Species scale, worldsheet CFTs and emergent geometry

Christian Aoufia

based on 2405.03683 [CA, Ivano Basile, Giorgio Leone]

SUSY24, Madrid, 13/06/2024

(see Alberto's parallel)

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However, it's crucial to know what happens when we give it up, and even more so in String Theory

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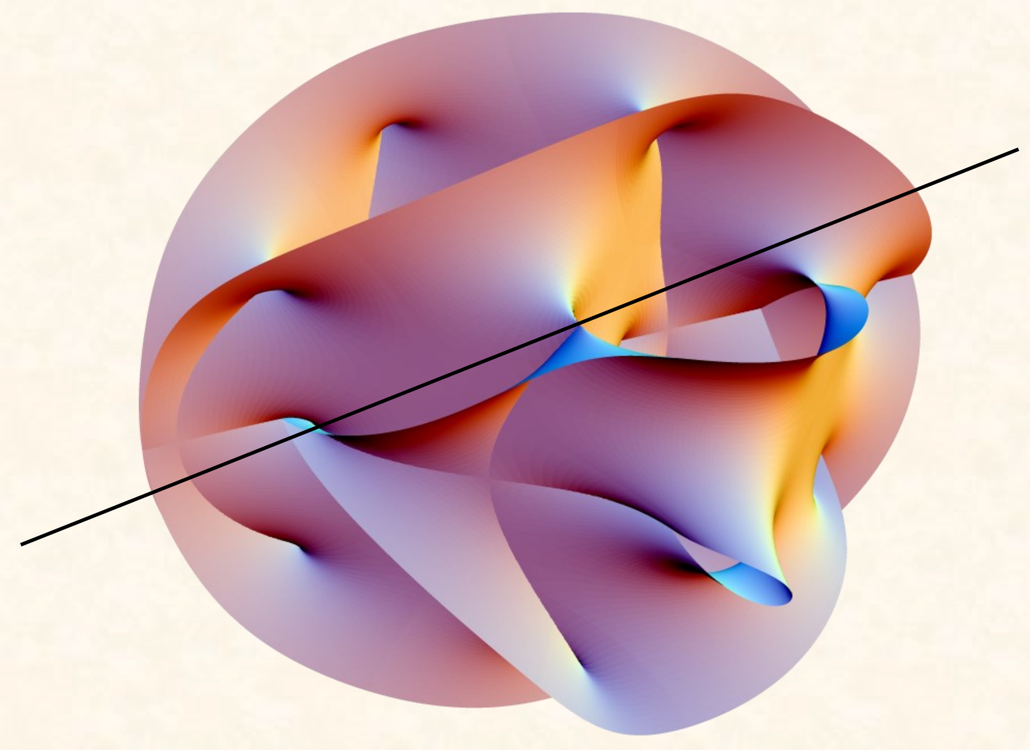
Here we will try to do even more!

~~SUSY~~ + 

Does string theory need extra dimensions[1] ?

1) *in the «classical sense» and asymptotically far in moduli space.*

The known story: worldsheet sigma model

- Polyakov action:

$$\mathcal{S} = \frac{1}{2\pi\alpha'} \int d^2\sigma \, G_{\mu\nu}(X) \, \partial X^\mu \bar{\partial} X^\nu$$

