Interpolation and cosmological constant in non-SUSY heterotic strings

Yuichi Koga

Osaka Metropolitan University

- Y.K., NPB 990 (2023) 116160
- H. Itoyama, Y.K. and Sota Nakajima, NPB 975(2022) 115667

String Phenomenology 2023 (IBS, Daejeon), 4 July

Introduction

■ Where is SUSY breaking scale?

- There is no evidence for SUSY in multi TeV scale according to the LHC.
- It is interesting to consider SUSY is already broken at very high energies.

■ We have more non-SUSY vacua than SUSY ones in 10D:

- Type IIA
- Type IIB
- Type I
- Heterotic $SO(32)$
- Heterotic $E_8 \times E_8$

- Type 0A
- Type 0B
- Heterotic $SO(32)$
- Heterotic $SO(16) \times E_8$
- Heterotic $SO(16) \times SO(16)$

- Heterotic $E_7^2 \times SU(2)^2$
- Heterotic $SO(24) \times SO(8)$
- ...

- difficulty: very large cosmological constant (vacuum energy density)

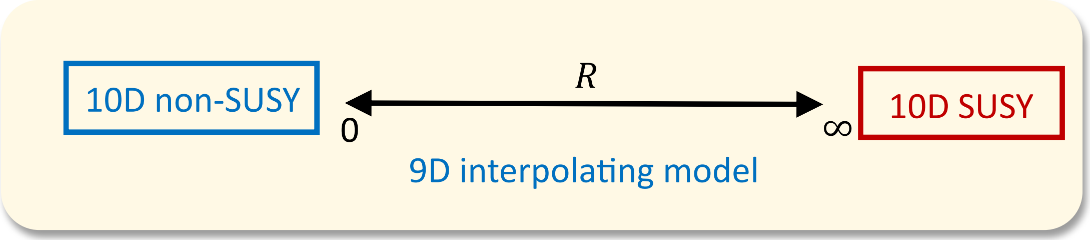
$$\Lambda^{(D)} \sim \mathcal{O}(M_s^D) \qquad M_s \text{ : string scale}$$

- We want to obtain small or vanishing cosmological const. without SUSY.

■ Our approach: "interpolating models"

- Low-dimensional models constructed by $\mathbb{Z}_2$ freely acting orbifolds
- The models are Non-SUSY where a radius R is finite.
- But SUSY can be restored in $R \to \infty$ (and/or 0) limits.

(Example)



Interpolate
between two 10D endpoints

■ In SUSY restored region ($R \approx \infty$),

$$\Lambda^{(9)} = \frac{\xi}{R^9}(n_F - n_B) + \mathcal{O}(e^{-R})$$

(ξ : positive constant
n_F, n_B : # (massless fermion,boson))

Itoyama, Taylor (1986)

➢ $n_F = n_B \Rightarrow$ exponentially suppressed cosmological constant

■ The general heterotic models constructed by $\mathbb{Z}_2$-twists:

- d-dim. compactified with #($\mathbb{Z}_2$-twisted directions) arbitrary
- With full set of moduli: $C_{ij} = G_{ij} + B_{ij}$ & A_i^I turned on

$$(i = 10 - d, \dots, 9\ , I = 1, \dots, 16)$$

(↔ with all marginal deformations considered)

➢Show various interpolation patterns in $d = 1, 2$

➢Find solutions of $n_F = n_B$ where cosmol. const. is exp. supp.

➢Analyze Wilson-line stability of the effective potential

Outline

1. Introduction
2. Non-SUSY heterotic strings with general Z_2 twists
3. Interpolation in 9D and 8D
4. Cosmological constant
5. Summary

Outline

1. Introduction
2. Non-SUSY heterotic strings with general Z_2 twists
3. Interpolation in 9D and 8D
4. Cosmological constant
5. Summary

Narain lattice of SUSY heterotic strings on T^d

- Modular inv. ⇒ internal momenta $P = Z\mathcal{E} \in \Gamma^{16+d,d}$
  - Narain lattice: even self-dual lattice w/ Lorentz. sign. $(16+d,d)$
  - Labeled by an integer vector $Z = (q, \underline{m}, \underline{n}) \in \boldsymbol{Z}^{16} \times \boldsymbol{Z}^{d} \times \boldsymbol{Z}^{d}$

    winding numbers (m)   KK momenta (n)

Narain lattice of SUSY heterotic strings on T^d

- Modular inv. ⇒ internal momenta $P = Z\mathcal{E} \in \Gamma^{16+d,d}$
  - Narain lattice: even self-dual lattice w/ Lorentz. sign. $(16+d,d)$
  - Labeled by an integer vector $Z = (q, \underline{m}, \underline{n}) \in \boldsymbol{Z}^{16} \times \boldsymbol{Z}^{d} \times \boldsymbol{Z}^{d}$

    winding numbers KK momenta
  - Turn on full moduli: $d(d+16) = d^2 + 16d \quad \Rightarrow \left(G_{ij} + B_{ij}\right)$ & A_i^I
  - Consider a rectangular d-torus: $G_{ij} = R_i^2 \delta_{ij}$

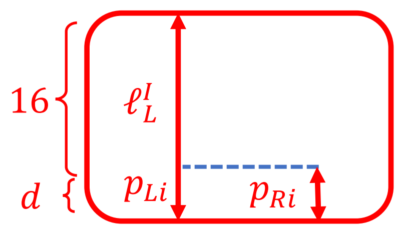
Narain lattice of SUSY heterotic strings on T^d

