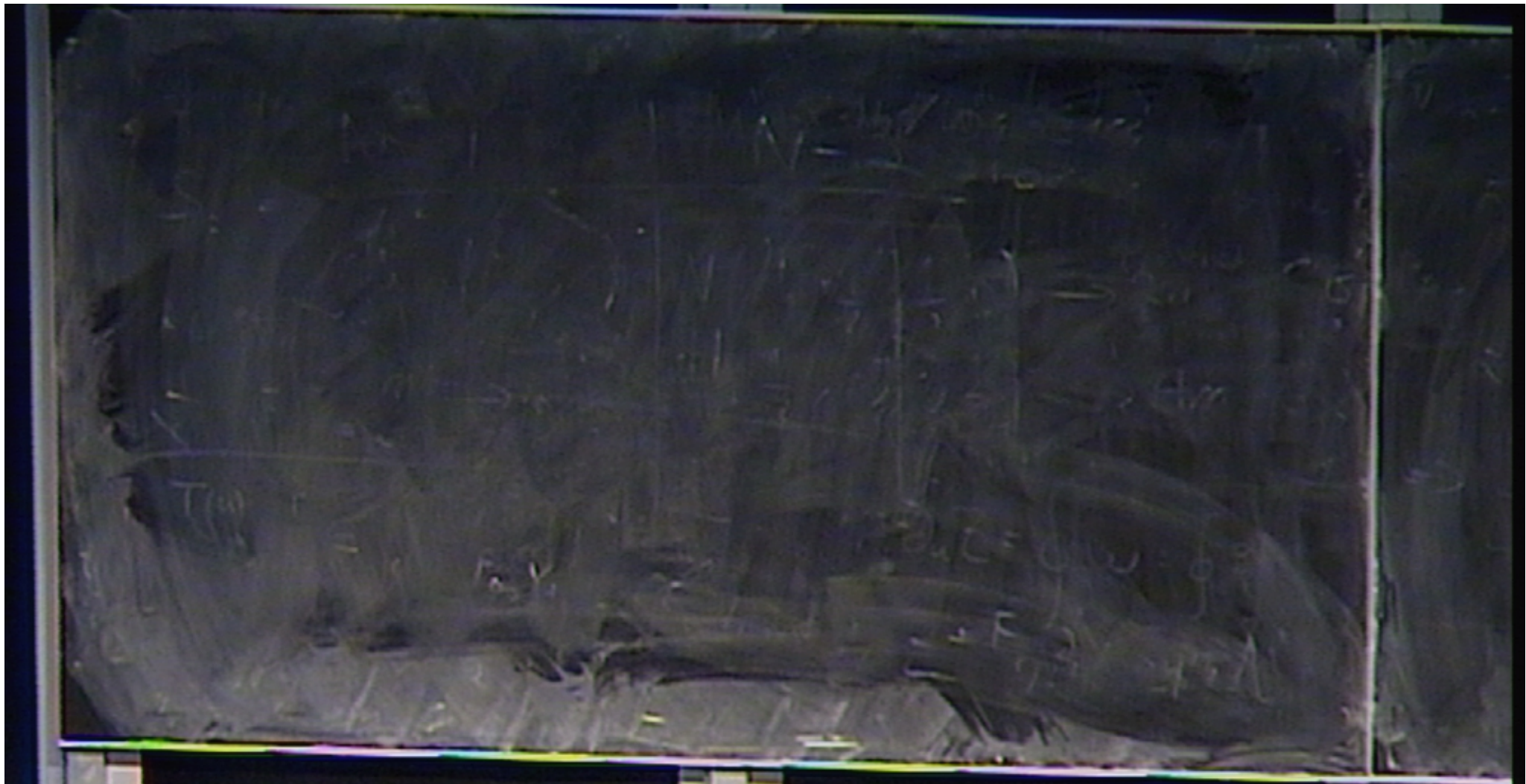


Title: Flux Compactifications

Date: Jul 01, 2005 09:30 AM

URL: <http://pirsa.org/05070063>

Abstract:



Review

$N = 2$

$T(u)$

r_0

$\phi(u) = \phi$

$\phi(u) = \phi$

Review

1) the m

Review

the manifold must be complex

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the manifold must be complex

$$\partial \bar{\partial} J = i (tr R \wedge R - tr F \wedge F)$$

$$d(e^{-2\Phi} J \wedge J) = 0$$

Review

the man. fold must be complex

$$\partial \bar{\partial} J = i (t, R \wedge R - t, F \wedge F)$$

$$d(e^{-2\Phi} J \wedge J) = 0$$

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$$d(e^{-2\Phi} J \wedge J) = 0$$

3) isomorphie (3,0) form w

$$\Phi(y) = \frac{1}{2} \log |w| + \text{const}$$

$$4) \quad J^{a\bar{b}} F_{a\bar{b}} = 0$$

$$F_{ab} = F_{a\bar{b}} = 0$$

3) holomorphic $(3,0)$ form ω

$$\Phi(y) = \frac{1}{2} |\log |\omega|| + \text{const}$$

$$4) \int \bar{a} \bar{b} \bar{F}_{a\bar{b}} = 0$$

$$F_{a\bar{b}} = \bar{F}_{a\bar{b}} = 0$$

3) holomorphic $(3,0)$ form ω

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$$F_{a\bar{b}} = \bar{F}_{\bar{a}b} = 0$$

3) holomorphic (3,0) form ω

$$\Phi(y) = \frac{1}{2} \log |\omega|^2 + \text{const}$$

$$4) \int \bar{a} \bar{b} \bar{F}_{a\bar{b}} = 0$$

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Example 1

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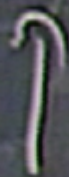
Example 1

$$g_{mn} = \sum_{i=1}^2 |y_i| g_{mn}^{u_i}$$

↑
Scalar function

Example 1

$$g_{mn} = \sum^2 |y|^2 g_{mn}^{(3)}$$



Scalar function

Example 1

$$g_{mn} = \int \sum |y|^2 g_{mn}$$



Scalar function

Using

$$*d*J = i(\bar{\partial} - \partial)l$$

$$2i(n-1) \partial l$$



complex dimension

Example 1

$$g_{mn} = \sum^2 |y|^2 g_{mn}^{(3)}$$

↑
Scalar function

Using $* d * J = i(\bar{\partial} - \partial) \log ||w||$

$$2i(n-1) \partial \log \Omega = i n \partial \log$$

↑
complex dimension

$\Rightarrow n =$

Example 1

$$g_{mn} = \sum \underbrace{(\gamma)^2}_{\text{scalar function}} g_{mn}^{(3)}$$

Using $* d * J = i(\bar{\partial} - \partial) \log ||w||$

$$2i(n-1) \partial \log \Omega = i n \partial (\log \Omega)$$

$\uparrow$ complex dimension $\Rightarrow \boxed{n=2}$

$$(\cancel{\not{D}}\Phi + \frac{1}{2} \partial h) \epsilon = 0$$

$$\nabla_m \epsilon - \frac{1}{2} \partial_n h \Gamma_m^n \epsilon = 0$$

$$\uparrow$$

$$d\bar{h} = \star H$$

$$(\not{\partial}\Phi + \frac{1}{2}\not{\partial}h)\epsilon = 0$$

$$\nabla_m \epsilon - \frac{1}{2}\not{\partial}_n h \Gamma_m^{n} \epsilon = 0$$

$$\uparrow$$

$$dh =$$

$$\Rightarrow \Phi = h \quad \epsilon = e^{-\frac{1}{2}\Phi}$$

$$(\delta\Phi + \frac{1}{2} \partial h) \epsilon = 0$$

$$\nabla_m \epsilon - \frac{1}{2} \partial_n h \Gamma_m^n \epsilon = 0$$

$$\uparrow$$

$$dh = \chi H$$

$$\Rightarrow \delta\Phi = h \chi$$

$$(\underline{\delta\Phi} + \frac{1}{2} \partial h) \epsilon = 0$$

$$\nabla_m \epsilon - \frac{1}{2} \partial_n h \Gamma_m^n \epsilon = 0 \leftarrow$$

