Exponentially suppressed cosmological constant with enhanced gauge symmetry in heterotic interpolating models

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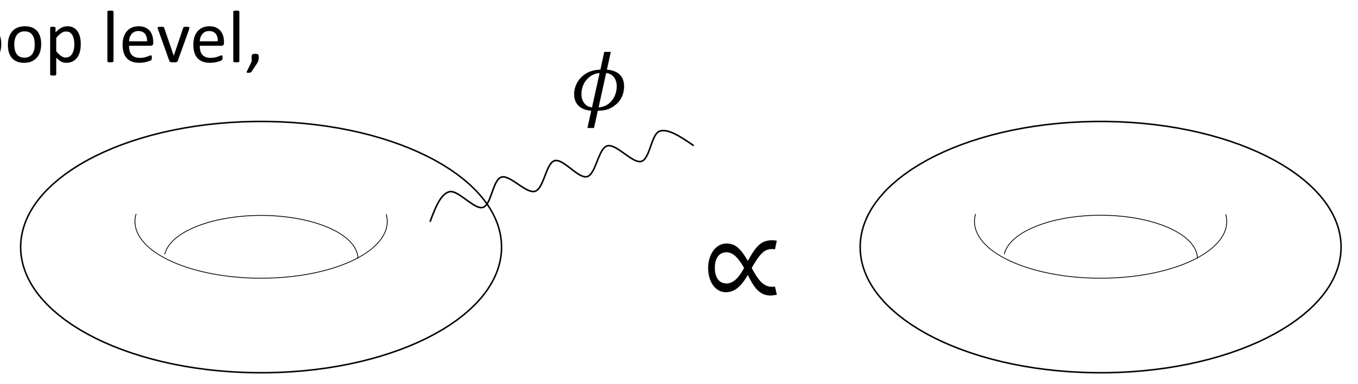
Based on arXiv: 1905.10745 with H. Itoyama

Introduction

Non-supersymmetric string models are generally unstable because of non-vanishing dilaton tadpoles;

