A Panorama of Tensor Networks: from Condensed Matter to Quantum Field Theory, Holography and Beyond

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Book of Abstracts

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A - Invited Talk / 33

Temporal Entanglement and Holography

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I will discuss how temporal entanglement known from the field of tensor networks manifests itself in holography.

B - Contributed Talk / 4

Density matrix renormalization group study of the competition between spin and quadrupolar correlations in the bilinear-biquadratic spin-1 model

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Ultracold gases of alkali metal atoms have attracted a lot of attention recently both in experiment and theory. The SU(2) symmetric bilinear-biquadratic (BLBQ) spin-1 Heisenberg Hamiltonian is able to model the behavior of such systems with $F = 1$:

$\mathrm{H} = \sum_i [(\vec{S}_i \otimes \vec{S}_{i+1}) \cos\theta + (\vec{S}_i \otimes \vec{S}_{i+1})^2 \sin\theta]$.

In the range $-\pi < \theta \leq \pi$ this model exhibits four quantum phases: the ordered ferromagnetic phase, the symmetry protected topological Haldane phase, the dimer phase, and the critical phase. The properties of the system in the critical phase have not been studied extensively so far. It was clarified, though, that the quadrupolar correlator of the system is larger than the spin correlator, therefore this phase was referred to as "quadrupolar phase" [1].

We study the competition between spin and quadrupolar correlations in the system comprehensively in *all* phases, both in coordinate and momentum space. The properties of BLBQ spin *rings* (which are translational invariant) are studied. To this end, we use our version of density matrix renormalization group (DMRG) with SU(2) symmetry for periodic boundary conditions (PBC) [2]. Incorporation of SU(2) symmetry allows for formulation of the PBC algorithm in terms of reduced tensors only and reduces memory requirements significantly. It is also particularly useful in the ferromagnetic phase due to ability to capture the entire ground state multiplet in a single DMRG run.

From our numerical results we deduce approximate analytical expressions for the correlators inside and close to the ferromagnetic phase. In particular, we find that the spin correlator $S(r) = 0$ for any $r > 0$ at the phase transition point $\theta = -3\pi/4$ and in the ferromagnetic phase, while the quadrupolar correlator $Q(k)$ diverges at the momentum $k = 0$ in the same area and therefore plays the decisive role there. In fact, our results indicate that the spin correlations dominate only in the area $-\pi/2 < \theta < \pi/4$.

Furthermore, we simulate numerically the power law decay of both correlation functions with distance ($|S(r)| \sim r^{-\alpha}$, $|Q(r)| \sim r^{-\beta}$) in the entire critical phase, which has not been done before. The critical exponents show opposite behavior when increasing θ: α increases monotonously while β decreases. We prove analytically and numerically that $\alpha = 2$ at the first-order transition point $\theta = \pi/2$, and find a discontinuous jump of both correlation functions there.

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[3] M. V. Rakov, M. Weyrauch, manuscript in preparation.

B - Contributed Talk / 26

Symmetry-resolved entanglement entropy in random tensor networks

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In quantum systems with global symmetries, entanglement exhibits a refined structure across symmetry sectors, captured by the symmetry-resolved entanglement (SRE) entropy. In $U(1)$-symmetric free field theories, SRE entropies typically exhibit equipartition, remaining independent of the charge sector. In this work, we demonstrate the breakdown of equipartition in a random tensor network state with $U(1)$ symmetry. By introducing novel charge constraints on the random tensors, we engineer an emergent $U(1)$ gauge field and derive its effective action on the curved space defined by the network. We uncover a holographic interpretation in which the SRE entropies receive contributions from the saddle-point configuration of the emergent gauge field on the minimal surface anchored to the boundary of the subsystem. The gauge field dynamics subjected to the charged boundary condition are directly responsible for the breakdown of equipartition.

B - Contributed Talk / 36

On Infinite Tensor Networks, Complementary Recovery and Type II Factors

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We initiate a study of local operator algebras at the boundary of infinite tensor networks, using the mathematical theory of inductive limits. In particular, we consider tensor networks in which each layer acts as a quantum code with complementary recovery, a property that features prominently in the bulk-to-boundary maps intrinsic to holographic quantum error-correcting codes. In this case, we decompose the limiting Hilbert space and the algebras of observables in a way that keeps track of the entanglement in the network. We apply this framework to the HaPPY code, networks prepared by stabilizer circuits, MERA and use it to provide a novel perspective on topological order and its relation to quantum computation.

B - Contributed Talk / 22

Intertwined Charge and Pairing Fluctuations in the Emergence of Stripe-Aligned d-Wave Superconductivity

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Stripe order is a defining feature of the high-temperature cuprate phase diagram and has been numerically shown to be the ground state of the two-dimensional Fermi-Hubbard and t-J models in specific regimes. Upon heating, stripe and superconducting orders give way to the strange metal and pseudogap phases, whose microscopic origins remain elusive. Using advanced tensor network techniques, we uncover critical aspects of this transition. Infinite projected entangled pair state (iPEPS) simulations reveal a pronounced maximum in the uniform charge susceptibility above the stripe phase, near hole doping p = 0.9 which intensifies upon cooling. Finite-width cylinder METTS simulations trace this maximum to the formation of fluctuating charge clusters, reminiscent of phase separation into hole-rich and hole-poor regions. However true phase separation is ultimately forestalled by the emergence of stripe order at low temperatures. Investigating the doped Mott regime within the t-t'-J model, we observe that fluctuating domain walls of doped holes serve as precursors to superconductivity. At low temperatures, transient mergers of hole-rich regions form larger clusters, within which distinct areas host fragmented superconducting channels. As the temperature decreases, these fragmented condensates gradually phase-lock into a globally coherent, stripe-aligned d-wave superconductor. Our findings suggest a unified framework where local charge and pairing fluctuations coalesce into stripe order and superconductivity, offering new insights into the intertwined nature of these phenomena in strongly correlated systems.

B - Contributed Talk / 28

Graph Representations and Circuit-Based Codes from GHZ States

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GHZ states are fundamental in quantum information science, playing roles in communication, nonlocality tests, and quantum error correction. In this work, we explore two complementary aspects of GHZ states relevant for both theory and implementation.

First, we address the structure of non-symmetric GHZ states, defined as unequal superpositions of computational basis states, which frequently occur in qudit-based experiments due to decoherence and imperfect amplitude or phase control during state preparation. While symmetric GHZ states are known to be locally unitary (LU) equivalent to graph states, their non-symmetric counterparts lack a comparable stabilizer or graph-theoretic framework. We show that these non-symmetric GHZ states are LU-equivalent to two graphical constructions: (i) fully connected weighted hypergraph states with multi-qudit controlled-phase gates, and (ii) controlled-unitary (CU) star-shaped graphs. Although weighted hypergraph states typically do not admit a stabilizer description, we construct a full set of stabilizers using only a single ancilla qubit, independent of system size.

