The Abdus Salam International Centre for Theoretical Physics

IAEA International Atomic Energy Agency

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ICTP 1964–2024

String-Math 2024 | (SMR 3944)

10 Jun 2024 - 14 Jun 2024
ICTP, Trieste, Italy

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T01

Coulomb and Higgs Phases of G2-manifolds

Daniel A. Baldwin [1] , **Bobby S. Acharya**[1,2]

[1] *King's College London*
[2] *Abdus Salam International Centre for Theoretical Physics*

We will discuss the physics of M-theory compactifications onto G2-orbifolds of the type that can be desingularised via the method of Joyce and Karigiannis i.e. orbifolds where one has a singular locus of A1 singularities that admits a nowhere-vanishing (Z2-twisted) harmonic 1-form. Interestingly, there are topologically distinct desingularisations of such orbifolds which we show can be physically interpreted as different branches of the 4d vacuum moduli space of the arising gauge theories: Coulomb and Higgs branches. Our results suggest generalisations of the results of Joyce and Karigiannis to G2-orbifolds with more diverse ADE singularities and higher order twists. As a bonus, we also get an isomorphism between the moduli space of flat connections on flat compact 3-manifolds and the moduli space of Ricci flat metrics on the G2-orbifolds. We will briefly discuss this. Based on [1,2].

[1] Acharya, B.S., Baldwin, D.A. Coulomb and Higgs phases of G2-manifolds. J. High Energ. Phys. 2024, 147 (2024).

[2] Acharya, B.S. and Baldwin, D.A., 2023. Ricci Flat Metrics, Flat Connections and G2-Manifolds. arXiv preprint arXiv:2312.12311.

T02

Maulik-Okounkov Lie algebras and BPS Lie algebras

T03

Crossing bridges: exact results from VOAs, topology and number theory

Ioana Coman

Kavli IPMU, University of Tokyo

In recent years, vertex operator algebras (VOAs) have become increasingly ubiquitous with respect to supersymmetric quantum field theories (SQFTs) in various dimensions, where they can emerge as characterising some distinguished algebras of local operators. I will present two instances where VOAs have appeared recently in relation to 3D SQFTs, based on [1, 2]. In [1] the boundary VOAs for a class of 3D theories which have a quiver description have been identified from the gauge theory data and the associated quiver varieties. A systematic analysis allows here to derive free-field realisations of the resulting VOAs. I will also discuss a curious relation between logarithmic VOAs, 3D SQFTs, topological invariants of 3-manifolds and number theory, highlighting a set of intriguing new results. In particular, I will show how modularity properties of the q-series which connect the different perspectives play a key role in building a unifying picture, leading to exact results outside the reach of usual field theory methods.

[1] I. Coman, M. Shim, M. Yamazaki and Y. Zhou, "Affine $\mathcal{W}$-algebras and Miura maps from 3d $\mathcal{N} = 4$ non-Abelian quiver gauge theories", [arXiv:2312.13363 [hep-th]].

[2] M. C. N. Cheng, I. Coman, P. Kucharski, D. Passaro and G. Sgroi, "3d Modularity Revisited", [arXiv:2403.14920 [hep-th]].

T04

Modular Resurgent Structures and Spectral Traces of local $\mathbb{P}^2$

V. Fantini[1], **and C. Rella**[2]

[1]*IHÉS*

[2]*Département de Physique Théorique, Université de Genève*

The resurgent structures of the first fermionic spectral trace of local $\mathbb{P}^2$ in both weak and strong coupling limits were solved exactly in [1].

In [2], we prove that a full-fledged strong-weak resurgent symmetry is at play, exchanging the perturbative/nonperturbative contributions to the holomorphic and anti-holomorphic blocks in the factorization of the spectral trace. This relies on a global net of relations connecting the perturbative series and the discontinuities in the dual regimes, which is built upon the analytic properties of the L-functions with coefficients given by the Stokes constants and the q-series acting as their generating functions. Then, we show that the latter are holomorphic quantum modular functions for $\Gamma_1(3)$ and are reconstructed by the median resummation of their asymptotic expansions.

