# Quantum Matter: Dynamics and Sensors

December 19 – 22, 2022
Storrs, Connecticut

UCONN
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The Nordic Institute for Theoretical Physics

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**Conference:** Innovation Partnership Building at UConn Tech Park,159 Discover Drive,Storrs, CT 06269-5279
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## Introduction

Quantum matter and materials have grown to be an active area of modern condensed matter. Fascinating properties of quantum materials might lead to technological applications such as spintronics, quantum technologies and quantum sensors. The combination of new materials discoveries and development of new probes of quantum matter has helped shape these topics into an exciting area. Recent dynamic and pumped probe experiments reveal a strong promise of Dynamic Quantum Matter as a new research direction. We strive to measure, understand and predict transient correlations and coherences in quantum materials upon different driving conditions. Therefore, we introduce it as a new topic of this year's quantum matter conference. We seek to have an active discussion on hidden, entangled and dynamic orders that emerge in quantum matter and the potential applications beyond it.

Main focus for this upcoming conference will be on the modeling and experimental observations of Quantum Matter. Overall, the goal of this workshop is to bring together researchers to discuss and highlight emerging topics and develop ideas for future research.

**Scope: Dynamics in Quantum Matter, Dark Matter and Quantum Sensors, Correlated systems, and topics including spin transport, superconductivity, and non-equilibrium dynamics**

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## Conference Schedule

All times are in Eastern Standard Time (EST = UTC – 5)

### Monday, December 19

8:00 a.m. – Registration Open and Continental Breakfast

8:45 – 9:00 a.m. – Welcome and Introduction

***Session I – Quantum Sensors and Metrology I (Chair: A. Balatsky)***

**9:00 – 9:45 a.m. – Pamir Alpay and Nayak Sanjeev – Quantum Materials Modeling and Properties Prediction using Density Functional Theory**

**9:45 – 10:30 a.m. – Paola Cappellaro – Multiparameter estimation: from ultimate bounds to practical implementations**

**10:30 – 11:15 a.m. – William Terrano – Searches for dark matter and tests of fundamental symmetries**

11:15 – 11:30 a.m. – Coffee Break

***Session II – Quantum Sensors and Metrology II (Chair: M. Jain)***

**11:30 – 12:15 p.m. – Qian Yang – Opportunities in Machine Learning for Quantum Matter**

**12:15 – 1:00 p.m. – Victor Batista – Quantum Dynamics on Modular Quantum Devices**

1:00 – 2:00 p.m. – Lunch Break (Provided)

2:00 – 3:00 p.m. – General Discussion

***Session III – Quantum Sensors and Metrology I (Chair: L. Santos)***

**3:00 – 3:45 p.m. – Pedram Roushan (Remote) – Toward discovering novel quantum dynamics on a NISQ processor**

**3:45 – 4:30 p.m. – Rodrigo Cortiñas – Controlling the interference of tunneling paths in a double well-system**

4:30 – 4:45 a.m. – Coffee Break

**4:45 – 5:30 p.m. – Carlos Trallero – Generation and control of non-local indistinguishable XUV photons**

**5:30 – 6:15 p.m. – Ilya Sochnikov – Quantum Sensing for Material Research**

6:15 p.m. – Break for the Day

## Tuesday, December 20

8:00 a.m. – Continental Breakfast

***Session IV – Quantum Matter and Dark Matter Sensing I (Chair: J.T. Haraldsen)***

**9:00 – 9:45 a.m. – Sinéad Griffin – Dark matter on the rocks**

**9:45 – 10:30 a.m. – Benjo Fraser – Dark Sound: collective modes of axionic dark matter**

10:30 – 10:45 a.m. – Coffee Break

***Session V – Quantum Matter and Dark Matter Sensing II - Remote (Chair: J. T. Haraldsen)***

**10:45 – 11:30 a.m. – Andrew Geraci (Remote) – Searching for "fifth-forces" from the QCD Axion**

**11:30 – 12:15 p.m. – Yonathan Kahn (Remote) – Axion wind detection with the homogeneous precession domain of superfluid helium-3**

**12:15 – 1:00 p.m. – James Sauls (Remote) – High Q superconducting RF cavities for axion detection**

1:00 – 2:00 p.m. – Lunch Break (Provided)

