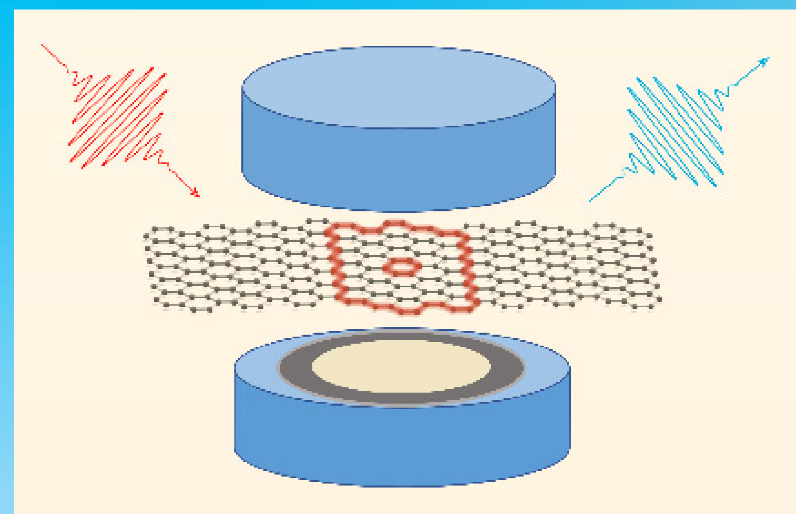
Center for Astrophysics| Harvard & Smithsonian
ITAMP
60 Garden Street
Cambridge, MA 02138 USA

Topological phases and strong correlations in many-body systems and light-matter

November 6 - 8, 2023

Organizers

Ceren Dag *(Harvard)*, **Eugene Demler** *(ETH Zurich)*
Nuh Gedik *(MIT),* **Vasilis Rokaj** *(Harvard)*



Credit: Vasilis Rokaj and Ceren Dag

Phillips Auditorium
Center for Astrophysics|Harvard & Smithsonian
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ITAMP is funded by the National Science Foundation

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Notes

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Please be patient as the reimbursement setup and payment process may take some time. Thank you

ITAMP began life in 1989 at the Harvard-Smithsonian Center for Astrophysics. It is the only theoretical AMO "user facility" in the United States. It hosts workshops (3-days), and visiting fellows (short- and long-term), sponsors a flagship speaker series, the Joint Quantum Science seminars, with HQI in the Physics Department, and a rigorous postdoctoral program. ITAMP workshops are recorded and avaliable on the ITAMP YouTube channel. There are on average 4-5 workshops each year. A Call for Proposal to organize workshops and a list of workshops are available at http://itamp.harvard.edu. The postdoctoral program has been a recognized success, placing energetic fellows into junior positions at universities and national labs.

ITAMP thrives in the larger Cambridge-area AMO physics ecosystem, drawing upon the considerable depth and breadth of experimental expertise. The mission of ITAMP continues to be in furthering the cause of theoretical AMO physics by providing resources, centrality of location, and scientific and administrative expertise, to enhance collaborative efforts between theory and experiment, and to be broad in advocating for theoretical AMO.

H. Sadeghpour

Synopsis

The aim of this workshop is to bring together scientists from the vibrant fields of topological and strongly correlated condensed matter, quantum simulation, Floquet engineering and cavity QED materials, in order create an interacting engagement between the different communities. This will allow the mutual exchange of knowledge, expertise and tools between the different communities, will push these fields in to new exciting directions and draw the future lines of research to be explored on how the nature of quantum matter can be probed, controlled and engineered.

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Ceren Dag *(Harvard)*
Eugene Demler *(ETH Zurich)*
Nuh Gedik *(MIT)*
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ITAMP Guide

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Buses servicing Harvard Square & CfA area are Buses # 72, 74, 75 and 78
Bus to Harvard Square to MIT is Bus #1
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Harvard Square to Boston: Red Line Train to Park Street Station
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Near the Observatory	Sarah’s Market, 200 Concord Ave. The Village Kitchen, 359 Huron Ave. House of Chang, 282 Concord Ave. Trattoria Pulcinella, 147 Huron Ave. Armanado’s Pizza, 163 Huron Ave. Hi-Rise Bread CO, 208 Concord Ave. Formaggio Kitchen, 244 Huron Ave
Massachusetts Ave.	Chang-Sho, 1712 Mass. Ave. Simons Coffee House, 1736 Mass. Ave. Nirvana The Taste of India 1680 Mass Ave Stone Hearth Pizza Co., 1782 Mass.Ave. Super Fusion, 1759 Mass. Ave. Cambridge Common, 1667 Mass Ave. Lizard Lounge, 1667 Mass. Ave.