$$\uparrow$$

$$dh = \chi H$$

$$\Rightarrow \underline{\delta\Phi} = h \chi_n$$

$$(\not{\partial}\Phi + \frac{1}{2}\partial h)\epsilon = 0$$

$$\nabla_m \epsilon - \frac{1}{2}\partial_n h \Gamma_m^n \epsilon = 0 \leftarrow$$

$$\uparrow$$

$$dh = *H$$

$$\Rightarrow \Phi = h \text{ und } \Omega = e^{-\Phi}$$

$$d \times d \Omega^2 = - \frac{\alpha'}{4} [\text{tr} R \wedge R - \text{tr} F \wedge F]$$

$$d \star d \Sigma^2 = -\frac{\alpha'}{4} [\star R \wedge R - \star F \wedge F]$$

$$F_{ab} = F_{\bar{a}\bar{b}} = \bar{F}_{a\bar{b}} g^{a\bar{b}} = 0$$

$$d \star d \Sigma^2 = -\frac{\alpha'}{4} [\star R \wedge R - \star F \wedge F]$$

$$F_{ab} = F_{\bar{a}\bar{b}} = \bar{F}_{a\bar{b}} g^{a\bar{b}} = 0 \checkmark$$

$$d \star d \Sigma^2 = -\frac{\alpha'}{4} [\text{tr} R \wedge R - \text{tr} F \wedge F] \checkmark$$

$$F_{ab} = F_{\bar{a}\bar{b}} = \bar{F}_{a\bar{b}} g^{a\bar{b}} = 0 \checkmark$$

$$d \star d \Sigma^2 = -\frac{\alpha'}{4} [\star R \wedge R - \star F \wedge F] \quad \checkmark$$

$$F_{ab} = F_{\bar{a}\bar{b}} = \bar{F}_{a\bar{b}} g^{a\bar{b}} = 0 \quad \checkmark$$

$$d \times d \Omega^2 = -\frac{\alpha'}{4} [tr R \wedge R - tr F \wedge F] \checkmark$$

$$F_{ab} = F_{\bar{a}\bar{b}} = \bar{F}_{a\bar{b}} g^{a\bar{b}} = 0 \checkmark$$

$\Rightarrow$ there is a bound on the volume of the internal dimensions

$$d \times d \Omega^2 = -\frac{\alpha'}{4} [tr R \wedge R - tr F \wedge F] \checkmark$$

$$F_{ab} = F_{\bar{a}\bar{b}} = \bar{F}_{a\bar{b}} g^{a\bar{b}} = 0 \checkmark$$

$\Rightarrow$ there is a bound on the volume of the internal dimensions

$$dH = \frac{\alpha'}{4} (tr R \wedge R - tr F \wedge F)$$

T-duality

T_{11}

$$G_{11} = -\alpha'^2 H$$

$$\Rightarrow \Phi = \frac{1}{2\pi\alpha'} \int_{\Sigma} \omega \quad \text{and} \quad \int_{\Sigma} \omega = \int_{\Sigma} \frac{1}{2\pi\alpha'} \int_{\Sigma} \omega$$

T-duality

T-duality

$$\int d^2\sigma \left(\frac{1}{2} V^\alpha V_\alpha - F^{\alpha\beta} X \right)$$

T-duality

$$\int d^2\sigma \left(\frac{1}{2} V^\alpha V_\alpha - \epsilon^{\alpha\beta} X \partial_\beta V_\alpha \right)$$

$$Q_n = x + i$$

$$\Rightarrow \frac{1}{\hbar} \ln \text{ind} = \sqrt{2} \pm \frac{\Phi}{2} + F_{T^2}$$

T-duality

$$\int d^2\sigma \left(\frac{1}{2} V^\alpha V_\alpha - \epsilon^{\alpha\beta} X \partial_\beta V_\alpha \right)$$

E.o.m for X : $\epsilon^{\alpha\beta} \partial_\beta V_\alpha = 0 \Rightarrow V_\alpha = \partial_\alpha \tilde{X}$

$$\Rightarrow \frac{1}{2} \int \partial^\alpha \tilde{X} \partial_\alpha \tilde{X} d^2\sigma$$

E.o.m. for V : $V_\alpha = -\epsilon_\alpha{}^\beta \partial_\beta X$

$$\rightarrow \frac{1}{2} \int \partial^\tau X \partial_\alpha X d^2\sigma$$

E.o.m. for V : $V_\alpha = -\epsilon_\alpha{}^\beta \partial_\beta X$

$\rightarrow \frac{1}{2} \int \partial^\tau X \partial_\alpha X d^2\sigma$

$\partial_\alpha \tilde{X} = -\epsilon_\alpha{}^\beta \partial_\beta X \rightarrow$

E.o.m. for V : $V_\alpha = -\epsilon_\alpha{}^\beta \partial_\beta X$

$\rightarrow \frac{1}{2} \int \partial^\tau X \partial_\alpha X d^2\sigma$

$\partial_\alpha \tilde{X} = -\epsilon_\alpha{}^\beta \partial_\beta X$

$X_R \rightarrow -X_R, \quad X_L \rightarrow X_L$

Type II strings + T-duality

$$X_L^9 \rightarrow X_L^9$$

$$X_R^9 \rightarrow -X_R^9$$

Type II strings + T-duality

$$X_L^9 \rightarrow X_L^9$$

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T-duality changes the chirality of the right moving R sector ground state $\Rightarrow$ IIA and IIB are interchanged
complete duality $\Rightarrow$

Type II strings + T-duality

$$X_L^9 \rightarrow X_L^9 \quad X_R^9 \rightarrow -X_R^9$$

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$$X_L^9 \rightarrow X_L^9 \quad X_R^9 \rightarrow -X_R^9$$

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T-duality changes the chirality of the right moving R sector ground state $\Rightarrow$ IIA and IIB are interchanged.

$$\left. \frac{\partial X^\mu}{\partial \sigma} \right|_{\sigma=0} = \left. \frac{\partial X^\mu}{\partial \sigma} \right|_{\sigma=0} = 0 \quad \mu = 0, \dots, p$$

X^μ

$$\partial_{\sigma} X^{\mu} \Big|_{\sigma=0} = \partial_{\sigma} X^{\mu} \Big|_{\sigma=\pi} = 0 \quad \mu = 0, \dots, p$$

$$X^{i'} \Big|_{\sigma=0} = d_{i'} \quad X^{i'} \Big|_{\sigma=\pi} = d_{i'} \quad i' = p+1, \dots, 9$$

$$\partial_\sigma X^\mu|_{\sigma=0} = \partial_\sigma X^\mu|_{\sigma=\pi} = 0 \quad \mu = 0, \dots, p$$

$$X^{i'}|_{\sigma=0} = d_{i'} \quad X^{i'}|_{\sigma=\pi} = d_{i'} \quad i' = p+1, \dots, 9$$

positions of the
D-branes

$$X^M(\tau, \sigma) = X^M + p^M \tau + i \sum_{n \neq 0} \frac{1}{n} \alpha_n^M \omega_n \sigma e^{-in\tau}$$

$\tau | \bar{\tau}$

$$X^M(\tau, \sigma) = X^M + p^M \tau + i \sum_{n \neq 0} \frac{1}{n} \alpha_n^M \cos n\sigma e^{-in\tau}$$

$$X^i(\tau, \sigma) = d_i^i + (d_i^i - \dot{X}^i) \tau + \sum$$

$$X^M(\tau, \sigma) = X^M + p^M \tau + i \sum_{n \neq 0} \frac{1}{n} \alpha_n^M \cos n\sigma e^{-in\tau}$$

$$X^i(\tau, \sigma) = d_1^i + (d_2^i - d_1^i) \frac{\sigma}{\pi} + \sum_{n \neq 0} \frac{1}{n} \alpha_n^i \sin n\sigma e^{-in\tau}$$

$$X^M(\tau, \sigma) = X^M + p^M \tau + i \sum_{n \neq 0} \frac{1}{n} \alpha_n^M \cos n\sigma e^{-in\tau}$$

$$X^i(\tau, \sigma) = d_1^i + (d_2^i - d_1^i) \frac{\sigma}{\pi} + \sum_{n \neq 0} \frac{1}{n} \alpha_n^i \sin n\sigma e^{-in\tau}$$

Dirichlet + Neumann boundary conditions are interchanged.