2:00 – 3:00 p.m. – Poster Session

***Session VI – Material and Strain Structures (Chair: J. Hancock)***

**3:00 – 3:45 p.m. – Charles Ahn – Coherent Imaging and Control of Antiferromagnetic Domain Dynamics**

**3:45 – 4:30 p.m. – Daniel Sheehy – Unruh effect and inversion of statistics in strained graphene**

4:30 – 4:45 a.m. – Coffee Break

**4:45 – 5:30 p.m. – Robert Konik – Post-quantum quench growth of Renyi entropies in perturbed Luttinger liquids**

5:30 p.m. – Reception

6:15 p.m. – Dinner (Provided by Workshop)

## Wednesday, December 21

8:00 a.m. – Continental Breakfast

*Session VII – Quantum Matter I (Chair: I. Sochnikov)*

**9:00 – 9:45 a.m. – Chandra Varma – Quantum-criticality and superconductivity in twisted bi-layer graphene**

**9:45 – 10:30 a.m. – Justin H. Wilson – Measurement and feedback driven entanglement transition in the probabilistic control of chaos**

**10:30 – 11:15 a.m. – Boris Spivak – Debye mechanism of giant microwave absorption in superconductors**

11:15 – 11:30 a.m. – Coffee Break

*Session VIII – Quantum Matter II (Chair: G. Fernando)*

**11:30 – 12:15 p.m. – Leonid Levitov – Chiral Stoner magnetism in Dirac bands**

**12:15 – 1:00 p.m. – Daniel Arovas (Remote)**

1:00 – 2:00 p.m. – Lunch Break (Provided)

2:00 – 3:00 p.m. – General Discussion

*Session IX – Quantum Matter Dynamics (Chair: J.T. Haraldsen)*

**3:00 – 3:45 p.m. – Boris Svistunov – Supertransport by superclimbing dislocations in Helium-4: When all dimensions matter**

**3:45 – 4:30 p.m. – Kenneth Burch – Axial Higgs mode from quantum geometry and a charge density wave**

4:30 – 4:45 a.m. – Coffee Break

**4:45 – 5:30 p.m. – Walter Krawec**

**5:30 – 6:15 p.m. – Pavel Volkov – Interacting electrons in critical polar metals**

6:15 p.m. – Break for the Day

## Thursday, December 22

8:00 a.m. – Continental Breakfast

***Session X – Quantum Matter III (Chair: J.T. Haraldsen)***

**9:00 – 9:45 a.m. – Ilya Vekhter – Bound states and controllable currents on topological Insulator surfaces with extended magnetic defects**

**9:45 – 10:30 a.m. – Boris Altshuler**

**10:30 – 11:15 a.m. – Anatoly Polkovnikov**

11:15 – 11:30 a.m. – Coffee Break

**11:30 – 12:15 p.m. – Daniel MaCarron**

12:15 p.m. – End of Conference

**12:30 – 1:30 p.m. – Uconn Round Table Discussion (Chair: A. Balatsky)**

# Invited Talks

### Charles Ahn – Coherent Imaging and Control of Antiferromagnetic Domain Dynamics

Yale University – New Haven, Connecticut – USA

In this work, we examine the dynamics and energetics of antiferromagnetic (AF) domains. A key enabler to understand and control AF domains involves the ability to image their structure and dynamics. The AF order parameter can be imaged in thin films using resonant soft x-ray diffraction, and information about their dynamics can be accessed by x-ray photon correlation spectroscopy (XPCS) measurements using coherent soft x-rays. Recent studies have revealed that the magnetic and electronic phase transitions in NdNiO (NNO) can be tuned by confining the NNO layers to reduced dimensions in heterostructures. We image the AF ground state in reciprocal space for atomically layered (NdNiO)-(NdAlO) heterostructures and show that dimensional confinement enhances the phase fluctuations at AF domain boundaries. The speckle patterns acquired from coherent x-ray scattering contain information on long- and short-range correlations and the 1D nature of AF boundaries in dimensionally confined nickelate layers. As the AF domain boundary approaches the 1D limit, the dynamics are enhanced. This study demonstrates an approach to characterize dimensional effects on long-range order and the ability to control AF domain configurations in oxide heterostructures.

### Daniel Arovas – Dissipation and Dephasing in the d=1 Aubry-Andre-Harper Model

University of California – San Diego – San Diego, California – USA

The Aubry-Andre-Harper (AAH) model describes fermions hopping in a quasiperiodic potential in one dimension. We explore the effects of dissipation and dephasing by effectively coupling the AAH chain to an environment and studying the evolution of its density matrix using the GKLS master equation formalism. We find that the extended phase is replaced by a fractal phase.

