Review of Double and Exceptional Field Theory

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- O. H., B. Zwiebach 1407.0708, 1407.3803; O. H., W. Siegel, B. Zwiebach 1306.2970
- O. H., H. Samtleben 1308.1673 [PRL], 1312.0614, 1312.4542, 1406.3348
- W. Siegel, hep-th/9305073, O. H., C. Hull, B. Zwiebach arXiv: 1003.5027, 1006.4823
- O. H., D. Lüst, B. Zwiebach arXiv:1309.2977

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Overview:

~~Just~~ reformulation of low-energy supergravity/string theory

Part I: Review of two-derivative DFT

- Efficient reformulation of supergravity ('generalized geometry')
- Beyond supergravity: generalized g.c.t. $\Rightarrow$ globally non-trivial spaces

Generalized Scherk-Schwarz compactifications/Non-geometric fluxes

[see Aldazabal's talk]

Part II: Beyond supergravity: α' corrections

- Higher-derivative corrections $\Rightarrow$ deformed gauge structure
- Geometry for Green-Schwarz mechanism; exact action

Part III: Exceptional Field Theory

- Gauge fields for 'generalized geometry brackets'
- $\mathrm{E}_{n(n)}$ covariant form of $D = 11$ supergravity

Part I: Two-derivative Double Field Theory

Reformulation (Extension?) of spacetime action for massless string fields:

$$S_{\mathsf{NS}} = \int d^D x \sqrt{-g} e^{-2\phi} \left[R + 4(\partial\phi)^2 - \frac{1}{12} H^{ijk} H_{ijk} + \frac{1}{4}\alpha' R^{ijkl} R_{ijkl} + \cdots \right]$$

generalized metric and doubled coordinates $X^M = (\tilde{x}_i, x^i)$,

$$\mathcal{H}_{MN} = \begin{pmatrix} g^{ij} & -g^{ik} b_{kj} \\ b_{ik} g^{kj} & g_{ij} - b_{ik} g^{kl} b_{lj} \end{pmatrix} \in O(D,D)$$

DFT Action (dilaton density $e^{-2d} = e^{-2\phi}\sqrt{-g}$):

$$S_{\mathsf{DFT}} = \int d^{2D} X \, e^{-2d} \, \mathcal{R}(\mathcal{H}, d) \quad \xrightarrow{\tilde{\partial}^i = 0} \quad S_{\mathsf{NS}}\big|_{\alpha'=0}$$

generalized curvature scalar

$$\mathcal{R} \equiv 4\,\mathcal{H}^{MN}\partial_M\partial_N d - \partial_M\partial_N\mathcal{H}^{MN} - 4\,\mathcal{H}^{MN}\partial_M d\,\partial_N d + 4\partial_M\mathcal{H}^{MN}\,\partial_N d$$
$$+ \frac{1}{8}\mathcal{H}^{MN}\partial_M\mathcal{H}^{KL}\,\partial_N\mathcal{H}_{KL} - \frac{1}{2}\mathcal{H}^{MN}\partial_M\mathcal{H}^{KL}\,\partial_K\mathcal{H}_{NL}$$

Gauge transformations and generalized Lie derivatives

In DFT gauge invariance governed by generalized Lie derivatives

$$\widehat{\mathcal{L}}_\xi \mathcal{H}_{MN} = \xi^P \partial_P \mathcal{H}_{MN} + \left(\partial_M \xi^P - \partial^P \xi_M\right) \mathcal{H}_{PN} + \left(\partial_N \xi^P - \partial^P \xi_N\right) \mathcal{H}_{MP}$$

$$\widehat{\mathcal{L}}_\xi \left(e^{-2d}\right) = \partial_M \left(\xi^M e^{-2d}\right)$$

Invariance and closure, $[\widehat{\mathcal{L}}_{\xi_1}, \widehat{\mathcal{L}}_{\xi_2}] = \widehat{\mathcal{L}}_{[\xi_1,\xi_2]_C}$,

$$\left[\,\xi_1\,,\;\xi_2\,\right]_C^M \;=\; \xi_1^N \partial_N \xi_2^M - \xi_2^N \partial_N \xi_1^M - \frac{1}{2}\xi_{1N}\partial^M \xi_2^N + \frac{1}{2}\xi_{2N}\partial^M \xi_1^N$$

modulo strong constraint

$$\eta^{MN}\partial_M \partial_N = 2\tilde{\partial}^i \partial_i = 0 \qquad\qquad \eta_{MN} = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

solved by

$$\partial_M = \begin{cases} \partial_i & \text{if } M = i \\ 0 & \text{else} \end{cases}$$