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Who to Contact:
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Shuyun Zhou

Tsinghua University

"Manipulation of two-dimensional materials by time-periodic light field"

Time-periodic light-field can dress the electronic states of quantum materials, providing a fascinating controlling knob for transient modifications of the electronic structure with light-induced emergent phenomena [1]. In this talk, I will present our recent experimental progress on the Floquet engineering of a model semiconductor – black phosphorus. Time- and angle-resolved photoemission spectroscopy (TrARPES) measurements with mid-infrared pumping reveal the light-induced manipulation of the transient electronic structure with pseudospin selectivity, both near-resonance pumping [2] and far below-gap pumping [3]. In both cases, a strong modification of the transient electronic structure is clearly identified near the top of the valence band, yet with distinctive behaviors. The implications of these results and insights for extending Floquet engineering to more materials will also be discussed.

References:

[1] Changhua Bao et al., "Light-induced emergent phenomena in two-dimensional materials and topological materials", Nat. Rev. Phys. 4, 33 (2022)
[2] Shaohua Zhou + , Changhua Bao + et al., "Pseudospin-selective Floquet band engineering in black phosphorus", Nature 614, 75 (2023)
[3] Shaohua Zhou + , Changhua Bao + , et al., "Floquet engineering of black phosphorus by below-gap pumping", Phys. Rev. Lett. 131, 116401 (2023)

Joel Yuen-Zhou

University of California San Diego

"Molecular polaritons as quantum impurity models"

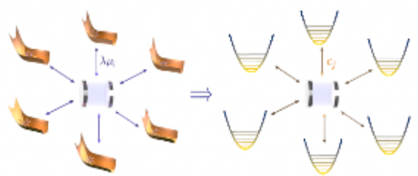

Fig. 1. Molecular polaritons as quantum impurity models.

In the collective coupling regime, molecular polaritons may be regarded as quantum impurity models, where the impurity is a photon and the complex anharmonic molecular degrees of freedom serve as a bath. If this bath is large enough, as in the case of most molecular polariton experiments, the quantum dynamics of such a system becomes very simple to compute [1], as demonstrated in our recent method, Collective Dynamics using Truncated Equations (CUT-E) [2]. The conceptual implications of this method are also discussed in light of recent experiments in polariton chemistry . If time permits, our work on topological phases with molecular systems will be reviewed.

References

1. J. Yuen-Zhou and A. Koner, Linear response of molecular polaritons, in preparation.
2. J. B. Pérez-Sánchez, A. Koner, N. P Stern, and J. Yuen-Zhou, Simulating molecular polaritons in the collective regime using few-molecule models, Proc. Nat. Acad. Sci. 120(15) e2219223120 (2023).
3. S. Pannir-Sivajothi , N. P. Stern and Joel Yuen-Zhou, Molecular and solid-state topological polaritons induced by population imbalance, Nanophotonics 12(15) (2023).
4. K. Schwennicke and J. Yuen-Zhou, Enantioselective topological frequency conversion, J. Phys. Chem. Lett. 13, 10, 2434 (2022).
5. J. Yuen-Zhou, S. K. Saikin, T. Zhu, M. Onbalsi, C. Ross, V. Bulovic, and M. Baldo, Plexcitons: Dirac points and topological modes, Nat. Commun. 7, 11783 (2016).
6. J. Yuen-Zhou, S. Saikin, N. Yao, and A. Aspuru-Guzik, Topologically protected excitons in porphyrin thin films, Nature Mater. 13, 1026 (2014). (†)

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Jie Wang

Harvard University

"Exact fractional Chern insulators in flatbands with ideal quantum geometry."

Moire material has been of intense interest for the range of correlated electron phenomena they exhibit and for their high degree of tenability. Recently, fractional Chern insulators (FCI) have been observed in various moire materials, including twisted TMD and graphene systems, opening promising future route towards experimental realization of non-abelian anyon and universal quantum computation. This talk presents an exact geometric criteria for the stability of FCI in general flatbands and discuss its implications. The common wisdom to find FCI is to engineer material to approach the limit with uniform Berry curvature. This talk will disprove such common lore by showing a new theory (ideal flatband) which emphasizes the fundamental importance of quantum metric. We prove ideal flatbands support exact zero energy ground state FCI for arbitrary amount of Berry curvature fluctuation for all nontrivial Chern number, and prove ideal quantum geometry alone can imply universal wavefunction and exactly closed density algebra. The ideal flatband is motivated by the chiral model of twisted bilayer graphene, but is a much general concept. It has direct implication for recently experimental observed FCI and composite Fermi liquid phases in moire materials.

