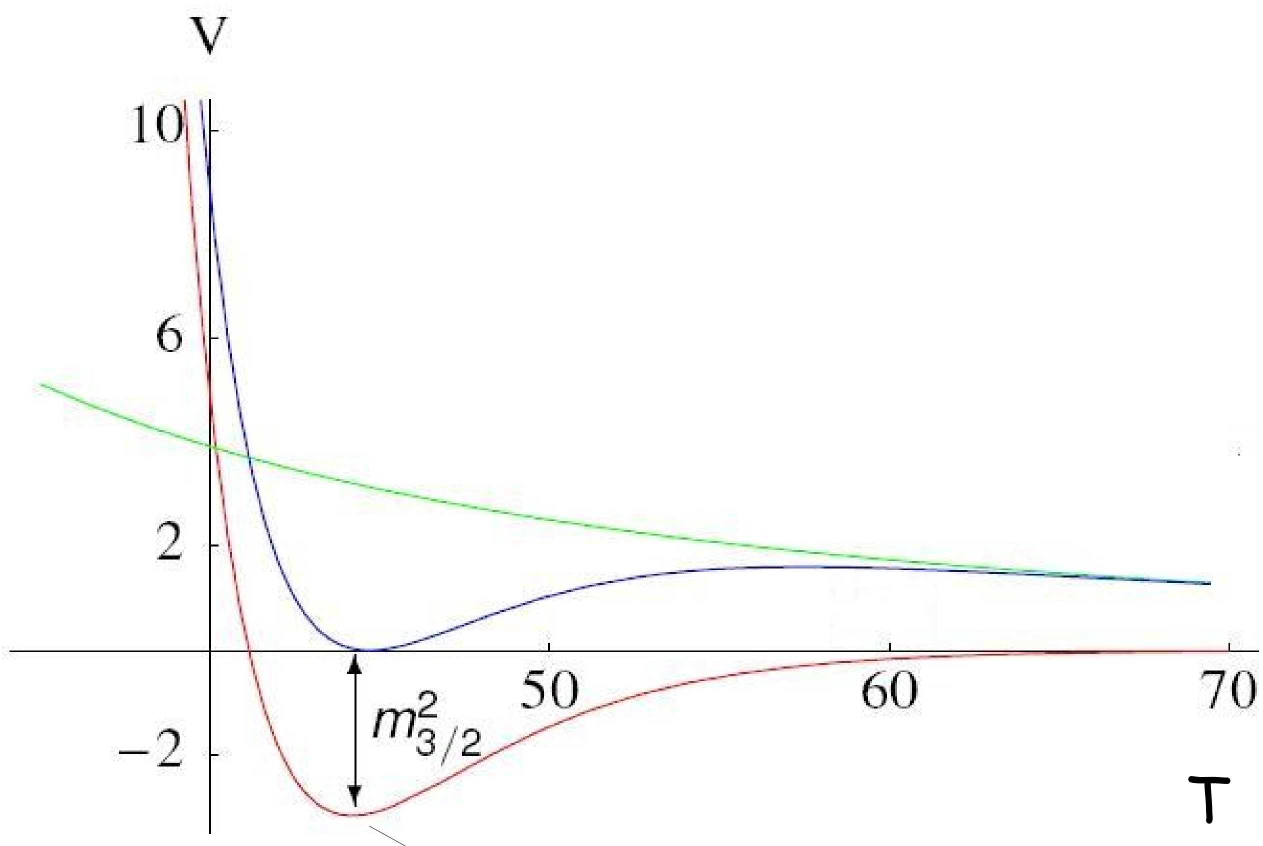
Kachru, Kallosh, Linde, Trivedi (2003)



