Aspen Winter Conference 2019: New Approaches to Strongly Correlated Quantum Systems

Dates:
February 3-9, 2019

Organizers:
Immanuel Bloch (Max Planck Institute of Quantum Optics, Munich)
Xie Chen (Caltech)
Frank Pollmann (Technical University of Munich)
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Conference Synopsis:
Recent years have seen the development of new non-perturbative approaches to the quantum many-body problem arising from surprising interdisciplinary sources. On the numerical side, insights from quantum information theory have led to the discovery of efficient tensor network methods, while machine learning techniques have been adapted to the study of quantum many-body states and the optimization of Monte Carlo sampling. Theoretically, new dualities and the bootstrap program are yielding surprising constraints on quantum critical phases, while quantum information theory has been used to derive bounds on even more general many-body systems. At the same time engineered quantum systems, both in cold atomic systems and the solid state, are providing an unprecedented level of control which is allowing these approaches to be tested in the laboratory. Our winter meeting will attempt to bring together leading practitioners to discuss the further development of these new approaches and their application to outstanding problems in condensed matter physics.

Program (Talks are 30 minutes presentation + 10 minutes for discussion):

Sunday:	Reception (5:00-7:00)					
	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
8:40 - 9:20	Eli Zeldov	Yizhi You	Ulrich Schollwoeck	Fakher Assaad	Masaki Oshikawa	Andriy Nevidomskyy
9:20 - 9:40	**Break**	Danny Bulmash	**Break**	**Break**	**Break**	Sun-Sik Lee
9:40 - 10:20	Dominic Else	**Break**	Norbert Schuch	Assa Auerbach	Itamar Kimchi	**Break**
10:20 - 11:00	Maia Vergniory	Mike Hermele	Roger Mong	Dima Feldman	Yong-Baek Kim	Adam Nahum
11:00 - 11:40		Peter Schauss	**Posters from 11:00**			Andrew Green
11:40 - 4:00	**Break**	**Break**		**Break**	**Break**	**Closing**
4:00 - 4:40	Feng Wang			Cecile Repellin	Lesik Motrunich	
4:40 - 5:20	Adrian Po			Christina Knapp	Yin-Chen He	
5:20 - 5:40	**Break**		Physics Café (4:30-5:30)	**Break**	**Break**	
5:40 - 6:20	Ivar Martin		Public Lecture (5:30-6:30):	Jeongwan Haah	David Poland	
6:20 - 7:00	Cenke Xu		Ulrich Schollwoeck	Bela Bauer	Anders Sandvik	
	Dinners in town	Dinners in town	Dinners in town	Banquet (7:30)	Dinners in town	

Talks

Monday

Eli Zeldov, "Nanoscale cryogenic thermal imaging: glimpse into dissipation in 2D quantum systems down to atomic scale": Energy dissipation is a fundamental process governing the dynamics of classical and quantum systems. Despite its vital importance, direct imaging and microscopy of dissipation in quantum systems is currently impossible because the existing thermal imaging methods lack the necessary sensitivity and are unsuitable for low temperature operation. We developed a scanning nanoSQUID with sub 50 nm diameter that resides at the apex of a sharp pipette [1], acting simultaneously as nanomagnetometer with single spin sensitivity and as nanothermometer providing cryogenic thermal imaging with four orders of magnitude improved thermal sensitivity of below 1 μK [2]. The non-contact non-invasive thermometry allows thermal imaging of minute energy dissipation down to the level equivalent to the fundamental Landauer limit for continuous readout of a single qubit. These advances enable observation of changes in dissipation due to single electron charging of a quantum dot and visualization and control of heat generated by electrons scattering off a single atomic defect in graphene [3], opening the door to direct imaging and spectroscopy of dissipation processes in quantum systems.
[1] Vasyukov et al, Nature Nanotech. 8, 639 (2013).
[2] Halbertal et al, Nature 539, 407 (2016).
[3] Halbertal et al, Science 358, 1303 (2017).

Dominic Else, "Three physical pictures for interacting topological crystalline phases": Topological crystalline phases are topological phases with spatial symmetries. In this talk, I propose a classification of such phases in interacting systems. I discuss three different physical pictures for understanding topological phases with spatial symmetries. I argue that when these pictures are formulated in a sufficiently precise way, they can be shown to lead to the same mathematical classification. Time permitting, I will mention applications to generalized Lieb-Schultz-Mattis theorems and to "fragile topological phases" in interacting systems.

Maia Vergniory, "Realization of toplogically protected magnetic fermions in materials": Weyl fermions are expected to exhibit exotic physical properties such as the chiral anomaly, large negative magnetoresistance or Fermi arcs. Recently a new platform to realize these fermions has been introduced based on the appearance of a high-order nodal crossings at high symmetry points of certain space groups. We describe the symmetry protected nodal points that can exist in magnetic space groups and show that only 3-fold, 6-fold, and 8-fold degeneracies are possible (in addition to the 2- and 4-fold degeneracies that have already been studied.) The 3-fold and 6-fold degeneracies are topologically equivalent to spin-1 Weyl and Dirac fermions. The 8-fold degeneracies come in different flavors. In particular, we introduce the first solid state realization of the non-chiral Rarita-Schwinger fermion and list the (magnetic and non-magnetic) space groups where these exotic fermions can be found. We will also show the experimental realization of some of these magnetic fermions in real materials.

Feng Wang, "Engineering Correlated Physics in Two-Dimensional Moire Superlattices": Van der Waals heterostructures of atomically thin crystals offer an exciting new platform to design novel electronic and optical properties. In this talk, I will describe a general approach to engineer correlated physics using moire superlattice in two dimensional heterostructures. One example is the tunable Mott insulator realized in the ABC trilayer graphene (TLG) and hexagonal boron nitride (hBN) heterostructure with a moiré superlattice, where the moiré leads to narrow electronic minibands and allows for the observation of gate-tunable Mott insulator states at 1/4 and 1/2 fillings. In addition, signatures of superconductivity are observed at low temperature near the ¼ filling Mott insulator state in the TLG/hBN heterostructures.