- Modular inv. ⇒ internal momenta $P = Z\mathcal{E} \in \Gamma^{16+d,d}$
  - Narain lattice: even self-dual lattice w/ Lorentz. sign. $(16+d, d)$
  - Labeled by an integer vector $Z = (q, \underline{m}, \underline{n}) \in \boldsymbol{Z}^{16} \times \boldsymbol{Z}^d \times \boldsymbol{Z}^d$
    winding numbers — KK momenta
  - Turn on full moduli: $d(d+16) = d^2 + 16d \quad \Rightarrow (G_{ij} + B_{ij})$ & A_i^I
  - Consider a rectangular d-torus: $G_{ij} = R_i^2 \delta_{ij}$

Narain, Sarmadi, Witten, (1986)

➢ $P = (\ell_L, p_L; p_R)$

$$\begin{cases} \ell_L^I = \pi^I - m^i A_i^I, \\ p_{Li} = \dfrac{1}{\sqrt{2}R_i}\left(\pi \cdot A_i + n_i + m^j \left(G_{ij} + B_{ij} - \dfrac{1}{2} A_i \cdot A_j\right)\right) \\ p_{Ri} = \dfrac{1}{\sqrt{2}R_i}\left(\pi \cdot A_i + n_i - m^j \left(G_{ij} - B_{ij} + \dfrac{1}{2} A_i \cdot A_j\right)\right) \end{cases}$$



$\pi^I \equiv q^I \alpha_{16} \in \underline{\Gamma^{16}} \Leftarrow Spin(32)/\boldsymbol{Z}_2$ or $E_8 \times E_8$ lattice

Construction of non-SUSY heterotic strings

- Z_2 freely acting orbifold (stringy Scherk-Schwarz comp.)
  - Project out SUSY hetero on T^d by $\frac{1+(-)^F\alpha}{2}$ (+ twisted sec. added)

    Z_2 generator : $(-)^F\alpha$
    - F: spacetime fermion #
    - α: shift of order 2 such as $\alpha\,|P\rangle = e^{2\pi i P\cdot\delta}\,|P\rangle$
  - δ is called a shift vector : $2\delta \in \Gamma^{16+d,d}$

Construction of non-SUSY heterotic strings

- Z_2 freely acting orbifold (stringy Scherk-Schwarz comp.)
  - Project out SUSY hetero on T^d by $\dfrac{1+(-)^F\alpha}{2}$ (+ twisted sec. added)

    Z_2 generator : $(-)^F\alpha$ $\begin{cases} F\text{: spacetime fermion \#} \\ \alpha\text{: shift of order 2 such as } \alpha\,|P\rangle = e^{2\pi i P\cdot\delta}\,|P\rangle \end{cases}$

  - δ is called a shift vector : $2\delta \in \Gamma^{16+d,d}$
    - labeled by a vector $\hat{Z} = \left(\hat{q}^I, \hat{m}^i, \hat{n}_i\right)$ whose components are 0 or 1

      → Non-SUSY strings depend on $\hat{Z}$
    - Splitting the Narain lattice $\Gamma^{16+d,d}$ into $\Gamma_+^{16+d,d}$ and $\Gamma_-^{16+d,d}$:

$$\Gamma_+^{16+d,d} = \left\{ P \in \Gamma^{16+d,d} \,\middle|\, \delta\cdot P \in \mathbb{Z} \right\}$$
$$\Gamma_-^{16+d,d} = \left\{ P \in \Gamma^{16+d,d} \,\middle|\, \delta\cdot P \in \mathbb{Z}+1/2 \right\}$$

$$\Rightarrow \alpha\,|P\rangle = \begin{cases} +\,|P\rangle & \text{for} \quad P \in \Gamma_+^{16+d,d} \\ -\,|P\rangle & \text{for} \quad P \in \Gamma_-^{16+d,d} \end{cases}$$

Construction of non-SUSY heterotic strings

- Z_2 freely acting orbifold (stringy Scherk-Schwarz comp.)
  - Project out SUSY hetero on T^d by $\frac{1+(-)^F\alpha}{2}$ (+ twisted sec. added)

    Z_2 generator : $(-)^F\alpha$ $\begin{cases} F\text{: spacetime fermion \#} \\ \alpha\text{: shift of order 2 such as } \alpha\,|P\rangle = e^{2\pi i P\cdot\delta}\,|P\rangle \end{cases}$

  - δ is called a shift vector : $2\delta \in \Gamma^{16+d,d}$
    - labeled by a vector $\hat{Z} = \left(\hat{q}^I, \hat{m}^i, \hat{n}_i\right)$ whose components are 0 or 1

      → Non-SUSY strings depend on $\hat{Z}$
    - Splitting the Narain lattice $\Gamma^{16+d,d}$ into $\Gamma_+^{16+d,d}$ and $\Gamma_-^{16+d,d}$:

$$\Gamma_+^{16+d,d} = \left\{ P \in \Gamma^{16+d,d} \,\middle|\, \delta \cdot P \in \mathbb{Z} \right\}$$
$$\Gamma_-^{16+d,d} = \left\{ P \in \Gamma^{16+d,d} \,\middle|\, \delta \cdot P \in \mathbb{Z} + 1/2 \right\}$$

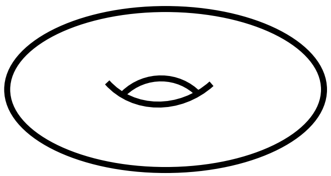
$$\Rightarrow \alpha\,|P\rangle = \begin{cases} +\,|P\rangle & \text{for} \quad P \in \Gamma_+^{16+d,d} \\ -\,|P\rangle & \text{for} \quad P \in \Gamma_-^{16+d,d} \end{cases}$$