Superpotential : Flux + Nonperturbative

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

Stabilize moduli T to SUSY AdS vacuum



SUSY AdS vacuum

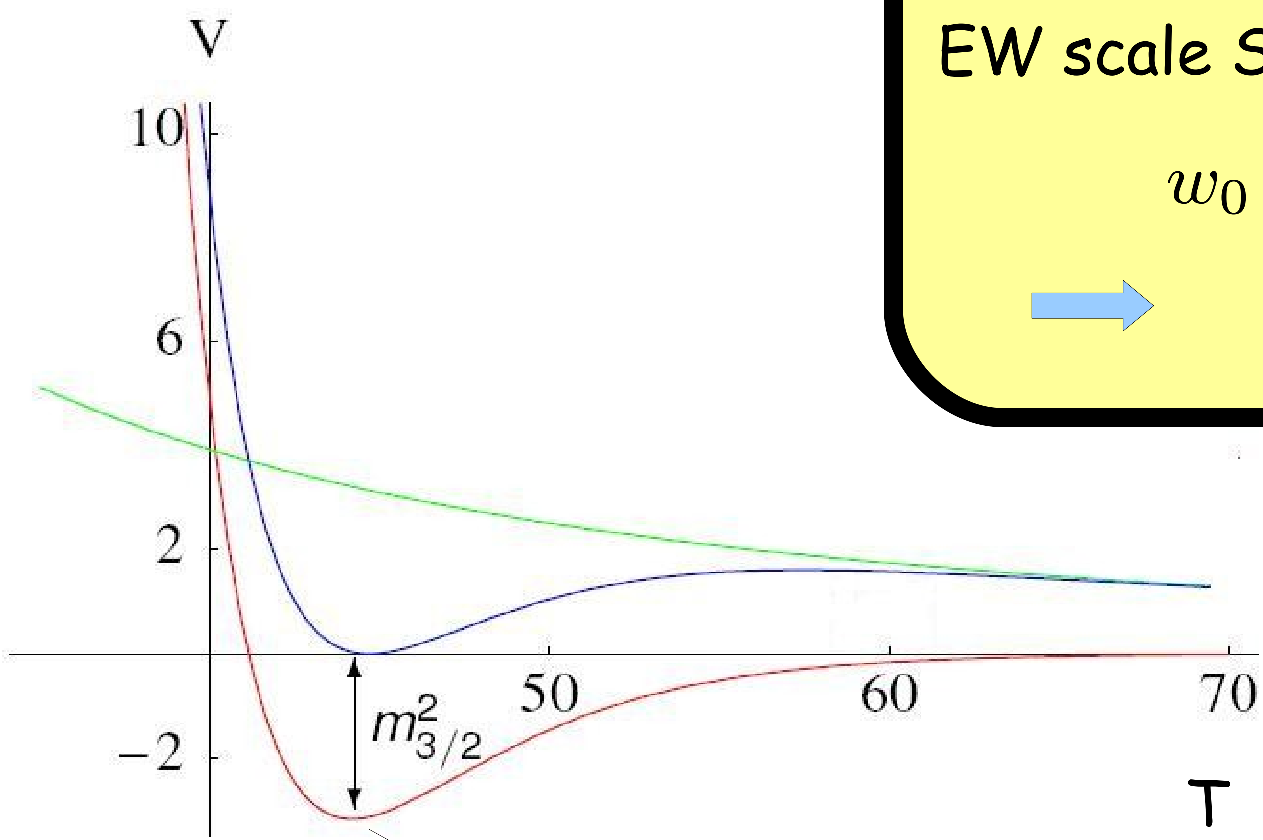
$$m_{3/2} = \frac{w_0}{(2T)^{3/2}}$$

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

EW scale SUSY requires

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

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



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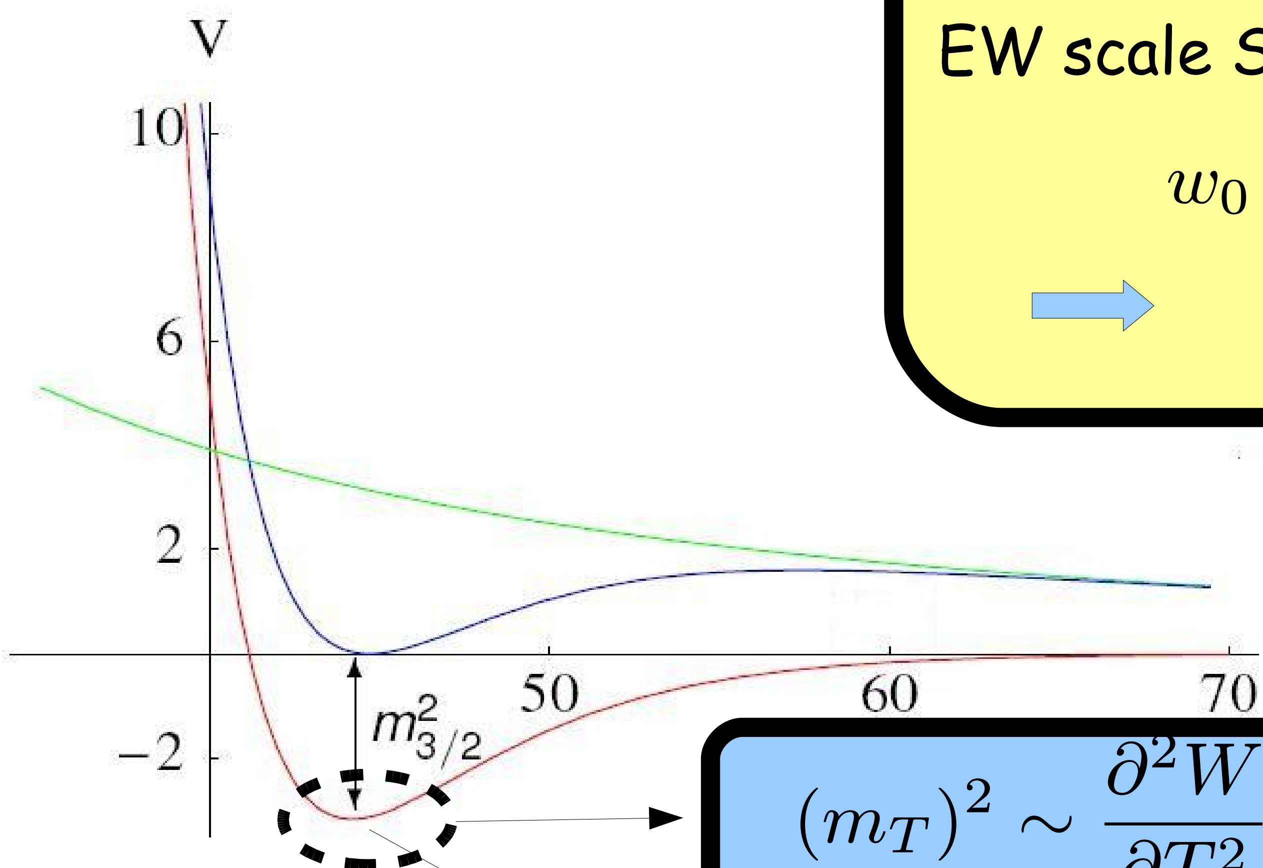
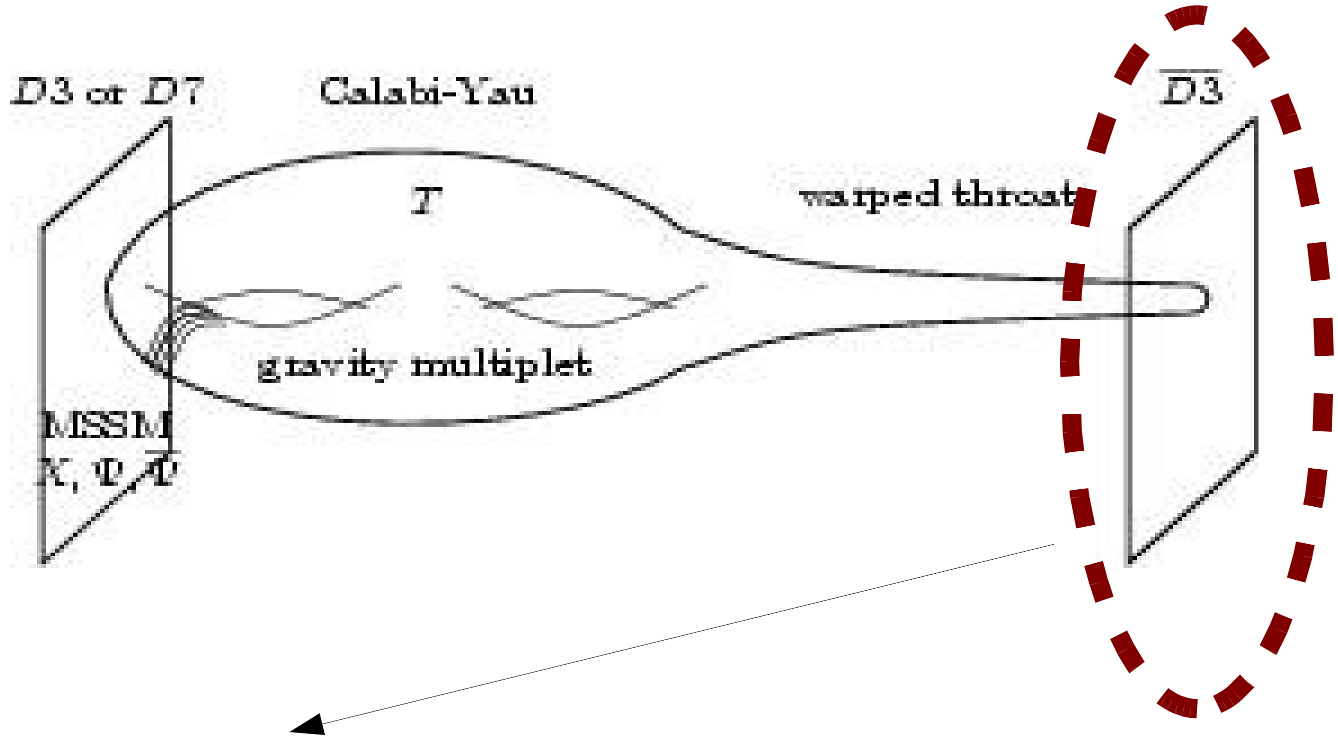