**S. Pamir Alpay and Sanjeev K. Nayak – Quantum Materials Modeling and Properties Prediction using Density Functional Theory**
University of Connecticut – Storrs, Connecticut – USA

In Stabilizing esoteric quantum effects in solid-state devices shows promise for the development of Quantum 2.0 technologies. Exhibiting many exotic electronic characteristics, topological insulators (Tis) have arisen in the past decade as a plausible vehicle for the realization of devices ranging from superconductors, to spintronics, to quantum computers. Because practical TI applications have so far remained unrealized, a great deal of research into these materials has been focused upon bridging the gap between physics fundamentals and matters of engineering—that is, materials properties tuning. The quantum phenomena present in Tis are generally modeled in-and-of-themselves with quantum field theory-based empirical Hamiltonians. However, in order to study these phenomena in real materials like Tis, electronic structure theory is imperative. Given that first-principles density functional theory (DFT) best matches experimental results, DFT is the best option for modeling quantum materials. We present the results of two works on binary pnictogen chalcogenides (BPCs) TI properties tuning using DFT [1,2], and the results of a third DFT study currently in progress. In the first work, we undertake a comprehensive assessment of the computational possibility space of prototypical TI BPCs Bi2Se3 and Bi2Te3, dispel methodological ambiguity in the literature, and provide a definitive framework for TI BPC modeling in DFT. In the second work, we extend this framework to the study of non-TI BPC β-As2Te3, show the potential of biaxial strain as a method of positive and negative bandgap modulation, and gesture toward the primary role sub-structural elements (SSEs)—sub-features of the overall atomic structure of the material—play as a tuning mechanism. Finally, in the third work, we expand upon the SSE concept, show its utility outside the BPC materials class, and demonstrate the effectiveness of a novel method for tuning the properties of TI and TI-adjacent materials by selectively targeting individual SSEs alone.

(Acknowledgement: Thomas K. Reid contributed to the abstract.)

[1] T. K. Reid, S. P. Alpay, A. V. Balatsky, and S. K. Nayak, First-Principles Modeling of Binary Layered Topological Insulators: Structural Optimization and Exchange-Correlation Functionals, Phys. Rev. B 101, 085140 (2020).

[2] T. K. Reid, S. K. Nayak, and S. P. Alpay, Strain-Induced Surface Modalities in Pnictogen Chalcogenide Topological Insulators, J. Appl. Phys. 129, 15304 (2021).

**Victor S. Batista – Quantum Dynamics on Modular Quantum Devices**
Yale University – New Haven, Connecticut – USA

There is currently a huge gap between the problems for which a quantum computer could be useful in chemistry and what we can actually simulate today with quantum computers, even with the largest and most impressive qubit platforms from IBM, Google, or Rigetti. The challenge is that most well-known quantum computing (QC) algorithms have qubit requirements and number of queries that far exceed the current scale by several orders of magnitude. Closing the so-called 'QC gap' is essential to making QC technology finally available to the physical sciences and engineering, beyond the rather simple proof-of-concept applications that so far have been developed. One approach is to wait until conventional quantum computers from the private sector become six orders of magnitude better. In this talk, we will introduce another approach which involves finding quantum computing platforms for efficient realizations of the problems of interest at the hardware level, with emphasis on the development and application of a new paradigm for quantum simulations of reaction dynamics, based on fully bosonic quantum devices.

**Kenneth Burch – Axial Higgs Mode from Quantum Geometry and a Charge Density Wave**
Boston College – Chestnut Hill, Massachusetts – USA

The Higgs boson is a key excitation of second-order phase transitions from the standard model to novel quantum orders. In condensed matter, the Higgs mode has been observed in magnetic, superconducting, and charge density wave systems (CDW) and is typically assumed to have a scalar representation due to a single broken symmetry. Indeed, uncovering the vector properties of a low-energy mode is extremely challenging, requiring going beyond typical spectroscopic or scattering techniques. Here I discuss our use of using Raman scattering to discover an axial Higgs mode heralding an unconventional CDW in $GdTe_3$. I will explain how the Axial Higgs mode emerges from the combination of the quantum geometry of the Fermi surface and the charge density wave, opening opportunities for new topological-correlated states in 2D.