Second, we introduce a new method for constructing quantum error-correcting codes by embedding perfect (symmetric) GHZ states into brickwall circuit architectures. The building blocks of these circuits are GHZ states forming a $[[3, 1, 2]]_d$ code, which we use to generate larger codes through circuit composition. This approach allows us to recover quantum codes such as $[[6, 1, 3]]$, $[[9, 1, 4]]$, and

[[12, 1, 4]], while providing insight into how stabilizer structures evolve through circuit dynamics. The method offers a modular and scalable framework for circuit-based quantum error correction, potentially useful for fault-tolerant computing and entanglement-assisted protocols.

B - Contributed Talk / **42**

Real-time simulations of scattering in two dimensions

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Real-time simulations of scattering are a promising avenue for exploring non-perturbative dynamical processes in strongly correlated systems. Unlike scattering experiments in particle colliders which measure the products of scattering, the simulations enable us to measure the system at any point in time. This allows us to directly probe the heart of the scattering process. This is particularly useful in strongly-coupled models, where the dynamics cannot be straightforwardly reconstructed from the scattering products. Accurate simulations of scattering promise to elucidate microscopic processes behind the creation of matter and its confinement into composite particles.

Due to methodological constraints, these simulations remain limited to one spatial dimension. We take the first step towards exploring higher-dimensional systems by simulating scattering of magnons in the quantum Ising model on a square lattice of 24×24 spins.

The ordered phase of the 2D Ising model is a particularly adept toy model for scattering, as its single-excitation spectrum consists entirely of bound states. This allows us to observe a rich interplay of scattering resonances, which produce various inelastic regimes.

Next, we tune the system into a symmetry-broken regime with a stable and a metastable vacuum. There, we investigate the stability of the false vacuum to the highly-energetic scattering of magnons of the stable species. We uncover a regime where the scattering generates a true vacuum bubble of the critical size, which violently expands and encompasses the whole system in a rapid false vacuum decay.

B - Contributed Talk / **21**

Continuous and field tensor network sates

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Tensor network methods have provided us with a powerful set of tools with which to study strongly interacting many-body systems on the lattice. Understanding the limitations of this approach is paramount for the success of both numerical algorithms and exact analytical representations of

the many-body wavefunction. In recent years, several generalizations making use of different notions of the continuum have appeared in the literature to tackle different limitations of tensor networks.

Firstly, continuous tensor network states (cTNS) is an ansatz that allows us to work directly in the continuum to answer questions related to quantum field theories, removing the need for sending the lattice spacing to zero in standard tensor network approaches. Secondly, field tensor network states (fTNS) aim to provide an exact tensor network approach to the analytical description of chiral gapped topological states in two spatial dimensions, such as the Laughlin wavefunction. While these states had been previously considered to be out of reach for the most prominent two dimensional tensor network, projected entangled pair states, by upgrading the virtual space of the network to an infinite dimensional one, we circumvent the previous no-go theorems to provide the first exact representations.

In this talk, I will present an overview of both cTNS and fTNS. I will present the main ideas behind both generalizations and relation to quantum field theories. I will also showcase some of the applications that we are currently working on, as well as some of the problems that one encounters along the way. Ongoing work with Arkadiusz Bochniak, Germán Sierra and Ignacio Cirac.

B - Contributed Talk / 56

Tensor network modeling of chain modes in Josephson junction arrays

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We present a nonperturbative tensor network approach for computing excited states in superconducting quantum circuits, leveraging the DMRG-X algorithm. DMRG-X extends the density matrix renormalization group to target individual excited states, given a well-prepared trial state. We introduce a general strategy for constructing such trial states from the normal modes of the linearized system, enabling efficient convergence to highly excited eigenstates while preserving the compact, nonlinear structure of Josephson potentials.

We apply this framework to Josephson junction arrays, which are core components of high-impedance elements in superconducting architectures such as fluxonium. While these systems are often modeled using single-mode approximations, we show that hybridization between low-energy and high-frequency internal modes can lead to significant deviations from these effective theories. Our method captures these nonperturbative effects, enabling quantitative benchmarking of perturbative approaches and providing a scalable tool for analyzing the many-body excitation spectra of superconducting circuits.

B - Contributed Talk / 47

Low-Temperature Gibbs States with Tensor Networks

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We introduce a tensor network method for approximating thermal equilibrium states of quantum many-body systems at low temperatures. Whereas the usual approach starts from infinite temperature and evolves the state in imaginary time (towards lower temperature), our ansatz is constructed from the zero-temperature limit, the ground state, which can be found with a standard tensor network approach. Motivated by properties of the ground state for conformal field theories, our ansatz is especially well-suited near criticality. Moreover, it allows an efficient computation of thermodynamic quantities and entanglement properties. We demonstrate the performance of our approach with a tree tensor network ansatz, although it can be extended to other tensor networks, and present results illustrating its effectiveness in capturing the finite-temperature properties in one- and two-dimensional scenarios. In particular, in the critical 1D case we show how the ansatz reproduces the finite temperature scaling of entanglement in a CFT.

B - Contributed Talk / 13

Exploring the Ground States of Higher-Spin Kitaev Models via QR-Accelerated iPEPS simulation

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Higher-spin extensions of the Kitaev honeycomb model offer a fertile ground for exploring quantum frustration and topological order beyond the spin-1/2 paradigm. Despite intensive interest, the nature of their ground states remains elusive, particularly in the large-spin regime where semiclassical intuition and entanglement effects intertwine. Accurate simulations in this limit are hindered by steep computational costs.

We build upon our previously established QR-accelerated iPEPS(infinite projected entangled pair states) framework, which achieves one to two orders of magnitude speedup in contraction time compared to conventional approaches, with excellent performance on modern GPU architectures. This enables controlled access to larger bond dimensions, which is crucial to obtain reliable ground state.

The improved efficiency enables simulations of higher-spin Kitaev models at unprecedented scale, laying the groundwork for deeper investigations into their entanglement structure and phase behavior.

B - Contributed Talk / 15

Bosonic vs. Fermionic Matter in Quantum Simulations of Gauge Theories

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Quantum link models extend lattice gauge theories beyond the traditional Wilson formulation and present promising candidates for both digital and analog quantum simulations. Fermionic matter coupled to quantum link gauge fields has been extensively studied, revealing a phase diagram that includes transitions from the columnar phase in the quantum dimer model to the resonating valence bond phase in the quantum link model, potentially passing through a disordered liquid-like phase. In this study, we investigate the model coupled to hardcore bosons and identify a similar phase structure, though with a more intricate mixture of phases around the transition. Our analysis reveals that near the transition region, a narrow and distinct ordered phase emerges, characterized by gauge fields forming plaquette configurations with alternating orientations, which is then followed by a thinner, liquid-like regime. This complexity primarily stems from the differences in particle statistics, which manifest prominently when the matter degrees of freedom become dynamic. Notably, our findings suggest that bosons can effectively replace fermions in lattice gauge theory simulations, offering solutions to the challenges posed by fermions in both digital and analog quantum simulations.

