

Title: Moduli stabilization and flavor structure in 5D SUGRA with multi moduli

Date: Jun 05, 2008 03:15 PM

URL: <http://pirsa.org/08060153>

Abstract: Moduli stabilization, SUSY breaking and flavor structure are discussed in 5D gauged supergravity models with two vector-multiplet moduli fields. One modulus field makes the fermion mass hierarchy while the other is relevant to the SUSY breaking mediation. We analyse the potential for the moduli from the viewpoint of the 4D effective theory to obtain the stabilized values of the moduli and their F-terms.

Introduction

Problems in Standard Model

- gauge hierarchy problem  SUSY?
 - Yukawa hierarchy  flavor sym., extra dim., ...
 - Charge quantization
 - Anomaly cancellation
- ⋮
- }
- 
- GUT?

SUSY flavor problem

$$\mathcal{L}_{\text{Yukawa}} = y_{ij}^u H_2 u_i q_j + \dots$$

$$\begin{aligned}\mathcal{L}_{\text{soft}} = & -A_{ij}^u H_2 \tilde{u}_i \tilde{q}_j - \dots \\ & -m_{ij}^{2(\tilde{u})} \tilde{u}_i^\dagger \tilde{u}_j - m_{ij}^{2(\tilde{q})} \tilde{q}_i^\dagger \tilde{q}_j - \dots\end{aligned}$$

Sfermion mass matrix:

$$m^{2(\tilde{f})} = \begin{pmatrix} m_{LL}^{2(\tilde{f})} & m_{LR}^{2(\tilde{f})} \\ m_{LR}^{2(\tilde{f})\dagger} & m_{RR}^{2(\tilde{f})} \end{pmatrix}, \quad (\tilde{f} = \tilde{u}, \tilde{d}, \tilde{e})$$

3x3 matrix

mass basis of **fermion** \neq mass basis of **sfermion**
(off-diagonal elements)  **FCNC**

Simple solution

$$\left. \begin{array}{l} m_{LL}^{2(\tilde{f})} \propto 1_3 \\ m_{RR}^{2(\tilde{f})} \propto 1_3 \end{array} \right\} \text{ degeneracy}$$

$$m_{LR}^{2(\tilde{f})} \propto m^{(f)} \quad (\text{i.e., } A_{ij}^f \propto y_{ij}^f) \quad \text{proportionality}$$

Then,

$$\tilde{m}_{LL}^{2(\tilde{u})} = V_q^\dagger m_{LL}^{2(\tilde{u})} V_q \propto 1_3,$$

$$\tilde{m}_{RR}^{2(\tilde{u})} = V_u^\dagger m_{RR}^{2(\tilde{u})} V_u \propto 1_3,$$

$$\tilde{m}_{LR}^{2(\tilde{u})} = V_u^\dagger m_{LR}^{2(\tilde{u})} V_q \propto \text{diag}(m_u, m_c, m_t)$$

