March 05, 2019 at Tohoku Univ.

# World-sheet approaches to non-geometric backgrounds in string theory

Yuji Satoh

(Fukui Univ.)

Based on work w/

Y. Sugawara, T. Wada, T. Uetoko (Ritsumeikan U.)

# Introduction

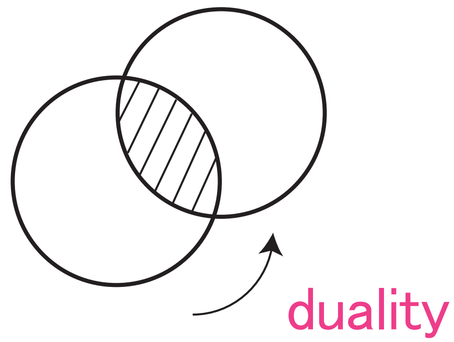
- in world-sheet approach,
  a consistent CFT gives a string vacuum

- in general, its target-space interpretation not obvious

- so, "non-geometric" backgrounds in string theory
  rather ubiquitous

- dualities are symmetries of string theory

  ⇒ transition fn. for target space
  may involve duality trans.




- "T–folds" in the case of T–duality [Dabholkar–Hull '02 , Hull '04]

- more generally,
  this type of non–geometric BG: "monodrofolds"

- relevant to string vacua, dualities

- relevant to "new" formulation of string theory
  w/ manifest dualities (Double Field Theory (DFT) etc)

- they are analyzed systematically by sugra, DFT⋯

- at string scale beyond low energy analysis,
  need world-sheet approach

take a step in this direction

In this talk, we discuss

1. a systematic construction of modular inv. partition fn. for T-folds based on lattice

2. application :
   non-susy backgrounds w/ small cosmological const.

3. use of conformal interfaces
   [ world-sheet objects implementing symmetry (T-duality) ]

# Plan of talk

1. Introduction

2. World-sheet partition for T-folds

3. Application : non-susy vacua w/
small cosmological const

4. Use of conformal interfaces/defects

5. Summary

# Partition function for T-folds

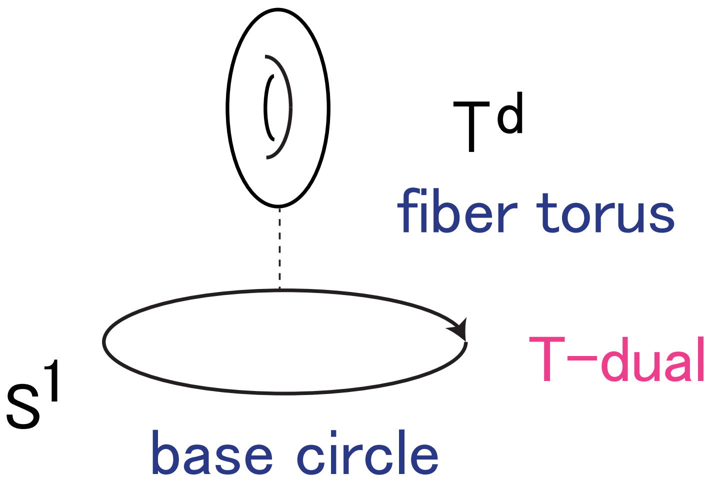
## (bosonic case)

[Sugawara-Y.S.-Wada ’15, ’16]

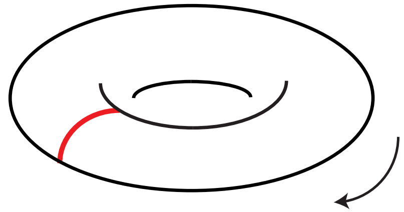
# T–folds

- our set up of T–folds

Target Space




World–sheet partition fn.



orbifold by T–dual twist

$$\sigma = (\text{shift})_{\mathrm{R}^1} \otimes (\text{T-dual})_{T^d}$$

- from world–sheet point of view, T–folds are generally described by (special class of) asymmetric orbifolds

  e.g., twist by $X^i \to X^i\,, \quad \bar{X}^i \to -\bar{X}^i$

  - construction of asymmetric orbifolds not automatic

- structure of partition fn. for T–folds

$$Z(\tau) = Z_M(\tau) \times \sum_{w,m\in\mathbb{Z}} Z^{S^1}_{(w,m)}(\tau) \times Z^{T^d}_{(w,m)}(\tau)$$

[non–compact part] [ $S^1$ part] [ $T^d$ part]