At 1-loop level,

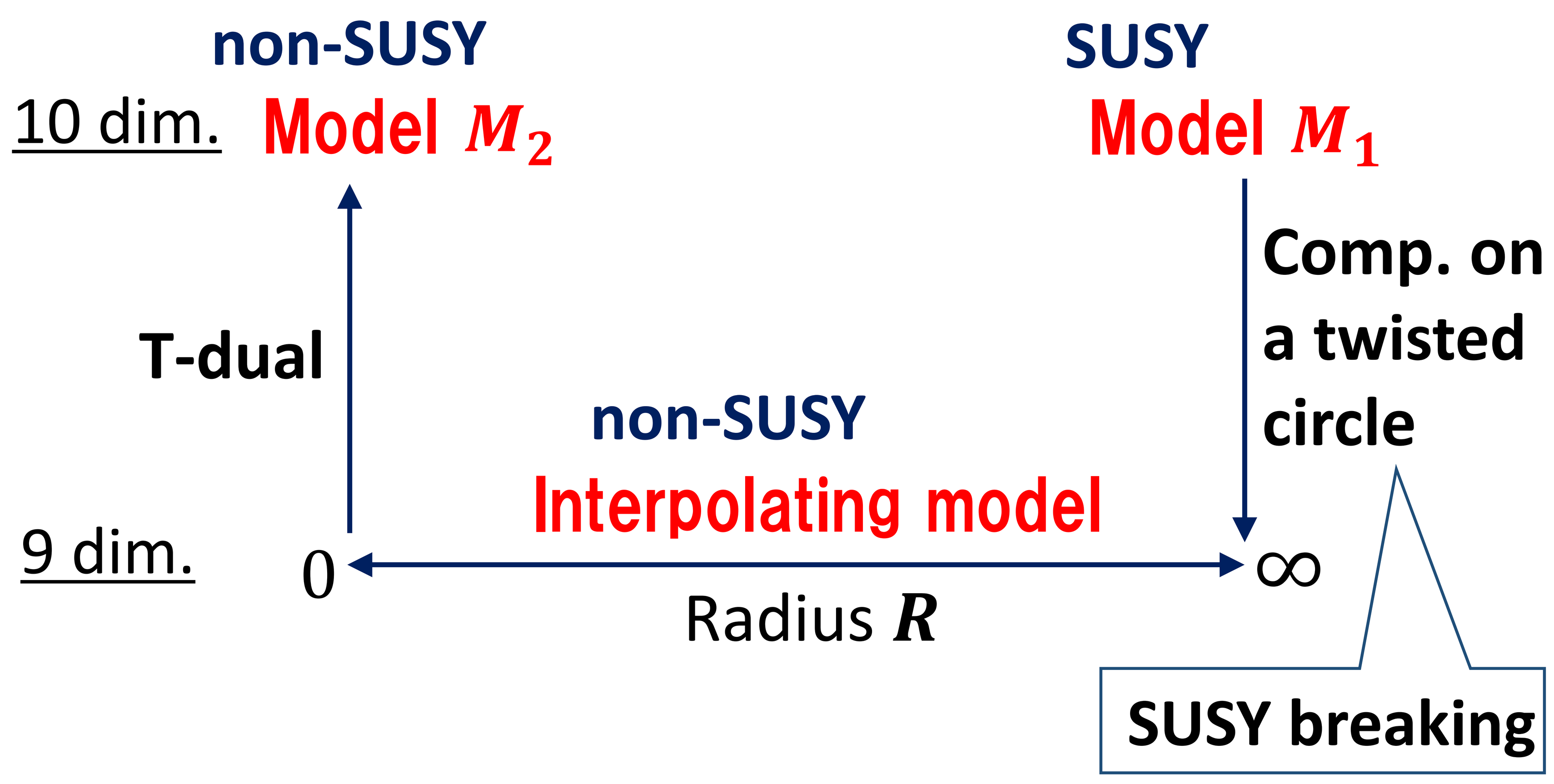


The desired model is a non-supersymmetric one whose **cosmolosical constant is vanishing or as small as possible.**

Interpolating models have the possibility of such properties. [Itoyama, Taylor, (1987)]

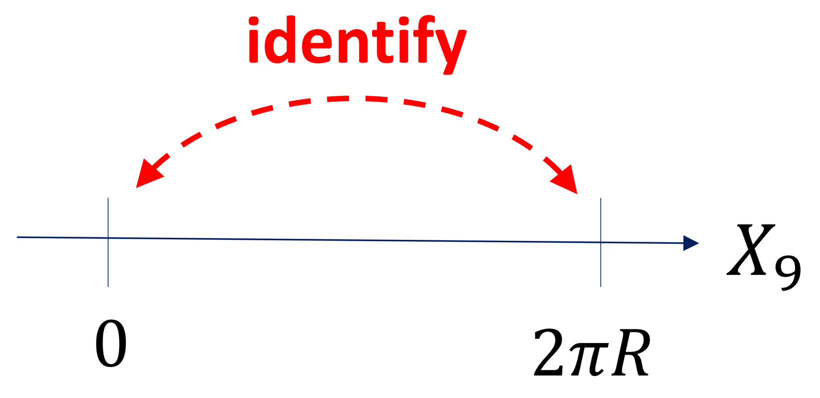
Interpolating models

An interpolating model is a lower dimensional string model relating two different higher dimensional string models continuously;