$O(D,D)$ covariant, captures IIA/M-theory & IIB simultaneously

Generalized coordinate transformations

Generalized g.c.t. that reproduce this infinitesimally:

$$S'(X') = S(X) \qquad\qquad A'_M(X') = \mathcal{F}_M{}^N A_N(X)$$

and analogously on higher tensors, where [O.H., Zwiebach, 1207.4198]

$$\mathcal{F}_M{}^N \equiv \frac{1}{2}\left(\frac{\partial X^P}{\partial X'^M}\frac{\partial X'_P}{\partial X_N} + \frac{\partial X'_M}{\partial X_P}\frac{\partial X^N}{\partial X'^P}\right)$$

Setting $X'^M = X^M - \xi^M(X)$ we get $\delta_\xi = \widehat{\mathcal{L}}_\xi$.

- $x^{i\prime} = x^{i\prime}(x)$, $\tilde{x}'_i = \tilde{x}_i$ leads to usual g.c.t.,

  $\tilde{x}'_i = \tilde{x}_i - \tilde{\xi}_i(x)$, $x^{i\prime} = x^i$ leads to $b_{ij} \to b_{ij} + \partial_i\tilde{\xi}_j - \partial_j\tilde{\xi}_i$
- composition according to BCH of C-bracket,

  but no 'intrinsic' picture yet
- equivalent to $\exp(\widehat{\mathcal{L}}_\xi)$ [Berman, Cederwall, Perry (2014)]

Non-geometric spaces and fluxes

Torus fibration over circle: T^2 with coordinates (x^1, x^2), and z for circle; globally well-defined iff generalized c.t. in $(x^1, x^2, \tilde{x}_1, \tilde{x}_2)$ so that

$$\mathcal{H}'(g', b')(z = 2\pi) \;=\; \mathcal{H}(g, b)(z = 0)$$

1) Non-geometric, but still T-dual to geometric:
Kähler parameter $\rho = -b_{12} + iV$ and complex structure $\tau = \frac{g_{12}}{g_{11}} + i\,\frac{V}{g_{11}}$

$$\rho(z) \;=\; \frac{1}{Hz - iR_1R_2}$$

Thus:

$$\rho(2\pi) \;=\; \frac{1}{2\pi H + \frac{1}{\rho(0)}} \;=\; \frac{\rho(0)}{1 + 2\pi H\rho(0)}$$

$\Rightarrow$ genuine T-duality transformation of ρ $\;\Rightarrow\;$ T-folds

$\Rightarrow$ implemented by generalized c.t.

$$x^{1\prime} = x^1 + 2\pi H\tilde{x}_2 \qquad x^{2\prime} = x^2$$

2) Truly non-geometric background: [Condeescu, Florakis, Kounnas & Lüst (2013)]

$$
\begin{aligned}
\tau(z) &= \frac{\tau_0 \cos(fz) + \sin(fz)}{\cos(fz) - \tau_0 \sin(fz)}\,, \qquad f \in \frac{1}{4} + \mathbb{Z}\,, \\
\rho(z) &= \frac{\rho_0 \cos(Hz) + \sin(Hz)}{\cos(Hz) - \rho_0 \sin(Hz)}\,, \qquad H \in \frac{1}{4} + \mathbb{Z}\,.
\end{aligned}
$$

Global structure:

$$
\tau(2\pi) = -\frac{1}{\tau(0)}\,, \qquad \rho(2\pi) = -\frac{1}{\rho(0)}\,.
$$

gluing by generalized c.t.

$$
\begin{aligned}
\tilde{x}'_1 &= -\tilde{x}_2 \qquad & \tilde{x}'_2 &= x^1 \\
x'^1 &= -x^2 \qquad & x'^2 &= \tilde{x}_1
\end{aligned}
$$

