Double Field Theory on Group Manifolds

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in collaboration with

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Max-Planck-Institut für Physik
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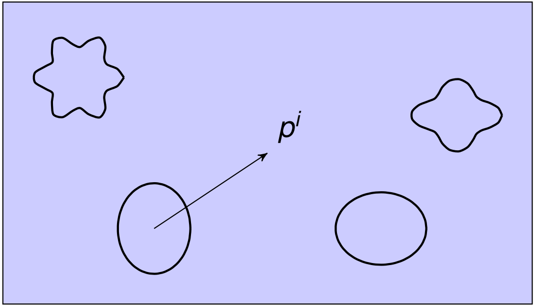
SUGRA

- closed strings in D-dim. flat space with momentum p^i
- truncate all massive excitations
- match scattering amplitudes of strings with EFT

$$S_{\mathrm{NS}} = \int \mathrm{d}^D x \sqrt{g} e^{-2\phi} \left(\mathcal{R} + 4\partial_i\phi\partial^i\phi - \frac{1}{12} H_{ijk} H^{ijk} \right)$$



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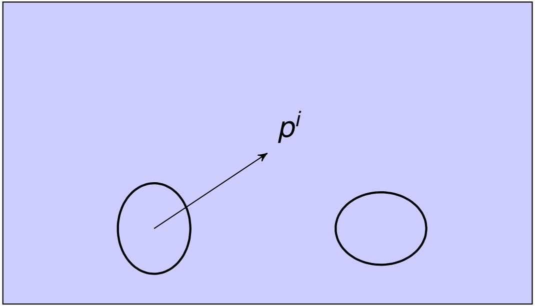

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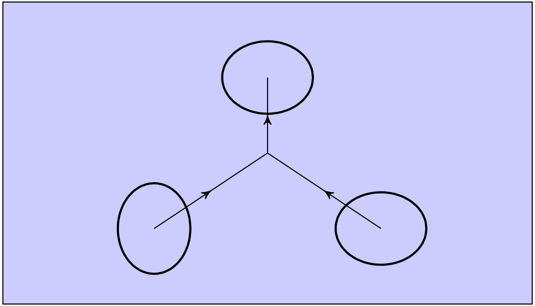
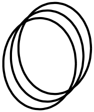
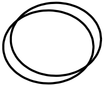




$g_{ij}(p^k)$



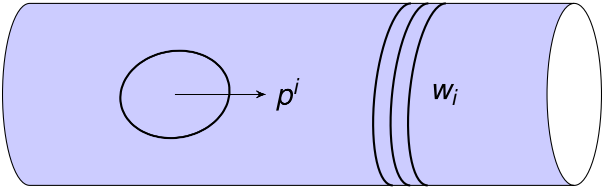
$\phi(p^i)$

DFT (Double Field Theory) [Siegel, 1993,Hull and Zwiebach, 2009,Hohm, Hull, and Zwiebach, 2010]

- closed strings on a flat torus with momentum p^i <u>and</u> winding w_i
- combine conjugated variables x_i and $\tilde{x}^i$ into $X^M = \begin{pmatrix} \tilde{x}_i & x^i \end{pmatrix}$
- repeat steps from SUGRA derivation

$$S_{\mathrm{DFT}} = \int \mathrm{d}^{2D}X \, e^{-2d} \mathcal{R}(\mathcal{H}_{MN}, d)$$

- fields are constrained by strong constraint $\boxed{\partial_M \partial^M \cdot = 0}$



Key questions

- Is DFT more general than SUGRA?
- Is DFT really background independent?
- Can we relax the strong constraint?

S^3, my elephant in the room

- switch on H-flux, solve eom

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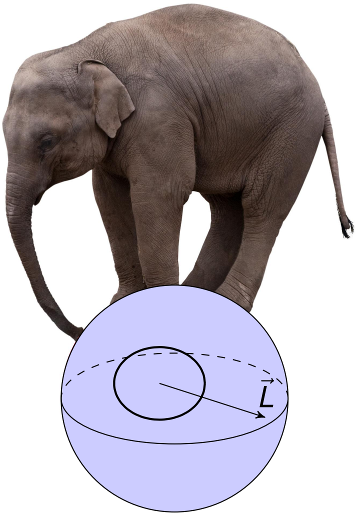