B - Contributed Talk / 54

Simulation of Shor's algorithm on a tensor network-based quantum emulator

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Shor's algorithm is a major milestone in the race to quantum supremacy which proposes to factorize semiprimes in time polynomial to the length of the binary string representation of the number. However, its practical implementation is limited due to several constraints in modern-day quantum hardware. Moreover, studies benchmarking the Shor's algorithm on quantum simulators are relatively few, focusing mostly on the success probability of factorization as the sole metric and statevector simulations as the primary technique. Our work presents a comprehensive study of the algorithm on a tensor network powered quantum simulator. In addition to the success probability, we also analyze the probability distribution of the sampled bitstring using different sampling strategies, quantify and evaluate the entanglement generated in the modular exponentiation circuit and examine the significance of so called 'lucky runs', cases where the number is factorized correctly even though the theoretical conditions are not completely met.

Several advancements have been made to allow for better scaling of Shor's algorithm. Some algorithms focus on reducing the number of qubits required to implement the quantum circuit [1, 2], others use specific optimization techniques to reduce the circuit depth and complexity [3, 4] while some others use methods like GPU accelerators and parallelization techniques [5, 6]. Building on the existing literature, we leverage the power of tensor networks to simulate larger instances as well as benchmark various aspects of its performance on our emulator.

We perform matrix product state (MPS) simulations of the Shor's algorithm based on the modular exponentiation quantum circuit proposed by Vedral, Barenco and Ekert [7]. This choice is driven by the fact that the scalability of the simulation is now dependent on the maximum bond dimension of the MPS and not on the number of qubits as for statevector simulations. Crucially, the bond dimension also allows systematic control over simulation fidelity and accumulated errors which is usually very difficult to do in noisy quantum hardware. The simulations are averaged over multiple semiprimes with the same bit length to minimize statistical errors. We compute the success probability across varying bond dimensions and numbers with increasing bit length, while also profiling

simulation time, circuit preprocessing/optimization time, and time for post-processing steps such as bitstring sampling and extraction of prime factors. To demonstrate that our results are trustworthy and credible, we implement a fidelity estimate for all simulations and also compare with exact (statevector) simulations for the smallest semi-prime.

Further, two different sampling methods are used to obtain the bitstring representing the final state and an evaluation is made on their probability distribution and how it varies with the bond dimension. We also give attention to distinguishing between "true"runs, where the correct order and factors are obtained and "lucky"runs where incorrect orders still lead to valid factorizations.

We benchmark our simulations on Quantum Matcha Tea, a logical quantum computer emulator fueled by MPS and Tree Tensor Networks (TTNs). We benchmark how the success probability scales with increasing bond dimension and how the underlying probability distribution obtained through sampling influences this quantity. Further, we use the Kullback–Leibler (KL) divergence to measure how accurate our obtained distribution is to the ideal output distribution as discussed in [8] and analyze the distribution of the bitstrings that are able to correctly determine the order of the modular exponentiation function. We further attempt to examine if a lower bound for the success probability depending on the bond dimension of the MPS can be determined. Finally, we also discuss potential improvements and future directions.

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B - Contributed Talk / **29**

Tensor networks for Hofstadter models

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The Bose-Hofstadter model, describing mobile bosons or fermions in a magnetic field on a lattice, hosts a plethora of interesting topological ground-state phases. The magnetic field is implemented through phases in the hopping amplitudes breaking translation invariance, which makes tensor network simulations particularly challenging. First, we show what are the convenient choices of the gauge for MPS simulations on the cylinder, making the connection with both the Lieb-Schultz-Mattis theorem and the "thin-torus" limit of the FQH effect. Next, for infinite PEPS we show that the phases in the hopping amplitudes can be absorbed into the virtual bonds, allowing for PEPS representations on the infinite plane that do not break any translation invariance. We argue that the combination of cylinder-MPS and infinite-PEPS simulations provide a comprehensive tensor-network approach for Hofstadter-like models.

B - Contributed Talk / **44**

Wavelet Tensor Network States for Quantum Fields

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Over the last few decades, significant progress has been made in the development of variational tensor network states (TNS) used to solve quantum field theories (QFTs). This is especially true in 1+1 dimensions, where one can take the continuum limit of matrix product states (MPS) to model both non-relativistic and relativistic fields. In this work, we instead employ a discrete approach to model quantum fields, decomposing the fields in the infinite basis of Daubechies wavelet scaling functions. This then allows us to exploit the full machinery of discrete MPS on continuous theories, which is not yet accessible by (relativistic) continuous MPS.

We study the Lieb-Liniger model of interacting non-relativistic bosons in 1+1 dimensions in the thermodynamic limit, utilizing two different orders of Daubechies wavelets. Importantly, at these orders the wavelets have continuous first derivatives. We calculate the ground state using the variational uniform MPS (VUMPS) algorithm. To gain better control, we then construct a refinement of this ansatz via an optimized isometry on the physical Hilbert space. Our wavelet approach could later be applied to a larger class of QFTs, such as relativistic fields or QFTs in higher dimensions. Also interesting is the connection between our model and wavelet MERA, which also uses Daubechies wavelets but cannot yet be applied to interacting theories.

B - Contributed Talk / 46

Finite-entanglement scaling and dynamical correlations of quasi-Fermi liquids

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Using tangent-space methods and an extension of finite-entanglement scaling for dynamical correlations, we show the existence of a new class of one-dimensional quantum liquids: the quasi-Femi liquid. This state exhibits characteristics similar to either a Luttinger liquid or a Fermi liquid, depending on the energy scale at which it is examined. We analyze the ground state and dynamical properties by computing the momentum distribution, spectral function and dynamical structure factor. The momentum distribution is discontinuous at the Fermi energy, which contrasts with the spectral function displaying both edge singularities and quasiparticles peaks. The dynamic structure factor resembles that of fermions with irrelevant interactions, with an additional excitonic peak located below the upper branch of the particle-hole continuum. Our results indicate that the quasi-Fermi liquid paradigm goes beyond the Luttinger and Fermi liquids models.

