Titles and abstracts

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Quantum field theory of electrons at human scales

CHEN Kun (Flatiron Institute)

In this talk, we present a new perspective on fundamental problems in electronic structure and superconductivity through the lens of modern quantum field theory (QFT). We propose a renormalized QFT approach to describe valence electrons in metals, uncovering hidden emergent localities in the electron self-energy and electron-electron interaction, which lays the foundation for the development of next-generation ab-initio methods. Additionally, we use finite-temperature QFT to analyze the fine structure of Cooper-pair correlations in (semi)metals at high temperatures, revealing that this correlation provides a robust probe for predicting pairing instability in low-density superconductors with ultra-low transition temperatures. This talk provides new insights and potential solutions to the many-electron problem through the innovative application of QFT.

Quantifying global symmetry violations in quantum gravity

CHEN Yiming (Princeton University)

It is long been conjectured that global symmetries can only be approximate in a theory of quantum gravity. In this talk, I discuss two pieces of work in quantifying this statement, putting lower bounds on the amount of violation. Specifically, I will discuss the global symmetry violation during a black hole evaporation process as well as charge violating scattering amplitudes. We'll see how the new insights on the black hole information problem play an important role in quantifying the violations. The talk will be based on arXiv:2011.06005 with Henry Lin and arXiv:2212.08668 with Ibrahima Bah and Juan Maldacena.

Quantum dynamics simulation and its application to Hamiltonian learning

FANG Di (University of California, Berkeley)

Recent years have witnessed tremendous progress in developing and analyzing quantum algorithms for quantum dynamics simulation (Hamiltonian simulation). The accuracy of quantum dynamics simulation is usually measured by the error of the unitary evolution operator in the operator norm, which in turn depends on the operator norm of the Hamiltonian. However, the operator norm measures the worst-case scenario, while practical simulation concerns the error with respect to a given initial vector or given observables at hand. In this talk, we will discuss a few ways to weaken the strong operator norm dependence in quantum simulation tasks by taking into account the initial condition and observables. We then discuss how such analysis can be applied in the setting of Hamiltonian learning. Using a Hamiltonian reshaping technique, we propose a first learning algorithm to achieve the Heisenberg limit for efficiently learning an interacting N-qubit local Hamiltonian.

Recent Progress in Quantum Gravity

GENG Hao (Harvard University)

The structure of the bulk Hilbert space in quantum gravity is very different from standard quantum field theory. An illustration of this assertion is the well-known holographic principle, which states that the dimension of the Hilbert space of a gravitational region scales with its boundary area instead of the volume. Mathematically, this is described by the fact that the diffeomorphism invariance enforces a dressing of any local bulk operator by a gravitational Wilson line to a place where gravity can be decoupled (in the absence of any diffeomorphism breaking background configurations). This has significant implications for the fine-structure of the states in the Hilbert space in quantum gravity, for example there is no factorization of the Hilbert space of a gravitational region into subregions which is the usual starting point to study entanglement properties of Hilbert space states in quantum field theories. Misunderstanding of this special property of quantum gravity constantly causes puzzles such as Hawking's famous black hole information paradox and the AMPS firewall paradox. The recent progress in the understanding of the brandly new emergent concept- entanglement island sheds light on these questions in quantum gravity. In this talk, I'll give a quick review of Hawking's information paradox, the AMPS firewall paradox and their resolution in the Karch-Randall braneworld by the emergence of entanglement island then I'll discuss the implications to these paradoxes and quantum gravity in general from the physics of the Karch-Randall braneworld.

Resonant side-jump thermal Hall effect of phonons

GUO Haoyu (Harvard University)

In recent experiments across various materials, it is shown that phonons can become chiral and demonstrate a sizable thermal Hall effect, sometimes even larger than the quantum unit $(\pi/6)(k_B^2/\hbar)T$. In this talk, I will present a mechanism for phonons to acquire chirality through scattering with the spin system. When a phonon is scattered from one band to another by the spin system, there is an associated coordinate shift of the phonon called "side jump". We will show that the side-jump process contributes to energy transport of phonons and can detect the time-reversal symmetry breaking in the spin sector. This contribution can be resonantly enhanced when the phonon energy matches level spacing of the spin system. I will apply the theory to explain recent experiments in cuprates and spin ice.

