January 8, 2016
Anna Komar, Graduate Student, Preskill Group
Title: An Energy Barrier is Necessary for the Thermal Stability of Stabilizer Quantum Memories

Abstract: We prove a lower bound to the spectral gap of the Davies generator for general N - qubit commuting Pauli Hamiltonians and for quantum doubles based on an Abelian group. We derive rigorous thermalization time bounds, also called mixing time bounds, for the Davies generators of these Hamiltonians. Davies generators are given in the form of a Lindblad equation and are known to converge to the Gibbs distribution of the particular Hamiltonian for which they are derived. The bound on the spectral gap essentially depends on a single number E referred to as the generalized energy barrier. When any local defect can be grown into a logical operator and in turn any product operator can be decomposed into a product of the clusters of such incomplete logical operators, then E corresponds to the largest energy barrier of the canonical logical operators. The main conclusion that can be drawn from our result is, that the presence of an energy barrier for the logical operators is in fact, although not sufficient, a necessary condition for a thermally stable quantum memory when we assume the full Davies dynamics as noise model. This rules out the possibility of entropic protection for this broad group of models.

This is a joint work with two past IQIM postdoctoral scholars, Olivier Landon-Cardinal (*McGill U.*) and Kristan Temme (*IBM*).

January 22, 2016
Boris Braverman, Graduate Student, Vladan Vuletić Group, MIT
Title: Progress toward a spin squeezed 171Yb optical atomic clock

Abstract: State of the art optical lattice atomic clocks have reached a relative inaccuracy level of order 10^-18, making them the most stable time references in existence. One of the limitations to the precision of these clocks is the quantum projection noise caused by the measurement of the atomic state. This limit, known as the standard quantum limit (SQL), can be overcome by entangling the atoms. By performing spin squeezing, it is possible to robustly generate such entanglement and therefore surpass the SQL of precision in optical atomic clocks. I will report on recent experimental progress toward realizing spin squeezing in an 171Yb optical lattice clock. A high-finesse micromirror-based optical cavity operating in the strong coupling regime of cavity quantum electrodynamics mediates the atom-atom interaction necessary for generating the entanglement. By exceeding the SQL in this state of the art system, we are aiming to advance precision time metrology and expand the boundaries of quantum control and measurement.

February 5, 2016
Charles Edouard Bardyn, Postdoctoral Scholar, Condensed Matter Theory
Title: Exponential Lifetime Improvement in Topological Quantum Memories
Abstract: We propose a simple yet efficient mechanism for passive error correction in topological quantum memories. Our scheme relies on driven-dissipative ancilla systems which couple to local excitations (anyons) and make them "sink" in energy, with no required interaction among ancillae or anyons. Through this process, anyons created by some thermal environment end up trapped in potential "trenches" that they themselves generate, which can be interpreted as a "memory foam" for anyons. This self-trapping mechanism provides an energy barrier for anyon propagation, and removes entropy from the memory by favoring anyon recombination over anyon separation (responsible for memory errors). We demonstrate that our scheme leads to an exponential increase of the memory-coherence

time with system size L, up to an upper bound Lmax which can increase exponentially with Δ/T, where T is the temperature and Δ is some energy scale defined by potential trenches. This results in a double exponential increase of the memory time with Δ/T, which greatly improves over the Arrhenius (single-exponential) scaling found in typical quantum memories.

February 17, 2016
Barak Dayan, Senior Scientist, Quantum Optics Group, Weizmann Institute of Science
Title: Demonstration of Deterministic Photon-Atom and Photon-Photon Interactions based on Single-Photon Raman Interaction (SPRINT)

Abstract: I will present our demonstration of a control-fields-free, deterministic interface between a single photon and a single atom [1, 2]. Relying on Single Photon Raman Interaction (SPRINT) [2-4], this completely-passive scheme swaps a flying qubit (encoded in the two possible input modes of a photon), with a stationary qubit (encoded in the two ground states of the atom), and can be also harnessed to perform universal quantum gates.