Ashvin Vishwanath

Harvard University

"From Nishimori's cat to non-Abelions: Using measurements to sculpt entanglement on quantum hardware"

Traditionally, measurements have been synonymous with extracting information from physical systems. Yet in the quantum realm, measurement can actively modify and steer quantum states, acting as a quantum chisel to sculpt new patterns of entanglement. I will describe how adaptive quantum circuits can leverage the power of measurements to efficiently create both well known ordered states as well as the long sought after non-Abelian topological phases. I will describe our recent collaborations with IBM and Quantinuum that implements these approaches, testing the stability of preparing GHZ states in the former collaboration and demonstrating the non-Abelian statistics of excitations in the latter.

Topological phases and strong correlations in many-body systems and light-matter hybrids

November 6 - 8, 2023
Phillips Auditorium

Monday, November 6, 2023

Chair: Eugene Demler

8:30 - 9:00 am	Refreshments/Introduction
9:00 - 9:40 am	Andrea Cavalleri
9:40 - 10:20 am	Mohammad Hafezi
10:20 - 10:50 am	Coffee Break
10:50 -11:10 am	John Sous
11:10 - 11:30 am	Donsung Choi
11:30 - 11:50 am	Jie Wang
12:00 - 2:00 pm	Lunch (Lobby)

Chair: Francisco Machado

2:00 - 2:40 pm	Dima Abanin
2:40 - 3:20 pm	Shuyun Zhou
3:20 - 3:50 pm	Coffee Break
3:50 - 4:30 pm	Daniele Fausti
4:30 - 5:10 pm	Aditi Mitra
5:10 - 5:50 pm	James McIver

Tuesday, November 7, 2023

Chair: Ceren Dag

8:00 - 8:30 am	Refreshments
8:30 - 9:10 am	Jie Shan
9:10 - 9:50 am	Takashi Oka
9:50 - 10:20 am	Coffee Break
10:20 - 11:00 am	Ashvin Vishwanath
11:00 - 11:20 am	Jon Curtis
11:20 - 11:40 am	Marios Michael
12:00 - 1:30 pm	Lunch (Library)

Location: Pratt

Chair: Johannes Feist

1:30 - 2:10 pm	Gil Refael
2:10 - 2:50 pm	Monika Aidelsburger
2:50 - 3:20 pm	Coffee Break
3:20 - 4:00 pm	Junichiro Kono
4:00 - 4:40 pm	Jonathan Simon
4:40 - 5:00 pm	Ceren B. Dag
5:15 - 7:00 pm	Poster Session (Phillips Auditorium)

Wednesday, November 8, 2023

Chair: Vasilis Rokaj

8:00 - 8:30 am	Refreshments
8:30 - 9:10 am	Jerome Faist
9:10 - 9:50 am	Martin Eckstein
9:50 - 10:20 am	Coffee Break
10:20 - 11:00 am	Monika Schleier-Smith
11:00 - 11:40 am	Angel Rubio
12:00 - 1:45 pm	Lunch (Library)

Chair: Nuh Gedik

1:45 - 2:25 pm	Joel Yuen-Zhou
2:25 - 3:05 pm	Johannes Feist
3:05 - 3:25 pm	Coffee Break
3:25 - 3:45 pm	Vasilis Rokaj
3:45 - 4:25 pm	Omar Mehio
4:25 - 5:05 pm	Matteo Mitrano
5:15 pm	Adjourn

John Sous

University of California, San Diego

"Light-induced insulating states in optically pumped metals from nonlinear electron-phonon coupling"

The non-equilibrium dynamics of matter excited by light may produce electronic phases that do not exist in equilibrium. Here I will discuss dynamics of a metal driven at initial time by a spatially uniform pump that excites dipole-active vibrational modes which couple nonlinearly to electrons. Based on insights obtained from numerically exact matrix product state simulations, I will provide an understanding of the dynamics in one-dimensional systems in two regimes: i) when the phonon energy scale lies within the electronic bandwidth, and ii) when the phonon energy scale is much smaller than the electronic bandwidth. In case i) I will provide evidence for rapid loss of spatial coherence, leading to emergent effective disorder in the dynamics, which arises in a system unitarily evolving under a translation-invariant Hamiltonian, and dominates the electronic behavior as the system evolves towards a correlated electron-phonon long-time state. In case ii), which is the subject of ongoing work, I will provide evidence that when the phonon frequency is sufficiently small, electron-electron correlations dominate the effective disorder giving rise to a transient state that appears to be a charge insulator. These results demonstrate that light can induce novel insulating states in the dynamics of optically excited metals. I willl further suggest new probes of phonon-induced dynamical electron behavior.