For type II Λ we have D_p Symos (p even) $\Rightarrow$



changes the character of the
 Reaching ground state $\Rightarrow$ IIA and IIB
 completion $\Rightarrow$

For type IIA we have D_p branes (p even) $\Leftrightarrow$
 type IIB where p is odd.

T-duality changes the dimensionality of the
 moving R sector ground state $\rightarrow$ IIA and IIB
 complementation $\Rightarrow$

For type IIA we have $Sp(2n+1)$

type IIIB where p is odd.

This is an example of a perturbative duality

T-duality changes the dimension

moving R sector ground state $\rightarrow$ IIA and IIIB

compactification $\Rightarrow$ IIA

For type IIA we have D_p branes (p even) $\Leftrightarrow$
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This is an example of a perturbative duality.

T -duality changes the dimensionality of the theory
 moving from D to $D-1$ or $D+1$
 (compactification) $\Rightarrow$ IIA and IIIB

For type IIA we have D_p branes (p even) $\Leftrightarrow$
 type IIIB where p is odd.

This is an example of a perturbative duality

In 10d: $\frac{1}{g_s} \int d^{10}x \mathcal{L}_{10}$

moving R sector ground state $\rightarrow$ IIA and IIIB
 (compactification) $\Rightarrow$

$$\frac{2\pi R}{g_s^2}$$

$\int$

$$\frac{2\pi R}{g_s^2}$$

$$\int d^9x \mathcal{L}_{NS}$$

(IIA)

2

$$\frac{2\pi R}{g_s^2} \int d^9x \mathcal{L}_{NS} \quad (\text{IIA})$$

$$\frac{2\pi \tilde{R}}{\tilde{g}_s^2} \int d^9x \mathcal{L}_{NS} \quad (\text{IIB})$$

$$\frac{2\pi R}{g_s^2} \int d^9 X \mathcal{L}_{NS} \quad (\text{IIA})$$

$$\frac{2\pi \tilde{R}}{\tilde{g}_s^2} \int d^9 X \mathcal{L}_{NS} \quad (\text{IIB})$$

$$R \tilde{R} = \alpha'$$

$$\tilde{g}_S = \frac{\sqrt{\alpha'}}{R} g_S$$

$$\tilde{g}_S = \frac{\sqrt{\alpha'}}{R} g_S$$

$$\frac{2\pi R}{g_s^2}$$

$$\int d^9x \mathcal{L}_{NS}$$

(IIA)

$$\frac{2\pi \tilde{R}}{\tilde{g}_s^2}$$

$$\int d^9x \mathcal{L}_{NS}$$

(IIB)

$$R \tilde{R} = \alpha'$$

$\Rightarrow$

$$\tilde{g}_s = \frac{\sqrt{\alpha'}}{R} g_s$$

Background fields.

$$S = S_g + S_B$$

Background fields.

$$S = S_g + S_B + S_\Phi$$

$$S_g = \int d^2\sigma \sqrt{-h} h^{\alpha\beta} g_{\mu\nu} \partial_\alpha X^\mu \partial_\beta X^\nu$$

$$(d^2)$$

Background fields.

$$S = S_g + S_B + S_\Phi$$

$$= \frac{1}{4\pi\alpha'} \int d^2\sigma \sqrt{-h} h^{\alpha\beta} g_{\mu\nu} \partial_\alpha X^\mu \partial_\beta X^\nu$$

$$\int d^2\sigma \epsilon^{\alpha\beta} B_{\mu\nu} \partial_\alpha X^\mu \partial_\beta X^\nu$$

Background fields.

$$S = S_g + S_B + S_\Phi$$

$$S_g = \frac{1}{4\pi\alpha'} \int d^2\sigma \sqrt{-h} h^{\alpha\beta} g_{\mu\nu} \partial_\alpha X^\mu \partial_\beta X^\nu$$

$$S_B = \frac{1}{4\pi\alpha'} \int d^2\sigma \epsilon^{\alpha\beta} B_{\mu\nu} \partial_\alpha X^\mu \partial_\beta X^\nu$$

$$S_\Phi = \frac{1}{4\pi} \int d^2\sigma \sqrt{-h} \Phi R^{(2)}$$

$$S = \frac{1}{4\pi\alpha'} \int d^2\sigma$$

$$S = \frac{1}{4\pi\alpha'} \int d^2\sigma \sqrt{-h} h^{\alpha\beta} (g_{\mu\nu} V_\alpha^\mu V_\beta^\nu + 2g_{\mu\nu} V_\alpha^\mu \partial_\beta x^\nu - g_{\mu\nu} \partial_\alpha x^\mu \partial_\beta x^\nu)$$

Maximizing Riemannian
complex dimension

$$S = \frac{1}{4\pi\alpha'} \int d^2\sigma \sqrt{-h} h^{\alpha\beta} (g_{\mu\nu} V_\alpha V_\beta + 2g_{\mu\nu} V_\alpha \partial_\mu X^\mu + g_{\mu\nu} \partial_\alpha X^\mu \partial_\beta X^\nu) +$$

$$+ \epsilon^{\alpha\beta} (B_{\mu\nu} V_\alpha \partial_\beta X^\mu + B_{\mu\nu} \partial_\alpha X^\mu \partial_\beta X^\nu) +$$

$$\begin{aligned}
 S = & \frac{1}{4\pi\alpha'} \int d^2\sigma \sqrt{-h} h^{\alpha\beta} \left(g_{\mu\nu} V_\alpha V_\beta + 2g_{\mu\nu} V_\alpha \partial_\mu X^\mu - g_{\mu\nu} \partial_\alpha X^\mu \partial_\beta X^\nu \right) \\
 & + \epsilon^{\alpha\beta} \left(B_{\mu\nu} V_\alpha \partial_\beta X^\mu + B_{\mu\nu} \partial_\alpha X^\mu \partial_\beta X^\nu \right) + \\
 & \tilde{X}^\mu \epsilon^{\alpha\beta} \partial_\alpha V_\beta + \alpha' \sqrt{-h} R^{(2)} \underline{\Phi}
 \end{aligned}$$

