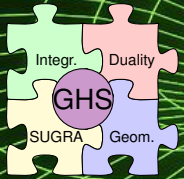
How Strings May Heal the Fabric of Cosmos

Falk Hassler



TEXAS A&M UNIVERSITY
Mitchell Institute

Uniwersytet Wrocławski


The Edge of All We Know

14th September 2015: first observation of gravitational waves

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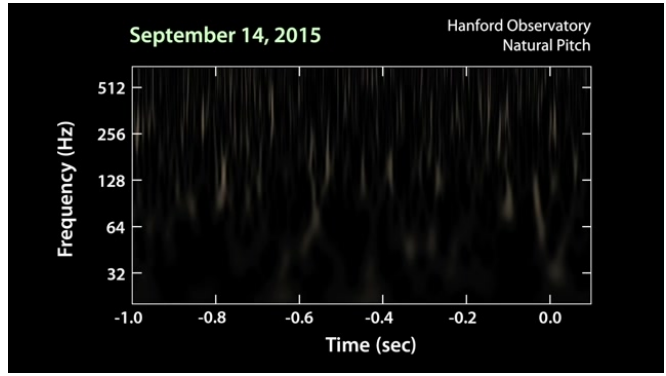

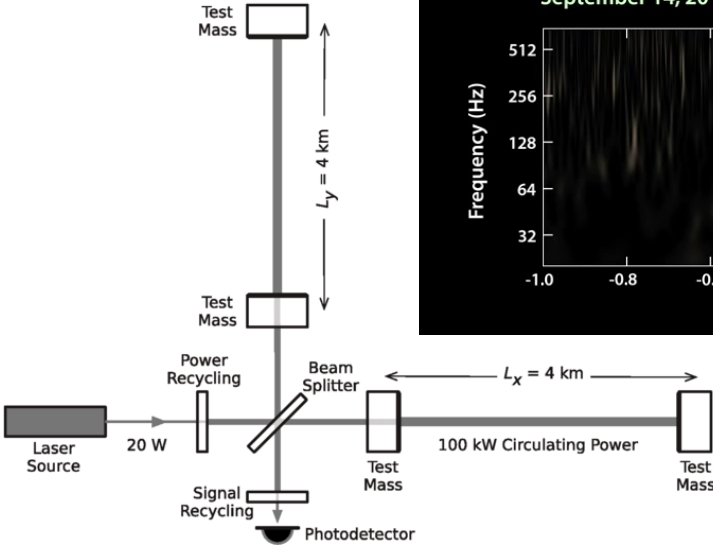

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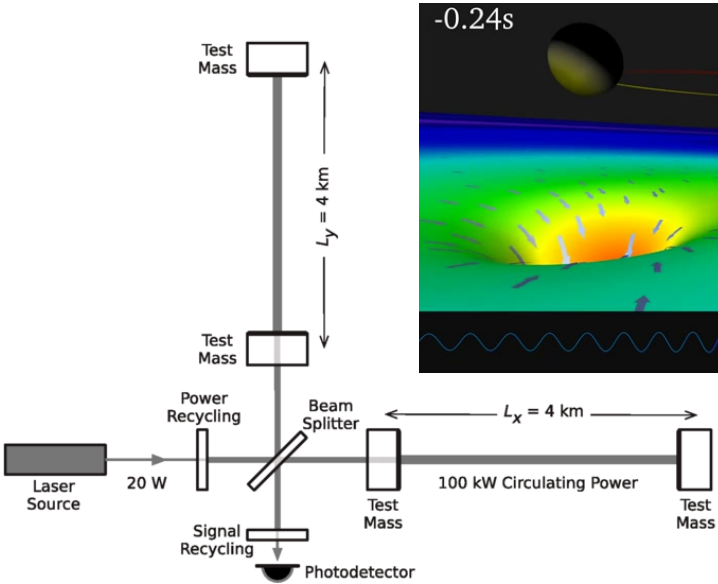
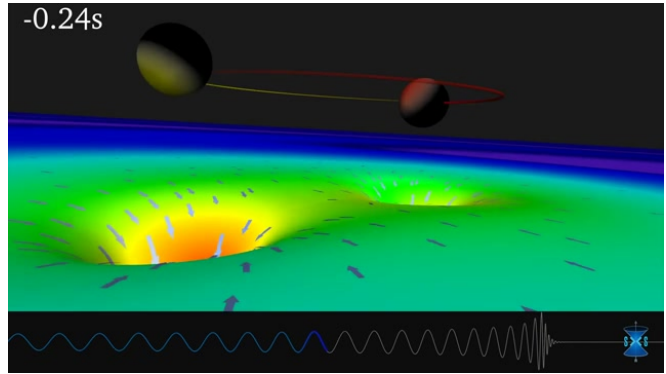
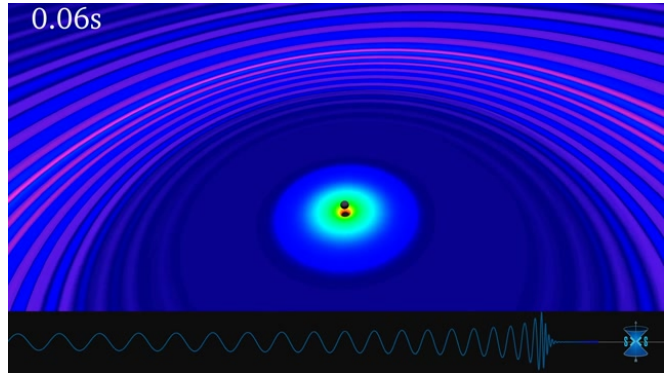


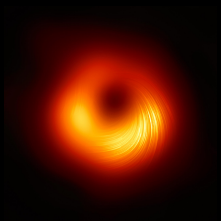


14th September 2015: first observation of gravitational waves

2017



10^{th} April 2019: first image of a black hole ($M87^*$)



10th April 2019: first image of a black hole (M87*)

Relativistic Jet

Accretion Disk

Event Horizon

Singularity

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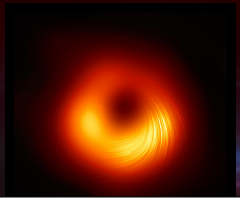

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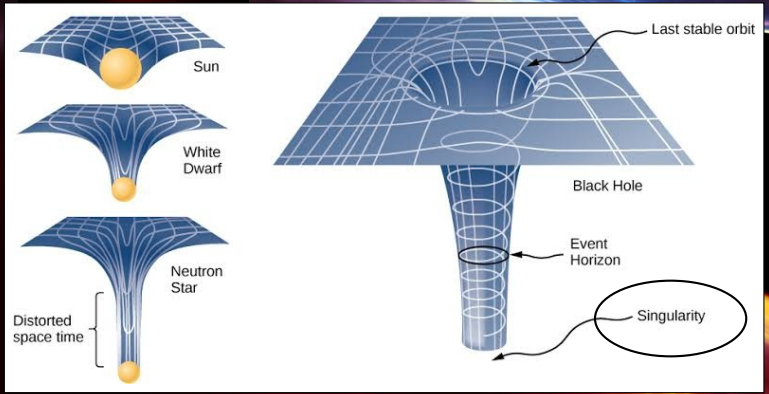

Why all the fuss about the singularity?

- Everything that ever fell into the BH is compressed to a point, the singularity.
- General relativity breaks down and needs to be altered, but how?
- Penrose-Hawking singularity theorems: “Occurrence of singularities is inevitable in GR”

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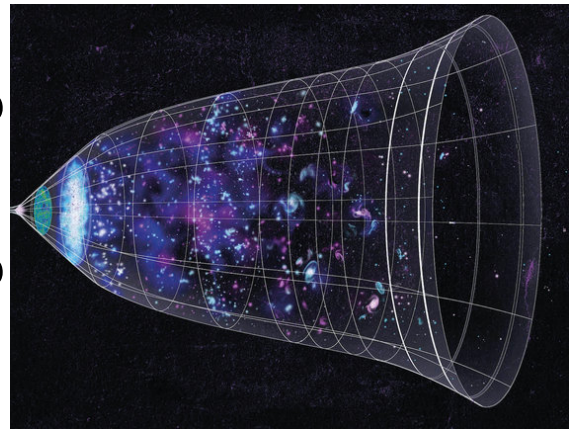
2020

Big Bang



Is the singularity an artifact of an incomplete description?

