Conserved Currents at Infinite Distance in the Conformal Manifold

José Calderón Infante

Based on 2305.xxxxx with Florent Baume

Eurostrings 2023, Gijón, 25/04/2023

Higher-Spin Points are at Infinite Distance

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Swampland Distance Conjecture in AdS/CFT ?

[Baume, JC '20] [Perlmutter, Rastelli, Vafa, Valenzuela '20]

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CFT Distance Conjecture:

Conformal manifold of local CFT in d>2

I. HS point ⟶ Infinite distance

II. Infinite distance ⟶ HS point

III. $\gamma_\ell = \Delta_\ell - (\ell + d - 2) \sim e^{-\alpha_\ell t}$

Zamolodchikov distance

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! No extra assumption, e.g., no supersymmetry

Sketch of the Proof

Conformal perturbation theory

Weakly-broken HS symmetry

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Thank you for your attention ...and stay tuned!

Symmetric fluxes and small tadpoles

Thibaut Coudarchet
Instituto de Física Teórica UAM-CSIC

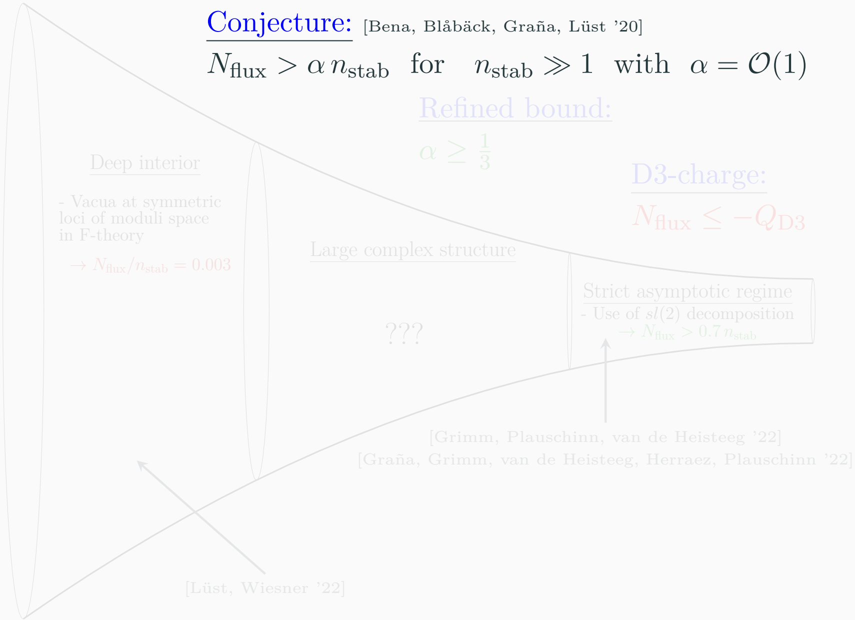
Eurostrings, Gijón, April 25, 2023

Based on 2212.02533 and 2304.04789, TC, F. Marchesano, D. Prieto and M. A. Urkiola

The Tadpole Conjecture

Conjecture: [Bena, Blåbäck, Graña, Lüst '20]

$$N_{\text{flux}} > \alpha\, n_{\text{stab}} \quad \text{for} \quad n_{\text{stab}} \gg 1 \quad \text{with} \quad \alpha = \mathcal{O}(1)$$



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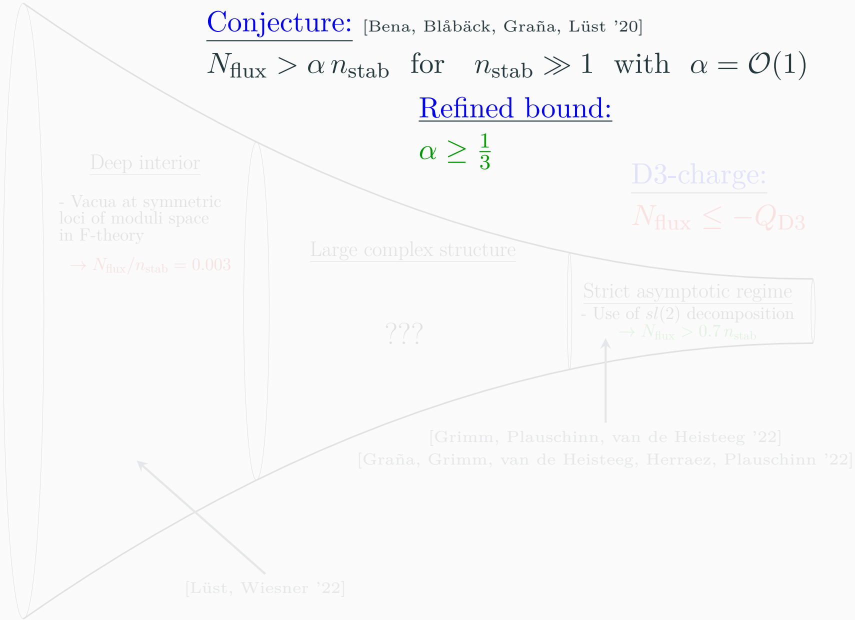
$$\alpha \geq \frac{1}{3}$$



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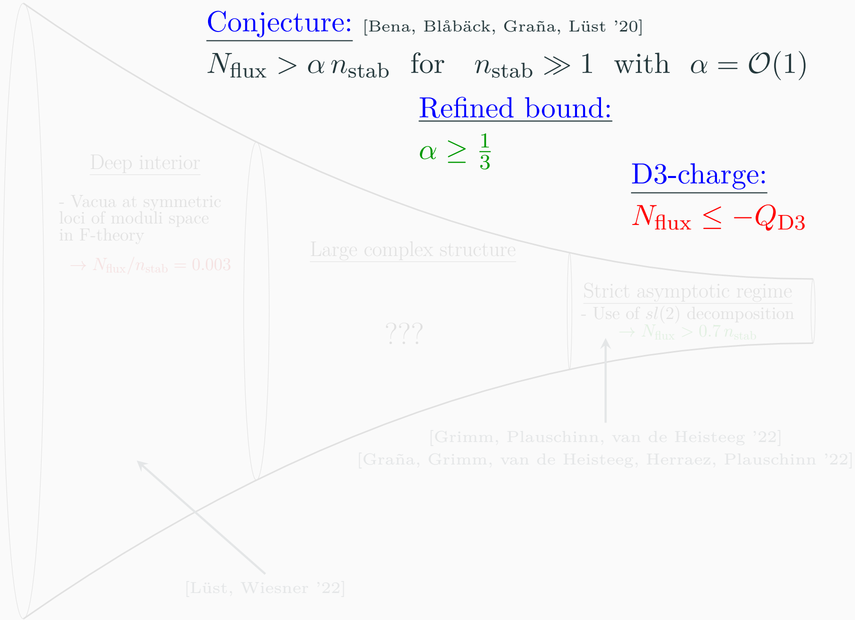

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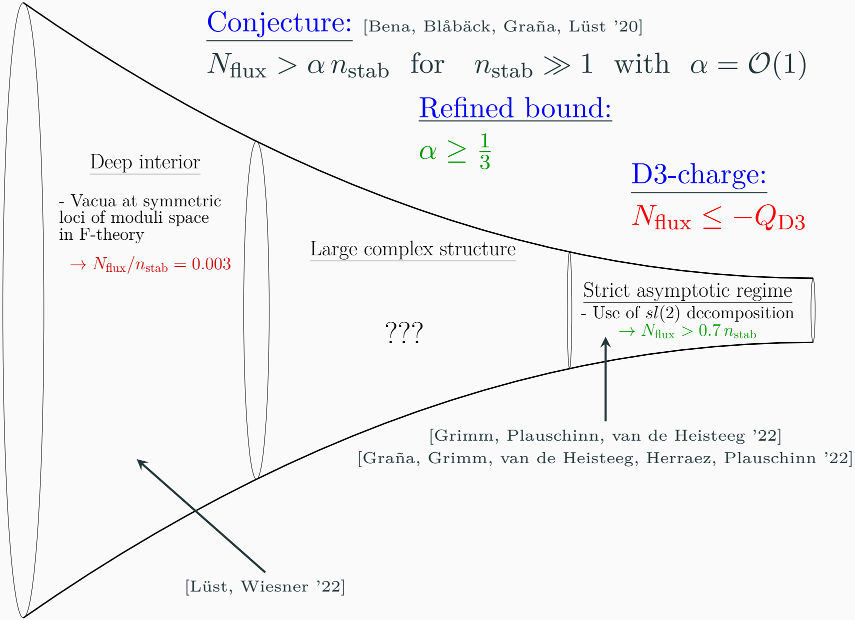

Type IIB flux compactifications and IIB1 scenario

- Axio-dilaton + CS sector
- Three-form fluxes:

$$\left(\int_{B^I} F_3, \int_{A_I} F_3\right) = (f_0^B, f_i^B, f_A^0, f_A^i) \quad | \quad H_3: \ (h_0^B, h_i^B, h_A^0, h_A^i)$$

IIB1 flux configuration: $f_A^0 = 0$, $h_A^0 = 0$ and $h_A^i = 0$
[Marchesano, Prieto, Wiesner '21]

W is quadratic $\Longrightarrow$ simple linear system for axions + saxions
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$\Longrightarrow$ Efficiently scan flux space $\longrightarrow$ Solutions in the LCS regime

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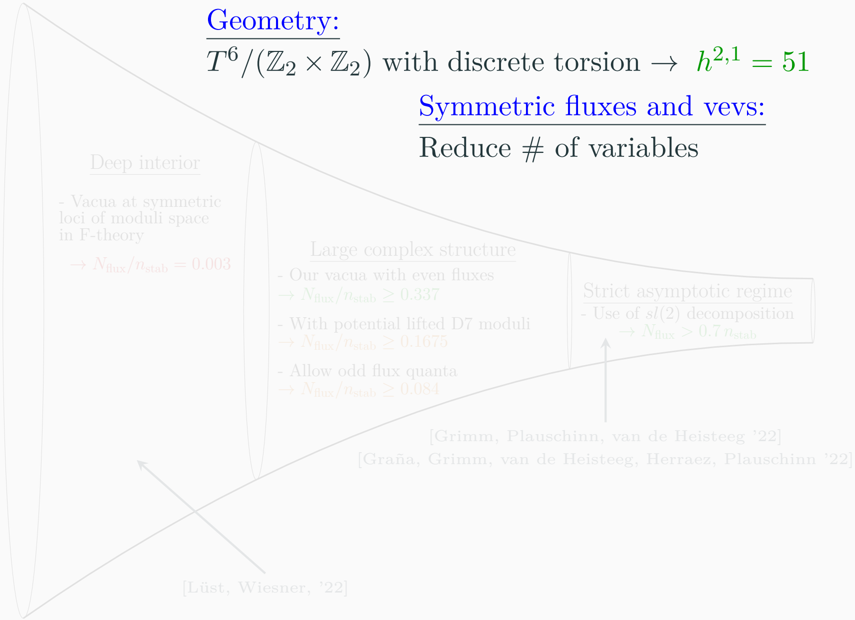
Results

<u>Geometry:</u>

$T^6/(\mathbb{Z}_2 \times \mathbb{Z}_2)$ with discrete torsion $\rightarrow$ $h^{2,1} = 51$

<u>Symmetric fluxes and vevs:</u>

Reduce # of variables



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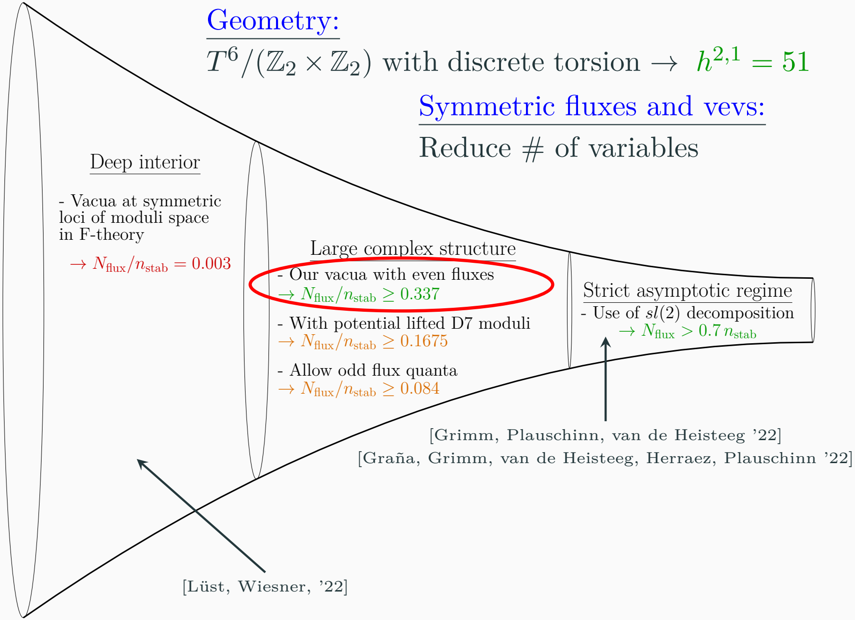

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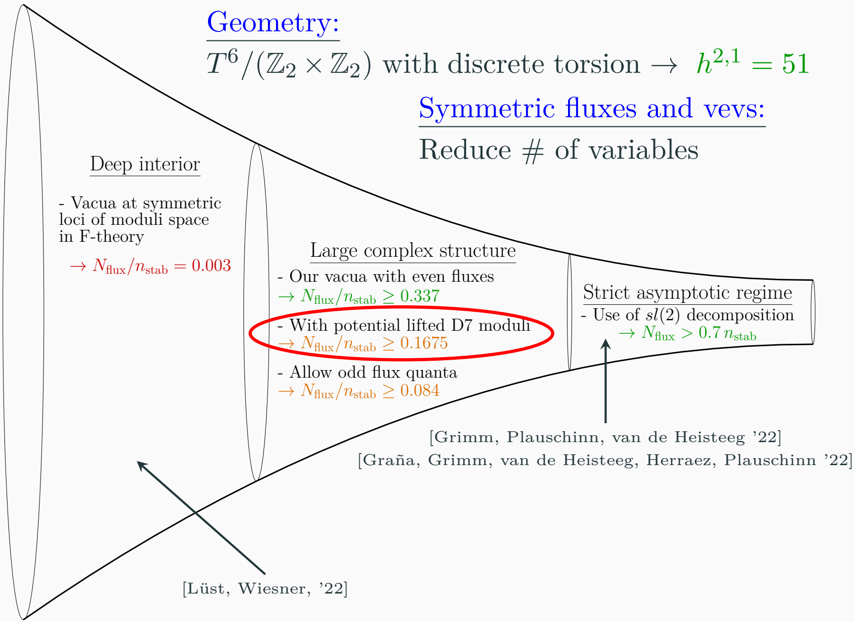

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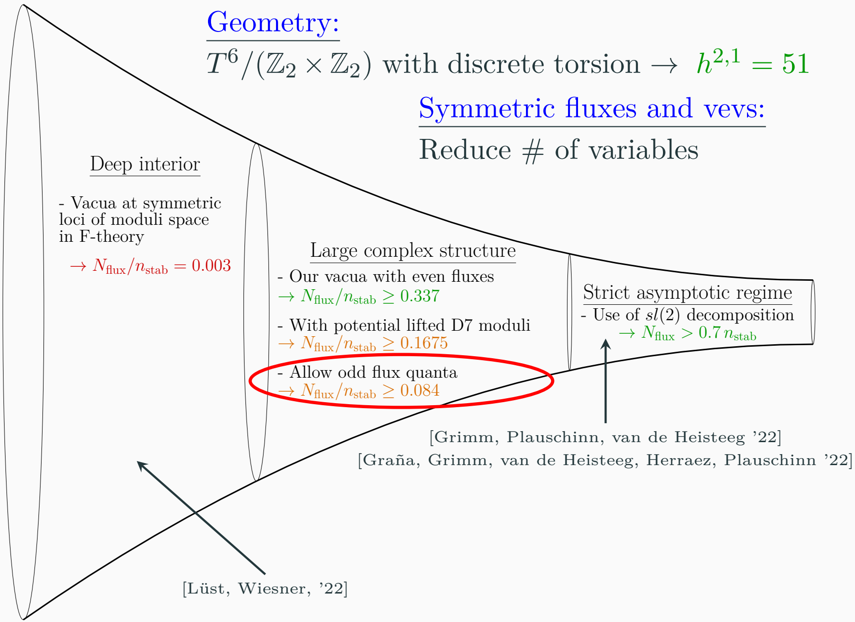

Thank you for your attention!

