Gong Show

- Sangmin Choi
- Gabriele Di Ubaldo
- Bastien Duboeuf
- Felipe Figueroa
- Baptiste Filoche
- Bernardo Fraiman
- Victor Godet
- Anthony Guillen
- Ludwig Horer
- Nat Levine
- Hynek Paul
- Yann Proto
- Yilu Shao
- Yihong Wang
- Vaios Ziogas

23 May, French Strings Meeting 2023, LAPTh, Annecy

Singular Supertranslations and Chern-Simons Theory on the Black Hole Horizon

Sangmin Choi

French Strings Meeting 2023

ERC STARTING GRANT HOLOHAIR 852386

Based on 2205.07923 and 2212.00170

with Ratindranath Akhoury and Malcolm Perry

Asymptotic symmetry group (ASG) of a theory is given by the coset

$$\text{ASG} = \frac{\text{allowed gauge symmetries}}{\text{trivial gauge symmetries}}$$

For QED and other gauge theories, its asymptotic symmetry is the gauge symmetry with parameter non-vanishing at the asymptotic boundary.

For gravity in asymptotically flat spacetimes, it is the BMS symmetry (Bondi, van der Burg, Metzner and Sachs), which includes supertranslations and possibly superrotations.

Among BMS transformations, **supertranslation** is a diffeomorphism that acts non-trivially on the Cauchy data.

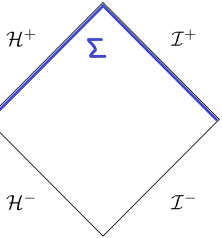
Just as translations are parametrized by a number, **supertranslations** are parametrized by a *function on* S^2. That is, there is an infinite number of supertranslation generators, one for each spherical harmonic $Y^{\ell}_{m}(\theta, \phi)$.

More recently, it has been found that there are symmetry transformations on the boundary Cauchy data that are *not diffeomorphisms*. [Godazgar, Godazgar, Pope 1812.01641]

Such transformations are called **dual supertranslations**.

Systematic method has been developed for deriving dual asymptotic symmetry charges. [Godazgar, Godazgar, Perry 2007.01257, 2007.07144]

In perturbative gravity around Schwarzschild background, there are horizon supertranslations on the future horizon $\mathcal{H}^+$ as well. [Hawking, Perry, Strominger 1601.00921, 1611.09175] [SC, Pradhan, Akhoury 1910.05882]



Generators break into two parts

$$Q^{\Sigma}[f] = Q^{\mathcal{H}^+}[f] + Q^{\mathcal{I}^+}[f]$$

$Q^{\mathcal{H}^+}[f]$ generates supertranslations on the Cauchy data on $\mathcal{H}^+$.

We compute standard and dual supertranslation charges on the Schwarzschild horizon, possibly with singularities in the parameter functions.

Singular supertranslations comprise a first step towards the full BMS algebra.

Without singularities, all generators commute. In the presence of singularities, the standard and dual supertranslation generators exhibit an anomalous algebra,

$$\left\{ Q^{\mathcal{H}^+}[\tfrac{1}{z-w}], \widetilde{Q}^{\mathcal{H}^+}[f] \right\} \sim \partial_z^2 \partial_{\bar{z}} f \Big|_{z=w}.$$

We demonstrate that this central term can be canceled by putting an $\mathrm{SL}(2,\mathbb{C})$ Chern-Simons theory on the horizon.

This hints that consistency of the full BMS algebra may naturally introduce a new structure on the horizon.

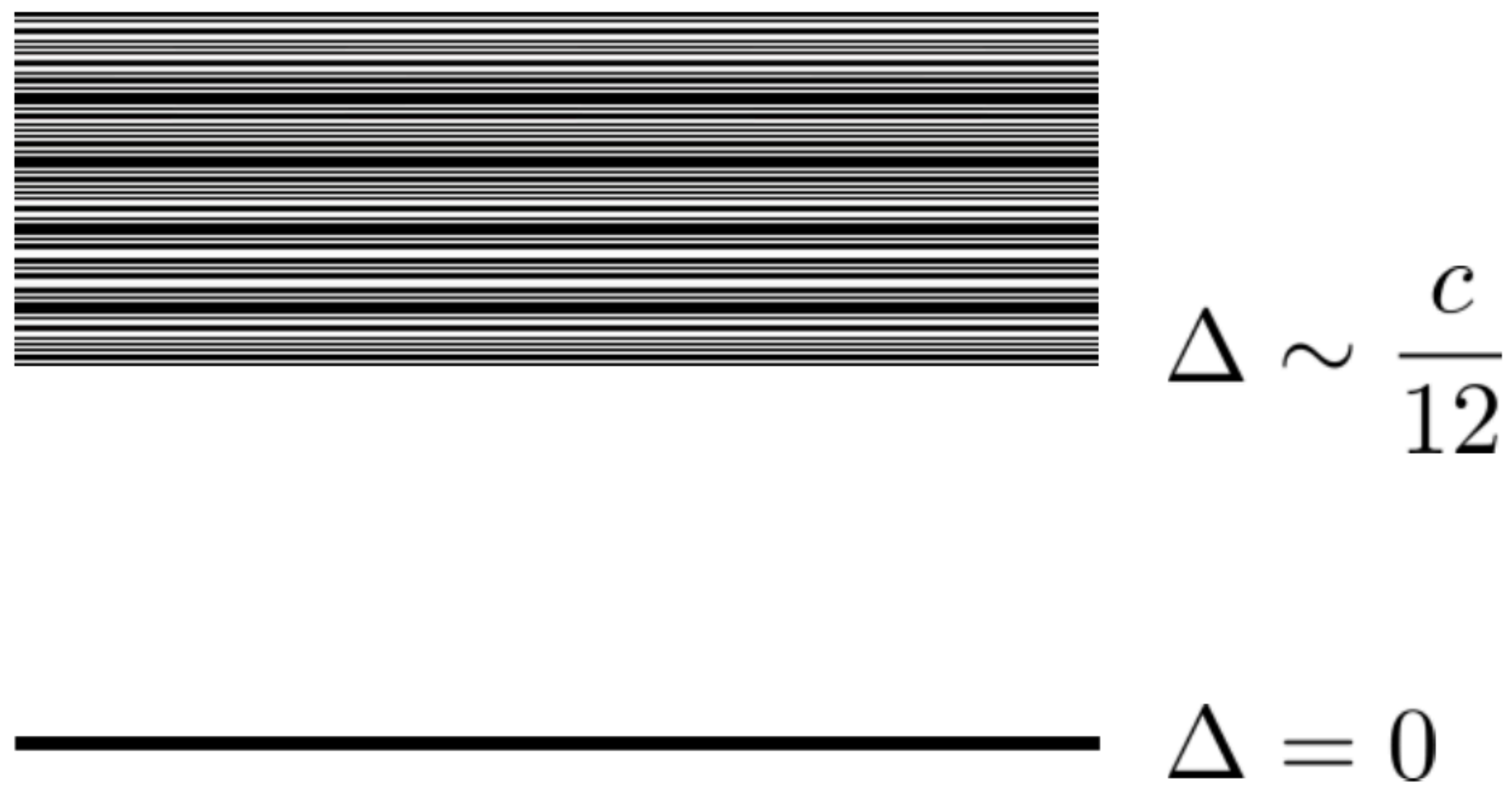
3D Gravity Revitalized

Gabriele Di Ubaldo, IPhT Saclay

Work to appear with Eric Perlmutter.

The spectrum of pure 3D Gravity

Pure $\equiv$ Spectrum with no primaries below the BH threshold.



Natural: build $Z_{\mathrm{grav}}(\tau)$ by summing over all smooth saddles

$\partial AdS_3 = T^2$

$$Z_{\mathrm{smooth}}(\tau) = \sum_{\substack{\text{Smooth}\\ \text{Classical}\\ \text{Saddles}}} Z_{\mathrm{saddle}}(\tau) = \sum_{\gamma \in SL(2,\mathbb{Z})} |\chi_{vac}(\gamma\tau)|^2$$

[Maloney, Witten, Keller]

The resulting spectrum is inconsistent: $\rho_j(\Delta) < 0$.

- **Does a consistent, pure $Z_{\mathrm{grav}}(\tau)$ exist?**

- *Unitary* $\rho_j(\Delta) > 0$
- *Modular invariant* $SL(2,\mathbb{Z})$
- *Pure* $\Delta_{\mathrm{gap}} \sim \frac{c}{12}$
- *Geometric*

Pure 3D gravity (with strings attached)

It does exist!

$$Z_{\rm grav}^{\rm pure}(\tau) = Z_{\rm smooth}(\tau) + \underbrace{\sum_{\gamma\in SL(2,\mathbb{Z})} |\chi_{\Delta,J}(\gamma\tau)|^2}_{Z_{\rm string}}$$

$$\Delta = \frac{c-1}{12} \qquad J = \frac{c-1}{48}$$

New states:

- Strongly coupled, highly spinning strings $g_s \sim O(1)$. [Maxfield, Wang]
- *Enigmatic* stringy BH: Sub-leading to BTZ entropy except near extremality.

A mechanism for non-factorization

Consider coarse-graining over $\delta E \sim \dfrac{1}{c}$

$$\langle Z_{\rm string}\rangle = 0$$

→

$$\langle Z(\tau)\rangle = Z_{\rm smooth}(\tau)$$

$$\mathrm{Var}(Z) = \langle Z_{\rm string}^2\rangle \neq 0$$

Kaluza-Klein spectrometry on the squashed S^7

Gong Show, French Strings Meeting 2023

Bastien Duboeuf, Emanuel Malek, Henning Samtleben

Laboratoire de Physique à l'ENS de Lyon

May 2023

Based on 2212.01135

Compactification of 11d Supergravity on S^7

Round S^7	Squashed S^7
$\mathcal{N} = 8$	$\mathcal{N} = 1$
$\frac{SO(8)}{SO(7)}$	$\frac{Usp(4) \times SU(2)_L}{Usp(2) \times SU(2)_D}$

The mass spectrum on the round seven-sphere

Spin	SO(8) rep	(Mass)^2	Lowest energy
2	$(n, 0, 0, 0)$	$(n+3)^2 - 9$	$(n+6)/2$
$\frac{3}{2}^{(1)}$	$(n, 0, 0, 1)$	n^2	$(n+5)/2$
$\frac{3}{2}^{(2)}$	$(n-1, 0, 1, 0)$	$(n+6)^2$	$(n+7)/2$
$1^{-(1)}$	$(n, 1, 0, 0)$	$(n+1)^2 - 1$	$(n+4)/2$
$1^{+(2)}$	$(n-1, 0, 1, 1)$	$(n+3)^2 - 1$	$(n+6)/2$
$1^{-(2)}$	$(n-2, 1, 0, 0)$	$(n+5)^2 - 1$	$(n+8)/2$
$\frac{1}{2}^{(1)}$	$(n+1, 0, 1, 0)$	n^2	$(n+3)/2$
$\frac{1}{2}^{(2)}$	$(n-1, 1, 1, 0)$	$(n+2)^2$	$(n+5)/2$
$\frac{1}{2}^{(3)}$	$(n-2, 1, 0, 1)$	$(n+4)^2$	$(n+7)/2$
$\frac{1}{2}^{(4)}$	$(n-2, 0, 0, 1)$	$(n+6)^2$	$(n+9)/2$
$0^{+(1)}$	$(n+2, 0, 0, 0)$	$(n-1)^2 - 1$	$(n+2)/2$
$0^{-(1)}$	$(n, 0, 2, 0)$	$(n+1)^2 - 1$	$(n+4)/2$
$0^{+(2)}$	$(n-2, 2, 0, 0)$	$(n+3)^2 - 1$	$(n+6)/2$
$0^{-(2)}$	$(n-2, 0, 0, 2)$	$(n+5)^2 - 1$	$(n+8)/2$
$0^{+(3)}$	$(n-2, 0, 0, 0)$	$(n+7)^2 - 1$	$(n+10)/2$

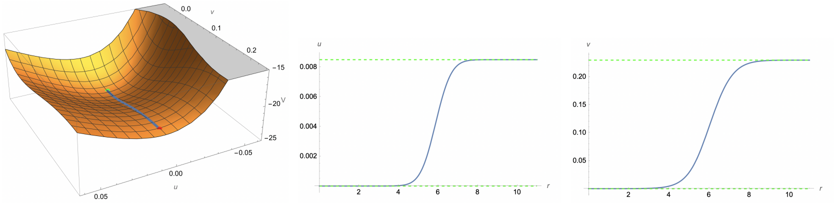
- Entire Kaluza-Klein spectrum on the round S^7 known since the 80's and organized according to $SO(8)$ representations.
- Open question since for the spectrum on the squashed S^7 (less constraints due to $\mathcal{N} = 1$).