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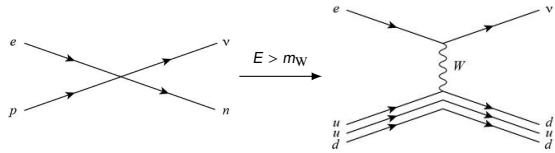
example Fermi theory of β-decay



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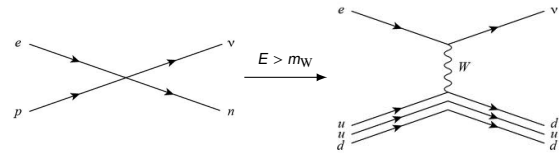
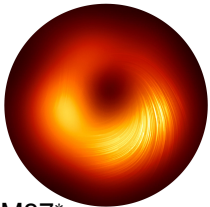


My research is driven by:

- Can we resolve the singularity?
- Effects on the notion of space and time, the fabric of cosmos?
- What are observable consequences?


String Theory

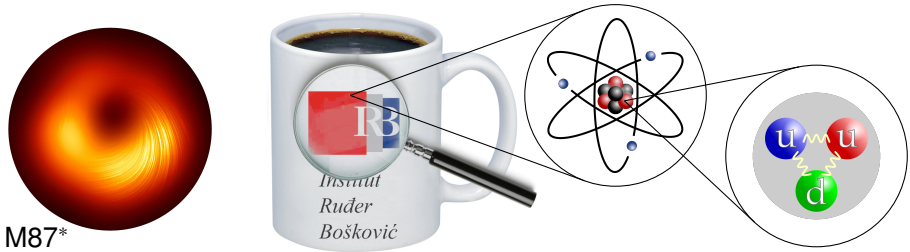
Smaller and smaller and smaller...



M87*

10^{13} length [m]

Smaller and smaller and smaller...



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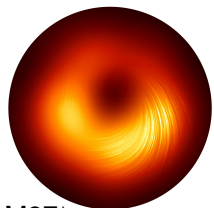

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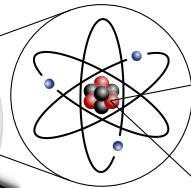
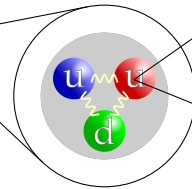
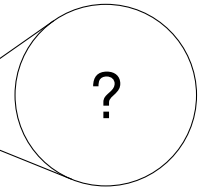
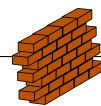




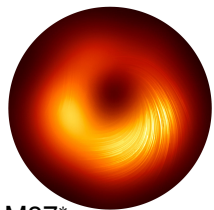


10^{13} length [m] 10^{-10} 10^{-15} 10^{-35}



Planck scale

Smaller and smaller and smaller...



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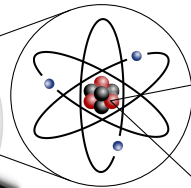

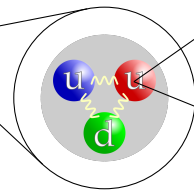

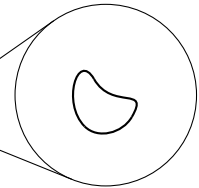

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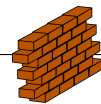

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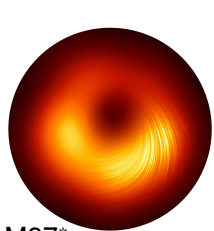

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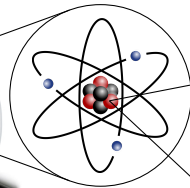

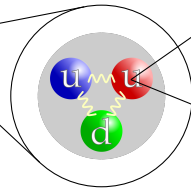

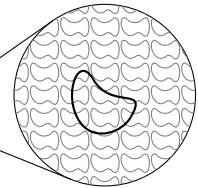

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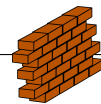

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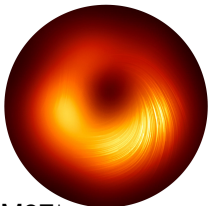

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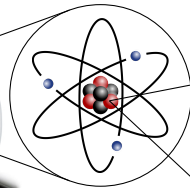
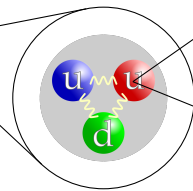
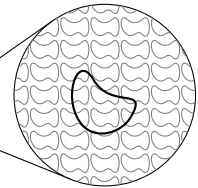






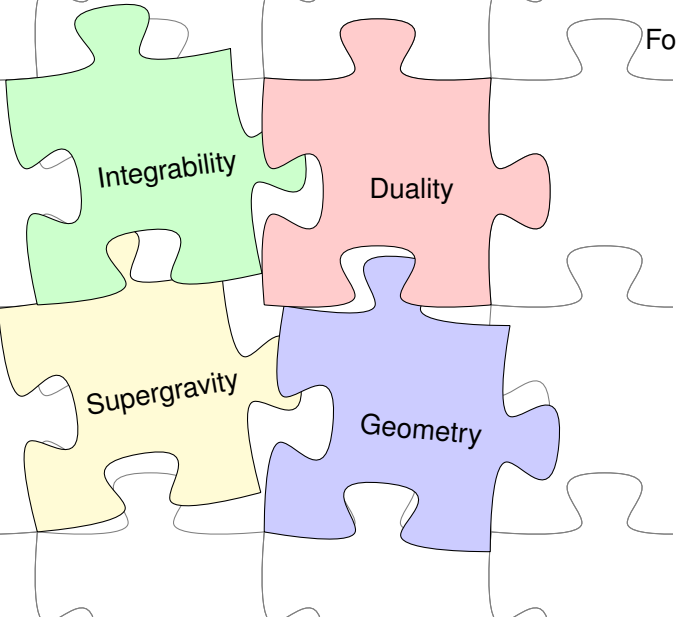
10^{13} length [m] 10^{-10} 10^{-15} 10^{-35} Planck scale

point particles — spacetime **geometry**

strings — **string geometry**

What do we learn from this new paradigm?

Enough to keep physicists busy for the last 50 years and many more to come...



Four subfields are relevant for our purpose.

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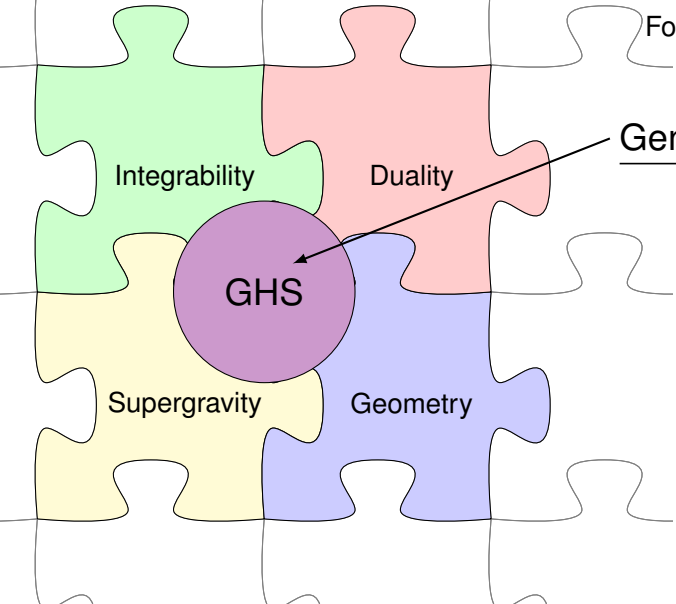

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They are intricately interconnected by