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- no T^3 but S^3

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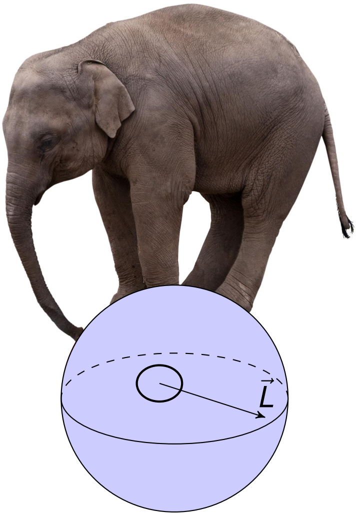

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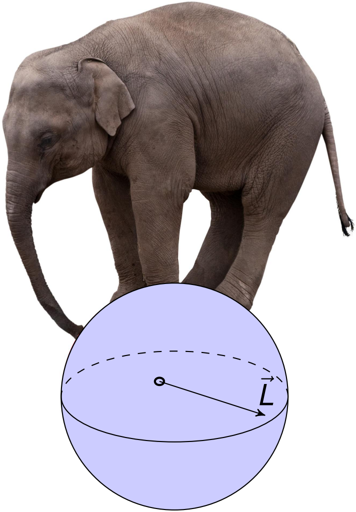

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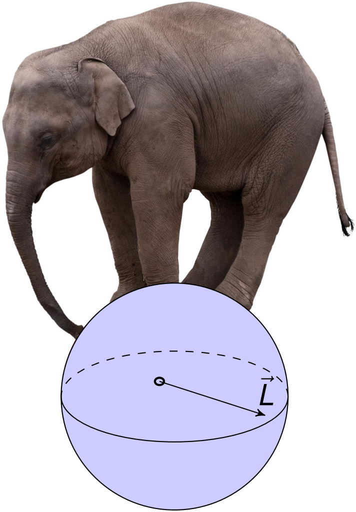

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$$\boxed{\text{DFT}_{\text{WZW}}} \supset \text{DFT}$$

NEW! strong constraint

NEW! action

NEW! symmetries

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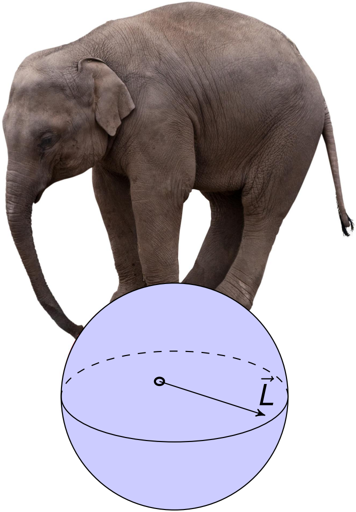

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$\text{DFT}_{\text{WZW}} \supset \text{DFT}$

- strong constraint
- action
- symmetries
- twist gen. Scherk-Schwarz
- genuinely non-geometric backgr.

Outline

1. **Deriving $\mathrm{DFT}_{\mathrm{WZW}}$ from CSFT** 1410.6374

2. **Generalized metric formulation** 1502.02428

3. **Flux formulation** 1507.?????

4. **Summary and outlook**

DFT$_{\mathrm{WZW}}$ = DFT on group manifolds

Use group manifold instead of a torus to derive DFT!

+ includes $\begin{cases} \mathrm{T}^D = \mathrm{U}(1)^D \\ S^3 = \mathrm{SU}(2) \end{cases}$
+ CFT exactly solvable
+ flux backgrounds with const. fluxes

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Double Field Theory =
- treat left and right mover independently
- $2D$ independent coordinates

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$$x^i = \frac{1}{\sqrt{2}}(x^i_{\text{L}} + x^i_{\text{R}})$$
$$\tilde{x}_i = \frac{1}{\sqrt{2}}(x_{\text{L}i} - x_{\text{R}i})$$

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Questions about DFT_{WZW}

- What are the covariant objects?
- How is it connected to DFT?
- Does it make non-abelian duality manifest?

} not trivial

WZW model & Kač-Moody algebra [Witten, 1983,Walton, 1999]

- $g \in G$, a compact simply connected Lie group

$$S_{\mathrm{WZW}} = \frac{1}{2\pi\alpha'} \int_M d^2 z \mathcal{K}(g^{-1}\partial g, g^{-1}\bar{\partial} g) + S_{\mathrm{WZ}}(g)$$

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- metric and 3-form flux in flat indices

$$\eta_{ab} := \mathcal{K}(t_a, t_b) \quad \text{and} \quad F_{abc} := \mathcal{K}([t_a, t_b], t_c)$$

- D chiral and D anti-chiral Noether currents (=$2D$ indep. currents)

$$j_a(z) = \frac{2}{\alpha'}\mathcal{K}(\partial g g^{-1}, t_a) \quad \text{and} \quad j_{\bar{a}}(\bar{z}) = -\frac{2}{\alpha'}\mathcal{K}(g^{-1}\bar{\partial}g, t_{\bar{a}})$$