B - Contributed Talk / 40

Equilibration of holographic random tensor networks

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Recent years have enjoyed substantial progress in capturing properties of complex quantum systems by means
of random tensor networks (RTNs). Such tensor networks, formed by locally contracting random tensors chosen from the unitary Haar measure, define ensembles of quantum states whose properties depend only on the
tensor network geometry and bond dimensions. Of particular interest are random tensor networks on hyperbolic
geometries, resembling those of critical boundary states of holographic bulk-boundary dualities. In this work,
we elevate static pictures of ensemble averages to a dynamic one, to show that RTN states exhibit equilibration
of time-averaged operator expectation values under a highly generic class of Hamiltonians with non-degenerate
spectra. We prove that RTN states generally equilibrate at large bond dimension, and that three classes of RTN
geometries –tensor trains, regular hyperbolic tilings, and single "black hole"tensors –equilibrate in the scaling
limit. Furthermore, we prove a hierarchy of equilibration between finite-dimensional instances of these three
classes, suggesting an equivalent hierarchy between corresponding many-body phases and reproducing a holo-
graphic degree-of-freedom counting for the effective dimension of each system. These results demonstrate that
RTN techniques can probe aspects of late-time dynamics of a wide range of quantum many-body phases.

B - Contributed Talk / **48**

Critical spin models from holographic disorder

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Discrete models of holographic dualities, typically modeled by tensor networks on hyperbolic tilings, produce quantum states with a characteristic quasiperiodic disorder not present in continuum holography. In this work, we study the behavior of XXZ spin chains with such symmetries, showing that lessons learned from previous non-interacting (matchgate) tensor networks generalize to more generic Hamiltonians under holographic disorder: While the disorder breaks translation invariance, site-averaged correlations and entanglement of the disorder-free critical phase are preserved at a plateau of nonzero disorder even at large system sizes. In particular, we show numerically that the entanglement entropy curves in this disordered phase follow the expected scaling of a conformal field theory (CFT) in the continuum limit. This property is shown to be non-generic for other types of quasiperiodic disorder, only appearing when our boundary disorder ansatz is described by a "dual" bulk hyperbolic tiling. Our results therefore suggest the existence of a whole class of critical phases whose symmetries are derived from models of discrete holography.

B - Contributed Talk / **9**

Matrix product state methods for excitations

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Matrix product state (MPS) numerics are the state of the art for studying ground state properties in low-dimensional quantum many-body systems. For studying low-lying excitations, there are two complementary approaches we may use: statics, where we find the low-lying eigenstates directly, and dynamics, where we simulate the time evolution of a non-stationary state. In this talk, we shall discuss the static approach in the form of the MPS excitation ansatz. In particular, we shall show that the excitation ansatz and its extensions can be expressed as an MPS with a special block-triangular structure, analogous to matrix product operators, which we can use to easily solve for expectation values. We shall also highlight some of our recent work in finding stable single-particle excitations inside of a multi-particle continuum, and using the excitation ansatz to construct real-space wave packets to study particle collisions.

B - Contributed Talk / 45

Variational tensor network study of the maple-leaf Heisenberg antiferromagnet

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We investigate the spin-1/2 Heisenberg antiferromagnet on the ruby and maple-leaf lattices, identifying a phase transition from a gapless paramagnetic or quantum spin liquid phase on the ruby lattice to a gapped counterpart on the maple-leaf lattice. This study leverages extensive infinite variational tensor network calculations to provide new insights into the competition between ordered and paramagnetic phases in these frustrated systems.

B - Contributed Talk / 18

Explore 2D groundstates by iPEPS optimization with VUMPS

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We present a general computational framework for studying ground-state properties of quantum spin models on infinite two-dimensional lattices. Our approach combines automatic differentiation (AD)-based gradient optimization of infinite projected entangled-pair states (iPEPS) with variational uniform matrix product states (VUMPS) to efficiently contract infinite tensor networks with unit cell structures.

We demonstrate the effectiveness of this framework by applying it to the Kitaev-type model, which features complex interactions and competing ground states. Benchmarking against exact solutions, our method achieves higher accuracy in computing various observables compared to previous tensor network approaches, such as imaginary-time projection or corner transfer matrix renormalization group (CTMRG). By employing dominant eigensolver techniques and GPU acceleration, we can handle large unit cells (e.g., 2×6) with bond dimensions up to 10.

B - Contributed Talk / 25

Probing the pseudogap with dynamical METTS

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We investigate spectral properties of the doped $t - J$ model using advanced tensor network techniques on finite cylinders. Individual METTS snapshots reveal a tendency for holes to cluster, eventually forming stripes upon cooling down. We complement these observations by using a recently developed dynamical METTS algorithm to calculate the spectral function and discuss the partition of its form between the insulating and hole-rich regions.

B - Contributed Talk / 35

Fractal Path Strategies for Efficient 2D DMRG Simulations

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Numerical simulations of quantum magnetism in two spatial dimensions are often constrained by the area law of entanglement entropy, which heavily limits the accessible system sizes in tensor network methods. In this work, we investigate how the choice of mapping from a two-dimensional lattice to a one-dimensional path affects the accuracy of the two-dimensional Density Matrix Renormalization Group algorithm. We systematically evaluate all mappings corresponding to a subset of the Hamiltonian paths of the $N \times N$ grid graphs up to $N = 8$ and demonstrate that the fractal space-filling curves generally lead to faster convergence in ground state searches compared to the commonly used "snake" path. To explain this performance gain, we analyze various locality metrics and propose a scalable method for constructing high-performing paths on larger lattices by tiling smaller optimal paths. Our results show that such paths consistently improve simulation convergence, with the advantage increasing with system size.

B - Contributed Talk / 7

The advantages of Infinite PEPS for quantum induced orders

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Numerically determining quantum phases of matter for interacting models in two dimension is still a challenging task. There are many complementary methods to address the challenges with the feasibility sensitive to physical details. Here I identify a class of problems for which infinite PEPS method have advantages. The spontaneous symmetry breaking can have classical origin which can be understood in the space of product states. There are also quantum induced phases such as Fermi surface instabilities and order from disorders. I will give examples to show that for these problems, iPEPS is a preferred choice comparing to cylindrical DMRG.

B - Contributed Talk / 39

Entanglement corner dependence in two-dimensional systems: A tensor network perspective

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In continuous quantum field theories with sharp corners, the entanglement entropy exhibits a universal contribution tied to the corner geometry. We investigate this intriguing phenomenon through the lens of discretized systems, specifically using infinite projected entangled pair states (iPEPS) on a lattice.
Our work demonstrates that the anticipated corner dependence naturally arises from the geometric structure of iPEPS. Through a rigorous counting argument, we demonstrate that the bond dimension of an iPEPS representation contains a corner-dependent term that matches the predictions for gapped continuous systems.
Crucially, this correspondence holds almost perfectly, but only when averaging over all possible lattice orientations. This highlights a fundamental requirement for accurately discretizing continuous systems. For conformal systems, the corner-dependent term appears only when the system is discretized as a fractal, a scale-invariant technique rarely employed in such studies.
These findings offer a geometric understanding of entanglement corner laws and establish a direct link between analytical field theory predictions and the structure of tensor network representations. Our results provide new insights into the intricate relationship between entanglement in continuous and discrete quantum systems.