  - w, m : spatial and temporal winding
  - $\tau = \tau_1 + i\tau_2$ : torus modulus
  - for a free boson X on circle of radius R $$Z^{S^1}_{(w,m)}(\tau) = \frac{R}{\sqrt{\tau_2}|\eta(\tau)|^2} e^{-\frac{\pi R^2}{\tau_2}|w\tau+m|^2}$$

- by construction, $Z^{T^d}_{(0,m)} = \mathrm{tr}\left(\sigma^m q^{L_0-\frac{d}{24}} \bar{q}^{\bar{L}_0-\frac{d}{24}}\right)$ , $q = e^{2\pi i\tau}$

$$\sigma = (\text{shift})_{R^1} \otimes (\text{T-dual})_{T^d}$$

- since

$$Z^{S^1}_{(w,m)}(\tau+1) = Z^{S^1}_{(w,m+w)}(\tau)\,, \quad Z^{S^1}_{(w,m)}(-1/\tau) = Z^{S^1}_{(m,-w)}(\tau)$$

if $Z^{T^d}_{(w,m)}$ has similar modular properties

⇒ total Z is modular inv.

- problem is to find such $T^d$ / construct Z

Useful to formulate problem
in terms of momentum lattices

# Partition fn. from lattices

# Momentum lattice

- moduli of $T^d$ compactification

$$E_{ij} := G_{ij} + B_{ij}$$ [ (metric) + (anti−symm); i,j = 1, ..., d ]

- momentum lattice

$$p_a = e_a^{*i}[n_i - E_{ij}w^j] , \quad \bar{p}_a = e_a^{*i}[n_i + E^t_{ij}w^j] \quad (n_i \, , w^i \in \mathbb{Z})$$

[vielbein] [momentum, winding]

⇒ (d+d)−dim lattice Λ: $P(m, w) := (p, \bar{p})$

w/ Lorentzian product $P \circ P' := pp' - \bar{p}\bar{p}'$

- Hamiltonian is invariant under O(d,d,Z) trans.

$$E \to g(E) := (aE+b)(cE+d)^{-1}$$

$$g := \begin{pmatrix} a & b \\ c & d \end{pmatrix} \in O(d,d,\mathbb{Z}) \qquad \text{i.e. ,}\ g^t \begin{pmatrix} 0 & I \\ I & 0 \end{pmatrix} g = \begin{pmatrix} 0 & I \\ I & 0 \end{pmatrix}$$

- untwisted torus partition fn.

$$Z^{T^d}_{(0,0)}(\tau) = \frac{1}{|\eta(\tau)|^2} \sum_{(p,\bar{p})\in\Lambda} e^{\pi i\tau p^2 - \pi i\bar{\tau}\bar{p}^2}$$

[lattice sum]

# T–dual twist

- we focus on simple T–dual twist

$$(X^i, \bar{X}^i) \;\rightarrow\; (X^i, -\bar{X}^i)$$ [ i, = 1, ..., d ]

$$\sigma = (\text{shift})_{\mathrm{R}^1} \otimes (-1_R)_{T^d}$$

- T–fold CFTs are defined at fixed points in moduli

$$\Rightarrow \quad E = g(E) = (aE + b)(cE + d)^{-1}$$ [ e.g. $R = \alpha'/R$ ]

$\because$) T–dual acts in the same Hilbert space [ cf. sugra analysis ]

- corresponding O(d,d) element [Erler '96]

$$g_{SD} = \begin{pmatrix} BG^{-1} & -BG^{-1}B + G \\ G^{-1} & -G^{-1}B \end{pmatrix} \in O(d, d, \mathbb{Z})$$

- after one twist

$$Z^{T^d}_{(0,1)}(\tau) = \overline{\Theta_{34}(\tau)}^{d/2} \frac{1}{\eta^d(\tau)} \sum_{Ew\in\mathbb{Z}^d} q^{w^t G w}$$ [Euclidean lattice sum]

$$\Theta_{ab}(\tau) := \theta_a(\tau)\theta_b(\tau)/\eta^2(\tau)$$ [theta, eta fn.]