**Paola Cappellaro – Multiparameter estimation: from ultimate bounds to practical implementations**
Massachusetts Institute of Technology – Cambridge, Massachusetts – USA

Measuring multiple signals associated with non-commuting observables is a challenge in quantum mechanics, but often a practical requirement in many applications. Here I will show how we can study bounds in sensitivity of multiparameter estimation experimentally, by linking them to quantum geometry. I will then provide examples of experimental implementations that provide practical and robust solutions to this problem, using Nitrogen Vacancy centers in diamond as a platform.

**Rodrigo Cortiñas – Controlling the interference of tunneling paths in a double well-system**
Yale University – New Haven, Connecticut – USA

Encoding and manipulating quantum information with logical cat qubits is a promising means to perform quantum error correction, but controlling undesired parametric processes, while preserving quantum control, remains an outstanding challenge. The Kerr-cat qubit, created by squeeze-driving a weakly nonlinear Kerr oscillator, provides a double-well system with minimal spurious parametric processes. The tunnel effect is expected to be cancelled in its ground state manifold. The logical errors induced by incoherent well-flipping are then dominated by tunneling through excited states under incoherent excitations. A key question is, how does this incoherent well-flipping affect the qubit manifold? Moreover, can the cancellation of tunneling be extended to the higher excited states? I will present experimental results, measuring the passage through zero of the tunneling amplitude in the excited state spectrum as a function of squeezing drive strength and frequency. Then, I will address the experimental cancellation of ground and excited state tunneling due to quantum interference effects. This quantum error correction strategy leads to a 500x enhancement of well-flipping lifetimes while maintaining coherent control, and high-fidelity quantum non-demolition readout.

**Benjo Fraser – Dark Sound: collective modes of axionic dark matter**
Nordic Institute for Theoretical Physics – Stockholm – Sweden

The axion is a leading dark matter candidate. One of its characteristics is its large occupation number, which leads to phenomenology more akin to systems of condensed matter physics than of particle physics. We examine one such behavior: sound modes. Study of these modes might lead to a new approach to detection.

**Andrew Geraci – Searching for "fifth-forces" from the QCD Axion**
Northwestern University – Evanston, Illinois – USA

The QCD axion could explain the lack of Charge-Parity (CP) violation in the strong interactions, while constituting all or part of the Dark matter in the universe, thus making it an "economical" solution to some of the greatest puzzles in cosmology and high-energy physics. While much focus in the community has been on cosmic axion searches, axions can also generate novel spin-dependent short-range forces in table-top experiments. The Axion Resonant InterAction Detection Experiment (ARIADNE) searches for the QCD axion using a technique based on nuclear magnetic resonance. The aim is to detect axion-mediated short-range interactions between laser-polarized 3He nuclei and an unpolarized tungsten source mass. The experiment has the potential to probe deep within the theoretically interesting regime for the QCD axion in the mass range of 0.01-10 meV. In this talk I will discuss the basic principle of the experiment, the current experimental status, and future prospects for detecting other varieties of novel spin-dependent axion-mediated fifth forces.

**Sinéad Griffin – Dark matter on the rocks**
Lawrence Berkeley National Laboratory – Berkeley, California – USA

New proposals for the direct detection of dark matter (DM) have steadily pushed into the sub-GeV 'light' DM range. In particular, for DM masses in the kev-GeV range motivates the exploration of low-energy excitations in condensed matter systems as possible direct detection channels. Recent proposals for DM detection in crystal targets include quasiparticle excitations such as electron and phonon scattering in conventional semiconductors such as Si and GaAs. In this talk, I will discuss our recent predictions that cryogenic ice has superior sensitivity than all other proposed targets for single phonon scattering, both in the low- and high-mass regimes. I discuss our derived quality factor for enhanced quasiparticle coupling with well-motivated dark matter models, and prospects for alternative and more exotic targets for low-mass DM detection.

### Jason T. Haraldsen – A-Spin: Open-source software for the analysis and understanding of spin dynamics

University of North Florida – Jacksonville, Florida – USA

A-Spin (Analytical-Spin) is open-source software that allows for the analytical understanding of any periodic lattice for both collinear and non-collinear spin systems. Starting with a Heisenberg spin-exchange Hamiltonian with single-ion anisotropy and applied external magnetic field, the A-Spin software will determine the analytical collinear ground states. Beyond the ground state energies and magnetic phase diagrams, A-Spin will also determine the spin-wave dynamics (including frequencies and intensities) for a give set of exchange parameters. The purpose of A-Spin is to provide a simple graphical user interface, where the use inputs a specific lattice space and labels different exchange interactions and is provide a magnetic phase diagram. With this diagram, the use can input specific regions of the diagram and determine the spin dynamics. It is hoped that this software will help experimentalist on the indenfication and analysis of magnetic material phases, as well as assist theorist in the understanding of how exchange parameters change the spin-wave dynamics. As this is open-source software, users are able to download and modify the software to their needs. For example, if coupled to a classical Monte Carlo, then non-collinear ground states will possible (under development). Additionally, we are working on adding a Dzyaloshinskii-Moriya interaction for applied electric fields or coupling to internal electric polarization.

