Mirage Mediation

特に大流行はなし。何が流行かは人による。。

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特定領域総括班会議@東大本郷
2006年11月16日

Low Energy Supersymmetry

A promising candidate beyond SM

- Soln to Naturalness Problem
- Gauge Coupling Unification

  → SUSY GUTs!
- Dark matter candidate
  – neutralino, gravitino ….

Experimental Signatures

sensitive to superparticle masses

→ Importance of Supersymmetry Breaking

Task of Theorists

Before Discovery

- Invent SUSY breaking scenarios
- Make predictions

After Discovery at LHC/MeG (our hope!)

Experimental Data

→ SUSY masses and couplings

→ Nature of SUSY breaking

& physics at Ultra HighEnergy Scale

Gaugino Mass

- Consider gaugino mass as an example

- Gauge coupling constant

$$\frac{1}{4g^2} F_{\mu\nu} F^{\mu\nu}$$

  – non-zero at tree level
  – receives radiative corrections

- Gaugino Mass: cousin of gauge coupling

- From gauge coupling const to gaugino mass

  1) 1/g^2 as VEV of some scalar field

$$\Downarrow \text{supersymmetry}$$

  2) 1/g^2 as VEV of some superfield

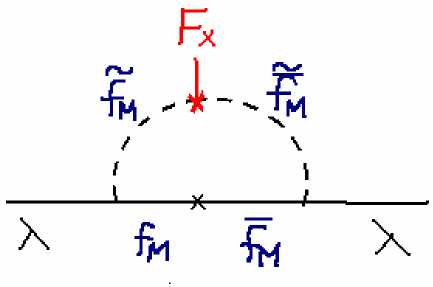
$$\frac{1}{g^2} = \langle Ref(X, ...)|_{\theta=0}\rangle$$

f: gauge kinetic function

  3) gaugino mass as SUSY breaking part of "gauge coupling const"(=gauge kinetic ftn)

$$M_\lambda \sim \left\langle \frac{\partial f}{\partial X_i} F_{X_i} \right\rangle$$

Origin of Gaugino Mass



- Gaugino mass from Loop
  - gauge mediation

    (threshold correction from messenger sector)
  - anomaly mediation (beta-function)

    … "low" energy origin of gaugino mass

- Gaugino mass from Tree

$$f = X + (\mathrm{radiativecorrections})$$

  - what is X?
  - the nature of X?

… "high" energy origin of gaugino mass

→ call for more fundamental theory = superstring theory

X?

- natural candidate for X

  = moduli in superstring theory
  - moduli: determine size and shape of compactified 6 dimensions

- moduli stabilization:
  - how moduli gets potential?
  - long standing problem

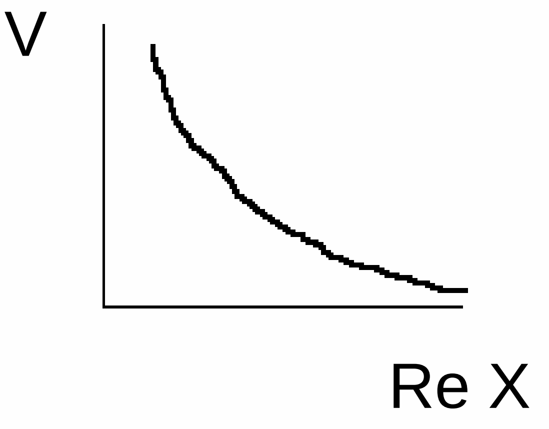
Gaugino Condensation and Runaway Potential

- strong gauge dynamics (e.g. gaugino condensation) → superpotential

$$W = e^{-bX}$$

exponetial superpotential

→runaway scalar potential

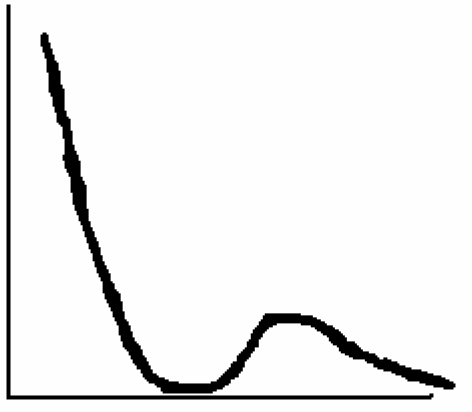


How to avoid runaway?

