The Many Facets of Poisson-Lie T-duality

Falk Hassler

University of Oviedo

based

1810.11446, 1905.03791 and work in progress

with

Saskia Demulder, Dieter Lüst, Giacomo Piccinini, Felix Rudolph and Daniel Thompson

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Universidad de Oviedo
Universidá d'Uviéu
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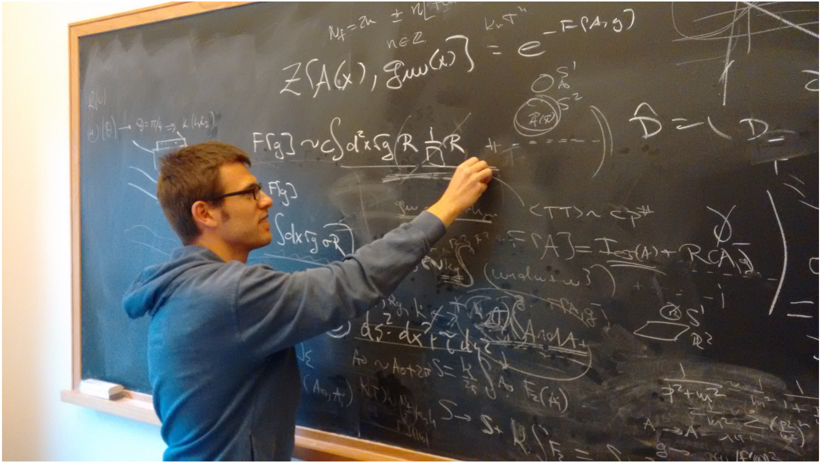
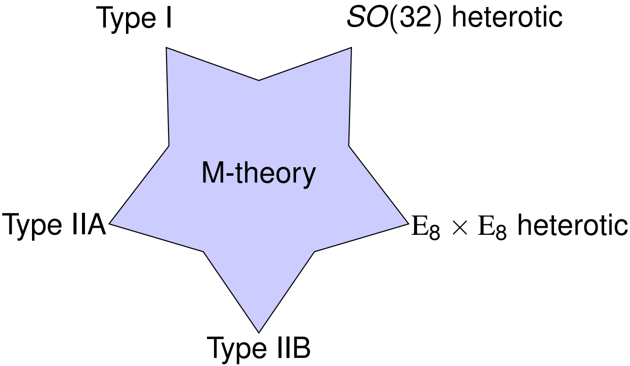


Motivation: Integrability, Duality and Beyond



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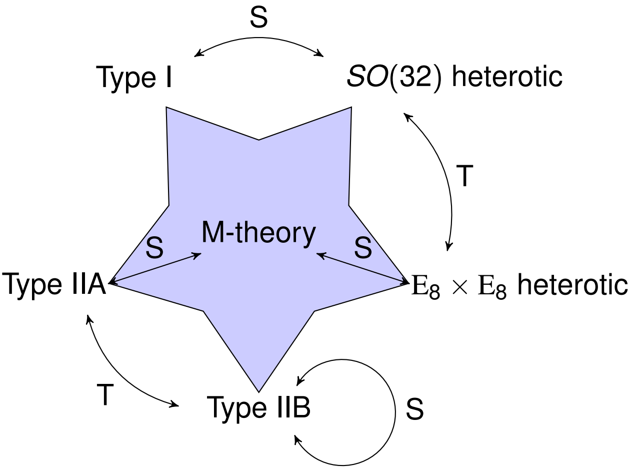
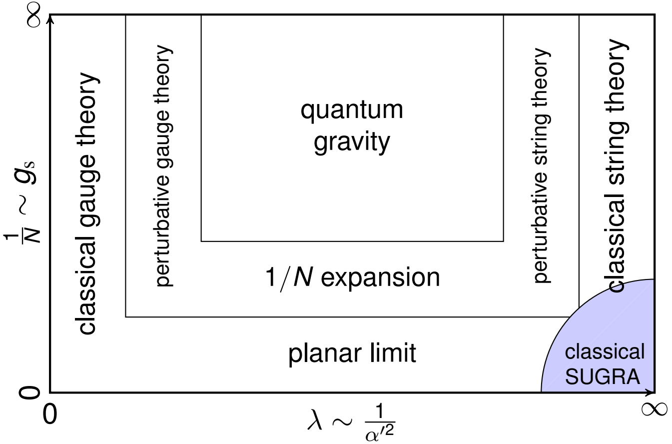