- general $Z^{T^d}_{(w,m)}$ may be obtained by taking modular orbit (if any)

- modular properties are well-controlled for Lie algebra lattices
  - more general than free-fermion construction

# Lie algebra (Englert–Neveu) lattices

- set torus moduli to be

$$E_{ij} = C_{ij}\ (i > j)\,,\ E_{ii} = \frac{1}{2}C_{ii}\,,\ E_{ij} = 0\ (i < j)$$

[ Cij : Cartan matrix for G ]

⇒ level 1 affine Lie–algebra symmetry [Elitzur et al '87]

- partition fn. (untwisted)

$$Z^{T^d}_{(0,0)}(\tau) = \sum_\alpha \left|\chi^G_\alpha(\tau)\right|^2$$

[ character of conjugacy class $\alpha$ for G ]

- condition $g_{SD} \in O(d,d,\mathbb{Z})$ is satisfied for

$$A_1\,,\ D_r\ (r : \text{even})\,,\ E_7\,,\ E_8$$

[ note $G^{-1} = 2C^{-1}$ in $g_{SD}$ ]

- partition fn. w/ one twist

$$Z_{(0,1)}^{T^d[G]}(\tau) = \overline{\Theta_{34}(\tau)}^{d/2} \chi^{G}_{\text{root}}(\tau)$$

- by explicit modular trans.
  - obtain $Z^{T^d[G]}_{(w,m)}$ for ${}^\forall w,\ m \in \mathbb{Z}$
  - find desired modular properties

$$(w,m) \underset{\tau\to\tau+1}{\longrightarrow} (w, m+w)\,, \quad (w,m) \underset{\tau\to -1/\tau}{\longrightarrow} (m, -w)$$

- combining these with other parts, we obtain modular invariant, $\alpha'$ exact partition fn. for T-folds

$$Z(\tau) = Z_M(\tau) \times \sum_{w,m\in\mathbb{Z}} Z^{S^1}_{(w,m)}(\tau) \times Z^{T^d[G]}_{(w,m)}(\tau)$$

a systematic construction of world-sheet partition fn. for T-folds from Lie algebra lattices

## $\underline{A_1}$ :

$$Z^{T^1[A_1]}_{(a,b)}(\tau) =$$

$$\begin{cases} \left|\chi^{A_1}_0(\tau)\right|^2 + \left|\chi^{A_1}_1(\tau)\right|^2 & \text{[a, b : even]} \\ e^{\frac{\pi i}{8}ab^3}\,\overline{\Theta_{34}(\tau)}^{\frac{1}{2}} \cdot \frac{1}{2}\left[\chi^{A_1}_+(\tau) + i^a \chi^{A_1}_-(\tau)\right] & \text{[a : even; b : odd]} \\ e^{-\frac{\pi i}{8}a^3 b}\,\overline{\Theta_{23}(\tau)}^{\frac{1}{2}} \cdot \frac{1}{\sqrt{2}}\left[\chi^{A_1}_0(\tau) + i^b \chi^{A_1}_1(\tau)\right] & \text{[a : odd; b : even]} \\ e^{-\frac{\pi i}{8}a^3 b}\,\overline{\Theta_{24}(\tau)}^{\frac{1}{2}} \cdot \frac{1}{\sqrt{2}}\left[\chi^{A_1}_0(\tau) + i^{a+b-1} \chi^{A_1}_1(\tau)\right] & \text{[a, b : odd]} \end{cases}$$

where $\Theta_{ab}(\tau) := \theta_a(\tau)\theta_b(\tau)/\eta^2(\tau)$

$$\chi^{A_1}_\pm := \chi^{A_1}_0 \pm \chi^{A_1}_1$$

$$\chi^{A_1}_0(\tau) = \frac{\theta_3(2\tau)}{\eta(\tau)}, \quad \chi^{A_1}_1(\tau) = \frac{\theta_2(2\tau)}{\eta(\tau)}$$

## $D_r$ :

$$Z_{(a,b)}^{T^r[D_r]}(\tau) =$$

$$\begin{cases} \dfrac{1}{2|\eta^r(\tau)|^{2r}}\left[\left|\theta_3(\tau)\right|^{2r} + \left|\theta_4(\tau)\right|^{2r} + \left|\theta_2(\tau)\right|^{2r}\right] & \text{[a, b : even]} \\ e^{\frac{\pi i r}{8}ab}\,\overline{\Theta_{34}(\tau)}^{\frac{r}{2}} \cdot \dfrac{1}{2\eta^r(\tau)}\left[\theta_3^r(\tau) + e^{\frac{\pi i r}{4}a}\theta_4^r(\tau)\right] & \text{[a : even; b : odd]} \\ e^{-\frac{\pi i r}{8}ab}\,\overline{\Theta_{23}(\tau)}^{\frac{r}{2}} \cdot \dfrac{1}{2\eta^r(\tau)}\left[\theta_3^r(\tau) + e^{\frac{\pi i r}{4}b}\theta_2^r(\tau)\right] & \text{[a : odd; b : even]} \\ e^{-\frac{\pi i r}{8}ab}\,\overline{\Theta_{24}(\tau)}^{\frac{r}{2}} \cdot \dfrac{1}{2\eta^r(\tau)}\left[\theta_4^r(\tau) + e^{\frac{\pi i r}{4}(a+b-1)}\theta_2^r(\tau)\right] & \text{[a, b : odd]} \end{cases}$$