No contribution to FCNC

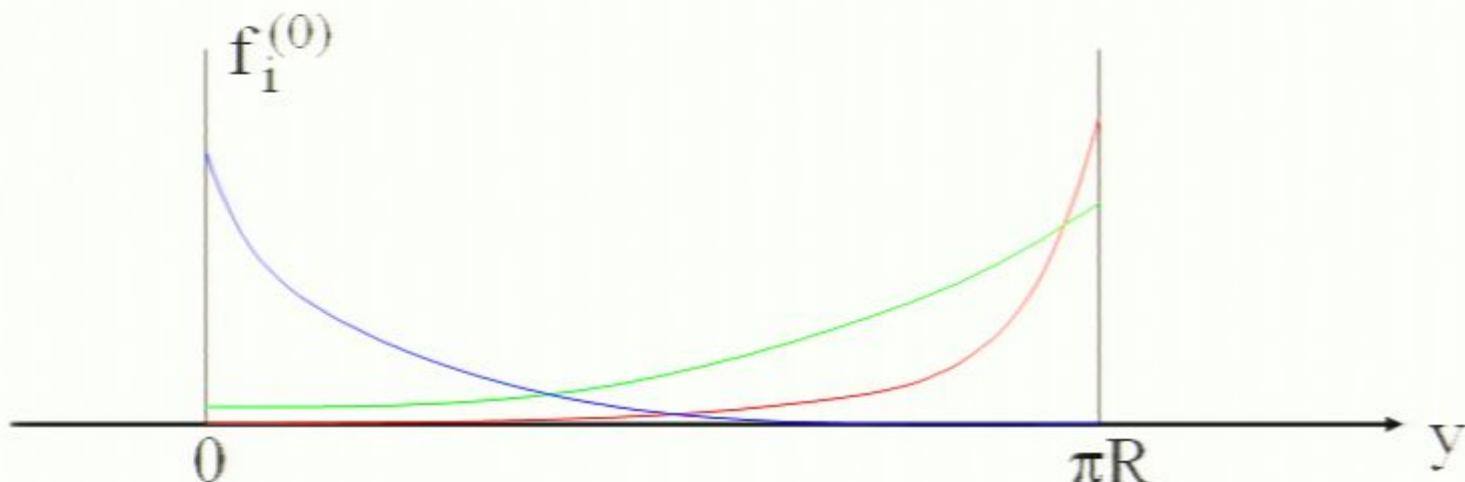
Yukawa hierarchy from extra dimension

(Kaplan & Tait, JHEP 0111 (2001) 051;...)

zero-mode: $f_i^{(0)}(y) = N_i e^{\textcolor{red}{m_i} y}$

\downarrow
5D mass

e.g.) $m_k < 0 < \textcolor{green}{m_j} < \textcolor{red}{m_i}$

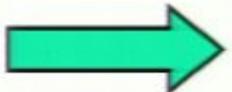


In 5D SUGRA,

$$\pi R \rightarrow \text{Re } T$$

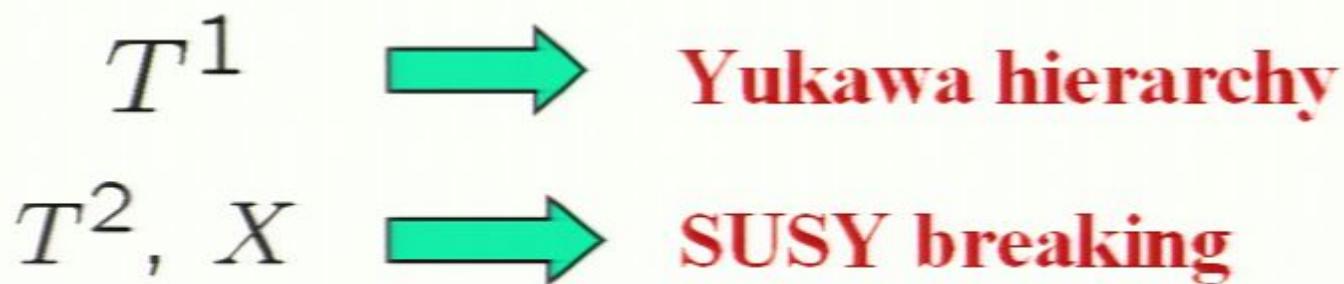
T : Radion (chiral) multiplet

$T|_{\theta=0}$  **Yukawa hierarchy**

F^T  **Flavor-dependent
SUSY breaking**

(e.g. Scherk-Schwarz SUSY breaking)

5D SUGRA with Multi moduli (T^1, T^2)



cf.) In string context,
“Mirror mediation”, Conlon, JHEP0803 (2008) 025

5D (off-shell) SUGRA on S^1/Z_2

(Kugo & Ohashi, 2000-2002)

Field content

- Weyl multiplet: (e_M^A, ψ_M^i, \dots)
- Vector multiplet: (V^I, Σ^I)
(One of them is the graviphoton multiplet.)
- Hypermultiplet:
 $(\Phi, \Phi^c), (Q_i, Q_i^c)$
compensator physical

Norm function

$$\mathcal{N}(M) = C_{IJK} M^I M^J M^K$$

where $M^I \equiv \text{Re}\Sigma^I|_{\theta=0}/e_y^4$

T^I = zero-mode of Σ^I

Radius: $\pi R = \mathcal{N}^{1/3}(\text{Re}\langle T \rangle)$

Single modulus case:

$$\pi R = \text{Re}\langle T \rangle$$

T is the radion multiplet.