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- radial quantization

$$\boxed{j_a(z) j_b(w) = -\frac{\alpha'}{2}\frac{1}{(z-w)^2}\eta_{ab} + \frac{1}{z-w}F_{ab}{}^c j_c(z) + \dots}$$

Action

- tree level action in CSFT [Zwiebach, 1993]

$$(2\kappa^2)S = \frac{2}{\alpha'}\left(\langle\Psi|c_0^- Q|\Psi\rangle + \frac{1}{3}\{\Psi,\Psi,\Psi\}_0 + \dots\right)$$

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- string field for massless excitations [Hull and Zwiebach, 2009]

$$|\Psi\rangle = \sum_R \Big[\frac{\alpha'}{4}\epsilon^{a\bar{b}}(R) j_{a\,-1} j_{\bar{b}\,-1} c_1 \bar{c}_1 + e(R) c_1 c_{-1} + \bar{e}(R)\bar{c}_1 \bar{c}_{-1} + \frac{\alpha'}{2}\left(f^a(R) c_0^+ c_1 j_{a\,-1} + f^{\bar{b}}(R) c_0^+ \bar{c}_1 j_{\bar{b}\,-1}\right)\Big]|\phi_R\rangle$$

- R is highest weight of $\mathfrak{g}\times\mathfrak{g}$ representation

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$$\frac{\alpha'}{2}\left(f^a(R) c_0^+ c_1 j_{a\,-1} + f^{\bar b}(R) c_0^+ \bar c_1 j_{\bar b\,-1}\right)\Big]|\phi_R\rangle$$

- R is highest weight of $\mathfrak{g}\times\mathfrak{g}$ representation
- BRST operator (L_m from Sugawara construction)

$$Q = \sum_m \left(:c_{-m} L_m: + \frac{1}{2} :c_{-m} L_m^{gh}:\right) + \text{anti-chiral}$$

Geometric representation of primary fields ($k \to \infty$)

- flat derivative $\boxed{D_a = e_a{}^i \partial_i \quad \text{with} \quad e_a{}^i = \mathcal{K}(g^{-1}\partial^i g, t_a)}$

operator algebra	geometry ($j_{a\,0} \to D_a$)
$L_0\vert\phi_R\rangle = j_{a\,0} j_0^a \vert\phi_R\rangle = h_R\vert\phi_R\rangle$	$D_a D^a Y_R(x^i) = h_R Y_R(x^i)$
$[j_{a\,0}, j_{b\,0}] = F_{ab}{}^c j_{c\,0}$	$[D_a, D_b] = F_{ab}{}^c D_c$
$\sum_R e(R)\vert\phi_R\rangle$	$\sum_R e(R) Y_R(x^i) := e(x^i)$

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$$E_A{}^I = \begin{pmatrix} e_a{}^i & 0 \\ 0 & e_{\bar a}{}^{\bar i} \end{pmatrix} \qquad S_{AB} = 2\begin{pmatrix} \eta_{ab} & 0 \\ 0 & \eta_{\bar a \bar b} \end{pmatrix} \qquad \eta_{AB} = 2\begin{pmatrix} \eta_{ab} & 0 \\ 0 & -\eta_{\bar a \bar b} \end{pmatrix}$$

Weak constraint (level matching), later strong constraint

- level matched string field $(L_0 - \bar{L}_0)|\Psi\rangle = 0$ requires

  $$(D_a D^a - D_{\bar{a}} D^{\bar{a}}) \cdot = 0 \quad \text{with} \quad \cdot \in \{\epsilon^{a\bar{b}}, e, \bar{e}, f^a, f^{\bar{b}}\}$$

- rewritten in terms of η^{AB} and $D_A = \begin{pmatrix} D_a & D_{\bar{a}} \end{pmatrix}$

  $$\eta^{AB} D_A D_B \cdot = D_A D^A \cdot = 0$$

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- change to curved indices using $E_A{}^M$

$$(\partial_M \partial^M - 2\partial_M d \partial^M) \cdot = 0 \qquad \text{with} \qquad d = \phi - \frac{1}{2} \log \sqrt{g}$$

- NEW! term which is absent in DFT → adsorb in cov. derivative

$$\boxed{\nabla_M \partial^M \cdot = 0} \quad \text{with} \quad \nabla_M V^N = \partial_M V^N + \Gamma_{MK}{}^N V^K \,, \quad \Gamma_{MK}{}^M = -2\partial_K d$$