Using SPRINT we experimentally demonstrated all-optical switching of single photons by single photons [1], and deterministic extraction of a single photon from an optical pulse [2]. Applicable to any atom-like Lambda system, SPRINT provides a versatile building block for scalable quantum networks based on completely passive nodes interconnected and activated solely by single photons.

[1] I. Shomroni, S. Rosenblum, Y. Lovsky, O. Bechler, G. Guendelman & B. Dayan, *Science* **345,** 903 (2014)

[2] S. Rosenblum, O. Bechler, Y. Lovski, I. Shomroni, G. Guendelman, & B. Dayan, *Nature Photonics* **10,** 19 (2016)

[3] S. Rosenblum, A.S. Parkins & B. Dayan, Phys. Rev. A 84, 033854 (2011)

[4] S. Rosenblum, A. Borne & B. Dayan, arXiv: quant-ph 1412.0604 (2014)

February 19, 2016
Hannah Price, Marie Skłodowska-Curie fellow, INO-CNR BEC Center, Università di Trento in Italy
Title: Four-Dimensional Quantum Hall Effect with Ultracold Atoms

Abstract: We propose a realistic scheme to detect the 4D quantum Hall effect using ultracold atoms. Based on contemporary technology, motion along a synthetic fourth dimension can be accomplished through controlled transitions between internal states of atoms arranged in a 3D optical lattice. From a semiclassical analysis, we identify the linear and nonlinear quantized current responses of our 4D model, relating these to the topology of the Bloch bands. We then propose experimental protocols, based on current or center-of-mass-drift measurements, to extract the topological second Chern number. Finally, we also introduce how to include synthetic dimensions in integrated photonics, where such ideas can be used to create higher-dimensional photonic lattices.

February 26, 2016
Charles Cao, Graduate Student, Physics, Caltech
Title: Casimir Effect, Theta Vacuum and Topological Order in QED

Abstract: We analyze the case where one imposes non-trivial spatial topology for a simple abelian gauge theory. As usual, the large gauge transformations present in the system allow one to discuss theta vacuum and magneto-electric effect via the theta term. However, even for zero theta parameter, the tunneling transitions between different topologically inequivalent pre-vacua give rise to an additional contribution to vacuum energy that can be measured in the context of Casimir effect. Furthermore, photon production and non-trivial electric and magnetic responses can be induced by applying a global external field which behaves similar to an effective theta parameter. The theory in the far IR can be described by a TQFT and a phase transition occurs at effective theta = pi where the quantum vacuum has degeneracy two. Possible experimental implementations will also be discussed.

April 1, 2016
Andy Lucas, Graduate Student, Subir Sachdev's group, Harvard University
Title: Revealing the Dirac fluid in graphene

Abstract: Although the electrons in metals are interacting, it has been notoriously hard to discover evidence for hydrodynamics in electron fluids. In the first half of the talk, I will review what hydrodynamics is, why it is interesting and why it is so hard to see in metals. In the second half, I will discuss the theoretical and experimental developments which enabled us to observe signatures of 'relativistic' hydrodynamics in a strongly-interacting Dirac fluid in charge neutral graphene.

April 15, 2016
Alberto de la Torre Duran, Postdoctoral Scholar, Hsieh Group
Title: Spectroscopic studies of layered iridium oxides

Abstract: The spin-orbit driven Mott insulator groundstate of some layered Iridates has been proposed as analogous to that of the cuprates and as such, a potential platform for engineering high-temperature superconductivity with carrier doping. In this talk I will discuss what we learned, and what remains to be answered, from our spectroscopic studies (ARPES, STM, RIXS) on the interplay between spin-orbit and electron-electron correlations in La (electron) doped single crystals of Sr_2IrO_4 and $Sr_3Ir_2O_7$.