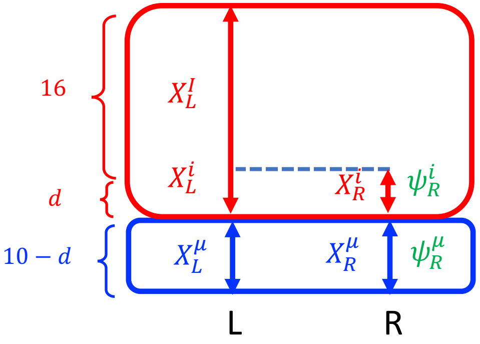
Bosons/Fermions live in $\Gamma_+^{16+d,d}$ / $\Gamma_-^{16+d,d}$ respectively → SUSY breaking

1-loop partition function

- Heterotic strings on T^d (with maximal SUSY)

$$Z^{T^d} = \underbrace{Z_B^{(8-d)}}_{X_L^\mu,\, X_R^\mu} \underbrace{\left(\bar{V}_8 - \bar{S}_8\right)}_{\psi_R^\mu,\, \psi_R^i} \underbrace{Z_{\Gamma^{16+d,d}}}_{X_L^I,\, X_L^i,\, X_R^i}$$





orbifolding by $(-)^F \alpha$

$$Z_B^{(8-d)} = \tau_2^{-\frac{8-d}{2}} (\eta\bar{\eta})^{-(8-d)}$$

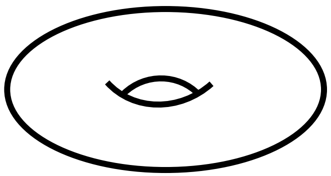
$$Z_{\Gamma^{16+d,d}} = \eta^{-(16+d)} \bar{\eta}^{-d} \sum_{p \in \Gamma^{16+d,d}} q^{\frac{1}{2}p_L^2} \bar{q}^{\frac{1}{2}p_R^2}$$

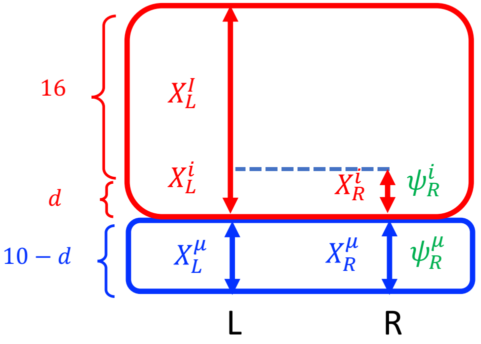
$q = e^{2\pi i \tau}$, V_8, S_8, O_8, C_8: $SO(8)$ characters

1-loop partition function

- Heterotic strings on T^d (with maximal SUSY)

$$Z^{T^d} = \underbrace{Z_B^{(8-d)}}_{X_L^\mu,\, X_R^\mu} \underbrace{(\bar{V}_8 - \bar{S}_8)}_{\psi_R^\mu,\, \psi_R^i} \underbrace{Z_{\Gamma^{16+d,d}}}_{X_L^I,\, X_L^i,\, X_R^i}$$





orbifolding by $(-)^F \alpha$

- Non-SUSY Heterotic strings

$$Z_{(\hat{Z})}^{\not{SUSY}} = Z_B^{(8-d)} \Big\{ \underbrace{\bar{V}_8 Z_{\Gamma_+^{16+d,d}}}_{\text{vector}} - \underbrace{\bar{S}_8 Z_{\Gamma_-^{16+d,d}}}_{\text{spinor}} + \underbrace{\bar{O}_8 Z_{\Gamma_\pm^{16+d,d}+\delta}}_{\text{scalar}} - \underbrace{\bar{C}_8 Z_{\Gamma_\mp^{16+d,d}+\delta}}_{\text{co-spinor}} \Big\}$$

$$Z_B^{(8-d)} = \tau_2^{-\frac{8-d}{2}} (\eta\bar{\eta})^{-(8-d)}$$

$$Z_{\Gamma^{16+d,d}} = \eta^{-(16+d)} \bar{\eta}^{-d} \sum_{p \in \Gamma^{16+d,d}} q^{\frac{1}{2}p_L^2} \bar{q}^{\frac{1}{2}p_R^2}$$

$q = e^{2\pi i \tau}$, V_8, S_8, O_8, C_8: $SO(8)$ characters

Outline

1. Introduction
2. Non-SUSY heterotic strings with general Z_2 twists
3. Interpolation in 9D and 8D
4. Cosmological constant
5. Summary

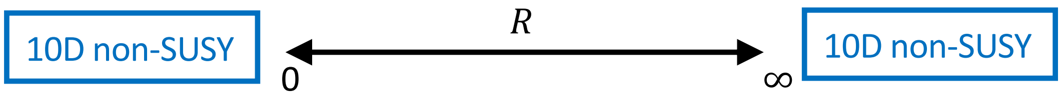
■ 9D Non-SUSY heterotic models ($d=1$)

Itoyama, Koga, Nkajima (2021)

