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Spring School on Superstring Theory and Related Topics | (SMR 4062)

31 Mar 2025 - 04 Apr 2025
ICTP, Trieste, Italy

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P01

Abstract template for Spring School in Supersymmetry and Related Topics

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Information-theoretic methods have led to significant advances in nonperturbative quantum field theory in flat space. For instance, some properties of the entanglement entropy combined with Poincaré invariance have led to proofs for the irreversibility theorems for the renormalization group flows in 2, 3 and 4 spacetime dimensions [1, 2, 3].

In a recent work [4], we showed that these ideas can be generalized to field theories in a fixed de Sitter space. We derived a boosted strong subadditivity inequality in de Sitter, and showed that it implies a C-theorem for renormalization group flows. Additionally, using the relative entropy, we established a Lorentzian bound on the entanglement and thermal entropies. We also discussed possible connections with recent developments using unitarity methods.

[1] H. Casini, M. Huerta, Phys. Rev. Lett B **600** (2004).
[2] H. Casini, M. Huerta, Phys. Rev. Lett D **85** (2012).
[3] H. Casini, E. Testé, G. Torroba, Phys. Rev. Lett D **118** no. 26, 1357 (2017).
[4] N. Abate, G. Torroba, arXiv:2409.18186 [hep-th] (2024).

P02

We investigate the fermionic perturbations of the asymptotically AdS background known as “holographic neutron star”, which represents a highly degenerate state of strongly coupled fermions on a sphere at finite temperature. We calculate the two-point correlator of a fermionic operator and obtain its scaling properties as we approach the critical region of the phase diagram. This work is already available at [arXiv:2407.16649 [hep-th]].

We obtained a fermionic correlator whose dependence on the energy has two main contributions: a pole structure and a power law regular part. As we move into the unstable critical metal region (given by the temperature and chemical potential of the holographic star), the poles get separated and the power on the regular part gets larger. This allows us to state that the power law contribution to the correlator gets more important as the chemical potential of the neutron star grows, an effect which is more marked at larger temperatures.

The above results contribute to the hypothesis of the criticality of the central region of the phase diagram of the holographic neutron star, stated in [doi:10.1088/1361-6382/abb1f5]. The conclusion is that, when finite volume effects are considered, the holographic description of a strongly coupled metal results in a phase diagram very similar to that of the metallic degrees of freedom of a High T_c superconductor. In particular, there is a central region at intermediate doping and low temperatures, which gets wider as the temperature is increased, where the system manifests critical features, which can be attributed to a quantum critical point.

P03

Abstract for the poster presentation at the spring school on superstring theory and related topics

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In the paper [1], we show a local generalized second law (the generalized entropy is nondecreasing) in crossed product constructions for maximally extended static and Kerr black holes using modular theory. The new ingredient is the use of results from a recent paper discussing the entropy of the algebra of operators in subregions of arbitrary spacetimes. These results rely on an assumption which we show is true in our setting. However, we do assume as in that paper, that the gravitational constraints are implemented on each partial Cauchy slice. We employ a slight generalization of the construction, by including an observer degree of freedom even for wedge shaped regions with an asymptotic boundary. In the last part of the paper, we look at mod- ular Hamiltonians of deformed half-spaces in a class of static spacetimes, including the Schwarzschild spacetime. These are computed using path inte- grals, and we primarily compute them to investigate whether these non-local modular Hamiltonians can be made local by subtracting off pieces from the algebra and its commutant, as has been surmised in the literature. Along the way, the averaged null energy condition (ANEC) also follows in this class of spacetimes.

[1] M. Ali and V. Suneeta,"Local generalized second law in crossed product constructions,"Phys. Rev. D **111**, no.2, 024015 (2025), doi:10.1103/PhysRevD.111.024015[arXiv:2404.00718 [hep-th]].

P04

Relative Quantum Gravity: Localized Gravity and the Swampland

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We perform a systematic study of the applicability of swampland constraints to theories of localized gravity. We find that these gravity theories can violate swampland constraints [2], but can be reconciled with them when coupled to a higher-dimensional gravity theory. They realize what we call *relative quantum gravity*: to become consistent at the quantum level, these gravity theories must be defined as *relative* to a host higher-dimensional gravity theory.
We show that these theories can admit global symmetries, even anomalous ones; they can violate the cobordism, completeness, weak gravity, and distance conjectures; they may admit stable non-supersymmetric AdS vacua, or dS vacua. All swampland constraints are however satisfied when these gravity theories are regarded as relative and completed by coupling them to a higher-dimensional one.
We discuss these properties in d-dimensional gravity theories localized on Karch-Randall End of the World (ETW) boundaries of AdS_{d+1} spacetime [1]. For AdS_d ETW branes we use the formalism of double holography [3] to describe the appearance of the species scale and the emergence of gauge dynamics from the quantum backreaction of CFT_d modes. We also study microscopically the swampland constraints in localized gravity in explicit string theory models. Concretely, we exploit the 10d supergravity solutions describing AdS_4 ETW branes for $\mathrm{AdS}_5 \times \mathbf{S^5}$ [5], holographically dual to semi-infinite D3-branes ending on NS5- and D5-brane configurations, realizing 4d $\mathcal{N} = 4$ $SU(N)$ on half-space coupled to a 3d Gaiotto-Witten superconformal boundary CFT_3 [4].

[1] A. Karch, L. Randall, *JHEP* **05**, 008 (1999).
[2] C. Vafa, (2005).
[3] E. Panella, J. F. Pedraza, A. Svesko, *Universe* **10**, 9 358 (2024).
[4] D. Gaiotto, E. Witten, *J. Statist. Phys* **135**, 789-855 (2009).
[5] E. D'Hoker, J. Estes, M. Gutperle, *JHEP* **06**, 021 (2007).

P05

SymTFT construction and exotic-foliated duality for XY-plaquette and related gapless fracton models

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Exotic and foliated theories are interesting QFTs used to describe fracton phases of matter. Recently, some exotic and foliated gapped models have been explicitly shown to be equal [2], [3]. The connection between exotic and foliated gapless models is still an open question.
In an upcoming paper [1], this connection is explored using a construction inspired by [4]. A gapped theory on a manifold with gapless boundary conditions is shown to be equal to a broken phase living on the boundary. Using the exotic-foliated duality, two constrained QTFs are built describing the same exotic gapless model.
This construction, similar to a SymTFT setup [5], is very useful to describe the topological operators of the gapless model and their condensation. In particular, the non-invertible symmetry defects previously described in [9] are built.