April 22, 2016
Alejandro González-Tudela, Postdoctoral Scholar, Max Planck Institute for Quantum Optics
Title: Atom waveguide QED for efficient multiphoton sources

Abstract: Engineering quantum states of light and matter provides a critical capability across quantum information science, including quantum metrology or teleportation. Among the different possibilities, the on-demand generation of propagating quantum states of light is of paramount importance as it plays a central role in long-distance quantum communication. However the travelling and non-interacting character of the photons makes difficult their engineering. In this talk, we show how to tailor arbitrary states for propagating photons on demand by using atom-like ensembles coupled to waveguide QED setups. The interaction of optical emitters coupled to one-dimensional (1D) waveguides give rise to strong and long-range interactions that are difficult to obtain with other platforms. We show how to take advantage of these properties to design a deterministic way for engineering photonic states

[1]. Moreover, we also show how to engineer the setup for the heralded preparation of these states with even better fidelity and high probability [2].

[1] A. Gonzalez-Tudela, V. Paulisch, D. E. Chang, H. J. Kimble, J. I. Cirac. Phys. Rev. Lett. 115, 163603 (2015), V. Paulisch, H. J. Kimble A. Gonzalez-Tudela, arXiv:1512.04803

[2] A. Gonzalez-Tudela, V. Paulisch, H. J. Kimble, J. I. Cirac. arXiv:1603.01243

April 29, 2016
Stefanos Kourtis, Postdoctoral Research Fellow, Princeton
Title: Spectroscopic signatures of Weyl semimetals beyond photoemission

Abstract: Weyl semimetals are a newly discovered class of three-dimensional topological materials, whose distinctive spectral properties have been recently visualized using angle-resolved photoemission. In this talk I will present how the defining topological features of Weyl semimetals — open Fermi surfaces at the boundary (Fermi arcs) and linear band touchings in the bulk (Weyl nodes) — are captured by two alternative spectroscopic probes of matter that measure exclusively either the surface or the bulk, namely, scanning tunneling spectroscopy (STS) and resonant inelastic x-ray scattering (RIXS). The quasiparticle interference (QPI) pattern obtained in STS of Weyl semimetals contains characteristic shapes that can be unequivocally associated with the presence of Fermi arcs at the surface. I will discuss the universal QPI signatures of Fermi arcs and their experimental observation. RIXS is a powerful core-level spectroscopy that can resolve charge, spin and orbital degrees of freedom in the bulk. I will demonstrate how the unique sensitivity of this method can be employed to measure the absolute topological charge of a Weyl node.

May 20, 2016
Michael Kolodrubetz, Postdoctoral Scholar, University of California, Berkeley
Title: Unexpected effects in periodic driving of gapless topological systems

Abstract: Floquet engineering is the emerging field of using periodic drive to realize novel Hamiltonians that are difficult or impossible to realize in static systems. In this talk I will highlight two examples where such a drive yields unexpected effects. First, I will discuss Floquet engineering of Weyl semimetals, which has been proposed for ultracold atoms in optical lattices. Unlike their condensed matter counterparts, these systems naturally have large magnetic fields whose two-dimensional physics is described by the Hofstadter butterfly. I will show how one realizes it natural extension, the "Weyl butterfly," in a three-dimensional Weyl semimetal and discuss how the chiral anomaly generalizes beyond the weak-field limit. In particular, I will describe how the chiral anomaly inherits the fractal structure of the Weyl butterfly, exhibiting a fractal set of quantized anomalies that originate from the gaps of the butterfly. Second, I will switch gears to a condensed matter realization of Floquet engineering, namely periodic driving of surface states in topological insulators. While in the absence of driving surface states are well-defined gapped excitations, I will show that driving the surface of such system naturally leads to resonant surface-bulk coupling. Furthermore, this coupling leads to coherent bulk-surface oscillations in the Wigner distribution -- a non-equilibrium observable measurable via ARPES -- and may be responsible for the non-adiabatic signal seen in recent experiments.