Jonathan Simon

Stanford University

Dima Abanin

Princeton University

"Temporal entanglement, non-Markovian many-body dynamics, and engineered dissipation"

In this talk, I will address a basic question: how many qubits does it take to emulate a many-body bath? The effect of a bath is encoded by an influence matrix — the Feynman-Vernon's functional on the space of subsystem's temporal trajectories. The complexity of this functional is determined by its temporal entanglement properties. I will show that in many cases of interest, temporal entanglement grows slowly with the evolution time, which enables compact representations of the influence matrix using a much smaller effective bath. After discussing applications including new efficient methods for quantum impurity models, I will switch gears and discuss a recent experiment using Google's superconducting quantum processor, where unitary evolution was combined with engineered dissipation. In this experiment, a few auxiliary qubits were periodically reset to emulate a small engineered bath. With the help of this protocol, we prepared steady low-energy correlated states of 1D and 2D spin systems. We will argue that the dissipative preparation of correlated states offers several advantages compared to unitary protocols. Furthermore, by coupling the system to auxiliaries emulating reservoirs with different chemical potentials, we discovered a new spin transport regime in the quantum Heisenberg model.

Monika Aidelsburger

Ludwig Maximilian University of Munich

"Floquet topological phases of matter with ultracold atoms in optical lattices"

Topological phases of matter can be generated in cold-atom systems using periodic driving, also known as Floquet engineering. While conventional topological insulators exhibit exotic gapless edge or surface states, as a result of nontrivial bulk topological properties. In periodically-driven systems the bulk-boundary correspondence is fundamentally modified and knowledge about conventional bulk topological invariants is insufficient. While ultracold atoms provide excellent settings for clean realizations of Floquet protocols, the observation of real-space edge modes has so far remained elusive. Here, I report on recent results, where we have demonstrated an experimental protocol for realizing chiral edge modes in optical lattices, by creating a topological interface in the form of a potential step using a programmable optical potential. We efficiently prepared particles in chiral edge modes in three distinct Floquet topological regimes that are realized in a periodically-driven honeycomb lattice. Moreover, the properties of the edge mode can be modified by controlling the height and sharpness of the potential step. In addition, I will present preliminary results on the interplay between disorder and topology and on the realization of many-body topological states in ladder systems with artificial magnetic flux and up to 40 strongly-interacting bosons.

Jie Shan

Cornell University

"Excitonic insulator in atomic double layers"

Excitonic insulators have been proposed as a solid-state platform for quantum many-boson physics. Although the concept of an excitonic insular has been understood for sixty years, it remains challenging to establish distinct experimental signatures of its realization. In this talk, I will discuss the development of transition metal dichalcogenide double layer structures and electrical injection of interlayer excitons up to 10^12 cm^(-2). We establish electrical control of the chemical potential of interlayer excitons and present thermodynamic evidence for an excitonic insulating phase by capacitance measurements. The strong interlayer excitonic correlation also gives rise to perfect Coulomb drag. A charge current in one layer induces an equal but opposite drag current in the other.

Monika Schleier-Smith

Stanford University

"Graph States of Atomic Ensembles Entangled by Light"

Graph states — entangled states in which the edges of a graph specify the structure of quantum correlations — are versatile resources for measurement-based computation and preparation of topologically ordered states. I will report on the generation of continuous-variable graph states of atomic spin ensembles in an optical cavity. Combining global photon-mediated interactions with local spin rotations in principle provides access to arbitrary nonlocal entanglement graphs. As an illustrative example, we have prepared a four-mode square graph state of ensembles that are physically arranged in a one-dimensional array. We have applied a related scheme to flexibly program the network of interactions in arrays of up to 18 sites, highlighting the scalability of our approach. I will describe avenues for applying this toolbox to explore topological physics, emphasizing the unique opportunities enabled by nonlocal connectivity.

Andrea Cavalleri

Max Planck Institute for the Structure and Dynamics of Matter, Hamburg

"Superconductivity induced by Driving"

I will discuss how coherent driving of certain quantum materials with electromagnetic radiation at mid-infrared frequencies can induce transient high temperature states that have striking similarities with equilibrium superconductors. These phases are observed at base temperatures as high as room temperature, underscoring the ability to induce coherence with light. This talk will also cover our search for new experimental methods that enable the characterization of these transient phases, to measure optical, structural, electrical and magnetic properties at very fast speeds.

Donsung Choi

Massachusetts Institute of Technology

"Light-induced insulator-metal transition in Sr 2 IrO 4 reveals the nature of the insulating ground state"

Sr_2IrO_4 has attracted considerable attention due to its structural and electronic similarities to La_2CuO_4, the parent compound of high-Tc superconducting cuprates. It was proposed as a strong spin-orbit coupled $J_{eff} = 1/2$ Mott insulator, but the Mott nature of its insulating ground state has not been conclusively established. Here, we use ultrafast laser pulses to realize an insulator-metal transition in Sr_2IrO_4 and probe the resulting dynamics using time- and angle-resolved photoemission spectroscopy. We observe a gap closure and the formation of weakly-renormalized electronic bands in the gap region. Comparing these observations to the expected temperature and doping evolution of Mott gaps and Hubbard bands provides clear evidence that the insulating state does not originate from Mott correlations. We instead propose a correlated band insulator picture, where antiferromagnetic correlations play a key role in the gap opening. More broadly, our results demonstrate that energy-momentum resolved nonequilibrium dynamics can be used to clarify the nature of equilibrium states in correlated materials.