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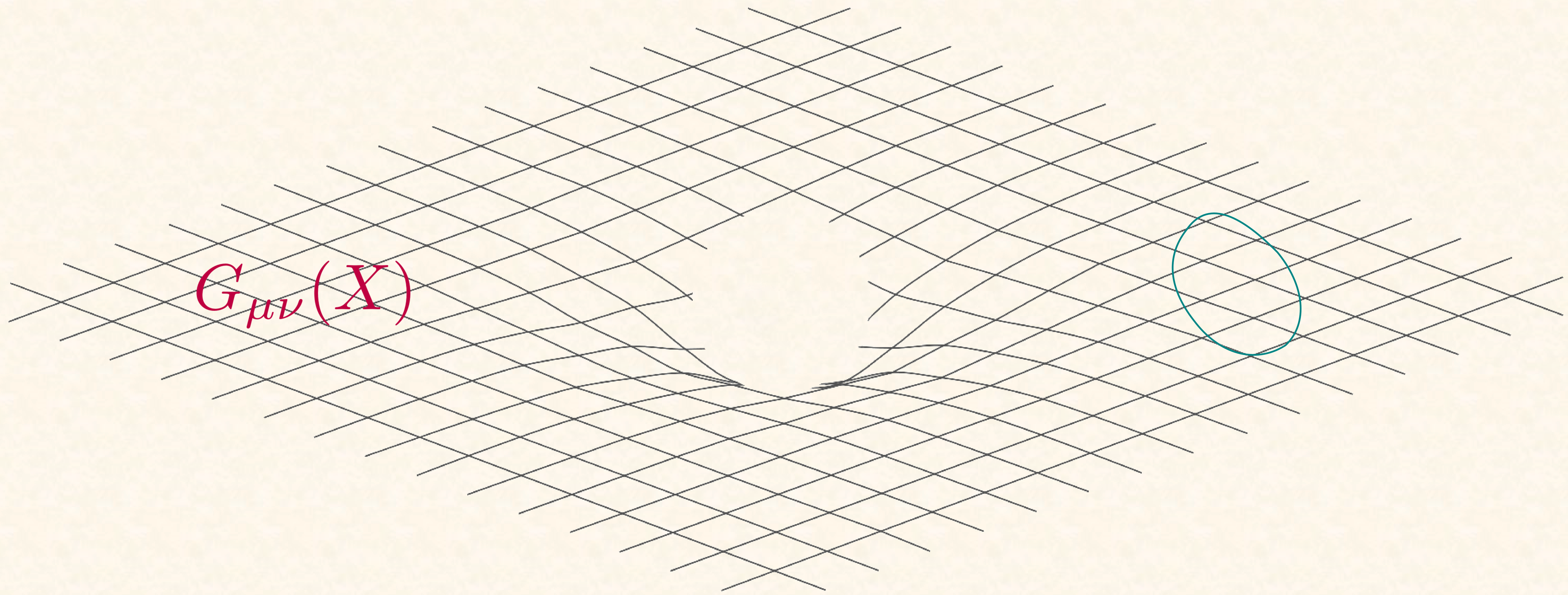
«geometric»

«spacetime metric»
=
«target space metric»

«worldsheet coordinates»
=
«2d CFT fields»



The known story: worldsheet sigma model

- Consider a spacetime of type $\mathcal{M}_d \times \mathcal{N}$.

e.g. Minkowski space

compact dimensions

The known story: worldsheet sigma model

- Consider a spacetime of type $\mathcal{M}_d \times \mathcal{N}$.
- Consistency of the worldsheet theory demands that

> c central charge of CFT on N proportional to number of compact dimensions.
> *(«internal CFT»)*

The known story: worldsheet sigma model

- Consider a spacetime of type $\mathcal{M}_d \times \mathcal{N}$.
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$$\mathcal{S}(t) = \frac{1}{2\pi\alpha'} \int d^2\sigma \, G^{\mathcal{N}}_{ab}(X, t) \, \partial X^a \bar{\partial} X^b$$

«moduli fields»

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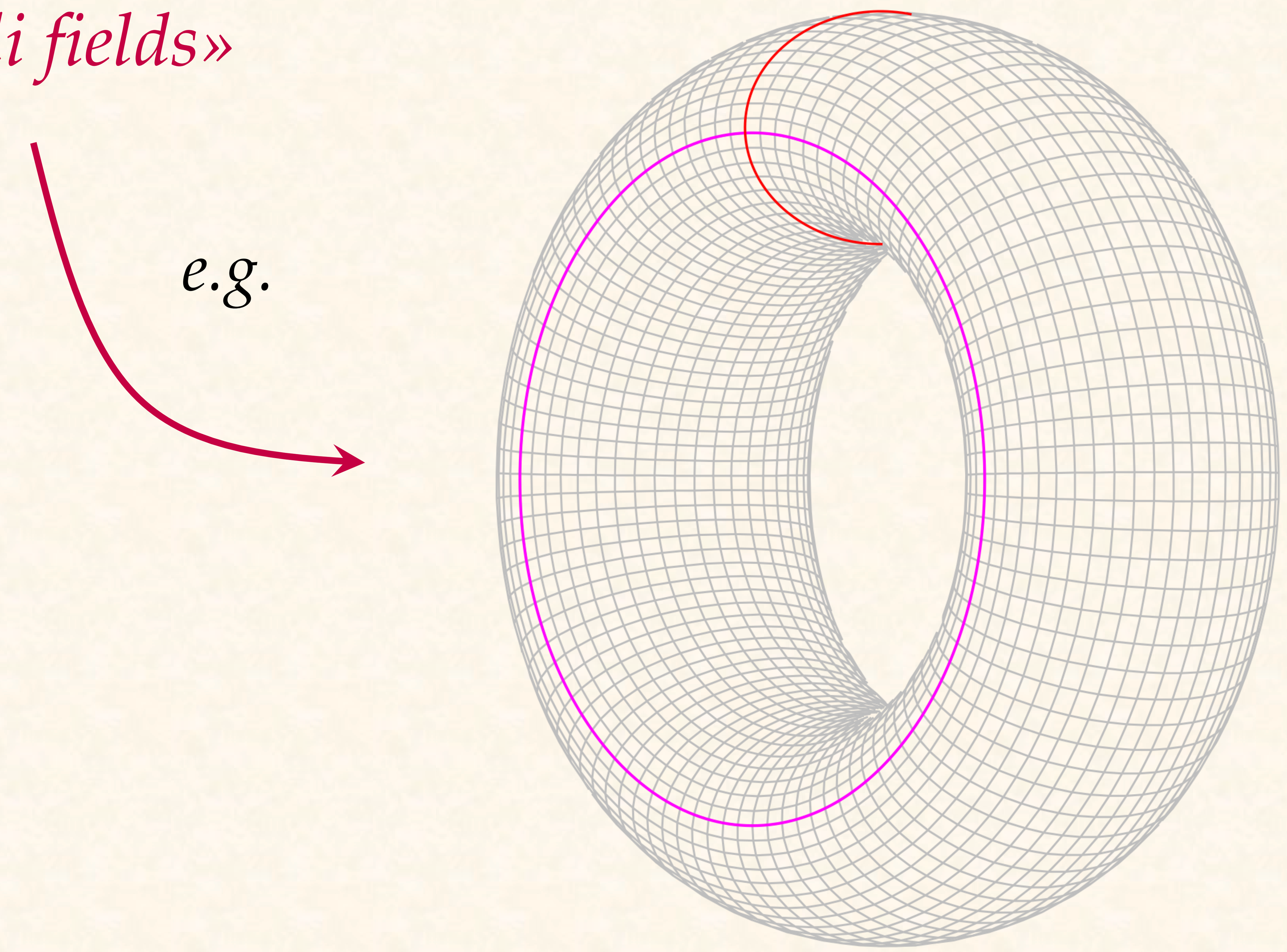