[1] Apruzi, Fabio and Bedogna, Francesco, and Mancani, Salvo, (2025) to appear
[2] Ohmori, Kantaro and Shimamura, Shutaro, SciPost Phys. **14.6**, (2023). 2210.11011
[3] Spieler, Ryan C. JHEP **09** (2023), 2304.13067
[4] Argurio, Riccardo and Collinucci, Andrés and Galati, Giovanni and Hulik, Ondrej and Paznokas, Elise, (2024), 2409.11822
[5] Cao, Weiguang and Jia, Qiang, JHEP **05** (2024), 2310.01474
[6] Antinucci, Andrea and Benini, Francesco, Phys. Rev. B **111.3** (2025), 2401.10165
[7] Brennan, T. Daniel and Sun, Zhengdi, JHEP **12**, (2024), 2401.06128
[8] Seiberg, Nathan and Shao, Shu-Heng, SciPost Phys. **10.2** (2021), 2003.10466
[9] Spieler, Ryan C. JHEP **06** (2024), 2402.14944

P06

Joint poster presentation with co-author Thomas Tappeiner (who submitted our abstract) about the quantum group origins of edge states in DSSYK.

P07

Light Behaviors around Black Holes in Starobinsky-Bel-Robinson Gravity from M-theory

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Motivated by M-theory compactifications, we investigate the optical properties of black holes in Starobinsky-Bel-Robinson gravity. Specifically, we study the shadows and deflection angles of light rays around non-rotating and rotating black holes in this novel gravity, highlighting the effect of the stringy parameter β. Using Event Horizon Telescope observational data, we provide predictions for this parameter, which could play a significant role in M-theory compactifications. We conclude with a discussion on the behavior of light rays near such four-dimensional black holes, computing the deflection angle within a moduli space framework.

[1] A. Belhaj, M. Benali and Y. Hassouni, Superentropic black hole shadows in arbitrary dimensions, Eur. Phys. J. C **82** (2022)

[2] A. Belhaj, H. Belmahi, M. Benali and H. El Moumni, Light deflection angle by superentropic black holes, Int. J. Mod. Phys. D **31** (2022)

P08

The String Dual to Two-dimensional Yang-Mills Theory Revisited

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We propose that chiral two-dimensional Yang-Mills theory on a Riemann surface is dual to a deformed stationary subsector of the Gromov-Witten theory of that surface. We begin by demonstrating that the algebraic structure that underlies the large N limit of the chiral gauge theory is a partial permutation algebra of observables which encodes covering maps of all degrees simultaneously. This algebra is the operator algebra of a grand canonical Hurwitz theory. The latter theory was shown in [1], by exploiting the Gromov-Witten/Hurwitz correspondence, to be dual to the stationary subsector of a Gromov-Witten theory. Vertex operators on the string side were identified with completed cycles on the field theory side. Building on this, we show that the correlators of Yang-Mills theory can be obtained from those of the grand canonical Hurwitz theory by finite deformations. This leads to the proposal that chiral two-dimensional Yang Mills theory is dual to a Gromov-Witten theory deformed by an area-dependent transposition interaction and an operator that codes a compactification of Hurwitz space. The proposed string dual manifestly includes an integral over the moduli space of Riemann surfaces as well as the identification of closed string states as completed cycles.

[1] L. Benizri and J. Troost, J. Phys. A **57** (2024) 50 [arXiv:2404.12543 [hep-th]].

P09

The DDF M-Reggeon and hidden Mandelstam maps

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We provide a compact expression for the generating function of correlators involving an arbitrary number of bosonic open string DDF states in [1]. The explicit correlators for M DDF states can then be obtained by differentiating this generating function with respect to the DDF polarization tensors.

The generating function depends on single and double complex integrals centered around the punctures corresponding to the insertion points of the DDF vertices on the real axis in the upper half-plane. We have explicitly evaluated these integrals for an arbitrary number M of external DDF states in the usual formalism, as well as in a more recent geometric reformulation of DDF operators using dual frames [2]. To verify our results, we computed some massive scalars and spin-2 amplitudes for $M = 3$ and $M = 4$, verifying that these amplitudes have the form expected from Lorentz invariance.

Finally, we show in [3] that on-shell DDF correlators naturally contain Mandelstam maps connecting the string lightcone interaction picture (on the upper half-plane with cuts) to the covariant DDF formulation (on the upper half-plane without cuts)! In the process, we also provide a very explicit formula for the conformal transformation of a generic vertex in the form of a compact generating function for free theories.

[1] Dripto Biswas, Raffaele Marotta, Igor Pesando, arxiv: 2410.17093 [hep-th] (accepted for publication in JHEP).
[2] Dripto Biswas, Igor Pesando, Eur.Phys.J.C **84** (2024) 7, 657.
[3] Dripto Biswas, Igor Pesando, arXiv:2411.06109 [hep-th] (submitted to a journal).

P10

Abstract for Poster

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I will present a brane world scenario called "Dark Bubble Cosmology" [1]-[2], which differs in crucial aspects from other proposals in string phenomenology: our four-dimensional universe rides an expanding bubble whose embedding naturally induces a positive cosmological constant. This model avoids the Swampland constraints of constructing fundamental de Sitter vacua [3] based on pure compactifications of String Theory and, at the same time, provides a concrete realization of a brane world with an asymmetric inside-outside construction. The bubble represents a Coleman-de Luccia or Brown-Teitelboim instanton which nucleates in an unstable five-dimensional Anti de Sitter spacetime. This proposal therefore involves inducing four-dimensional gravity on a brane which mediates the decay from a non-supersymmetric false AdS_5 vacuum to a lower energy vacuum.

In this context, I will describe brane world constructions based both on Type IIB and 0'B string theories, and I will present a general mechanism to embed electromagnetic gauge fields living on the brane. The latter requires a non-trivial interplay between gauge fields on the brane and stringy fields in the bulk, and can be hopefully generalized to include non-abelian gauge fields, with the perspective of embedding the full Standard Model of Particle Physics in the Dark Bubble scenario. In the setup of the (non-supersymmetric) Type 0'B string theory, the Dark Bubble model yields precise predictions for the evolution of the cosmological constant and of the scale factor of the universe. However, it turns out this setup is incompatible with experimental observations and has to be discarded.

[1] S. Banerjee, U. Danielsson, G. Dibitetto, S. Giri, and M. Schillo, "Emergent de Sitter Cosmology from Decaying Anti–de Sitter Space", Phys. Rev. Lett. 121, 261301 (2018), arXiv:1807.01570 [hep-th].