- A way to avoid runway:

  add constant to superpotential

$$W \sim e^{-bX} + w_0$$



Is it possible to add such a constant term?

Yes! Flux Compctification

- IIB superstring
  - 2-form potential (NS-NS, RR)
  - 3-form field strength

$$H_{(3)} = dB_{(2)},\ F_{(3)} = dC_{(2)}$$

$$B_{(2)},\ C_{(2)}$$

Gukov-Vafa-Witten '99

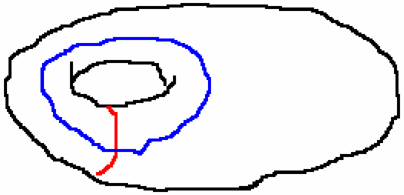
- superpotential for IIB theory

$$W = \int_{\mathcal{M}} \Omega \wedge G_{(3)}$$

$$G_{(3)} = H_{(3)} - \tau F_{(3)}$$

$$\Omega(\sim \epsilon_{abc} dx^a \wedge dx^b \wedge dx^c):$$ (3,0) form

- complex moduli $z_i = \int_{A_i} \Omega, \quad \mathcal{G}_i(z) = \int_{B_i} \Omega$



- qu $\dfrac{1}{(2\pi)^2\alpha'} \int_{A,B} H_{(3)} = \text{integer}, \quad \dfrac{1}{(2\pi)^2\alpha'} \int_{A,B} F_{(3)} = \text{integer}$

$$
\begin{aligned}
W &= \sum_i \left[\int_{A_i} \Omega \int_{B_i} G_{(3)} + \int_{B_i} \Omega \int_{A_i} G_{(3)} \right] \\
&= \sum_i \left[z_i \int_{B_i} G_{(3)} + \mathcal{G}_i(z) \int_{A_i} G_{(3)} \right]
\end{aligned}
$$

→ superpotential for complex moduli (z) and dilaton (τ)

- **Consistent solution for flux compactifications in IIB**
  - fluxes → warped throat
  - W stabilizes complex moduli as well as dilaton
  - Kaehler moduli are not stabilized by fluxes

Giddinge-Kachru-Polchinski 02

KKLT set-up

Kachru-Kallosh-Linde-Trivedi 03

- Potential for Kaehler moduli:

  $\leftarrow$ non-perturbative effects

  e.g. gaugino condensate on D7 brane

- case of single overall moduli:

  $T = R^4 + i \cdots$ $\quad R$: size of compact manifold

- gauge kinetic function on D7: $f = T$
- superpotential from gaugino condensate

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

$a \propto$ beta function coefficient

- Kaehler potential: $K = -3\ln(T + T^*)$
- superpotential: $W = w_0 - Ae^{-aT}$
- Assume $w_0 \ll 1$ in Planck unit (low-energy SUSY)

  (Note: runaway potential if $w_0 = 0$)

- Potential minimum:

$$m_{3/2} = \langle W \rangle \simeq w_0$$

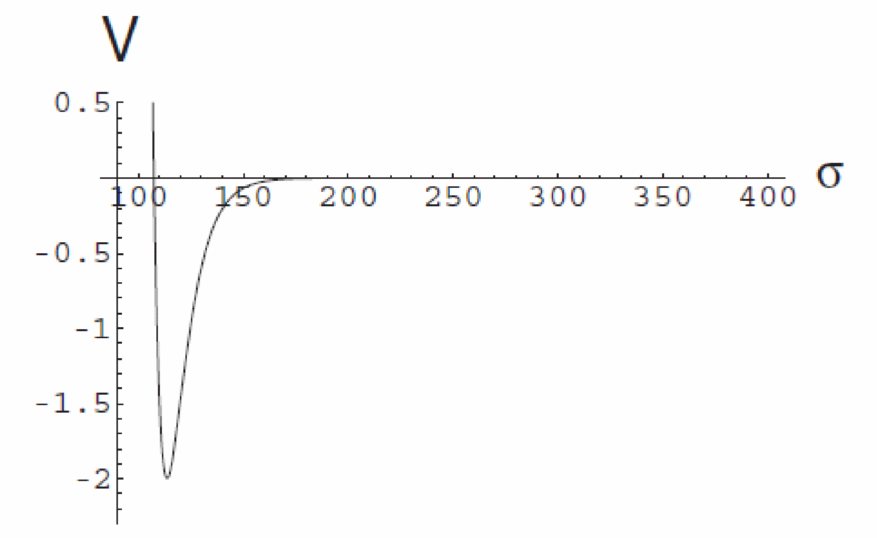
$$0 \simeq D_T W \simeq -\frac{3}{T + T^*} w_0 + aAe^{-aT}$$