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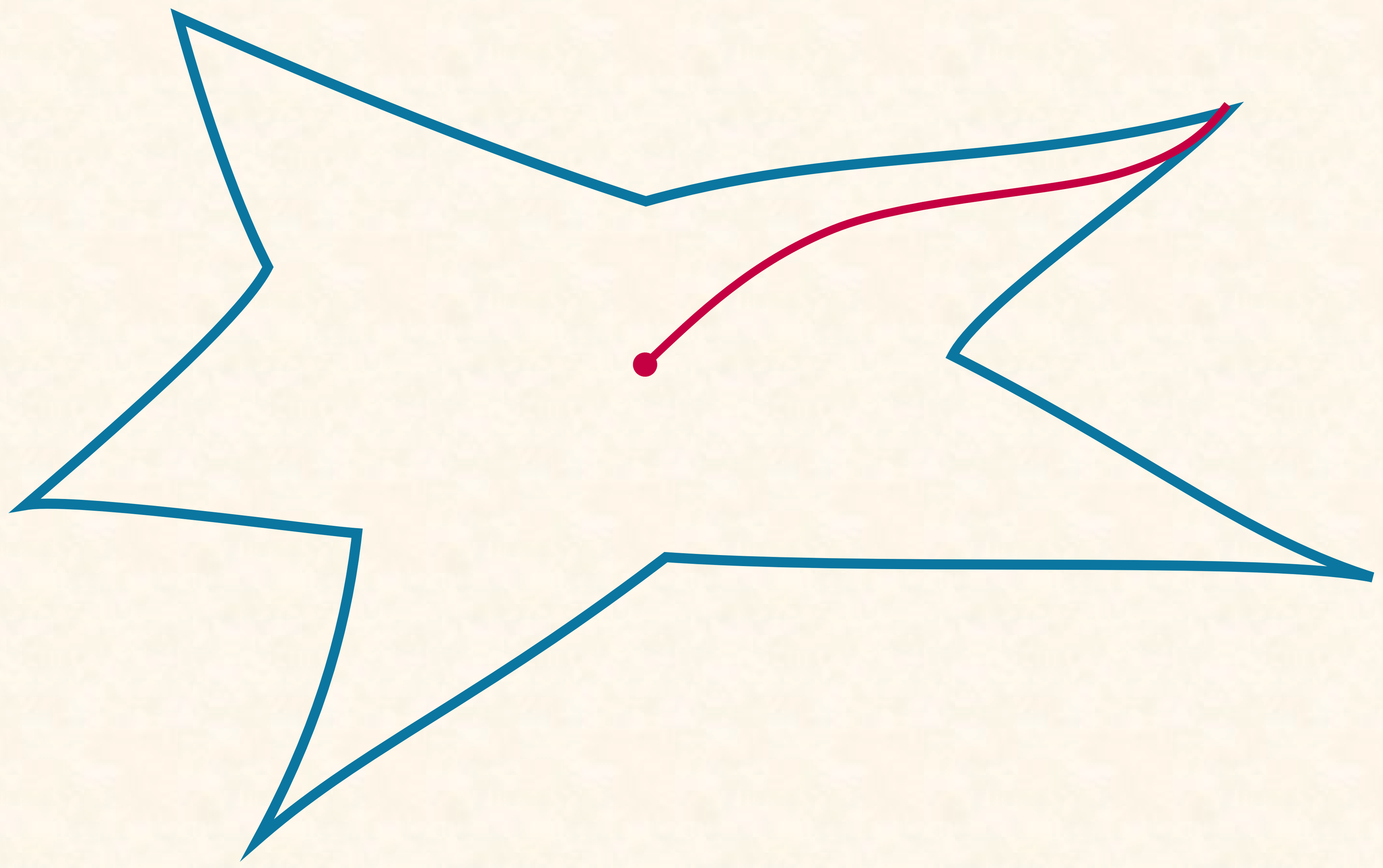
«moduli fields»