### Yonatan Kahn – Axion wind detection with the homogeneous precession domain of superfluid helium-3

University of Illinois Urbana-Champaign – Champaign, Illinois – USA

Axions and axion-like particles may couple to nuclear spins like a weak oscillating effective magnetic field, the “axion wind.” Existing proposals for detecting the axion wind sourced by dark matter exploit analogies to nuclear magnetic resonance (NMR) and aim to detect the small transverse field generated when the axion wind resonantly tips the precessing spins in a polarized sample of material. I will describe a new proposal using the homogeneous precession domain (HPD) of superfluid 3He as the detection medium, where the effect of the axion wind is a small shift in the precession frequency of a large-amplitude NMR signal. I will show that this setup can provide broadband detection of multiple axion masses simultaneously and has competitive sensitivity to other axion wind experiments such as CASPEr-Wind at masses below 1e-7 eV by exploiting precision frequency metrology in the readout stage.

**Robert Konik – Post-quantum quench growth of Renyi entropies in perturbed Luttinger liquids**
Brookhaven National Laboratory – Upton, New York – USA

The growth of Renyi entropies after the injection of energy into a correlated system provides a window upon the dynamics of its entanglement properties. We provide here a scheme by which this growth can be determined in Luttinger liquids systems with arbitrary interactions, even those introducing gaps into the liquid. This scheme introduces the notion of a generalized mixed state Renyi entropy. We show that these generalized Renyi entropies can be computed and provide analytic expressions thereof. Using these generalized Renyi entropies, we provide analytic expressions for the short time growth of the second and third Renyi entropy after a quantum quench of the coupling strength between two Luttinger liquids, relevant for the study of the dynamics of cold atomic systems. For longer times, we use truncated spectrum methods to evaluate the post-quench Renyi entropy growth.

**Leonid Levitov – Chiral Stoner magnetism in Dirac bands**
Massachusetts Institute of Technology – Cambridge, Massachusetts – USA

This talk will argue that Stoner magnetism in bands endowed with Berry curvature is profoundly influenced by the chiral interaction between Berry's orbital magnetization and spin chirality density. The key effect is that carriers moving in the presence of a spin texture see it as a source of a pseudo-magnetic field coupled to their orbital motion through a chiral Aharonov-Bohm effect. This interaction favors chiral spin textures such as skyrmions – the topologically protected objects with particle-like properties, stabilized in the ground state. The chiral interaction softens the threshold for Stoner instability, rendering chiral spin-ordered phases readily accessible under realistic conditions. We illustrate this effect for a graphene multilayer model, with magnetization and pseudo-magnetic fields taking different values in different valleys, yet the results are applicable to generic Stoner magnets.

**Pedram Rousha – Toward discovering novel quantum dynamics on a NISQ processor**
Google Quantum AI – Santa Barbara, California – USA

In 2019, it was experimentally demonstrated that a quantum processor could perform certain computational tasks exponentially faster than a classical computer [1]. Going beyond this milestone, we seek to utilize these Noisy Intermediate Scale Quantum (NISQ) processors to study computationally intractable physics problems. The class of problems that seems within reach are quench dynamics in interacting spin systems far

away from equilibrium. I will provide an overview of our progress by describing some of our recent works [2,3]. The aim of the talk is to provide a sense of what NISQ discoveries to anticipate and a time scale for them.

[1] Nature 574, 505–510 (2019)

[2] Nature 601, 531–536 (2022)

[3] Nature 612, 240-245 (2022)

### James Sauls – High Q superconducting RF cavities for axion detection

Louisiana State University – Baton Rouge, Louisiana – USA

Superconducting RF cavities provide technology platforms ranging from multi-mode quantum processors to sensitive detectors for dark matter candidates such as dark photons and axions. I discuss the potential of high Q SRF cavities as detectors for the pseudo-scalar axion field that has a symmetry allowed coupling to the EM field confined in an SRF cavity. The proposal for axion field detection using a single SRF cavity is based on detection of signal photons generated by the nonlinear axion field to the EM field [1]. In addition to a high Q, a key to detection is suppressing false positive signal photons from background noise sources. I show that the screening currents for high Q of SRF cavities are intrinsically nonlinear [2], and that the nonlinear current response generates a false positive background that is sensitive to disorder and the amplitude of the EM field of the drive modes used to couple to the axion field.