where $\chi_0^{D_r}(\tau) = \dfrac{1}{2\eta^r(\tau)}\left[\theta_3^r(\tau) + \theta_4^r(\tau)\right]$ , $\chi_1^{D_r}(\tau) = \dfrac{1}{2\eta^r(\tau)}\left[\theta_3^r(\tau) - \theta_4^r(\tau)\right]$

$$\chi_2^{D_r}(\tau) = \chi_3^{D_r}(\tau) = \frac{\theta_2^r(\tau)}{2\eta^r(\tau)}$$

- obtained also by free fermion construction

## $\underline{E_7}$ :

$$Z^{T^7[E_7]}_{(a,b)}(\tau) =$$

$$\begin{cases} \left|\chi_0^{E_7}(\tau)\right|^2 + \left|\chi_1^{E_7}(\tau)\right|^2 & \text{[a, b : even]} \\ e^{\frac{7\pi i}{8}ab^3}\,\overline{\Theta_{34}(\tau)}^{\frac{7}{2}}\cdot\frac{1}{2}\left[\chi_+^{E_7}(\tau) + (-i)^a\chi_-^{E_7}(\tau)\right] & \text{[a : even; b : odd]} \\ e^{-\frac{7\pi i}{8}a^3b}\,\overline{\Theta_{23}(\tau)}^{\frac{7}{2}}\cdot\frac{1}{\sqrt{2}}\left[\chi_0^{E_7}(\tau) + (-i)^b\chi_1^{E_7}(\tau)\right] & \text{[a : odd; b : even]} \\ e^{-\frac{7\pi i}{8}a^3b}\,\overline{\Theta_{24}(\tau)}^{\frac{7}{2}}\cdot\frac{1}{\sqrt{2}}\left[\chi_0^{E_7}(\tau) + (-i)^{a+b-1}\chi_1^{E_7}(\tau)\right] & \text{[a, b : odd]} \end{cases}$$

where $\chi_\pm^{E_7} := \chi_0^{E_7} \pm \chi_1^{E_7}$

$$\chi_0^{E_7}(\tau) = \frac{1}{2\eta^7(\tau)}\left[\theta_2(2\tau)\theta_2^6(\tau) + \theta_3(2\tau)\Big(\theta_3^6(\tau) + \theta_4^6(\tau)\Big)\right]$$

$$\chi_1^{E_7}(\tau) = \frac{1}{2\eta^7(\tau)}\left[\theta_3(2\tau)\theta_2^6(\tau) + \theta_2(2\tau)\Big(\theta_3^6(\tau) - \theta_4^6(\tau)\Big)\right]$$

## $E_8$ :

$$Z^{T^8[E_8]}_{(a,b)}(\tau) = \begin{cases} \left|\chi^{E_8}_0(\tau)\right|^2 & \text{[a, b : even]} \\ \overline{\Theta_{34}(\tau)}^4 \cdot \chi^{E_8}_0(\tau) & \text{[a : even; b : odd]} \\ \overline{\Theta_{23}(\tau)}^4 \cdot \chi^{E_8}_0(\tau) & \text{[a : odd; b : even]} \\ -\overline{\Theta_{24}(\tau)}^4 \cdot \chi^{E_8}_0(\tau) & \text{[a, b : odd]} \end{cases}$$

where $\chi^{E_8}_0(\tau) = \chi^{D_8}_0 + \chi^{D_8}_2$

- E8 lattice is even, self–dual ⇒ modular properties are trivial
- construction is applied to other even, self–dual lattices

# Uplift of T-duality on world-sheet

- phases in $Z^{T^d[G]}_{(w,m)}$ imply that
  action on fiber torus is not Z2 cf. half-integral spin for su(2)

- action of T-duality on world-sheet CFT
  generally uplifted [cf. Aoki-D'Hoker-Phong '04]

- a systematic analysis based on lattice [Harvey-Moore '17]
  ⇒ more general asymmetric orbifold toward 'Moonshine'?
  cf. Monstrous CFT [Frenkel-Lepowski-Meurman '86]
  "no-go theorem" for Mathieu Moonshine
  [Gaberdiel-Hohenegger-Volpato '17]