$\Rightarrow$ well-defined in DFT, not contained in supergravity

[more non-geometric spaces in: Hassler & Lüst (2014)]

Part II: Higher-derivative α' deformations

Geometrical structures for generalized vector ξ^M in $\alpha' = 0$ DFT:

$$\langle \xi_1 | \xi_2 \rangle \;=\; \xi_1^M \xi_2^N \eta_{MN}\,, \qquad \big[\xi_1, \xi_2\big]_C^M \;=\; 2\,\xi_{[1}^N \partial_N \xi_{2]}^M \;-\; \frac{1}{2}\,\xi_1^K \overleftrightarrow{\partial}^M \xi_{2K}$$

$$\widehat{\mathcal{L}}_\xi V^M \;=\; \xi^P \partial_P V^M + (\partial^M \xi_P - \partial_P \xi^M) V^P$$

All receive non-trivial higher-derivative corrections:

$$\langle \xi_1 | \xi_2 \rangle \;=\; \xi_1^M \xi_2^N \eta_{MN} - (\partial_N \xi_1^M)(\partial_M \xi_2^N)$$

$$\big[\xi_1, \xi_2\big]_C^M \;=\; 2\,\xi_{[1}^N \partial_N \xi_{2]}^M \;-\; \frac{1}{2}\,\xi_1^K \overleftrightarrow{\partial}^M \xi_{2K} \;+\; \frac{1}{2}\,(\partial_K \xi_1^L) \overleftrightarrow{\partial}^M (\partial_L \xi_2^K)$$

$$\mathbf{L}_\xi V^M \;=\; \xi^P \partial_P V^M + (\partial^M \xi_P - \partial_P \xi^M) V^P - \,(\partial^M \partial_K \xi^L) \partial_L V^K$$

Closure and gauge invariance exact! ($\mathbf{L}_\xi \langle V, W \rangle = \xi^N \partial_N \langle V, W \rangle$, etc.)

Not removable by $O(D, D)$ covariant redefinitions

DFT relations for $\mathcal{H} \in O(D,D)$

$$(\mathcal{H}^2)_{MN} \equiv \mathcal{H}_{MK}\mathcal{H}^K{}_N = \eta_{MN} \qquad \text{Tr}\,\mathcal{H} \equiv \eta^{MN}\mathcal{H}_{MN} = 0$$

get deformed $\Rightarrow$ dynamical equations!

$$(\mathcal{M} \star \mathcal{M})_{MN} \equiv 2(\mathcal{M}^2)_{MN} - \frac{1}{2}\partial_M \mathcal{M}^{PQ}\partial_N \mathcal{M}_{PQ} + \cdots = 2\eta_{MN}$$

$$\text{tr}\,\mathcal{M} \equiv \eta^{MN}\mathcal{M}_{MN} - 3\partial_M\partial_N\mathcal{M}^{MN} + \cdots = 0$$

In derivative expansion:

$$\mathcal{M}_{MN} = \mathcal{H}_{MN} + \frac{1}{2}\{\mathcal{H}, \mathcal{V}^{(2)}\}_{MN} + \cdots, \qquad \mathcal{H}^2 = \eta$$

$\Rightarrow$ dilaton eq. & gravity eq. plus α' corrections!

Exact gauge invariant action (with deformed products)

$$S = \int e^{\phi}\big(\,\text{Tr}\mathcal{M} - \frac{1}{3}\mathcal{M}^3 + \cdots\big)$$

Interpretation on physical subspace?

(Perturbative) analysis shows that b-field transforms as

$$\delta_{\xi+\tilde{\xi}}\, b \;=\; \mathrm{d}\tilde{\xi} \;+\; \mathcal{L}_{\xi} b \;+\; \tfrac{1}{2}\,\mathrm{tr}\big(\mathrm{d}(\partial\xi) \wedge \Gamma\big)$$

with (Christoffel) connection 1-form $(\Gamma)^{k}{}_{l} \equiv \Gamma^{\,k}_{\,il}\, dx^{i}$

deformed gauge invariant 3-form curvature

$$\widehat{H}(b,\Gamma) \;=\; \mathrm{d}b + \tfrac{1}{2}\,\Omega(\Gamma)\,, \quad \Omega(\Gamma) \;=\; \mathrm{tr}\big(\Gamma \wedge \mathrm{d}\Gamma + \tfrac{2}{3}\,\Gamma \wedge \Gamma \wedge \Gamma\big)$$