- Use and generalize Exceptional Field Theory techniques to compute the complete Kaluza-Klein spectrum on the squashed S^7 (only Generalized parallelisable).

$$\bigoplus L[J, \Delta] \otimes [p, q, r] \tag{1}$$

$$\Delta_{J,s} = 1 + \frac{5}{3}s + \frac{1}{3}\sqrt{(3J + 2s^2)^2 + 5\mathcal{C}_3} \tag{2}$$

- Exists a two scalar consistent truncations interpolating between the round and the squashed S^7.
- Domain wall solution between the two AdS points on the Supergravity side, dual to an holographic renormalization flow on the CFT side.



- Round S^7 corresponds to an ABJM theory and squashed to a Superconformal $\mathcal{N} = 1$ Chern-Simons theory.
- Allows us to compute spectrum and couplings along the flow $\rightarrow$ gives access to two-point functions along the RG flow.

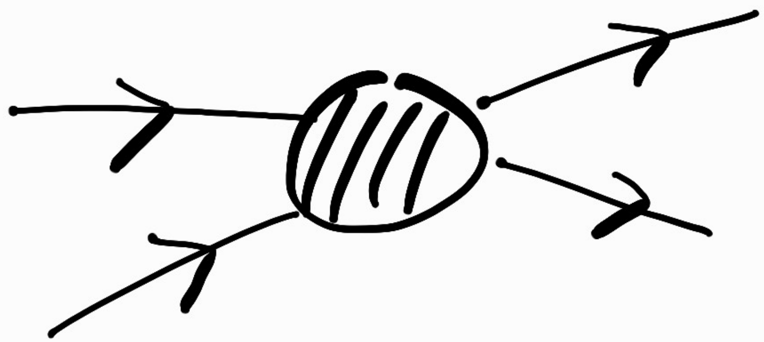
Perspectives and related work

- Extend the technique to a broader range of vacua and consistent truncations, with a more general framework.
- Compute cubic and higher order couplings in the Exceptional Field Theory framework. Seek for universal patterns in holographic three-point functions.

Thank you !

The Coon Amplitude

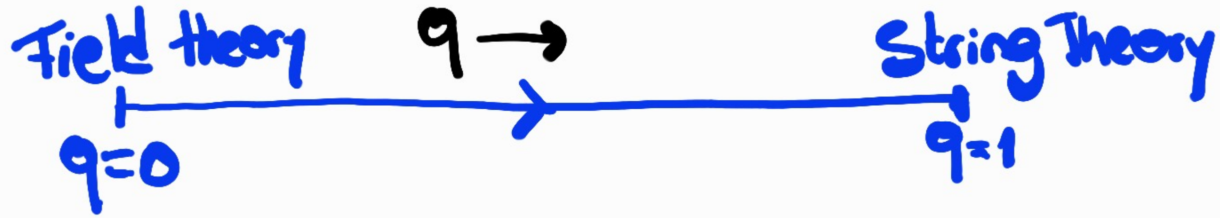
(or towards new tree-level S-matrices)



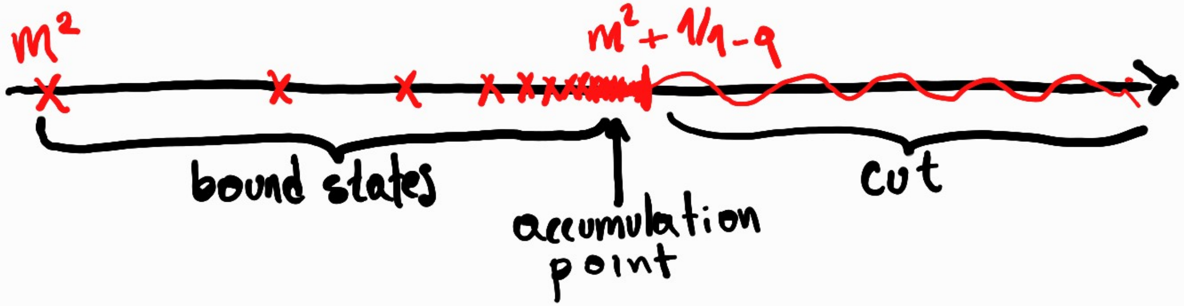
Felipe Figueroa - LAPTh, CNRS

The Coon Amplitude: A brief portrait

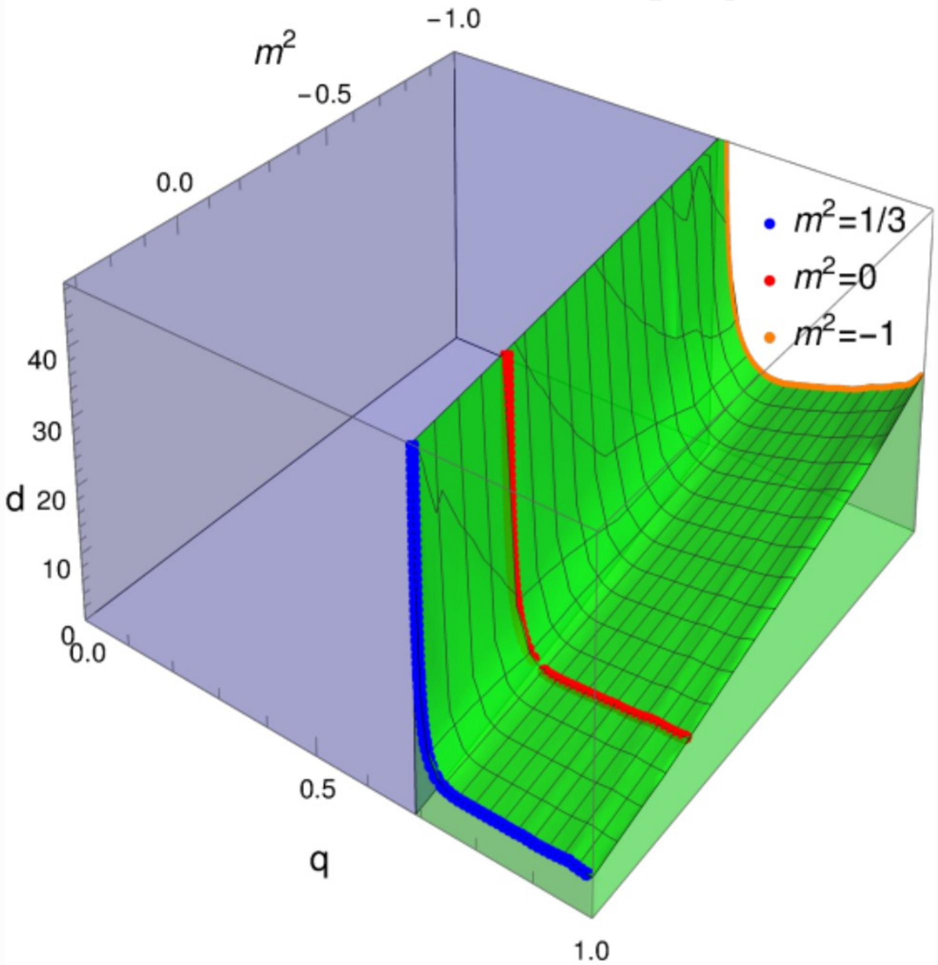
- Weakly coupled, infinitely many exchanged resonnances
- Coon: Deformation of Veneziano:



- For $0<q<1$: Accumulation point in the spectrum:



- Discovered in the 60s, but little known about it til recently
- In FF, Tourkine / PRL: Unitarity properties



- Since then, lots of activity

Coon ~ Strings in AdS ?

Inspired by Coon: Method to generate new amplitudes

- Coon's idea: Ansatz + Locality $\rightsquigarrow$ Coon & Veneziano

We generalized this approach: Coon, Veneziano (+ P-spectrum?)

→ Coon unique as solution to this procedure

Upshot: Seems like extending Coon's method is not the way to go. BUT...

Stay tuned

Little String Instanton Partition Functions and Scalar Propagators

Baptiste Filoche

Institut de Physique des 2 Infinis de Lyon

based on arXiv:2212.09602 in collaboration with Stefan Hohenegger

May 23, 2023

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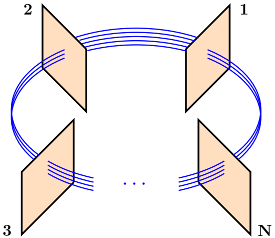
Type A Little String Theories on the Ω-background

We focus on Little String Theories (LSTs) that correspond to low energy $U(N)$ gauge theories on $\mathbb{C}^2 \times T^2$ with matter in the adjoint representation:



- τ: complex gauge coupling
- S: mass deformation parameter
- $\widehat{b}_i$: gauge parameters
- ρ: affine extension parameter

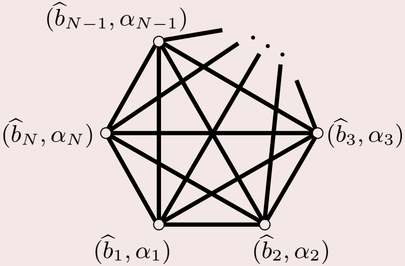
Diagrammatic decomposition of the instanton partition function

The instanton partition function can be organised as a sum over external integer partitions

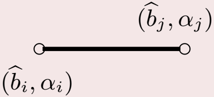
$$\mathcal{Z}_{N,1}(\widehat{\mathbf{b}}, S, \rho, \tau) = \sum_{\alpha_1,\dots,\alpha_N} Q_\tau^{\sum |\alpha_i|} \mathcal{P}_{\alpha_1,\dots,\alpha_N}$$

Fixed external partition contribution has a natural diagrammatic decomposition in term of scalar propagators [BF, Hohenegger '22]

$\mathcal{P}_{\alpha_1,\dots,\alpha_N} \propto$



with



$$= \text{"} \prod_{\square \in \alpha_i} \Omega\,\Omega \prod_{\square \in \alpha_j} \Omega\,\Omega \text{"}$$

scalar propagators

Systematic extension of the diagrammatic expansion found for $\log \mathcal{Z}_{N,1}$ [Hohenegger '19,'20]

Recursive structure in the Nekrasov-Shatashvili limit

The instanton partition can be organised as a sum over instanton levels:

$$\mathcal{Z}_{N,1} = \sum_{r=0}^{\infty} \left(\epsilon_2^{-r} K_0^{r,N} + \epsilon_2^{-r+2} K_1^{r,N} + \dots \right)$$

Diagrammatic expansion has been used to derive recursion relations on the maximal order pole of the Laurent expansion in ϵ_2 [BF, Hohenegger '22]

$$\boxed{K_0^{N,(r)} = \frac{1}{r!} \left(K_0^{N,(1)} \right)^r, \quad \forall r, N \geq 1}$$

Outlook

- Extension to others LSTs (type A with M $U(N)$ nodes cyclic quiver and type D,E)
- Establish a connection to elliptic W-algebra of quiver gauge theories [Kimura, Pestun '18] and more generally to q-deformed Toda theories through AGT-like correspondences [Aganagic, Haouzi, Kozcaz, Shakirov '13] and understand if the diagrammatic decomposition has a natural counterpart on the CFT side
- Use the diagrammatic expansion to explore the rewriting of the instanton partition function in lower dimensions

Thank you for your attention!