Papers: 2212.02533 and 2304.04789

KU LEUVEN

T-duality building blocks in stringy corrections

based on 2210.16593, 2108.04370 [MD, James Liu]

Marina David, KU Leuven

25 April 2023 EuroStrings

Motivation

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Use manifest symmetries $\rightarrow$ T-duality, constrains background to be $O(d,d)$ invariant

Strategy

- revisit higher derivative corrections

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Type II String Theory —compactification→ d-dimensional EFT

- formulate $O(d,d)$ invariant building blocks

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Bounds on quantum evolution complexity via lattice cryptography

Gongshow Eurostrings 2023

Marine De Clerck

University of Cambridge

Based on work with B. Craps, O. Evnin, P. Hacker and M. Pavlov (arXiv:2202.13924).

Nielsen's complexity in a nutshell

Quantum computing: what is the smallest number of simple gates needed to construct a given unitary:

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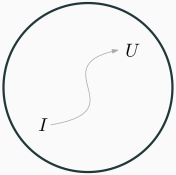
Nielsen geometrized this idea and defined the complexity via the **shortest length** between the identity and U on the manifold of unitaries



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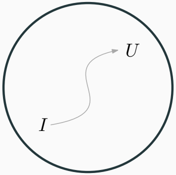

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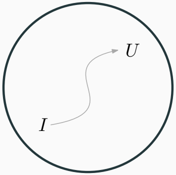

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Goal

Apply Nielsen's complexity to dynamical models and characterize their unitary evolution operator $U = e^{-iHt}$.

A practical upper bound on Nielsen's complexity

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Variational ansatz: Restrict the minimization to curves of constant velocity

$\rightarrow$ using the boundary conditions, one finds:

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with $$Q_{nm} \equiv \delta_{nm} - \sum_{\alpha} \langle n|T_\alpha|n\rangle\langle m|T_\alpha|m\rangle.$$

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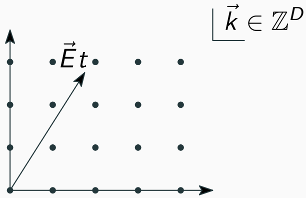

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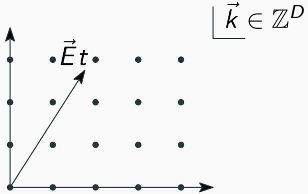
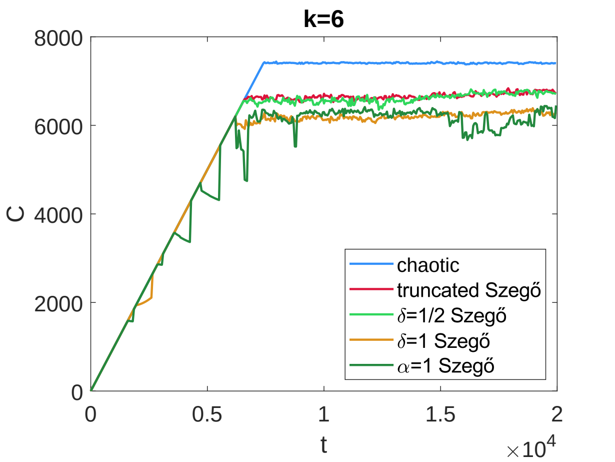


Question

Is this upper bound sensitive to different types of dynamics ?

Integrable models have lower complexity



In an upcoming paper,[1] we demonstrate that:

- **random matrix theory** can be used to understand the behavior of our bound for generic chaotic models
- the complexity reduction in **integrable systems** originates from **shortcuts** on the manifold of unitaries that appear when **conserved operators** point in 'easy' directions

[1] with B. Craps, O. Evnin and P. Hacker.

Unifying the 6D N = (1,1) String Landscape

Bernardo Fraiman (CERN)

Based on

arXiv:2209.06214 [with H.P de Freitas]

Eurostrings Gijón 2023 | Gong-Show talk

What kind of QFTs can be coupled to gravity?

$\rightarrow$ Exploration of string landscape.

Restricting to **16** supercharges $\longrightarrow$ it seems possible to **be exhaustive**.

In $D = 10$: $E_8 \times E_8$ and SO(32) string theories $\rightarrow$ fixed gauge symmetry

In $D \leq 9$: Het on T^d $\rightarrow$ rank **16+*d*** *simply*-laced groups
Complete classification for $D \geq 6$
studying **charge lattices.**

[Font, BF, Graña, Núñez, P. de Freitas '20]
[BF, P. de Freitas '21]

Theories with **reduced rank** symmetries $\rightarrow$ Het. on orbifolds, M-th., F-th, IIA on K3 with frozen sing. Also *doubly* and *triply*-laced groups.

In D = 6 there are **17** known theories:

[Narain '85] Narain theory (Het on T^4)

[de Boer et al. '01]
- M-theory on $(\mathrm{K3} \times S^1)/\mathbb{Z}_n$ with n = 2 to 8
- M-theory on $(T^4 \times S^1)/\mathbb{Z}_n$ with n = 2, 3, 4, 6
- Het on $T^4/(\mathbb{Z}_2 \times \mathbb{Z}_2)$ (quadruple)

[Dabholkar, Harvey '98] IIA on $T^4/\mathbb{Z}_5$ (string island)

[P. de Freitas, Montero '22] F-th. on $S^1 \times (T^4 \times S^1)/\mathbb{Z}_n$ (θ angle) with n = 2, 3, 4

Our construction reproduces all of them and predicts 30 more!

Connections between these theories: rank reduction **maps** on gauge **groups.**

$\mathcal{M}_{17} \to \mathcal{M}_9,\ \mathcal{M}_{17} \to \mathcal{M}_1,\ \mathcal{M}_{17} \to \mathcal{M}_1',\ \mathcal{M}_{17} \to \mathcal{M}_1''$

$\mathcal{M}_{17}$	$\mathcal{M}_9$	$\mathcal{M}_1$	$\mathcal{M}_1'$	$\mathcal{M}_1''$
Narain	CHL	M on KB	DP, θ = 0	DP, θ = π

[BF, P. de Freitas '21]

[P. de Freitas '22]

The map:

In D = 6, map acts on vacua at the level of gauge groups, only if they have nontrivial topology.

$$\frac{Spin(32)}{\mathbb{Z}_2} \quad \rightarrow \quad Spin(17)$$

(Rank reduced by 8)

$$\frac{E_6 \times E_6 \times E_6}{\mathbb{Z}_3} \quad \rightarrow \quad G_2 \times G_2 \times G_2$$

(Rank reduced by 12)

Transformation is determined by **element of fundamental group** and maps to a given moduli space.

Classification of **gauge groups** **=** Classification of **moduli spaces**

(In Narain moduli space)

Conclusions:

- ✓ 17 known moduli spaces in D = 6 with 16 supercharges are **related through map** according to gauge group topology.
- ✓ This map naturally predicts a total of **47 moduli spaces** in an unified way.
- ✓ 16 of these moduli spaces are **UV completions of pure SUGRA** (1 is known).
- ✓ **Odd rank** reduction is possible in D = 6.

Future work:

- ❑ How can these new theories be constructed?
- ❑ Generalization to **less (or none) supercharges**.
- ❑ Explain this structure trough swampland constraints.

Thank you very much!

Black holes' quasinormal modes from $\mathcal{N} = 2$ gauge theory and integrability

Daniele Gregori

Nordic Institute for Theoretical Physics (NORDITA), Stockholm, Sweden

Eurostrings 2023, Apr 25th 2023

Based on: arXiv:2208.14031, arXiv:2112.11434, arXiv:1908.08030

with Davide Fioravanti (INFN, Univ. Bologna) and Hongfei Shu (BIMSA)

On quantum integrability and $\mathcal{N} = 2$ gauge theory

- Broadly speaking, integrability can be considered as the study of **non-linear** phenomena in nature in a quantitative **exact way (non perturbative)**.
- The hallmark of quantum integrability is the presence of **infinite (local) integrals of motion commuting** with each other

$$[\mathbf{I}_{2n-1}, \mathbf{I}_{2m-1}] = 0\,, \tag{1}$$

which are also asymptotic expansion coefficients of the **Baxter's Q operator**

$$\ln \mathbf{Q}(\theta) \simeq -C_0 e^{\theta} - \sum_{n=1}^{\infty} e^{\theta(1-2n)} C_n \mathbf{I}_{2n-1} \qquad \theta \to +\infty\,. \tag{2}$$

- Integrable structures appear also in **4D SUSY gauge theories**, typically with $\mathcal{N} = 4$ supersymmetry (AdS/CFT correspondence) but also with $\mathcal{N} = 2$.
- In $\mathcal{N} = 2$ SUSY, the **prepotential** $\mathcal{F}$ is obtained from **gauge periods** a, a_D of Seiberg-Witten differential λ as

$$(a, a_D) = \oint_{A,B} \lambda(x)\, dx\,, \quad a_D = \frac{\partial \mathcal{F}}{\partial a} \quad \Longrightarrow \quad \mathcal{F} \tag{3}$$

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Three different physical theories, same mathematics!

- The **ODE/IM correspondence** allows to derive the integrability structures from some ODE. In particular, the Q **function** (vacuum eigenvalue of Q operator) is defined as

$$Q = W[\psi_+, \psi_-] \qquad \text{with} \qquad \psi_\pm(y) \to 0 \quad y \to \pm\infty \,. \tag{4}$$

$$-\frac{d^2}{dy^2}\psi(y) + \left[2e^{2\theta}\cosh y + P^2\right]\psi(y) = 0 \quad \text{INTEGRABILITY (sd-Liouville)} \tag{5}$$

$$\frac{\hbar}{\Lambda_0} = \frac{\epsilon_1}{\Lambda_0} = e^{-\theta} \qquad \frac{u}{\Lambda_0^2} = \frac{1}{2}P^2 e^{-2\theta} \qquad \Downarrow \tag{6}$$

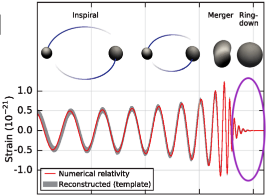
$$-\frac{\hbar^2}{2}\frac{d^2}{dy^2}\psi(y) + [\Lambda^2\cosh y + u]\psi(y) = 0 \quad \mathcal{N} = 2 \text{ NS GAUGE TH. } (SU(2)\ N_f = 0) \tag{7}$$

$$r = Le^{y/2} \quad \omega L = -2ie^{\theta} \quad P = \frac{1}{2}(l+2) \qquad \Downarrow \qquad \phi(r) = e^{y/2}\psi(y) \tag{8}$$

$$\frac{d^2\phi}{dr^2} + \left[\omega^2\left(1 + \frac{L^4}{r^4}\right) - \frac{(l+2)^2 - \frac{1}{4}}{r^2}\right]\phi(r) = 0 \quad \text{BLACK HOLES PERT. (D3 brane)} \tag{9}$$

Quasinormal modes in integrability and $\mathcal{N}=2$ gauge theory

- The **quasinormal modes (QNMs)** are the frequencies of the **damped oscillations** in the **ringdown phase** of BHs merging and have a direct connection to **GWs observations**.
- While **computing QNMs** is well understood in General Relativity, in **modified gravity theories** it is still a challenge and it is important to **develop new methods** (analytic and numeric).



- We proved that the **QNMs definition** is a **Bethe root** (zero) condition on the $Q = W[\psi_+, \psi_-]$ function

$$Q(\theta_n) = 0 \qquad \Longleftrightarrow \qquad Q(\theta_n \pm i\pi/2) = \pm i \,. \tag{10}$$

- We proved an **identification of Q function with the gauge period** from which it follows that QNMs are given also by it

$$Q(\theta, P) = \exp \frac{2\pi i}{\hbar} a_D(\hbar, u, \Lambda_0) \implies \frac{1}{\hbar} a_D(i\hbar, -u, \Lambda_0) = \frac{i}{2}\left(n + \frac{1}{2}\right) . \tag{11}$$

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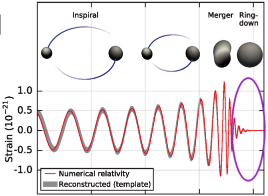

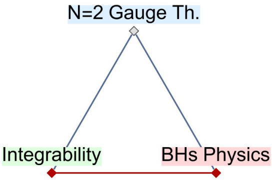

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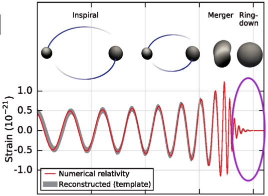

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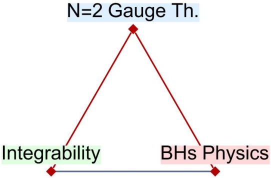

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Computing QNMs from Thermodynamic Bethe Ansatz

- The Q (or $Y = Q^2$) functions satisfy functional equations which can be inverted into the **Thermodynamic Bethe Ansatz (TBA)** for $\varepsilon(\theta) = -2\ln Q(\theta)$ (here for $SU(2)$ $N_f = 0$):

$$\varepsilon(\theta) = \frac{16\sqrt{\pi^3}}{\Gamma(\frac{1}{4})^2} e^{\theta} - 2\int_{-\infty}^{\infty} \frac{\ln\left[1+\exp\{-\varepsilon(\theta')\}\right]}{\cosh(\theta-\theta')} \frac{d\theta'}{2\pi}\,, \tag{12}$$

  with $\varepsilon(\theta, P) \simeq 8P\theta$, $l \sim P > 0$ as $\theta \to -\infty$.

- Through the we have a **new exact method to numerically compute QNMs**, through

$$\varepsilon(\theta_n - i\pi/2) = -i\pi(2n+1)\,. \tag{13}$$

- For now we have all this for **D3 branes** and **extremal black holes**, but we are working in its **generalization**.

n	l	TBA	Leaver
0	0	1.36912 − 0.504048i	1.36972 − 0.504311i
0	1	2.09118 − 0.501788i	2.09176 − 0.501811i
0	2	2.8057 − 0.501009i	2.80629 − 0.501000i
0	3	3.51723 − 0.500649i	3.51783 − 0.500634i
0	4	4.22728 − 0.500453i	4.22790 − 0.500438i

Table: Comparison of QNMs of the D3 brane from TBA (12) (through (13) with $n = 0$), Leaver method (with $L = 1$).