- The moduli fields t parametrize marginal deformations of the CFT on $\mathcal{N}$.



«moduli space»
(conformal manifold)

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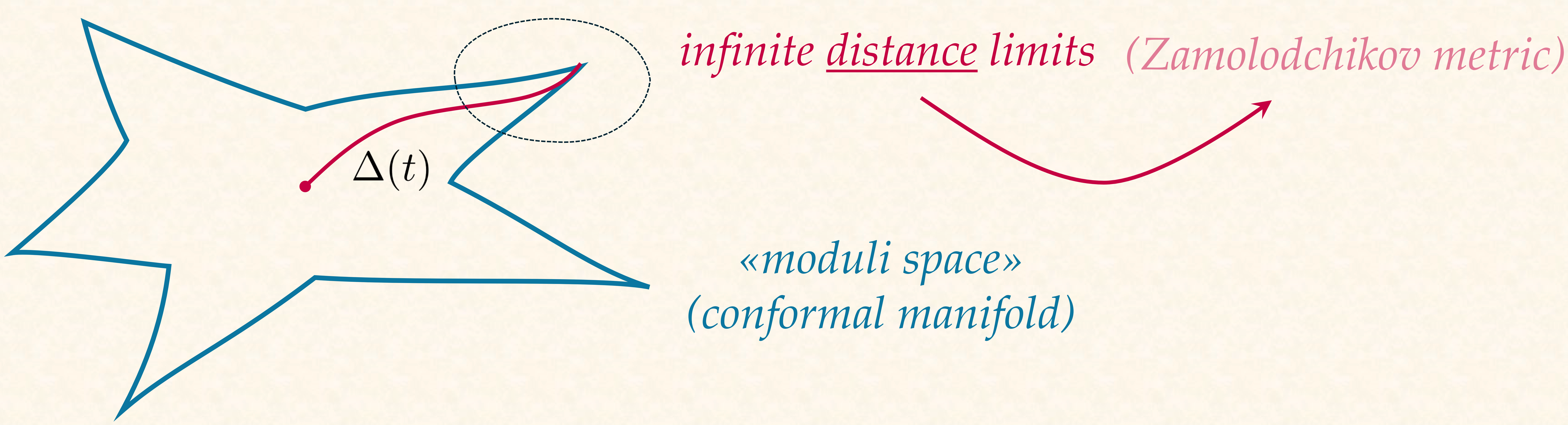