Cosmological Constant Extrema in the O(16)xO(16) Heterotic String

Bernardo Fraiman (CERN)

Based on upcoming work

[with H. **P. de Freitas** (Saclay), M. **Graña** (Saclay)

and S. **Sethi** (Chicago U.)]

French Strings Meeting, LAPTh, Annecy|Gong-Show talk

Non-SUSY heterotic theories:

10D

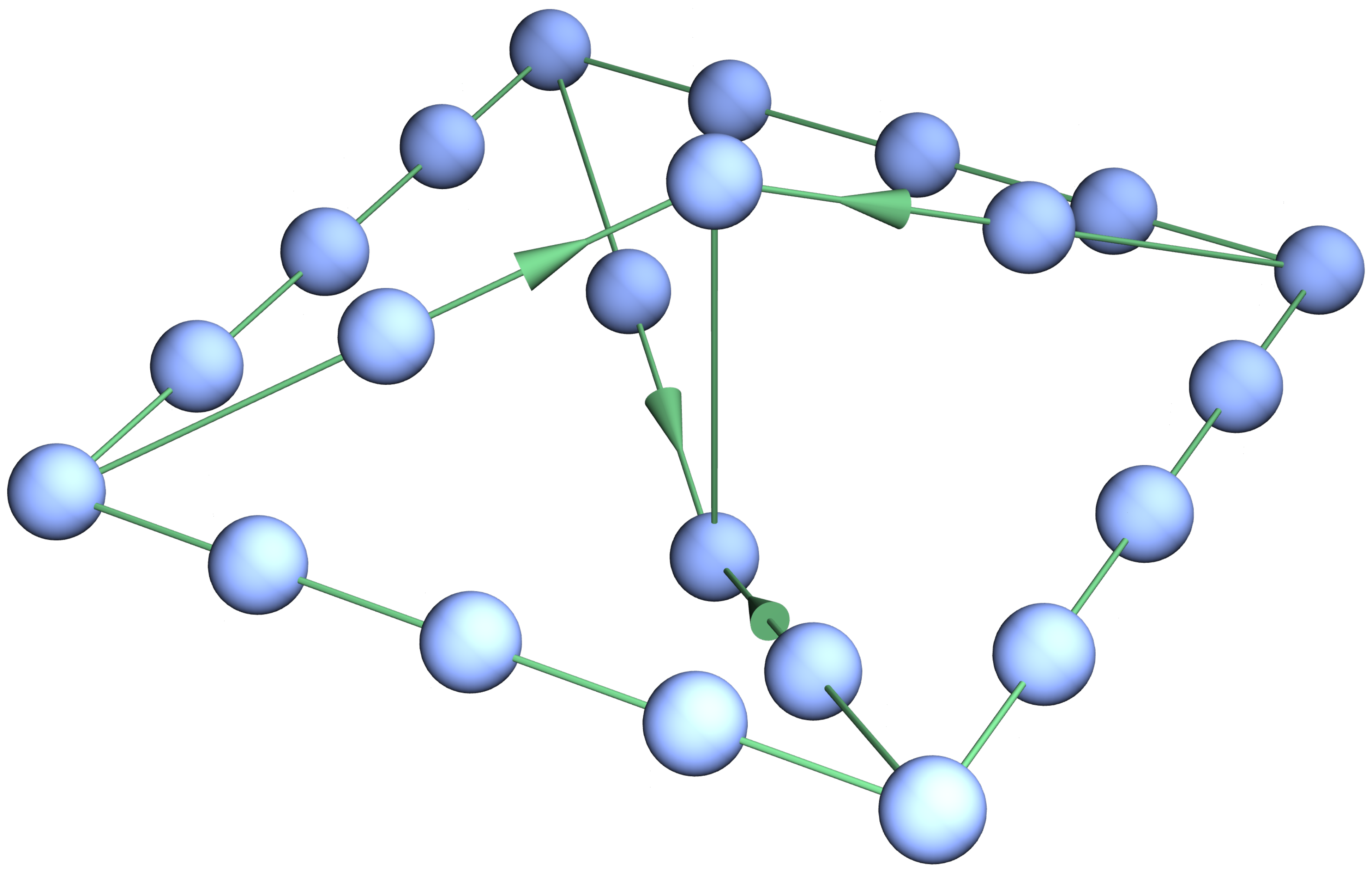
Tachyonic: $SO(32)$ $E_8 \times SO(16)$ $U(16)$

(ignoring the E_8 theory) $(E_7 \times SU(2))^2$ $SO(24) \times SO(8)$

Non-tachyonic: $SO(16) \times SO(16)$

S^1 → **Equivalent in 9D**

9D **Fundamental region** of moduli space (radius and Wilson line)



107 maximal enhancements

$N_B \neq N_F$ **—> non-zero cosmological constant Λ**

8 free of tachyons → **They extremize Λ at finite values!**

Extrema of the cosmological constant:

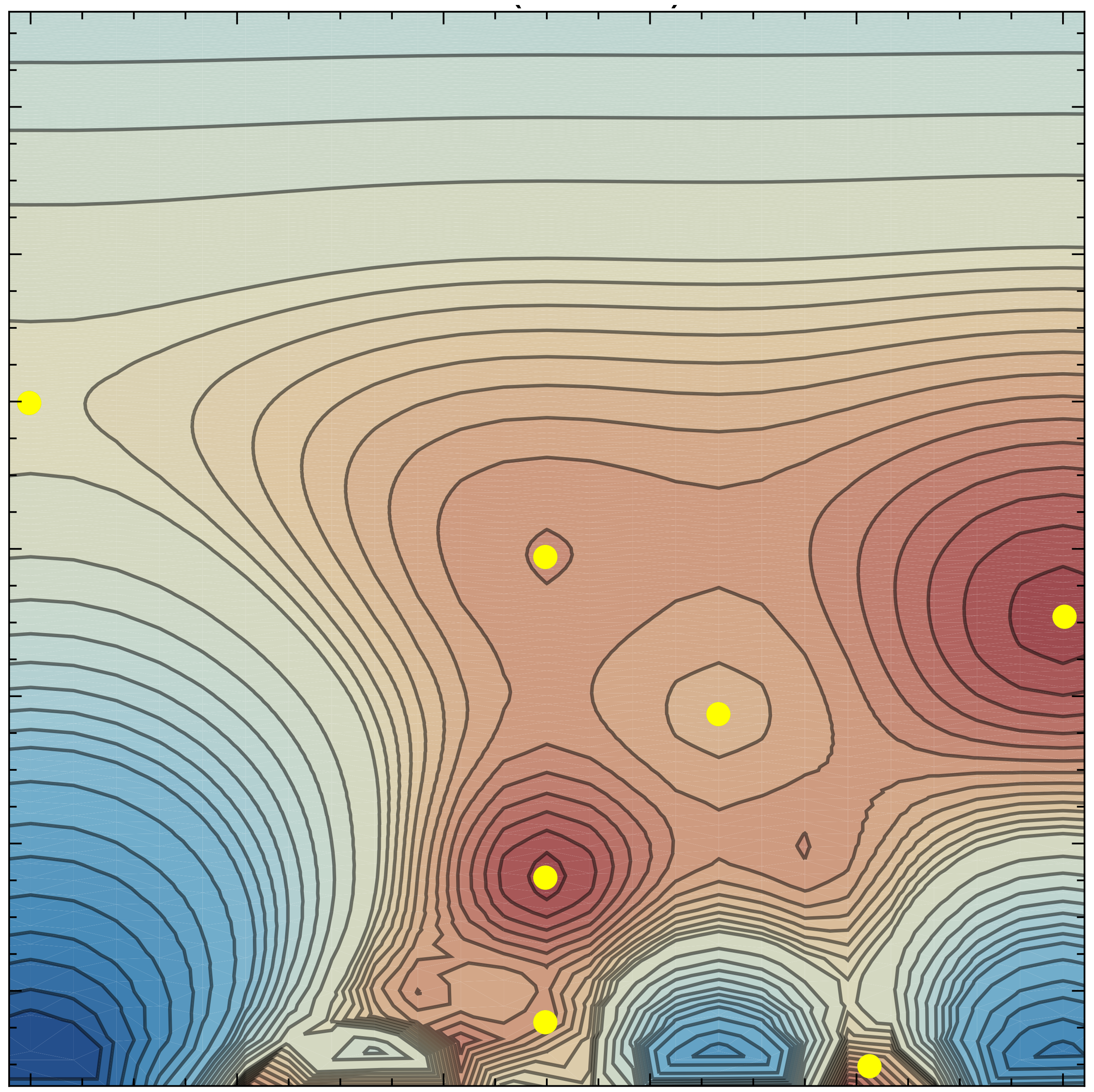
Positive CC:

Saddle points

$SO(16)^2 \times SU(2)$

$SO(16) \times SO(10) \times SU(5)$

$SO(16) \times SO(12) \times SU(3) \times SU(2)$



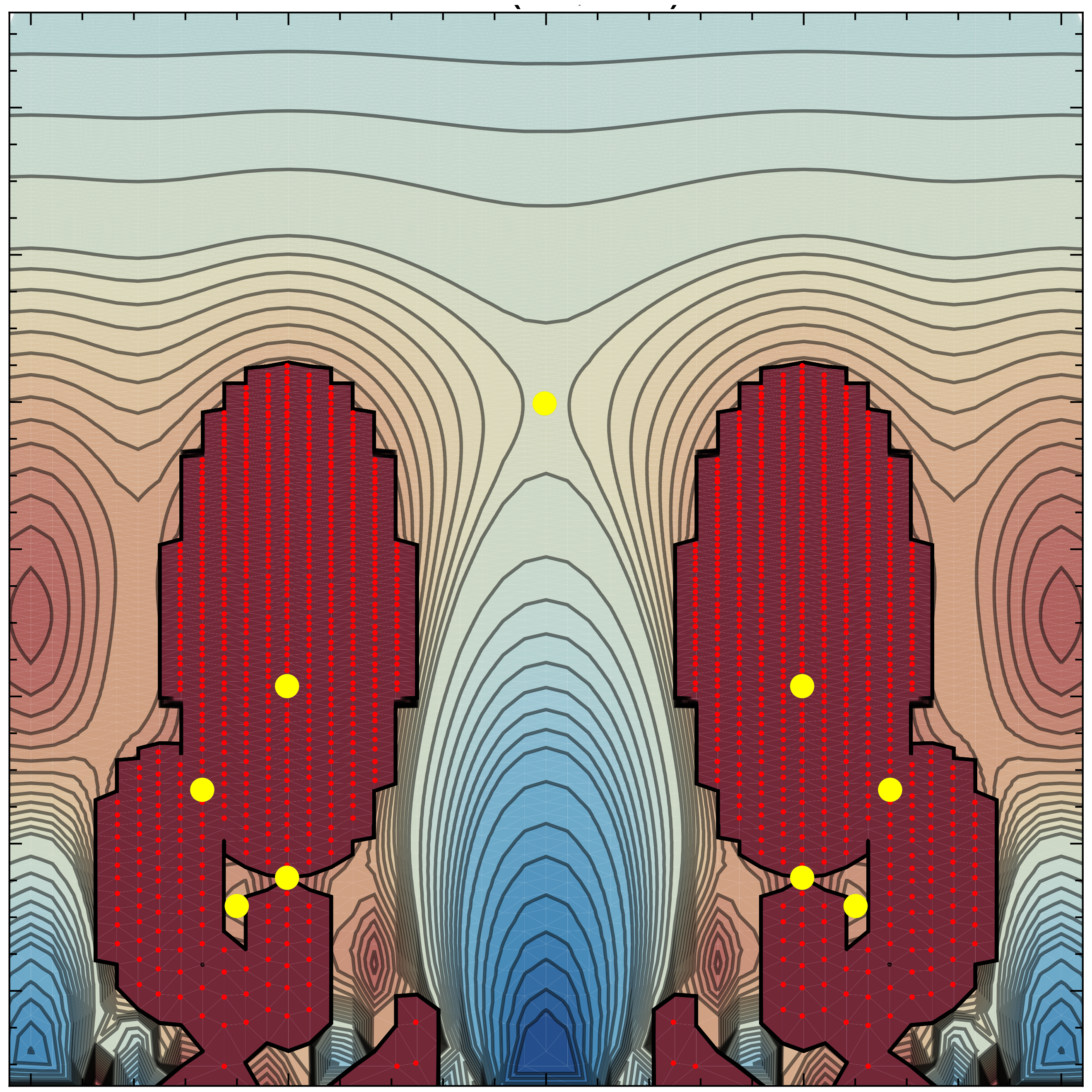
$SO(10)^2 \times SU(8)$ <— (local **maximum**)