T $=$ T-duality

S $=$ S-duality

Motivation: Integrability, Duality and Beyond

AdS/CFT correspondence



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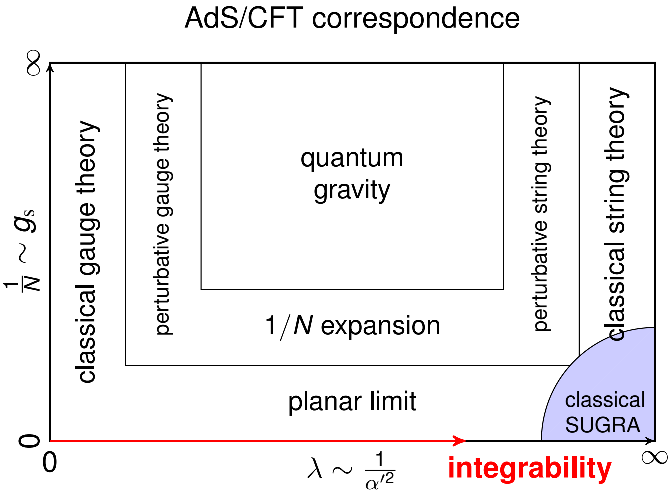

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β-deformation

λ-deformation

$AdS_5 \times S^5$

η-deformation

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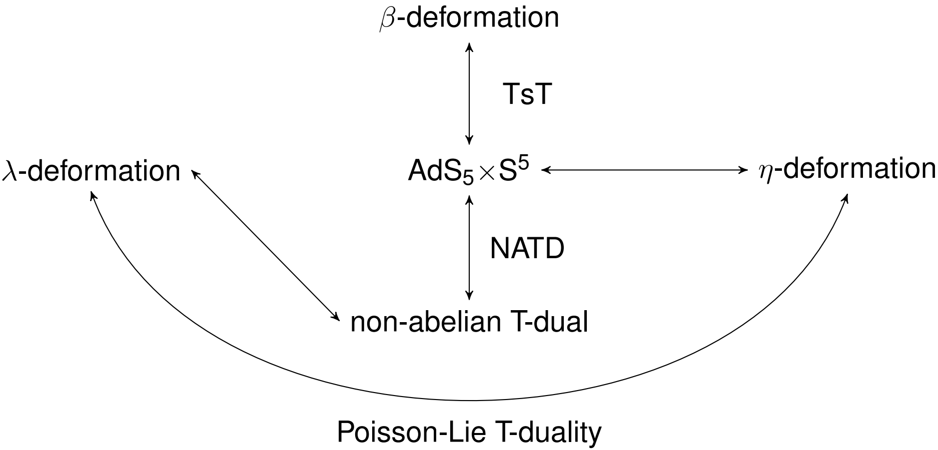

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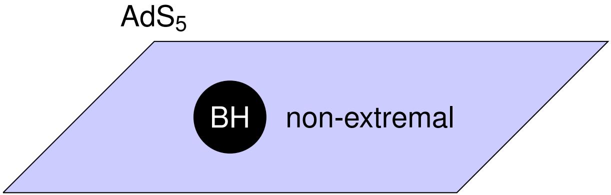

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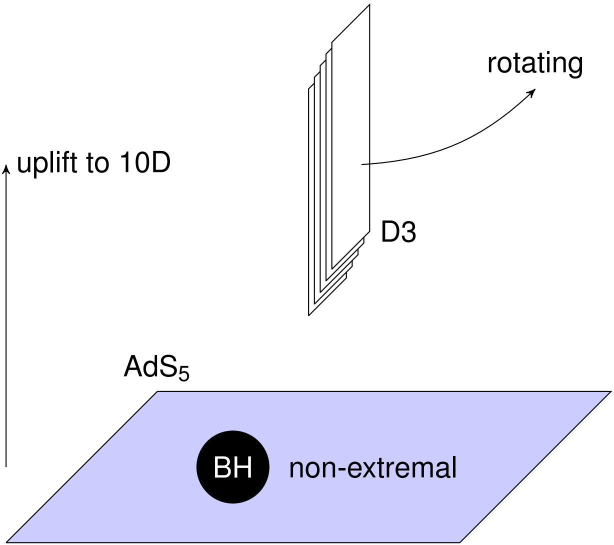