Adrian Po, "Modeling twisted bilayer graphene": Strongly coupled correlated systems are conventionally modeled in the real space, say through a Hubbard-like or a quantum spin model. The degrees of freedom in these models have a clear physical interpretation, arising from the (partially filled) electronic orbitals well-localized to the underlying atoms. The recent discoveries of correlated insulators and superconductivity in twisted bilayer graphene, however, have revealed a new class of exciting materials which do not immediately yield to the conventional modeling methods. In stark contrast to the more familiar materials, the underlying degrees of freedom in twisted bilayer graphene are anomalous Dirac electrons, which do not admit any real-space description on their own. I will discuss how this anomaly can obstruct the theoretical modeling of the system, as well as some approaches for resolving the obstructions.

Ivar Martin, "Phonon-induced pairing in twisted bilayer graphene"

Cenke Xu, "Coupled conformal field theory description of the Correlated Physics on Moire superlattice", Since the discovery of superconductivity and correlated insulator at fractional electron fillings in the twisted bilayer graphene, most theoretical efforts have been focused on describing this system in terms of an effective extended Hubbard model. However, it was recognized that an exact tight binding model on the Moiré superlattice which captures all the subtleties of the bands can be exceedingly complicated. Here we pursue an alternative coupled wire description of the system based on the observation that the lattice relaxation effect is strong at small twist angle, which substantially enlarges the AB and BA stacking domains. Under an out-of-plane electric field which can have multiple origins, the low energy physics of the system is dominated by interconnected wires with (approximately) gapless 1d conducting quantum valley hall domain wall states. We demonstrate that the Coulomb interaction likely renders the wires a U(2)_2 (1+1)d conformal field theory with a tunable Luttinger parameter for the charge U(1) sector. Spin triplet and singlet Cooper pair operator both have quasi-long range order in this CFT. The junction between the wires at the AA stacking islands can lead to either a two dimensional superconductor, or an insulator.

Tuesday

Yizhi You,"Fracton phase of matter: From gauge theory to Majorana Lego realization": Fracton topological phases host fractionalized topological quasiparticles with restricted mobility, with promising applications to fault-tolerant quantum computation. While a variety of exactly solvable fracton models have been proposed, there is a need for platforms to realize them experimentally. We show that a rich set of fracton phases emerges in interacting Majorana band models whose building blocks are within experimental reach. The basic building blocks of the proposed constructions include Coulomb blockaded Majorana islands and weak inter-island Majorana hybridizations. This setting produces a wide variety of fracton states and promises numerous opportunities for probing and controlling fracton phases experimentally. Our approach also reveals the relation between fracton phases and Majorana fermion codes and further generates a hierarchy of fracton spin liquids.

Danny Bulmash, "Coupling Fractons to TQFTs: a New Class of non-Abelian Fracton Models": Fracton phases are a new type of phase in three dimensions which share some features with conventional topological order, such as protected ground state degeneracy, but which have excitations which are unable to move freely in all directions. We construct a new class of exactly solvable models with non-Abelian fracton excitations by coupling Abelian fracton systems to conventional topological order, that is, gauging a global symmetry. By applying the gauging procedure to the layer-swap symmetry of two copies of the X-cube model, a canonical model of fracton order, we obtain a model with non-Abelian immobile excitations and a novel string excitation whose topological degeneracy depends on its geometry. We also apply this procedure to Haah's code, a so-called "type-II" models for which non-Abelian variants have been elusive. Our gauged model contains non-Abelian immobile excitations which are created at the corners of fractal-shaped operators in addition to a non-Abelian string operator.

Mike Hermele, "Abelian and non-Abelian excitations in fracton phases of matter": Fracton phases of matter are a new class of quantum phases of matter characterized by excitations that exhibit restricted mobility. These phases, the most interesting examples of which occur in three-dimensional systems, have attracted recent interest in large part because they do not appear to fit into existing paradigms to characterize or classify quantum phases of matter. In this talk, I will first give a brief overview of fracton phases, and then discuss two recent works focusing on the excitations of fully gapped fracton phases in three dimensions. First, I will outline an approach to describe fusion and statistical processes in fracton phases with Abelian excitations. Second, I will describe a relatively simple fracton model supporting non-Abelian excitations restricted to move along lines, and demonstrate that the restricted mobility and non-Abelian nature of these excitations is a fundamentally three-dimensional phenomenon.

Peter Schauss, “Quantum gas microscopy of many-body dynamics in Fermi-Hubbard and Ising systems”: The ability to probe and manipulate cold atoms in optical lattices at the atomic level using quantum gas microscopes enables quantitative studies of quantum many-body dynamics. While there are many well-developed theoretical tools to study many-body quantum systems in equilibrium, gaining insight into dynamics is challenging with available techniques. Approximate methods need to be benchmarked, creating an urgent need for measurements in experimental model systems. In this talk, I will discuss two such measurements. First, I will present a study that probes the relaxation of density modulations in the doped Fermi-Hubbard model. This leads to a hydrodynamic description that allows us to determine the conductivity. We observe bad metallic behavior that we compare to predictions from finite-temperature Lanczos calculations and dynamical mean field theory. Second, I introduce a new platform to study the 2D quantum Ising model. Via optical coupling of atoms in an optical lattice to a low-lying Rydberg state, we observe quench dynamics in the resulting Ising model and prepare states with antiferromagnetic correlations.