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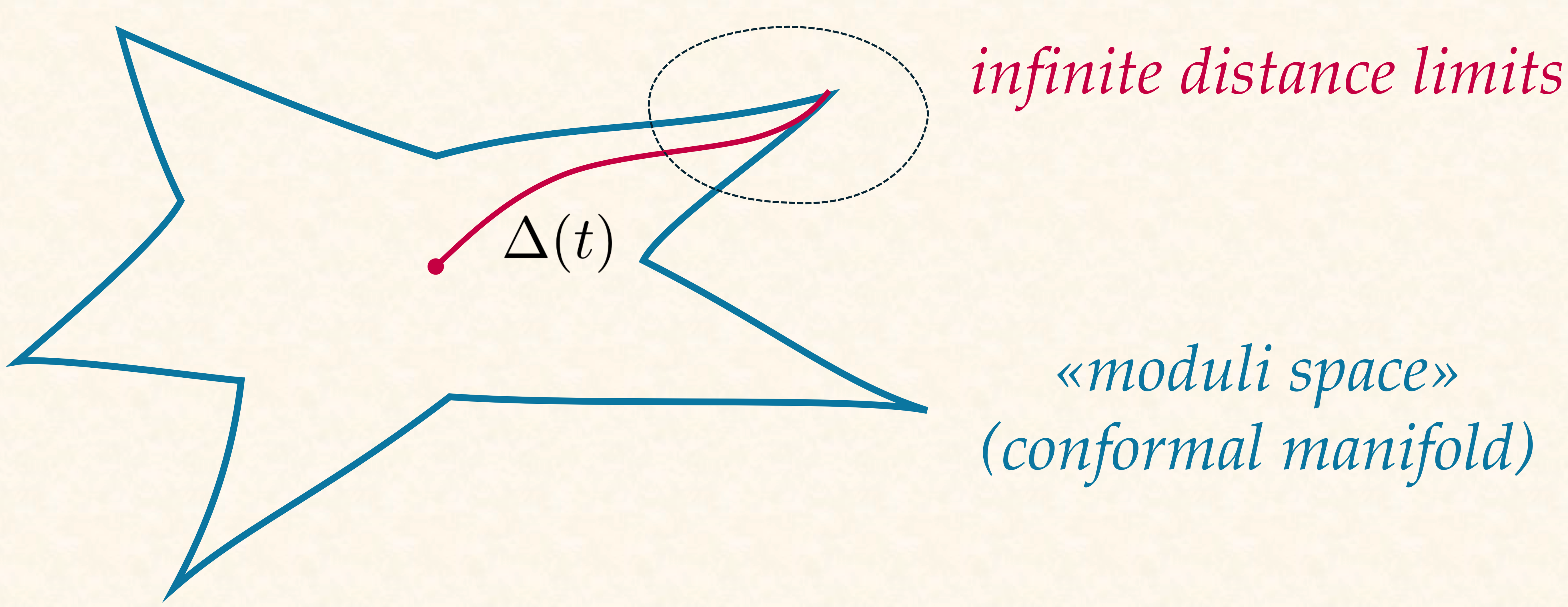
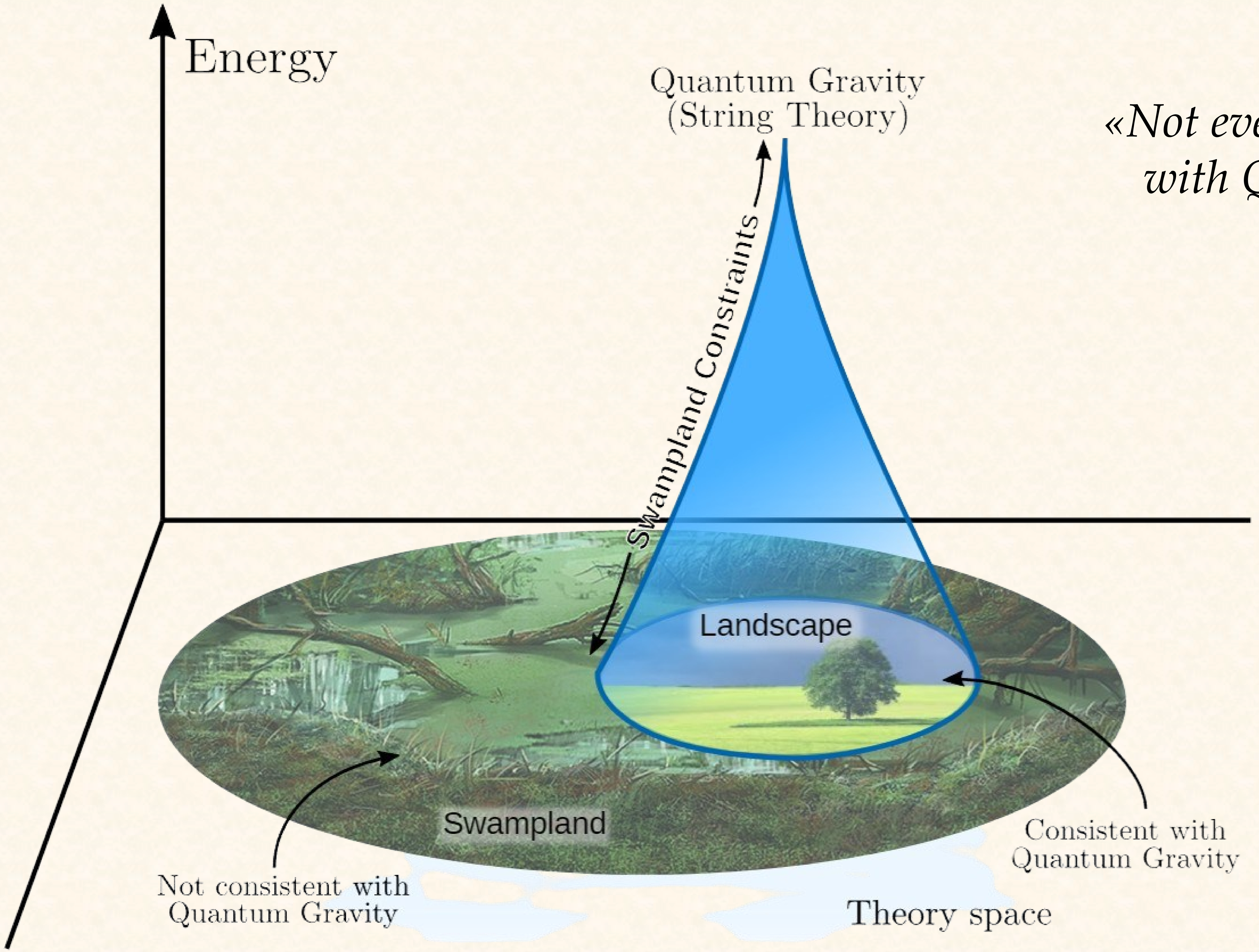