$$(m_T)^2 \sim \frac{\partial^2 W}{\partial T^2} \sim (aT)^2 m^2_{3/2}$$

SUSY AdS vacuum

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



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

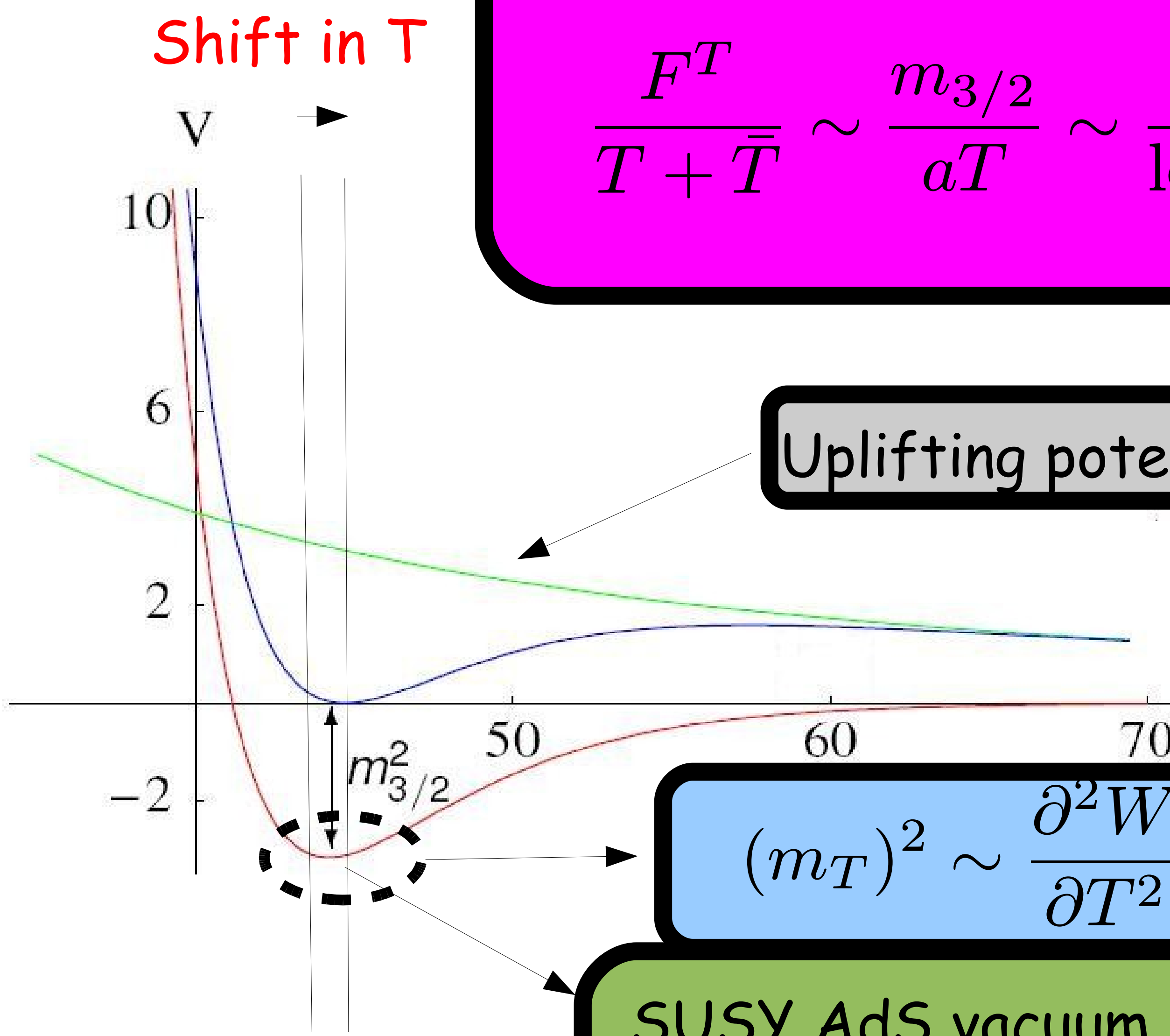
Uplifting scalar potential

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

→ 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

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

SUSY AdS vacuum

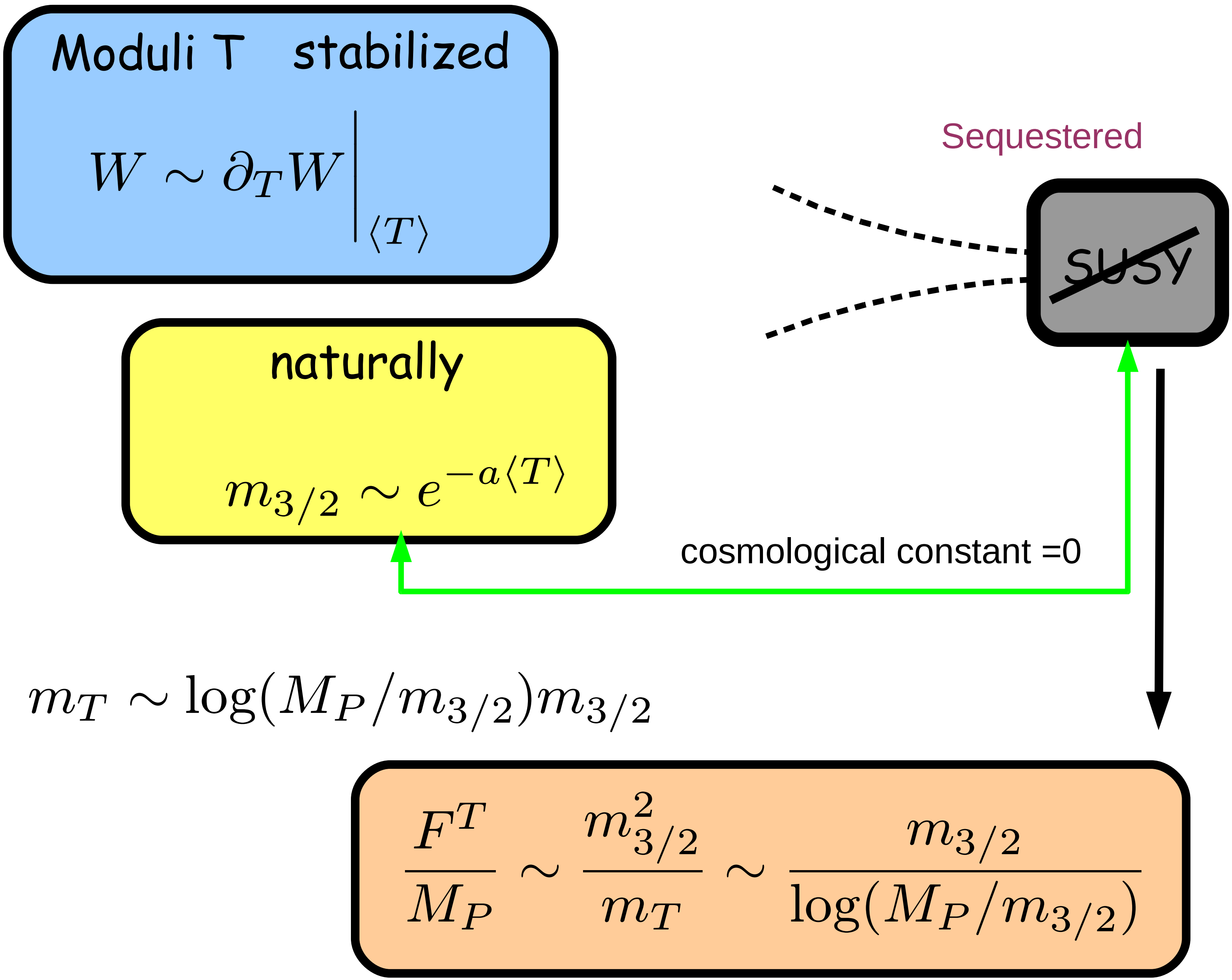
$$m_{3/2} = \frac{w_0}{(2T)^{3/2}}$$

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)



Moduli T stabilized
$W \sim \partial_T W \Big|_{\langle T \rangle}$
Sequestered
SUSY
naturally
$m_{3/2} \sim e^{-a\langle T \rangle}$
cosmological constant =0
$m_T \sim \log(M_P/m_{3/2}) m_{3/2}$
$\frac{F^T}{M_P} \sim \frac{m_{3/2}^2}{m_T} \sim \frac{m_{3/2}}{\log(M_P/m_{3/2})}$

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

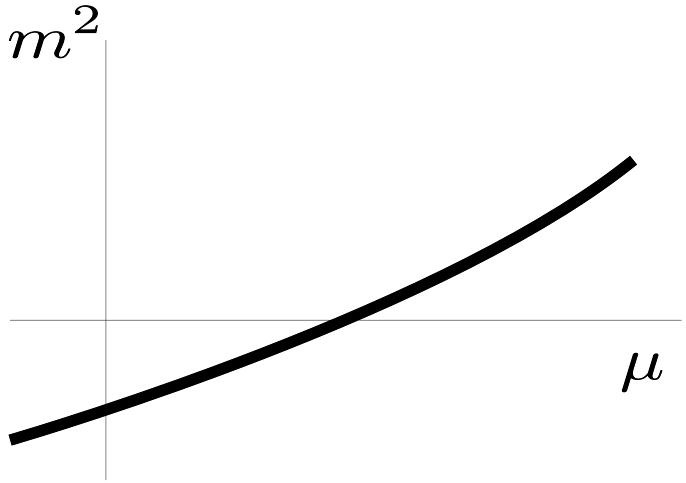