5D Lagrangian

$$\mathcal{L} = \int d^2\theta \left\{ -\frac{\mathcal{N}_{IJ}}{4}(\Sigma) W^J W^K + \dots \right\} + \text{h.c.}$$

bulk part

$$- 3 \int d^4\theta \mathcal{N}^{1/3} (-\partial_y V + 2\text{Re}\Sigma) \left\{ |\Phi|^2 + |\Phi^c|^2 \right.$$

$$\left. - \sum_i \left(\bar{Q}_i e^{-2\mathbf{m}_i V^I} Q_i + \bar{Q}_i^c e^{2\mathbf{m}_i V^I} Q_i^c \right) \right\}^{2/3}$$

$$- 2 \int d^2\theta \left\{ \Phi^c \partial_y \Phi - \sum_i Q_i^c \left(\partial_y - \mathbf{m}_i \Sigma^I \right) Q_i \right\} + \text{h.c.}$$

$$+ \int d^2\theta \Phi^2 \left\{ W^{(0)} \left(\frac{Q}{\Phi} \right) \delta(y) + W^{(\pi)} \left(\frac{Q}{\Phi} \right) \delta(y - \pi R) \right\} + \text{h.c.}$$

$$+ \dots$$

5D Lagrangian

$$\begin{aligned}
 \mathcal{L} = & \int d^2\theta \left\{ -\frac{\mathcal{N}_{IJ}}{4}(\Sigma) W^J W^K + \dots \right\} + \text{h.c.} \\
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 & \quad \left. - \sum_i \left(\bar{Q}_i e^{-2\mathbf{m}_i V^I} Q_i + \bar{Q}_i^c e^{2\mathbf{m}_i V^I} Q_i^c \right) \right\}^{2/3} \\
 & - 2 \int d^2\theta \left\{ \Phi^c \partial_y \Phi - \sum_i Q_i^c \left(\partial_y - \mathbf{m}_i \Sigma^I \right) Q_i \right\} + \text{h.c.} \\
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 & + \dots
 \end{aligned}$$

bulk part

(gauge coupling) = (bulk mass)

5D Lagrangian

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 & + \dots
 \end{aligned}$$

bulk part

(gauge coupling) = (bulk mass)

5D SUGRA with multi moduli

Field content

Vector multiplet:

$$(V^1, \Sigma^1), \quad (V^2, \Sigma^2)$$

Hypermultiplet: $m_i \downarrow \quad \downarrow m_X \quad m_H \downarrow$ gauging