Wednesday

Ulrich Schollwoeck, “Realistic DMFT with Matrix Product State Impurity Solvers”: In this talk I will discuss the use of matrix product states to solve the effective impurity problem of multiorbital-DMFT or DCA for realistic strongly correlated materials, where realistic DFT-based band structures are used and both Hund’s coupling terms and spin-orbit coupling terms are properly accounted for without phenomenological modelling or a sign problem. Based on the example of strontium ruthenate Sr2RuO4, I will benchmark MPS impurity solvers for the case without spin-orbit coupling where high-precision data is available from other DMFT impurity solvers, and move on to show new results for the case with spin-orbit coupling which give a clear physical picture of its effects in Sr2RuO4. I will conclude by discussing the future potential of the method.

Norbert Schuch, “Study of topological spin liquids with projected entangled pair states”: Topological spin liquids are novel phases of matter where spins order topologically rather than magnetically, making them challenging to construct and characterize. In my talk, I will discuss how projected entangled pair states (PEPS) can be used to construct and characterize topological spin liquid wavefunctions. In particular, I will explain how they can be used to construct spin liquids with higher SU(N) symmetry, and how the PEPS description gives us direct access to order parameters which allow to characterize topological phase transitions.

Roger Mong, “Emergent mode and bound states in single-component fermionic systems”: From the ubiquitous baryonic matter to superconductivity, studies of matter comprised of bound states of fermions span many branches of physics. Here, we study bound states form among fermions of the same species (in contrast to baryons and conventional Cooper pairing), in a one dimensional setting. Specifically, we study the formation of bound states in a one-dimensional, single-component Fermi chain with attractive interactions. The phase diagram, computed from DMRG, shows not only a superfluid of paired fermions (pair phase) and a liquid of fermion triplets (trion phase), but also a phase with two gapless modes. We argue that the latter phase consists of a charged and an emergent neutral mode--and that all other bound-state phases (single, pair, trion, etc.) are descendants of this two-mode-phase.

Thursday

Fakher Assaad "Intertwined orders in Dirac Fermions": There has recently been a flurry of negative sign free fermionic models that exhibit exotic phases and phase transitions. After reviewing these advances, I will place emphasis on models of Dirac fermions in 2+1 dimensions with dynamically generated anti-commuting mass terms. In particular we will consider a model of Dirac fermions where s-wave superconductivity (SC) as well as the quantum spin Hall state emerge from spontaneous symmetry breaking. On our finite lattices, this transition turns out to be continuous and follows the idea that skyrmions of the SO(3) QSH order parameter, carrying charge 2e, condense. The transition falls in the same universality class as that of the antiferromagnetic to valence bond solid transition observed in JQ and loop models. However since the U(1) symmetry is not broken by the lattice discretization, it is not subject to a dangerously irrelevant operator and associated two length scales.

Assa Auerbach, "Equilibrium Formulae for Transverse Magneto-transport of Strongly Correlated Metals": In metals, transport coefficients involve non-adiabatic relaxational dynamics which are in general, much harder to compute than equilibrium susceptibilities.In this talk I present three formulas derived from Kubo formula [1,2], for DC transport coefficients which can be expressed as sums of equilibrium susceptibilities: (1) The Hall coefficient, (2) A modified Nernst coefficient, and (3) The Thermal Hall coefficient. The formulas are valid for general strongly interacting Hamiltonians which describe "bad metals", which are beyond the applicability of Fermi liquid theory and Boltzmann equation. Recent results for the square lattice t-J model, and lattice bosons near the Mott insulator phases are presented.

1. A. Auerbach, Phys. Rev. Lett. 121, 066601 (2018).
2. https://arxiv.org/abs/1811.05775

Dima Feldman, "Partial equilibration of integer and fractional edge channels in the thermal quantum Hall effect": Since the charged mode is much faster than the neutral modes on quantum Hall edges at large filling factors, the edge may remain out of equilibrium in thermal conductance experiments. This sheds light on the observed imperfect quantization of the thermal Hall conductance at $\nu=8/3$ and can increase the observed thermal conductance by two quanta at $\nu=8/5$. Under certain unlikely but not impossible assumptions, this might also reconcile the observed thermal conductance at $\nu=5/2$ with not only the PH-Pfaffian order but also the anti-Pfaffian order.

Cecile Repellin, "Detecting fractional Chern insulators through circular dichroism": Great efforts are currently devoted to the engineering of topological Bloch bands in ultracold atomic gases. Recent achievements in this direction, together with the possibility of tuning inter-particle interactions, suggest that strongly-correlated states reminiscent of fractional quantum Hall (FQH) liquids could soon be generated in these systems. In this experimental framework, where transport measurements are limited, identifying unambiguous signatures of FQH-like states constitutes a challenge on its own. Here, we demonstrate that the fractional nature of the quantized Hall conductance, a fundamental characteristic of FQH states, could be detected in ultracold gases through a circular-dichroic measurement, namely, by monitoring the energy absorbed by the atomic cloud upon a circular drive. We validate this approach by comparing the circular-dichroic signal to the many-body Chern number, and discuss how such measurements could be performed to distinguish FQH-type states from competing states. Our scheme offers a practical tool for the detection of topologically-ordered states in quantum-engineered systems, with potential applications in solid state.

Christina Knapp, "Fractional Chern insulator edges and layer-resolved lattice contacts": Fractional Chern insulators (FCIs) realized in fractional quantum Hall systems subject to a periodic potential are topological phases of matter for which space group symmetries play an important role. Lattice dislocations in an FCI can host topology-altering non-Abelian topological defects, known as genons. Here, we propose how FCI edges can be used to detect genons. Translation symmetry can impose a quantized momentum difference between the edge electrons of a partially filled Chern band. We propose layer-resolved lattice contacts, which utilize this momentum difference to selectively contact a particular FCI edge electron. The relative current between FCI edge electrons can then be used to detect the presence of genons in the bulk FCI. These lattice contacts could be implemented in graphene subject to an artificial lattice.