Moduli space of the worldsheet theory
 (simple, dimension) $\Rightarrow$ $\frac{D-2}{2}$

$$S = \frac{1}{4\pi\alpha'} \int d^2\sigma \sqrt{-h} h^{\alpha\beta} \left(g_{\mu\nu} V_\alpha V_\beta + 2g_{\mu\nu} V_\alpha \partial_\mu X^\mu - g_{\mu\nu} \partial_\mu X^\mu \partial_\nu X^\nu \right) \\
+ \epsilon^{\alpha\beta} \left(B_{\mu\nu} V_\alpha \partial_\beta X^\mu + B_{\mu\nu} \partial_\alpha X^\mu \partial_\beta X^\nu \right) + \\
\epsilon^{\alpha\beta} \partial_\alpha V_\beta + \alpha' \sqrt{-h} R^{(2)} \underline{\Phi}$$

tion in terms of dual variables (eliminate V with

II A and II B
 $\Rightarrow$

$$S = \frac{1}{4\pi\alpha'} \int d^2\sigma \sqrt{-h} h^{\alpha\beta} \left(g_{\mu\nu} V_\alpha V_\beta + 2g_{\mu\nu} V_\alpha \partial_\mu X^\mu - g_{\mu\nu} \partial_\alpha X^\mu \partial_\beta X^\nu \right) +$$

$$+ \epsilon^{\alpha\beta} \left(B_{\mu\nu} V_\alpha \partial_\beta X^\mu + B_{\mu\nu} \partial_\alpha X^\mu \partial_\beta X^\nu \right) +$$

$$\tilde{X}^\mu \epsilon^{\alpha\beta} \partial_\alpha V_\beta + \alpha' \sqrt{-h} R^{(2)} \underline{\Phi}$$

The action in terms of dual variables (eliminate V with its eqn)

Moving $R^{(2)}$ to the right hand side of the equation $\Rightarrow$ II A and II B

$$\tilde{g}_{\eta\eta} = \frac{1}{g_{\eta\eta}}$$

$$\tilde{g}_{\eta\mu} = \frac{B_{\eta\mu}}{g_{\eta\eta}}$$

$$\tilde{g}_{\mu\nu} = \frac{(g_{\mu\eta} g_{\eta\nu} - B_{\mu\eta} B_{\eta\nu})}{g_{\eta\eta}}$$

$$\tilde{g}_{\eta\eta} = \frac{1}{g_{\eta\eta}} \quad \tilde{g}_{\eta\mu} = \frac{B_{\eta\mu}}{g_{\eta\eta}}$$

$$\tilde{g}_{\mu\nu} = \frac{(g_{\mu\eta} g_{\eta\nu} - B_{\mu\eta} B_{\eta\nu})}{g_{\eta\eta}}$$

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$$\tilde{g}_{\mu\nu} = \frac{(g_{\mu\mu} g_{\nu\nu} - B_{\mu\mu} B_{\nu\nu})}{g_{\eta\eta}}$$

$$\tilde{g}_{\eta\eta} = \frac{1}{g_{\eta\eta}} \quad \tilde{g}_{\eta\mu} = \frac{B_{\eta\mu}}{g_{\eta\eta}}$$

$$\tilde{g}_{\mu\nu} = g_{\mu\nu} - \frac{(g_{\eta\mu} g_{\eta\nu} - B_{\eta\mu} B_{\eta\nu})}{g_{\eta\eta}}$$

$$\tilde{B}_{\eta\mu} = -\tilde{B}_{\mu\eta} = \frac{g_{\eta\mu}}{g_{\eta\eta}} \quad \Bigg| \quad \tilde{B}_{\mu\nu} = B_{\mu\nu} + \frac{(g_{\eta\mu} B_{\eta\nu} - B_{\eta\mu} g_{\eta\nu})}{g_{\eta\eta}}$$

$$\tilde{g}_S = g_S \frac{\sqrt{\alpha'}}{R} \quad | \quad g_{\tau\tau} = \frac{R^2}{\alpha'}$$

$$S = \frac{1}{4\pi}$$

+

X^2

The
its

$$\tilde{g}_s = g_s \frac{\sqrt{\alpha'}}{R} \quad | \quad g_{\eta\eta} = \frac{R^2}{\alpha'}$$

$$g_s = e^{\Phi}$$

$$\Rightarrow \tilde{\Phi} = \Phi - \frac{1}{2} \log g_{\eta\eta}$$

$$\tilde{g}_s = g_s \frac{\sqrt{\alpha'}}{R} \quad | \quad g_{\eta\eta} = \frac{R^2}{\alpha'}$$

$$g_s = e^{\Phi}$$

$$= \Phi - \frac{1}{2} \log g_{\eta\eta}$$

$$m_{B_{UV}} - B_{UV} g_{\eta\eta})$$

A six dimensional example in the orbifold limit

A six dimensional example in the orbifold limit

A six dimensional example in the orbifold limit

Type II B (with

A six-dimensional example in the orbifold limit

Type II B (without fluxes) compactified

A six-dimensional example in the orbifold limit

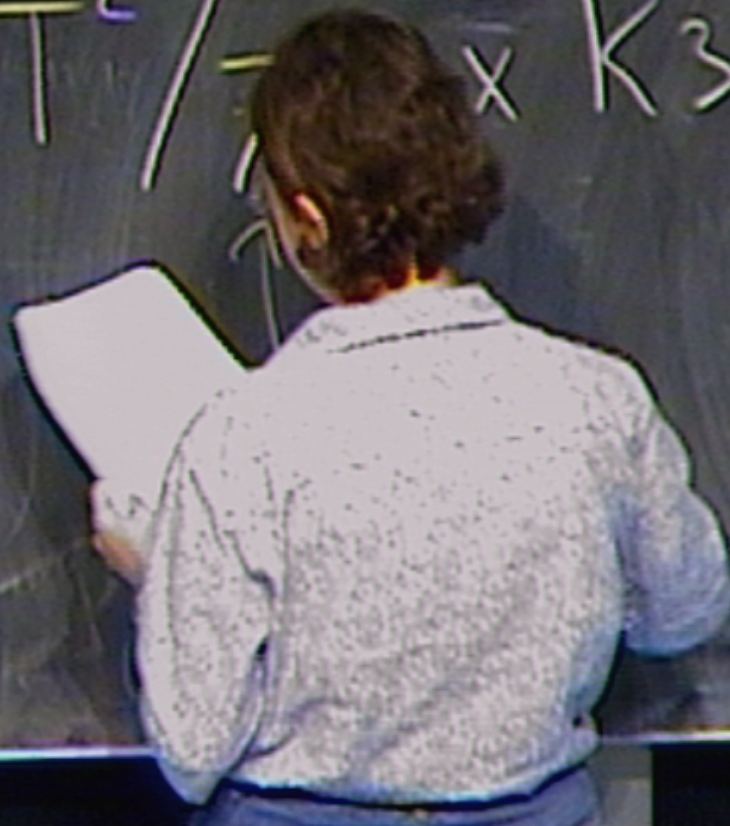
Type IIB (without fluxes) compactified on:

$$T^2 / \mathbb{Z}_2 \times K3$$

A six-dimensional example in the orbifold limit

Type II B (without fluxes) compactified on:

$$T^2 / \Gamma \times K3$$



A six-dimensional example in the orbifold limit

Type II B (without fluxes) compactified on:

$$T^2 / \mathbb{Z}_2 \times K3$$

$$\uparrow \mathbb{Z}_2 = \Omega(1-1)^F \cdot I_{89}$$

A six-dimensional example in the orbifold limit

Type IIB (without fluxes) compactified on:

$$X_{8,9} \rightarrow T^2 / \mathbb{Z}_2 \times K3$$

$$\uparrow \quad \uparrow$$

$$\mathbb{Z}_2 = \Omega(1-1)^F \cdot I_{89}$$

A six dimensional example in the orbifold limit

Type II B (without fluxes) compactified on:

$$X_{8,9} \rightarrow T^2 / \mathbb{Z}_2 \times K3$$

$$\uparrow \mathbb{Z}_2 = \Omega(1-1)^F \cdot \frac{I}{\sqrt{2}}$$

$$X_{8,9} \rightarrow -X_{8,9}$$

Σ : world-sheet parity $\sigma \rightarrow 2\pi - \sigma$

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(in exchange X_L, X_R)