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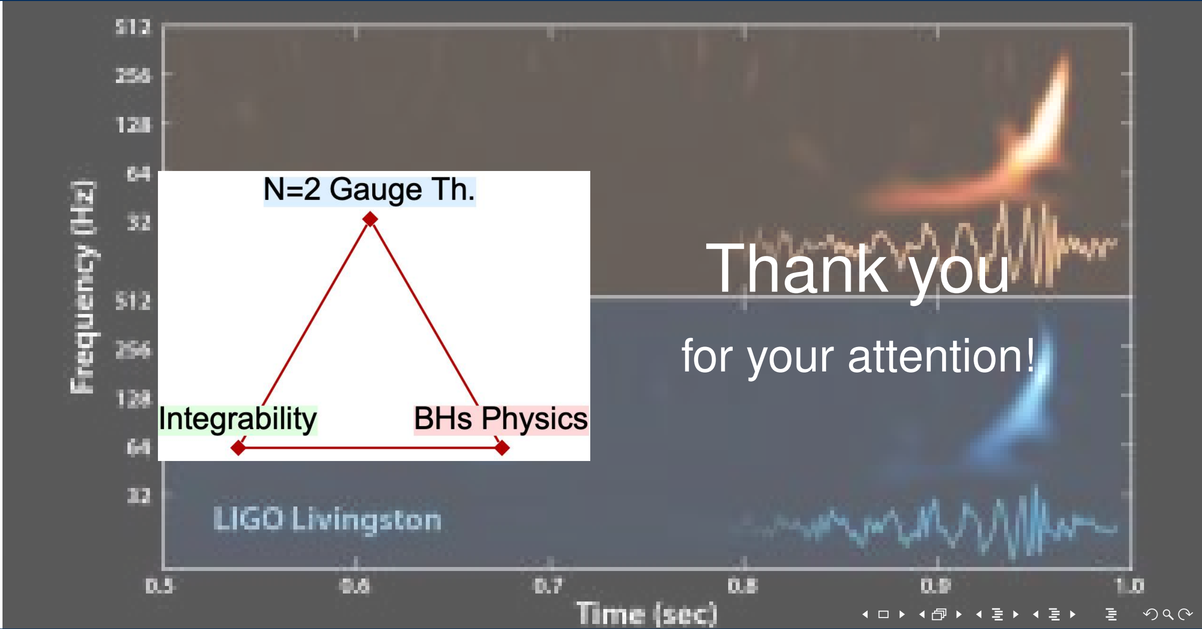


Thank you

for your attention!

Cubic vector model on the boundary

Sabine Harribey

Work in progress with Igor Klebanov and Zimo Sun

Eurostrings 2023 - April 25th - Gijón

NORDITA
The Nordic Institute for Theoretical Physics

General motivations

- Yang-Lee model: purely imaginary fixed point, no unitarity
- Cubic vector model: real stable IR fixed point for large N
- Complex fixed points for $N < N_{crit} \approx 1038.27$

What happens on a boundary?

- What is the range of N with real stable IR fixed points
- Can we find unitary fixed points?

Model

$$S[\phi] = \int d^{d+1}x \left[\frac{1}{2}\partial_\mu\phi_I(x)\partial^\mu\phi_I(x) + \frac{\lambda_4}{4!}\left(\phi_I(x)\phi_I(x)\right)^2\right] + \int d^d x\left[\frac{\lambda_1}{2}\,\phi_N(x)\phi_a(x)\phi_a(x) + \frac{\lambda_2}{3!}\phi_N^3\right]$$

$d = 3$:

- Cubic interaction marginal on the boundary
- Quartic interaction marginal in the bulk

$\Rightarrow$ Bulk interactions modify boundary fixed points

Results and future work

- $N = 1$: **Real** fixed points but **unstable**
- Large N:
  - Only **complex** fixed points
  - One pair of purely imaginary stable fixed points
- Critical N: no real fixed points for $N > N_{crit} = 7.1274 - 3.6951\epsilon$
- **Stable** fixed points always **purely imaginary**

- Dimensions of operators, CFT data
- $\epsilon = 1$: compare with plane defect of [Krishnan, Metlitski arXiv:2301.05728]?

New Inequalities in Extended Black Hole Thermodynamics

Robie A. Hennigar

ICCUB Institut de Ciències del Cosmos
UNIVERSITAT DE BARCELONA

Eurostrings 2023

Based on Work with Masaya Amo and Antonia Frassino (to appear)

What is Extended Thermodynamics?

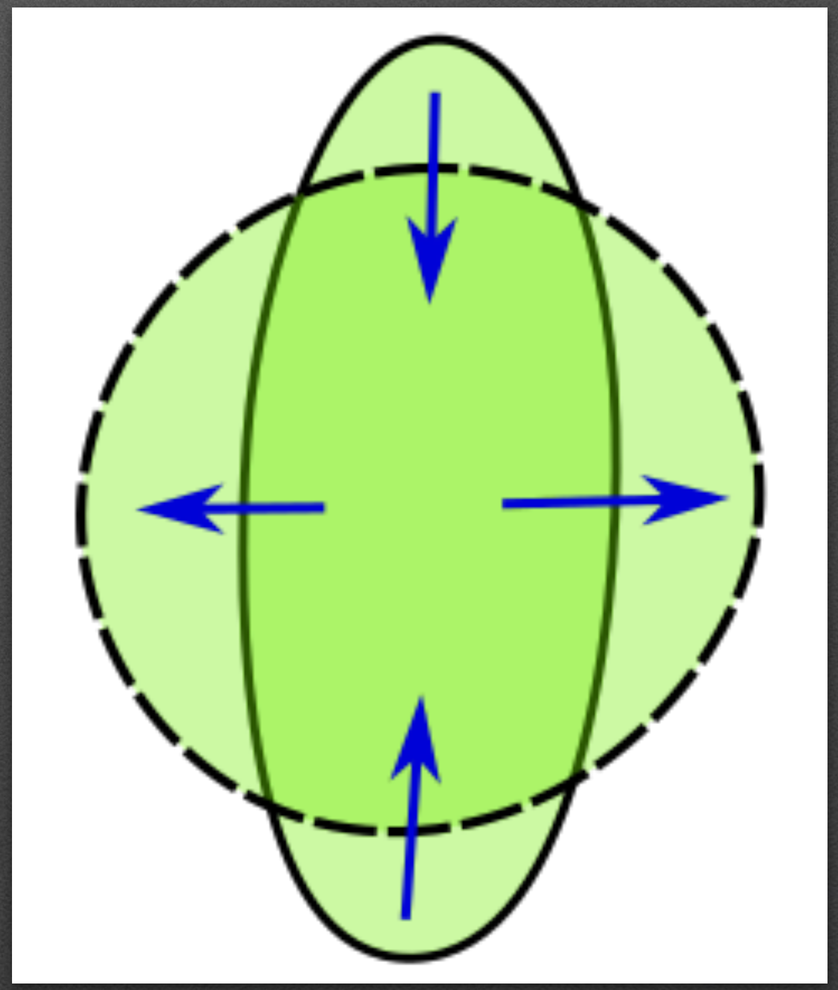
- Study the role of ***Pressure*** and ***Volume*** terms in the laws of black hole thermo
    - Pressure ⇔ Cosmological constant
    - Volume ⇔ Komar integrals
- Original motivation: Smarr's formula/first law with Λ

D. Kastor, J. Traschen, S. Ray [0904.2765]

The Reverse Isoperimetric Inequality

- CGKP: the thermodynamic volume and entropy satisfy a *reverse* isoperimetric inequality

$$\left(\frac{V}{\mathscr{V}_0}\right)^{1/(D-1)} \left(\frac{\mathscr{A}_0}{A}\right)^{1/(D-2)} \geq 1$$



- "Proof by example"

- No counter-examples for asymptotically AdS black holes in $D \geq 4$

M. Cvetic, G. Gibbons, D. Kubiznak, C. Pope [1012.2888]

Refining the Conjecture

- Our objective: Understand the necessary/sufficient conditions for the validity of the conjecture

$$\left(\frac{V}{\mathscr{V}_0}\right)^{1/(D-1)} \left(\frac{\mathscr{A}_0}{A}\right)^{1/(D-2)} \geq 1 \quad \Leftrightarrow \quad A(V) \leq A_{\mathrm{Schw}}(V)$$

- One path: Construct stronger versions; easier to find counter-examples? **Hierarchy of inequalities**

$$A(V,J) \leq A_{\mathrm{Kerr-AdS}}(V,J)$$

M. Amo, A. M. Frassino, R. A. Hennigar (to appear) [2305.?????]

Large N Partition Functions, Holography, and Black Holes

Junho Hong

Eurostrings 2023 Gijón

April 2023

2203.14981, 2210.09318, 2304.01734, & 2210.15326

with Nikolay Bobev, Valentin Reys, & Sunjin Choi

KU LEUVEN

Question & Approach

- String/M-theory: theories of quantum gravity!
- Question:

Path integral of string/M-theory beyond the 2-derivative supergravity approximation?

- Step I. AdS/CFT correspondence provides a stage:

$$Z_{\text{CFT}} = Z_{\text{string/M-theory}}\Big|_{\text{AdS solution}} .$$

- Step II. Supersymmetry (localization) allows for the exact calculation of

$$Z_{\text{SCFT}} = Z_{\text{string/M-theory}}\Big|_{\text{susy AdS solution}} .$$

Example: ABJM $\leftrightarrow$ M-theory, setup

3d $\mathrm{U}(N)_k \times \mathrm{U}(N)_{-k}$ ABJM theory $\leftrightarrow$ M-theory on $\mathrm{AdS}_4 \times S^7/\mathbb{Z}_k$

- **S_b^3 partition function**

$$Z_{\text{ABJM}}^{S_b^3} = Z_{\text{M-theory}}\Big|_{\textbf{Squashed AdS}_4 \times S^7/\mathbb{Z}_k}$$

- **$S^1 \times \Sigma_{\mathfrak{g}}$ topologically twisted index**

$$Z_{\text{ABJM}}^{S^1 \times \Sigma_{\mathfrak{g}}} = Z_{\text{M-theory}}\Big|_{\textbf{Reissner-Nordström AdS}_4\textbf{ BH} \times S^7/\mathbb{Z}_k}$$

- **$S^1 \times_\omega S^2$ superconformal index**

$$Z_{\text{ABJM}}^{S^1 \times_\omega S^2} = Z_{\text{M-theory}}\Big|_{\textbf{Kerr-Newman AdS}_4\textbf{ BH} \times S^7/\mathbb{Z}_k}$$

Evaluate them beyond the large N limit ($=$ 2-der sugra limit)!

Example: ABJM $\leftrightarrow$ M-theory, results

S_b^3 **partition function** $(Q \equiv b + b^{-1})$ [Bobev-JH-Reys 22] [Hristov 22] :

$$F_{\text{ABJM}}^{S_b^3} = -\log\left[\left(\frac{32}{\pi^2 k Q^4}\right)^{\frac{1}{3}} e^{\mathcal{A}_b(k)} \text{Ai}\left[\left(\frac{32}{\pi^2 k Q^4}\right)^{-\frac{1}{3}}\left(N - \frac{k}{24} - \frac{1}{k}\left(\frac{4}{Q^2} - \frac{2}{3}\right)\right)\right]\right] + \mathcal{O}(e^{-\sqrt{N}})\,.$$

$S^1 \times \Sigma_{\mathfrak{g}}$ **topologically twisted index** [Bobev-JH-Reys 22] :

$$F_{\text{ABJM}}^{S^1\times\Sigma_{\mathfrak{g}}} = \frac{\pi(1-\mathfrak{g})\sqrt{2k}}{3}\left[\left(N - \frac{k}{24} + \frac{2}{3k}\right)^{\frac{3}{2}} - \frac{3}{k}\left(N - \frac{k}{24} + \frac{2}{3k}\right)^{\frac{1}{2}}\right] + \frac{1-\mathfrak{g}}{2}\log\left(N - \frac{k}{24} + \frac{2}{3k}\right) - (1-\mathfrak{g})\hat{f}_0(k) + \mathcal{O}(e^{-\sqrt{N}})\,.$$

$S^1 \times_\omega S^2$ **superconformal index** $(\omega \to 0)$ [Bobev-Choi-JH-Reys 22] :

$$F_{\text{ABJM}}^{S^1\times_\omega S^2} = \frac{2}{\omega}\left[\frac{\pi\sqrt{2k}}{12}\left(N - \frac{k}{24} + \frac{2}{3k}\right)^{\frac{3}{2}} + \hat{g}_0(k)\right] + F_{\text{ABJM}}^{S^1\times\Sigma_{\mathfrak{g}=0}} + \mathcal{O}(\omega, e^{-\sqrt{N}})\,.$$

$\frac{1}{N}$-perturbative expansions of $F = -\log Z$ have closed-form expressions!

On non-supersymmetric fixed points in five dimensions

Francesco Mignosa (Technion)

TECHNION
Israel Institute
of Technology

Based on:
M.Bertolini, F.M., J.Van Muiden *JHEP 10 (2022) 064*

Eurostrings 2023, Gijón, 25/04/2023

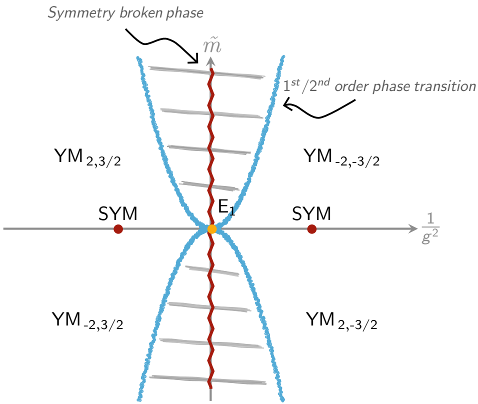
Brief motivation

- CFTs are interesting: second order phase transition, endpoints of RG flows, perturbative quantum gravity via AdS/CFT...;
- In 5d, CFTs only known thanks to SUSY and string constructions

Are there non-SUSY CFTs in 5d?

Soft SUSY breaking

SUSY breaking deformation $\tilde{m}$ of E_1 SCFT: PT at $1/g^2 \sim \sqrt{\tilde{m}}$;

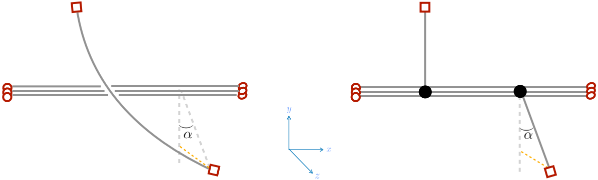


Order of phase transition?

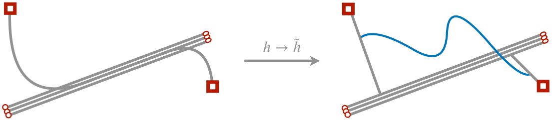
pq-web analysis

Generalization: $X_{1,N}$ theory at large N

- (1,-1) 5-brane in (1,1) bckg: distinct vacua if $1/g^2 < \sqrt{\tilde{m}}$:



- $1/g^2 \sim \tilde{h} \equiv \sqrt{\tilde{m}}$: single vacuum $\rightarrow$ 2nd order PT!



