LARGE volume scenario in 5D SUGRA models

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Introduction

In STRING THEORY,
LARGE volume scenario (LVS) [1] was suggested as a model which naturally realizes an exponentially large extra dimensions and may solve the hierarchy problem .

[1] J.P.Conlon et al. JHEP 0508,007 (2005)

$m_{\rm soft} \sim \mathcal{O}(1{\rm TeV})$ from Planck scale parameters without fine-tunings!!

cf. KKLT scenario requires a fine-tuned small parameter.

The important ingredients in this scenario are

- multi-moduli (at least two),
- breaking of the no scale structure $K_I K^{I\bar{J}} K_{\bar{J}} = 3$ by the α' correction.

We show that LVS can be realized in 5D supergravity without stringy effects.

Set-up

In the well investigated 5D SUGRA models on S^1/Z_2 orbifold, there is only a single modulus multiplet (radion multiplet).

However,
in general, there are multi-moduli multiplets from 5D vector multiplets.

5D multiplet	Hypermultiplet		Vector multiplet			
Role in 4D	matter		vector		moduli	
Superfield in 4D	$\mathcal{Q}_a$ (chiral)	$\mathcal{Q}^c_a$ (chiral)	V^{I_e} (vector)	Σ^{I_e} (chiral)	V^{I_o} (vector)	Σ^{I_o} (chiral)
Z_2 parity	$+$	$-$	$+$	$-$	$-$	$+$
Zero mode	Q_a		V^{I_e}			T^{I_o}

The number of moduli multiplets and their Kahler potential are determined by the norm function $\hat{\mathcal{N}}$.

Model

$$K = -\log(\hat{\mathcal{N}} + \xi)$$

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

$$W = W_0 + Ae^{-aT_s}$$

ξ : correction from 1 -loop effects
(The role of this correction is same as the α' correction in stringy LVS.)

$$K_I K^{I\bar{J}} K_{\bar{J}} = 3 + \frac{6\xi}{\hat{\mathcal{N}}}\left(1 + \frac{C_s\tau_s^3}{3\xi}\epsilon(1+\frac{\epsilon}{12})\right)$$ (Broken no-scale relation)

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

n_V: number of vector multiplets
$\bar{n}_H$: effective number of hypermultiplets

(Detailed derivation of 1-loop effects can be found in Ref.[2].)

[2] Y. Sakamura, Nucl. Phys.B 873,165 (2013)

$T_b = \tau_b + i\rho \sim$ Radion

$T_s = \tau_s + i\sigma \sim$ Non-geometric modulus

Stabilization

$$V = e^K(D_I W K^{I\bar{J}} D_{\bar{J}}\bar{W} - 3|W|^2)$$
$$\sim \frac{1}{\hat{\mathcal{N}}}\left(\frac{2\hat{\mathcal{N}}}{3C_s\tau_s(1-\frac{\delta}{6})}(aA)^2 e^{-2a\tau_s} + 4a\tau_s(1+\frac{\epsilon}{6})W_0 A e^{-a\tau_s}\cos(a\sigma)\right)$$
$$+\frac{6\xi W_0^2}{\hat{\mathcal{N}}^2}\left(1 + \frac{C_s\tau_s^3}{3\xi}\epsilon + \frac{C_s\tau_s^3}{36\xi}\epsilon^2\right)$$

minimization

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

$$L_{\rm phys} = \langle\hat{\mathcal{N}}^{1/3}\rangle \gg 1$$

The size of the extra dimension is exponentially larger than the Planck length.