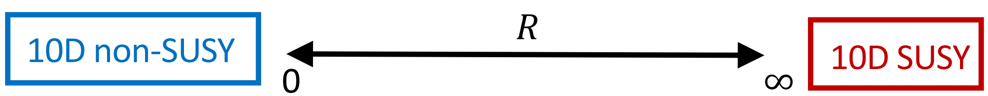
➢ $2^2 = 4$ classes exist

$$|\hat{\pi}|^2 + 2\hat{m}\hat{n}^t = 0 \pmod 4$$

- class (1): $|\hat{\pi}|^2 = 0 \pmod 4$, $(\hat{m};\hat{n}) = (0;0)$

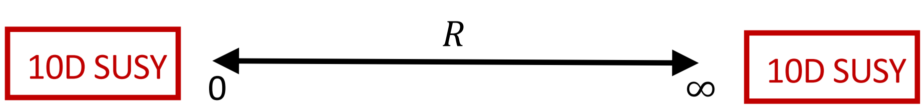


- class (2): $|\hat{\pi}|^2 = 0 \pmod 4$, $(\hat{m},\hat{n}) = (1;0)$



- class (3): $|\hat{\pi}|^2 = 0 \pmod 4$, $(\hat{m},\hat{n}) = (0;1)$

- class (4): $|\hat{\pi}|^2 = 2 \pmod 4$, $(\hat{m},\hat{n}) = (1;1)$



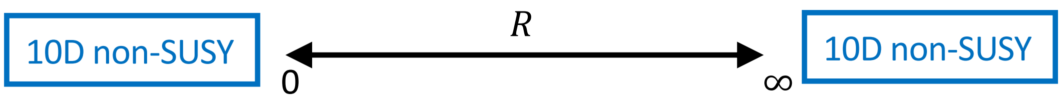
■ 9D Non-SUSY heterotic models ($d = 1$)

Itoyama, Koga, Nkajima (2021)

➢ $2^2 = 4$ classes exist

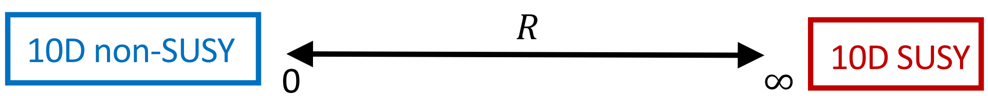
$$|\hat{\pi}|^2 + 2\hat{m}\hat{n}^t = 0 \pmod 4$$

- class (1): $|\hat{\pi}|^2 = 0 \pmod 4$, $(\hat{m};\hat{n}) = (0;0)$



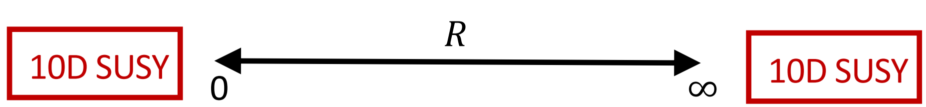
non-SUSY heterotic strings on a circle

- class (2): $|\hat{\pi}|^2 = 0 \pmod 4$, $(\hat{m},\hat{n}) = (1;0)$



- class (3): $|\hat{\pi}|^2 = 0 \pmod 4$, $(\hat{m},\hat{n}) = (0;1)$

- class (4): $|\hat{\pi}|^2 = 2 \pmod 4$, $(\hat{m},\hat{n}) = (1;1)$



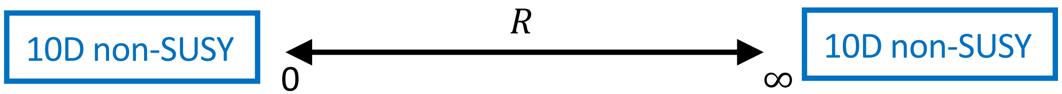
■ 9D Non-SUSY heterotic models ($d = 1$)

Itoyama, Koga, Nkajima (2021)

➢ $2^2 = 4$ classes exist

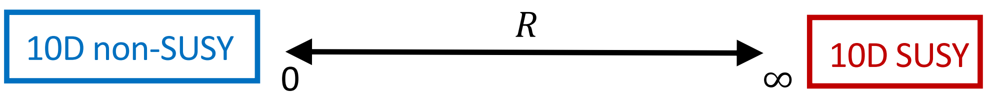
$$|\hat{\pi}|^2 + 2\hat{m}\hat{n}^t = 0 \pmod 4$$

- class (1): $|\hat{\pi}|^2 = 0 \pmod 4$, $(\hat{m};\hat{n}) = (0;0)$



non-SUSY heterotic strings on a circle

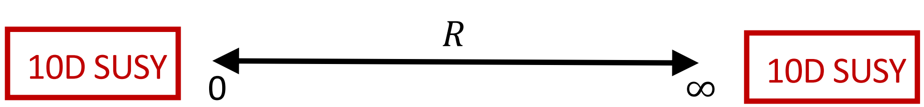
- class (2): $|\hat{\pi}|^2 = 0 \pmod 4$, $(\hat{m},\hat{n}) = (1;0)$



- class (3): $|\hat{\pi}|^2 = 0 \pmod 4$, $(\hat{m},\hat{n}) = (0;1)$

interpolation between SUSY and non-SUSY vacua

- class (4): $|\hat{\pi}|^2 = 2 \pmod 4$, $(\hat{m},\hat{n}) = (1;1)$



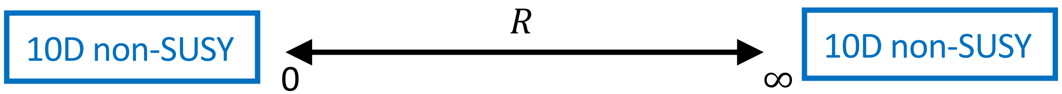
■ 9D Non-SUSY heterotic models ($d = 1$)

Itoyama, Koga, Nkajima (2021)

➢ $2^2 = 4$ classes exist

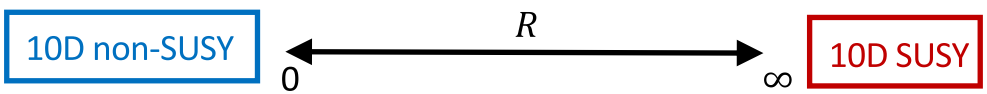
$$|\hat{\pi}|^2 + 2\hat{m}\hat{n}^t = 0 \pmod 4$$