Thank you for the attention!

Universal aspects of holographic quantum critical transport with self-duality

Ángel Jesús Murcia Gil
Istituto Nazionale di Fisica Nucleare, Sezione di Padova (Italy)

Eurostrings 2023

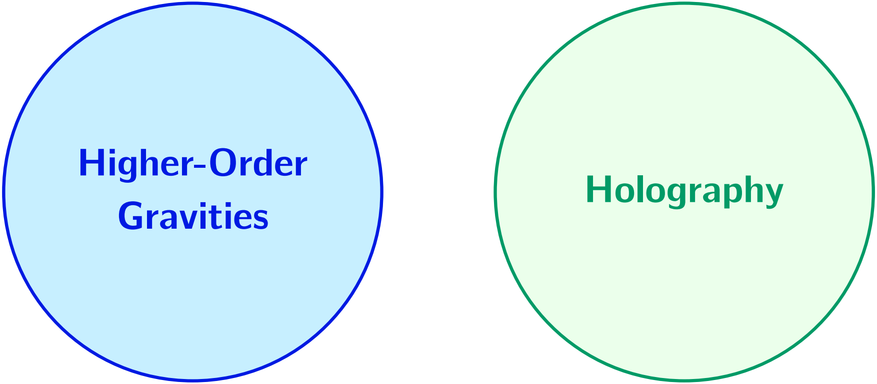
Gijón (Kingdom of Spain)

Based on arXiv:2304.08510

Carried out in collaboration with Dmitri Sorokin

Introduction

This work lies in the interface between **two fundamental realms** of today's **high-energy physics**:



Higher-order gravities

A **higher-order gravity** is characterized by the presence of (purely gravitational) **higher-curvature terms** like

$$R^2\,, \quad R_{\alpha\beta}R^{\alpha\beta}R_{\mu\nu\rho\sigma}R^{\mu\nu\rho\sigma}\,, \quad R^{27}R_{\mu\nu}R_{\alpha\beta}R^{\mu\alpha\nu\beta}\,.$$

and/or **matter terms** with nonminimal couplings to gravity, like

$$R^{14}F^2\,, \quad R^3R_{\mu\nu}F^{\mu\alpha}F^{\nu}{}_{\alpha}\,, \quad R^{\mu\nu\rho\sigma}F_{\mu\rho}F_{\nu\sigma}\,.$$

for a $\mathrm{U}(1)$ gauge vector with field strength $F_{\mu\nu}$.

A **higher-order gravity** is characterized by the presence of (purely gravitational) **higher-curvature terms** like

$$R^2\,, \quad R_{\alpha\beta}R^{\alpha\beta}R_{\mu\nu\rho\sigma}R^{\mu\nu\rho\sigma}\,, \quad R^{27}R_{\mu\nu}R_{\alpha\beta}R^{\mu\alpha\nu\beta}\,.$$

and/or **matter terms** with nonminimal couplings to gravity, like

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We focus on **higher-order extensions** of four-dimensional **Einstein-Maxwell** theory with **exact electromagnetic duality** invariance.

Such theories exist and have been fully characterized to quadratic order in $F_{\mu\nu}$ [Cano, Murcia '21].

Holographically, **theories** of **gravity** and **vector** field on **AdS** correspond to boundary **CFTs** with a **current** J_a.

Natural to compute the linear **response** of the current in presence of non-trivial **source** (given by boundary value of vector field).

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This is **encoded** in the **conductivity**. For CFT in flat space:

$$\sigma_j(\omega, k) = -\mathrm{Im}\left(\frac{C_{jj}}{\omega}\right), \quad j = \text{spatial directions},$$

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We have proven several **universal properties** of **conductivities** which hold in **every CFT holographic** to a general four-dimensional duality-invariant higher-order theory:

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¡Muchas gracias!

AdS_3 SOLUTIONS AND HOLOGRAPHY

ANAYELI RAMÍREZ

Università di Milano-Bicocca

Based on 2304.today with N. Macpherson

EUROSTRINGS 2023, GONG SHOW

In one sentence:

We provide two new AdS_3 classes of solutions to massive type IIA supergravity realising an $\mathfrak{osp}(n|2)$ superconformal algebra for $n = 5,6$

Motivation:

- AdS_3 geometries arise as near horizon geometries of 5d extremal BHs, so these scenarios are relevant for the microscopic description of BHs.
- Via the AdS/CFT correspondence one might presume that there is a 2d conformal field theory
    - 2d CFTs play a prominent role in string theory and provide the best arena to test the AdS/CFT correspondence.
    - The conformal group in 2d is infinite dimensional and this makes two dimensional CFTs much more tractable than their higher dimensional counterparts.

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- Canonical example: Near horizon of D1-D5 system.

$AdS_3 \times S^3 \times CY_2$ geometry realising small (4,4) superconformal symmetry

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(Giveon, Kutasov and Seiberg ' 98)
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Goal: We partially fill this gap by finding two new classifications of AdS_3 solutions to massive IIA supergravity with an $\mathfrak{osp}(n|2)$ superconformal algebra, for $n = 5,6$, with a view towards holography

The strategy:

- We seek solutions AdS_3 solutions of type II supergravity with a superconformal algebra

$$\mathfrak{sl}(2) \oplus \mathfrak{so}(n) \quad \text{for} \quad n = 5,6$$

We want supersymmetric solutions,

$(6,0)$: $SO(6)$ R-symmetry ➡ $\mathbb{CP}^3$

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Geometrically,

$$ds^2 = e^{2A} ds^2_{\text{AdS}_3} + \frac{1}{4}\overbrace{\left(e^{2C} ds^2_{\text{S}^4} + e^{2D} \underbrace{(Dy_i)^2}_{\textit{fibered } S^2}\right)}^{\widehat{\mathbb{CP}}^3} + e^{2k} dr^2$$

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- We set up our work in terms of pure spinor formalism, which implies the construction of spinors that ensure consistency with the superconformal algebra $\mathfrak{sl}(2) \oplus \mathfrak{so}(n)$
- Exploit an existing $\mathcal{N} = 1$ AdS_3 classification to obtain sufficient conditions on the geometry and fluxes for a solution with $\mathcal{N} = (5{,}0)$ in IIA to exist.

(Dibitetto, Lo Monaco, Passias, Petri, Tomasiello' 18)
(Passias, Prins' 19)
(Macpherson, Tomasiello' 21)

Results:

The local $\mathcal{N} = (5,0)$ are defined in terms of two functions, $h(r)$ and $u(r)$,

$$\frac{ds^2}{2\pi} = \frac{|hu|}{\sqrt{\Delta_1}} ds^2_{\text{AdS}_3} + \frac{\sqrt{\Delta_1}}{4|u|}\left[\frac{2}{|h''|}\overbrace{\left(ds^2_{\text{S}^4} + \frac{1}{\Delta_2}(Dy_i)^2\right)}^{\widehat{\mathbb{CP}}^3} + \frac{1}{|h|}dr^2\right], \qquad e^{-\Phi} = \frac{\sqrt{|u|}\,|h''|^{\frac{3}{2}}\sqrt{\Delta_1}}{2\sqrt{\pi}\Delta_2^{\frac{1}{4}}},$$

$$\Delta_1 = 2hh''u^2 - (uh' - hu')^2, \qquad \Delta_2 = 1 + \frac{2h'u'}{uh''}, \qquad B_2 = 4\pi\left[\left(\frac{uh' - hu'}{uh''} - (r-k)\right)J_2 + \frac{u'}{2h''}\left(\frac{h}{u} + \frac{hh'' - 2(h')^2}{2h'u' + uh''}\right)(J_2 - \tilde{J}_2)\right].$$

the RR sector: $F_0 = -\frac{1}{2\pi}h'''$, $\qquad F_2 = B_2F_0 + 2(h'' - (r-k)h''')J_2$, $\qquad F_4 = -\pi \text{vol}_{\text{AdS}_3} \wedge d\left(h' + \frac{hh''u(uh' + hu')}{\Delta_1}\right)$ + magnetic terms.

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- Supersymmetry implies $u''=0$ globally
  - $u'=0$ we have a round $\mathbb{CP}^3$ → $\mathfrak{osp}(6|2)$ AdS_3 solutions
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- Bianchi identities imply $h''''=0$
  - Locally $\quad h=c_0+c_1r+\frac{1}{2}c_2r^2+\frac{1}{3!}c_3r^2$
  - Globally h''' can be discontinuities which imply D8 sources

Conclusions & Open problems

- We present two new AdS_3 solutions to massive type IIA, for the case of an $\mathfrak{osp}(n|2)$ superconformal algebra with $n = 5,6$
  - These solutions suggest new (6, 0) and (5, 0) quiver SCFTs
  - CFT side appears undeveloped but AdS/CFT suggests such constructions exist

- In the massless $\mathcal{N} = (6,0)$ case, we obtain the $AdS_4 \times \mathbb{CP}^3$
  - Can construct duals to CFT_3
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Thank you!

Cosmic Strings and Celestial Entanglement

Ronnie Rodgers, with **Federico Capone,** A. O'Bannon, S. Thakur, E. Parisini

NORDITA

Asymptotically flat space:

$$\mathrm{d}s^2 = -\,\mathrm{d}u^2 - 2\,\mathrm{d}u\,\mathrm{d}r + \frac{4r^2}{(1+|z|^2)^2}\mathrm{d}z\,\mathrm{d}\bar{z} + \ldots$$

Superrotations:

$$z \to w(z) + \ldots \qquad u \to \frac{1+|z|^2}{1+|w|^2}|w'|\,u + \ldots \qquad r \to \frac{1+|w|^2}{1+|z|^2}\frac{1}{|w'|}r + \ldots$$

= Lorentz transformations

when $w(z) = \dfrac{az+b}{cz+d}$

Celestial holography: 4D flat space scattering amplitudes = 2D CFT correlators

[He-Mitra-Strominger, Pasterski-Strominger-Shao, …]

Conformal transformations ⟷ **Superrotations**

$$w(z) = \left(\frac{z - z_1}{z - z_2}\right)^{1/n}$$

Uniformisation map

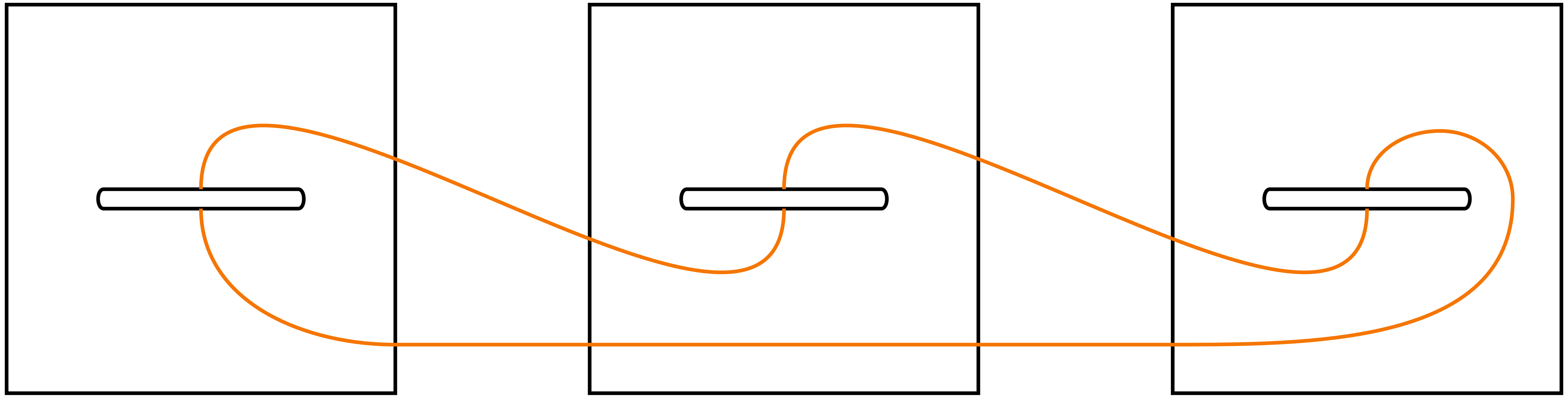
Entanglement entropy via replica trick

[Calabrese-Cardy]

Cosmic string

Bulk conical singularity

[Penrose, Strominger-Zhiboedov]



c.f. AdS/CFT [Ryu-Takayanagi, Lewkowycz-Maldacena, Dong]

Partition function with cosmic string:

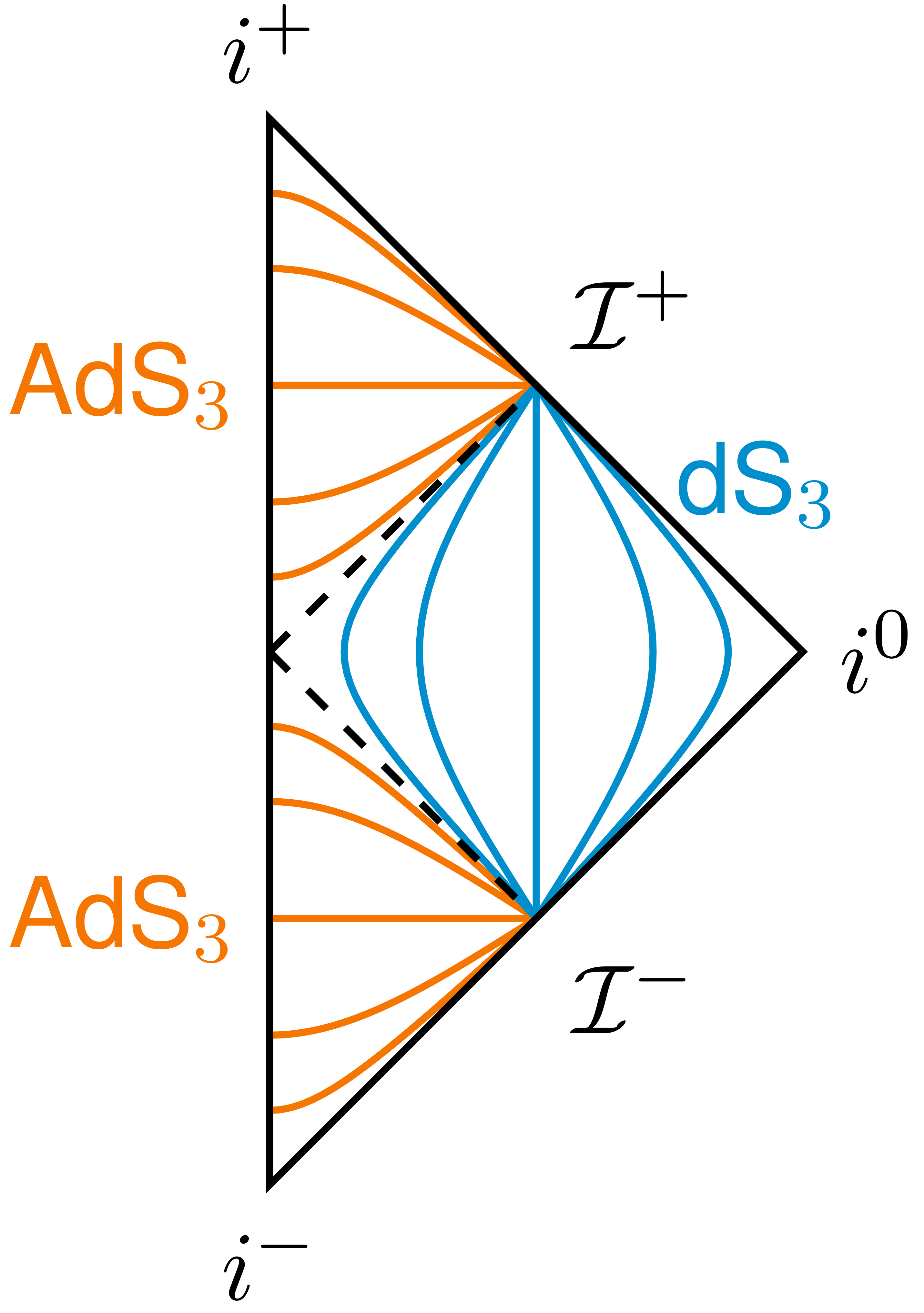
$$S_n = \frac{c}{6}\left(1+\frac{1}{n}\right)\log\left[\frac{2}{\epsilon}\sin\left(\frac{\ell}{2}\right)\right]$$

$$c = \frac{3iL^2}{4G_N}$$

Outlook:

Multiple intervals?