Then, building on these remarkable results and on examples from the theory of Maass cusp forms, in the companion paper [3] we introduce the notion of modular resurgent structures. We conjecture that asymptotic series with this structure have specific summability properties and are related with quantum modular forms. Furthermore, we propose a new paradigm of modular resurgence that focuses on the role of the Stokes constants and the interplay of the q-series acting as their generating functions with the corresponding L-functions.

In this talk, we will describe the modular resurgent structure of the first fermionic spectral trace of local $\mathbb{P}^2$.

[1] C. Rella, Comm. Numb. Th. and Phys. **17**, 709–820 (2023).
[2] V. Fantini, C. Rella, arXiv:2404.10695, (2024).
[3] V. Fantini, C. Rella, arXiv:2404.11550, (2024).

T05

Mixed boundary conditions in AdS_2/CFT_1 from the coupling with a Kalb-Ramond field

Diego H. Correa , **Maximiliano G. Ferro** and Victor I. Giraldo-Rivera

Instituto de Física La Plata - CONICET &
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La Plata, Argentina

The dynamics of fields propagating within Anti-de Sitter (AdS) space is known to encode the set of correlation functions of certain conformal field theories (CFTs). The presence of a boundary in AdS implies that different boundary conditions for fields give rise to diverse behaviors and properties in the corresponding dual CFT.

For massless scalar fields in AdS_2, a different type of boundary conditions that mix longitudinal and transverse derivatives was considered in [1]. Since the mixing parameter is dimensionless in that case, one might expect these boundary conditions to be associated with a marginal deformation rather than with a flow of the renormalization group. However, determining whether these boundary conditions correspond to a conformal theory on the line or not, is not straightforward, as this will depend on the actual details of the AdS_2/CFT_1 realization.

Massless scalar fields in AdS_2 typically arise when studying the fluctuations on an open string world-sheet dual to line operators in various d-dimensional CFTs.

An interesting case is that of the Wilson loops in the ABJ(M) model, a prototypical example of the AdS/CFT correspondence where the $\mathcal{N} = 6$ super Chern-Simons theory with gauge group $U(N)_k \times U(N)_{-k}$ is conjectured to be equivalent to type IIA string theory in $AdS_4 \times \mathbb{CP}^3$.

This model admits a simple and interesting generalization, in which the gauge group in the Chern-Simons theory is taken to be $U(N + \ell)_k \times U(N)_{-k}$. In this case, the dual string theory description includes an additional flat Kalb-Ramond field, having a non-trivial holonomy on the non-contractible $\mathbb{CP}^1 \subset \mathbb{CP}^3$. Being the Kalb-Ramond field flat, its coupling to the open string only leads to a boundary term. The boundary term from the coupling with the Kalb-Ramond field is responsible for the materialization of the aforementioned kind of mixed boundary conditions when we study the open string dual to the 1/6 BPS *bosonic* Wilson line.

A Witten diagram computation with fluctuations on an AdS_2 world-sheet enables the holographic realization of the correlation functions of operators inserted on the Wilson line.

This effective theory on a line can preserve conformal symmetry at the quantum level or not, which should be reflected in the functional dependence of the correlation functions of excitations.

The main result of our work [2] is a perturbatively test of conformal covariance of the theory on the line dual to the open string with mixed boundary conditions. To achieve this, we find the functional dependence of holographic 4-point correlators as a cross-ratio function.

[1] Correa, D.H., Giraldo-Rivera, V.I., Silva, G.A. "Supersymmetric mixed boundary conditions in AdS2 and DCFT1 marginal deformations" J. High Energ. Phys. 2020, 10 (2020), [arXiv:1910.04225 [hep-th]].

[2] Correa, D.H., **Ferro, M.G.**, Giraldo-Rivera, V.I. "Mixed boundary conditions in AdS2/CFT1 from the coupling with a Kalb-Ramond field." J. High Energ. Phys. 2024, 141 (2024) [arXiv:2312.13258 [hep-th]].

T06

Exploring the spontaneous and explicit braking of (-1)-form symmetries.