May 27, 2016
Sarang Gopalakrishnan, Sherman Fairchild Postdoctoral Scholar in Theoretical Physics
Title: Many-body localization: a dynamical perspective

Abstract: Many-body localized (MBL) states are dynamical phases of isolated, interacting quantum systems in which they do not approach equilibrium from generic initial conditions. MBL states thus defy various expectations from conventional statistical mechanics -- for example, their response to slowly varying perturbations violates linear-response theory. I will present recent results on the response of many-body localized (MBL) systems to time-dependent external perturbations. First, I will discuss the low-frequency behavior of the linear-response optical conductivity and related dynamical response functions. Second, I will explore the regime of validity of linear-response theory, arguing that the conductivity has no well-defined d.c. limit, and discussing the crossovers between the linear-response regime and the nonlinear regime in which saturation effects are dominant. If time permits, I will also discuss the dynamics of localized systems subject to external classical noise.

June 3, 2016
Sujeet Shukla, Graduate Student, Preskill Group
Title: Boson condensation and instability in the tensor network representation of topological states

Abstract: The tensor network representation of many-body quantum states, given by local tensors provides a promising numerical tool for the study of strongly correlated topological phases in two dimension. However, the topological order in tensor network representations of the Toric code ground state has been shown to be unstable under certain small variations of the local tensor, if these small variations does not obey the local Z2 symmetry of the local tensor. In this work we ask the questions of whether other types of topological orders suffer from similar kinds of instability and if so, whether we can protect the order by enforcing certain symmetry on the tensor. We answer these questions by showing that the tensor network representation of all string-net models are indeed unstable, but the matrix product operator (MPO) symmetry identified by Burak *et al.* can help to protect the order. We find that, `stand-alone' variations that break MPO symmetry lead to instability because they induce the condensation of bosonic quasi-particles and destroy the topological order in the system. Therefore, such variations must be forbidden for the encoded topological order to be reliably extracted from the local tensor. On the other hand, if a tensor network algorithm is used to simulate the phase transition due to boson condensation, then such variation directions must be allowed in order to access the continuous phase transition process correctly.

June 17, 2016
Paraj Titum Bhattacharjee, Graduate Student, Refael Group
Title: Anomalous Floquet-Anderson Insulator as a Nonadiabatic Quantized Charge Pump

Abstract: We show that two-dimensional periodically driven quantum systems with spatial disorder admit a unique topological phase, which we call the anomalous Floquet-Anderson insulator (AFAI). The AFAI is characterized by a quasienergy spectrum featuring chiral edge modes coexisting with a fully localized bulk. Such a spectrum is impossible for a time-independent, local Hamiltonian. These unique characteristics of the AFAI give rise to a new topologically protected nonequilibrium transport phenomenon: quantized, yet nonadiabatic, charge pumping. We distinguish the AFAI from a trivial, fully localized phase, and show that the two phases are separated by a phase transition.

September 29, 2016
Jacob Covey, Graduate Student, Jun Ye's Group, JILA/ University of Colorado, Boulder
Title: A quantum gas of polar KRb molecules in an optical lattice

Abstract: Ultracold polar molecules allow for investigation of quantum-state-controlled chemistry as well as strongly correlated many-body dynamics. After the first realization of polar molecules in the quantum regime, chemical reactions immediately became apparent in our KRb system. Upon obtaining a detailed understanding of the chemical reaction processes near absolute zero, we loaded our molecules in optical lattices that suppressed molecular reaction loss. In doing so, we were able to observe many-body spin dynamics between molecules pinned in a deep lattice, even though the filling fraction of the molecules was only ~5%. We have recently performed a thorough investigation of the molecule creation process in an optical lattice, and consequently improved our filling fraction to ~30% by preparing and overlapping Mott and band insulators of the initial atomic gases. This improvement realizes a fully connected quantum gas of polar molecules for the investigation of non-equilibrium, many-body spin dynamics. More recently, we switched to a second generation KRb apparatus that will allow application of large, stable electric fields as well as high-resolution addressing and detection of polar molecules in optical lattices. I will present our work on molecule creation in a three-dimensional optical lattice and the corresponding increase in the molecular filling fraction, as well as the status and direction of the second generation apparatus.

