CMTC Spring Symposium 2019

Speaker: Danny Bulmash

Title: Gauging fractons: a new class of non-Abelian fracton models

Abstract:
The study of gapped quantum many-body systems in three spatial dimensions has uncovered the existence of quantum states hosting quasiparticles that are confined, not by energetics but by the structure of local operators, to move along lower dimensional submanifolds. These so-called ``fracton'' phases are beyond the usual topological quantum field theory description, and thus require new theoretical frameworks to describe them. Here we consider coupling fracton models to topological quantum field theories in (3+1) dimensions by starting with two copies of a known fracton model and gauging the $\mathbb{Z}_2$ symmetry that exchanges the two copies. This yields a class of exactly solvable lattice models that we study in detail for the case of the X-cube model and Haah's cubic code. The resulting phases host finite-energy non-Abelian immobile quasiparticles with robust degeneracies that depend on their relative positions. The phases also host non-Abelian string excitations with robust degeneracies that depend on the string geometry. Applying the construction to Haah's cubic code in particular provides an exactly solvable model with finite energy yet immobile non-Abelian quasiparticles that can only be created at the corners of operators with fractal support.

No reference yet, the paper will be submitted in about a week.

Speaker: Will Cole

Title: Simulating capacitively-shunted Josephson junctions

Abstract:
I describe a new method for simulating Josephson junctions with a Coulomb energy, beyond the Cooper pair box model. The junction can be described by an arbitrary Bogoliubov-de Gennes Hamiltonian, and the resulting Josephson potential is matrix-valued in the space of (non-conserved) quasiparticle occupation numbers. I will present the formulation of the method and results of its application to both conventional and topological junctions.

Reference: in preparation

Speaker: Victor Galitski

Title: Quantum Lyapunov Exponents

Abstract:
Classical chaotic systems exhibit exponential divergence of initially infinitesimally close trajectories, which is characterized by the Lyapunov exponent. This sensitivity to initial conditions is popularly known as the "butterfly effect." Of great recent interest has been to understand how/if the butterfly effect and Lyapunov exponents generalize to quantum mechanics, where the notion of a trajectory does not exist. In this talk, I will introduce the measure of quantum chaoticity – a so-called out-of-time-ordered four-point correlator (whose semiclassical limit reproduces classical Lyapunov growth), and use it to describe quantum chaotic dynamics and its eventual disappearance in the standard models of classical and quantum chaos – Bunimovich stadium billiard and standard map or kicked rotor [1]. I will describe our recent results on the quantum Lyapunov exponent in these single-particle models as well as results in interacting many-body systems, such as disordered metals [2]. The latter many-body model exhibits an interaction-induced transition from quantum chaotic to non-chaotic dynamics, which may manifest itself in a sharp change of the distribution of energy levels from Wigner-Dyson to Poisson statistics. I will conclude by formulating a many-body analogue of the Bohigas-Giannoni-Schmit conjecture.

References:
[1] "Lyapunov exponent and out-of-time-ordered correlator's growth rate in a chaotic system," E. Rozenbaum, S. Ganeshan, and V. Galitski, Physical Review Letters **118**, 086801 (2017)
[2] "Non-linear sigma model approach to many-body quantum chaos," Y. Liao and and V. Galitski, Phys. Rev. B **98**, 205124 (2018)

Speaker: Yi-Ting Hsu

Title: Inversion-protected topological crystalline superconductivity in monolayer WTe$_2$

Abstract:
Monolayer $\rm WTe_2$, a centrosymmetric transition metal dichacogenide, has recently been established as a quantum spin Hall insulator and found superconducting upon gating. Here we point out that generally a superconducting inversion-symmetric quantum spin Hall material, such as gated monolayer $\rm WTe_2$, can be an inversion-protected topological crystalline superconductor featuring ``higher-order topology" if the superconductivity is parity-odd. By investigating the pairing symmetry of the superconducting $\rm WTe_2$ at mean-field level in the absence and presence of magnetic field, we find two types of exotic pairing. First is a time-reversal symmetric odd-parity pairing favored by nearest-neighbor attractions. We show that this self-consistently obtained paired state possesses a nontrivial bulk symmetry indicator, and hosts two Majorana Kramers pairs localizing at opposite corners on an open-boundary geometry. Even when on-site attractions dominate and favor the conventional pairing, we find that an intermediate in-plane field exceeding the Pauli limit stabilizes an unconventional equal-spin pairing aligning with the field. Our findings suggest gated monolayer $\rm WTe_2$ is a playground for exotic odd-parity superconductivity, and possibly the first material realization for inversion-protected Majorana corner modes without utilizing proximity effect.