Moduli & KK mass

$$m_{KK} \sim \frac{1}{L_{\rm phys}} \sim \mathcal{O}\left(\frac{1}{\hat{\mathcal{N}}^{1/3}}\right)$$

$$m_{\tau_b} \sim \mathcal{O}\left(\frac{1}{\langle\hat{\mathcal{N}}\rangle}\right)$$

$$m_{\tau_s} \sim \mathcal{O}\left(\frac{\ln\langle\hat{\mathcal{N}}\rangle}{\langle\hat{\mathcal{N}}\rangle}\right)$$

Gravitino mass & F-terms

$$m_{3/2} \sim \frac{W_0}{\langle\sqrt{\hat{\mathcal{N}}}\rangle} \quad \frac{\langle F^{T_b}\rangle}{\langle T_b + \bar{T}_b\rangle} \sim \frac{W_0}{\sqrt{\langle\hat{\mathcal{N}}\rangle}} = m_{3/2} \quad \frac{\langle F^{T_s}\rangle}{\langle T_s + \bar{T}_s\rangle} \sim \frac{W_0}{\sqrt{\langle(a\tau_s)\hat{\mathcal{N}}\rangle}} = \frac{m_{3/2}}{\langle a\tau_s\rangle}$$

Soft terms

$$\mathcal{L} = \int d^4\theta|\phi_C|^2(\Omega_{\rm bulk} + \Omega_{\rm brane}) + \left[\int d^2\theta\phi^3 W + {\rm h.c.}\right]$$
$$-\left[\int d^2\theta\frac{1}{2}f^r{\rm tr}(\mathcal{W}_r^2) + {\rm h.c.}\right]$$

$$\Omega_{\rm bulk} = \mathcal{Y}_a|Q_a|^2 + \cdots \qquad \Omega_{\rm brane} = h_q|q|^2\left(1 - \frac{\zeta(3)}{8\pi^2\hat{\mathcal{N}}}\right) + \cdots$$

1-loop correction

$$f^r = \begin{cases} c^r T_s & ({\rm bulk}) \\ {\rm const} & ({\rm brane}) \end{cases}$$

$$\mathcal{Y}_a = 2\hat{\mathcal{N}}^{1/3}\frac{1-e^{-2d_a\cdot{\rm Re}T}}{2d_a\cdot{\rm Re}T}$$

h_q does not depend on the moduli.

※ In this scenario, the anomaly mediation is extremely suppressed by the leading no-scale relation. $\frac{\langle F^{\phi_C}\rangle}{\langle\phi_C\rangle} \sim \frac{m_{3/2}}{\langle\hat{\mathcal{N}}\rangle}$

	Gaugino (bulk)	Scalar (bulk)	Scalar (brane)
Soft mass	$M^r = F^I\partial_I\ln({\rm Re}f^r)$ $\sim \frac{m_{3/2}}{\langle a\tau_s\rangle}$	$m_{Q_a} = \sqrt{-F^I F^{\bar{J}}\partial_I\partial_{\bar{J}}\ln\mathcal{Y}_a}$ $\sim m_{3/2}$	$m_q = \sqrt{-F^I F^{\bar{J}}\partial_I\partial_{\bar{J}}h_q\left(1-\frac{\zeta(3)}{8\pi^2\hat{\mathcal{N}}}\right)}$ $\sim \frac{m_{3/2}}{\langle\sqrt{\hat{\mathcal{N}}}\rangle}$

sample $(\xi, C_s, W_0/A, a) = (0.1, 0.8, 1, 8\pi^2)$ $L_{\rm phys} = \langle\hat{\mathcal{N}}^{1/3}\rangle \sim 10^5$
(in Planck unit)

$M^r \sim 10^{-9} = \mathcal{O}(10^9)[{\rm GeV}]$ $\quad m_{Q_a} \sim \mathcal{O}(10^{10})[{\rm GeV}]$ $\quad m_q \sim \mathcal{O}(10^3)[{\rm GeV}]$

Summary

General set-up of 5D SUGRA contains non-geometric moduli and they give new possibility for the model buildings.

e.g. LVS can be realized with
non-geometric moduli
&
1-loop correction.

Another application of the non-geometric moduli model was studied in Ref.[3]. In Ref.[3], we focused on SUSY flavor structure.

[3] H.Abe, H.Otsuka, Y.Sakamura and Y.Yamada, Eur. Phys. J. C 72, 2018 (2012)