Mandatory Swampland Slide

[Vafa '05]



«Not every EFT is consistent with Quantum Gravity»

[van Beest, Calderon-Infante, Mirfendereski, Valenzuela '21]

Emergent String Conjecture (ESC)

[Lee,Lerche,Weigand '19]

- Swampland Distance Conjecture (SDC) [Ooguri, Vafa '06; Perlmutter, Rastelli, Vafa, Valenzuela '21]

$$\Delta(t) \to \infty \quad \Rightarrow \quad \frac{m}{M_{\mathrm{Pl}}} \sim e^{-\lambda \Delta}$$

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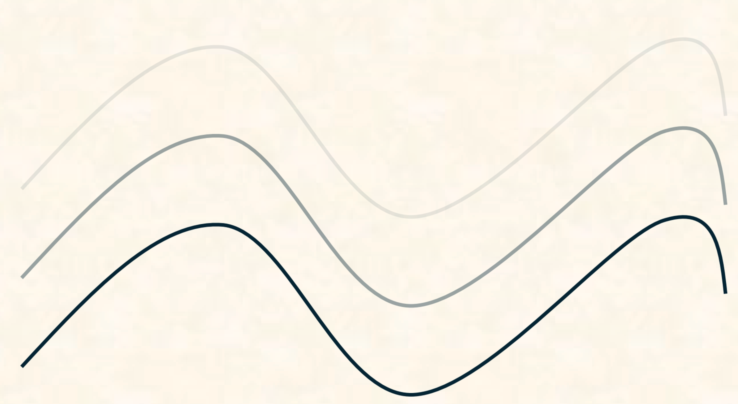
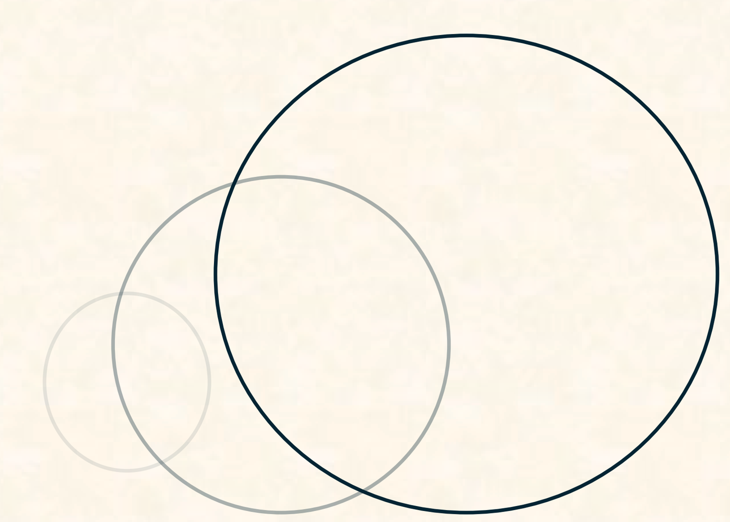
- Emergent String Conjecture: towers can only be of two types



«(critical) String tower»

or



«Kaluza-Klein (KK) tower»