$\Rightarrow$ Green-Schwarz anomaly cancellation mechanism of heterotic string but with deformed diffeomorphisms rather than deformed Lorentz

Green-Schwarz terms of heterotic string theory subsector to $\mathcal{O}(\alpha')$

but: in terms of g, b arbitrary orders in $\mathcal{O}(\alpha')$

[work in progress with B. Zwiebach and A. Sen]

Deformation of Courant bracket

Deformed gauge transformations close according to bracket

$$\Big[\,\xi_1 + \tilde{\xi}_1, \xi_2 + \tilde{\xi}_2\,\Big]' \;=\; \big[\,\xi_1\,, \xi_2\,\big] \;+\; \mathcal{L}_{\xi_1}\tilde{\xi}_2 - \mathcal{L}_{\xi_2}\tilde{\xi}_1 - \tfrac{1}{2}\mathsf{d}\big(i_{\xi_1}\tilde{\xi}_2 - i_{\xi_2}\tilde{\xi}_1\big)$$
$$-\;\tfrac{1}{2}\big(\tilde{\varphi}(\xi_1, \xi_2) - \tilde{\varphi}(\xi_2, \xi_1)\big)$$

with the map $\tilde{\varphi}$ that produces a 'one-form' from 2 vectors

$$\tilde{\varphi}(V, W) \;\equiv\; \mathsf{tr}\big(\mathsf{d}(\partial V)\partial W\big) \;\equiv\; \partial_i\partial_k V^l \partial_l W^k dx^i$$

not genuine 1-form $\;\Rightarrow\;$ anomalous transformation under diffeomorphisms

Bracket covariant under *deformed* diffeomorphisms

$$\delta_{\xi+\tilde{\xi}}\tilde{V} \;\equiv\; \mathcal{L}_{\xi}\tilde{V} - i_V\mathsf{d}\tilde{\xi} \;-\; \tilde{\varphi}(\,\xi, V)$$

α' Corrections for Bosonic Strings and Closed SFT

α' corrections for bosonic string (Riemann-sq.) ? ($\mathbb{Z}_2$ invariant $b \to -b$)

Closed bosonic SFT $\Rightarrow$ deformed gauge algebra for *cubic* theory

$$\big[\,\xi_1,\,\xi_2\,\big]_+^M \;=\; \big[\,\xi_1,\,\xi_2\,\big]_C^M \;+\; \tfrac{1}{2}\,\bar{\mathcal{H}}^{KL}\,K_{[1\,K}{}^P\,\partial^M K_{2]\,LP}$$

with $K_{MN} = 2\partial_{[M}\xi_{N]}$ and background generalized metric $\bar{\mathcal{H}}_{MN}$

$\Rightarrow$ α'-deformed diffeomorpisms as implied by (perturbative) redefinition

$$h'_{ij} \;=\; h_{ij} - \tfrac{1}{4}\,\alpha'\,\partial_k h_i{}^p\,\partial^k h_{jp} + \cdots\;,$$

agrees with earlier results on duality-invariant Riemann-sq.

[Meissner (1996), Hohm & Zwiebach (2011)]

More general $\mathbb{Z}_2$ even/odd deformations (with parameters $\gamma^{\pm}$)

$$\big[\,\xi_1,\,\xi_2\,\big]_{\alpha'}^M \;=\; \big[\,\xi_1,\,\xi_2\,\big]_C^M \;+\; \tfrac{1}{2}\big(\gamma^+\bar{\mathcal{H}}^{KL} - \gamma^-\eta^{KL}\big)\,K_{[1\,K}{}^P\,\partial^M K_{2]\,LP}$$