SUSY breaking by Compactification

- **Compactification on a circle**



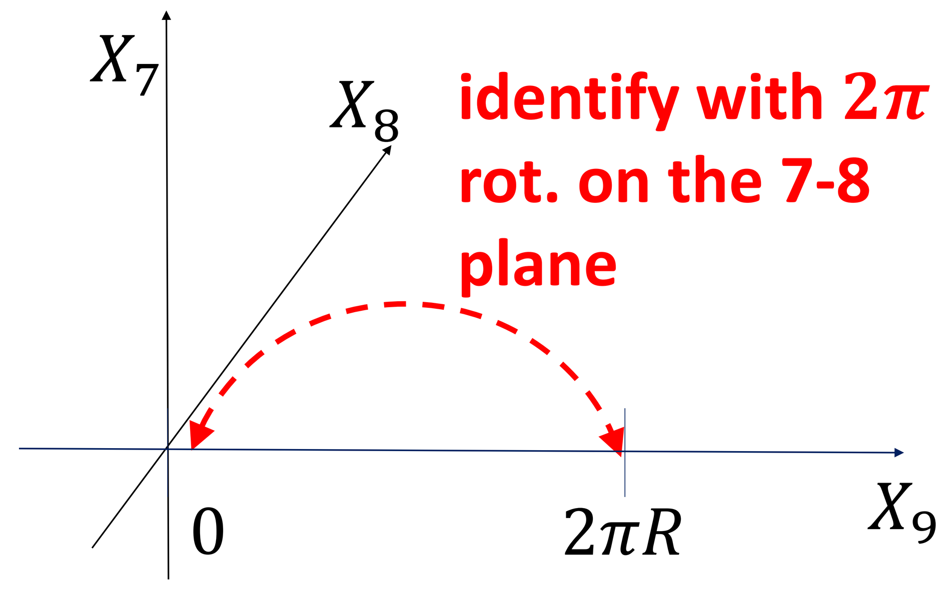
The translation operator for X_9 satifies

$$e^{2\pi i P_9 R} = 1$$

$$\therefore P_9 = \frac{n}{R} \quad (n \in \boldsymbol{Z})$$

➡ **SUSY is NOT broken**

- **Compactification on a twisted circle**



The translation operator for X_9 satifies

$$e^{2\pi i P_9 R} = e^{2\pi i J_{78}}$$

$$\therefore P_9 = \frac{n + \frac{F}{2}}{R} \quad (n \in \boldsymbol{Z})$$

➡ **SUSY is broken** [Rohm, (1984)]

In the large R (small a) region, the cosmological constant is

$$\Lambda_9 \simeq (n_F - n_B)\, a^{-9} \xi + \mathcal{O}\left(e^{-a^{-2}}\right)$$

$a = \sqrt{\alpha'}/R,\ n_F,\ n_B$: # of massless fermions, bosons

If $n_F = n_B$, the cosmological constant is exponentially suppressed. [Itoyama, Taylor, (1987)]

Ex). Interpolation between $SO(32)$ and $SO(16) \times SO(16)$

- **The one-loop partition function**

$$\begin{aligned} Z_{\text{int}}^{(9)} = Z_B^{(7)} \{ & \Lambda_{0,0} \left[\bar{V}_8 (O_{16}O_{16} + S_{16}S_{16}) - \bar{S}_8 (V_{16}V_{16} + C_{16}C_{16}) \right] \\ & + \Lambda_{1/2,0} \left[\bar{V}_8 (V_{16}V_{16} + C_{16}C_{16}) - \bar{S}_8 (O_{16}O_{16} + S_{16}S_{16}) \right] \\ & + \Lambda_{0,1/2} \left[\bar{O}_8 (V_{16}C_{16} + C_{16}V_{16}) - \bar{C}_8 (O_{16}S_{16} + S_{16}O_{16}) \right] \\ & + \Lambda_{1/2,1/2} \left[\bar{O}_8 (O_{16}S_{16} + S_{16}O_{16}) - \bar{C}_8 (V_{16}C_{16} + C_{16}V_{16}) \right] \} \end{aligned}$$

$$\begin{aligned} \Lambda_{\alpha,\beta} &= (\bar{\eta}\eta)^{-1} \sum_{n,w} \bar{q}^{\alpha' p_R^2/2} q^{\alpha' p_L^2/2} \\ &= (\bar{\eta}\eta)^{-1} \sum_{n,w} \exp\left[2\pi i n w \tau_1 - \pi \tau_2 \left(n^2 a^2 + w^2/a^2 \right) \right] \end{aligned}$$

where the sum is taken over

$$n \in 2(\boldsymbol{Z} + \alpha), \quad w \in \boldsymbol{Z} + \beta$$

- **The limiting cases**

  - $R \to \infty$: the contribution from zero winding # only;

$$\Lambda_{\alpha,0} \to (2a)^{-1} Z_B^{(1)}, \quad \Lambda_{\alpha,1/2} \to 0$$

➡ **The 1st and 2nd lines survive**

  - $R \to 0$: the contributions from zero momentum only;

$$\Lambda_{0,\beta} \to a Z_B^{(1)}, \quad \Lambda_{1/2,\beta} \to 0$$

➡ **The 1st and 3rd lines survive**

$Z_{\text{int}}^{(9)}$ realizes
- SUSY $SO(32)$ model in $R \to \infty$
- $SO(16) \times SO(16)$ model in $R \to 0$