$$\rightarrow a\mathrm{Re}T \simeq \ln(A/w_0) \simeq \ln(M_{Pl}/m_{3/2}) \ (\simeq 8\pi^2)$$

- moduli mass → 100 times heavier than gravitino

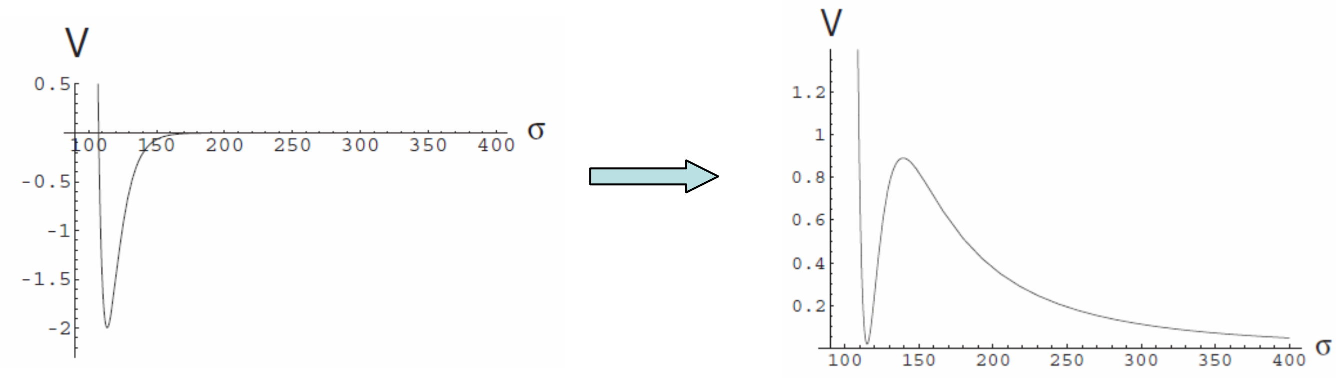
$$m_T \simeq \frac{(T + T^*)^2}{3} W_{TT} \simeq 4/3a\mathrm{Re}T \cdot m_{3/2} \sim 8\pi^2 m_{3/2}$$

- However the vacuum is SUSY AdS

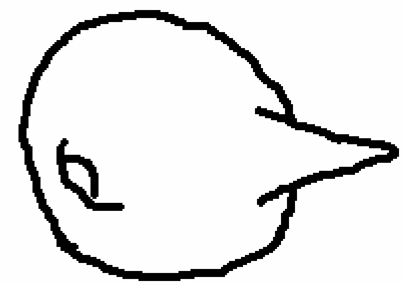


- One needs to add something to obtain flat Minkowski (vanishing potential energy)

- Up-lifting of the scalar potential



  – KKLT: anti-D3 on top of warped throat



(Dynamical SUSY breaking sector on D-branes
may also be OK)

- overall moduli in KKLT:
  - mass: $$\frac{m_T}{m_{3/2}} \sim 8\pi^2$$
  - SUSY breaking: $$\frac{F_T}{m_{3/2}} \sim \frac{1}{8\pi^2}$$

Buchmuller-Hamaguchi-Lebedev-Ratz 04
Kohri-MY-Yokoyama 05
Choi-Falkowski-NiIlles-Olechowski 05
Endo-MY-Yoshioka 05
Choi-Jeong-Okumura 05

- Heavy Moduli:
  - generic feature if superpotential is generated by non-perturbative effects

→ interesting implications to phenomenology and cosmology flux compactification in type IIB superstring

$$\begin{aligned} W &= \int_{CY} \Omega \wedge G_{(3)} \\ &\sim \sum (M_i \mathcal{G}_i(z) + N_i z_i) \longrightarrow w_0 \end{aligned}$$

Small SUSY breaking scale ← small w_0

cancellation among big numbers???