Cubic Action

$$
\begin{aligned}
S \;=\; & S^{(2,2)} + S^{(3,2)} \\
& + \tfrac{1}{4}\,\mathcal{R}^{\underline{M}\,\underline{N}\bar{K}\bar{L}}\,\mathcal{R}_{\underline{M}\,\underline{N}\bar{K}\bar{L}} + \tfrac{1}{4}\,\phi\,\mathcal{R}^{\underline{M}\,\underline{N}\bar{K}\bar{L}}\,\mathcal{R}_{\underline{M}\,\underline{N}\bar{K}\bar{L}} \\
& - \tfrac{1}{8}\Big(\Gamma^{\underline{P}\bar{M}\bar{N}}\,\Gamma_{\bar{M}}{}^{\underline{K}\,\underline{L}}\,\partial_{\underline{P}}\Gamma_{\bar{N}\underline{K}\,\underline{L}} \;-\; \Gamma^{\bar{P}\underline{M}\,\underline{N}}\,\Gamma_{\underline{M}}{}^{\bar{K}\bar{L}}\,\partial_{\bar{P}}\Gamma_{\underline{N}\bar{K}\bar{L}} \\
& \qquad - \Gamma^{\bar{M}}{}_{\underline{K}\,\underline{L}}\,\Gamma^{\bar{N}\underline{K}\,\underline{L}}\,\partial_{\bar{M}}\Gamma_{\bar{N}} \;+\; \Gamma^{\underline{M}}{}_{\bar{K}\bar{L}}\,\Gamma^{\underline{N}\bar{K}\bar{L}}\,\partial_{\underline{M}}\Gamma_{\underline{N}}\Big) \\
& - \tfrac{1}{2}\,\mathcal{R}_{\underline{M}\,\underline{N}\bar{K}\bar{L}}\,\Gamma^{\bar{K}\underline{M}\,\underline{P}}\,\Gamma^{\bar{L}\underline{N}}{}_{\underline{P}} + \tfrac{1}{2}\,\mathcal{R}_{\underline{K}\,\underline{L}\bar{M}\bar{N}}\,\Gamma^{\underline{K}\bar{M}\bar{P}}\,\Gamma^{\underline{L}\bar{N}}{}_{\bar{P}} \\
& - \tfrac{1}{2} m_{\underline{M}\bar{N}}\,\mathcal{R}^{\underline{M}\,\underline{K}\bar{P}\bar{Q}}\,\partial^{\bar{N}}\Gamma_{\underline{K}\bar{P}\bar{Q}} + \tfrac{1}{2} m_{\underline{M}\bar{N}}\,\mathcal{R}^{\underline{P}\,\underline{Q}\bar{N}\bar{K}}\,\partial^{\underline{M}}\Gamma_{\bar{K}\underline{P}\,\underline{Q}} \\
& + \tfrac{1}{2}\,\mathcal{R}_{\underline{M}\,\underline{N}\bar{K}\bar{L}}\,\partial^{\underline{P}} m^{\underline{M}\bar{K}}\,\partial_{\underline{P}} m^{\underline{N}\bar{L}}\;.
\end{aligned}
$$

Part III: Exceptional Field Theory

Cremmer-Julia [1979]: torus reduction of $D = 11$ SUGRA

$\rightarrow$ $\mathsf{E}_{6(6)}$ $[D = 5]$, $\mathsf{E}_{7(7)}$ $[D = 4]$, $\mathsf{E}_{8(8)}$ $[D = 3]$

Larger mathematical framework that explains/makes it manifest?

[de Wit, Nicolai (1986)]

Truncation of $D = 11$ SUGRA in $4 + 7$ split,

keeping only 'internal' field components and coordinates,

$$G_{MN} = \begin{pmatrix} e^{2\Delta}\eta_{\mu\nu} & 0 \\ 0 & g_{mn}(y) \end{pmatrix}, \qquad \text{etc.}$$

extending coordinates to fundamental $56 \Rightarrow \mathsf{E}_{7(7)}$ covariant action

more recently: other groups, geometry, covariant section constraints, etc.

[Hillmann (2009), Berman & Perry (2010), Coimbra, Strickland-Constable & Waldram (2011), etc.]

Complete $D = 11$ SUGRA?? duality transformations in $D = 11$??