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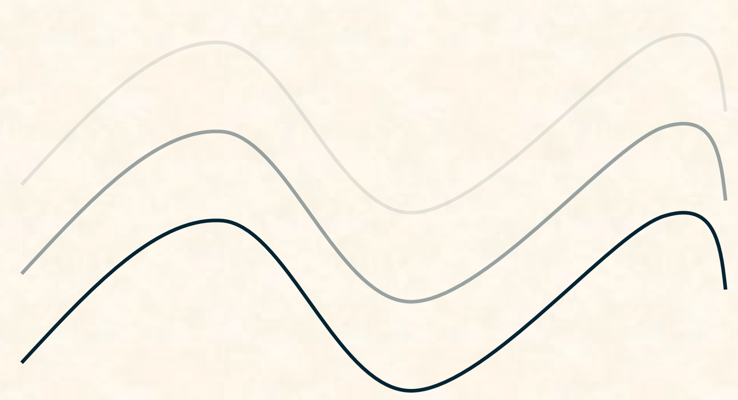

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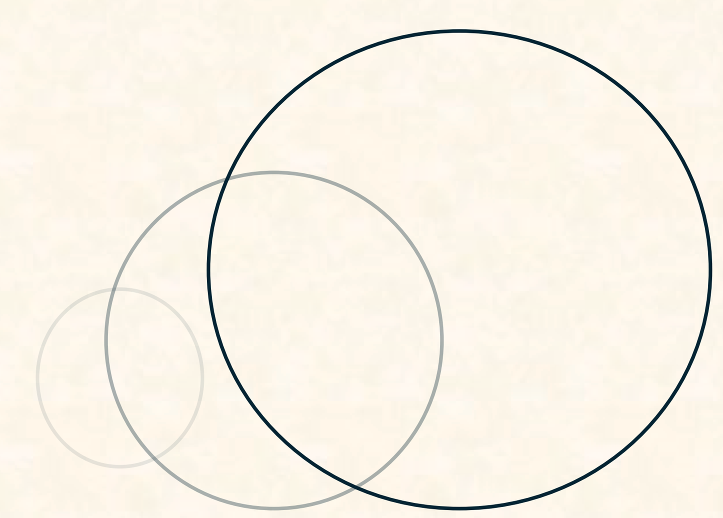

«(critical) String tower»

«Kaluza-Klein (KK) tower»

↓

probed by worldsheet theory on N

$\Rightarrow$ *every infinite distance limit is «geometric»*

(see Veronica and Ignacio's parallels)

However, the worldsheet theory can be more general than a non-linear sigma model…

«non-geometric models»

(e.g. asymmetric orbifolds, i.e. left and right moving excitations of a string move in different spacetimes)

(not clear if they are all perturbatively connected to geometric ones)

[Kawai, Lewellen, Tye ‘86; Narain, Sarmadi, Vafa ‘87; Lerche, Lust, Schellekens ‘87; Antoniadis, Bachas, Kounnas ‘87; Antoniadis, Bachas ‘88; Gepner ‘1988; Green, Hubsch ’88; Kamaza, Suziku ‘89; Vafa, Warner ‘89; Witten ‘93; Kachru, Vafa ’95; Angelantonj, Bainchi, Pradisi, Sagnotti, Stanev ‘96; Blumenhagen, Wisskirchen ’98; Israël and V. Thiéry ‘14; Hull, Israël, Sarti ’17; Gkountoumis, Hull, Stemerdink, Vandoren ‘23; baykara, hamada, Tarazi, Vafa ‘23; Baykara, Tarazi, Vafa ‘24]

Given a generic worldsheet internal CFT,
possibly non-geometric and non-supersymmetric…

Does geometry «emerge» at infinite distance?

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(spoiler: yes!)

Worldsheet CFT and emergent geometry

- Take a generic (internal) CFT [1], and compute its (reduced) torus partition function