- class (1): $|\hat{\pi}|^2 = 0 \pmod 4$, $(\hat{m};\hat{n}) = (0;0)$



non-SUSY heterotic strings on a circle

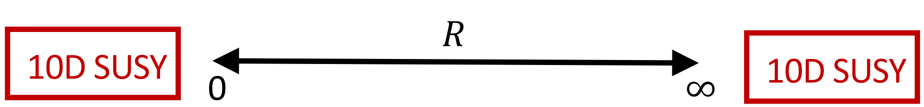
- class (2): $|\hat{\pi}|^2 = 0 \pmod 4$, $(\hat{m},\hat{n}) = (1;0)$



- class (3): $|\hat{\pi}|^2 = 0 \pmod 4$, $(\hat{m},\hat{n}) = (0;1)$

interpolation between SUSY and non-SUSY vacua

- class (4): $|\hat{\pi}|^2 = 2 \pmod 4$, $(\hat{m},\hat{n}) = (1;1)$

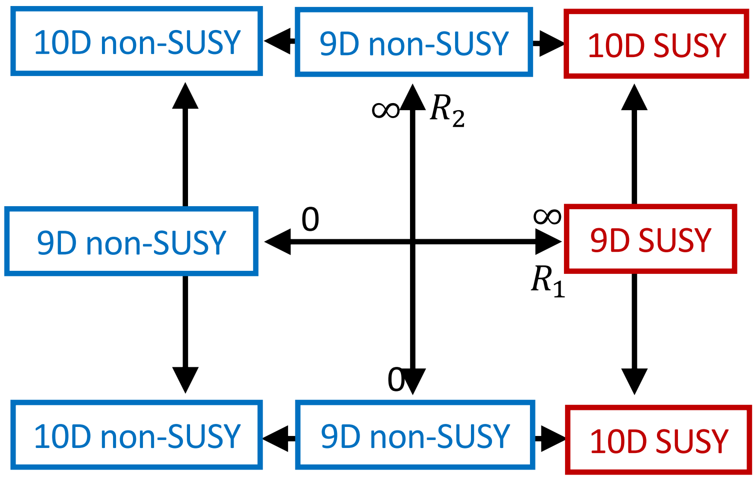


SUSY restored at both of the endpoints

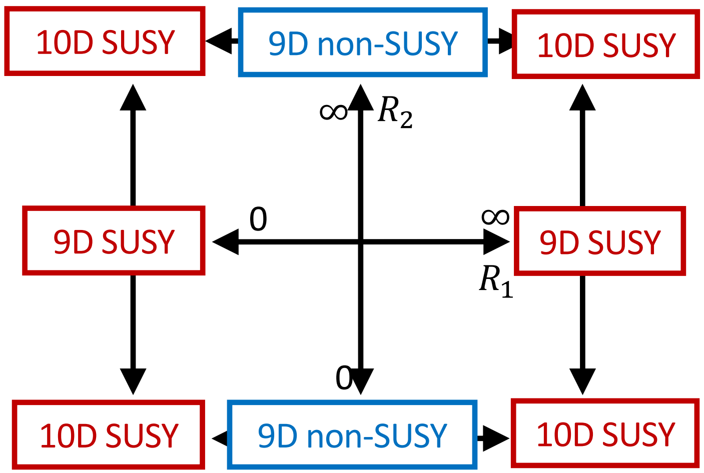
■ 8D Non-SUSY heterotic models ($d = 2$)

➢ $2^4 = 16$ classes exist

- class (2) & (1) :
  $|\hat{\pi}|^2 = 0$ (mod 4), $(\hat{m};\hat{n}) = (1,0;0,0)$



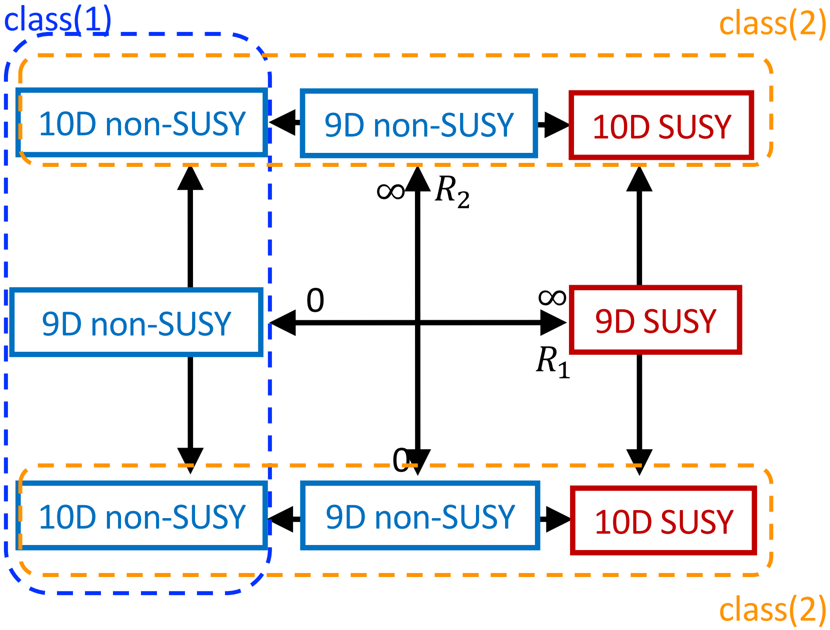
- class (4) & (1) :
  $|\hat{\pi}|^2 = 2$ (mod 4), $(\hat{m};\hat{n}) = (1,0;1,0)$