[2] S. Banerjee, U. Danielsson, G. Dibitetto, S. Giri, and M. Schillo, "De sitter cos- mology on an expanding bubble", Journal of High Energy Physics 2019, 10.1007/ jhep10(2019)164 (2019).

[3] M. van Beest, J. Calderón-Infante, D. Mirfendereski, and I. Valenzuela, "Lectures on the swampland program in string compactifications", Physics Reports 989, 1–50 (2022).

P11

Deep Observations of the Type IIB flux ladscape

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We present deep observations in targeted regions of the string landscape through a combination of analytic and dedicated numerical methods. Specifically, we devise an algorithm designed for the systematic construction of Type IIB flux vacua in finite regions of moduli space. Our algorithm is universally applicable across Calabi-Yau orientifold compactifications and can be used to enumerate flux vacua in a region given sufficient computational efforts. As a concrete example, we apply our methods to a two-modulus Calabi-Yau threefold, demonstrating that systematic enumeration is feasible and revealing intricate structures in vacuum distributions. Our results highlight local deviations from statistical expectations, providing insights into vacuum densities, superpotential distributions, and moduli mass hierarchies. This approach opens pathways for precise, data-driven mappings of the string landscape, complementing analytic studies and advancing the understanding of the distribution of flux vacua. This allows us to obtain different types of solutions with hierarchical suppressions, e.g. vacua with small values of the Gukov-Vafa-Witten superpotential $|W_0|$. We find an example with $|W_0| = 5.547 \times 10^{-5}$ at large complex structure, without light directions and the use of non-perturbative effects.

[1] A. Chauhan, M. Cicoli, S. Krippendorf, A. Maharana, P. Piantadosi, and A. Schachner, arXiv:2501.03984 [hep-th] (2025).

P12

Bit threads and entropy

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The Ryu-Takayanagi (RT) formula [1] links entanglement entropy in holographic scenarios to a geometric quantity: a minimal codimension-2 surface. Recently, it has been recast using flow-based representations called "bit threads" [2], which start and end at boundaries or other codimension-2 surfaces, achieving maximal density at the RT surface. These bit threads represent entangled degrees of freedom, but their configurations are non-unique. First, we aim to identify and analyse some of the ambiguities present in a valid thread configuration. It turns out that we can always add some ambiguities to a thread configuration that do not affect the calculation of holographic entanglement entropy (HEE). Then, we examine the broader applicability of the bit-thread formalism beyond holography. We have found that the bit-thread framework can also accommodate black hole entropy and differential entropy for spacetimes with holes. We use a codimension-2 current form from the covariant phase space (CPS) formalism [3, 4] to construct these flows for these different entropies. The first laws of the entropies can also be reformulated in terms of bit threads.

[1] S. Ryu and T. Takayanagi, Holographic derivation of entanglement entropy from AdS/CFT, Phys. Rev. Lett. 96, 181602, 2006.
[2] M. Freedman and M. Headrick, Bit threads and holographic entanglement, Commun. Math. Phys. 352, 2017.
[3] V. Iyer and R. M. Wald, Some properties of Noether charge and a proposal for dynamical black hole entropy, Phys. Rev. D 50, 1994, 846–864.
[4] D. Harlow and Jq. Wu, Covariant phase space with boundaries, J. High Energ. Phys. 2020, 146.

P13

Supersymmetric Solutions of $D = 3$, $N = 4$ Supergravity and Their Uplift to $D = 6$

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We construct supersymmetric solutions of a particular $D = 3$, $N = 4$ $U(1) \times U(1)$ gauged supergravity [1] which is connected to $D = 6$, $N = (1, 0)$ supergravity coupled to a single chiral tensor multiplet [2] by a consistent S^3 reduction [3]. Because the dimensional reduction is consistent, any solution in $D = 3$ can be uplifted to a solution in $D = 6$, which provides a strong motivation to look for its supersymmetric solutions. Starting with a general spinor analysis based on Killing spinor bilinears [4, 5], we first construct a Killing vector of the $D = 3$ theory that is either null or timelike. These two cases are investigated in [6] and [7], respectively.

The existence of a null Killing vector gives rise to a rich set of solutions as shown in [6]. We found three new families of solutions, in addition to those presented in [1], two of which admit nontrivial gauge fields. The charged solutions in $D = 3$ are observed to be uplifted to rotating solutions in $D = 6$. The uplift of the first solution, the null warped AdS_3, produces a rotating $AdS_3 \times S^3$. The second one, the charged domain wall solution, leads to the well-known rotating dyonic string solution. The uplift of our third solution, which is a domain wall solution with no gauge fields, results in a distribution of dyonic strings.

We considered the timelike case in [7] and showed that AdS_3 is the only solution for the gauged theory. In contrast, the ungauged model has proven to be more interesting. It effectively reduces to a supergravity coupled to a sigma model with a hyperbolic target space $\mathbb{H}^2$, and all solutions of the ungauged model can be expressed using two arbitrary holomorphic functions. If the holomorphic function determining the scalar fields (ρ, θ) is nonconstant, the sigma model target space metric becomes a part of the spacetime metric, with a warp factor containing the Kähler potential of the target space, as well as a harmonic function determined by both holomorphic functions.

[1] N. S. Deger, N. Petri and D. Van den Bleeken, JHEP **04**, 168 (2019)
[2] H. Nishino and E. Sezgin, Nucl. Phys. B **278**, 353-379 (1986)
[3] N. S. Deger, H. Samtleben, O. Sarioglu and D. Van den Bleeken, Nucl. Phys. B **890**, 350-362 (2014)
[4] K. P. Tod, Phys. Lett. B **121**, 241-244 (1983)
[5] K. P. Tod, Class. Quant. Grav. **12**, 1801-1820 (1995)
[6] N. S. Deger, C. A. Deral, A. Saha and Ö. Sarıoğlu, JHEP **10**, 185 (2024)
[7] N. S. Deger and C. A. Deral, arXiv:2411.04437 [hep-th] [*to be published in Phys. Rev. D*].