Higher dimensions?



T-linear resistivity and optical conductivity for a holographic local quantum critical metal in a periodic potential

F.Balm, N. Chagnet, S. Arend, J. Aretz, K. Grosvenor, M. Janse, O. Moors, J. Post, V. Ohanesjan, D.R.F., K. Schalm, J. Zaanen

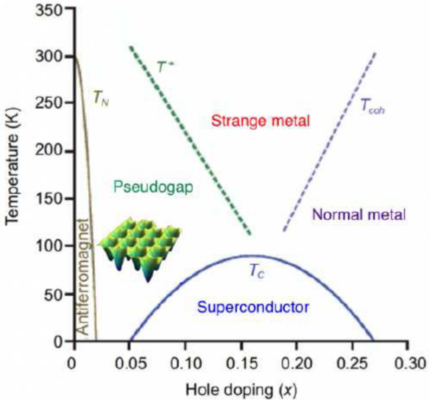
Based on
arXiv:[2211.05492]

Instituto de Física Teórica

April 25, 2023

Motivation

- High T_c superconductors have been widely explored, both theoretically and experimentally
- Cuprates display a phase whose properties elude Fermi liquid theory ($\rho \sim T$)



The ions that conform the crystal lattice interact with the flowing electrons (**Umklapp effect**). The lattice breaks translational invariance.

In our work, we examine the gauge dual to the **Gubser-Rocher (GR)** geometry with 2-Dim/1-Dim lattice potential (ESB).

$$S = \frac{1}{16\pi G_N} \int d^4x \sqrt{-g} \left[R - \frac{Z(\phi)}{4} F^2 - \frac{1}{2} \partial(\phi)^2 + V \right]$$

$$Z(\phi) = exp\left(\phi/\sqrt{3}\right), V(\phi) = \frac{6}{L^2} \cosh\left(\phi/\sqrt{3}\right)$$

This model is a consistent truncation of d $=$ 11 supergravity compactified on $AdS_4 \times S_7$

ESB given by

$$\mu(x, y) = \mu\{1 + A[\cos(Gx) + \cos(Gy)]\}$$

Comment

At large lattice potentials, momentum is strongly broken. The system approaches the incoherent metal regime [Hartnoll]. Hydrodynamics relies then only on energy and charge conservation.

Results

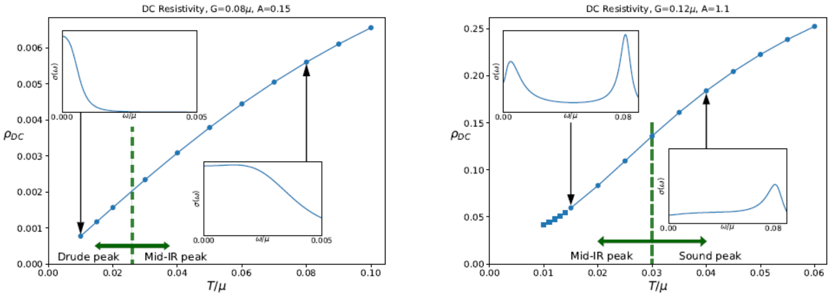


Figure: DC resistivity at small ($A = 0.15$, left panel) and intermediate ($A = 1.1$, right panel) lattice potential of the GR metal.

$$\boxed{\rho_{DC} \sim T \text{ reasonably good at } T/\mu \ll 1}$$

We define

$$\mathrm{FSum}(\Delta) \int_0^{\Delta} \sigma(\omega) \mathrm{d}\omega, \;\; \Gamma^{-1}_{\text{corrected}} = \sigma_{\mathrm{DC}}/\mathrm{FSum}(\Delta), \;\; \Gamma_{\text{bare}} = \sigma_{\mathrm{DC}}/\omega_{\mathrm{p}}^2$$

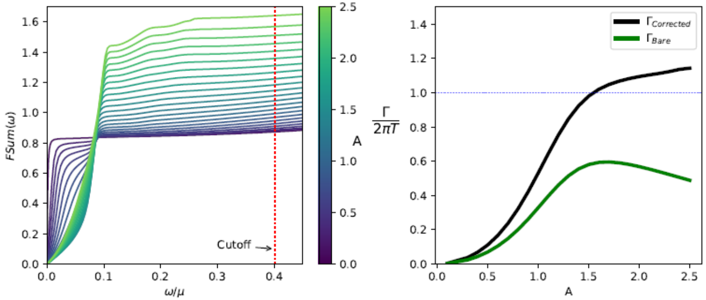
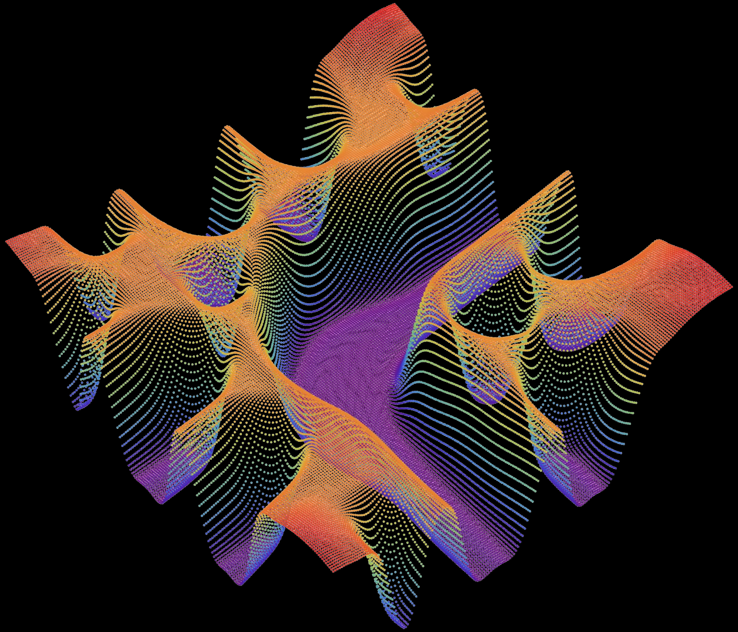


Figure: Left figure: *FSum* as a function of ω/μ. Right figure: "Bare" and "corrected" relaxation rates. Data for 1D GR model with $T = 0.06\,, G = 0.12$

At large A, the saturation of $\Gamma^{-1}_{\rm bare}$ is not exact, whilst the saturation of $\Gamma^{-1}_{\rm corrected}$ it is

$$\Gamma^{-1}_{\rm corrected} \sim 2\pi T\,, (\tau_{\rm GR} \sim \hbar/(2\pi k_B T))\,.$$

Gravitational Waves from First Order Phase Transitions



European Research Council
Established by the European Commission

Mikel Sanchez Garitaonandia

ÉCOLE POLYTECHNIQUE

First Order Phase Transitions

First-order phase transitions are common in nature

Presumably also in Neutron Star mergers and the Early Universe

Naturally induce out-of-equilibrium physics ⟶ Gravitational Waves

No FOPT in the SM and QCD phase diagram is unknown

Detecting GW means potential observation of new/unknown physics

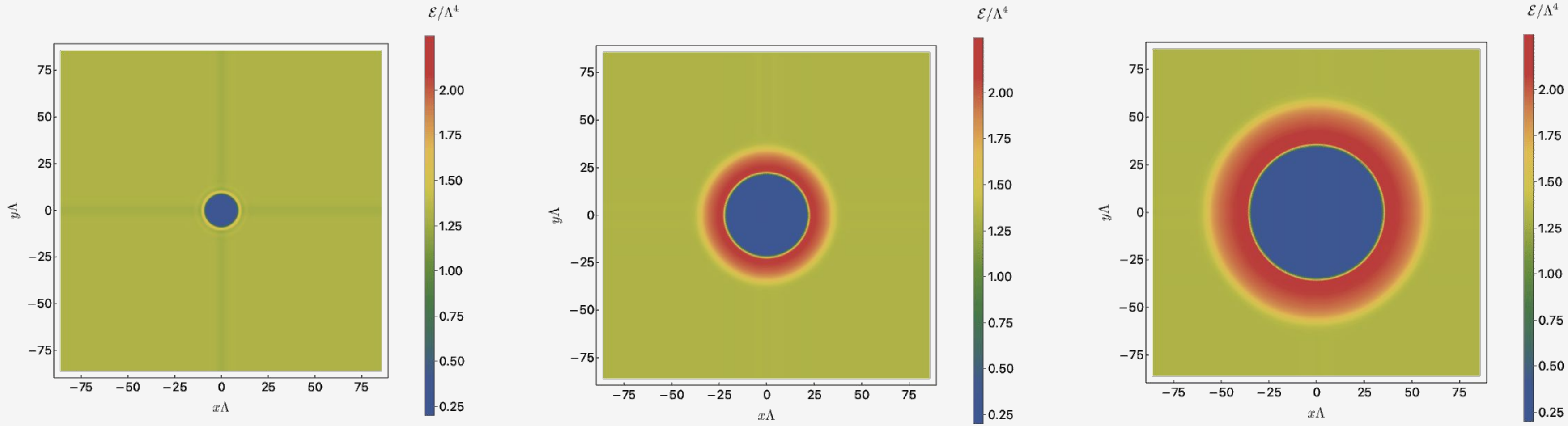
Bubble dynamics and GW

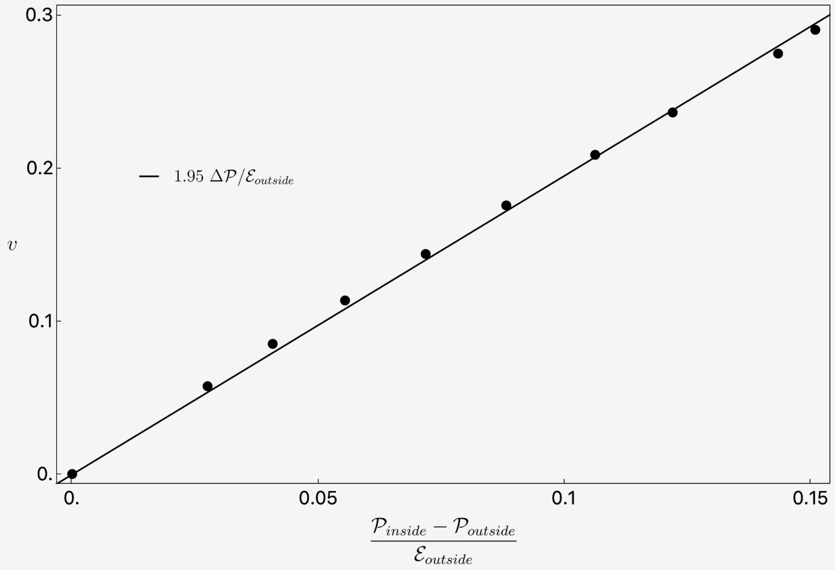
FOPT get realized through nucleation of bubbles on the metastable phase

Bubbles expand and their collision drives the system out of equilibrium

Crucial parameter is the wall speed: out-of-equilibrium ⟶ Holography

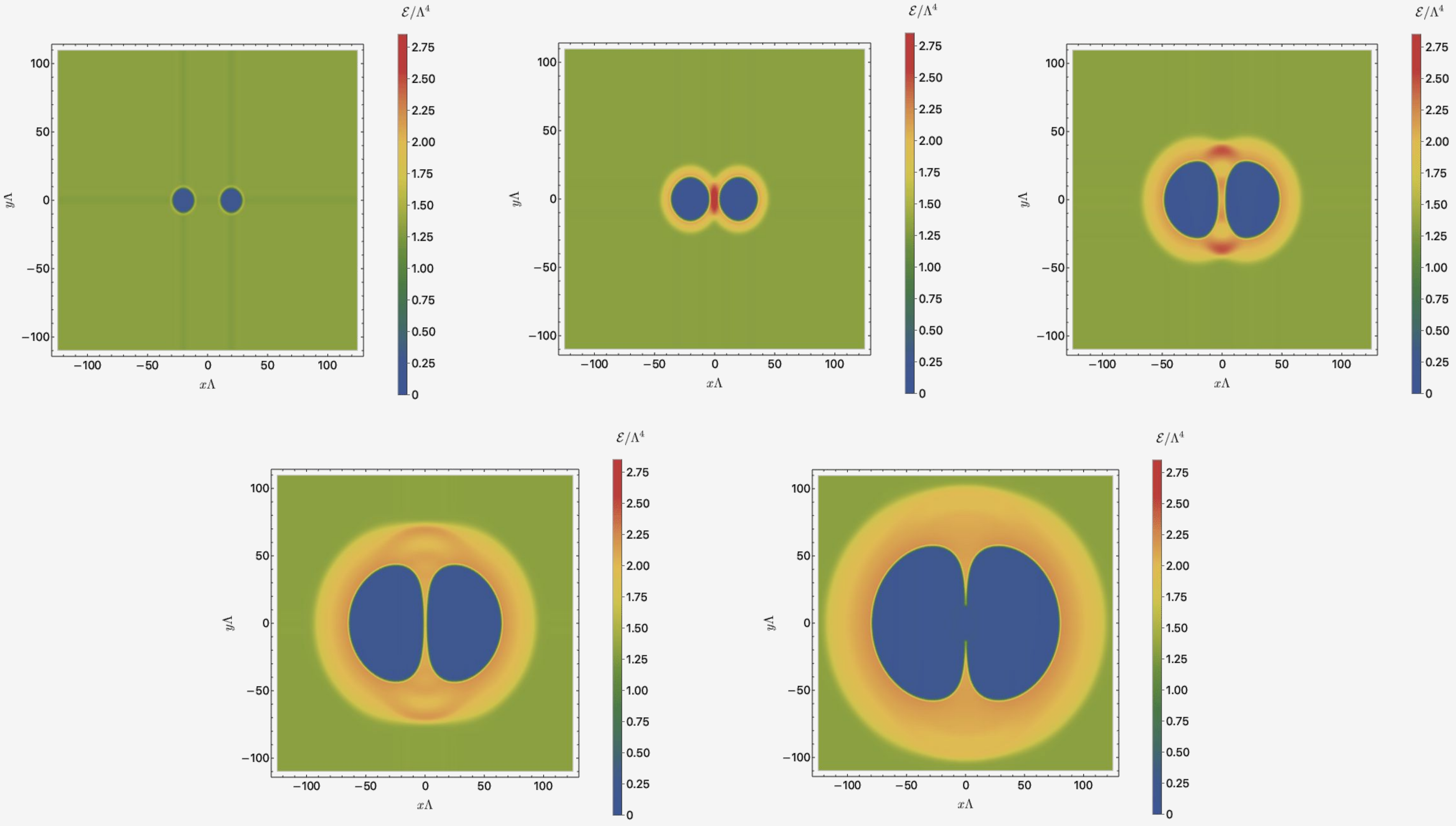
Direct signal from FOPT in NS mergers not considered in the past