B - Contributed Talk / 24

Topological Order in the Rydberg Blockade on the Kagome Lattice with PEPS

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The Rydberg blockade model on the Kagome lattice has recently been realized experimentally [1] and shown numerically—via 2D DMRG [2]—to host a $\mathbb{Z}_2$ topologically ordered phase. In this work, we investigate its phase diagram using the inherently two-dimensional tensor network ansatz: Projected Entangled Pair States (PEPS). To this end, we perform state-of-the-art variational ground state optimization, with energy gradients computed via automatic differentiation applied to the fixed point equations of the VUMPS algorithm [3], which is used to contract the infinite PEPS. The resulting ground states are analyzed to identify various types of order, with particular focus on topological order. This study provides a complementary PEPS-based perspective on the model and offers insight into the robustness of topological order in a highly frustrated, experimentally relevant setting.

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B - Contributed Talk / 52

Accelerating two-dimensional tensor network contractions using QR-decompositions

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Infinite projected entangled-pair states (iPEPS) provide a powerful tool for studying strongly correlated systems directly in the thermodynamic limit. A core component of the algorithm is the approximate contraction of the iPEPS, where the computational bottleneck typically lies in the singular value or eigenvalue decompositions involved in the renormalization step. This is particularly true on GPUs, where tensor contractions are substantially faster than these decompositions. We propose a new contraction scheme for C4v-symmetric tensor networks that combines the corner transfer matrix renormalization group (CTMRG) with QR decompositions, are substantially faster – especially on GPUs. This approach achieves up to two orders of magnitude speedup over standard CTMRG, enabling state-of-the-art results for the Heisenberg and J1–J2 models in about one hour on an H100 GPU.

B - Contributed Talk / 16

Symmetry defects and gauging for quantum states with matrix product unitary symmetries

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Gauging global symmetries—promoting them to local symmetries—has been fundamental to advances in both particle physics and quantum many-body theory. In tensor network formalism, on-site unitary symmetries give rise to virtual symmetry defects within Matrix Product States (MPSs), represented by operator insertions along virtual bonds. We extend this framework to non-on-site symmetries implemented via Matrix Product Unitaries (MPUs) and use it to propose a formal gauging procedure based on a group-cohomological condition we call block-independence. When this

condition is satisfied, the gauging preserves the bond dimension of the original MPS and yields commuting Gauss projectors built from fusion operators. For systems that violate block-independence, we introduce a state-level gauging scheme that also preserves bond dimension but relaxes the commutativity of projectors—potentially allowing for a broader class of gauge theories.Our results offer a systematic approach to gauging MPU symmetries and highlight new directions in the interplay between symmetry, topology, and tensor networks.

B - Contributed Talk / 53

An RCMPS study of two coupled scalar QFT

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We study a generalisation of ϕ_2^4 with self coupling constant g to two species coupled via the cross term $2\lambda\phi_1^2\phi_2^2$. The $\mathbb{Z}_2$ symmetry group of ϕ_2^4 is now generalised to the diherdral group D_4, apart from $g = \lambda$ line where the symmetry is enhanced to $O(2)$. In $1+1\,d$, spontaneous breaking of continuous symmetries is forbidden. Nonetheless, such systems can still undergo phase transitions of topological nature of BKT type as exemplified by compactified boson. Away from the $O(2)$ line, the model has a potentially rich phase diagram akin to the Ashkin-Teller model. We use the RCMPS ansatz to variationally optimise for the ground state and study the physics of this model.

B - Contributed Talk / 17

Tensor network methods to compute many-body magic

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Quantum resources have played a crucial role in our understanding of many-body systems over the past two decades. While entanglement has been extensively studied, the role of other quantum resources—such as magic, which is essential for quantum computational advantage—remains less explored.

I will begin by reviewing stabilizer Rényi entropies as a powerful measure of magic and their utility in characterizing complex quantum states. Building on this framework, I will present three complementary approaches based on tensor networks to measure and understand the role of magic in quantum many-body dynamics.

First, I will introduce a Markov chain sampling method for measuring many-body magic via Pauli strings. By leveraging tree tensor networks, this approach enables efficient extraction of long-range magic in one-dimensional critical systems and two-dimensional gauge theories, revealing novel connections between magic, conformal criticality, and confinement-deconfinement transitions [1].

Second, I will discuss a new framework for computing nonstabilizerness in matrix product states (MPS) by directly expressing them in the Pauli basis. This method allows for the efficient evaluation of stabilizer Rényi entropies, stabilizer nullity, and Bell magic. I will showcase its application to the

ground states of spin chains and to recent Rydberg atom circuit experiments, providing benchmarks for logical qubit encoding [2].

Finally, I will explore the classical simulability of quantum many-body systems through a combination of tensor network methods and the stabilizer formalism. I will present results on efficiently computing Pauli expectation values in Clifford circuits doped with non-Clifford gates, and discuss the use of matchgate circuits alongside tensor networks for simulating many-body systems near free-fermion integrability [3].

I will conclude by discussing experimental implications, outlining potential avenues for realizing these phenomena in near-term quantum devices, and addressing the challenges in probing and controlling magic in many-body settings.

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B - Contributed Talk / **43**

Bootstrapping spectral functions of 1+1d QFTs via relativistic cMPS

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We present a new method for extracting dynamical information from the ground state of relativistic 1+1-dimensional quantum field theories (QFTs) directly in the continuum and thermodynamic limit, using the framework of relativistic continuous matrix product states (RCMPS).
We reconstruct smeared spectral densities from static (Euclidean) two-point correlation functions, which are directly accessible from the RCMPS ground state approximation. Mathematically, this task corresponds to solving an inverse Laplace transform —an inherently ill-posed problem. Building on a recent approach in arxiv:2408.11766, we recast the reconstruction as a convex linear optimization problem by imposing positivity constraints and constraints from the Källén-Lehmann spectral representation, thereby systematically constraining the space of physically allowed spectral functions. This yields rigorous bounds on the spectral density and real-time correlation functions consistent with the RCMPS Euclidean data.
We bootstrap the mass gap by scanning over spectral ansätze with a given gap and identifying values for which the reconstruction is feasible. This also provides an *a posteriori* estimate of the systematic error on the RCMPS two-point functions as a function of the bond dimension. Additionally, we derive a direct analytic relation between the RCMPS variational parameters and the mass gap of the theory via the spectrum of the transfer operator. Our results demonstrate how continuum tensor network methods can be used to extract non-trivial dynamical information from purely static observables.

B - Contributed Talk / **50**

Tensor Networks with respect to connected graphs

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We extend the known tensor decompositions for discrete tensors, as: Canonical Polyadic, Tucker, Tensor Train, Tensor Chain (MPS), Hierarchical, PEPS, etc. to a general decomposition scheme called here *tensor network graph decomposition.* For a given connected graph G with n nodes and d open edges, we can decompose a given d-order tensor $calT \in \mathbb{R}^{n_1 \times \cdots \times n_d}$ as contractions of n component tensors of smaller dimensions, which contract along the common indices indicated by the common edges of G. The main tools for such representations are the singular value decomposition (for general tensor) and non-negative matrix factorization (for non-negative tensors). We present an improvement of the Tensor Train decomposition, which is also implemented in the general tensor network decomposition. Another approach for such general decomposition is also introduced, based on the alternating least squares method. We present algorithms for such general decomposition and discuss with examples some of its advantages and disadvantages.