P14

Unimodular JT gravity and de Sitter quantum cosmology

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Abstract: In this work, we show that a gauge-theoretic description of Jackiw-Teitelboim (JT) gravity naturally yields a Henneaux-Teitelboim (HT) unimodular gravity via a central extension of its isometry group, valid for both flat and curved two-dimensional spacetimes. HT gravity introduces a unimodular time canonically conjugate to the cosmological constant, serving as a physical time in quantum cosmology. By studying the mini-superspace reduction of HT_2 gravity, the Wheeler-DeWitt equation becomes a Schrödinger-like equation, giving a consistent and unitary quantum theory. Analysis of the wavefunction's probability density reveals a quantum distribution for the scale factor a, offering a quantum perspective on the expansion and contraction of the universe. In this perspective, the possibility of reaching the singular point a=0 signals that topology change could occur. Finally, we give a consistent quantum description of unimodular time that aligns seamlessly with Page-Wootters formulation of quantum mechanics, where quantum correlations between unimodular time and JT gravity are studied in HT_2 quantum cosmology.

[1] B. Alexandre, A. Etkin, F.S. Rassouli, arXiv: 2501.17213 [gr-qc] (2025)

P15

Exact results on the Bethe Ansatz evaluation of the SCI

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We evaluate the superconformal index using the Bethe Ansatz (BA) approach for 4d $\mathcal{N} = 1$ toric quiver gauge theories of increasing complexity. We restrict to $\mathrm{SU}(2)$ gauge factors and compare the results with the ones obtained by a direct evaluation of the index. The outcome of our spectroscopy is that the answer obtained from the BA approach, using only discrete solutions for the BA equations, does not always reproduce the expected results. A similar problem affects the case of $\mathrm{SU}(N)$ $\mathcal{N} = 4$ SYM for $N \geq 3$, and it requires to introduce continuous solutions to the BA equations. We furnish a detailed analysis for the models where the matching is exact, like the conifold and the suspended pinch point singularity.

[1] A. Amariti, M. Fazzi, P. Glorioso, K. Krawczyk, C. Mascherpa, A. Zanetti, to appear (2025).

P16

No manifest T-duality at alpha'^3

P17

Heterotic blackholes with higher derivative corrections in diverese dimensions

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Black hole solution to heterotic supergravity have been studied extensively in the past. At the two derivative level, these solutions are well known and classified. When higher curvature corrections are taken into account the story gets more complicated.

We reduce heterotic supergravity on $S^1 \times T^{9-d}$ and truncate out the internal torus fields. This describes supergravity coupled to one vector multiplet in $10 - d$ dimensions. We then construct multi-centred BPS black hole solutions carrying two charges. In the special case of $d = 5$, the heterotic two form can be dualised into a gauge field, which allows one to construct three charged blackhole solutions to the dualised Bergshoeff-de Roo action. This can be thought of as $\mathcal{N} = 2$ supergravity coupled to two vector multiplets. This five dimensional theory can be compared with the four derivative corrected STU model. We find that the four derivative corrections coming from heterotic supergravity differs from the four derivative completion of the STU model discussed previously in the literature.

[1] Y. Cai, S. Jayaprakash, J.T. Liu and R.J. Saskowski, Multi-center higher derivative black holes, in progress.

[2] Y. Cai, S. Jayaprakash, J.T. Liu and R.J. Saskowski, The four derivative STU model, in progress.

[3] S. Chimento, P. Meessen, T. Ortin, P.F. Ramirez and A. Ruiperez, On a family of α'-corrected solutions of the Heterotic Superstring effective action, JHEP 07 (2018) 080

[4] D. Cassani, A. Ruip´erez and E. Turetta, Higher-derivative corrections to flavoured BPS black hole thermodynamics and holography, JHEP 05 (2024) 276

P18

3 bulk field theories for 2 Virasoro minimal models

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Using 3 -3 correspondence, we construct 3 dual bulk field theories for general Virasoro minimal models $M\ P\ Q)$. These theories correspond to Seifert fiber spaces $S^2\ \ P\ P\ \ R)\ \ Q\ S)\ \ 3\ 1))$ with two integers $R\ S)$ satisfying $PS\ \ \ QR = 1$. In the unitary case, where $|P\ \ \ Q| = 1$, the bulk theory has a mass gap and flows to a unitary topological field theory (TQFT) in the IR, which is expected to support the chiral Virasoro minimal model at the boundary under an appropriate boundary condition. For the non-unitary case, where $|P\ \ \ Q| > 1$, the bulk theory flows to a 3 $\mathcal{N} = 4$ rank-0 superconformal field theory, whose topologically twisted theory supports the chiral minimal model at the boundary. We also provide a concrete field theory description of the 3 bulk theory using $T[SU\ 2)]$ theories. Our proposals are supported by various consistency checks using 3 -3 relations and direct computations of various partition functions.

P19

Machine Learning Complete Intersection Calabi-Yau 3-folds

P20

Generalised Symmetries in the 3d A-model

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The 3d A-model is a two-dimensional approach to the computation of supersymmetric observables of three-dimensional $\mathcal{N} = 2$ supersymmetric gauge theories. In principle, it allows us to compute half-BPS partition functions on arbitrary compact Seifert three-manifolds (smooth circle fibrations over orbifold Riemann surfaces), but previous results focussed on the case where the gauge group $\tilde{G}$ is a product of simply-connected and/or unitary gauge groups. We are interested in the more general case of a compact gauge group $G = \tilde{G}/\Gamma$, which is obtained from the $\tilde{G}$ theory by gauging a discrete one-form symmetry. This gauging can be implemented from the A-model perspective by summing over all possible insertions of the relevant symmetry operators in the path integral, with the various correlators computed in the effective two-dimensional theory on the base Riemann surface.

We study in detail the case of 3d $\mathcal{N} = 2$ supersymmetric Chern-Simons theory without matter for simple groups G. When $G = \tilde{G}$ is simply-connected, we demonstrate the exact matching between the supersymmetric approach in terms of Seifert fibering operators and the 3d TQFT approach based on topological surgery in the infrared Chern–Simons theory $\tilde{G}_k$, including through the identification of subtle counterterms that relate the two approaches. We then extend this discussion to the case where the Chern–Simons theory G_k can be obtained from $\tilde{G}_k$ by the condensation of abelian anyons which are bosonic.

This poster is based on work in [1]

[1] Closset, C., Furrer, E., Keyes, A., & Khlaif, O., The 3d A-model and generalised symmetries, Part I: bosonic Chern-Simons theories, arXiv:2501.11665 (2025).

P21

Bubbles in dS

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bstract

Considering a CFT dual to the quartic theory in AdS, we used the analytic bootstrap techniques, to nd a piece of the anomalous dimensions of double trace operators corresponding to bubbles in AdS at every loop order solely reconstructed from the tree-level data. We then illustrated a relation between these pieces and the iterated unitarity cuts of AdS amplitudes. The work is in progress and is related to the previous studies such as [1] and [2].