# Case of Superstrings

# Case of superstrings

- arguments are applied also for superstrings
- twist on fermions $\sigma : \psi_R^i \mapsto -\psi_R^i$
- taking into account Ramond sector, bosonization, essentially two cases of twist on world-sheet fermions

  i ) $\sigma^2 = 1$ ⇒ half-susy from right-mover

  ii ) $\sigma^2 = (-1)^{F_R}$ ⇒ no susy from right-mover

  $F_R$ : space-time fermion #

- corresponding partition fn. for fermion

  i ) $\overline{f_{(w,m)}(\tau)}$ ii ) $\overline{\widehat{f}_{(w,m)}(\tau)}$

# half-susy fermion block :

$$f_{(a,b)}(\tau) =$$

$$\begin{cases} (-1)^{\frac{a}{2}} \left\{ \left(\frac{\theta_3}{\eta}\right)^2 \left(\frac{\theta_4}{\eta}\right)^2 - \left(\frac{\theta_4}{\eta}\right)^2 \left(\frac{\theta_3}{\eta}\right)^2 + 0 \right\} (= 0) & (a \in 2\mathbb{Z},\ b \in 2\mathbb{Z}+1) \\ (-1)^{\frac{b}{2}} \left\{ \left(\frac{\theta_3}{\eta}\right)^2 \left(\frac{\theta_2}{\eta}\right)^2 + 0 - \left(\frac{\theta_2}{\eta}\right)^2 \left(\frac{\theta_3}{\eta}\right)^2 \right\} (= 0) & (a \in 2\mathbb{Z}+1,\ b \in 2\mathbb{Z}) \\ -e^{\frac{i\pi}{2}ab} \left\{ 0 + \left(\frac{\theta_2}{\eta}\right)^2 \left(\frac{\theta_4}{\eta}\right)^2 - \left(\frac{\theta_4}{\eta}\right)^2 \left(\frac{\theta_2}{\eta}\right)^2 \right\} (= 0) & (a \in 2\mathbb{Z}+1,\ b \in 2\mathbb{Z}+1) \\ \left(\frac{\theta_3}{\eta}\right)^4 - \left(\frac{\theta_4}{\eta}\right)^4 - \left(\frac{\theta_2}{\eta}\right)^4 (= 0) & (a \in 2\mathbb{Z},\ b \in 2\mathbb{Z}) \end{cases}$$

# non-susy fermion block :

$$\widehat{f}_{(a,b)}(\tau) =$$

$$\begin{cases}
(-1)^{\frac{a}{2}}\left\{\left(\frac{\theta_3}{\eta}\right)^2\left(\frac{\theta_4}{\eta}\right)^2-\left(\frac{\theta_4}{\eta}\right)^2\left(\frac{\theta_3}{\eta}\right)^2+0\right\}(=0) & (a\in 2\mathbb{Z},\ b\in 2\mathbb{Z}+1)\\
(-1)^{\frac{b}{2}}\left\{\left(\frac{\theta_3}{\eta}\right)^2\left(\frac{\theta_2}{\eta}\right)^2+0-\left(\frac{\theta_2}{\eta}\right)^2\left(\frac{\theta_3}{\eta}\right)^2\right\}(=0) & (a\in 2\mathbb{Z}+1,\ b\in 2\mathbb{Z})\\
-e^{\frac{i\pi}{2}ab}\left\{0+\left(\frac{\theta_2}{\eta}\right)^2\left(\frac{\theta_4}{\eta}\right)^2-\left(\frac{\theta_4}{\eta}\right)^2\left(\frac{\theta_2}{\eta}\right)^2\right\}(=0) & (a\in 2\mathbb{Z}+1,\ b\in 2\mathbb{Z}+1)\\
\\
\left(\frac{\theta_3}{\eta}\right)^4-\left(\frac{\theta_4}{\eta}\right)^4-\left(\frac{\theta_2}{\eta}\right)^4(=0) & (a\in 4\mathbb{Z},\ b\in 4\mathbb{Z})\\
\left(\frac{\theta_3}{\eta}\right)^4-\left(\frac{\theta_4}{\eta}\right)^4+\left(\frac{\theta_2}{\eta}\right)^4 & (a\in 4\mathbb{Z},\ b\in 4\mathbb{Z}+2)\\
\left(\frac{\theta_3}{\eta}\right)^4+\left(\frac{\theta_4}{\eta}\right)^4-\left(\frac{\theta_2}{\eta}\right)^4 & (a\in 4\mathbb{Z}+2,\ b\in 4\mathbb{Z})\\
-\left\{\left(\frac{\theta_3}{\eta}\right)^4+\left(\frac{\theta_4}{\eta}\right)^4+\left(\frac{\theta_2}{\eta}\right)^4\right\} & (a\in 4\mathbb{Z}+2,\ b\in 4\mathbb{Z}+2)
\end{cases}$$