Reference: arxiv:1904.06361

Speaker: Tom Iadecola

Title: Quantum Many-Body Scars and Space-Time Crystalline Order from Magnon Condensation

Abstract:
We study the eigenstate properties of a nonintegrable spin chain that was recently realized experimentally in a Rydberg-atom quantum simulator. In the experiment, long-lived coherent many-body oscillations were observed only when the system was initialized in a particular product state. This pronounced coherence has been attributed to the presence of special "scarred" eigenstates with nearly equally-spaced energies and putative nonergodic properties despite their finite energy density. In this paper we uncover a surprising connection between these scarred eigenstates and low-lying quasiparticle excitations of the spin chain. In particular, we show that these eigenstates can be accurately captured by a set of variational states containing a macroscopic number of magnons with momentum π. This leads to an interpretation of the scarred eigenstates as finite-energy-density condensates of weakly interacting π-magnons. One natural consequence of this interpretation is that the scarred eigenstates possess long-range order in both space and time, providing a rare example of the spontaneous breaking of continuous time-translation symmetry. We verify numerically the presence of this space-time crystalline order and explain how it is consistent with established no-go theorems precluding its existence in ground states and at thermal equilibrium.

Reference: arXiv:1903.10517

Speaker: Anibal Iucci

Title: Quantum phase diagram of Shiba impurities from bosonization

Abstract:
A characteristic feature of Shiba impurities is the existence of a spin- and parity-changing quantum phase transition (known as ``0-π'' transition) which has been observed in scanning tunneling microscopy (STM) and transport experiments. Using the Abelian bosonization technique, here we analyze the ground-state properties and the quantum phase diagram of a classical (i.e., Ising-like) Shiba impurity. In particular, we analyze the cases of an impurity in a three- and a one-dimensional superconductor. Within the bosonization framework, the ground-state properties are determined by simple soliton-like solutions of the classical equations of motion of the bosonic fields, whose topological charge is related to the spin and parity quantum numbers. Our results indicate that the quantum phase diagram of the superconductor can be strongly affected by geometrical and dimensional effects. Exploiting this fact, in the one-dimensional case we propose an experimental superconducting nanodevice in which a novel parity-preserving, spin-changing ``0-0'' transition is predicted.

Speaker: Yunxiang Liao

Title: Two-Fluid Hydrodynamics and Viscosity Suppression in Fluctuating Superconductors

Abstract:
In the normal phase of a superconductor, there exist fluctuating Cooper pairs which are not condensed and possess a finite life time. I will talk about our recent work which investigates the effect of such fluctuating Cooper pairs on the shear viscosity of a superconductor in the vicinity of transition temperature T_c. Due to the presence of Cooper pairs, the electron density of states at the Fermi level decreases, leading to a negative correction to viscosity, the so-called density of state correction. The second contribution originates from scattering of electron off of the fluctuating Cooper pairs and also gives rise to a negative correction to viscosity, i.e., the Maki-Thompson correction. Besides these two indirect effects, there is also the Aslamazov-Larkin correction which results from the fluctuating Cooper pairs' direct contribution to viscosity. It is found to be much less singular in $T-T_c$ compared with the other two corrections. Combining these three, we find a negative fluctuation correction that scales as $\ln(T-T_c)$ in the vicinity of T_c. The suppression of the viscosity due to the superconducting fluctuations suggests that superconductor near transition temperature may be a potential candidate for a low-viscosity system that can host electronic turbulence and magnetic dynamo effect.

Reference: arXiv:1903.08666

Speaker: Jay D. Sau

Title: Theory of coherent phase modes in insulating Josephson junction chains

Abstract:
Recent microwave reflection measurements of Josephson junction chains have suggested the presence of nearly coherent collective charge oscillations deep in the insulating phase. Here we develop a qualitative understanding of such coherent charge modes by studying the local dynamical polarizability of the insulating phase of a finite length sine-Gordon model. By considering parameters near the non-interacting fermion limit where the charge operator dominantly couples to soliton-antisoliton pairs of the sine-Gordon model, we find that the local dynamical polarizability shows an array of sharp peaks in frequency representing coherent phase oscillations on top of an incoherent background. The strength of the coherent peaks relative to the incoherent background increases as a power law in frequency as well as exponentially as the Luttinger parameter approaches a critical value. The dynamical polarizability also clearly shows the insulating gap. We then compare the results in the high frequency limit to a perturbative estimate of phase-slip-induced decay of plasmons in the Josephson junction chain.