[1] O. Aharony, L. F. Alday, A. Bissi, and E. Perlmutter, "Loops in AdS from conformal eld theory," *Journal of High Energy Physics*, vol. 2017, no. 7, pp. 1–56, 2017..

[2] A. Bissi, G. Fardelli, and A. Georgoudis, "All loop structures in supergravity amplitudes on AdS S from CFT," *Journal of Physics A Mathematical and Theoretical*, vol. 54, no. 32, p. 324002, 2021.

P22

Abstract template for Spring School on Superstring Theory and Related Topics — Smr (4062)

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On a recent article [1], we compute the entanglement entropy of an interval for a chiral scalar on a circle at an arbitrary temperature. We use the resolvent method, which involves expressing the entropy in terms of the resolvent of a certain operator, and we compute that resolvent by solving a problem that entails finding an analytic function on the complex torus with certain jump conditions at the interval. The resolvent is relevant by itself, since it can be used to compute any function of the reduced density matrix. We illustrate that by also computing all the Rényi entropies for the model. This follows a series of previous works [2, 3] where we have studied the entanglement of a chiral fermion.

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[2] N. Abate, D. Blanco, M. Koifman, and G. Pérez-Nadal, *Modular conjugation for multicomponent regions, Phys. Rev. D* **107** (2023), no. 4 045015, [arXiv:2209.1071].

[3] N. Abate and M. Koifman, *Modular conjugation for the chiral fermion in multicomponent regions on the torus, Phys. Rev. D* **108** (2023), no. 8 085003, [arXiv:2307.1181].

P23

The large N vector model on $S^1 \times S^2$

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We develop a method to evaluate the partition function and energy density of a massive scalar on a 2-sphere of radius r and at finite temperature β as power series in $\frac{\beta}{r}$. Each term in the power series can be written in terms of polylogarithms. We use this result to obtain the gap equation for the large N, critical $O(N)$ model with a quartic interaction on $S^1 \times S^2$ in the large radius expansion. Solving the gap equation perturbatively we obtain the leading finite size corrections to the expectation value of stress tensor for the $O(N)$ vector model on $S^1 \times S^2$. Applying the Euclidean inversion formula on the perturbative expansion of the thermal two point function we obtain the finite size corrections to the expectation value of the higher spin currents of the critical $O(N)$ model. Finally we show that these finite size corrections of higher spin currents tend to that of the free theory at large spin as seen earlier for the model on $S^1 \times R^2$.

[1] Srijan Kumar, Justin R. David, https://arxiv.org/abs/2411.18509.

P24

Higher Gauge Theory and Integrability

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In recent years, significant progress has been made in the study of integrable systems from a gauge theoretic perspective. This development originated with the introduction of 4d Chern-Simons theory with defects, which provided a systematic framework for constructing two-dimensional integrable systems. In this article, we propose a novel approach to studying higher-dimensional integrable models employing techniques from higher category theory. Starting with higher Chern-Simons theory on the 4-manifold $\mathbb{R} \times Y$, we complexify and compactify the real line to $\mathbb{C}P^1$ and introduce the disorder defect $\omega = z^{-1}\mathrm{d}z$. This procedure defines a holomorphic five-dimensional variant of higher Chern-Simons theory, which, when endowed with suitable boundary conditions, allows for the localisation to a three-dimensional theory on Y. The equations of motion of the resulting model are equivalent to the flatness of a 2-connection (L, H), that we then use to construct the corresponding higher holonomies. We prove that these are invariants of homotopies relative boundary, which enables the construction of conserved quantities. The latter are labelled by both the categorical characters of a Lie crossed-module and the infinite number of homotopy classes of surfaces relative boundary in Y. Moreover, we also demonstrate that the 3d theory has left and right acting symmetries whose current algebra is given by an infinite dimensional centrally extended affine Lie 2-algebra. Both of these conditions are direct higher homotopy analogues of the properties satisfied by the 2d Wess-Zumino-Witten CFT, which we therefore interpret as facets of integrable structures.

[1] H. Chen, J. Liniado Phys. Rev. D **110**, 086017 (2024).

P25

Consistent truncation to pure supergravities

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The poster will based on the paper [1]. We study compactifications of eleven- and ten-dimensional maximal supergravity on Calabi-Yau threefolds. We explicitly construct truncations to pure supergravity with eight supercharges in five and four dimensions and show that they are consistent, *i.e.* that every solution of the lower-dimensional equations of motion fully solves the higher-dimensional ones. We furthermore match the supersymmetry transformations and demonstrate the consistency to full non-linear order in fermions. Our construction is independent of the choice of Calabi-Yau threefold and only involves the universal structures such as the Kähler form and the holomorphic three-form, in agreement with implicit constructions in the generalised geometry literature [2].

[1] J. Lin, T. Skrzypek, K.S. Stelle, arXiv. 2412.00186.
[2] D. Cassani, G. Josse, M. Petrini and D. Waldram, JHEP **11** (2019) 017.

P26

Lattice defect networks in 2d Yang-Mills

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In the context of quantum field theory (QFT), there are no known examples of non-topological fully local theories. In the topological case, constructing a fully local theory is equivalent to finding all defects. We extend this framework to non-topological theories, proposing that defects might arise from quantizing classical degrees of freedom. This idea seems particularly plausible within the context of Lagrangian field theory. In this project, we test these assumptions in the setting of two-dimensional Yang-Mills theory.
Using a refined lattice approach, we are able to construct defect networks in pure Yang-Mills theory in two dimensions. This refinement preserves the locality of individual defects while maintaining compatibility with the solvability of the theory via subdivision invariance. We also explicitly demonstrate that the building blocks of these defect networks close under fusion. This is based on our recent paper [1].

[1] L. Griguolo, E. I. Marieni, I. Yaakov, arxiv preprint arxiv: 2501.12351.

P27

How to Implement Symmetries with Local Operators in QFT: The Twist Operator

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Twists are local operators that implement symmetries in bounded regions of the space. We show how to construct several types of twists using modular tools and the split property. In the case of the theory of the massless chiral fermion in two dimensions we can explicitly construct the twist and study its action because the modular tools are well known. Twist operators serve as a valuable tool for understanding the properties of quantum field theory (QFT), including Noether's Theorem and Anomalies.
Related publication: 10.1103/PhysRevD.109.045001

P28

An Exterior Field Theory for Hawking Radiation

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In the last few years, a contour prescription for computing real-time correlators in AdS black holes has been proposed, called the gravitational Schwinger Keldysh contour (grSK). The real-time correlators computed using grSK are naturally given in terms of Witten diagrams in a doubled black hole geometry.