Generalised Homogeneous Space,

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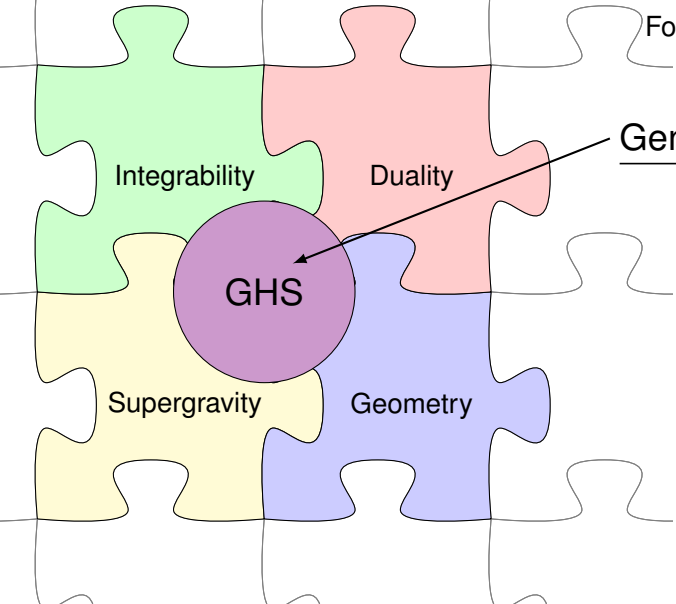

Four subfields are relevant for our purpose.
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Generalised Homogeneous Space,

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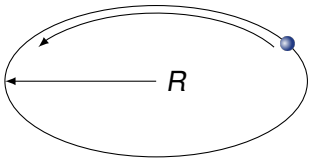
One ~~ring~~ GHS to
rule them all,
one ~~ring~~ GHS to
find them,
...

Abelian T-duality

point particle

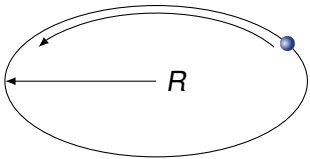


$\neq$

$$E_n \sim \frac{n^2}{R}$$

Abelian T-duality

point particle



$\neq$

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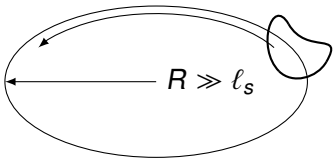
string



$=$

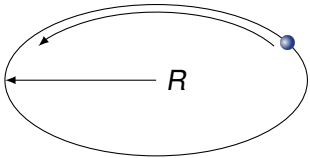
T-duality

$$\frac{\ell_S^2}{R}$$

$$E_{nm} \sim \frac{n^2}{R} + \frac{m^2 R}{\ell_S^2}$$

Abelian T-duality

point particle



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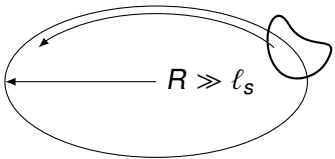


$=$

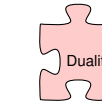
T-duality

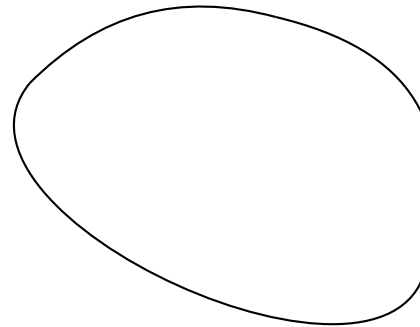
$$\frac{\ell_S^2}{R}$$

$$E_{nm} \sim \frac{n^2}{R} + \frac{m^2 R}{\ell_S^2}$$

only works for circles and flat tori

A more general version of T-duality: Poisson-Lie T-duality





phase space of the string,
a Drinfeld double $\mathbb{D}$

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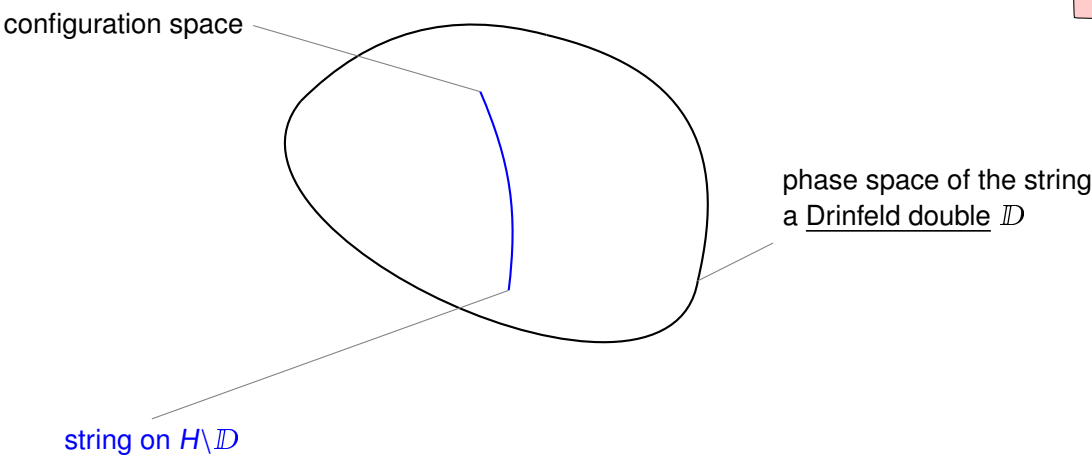

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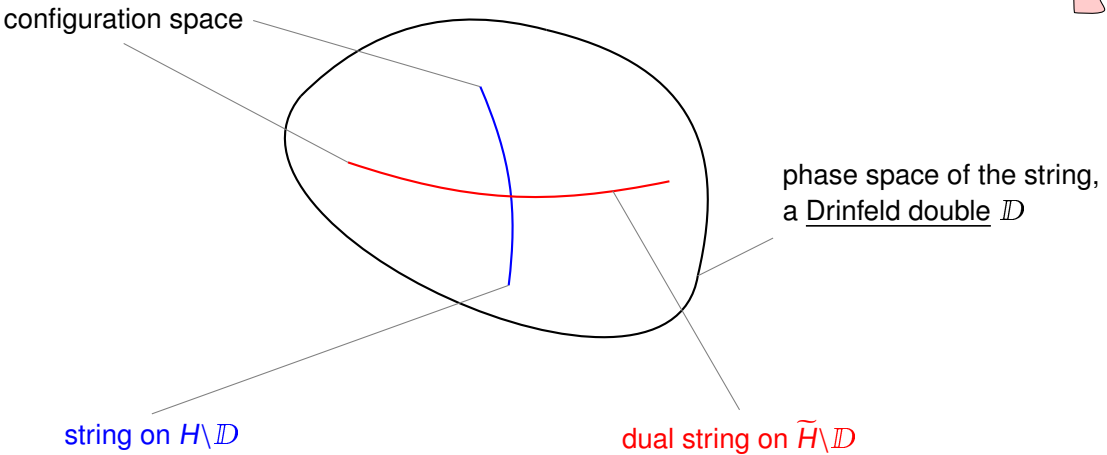

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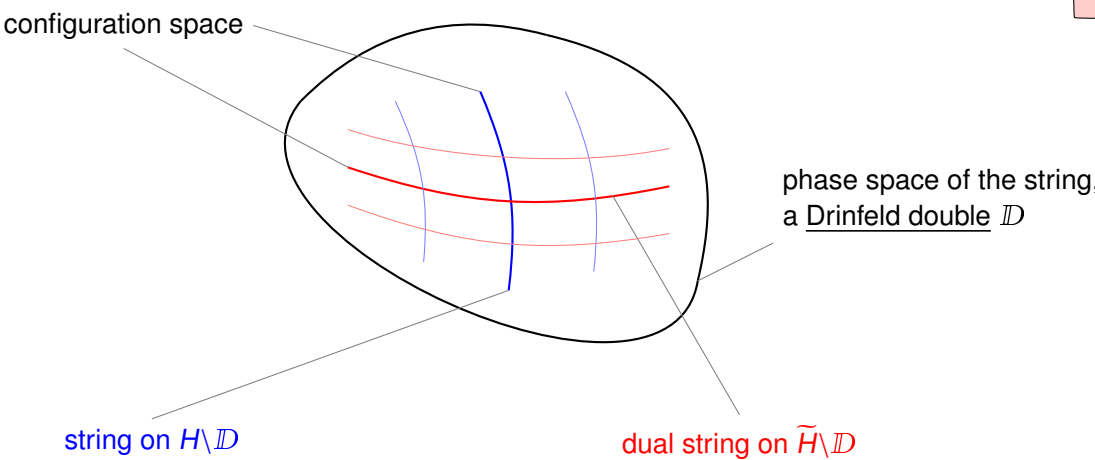