Focusing bounds for CFT correlators and the S-matrix

JIANG Yikun (Cornell University)

The focusing theorem in General Relativity underlies causality, singularity theorems, entropy inequalities, and more. In AdS/CFT, we show that focusing in the bulk leads to a bound on CFT n-point functions that is generally stronger than causality. Causality is related to the averaged null energy condition (ANEC) on the boundary, while focusing is related to the ANEC in the bulk. The bound is derived by translating the Einstein equations into a relation between bulk and boundary light-ray operators. We also discuss the consequences of focusing for the flat space S-matrix, which satisfies a similar inequality, and give a new derivation of bounds on higher derivative operators in effective field theories. The string theory S-matrix and CFT correlators in conformal Regge theory also satisfy the focusing bound, even though in these cases it cannot be derived from the standard focusing theorem.

This talk will be based on: arXiv:2212.01942.

Mixed state entanglement measures in topological orders

LIU Shang (University of California, Santa Barbara)

We study two mixed state entanglement measures in topological orders: the so-called "computable cross-norm or realignment" (CCNR) negativity, and the more well-known partial-transpose (PT) negativity, both of which are based on separability criteria. We first compute the CCNR negativity between two spatial regions for tripartite pure states in (2+1)D Chern-Simons (CS) theories using the surgery method, and compare to the previous results on PT negativity. Under certain simplifying conditions, we find general expressions of both mixed state entanglement measures and relate them to the entanglement entropies of different subregions. Then we derive general formulas for both CCNR and PT negativities in the Pauli stabilizer formalism, which is applicable to lattice models in all spatial dimensions. Finally, we demonstrate our results in the Z2 toric code model. For tripartitions without trisection points, we provide a strategy of extracting the provably topological and universal terms in both entanglement measures. In the presence of trisection points, our result suggests that the subleading piece in the CCNR negativity is topological, while that for PT is not and depends on the local geometry of the trisections.

Efficient, scalable, and robust quantum algorithms for quantum chemistry

LIU Yuan (Massachusetts Institute of Technology)

In this talk, I will present the development of efficient, scalable, and robust quantum algorithms to address challenging problems in quantum chemistry, targeting the fault-tolerant era. In the first part, I will start from recent results on a unifying perspective of modern quantum algorithms via quantum signal processing (QSP) and quantum singular value transformation (QSVT). I will discuss progress on improving the efficiency of QSVT for Hamiltonian simulation as well as how QSP/QSVT enables performing error-correction at the level of quantum algorithms. In the second part, I will delve more into quantum chemistry and present one recent work on leveraging small quantum computers to solve large molecular electronic structure problems via quantum bootstrap embedding. This enables the solution of the electronic structure problem of a large molecule as an optimization problem for a composite Lagrangian governing fragments of the total system, in such a way that fragment solutions can harness the capabilities of quantum computers. By employing state-of-the-art quantum subroutines including the quantum swap test and quantum amplitude amplification, a quadratic speedup can be achieved in principle. Current quantum computers are small, but quantum bootstrap embedding provides a potentially generalizable strategy for harnessing such small machines through quantum fragment matching.

Generating Kitaev spin liquid from a stochastic measurement-only circuit

LUO Zhu-Xi (University of California, Santa Barbara)

Experimental realizations of long-range entangled states such as quantum spin liquids are challenging due to numerous complications in solid state materials. Digital quantum simulators, on the other hand, have recently emerged as a promising platform to controllably simulate exotic phases. I will talk about a constructive design of long-range entangled states in this setting, and exploit competing measurements as a new source of frustration to generate spin liquid. Specifically, we consider random projective measurements of the anisotropic interactions in the Kitaev honeycomb model. The monitored trajectories can produce analogues of the two phases in the original Kitaev model: (i) a topologically-ordered phase with area-law entanglement and two protected logical qubits, and (ii) a "critical" phase with a logarithmic violation of area-law entanglement and long-range tripartite entanglement. A Majorana parton description permits an analytic understanding of these two phases through a classical loop model. Extensive numerical simulations of the monitored dynamics confirm our analytic predictions.

This talk is based on https://arxiv.org/abs/2207.02877.

