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LARGE volume scenario in 5D SUGRA

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based on arXiv:JHEP11(2013)090 & work in progress
in collaboration with Yutaka Sakamura (KEK)

Introduction

Low scale SUSY is a possible candidate for new physics.

e.g. dark matter, gauge hierarchy, etc…

The order parameter of the SUSY breaking is gravitino mass $m_{3/2}$

$$m_{3/2} = \langle e^{K/2} W \rangle$$

$$W = W_0 + \cdots$$

If the constant term is forbidden only by the global R symmetry,
the constant term can arise from the gravitational effects !

To realize low scale SUSY breaking, we have to tune the constant term W_0

Introduction

LARGE volume scenario (LVS)
in string theory

Moduli stabilization: exponentially large extra dimension

SUSY breaking: The scale is much smaller than the Planck scale

Without fine-tuned small constant term !

V. Balasubramanian, P. Berglund, J. P. Conlon, and F. Quevedo (2005)

J. P. Conlon, F. Quevedo, and K. Suruliz (2005)

LVS was constructed in the string theory.

Our question: Can we realize the LVS in a simple set-up?

In this talk, I will show

- Realization of the LVS in effective theory of 5D SUGRA model
- Possible mass spectrum in 5D LVS

Multiple moduli in 5D SUGRA

General 5D SUGRA on S^1/Z_2 → General 4D effective theory
reduction

T. Kugo and K. Ohashi (2001)

5D vector multiplet → 4D vector multiplet
→ 4D chiral multiplet

* Only the vector or the chiral multiplet has its zero-mode.

Zero mode of the chiral mutiplet = moduli multiplet

Multiple moduli in 5D SUGRA

General 5D SUGRA on S^1/Z_2 → General 4D effective theory

reduction

T. Kugo and K. Ohashi (2001)

5D vector multiplet → 4D vector multiplet

→ 4D chiral multiplet = moduli multiplet

Well known set-up : one modulus

= radion

Multiple moduli in 5D SUGRA

General 5D SUGRA on S^1/Z_2 → (reduction) General 4D effective theory

T. Kugo and K. Ohashi (2001)

5D vector multiplet → 4D vector multiplet

5D vector multiplet → 4D chiral multiplet = moduli multiplet

General set-up : multiple moduli

= radion + non-geometric moduli

H. Abe, H. Otsuka, Y. Sakamura and Y.Y (2011)

The norm function and Kahler potential in 5D SUGRA

The size of the extra dim. → $L_{\mathrm{phys}} = \langle \mathcal{N}^{\frac{1}{3}} \rangle$

$$\mathcal{N} = C_{IJK} \mathrm{Re} T^I \mathrm{Re} T^J \mathrm{Re} T^K$$

The norm function and Kahler potential in 5D SUGRA

The size of the extra dim. ⟶ $L_{\rm phys} = \langle \mathcal{N}^{\frac{1}{3}} \rangle$