At the edge of tachyonic regions

$SO(16) \times SO(18)$

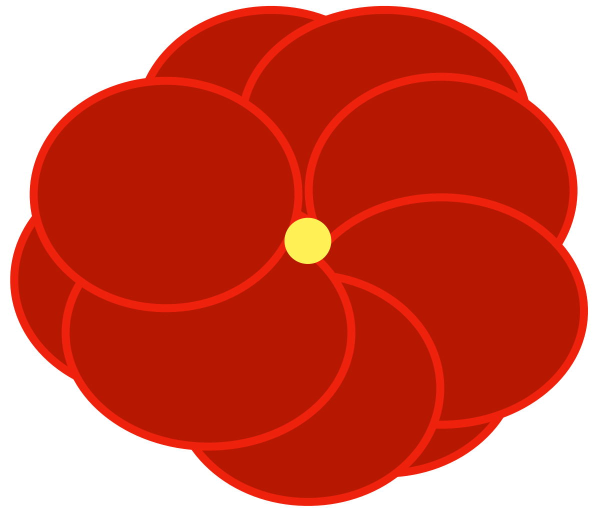
$SO(16) \times SO(10) \times SO(8)$

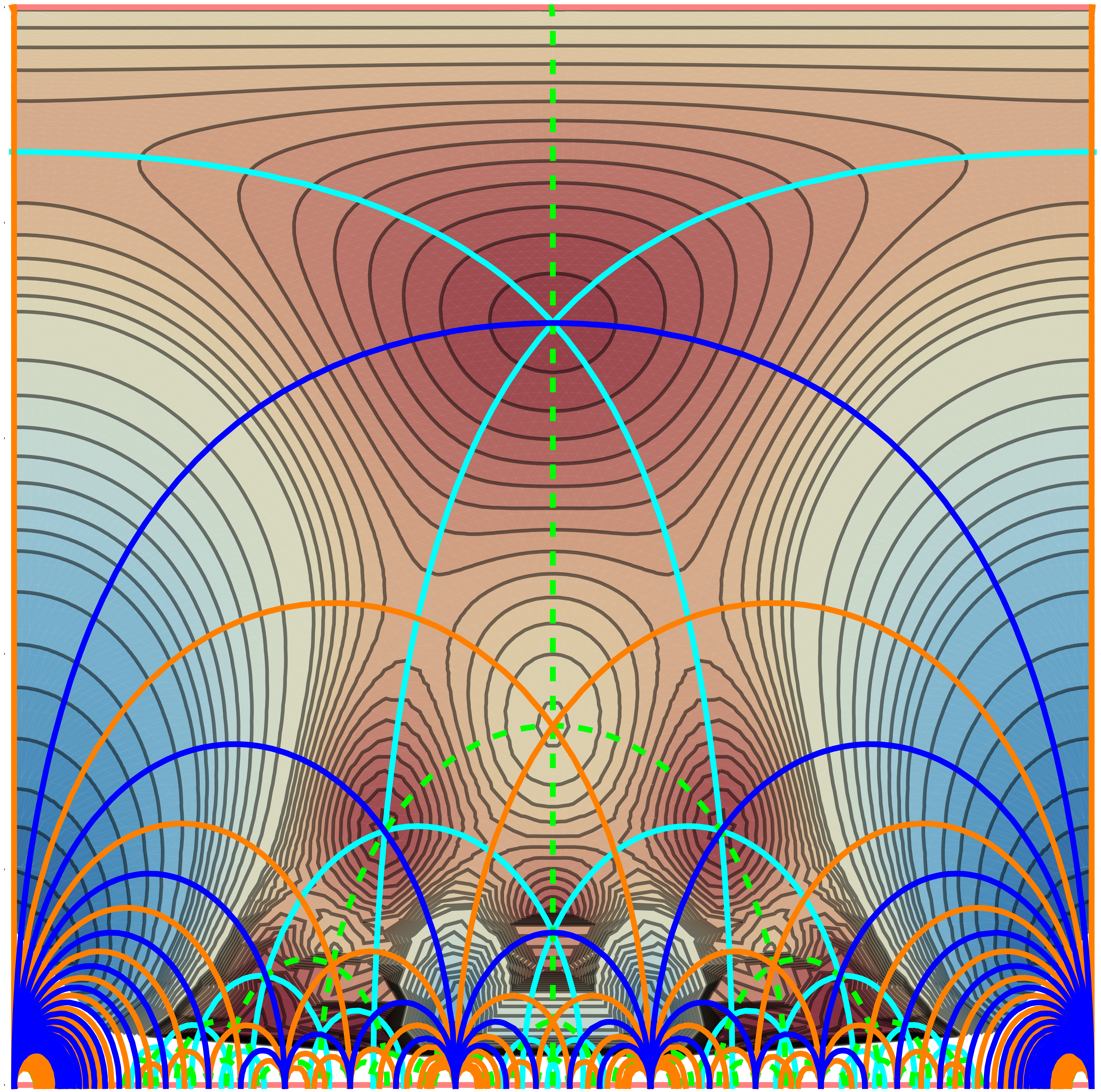
$(SO(12) \times SU(2))^2 \times SU(4)$



Negative CC:

$E_6 \times SU(12)$ (surrounded by tachyons)





- Some enhancement curves give **interpolations** between all **10D** theories at **infinite distance limits**
- Compactifying to less space-time dimensions (**torus**, **orbifolds**): many more **cosmological constant extrema** (some with $N_B = N_F$)
- These compactifications can be used to construct **AdS_3 vacua!**

Thank you very much!

The Hilbert space of de Sitter quantum gravity

French Strings Meeting, Annecy

Victor Godet

ICTS, Bangalore

May 23, 2023

2303.16315 and 2303.16316 with T. Chakraborty, J. Chakravarty, P. Paul and S. Raju

The Wheeler-DeWitt equation

In canonical quantum gravity, states are wavefunctionals of the metric and matter configurations on a Cauchy slice,

$$\Psi[g,\chi] \ ,$$

and the classical constraints must be imposed as operator equations

$$\mathcal{H}_i \, \Psi = 0 \ , \qquad \mathcal{H} \, \Psi = 0 \ .$$

[Dirac, Wheeler-DeWitt]

The momentum constraint $\mathcal{H}_i$ enforces spatial diffeomorphism invariance.

The Hamiltonian constraint is known as the Wheeler-DeWitt (WDW) equation

$$\mathcal{H} = \frac{16\pi G_N}{g}\left(g_{ik}g_{jl}\pi^{kl}\pi^{ij} - \frac{1}{d-1}(g_{ij}\pi^{ij})^2\right) - \frac{1}{16\pi G_N}(R-2\Lambda) + \mathcal{H}_{\mathrm{matter}}$$

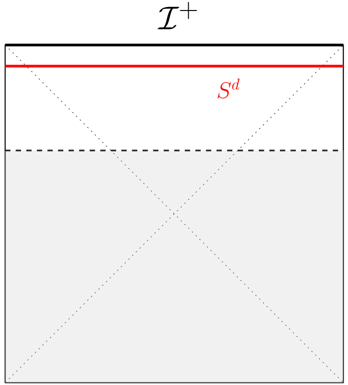
where $\pi^{ij} = -i\delta/\delta g_{ij}$. It is a second order functional equation whose solutions are the physical states of quantum gravity.

Large volume expansion

We obtain the solutions of the WDW equation in the late time expansion of an asymptotically dS$_{d+1}$ spacetime. In terms of Ω, γ_{ij} such that

$$g_{ij} = \Omega^2 \gamma_{ij}, \qquad \det(\gamma_{ij}) = 1 \ ,$$

this is an expansion around $\Omega \to +\infty$. The Weyl factor appears here as a canonical incarnation of time. [York]



The Hilbert space as theory space

The WDW equation can be expanded and solved order by order around $\Omega \to +\infty$. The solutions take the form

$$\Psi[g,\chi] = e^{iS[g,\chi]} Z[g,\chi] + O(\Omega^{-1}) \ ,$$

where S is a universal phase and Z is an arbitrary functional constrained to transform under diff-and-Weyl as a CFT$_d$ partition function:

$$Z[g,\chi] \sim Z_{\mathrm{CFT}}[g,\chi] \ .$$

These solutions are valid only in the late time expansion but to all order in G_N. The resulting Hilbert space is "theory space".

The Hartle-Hawking state, defined by a Euclidean path integral, is an example of such a state (dS/CFT). Our result is that every state is of this form.

Inner product and gauge-fixing

The inner product can be defined as

$$(\Psi, A\Psi) = \int \frac{DgD\chi}{\mathrm{vol}(\mathrm{diff} \times \mathrm{Weyl})} \, |\Psi[g,\chi]|^2 A[g,\chi] \ .$$

We use the Faddeev-Popov procedure with the gauge-fixing conditions

$$g_{ii} = d, \qquad \partial_i g_{ij} = 0$$

for the diff-and-Weyl invariance. There is a residual gauge invariance of the conformal group $\mathrm{SO}(1, d+1)$ which is fixed similarly as in string theory.

Cosmological correlators can be defined as gauge-fixed observables. They are covariant under the residual symmetries. This implies a version of holography of information: for any state on S^d, the knowledge of cosmological correlators in an arbitrary small region is enough to fully determine the state.

Summary

- We have obtained the late time solutions of the WDW equation in an asymptotically dS_{d+1} spacetime, to all order in G_N.
- They take the form $\Psi = e^{iS}Z$ where S is a universal phase and Z is a functional obeying the same Ward identities as a CFT_d partition function.
- The Hartle-Hawking state is not special as every state has the same symmetries.
- The inner product and expectation values are defined using a suitable procedure to gauge-fix the diff-and-Weyl and residual conformal invariance.
- Cosmological correlators are gauge-fixed observables. They are invariant under scalings and translations in any state, which implies a cosmological version of holography of information.

Thank you!

Moduli stabilisation and de Sitter vacua (?)

Anthony Guillen (ft. Ignatios Antoniadis & Osmin Lacombe)

LPTHE

(ongoing work)

What you probably all know

String theory $\longrightarrow$ 10 dimensions = 4 + 6 $\longrightarrow$

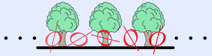
$\times$

Calabi-Yau

"Sizes" and "shapes" = scalar fields in 4d (moduli)

Problem: a priori, no potential

We must give them a potential !



$\longrightarrow$

Standard (KKLT) approach:

keep everything under control !

1 - stabilise complex structure moduli + dilaton with fluxes

2 - invoke something else to stabilise the Kahler moduli

D3 brane instanton, gluino condensation, logarithmic corrections, ...

Logarithmic corrections

Euler characteristic

One loop corrections (perturbative) $\longrightarrow \int_{M_{10}} \epsilon_8 \epsilon_8 R^4 \longrightarrow \chi \int_{M_4} (\cdots)\, \mathcal{R}_{(4)}$

$\longrightarrow \cdots$ [1909.10525]

depend on dilaton + geometry

$$\longrightarrow \mathcal{K} = -2\log(\mathcal{V} + \xi + \gamma \log \mathcal{V})$$

Goal: stabilise the Kahler moduli with these (+ other ingredients)...