- these also have desired modular properties

$$(w,m) \longrightarrow (w, m+w)\,, \qquad (w,m) \longrightarrow (m,-w)$$
$$\tau \to \tau + 1 \qquad\qquad \tau \to -1/\tau$$

- combining modular blocks

variety of partition fn. for T–folds
in type II and hetero. w/ appropriate # of susy

e.g.)
$$Z(\tau) = Z_{\mathbb{R}^{1,3}\times S^1}(\tau)$$
$$\times \sum_{w,m\in\mathbb{Z}} Z^{S^1}_{(w,m)}(\tau) Z^{T^4[D_4]}_{(w,m)}(\tau)\cdot \mathcal{J}(\tau)\cdot \overline{f_{(w,m)}(\tau)}$$

[ 3/4 susy in type II ]

$$\mathcal{J} = \frac{1}{\eta^4}(\theta_3^4 - \theta_4^4 - \theta_2^4)$$

# Non-geometric fluxes

- under T-duality $H \leftrightarrow \omega \leftrightarrow Q \leftrightarrow R$

  geometric non-geometric

  [Shelton-Taylor-Wecht '05]

- by $T^D$ compactification, gauging

  [Shelton-Taylor-Wecht '05, Dabholkar-Hull '05]

$$[\mathcal{Z}_M, \mathcal{Z}_N] = \omega^P_{MN} \mathcal{Z}_P + H_{MNP} \mathcal{X}^P$$

$$[\mathcal{Z}_M, \mathcal{X}^N] = -\tilde{\omega}^N_{MP} \mathcal{X}^P + Q^{NP}_M \mathcal{Z}_P \qquad (M, N = 1, ..., D)$$

$$[\mathcal{X}_M, \mathcal{X}^N] = -\tilde{Q}^{MN}_P \mathcal{X}^P + Q^{MNP} \mathcal{Z}_P$$

$\mathcal{Z}_M \, , \mathcal{X}_M$ : generators corresponding to $g_{\mu M} \, , B_{\mu M}$

- read off charges and vertex op.
  from world-sheet partition fn. of asymmetric orbifolds

  [Condeescu-Florakis-Kounnas-Lust '13]

  ⇒ OPE ⇒ gauge algebras

  - asymmetry in the fiber ⇒ Q-flux
  - asymmetry in the base ⇒ R-flux

Application :

Non-supersymmetric vacua w/
vanishing cosmological constant (1-loop)

[Sugawara-Y.S.-Wada '15, '16]

# Non-supersymmetric vacua

- further add twist by space-time fermion # in type II

$$\sigma \;\longrightarrow\; \sigma' := \sigma \otimes (-1)^{F_L}$$
$$= (\text{shift})_{\mathrm{R}^1} \otimes (-1_R)_{T^d} \otimes (-1)^{F_L}$$

$$(\sigma')^2 = (-1)^{F_R}$$

⇒ break all susy

e.g.) $Z(\tau) = Z_{\mathbb{R}^{1,3}\times S^1}(\tau)$

$$\times \sum_{w,m\in\mathbb{Z}} Z^{S^1}_{(w,m)}(\tau) Z^{T^4[D_4]}_{(w,m)}(\tau) \widehat{f}_{(2w,2m)}(\tau) \overline{\widehat{f}_{(w,m)}(\tau)}$$

- $\overline{\widehat{f}_{(w,m)}(\tau)} = 0$ for m or w is odd

  $\widehat{f}_{(2w,2m)}(\tau) = 0$ for m and w are even

  $\Rightarrow$ partition fn. Z vanishes (in spite that susy is broken)

  $\Rightarrow$ cosmological const at 1 loop vanishes

- can check unitarity, absence of tachyon

- this mechanism generally holds

# Comments:

- windings w,m prevent supercharges from twisted sectors

- Kachru-Kumar-Silverstein ’98 : non-abelian orbifold

  ⇔ T-fold structure simplifies construction

> T-folds provide simple setting of
> non-susy vacua w/ vanishing cosmological const