$$\mathcal{N} = C_{IJK}{\rm Re}T^I{\rm Re}T^J{\rm Re}T^K$$

$$\text{Kähler potential: } K = -\log \mathcal{N}$$

$$K_I K^{I\bar{J}} K_{\bar{J}} = 3$$

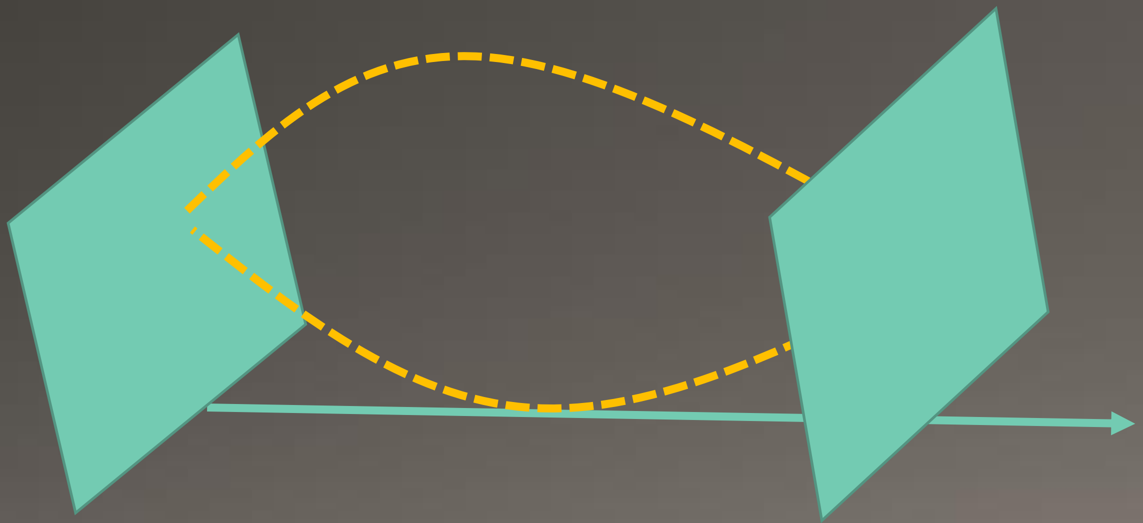
(no-scale relation)

The norm function and Kahler potential in 5D SUGRA

The size of the extra dim. → $L_{\rm phys} = \langle \mathcal{N}^{\frac{1}{3}} \rangle$

$$\mathcal{N} = C_{IJK} {\rm Re} T^I {\rm Re} T^J {\rm Re} T^K$$

1-loop corrected Kähler potential: $K = -\log(\mathcal{N} + \xi)$



$$K_I K^{I\bar{J}} K_{\bar{J}} = 3 + \frac{6\xi}{\hat{\mathcal{N}}} + \cdots$$

LVS in 5D SUGRA

$$K = -\log(\mathcal{N} + \xi) \qquad W = W_0 + Ae^{-aT_s}$$

where

$$a = \mathcal{O}(4\pi^2)$$

$$W_0 = \mathcal{O}(M_{pl}^3)$$

$$\mathcal{N} = (\mathrm{Re}T_b)^3 - C_s(\mathrm{Re}T_s)^3$$

$T_b = \tau_b + i\rho$ ~ radion

$T_s = \tau_s + i\sigma$ ~non-geometric modulus

Moduli stabilization

$$V \sim \frac{1}{\mathcal{N}}\left(\frac{2\mathcal{N}}{3C_s\tau_s}(aA)^2 e^{-2a\tau_s} + 4a\tau_s W_0 A e^{-a\tau_s}\cos(a\sigma)\right) + \frac{6\xi W_0^2}{\mathcal{N}^2}$$

$$= \frac{2(aA)^2}{3C_s\tau_s}e^{-2a\tau_s} + 4a\tau_s W_0 A\cos(a\sigma)\frac{e^{-a\tau_s}}{\mathcal{N}} + 6\xi W_0^2\frac{1}{\mathcal{N}^2}$$

Non-perturbative term ~ Volume suppressed term

$$\langle\mathcal{N}\rangle \sim \frac{3\xi W_0 e^{a\langle\tau_s\rangle}}{a\langle\tau_s\rangle A} \qquad \langle\tau_s\rangle \sim \left(\frac{\xi}{C_s}\right)^{\frac{1}{3}}$$

$$L_{\text{phys}} = \langle\mathcal{N}^{\frac{1}{3}}\rangle \gg 1$$ (In Planck unit)

Exponentially large extra dimension!

Uplifting the vacuum

To realize the almost vanishing cosmological constant, an extra SUSY breaking effect is needed.