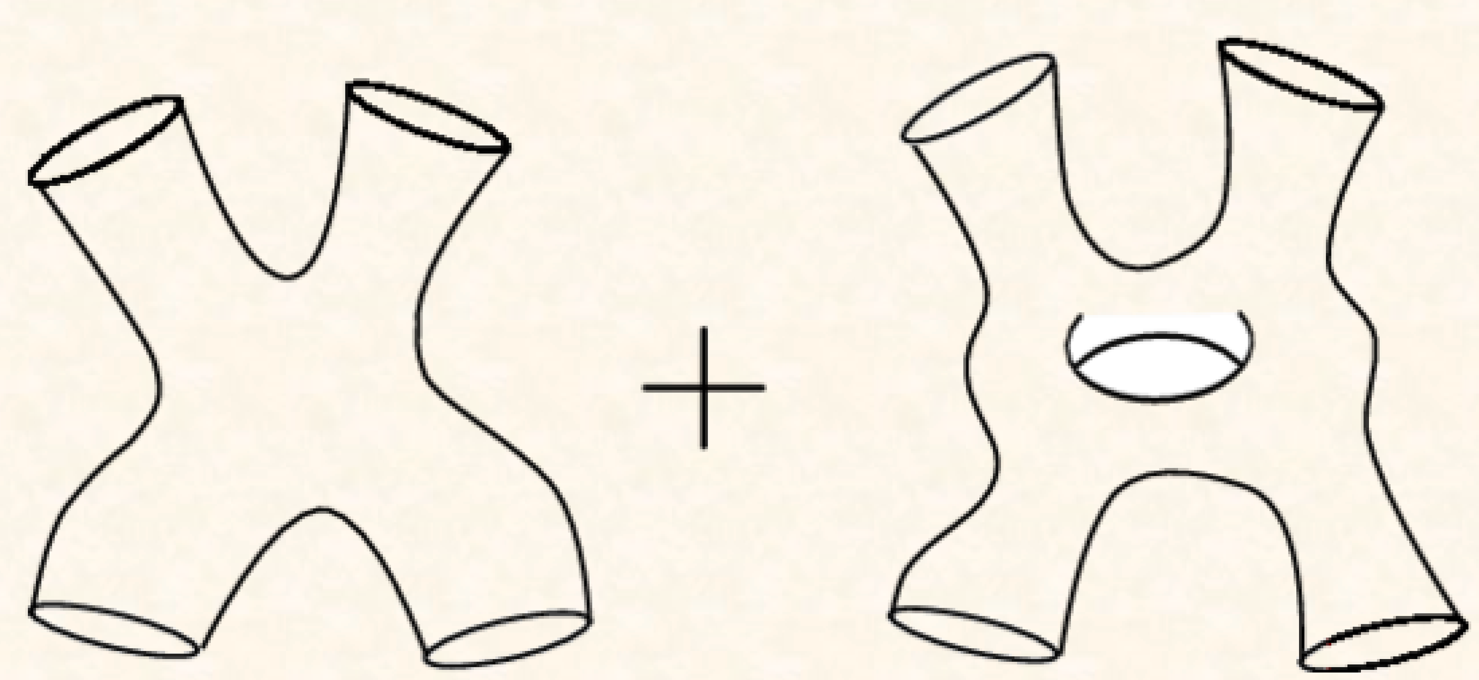
$$Z(t) = \int_{\mathcal{F}} d\mu\, \mathcal{Z}_{T^2}(t)$$

«modulus»

«fundamental domain»

$$\alpha = 2^{-6} \left(\frac{\ell_s}{\ell_{\rm Pl}}\right)^{8-d} \left(2\zeta(3)\left(\frac{\ell_s}{\ell_{\rm Pl}}\right)^{d-2} + 2\pi\, Z(t)\right)$$

1-loop Wilson coefficient of $\mathcal{R}^4$



1) $c_L = c_R = c$

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- The (modular) integrand contains information about the spectrum dependence on t

$$\mathcal{Z}_{T^2}(t) \equiv y^{c/2} \sum_{j,\Delta} e^{2\pi i j x} e^{-2\pi \Delta(t) y}$$

«conformal weights» of CFT states

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Assume SDC: $\Delta_{\text{light}}(t) \sim \frac{\Delta *}{t}$ as $t \to \infty$ + $\Delta_{\text{heavy}}(t) \to \infty$ as $t \to \infty$

(bonus: in the paper, derive presence of a tower from diverging Wilson coefficient)

(bonus: in the paper, relax this assumption to include parametrically constant conformal weights)

exponential decay: [Ooguri, Wang '24]

Then, compare with the geometric case…

$$Z(t) \overset{t\gg 1}{\sim} t^{c/2} \equiv \Delta_{\text{gap}}(t)^{-c/2} \quad \text{vs} \quad Z_{\text{geometric}} \overset{\mathcal{V}\gg 1}{\sim} \mathcal{V} \equiv \Delta_{\text{gap}}^{-c/2}$$

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The Wilson coefficient is:

$$\alpha_{\text{1-loop}} \overset{t\gg 1}{\sim} \left(\frac{M_{\text{Pl}}}{M_s}\right)^{8-(c+d)} \left(\frac{m_{\text{gap}}}{M_{\text{Pl}}}\right)^{-c} = \left(\frac{\Lambda_{\text{sp}}}{M_{\text{Pl}}}\right)^{-6}$$

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[Ooguri, Wang '24]

They are the same!

In this sense, starting from a generic CFT, geometry «emerges» at infinite distance.

Take home message

- It is important to understand what happens in the non-geometric and non-susy string landscape;

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- It is important to understand what happens in the non-geometric and non-susy string landscape;

- Abandoning geometry, and focusing on pure CFT quantities, we were able to show that *asymptotically* in moduli space, a certain Wilson coefficient in the EFT scales as in the geometric case (*and much more in the paper*☺);

Thank you!