How does this doubled geometry picture reconcile with the physics seen by a bulk observer? We expect that the bulk description should be in terms of a QFT in a *single copy* of the space-time: in fact, we expect a real-time thermal QFT with the associated bulk diagrammatics. The primary message of my poster is that, at least for non-derivative interactions, this expectation is indeed met.

There is a clear bulk exterior field theory from which real-time correlators can be computed [1, 2]. With this poster, I will explain how this result comes out of the grSK geometry.

The tentative layout of my poster is as follows. I would like to explain

1. The physical problem: **Scattering against hawking radiation of black holes**.
2. The gravitational version of the **Schwinger-Keldysh technique**.
3. Why we expect an **exterior field theory for scattering processes around a black hole**.
4. The **exterior field theory** and its **Feynman rules** coming from grSK.
5. Computation of a **4-point function as an example**.

[1] R.Loganayagam, Godwin Martin, arXiv:2403.10654.
[2] Godwin Martin, Shivam K. Sharma, arXiv:2403.10604.

P29

Differential Representation for Carrollian Correlators

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Abstract: The differential representation of AdS correlators offers a framework to express exchange Witten diagrams as functions of non-local differential operators applied to contact Witten diagrams. In this paper, we develop the differential representation for scalar Carrollian correlators. We first construct this representation using the recently formulated Carrollian limit of AdS Witten diagrams. We then provide an alternate intrinsic analysis that leverages the properties of the Carrollian bulk-to-boundary propagator. Using the differential representation, we also obtain differential Bern-Carrasco-Johansson (BCJ) relations for Carrollian correlators.

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[1] L. Eberhardt, S. Komatsu and S. Mizera, JHEP 11 (2020) 158 [2007.06574].
[2] K. Roehrig and D. Skinner, JHEP 02 (2022) 073 [2007.07234].
[3] A. Herderschee, R. Roiban and F. Teng, JHEP 05 (2022) 026 [2201.05067].
[4] A. Bagchi, P. Dhivakar and S. Dutta, JHEP 04 (2023) 135 [2303.07388].
[5] A. Bagchi, P. Dhivakar and S. Dutta, JHEP 08 (2024) 144 [2311.11246].

P30

Geometric interpretation of timelike entanglement entropy

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Entanglement entropy represents a prolific notion in the contemporary physics landscape, with applications in quantum information, dynamics of quantum many-body systems and holography [1]. In the latter context, entanglement on the boundary field theory is understood in terms of geometric probes of the bulk spacetime, namely extremal surfaces anchored on a spacelike boundary subregion [2, 3]. The relation between boundary entanglement and bulk causality paves the way for understanding the holographic emergence of gravity in a quantum information-inspired setup [4, 5]. Still, entanglement is a property of a given state, as it is not sensitive to the past history of the system: generalizing the notion of entanglement to include information about time evolution opens a new window into the possibility of studying the dynamics of strongly-coupled quantum systems from a more general perspective.

Analytic continuations of holographic entanglement entropy in which the boundary subregion extends along a timelike direction promise such a novel, time-centric probe of the emergence of spacetime [6]. Aiming at a covariant definition of the quantity, we propose that the bulk carriers of holographic timelike entanglement entropy are boundary-anchored extremal surfaces probing analytic continuation of holographic spacetimes into complex coordinates [7]. This proposal not only provides a geometric interpretation of all the known cases obtained by direct analytic continuation, but crucially opens a window to study holographic timelike entanglement entropy in full generality, when the quantity cannot be expressed in closed form. With this spirit, we explore the investigation of complex extremal surfaces anchored on a timelike strip at the boundary of anti-de Sitter black branes. We find multiple complex extremal surfaces, some of which probe a specific complexification of the spacetime singularity.

Tensor network techniques have reproduced the holographic prediction for timelike entanglement in 1+1 boundary dimensions [8]. Currently ongoing investigation aims at understanding the relations between the gravitational and the field theory side, to qualify timelike entanglement as a fully-fledged measure for time evolution [9]. Moreover, complex holographic probes of the bulk find applications in de Sitter spacetimes [10] and could exhibit the peculiar property of probing the black hole interior and even singularity, which is extremely rare among the presently known single-sided probes of holographic spacetimes.

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P31

Effective Actions in String Theory and String Field Theory

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Various techniques in string theory, including scattering amplitudes, beta functions, and string dualities, have been employed to derive low-energy effective actions. Additionally, innovative approaches like generalized geometry and double field theory (DFT) provide new avenues for obtaining these results. In this study, we use string field theory to explore higher-order corrections to the effective actions of bosonic and heterotic string theories and give an overview of previous works and comment on future directions. The results obtained through this approach align with those derived from other methods, albeit potentially requiring field redefinitions.

P32

Three Dimensional Topological Field Theories and Nahm Sum Formulas

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It is known that a large class of characters of 2d conformal field theories (CFTs) can be written in the form of a Nahm sum. In [1], D. Zagier identified a list of Nahm sum expressions that are modular functions under a congruence subgroup of $SL(2,Z)$, which can be thought of as candidates for characters of rational CFTs. Motivated by the observation that the same formulas appear as the half-indices of certain 3d $\mathcal{N}=2$ supersymmetric gauge theories, we perform a general search over low-rank 3d $\mathcal{N}=2$ abelian Chern-Simons matter theories which either flow to unitary TFTs or $\mathcal{N}=4$ rank-zero SCFTs in the infrared. These are exceptional classes of 3d theories, which are expected to support rational and C_2-cofinite chiral algebras on their boundary. We compare and contrast our results with Zagier's and comment on a possible generalization of Nahm's conjecture.

[1] D. Zagier, "The Dilogarithm Function", in: "Les Houches School of Physics: Frontiers in Number Theory, Physics and Geometry", pp. 3–65.