Jeongwan Haah, "Nontrivial Quantum Cellular Automata in higher dimensions": We discuss automorphisms of local operator algebra on lattices, in connection to invertible topological phases of matter.

Bela Bauer, "Topologically protected braiding in a single wire using Floquet Majorana modes": Floquet systems offer a versatile toolbox for engineering quantum phases that are not allowed or at least more difficult to obtain in equilibrium systems. A prominent example are time crystals, which spontaneously break discrete time-translation symmetry. Closely related to time crystals are Floquet topological phases, such as those found in the driven Kitaev chain. I will discuss how to perform braiding of non-Abelian degrees of freedom - the elementary operation of topological quantum computation - in such a driven topological superconductor. Unlike the equilibrium case, where braiding can only be performed in two-dimensional systems (or at least 2d networks of 1d systems), braiding here is realized in a strictly one-dimensional system, thus potentially simplifying experimental demonstration.

Friday

Masaki Oshikawa, "Universal gap scaling of finite Ising/Kitaev chains": The quantum (transverse-field) Ising chain has been studied for a long time as a canonical model exhibiting a quantum phase transition, and is also deeply related to the Kitaev chain which hosts Majorana zero modes as edge states. I will discuss a universal scaling of the lowest gap of finite-size quantum Ising chains for general boundary conditions.

Itamar Kimchi, ”Dirty quantum magnets”: Several longstanding problems in spin-1/2 quantum magnetism concern quenched disorder. In this talk I will discuss the role of random exchange energies in spin-1/2 magnets where magnetic frustration promotes the formation of entangled valence bonds. Results include a theory of 2D valence-bond-solids subject to weak bond randomness, and an instability of classical dimer models that is applicable to strongly disordered spin liquids. In both cases we find that bond disorder nucleates topological defects that carry spin-1/2 moments, thereby renormalizing the lattice into a strongly random spin network with interesting low-energy excitations. The results lead to conjectures, and a proof in 1D, of Lieb-Schultz-Mattis-type restrictions for disordered magnets with spin-1/2 per statistical unit cell. I will then turn to experimental connections: most strikingly, recent heat capacity data of multiple magnetic materials -- all with frustration and disorder but no other common relation -- nevertheless all show quasi-universal one-parameter data collapse of C[H,T] in a magnetic field. I will show how this data collapse and its scaling function can be understood in terms of the theory as an emergent network of long range valence bonds at low energies. If time permits I will also re-interpret this theory in terms of quantum anomalies and connect to other 2D anomalies of 3D topological states.

Yong-Baek Kim, “Topological superconductors from quantum spin liquid and topological semimetal”: We discuss two different routes to obtain topological superconductors. The first one is to use the Kondo coupling between the Kitaev spin liquid and semi-metallic conduction electrons in two-dimensional honeycomb lattice. This is an explicit example where the coupling between a quantum spin liquid and low-density conduction electrons leads to topological superconductivity. For sufficiently large Kondo coupling, two successive phase transitions lead to the appearance of a ferromagnetic topological superconductor with a single chiral Majorana edge mode and a paramagnetic topological superconductor with a single pair of helical Majorana edge modes.

The second system is a multi-orbital Luttinger model with interacting $j = 3/2$ electrons in three dimensions. The kinetic part of the model is described by a quadratic band touching with a small finite chemical potential. We demonstrate that two kinds of topological superconductors are energetically favored when the model possesses SO(3) symmetry. These superconductors contain either nodal lines or Fermi pockets of gapless Bogoliubov quasiparticles in the bulk and exhibit non-trivial bulk-boundary correspondence. We discuss applications of this theory to relevant families of materials, especially half-heusler compound YPtBi.

Lesik Motrunich, “Ising ferromagnet to valence bond solid transition in a 1d spin chain”: We study a 1d system that shows many analogies to proposed 2d deconfined quantum critical points (DQCP). Our system is a translationally invariant spin-1/2 chain with on-site $Z2 \times Z2$ symmetry and time reversal symmetry. It undergoes a direct continuous transition from a ferromagnet (FM), where one of the Z2 symmetries and the time reversal are broken, to a valence bond solid (VBS), where all on-site symmetries are restored while the translation symmetry is broken. The other Z2 symmetry remains unbroken throughout, but its presence is crucial for both the direct transition (via specific Berry phase effect on topological defects, also related to a Lieb-Schultz-Mattis-like theorem) and the precise characterization of the VBS phase (which has crystalline-SPT-like property). The transition has a description in terms of either two domain wall species that \"fractionalize\" the VBS order parameter or in terms of partons that \"fractionalize\" the FM order parameter, with each picture having its own Z2 gauge structure. The two descriptions are dual to each other and, at long wavelengths, take the form of a self-dual \\emph{gauged} Ashkin-Teller model, reminiscent of the self-dual easy-plane non-compact CP1 model that arises in the description of the 2d easy-plane DQCP. We also find an exact reformulation of the transition that leads to a simple field theory description that explicitly unifies the FM and VBS order parameters; this reformulation can be interpreted as a new parton approach that does not attempt to fractionalize either of the two order parameters but instead encodes them in instantons. Besides providing explicit realizations of many ideas proposed in the context of the 2d DQCP, here in the simpler and fully tractable 1d setting with continuous transition, our study also suggests possible new line of approach to the 2d DQCP.