Results (leading order k^{-1})

- calculate quadratic and cubic string functions
- integrate out auxiliary fields f^a and $f^{\bar{b}}$
- perform field redefinition

$$
\begin{aligned}
(2\kappa^2)S = \int d^{2D}X\sqrt{H}\,\Big[&\frac{1}{4}\epsilon_{a\bar{b}}\Box\epsilon^{a\bar{b}} + \ldots \\
&-\frac{1}{4}\epsilon_{a\bar{b}}\big(F^{ac}{}_d \bar{D}^{\bar{e}}\epsilon^{d\bar{b}}\epsilon_{c\bar{e}} + F^{\bar{b}\bar{c}}{}_{\bar{d}} D^e\epsilon^{a\bar{d}}\epsilon_{e\bar{c}}\big) \\
&-\frac{1}{12}F^{ace}F^{\bar{b}\bar{d}\bar{f}}\epsilon_{a\bar{b}}\epsilon_{c\bar{d}}\epsilon_{e\bar{f}} + \ldots\Big]
\end{aligned}
$$

- 

terms e.g. potential
- vanish in abelian limit $F_{abc} \to 0$ and $F_{\bar{a}\bar{b}\bar{c}} \to 0$

Gauge transformations

- tree level gauge transformation in CSFT [Zwiebach, 1993]

$$\delta_\Lambda |\Psi\rangle = Q|\Lambda\rangle + [\Lambda, \Psi]_0 + \cdots$$

- string field for gauge parameter [Hull and Zwiebach, 2009]

$$|\Lambda\rangle = \sum_R \left[\frac{1}{2} \lambda^a(R) j_{a\,-1} c_1 - \frac{1}{2} \lambda^{\bar{b}}(R) j_{\bar{b}\,-1} \bar{c}_1 + \mu(R) c_0^+ \right] |\phi_R\rangle$$

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- after field redefinition and μ gauge fixing

$$\begin{aligned}
\delta_\lambda \epsilon_{a\bar b} =& D_{\bar b}\lambda_a + \frac{1}{2}\big[D_a \lambda^c \epsilon_{c\bar b} - D^c\lambda_a \epsilon_{c\bar b} + \lambda_c D^c \epsilon_{a\bar b} + F_{ac}{}^d \lambda^c \epsilon_{d\bar b}\big] \\
& D_a \lambda_{\bar b} + \frac{1}{2}\big[D_{\bar b} \lambda^{\bar c} \epsilon_{a\bar c} - D^{\bar c}\lambda_{\bar b} \epsilon_{a\bar c} + \lambda_{\bar c} D^{\bar c} \epsilon_{a\bar b} + F_{\bar b\bar c}{}^{\bar d} \lambda^{\bar c} \epsilon_{a\bar d}\big] \\
\delta_\lambda d =& -\frac{1}{4} D_a \lambda^a + \frac{1}{2}\lambda_a D^a d - \frac{1}{4} D_{\bar a}\lambda^{\bar a} + \frac{1}{2}\lambda_{\bar a} D^{\bar a} d
\end{aligned}$$

Doubled objects

promising results, but bulky

Rewrite action/gauge trafo in terms of doubled object

+ simplifies expressions considerably
+ extrapolation from cubic to all order in fields

Doubled objects

object	doubled version
η_{ab}, $\eta_{\bar{a}\bar{b}}$	$\eta_{AB} = 2\begin{pmatrix}\eta_{ab} & 0 \\ 0 & -\eta_{\bar{a}\bar{b}}\end{pmatrix} \qquad S_{AB} = 2\begin{pmatrix}\eta_{ab} & 0 \\ 0 & \eta_{\bar{a}\bar{b}}\end{pmatrix}$
$e_a{}^i$, $e_{\bar{a}}{}^{\bar{i}}$	$E_A{}^I = \begin{pmatrix}e_a{}^i & 0 \\ 0 & e_{\bar{a}}{}^{\bar{i}}\end{pmatrix}$
D_a, $D_{\bar{a}}$	$D_A = \begin{pmatrix}D_a & D_{\bar{a}}\end{pmatrix} = E_A{}^I\partial_I$ with $\partial_I = \begin{pmatrix}\partial_i & \partial_{\bar{i}}\end{pmatrix}$