P33

The Landscape of complexity measures in 2D gravity

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Recently, an infinite class of holographic generalized complexities was proposed. These gravitational observables display the behavior required to be duals of complexity, in particular, linear growth at late times and switchback effect. In this work, we develop the proposal for codimension-1 generalized measures of complexity for a wide class of two-dimensional dilaton gravity theories. Our proposal is motivated by the specific class of observables found from a spherical dimensional reduction of the codimension-1 observables used to characterize holographic complexity for higher-dimensional charged black holes. We also analyse the parameter space of the allowed complexity observables in these charged black hole backgrounds which leads to the discovery of an interesting degeneracy of the surfaces on which the complexity measure is defined. We provide two different interpretations of these degeneracies.

P34

Non-Invertible Self-Duality Symmetries via Non-Compact SymTFT

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Using a non-compact symmetry topological field theory (symTFT) to encode continuous global symmetries of the boundary theory [1, 2], we are able to describe d-dimensional theories that admit non-invertible self-duality symmetries from the perspective of a $d+1$-dimensional topological bulk. By allowing for gauging continuous symmetries with flat connections, such self-duality symmetries can be formulated at any value of the coupling. The corresponding symmetry generators are constructed as open condensation defects of the $d+1$-dimensional bulk [3, 4, 5], and are shown to be generically non-invertible via fusion arguments. These concepts are exemplified in both the $d=2$ case, the compact boson [6], as well as in $d=4$ free Maxwell theory [7].

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P35

Information Scrambling in Brownian SYK Chains

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We study operator growth in a Brownian SYK chain with N fermions at each site. In the limit $N \to \infty$, the operator growth equation is a special case of the Fisher-Kolmogorov-Petrovsky-Piskounov (FKPP) equation. As a consequence of the FKPP equation, the operators spread linearly at late times with the butterfly velocity. Then, we consider a maximally entangled state between a chain and its copy (a Choi-Jamiolkowski state). In this state we compute the time dependence of entanglement entropy of a two-sided subregion under the time evolution of one side. We show that if a subregion on one-side contains a small fraction of N fermions on a site, then the time evolution of entanglement entropy is fixed by the operator growth equation. As a consequence, we find that entanglement of a small subregion in the Choi-Jamiolkowski state spreads with the butterfly velocity. We conclude with some comments on the connection of our results with the membrane formula [1].

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P36

Black Hole Cohomologies in BMN sector

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In this work we have tried to see the black hole cohomologies in the BMN sector of SO(2N+1) and SP(N) gauge groups. We try to use the S-duality framework of SO(2N+1) and SP(N) to investigate these cohomologies. Generically, the full $1/16$-BPS indices matches between the two gauge groups. Here, we see numerically that in the BMN limit these indices are not S-dual to each other. Here we report about this discrepancy and make some comments on it.

P37

Chaotic and Thermal Aspects in High-Energy String S-Matrix

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We compute tree level scattering amplitudes in [1], involving more than one highly excited states and tachyons in bosonic string theory. We use these amplitudes to understand the chaotic and thermal aspects of the excited string states lending support to the Susskind-Horowitz-Polchinski correspondence principle. The unaveraged amplitudes exhibit chaos in the resonance distribution as a function of the kinematic parameters, which can be described by random matrix theory. Upon coarse-graining, these amplitudes are shown to exponentiate, and capture various thermal features, including features of a stringy version of the eigenstate thermalization hypothesis as well as notions of typicality. Further, we compute the effective string form factor corresponding to the highly excited states, and argue for the random walk behaviour of the long strings.

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Deforming the Double Liouville string

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We consider a generalization of the double Liouville theory, which can be thought of as a two-parameter family of marginal deformations of the so-called Virasoro Minimal String (VMS) [1]. The latter consists of a timelike ($c_- < 1$) and a spacelike ($c_+ > 25$) Liouville field theory formulated on a fluctuating Riemann surface. For the deformed theory, we compute the sphere partition function exactly in $1 \,/\, c_\pm$ and at third order in the coupling constant (λ) that controls the deformation. We also discuss the analogous computation in the case of the Complex Liouville String (CLS) theory [2], which is defined as two spacelike Liouville theories with complex central charges $c_\pm = 13 \pm iR > 0$. We show that the partition functions of VMS and CLS differ at leading order in λ due to the presence of elliptic functions in the observables of the latter. Both VMS and CLS theories have recently been studied in relation to many interesting models, including the double scaled Sachdev–Ye Kitaev model, matrix models, and de Sitter gravity in 2 and 3 dimensions [3]. We comment on the interpretation of the marginal deformation in some of these contexts.

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[2] S. Collier, L. Eberhardt, B. Mühlmann and V. A. Rodriguez, [arXiv:2409.17246 [hep-th]].

[3] H. Verlinde and M. Zhang, [arXiv:2402.02584 [hep-th]].

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Poster abstract: Spring School on Superstring Theory and Related Topics

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Understanding black hole interiors has been an important theme of research in quantum gravity ever since the foundational papers on black holes appeared. A major modern incarnation of this research front has been studies of holographic complexity [1, 2]. This research direction stems from a heuristic yet convincing observation in [3] that connected perpetual growth of the volume of the black hole interiors with the expected behaviour of quantum circuit complexity in chaotic systems. The key open question in the studies of holographic complexity is that of its interpretation in the microscopic description on the boundary. To date, despite a decade of research on the topic, there has been only one fully quantitative match discovered. In 2023 [4] showed that complexity = volume in the simplest holographic gravity theory (JT gravity) is given by the Krylov spread complexity [5] in the dual description in terms of a particular (triple-scaling) limit of the SYK model. The so far isolated nature of [4] raises the crucial question: Does the relation between holographic complexity and microscopic Krylov spread complexity extend to other gravity setups?

The aim of this poster is to present that the answer is affirmative within the freshly discovered duality between two-dimensional sine-dilaton gravity at disk level and the double-scaled SYK model put forward in [6]. From the point of view of the parameter space of the double-scaled SYK model, the result of [4] lies at a single point and our work extends it to a two-dimensional plane spanned by the interaction strength q (nonlocality of the model) and inverse temperature β. One key lesson is that, to establish this duality, gravity demands to assign complexity to the Euclidean preperation of the Hartle-Hawking state. We exemplify the quantum nature of the derived match by numerical comparison of the derived Krylov spread complexity with the first quantum correction to the length [7] where perfect agreement is observed where the full quantum length is expected to be well approximated by the first quantum correction. We also propose arguments to view the first quantum correction to the length as complexity of bulk quantum fields and comment on the switchback effect, whose presence would make the Krylov spread complexity a fully fledged holographic complexity in sine-dilaton gravity. The duality studied in this work can also be made manifest as an operator statement. Based on [8].