Yin-Chen He, "Field- induced neutral Fermi surface and QCD3 quantum criticalities in Kitaev": We perform both numerical and theoretical studies on the phase diagram of the Kitaev materials in the presence of a magnetic field. We find that a new quantum spin liquid state with neutral Fermi surfaces emerges at intermediate field strengths, between the regimes for the non-Abelian chiral spin liquid state and for the trivial polarized state. We discuss the exotic field-induced quantum phase transitions from this new state with neutral Fermi surfaces to its nearby phases. We also theoretically study the field-induced quantum phase transitions from the non-Abelian chiral spin liquid to the symmetry-broken zigzag phase and to the trivial polarized state. Utilizing the recently developed dualities of gauge theories, we find these transitions can be described by critical bosons or gapless fermions coupled to emergent non-Abelian gauge fields, and the critical theories are of the type of a QCD3-Chern- Simons theory. We propose that all these exotic quantum phase transitions can potentially be direct and continuous in the Kitaev materials, and we present sound evidence for this proposal. Therefore, besides being systems with intriguing quantum magnetism, Kitaev materials may also serve as table-top experimental platforms to study the interesting dynamics of emergent strongly interacting quarks and gluons in 2 + 1 dimensions. Finally, we address the experimental signatures of these phenomena.

David Poland, "Bootstrapping 3D CFTs": I will review progress at using the numerical conformal bootstrap to isolate 3D CFTs of interest to condensed matter systems, including the 3D Ising, O(N) vector, and Gross-Neveu-Yukawa models, the latter of which describe fixed points involving N interacting fermions. When N=1, there exists a supersymmetric fixed point which has been proposed to be potentially realizable on the boundaries of topological superconductors. I'll describe recent progress at isolating this minimal 3D SCFT using the numerical bootstrap, yielding high precision determinations of its leading scaling dimensions and OPE coefficients. These determinations show a remarkable consistency with being expressible in terms of the transcendental number tan(1).

Anders Sandvik, "Analytic continuation of quantum Monte Carlo data:
beyond the Maximum Entropy method": The Maximum Entropy method traditionally used to carry out analytic continuation from imaginary-time correlation functions to real-frequency spectral functions cannot resolve sharp features such as delta-functions or edge singularities. I will present an approach where these features can be resolved within the

approach of stochastic analytic continuation, by using a suitable parametrization of the spectrum. The imposed features are optimized using an unbiased method relying only on the goodness of the fit to the Monte Carlo data. I will show several examples of the so obtained dynamic structure factor of quantum magnets in one and two dimensions.

Saturday

Andriy Nevidomskyy, "Revealing the Emergent Spinon Fermi Surface of the Critical Spin Liquids": Among different kinds of quantum spin liquids, of particular relevance to experiments are the critical spin liquids with a spinon Fermi surface. Since such a gapless surface in the momentum space is emergent, revealing its presence beyond mean-field-type argument is very challenging. In this talk, we will present a new direct probe of both the size and shape of the spinon Fermi surface using real- space entanglement entropy in a numerically exact way. In particular, we demonstrate strong evidence that the scaling of the leading term in the entanglement entropy follows the Widom formula, from which the geometry of the spinon Fermi surface can be deduced. We benchmark the method and show that it works for the Gutzwiller projected U(1) spin liquid on a triangular lattice.

Sun-Sik Lee, "State dependent spread of entanglement in relatively local Hamiltonians": In this talk, I will present a background independent non-local Hamiltonians from which local theories emerge within a set of short-range entangled states. The dimension, topology and geometry of the emergent local theory is determined by the initial state to which the Hamiltonian is applied. In this relatively local Hamiltonian, the coordinate speeds at which entanglement spreads and local disturbance propagates in space strongly depend on state.

Adam Nahum, "Emergent symmetry and quasi-universality at critical points in three spacetime dimensions", I will talk about emergent symmetry in phase transitions and quantum field theories in 2+1 or 3+0 dimensions. I will argue that emergent symmetries can be surprisingly robust, and important for phenomenology, even in situations where they are not strictly speaking exact. I will discuss the relation to some field theory dualities.

Andrew Green, "The Lyapunov Spectra of Quantum Thermalisation": Thermalisation in closed quantum systems occurs through a process of dephasing due to parts of the system outside of the window of observation, gradually revealing the underlying thermal nature of eigenstates. In contrast, closed classical systems thermalize due to dynamical chaos. We demonstrate a deep link between these processes. Projecting quantum dynamics onto variational states using the time-dependent variational principle, results in classical chaotic Hamiltonian dynamics. We study an infinite spin chain in two ways --- using the matrix product state ansatz for the wavefunction and for the thermofield purification of the density matrix --- and extract the full Lyapunov spectrum of the resulting dynamics. We show that the entanglement growth rate is related to the Kolmogorov-Sinai entropy of dynamics projected onto states with appropriate entanglement, extending previous results about initial entanglement growth to all times. The Lyapunov spectra for thermofield descriptions of thermalizing systems show a remarkable semi-circular distribution.

Posters

Andrey Antipov, "Engineering Majorana zero modes": The initial theoretical proposal for the realization of Majorana bounds states in a condensed matter setup requires three simple ingredients: superconductivity, spin-orbit coupling and magnetic field. While this proposal is simple, the experiments are not, as they involve material science, fabrication steps, cooling, electrostatic control and actual measurements. The results of experiments are not unambiguous and allow for multiple interpretation by simple theoretical models. In order to bridge the gap one has to include peculiarities of experimental setup and engineer the modelling of systems supporting Majorana zero modes. In this presentation I will show how the next generation of numerical models captures the effects of electric fields, interaction, disorder, orbital effects and how it can feedback and guide the ongoing experimental effort in the field.