...and get a de Sitter vacuum ?

Stabilisation with fluxes

c.s. moduli

integers prepotential

More standard way: $W = \int \Omega \wedge G = n_a X^a + m_a \mathcal{F}^a$

Tadpole constraint: $m^H \cdot n^F - m^F \cdot n^H \leq N_{\max}$

makes thing more interesting / complicated

What I did (so far)

$$n_0 + n_1\bar{\mathcal{U}}^1 + n_2\mathcal{U}^2 + n_3\mathcal{U}^3 + m_1\mathcal{U}^2\mathcal{U}^3 + m_2\bar{\mathcal{U}}^1\mathcal{U}^3 + m_3\bar{\mathcal{U}}^1\mathcal{U}^2 - m_0\bar{\mathcal{U}}^1\mathcal{U}^2\mathcal{U}^3 = 0$$
$$n_0 + n_1\mathcal{U}^1 + n_2\bar{\mathcal{U}}^2 + n_3\mathcal{U}^3 + m_1\bar{\mathcal{U}}^2\mathcal{U}^3 + m_2\mathcal{U}^1\mathcal{U}^3 + m_3\mathcal{U}^1\bar{\mathcal{U}}^2 - m_0\mathcal{U}^1\bar{\mathcal{U}}^2\mathcal{U}^3 = 0$$
$$n_0 + n_1\mathcal{U}^1 + n_2\mathcal{U}^2 + n_3\bar{\mathcal{U}}^3 + m_1\mathcal{U}^2\bar{\mathcal{U}}^3 + m_2\mathcal{U}^1\bar{\mathcal{U}}^3 + m_3\mathcal{U}^1\mathcal{U}^2 - m_0\mathcal{U}^1\mathcal{U}^2\bar{\mathcal{U}}^3 = 0$$
$$n_0 + n_1\bar{\mathcal{U}}^1 + n_2\bar{\mathcal{U}}^2 + n_3\bar{\mathcal{U}}^3 + m_1\bar{\mathcal{U}}^2\bar{\mathcal{U}}^3 + m_2\bar{\mathcal{U}}^1\bar{\mathcal{U}}^3 + m_3\bar{\mathcal{U}}^1\bar{\mathcal{U}}^2 - m_0\bar{\mathcal{U}}^1\bar{\mathcal{U}}^2\bar{\mathcal{U}}^3 = 0$$

Studied c.s. moduli stabilisation with fluxes in $T^6/\mathbb{Z}_2 \times \mathbb{Z}_2$

can be solved analytically but the result is atrocious

Semi-exhaustive tests with billions of integers combinations

If $N_{\text{flux}} \leq N_{\max}$, I always find $g_s \geq 5^{-1/4} \simeq 0.67$ (not very perturbative)

The bigger N_{flux}, the smaller g_s can be (similar result in [2207.13721])

What I'll do next

Convince myself (and my advisor) of the above

Look at other orbifolds / manifolds ?

Short term: probably go climbing !

Thanks for your attention !

Negative scalar potentials and the swampland

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based on arXiv:2212.04517 with D. Andriot, G. Tringas

French Strings Meeting, May 2023

Trans-Planckian Censorship Conjecture (TCC)

[Bedroya, Vafa '19]

- Idea: Properties of negative scalar potentials, coming from string theory

- Cosmological model, with scale factor $a(t)$

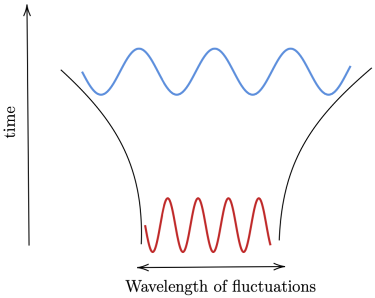
$$\mathcal{S} = \int \mathrm{d}^d x \sqrt{|g_d|} \left(\frac{M_{pl}^2}{2} \mathcal{R}^{(d)} - \frac{1}{2} g_{ij} \partial_\mu \varphi^i \partial^\mu \varphi^j - V(\varphi) \right)$$

- Swampland program, study scalar potential: e.g. expanding de Sitter universe $V > 0$

Trans-Planckian Censorship Conjecture (TCC)

[Bedroya, Vafa '19]

- Modes with super-Planckian energy, $a(t_i) \sim \frac{1}{M_{pl}}$
- Expansion $\Rightarrow$ redshift
- Reach typical energy scale of the EFT, $a(t) \sim \frac{\sqrt{V}}{M_{pl}}$
- Contribute to physics of EFT, violating its validity



from [Agmon, Bedroya, Kang, Vafa '23]

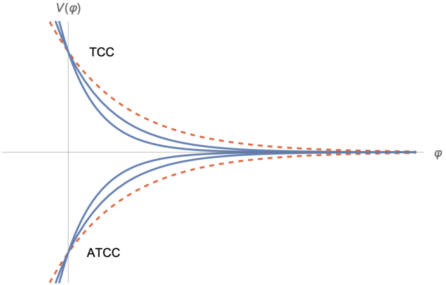
$$\text{Therefore :} \qquad 1 \geq \frac{a(t_i)}{a(t)} \geq \frac{\sqrt{V}}{M_{pl}^2}$$

Negative scalar potentials

Anti-Trans-Planckian Censorship Conjecture (ATCC)

- $V < 0$, including AdS vacua. Contracting universe, redshift $\Rightarrow$ blueshift

$$\frac{a(t)}{a(t_i)} \geq \frac{\sqrt{|V|}}{M_{pl}^2}$$



- Exponential bound, in Planckian units

$$\text{TCC}: \quad 0 < V(\varphi) \leq e^{-c_0 \Delta\varphi}$$

$$\text{ATCC}: \quad 0 > V(\varphi) \geq -e^{-c_0 \Delta\varphi}$$

with $c_0 = \frac{2}{\sqrt{(d-1)(d-2)}}$.

Consequences

Asymptotic condition on V'

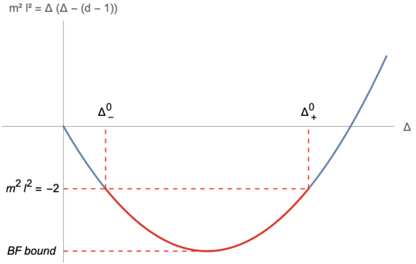
$$\left\langle -\frac{V'}{V} \right\rangle_{\varphi\to\infty} \geq \frac{2}{\sqrt{(d-1)(d-2)}}$$

- New result: bound on V''/V, valid for (A)TCC

$$\left\langle \frac{V''}{V} \right\rangle_{\varphi\to\infty} \geq \frac{4}{(d-1)(d-2)}$$

- $\mathrm{AdS}_{d\geq 4}$, $V'' = m^2$:

$$\text{BF-bound} < m^2 l_{AdS}^2 \lesssim -2$$

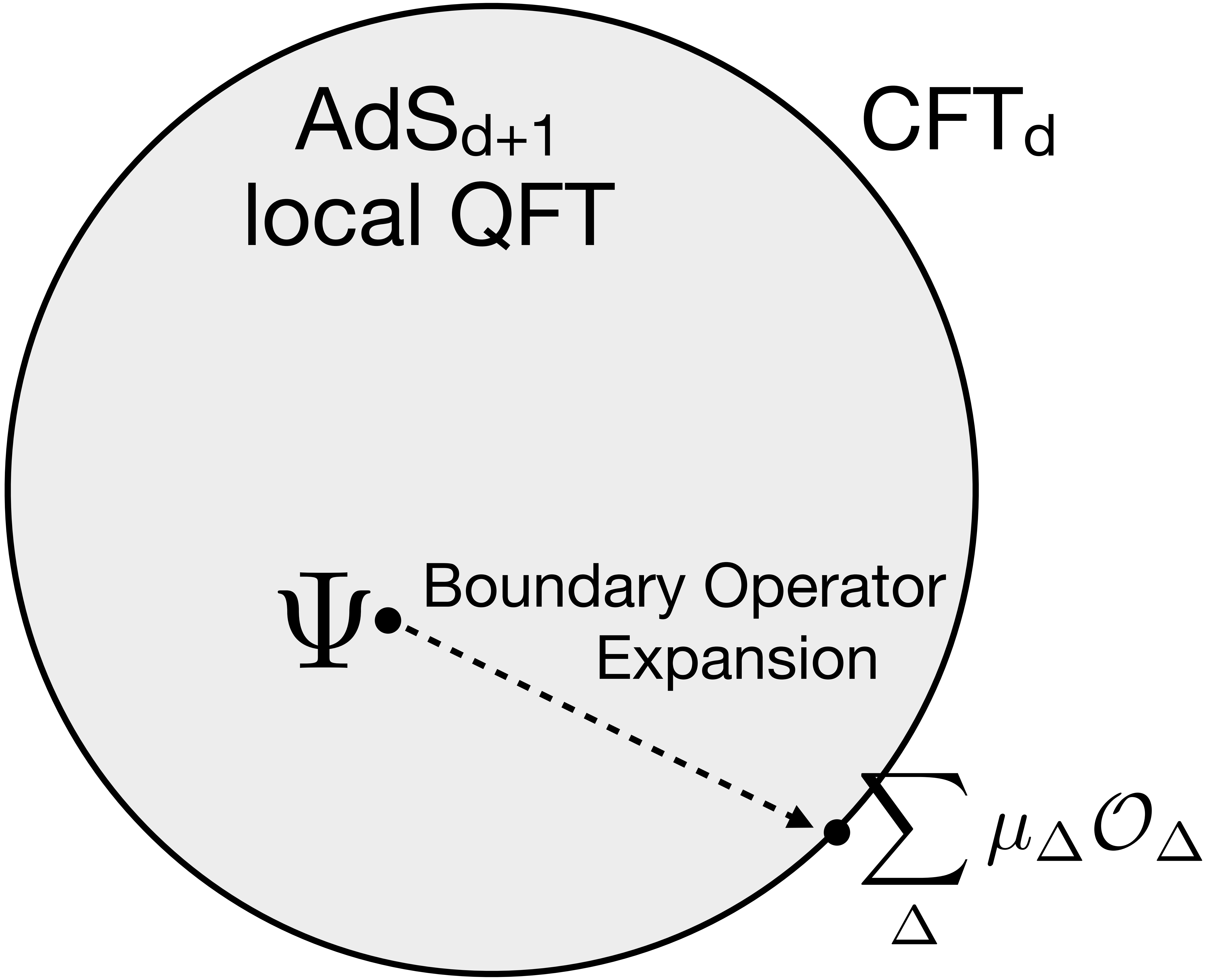


Thank you for your attention!