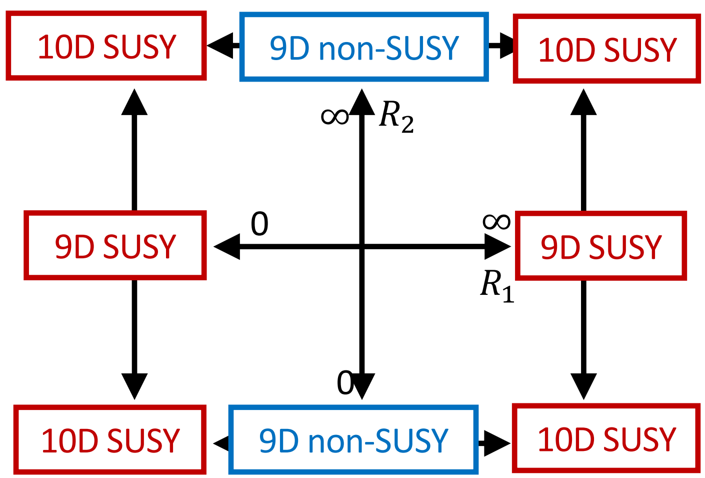
■ 8D Non-SUSY heterotic models ($d = 2$)

➢ $2^4 = 16$ classes exist

- class (2) & (1) :
  $|\hat{\pi}|^2 = 0 \pmod 4$, $(\hat{m};\hat{n}) = (1,0;0,0)$



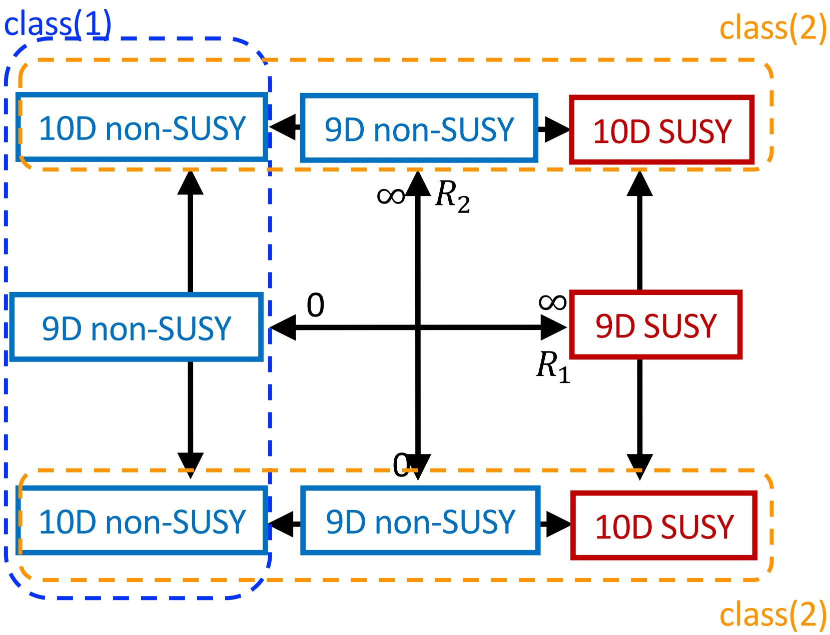
- class (4) & (1) :
  $|\hat{\pi}|^2 = 2 \pmod 4$, $(\hat{m};\hat{n}) = (1,0;1,0)$



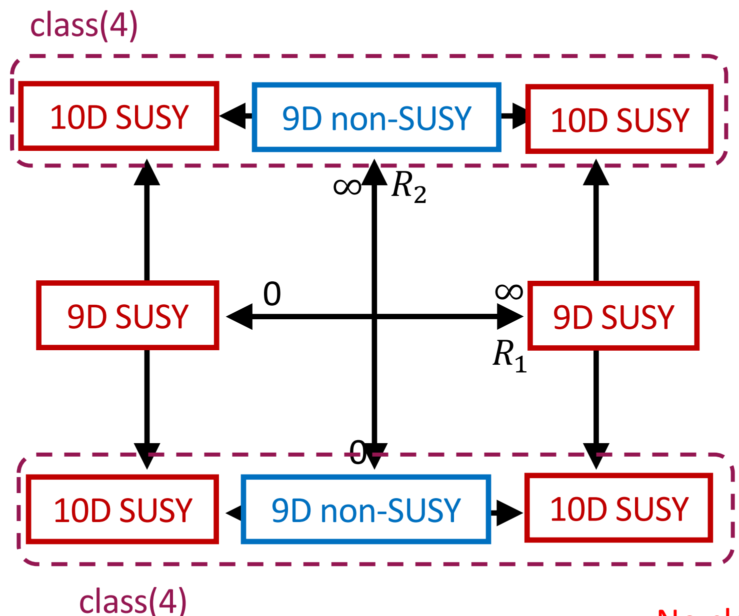
■ 8D Non-SUSY heterotic models ($d = 2$)

- $2^4 = 16$ classes exist

- class (2) & (1) :
  $|\hat{\pi}|^2 = 0$ (mod 4), $(\hat{m};\hat{n}) = (1,0;0,0)$



- class (4) & (1) :
  $|\hat{\pi}|^2 = 2$ (mod 4), $(\hat{m};\hat{n}) = (1,0;1,0)$