Przemyslaw Bienias, **"Fractional quantum Hall phases of bosons with tunable interactions"**: Highly tunable platforms for realizing topological phases of matter are emerging from atomic and photonic systems, and offer the prospect of designing interactions between particles. The shape of the potential, besides playing an important role in the competition between different fractional quantum Hall phases, can also trigger the transition to symmetry-broken phases, or even to phases where topological and symmetry-breaking order coexist. Here, we explore the phase diagram of an interacting bosonic model in the lowest Landau level at half-filling as two-body interactions are tuned. Apart from the well-known Laughlin liquid, Wigner crystal phase, stripe, and bubble phases, we also find evidence of a phase that exhibits crystalline order at fractional filling per crystal site. The Laughlin liquid transits into this phase when pairs of bosons strongly repel each other at relative angular momentum $4\\hbar$. We show that such interactions can be achieved by dressing ground-state cold atoms with multiple different-parity Rydberg states.

Michael Buchhold, "Exploring self-organized criticality in driven Rydberg gases": Recent experiments with strongly interacting, driven Rydberg ensembles have demonstrated aspects of self- organized criticality (SOC) in the dynamics of the atomic pseudo-spins. Their setup presents a means for precise control of the microscopic origin of SOC and offers a new playground for its exploration with cold atoms. Here we extend the experimental setup and introduce a feasible recharging scheme by which prototypical avalanche dynamics can be maintained and controlled. It gives access to an extended SOC phenomenology including i) subcritical, periodically occurring avalanches, ii) an extended regime featuring scale invariant avalanches and fractal real-space structures, and iii) a supercritical, disordered regime. This relates driven Rydberg ensembles to other SOC scenarios with a similar phenomenology, such as e.g. neural networks. We illustrate this connection by exploring the dependence of SOC on external time scales and the ensemble dimensionality.

Hossein Dehghani, "Light- Enhanced Superconductivity": In cuprate materials in addition to the superconducting phase, there are other many-body phases which compete with this order. One way to enhance superconductivity is to suppress these orders. In this work we show that how irradiation of certain modes of light can enhance superconductivity.

Elmer V. H. Doggen, "Many-body localization and delocalization in large quantum chains": We theoretically study the quench dynamics for an isolated Heisenberg spin chain with a random on-site magnetic field, which is one of the paradigmatic models of a many-body localization transition. We use the time-dependent variational principle as applied to matrix product states, which allows us to controllably study chains of a length up to L=100 spins. For the analysis of the data, three complementary approaches are used: (i) determination of the exponent which characterizes the power-law decay of the antiferromagnetic imbalance with time; (ii) similar determination of the exponent which characterizes the decay of a Schmidt gap in the entanglement spectrum; and (iii) machine learning with the use, as an input, of the time dependence of the spin densities in the whole chain. We find that the consideration of the larger system sizes substantially increases the estimate for the critical disorder that separates the ergodic and many-body localized regimes, compared to the values in the literature. From a technical perspective, we develop an adaptation of the "learning by confusion" machine-learning approach that can determine the critical disorder.

Philipp Dumitrescu, "Kosterlitz- Thouless scaling at many-body localization phase transitions": We propose a scaling theory for the many-body localization (MBL) phase transition in one dimension, building on the idea that it proceeds via a \'quantum avalanche\'. We argue that the critical properties can be captured at coarse-grained level by a Kosterlitz-Thouless (KT) renormalization group (RG) flow. On phenomenological grounds, we identify the scaling variables as the density of thermal regions and the lengthscale that controls the decay of typical matrix elements. Within this KT picture, the MBL phase is a line of fixed points that terminates at the delocalization transition. We discuss two possible scenarios distinguished by the distribution of fractal rare thermal inclusions within the MBL phase. In the first scenario, these regions have a stretched exponential distribution in the MBL phase. In the second scenario, the near-critical MBL phase hosts rare thermal regions that are power-law distributed in size. This points to the existence of second transition within the MBL phase, at which these power-laws change to the stretched exponential form expected at strong disorder. We provide additional support for the latter scenario via numerical simulations of a phenomenological model for the critical properties near the MBL transition.

Tobias Grass, "Optical Control in Fractional Quantum Hall Systems": Light-matter interactions provide a powerful tool for controlling the electronic properties of a material. Here, we demonstrate the possibility of light-induced topological phase transitions for graphene in the fractional quantum Hall regime. The optical coupling mimics an artificial bilayer scenario with tunable pseudopotentials giving rise to exotic non-Abelian phases. They include the gapless Haldane-Rezayi phase at filling 1/2, and the Fibonacci anyon phase at filling 2/3. For both Dirac materials and non-relativistic quantum Hall systems, we show that coupling to light with orbital angular momentum can be used as a synthetic \"flux\" pump. This enables the controlled insertion of individual quasiparticles in a quantum Hall system. Moreover, light-induced potentials, based on AC Stark shift, can trap such quasiparticles.

Edwin Huang, "Strange metallicity in the doped Hubbard model": Strange or bad metallic transport, defined by its incompatibility with conventional quasiparticle pictures, is a theme common to strongly correlated materials and ubiquitous in many high temperature superconductors. The Hubbard model represents a minimal starting point for modeling strongly correlated systems. Here we demonstrate strange metallic transport in the doped two-dimensional Hubbard model using determinantal quantum Monte Carlo calculations. Over a wide range of doping, we observe resistivities exceeding the Mott-Ioffe-Regel limit with linear temperature dependence. The temperatures of our calculations extend to as low as 1/40 the non-interacting bandwidth, placing our findings in the degenerate regime relevant to experimental observations of strange metallicity. Our results provide a foundation for connecting theories of strange metals to models of strongly correlated materials.