Eduardo Garcia Valdecasas[1]

[1] *SISSA*

We explore a feature of Quantum Field Theories that shares some similarities with higher-form symmetries and sometimes goes under the name of (-1)-form symmetry. We discuss a notion of spontaneous breaking for these symmetries, to which we associate universal physics. We further connect this physics to the Strong CP problem, which arises in particle phenomenology. If time permits we will also discuss the explicit breaking of these symmetries in theories with dynamical monopoles.

T07

Resurgent large genus asymptotics of intersection numbers

T08

Trace Map on Chiral Weyl Algebras

ABSTRACT: We construct a trace map on the chiral homology of chiral Weyl algebra for any smooth Riemann surface. Our trace map can be viewed as a chiral version of the deformed HKR quasi-isomorphism. This also provides a mathematical rigorous construction of correlation function for symplectic bosons in physics. We calculate some examples of trace maps with one insertion and find they are closely related to the variation of analytic torsion for holomorphic bundles on Riemann surfaces.

T09

Abelianization of $c = 1$ Virasoro conformal blocks

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[2] *Department of Mathematics, Yale University, PO Box 208283, New Haven, CT 06520-8283, United States*

Virasoro conformal blocks are the building blocks of the 2d Liouville CFTs. The Virasoro conformal block at $c = 1$ is especially interesting because of its relation to the integrable system. I will describe a new way of making $c = 1$ Virasoro conformal blocks. We build them from "abelian" objects, the Heisenberg conformal blocks, using the nonabelianization approach. The core new idea is the insertion of an operator which has an integral along the spectral network walls. The nonabelianization construction can be used for many interesting applications, like studying the τ functions, constructing the W_N conformal blocks which are less studied, etc. This is a joint work in progress with Andrew Neitzke.

T10

Symmetry topological field theories from self-dual fields in string theory

Iñaki García Etxebarria [1] , Saghar Hosseini [1,2]

[1] *Durham University*
[2] *Kalvi IPMU*

Non-invertible (D+1)-dimensional symmetry topological field theories, known as SymTFTs [1], contain information about choices of generalised symmetries and anomalies of D-dimensional QFTs. In this talk I will give a quick introduction to SymTFTsand discuss how they emerge in the case of geometrically engineered QFTs. More specifically, I will argue that in type II string theory, they arise from the reduction of a topological action, given by the quadratic refinement in twisted differential K-theory [2], which realises self-dual fields in string theory as edge modes.

[1] F. Apruzzi, F. Bonetti, I. García Etxebarria, S. Hosseini, and S. Schafer-Nameki, *Commun.Math.Phys.* 402 (2023).
[2] M.J. Hopkins, I.M. Singer, *J.Diff.Geom.* 70 (2005).

T11

Quantum K-Theory of Partial Flag Varieties

Irit Huq-Kuruvilla[1]

[1] *Virginia Tech*

Based on physical predictions coming from the theory of three-dimensional gauged linear sigma models, Gu-Mihalcea-Sharpe-Xu-Zhang-Zhou [1] conjectured a presentation of the T-equivariant quantum K-theory of (complete and partial) flag varieties in type A. This presentation is a quantum deformation of the Whitney relations which determine the classical K-ring.

We prove the conjecture for all type A flag varieties, via the machinery of twisted Gromov-Witten invariants. We prove an abelian-non-abelian correspondence relating the quantum K-ring of the partial flag variety to the twisted quantum K-ring of its associated toric GIT quotient, which can be calculated explicitly. This procedure also gives a mathematical interpretation of the appearance of the Bethe Ansatz in the corresponding GLSM.

[1] W. Gu, L. Mihalcea, E. Sharpe, W. Xu, H. Zhang, H. Zhou, Journal of Geometry and Physics **198**, 105-127 (2012).

T12

Miura operators as R-matrices from M-brane intersections I will discuss how M2-M5 intersections in twisted M-theory backgrounds yield R-matrices of quantum toroidal algebra. These intersections, identified as Miura operators, provide free-field realizations for q-deformed W- and Y-algebras, illuminating the intertwining relation of the q-deformed Maulik-Okounkov R-matrix as a Yang-Baxter equation.