October 7, 2016
Liyuan Zhao, Richard Chase Tolman Postdoctoral Scholar in Experimental Physics, Hsieh Group
Title: An Odd-Parity Hidden Order in a Perovskite Iridate Revealed Using Nonlinear Optics

Abstract: Iridium oxides are electronic systems that combine two central threads of modern quantum materials research - correlated electron physics that underlies phenomena such as high-Tc superconductors, and spin-orbit physics that describes systems such as topological insulators. The perovskite iridate Sr2IrO4 is of particular interest owing to its remarkable analogy to high-Tc cuprates, including its striking structural and electronic similarities to the cuprate parent compound La2CuO4 and recent observations of pseudogap and d-wave gap behaviors upon doping. In this talk, I will describe the nonlinear optical spectroscopy and microscopy techniques that we developed recently to identify unconventional multipolar ordered phases. I will show the experimental evidences for an odd-parity non-dipolar ordered phase in both undoped and hole-doped Sr2IrO4, and discuss the potential relevance of this novel phase to pseudogap and superconductivity in both Sr2IrO4 and high-Tc cuprate YBa2Cu3Oy.

October 21, 2016
Alon Ron, Richard Chase Tolman Postdoctoral Scholar, Hsieh Group
Title: 2D to 1D Oxide interfaces: superconductivity, magnetism and ballistic transport effects

Abstract: Recent developments in thin-film-fabrication techniques have enabled the deposition of newly designed and well controlled oxide interfaces. These interfaces can have properties which are significantly different from their constituent materials. An electronic reconstruction occurring at the interfaces may be at the origin of these phenomena. Correlated electrons in oxide interfaces result in a variety of properties, such as metal-insulator transition, superconductivity and magnetism. In my talk I will present quantum oscillations data and their correlation to the superconducting dome in the SrTiO3/LaAlO3 system, then I will describe our new methods of fabricating ballistic quantum wires from

oxide interfaces. The quantum wires exhibit quantized conductance with long ballistic path and lifted spin degeneracy.

November 4, 2016
John Bartholomew, Postdoctoral Scholar, Faraon Group
Title: Rare-earth ions in crystals for integrating quantum resources

Abstract: Quantum technology that surpasses any possible classical counterpart will likely require a scalable platform that enables the large scale integration of entangled qubits. Crystals containing rare-earth ions are one system that possesses many appealing attributes to facilitate such large scale quantum integration. These attributes include optically accessible spins with long coherence times (up to 6 hours [1]), demonstrated performance as photonic quantum memories [2,3], and their potential for single-spin qubits [4] and on-chip photonic platforms [5].

In this seminar I will introduce the solid-state rare-earth ion system and highlight its appeal for creating a versatile platform for integrating quantum resources. I will then focus on some of the work being undertaken in the Faraon group to engineer the properties of rare-earth ions in crystals using nanophotonic resonators. These photonic crystal cavities provide significant miniaturization and enhancement of the rare-earth system, providing a route toward integrated on-chip quantum devices.

[1] Zhong et al., Nature, 517(7533), 2015.

[2] Hedges et al., Nature, 465(7301), 2010.

[3] Jobez et al., Phys. Rev. Lett., 114(23), 230502, 2015.

[4] Siyushev et al., Nat. Commun., 5, 3895, 2014.

[5] Zhong et al., Nat. Commun., 6, 8206, 2015.

November 11, 2016
Shenghan Jiang, Graduate Student, Boston College
Title: Classification and simulation of quantum phases by symmetric tensor networks

Abstract: In this talk, we introduce a general method to construct fully symmetric quantum wavefunctions using projected entangled pair states (PEPS). We find that quantum phases can be organized into crude classes distinguished by local tensor properties, which is related to the symmetry enriched topological phases (SET) and/or symmetry protected topological phases (SPT) of both on-site and lattice symmetries. The tensor network constructions also indicate a general connection between SET and SPT via anyon condensation. Based on the analytical work, we develop an efficient simulation algorithm, which is able to sharply determine crude classes in interacting quantum systems. We show the power of this method in half-integer quantum spin systems on the kagome lattice, where we identify the ground state likely to be a U(1) spin liquid.