We assume the SUSY breaking sector X

$$\langle V_{\rm AdS}\rangle = -\frac{27\xi W_0^2}{2(a\langle\tau_s\rangle)^2\hat{\mathcal{N}}^2} \quad \Rightarrow \quad |F^X|^2 = K^{-1}_{X\bar{X}}|\langle V_{\rm AdS}\rangle|$$

The relative size of the F-term differ from the Kahler metric of X

$$|F^X| \sim \begin{cases} \dfrac{m_{3/2}}{(\log\mathcal{N})\mathcal{N}^{1/2}} & (\ X \text{ lives in the bulk }) \\[2ex] \dfrac{m_{3/2}}{(\log\mathcal{N})\mathcal{N}^{1/3}} & (\ X \text{ lives on a brane}) \end{cases}$$

SUSY breaking in 5D LVS

Gravitino mass: $m_{3/2} = \langle e^{K/2} W \rangle \sim \frac{W_0}{\sqrt{\mathcal{N}}} \sim \mathcal{O}(M_{pl}/\sqrt{\mathcal{N}}) \ll M_{pl}$

F-terms:

$$\frac{F^{T_b}}{T_b + \bar{T}_b} \sim \frac{W_0}{\sqrt{\mathcal{N}}} = m_{3/2}$$

$$\frac{F^{T_s}}{T_s + \bar{T}_s} \sim \frac{W_0}{(a\tau_s)\sqrt{\mathcal{N}}} \sim \frac{m_{3/2}}{\log \mathcal{N}}$$

$$\frac{F^X}{M_{pl}} \sim \begin{cases} \mathcal{O}\left(\frac{m_{3/2}}{(\log \mathcal{N})\mathcal{N}^{1/3}}\right) & \text{(on Brane)} \\ \mathcal{O}\left(\frac{m_{3/2}}{(\log \mathcal{N})\mathcal{N}^{1/2}}\right) & \text{(in the bulk)} \end{cases}$$

Small SUSY breaking scale can be realized naturally!

Anomaly mediation in 5D LVS

$$\frac{F^\phi}{\phi} = \frac{m_{3/2}}{\mathcal{N}} \ll m_{3/2}$$

Anomaly mediation is much suppressed by the leading no-scale structure.

M.A. Luty and N. Okada (2002)
N. Arkani-Hamed and S. Dimopoulos (2005)

Soft terms of the bulk fields

The 4D effective action of the bulk fields

$$\int d^4\theta |\phi|^2 \Omega + \int d^2\theta f^{(r)} \mathcal{W}_\alpha \mathcal{W}^\alpha + \text{h.c.} + \cdots$$

where

$$\Omega = \cdots + 2\mathcal{N}^{1/3} Y_a(T_b, T_s)|Q_a|^2 + \cdots$$

$$f^r = C^r_s T_s$$

$$Y_a(T_b, T_s) = \frac{1 - e^{-2c_{aI}\mathrm{Re}T^I}}{2c_{aI}\mathrm{Re}T^I}$$

→

Scalar mass	Gaugino mass
$m_a \sim m_{3/2}$	$M_r \sim \frac{m_{3/2}}{\log \mathcal{N}}$

$$\log \mathcal{N} \sim \mathcal{O}(10)$$

This spectrum is similar to ones of the pure gravity mediation and mini-split SUSY.

M. Ibe and T. T. Yanagida (2011)

N. Arkani-Hamed, A. Gupta, D. E. Kaplan, N. Weiner, and T. Zorawski (2012)

Soft terms of the brane fields

We assume the following couplings between brane localized sector and X

$$\int d^4\theta |\phi|^2 \Omega_b + \int d^2\theta f_b^{(R)} \mathcal{W}_\alpha \mathcal{W}^\alpha + \text{h.c.} + \cdots$$

$$\Omega_b = h_A \left(1 - \frac{\zeta(3)}{8\pi^2 \mathcal{N}}\right) |q^A|^2 - \kappa_{AX} |q^A|^2 |X|^2$$

$$f_b^{(R)} = f_0^R + k_X X$$

Scalar mass

$$m_A \sim \begin{cases} \dfrac{m_{3/2}}{\mathcal{N}^{1/2}} \\ \dfrac{m_{3/2}}{(\log \mathcal{N}) \mathcal{N}^{1/3}} \end{cases}$$