Bootstrapping bulk locality

Nat Levine (ENS)

[Part I: 2305.07078 with Miguel Paulos]



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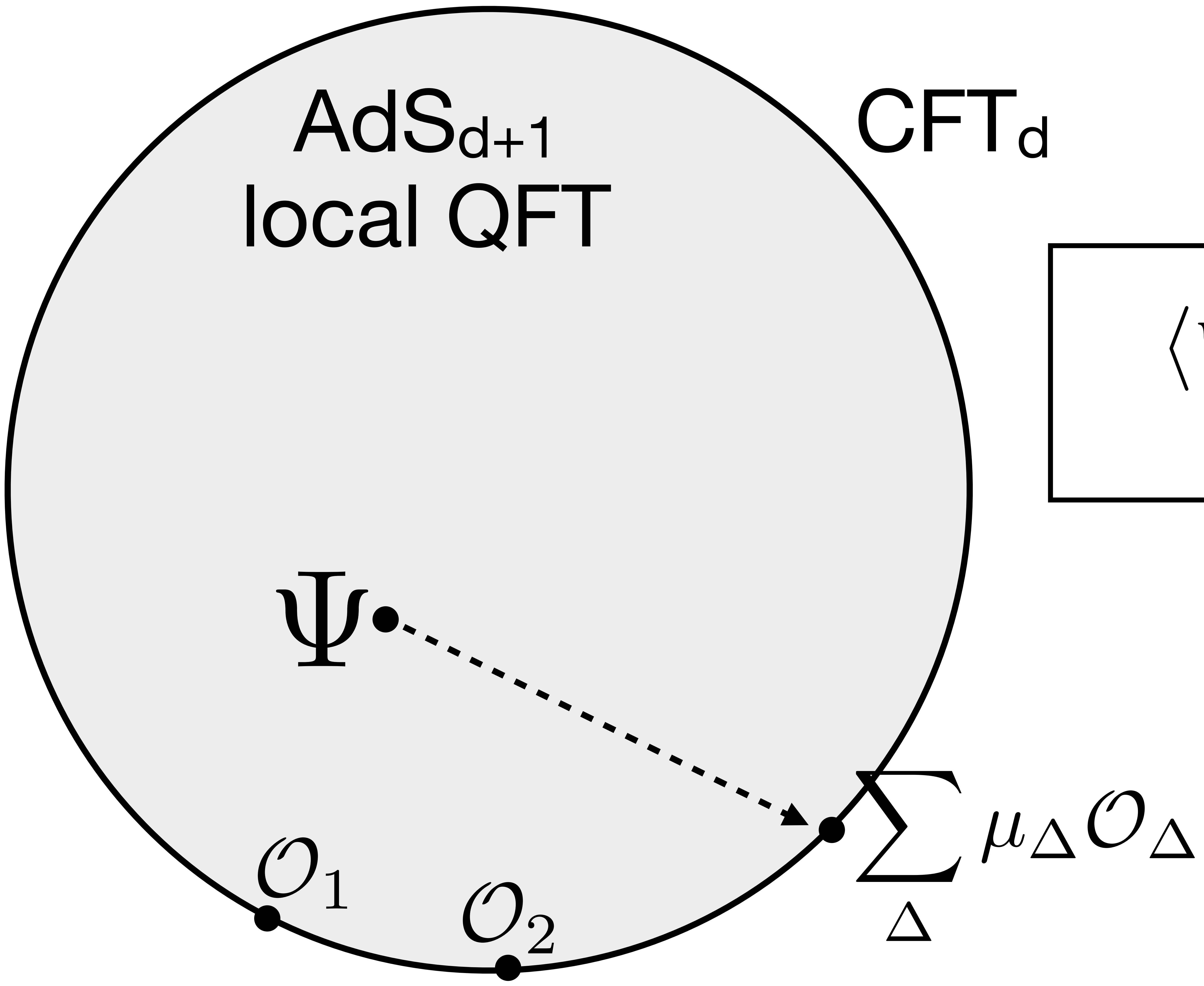
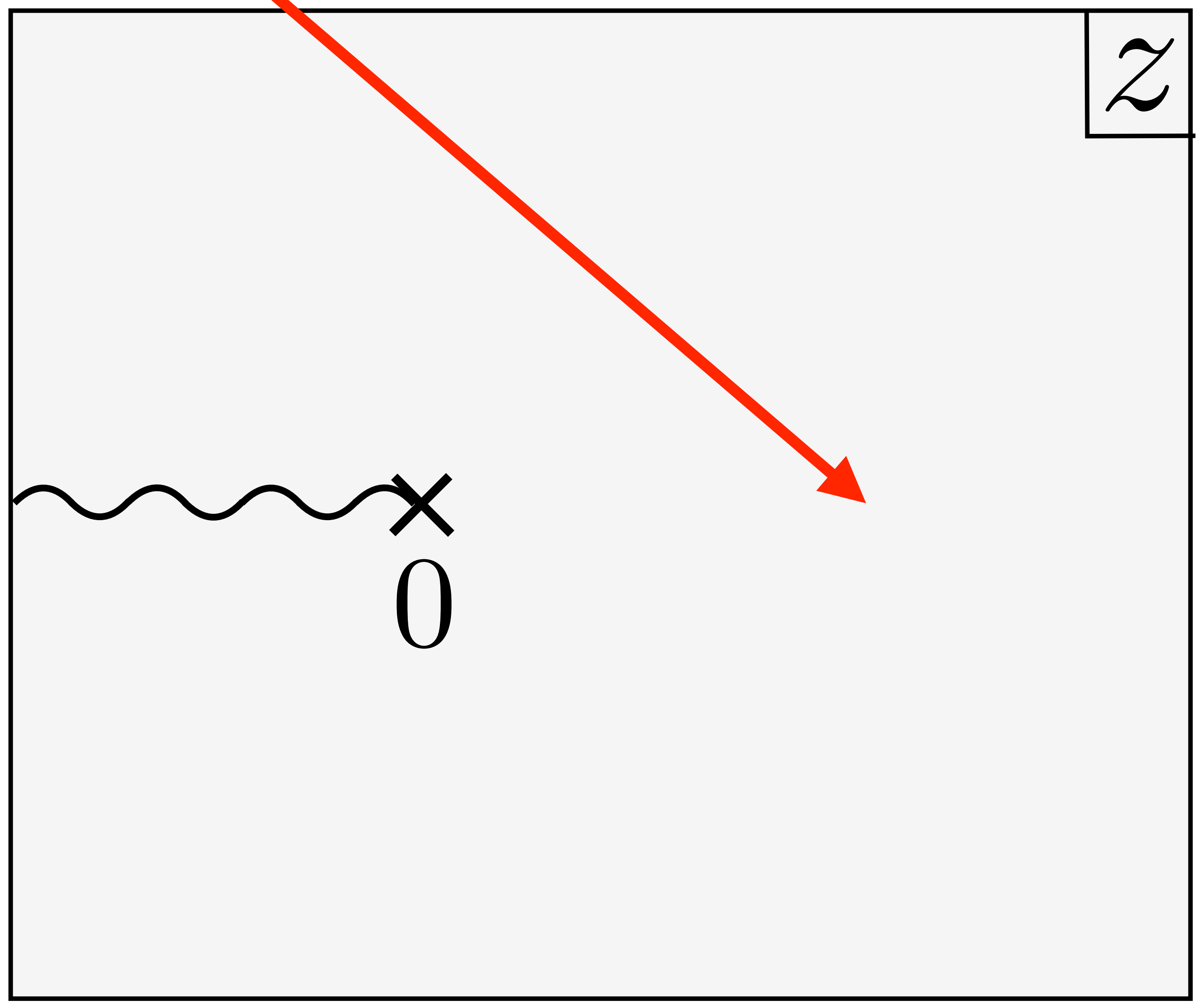


$$\boxed{\langle \Psi | \mathcal{O}_1 \mathcal{O}_2 \rangle \sim \sum_\Delta c^{12}_\Delta \, G^{12}_\Delta(z)}$$

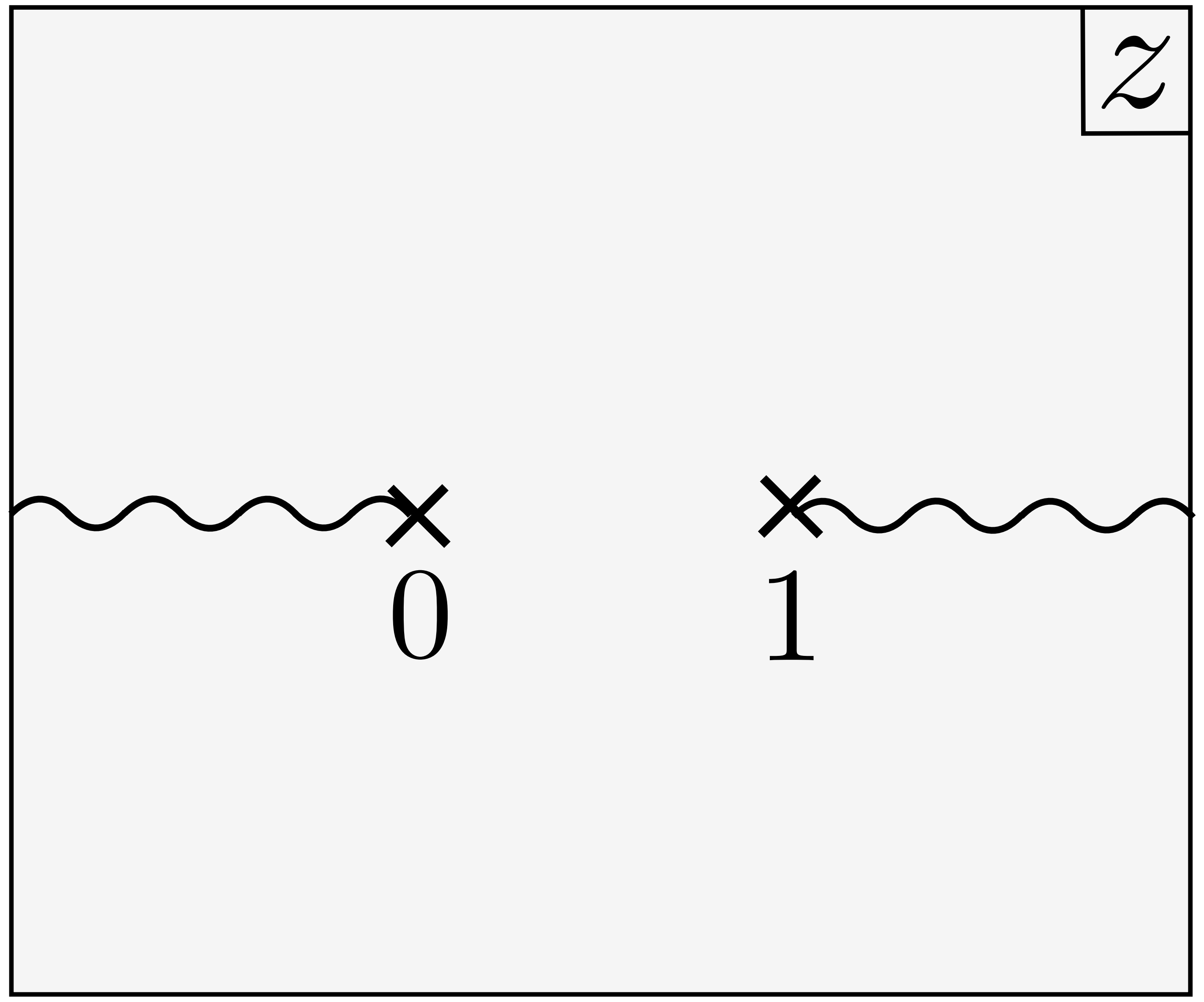
$$c^{12}_\Delta = \mu_\Delta \, \lambda_{\Delta 12}$$

Locality

$$\langle\Psi|\mathcal{O}_1\mathcal{O}_2\rangle \sim \sum_\Delta c_\Delta^{12}\; G_\Delta^{12}(z)$$



$$\sim \sum_\Delta c_\Delta^{12}$$



Locality bootstrap: $\quad \underset{z\geq 1}{\mathrm{Im}} \sum_\Delta c_\Delta^{12}\; G_\Delta^{12}(z) = 0$

cf. [Kabat Lifschytz 16]

Results

Locality

Complete set of sum rules $\sum_{\Delta} c^{12}_{\Delta}\ \theta^{12}_n(\Delta) = 0$

'Dual' to free solution

$$\theta^{12}_n(\Delta_1 + \Delta_2 + 2m) = \delta_{mn}$$

Eliminate $\mu_\Delta \longrightarrow \infty$ constraints on CFT

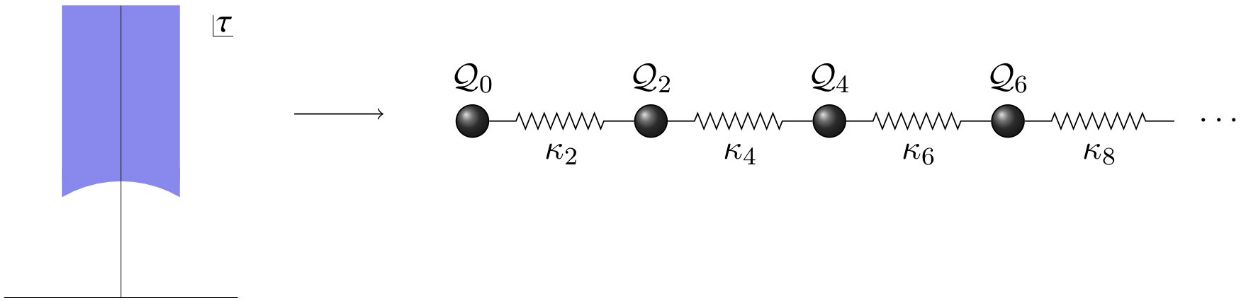
Flat space limit: Form factor

Future directions

- Part II   Functionals dual to ‘extremal’ interacting solutions
- Part III   Bulk gauge/gravitational symmetries

- Extra constraints for BCFT
- Extra ‘strong locality’ constraints for S-matrix ?