$$F^X = -e^{K/2} K^{X\bar{X}} D_{\bar{X}} \bar{W}$$
$$= \underbrace{-e^{K/2} K^{X\bar{X}} \partial_{\bar{X}} \bar{W}}_{(A)} \underbrace{-e^{K/2} K^{X\bar{X}} K_{\bar{X}} \bar{W}}_{(B)}$$

(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.

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

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

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

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

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

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 $(m_0, \alpha_m, \alpha_g)$

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

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

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

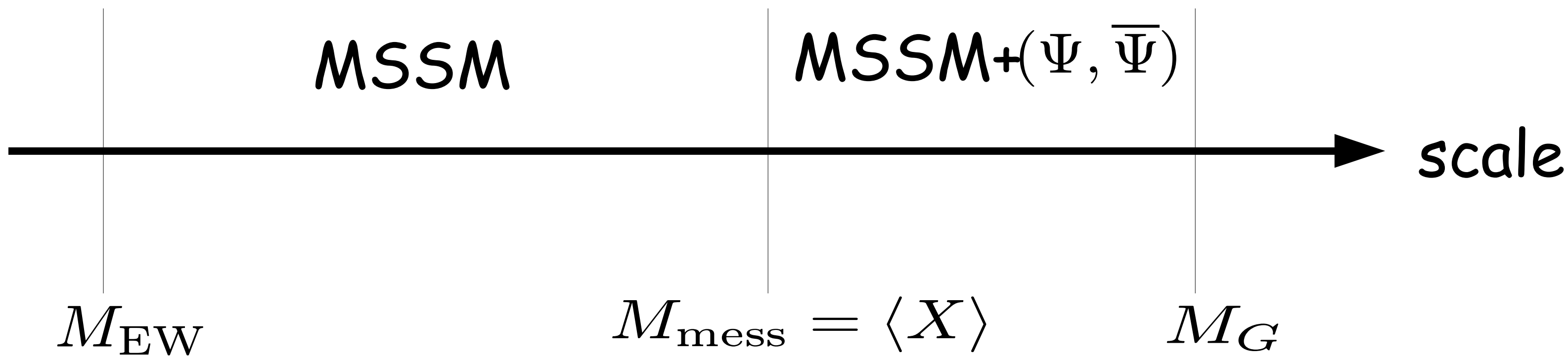
We also have $\tan\beta$ and $M_{\rm mess} \equiv \langle X \rangle$

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:

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

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

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

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

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

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

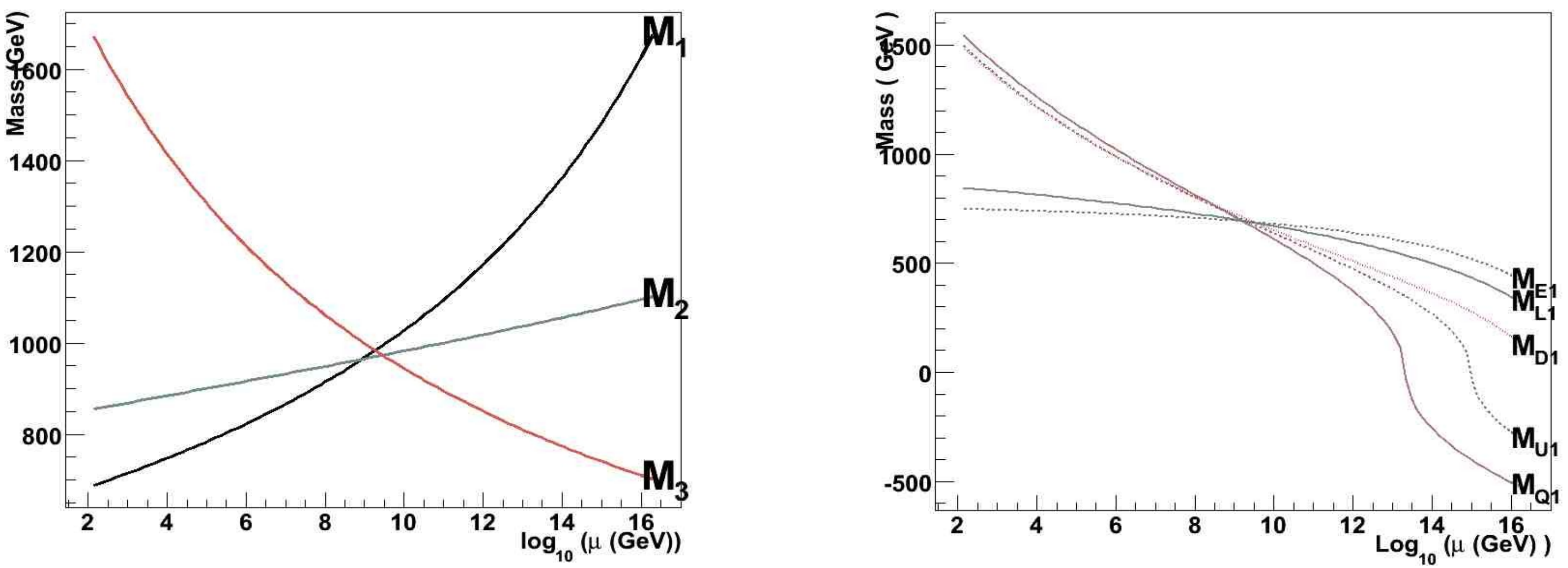
$$\Delta m_i^2 = m_0^2 \sum_a 2 c_a N \frac{g_a^4(M_{\rm mess})}{(16\pi^2)^2} \left[\alpha_m (1 + \alpha_g) \log \frac{M_P}{m_{3/2}} \right]^2$$

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)

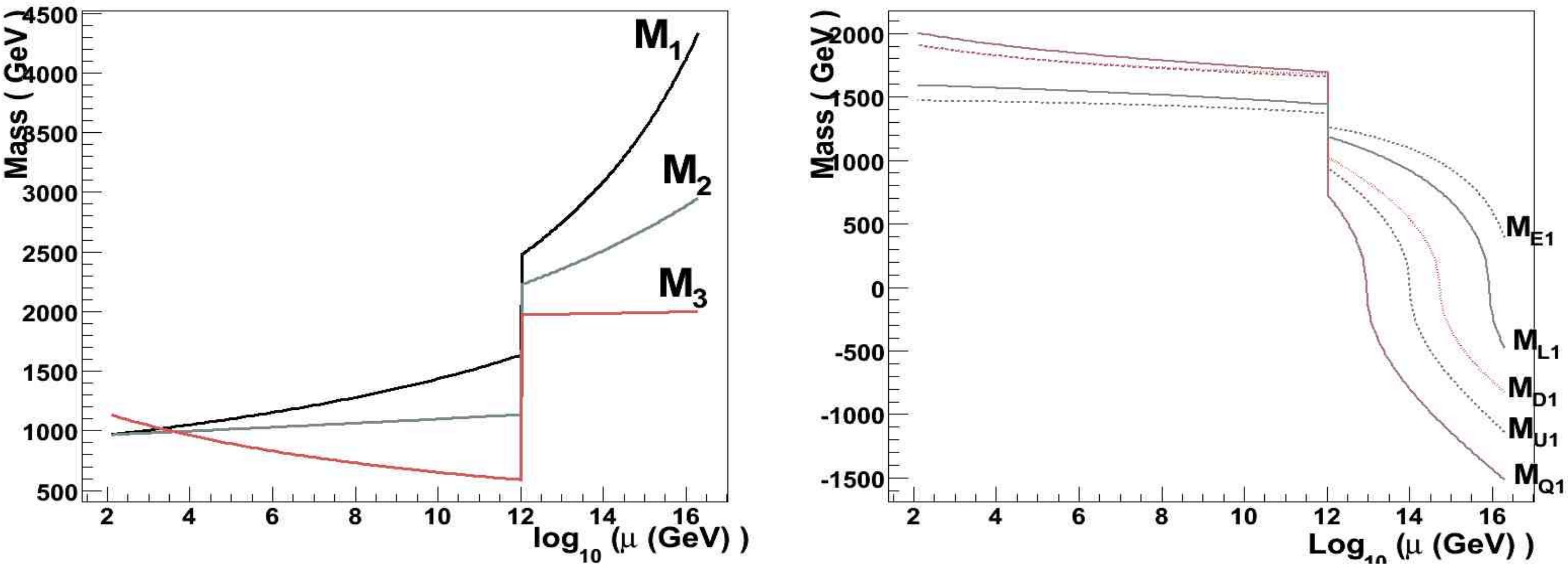


Mirage scale:

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

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.)