Angel Rubio

Max Planck Institute for the Structure and Dynamics of Matter, Hamburg

"Quantum materials engineering with light: a QEDFT perspective"

One of the principal challenges in computational physics is to formulate an accurate yet computationally viable theory that can address non-equilibrium light-driven phenomena in molecules and quantum materials. Additionally, there is a need to simulate spatially and temporally resolved spectroscopies, ultrafast events, and newly emerging states of matter. In pursuit of this goal, TDDFT has emerged as the cutting-edge ab initio theoretical framework, enabling reliable and precise simulations of light-induced alterations in the physical and chemical characteristics of intricate systems. In this context, I will also introduce the recently developed framework of Quantum Electrodynamics Density-Functional Formalism (QEDFT). This framework offers a first-principles approach to predict, characterize, and manipulate the spontaneous emergence of ordered phases in strongly interacting light-matter hybrids, referred to as polaritons. These phases manifest both as ground states, resulting in novel states of matter, as well as metastable states. Noteworthy examples include photon-mediated superconductivity, cavity fractional quantum Hall physics, and optically driven topological phenomena in low dimensions. This exploration brings to light a burgeoning field, which we term "Cavity Materials Engineering" or the science of strongly correlated electron-photon interactions. We will conclude with the great challenges ahead in this captivating field of research.

Vasilis Rokaj

Harvard University

"Quantum Hall Physics in a Cavity"

We study the quantum Hall effect in a two-dimensional homogeneous electron gas coupled to a quantum cavity field [1]. As initially pointed out by Kohn, Galilean invariance for a homogeneous quantum Hall system implies that the electronic center of mass (CM) decouples from the electron-electron interaction, and the energy of the CM mode, also known as Kohn mode, is equal to the single particle cyclotron transition. In this talk, we point out that strong light-matter hybridization between the Kohn mode and the cavity photons gives rise to collective hybrid modes between the Landau levels and the photons. We provide the exact solution for the collective Landau polaritons and we demonstrate the weakening of topological protection at zero temperature due to the existence of the lower polariton mode which is softer than the Kohn mode. This provides an intrinsic mechanism for the recently observed topological breakdown of the quantum Hall effect in a cavity [2]. Importantly, our theory predicts the cavity suppression of the thermal activation gap in the quantum Hall transport. Our work paves the way for future developments in the cavity control of quantum materials and some interesting future directions will be discussed.

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Jonathan Curtis

University of California Los Angeles

"Multimode cavity control of ferroelectric fluctuations"

Electromagnetic cavities and metamaterials have been used to great effect in the field of AMO physics and electrical engineering. By shaping the spatial, spectral, or polarization characteristics of the electromagnetic environment, the coherent interaction between light and matter can be focused and amplified, leading to phenomena such as lasing, the Purcell effect, the Casimir effect, and superradiance. In this talk I will show how these ideas may be extended and applied to solid state quantum materials. In particular, I will consider polarization fluctuations in a quantum paraelectric insulator, and consider their coupling to a Fabry-Perot type optical cavity. By using the full multimode continuum description of the system, I will show how the ferroelectric fluctuations respond in a local, spatially resolved manner. The presence of the cavity indeed is shown to renormalize the sof-mode frequency, with effects primarily confined to the surface, and thus for thin films this effect can be pronounced. The temperature dependence shows this effect only onsets at low temperatures, indicating its origin from quantum electrodynamics effects -- in close analogy with the Casimir effect.

Ceren Dag

Harvard University

"Cavity Induced Topology in Graphene"

Strongly coupling materials to cavity modes can affect their electronic properties altering the phases of matter. We study a setup where graphene electrons are coupled to chiral photons with both left and right circularly polarized photons, and time-reversal symmetry is broken due to a phase shift between them. We develop a many-body perturbative theory, and derive cavity mediated electronic interactions induced in graphene. This theory leads to a gap equation which predicts a sizable topological band gap at Dirac nodes in vacuum and when the cavity is prepared in an excited Fock state. Remarkably, topological band gaps also open in light-matter hydbrization points away from the Dirac nodes giving rise to topological photo-electron bands with high Chern numbers. We reveal the physical mechanism of this phenomenon based on the photon exchange processes with electronic matter as the photo-electronic wavefunctions sweep through the avoided crossings in the band structure. This seems to be a generic microscopic mechanism for the photo-electron band topology. Our theory shows that graphene-based materials, with no need of Floquet engineering and hence protected from the heating effects, host high Chern insulator phases when coupled to chiral cavity fields.