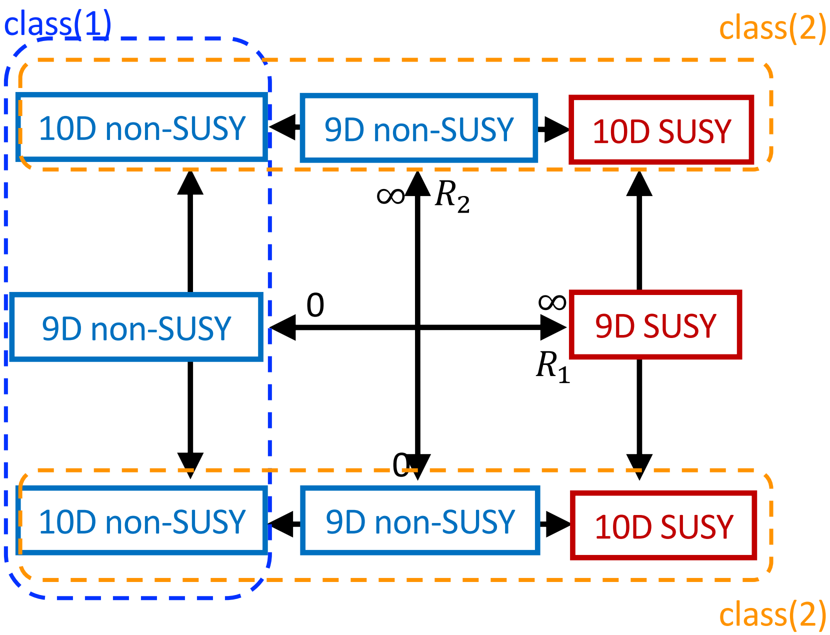


No class(1)

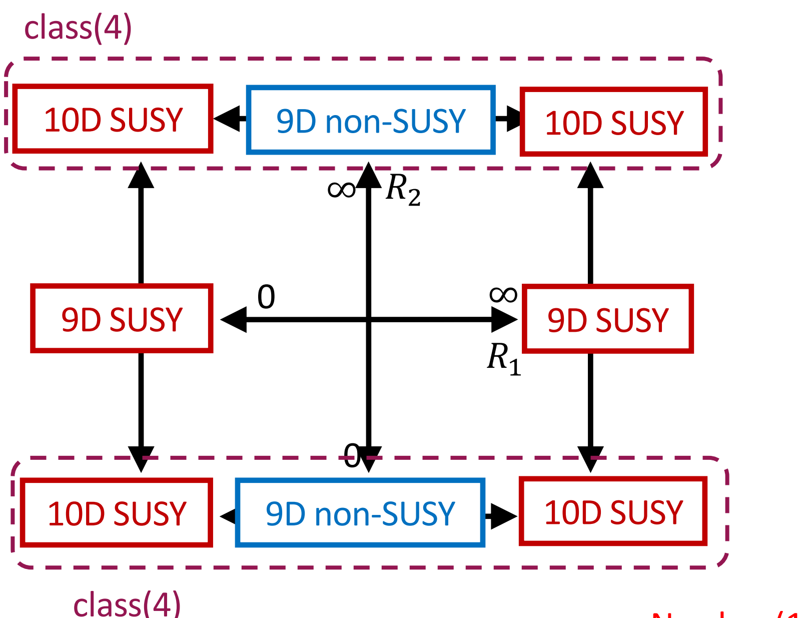
■ 8D Non-SUSY heterotic models ($d = 2$)

➢ $2^4 = 16$ classes exist

- class (2) & (1) :
  $|\hat{\pi}|^2 = 0$ (mod 4), $(\hat{m};\hat{n}) = (1,0;0,0)$



- class (4) & (1) :
  $|\hat{\pi}|^2 = 2$ (mod 4), $(\hat{m};\hat{n}) = (1,0;1,0)$



No class(1)

10D (Non-)SUSY condition:

Limits of R_1, R_2	10D SUSY model	10D Non-SUSY model
$(R_1, R_2) \to (\infty, \infty)$	$\hat{m}^1 + \hat{m}^2 > 0$	$\hat{m}^1 + \hat{m}^2 = 0$
$(R_1, R_2) \to (\infty, 0)$	$\hat{m}^1 + \hat{n}_2 > 0$	$\hat{m}^1 + \hat{n}_2 = 0$
$(R_1, R_2) \to (0, \infty)$	$\hat{n}_1 + \hat{m}^2 > 0$	$\hat{n}_1 + \hat{m}^2 = 0$
$(R_1, R_2) \to (0, 0)$	$\hat{n}_1 + \hat{n}_2 > 0$	$\hat{n}_1 + \hat{n}_2 = 0$

Outline

1. Introduction
2. Non-SUSY heterotic strings with general Z_2 twists
3. Interpolation in 9D and 8D
4. Cosmological constant
5. Summary

Cosmological Constant

- 1-loop cosmological constant (effective potential) :

$$\Lambda^{(10-d)} = -\frac{1}{2}(2\pi\sqrt{\alpha'})^{-(10-d)} \int_{\mathcal{F}} \frac{d^2\tau}{\tau_2^2} Z^{\cancel{SUSY}}_{(\hat{Z})}$$

Fundamental Region :

$$\mathcal{F} = \left\{ \tau = \tau_1 + i\tau_2 \in \mathbb{C} \,\middle|\, -\frac{1}{2} \leq \tau_1 \leq \frac{1}{2},\ |\tau| \geq 1 \right\}$$

- Assignment of $(\hat{m}, \hat{n})$:

$$(\hat{m}^{a_{(2)}}, \hat{n}_{a_{(2)}}) = (1, 0) \quad \text{for} \quad a_{(2)} = 1, \ldots, D_2$$

$$(\hat{m}^{a_{(4)}}, \hat{n}_{a_{(4)}}) = (1, 1) \quad \text{for} \quad a_{(4)} = D_2 + 1, \ldots, D$$

SUSY at $R_a \to \infty$

$$(\hat{m}^{b_{(3)}}, \hat{n}_{b_{(3)}}) = (0, 1) \quad \text{for} \quad b_{(3)} = D + 1, \ldots, D + D_3$$

$$(\hat{m}^{b_{(1)}}, \hat{n}_{b_{(1)}}) = (0, 0) \quad \text{for} \quad b_{(1)} = D + D_3 + 1, \ldots, d$$