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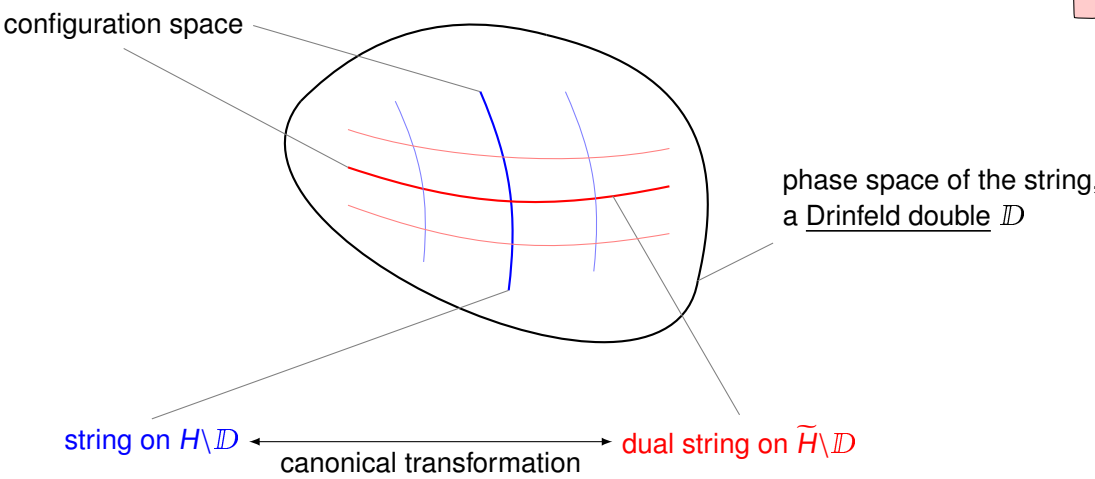

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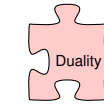
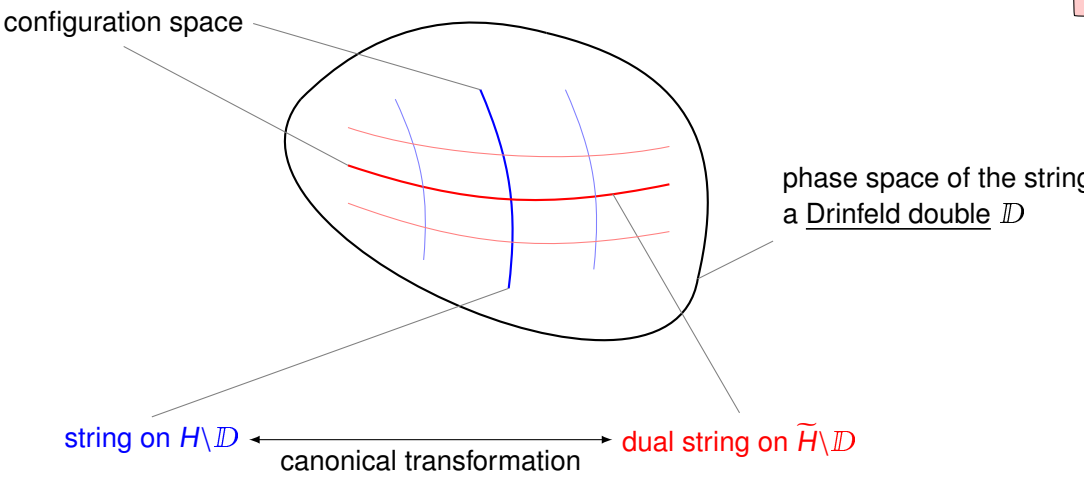
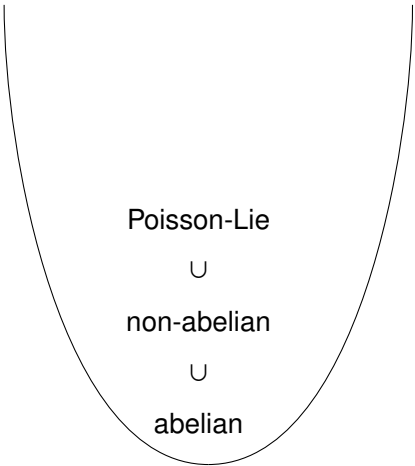




$\widetilde{H}$=$H\backslash\mathbb{D}$ and H=$\widetilde{H}\backslash\mathbb{D}$ are dual Poisson-Lie groups

A hierarchy of T-dualities



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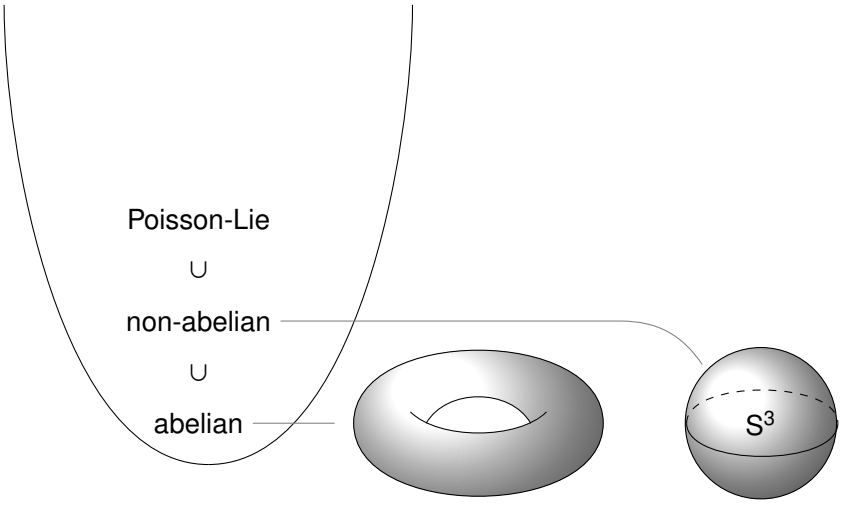

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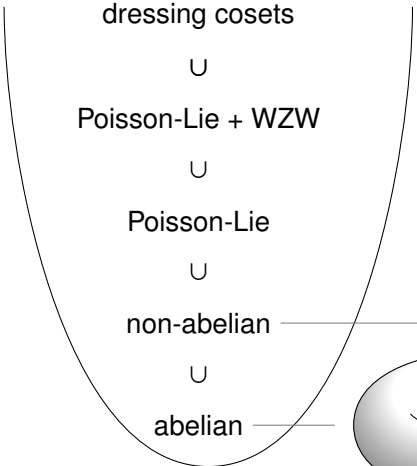
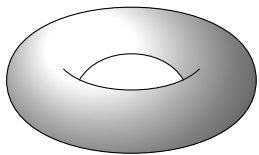
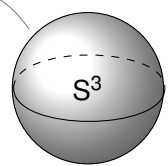