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${e_a}^i, {e_{\bar{a}}}^{\bar{i}}$	${E_A}^I = \begin{pmatrix}{e_a}^i & 0 \\ 0 & {e_{\bar{a}}}^{\bar{i}}\end{pmatrix}$
$D_a, D_{\bar{a}}$	$D_A = \begin{pmatrix}D_a & D_{\bar{a}}\end{pmatrix} = {E_A}^I \partial_I$ with $\partial_I = \begin{pmatrix}\partial_i & \partial_{\bar{i}}\end{pmatrix}$
$\xi^i, \xi^{\bar{i}}$	$\xi^I = \begin{pmatrix}\xi^i & \xi^{\bar{i}}\end{pmatrix}$
${F_{ab}}^c, {F_{\bar{a}\bar{b}}}^{\bar{c}}$	${F_{AB}}^C = \begin{cases}{F_{ab}}^c \\ {F_{\bar{a}\bar{b}}}^{\bar{c}} \\ 0 & \text{otherw.}\end{cases}$ $\quad [D_A, D_B] = {F_{AB}}^C D_C$

Gauge transformations

- "doubled" version of fluctuations $\epsilon^{a\bar{b}}$

$$\epsilon^{AB} = \begin{pmatrix} 0 & -\epsilon^{a\bar{b}} \\ -\epsilon^{\bar{a}b} & 0 \end{pmatrix} \quad \text{with} \quad \epsilon^{a\bar{b}} = (\epsilon^T)^{\bar{b}a}$$

- generate generalized metric [Hohm, Hull, and Zwiebach, 2010]

$$\mathcal{H}^{AB} = S^{AB} + \epsilon^{AB} + \frac{1}{2}\epsilon^{AC} S_{CD} \epsilon^{DB} + \cdots = \exp(\epsilon^{AB})$$

with the defining property $\mathcal{H}^{AC}\eta_{CD}\mathcal{H}^{DB} = \eta^{AB}$

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with the defining property $\mathcal{H}^{AC}\eta_{CD}\mathcal{H}^{DB} = \eta^{AB}$

- generalized Lie derivative [Hull and Zwiebach, 2009,Grana and Marques, 2012]

$$\mathcal{L}_\lambda \mathcal{H}^{AB} = \lambda^C D_C \mathcal{H}^{AB} + (D^A \lambda_C - D_C \lambda^A)\epsilon^{CB} + \\ (D^B \lambda_C - D_C \lambda^B)\mathcal{H}^{AC} + F^A{}_{CD}\lambda^C \mathcal{H}^{DB} + F^B{}_{CD}\lambda^C \mathcal{H}^{AD}$$

- setting $\delta_\lambda S^{AB} := 0$ and using

$$\delta_\lambda \epsilon^{AB} = \mathcal{L}_\lambda S^{AB} + \mathcal{L}_\lambda \epsilon^{AB} + \mathcal{L}_\lambda S^{(A}{}_C S^{B)}{}_D \epsilon^{CD} \,.$$

results in $\boxed{\delta_\lambda \mathcal{H}^{AB} = \mathcal{L}_\lambda \mathcal{H}^{AB} + \mathcal{O}(\epsilon^2)}$

- similar for the generalized dilaton d

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- similar for the generalized dilaton d
- introduce covariant derivative

$$\nabla_A V^B = D_A V^B + \frac{1}{3} F^B{}_{AC} V^C$$

- 

generalized Lie derivative, e.g. for vector

$$\mathcal{L}_\lambda V^A = \lambda^B \nabla_B V^A + (\nabla^A \lambda_B - \nabla_B \lambda^A) V^B \quad \text{instead of}$$

$$\mathcal{L}_\lambda V^I = \lambda^J \partial_J V^I + (\partial^I \lambda_J - \partial_J \lambda^I) V^J \quad \text{in traditional DFT}$$

Gauge algebra

- CSFT to cubic order fulfills

$$\delta_{\Lambda_1}\delta_{\Lambda_2} - \delta_{\Lambda_2}\delta_{\Lambda_1} = \delta_{\Lambda_{12}} \quad \text{with} \quad \Lambda_{12} = [\Lambda_2, \Lambda_1]_0$$

- after field redefinition and μ fixing $\lambda_{12}^A = [\lambda_2, \lambda_1]_{\mathrm{C}}^A$ with

$$[\lambda_1, \lambda_2]_C^A = \lambda_1^B \nabla_B \lambda_2^A - \frac{1}{2}\lambda_1^B \nabla^A \lambda_{2\,B} - (1 \leftrightarrow 2)$$

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$$\delta_{\Lambda_1}\delta_{\Lambda_2} - \delta_{\Lambda_2}\delta_{\Lambda_1} = \delta_{\Lambda_{12}} \quad \text{with} \quad \Lambda_{12} = [\Lambda_2, \Lambda_1]_0$$