- **Massless spectrum**

For generic *R*, massless states come from the *n=w=0* parts (1st line);

Massless bosons

- **graviton, anti-symmetric tensor, dilaton**
- **Gauge bosons in adj rep of $SO(16) \times SO(16)$**

Massless fermions

- **$8_S \otimes (16, 16)$**

$$\Rightarrow \quad n_F - n_B = 64$$

Boost on momentum lattice

After turning on WL, the momenta of $X_L^{I=1}$, $X_L^{a=9}$ and $X_R^{a=9}$ are changed as

boost and rotation

$$\begin{cases} l_L = \frac{1}{\sqrt{\alpha'}} m \\ p_L = \frac{1}{\sqrt{2\alpha'}}\left(an + \frac{w}{a}\right) \\ p_R = \frac{1}{\sqrt{2\alpha'}}\left(an - \frac{w}{a}\right) \end{cases} \Rightarrow \begin{cases} l'_L = \frac{1}{\sqrt{2\alpha'}}\left(\sqrt{2}m - 2\frac{A}{\sqrt{1+A^2}}\frac{w}{a}\right) \\ p'_L = \frac{1}{\sqrt{2\alpha'}}\left(\sqrt{2}Am + \sqrt{1+A^2}an - \frac{1-A^2}{\sqrt{1+A^2}}\frac{w}{a}\right) \\ p'_R = \frac{1}{\sqrt{2\alpha'}}\left(\sqrt{2}Am + \sqrt{1+A^2}an - \sqrt{1+A^2}\frac{w}{a}\right) \end{cases}$$

The effective change in the 1-loop partition function is

Turning on WL

$$\Lambda_{\alpha,\beta}(a)\left(\frac{\vartheta\begin{bmatrix}\gamma\\ \delta\end{bmatrix}}{\eta}\right)^8 \Rightarrow \Lambda^{(\alpha,\beta)}_{(\gamma,\delta)}(a,A)\left(\frac{\vartheta\begin{bmatrix}\gamma\\ \delta\end{bmatrix}}{\eta}\right)^7$$

$$\Lambda^{(\alpha,\beta)}_{(\gamma,\delta)} = (\bar{\eta}\eta)^{-1}\eta^{-1}\sum_{n,w,m}(-1)^{2\delta m} q^{\frac{\alpha'}{2}(l'^2_L + p'^2_L)}\bar{q}^{\frac{\alpha'}{2}p'^2_R}$$

$$\left(n \in 2(Z+\alpha),\ w \in Z+\beta,\ m \in Z+\gamma\right)$$

- **The fundamental region of moduli space**

It is convenient to introduce a modular parameter $\tilde{\tau}$ as

$$\tilde{\tau} = \tilde{\tau}_1 + i\tilde{\tau}_2 = \frac{A}{\sqrt{1+A^2}}a^{-1} + i\frac{1}{\sqrt{1+A^2}}a^{-1}$$

The momentum lattice $\Lambda^{(\alpha,\beta)}_{(\gamma,\delta)}$ is invariant under the shift