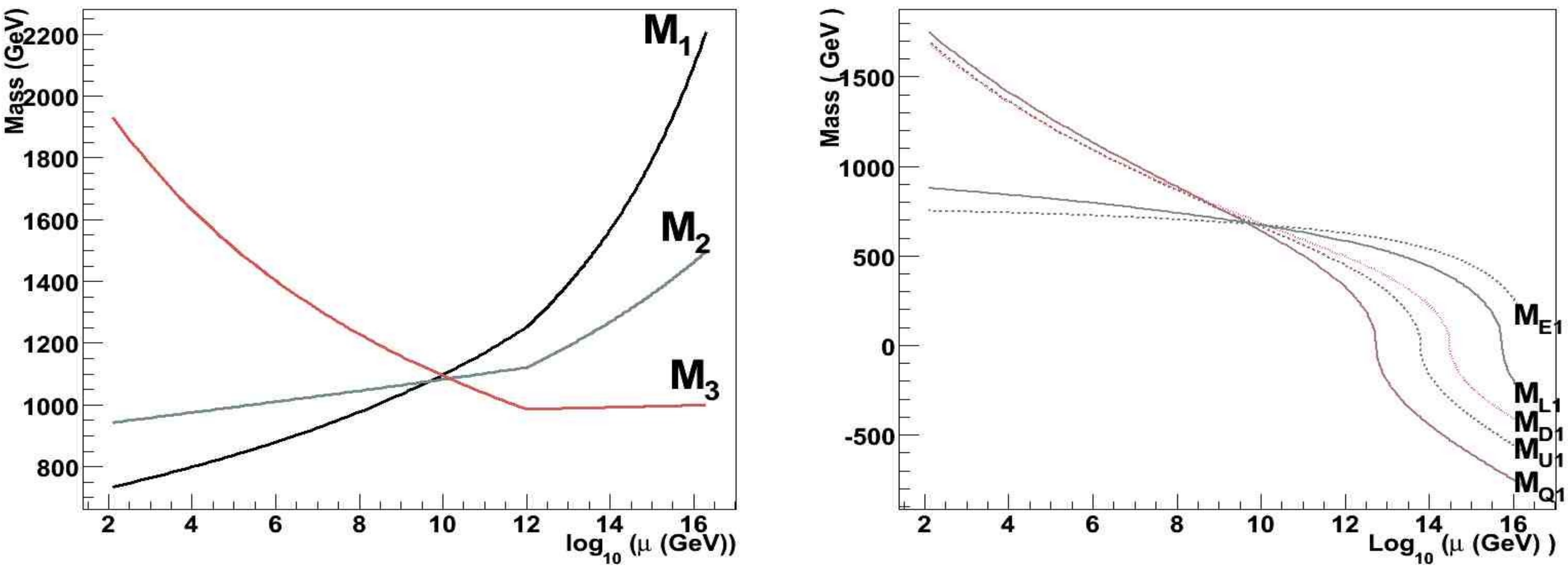
- ⇨ Sizable mixing between bino and wino

  → Well-tempered neutralino

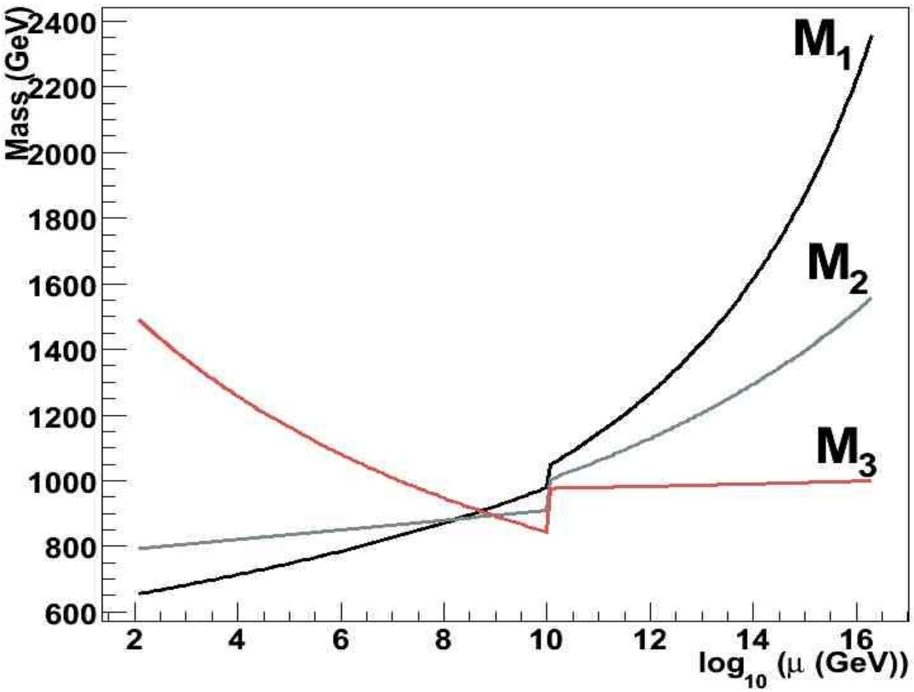
- ⇨ Relatively less severe fine-tuning due to light gluino, negative stop mass square and large A-term.
  But gauge mediation contribution does not help reducing fine-tuning.

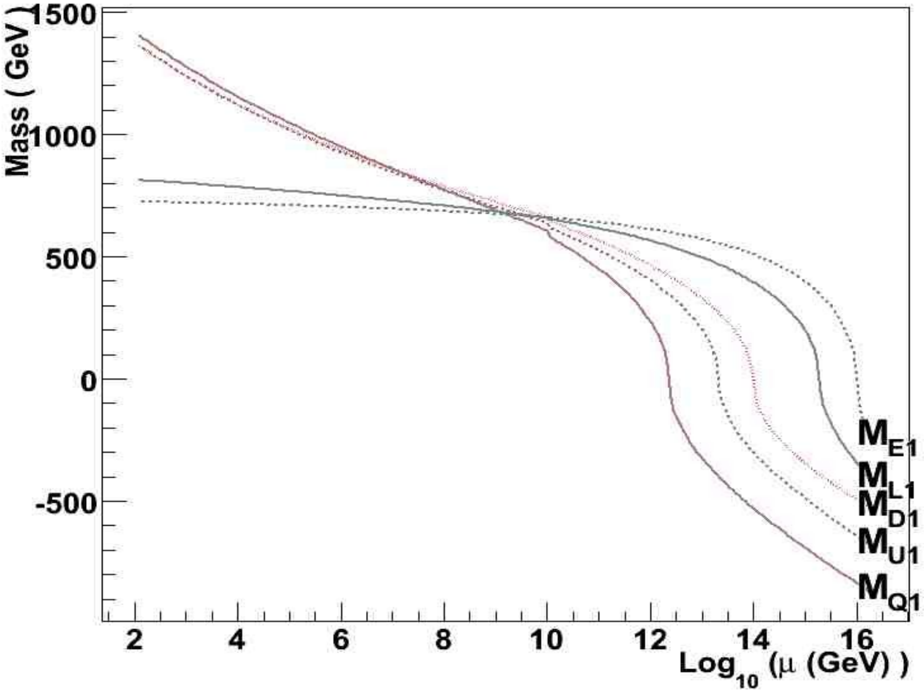
RG evolution pattern

Coleman-Weinberg stabilization (W=0)