Bea, Casalderrey-Solana, Giannakopoulos, Mateos, MSG, Zilhão ‘21

Bea, Casalderrey-Solana, Giannakopoulos, Jansen, Mateos, MSG, Zilhão ‘22



$\mathcal{E}/\Lambda^4$
$x\Lambda$
$y\Lambda$

GW from FOPT in NS mergers

Simple arguments suggest that the signal is peaked in MHz >> kHz

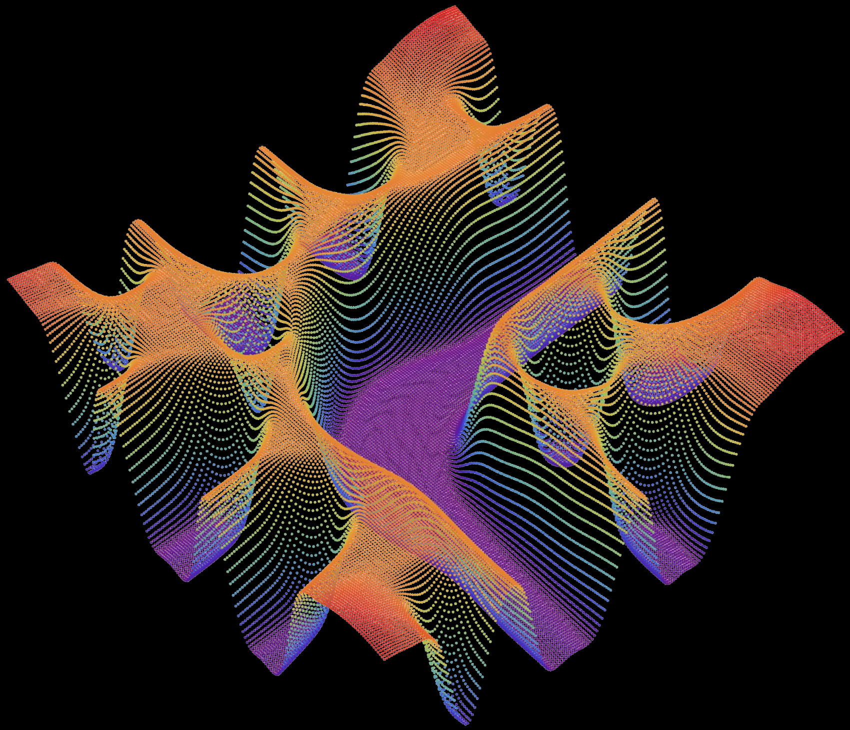
Casalderrey-Solana, Mateos, MSG ‘22

Potentially observable by future superconducting radio-frequency detectors

D’Agnolo ‘21

Holography can help understanding the dynamics of bubbles at finite density and at strong coupling

Thank you!



5d theories, defects and F-theorems

with Christoph Uhlemann *(out very soon!)*

Leonardo Santilli

丘成桐数学科学中心
YAU MATHEMATICAL SCIENCES CENTER

Yau Mathematical Sciences Center
Tsinghua University, Beijing

Gijón, Spain
April 25, 2023

Goal: To study **codimension 2 defects** in 5d CFT with 8 supercharges.

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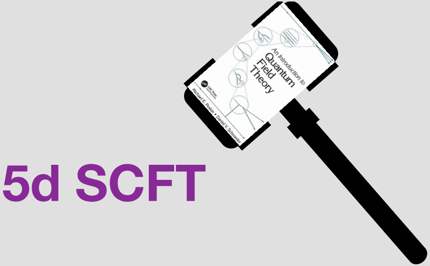
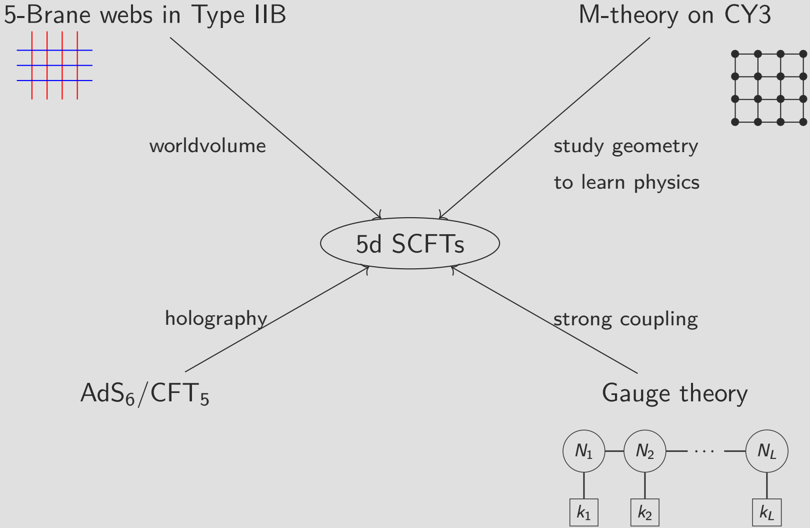
Problem: 5d SCFTs are strongly coupled.



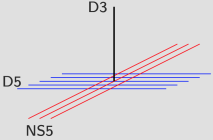
$\Longrightarrow$ Need better tools.

5d SCFTs, string and M-theory



3d defects in 5d SCFTs

D3-brane ⊥ 5-brane web in Type IIB

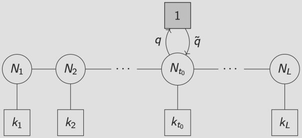


M5-brane on Lagrangian $\mathfrak{L} \subset$ CY3

3d defects $\subset$ 5d SCFTs

$\mathrm{AdS}_4 \subset \mathrm{AdS}_6$

3d chirals on S^3 $\subset$ 5d gauge theory on S^5



Defect F-maximization

Massive deformations of the defect $\Longrightarrow$ Defect **F-theorem** $F_{UV} > F_{IR}$.

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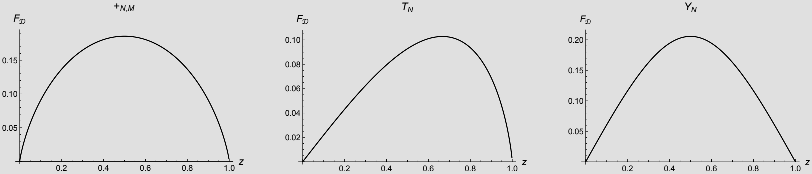
?
- 3d defects in 5d gauge theory $\Longrightarrow$ 1 parameter = position along quiver.
- 3d defects in 5d SCFT $\Longrightarrow$ no parameter.

F-maximization along the quiver gives conformal defect.

Defect RG flows $\Longrightarrow$ defects attached to other nodes.



Summary

Study 3d defects inside 5d *linear* quiver SCFTs, via:

- D3-brane defects in Type IIB 5-brane webs;
- M5-brane on Lagrangian inside toric CY3;
- AdS_4 defect inside AdS_6;
- 3d chiral multiplets inside 5d gauge theory.

Many 3d defects in 5d gauge theory $\xrightarrow{?}$ one 3d defect in 5d SCFT:

$$\boxed{\text{F-maximization of position of defect along quiver}}$$

2 deformations: mass & position $\Longrightarrow$ Defect F-theorem.

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Thank you for your attention.

EuroStrings 2023 Gong Show

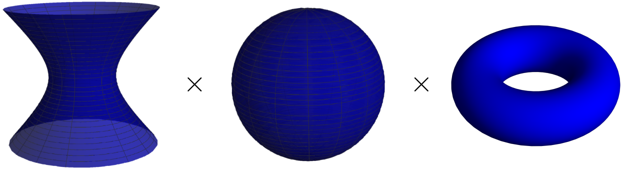
Integrable deformations of AdS_3 superstrings

Fiona Seibold

Imperial College London

Mainly based on [1] JHEP 09 (2022) 018 arXiv:2206.12347 with B. Hoare and A. Tseytlin
[2] JHEP 04 (2023) 024 arXiv:2212.08625 with B. Hoare and N. Levine

Strings on $\mathbf{AdS_3 \times S^3 \times T^4}$



- Can be supported by a mixture of NSNS and RR fluxes

$$H_3 = x\,\hat{G}\ , \qquad F_3 = \sqrt{1-x^2}\,\hat{G}\ , \qquad \hat{G} = \mathrm{Vol}(AdS_3) + \mathrm{Vol}(S^3)\ .$$

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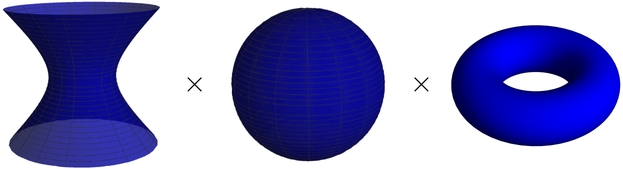

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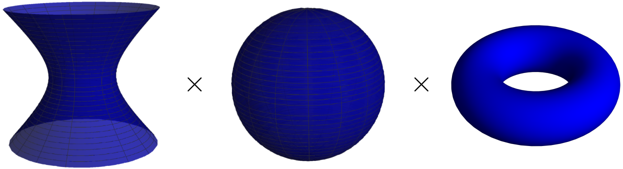

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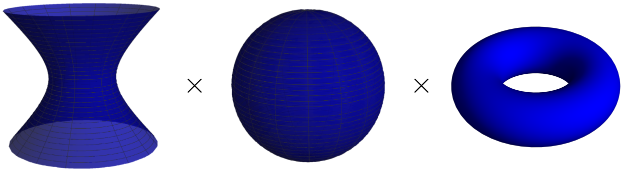

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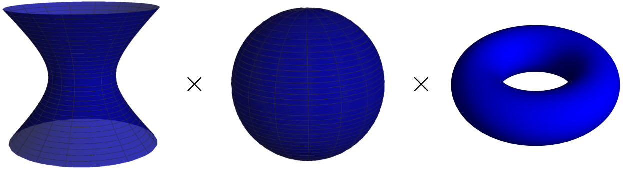

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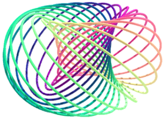
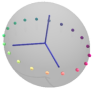
- **Deform target space geometry while preserving exact solvability?**

Strings on squashed $(\mathbf{AdS}_3 \times \mathbf{S}^3)_\Delta \times \mathbf{T}^4$

[picture: Niles Johnson]





$$ds^2(S^3_\Delta) = \frac{1}{4}\Big(\underbrace{d\theta^2 + \sin^2\theta d\phi^2}_{ds^2(S^2)} + (1-\Delta)\big(\underbrace{d\varphi - \cos\theta d\phi}_{A(S^2)}\big)^2\Big)$$

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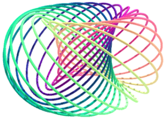

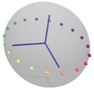

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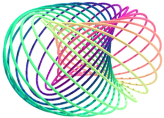

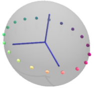

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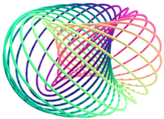

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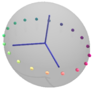

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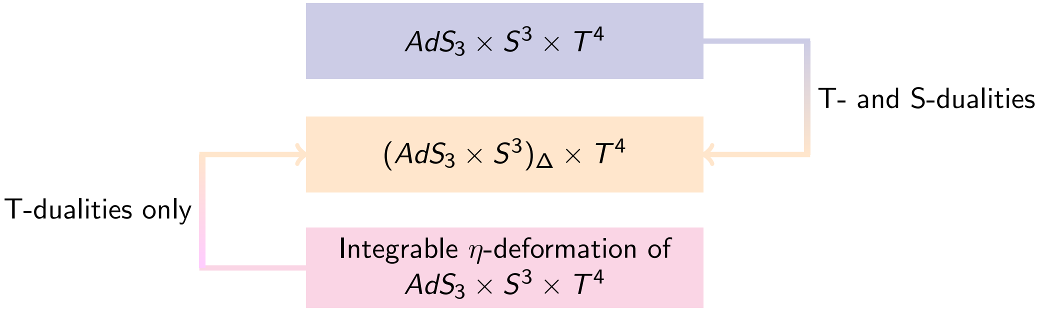
What about Integrability?

$AdS_3 \times S^3 \times T^4$

T- and S-dualities

$(AdS_3 \times S^3)_\Delta \times T^4$

What about Integrability?