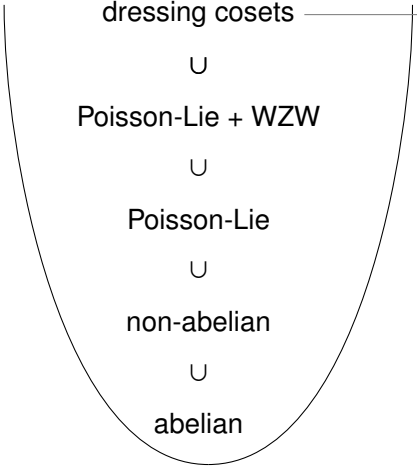


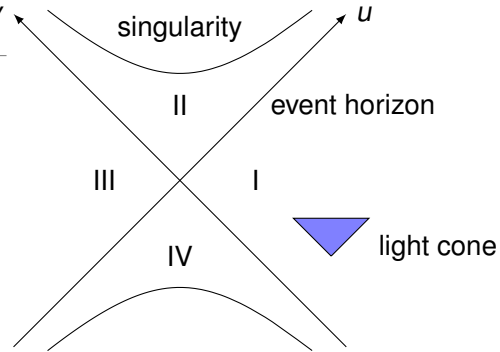


H and $\widetilde{H}$ are abelian

H or $\widetilde{H}$ is abelian

A hierarchy of T-dualities

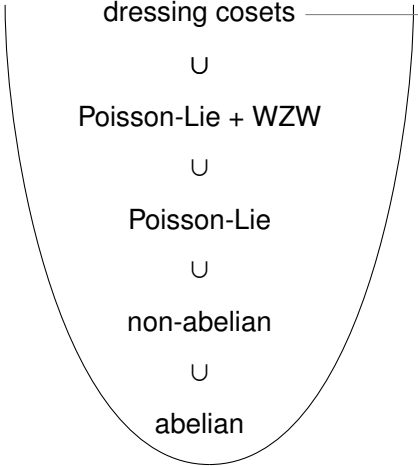


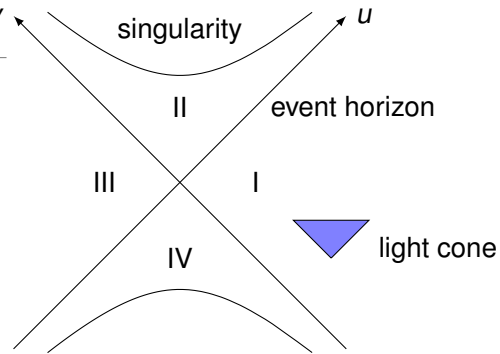


2D Schwarzschild BH in Kruskal–Szekeres coordinates

$$\mathrm{d}s^2 = -\frac{k}{2}\frac{\mathrm{d}u\mathrm{d}v}{(1-uv)}$$

A hierarchy of T-dualities





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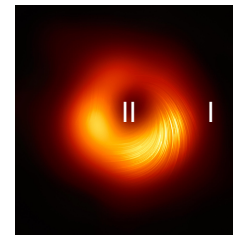
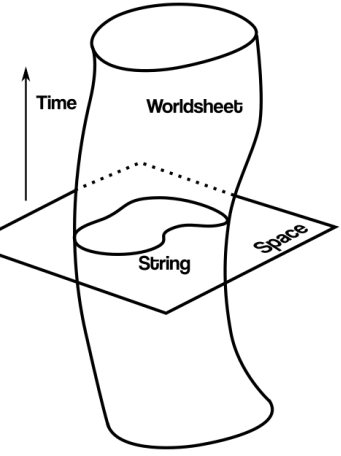
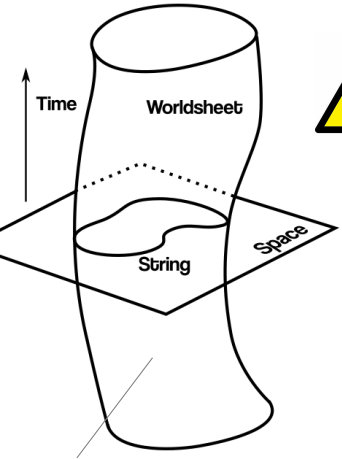


2D σ-model and integrable strings



1. 2D (Q)FT, aka σ-model
2. couplings governed by the spacetime of the string probes

2D σ-model and integrable strings



σ-models are in general highly non-linear and therefore impossible to solve.

Exception: integrable strings

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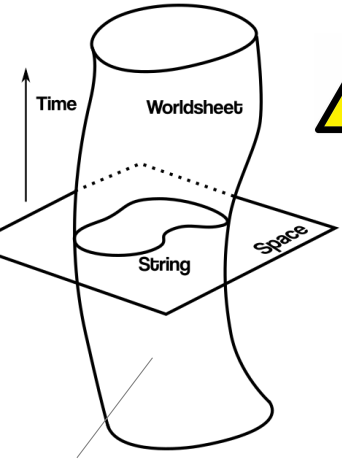

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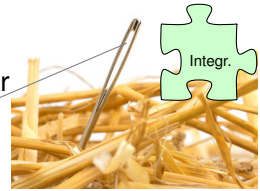

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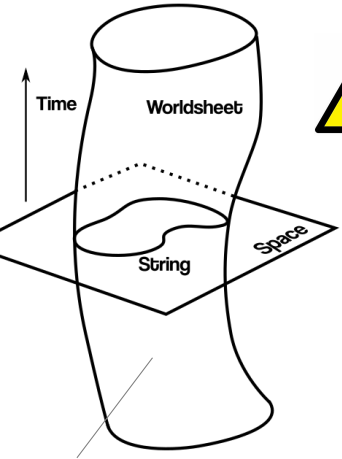

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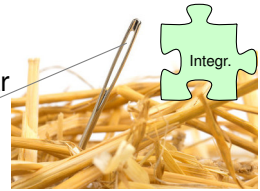

- ∞ number of independent, conserved charges from flat Lax connection
- huge toolbox to construct exact solutions
- important to “prove” AdS/CFT correspondence

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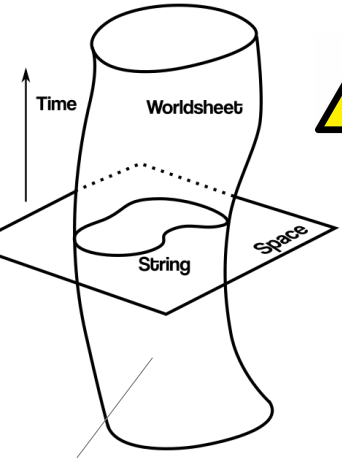
2D σ-model and integrable strings



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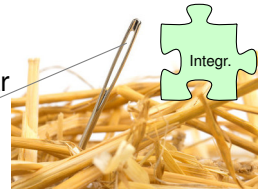
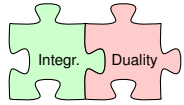


- ∞ number of independent, conserved charges from flat Lax connection
- huge toolbox to construct exact solutions
- important to “prove” AdS/CFT correspondence
- most known examples are Poisson-Lie symmetric



1. 2D (Q)FT, aka σ-model
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Example: the sine-Gordon model

classical string in $t \nearrow \times$ 

has one transverse mode φ governed by

$$\partial_\tau^2 \varphi - \partial_\sigma^2 \varphi = -\sin\varphi = -\varphi + \frac{\varphi^3}{6} + \dots$$

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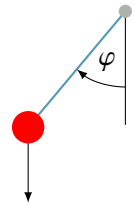

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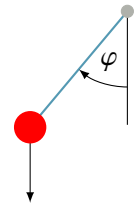
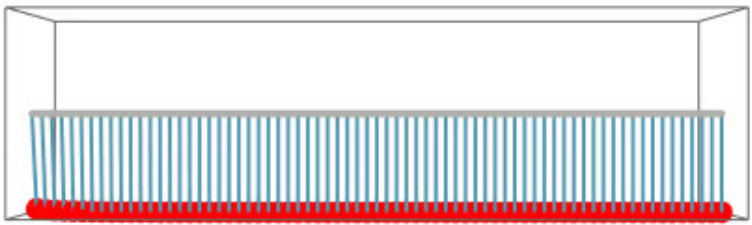


- integrable
- exhibits solitons = waves that behave like particles



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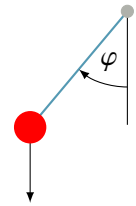

