Flux Compactification and SUSY Phenomenology

Komaba07
On occasion of Prof. Yoneya’s 60th birthday

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Talk Plan

• Introduction: Flux compactification and KKLT set-up
• Naturalness Problem of Weak Scale
• Warped Superstring Compactification
• SUSY phenomenology: mirage mediation
String Theory

Candidates for
1) Quantum Gravity (Yoneya)

2) Ultimate Unified Theory
   - gauge structure
   - matter representations
   - generations
   - Yukawa couplings
   - secret of weak scale

→ I will discuss possible implications to TeV scale physics.
Moduli Stabilization: A long-standing problem

• Moduli/Dilaton Stabilization
  – Moduli have not been stabilized at tree level.
  – Non-perturbative effects important

• Why moduli?
  – structure of compact dimensions
  – gauge & matter structure

• if light moduli
  – SUSY breaking
  – Cosmological implications
Gaugino condensate: runaway potential

\[ W \sim M_{Pl}^3 \exp(-aS) \]

exponential superpotential
\[ \rightarrow \text{runaway scalar potential} \]

How to avoid runaway?
race track: multiple gaugino condensates
non-perturbative corrections to Kaehler potential

\[ \cdots \cdots \]
Flux Compactifications

- Switch on Fluxes: $H_{(3)}$ and $F_{(3)}$ type IIB side
- Consistent solution
- Complex moduli & dilaton are stabilized

\[
T_\alpha: \quad \text{Kaehler moduli} \\
\bar{z}_i: \quad \text{complex moduli} \\
S = -i\tau: \quad \text{dilaton}
\]
• IIB superstring
  – 2-form potential (NS-NS, RR) \( B_{(2)}, C_{(2)} \)
  – 3-form field strength \( H_{(3)} = dB_{(2)}, F_{(3)} = dC_{(2)} \)

• superpotential for IIB theory

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

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

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

• complex moduli

\[
z_i = \int_{A_i} \Omega, \quad g_i(z) = \int_{B_i} \Omega
\]

• quantization of fluxes

\[
\frac{1}{(2\pi)^2\alpha'} \int_{A,B} H_{(3)} = \text{integer}, \quad \frac{1}{(2\pi)^2\alpha'} \int_{A,B} F_{(3)} = \text{integer}
\]
\[ W = \sum_i \left[ \int_{A_i} \Omega \int_{B_i} G_{(3)} + \int_{B_i} \Omega \int_{A_i} G_{(3)} \right] \]
\[ = \sum_i \left[ z_i \int_{B_i} G_{(3)} + g_i(z) \int_{A_i} G_{(3)} \right] \]

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

- Consistent solution for flux compactifications in IIB
  - fluxes → warped throat (Klebanov-Strassler throat) (Giddings-Kachru-Polchinski 02)
  - \( W \) stabilizes complex moduli as well as dilaton
  - Kaehler moduli are not stabilized by fluxes
KKLT set-up

Kachru-Kallosh-Linde-Trivedi 03

• Potential for Kaehler moduli:
  ⇐ non-perturbative effects
  e.g. gaugino condensate on D7 brane

• case of single overall moduli:
  \[ T = R^4 + i \cdots \] \( R \): 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
• Constant term in Superpotential
  → simplest way to avoid runaway behavior

• T modulus stabilized but with SUSY AdS vacuum
• Up-lifting of the scalar potential
  – Adding SUSY breaking sector
  – Minkowski, SUSY broken vacuum

• KKLT: anti-D3 on top of warped throat
• Dynamical SUSY breaking sector on D-branes can also be OK
Naturalness of Weak Scale

- Why is weak scale much smaller than Planck scale?
- How is weak scale stabilized against radiative corrections?

- Proposed Solutions:
  - Low energy supersymmetry
  - Large/Warped extra dimensions
  - Unknown strong dynamics

- Ingredients in string theory. Question is which plays a crucial role.
Warped Extra Dimension vs Low Energy SUSY in KKLT set-up

Similar set-up with different flux configurations and SM-brane configuration

Macroscopically (phenomenologically) important information: $w_0$, warp factor

$\Rightarrow$ warped extra dim. and low-E SUSY

large $w_0$ strong warping

small $w_0$ mild warping
LHC (Large Hadron Collider) Experiment

pp collider at CERN
Center of mass energy = 14 TeV
Starts 2007!
Expects new physics discovery at TeV scale
Warped Superstring Compactification at LHC

- Graviton Kaluza-Klein modes
  - Masses and Couplings different from those of Randall-Sundrum model
    (Geometry of Klebanov-Strassler throat is very different from $\text{AdS}_5 \times X$ near top of warped throat)

- Resonances via Drell-Yan process
  → Probe of (warped) extra dimension

Drell-Yan cross section at LHC for $\text{AdS}_5 \times S^1/Z_2$

Davoudiasl-Hewett
-Rizzo ‘02

Noguchi, Yamashita & MY 04
Implications to Low-E SUSY

• Original Motivation of KKLT: realization of dS vacuum in string theory

• Simple KKLT set-up can also provide a new mediation mechanism of SUSY breaking.

• mixed modulus anomaly mediation = mirage mediation

Choi-Falkowski-Nilles - Olechowski-Pokorski 04,05
Endo-MY-Yoshioka 05
Choi-Jeong-Okumura 05
Phenomenology with KKLT-like model

\[ K = -n \ln(T + T^*) \quad W = w_0 - Ae^{-aT} \]

SUSY breaking sector added to uplift potential

Overall SUSY breaking characterized by gravitino mass: \( m_{3/2} \approx w_0 \)

SUSY breaking effect of Moduli T: \( F_T/ReT \approx m_{3/2}/(8\pi^2) \)

suppressed by one-loop factor
Gaugino Masses

Consider SM on D7 brane

Gauge kinetic function \( f_7 = T \)

Gaugino Mass

\[
M_i = \frac{F_T}{2T_R} + \frac{\beta g_i}{g_i} F_\phi = \frac{F_T}{2T_R} + \frac{\beta g_i^2}{16\pi^2} F_\phi \quad \text{@GUT scale}
\]

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

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

moduli+anomaly mediation:

two contributions comparable
Gaugino Masses

\[ R \equiv \frac{F_\phi}{F_T/2\text{Re}T} \]

For \( R \sim 35 \) (KKLT),
\[ M_1 : M_2 : M_3 \sim 1 : 1.3 : 2 \]

cf.
\[ M_1 : M_2 : M_3 \sim 1 : 2 : 7 \]

(mSUGRA)
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

- Compact Sparticle Mass Spectrum
- small $\mu$ parameter ($\sim M_1$)
  $\leftarrow$ small gluino mass/ RGE
- LSP(lightest superparticle): 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)

Endo-MY-Yoshioka 05
Choi-Jeong-Okumura 05
Mass Spectrum: Case Study

$n=1, l=1/3$

$n=3, l=0$

(KKLT)

Endo, MY, Yoshioka 05
Conclusions

• Moduli Stabilization: Flux compactification
• Implications to Weak Scale Stabilization
• warped superstring compactification
• low-E SUSY: mirage mediation

• LHC will provide crucial information beyond SM, and hopefully structure of unified theory.