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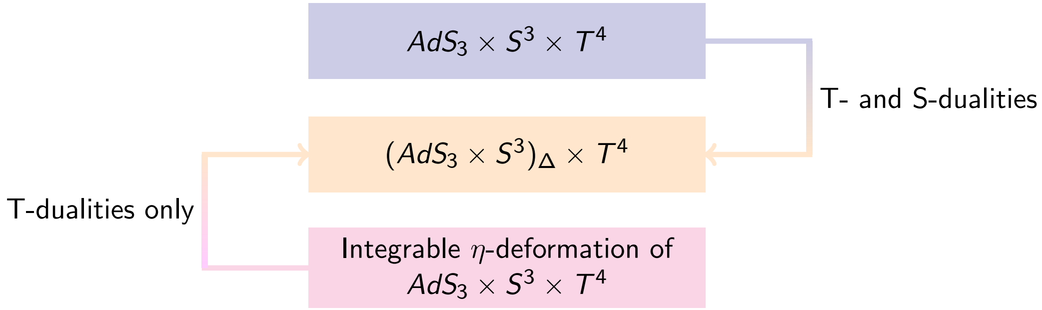

- Classically integrable $\rightarrow$ Another example where S-duality preserves integrability

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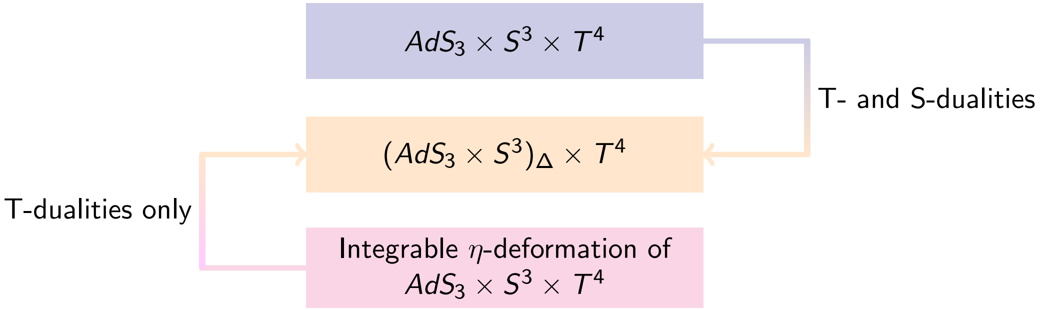

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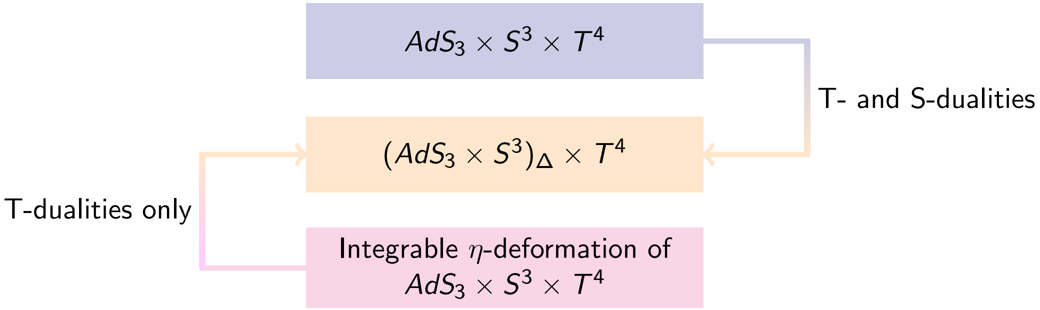

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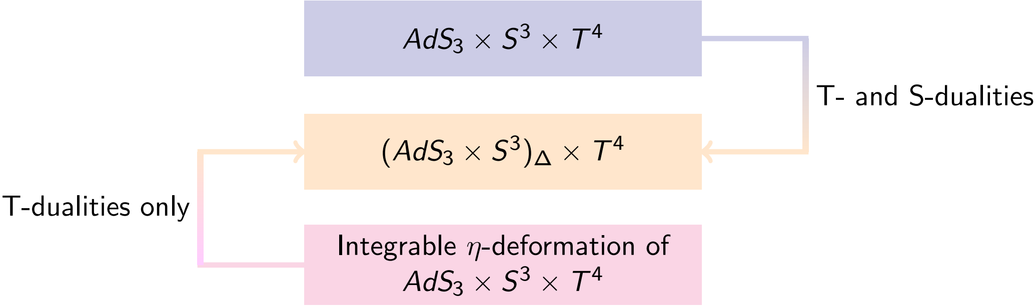

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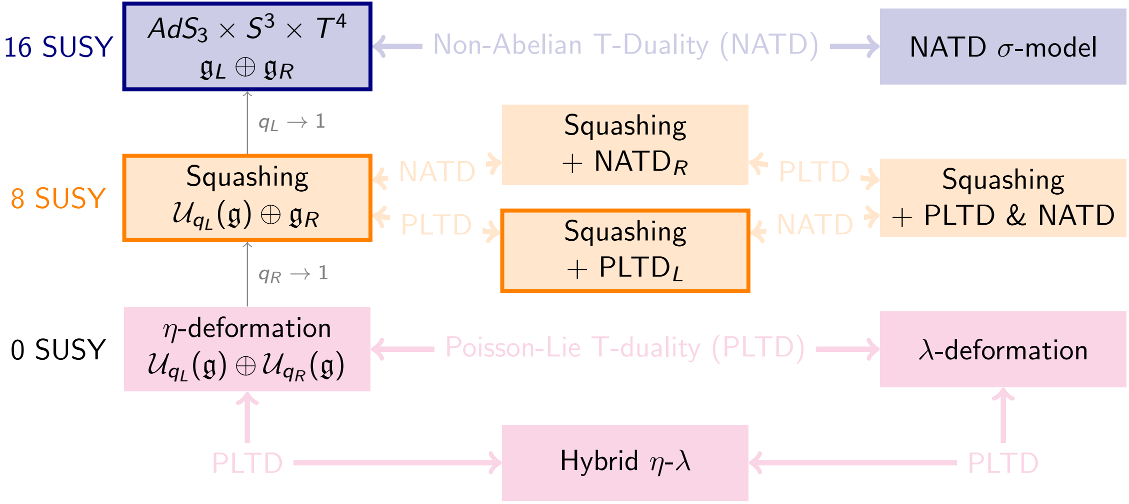
- Can bootstrap the worldsheet S-matrix & compute physical observables
- In some limits $\exists$ brane construction and holographic interpretation has been studied

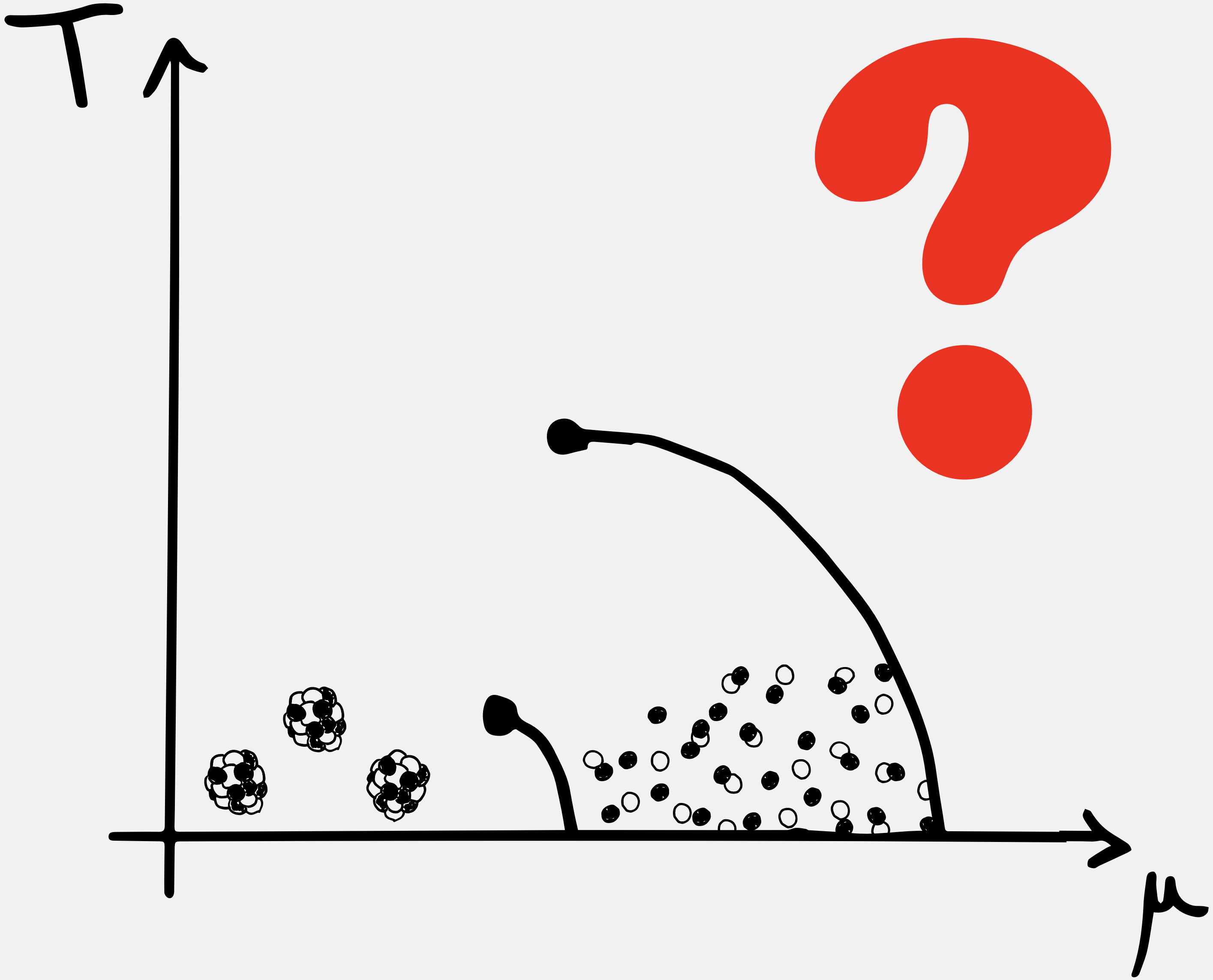
A whole web of integrable deformations!



NORDITA
The Nordic Institute for Theoretical Physics

Javier Subils

Gijón, April 25, 2023
Eurostrings 2023.



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Gijón, April 25, 2023
Eurostrings 2023

The first realization

- in **string theory,**
- of a **fully-backreacted** holographic dual of a **confining** theory in 3D,
- at **finite baryon density,**
- (**without flavor** branes).

Javier Subils

Gijón, April 25, 2023
Eurostrings 2023.

In collaboration with Antón Faedo and Carlos Hoyos.

Solutions to type IIA supergravity

$$F_4 \propto *\Omega_{\mathbb{CP}^3} + \text{additional terms}$$

$$F_2 = \mathrm{d}C_1$$

$$C_1 = a_t(r)\,\mathrm{d}t + B\,(x_1 \mathrm{d}x_2 - x_2 \mathrm{d}x_1)$$

The theory is N = 1 SUSY.

"in **string theory, fully - backreacted**"

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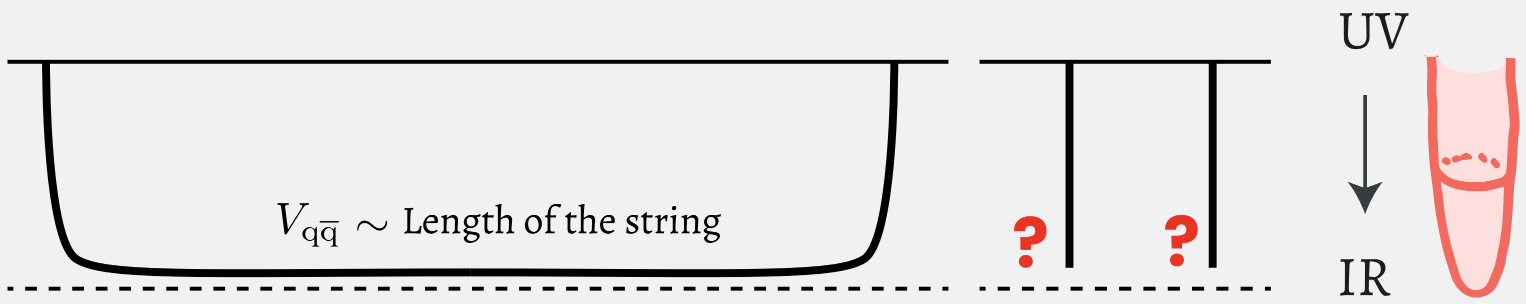

“confining theory”

Dirichlet boundary conditions

C_1

$\mathrm{U}(N) \times \mathrm{U}(N+M)$

[Bergman, Tachikawa & Zafrir (2020)]

Dirichlet boundary conditions

C_1

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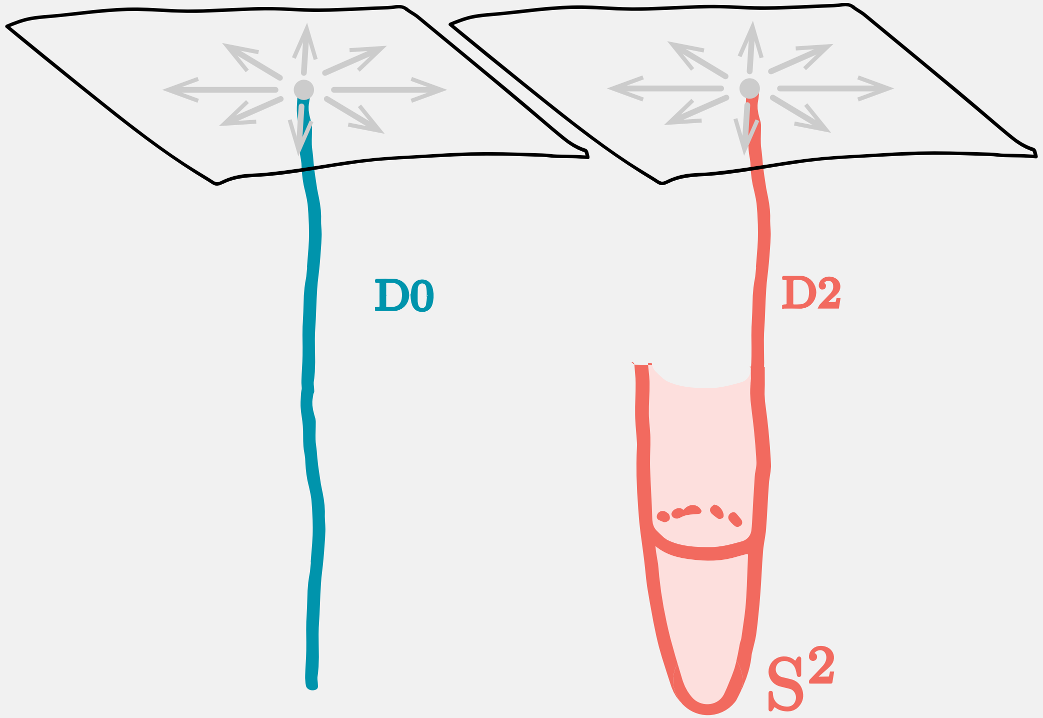

Monopoles

[Bergman, Tachikawa & Zafrir (2020)]

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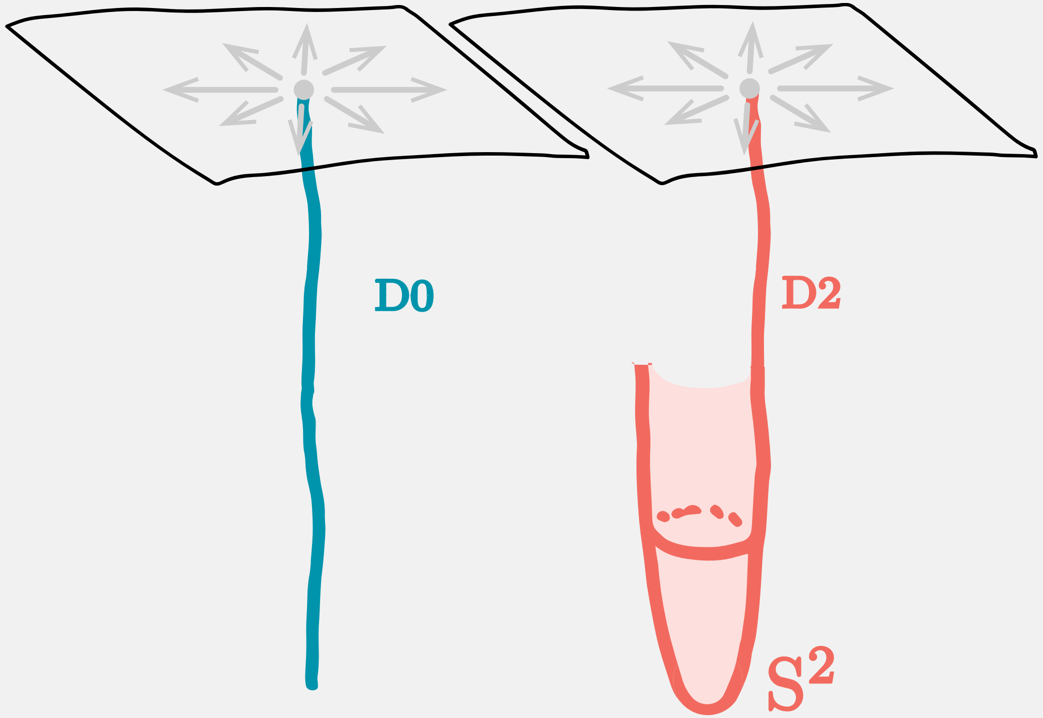
C_1