B - Contributed Talk / 51

Effects of virtual gauge degrees of freedom in the variational optimization of projected entangled pair states

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Projected entangled-pair states (PEPS) constitute a powerful variational ansatz for two-dimensional quantum systems, but accurately computing and minimizing the energy expectation value remains challenging. A recent work [Tang et al., Phys. Rev. B 111, 035107 (2025)] showed that virtual gauge degrees of freedom can significantly affect the accuracy of tensor network contractions, raising questions about their impact on PEPS optimization. In this work, we consider a U(1)-symmetric PEPS with point group symmetry, reducing the gauge degrees of freedom to a single class, which enables an efficient manifold optimization scheme that fixes the gauge throughout the optimization. Applying this method to the prototypical Bose-Hubbard model, we find that the gradients during unconstrained PEPS optimization typically contain components along gauge directions, causing the tensor network contraction to become increasingly inaccurate and producing artificially low variational energies. In contrast, in gauge-fixed PEPS optimization, this effect can be largely suppressed, resulting in a more robust and reliable optimization. Our study paves the way for future efforts to systematically increase the robustness and reliability of PEPS optimization in general settings.

B - Contributed Talk / 14

Fragmented superconductivity in the Hubbard model as solitons in Ginzburg–Landau theory

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The phenomena of superconductivity and charge density waves are observed in close vicinity in many strongly correlated materials. Increasing evidence from experiments and numerical simulations suggests both phenomena can also occur in an intertwined manner, where the superconducting order parameter is coupled to the electronic density. Employing density matrix renormalization group simulations, we investigate the nature of such an intertwined state of matter stabilized in the phase diagram of the elementary Hubbard model in the strong coupling regime. Remarkably, the condensate of Cooper pairs is shown to be fragmented in the presence of a charge density wave where more than one pairing wave function is macroscopically occupied. Moreover, we provide conclusive evidence that the macroscopic wave functions of the superconducting fragments are well-described by soliton solutions of a Ginzburg-Landau equation in a periodic potential constituted by the charge density wave. In the presence of an orbital magnetic field, the order parameters are gauge invariant, and superconducting vortices are pinned between the stripes. This intertwined Ginzburg-Landau theory is proposed as an effective low-energy description of the stripe fragmented superconductor.

B - Contributed Talk / 49

TT-Metadynamics: Tensor Train Enhanced Sampling for High-Dimensional Molecular Systems

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Tensor networks offer powerful tools for compressing and manipulating high-dimensional functions, but their application outside quantum many-body theory remains relatively unexplored. In this work, we introduce TT-metadynamics, a novel adaptive biasing algorithm for classical molecular dynamics that leverages tensor train (TT) decompositions to overcome the curse of dimensionality in enhanced sampling. Standard metadynamics accumulates a bias potential by summing Gaussians in a low-dimensional collective variable space. However, the cost of evaluating and storing this bias grows rapidly with dimension, rendering such methods impractical beyond 4–5 variables. TT-metadynamics circumvents this bottleneck by periodically compressing the accumulated bias into a TT format, enabling linear scaling with the number of collective variables, independent of the number of accumulated Gaussians. We demonstrate the scalability and effectiveness of this approach on a range of benchmark systems, from alanine dipeptide (2D) to ditryptophan (8D) and Aib9 (10D–14D), showing that TT-metadynamics matches or exceeds the accuracy of standard metadynamics over long simulations. Our results establish TT-metadynamics as a promising interdisciplinary application of tensor networks, with potential implications for nonequilibrium statistical mechanics, complex energy landscapes, and scalable high-dimensional modeling in chemistry and biophysics.

B - Contributed Talk / 55

From Frustrated Ladders to Effective Spin Chains: A Study of Nanographene-Inspired Fermi-Hubbard Systems

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Graphene-based systems provide an outstanding platform for the study of emergent physical phenomena and exotic phases of matter. By envisioning certain low-dimensional structures with sublattice imbalances, topological defects or frustration, strongly correlated magnetic ground states with long spin coherence times have been predicted, with a plethora of applications in spintronics, quantum information and quantum simulation [1]. Recently, experimental on-surface synthesis techniques have allowed for the fabrication of such structures, enabling the development of highly controllable spin chains [2, 3]. In this work we employ Density Matrix Renormalization Group (DMRG) to study quasi 1-dimensional structures and their links to effective spin models. We consider chains composed of hexagon/pentagon rings which have previously been analyzed using mean field and complete active space (CAS) based techniques [4]. Our tensor-network approach allows for accurately quantifying this picture, and extending it to low-lying excited states. We propose a formalism that can be used to identify *where* the effective spins in the chain are located via Matrix Product Operators representing delocalized fermionic modes, used to build the effective spin operators with high fidelity. This allows for direct comparison of correlations, magnetizations, entanglement entropies, transition amplitudes and more, between the Fermi-Hubbard ladder and the target system, which gives rise to an accurate and controllable spin model for the low-energy subspace. Our results offer a robust characterization of frustrated carbon-based ladder systems and support their use as tunable, synthetic models for exploring strongly correlated spin physics at the molecular scale.

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B - Contributed Talk / 3

Hyperinvariant Spin Network States - An AdS/CFT Model from First Principles

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We study existence and limitations for hyperinvariant tensor networks incorporating a local SU(2) Gauss constraint (HITs). As discrete implementations of the celebrated anti de-Sitter/conformal field theory (AdS/CFT) correspondence, holographic states and codes have created methodological and conceptual bridges between the fields of quantum information, entanglement theory and quantum gravity. Adding SU(2) symmetry onto the tensor network allows for a direct connection to spin network states, a basis of the kinematic Hilbert space of loop quantum gravity (LQG). We show that important aspects of the AdS/CFT correspondence are realized in certain quantum states of the gravitational field in LQG, thus justifying, from first principles, a class of models introduced by [Pastawski et al., 2015]. An approximate duality of bipartite entanglement on the boundary and a geodesic path length in the bulk is given on HITs, as the expectation value of the path length operator of LQG exactly matches the graph length previously used to show this duality. We provide examples of HITs and show clear boundaries for their existence in the form of no-go theorems that exclude absolutely maximally entangled (AME) states as well as general holographic codes from local SU(2) invariance.