Ω : world-sheet parity $\sigma \rightarrow 2\pi - \sigma$

(interchanges X_L, X_R)

$$S = \int d^2\sigma \left(\frac{1}{2\alpha'} \partial_\mu X^\mu \partial_\nu X^\nu + \dots \right)$$

Ω : world-sheet parity $\sigma \rightarrow 2\pi - \sigma$

(interchanges X_L, X_R)

$$\int^2 \sigma \left(\partial_+ X^\mu \partial_- X^\mu - i \dot{S}^a \partial_- S^a - i \tilde{S}^a \partial_+ \tilde{S}^a \right)$$

Ω : world-sheet parity $\sigma \rightarrow 2\pi - \sigma$

(interchanges X_L, X_R)

$$S = \int d^2\sigma \left(\partial_\mu X^\mu \partial_\nu X^\nu - i \bar{S}^a \partial_- S^a - i \tilde{S}^a \partial_+ \tilde{S}^a \right)$$

$(-1)^{F_L} : S_a \rightarrow -S_a$

Ω : world-sheet parity $\sigma \rightarrow 2\pi - \sigma$

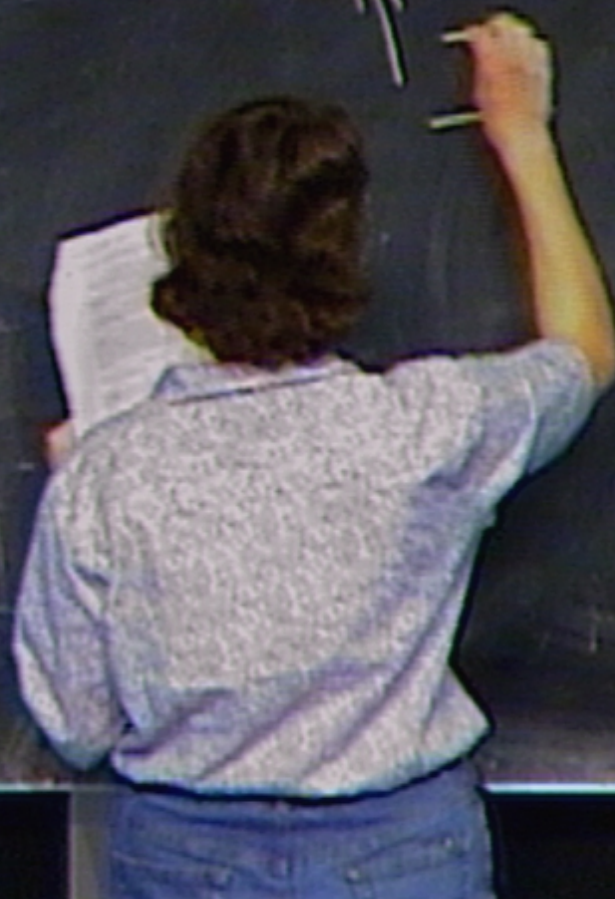
(interchanges X_L, X_R)

$$S = \int d^2\sigma \left(\partial_\mu X^\mu \partial_\nu X^\nu - i \bar{S}^a \partial_- S^a - i \tilde{S}^a \partial_+ \tilde{S}^a \right)$$

$$(-1)^{F_L} : S_a \rightarrow -S_a$$

$$K_3 = T^4 / \pi_2 = (T^2 \times T^2) / \pi_2$$

↑



$$K_3 = T^4 / \pi_2 - (T^2 \times T^2) / \pi_2$$

$\uparrow$
 I_{4567}

$$K_3 = T^4 / \pi_2 = (T^2 \times T^2) / \pi_2$$

↑
I 4567

1. You can check that the Lethi number is 4567

$$K3 = T^4 / \pi_2 = (T^2 \times T^2) / \pi_2$$

$\uparrow$
 I_{4567}

(You can check that the L₂ H₁ numbers work out)

$$K3 = T^4 / \pi_2 = (T^2 \times T^2) / \pi_2$$

$\uparrow$
 I_{4567}

(You can check that the L₂ numbers work out)

$$\sum \pi = 15$$

Dimensional example, 100 years or

B (without fluxes) compactified

$$T^2 / \mathbb{Z}_2 \times K3$$

$$\mathbb{Z}_2 = \Omega(1,1)^F \subset T$$

Ref:

$$\sum_{n=1}^{\infty} \frac{1}{n^2} = \frac{\pi^2}{6}$$

$$\sum_{n=1}^{\infty} \frac{1}{n^4} = \frac{\pi^4}{90}$$

$$2x^2$$

Ref: "Lectures on orientifolds + duality", Dabholkar, 980420

$\mathbb{Z}_2$ quotient of $\mathbb{R}^{1,9}$ by $x \rightarrow -x$

$\mathbb{Z}_2$

Ref: "Lectures on orientifolds + duality"

Ω ... sheet ...

$$\pi_2 = \Omega$$

Ref: "Lectures on orientifolds + duality", Dabholkar.

$$\pi_2 = \Omega(-1)^{F_L} \underline{I}_{89} \xrightarrow{T_{89}} \Omega$$

Ref: "Lectures on orientifolds + duality", Pabholkar

$$\pi_L = \Omega(-1)^{F_L} \mathbb{I}_{89} \xrightarrow{T_{89}} \Omega$$

Homework

Ref: "Lectures on orientifolds + duality", Pabholkar

$$\pi_L = \Omega(-1)^{F_L} \underline{I}_{89} \xrightarrow{T_{89}} \Omega$$

Homework

$$\Omega(-1)^{F_L^X} \underline{I}_{89} = \underline{I}_{89}$$

Ref: "Lectures on orientifolds + duality", Dabholkar

$$\pi_2 = \Omega(-1)^{F_L} \mathbb{I}_{89} \xrightarrow{T_{89}} \Omega$$

Homework

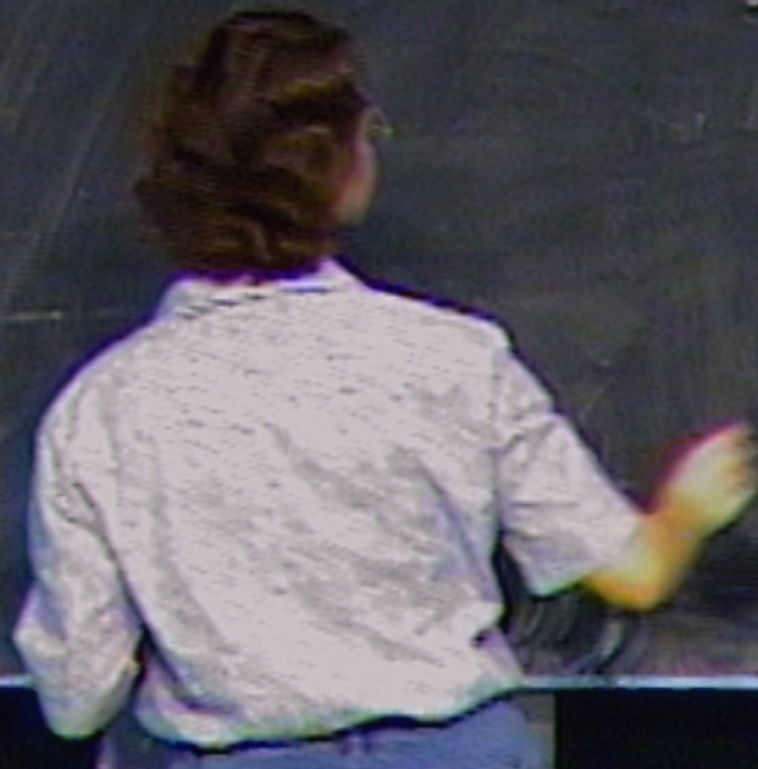
$$\Omega(-1)^{F_L} \mathbb{I}_{89} = T_{89}^{-1} \Omega T_{89}$$

After two T-dualities

After two T-dualities we have a type II background

After two T-dualities we have a type II background
in which only Ω invariant

After two T-dualities we have a type II background
in which only Ω invariant states are kept



background -

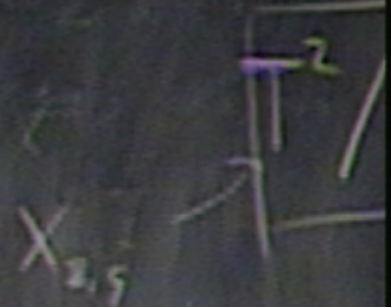
are kept 

A

By

After two T-dualities we have a type II background
 in which only SZ invariant states are kept $\rightarrow$
 this is a background for type I.