[1] Z. Bogorad et al., Phys. Rev. Lett. 123, 021801 (2019), https://doi.org/10.1103/PhysRevLett.123.021801.

[2] J. A. Sauls, Prog. Theor. Expt. Phys., 2022, 033I03 (2022); https://doi.org/10.1093/ptep/ptac034.

### Daniel Sheehy – Unruh effect and inversion of statistics in strained graphene

Louisiana State University – Baton Rouge, Louisiana – USA

I will describe recent theoretical work [arXiv:2209.08053] on how a spatially-varying quasiparticle velocity in honeycomb lattices, achievable using strained graphene or in engineered cold-atom optical lattices that have a spatial dependence to the local tunneling amplitude, can yield the Rindler Hamiltonian embodying an observer accelerating in Minkowski spacetime. Within this setup, a sudden switch-on of the spatially-varying tunneling (or strain) yields a spontaneous production of electron-hole pairs, an analogue version of the Unruh effect characterized by the Unruh temperature. I will discuss how this thermal behavior, along with Takagi's statistics inversion, can manifest themselves in photo-emission and scanning tunneling microscopy and optical conductivity experiments.

**Ilya Sochnikov – Quantum Sensing for Material Research**
University of Connecticut – Storrs, Connecticut – USA

During this talk, I will present research on materials with superconducting quantum sensors conducted at the Quantum Imaging Lab at UCONN. As the first case, I will discuss a metastable magnetic phase in a ferromagnetic Weyl semimetal. In the second case, I will present an emergent magnetic phase in a quantum paraelectric. I will present an outlook for new superconducting sensors if time permits.

**Boris Spivak – Debye mechanism of giant microwave absorption in superconductors**
University of Washington – Seattle, Washington – USA

I will discuss a mechanism of microwave absorption in conventional and unconventional superconductors which is similar to the Debye absorption mechanism in molecular gases. The contribution of this mechanism to AC conductivity is proportional to the inelastic quasiparticle relaxation time rather than the elastic one and therefore it can be much larger than the conventional one. The Debye contribution to the linear conductivity arises only in the presence of a DC supercurrent in the system and its magnitude depends strongly on the orientation of the microwave field relative to the supercurrent. The Debye contribution to the non-linear conductivity exists even in the absence of the supercurrent. It provides an anomalously low non-linear threshold. Microwave absorption measurements may provide direct information about the inelastic relaxation times in superconductors. I will also discuss a closely related problems of resistance of superconductor-normal metal-superconductor junctions, and the problem of flux flow in the presence of magnetic field.

**Boris Svistunov – Supertransport by superclimbing dislocations in Helium-4: When all dimensions matter**
University of Massachusetts Amherst – Amherst, Massachusetts – USA

I will describe recent theoretical work [arXiv:2209.08053] on how a spatially varying quasiparticle velocity in honeycomb lattices, achievable using strained graphene or in engineered cold-atom optical lattices that have a spatial dependence to the local tunneling amplitude, can yield the Rindler Hamiltonian embodying an observer accelerating in Minkowski spacetime. Within this setup, a sudden switch-on of the spatially varying tunneling (or strain) yields a spontaneous production of electron-hole pairs, an analogue version of the Unruh effect characterized by the Unruh temperature. I will discuss how this thermal behavior, along with Takagi's statistics inversion, can manifest themselves in photoemission and scanning tunneling microscopy and optical conductivity experiments.

**William Terrano – Searches for dark matter and tests of fundamental symmetries**
Arizona State University – Tempe, Arizona – USA

Quantum sensors based on the interference of superposition states have been used to study fundamental physics since the invention of Ramsey's technique decades ago. In recent years, it has been realized that this technique is likely to be the most sensitive way to detect a broad class of dark matter candidates – ultra-low mass axions. I will describe how these sensors work and why they can achieve such tremendous energy sensitivity (down to 10^-25 eV!). I will describe the signature of a dark matter detection and some results from recent dark matter searches, and how quantum control may allow us to unlock new regimes of sensitivity.