$$\tilde{\tau} \to \tilde{\tau} + 2\sqrt{2}$$

➡ **The fundamental region of moduli space is**

$$-\sqrt{2} \le \tilde{\tau}_1 \le \sqrt{2}$$

Ex1). Interpolation between $SO(32)$ and $SO(16) \times SO(16)$ with WL

- **The one-loop partition function**

$$\begin{aligned} Z^{(9)}_{\rm int} = Z^{(7)}_B \Big\{ &\bar{V}_8\left(O^{(0,0)}_{16}O_{16} + S^{(0,0)}_{16}S_{16}\right) - \bar{S}_8\left(V^{(0,0)}_{16}V_{16} + C^{(0,0)}_{16}C_{16}\right) \\ &+\bar{V}_8\left(V^{(1/2,0)}_{16}V_{16} + C^{(1/2,0)}_{16}C_{16}\right) - \bar{S}_8\left(O^{(1/2,0)}_{16}O_{16} + S^{(1/2,0)}_{16}S_{16}\right) \\ &+\bar{O}_8\left(V^{(0,1/2)}_{16}C_{16} + C^{(0,1/2)}_{16}V_{16}\right) - \bar{C}_8\left(O^{(0,1/2)}_{16}S_{16} + S^{(0,1/2)}_{16}O_{16}\right) \\ &+\bar{O}_8\left(O^{(1/2,1/2)}_{16}S_{16} + S^{(1/2,1/2)}_{16}O_{16}\right) - \bar{C}_8\left(V^{(1/2,1/2)}_{16}C_{16} + C^{(1/2,1/2)}_{16}V_{16}\right)\Big\} \end{aligned}$$

$$\begin{pmatrix} O^{(\alpha,\beta)}_{16} \\ V^{(\alpha,\beta)}_{16}\end{pmatrix} = \frac{1}{2\eta^7}\left(\Lambda^{(\alpha,\beta)}_{(0,0)}\vartheta\begin{bmatrix}0\\0\end{bmatrix}^7 \pm \Lambda^{(\alpha,\beta)}_{(0,1/2)}\vartheta\begin{bmatrix}0\\1/2\end{bmatrix}^7\right)$$

$$\begin{pmatrix} S^{(\alpha,\beta)}_{16} \\ C^{(\alpha,\beta)}_{16}\end{pmatrix} = \frac{1}{2\eta^7}\left(\Lambda^{(\alpha,\beta)}_{(1/2,0)}\vartheta\begin{bmatrix}1/2\\0\end{bmatrix}^7 \pm \Lambda^{(\alpha,\beta)}_{(1/2,1/2)}\vartheta\begin{bmatrix}1/2\\1/2\end{bmatrix}^7\right)$$

- **Massless spectrum**

For generic *R*, massless states come from the *n=w=0* parts (1st line);

Massless bosons

- **graviton, anti-symmetric tensor, dilaton**
- **Gauge bosons in adj rep of $SO(16) \times SO(14) \times U(1)$**

Massless fermions

- $\mathbf{8}_S \otimes (\mathbf{16}, \mathbf{14})$

We found a few conditions under which the additional massless states appear:

Condition	$\tilde{\tau}_1 = n_1/\sqrt{2}$ $(n_1 \in 2Z)$	$\tilde{\tau}_1 = n_2/\sqrt{2}$ $(n_2 \in 2Z+1)$
Additional states	· two $\mathbf{8}_V \otimes (\mathbf{1}, \mathbf{14})$ · two $\mathbf{8}_S \otimes (\mathbf{16}, \mathbf{1})$	· two $\mathbf{8}_V \otimes (\mathbf{16}, \mathbf{1})$ · two $\mathbf{8}_S \otimes (\mathbf{1}, \mathbf{14})$
Gauge group	$\mathbf{SO(16) \times SO(16)}$	$\mathbf{SO(18) \times SO(14)}$
Leading term	$n_F - n_B = 64$	$n_F - n_B = 0$

