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LARGE volume scenario in 5D SUGRA

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based on arXiv:1307.5585
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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 parameters !

But the sring theoretical effects and the non-trivial geometry are required…

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

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

Introduction

Q. Can we realize the LVS with the simpler theory?

A. Yes,

I'll show that the LVS can be realized

in the 5D supergravity on S^1/Z_2

without the stringy effects.

Multiple moduli in 5D SUGRA

General 5D SUGRA on S^1/Z_2 $\xrightarrow{\text{reduction}}$ General 4D effective theory

T. Kugo and K. Ohashi (2001)

5D vector multiplet → 4D vector multiplet

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

Well known set-up : one modulus

= radion

Multiple moduli in 5D SUGRA

General 5D SUGRA on S^1/Z_2 $\xrightarrow{\text{reduction}}$ General 4D effective theory

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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. $\Longrightarrow$ $L_{\text{phys}} = \langle \mathcal{N}^{\frac{1}{3}} \rangle$

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

The norm function and Kahler potential in 5D SUGRA

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

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

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

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

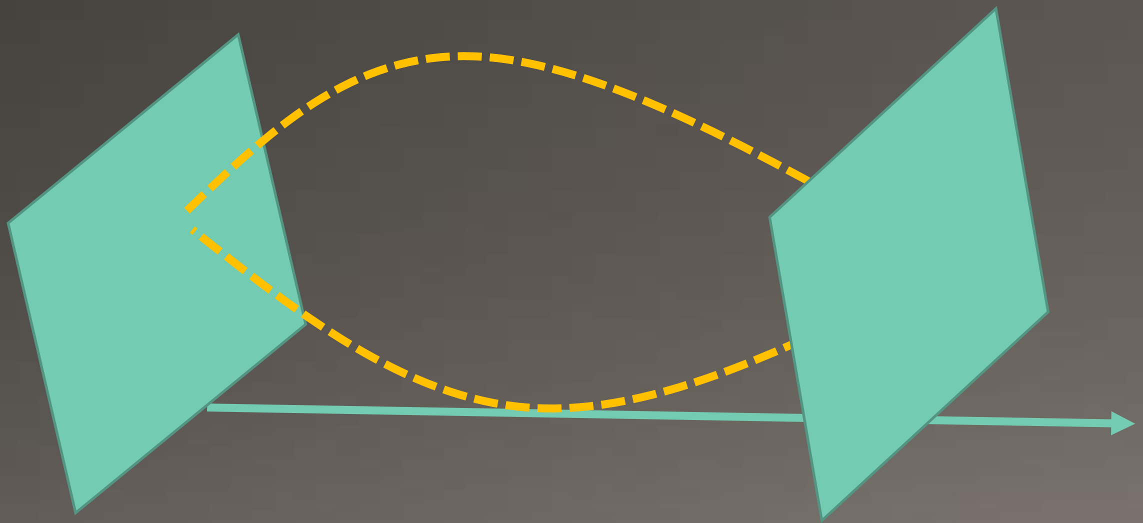
(no-scale relation)

The norm function and Kahler potential in 5D SUGRA

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

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

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 vs Volume suppressed term

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

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

Exponentially large extra dimension!

SUSY breaking in 5D LVS

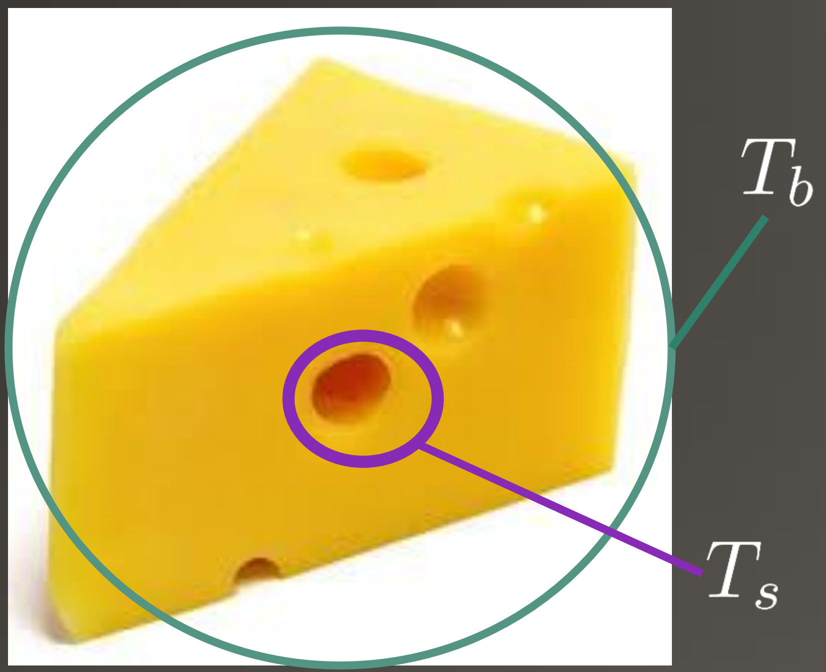
Gravitino mass: $m_{3/2} = \frac{W_0}{\sqrt{\mathcal{N}}} \sim \mathcal{O}(M_{pl}/\sqrt{\mathcal{N}}) \ll M_{pl}$

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

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

Small SUSY breaking scale can be realized naturally!

Comparison of the 5D LVS with the string LVS



``Swiss-cheese" Calabi- Yau manifold

$$\mathcal{V} = (T_b + \bar{T}_b)^{3/2} - (T_s + \bar{T}_s)^{3/2}$$

$$K = -2\log(\mathcal{V} + \xi)$$ ← α′-correction

5D LVS		Stringy LVS
Non-geometric modulus	⟷	Small cycle modulus
Casimir effect	⟷	α′ correction

Summary

We construct the LVS in 5D SUGRA without stringy effects.

- General set-up of 5D SUGRA $\longrightarrow$ multi-moduli
- Casimir term $\longrightarrow$ role of the α' correction in string theory

Future work

Construction of a realistic model in 5D LVS
(Dark matter, inflation, Higgs mass...etc)

Thank you.

Appendix

Anomaly mediation in 5D LVS

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

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)

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

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

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

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

Analysis by the effective theory is valid !