- after field redefinition and μ fixing $\lambda_{12}^A = [\lambda_2, \lambda_1]_{\mathrm{C}}^A$ with

$$[\lambda_1, \lambda_2]_C^A = \lambda_1^B \nabla_B \lambda_2^A - \frac{1}{2}\lambda_1^B \nabla^A \lambda_{2\,B} - (1 \leftrightarrow 2)$$

- algebra closes up to a trivial gauge transformation if
  1. fluctuations and parameter fulfill NEW! strong constraint $D_A D^A \cdot$
  2. background fulfills Jacobi identity

$$F_{E[AB}F^E{}_{C]D} = 0$$

- no strong constraint required for background

Covariant derivative [Cederwall, 2014]

- non-vanishing torsion and Riemann curvature

$$[\nabla_A, \nabla_B] V_C = R_{ABC}{}^D V_D - T^D{}_{AB} \nabla_D V_C \quad \text{with}$$

$$T^A{}_{BC} = -\frac{1}{3} F^A{}_{BC} \quad \text{and} \quad R_{ABC}{}^D = \frac{2}{9} F_{AB}{}^E F_{EC}{}^D$$

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$$\nabla_C E_A{}^I = \nabla_C \eta_{AB} = \nabla_C S_{AB} = 0$$

- compatible with partial integration

$$\int d^{2D} X e^{-2d} U \nabla_M V^M = -\int d^{2D} X e^{-2d} \nabla_M U V^M$$

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$$\int d^{2D} X e^{-2d} U \nabla_M V^M = - \int d^{2D} X e^{-2d} \nabla_M U V^M$$

- non-vanishing generalized torsion

Action

$$X^I = \begin{pmatrix} x^i & x^{\bar{i}} \end{pmatrix}$$

$$S = \int \mathrm{d}^{2D} X \, e^{-2d} \mathcal{R}(\mathcal{H}_{MN}, d)$$

Action

$$X^I = \begin{pmatrix} x^i & x^{\bar{i}} \end{pmatrix} \qquad d = \tilde{d} - \tfrac{1}{2}\log\sqrt{H}$$

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$$\begin{aligned}\mathcal{R} =& 4\mathcal{H}^{MN}\nabla_M\nabla_N d - \nabla_M\nabla_N\mathcal{H}^{MN} - 4\mathcal{H}^{MN}\nabla_M d\nabla_N d + 4\nabla_M\mathcal{H}^{MN}\nabla_N d \\ &+ \frac{1}{8}\mathcal{H}^{MN}\nabla_M\mathcal{H}^{KL}\nabla_N\mathcal{H}_{KL} - \frac{1}{2}\mathcal{H}^{MN}\nabla_N\mathcal{H}^{KL}\nabla_L\mathcal{H}_{MK} + \frac{1}{6}F_{MKL}F_N{}^{KL}H^{MN}\end{aligned}$$

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- lower indices with $\eta_{MN} = E^A{}_M E^B{}_N \eta_{AB} \neq$ const.
- $H_{IJ} = E^A{}_M E^B{}_N S_{AB}$ background generalized metric

$$\nabla_M d = \partial_M \tilde{d}$$

$$\nabla_M \mathcal{H}^{KL} = \partial_M \mathcal{H}^{KL} + \Gamma_{MJ}{}^K \mathcal{H}^{JL} + \Gamma_{MJ}{}^L \mathcal{H}^{KJ}$$

Symmetries

- generalized diffeomorphisms (only under strong constraint)

$$\delta_\xi \mathcal{H}^{MN} = \mathcal{L}_\xi \mathcal{H}^{MN}$$

$$\delta_\xi d = \mathcal{L}_\xi d = \xi^M \nabla_M d + \frac{1}{2} \nabla_M \xi^M$$

NEW! 2D-diffeomorphisms (always)

$$\delta_\xi \mathcal{H}^{MN} = L_\xi \mathcal{H}^{MN} = \xi^I \partial_I \mathcal{H}^{MN} + \mathcal{H}^{IN} \partial_I \xi^M + \mathcal{H}^{MI} \partial_I \xi^N$$

$$\delta_\xi e^{-2d} = L_\xi e^{-2d} = \partial_I (\xi^I e^{-2d})$$

- $\left.\begin{matrix} e^{-2d} \\ \mathcal{R} \end{matrix}\right\}$ transform as $\left\{\begin{matrix} +1 \text{ desity} \\ \text{scalar} \end{matrix}\right\}$ under gen. <u>and</u> 2D-diff.