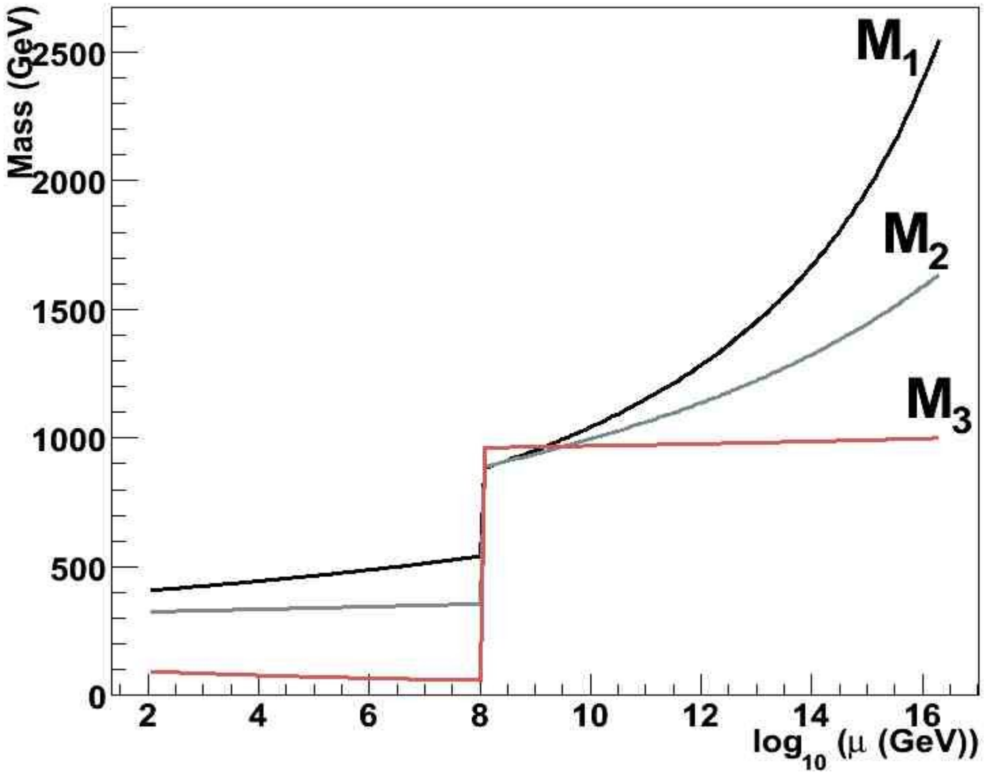
Stabilization by nonrenormalizable op. $$W(X) = \frac{X^4}{M_P}$$

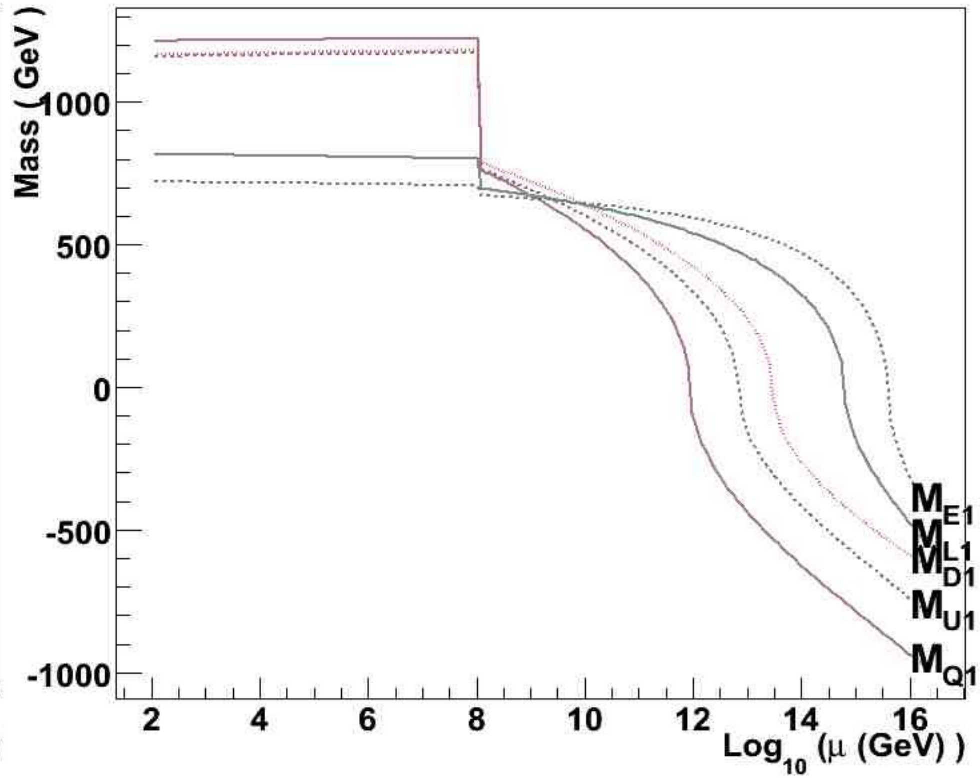




Stabilization by nonpertubative potential

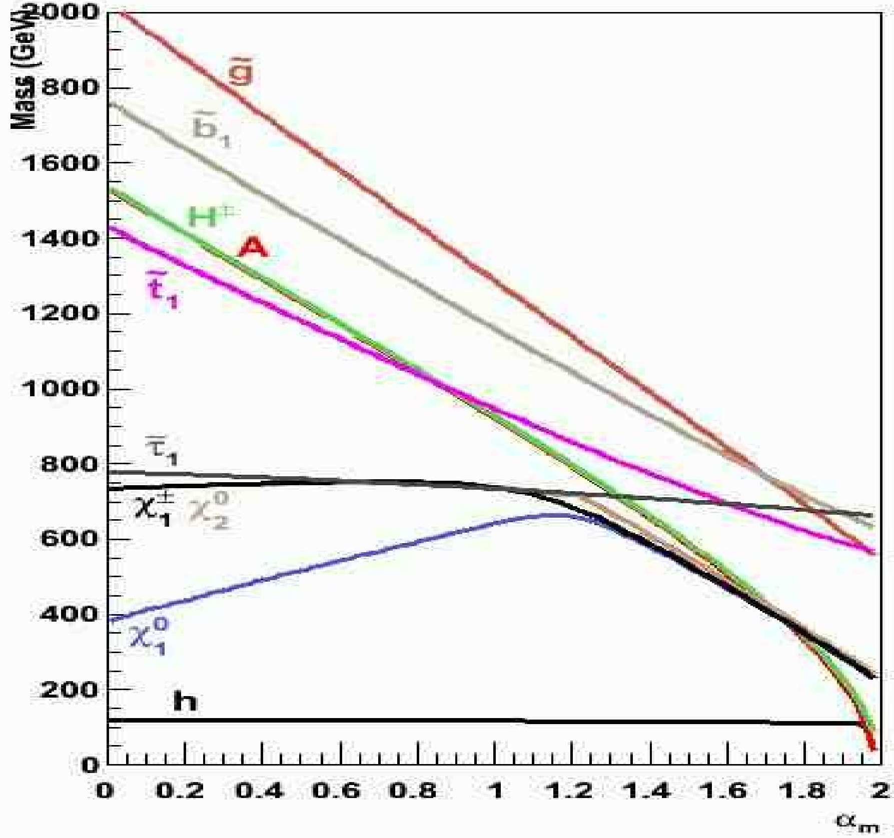
$$W(X) = \frac{\Lambda^4}{X} \qquad \Lambda \sim 10^7 \text{ GeV}$$