## Application :

# Non-BPS D-branes w/ vanishing cylinder amplitudes

[Sugawara-Y.S.-Uetoko '17]

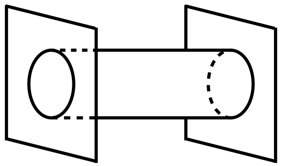
# Non–BPS D–branes w/ vanishing cylinder amplitudes

- by similar orbifolding breaking all susy from left movers

  ⇒ no BPS D–branes :

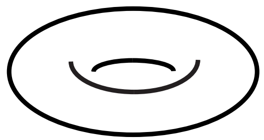
$$(\cancel{Q^{\alpha}_{L}} + M^{\alpha}{}_{\beta}\, Q^{\beta}_{R})\,|\,B\,\rangle = 0$$

- can construct D–branes w/ vanishing cylinder amplitudes



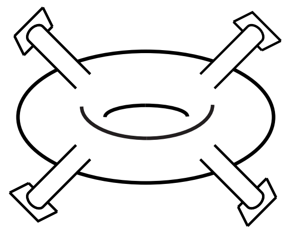
$$= \langle\, B\,|\,q^{-sH}\,|\,B\,\rangle = 0$$

- bulk susy ⇒ loop amplitudes vanish



$$= 0$$

  ⇒ non–perturbatively small cosmological const. from non–BPS D–branes



# Use of conformal interfaces/defects

# Conformal interfaces/defects

- a generalization of conformal boundary/D-brane


- condition of conformal invariance

$$T_1(z) - \bar{T}_1(\bar{z}) \approx T_2(z) - \bar{T}_2(\bar{z})$$

[along interface]


[Won-Affleck '94, Petkova-Zuber '00]

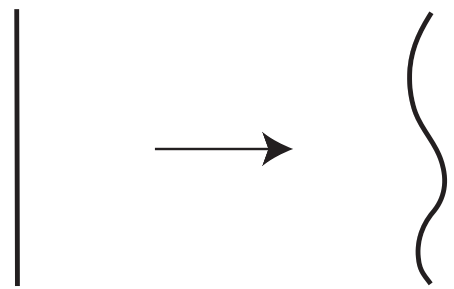
# Topological interfaces/defects

- when they satisfy stronger condition

$$T_1(z) \approx T_2(z)\,, \quad \bar{T}_1(\bar{z}) \approx \bar{T}_2(\bar{z})$$

$\Rightarrow$ freely deformed; called topological

[Petkova–Zuber '00, Bachas–Gaberdiel '04]



- topological interfaces generate symmetries/dualities

[Frohlich–Fuchs–Runkel–Schweigert '04, '07]

- two subclasses of top. interfaces
  - group-like defects : generate symmetries

    (e.g., Z2 for Ising)

    ∃ inverse s.t. $D \cdot \bar{D} = 1$

  - duality defects : generate dualities

    (e.g., KW duality for Ising)

    fuse into group-like defects

$$D \cdot \bar{D} = \sum_k D_k \quad \text{[group-like]}$$

# Interfaces in T$^d$ compactification

- conformal interfaces for T$^d$ compactification

[Bachas-de Boer-Dijkgraaf-Ooguri '01;
Y.S. '11; Bachas-Brunner-Roggenkamp '12]

$$I_{12}^{c} = \prod_{n=1}^{\infty} e^{\frac{1}{n}\left(S_{11}^{IJ}\alpha_{-n}^{1I}\tilde{\alpha}_{-n}^{1J} - S_{12}^{IJ}\alpha_{-n}^{1I}\alpha_{n}^{2J} - S_{21}^{IJ}\tilde{\alpha}_{n}^{2I}\tilde{\alpha}_{-n}^{1J} + S_{22}^{IJ}\tilde{\alpha}_{n}^{2I}\alpha_{n}^{2J}\right)} I_0$$

$$I_0 = \sum_{\tilde{p}^{1J},\tilde{p}^{2J}} |S_{1B}^{IK}\tilde{p}^{BK}\rangle_{1R}|\tilde{p}^{1J}\rangle_{1L} \cdot {}_{2L}\langle -S_{2B}^{I'K}\tilde{p}^{BK}|_{2R}\langle -\tilde{p}^{2J'}|$$

$\alpha_n^{1(2)}, \ \tilde{\alpha}_n^{1(2)}$ : modes of CFT1(2)