$E_{7(7)}$ Exceptional Field Theory

Coordinates (x^μ, Y^M), $\mu = 0, \ldots, 3$, $\;M$: fundamental $\mathbf{56}$ of $E_{7(7)}$

$$(t_\alpha)^{MN}\,\partial_M \otimes \partial_N \;=\; 0\;, \qquad \Omega^{MN}\,\partial_M \otimes \partial_N \;=\; 0$$

with Ω^{MN} symplectic form of $E_{7(7)} \subset \mathrm{Sp}(56)$

Generalized Lie derivative

[Coimbra, Strickland-Constable & Waldram (2011), Berman, Cederwall, Kleinschmidt & Thompson (2012)]

$$\mathbb{L}_\Lambda V^M \;\equiv\; \Lambda^K \partial_K V^M - 12\,\mathbb{P}^M{}_N{}^K{}_L\,\partial_K \Lambda^L\,V^N + \lambda\,\partial_P \Lambda^P\,V^M$$

with projector $\mathbb{P}^M{}_N{}^K{}_L$ onto adjoint; $\quad\lambda(V)$ density weight.

$\to$ $E_{7(7)}$ bracket

$$\big[\Lambda_1, \Lambda_2\big]_{\mathsf{E}}^M = 2\Lambda^K_{[1}\partial_K \Lambda^M_{2]} + 12\,(t_\alpha)^{MN}(t^\alpha)_{KL}\,\Lambda^K_{[1}\partial_N \Lambda^L_{2]} - \frac{1}{4}\Omega^{MN}\Omega_{KL}\partial_N\big(\Lambda^K_1 \Lambda^L_2\big)$$

Jacobiator

$$J^M(\Lambda_1,\Lambda_2,\Lambda_3) \;=\; (t^\alpha)^{MN}\partial_N\chi_\alpha(\Lambda) + \Omega^{MN}\chi_N(\Lambda)\;,$$

where

$$\chi_\alpha = -\frac{1}{2}\,(t_\alpha)_{PQ}\Lambda_1^P[\Lambda_2,\Lambda_3]_{\mathsf{E}}^Q + \cdots$$
$$\chi_N = \frac{1}{12}\,\Omega_{PQ}\big(\Lambda_1^P\partial_N[\Lambda_2,\Lambda_3]_{\mathsf{E}}^Q + [\Lambda_2,\Lambda_3]_{\mathsf{E}}^P\,\partial_N\Lambda_1^Q + \cdots\big)$$

χ_M 'covariantly constrained', satisfying the same constraints as ∂_M

${A_\mu}^M$ gauge field for *local* Λ^M: $\qquad \delta {A_\mu}^M \equiv \mathcal{D}_\mu\Lambda^M$

Covariant curvature (Jacobiator for bracket → tensor hierarchy → 2-forms)

[de Wit, Nicolai, Samtleben & Trigiante (2001–2003)]

$${\mathcal{F}_{\mu\nu}}^M \equiv {F_{\mu\nu}}^M - 12\,(t^\alpha)^{MN}\partial_N B_{\mu\nu\,\alpha} - \frac{1}{2}\,\Omega^{MN}B_{\mu\nu\,N}$$

3-form field strength $\mathcal{H}_{(3)M}$ of 2-forms by generalized Bianchi identity

$$3\,\mathcal{D}_{[\mu}{\mathcal{F}_{\nu\rho]}}^M \;=\; -12\,(t^\alpha)^{MN}\partial_N\mathcal{H}_{\mu\nu\rho\,\alpha} - \frac{1}{2}\,\Omega^{MN}\,\mathcal{H}_{\mu\nu\rho\,N}$$

Complete action:

$$S_{\mathsf{EFT}} \;=\; \int d^4x\, d^{56}Y\, e\,\Big(\widehat{R} + \frac{1}{48}\, g^{\mu\nu}\, \mathcal{D}_\mu\mathcal{M}^{MN}\, \mathcal{D}_\nu\mathcal{M}_{MN} - \frac{1}{8}\,\mathcal{M}_{MN}\,\mathcal{F}^{\mu\nu M}\mathcal{F}_{\mu\nu}{}^{N} + e^{-1}\mathcal{L}_{\mathsf{top}} - V(\mathcal{M}_{MN}, g_{\mu\nu})\Big)$$