Exact Large Charge in $\mathcal{N}$=4 SYM and Semiclassical String Theory



Hynek Paul

Based on [2303.13207]
w/ Eric Perlmutter & Himanshu Raj

French Strings Meeting
23/05/2023

In N=4 SYM with gauge group SU(N), we study an infinite class of integrated correlators

In N=4 SYM with gauge group SU(N), we study an infinite class of integrated correlators

$$\mathcal{G}_p^{(N)}(\tau) = \int du\, dv\, \mu(u,v)\, \langle \mathcal{O}_2 \mathcal{O}_2 \mathcal{O}_p \mathcal{O}_p \rangle$$

where $\begin{cases} \mathcal{O}_2 = y_I\, y_J\, \mathrm{Tr}\big(\Phi^I \Phi^J\big) \\ \mathcal{O}_p = \big[\mathcal{O}_2\big]^{\frac{p}{2}} \end{cases}$

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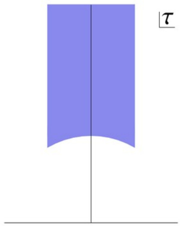

SL(2,Z) invariance

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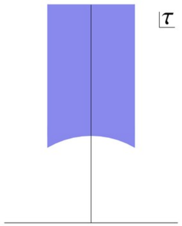

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supersymmetric localisation

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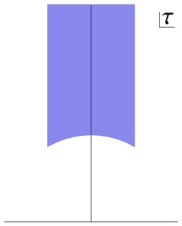

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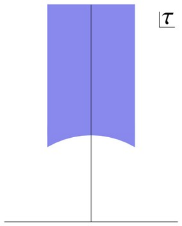

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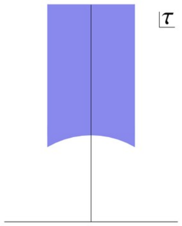

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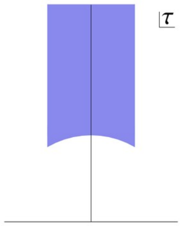

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spectral overlap

→ **exact function of N and p:**
$$\boxed{g_p^{(N)}(s) = \frac{N(N-1)}{2s(1-s)}\left[1 - {}_3F_2\Big(-\frac{p}{2}, s, 1-s; 1, \frac{N^2-1}{2}; 1\Big)\right] {}_3F_2(2-N, s, 1-s; 3, 2; 1)}$$

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Can study various large N, large p limits $\rightarrow$ **'gravity regime'** $p, N \to \infty$ with $p \sim N^2$

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- **at genus 0, at strong coupling we have** $\mathcal{G}^{(0)}_{\alpha}(\lambda) = \dfrac{\log(\alpha+1)}{4} + O\big(\lambda^{-\frac{3}{2}}\big)$ **(Semiclassical String Theory)**

Heterotic flux backgrounds and (0,2) linear models

Yann Proto
LPTHE, Paris

French Strings Meeting
May 23, 2023

based on [2302.01889] with Dan Israël

LABORATOIRE DE PHYSIQUE THEORIQUE ET HAUTES ENERGIES

Heterotic backgrounds with non-trivial H-flux

- Supersymmetric heterotic compactifications with H-flux require a non-Kähler internal space X with $SU(3)$ structure [Hull 1986, Strominger 1986]

- Topology constrained by the Bianchi identity $\mathrm{d}H = \frac{\alpha'}{4}\left(\mathrm{tr}\, R^+ \wedge R^+ - \mathrm{tr}\, F \wedge F\right)$

Classical flux solution

- X is a principal torus fibration over a $K3$ surface [Dasgupta et al 1999, Goldstein–Prokushkin 2004]
- Bianchi identity is pulled back from $K3$
  $\rightarrow$ single equation in $H^4(K3, \mathbb{Z})$ [Fu–Yau 2008]
- $\mathcal{N} = 2$ spacetime supersymmetry

$$\begin{array}{ccc} T^2 & \hookrightarrow & X \\ & & \downarrow \\ & & K3 \end{array}$$

Linear worldsheet models for heterotic compactifications

Gauged Linear Sigma Models (GLSMs)

[Witten 1993]

- $2d$ abelian gauge theory with (2,2) worldsheet susy
- Flow in the IR gives a NLSM on a Kähler manifold

GLSM	*RG flow* $\rightarrow$	NLSM
$U(1)^r$ gauge group	$\rightarrow$	$(\mathbb{C}^*)^r$ action on a toric variety
vector multiplet v^α	$\rightarrow$	inherited 2-cycle η^α
Fayet–Iliopoulos parameters	$\rightarrow$	complexified Kähler moduli
superpotential couplings	$\rightarrow$	complex structure moduli

- Generalization to non-Kähler spaces through Torsional Linear Sigma Models
  - $\rightarrow$ $K3$ base and gauge bundle described by a GLSM with (0,2) susy
  - $\rightarrow$ Gauged anomaly cancelled by a non-gauge invariant coupling of the torus
  - $\rightarrow$ Condition for gauge invariance reproduces the Bianchi identity!

[Adams–Ernebjerg–Lapan 2008]

Worldsheet constructions of $\mathcal{N} = 1$ backgrounds

- Orbifolds of $\mathcal{N} = 2$ backgrounds can be implemented at the level of the TLSM
  - → quotient by a cyclic group Γ to obtain $\mathcal{N} = 1$ spacetime supersymmetry
  - → worldsheet analogue of [Becker–Tseng–Yau 2008]
  - → explicit geometries solving all constraints (complete intersections in toric varieties)

[Israël–YP 2023]

- Orbifold geometry constrained by the orbifold group Γ

Γ	Quotient space
$\mathbb{Z}_2$	smooth $SU(2) \times \mathbb{Z}_2$ background (flux version of FHSV)
$\mathbb{Z}_3, \mathbb{Z}_4, \mathbb{Z}_6$	singular space with isolated $\mathbb{C}^3/\Gamma$ singular points

→ GLSM framework to address the resolution of conical singularities

Thank you!

Orthosymplectic Superinstanton Counting

Yilu Shao

Institut de Mathématiques de Bourgogne

LAPTh, May 23, 2023

Supergroups?

Anticommuting variables as internal space

Supergroup gauge theories (see [Kimura23] for a review)

Unitary supergroups [DHJV18, Kimura-Pestun19]

Orthosymplectic supergroups [Kimura-YS] (to appear)

Partition Function

$$Z_{k_0|k_1} = \oint_{T_K} \prod_{a=1}^{k_0} \frac{d\phi_a^0}{2\pi\iota} z_{k_0}^{SO(2n_0+\chi_n)}(\phi^0, u^0) \prod_{a=1}^{\xi} \frac{d\phi_a^1}{2\pi\iota} z_{k_1}^{Sp(n_1)}(\phi^1, u^1)$$

$$\times \prod_{a=1}^{k_0} \prod_{b=1}^{\xi} \frac{[\pm\phi_a^0 \pm \phi_b^1 + \epsilon_1][\pm\phi_a^0 \pm \phi_b^1 + \epsilon_2]}{[\pm\phi_a^0 \pm \phi_b^1][\pm\phi_a^0 \pm \phi_b^1 + \epsilon_{12}]}$$

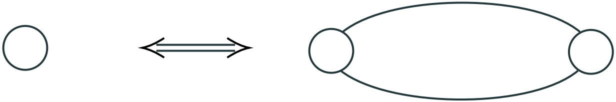
$$\times \prod_{a=1}^{\xi} \prod_{\alpha=1}^{n_0} [\pm\phi_a^1 \pm u_\alpha^0] \prod_{a=1}^{k_0} \prod_{\alpha=1}^{n_1} [\pm\phi_a^0 \pm u_\alpha^1]$$

$$\times \left(\prod_{\alpha=1}^{n_0} [\pm u_\alpha^0] \prod_{a=1}^{k_0} \frac{[\pm\phi_a^0 + \epsilon_1][\pm\phi_a^0 + \epsilon_2]}{[\pm\phi_a^0][\pm\phi_a^0 + \epsilon_{12}]} \right)^{\chi_k}$$

$$\times \left(\prod_{a=1}^{\xi} [\pm\phi_a^1] \right)^{\chi_n} \times ([0])^{\chi_n \chi_k} .$$

Quiver Realization

The orthosymplectic supergroup gauge theory can be realized as



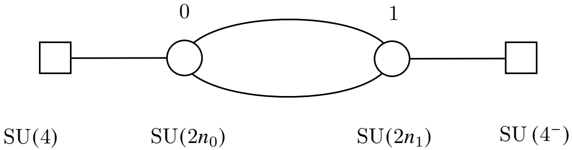
$\mathrm{OSp}(2n_0+\chi_n|n_1)$ $\qquad$ $\mathrm{SO}(2n_0+\chi_n)$ $\qquad$ $\mathrm{Sp}(n_1)$

because the partition function coincides with double SO-Sp half-bifundamental formula in [Hollands-Keller-Song11] but with an unphysical coupling.

Seiberg-Witten Geometry

D-type

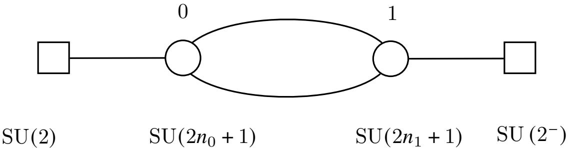
$$y + \frac{\mathfrak{q}}{y} = \frac{\prod_{\alpha=1}^{n_0}(x^2 - (a_\alpha^0)^2)}{\prod_{\alpha=1}^{n_1}(x^2 - (a_\alpha^1)^2) + 2/x^2}.$$



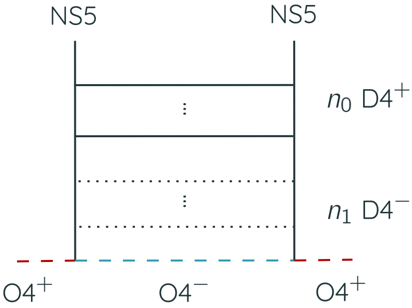
Seiberg-Witten Geometry

B-type

$$y + \frac{\mathfrak{q}}{y} = \frac{\prod_{\alpha=1}^{n_0}(x^2 - (a_\alpha^0)^2)}{x\prod_{\alpha=1}^{n_1}(x^2 - (a_\alpha^1)^2) + 2/x}.$$

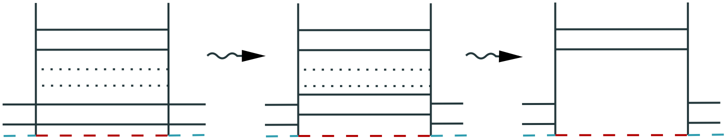


Brane Construction

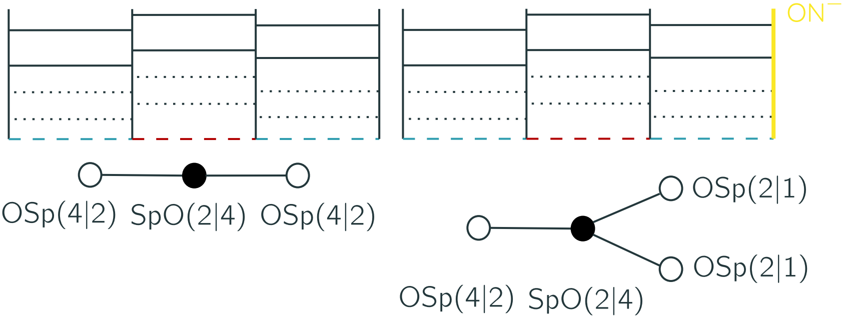


”negative branes” [Okuda-Takayanagi06]

Gauging



Quiver Gauge Theory



Scattering Amplitudes as Bilinear Forms

Yihong Wang

May 23, 2023

Scattering Amplitudes as Bilinear Forms

By definition, scattering amplitudes are bilinear forms:

$$M = \langle in | out \rangle$$

where *in* and *out* represent the incoming and outgoing particles, respectively.