- topological ⇒ $S_{11} = S_{22} = 0$
- no projection in zero-modes ⇒ group-like
  implement T-duality
- projection in zero-modes ⇒ duality defect
  T-duality + projection

Conformal interfaces :

(probably) fundamental objects implementing T-duality on world-sheet

# Application to T-folds

- twist by group-like defects ⇒ partition fn of T-folds
  - actual construction goes back, e.g., to our previous one

# Application to “monodrofold”

- twist by duality defects ⇒ monodrofolds of T–fold type

  [Sugawara–Y.S. ’15]

  - from CFT point of view, they are `generalized orbifolds’

    [twist by not–exact symmetry]

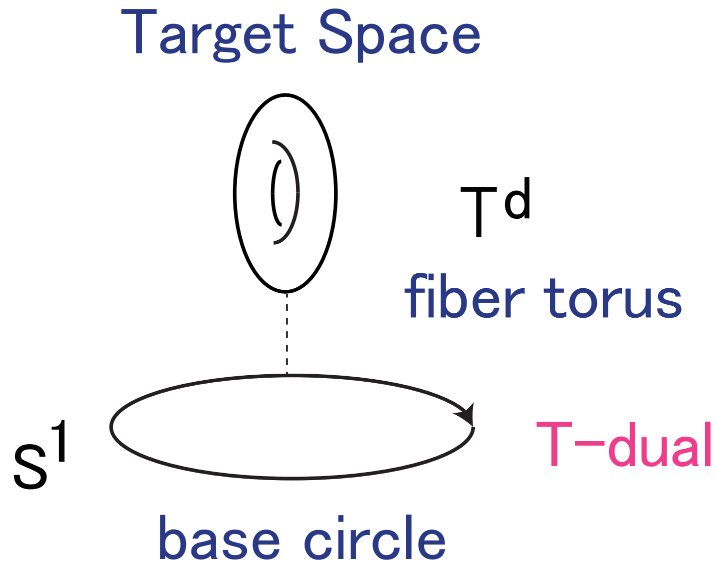
    [cf. Frohlich, Fuchs, Runkel, Schwegert’09, Brunner, Carqueville, Plencner ’13, …]

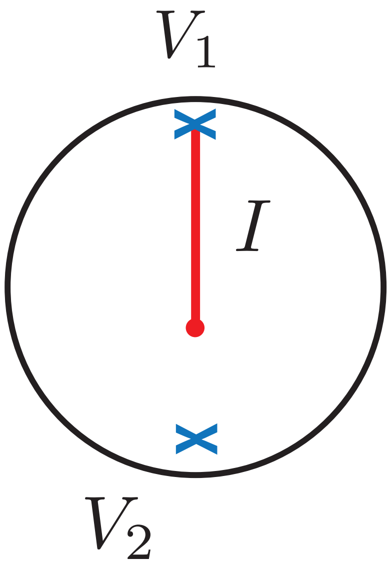
- modular inv. dictates how to sum up interfaces (moduli)

# Transition of wrapped/unwrapped strings

[cf. Sakatani]

- strings wrapped on base circle receive T-dual monodromy
- transition to ordinary string (monodromy-free) would be



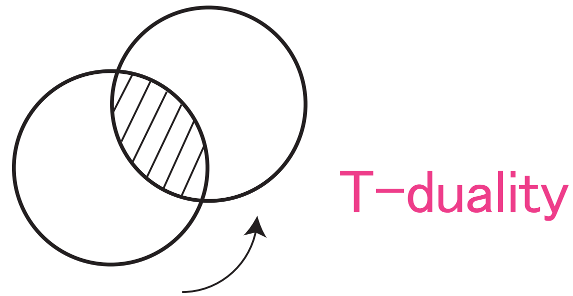




new effects/phenomena?

# Summary

# Summary

- T–folds are non–geometric backgrounds of strings
    - involve T–duality in transition fn.
    - intrinsic to string theory




- obtained exact partition fn. for T–folds
  systematically by using momentum lattices

- T–fold set–up naturally leads to non–susy string vacua
  w/ vanishing cosmological constant (at least) at 1 loop

- from such asymmetric orbifolds, can obtain
  susy vacua w/ stable non-BPS D-branes

  ⇒ non-perturbatively small cosmological constant

- conformal interfaces:

  fundamental objects implementing T-duality on world-sheet

- asymmetric orbifold by group-like defects ⇒ T-folds
  asymmetric orbifold by general defects ⇒ monodrofolds

- amplitudes w/ interfaces :
  transition from wrapped to unwrapped strings