C - Poster Session / 10

A coherent approach to quantum-classical optimization

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Hybrid quantum-classical optimization techniques, which incorporate the pre-optimization of Variational Quantum Algorithms (VQAs) using Tensor Networks (TNs), have been shown to allow for the reduction of quantum computational resources. In the particular case of large optimization problems, commonly found in real-world use cases, this strategy is almost mandatory to reduce the otherwise unfathomable execution costs and improve the quality of the results. We identify the coherence entropy as a crucial metric in determining the suitability of quantum states as effective initialization candidates. Our findings are validated through extensive numerical tests for the Quantum Approximate Optimization Algorithm (QAOA), in which we find that the optimal initialization states are pure Gibbs states. Further, these results are explained with the inclusion of a simple and yet novel notion of expressivity adapted to classical optimization problems. Based on this finding, we propose a quantum-classical optimization protocol that significantly improves on previous approaches for such tasks, with specific focus on its effectiveness.

C - Poster Session / 19

Confinement and Dynamical Quantum Phase Transitions in $\mathbb{Z}_2$ Lattice Gauge Theories

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Lattice gauge theories (LGTs) have gained increasing attention in both condensed matter and high-energy physics in recent years and have become the centre of many quantum simulation experiments. Theoretical and experimental works have shown that LGTs exhibit rich far-from-equilibrium phenomena relevant to central questions in quantum many-body physics. In this work, we discuss the connection between confinement and dynamical quantum phase transitions (DQPTs) in LGTs. The existence of confinement can be indicated by the nature of DQPTs occurring during the unitary time evolution of the system. We demonstrate the idea in a 1+1D $\mathbb{Z}_2$ LGT. Finally, we reveal more intriguing dynamics behind the interplay of a staggered mass term and an external electric field. We provide an outlook on the possibility of extracting universal behaviour from explicit out-of-equilibrium critical exponents in LGTs from DQPTs.

C - Poster Session / 37

Variationally optimizing infinite projected entangled-pair states at large bond dimensions: A split corner transfer matrix renormalization group approach

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Projected entangled-pair states (PEPS) have become a powerful tool for studying quantum many-body systems in the condensed matter and quantum materials context, particularly with advances in variational energy optimization methods. A key challenge within this framework is the computational cost associated with the contraction of the two-dimensional lattice, crucial for calculating state vector norms and expectation values. The conventional approach, using the corner transfer matrix renormalization group (CTMRG), involves combining two tensor network layers, resulting in significant time and memory demands. We present an alternative "split-CTMRG" algorithm, which maintains separate PEPS layers and leverages new environment tensors, reducing computational complexity while preserving accuracy.

https://journals.aps.org/prb/abstract/10.1103/PhysRevB.111.235116

C - Poster Session / **27**

Real-time simulation of pure Yang-Mills SU(3) glueballs scattering processes with MPS

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We introduce a model-independent method to construct Matrix Product Operator (MPO) representations of quasiparticle creation operators acting on the interacting vacuum of (quasi-)one-dimensional quantum many-body systems. This method exploits maximally localized Wannier functions constructed from single-particle states at intermediate system sizes, which provides the building blocks for a generic single-quasiparticle MPO wave-packet creation operator. This enables the preparation of arbitrary input states for real-time scattering simulations. We test this approach on a relevant scenario for Lattice Gauge Theory: the glueball-glueball scattering on a pure Yang-Mills SU(3) ladder, opening a path to real-time simulations of non-abelian scattering processes, a still largely unexplored frontier.

C - Poster Session / **38**

Gauge invariance for error detection in quantum simulations of the Schwinger model

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We use quantum devices from IBMQ to perform digital quantum simulations of the Schwinger model. We work with a quantum link model description of the Schwinger model in its lowest dimensional representation, and use gauge invariance, in the form of the Gauss' law, to enhance quality of data from quantum simulations. One of our goals in this project is to find out if there are advantages of keeping the Gauss' law at the expense of simulating both matter and gauge degrees of freedom. The

main ideas here can be extended to other lattice gauge theories or higher dimensional representations of this quantum link model.

C - Poster Session / 6

Lattice Gauge theory using Symmetric tensor networks

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In this presentation, I shall discuss how one can use Symmetric tensors to study theories with local gauge symmetries and how this can be used to study 2+1D Quantum lattice models or two and three dimensional classical gauge theories using Tensor network methods like PEPS or Tensor renormalisation group.

C - Poster Session / 30

Phases of the Maple Leaf Antiferromagnet

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The Heisenberg antiferromagnet on the maple leaf lattice is a recent candidate host for spin liquid phases ([1, 2, 3]) and can also be realized experimentally both in natural minerals ([4, 5]) as well as synthetic compounds ([6, 7]). Employing exact diagonalization we investigate different ground states and map out the phase diagram under variations of three symmetry-inequivalent nearest-neighbor bonds. In particular, we focus on the presence of long-range magnetic order and the transition into the dimer phase, trying to elucidate conflicting reports originating from differing techniques (see e.g. [3] vs. [8]) through exact results. Lastly, we discuss the possibility of emergent quantum spin liquids in the nearest-neighbor antiferromagnet.

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C - Poster Session / 32

Spin Seebeck Effect of Triangular-lattice Spin Supersolid

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Using the developed thermal tensor-network approach, we investigate the spin Seebeck effect (SSE) of the triangular-lattice quantum antiferromagnet hosting spin supersolid phase. We focus on the low-temperature scaling behaviors of the normalized spin current across the interface. Using the 1D Heisenberg chain as a benchmark system, we observe a negative spinon spin current exhibiting algebraic scaling T^{α}, with exponent α, in the Tomonaga-Luttinger liquid phase. On the triangular lattice, spin frustration dramatically enhances the low-temperature SSE, with distinct spin-current signatures - particularly the sign reversal and characteristic temperature dependence - distinguishing different spin states. Remarkably, we discover a persistent, negative spin current in the spin supersolid phase. It saturates to a non-zero value in the low-temperature limit, and can be ascribed to the Goldstone-mode-mediated spin supercurrents. Moreover, a universal scaling $T^{d/z}$ is found at the U(1)-symmetric polarization quantum critical points. These distinct quantum spin transport traits provide sensitive probes for spin-supersolid compounds such as $Na_2BaCo(PO_4)_2$. Furthermore, our results establish spin supersolids as a tunable quantum platform for spin caloritronics in the ultralow-temperature regime.

C - Poster Session / **31**

Strong long-range interactions and geometrical frustration in subwavelength lattices

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Non-local interactions are the key building block to allow for a spontaneous breaking of the translational symmetry. The latter represents one of the most fundamental symmetries in physics as it reflects the formation of periodic structures of mass and electric charge. Quantum matter with such a feature falls in the class of spontaneously symmetry broken (SSB) many-body phases with broken translational invariance. Their ubiquity in nature has made the investigation and creation of such states of matter of central importance. In this respect, quantum simulators made of ultracold magnetic atoms with large magnetic dipolar momentum (e.g., erbium) represent a promising and powerful resource. However, current setups only explore frustrated regimes with weak local interactions or regimes where quantum fluctuations are suppressed. To the best of our knowledge, there are no experimental schemes able to simultaneously realize long-range interactions and geometrical frustration.