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[3] L. Susskind, Computational Complexity and Black Hole Horizons, Fortsch. Phys. 64 (2016) 24–43 [arXiv:1403.5695]. [Addendum: Fortsch.Phys. 64, 44–48 (2016)].

[4] E. Rabinovici, A. Sanchez-Garrido, R. Shir and J. Sonner, A bulk manifestation of Krylov complexity, JHEP 08 (2023) 213 [arXiv:2305.04355].

[5] V. Balasubramanian, P. Caputa, J. M. Magan and Q. Wu, Quantum chaos and the complexity of spread of states, Phys. Rev. D 106 (2022), no. 4 046007 [arXiv:2202.06957].

[6] A. Blommaert, T. G. Mertens and J. Papalini, The dilaton gravity hologram of double-scaled SYK, arXiv:2404.03535.

[7] L. Bossi, L. Griguolo, J. Papalini, L. Russo and D. Seminara, Sine-dilaton gravity vs double-scaled SYK: exploring one-loop quantum corrections, arXiv:2411.15957.

[8] M.P. Heller, J. Papalini and T. Schuhmann, Krylov spread complexity as holographic complexity beyond JT gravity, arXiv:2412.17785

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Carroll dilaton supergravity in two dimensions

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Spread of Information in Euclidean path integral states and entanglement wedges

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Quantum group origins of edge states in double-scaled SYK

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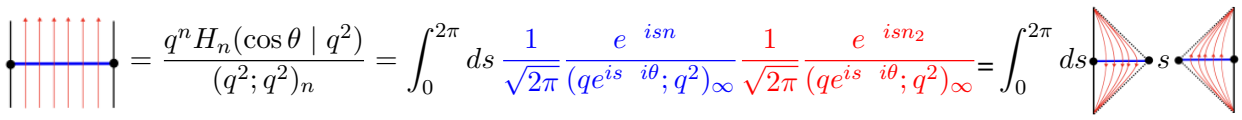
The factorisation (or lack thereof) of the bulk Hilbert space is a problem that has garnered considerable attention in the setting of quantum gravity. It is understood that in effective theories factorisation can be facilitated by extending the Hilbert space to include an edge state sector i.e. an auxilliary quantum number consistent with the existence of gravitational microstates behind the entangling surface. We investigate the implementation of these edge states in the double-scaled SYK (DSSYK) model from a quantum group theoretic perspective [2].
In this setting the two-sided gravitational wavefunctions are realized as matrix elements $R_{ab}\ g)$ of principal series representations of a q-deformed $\mathfrak{s}\ \ 2\ \ )$ gauge theory. Factorisation is then naturally implemented via the coproduct of the quantum group

$$R_{ab}\ g_1 \cdot g_2) = \sum_s R_{as}\ g_1) R_{sb}\ g_2) \tag{1}$$

where the extra (hyperbolic) label s captures the edge degrees of freedom introduced above. Implementing this strategy requires a deeper analysis of the quantum group theoretic structure underlying DSSYK leading us to proposing a specific (twisted) real form $U_q^\tau\ sl\ 2\ \ ))$ for the realization of double scaled SYK, extending previous proposals [1]. We explicitly implement the factorization of the bulk Hilbert space in terms of one sided wavefuntions



where the colored factors are the one sided wave functions and the s label is interpreted to live on the entangling surface, n is the discrete cord number and energy parameter θ is related to the representation label in the quantum group. novel feature of the edge modes in this model is their compact (or equivalently periodic) range which can be traced back to discretisation of geometry natural in DSSYK.

We further apply our detailed investigation of the quantum group structure to the calculation of other non-trivial amplitudes in the model. Generalizing known calculations from JT-gravity [3] we derive the single trumpet and end of the world (EOW) brane amplitudes in DSSYK via the computation of principal series and heighest weight discrete series characters in the gravitational path integral. The first of these is known to produce bulk defects that can be used to produce the non trivial topology of the single trumpet while the latter describes the degrees of freedom of the EOW-brane glued to the neck of the trumpet. This setup produces the amplitude

$$Z_{\text{EOW}}(\ \ ,\ \ ) = \quad = \sum_{n=0}^{\infty} \int_0^{2\pi} d\theta\ e^{\ \ E(\theta)} \cos(n\theta) \frac{q^{2n}}{1\ \ \ q^{2n}}.$$

which was previously conjectured in [4] and recently derived in a canonical framework by [5]. Finally we present some supersymmetric generalizations of our framework working towards a full quantum group theoretic description of $\mathcal{N} = 1$ DSSYK.

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[3] . Belaey, F. Mariani, T. Mertens, JHEP **02**, 058 (2024)
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A microscopic model of de Sitter spacetime with an observer

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In [1] we introduce a simple microscopic quantum mechanical model of low-dimensional de Sitter holography with an observer. Using semiclassical gravity and elementary thermodynamic considerations, we derive a formula for the total entropy of a 3D Schwarzschild-de Sitter universe with an observer. We then match this entropy formula with the exactly known spectral density of the double scaled SYK model. Our result gives a de Sitter interpretation of the appearance of two notions of temperature in DSSYK.

[1] Damiano Tietto, Herman Verlinde, arXiv:2502.03869 (2025).

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Spectral flow and extremal four-point functions on $AdS_3 \times S^3 \times T^4$

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String propagation in AdS_3 is one of the most studied realizations of the AdS/CFT correspondence, in part because it allows for a level of computational control that is perhaps unprecedented beyond the purely topological instances of the holographic duality in more than two bulk dimensions. Indeed, this applies to the boundary theory, which is a two-dimensional CFT believed to be closely related to a symmetric orbifold model, but also to the worldsheet theory which, in the pure NS-NS case, is given by a potentially solvable Wess-Zumino-Witten (WZW) model. This provides access to the description of string dynamics well beyond the supergravity limit. However, for general values of n_5 — the number of NS5-brane sources — the latter is *not* dual to a symmetric orbifold CFT. Therefore, when comparing these two theories, one must restrict to observables that are protected by non-renormalization theorems.

In this work we extend the analysis initiated in [1] to the supersymmetric theory by combining the techniques developed in [2] for the computation of descendant correlators and the proposal of [3] regarding the spectrally flowed four-point functions. We compute the extremal four-point functions of chiral primary operators in the worldsheet theory, reproducing the prediction from the boundary theory. We also study the spacetime factorization for arbitrary spectral flow charges and show how the expected structure is realized from the worldsheet perspective.

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Black Hole Singularity from OPE

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Duality constraints in large-N thermal QFT