Bousso-Polchinski

- At this moment we do not yet understand the ultimate reason of why SUSY breaking scale is much smaller than the fundamental scale (even if low-energy SUSY is correct).
- In the following, we consider the simplest KKLT set-up and examine phenomenological consequences.

Phenomenology

- motivation of KKLT:
  - realization of dS vacuum in string theory: cosmological interest

- KKLT set-up is also an interesting setting for low-energy SUSY

Choi-Falkowski-NiIlles-Olechowski 05
Endo-MY-Yoshioka 05
Choi-Jeong-Okumura 05

  - Cf: conventional thought

$$m_T/m_{3/2} \sim 1, \quad F_T/m_{3/2} \sim 1$$

Phenomenology with KKLT-like model

Endo-MY-Yoshioka 05
Choi-Jeong-Okumura 05

$$K = -n \ln(X + X^*) \quad W = w_0 - Ae^{-aX}$$

Consider the case where SM gauge sector is on a D7 brane with $f_7 = X$

Gaugino Masses

$$M_i = \frac{F_X}{2X_R} + \frac{\beta_{gi}}{g_i} F_\phi = \frac{F_X}{2X_R} + \frac{\beta_i g_i^2}{16\pi^2} F_\phi \quad \text{@GUT scale}$$

$F_\phi \simeq m_{3/2}$ chiral compensator

$\beta_i = (-3, 1, 33/5)$

moduli+anomaly mediation:
two contributions comparable

Sparticle Mass Spectrum

Gaugino Masses

$$R_{bX} \equiv \frac{F_\phi}{F_X/2X_R} = \frac{bX_R}{1+\frac{3l}{2n}}$$

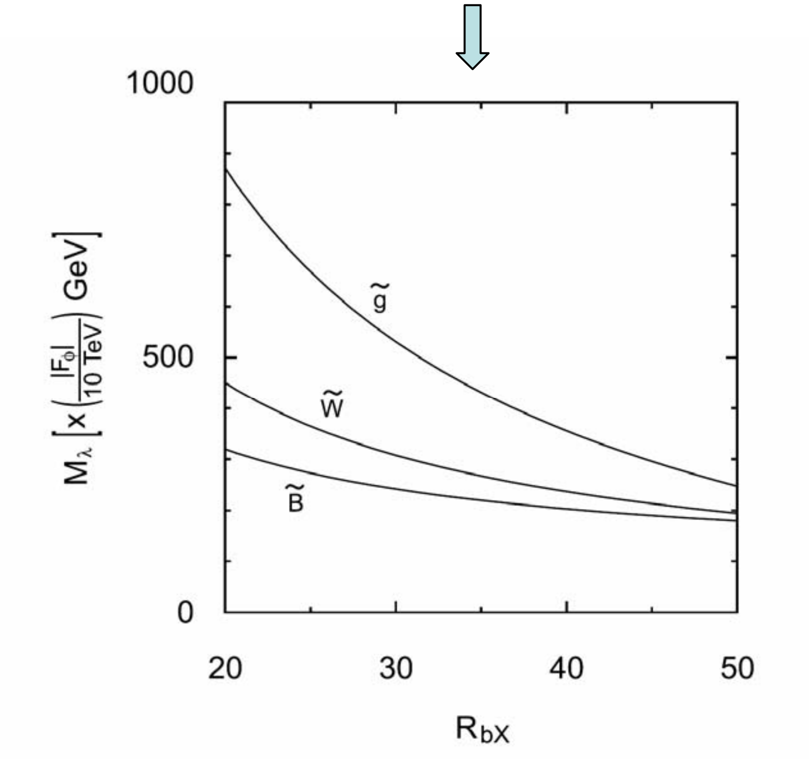
For R_{bX}~35,

$M_1: M_2: M_3$~1 : 1.3: 2

cf.