Shapovalov Form

The Lie algebra G has k_i as simple roots. The following relations hold:

$$[E_i, F_j] = \delta_{ij} H_{k_i}, [H_{k_i}, E_j] = k_i \cdot k_j E_j, [H_{k_i}, F_j] = -k_i \cdot k_j F_j$$

for $i, j = 2, \ldots, n$. Shapovalov Form $\langle , \rangle$

$$\langle E_i, E_j \rangle = \delta_{ij}, \langle E_i, X \rangle = 0,$$

$$i, j \in \{1, ..., n\}, X \in G, X \notin \mathrm{Span}\left(\{E_1, ..., E_{n-1}\}\right)$$

$$\langle [E_i, X], Y \rangle = \langle X, [F_i, Y] \rangle, \quad i, j \in \{1, ..., n\}, X, Y \in G$$

BCJ Numerators

The BCJ numerators $N(X)$ are defined as:

$$N(X) = \langle X, U_n \rangle$$

where $X \in G$ and U_n is given by:

$$U_n = (-1)^{n/2} \frac{\pi^2}{2} \sum_{\tau \in S_{n-2}} N(\ell(\tau))(\ell(\tau))^*$$

4pt NLSM

$$U_4 = \frac{s_{12} + s_{23}}{s_{123}} \left[\left[E_1, E_2 \right], E_3 \right] + \frac{s_{13} + s_{23}}{s_{123}} \left[\left[E_1, E_3 \right], E_2 \right]$$

$$N \left(\left[\left[E_1, E_2 \right], E_3 \right] \right) = \left(\left[\left[E_1, E_2 \right], E_3 \right], U_4 \right)$$

$$N \left(\left[\left[E_1, E_3 \right], E_2 \right] \right) = \left(\left[\left[E_1, E_3 \right], E_2 \right], U_4 \right)$$

$$N \left(\left[E_1, \left[E_2, E_3 \right] \right] \right) = \left(\left[\left[E_1, E_2 \right], E_3 \right], U_4 \right)$$

Color Ordered Amplitude

The color ordered amplitude is then given by:

$$A(1\sigma_n) = \langle \ell^*(\sigma), U_n \rangle$$

and for example, $A(1234) = ([E_1, E_2], E_3)^* U_4$. 4pt NLSM ampliude

$$A\,(1234) = (([[E_1, E_2]\,, E_3])^*\,, U_4)$$

Color Kinematic Duality

Color kinematic duality relates color and kinematic information in scattering amplitudes. It is given by:

$$C(\Gamma_s) = f_{ab}^{e_1} f_{e_1}^{ce_2} \delta_{e_2}^{d} = Tr([[t_a, t_b], t_c] t_d) = ([[E_a, E_b], E_c], F_d)$$

where Γ represents the 4pt s-Channel Feynman diagram.

3 Recursive Relation and Biadjoint Scalar Amplitudes

- Recursive relation:

$$F_i \ell^* (\alpha) = \delta_{i,\alpha_{-1}} \ell^* (\alpha \backslash i)$$

- Biadjoint scalar amplitudes:

$$\langle \ell^* (\alpha) , \ell^* (\beta) \rangle = m (\sigma | \beta)$$
$$\ell^* (\alpha) = m (\sigma | \beta) \ell (\beta)$$

- For example:

$$\begin{aligned}
&(s_{14} + s_{24} + s_{34}) m(234|234) \\
&+ (s_{14} + s_{24}) m(234|243) \\
&+ s_{14} m(234|423) \\
&= m(23|23) \\
&(s_{14} + s_{24} + s_{34}) m(243|234) \\
&+ (s_{14} + s_{24}) m(243|243) \\
&+ s_{14} m(243|423) \\
&= 0
\end{aligned}$$

Inverse Relation: Momentum Kernel and Biadjoint Scalar

$$S[\sigma(2), ..., \sigma(n)|k_1, \tau(2), ..., \tau(n)] = k_1$$

where k_1 is a product over all possible pairs of external legs, and $\theta(\sigma(t), \sigma(q))$ is a step function defined as:

$$\theta(\sigma(t), \sigma(q)) = \begin{cases} 1 & \text{if } (\sigma(t) - \sigma(q))(\tau^{-1}(t) - \tau^{-1}(q)) < 0 \\ 0 & \text{otherwise} \end{cases}$$

$$S\,[234|\,234] = (s_{34} + s_{24} + s_{14})\,(s_{23} + s_{13})\,s_{12}$$

$$S\,[234|\,243] = (s_{24} + s_{14})\,(s_{23} + s_{13})\,s_{12}$$

Inverse Relation: Momentum Kernel and Biadjoint Scalar

$$m(1234|1234)$$
$$= \frac{1}{s_{1234}s_{123}s_{12}} + \frac{1}{s_{1234}s_{123}s_{23}} + \frac{1}{s_{1234}s_{234}s_{23}} + \frac{1}{s_{1234}s_{234}s_{34}} + \frac{1}{s_{1234}s_{12}s_{34}}$$

$$m(234|324) = \frac{1}{s_{1234}s_{123}s_{23}} + \frac{1}{s_{1234}s_{234}s_{23}}$$

Inverse Relation: Momentum Kernel and Biadjoint Scalar

$$\langle \ell^* (\alpha), \ell^* (\beta) \rangle = m(\sigma | \beta)$$

$$S[\sigma | \tau] = \langle \ell(1\sigma), \ell(1\tau) \rangle$$

$$S[\sigma | \tau] = m^{-1}(\sigma | \beta)$$

Acknowledgements

Thank you for your attention!

Presentation prepared with the assistance of ChatGPT

U(1) quasi-hydrodynamics: Schwinger-Keldysh effective field theory and holography

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Based on 2304.14173 w/ M. Baggioli, Y. Bu

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Quasi-hydrodynamics

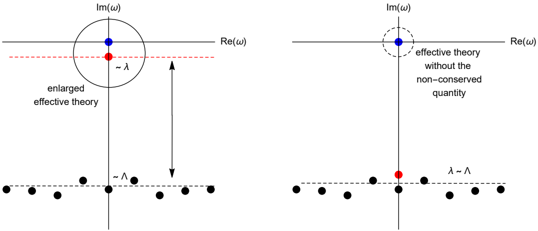
Symmetries are a guiding principle in constructing low-energy EFTs

- **Exact symmetries** lead to conserved quantities

Typically also involve some small **explicit** breaking $\sim \lambda \ll T$

- **Approximately** conserved quantities

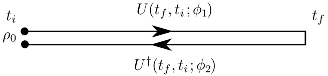
$$\dot{n} + \nabla \cdot j = O = -\Gamma n + \cdots$$



Construct finite temperature **quasi-hydrodynamic EFTs** including **dissipative** effects

Schwinger-Keldysh EFT for $U(1)$ quasi-hydrodynamics

Systematic construction of hydrodynamic S_{EFT} from **SK contour** [Crossley,Glorioso,Liu]



- **Doubling** of the fields: **physical** $\phi_r = \frac{1}{2}(\phi_1 + \phi_2)$, **stochastic** $\phi_a = \phi_1 - \phi_2$

(i) **Identify** low-energy **dofs**

- Conserved $U(1)$: **gauge invariance** $\Longrightarrow B_\mu \equiv A_\mu + \partial_\mu \phi$
- Broken $U(1)$: **external scalar source** $\Phi \Longrightarrow \vartheta \equiv \Phi + \phi$

(ii) Write down effective Lagrangian $\mathcal{L}_{EFT}$ in **derivative expansion**

(iii) Impose **unitarity constraints** & **dynamical KMS condition**

Schwinger-Keldysh EFT for $U(1)$ quasi-hydrodynamics

EFT Lagrangian for $U(1)$ charge relaxation

$$\mathcal{L}_{EFT} = (\chi_0 + \chi_2)\, B_{a0} B_{r0} + (\sigma_0 + \sigma_2)\, B_{ai} \partial_0 B_{ri} + \tilde{\Gamma} \vartheta_a \partial_0 \vartheta_r + c_1' (B_{a0} \Xi_{r0} + \Xi_{a0} B_{r0}) + \Gamma_1' \Xi_{a0} \Xi_{r0} + \Gamma_2' \Xi_{ai} \Xi_{ri} + \mathcal{O}(a^2, \partial^2)$$

where $\Xi_\mu = \partial_\mu \Phi - A_\mu$

- χ_0: **charge susceptibility**, σ_0: **electric conductivity**
- $\tilde{\Gamma}$: **charge relaxation rate**
- Also **novel transport coefficients** [Armas,Jain,Lier; Delacrétaz,Goutéraux,VZ]

Derive constitutive relations, current (non-)conservation, **pseudo-diffusive mode**, ...

Holography for SK $U(1)$ quasi-hydrodynamics

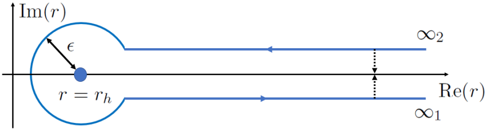
Softly break bulk $U(1)$ gauge symmetry $\Rightarrow$ **Proca theory**

$$S_{\rm bulk} = \int d^5x\sqrt{-g}\left[-\frac{1}{4}F_{MN}F^{MN} - \frac{m^2}{2}(C_M - \nabla_M\theta)(C^M - \nabla^M\theta)\right]$$

- Schwarzschild-AdS background

$$ds^2 = 2drdv - r^2\left(1 - r_h^4/r^4\right)dv^2 + r^2\delta_{ij}dx^i dx^j$$

HoloSK contour: [Glorioso,Crossley,Liu]



Complexify radial coordinate r and **analytically continue** around the horizon

- (Partially) solve the bulk eoms in derivative expansion $\partial \sim m$, ...

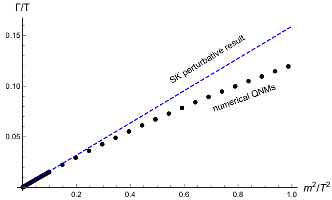
Holography for SK $U(1)$ quasi-hydrodynamics

... and derive the full **SK action** for $U(1)$ quasi-hydrodynamics!

- Finite values for **novel transport coefficients**

- **Ward identity** with charge relaxation

$$\boxed{\partial_\mu J^\mu = -\Gamma J^0 + \cdots \,, \qquad \Gamma \approx \frac{m^2 r_h}{2} = \frac{m^2 \pi T}{2}}$$



- Dispersion relation

$$\boxed{\omega = -i\Gamma - iD_q k^2 + \cdots \,, \qquad D_q = \frac{1}{2r_h} + \mathcal{O}(m^4)}$$

with no $\mathcal{O}(m^2 k^2)$ correction: **artifact or generic feature?**

Outlook

Future directions:

- SK action for **pinned holographic superfluids**
- Pinning at higher orders and **beyond linear response**
- Include **dynamical topological defects**

- Applications to:
  - Criticality, higher-form symmetries, QCD, spin relaxation, Wigner crystals/Charge density waves, strange metals,...

Thank You!