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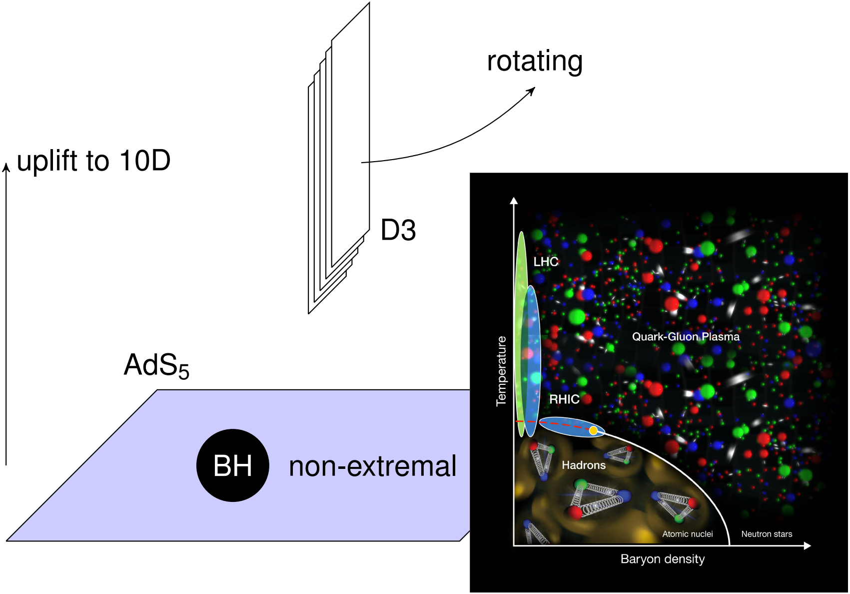

Outline

1. Motivation
2. Worldsheet
3. Target space
4. Outlook

Worldsheet perspective

- What is Poisson-Lie T-duality?
- How does it connects to integrability?

Two-dimensional σ-model: Lagrangian and Hamiltonian

- action $S = \frac{1}{2}\int \mathrm{d}^2\sigma \sqrt{-h}h^{\mu\nu}\partial_\mu X^i (G_{ij} + B_{ij})\partial_\nu X^j$

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- alternatively use momentum

  $$\Pi_i = G_{ij} \partial_\tau X^j + B_{ij} \partial_\sigma X^j$$

  to write

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- with the Hamiltonian

  $$\mathrm{Ham}(X, \Pi) = \frac{1}{2} \int \mathrm{d}\sigma \begin{pmatrix} \partial_\sigma X & \Pi \end{pmatrix} \underbrace{\begin{pmatrix} G - BG^{-1}B & BG^{-1} \\ -G^{-1}B & G^{-1} \end{pmatrix}}_{\text{generalized metric } \mathcal{H}} \begin{pmatrix} \partial_\sigma X \\ \Pi \end{pmatrix}$$

[Tseytlin, 1990,Tseytlin, 1991]

Dynamics in the first order formulation

- time evolution for observable $\frac{\mathrm{d}}{\mathrm{d}\tau} f(X, \Pi) = \{f, \mathrm{Ham}\}$
- we need Poisson brackets

  $\{X^i(\sigma), X^j(\sigma')\} = 0$

  $\{X^i(\sigma), \Pi_j(\sigma')\} = \delta^i_j \delta(\sigma - \sigma')$

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When is it possible to

1. make the Hamiltonian quadratic
2. while keeping the “simple” Poisson brackets?

Current algebra...

- naive answer $\mathcal{H}$ is constant (independent of X)
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$$\{J_I(\sigma), J_J(\sigma')\} = \eta_{IJ}\delta'(\sigma - \sigma')$$

with

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2. use ${E_A}^I(X)$ to transform

$$J'_A = {E_A}^I J_I \,, \quad \eta_{AB} = {E_A}^I \eta_{IJ} {E_B}^J \,, \quad \mathcal{H}_{AB} = {E_A}^I \mathcal{H}_{IJ} {E_B}^J$$

. . . and its transformation [Alekseev and Strobl, 2005]