Reference: Wu and Sau, Theory of coherent phase modes in insulating Josephson junction chains, arxiv:1811.07941 (2018)

Speaker: Mike Schecter

Title: Configuration-Controlled Many-Body Localization and the Mobility Emulsion

Abstract:
We uncover a new non-ergodic phase, distinct from the full MBL phase, in a disordered two-leg ladder of interacting hardcore bosons. The dynamics of this emergent phase is determined by the many-body configuration of the initial state and features the *coexistence* of localized and extended many-body states at fixed energy density. We show that eigenstates in this phase can be described in terms of interacting emergent Ising spin degrees of freedom suspended in a mixture with inert charge-like degrees of freedom (doublons), and thus dub it a *mobility emulsion* (ME). We argue that grouping eigenstates by their doublon 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 thermalizing or localized behavior depending on the doublon density of the initial product state. These results establish a new paradigm for using many-body configurations as a tool to study and control non-ergodic dynamics which can be realized in existing disordered Bose-Hubbard ladders.

Reference: Michael Schecter, Thomas Iadecola, and Sankar Das Sarma, Phys. Rev. B **98**, 174201 (2019)

Speaker: Brian Swingle

Title: Sparse SYK Model

Abstract:
I will describe nearly finished work on a sparse version of the Sachdev-Ye-Kitaev model, the s-SYK model. Topics include gravitational dynamics at low energy, the classical and quantum simulation of the model, possible glassy physics, and the possibility that the ground state space forms an interesting quantum error correcting code. I will also comment briefly on what I think is a "valid" or "physical" quantum many-body system.

Speaker: Robert Throckmorton

Title: Several topics in qubit error correction

Abstract:
This talk will address several topics in error correction in qubits, with an emphasis on semiconductor-based singlet-triplet double quantum dot qubits. We first consider the problem of crosstalk in two coupled singlet-triplet qubits, considering both the capacitively-coupled and exchange-coupled cases. In addition to magnetic field and electric charge noise adversely affecting spin-qubit operations, performing single-qubit gates on one of multiple coupled singlet-triplet qubits presents a new challenge: crosstalk, which is inevitable (and must be minimized) in any multiqubit quantum computing architecture. For both types of coupling, we develop a set of dynamically corrected pulse sequences that are designed to cancel the effects of both types of noise (i.e., field and charge) as well as crosstalk to leading order, and provide parameters for these corrected sequences for all 24 of the single-qubit Clifford gates. We then provide an estimate of the error as a function of the noise and capacitive coupling to compare the fidelity of our corrected gates to their uncorrected versions. Dynamical error correction protocols presented in this work are important for the next generation of singlet-triplet qubit devices where coupling among many qubits will become relevant.

The case of exchange coupling in particular presents a new challenge not present in the capacitively-coupled case. While exchange coupling allows the coupling strength to be controlled independently of the intraqubit exchange couplings, there is also the problem of leakage, which must be addressed. We show that, if a large magnetic field difference is present between the two qubits, leakage is suppressed. We then, as in the capacitively-coupled case, develop pulse sequences that correct for crosstalk- and noise-induced errors, present parameters describing them for the 24 Clifford gates, and determine the infidelity for both the uncorrected and corrected gates as a function of the error-inducing terms and show that our corrected pulse sequences reduce the error by several orders of magnitude.

Finally, we consider a different topic - the case of a generic qubit that is driven along its logical z axis, with noise along the *z* axis in the driving field proportional to some function *f*(Omega), as well as noise along the logical *x* axis. We establish that whether or not errors due to both types of noise can be canceled out, even approximately, depends on the explicit functional form of *f*(Omega) by considering a power-law form, *f*(Omega) propto Omega^*k*. In particular, we show that such cancellation is impossible for *k* = 0, 1, or any even integer. However, any other odd integer value of *k* besides 1 does permit cancellation; in fact, we show that both types of errors can be corrected with a sequence of four square pulses of equal duration. We provide sets of parameters that correct for errors for various rotations and evaluate the error, measured by the infidelity, for the corrected rotations versus the naïve rotations, i.e., the operations that, in the complete absence of noise, would produce the desired rotations (in this case a single pulse of appropriate duration and magnitude). We also consider a train of four trapezoidal pulses, which take into account the fact that there will be, in real experimental systems, a finite rise time, again providing parameters for error-corrected rotations that employ such pulse sequences. Our dynamical decoupling error correction scheme works for any qubit platform as long as the errors are quasistatic.
References:
D. Buterakos, R. E. Throckmorton, and S. Das Sarma, Phys. Rev. B **97**, 045431 (2018).
D. Buterakos, R. E. Throckmorton, and S. Das Sarma, Phys. Rev. B **98**, 035406 (2018).
R. E. Throckmorton, and S. Das Sarma, Phys. Rev. B **99**, 045422 (2019).