A 4d dimensional
 Type II B (with



After two T-dualities we have a type II background in which only Ω invariant states are
this is a background for type I.

After two T-dualities we have a type II background
in which only Ω invariant states are kept $\rightarrow$

This is a background for type I.

After two T-dualities we have a type II background -
in which only $\mathcal{N}$ invariant states are kept $\rightarrow$

this is a background for type I.

$\rightarrow$ to a background for the het:

After two T-dualities we have a type II background -
in which only Ω invariant states are kept $\rightarrow$

this is a background for type I.

To get to a background for the het:

$$g_{MN}^{\text{het}} = g_{\text{I}} g_{MN}^{\text{I}} \quad g_{\text{het}} = g_{\text{I}}^{-1}$$

After two T-dualities we have a type II background -
in which only $\mathcal{N}$ invariant states are kept $\rightarrow$

this is a background for type I.

To get to a background for the het:

$$g_{MN}^{\text{het}} = g_{\text{I}} g_{MN}^{\text{I}} \quad g_{\text{het}} = g_{\text{I}}^{-1} \checkmark$$

After two T-dualities we have a type II background
in which only Ω invariant states are kept $\rightarrow$

this is a background for type I.

To get to a background for the het:

$$g_{MN}^{\text{het}} = g_{\text{I}} g_{MN}^{\text{I}} \quad g_{\text{het}} = g_{\text{I}}^{-1}$$

in which only SO invariant states are

this is a background for type I.

To set to a background for the het:

$$g_{MN}^{\text{het}} = g_{\text{I}} g_{MN}^{\text{I}}$$

metric

string coupling

$$g_{\text{het}} = g_{\text{I}}^{-1} \checkmark$$

A six-dimensional example in the orbifold limit

Type II B (without fluxes) compactified on:

$$X_{8,9} \rightarrow \left[T^2 / \mathbb{Z}_2 \times K3 \right] \xrightarrow{\mathbb{Z}_2 = \Omega(1-1)^F} I_{39}$$

Then the compactification $\Rightarrow X_{8,9} \rightarrow -X_{8,9}$

After two T-dualities we have a type II background -
in which only Ω invariant states are kept $\rightarrow$

this is a background for type I.

To get to a background for the het:

$$g_{MN}^{\text{het}} = g_{\text{I}} g_{MN}^{\text{I}} \quad g_{\text{het}} = g_{\text{I}}^{-1} \checkmark$$

$\uparrow$ α' $\uparrow$ string coupling

A six dimensional example in the orbifold limit
without fluxes +

A six dimensional example in the orbifold limit
without fluxes the metric on the left side

A six-dimensional example in the orbifold limit

Without fluxes the metric on the left side

$$ds^2 = ds_{0123}^2 + ds_{K3}^2 + dz_3 d\bar{z}_3$$

A six-dimensional example in the orbifold limit

Without fluxes the metric on the hot side
 $K3 \times T^2$

$$ds^2 = ds_{0123}^2 + \overbrace{ds_{K3}^2 + dz_3 d\bar{z}_3}$$

A six-dimensional example in the orbifold limit

Without fluxes the metric on the left side
 $K3 \times T^2$

$$ds^2 = ds_{0123}^2 + \underbrace{ds_{K3}^2}_{\text{wavy line}} + \underbrace{dz_3 d\bar{z}_3}_{\text{wavy line}}$$

$$h_1(T^2) = 1, 2, 1$$

$$h_1(K3, 22, 0, 1)$$

A six-dimensional example in the orbifold limit

Without fluxes the metric on the left side
 $K3 \times T^2$

$$ds^2 = ds_{0123}^2 + ds_{K3}^2 + dz^2$$

$$br(k3) = 1, 0, 22, 0,$$

$$l_1 = 9.14$$

A six-dimensional example in the orbifold limit

Without fluxes the metric on the left side
 $K3 \times T^2$

$$ds^2 = ds_{0123}^2 + \underbrace{ds_{K3}^2}_{\text{wavy line}} + \underbrace{dz_3 d\bar{z}_3}_{\text{wavy line}}$$

$$b_i(k3) = 1, 0, 22, 0, 1$$

$$b_i(T^2) = 1, 2, 1$$

$$\uparrow i = 0, 1, 2$$

$$b_i = 0, 1, 4$$

$$b_i(K3 \times T^2) = 1, 2, 23, 44, 23, 2, 1, \quad i = 0 \dots 6$$

$\chi(K3)$

$$b_i (K^3 \times T^2) = 1, 2, 23, 44, 23, 2, 1, \quad i = 0, \dots, 6$$

$$\chi (K^3 \times T^2) = 0$$

Include fluxes on the d

Include fluxes on the type II B side

Include fluxes on the type II B side

$$\rightarrow G_{(3)} = \epsilon' G_{(3)}$$

$$G_{(0,2)}$$

Include fluxes on the type II B side

$$\rightarrow G_{(3)} = i' G_{(3)}$$

$$G_{(0,3)} = 0$$

Include fluxes on the type II B side

$$\rightarrow G_{(3)} = i' G_{(3)}$$

$$G_{(0,3)} = 0$$

$$H_{(3)} = A d\bar{z}_1 \wedge dz_2 \wedge d\bar{z}_2$$

Include fluxes on the type IIB side

$$\rightarrow G_{(3)} = \tau' G_{(3)}$$

$$G_{(0,3)} = 0$$

$$= A d\bar{z}_1 \wedge dz_2 \wedge d\bar{z}_3 + D dz_1 \wedge d\bar{z}_2 \wedge d\bar{z}_3 + \text{c.c.}$$

Include fluxes on the type II B side

$$\times G_{(3)} = i' G_{(3)}$$

$$G_{(0,3)} = 0$$

$$H_{(3)} = A d\bar{z}_1 \wedge dz_2 \wedge dz_3 + \text{c.c.}$$

$$F_{(3)} = \tau (-A d\bar{z}_1 \wedge dz_2 \wedge dz_3 + \text{c.c.})$$

Include fluxes on the type II B side

$$\times G_{(3)} = \epsilon' G_{(3)} \leftarrow G_{(0,3)} = 0$$

$$H_{(3)} = A d\bar{z}_1 \wedge dz_2 \wedge d\bar{z}_3 + D dz_1 \wedge d\bar{z}_2 \wedge d\bar{z}_3 + \text{c.c.}$$

$$F_{(3)} = \tau \left(-A d\bar{z}_1 \wedge dz_2 \wedge d\bar{z}_3 - D dz_1 \wedge d\bar{z}_2 \wedge d\bar{z}_3 \right) + \text{c.c.}$$

$$G_{(3)} = F_{(3)} - \tau H_3$$

Include fluxes on the type II B side

$$\rightarrow G_{(3)} = i' G_{(3)} \leftarrow \quad G_{(0,3)} = 0$$

$$H_{(3)} = A d\bar{z}_1 \wedge dz_2 \wedge d\bar{z}_3 + D dz_1 \wedge d\bar{z}_2 \wedge d\bar{z}_3 + \text{c.c.}$$