Ex2). Interpolation between $E_8 \times E_8$ and $SO(16) \times SO(16)$ with WL

- **The one-loop partition function**

$$\begin{aligned} Z^{(9)}_{\rm int} = Z^{(7)}_B \Big\{ &\bar{V}_8\left(O^{(0,0)}_{16}O_{16} + S^{(0,0)}_{16}S_{16}\right) - \bar{S}_8\left(O^{(0,0)}_{16}S_{16} + S^{(0,0)}_{16}O_{16}\right) \\ &+\bar{V}_8\left(O^{(1/2,0)}_{16}S_{16} + S^{(1/2,0)}_{16}O_{16}\right) - \bar{S}_8\left(O^{(1/2,0)}_{16}O_{16} + S^{(1/2,0)}_{16}S_{16}\right) \\ &+\bar{O}_8\left(V^{(0,1/2)}_{16}C_{16} + C^{(0,1/2)}_{16}V_{16}\right) - \bar{C}_8\left(V^{(0,1/2)}_{16}V_{16} + C^{(0,1/2)}_{16}C_{16}\right) \\ &+\bar{O}_8\left(V^{(1/2,1/2)}_{16}V_{16} + C^{(1/2,1/2)}_{16}C_{16}\right) - \bar{C}_8\left(V^{(1/2,1/2)}_{16}C_{16} + C^{(1/2,1/2)}_{16}V_{16}\right)\Big\} \end{aligned}$$

- **Massless spectrum for generic *R***

Massless bosons

- **graviton, anti-symmetric tensor, dilaton**
- **Gauge bosons in adj rep of $SO(16) \times SO(14) \times U(1)$**

Massless fermions

- $\mathbf{8}_S \otimes (\mathbf{128}, \mathbf{1})$

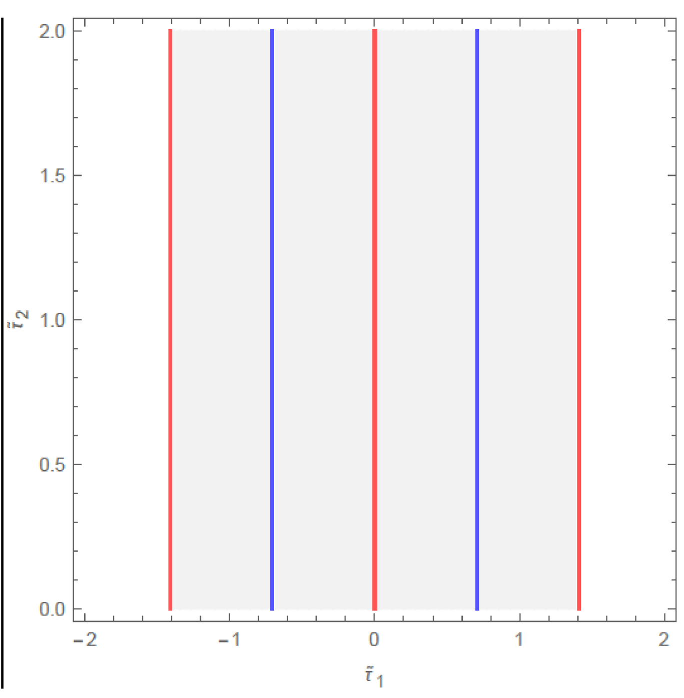
Condition	$\tilde{\tau}_1 = n_1/\sqrt{2}$ $(n_1/2 \in 2Z)$	$\tilde{\tau}_1 = n_1/\sqrt{2}$ $(n_1/2 \in 2Z+1)$	$\tilde{\tau}_1 = n_2/\sqrt{2}$ $(n_2 \in 2Z+1)$
Additional states	· two $\mathbf{8}_V \otimes (\mathbf{1}, \mathbf{14})$ · two $\mathbf{8}_S \otimes (\mathbf{16}, \mathbf{1})$	· two $\mathbf{8}_V \otimes (\mathbf{1}, \mathbf{14})$ · two $\mathbf{8}_V \otimes (\mathbf{16}, \mathbf{1})$	· two $\mathbf{8}_S \otimes (\mathbf{1}, \mathbf{14})$
Gauge group	$\mathbf{SO(16) \times SO(16)}$	$\mathbf{SO(16)} \times \boldsymbol{E_8}$	$\boldsymbol{SO(16) \times SO(14) \times U(1)}$
Leading term	$n_F - n_B = 64$	$n_F - n_B = -1984$	$n_F - n_B = -512$

The orbits in the fundamental region

In the fundamental region, there are only four inequivalent orbits on which the additional massless states appear;

- **Example 1).**

- $n_1 = 0$
- $n_1 = 2$ (or -2)
- $n_2 = 1$
- $n_2 = -1$



- **Example 2).**

- $n_1 = 0$
- $n_1 = 2$ (or -2)
- $n_2 = 1$
- $n_2 = -1$