Speaker: Fengcheng Wu

Title: Phonon-induced giant linear-in-T resistivity and exotic superconductivity in twisted bilayer graphene

Abstract:
I will present our work on phonon-induced giant linear-in-temperature resistivity and exotic superconductivity in twisted bilayer graphene [1]. We theoretically show that twisted bilayer graphene should have an enhanced and strongly twist-angle dependent linear-in-temperature resistivity in the metallic regime with the resistivity magnitude increasing as the twist angle approaches the magic angle. The slope of the resistivity versus temperature could approach one hundred ohms per kelvin with a strong angle dependence, but with a rather weak dependence on the carrier density. This angle-tuned resistivity enhancement arises from the huge increase in the effective electron-acoustic phonon coupling in the system due to the suppression of graphene Fermi velocity induced by the flatband condition in moire superlattices. We also show that the same enhanced electron-acoustic phonon coupling mediates effective attractive interactions in s, p, d and f pairing channels with a theoretical superconducting transition temperature on the order of 5 K near magic angle. The fact that ordinary acoustic phonons can produce exotic non-s-wave superconducting pairing arises from the unusual symmetries of the system. We propose that the pairing symmetry of superconducting states in twisted bilayer graphene can be experimentally identified using externally applied in-plane magnetic field and strain [2].

References:
1. F. Wu, E. Hwang, and S. Das Sarma, PRB **99**, 165112 (2019).
2. F. Wu and S. Das Sarma, arXiv:1904.07875.

Speaker: Shenglong Xu

Title: Quantum information dynamics in many-body systems

Abstract:
In this talk, I will discuss new perspectives on many-body dynamics based on quantum information. Under unitary time evolution, information about a single spin gradually spreads out in space, and an effective light cone naturally emerges as an intrinsic property of the time evolution operator. Based on this picture, I will present a low-cost tensor network method that can accurately capture the shape of the causal light cone for generic 1D systems of hundreds of spins, a regime that was previously beyond reach. Using the method, we identify a new dynamical phase, characterized by a power-law-like causal light cone. Signatures of this new phase have already been observed in recent ultracold atom experiments on interacting quasi-periodic systems.

Ref:
[1] S. Xu, B. Swingle arxiv:1802.00801
[2] S. Xu, B. Swingle arxiv:1805.05376
[3] S. Xu, X. Li, Y.-T. Hsu, B. Swingle, S.Das Sarma arxiv:1902.07199

Speaker: Ruixing Zhang

Title: Higher order topology in iron-based superconductors

Abstract:
Motivated by recent experiments on $FeTe_{1-x}Se_x$, we construct an explicit minimal model of an iron-based superconductor with band inversion at the Z point and non-topological bulk s± pairing. While there has been considerable interest in Majorana zero modes localized at vortices in such systems, we find that our model - without any vortices - intrinsically supports 1D helical Majorana modes localized at the hinges between (001) and (100) or (010) surfaces, suggesting that this is a viable platform for observing "higher-order" topological superconductivity. I will describe a general theory for these hinge modes and discuss their stability and experimental manifestation.
In the second part of the talk, I will focus on the monolayer $FeTe_{1-x}Se_x$ system which was recently identified as a superconducting quantum spin Hall system. In particular, I will describe how Majorana zero modes naturally emerge on the physical corners when an additional FeTe layer is deposited on top of $FeTe_{1-x}Se_x$ monolayer. The bicollinear antiferromagnetic order of FeTe is the key to enable higher order topology in this heterostructure and thus bind the corners with localized Majorana zero modes, which does not rely on the choice of pairing symmetry. We construct a minimal lattice model to explain the origin of higher order topology in this heterostructure and study the stability of Majorana corner modes with respect to finite chemical potential and disorder effects. In the large chemical potential limit, the FeTe layer also enables a novel topological nodal superconducting phase with edge Majorana flat bands.

Reference: [1] arXiv:1812.10493 (2018) (To appear in Phys. Rev. Lett)