– Twisted (electric-magnetic) self-duality relations

$$\mathcal{F}_{\mu\nu}{}^{M} \;=\; -\frac{1}{2}\, e\, \varepsilon_{\mu\nu\rho\sigma}\, \Omega^{MN}\mathcal{M}_{NK}\mathcal{F}^{\rho\sigma\, K}$$

$A_\mu{}^M$ include 7 Kaluza-Klein vectors from $D = 11$ metric

→ 7 dual vectors → dual graviton in *non-linear* duality relation

[no-go theorems: Bekaert, Boulanger, Henneaux (2002)]

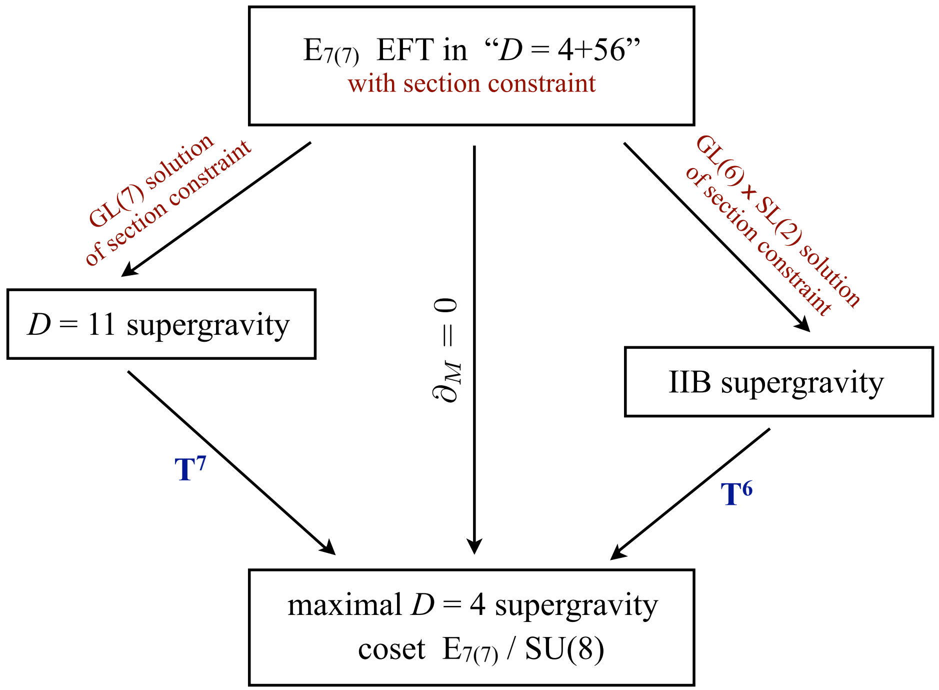
solving constraint → only 7 $B_{\mu\nu N}$ left → ‘dual gravitons’ pure gauge

– Topological terms guarantees consistency with self-duality

– $\mathcal{N} = 8$ supersymmetric extension [Godazgar^2, Hohm, Nicolai, Samtleben]

consistent supersymmetry variations for $B_{\mu\nu M}$

– GL(7) → M-theory, GL$(6)\times$ SL$(2,\mathbb{R})$ → Type IIB → F-theory?



E7(7) EFT in "D = 4+56"
with section constraint
GL(7) solution of section constraint
∂M = 0
GL(6) × SL(2) solution of section constraint
D = 11 supergravity
IIB supergravity
T7
T6
maximal D = 4 supergravity
coset E7(7) / SU(8)

Summary & Outlook

- DFT/EFT provides strikingly economic reformulation of supergravity
- good evidence that it gives more than supergravity:
  truly non-geometric backgrounds well-defined thanks to
  DFT diffeomorphisms $\rightarrow$ compactification, generalized Scherk-Schwarz
  [Aldazabal, Baron, Marques & Nunez, Geissbühler (2011)]
- complete formulation of exceptional field theory for $E_{6(6)}$, $E_{7(7)}$, $E_{8(8)}$
- intriguing new 'quantum geometry' beyond lowest order in α'
  $\Rightarrow$ forget about g and b !
  $\Rightarrow$ underlying gauge principle of string theory?
- for higher-derivatives corrections so far only partial results:
  background-independent extension for bosonic strings?
  Field-dependent gauge algebra? Higher order in α'?
  Type II Strings and M-theory extensions?