Gaugino mass

$$M_R \sim \begin{cases} \dfrac{m_{3/2}}{(\log \mathcal{N}) \mathcal{N}^{1/2}} & (X \text{ in the bulk}) \\ \dfrac{m_{3/2}}{(\log \mathcal{N}) \mathcal{N}^{1/3}} & (X \text{ on the brane}) \end{cases}$$

Soft terms of the brane fields

We assume the following couplings between brane localized sector and X

$$\int d^4\theta |\phi|^2 \Omega_b + \int d^2\theta f_b^{(R)} \mathcal{W}_\alpha \mathcal{W}^\alpha + \text{h.c.} + \cdots$$

$$\Omega_b = h_A \left(1 - \frac{\zeta(3)}{8\pi^2 \mathcal{N}}\right)$$

$$f_b^{(R)} = f_0^R + k_X X$$

Mini-splitting as in the previous case

Scalar mass

Gaugino mass

$$m_A \sim \begin{cases} \dfrac{m_{3/2}}{\mathcal{N}^{1/2}} \\ \dfrac{m_{3/2}}{(\log \mathcal{N})\mathcal{N}^{1/3}} \end{cases} \qquad M_R \sim \begin{cases} \dfrac{m_{3/2}}{(\log \mathcal{N})\mathcal{N}^{1/2}} & (X \text{ in the bulk}) \\ \dfrac{m_{3/2}}{(\log \mathcal{N})\mathcal{N}^{1/3}} & (X \text{ on the brane}) \end{cases}$$

Summary

We construct the LVS in 5D SUGRA
and show the patterns of mass spectrum in this model.

- General set-up of 5D SUGRA → multi-moduli
- Casimir term →breaking the no-scale relation

- Mass spectrum of the brane matters depends on the SUSY breaking sector
- Mini-splitting between the scalars and gauginno mass is realized in some cases

Thank you.

Appendix

The value of ξ

$$\xi \equiv \frac{(\bar{n}_H - n_V - 1)\zeta(3)}{32\pi^2}$$

n_V : The number of the vector multiplets

$\bar{n}_H$: The effective number of the hypermultiplets

where

$$\bar{n}_H = \sum_a n_a \frac{\mathcal{Z}(d_a \cdot \mathrm{Re}T/2)}{\mathcal{Z}(0)} \qquad \mathcal{Z}(x) = -\int_0^\infty d\lambda \lambda \ln\left(2e^{-\sqrt{\lambda^2+x^2}} \sinh\sqrt{\lambda^2+x^2}\right)$$

Multiplets in 4D effective theory

	5D vector multiplet (even)		5D vector multiplet(odd)		Hypermultiplet	
4D multiplet	V^I Vector	$\tilde{T}^I$ chiral	$\tilde{V}^{I'}$ vector	$T^{I'}$ chiral	Q_a chiral	Q'_a chiral
parity	$+$	$-$	$-$	$+$	$+$	$-$
Zero mode	V^I			$T^{I'}$	Q_a	
Role in 4D	vector (gauge)			moduli	matter	

KK mass & moduli masses

Gravitino mass: $m_{3/2} = \frac{W_0}{\sqrt{\mathcal{N}}} \sim \mathcal{O}(M_{pl}/\sqrt{\mathcal{N}})$

KK mass & Moduli mass: $m_{\tau_b} \sim \frac{m_{3/2}}{\sqrt{\mathcal{N}}} \qquad m_\rho \sim 0$

$$m_{\tau_s} \sim m_\sigma \sim (\log \mathcal{N}) m_{3/2} \qquad m_{KK} \sim \frac{M_{pl}}{\mathcal{N}^{1/3}}$$

$$\Rightarrow \quad M_{pl} \gg m_{KK} \gg m_{3/2}$$

Analysis by the effective theory is valid !