Gil Refael

California Institute of Technology

"Topological energy pumping in doubly driven Weyl semimetal"

Topological quantum phases gives rise to new ideas of dynamical control of quantum phases. One such idea is topological energy pumping facilitated by a spin irradiated by two frequencies. In my talk I will explore the possibility of this effect emerging in a Weyl semimetal driven by two THz beams, and will show that if relaxation time in the Weyl material is sufficiently long, a Weyl material could become a parametric energy converter.

Takashi Oka

University of Tokyo

"Heterodyne Hall effect in oscillating magnetic fields"

Floquet engineering [1] introduces new dynamical functions within quantum materials. The process of heterodyning, a signal processing technique, produces output signals by combining an input signal with the dynamics of a designated multiplier [2]. This multiplier operates as a Floquet system, which is periodically influenced by an external drive over time [2, 3]. By designating electrons in oscillating magnetic fields as this multiplier, the Heterodyne Hall effect can be achieved [2]. We have recently broadened this concept to encompass 2D Dirac electrons, leading to the discovery of Floquet Landau levels and an effect reminiscent of the chiral magnetic effect [4].

References:

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[4] S. Kitamura, T. Oka, in preparation.

Martin Eckstein

University of Hamburg

"Light-matter hybrids and cavity-induced long-range spin interactions in the Hubbard model"

Enhancing the light-matter coupling in cavities provides an intriguing avenue to control properties of matter, from chemical reactions to transport and thermodynamic phase transitions. In this talk, I discuss two mechanisms in which quantum light can influence extended condensed matter systems, in particular strongly correlated electron systems: (i) The hybridization of light and matter can affect first-order metal insulator transitions, because light selectively modifies the free energy of the metallic phase . This mechanism has been discussed in relation to the cavity-controlled metal-insulator transition in 1T-TaS2 [1]. While it most likely is not the relevant mechanism in this case, we discuss other situations where it can be decisive. (ii) We discuss the possibility to induce photon mediated long-range interactions between spin and orbital degrees of freedom, which rely on the nonlinear light matter interaction (Raman scattering or two-photon absorption and emission). Both mechanisms are discussed for the Hubbard model, a paradigmatic model for correlated electrons.

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Jerome Faist

ETH Zurich

"Cavity quantum electrodynamics contributions to the integer Quantum Hall effect"

When a collection of electronic excitations are strongly coupled to a single mode cavity, mixed light-matter excitations called polaritons are created. The situation is especially interesting when the strength of the light-matter coupling ΩR is such that the coupling energy becomes close to the one of the bare matter resonance ω0. For this value of parameters, the system enters the so-called ultra-strong coupling regime, in which a number of very interesting physical effects were predicted caused by the counter-rotating and diamagnetic terms of the Hamiltonian.
In a microcavity, the strength of the electric field caused by the vacuum fluctuations, to which the strength of the light matter coupling ΩR is proportional, scales inversely with the cavity volume. One very interesting feature of the circuit based metamaterials is the fact that this volume can be scaled down to deep subwavelength values in all three dimension of space.1 Using metamaterial coupled to two-dimensional electron gases under a strong applied magnetic field, we have now explored to which extend this volume can be scaled down and reached a regime where the stability of the polariton is limited by diffraction into a continuum of plasmon modes2. We used transport to probe the ultra-strong light-matter coupling3, and show now that the latter can induce a breakdown of the integer quantum Hall effect4. The phenomenon is explained in terms of cavity-assisted hopping, an anti-resonant process where a an electron can scatter from one edge of the sample to the other by "borrowing" a photon from the cavity5. Our experiments show the importance of "photonic disorder" or field gradients on the effect.
Recently a proposal suggested that the value of the quantization voltage can be renormalized by the cavity6, but later work demonstrated that such renormalization corresponds to a singular point in the parameter space 7. We have investigated this effect experimentally using a Wheatstone bridge geometry8 and found the quantization to be held. In a recent development, we have investigated a tunable cavity which allows an in-situ control of the light-matter coupling.

Matteo Mitrano

Harvard University

"Ultrafast many-body dynamics of a driven quantum chain"

Over the last two decades, intense ultrashort electromagnetic fields have enabled observing and controlling a number of emergent states in quantum materials. Some of the most spectacular light-induced phenomena, such as superconducting-like phases, transient charge density wave ordering, and excitonic condensation, are found to occur in materials dominated by strong electronic correlations with a large susceptibility to external stimuli. Recently, it has been theoretically argued that quasi-one-dimensional Mott insulators might host exotic and genuinely nonequilibrium ordering phenomena upon photoexcitation, such as η-pairing superconductivity. In these systems, the light-matter interaction can promote a nonthermal population of holes and double-occupancies, but also directly modify the effective many-body interactions, such as electron hopping amplitudes and electron-electron repulsion.