- then we get the brackets

$$\{J_A(\sigma), J_B(\sigma')\} = F_{AB}{}^C J_C \delta(\sigma - \sigma') + \eta_{AB}\delta'(\sigma - \sigma')$$

and

$$\mathrm{Ham} = \frac{1}{2}\int \mathrm{d}\sigma\, J^A \mathcal{H}_{AB} J^B$$

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$$\boxed{\mathcal{L}_{E_A} E_B{}^I = F_{AB}{}^C E_C{}^I}$$

- the generalized Lie derivative

$$\mathcal{L}_{(x\quad \phi)}(y\quad \xi) = \left([x, y]_{\mathrm{Lie}}\quad L_x\xi - L_y\phi + \iota_y \mathrm{d}\phi\right)$$

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  1. generators T_A with $[T_A, T_B] = F_{AB}{}^C T_C$
  2. ad-invariant, symmetric pairing $\langle T_A, T_B \rangle = \eta_{AB}$
- use Lie group element $g \in D$ generated by $\mathfrak{d}$ to write

  $$J_A = \langle T_A, g^{-1}\partial_\sigma g \rangle$$

  $$\mathrm{Ham} = \frac{1}{2}\int \mathrm{d}\sigma \, \langle g^{-1}\partial_\sigma g, \mathcal{E} g^{-1}\partial_\sigma g \rangle \qquad \mathcal{H}_{AB} = \langle T_A, \mathcal{E} T_B \rangle$$

- coined as $\mathcal{E}$-model [Klimcik and Severa, 1996,Klimcik and Severa, 1996,Klimcik, 2015]

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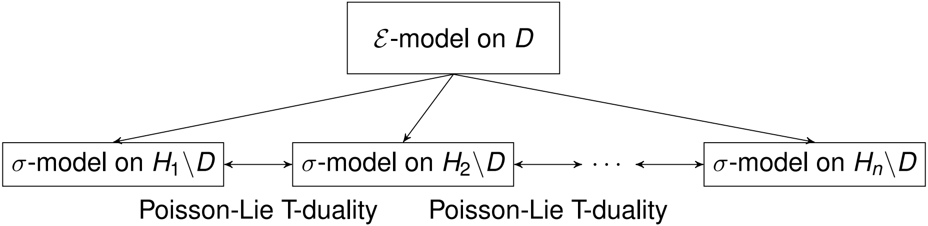
- physical target space $M = H \backslash D$
- in general different ways to choose H



Relation to integrable worldsheet σ-models

- on D=$G^{\mathbb{C}}$ decompose current $\mathfrak{d} \ni J = \mathcal{R} \oplus \mathcal{J}$ and $\mathcal{R}, \mathcal{J} \in \mathfrak{g}$

+ use $\mathcal{E}\mathcal{R} = \mathcal{J}$ and $\mathcal{E}\mathcal{J} = \mathcal{R}$

  such that time evolution $\partial_\tau J = \{J, \mathrm{Ham}\}$ decomposes into

  $\partial_\tau \mathcal{R} = \partial_\sigma \mathcal{J} + [\mathcal{J}, \mathcal{R}]$

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- alternatively express in terms of flat Lax connections

$$A(\lambda) = \frac{\mathcal{R} + \mathcal{J}}{1+\lambda} \mathrm{d}\xi^+ + \frac{\mathcal{R} - \mathcal{J}}{1-\lambda} \mathrm{d}\xi^- \qquad \xi^\pm = \frac{1}{2}(\tau \pm \sigma)$$

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- eigenvalues of the monodromies

  $$Q(\lambda) = P \exp \oint A(\lambda)$$

  are conserved $\rightarrow$ infinite number of conserved quantities

Example η-deformation [Klimcik, 2002]

- D=SL(2,$\mathbb{C}$) has two maximal isotropic subgroups:

  SU(2) with generators T_a and B_2 with generators $\tilde{T}_a$

- pairing on corresponding Lie algebra $\mathfrak{d}$

  $\langle T_a, T_b \rangle = \langle \tilde{T}_a, \tilde{T}_b \rangle = 0$ and $\langle T_a, \tilde{T}_b \rangle = \delta_{ab}$ (Killing form of $\mathfrak{su}(2)$)

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- decomposition into $\mathcal{R}$ and $\mathcal{J}$

$$\mathcal{R}_a = (\eta^{-2} + 1) T_a$$
$$\mathcal{J}_a = (\eta^{-1} + \eta)(R T_a - \tilde{T}_a)$$

  with R a solution to the modified classical Yang-Baxter

$$[Rx, Ry] = R([Rx, y] + [x, Ry]) + [x, y] \qquad \forall\, x,\, y\, \in \mathfrak{g}$$