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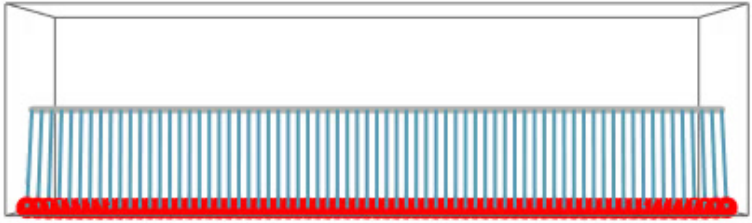
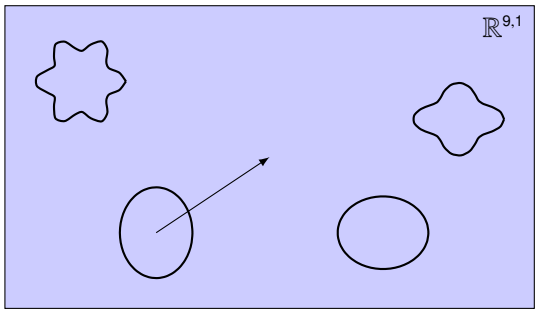


Strings come with gravity built in



- closed strings in flat space

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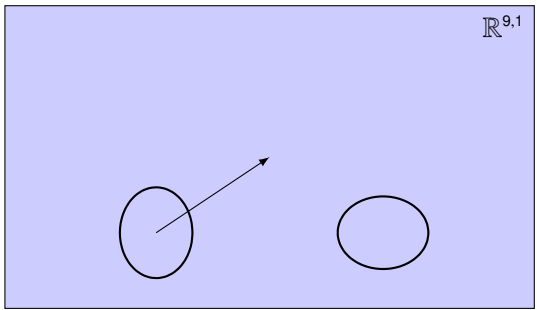
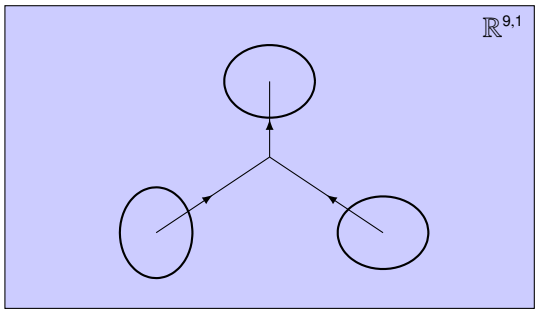


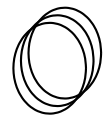
- closed strings in flat space
- truncate all massive excitations

Strings come with gravity built in

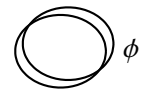
$$S_{\mathrm{NS}} = \int \mathrm{d}^{10}x\ \sqrt{g}e^{-2\phi}\left(R + 4\partial_\mu\phi\partial^\mu\phi - \frac{1}{12}H_{\mu\nu\rho}H^{\mu\nu\rho}\right) \qquad H_{\mu\nu\rho} = 3\partial_{[\mu}B_{\nu\rho]}$$



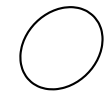
- closed strings in flat space
- truncate all massive excitations
- match scattering amplitudes with EFT



$g_{\mu\nu}$



ϕ



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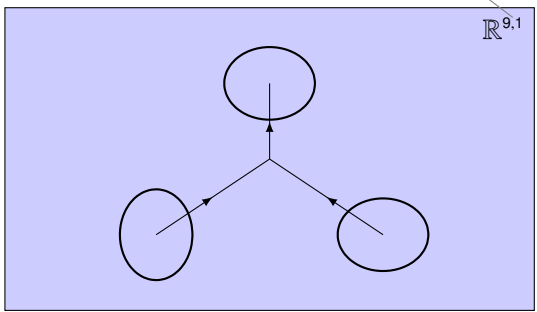
$D \neq 4 \longrightarrow$ compactification required!



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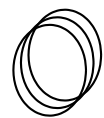

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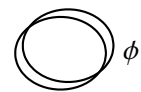

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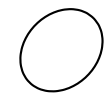
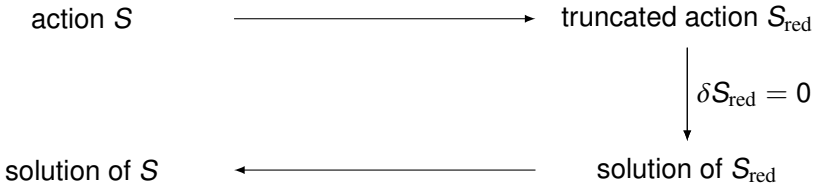


$B_{\mu\nu}$

The art of consistent truncations

action S ⟶ truncated action S_{red}

The art of consistent truncations



The art of consistent truncations

action S → truncated action S_{red}

$\delta S = 0$ ↓

consistent ansatz

$\delta S_{\text{red}} = 0$ ↓

solution of S ← solution of S_{red}

The art of consistent truncations

action S → truncated action S_{red}

$\delta S = 0$ ↓ consistent ansatz ↓ $\delta S_{\text{red}} = 0$

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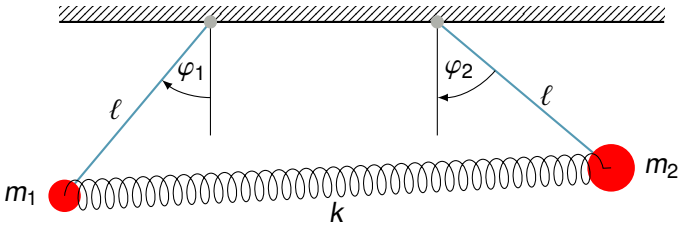
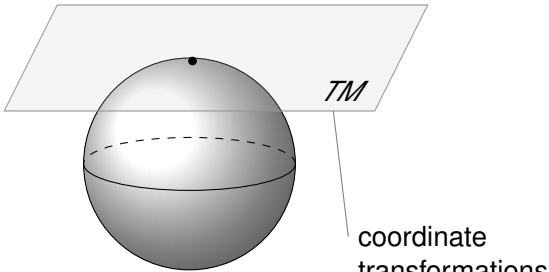


$\varphi_2 = 0$

✓ $m_2 = \infty$ and $\varphi_2 = 0$

✓ $m_1 = m_2$ and $\varphi_1 = \varphi_2$

What have all three in common? Geometry!



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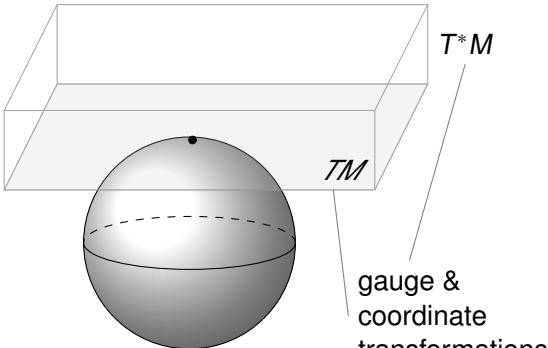

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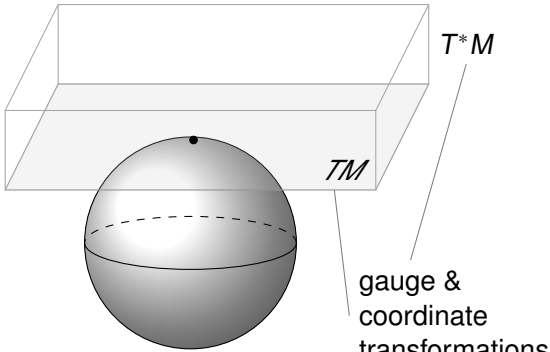

synthesis of { geometry, group theory } → homogeneous space G/H

Felix Klein

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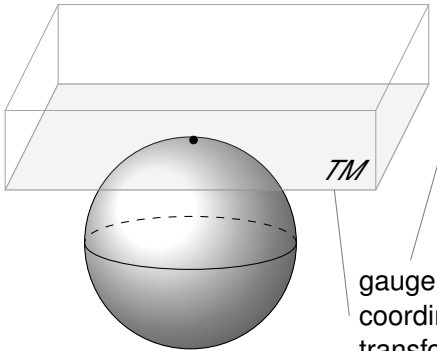