**Carlos Trallero – Generation and control of non-local indistinguishable XUV photons**
University of Connecticut – Storrs, Connecticut – USA

Through the process of high-harmonic generation we are able to generate two spatially separated ultrafast XUV beams that have a phase jitter of ~10-4 radians which translate to a temporal jitter of <100zs. These two beams can be controlled temporally with a resolution of <100zs. By reconstructing the harmonic spectra one and two photons at a time we are able to establish that a) the each XUV photon contains information about the entire spectrum, and b) that there is small but detectable spatial bias towards each optical beam while both beams remain almost perfectly phase locked. We discuss applications towards time-resolved non-local studies.

**Chandra Varma – Quantum-criticality and superconductivity in twisted bi-layer graphene**
University of California, Berkeley – Berkeley, California – USA

Twisted bi-layer graphene shares with cuprates, and heavy-fermion and Fe-based anti-ferromagnets, quantum-critical regimes with linear in T or in H resistivity for whichever kBT or gμBH is much larger than the other. I will show why the statistical mechanical model for it is the quantum-xy model coupled to fermion currents. The essentially exact solution of this model will be summarized. The transport properties as well as the specific heat and thermopower proportional to T ln T with a coefficient related to that of the linear in T and the linear in H resistivity follow. The d-wave symmetry of the superconductivity from the coupling to the fermion-loop current fluctuations in TBG is shown. Time permitting, I will touch also on work with Liang Fu on Wse2, which has similar properties.

**Ilya Vekhter – Bound states and controllable currents on topological Insulator surfaces with extended magnetic defects**

Louisiana State University – Baton Rouge, Louisiana – USA

We show that a magnetic line defect on the surface of a topological Insulator generically supports two branches of spin-polarized and current carrying one-dimensional bound states. We identify the components of magnetic scattering that lead to the bound states. The velocity, and hence spin texture, of each of those branches can be independently tuned by a magnetic field rotated in the plane of the surface. We compute the local net and spin-resolved density of states to identify experimental signatures of the bound states. The net spin polarization and current due to both bound and scattering states vary stepwise as a function of the magnetic component of the scattering potential, and can be tuned by an applied field. We discuss stability of the bound states with respect to impurity scattering.

**Pavel Volkov – Interacting electrons in critical polar metals**

Harvard University – Cambridge, Massachusetts – USA

University of Connecticut – Storrs, Connecticut – USA

Recent years have seen the discovery of a number of polar metals, materials in which itinerant electrons coexist with an inversion-symmetry breaking order. In this talk I will discuss the properties of such systems when the polar ordering temperature is tuned to zero – i. e. at a quantum critical point. Unlike other examples of quantum criticality, the conventional coupling of the soft modes of the polar order (transverse optical phonons) to the electrons is extremely weak. I will demonstrate that unconventional electron-phonon coupling mechanisms allow to circumvent this restriction, leading to rich variety of interacting electron physics. Examples will include non-Fermi liquid states in multiband systems [1], collective modes [2], and superconductivity at low densities [3], where conventional electron-phonon mechanism is not operative. The latter may shed light on the yet unresolved mystery of superconductivity in doped SrTiO3.

[1] P. A. Volkov and P. Chandra, Phys. Rev. Lett. 124, 237601 (2020)

[2] A. Kumar, P. Chandra, Pavel A. Volkov, Phys. Rev. B 105, 125142 (2022)

[3] Pavel A. Volkov, P. Chandra, P. Coleman, Nature Communications, 13 4599 (2022)

**Justin H. Wilson – Measurement and feedback driven entanglement transition in the probabilistic control of chaos**

Louisiana State University – Baton Rouge, Louisiana – USA

In this talk, I show how a dynamical entanglement transition in a monitored quantum system is revealed by a local order parameter with the addition of feedback. Classically, chaotic systems can be stochastically controlled onto unstable periodic orbits and exhibit controlled and uncontrolled phases as a function of the rate at which the control is applied. We show that such control transitions persist in open quantum systems where control is implemented with local measurements and unitary feedback. Starting from a simple classical model with a known control transition, we define a quantum model that exhibits a diffusive transition between a chaotic volume-law entangled phase and a disentangled controlled phase. Unlike other entanglement transitions in monitored quantum circuits, this transition can also be probed by correlation functions without resolving individual quantum trajectories.