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- q-deformed global symmetry

There are many more

- η-deformations: Yang-Baxter Wess-Zumino, bi-Yang-Baxter
- λ-deformations [Sfetsos, 2014]: two-parameter anisotropic,

  products of interacting WZW factors
- β-deformations: TsT from CYBE

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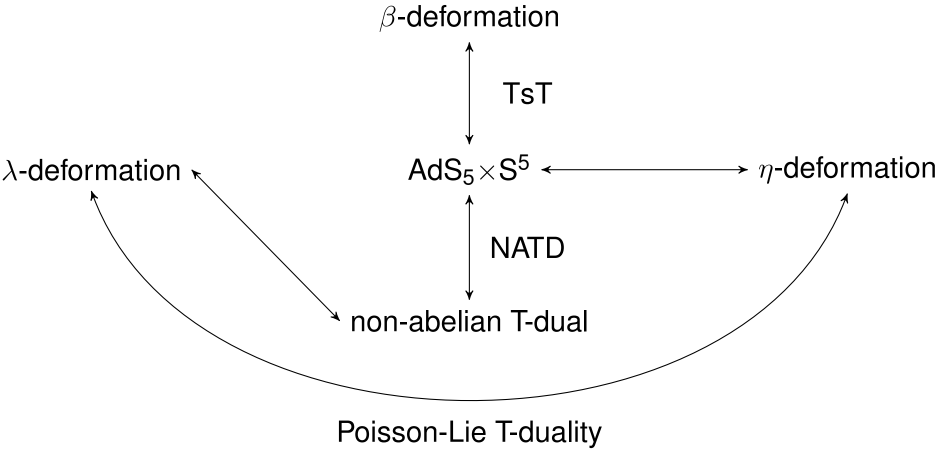

Target space perspective

- What are consistent truncations of SUGRA?
- Why are they useful?
- How are they related to Poisson-Lie symmetry?

Motivation: 1-loop quantum corrections

- σ-model $S = \frac{1}{2}\int \mathrm{d}^2\sigma\sqrt{-h}\left[h^{\mu\nu}\partial_\mu X^i(G_{ij}+B_{ij})\partial_\nu X^j + \phi R^{(2)}\right]$ is renormalizable

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- β-functions match the field equations of the target space action

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

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- symmetries:
  1. diffeomorphisms: $\delta G = L_x G \quad \delta B = L_x B$
  2. B-field gauge transformation: $B \to B - \mathrm{d}\phi$

- both captured by generalized Lie derivative

  $$\delta\mathcal{H} = \mathcal{L}_{\begin{pmatrix} x & \phi\end{pmatrix}}\mathcal{H}$$

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  1. Calabi-Yau manifold and F-theory
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  3. apply dualities to known solutions
  4. ...

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  4. . . .
- a prominent idea: reduce dimensions

= get ride of some degrees of freedom

→ simpler to find solution

New challenge: find consistent truncations

1. **consistent** ansatz for fields in 10/11D
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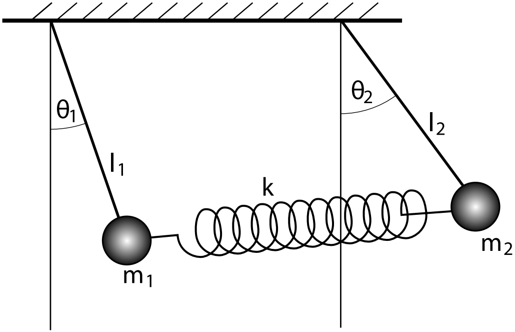

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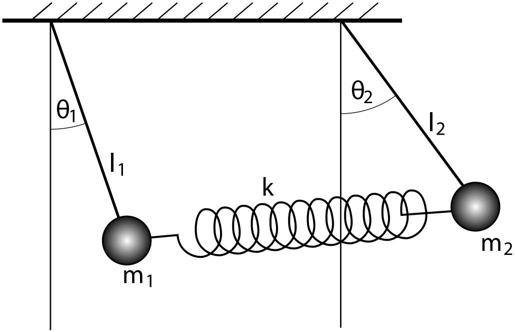