generalised geometry

gauge & coordinate transformations

GHS $H_2 \backslash G / H_1$

lift to generalised geometry

synthesis of geometry group theory

homogeneous space G/H

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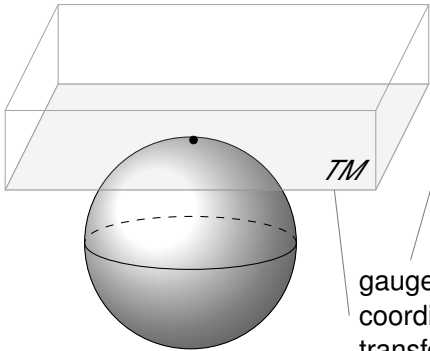

generalised geometry

gauge & coordinate transformations

implements dual backgrounds

GHS $H_2 \backslash G / H_1$

lift to generalised geometry

synthesis of geometry group theory

homogeneous space G/H

Felix Klein

The Munich-NYC-Chapel Hill-Philly-Oviedo-College Station-Programme

2014

♥ geometry
of dualities
beyond tori

The Munich-NYC-Chapel Hill-Philly-Oviedo-College Station-Programme

2014 — 2016

♥ geometry
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beyond tori

The Munich-NYC-Chapel Hill-Philly-Oviedo-College Station-Programme

2014 — 2016 — 2017

♥ geometry of dualities beyond tori

framework that unifies PL T-duality, geometry, consistent truncations [FH 2017]

The Munich-NYC-Chapel Hill-Philly-Oviedo-College Station-Programme

2014

♥ geometry of dualities beyond tori

2016

2017

framework that unifies PL T-duality, geometry, consistent truncations [FH 2017]

2018

connection to integrability

The Munich-NYC-Chapel Hill-Philly-Oviedo-College Station-Programme

2014 — 2016 — 2017 — 2018 — 2019

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connection to integrability

dressing cosets

The Munich-NYC-Chapel Hill-Philly-Oviedo-College Station-Programme

2014 — 2016 — 2017 — 2018 — 2019 — 2020

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connection to integrability

dressing cosets

quantum corrections

The Munich-NYC-Chapel Hill-Philly-Oviedo-College Station-Programme

- ~ 25 publications building directly on this idea
- Poisson-Lie U-duality

2014 — 2016 — 2017 — 2018 — 2019 — 2020

♥ geometry of dualities beyond tori

framework that unifies PL T-duality, geometry, consistent truncations [FH 2017]

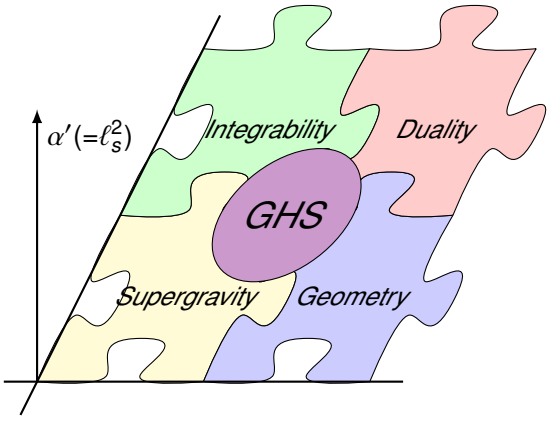
connection to integrability

dressing cosets

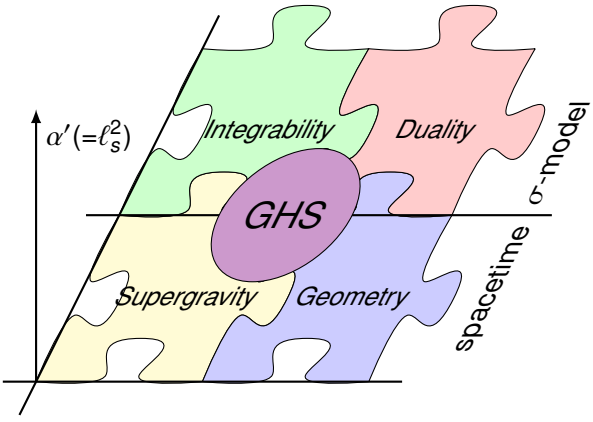
quantum corrections


Where to go from here?

The future are quantum/higher derivative corrections



The future are quantum/higher derivative corrections

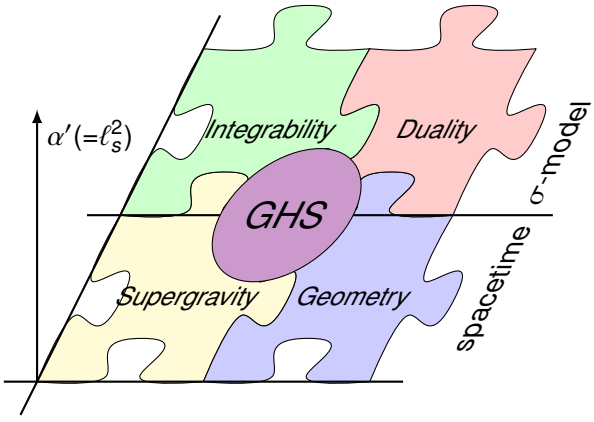


- σ-model loop corrections

  ||

  higher derivative corrections in spacetime

The future are quantum/higher derivative corrections



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- [FH, Thomas Rochais 20][2]:
  α'-corrected Poisson-Lie T-duality
- Higher orders in α'? Even all orders?

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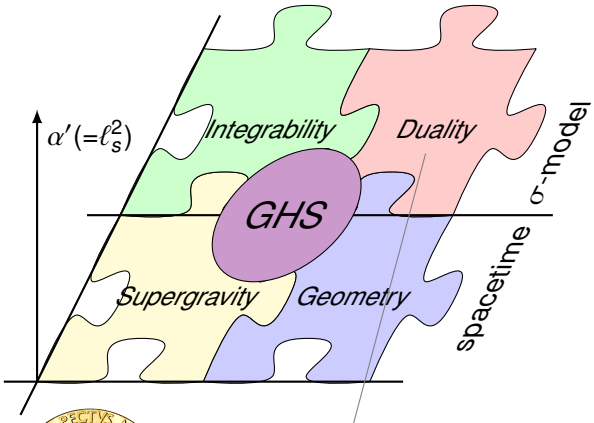
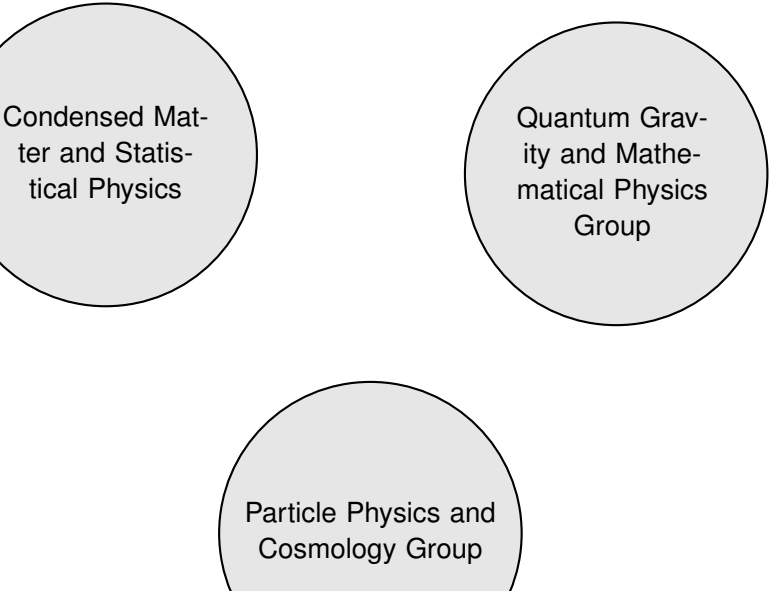


- σ-model loop corrections
  $\shortparallel$
  higher derivative corrections in spacetime
- [FH, Thomas Rochais 20][2]:
  α'-corrected Poisson-Lie T-duality
- Higher orders in α'? Even all orders?
  Most likely quantum GHS!
- Should resolve singularities!