$M_1: M_2: M_3$~1: 2: 7

(mSUGRA)



mass scales: little hierarchy

- soft masses $m_{soft} \sim 100\ \mathrm{GeV}$

- gravitino mass $m_{3/2} \sim 8\pi^2 m_{soft} \sim 10^4 \mathrm{GeV}$

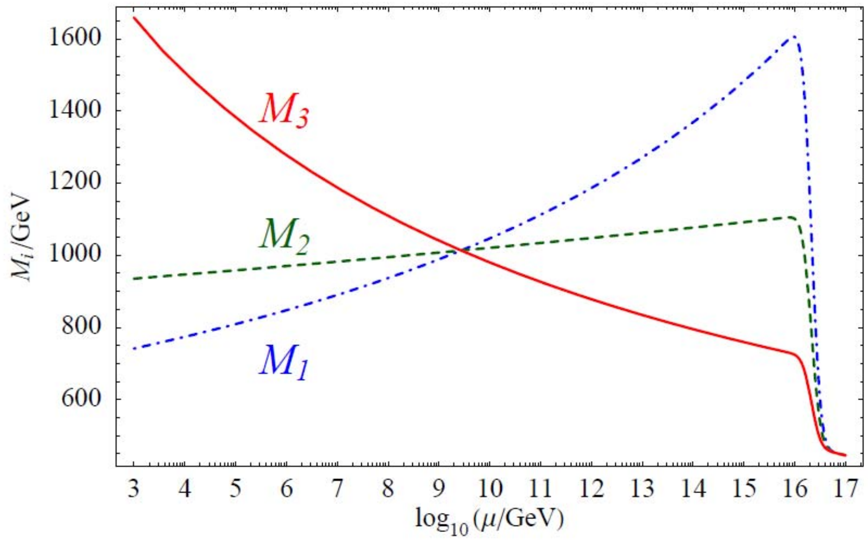
- moduli mass $m_X \sim 8\pi^2 m_{3/2} \sim 10^6 \mathrm{GeV}$

Mirage Mediation

Choi, Jeong, Okumura 05

RG properties: Gaugino masses (as well as scalar masses) are unified at a mirage scale.

$$M_a(\mu) = M_0\left[1 - \frac{1}{4\pi^2} b_a g_a^2(\mu) \ln\left(\frac{M_{GUT}}{(M_{Pl}/m_{3/2})^{\alpha/2}\mu}\right)\right].$$



from Lebedev, Nilles, Ratz 05

General Features of Mirage Mediation

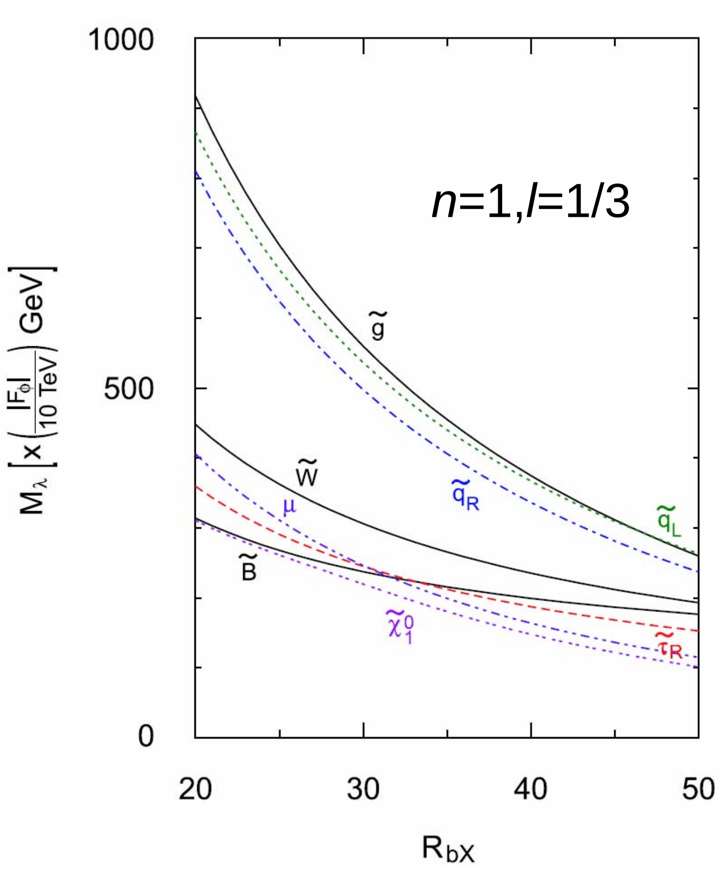
Endo-MY-Yoshioka 05
Choi-Jeong-Okumura 05