In this talk, I will report on our recent ultrafast x-ray studies on a paradigmatic quantum chain – the quasi-1D cuprate Sr_2CuO_3 – and discuss implications for the realization of new driven states in photoexcited Mott insulators. I will focus on the connection with a previously observed light-induced renormalization of effective interactions and on how to fully reconstruct the driven many-body state via time-resolved x-ray spectroscopy.

Aditi Mitra

New York Uniuversity

"Topological Defects in Floquet Circuits"

I will discuss how one may construct Floquet models from a fusion category, and how this formalism is a natural way to construct topological defects: non-local operators that can be deformed in the space and time direction without changing the physics. One of these topological defects is the "duality defect" that implements the Kramers-Wannier duality transformation and is a "non-invertible symmetry" as it projects out states of a given parity. I will highlight the consequence of the duality defect on Floquet time-evolution, first for the exactly solvable Floquet-Ising model, and then by adding integrability breaking perturbations to the model.

Daniele Fausti

Friedrich Alexander University Erlangen-Nürnberg

"Measuring and controlling fluctuations in quantum materials"

The rich phase diagrams of many transition metal oxides (TMOs) is the result of the intricate interplay between electrons, phonons, and magnons. This makes TMOs very susceptible to external parameters such as pressure, doping, magnetic field, and temperature which in turn can be used to finely tune their properties. The same susceptibility makes TMOs the ideal playground to design experiments where the interaction between tailored electromagnetic fields and matter can trigger the formation of new, sometimes exotic, physical properties. This aspect has been explored in time domain studies [1] and has led to the demonstration that ultrashort mid-IR light pulses can "force" the formation of quantum coherent states in matter, disclosing a new regime of physics where thermodynamic limits may be bridged and quantum effects can, in principle, appear at ambient temperatures.

In this presentation, I will review our recent results in archetypal strongly correlated cuprate superconductors and demonstrate the feasibility of a light-based control of quantum phases in real materials [2,3,4]. I will then introduce our new approaches to time domain spectroscopy going beyond mean photon number observables [5-10] and show that the statistical features of light can provide information on superconducting fluctuations beyond standard linear and non-linear optical spectroscopies[11]. Finally, I will elaborate on our current research effort to use cavity electrodynamics to control the onset of quantum coherent states in complex materials[12].

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Johannes Feist

Autonomous University of Madrid

"Cavity-mediated modification of materials: Fundamentals & pitfalls"

The use of cavity quantum electrodynamical effects, i.e., of vacuum electromagnetic fields, to modify material properties in cavities has rapidly gained popularity and interest in the last few years. However, there is still a scarcity of general results that provide guidelines for intuitive understanding and limitations of what kind of effects can be achieved. I will present some of our recent work addressing these issues. One is the fundamental question of whether or not it is possible to achieve conditions under which the coupling of a single dipole to a strongly confined electromagnetic vacuum can result in nonperturbative corrections to the dipole's ground state. We find that this regime can in principle be reached, but doing so requires the presence of high-impedance "cavity" modes such as plasmons or engineered LC resonances, which are dominated by material degrees of freedom (e.g., collective electron motion) instead of by the transverse (photonic) degrees of freedom of the electromagnetic field. I will then discuss a recent result on the effective interactions between low-energy matter excitations that couple to the electromagnetic field either directly, or indirectly through coupling to mediator modes. We demonstrate that when taking into account all cavity modes, the induced interaction is the electrostatic dipole-dipole interaction in the cavity geometry. These findings provide a physically transparent interpretation of possible cavity-induced modifications, and also imply that reduced models with one or a few cavity modes can easily give misleading results.

Marios Michael

Max Planck Institute for the Structure and Dynamics of Matter, Hamburg

"Strong light matter coupling and surface plasmons"

The power of laser light to manipulate many body phases has inspired the new field of cavity - matter hybrids, aiming at photo-inducing exciting new functionalities in equilibrium merely using quantum photon fluctuations instead. Theoretical progress has shown that quantum light can indeed lead to exciting new possibilities, from topology to superconductivity to spin liquid phases. However, a central question has been evading theorists: how to compute the strength of the light matter coupling ? In this talk, I will argue that to answer this question we need to employ a multi-mode approach in order to correctly regularize with the background vacuum photons that are present without the drive. As examples, I will demonstrate the effect of a Fabry Perot cavity and a surface phonon polariton structure on the free electron gas as well as provide a recipe for reviving the single mode approximation for surface phonon polaritons[1]. Finally, I will mention how cavities can be used to manipulate Raman modes in equilibrium[2].