T13

Twisted Tools for (Untwisted) Quantum Field Theory

T14

Categorification of tangle invariants and quantum groups from categories of A-branes

Elise LePage[1]

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A previous work of Aganagic showed homological invariants of links come from a category of A-branes. In this work, we describe two extensions. The first is to tangle invariants. While a single category of A-branes categorifies quantum link invariants, tangle invariants are categorified by functors which relate different A-brane categories. A particular instance of such functors are raising and lowering functors, whose construction turns out to be canonical. This shows that the category of A-branes naturally fits into a 2-category of representations of the categorified quantum group. This is joint work with Mina Aganagic, Yegor Zenkevich, and Peng Zhou.

[1] M. Aganagic, "Knot Categorification from Mirror Symmetry, Part II: Lagrangians" (2021). arXiv:2105.06039

T15

Partition function of Argyres-Douglas theories on the blowup

T16

Deriving the Simplest Gauge/String Duality

Edward A. Mazenc[1] **and Rajesh Gopakumar**[2]

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[2] *ICTS Bangalore*

't Hooft's vision suggests that the Feynman diagram expansion of a large N gauge theory should admit a dual description in terms of a sum over string worldsheets. How can this be made precise? In this work, we derive the closed string dual to the simplest possible gauge theory, a single hermitian matrix integral, in the conventional "holographic" 't Hooft limit. This provides a mathematically rigorous example of gauge/string duality, as well as novel connections between random matrix theory and algebraic geometry. Without the clutch of the oft studied double-scaling limit, we propose a new dictionary as to how the Feynman diagrams of the matrix theory explicitly realize the dual closed string worldsheets. This relies crucially on the Strebel parametrization of the moduli space of (punctured) Riemann surfaces, inspired by Kontsevich's proof of the Witten conjecture.

More specifically, we propose and verify an explicit correspondence with a (mirror) pair of closed topological string theories. On the A-model side, this is a supersymmetric $SL(2, R/U(1)$ Kazama-Suzuki coset (with background momentum modes turned on). The mirror B-model description is in terms of a Landau-Ginzburg theory with superpotential $W(Z) = Z^{-1} + tZ$ and its deformations. Finally, we comment on how this duality is embedded as a topological subsector of the full AdS/CFT correspondence.

[1] Rajesh Gopakumar, Edward A. Mazenc, "Deriving the Simplest Gauge-String Duality – I: Open-Closed-Open Triality", "2212.05999"
[2] Matthias Gaberdiel, Rajesh Gopakumar, Edward A. Mazenc, "Deriving the Simplest Gauge-String Duality – II: The A-Model ", (to appear)
[3] Rajesh Gopakumar, Edward A. Mazenc, "Deriving the Simplest Gauge-String Duality – III: The B-Model ", (to appear)

T17

Calabi-Yau threefold flops as quiver varieties from monopole deformations

T18

Deformations of monoidal categories

Bhanu Kiran Sandepudi[1], **Pranav Pandit**[1]

[1]*(Presenting author underlined) International Centre for Theoretical Sciences*

Historically, mathematicians noticed a correspondence between deformations of an object and Maurer-Cartan elements in an associated dg-Lie algebra. In the setting of homotopical mathematics, Lurie and Pridham sharpened this phenomenon to a theorem. They established an equivalence between dg-Lie algebras over a field of characteristic zero and formal moduli problems over the same field. In the axiomatic framework of Lurie, the natural functor one constructs to study deformations of an object may fail to be a formal moduli problem. This discrepancy can be quantified within this framework. Subsequent work by Blanc, Katzarkov and Pandit established that for ∞-categories satisfying a suitable hypothesis this discrepancy does not occur for deformations over the ring of formal power series. We extend these findings to monoidal ∞-categories and, using the framework of Freed, Moore and Teleman interpret the results from the view point of symmetries in topological field theory.