Quantum dynamics and non-equilibrium physics through the lens of quantum information

NIE Laimei (Purdue University)

Understanding the dynamics in many-body quantum systems has proved to be a key to unlocking many fundamental questions in condensed matter, AMO, and high energy physics. Recent years have seen a range of tools being utilized to characterize many-body dynamics, from out-of-time-ordered correlation functions to spectral statistics. In this talk, we will discuss a new way to look at the problem from a quantum information perspective: we will study the multi-partite entanglement and mutual information associated with the time evolution operator of the dynamics. We will test this idea in a variety of systems, including the Sachdev-Ye-Kitaev model and 2D conformal field theories, and reveal a hierarchy of information scrambling ability of their dynamics. Furthermore, we will show that nature may have a bound on the amount of scrambled information in quantum evolutions, and illustrate how certain systems are prohibited from saturating the bound due to conservation laws. We will also discuss the relation and distinction between our entanglement measure and other probes of quantum dynamics.

Entanglement bootstrap and the "DNA era" of quantum phases

SHI Bowen (University of California, San Diego)

Quantum phases of matter can have intricate many-body entanglement in its ground state wave function. Entanglement bootstrap is a research program that aims to "understand everything" from a wave function. Given a reference (vacuum) state satisfying a few axioms on the entanglement, we report progress in answering: "What are the universal properties of the phase? Why? How to detect universal data from a wave function?" In particular, we only need the state on a ball-like subsystem, which is analogous to using the DNA in a piece of tissue of a plant to detect its species. In this talk, I highlight the topological idea of immersion, which allows the construction of states on regions with interesting topology by recycling qubits in a ball. As applications, we prove the remote detectability of topological excitations and discuss things we hope to learn by nontrivially deforming an immersed region back to itself.

Gaplessness from symmetry in Dirac materials in periodic magnetic field and twisted cuprates

SONG Xue-Yang (Massachusetts Institute of Technology)

Quantum hall systems and cuprates are two prominent examples of strongly correlated systems. The emerging fields of Moire systems sheds new light on strong correlation physics. In this talk I'll describe 2 gapless states, arising from symmetry constraints, in half-filled Landau levels under long-wavelength modulations and Moire cuprates.

We show that quantum electrodynamics (QED_3) emerges in the simple setup of Dirac materials on a vortex lattice. Chemical potential modulation further drives a fractional quantum hall transition, at charge-neutrality for the Dirac electrons. Physical observables, numerical and experimental prospects are discussed.

Time permitting I'll discuss a gapless chiral superconducting state in twisted cuprates. We examine the vital role played by realistic aspects and strong correlations that impact the resulting ground states. We discuss signatures which are being studied in ongoing experiments.

Entanglement features of random neural network quantum states

SUN Xiao-Qi (University of Illinois Urbana-Champaign)

Neural networks offer a novel approach to represent wave functions for solving quantum many-body problems. But what kinds of quantum states are efficiently represented by neural networks? In this talk, we will discuss both analytic and numerical results on the entanglement properties of an ensemble of neural network states represented by random restricted Boltzmann machines. Phases with distinct entanglement features are identified and characterized which may help inform the initialization of neural network ansatzes for future computational tasks. For certain parameters, we will show that these random neural network quantum states generically have nearly maximal entanglement similar to a typical state. While entanglement is not the limiting factor for representing quantum states with restricted Boltzmann machines, we will show that generic wavefunctions represented by restricted Boltzmann machines are multifractal in the Ising spin basis which may limit the applications of these ansatzes in certain tasks.

Majorana Scars as Group Singlets

SUN Zimo (Princeton University)

Based on the framework proposed in 2007.00845 and 2106.10300, we present a class of lattice models of Majorana fermions, that possess two sectors of many-body scar states. These scar states, realized as group singlets of certain large rank group, generalized the eta-pairing states and zeta states in Ferm-Hubbard model. They have lower entanglement entropy compared to generic states at the same energy, showing the (weak) ergodicity breaking. This is also the first concrete example of many-body scars that are not equally spaced in energy, which can lead to the lack of revivals.

Reference: https://arxiv.org/abs/2212.11914 (by Zimo Sun, Fedor Popov, Igor Klebanov and Kiryl Pakrouski)

“Ferron” excitations in ferroelectrics and polarization caloritronics

TANG Ping (Tohoku University)

Ferromagnets and ferroelectrics are “ferroic” materials that exhibit spontaneous order of magnetic and electric dipoles below a critical temperature, respectively. The quasi-particle excitations of magnetic order are magnons that carry energy as well as elementary magnetic dipoles or spins. The transport of spin and heat by magnons has been extensively studied in the past decade in the field of spin caloritronics which features the spin Seebeck and Peltier effects. However, to our best knowledge, the quasi-particles and associated transport in ferroelectrics, an important material class with many technological applications, have so far remained unexplored. In this talk, I will introduce the elementary excitations, ferrons, which carry a net electric dipole as well as energy and the associated polarization and heat transport in ferroelectrics. We predict a measurable magnetic stray field produced by an electric polarization current, the ferronic electric-field-tunable thermal conductivity, and ferron-photon hybridization.