$\mathrm{U}(N) \times \mathrm{U}(N+M)$



Monopoles

Neumann boundary conditions

C_7

$\mathrm{SU}(N) \times \mathrm{SU}(N+M)$

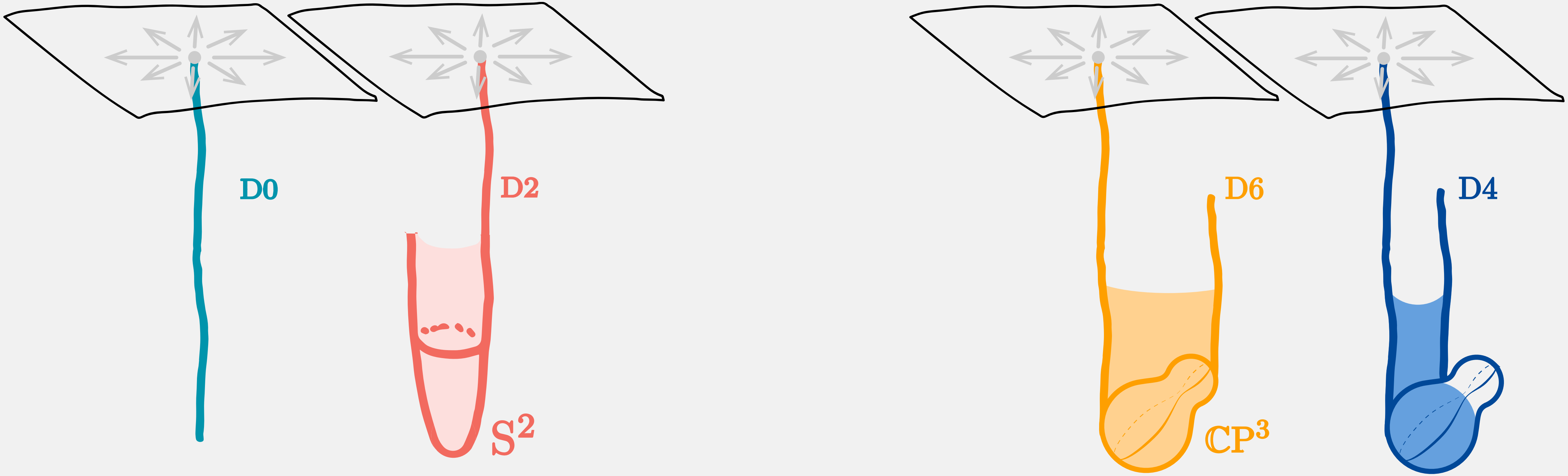
[Bergman, Tachikawa & Zafrir (2020)]

Dirichlet boundary conditions C_1

$\mathrm{U}(N) \times \mathrm{U}(N+M)$

Neumann boundary conditions C_7

$\mathrm{SU}(N) \times \mathrm{SU}(N+M)$



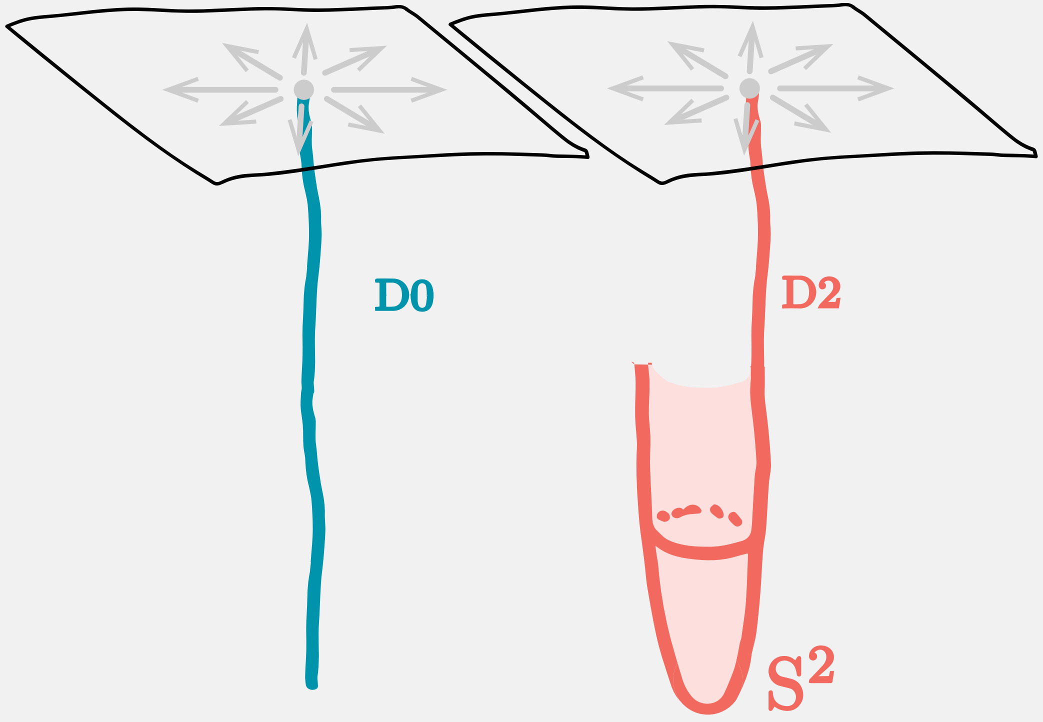
Monopoles

Baryons

[Bergman, Tachikawa & Zafrir (2020)]

Dirichlet boundary conditions C_1

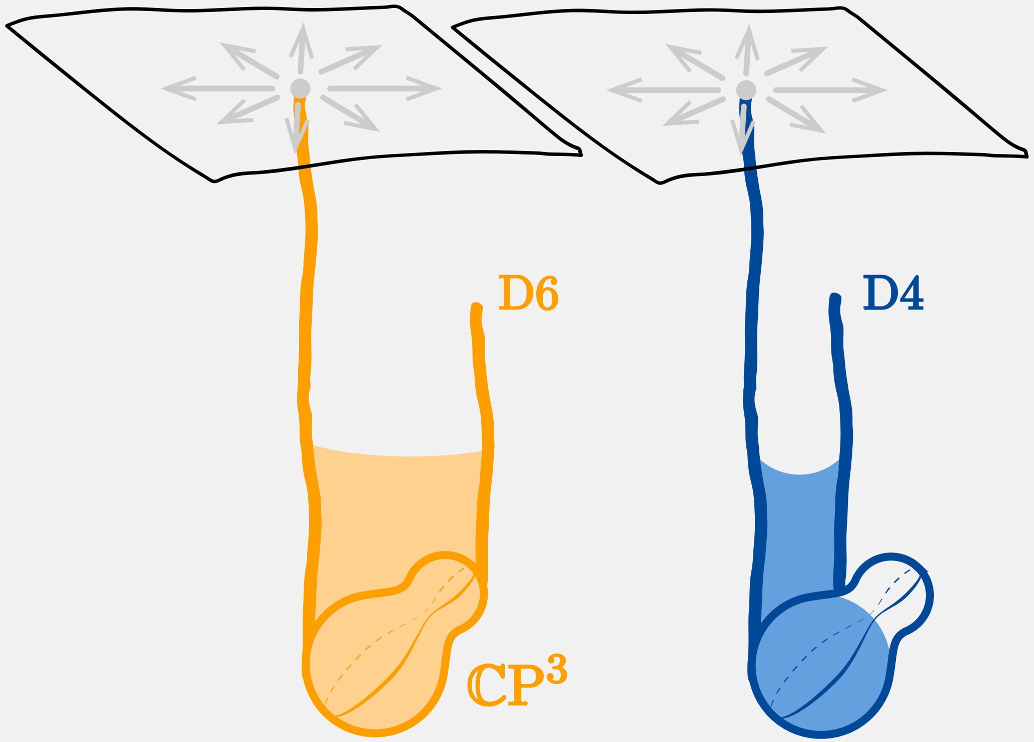
$U(N) \times U(N+M)$



Monopoles

Neumann boundary conditions C_7

$SU(N) \times SU(N+M)$

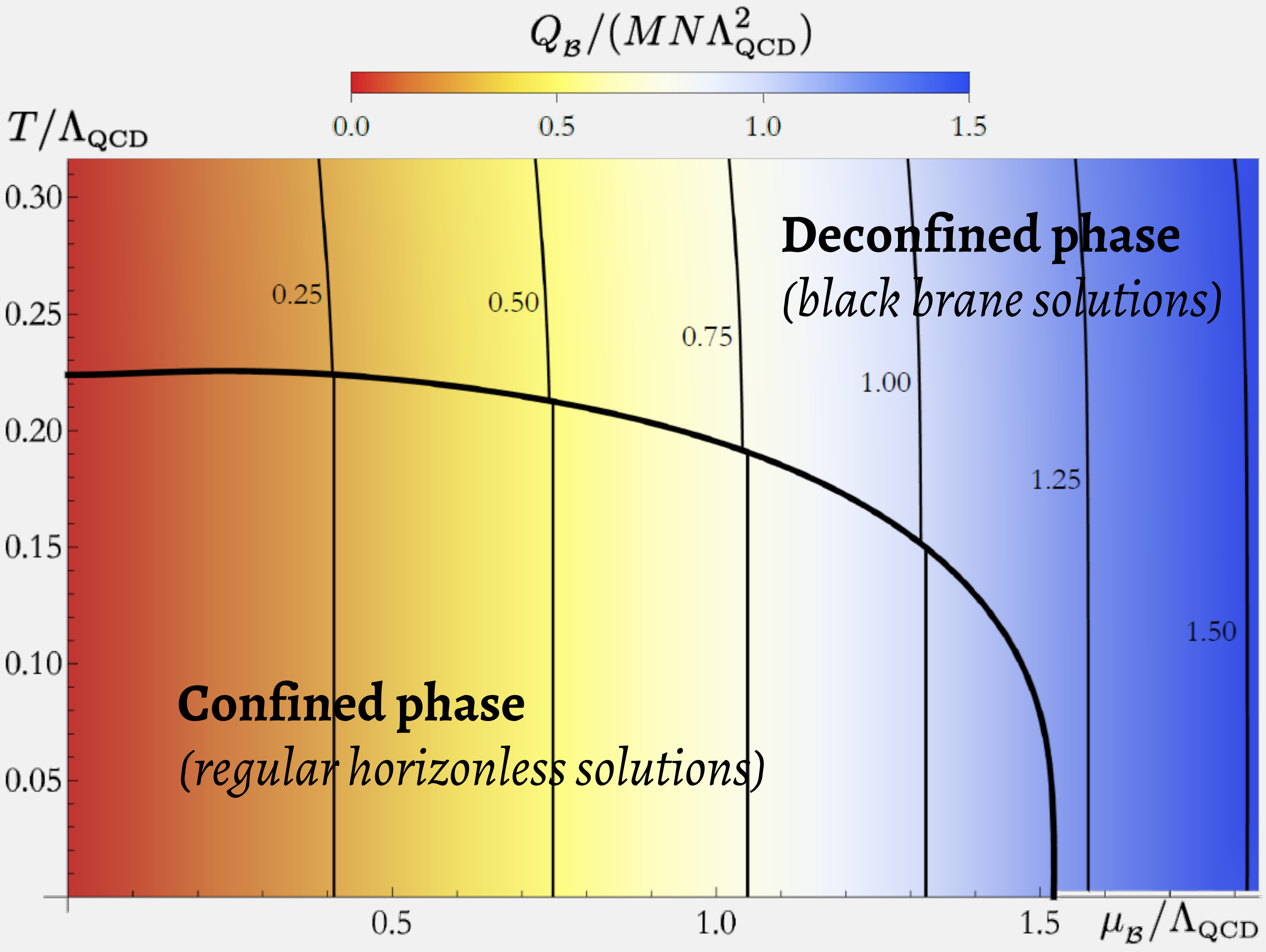


Baryons

$$\mathsf{B} \leftrightarrow \tilde{Q}$$
$$\mathsf{M} \leftrightarrow \tilde{\mu}$$

$$Q \leftrightarrow \tilde{\mathsf{B}}$$
$$\mu \leftrightarrow \tilde{\mathsf{M}}$$

[Bergman, Tachikawa & Zafrir (2020)]



"at **finite baryon density**"

The first realization

- in **string theory,**
- of a **fully-backreacted** holographic dual of a **confining** theory in 3D,
- at **finite baryon density,**
- (**without flavor** branes).

In collaboration with Antón Faedo and Carlos Hoyos.

Check digital poster here!

Thanks!

Wilson loops and RG flows in ABJM theory

Marcia Tenser

Università Degli Studi di Milano-Bicocca

April 25, 2023

Motivation

$$W = \mathrm{Tr}\,\mathcal{P}\exp\left[i\oint\left(A_\mu + \mathsf{matter}\right)\,dx^\mu\right]$$

- Mapped to fundamental strings via AdS/CFT
- Localization
  - probe at weak and strong coupling
- 1 dCFT
  - superconformal bootstrap

Features

$$W = \mathrm{Tr}\,\mathcal{P}\exp\left[i\oint\left(A_\mu + \text{matter}(\circledast, \ominus, \oslash, \circledcirc)\right)dx^\mu\right]$$

- Parametric dependence: $\langle W \rangle = f(\circledast, \ominus, \oslash, \circledcirc)$
- Non-trivial β-functions $(\beta_{\circledast}, \cdots, \beta_{\circledcirc})$: RG flows connecting WLs

1 Constrain parameters such that WLs are BPS $\Rightarrow$ Enriched flows '22

MT, L. Castiglioni, S. Penati, D. Trancanelli

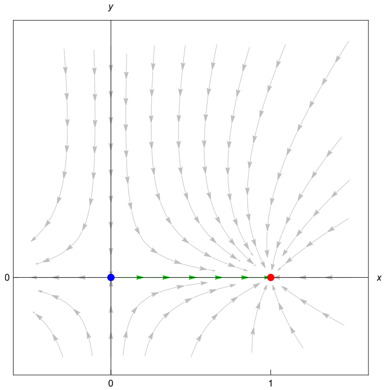
2 Generic parameters $\Rightarrow$ Defect RG flows '23

MT, L. Castiglioni, S. Penati, D. Trancanelli

(to appear soon)

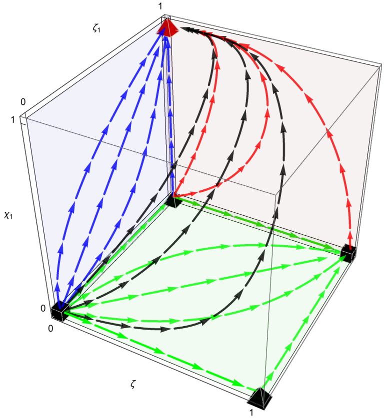
Results

Enriched flows



Results

Defect RG flows



Open questions

- Holographic description: interpolation and boundary conditions
- Framing and anomaly
- g-theorem and defect entropy
- 1/2 BPS fixed points: (non-)unitary dCFT and its dual distinction

Thank You