November 18, 2016
Hannes Pichler, AMP, Harvard-Smithsonian, Center for Astrophysics
Title: Measurement protocols for entanglement entropies and entanglement spectra of cold atoms

Abstract: Entanglement is fundamental to our understanding of many-body quantum systems, and it is a key concept underlying a plethora of phenomena such as topological properties. A powerful theoretical tool to characterize entanglement in a quantum many-body system is the so-called entanglement spectrum, which characterizes the statistical properties of a (reduced) quantum state. We build on versatile tools to control and manipulate cold atoms available in current experiments, and we develop protocols to measure entanglement entropies and the largest eigenvalues of the entanglement spectrum.

November 21, 2016
Guanyu Zhu, Joint Quantum Institute (NIST-University of Maryland)
Title: Entanglement Spectroscopy of Quantum Many-body Systems

Abstract: Entanglement spectrum, the full spectrum of the reduced density matrix of a subsystem, plays a major role in characterizing many-body quantum systems. In recent years, it has been widely studied in the fields of condensed matter physics, quantum information, and high energy physics. As first pointed out by Haldane and Li in the context of fractional quantum Hall effect, the entanglement spectrum can serve as fingerprint of topological order (TO). The correspondence between ES and TO has been further explored since then and the importance of ES has been extended to the context of quantum criticality, symmetry-breaking phases, tensor networks, eigenstate thermalization, and many-body localization.

While there has been a surge of theoretical works on the subject, no experimental measurement has been performed to this date, since the highly non-local ES is impossible to be extracted from local measurements. In this talk, I present a measurement protocol to access the entanglement spectrum of many-body states in experiments with cold atoms or cavity quantum electrodynamics, where non-local coupling between the many-body system and an ancilla qubit is possible. Our scheme effectively performs a Ramsey spectroscopy of the entanglement Hamiltonian, and is based on the ability to produce several copies of the state under investigation together with the possibility to perform a global swap gate between two copies conditioned on the state of the ancilla. We show that this protocol can be implemented with state-of-the-art techniques in cold atom and circuit-QED experiments. We illustrate these ideas on a simple (extended) Bose-Hubbard model where such a measurement protocol reveals topological features of the Haldane phase, and the bulk-edge correspondence between the entanglement and physical spectra. In addition, I also show how a modified scheme can also be used to measure the out-of-time-order correlator in many-body system, which features the scrambling of quantum information.

References:

[1] arXiv:1605.08624

[2] arXiv:1607.00079

December 2, 2016
Aram Harrow, Assistant Professor of Physics, MIT
Title: Local Hamiltonians Whose Ground States are Hard to Approximate

Abstract: Ground states of local Hamiltonians can be generally highly entangled: any quantum circuit that generates them (even approximately) must be sufficiently deep to allow coupling (entanglement) between any pair of qubits. Until now this property was not known to be "robust" - the marginals of such states to a subset of the qubits containing all but a small constant fraction of them may be only locally entangled, and hence approximable by shallow quantum circuits. In this work we construct a family of 16-local Hamiltonians for which any 1-10^{-9} fraction of qubits of any ground state must be highly entangled.

This provides evidence that quantum entanglement is not very fragile, and perhaps our intuition about its instability is an artifact of considering local Hamiltonians which are not only local but spatially local. Formally, this result is weaker than both the qLDPC conjecture, positing the existence of "good" quantum LDPC codes, and the NLTS conjecture due to Freedman and Hastings positing the existence of local Hamiltonians in which any low-energy state is highly entangled.

Our Hamiltonian is based on applying the hypergraph product by Tillich and Zemor to a classical locally testable code. A key tool in our proof is a new lower bound on the vertex expansion of the output of low-depth quantum circuits, which may be of independent interest.

Based on 1510.02082 which is joint work with Lior Eldar.