$$(Q_i, Q_i^c), \quad (X, X^c), \quad (H, H^c)$$

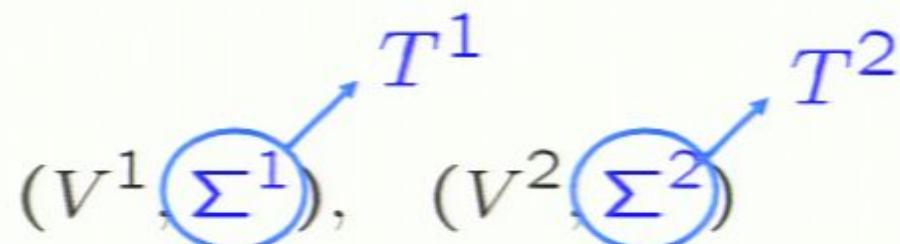
Orbifold parity

V^1	Σ^1	V^2	Σ^2	Q_i	Q_i^c	H	H^c	X	X^c
-	+	-	+	+	-	+	-	+	-

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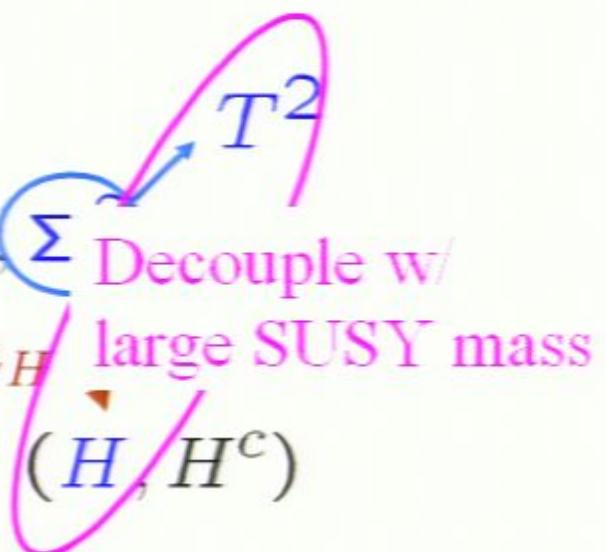
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Hypermultiplet: $m_i \downarrow$ m_X m_H Decouple w/
large SUSY mass

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Orbifold parity

V^1	Σ^1	V^2	Σ^2	Q_i	Q_i^c	H	H^c	X	X^c
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5D SUGRA with multi moduli

Field content

Vector multiplet:

$$(V^1, \Sigma^1)$$

Yukawa hierarchy

Hypermultiplet: $m_i \downarrow$

$$(Q_i, Q_i^c)$$

$$T^1$$

$$m_X$$

$$(V^2, \Sigma^2)$$

$$m_H$$

$$T^2$$

$$m_{H^c}$$

Decouple w/
large SUSY mass

$$(X, X^c)$$

$$\cancel{\text{SUSY}}$$

$$(H, H^c)$$

Orbifold parity

V^1	Σ^1	V^2	Σ^2	Q_i	Q_i^c	H	H^c	X	X^c
-	+	-	+	+	-	+	-	+	-

4D effective theory

(cf. H.Abe & Y.S., PRD75 (2007) 025018)

$$\left\{ \begin{array}{l} \Omega \equiv -3e^{-K/3} \\ = -3N^{1/3}(\text{Re}T) + \sum_i Y_i(\text{Re}T, X) |Q_i|^2 + \dots, \\ W = W_{\text{stb}} + \sum_{ijk} \lambda_{ijk} Q_i Q_j Q_k + \dots \end{array} \right.$$

Soft ~~SUSY~~ parameters

$$\left\{ \begin{array}{l} m_{\text{soft}i}^2 = -F^\alpha \bar{F}^{\bar{\beta}} \partial_\alpha \partial_{\bar{\beta}} \ln Y_i, \\ A_{ijk} = -y_{ijk} F^\alpha \partial_\alpha \ln (Y_i Y_j Y_k) \end{array} \right.$$

physical Yukawa coupling

$$Y_i(\text{Re}T, X) = \mathcal{N}^{1/3} \left\{ \frac{e^{2m_i \text{Re}T^1} - 1}{m_i \text{Re}T^1} + \tilde{Y}_{iX}(\text{Re}T) |X|^2 \right\}$$

Single modulus case

(cf. H.Abe's talk)

$$\tilde{Y}_{iX}(\text{Re}T) = \mathcal{N}^{1/3} \cdot \frac{e^{2(\textcolor{blue}{m}_i + m_X) \text{Re}T} - 1}{6(\textcolor{blue}{m}_i + m_X) \text{Re}T}$$

tachyonic soft masses from F^X

4D effective theory

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Multi moduli case

$$\begin{aligned} \tilde{Y}_{iX}(\text{Re}T) &= \frac{\mathcal{N}\mathcal{N}_{11}}{3\mathcal{N}\mathcal{N}_{11} - 2\mathcal{N}_1^2} \frac{e^{2(m_i + m_X)\text{Re}T^1} - 1}{(m_i + m_X)\text{Re}T^1} \\ &\quad - \frac{\mathcal{N}_1^2(e^{2m_i \text{Re}T^1} - 1)(e^{2m_X \text{Re}T^1} - 1)}{3(3\mathcal{N}\mathcal{N}_{11} - 2\mathcal{N}_1^2)m_i \text{Re}T^1 \cdot m_X \text{Re}T^1} \end{aligned}$$