James McIver

Columbia University

"Ultrafast control of topological transport in quantum materials"

Quantum materials exhibit remarkable non-equilibrium phenomena when driven by the strong fields in femtosecond laser pulses. Recent years have seen a surge of interest in using ultrafast light-matter interaction to create and manipulate photon-dressed Floquet-Bloch states as a strategy for controlling material properties. This excitement is fueled by the predictive power of Floquet theory, which has been used, for example, to correctly predict the formation of topological edge modes in periodically-driven systems that exhibit no topological properties in equilibrium. Many of these proposals have been verified in quantum simulation settings, but are only just beginning to be explored in solids.

In this talk, I will present results on the electrical transport properties of quantum materials driven by mid-infrared laser pulses, probed using an ultrafast optoelectronic device architecture. The talk will primarily focus on recent results obtained on the Weyl semimetal T_d-$MoTe_2$, where a rectified, helicity-dependent injection current that scales linearly with the applied laser field was observed. This scaling violates the perturbative description of nonlinear optics/transport, which demands a quadratic field scaling for current rectification to occur. The results can be explained using Floquet theory, which predicts that the observed linear scaling arises from the stimulated emission that accompanies the hybridization of Floquet-Bloch states. I believe this description can be generalized to describe nonperturbative nonlinear transport in all quantum materials, with intimate links to nonperturbative nonlinear optical observables.

Unexpectedly, we find that upon photoexciting T_d-$MoTe_2$ above a certain fluence threshold, it enters a persistently metastable phase characterized by the disappearance of the nonlinear anomalous Hall effect, a topological transport observable that arises from the tilted Weyl nodes in this material. Remarkably, this transition can be reversed by applying laser light in the near-infrared, providing a pathway to creating a topological nonvolatile memory device that can be deterministically switched with single pulses of light.

Mohammad Hafezi

University of Maryland

"Quantum optics of correlated excitons in layered TMDs"

Multi-layer moire transition metal dichalcogenides (TMDs) have emerged as a remarkable platform for studying Bose-Fermi mixture physics, with unprecedented optical and electrical tunability. We report observations of strongly interacting excitons in such systems, with signatures of bosonic Mott insulating phases. Moreover, we show how various spin- and charge-order physics, such as formation of Mott-moire excitons and magnetic polarons, can be inferred via various optical measurements such as diffusion. We discuss the validity of the driven-dissipative Bose-Hubbard model for such strongly interacting excitons. Specifically, for certain material conditions, the system experiences a strong phase space filling that renders the bosonic description of such excitons invalid. Lastly, we discuss the prospect of coupling such strongly interacting excitons to two-dimensional in planar cavities made of TMDs.

Omar Mehio

California Institute of Technology

"Hubbard exciton fluids in Mott antiferromagnets"

Antiferromagnetic correlations in Mott insulators are predicted to enhance the attractive interactions between holons and doublons, leading to the formation of a bound state known as a Hubbard exciton. However, experimental evidence for Hubbard excitons and their magnetic binding mechanism remain sparse. In this talk, I will discuss recent ultrafast time-resolved time-domain THz spectroscopy measurements directed at searching for signatures of intra-excitonic transitions in Mott antiferromagnets. These measurements reveal the ultrafast formation of a transient Hubbard excitonic fluid in several Mott insulating compounds. The effects of magnetic correlations on the excitonic stability will be discussed, along with an analysis of the excitonic recombination pathways. These results establish a platform to study and manipulate Hubbard excitons, paving the path to engineer excitonic states not accessible in traditional rigid band insulators.

Junichiro Kono

Rice University

"Cavity QED in the Ultrastrong Coupling Regime"

Recent experiments have demonstrated that light and matter can mix together to an extreme degree, and previously uncharted regimes of light–matter interactions are currently being explored in a variety of settings [1]. The so-called ultrastrong coupling (USC) regime is established when the light–matter interaction energy becomes a comparable fraction of the bare frequencies of the uncoupled systems. Most intriguingly, when a material is ultrastrongly coupled with cavity-enhanced vacuum electromagnetic fields (or zero-point fields), novel equilibrium phases with exotic properties are predicted to emerge. This talk will describe our recent studies of USC phenomena in various solid-state systems in search of such vacuum-induced phases of matter [2-11]. We employ the quantum optics concept of Dicke cooperativity [5], i.e., many-body enhancement of light–matter interaction, to realize USC in condensed matter in terahertz (THz) cavities. Several examples including Landau polaritons in 2D electron systems in the quantum Hall regime, THz phonon polaritons in PbTe, spin-Zeeman polaritons in gadolinium gallium garnet, and possible enhancement of superconductivity in NbN in THz cavities will be discussed.