T19

Modularity of certain Gromov-Witten invariants from K3 mirror symmetry, irrationality of zeta values, and the Gamma conjecture

Michael T. Schultz[1], **Andreas Malmendier**[2]

[1] *Virginia Tech*
[2] *Utah State University*

It is well known that genus zero Gromov-Witten invariants of both elliptic curves and K3 surfaces are trivial. Suppose that X is an anticanonical K3 surface on a Fano threefold F. Via mirror symmetry, the vanishing of genus zero Gromov-Witten invariants on X can be understood in terms of quadratic relations between the period integrals on the mirror K3 surface $\check{X}$. When the Picard rank of F is one, the A-side connection on quantum cohomology of F is a fourth order ODE with regular and irregular singular points, and is related to the derivative of the third order Picard-Fuchs operator of $\check{X}$ via the Borel-Laplace transform.
In this talk, we study this resulting fourth order ODE $\mathcal{D}_4$ operator on $\check{X}$, deemed the *quantum* differential operator of the mirror K3. The operator $\mathcal{D}_4$ is maximally unipotent, and behaves in many respects like the Picard-Fuchs operator of a pencil of Calabi-Yau threefolds with $h^{2,1} = 1$. Inspired by work of W. Yang [1] on the Beukers-Peters pencil of K3 surfaces associated to Apéry's proof of the irrationality of $\zeta(3)$, we define in [2] analogues of the standard ingredients of Calabi-Yau mirror symmetry for the operator $\mathcal{D}_4$: holomorphic prepotentials, virtual Yukawa couplings, and virtual instanton numbers. For the precisely 17 deformation classes of rank one Fano threefolds classified by Iskovskikh, these quantities end up being very closely connected to modular forms of weight-4 for certain congruence subgroups, originally utilized by Golyshev & Zagier in their proof of the Gamma conjecture for such Fanos [3].
We will show that the modularity of these quantities allows for a direct proof of the integrality - and surprisingly, periodicity - of virtual instanton numbers. One then wonders what sort of geometric content the virtual instanton numbers encode. Inspired by previous work by Stienstra [4] on elliptic curves, we show that the virtual Yukawa coupling can be inverted in a natural way, and the conjecture that resulting expansion encodes genus zero Gromov-Witten invariants of the local Calabi-Yau fourfold K_F, the total space of the canonical bundle of F. The conjecture is verified for the case $F = P^3$, projective 3-space. Such phenomena seems completely consistent with Iritani's recent work on the mirror symmetric Gamma conjecture [5].

[1] W. Yang, Apéry's irrationality proof, Beukers's modular forms and mirror symmetry, arXiv 1911.02608, (2021).
[2] A. Malmendier, M.T. Schultz, On mirror symmetry and irrationality of zeta values, arXiv:2403.07349 (2024).
[3] V. V. Golyshev and D. Zagier, Proof of the gamma conjecture for Fano 3-folds of Picard rank 1, Izv. Math. 80 24 (2016)
[4] J. Stienstra, Mahler Measure Variations, Eisenstein Series and Instanton Expansions, Mirror symmetry. V., AMS/IP Stud. Adv. Math., 38, 139–150, (2006)
[5] H. Iritani, Mirror symmetric Gamma conjecture for Fano and Calabi-Yau manifolds, arXiv 2307.15940 (2023)

T20

Abstract for talk and poster presentation at String-Math 2024

Shiraz Minwalla[1], Souparna Nath[1], Nikhil Tanwar[1], and Vatsal[1,2]

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Indian Institute of Technology Bombay, Powai, Mumbai 400076, India

This is an abstract for a talk and a poster presentation on *"Fermionic Chern–Simons theory on $S^2 \times S^1$ at large-N in the 'temporal' gauge"* during the String-Math 2024 conference (June 10-14, 2024).

Most of the computational evidence for the Bose–Fermi duality of fundamental fields coupled to $U(N)$ Chern–Simons theories originates in the large-N calculations performed in the light-cone gauge. The evaluation of the thermal free energy on a finite-sized sphere is elusive in the light-cone gauge but more natural in another gauge, the 'temporal' gauge. We use it to evaluate the finite-temperature partition function of $U(N)$ coupled fermions on $\mathbb{S}^2$ at large N, which is a novel physical setting for the problem. We set up the finite-temperature gap equations, solve them, and evaluate the partition function, closely following the tricks explored in [1], where we work out the results on $\mathbb{R}^2$ at large N, which demonstrate perfect agreement with the earlier light-cone gauge results.

[1] S. Minwalla, S. Nath, N. Tanwar, Vatsal, **arXiv:2307.11020**.