Bootstrap our way towards inflationary new physics

WANG Dong-Gang (University of Cambridge)

Cosmological correlation functions contain valuable information about the primordial Universe, with possible signatures of new physics at extremely high energies. Recently, the advances of the “cosmological bootstrap” program offer new perspectives and powerful tools to study these primordial imprints. In this talk, I will apply the bootstrap approach to systematically classify the leading observational target — primordial non-Gaussianities (three-point functions/bispectrum) from cosmic inflation. For the first time, we derive a complete set of scalar bispectra by incorporating possible new physics effects in the primordial era, and in particular, we identify new phenomenologies from the bootstrap analysis. The correlators are presented in analytic form, for any kinematics. Furthermore, as more and more observational experiments provide exciting opportunities for measuring these non-Gaussian signals, the systematic bootstrap analysis paves the way towards the potential discoveries of new physics in upcoming cosmological surveys.

Binary Dynamics from Worldline QFT for Scalar-QED

WANG Tianheng (Institute of Theoretical Physics, Chinese Academy of Sciences)

We investigate the worldline quantum field theory (WQFT) formalism for scalar-QED and observe that a generating function emerges from WQFT, from which the scattering angle ensues. This generating function bears important similarities with the radial action in that it requires no consideration of exponentiation of lower-order contributions. We demonstrate the computations of this generating function and the resulting scattering angle of a binary system coupled to electromagnetic field up to the third order in the Post-Minkowskian expansion (3PM).

Bootstrapping the gap of quantum many-body systems

XIN Yuan (Yale University)

Determining the long-range phase of matter of a strongly coupled system from its microscopic description has long been one of the central topics in physics. Significant progress is recently made in this aspect with bootstrap approaches on the lattice. In this talk, I will introduce a new bootstrap method for quantum many-body problems that closely mirrors the setup from conformal field theory (CFT). The method is general and we test it on the (1+1)-dimensional transverse field Ising model, where we show that the Hamiltonian equations of motion, translational invariance and global symmetry selection rules impose a rigorous bound on the gap and correlators of local operators. Our method provides a way to probe the low energy spectrum of an infinite lattice from the Hamiltonian rigorously and without approximation.

Mixed-State Topological Phases with Average Symmetries

ZHANG Jian-Hao (Pennsylvania State University)

In this talk, I will systematically construct the average SPT (ASPT) and SET (ASET) phases that the symmetry-protected/symmetry-enriched entanglement can still prevail even if part of the protecting symmetry is broken by quenched disorder locally but restored upon disorder averaging. In particular, some ASPT/ASET phases may not be realized in a clean system without any disorder. I will also design the strange correlator of the ASPT phases via a strange density matrix to detect the nontrivial ASPT state. Moreover, it is amazing that the strange correlator of ASPT can be precisely mapped to the watermelon correlation functions of some proper statistical loop models, with power-law behavior.

Superheavy dark matter production from symmetry restoration first-order phase transition during inflation

ZHOU Siyi (Kobe University)

We propose a scenario where superheavy dark matter (DM) can be produced via symmetry restoration first-order phase transition during inflation triggered by the evolution of the inflaton field. The phase transition happens in a spectator sector coupled to the inflaton field. During the phase transition, the spectator field tunnels from a symmetry-broken vacuum to a symmetry-restored vacuum. The massive particles produced after bubble collisions are protected against decaying by the restored symmetry and may serve as a DM candidate in the later evolution of the Universe. We show that the latent heat released during the phase transition can be sufficient to produce the DM relic abundance observed today. In addition, accompanied with the super heavy DM, this first-order phase transition also produces gravitational waves detectable via future gravitational wave detectors.

A minimalist's approach to the physics of emergence

ZOU Liujun (Perimeter Institute for Theoretical Physics)

One of the central themes of condensed matter physics is the emergence of universality classes. In general, it is highly complex to determine which universality class emerges in a quantum matter based on its microscopic properties. In this talk, I will argue that the perspective of quantum anomaly provides powerful insights into the understanding of the landscape of universality classes that can emerge in quantum matter, and I will present some interesting applications.