Non-SUSY at $R_b \to \infty$

Formula for cosmological constant

■ Consider $D \geq 1$, all $R_i \approx \infty$: SUSY is restored

- Up to exponentially suppressed terms,

$$\Lambda^{(10-d)} \sim -\frac{4! \cdot 2^{d-1}}{\pi^{15-d}(\sqrt{\alpha'})^{10-d}} \left(\prod_{i=1}^{d} R_i\right) \sum_{\boldsymbol{n}} \left\{\sum_{a=1}^{D}(2n_a-1)^2 R_a^2 + \sum_{b=D+1}^{d}(2n_b)^2 R_b^2\right\}^{-5}$$

$$\times\, 8\left(24 + \sum_{\pi\in\Delta_g} \exp\left[2\pi i\left\{\sum_{a=1}^{D}(2n_a-1)(\pi\cdot A_a) + \sum_{b=D+1}^{d} n_b(\pi\cdot A_b)\right\}\right]\right)$$

Δ_g: nonzero roots of $SO(32)$ or $E_8 \times E_8$, not $\Delta_\pm$

⇒ CC does not depend on all the other endpoint models

massless condition

$2\pi \cdot A_a \in \mathbb{Z}$

$\pi \cdot A_b \in \mathbb{Z}$

$$\Lambda^{(10-d)} \sim \frac{4! \cdot 2^{d-1}}{\pi^{15-d}} \left(\prod_{i=1}^{d} R_i\right) \sum_{\vec{n}} \left\{\sum_{a}(2n_a-1)^2 R_a^2 + \sum_{b}(2n_b)^2 R_b^2\right\}^{-5} (n_F - n_B)$$

Solutions of $n_F = n_B$

- SUSY $SO(32)$ endpoint model:

$$\Delta_{SO(32)} = \left\{ \left(\underline{\pm, \pm, 0^{14}} \right) \right\}$$

- Simplest configurations:
  - A_a^I $(a = 1, \ldots, D)$ are the same configuration
  - $A_b^I (b = D + 1, \ldots, d)$ are taken to be 0

$$A_a = \left(0^p, \left(\frac{1}{2} \right)^q \right) \quad (p + q = 16) \,, \quad A_b = \left(0^{16} \right)$$

Solutions of $n_F = n_B$

- SUSY $SO(32)$ endpoint model:

$$\Delta_{SO(32)} = \{(\underline{\pm, \pm, 0^{14}})\}$$

- Simplest configurations:
  - A_a^I $(a = 1, \ldots, D)$ are the same configuration
  - $A_b^I (b = D + 1, \ldots, d)$ are taken to be 0

$$A_a = \left(0^p, \left(\frac{1}{2}\right)^q\right) \quad (p + q = 16)\,, \quad A_b = \left(0^{16}\right)$$

  - $D \in 2\boldsymbol{Z}$: $\quad n_F - n_B = -504 \neq 0$

Solutions of $n_F = n_B$

■SUSY $SO(32)$ endpoint model:

$$\Delta_{SO(32)} = \{(\underline{\pm, \pm, 0^{14}})\}$$

■Simplest configurations:

- A_a^I $(a = 1, \dots, D)$ are the same configuration
- $A_b^I (b = D + 1, \dots, d)$ are taken to be 0

$$A_a = \left(0^p, \left(\frac{1}{2}\right)^q\right) \quad (p + q = 16)\,, \quad A_b = (0^{16})$$

- $D \in 2\boldsymbol{Z}$: $\quad n_F - n_B = -504 \neq 0$
- $D \in 2\boldsymbol{Z} + 1$: $\quad n_F - n_B = 4pq - \{2p(p-1) + 2q(q-1)\} - 24$

$$n_F = n_B \Rightarrow (p, q) = (9,7), (7,9)$$

Solutions of $n_F = n_B$

■SUSY $SO(32)$ endpoint model:

$$\Delta_{SO(32)} = \{ (\underline{\pm, \pm, 0^{14}}) \}$$

■Simplest configurations:

- A_a^I $(a = 1, \ldots, D)$ are the same configuration
- $A_b^I (b = D + 1, \ldots, d)$ are taken to be 0

$$A_a = \left(0^p, \left(\frac{1}{2}\right)^q\right) \quad (p + q = 16)\,, \quad A_b = (0^{16})$$

- $D \in 2\boldsymbol{Z}$: $\quad n_F - n_B = -504 \neq 0$
- $D \in 2\boldsymbol{Z} + 1$: $\quad n_F - n_B = 4pq - \{2p(p-1) + 2q(q-1)\} - 24$

$$n_F = n_B \Rightarrow (p, q) = (9,7), (7,9)$$

Cosmological constant is exponentially suppressed when the gauge group is $SO(18) \times SO(14)$

Outline

1. Introduction
2. Non-SUSY heterotic strings with general Z_2 twists
3. Interpolation in 9D and 8D
4. Cosmological constant
5. Summary

Summary

- $(10-d)$D Non-SUSY models are constructed by orbifolding by $(-)^F \alpha$

  (α : shift of order 2 in Narain lattice)

- Various interpolations are shown in $d=2$ case
- Cosmological constant of $(10-d)$D Non-SUSY models in $R_i \approx \infty$ is

$$\Lambda^{(10-d)} \sim \frac{4! \cdot 2^{d-1}}{\pi^{15-d}} \left(\prod_{i=1}^{d} R_i \right) \sum_{\vec{n}} \left\{ \sum_a (2n_a - 1)^2 R_a^2 + \sum_b (2n_b)^2 R_b^2 \right\}^{-5} (n_F - n_B) + \mathcal{O}(e^{-R/\sqrt{\alpha'}})$$

- Find the configurations of WLs which give exp. supp. cosmol. const.

<u>Out look</u>

Higher-loop correction, (meta)stable vacua, cosmology, …