Thomas Iadecola, "Configuration-Controlled Many-Body Localization and the Mobility Emulsion": We uncover a new non-ergodic phase, distinct from the many-body localized (MBL) phase, in a disordered two-leg ladder of interacting hardcore bosons. This phase, which requires strong disorder and finite interaction, features dynamics depending strongly on the many-body configuration of the initial state. Remarkably, this phase features the coexistence of localized and extended many-body states at fixed energy density and thus does not exhibit a many-body mobility edge, nor does it reduce to a model with a single-particle mobility edge in the noninteracting limit. We show that eigenstates in this phase can be described in terms of interacting emergent Ising spin degrees of freedom (\"singlons\") suspended in a mixture with inert charge degrees of freedom (\"doublons\" and \"holons\"), and thus dub it a mobility emulsion (ME). We argue that grouping eigenstates by their doublon/holon density reveals a transition between localized and extended states that is invisible as a function of energy density. We further demonstrate that the dynamics of the system following a quench may exhibit either delocalized or localized behavior depending on the doublon/holon density of the initial product state. Intriguingly, the ergodicity of the ME is thus tuned by the initial state of the many-body system.

Dmitri Khveshchenko, **"Seeking to develop global SYK-ness":** Seeking to develop global SYK- ness Inspired by the recent interest in the Sachdev-Ye-Kitaev (SYK) model we study a class of multi-flavored one- and two-band fermion systems with no bare dispersion. In contrast to the previous work on the SYK model that would routinely assume spatial locality, thus unequivocally arriving at the so-called \\\\\\\'locally-critical\\\\\\\' scenario, we seek to attain a spatially-dispersing \\\\\\\'globally-SYK\\\\\\\' behavior. To that end, a variety of the Lorentz-(non) invariant space-and/or-time dependent algebraically decaying interaction functions is considered and some of the thermodynamic and transport properties of such systems are discussed.

Jian Lin, "Machine learning search for quantum algorithms": Quantum algorithm design lies in the hallmark of applications of quantum computation and quantum simulation. Recent theoretical progress has established complexity-equivalence of circuit and adiabatic quantum algorithms. Here we utilize deep reinforcement learning methods to search for optimal Hamiltonian path in the framework of quantum adiabatic algorithm. We benchmark our approach in Grover search and 3-SAT problems, and find that the adiabatic algorithm obtained by our reinforcement learning approach leads to improved performance in the final state fidelity and significant computational speedups for both moderate and large number of qubits compared to conventional algorithms. Our approach offers a recipe to design quantum algorithms for generic problems through a systematic search. This approach paves a novel way to automated quantum algorithm design by artificial intelligence.

Rex Lundgren, "Confined Dynamics in Long- Range Interacting Quantum Spin Chains": We study the quasiparticle excitation and quench dynamics of the one-dimensional transverse-field Ising model with power-law interactions. We find that long-range interactions give rise to a confining potential, which couples pairs of domain walls (kinks) into bound quasiparticles, analogous to mesonic bound states in high-energy physics. We show that these bound states have dramatic consequences for the non-equilibrium dynamics following a global quantum quench, such as suppressed spreading of quantum information and oscillations of order parameters. The masses of these bound states can be read out from the Fourier spectrum of these oscillating order parameters. We then use a two-kink model to qualitatively explain the phenomenon of long-range-interaction-induced confinement. The masses of the bound states predicted by this model are in good quantitative agreement with exact diagonalization results. Moreover, we illustrate that these bound states lead to weak thermalization of local observables for initial states with energy near the bottom of the many-body energy spectrum. Our work is readily applicable to current trapped-ion experiments.

Siddhardh Morampudi, "Spectroscopy of spinons in quantum spin ice": We calculate the effect of the emergent photon on spectroscopic cross-sections of spinons in quantum spin ice which realizes an emergent phase of QED at low energies. We show that the photon drastically modifies cross-sections of spinons from a naive density of states analysis resulting in effects such as an analogue of the Sommerfeld enhancement. We point out signatures in neutron scattering and Raman spectroscopy and show that this explains some recent numerical and experimental results.

Johannes Motruk, "Evidence for a chiral spin liquid in the triangular lattice Hubbard model", Motivated by experimental studies that have found signatures of a quantum spin liquid phase in organic crystals whose structure is well described by the two-dimensional triangular lattice, we study the Hubbard model on this lattice at half filling using the infinite-system density matrix renormalization group (iDMRG) method. On infinite cylinders with finite circumference, we identify an intermediate phase between observed metallic behavior at low interaction strength and Mott insulating spin-ordered behavior at strong interactions. Chiral ordering from spontaneous breaking of time-reversal symmetry, a fractionally quantized spin Hall response, and characteristic level statistics in the entanglement spectrum in the intermediate phase provide strong evidence for the existence of a chiral spin liquid in the full two-dimensional limit of the model.

Olexei Motrunich, **"Exact Quantum Many-body Scar States in the Rydberg-blockaded Atom Chain"**, A recent experiment in the Rydberg atom chain observed unusual oscillatory quench dynamics with a charge density wave initial state, and theoretical works identified a set of many-body ``scar states'' showing nonthermal behavior in the Hamiltonian as potentially responsible for the atypical dynamics. In the same nonintegrable Hamiltonian, we discover several eigenstates at \emph{infinite temperature} that can be represented exactly as matrix product states with \emph{finite} bond dimension, for both periodic boundary conditions (two exact $E = 0$ states) and open boundary conditions (two $E = 0$ states and one each $E = \pm \sqrt{2}$). This discovery explicitly demonstrates violation of strong eigenstate thermalization hypothesis in this model and uncovers exact quantum many-body scar states. These states show signatures of translational symmetry breaking with period-2 bond-centered pattern, despite being in one dimension at infinite temperature. We show that the nearby many-body scar states can be well approximated as ``quasiparticle excitations'' on top of our exact $E = 0$ scar states, and propose a quasiparticle explanation of the strong oscillations observed in experiments.