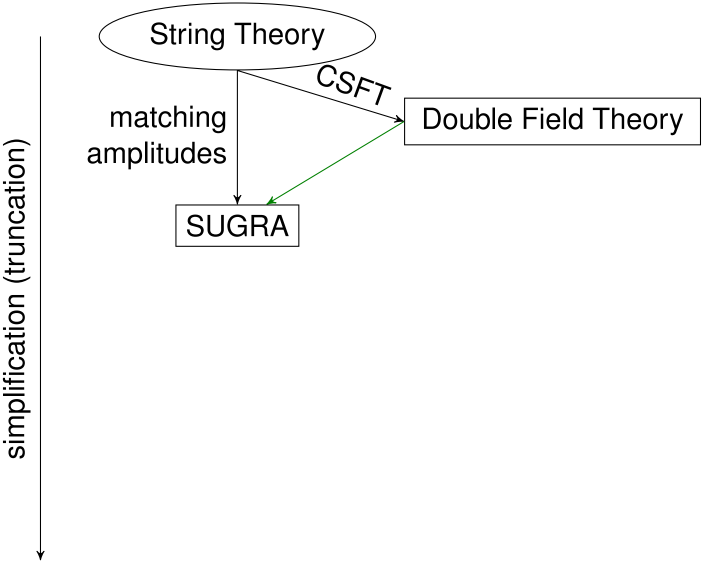
↯ $\theta_2 = 0$

✓ for $m_2 \to \infty$ set $\theta_2 = 0$

✓ for $m_1 = m_2$ set $\theta_1 = \theta_2$

Generalized Scherk-Schwarz compactification

[Aldazabal, Baron, Marques, and Nunez, 2011,Geissbuhler, 2011]



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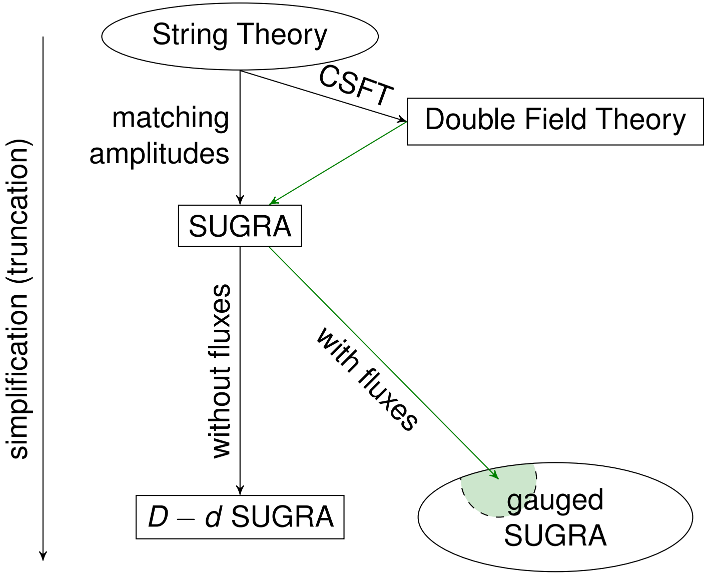

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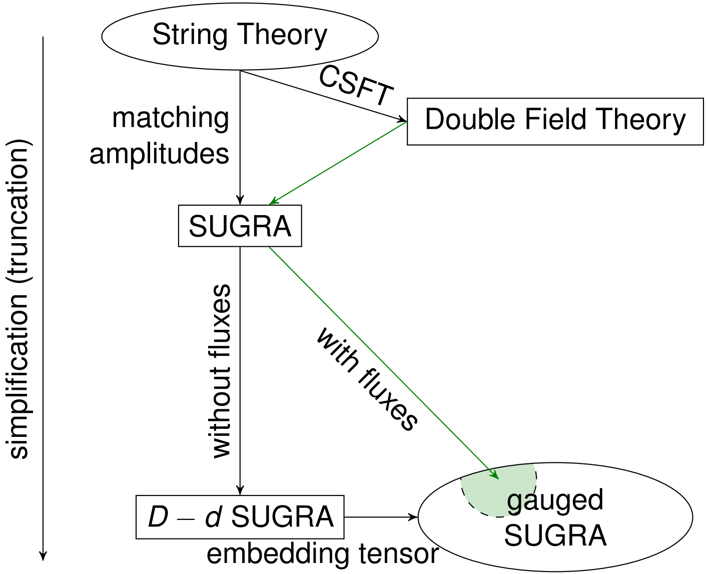