Here we consider a possible alternative to current setups - a recently realized subwavelength lattice formed by a pair of counter-propagating lasers driving two photon Raman transitions in an ensemble of ultracold atoms. It was shown that one may precisely control the tunneling amplitude, range, and phase by tuning the detunings. One also achieves significantly stronger interactions in the proposed scheme due to its subwavelength nature. Thus, one may realize intriguing phases of matter, such as density waves and chiral superfluids. Our results show several possible scenarios may occur, depending on the lattice depth and detunings.

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C - Poster Session / **34**

Quantum Optimal Control Using Tensor Networks

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Determining optimal time-dependent fields to steer quantum systems is a critical yet computationally demanding
task, often complicated by vast and complex search landscapes. This work explores the application of tensor network methodologies to navigate these high-dimensional parameter spaces in quantum optimal
control effectively. We investigate how structured, low-rank tensor representations can be utilized for the
efficient parameterization and discovery of effective control trajectories. Our approach involves an iterative
refinement process where the tensor network model is adaptively updated based on simulated quantum system
performance. This allows for a guided exploration of the control landscape, aiming to identify highly effective control strategies. The potential benefits include enhanced search efficiency and the ability to tackle
complex control problems relevant to emerging quantum technologies.

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String dynamics in 2+1 D lattice gauge theory

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We discuss the string breaking dynamics in the presence of creation of dynamical charge pair. We consider different string configuration that belong to different sectors and their ability to escape a false vacuum. We then further analyze how they set the onset critical time and critical point and local observables and entanglement profile that signal the dynamical quantum phase transition.

C - Poster Session / **11**

Quantum simulations of lattice gauge theories

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We propose digital quantum simulation schemes of 2+1D U(1) link quantum electrodynamics and compare the results with classical tensor network simulations for benchmarking. To verify the accuracy of our quantum simulations, we employ tensor network methods as a classical benchmark, ensuring consistency in regimes where classical computations remain tractable. Our findings demonstrate the reliability of quantum simulations for U(1) gauge theories while highlighting the role of tensor networks in validating near-term quantum algorithms.

C - Poster Session / **8**

Robustness of Magic in the quantum Ising chain via Quantum Monte Carlo tomography

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We study the behavior of magic as a bipartite correlation in the quantum Ising chain across its quantum phase transition, and at finite temperature. In order to quantify the magic of partitions rigorously, we formulate a hybrid scheme that combines stochastic sampling of reduced density matrices via quantum Monte Carlo, with state-of-the-art estimators for the robustness of magic - a *bona fide* measure of magic for mixed states. This allows us to compute the mutual robustness of magic for partitions up to 8 sites, embedded into a much larger system. We show how mutual robustness is directly related to critical behaviors: at the critical point, it displays a power law decay as a function of the distance between partitions, whose exponent is related to the partition size. Once finite temperature is included, mutual magic retains its low temperature value up to an effective critical temperature, whose dependence on size is also algebraic. This suggests that magic, differently from entanglement, does not necessarily undergo a sudden death.

C - Poster Session / **23**

Interplay of localization and topology in disordered dimerized array of Rydberg atoms

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Rydberg tweezer arrays provide a platform for realizing spin-1/2 Hamiltonians with long-range tunnelings decaying according to power-law with the distance. We numerically investigate the effects of positional disorder and dimerization on the properties of excited states in such a one-dimensional system. Our model allows for the continuous tuning of dimerization patterns and disorder strength.

We identify different distinct ergodicity-breaking regimes within the parameter space constrained by our geometry. Notably, one of these regimes exhibits a unique feature in which non-trivial symmetry-protected topological (SPT) properties of the ground state extend to a noticeable fraction of states across the entire spectrum. This interplay between localization and SPT makes the system particularly interesting, as localization should help with stabilization of topological excitations, while SPT states contribute to an additional delocalization. We study excited spectra using state-of-the-art diagonalization tools and perform simulations of dynamics with tensor networks.

C - Poster Session / **41**

Stripe Order vs. Superconductivity: Revisiting the doped t-J model with iPEPS and AD

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The t-J model is one of the simplest theoretical models believed to capture key aspects of high-temperature superconductivity in cuprate materials. Despite extensive study, the nature of its ground state at finite doping remains unsettled. Stripe order, characterized by intertwined charge and spin density waves, appears to compete closely with d-wave superconductivity. Previous DMRG studies using up to six-leg cylinders pointed towards a stripe-ordered ground state without coexisting superconductivity [1, 2], while iPEPS simulations suggested competition between uniform and striped d-wave superconducting states [3]. More recently, DMRG on eight-leg cylinders indicated a d-wave superconducting ground state that may coexist with weak pair-density wave and stripe orders [4]. With the inclusion of negative nearest-neighbour hopping t', uniform superconductivity was favoured, contrasting with iPEPS predictions for the corresponding t-t' Hubbard model, which favour period-4 stripes, either with suppressed superconductivity near 1/8 doping or with coexisting superconductivity at higher doping [5].

In view of these contrasting results, we revisit the problem using iPEPS simulations combined with gradient-based optimization using automatic differentiation. We investigate the ground-state phase diagrams of both the plain t-J and t-t'-J models at finite hole doping, focusing on the competition between uniform and striped superconducting phases. To reliably compare these competing states, we employ energy extrapolation techniques, including extrapolations based on a new developed method for computing the energy variance of iPEPS.

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C - Poster Session / **5**

Simulating Quantum Circuits with Tree Tensor Networks using Density-Matrix Renormalization Group Algorithm

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Quantum computing offers the potential for computational abilities that can go beyond classical machines. However, they are still limited by several challenges such as noise, decoherence, and gate errors. As a result, efficient classical simulation of quantum circuits is vital not only for validating and benchmarking quantum hardware but also for gaining deeper insights into the behavior of quantum algorithms. A promising framework for classical simulation is provided by tensor networks. Recently, the Density-Matrix Renormalization Group (DMRG) algorithm was developed for simulating quantum circuits using matrix product states (MPS). Although MPS is efficient for representing quantum states with one-dimensional correlation structures, the fixed linear geometry restricts the expressive power of the MPS. In this work, we extend the DMRG algorithm for simulating quantum circuits to tree tensor networks (TTNs). To benchmark the method, we simulate random and QAOA circuits with various two-qubit gate connectivities. For the random circuits, we devise tree-like gate layouts that are suitable for TTN and show that TTN requires less memory than MPS for the simulations. For the QAOA circuits, a TTN construction that exploits graph structure significantly improves the simulation fidelities. Our findings show that TTNs provide a promising framework for simulating quantum circuits, particularly when gate connectivities exhibit clustering or a hierarchical structure.