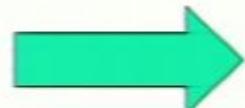
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If the second term of \tilde{Y}_{iX} dominates and $|F^X| \gg |F^{T^1}|$,

$$\begin{cases} m_{\text{soft}i}^2 & : \text{ } i\text{-independent} \\ A_{ijk} & \propto y_{ijk} \end{cases}$$



No SUSY flavor problem

e.g.) $\mathcal{N} = (\text{Re}T^1)^2 \text{Re}T^2,$

$$W_{\text{stb}} = \left(J_0 - J_\pi e^{-m_H T^2} \right) H$$
$$+ c - A e^{-a T^1} + \mu^2 X.$$

$$\left(c, \mu^2 \ll 1, \quad a = \mathcal{O}(4\pi^2), \quad (\text{others}) = \mathcal{O}(1) \right)$$

vacuum

$$\begin{cases} \text{All moduli are stabilized.} \\ |F^X| \gg |F^{T^1}|, |F^{T^2}| \end{cases}$$

In this case,

$$\tilde{Y}_{Xi}(\text{Re}T) = \hat{\mathcal{N}}\hat{\mathcal{N}}_{11} \left\{ \frac{e^{2(m_i+m_X)\text{Re}T^1} - 1}{(m_i + m_X)\text{Re}T^1} - \frac{(e^{2m_i\text{Re}T^1} - 1)(e^{2m_X\text{Re}T^1} - 1)}{3m_i\text{Re}T^1 \cdot m_X\text{Re}T^1} \right\}$$

When $e^{2m_i\text{Re}T^1} \gg 1$ and $e^{2m_X\text{Re}T^1} \ll 1$,
the second term dominates.



- Positive soft squared masses
- No SUSY flavor problem

In this case,

from KK vector multiplets

$$\tilde{Y}_{Xi}(\text{Re}T) = \hat{\mathcal{N}}\hat{\mathcal{N}}_{11} \left\{ \frac{e^{2(m_i+m_X)\text{Re}T^1} - 1}{(m_i + m_X)\text{Re}T^1} - \frac{(e^{2m_i\text{Re}T^1} - 1)(e^{2m_X\text{Re}T^1} - 1)}{3m_i\text{Re}T^1 \cdot m_X\text{Re}T^1} \right\}$$

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- Positive soft squared masses
- No SUSY flavor problem

Physical vector multiplets

Vector multiplets ($I=1, 2, \dots, n$)

$$\begin{aligned} V^I &= (W_\mu^I, \Omega_1^I, \dots) && : \text{parity-odd} \\ \Sigma^I &= (e_y^{-4} M^I + i W_y^I, \dots) && : \text{parity-even} \end{aligned}$$

Physical vector multiplets

Vector multiplets ($I=1, 2, \dots, n$)

$$\begin{array}{ll} V^I = (W_\mu^I, \Omega_1^I, \dots) & : \text{parity-odd} \\ T^I \leftarrow \text{green arrow} \Sigma^I = (e_y^{-4} M^I + i W_y^I, \dots) & : \text{parity-even} \end{array}$$

Physical vector multiplets

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Superconformal gauge-fixing

$$\begin{cases} \mathcal{N}(M) = 1, \\ \mathcal{N}_I(M) \Omega_i^I = 0. \end{cases}$$

Physical vector multiplets

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Superconformal gauge-fixing

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(# of physical vector multiplets) = $n-1$

Summary

5D SUGRA with multi moduli (T^1, T^2)

Radius: $\pi R = \mathcal{N}^{1/3}(\text{Re}\langle T \rangle)$

T^1  **Yukawa hierarchy**

T^2, X  **SUSY breaking**

Additional contribution to the Kahler potential can save

- **Tachyonic sfermion masses at tree level**
- **SUSY flavor problem**

Microsoft PowerPoint - [PASCOS08_sakamura]

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Outline Slides

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(One of them is the graviphoton multiplet.)
- Hypermultiplet:

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Summary

5D SUGRA with multi moduli (T^1, T^2)

Radius: $\pi R = N^{1/3}(\text{Re}(T))$

$T^1 \rightarrow$ Yukawa hierarchy

$T^2, X \rightarrow$ SUSY breaking

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