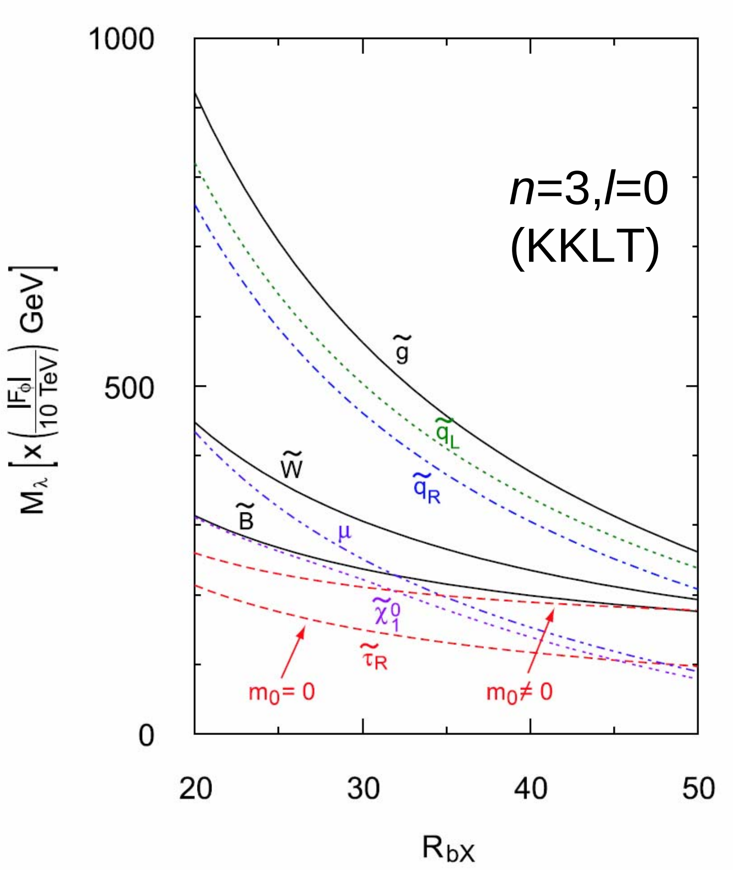
- Compact Sparticle Mass Spectrum
- small μ parameter ($\sim M_1$)
  ← small gluino mass/ RGE
- LSP: neutralino
  – admixture of gauginos and higginos
- stau: tends to be light

- Mass Spectrum is very different from mSUGRA (CMSSM).
  gauge mediation & anomaly mediation
- Testable at future collider experiments (LHC/ILC)

Mass Spectrum: Case Study

Endo,MY,Yoshioka 05





Recent Developments

Extensions of model (relaxing R=35)

e.g. Abe, Higaki, Kobayashi 05

μ and $B\mu$ problem

Choi, Jeong, Okumura 05

Choi, Jeong, Kobayashi, Okumura 05

Asaka, Yamaguchi (in preparation)

little hierarchy problem

Choi, Jeong, Kobayashi, Okumura 06

Kitano, Nomura 06

Collider signatures (LHC)

Baer, Park, Tata, Wang 06

Kawagoe, Nojiri 06