Flux formulation

[Geissbuhler, 2011,Aldazabal, Baron, Marques, and Nunez, 2011,Geissbuhler, Marques, Nunez, and Penas, 2013,...]

Connect results to flux formulation of traditional DFT

1. introduce generalized vielbein $\tilde{E}_{\hat{A}}{}^{B}$ for fluctuations with

$$\eta_{AB} = \tilde{E}^{\hat{C}}{}_{A}\tilde{E}^{\hat{D}}{}_{B}\eta_{\hat{C}\hat{D}} \quad \text{and} \quad \mathcal{H}_{AB} = \tilde{E}^{\hat{C}}{}_{A}\tilde{E}^{\hat{D}}{}_{B}S_{\hat{C}\hat{D}}$$

2. combine it with background

$$\mathcal{E}_{\hat{A}}{}^{I} = \tilde{E}_{\hat{A}}{}^{B}E_{B}{}^{I}$$

3. find covariant fluxes
4. rewrite action

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absent in traditional DFT

$$\mathrm{O}(D)\times\mathrm{O}(D) \xleftarrow[\tilde{E}_{\hat{A}}{}^{B}]{\mathcal{H}_{AB}} \mathrm{O}(D,D) \xleftarrow[E_{B}{}^{I}]{\eta_{IJ}} \mathrm{GL}(2D)$$

Covariant fluxes

- covariant flux in DFT

$$\mathcal{F}_{ABC} = (\mathcal{L}_{E_A} E_B{}^I) E_{CI}$$

$$\mathcal{F}_A = -(\mathcal{L}_{E_A} e^{-2d}) e^{2d}$$

Covariant fluxes

- covariant flux in DFT and in DFT_{WZW}

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$$\boxed{\begin{aligned}\mathcal{F}_{\hat{A}\hat{B}\hat{C}} &= (\mathcal{L}_{\mathcal{E}_{\hat{A}}} \mathcal{E}_{\hat{B}}{}^I) \mathcal{E}_{\hat{C}I} \\ \mathcal{F}_{\hat{A}} &= -(\mathcal{L}_{\mathcal{E}_{\hat{A}}} e^{-2d}) e^{2d}\end{aligned}}$$

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- scalars under generalized and 

$2D$-diffeomorphisms
- split into background and fluctuation part, e.g.

$$\mathcal{F}_{\hat{A}\hat{B}\hat{C}} = F_{\hat{A}\hat{B}\hat{C}} + \tilde{F}_{\hat{A}\hat{B}\hat{C}}$$

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Jacobi identity	SC
full O(D, D) gaugings	only $\mathrm{GL}(D) \ltimes \Lambda_2 \subset \mathrm{O}(D,D)$
$F_{ABC} = 2\Omega_{[AB]C}$	$\tilde{F}_{\hat{A}\hat{B}\hat{C}} = 3\tilde{\Omega}_{[\hat{A}\hat{B}\hat{C}]}$
$\Omega_{ABC} = D_A E_B{}^I E_{CI}$	$\tilde{\Omega}_{\hat{A}\hat{B}\hat{C}} = D_{\hat{A}} \tilde{E}_{\hat{B}}{}^D \tilde{E}_{\hat{C}D}$

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- covariant flux in DFT and in $\mathrm{DFT}_{\mathrm{WZW}}$

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FREE

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Action

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- looks like traditional flux formulation

  BUT remember covariant fluxes are different

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- also invariant under double Lorentz transformations
- SC violating term $\frac{1}{6}F_{\hat{A}\hat{B}\hat{C}}F^{\hat{A}\hat{B}\hat{C}}$ absent

✓ consistent with CFT with vanishing central charges

$$c_{\text{tot}} - \bar{c}_{\text{tot}} = \tfrac{\alpha'}{2}F_{\hat{A}\hat{C}\hat{B}}F^{\hat{A}\hat{B}\hat{C}} = 0$$

Extended strong constraint

Questions:

- ✓ What are the covariant objects?
- ▸ How is it connected to traditional DFT?

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2. pull background part into the fluctuation part, requires
   - $E_A{}^I \in \mathrm{O}(D,D) \subset \mathrm{GL}(2D)$
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     $$\boxed{\partial_I b \partial^I f = 0}$$

     linking background fields b with fluctuations f

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$\mathrm{DFT} \subset \mathrm{DFT}_{\mathrm{WZW}}$

both break $2D$-diffeomorphism invariance

Scherk-Schwarz ansatz [Scherk and Schwarz, 1979,Geissbuhler, 2011,...]