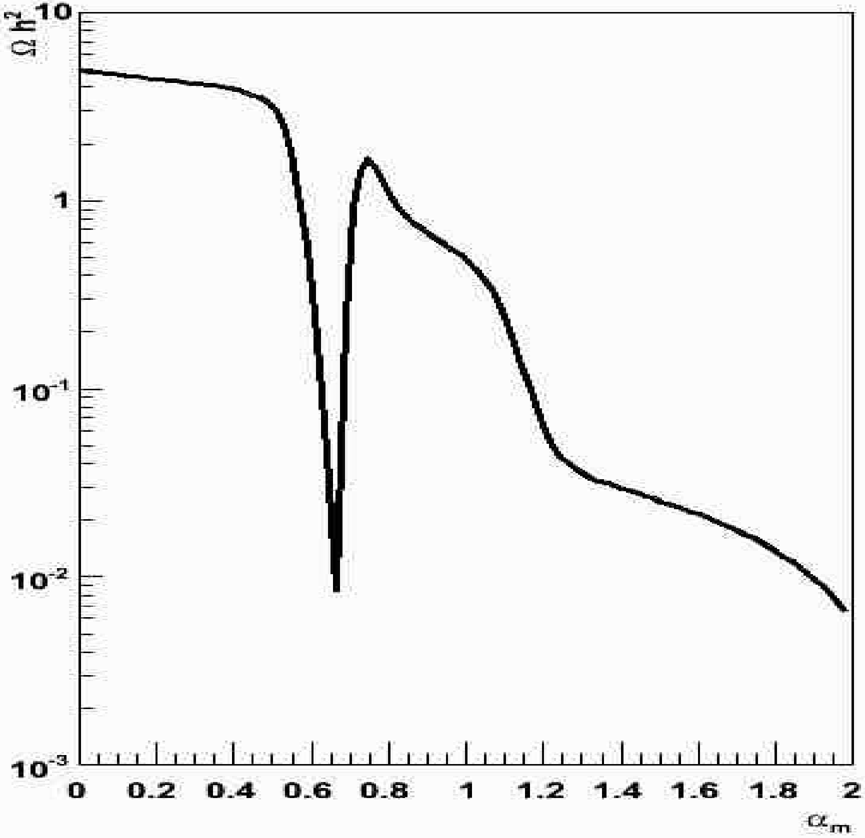




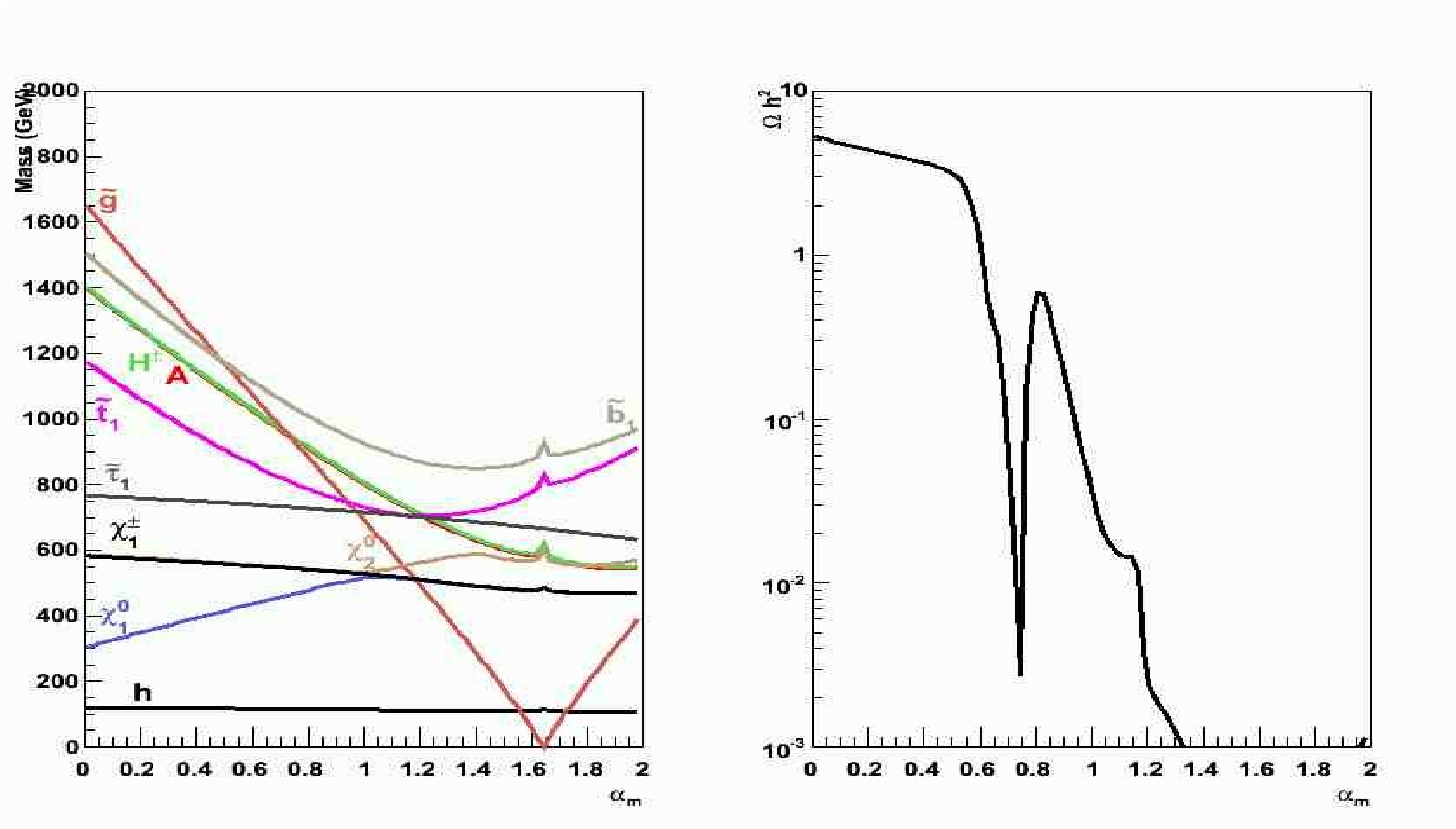
Sparticle Spectrum and neutralino relic density

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 $\sim \left(\frac{F^C}{C} + \frac{F^X}{X} \right)$

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

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