David Pekker, "Scaling in the many- body localized phase and its spectral signatures": We compute and compare the decay (localization) lengths in the many-body localized (MBL) phase as extracted numerically from different correlations functions and renormalized coupling constants. We find that all observables of interest in MBL systems exhibit log-normal statistics with mean and variance growing linearly in separation, thereby implying sharply defined (inverse) decay lengths associated with log-averaged quantities, with values differing one observable to another. Importantly, all these lengths remain quite short over a broad range of parameter space, implying stability of the MBL phase identified in previous studies against rare isolated ergodic inclusions. We also show how these broad distributions may be extracted using interferometric probes such as double electron-electron resonance (DEER) and the statistics of local spin precession frequencies.

Syed Raza, "3D topological order from many-body interaction enabled topological semimetals and Dirac nodal superconductors": We build exactly solvable models for many-body interactions in Dirac semimetals and Dirac nodal superconductors. Dirac semimetals are 3D materials that have electrons which behave as if they are massless. We describe a many-body interacting model that makes these electrons massive in a symmetry-preserving way. Such gapping leads to a 3D topological order, exotic point-like and loop-like quasiparticle excitations. This is the first work that points towards the material realization of 3D topological order. Another key finding is the realization of a single pair of Weyl fermions. For a single pair of Weyl nodes with opposite chirality, time-reversal symmetry (TRS) must be broken. Hence, for time-reversal symmetric systems, at least 4 Weyl nodes are required. In this work, we have shown that, as enabled by many-body interactions, an electronic system can support a single pair of massless Weyl fermions without TRS breaking in 3+1D. The techniques and exactly solvable models built in this work can be useful in studying other interacting topological phases. We also use this technique to study 3D topological order in interacting Dirac nodal superconductors. The talk will be based on arXiv:1711.05746 and arXiv:1806.09599.

Maximilian Schulz, "Stark many-body localization": The phenomena of the many-localized phase are in general well understood. In this talk we want to present a model in which many of these phenomena can be reproduced without the need for quenched disorder. We consider spinless fermions on a finite one-dimensional lattice, interacting via nearest-neighbor repulsion and subject to a strong electric field. In the non-interacting case, due to Wannier-Stark localization, the single-particle wave functions are exponentially localized even though the model has no quenched disorder. We show that this system remains localized in the presence of interactions and exhibits physics analogous to models of conventional many-body localization (MBL). In particular, the entanglement entropy grows logarithmically with time after a quench, albeit with a slightly different functional form from the MBL case, and the level statistics of the many-body energy spectrum are Poissonian. We moreover predict that a quench experiment starting from a charge-density wave state would show results similar to those of Schreiber et al. [Science 349, 842 (2015)].

Kazuya Shinjo, "Characteriz ation of photoexcited states in the half-filled one-dimensional extended Hubbard": Nonequilibrium processes in strongly correlated electron systems can provide new insights into the dynamical properties of these systems, which can be qualitatively different from their weakly interacting counterparts. One such example is nonequilibrium induced phase transition. As the system is driven away from the equilibrium, under certain conditions, a "crossover" from one state to another (metastable) state may occur. To characterize the photoexcited states in the half-field one-dimensional extended Hubbard model (1DEHM), we apply supervised machine learning. We use the following procedure. Firstly, using density-matrix renormalization group (DMRG), we calculate the ground state of 1DEHM with correlated hopping terms that are suggested from the Floquet time- independent effective model of driven Hubbard model. We next prepare entanglement spectrum (ES) for possible ground states with spin-density-wave, charge-density-wave, bond-charge-density-wave, and bond-spin-density- wave. Using these ES, we construct neural network with four layers. Finally, we use the neural network to judge the ES of photoexcitaed wave function of 1DEHM. Predicted phases are checked by time-dependent local and non-local order parameters obtained by time-dependent DMRG. Using this procedure, we discuss possible order for the photo-driven 1DEHM.

Kevin Slagle, "Foliated Field Theory and String- Membrane- Net Condensati on of Fracton order": Foliated fracton order is a qualitatively new kind of phase of matter. It is similar to topological order, but with the fundamental difference that a layered structure, referred to as a foliation, plays an essential role and determines the mobility restrictions of the topological excitations. I will introduce a new kind of field theory to describe these phases: a foliated field theory. I will also discuss a new string-membrane-net condensation picture of these phases, which is analogous to the string-net condensation picture of topological order.

Xueda Wen, "Distinguish modular category beyond modular data": It was believed that modular data are enough to distinguish different modular categories. Then counterexamples to this conjecture were found in 2017. In this work, we show how to distinguish these counterexamples by studying the mapping class groups of higher-genus manifolds.

Yunqin Zheng, "Restricted Boltzmann Machines and Matrix Product States of 1D Translational Invariant translational invariant stabilizer codes": We discuss the relations between the restricted Boltzmann machine (RBM) states and the matrix product states (MPS) for the ground states of 1D translational invariant stabilizer codes. A generic translational invariant and finitely connected RBM state can be expressed as an MPS, and the matrices of the resulting MPS are of rank 1. We dub such an MPS as RBM-MPS. This provides a necessary condition for exactly realizing the ground state as an RBM state, if the ground state can be written as an MPS. We mostly focus on generic 1D stabilizer codes having a non-degenerate ground state with periodic boundary condition. We obtain an expression for the lower bound of their MPS bond dimension, and also the upper bound for the rank of their MPS matrices. In terms of RBM, we present an algorithm to derive the RBM for the cocycle Hamiltonians whose MPS matrices are proved to be of rank 1. Moreover, the RBM-MPS produced by our algorithm has the minimal bond dimension. A family of examples is provided to explain the algorithm. We finally conjecture that for all the 1D stabilizer codes having a non-degenerate ground state with periodic boundary condition, whose MPS matrices are of rank 1, the ground state can be exactly written as an RBM state whose RBM-MPS has the minimal bond dimension.