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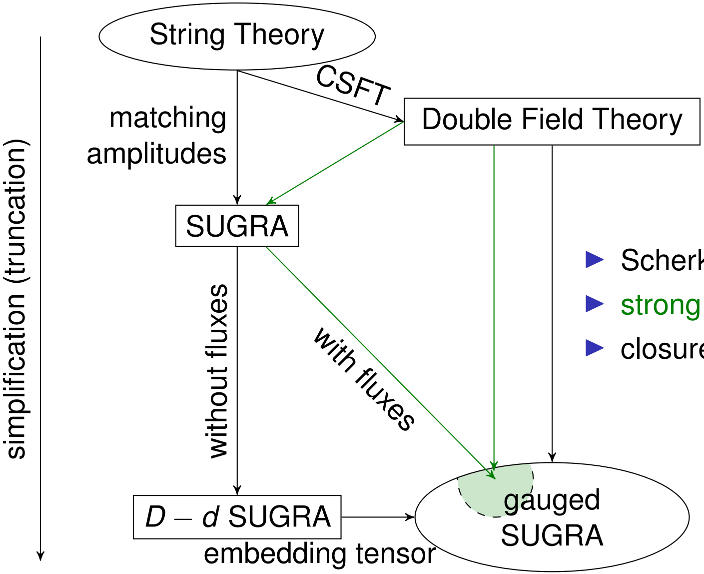

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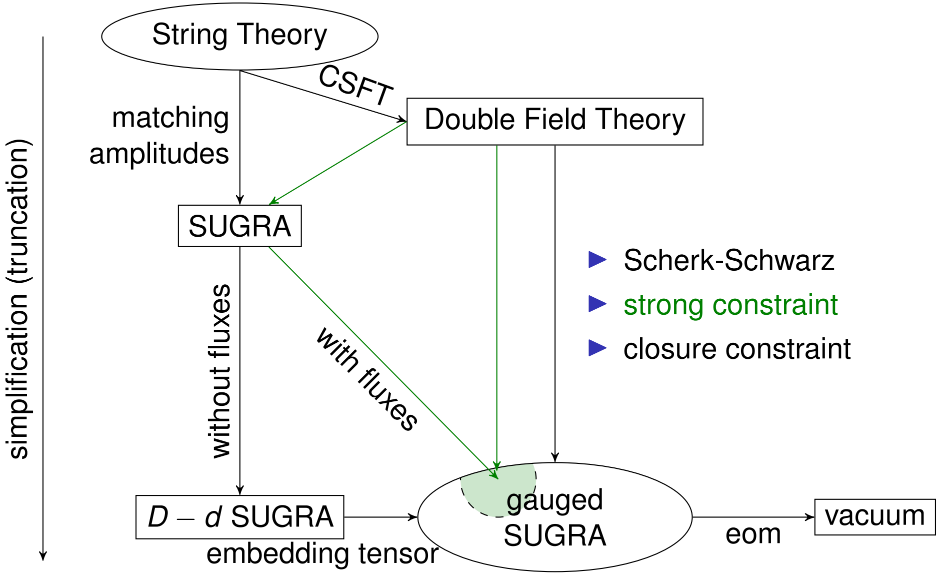

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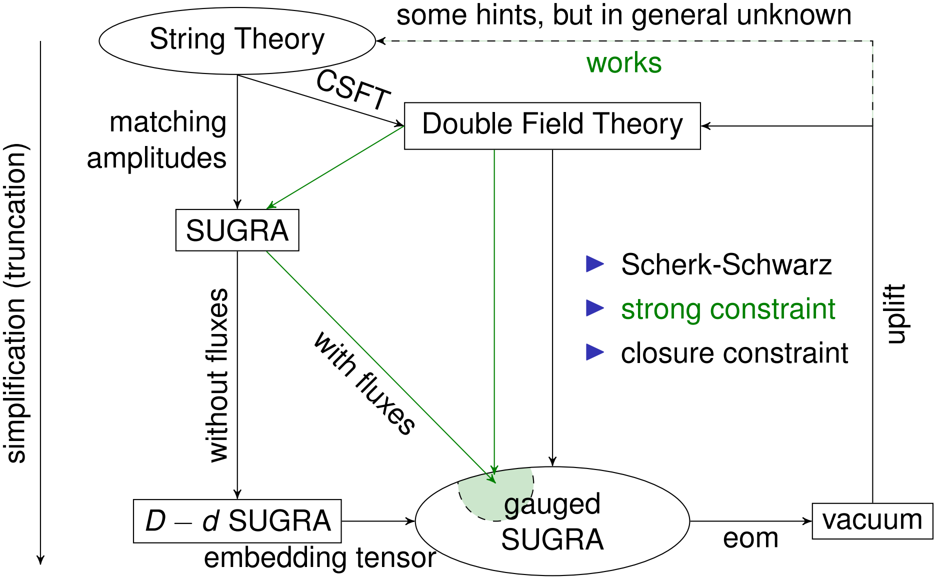