$$F_{(3)} = T \left(-A d\bar{z}_1 \wedge dz_2 \wedge d\bar{z}_3 - D dz_1 \wedge d\bar{z}_2 \wedge d\bar{z}_3 \right) + \text{c.c.}$$

$$G_{(3)} = F_{(3)} - T H_3 \quad \boxed{T = i}$$

Include fluxes on the type II B side

$$\rightarrow G_{(3)} = i' G_{(3)} \leftarrow \quad G_{(0,3)} = 0$$

$$H_{(3)} = A d\bar{z}_1 \wedge dz_2 \wedge d\bar{z}_3 + D dz_1 \wedge d\bar{z}_2 \wedge d\bar{z}_3 + \text{c.c.}$$

$$F_{(3)} = \tau \left(-A d\bar{z}_1 \wedge dz_2 \wedge d\bar{z}_3 - D dz_1 \wedge d\bar{z}_2 \wedge d\bar{z}_3 \right) + \text{c.c.}$$

$$G_{(3)} = F_{(3)} - \tau H_3 \quad \boxed{\tau = i} \quad \tau = G_0 + i e^{-\phi}$$

Include fluxes on the type II B side

$$\rightarrow G_{(3)} = i' G_{(3)} \leftarrow \quad G_{(0,3)} = 0$$

$$H_{(3)} = A d\bar{z}_1 \wedge dz_2 \wedge d\bar{z}_3 + D dz_1 \wedge d\bar{z}_2 \wedge d\bar{z}_3 + \text{c.c.}$$

$$F_{(3)} = \tau \left(-A d\bar{z}_1 \wedge dz_2 \wedge d\bar{z}_3 - D dz_1 \wedge d\bar{z}_2 \wedge d\bar{z}_3 \right) + \text{c.c.}$$

$$G_{(3)} = F_{(3)} - \tau H_3 \quad \boxed{\tau = i} \quad \tau = G_0 + i e^{-\phi} = i$$

$$(A, D) = (1 + i, 0)$$

$$(A, D) = (1, 1)$$

NS-NS



NS-NS

$$(A, D) = (1 + i, 0)$$

$$(A, D) = (1, 1)$$

NS-NS

$$(A, D) = (1 + i, 0)$$

$$(A, D) = (1, 1)$$

ϵ
 $\epsilon = 0$
 NS-M

$$\sqrt{2} \, dz_2 \wedge d\bar{z}_3 + \text{c.c.}$$

$$(\sqrt{2} \, dz_2 \wedge d\bar{z}_3) + \text{c.c.}$$

$$T = G_0 + i e^{-\phi} = i$$

$$(A, D) = (1 + i, 0)$$

$$(A, D) = (1, 1)$$

$$(A, D) = (1 + i, 0)$$

$$(A, D) = (1, 1)$$

NS-NS

After 1 + two T-dualities

$$ds^2 = 2 \alpha$$

$$(A, D) = (1 + i, 0)$$

NS-NS

$$(A, D) = (1, 1)$$

After two T-dualities

$$ds^2 = 2g_{11} dz' d\bar{z}' + 2g_{22} d\bar{z}' d\bar{z}'$$

$$(A, D) = (1 + i, 0)$$

$$(A, D) = (1, 1)$$

After two T-dualities:

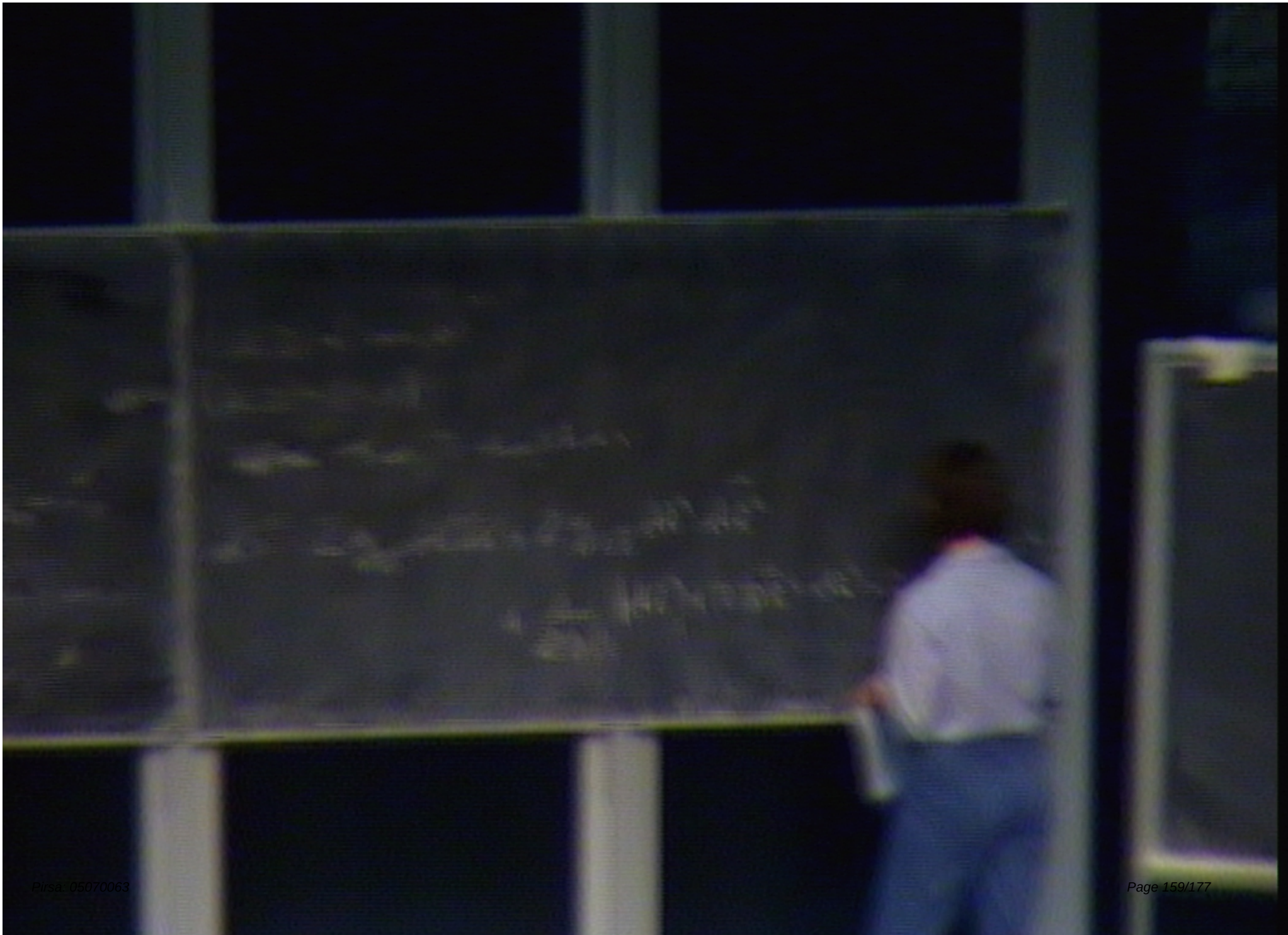
$$ds^2 = 2g_{11} dz' d\bar{z}' + 2g_{2\bar{2}} dz^2 d\bar{z}^2 + \frac{1}{2g_{33}} |dz^3 + 2D\bar{z}^2 dz' - 2A\bar{z}' dz^2|^2$$

$$(A, D) = (1 + i, 0)$$

$$(A, D) = (1, 1)$$

After two T-dualities:

$$ds^2 = 2g_{1\bar{1}} dz' d\bar{z}' + 2g_{2\bar{2}} dz^2 d\bar{z}^2 + \frac{1}{2g_{3\bar{3}}} |dz^3|^2 + 2D\bar{z}^2 dz' - 2A\bar{z}' dz^2$$



$$(A, D) = (1 + i, 0)$$

$$(A, D) = (1, 1)$$

After two T-dualities

$$ds^2 = 2g_{11} dz^1 d\bar{z}^1 + 2g_{2\bar{2}} dz^2 d\bar{z}^2 + \frac{1}{2g_{33}} |dz^3|^2 + 2D\bar{z}^2 dz^1 - 2$$

$$(A, D) = (1 + i, 0)$$

$$(A, D) = (1, 1)$$

After two T-dualities

$$ds^2 = 2g_{11} dz' d\bar{z}' + 2g_{2\bar{2}} dz^2 d\bar{z}^2 + \frac{1}{2g_{33}} |dz^3 + 2D\bar{z}^2 dz' - 2A\bar{z}' d\bar{z}^2|^2$$

$$\top$$

$$(z_1, z_2, z_3) \cong (z_1, z_2, z_3 + 1) \cong (z_1, z_2, z_3 + n)$$

z_1, z_2

$$(\tau, z_1, z_2, z_3) \simeq (z_1, z_2, z_3 + t) \simeq (z_1, z_2, z_3 + t')$$

$$(z_1, z_2, z_3) \simeq (z_1, z_2 + t, z_3)$$

$$(z_1, z_2, z_3) \cong (z_1, z_2, z_3 + 1) \cong (z_1, z_2, z_3 + 1)$$

$$(z_1, z_2, z_3) \cong (z_1, z_2 + 1, z_3 + 2Dz_1) \cong$$

6

$$(z_1, z_2, z_3) \simeq (z_1, z_2, z_3 + 1) \simeq (z_1, z_2, z_3 - 1)$$

$$(z_1, z_2, z_3) \simeq (z_1, z_2 + 1, z_3 + 2 \cdot z_1) \simeq (z_1, z_2 + 1, z_3 - 2 \cdot z_1)$$

 z_1

$$(z_1, z_2, z_3) \simeq (z_1, z_2, z_3 + 1) \simeq (z_1, z_2, z_3 + 1')$$

$$(z_1, z_2, z_3) \simeq (z_1, z_2 + 1, z_3 + 2 \cdot D z_1) \simeq (z_1, z_2 + 1, z_3 - 2 \cdot D^2 z_1)$$

$$(z_1, z_2, z_3) \simeq (z_1 + 1, z_2 - 4 z_2) \simeq$$

$$\top$$

$$(z_1, z_2, z_3) \cong (z_1, z_2, z_3 + 1) \cong (z_1, z_2, z_3 + i)$$

$$(z_1, z_2, z_3) \cong (z_1, z_2 + i, z_3 + 2Dz_1) \cong (z_1, z_2 + i, z_3 - 2iDz_1)$$

$$(z_1, z_2, z_3) \cong (z_1 + i, z_2, z_3 - 2Az_2) \cong (z_1 + i, z_2, z_3 + 2Aiz_2)$$

6

$$(\bar{z}_1, \bar{z}_2, \bar{z}_3) \simeq (\bar{z}_1, \bar{z}_2, \bar{z}_3 + 1) \simeq (\bar{z}_1, \bar{z}_2, \bar{z}_3 + 4)$$

$$(\bar{z}_1, \bar{z}_2, \bar{z}_3) \simeq (\bar{z}_1, \bar{z}_2 + 1, \bar{z}_3 + 2 \cdot 0 \cdot \bar{z}_1) \simeq (\bar{z}_1, \bar{z}_2 + 1, \bar{z}_3 - 2 \cdot 1)$$

$$(\bar{z}_1, \bar{z}_2, \bar{z}_3) \simeq (\bar{z}_1 + 1, \bar{z}_2, \bar{z}_3 - 2 \cdot \bar{z}_2) \simeq (\bar{z}_1 + 1, \bar{z}_2, \bar{z}_3 + 2 \cdot 1 \cdot \bar{z}_1)$$

$$\Rightarrow \log(K_3 X_t T^2) = 1, 0 \quad 4 \bar{z}_1, \bar{z}_2$$

$$\tau$$

$$(z_1, z_2, z_3) \cong (z_1, z_2, z_3 + 1) \cong (z_1, z_2, z_3 + \tau)$$

$$(z_1, z_2, z_3) \cong (z_1, z_2 + \tau, z_3 + 2\tau z_1) \cong (z_1, z_2 + \tau, z_3 - 2iDz_1)$$

$$(z_1, z_2, z_3) \cong (z_1 + 1, z_2, z_3 - 2Az_2) \cong (z_1 + i, z_2, z_3 + 2A\tau z_2)$$

$$\Rightarrow \text{br}(K3 X_t, T^2) = 1, 0, 20, 42, 20, 0, 1$$

$$(\tau, z_1, z_2, z_3) \simeq (z_1, z_2, z_3 + 1) \simeq (z_1, z_2, z_3 + \tau)$$

$$(z_1, z_2, z_3) \simeq (z_1, z_2 + \tau, z_3 + 2Dz_1) \simeq (z_1, z_2 + \tau, z_3 - 2iDz_1)$$

$$(z_1, z_2, z_3) \simeq (z_1 + 1, z_2, z_3 - 2Az_2) \simeq (z_1 + i, z_2, z_3 + 2A\tau z_2)$$

$$\Rightarrow \text{br}(K3 X_t, T^2) = 1, 0, 20, 42, 20, 0, 1 \checkmark$$

$$\begin{aligned}
 (z_1, z_2, z_3) &\simeq (z_1, z_2, z_3 + 1) \simeq (z_1, z_2, z_3 + \tau) \\
 (z_1, z_2, z_3) &\simeq (z_1, z_2 + \tau, z_3 + 2Dz_1) \simeq (z_1, z_2 + \tau, z_3 - 2iDz_1) \\
 (z_1, z_2, z_3) &\simeq (z_1 + 1, z_2, z_3 - 2Az_2) \simeq (z_1 + i, z_2, z_3 + 2A\tau z_2)
 \end{aligned}$$

$$\Rightarrow \text{br}(K3 X_t T^2) = 1, 0, 20, 42, 24$$

$$B^2 = \frac{1}{g_{\alpha\beta}} (A \bar{z})' dz$$

$$B^2 = -\frac{1}{g_{15}} (A \bar{z}^1 dz^2 \wedge d\bar{z}^3 - D \bar{z}^2 dz^3)$$

$$B^2 = \frac{1}{g_B} (A \bar{z}' dz^2 \wedge d\bar{z}^3 - D \bar{z}^2 dz' \wedge d\bar{z}^3 + c.c.)$$

g_1

$$B^2 = \frac{1}{g_B} (A \bar{z}' dz^2 \wedge d\bar{z}^3 - D \bar{z}^2 dz' \wedge d\bar{z}^3 + c.c.)$$

$$g_I = \frac{g_B}{2g_{35}}$$

It's possible to



$$B^2 = \frac{1}{g_R} (A \bar{z}' dz^2 + d\bar{z}' A \bar{z}^3 - D \bar{z}^2 dz' + d\bar{z}' D \bar{z}^3 + c.c.)$$

$$g_I = \frac{g_R}{2g_{NS}}$$

It's possible to check that $H = 1/2$

$$B^2 = \frac{1}{g_B} (A \bar{z}' dz^2 + d\bar{z}' A \bar{z}^3 - D \bar{z}^2 dz' + d\bar{z}' A \bar{z}^3 + c.c.)$$

$$g_I = \frac{g_B}{2g_{35}}$$

It's possible to check that $H = i(\partial - \bar{\partial})J$