DFT	DFT_{WZW}
$E_A{}^M = \widehat{E}_A{}^N(\mathbb{X}) U_N{}^M(\mathbb{Y})$	$\mathcal{E}_{\hat{A}}{}^M = \tilde{E}_{\hat{A}}{}^B(\mathbb{X}) E_B{}^M(\mathbb{Y})$

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$U_N{}^M \in \mathrm{O}(D,D)$	$E_B{}^M \in \mathrm{GL}(2D)$
strong constraint	–
$F_{IJK} = 3U_{[I}{}^M\partial_M U_J{}^N U_{K]N}$	$F_{ABC} = 2E_{[A}{}^M\partial_M E_{B]}{}^N E_{CN}$

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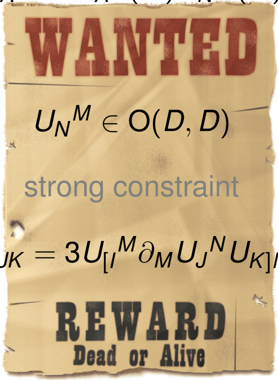

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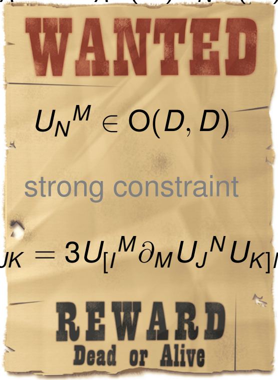

- no explicit construction of DFT twists for arbitrary embeddings
- in DFT_{WZW} one takes left invariant Maurer-Cartan form

Summary

DFT$_{\mathrm{WZW}}$ is a generalization of DFT

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- basic: idea go beyond the torus
- strong constraint, symmetries, action
- genuinely non-geometric backgrounds and twist
- DFT arises under the optional extended strong constraint

Summary

DFT_{WZW} is a generalization of DFT

- basic: idea go beyond the torus
- NEW! strong constraint, symmetries, action
- FREE genuinely non-geometric backgrounds and twist
- DFT arises under the optional extended strong constraint

Todo

- find solutions of the new strong constraint

$\rightarrow$ key to understand T-duality in DFT_{WZW}

- α' corrections (here k^{-2}, k^{-3}, $\dots$) [Hohm, Siegel, and Zwiebach, 2013]
- coset and orbifold CFTs

Thank you for your attention. Are there any questions?

Embedding tensor

ID	$M_{mn}/ \cos\alpha$	$\tilde{M}^{mn}/ \sin\alpha$	range of α	gauging
1	$\mathrm{diag}(1,1,1,1)$	$\mathrm{diag}(1,1,1,1)$	$-\frac{\pi}{4} < \alpha \leq \frac{\pi}{4}$	$\begin{cases} \mathrm{SO}(4)\,, & \alpha \neq \frac{\pi}{4}\,, \\ \mathrm{SO}(3)\,, & \alpha = \frac{\pi}{4}\,. \end{cases}$
2	$\mathrm{diag}(1,1,1,-1)$	$\mathrm{diag}(1,1,1,-1)$	$-\frac{\pi}{4} < \alpha \leq \frac{\pi}{4}$	$\mathrm{SO}(3,1)$
	(1,1	diag(... 1)	$< \frac{\pi}{4}$	$\mathrm{SO}(2,2)\,, \ \alpha \neq \frac{\pi}{4}\,,$

[Dibitetto, Fernandez-Melgarejo, Marques, and Roest, 2012]

- fluxes for embedding one

$$F_{abc} = \sqrt{2}\epsilon_{abc}(\cos\alpha + \sin\alpha) \quad \text{and} \quad F_{\bar{a}\bar{b}\bar{c}} = \sqrt{2}\epsilon_{abc}(\cos\alpha - \sin\alpha)$$

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2	$\mathrm{diag}(1,1,1,-1)$	$\mathrm{diag}(1,1,1,-1)$	$-\frac{\pi}{4} < \alpha \leq \frac{\pi}{4}$	$\mathrm{SO}(3,1)$
[illegible]	(1,1 [illegible]	diag([illegible] 1)	[illegible] $< \frac{\pi}{4}$	SO(2,2) , α [illegible] $\frac{\pi}{4}$, [illegible]

[Dibitetto, Fernandez-Melgarejo, Marques, and Roest, 2012]

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- DFT strong constraint holds only for

$$F_{ABC}F^{ABC} = 6\sin(2\alpha) = 0 \quad \to \alpha = \frac{\pi}{2}n \quad n \in \mathbb{Z}$$

- Jacobi identity holds always