The compactification ansatz

- internal coordinates y, external coordinates x

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- $F_{AB}{}^C$ is the embedding tensor; embeds gauge group $G \hookrightarrow \mathrm{O}(d,d)$

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2. frame algebra

$$\mathcal{L}_{E_A} E_B{}^I = F_{AB}{}^C E_C{}^I$$

- $F_{AB}{}^C$ is the embedding tensor; embeds gauge group $G \hookrightarrow \mathrm{O}(d,d)$
- ansatz is consistent
- remaining challenge:

find one E_A (unique?) for each $F_{AB}{}^C$

The solution

- the same structure as on the worldsheet
- E_A follows from $\mathcal{E}$-model $\rightarrow$ σ-model [Klimcik and Severa, 1996]

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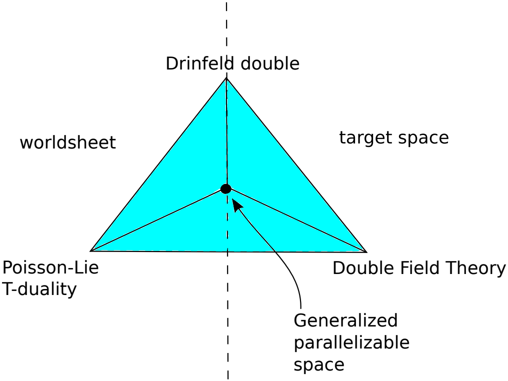
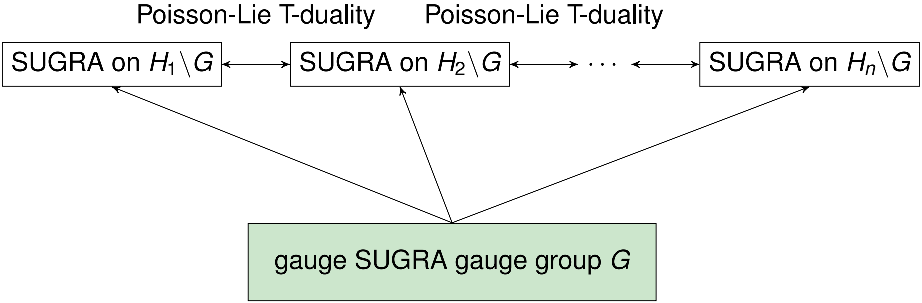
→



The solution

- the same structure as on the worldsheet
- E_A follows from $\mathcal{E}$-model $\to$ σ-model [Klimcik and Severa, 1996]
- also resolve some conceptual subtleties in DFT
- criteria for uplift of gauged SUGRAs to 10/11D SUGRA



Dictionary

worldsheet		target space
bosonic closed string	⟷	NS/NS sector of SUGRA
$\mathcal{E}$-model	⟷	Double Field Theory
renormalizable	⟷	consistent trunction
Poisson-Lie T-duality	⟷	different uplifts
Green-Schwarz superstring	⇠ - - - - - ⇢	R/R sector
integrablitly		?
q-deformed symmetry		?
?		Exceptional Field Theory

Open questions

- complete the dictionary
- extension the Exceptional Field Theory
- include higher derivative corrections
- discuss branes
- what is the fade of supersymmetry
- applications to AdS/CFT

There is an intriguing web of relations between

Poisson-Lie symmetry, *integrable deformations* and *(g)SUGRA*.

It is quite likely the it will give rise to more interesting results in the future. Existing insights in one of them can lead to a better understanding of the others.