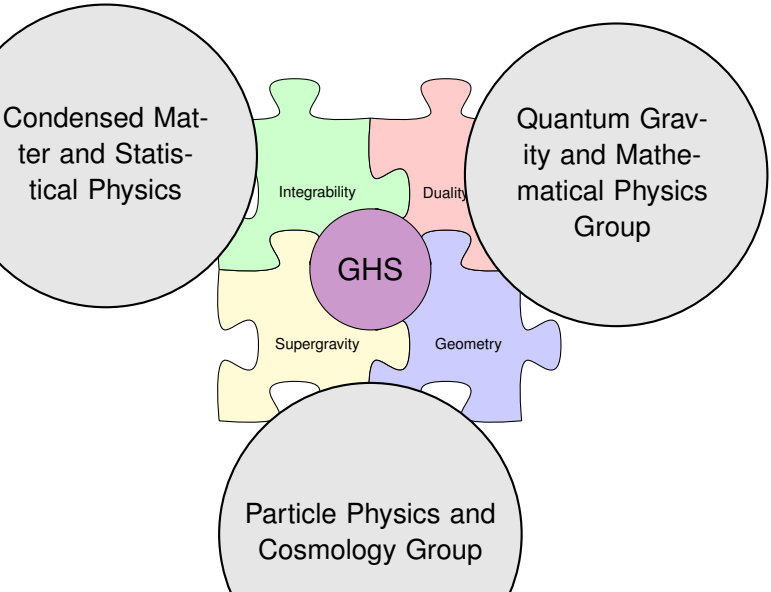
1990

Poisson-Lie group $\xrightarrow[\text{deformation quantisation}]{0 \quad \hbar}$ quantum group

Integration into the Division of Theoretical Physics of the RBI



Integration into the Division of Theoretical Physics of the RBI



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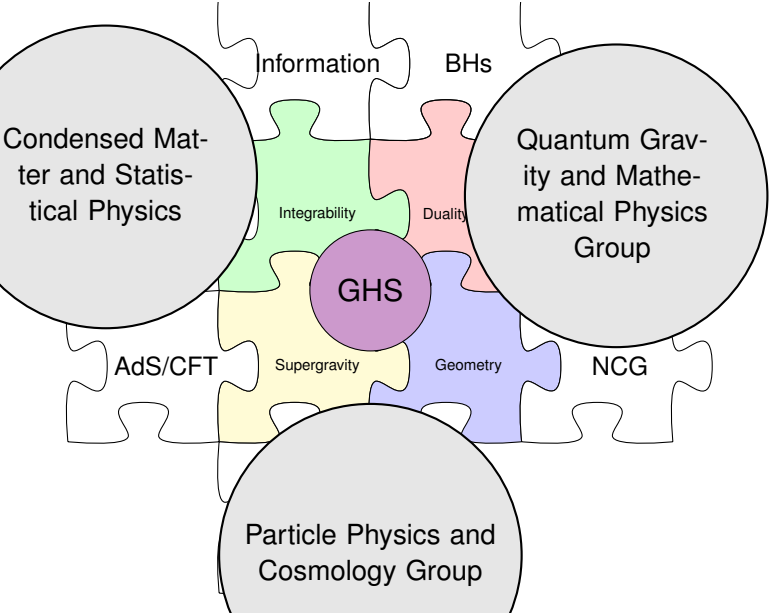

- various opportunities for synergies
- I bring new fields of research and their int'l. communities
- application for funding ERC-2022-STG

European Research Council

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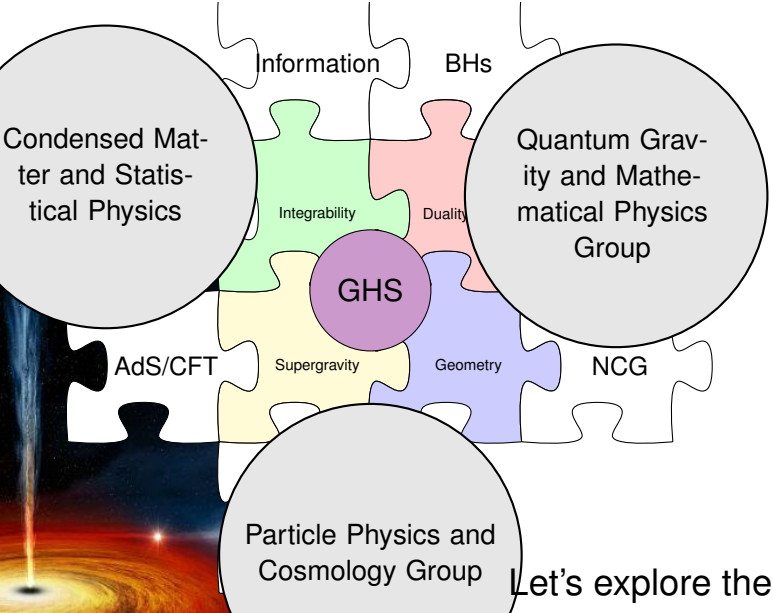

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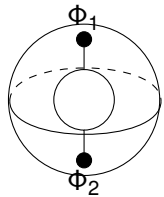
Let's explore the fabric of cosmos together!

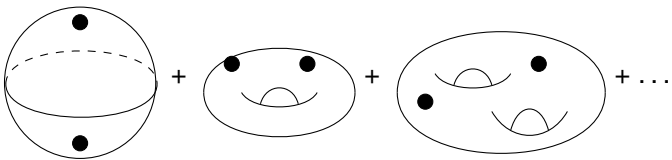

DETAILS

Quantum corrections



- loop corrections on fixed genus g wordsheets for correlator $\langle \Phi_1 \Phi_2 \rangle$
  α'-corrections

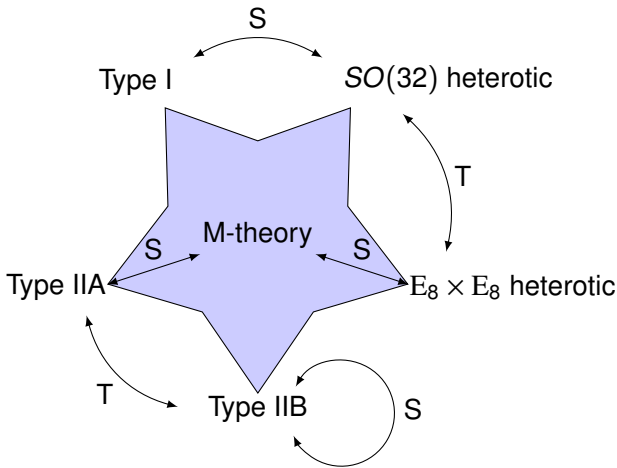
- string path integral genus expansion



g_s-corrections

1. requires knowledge about global properties of the worldsheet
2. relevant for branes if considering S-/U-duality

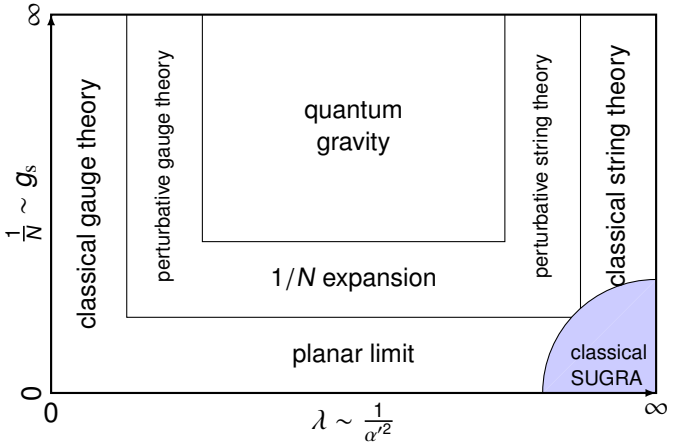
S- and T-duality



T = T-duality

S = S-duality

AdS/CFT correspondence



Integrable deformations