**Qian Yang – Opportunities in Machine Learning for Quantum Matter**

Louisiana State University – Baton Rouge, Louisiana – USA

In recent years, machine learning has found a resurgence of popularity in scientific fields as a tool with the potential to not only significantly increase the scale and power of current computational and experimental techniques, but also to fundamentally change our ability to derive models and make decisions in scientific applications. In this talk, I will explore keyways in which machine learning may be used for quantum matter research, from speeding up analysis of experimental and computational data, to designing more efficient experiments, to building faster computational models and even generating new ideas. I will also touch on ways in which research in quantum matter in return can help the machine learning community develop better algorithms.

## Posters

### Jorge Chavez-Carlos – Spectral kissing and its dynamical consequences in the squeezed Kerr-nonlinear oscillator

University of Connecticut – Storrs, Connecticut – USA

Transmon qubits are the predominant element in circuit-based quantum information processing due to their controllability and ease of engineering implementation. But more than qubits, transmons are multilevel nonlinear oscillators that can be employed in the discovery of new fundamental physics. Here, they are explored as simulators of excited state quantum phase transitions (ESQPTs), which are generalizations of quantum phase transitions to excited states. We show that the coalescence of pairs of adjacent energy levels (spectral kissing) recently observed with a squeezed Kerr oscillator [arXiv:2209.03934] is an ESQPT precursor. The classical limit of this system explains the origin of the quantum critical point and its consequences for the quantum dynamics, which includes both the fast scrambling of quantum information, characterized by the exponential growth of out-of-time-ordered correlators, and the slow evolution of the survival probability at initial times, caused by the localization of the energy eigenstates at the vicinity of the ESQPT. These signatures of ESQPT in the spectrum and in the quantum dynamics are simultaneously within reach for current superconducting circuits experiments.

### Patrick Keeney – Investigation of the magnetic exchange pathways of transition-metal substituted $TiS_2$

University of North Florida – Jacksonville, Florida – USA

2D materials have been of growing interest since the development of graphene in 2004. In particular, transition-metal dichalcogenides (TMD's) are of special interest due to their potential applications toward electrodes, solar cells, and nanoscale technology as a whole. In this study, we use Density Functional Theory (DFT) to analyze how the magnetic exchange pathways of TiS2 change as a function of transition-metal (V, Cr, Mn) dopants and separation between dopants. This is done by analyzing the Heisenberg exchange, electron density, and Mullikan population of dopants as they are separated by further distances inside the lattice. In addition, electronic properties are analyzed through band structure, density of states and orbital interactions.

**Joseph Prescott – Probing intermolecular magnetic interactions in a metal complex by inelastic neutron scattering**

University of North Florida – Jacksonville, Florida – USA

Molecular magnetic materials, such as single-molecule magnets (SMMs) composed of a single paramagnetic metal center complexed by organic ligands, are of intense interest for their potential applications as traditional bits in high-density data storage devices or as qubits in quantum computers. It is generally assumed that these paramagnetic centers behave independently of one another. However, spin-spin couplings among the molecules are known to contribute to magnetic relaxation. Few techniques exist to directly probe the intermolecular magnetic interactions. We have utilized inelastic neutron scattering (INS) to reveal these interactions in a field-induced single-molecule magnet, Mn(TPP)Cl ($TPP^{2-}$ = meso-tetraphenylporphyrinate) as an oscillatory Q-dependence of the magnetic transition. We analyze the INS results using a combination of Heisenberg spin-spin exchange for intermolecular spin interactions in combination with single-ion excitations.

**Priya Sharma – Writeable Vortices in Superconductors via the Inverse Faraday Effect**

University of Connecticut – Storrs, Connecticut – USA

We propose a purely optical mechanism to induce vortices in superconductors in the absence of applied magnetic fields. A static local magnetic moment is induced via the inverse Faraday effect (IFE) on the application of terahertz light. In the clean limit, this induced moment can be large enough to create topological excitations in conventional superconductors in the zero-field limit. The effect can be enhanced by tuning the magnitude of the superconducting order parameter. We present a microscopic calculation of the induced local field that can generate vortices.

**Wenzheng Wei – Solid state reduction of nickelate thin films**

Louisiana State University – Baton Rouge, Louisiana – USA

The square-planar nickelates are a novel class of superconductors. The parent phase of doped superconducting films is $NdNiO_2$, which is prepared by reducing 3+ Ni in $NdNiO_3$ films. Here we demonstrate an ultra-high vacuum reduction method using aluminum deposited on top of the 3+ nickelates, and monitor the reduction process in real time through in-situ crystal truncation rod (CTR) measurements and diffraction XANES (dXANES) measurements across the Ni K edge. We establish a relation between Ni valence and the lattice constant of $NdNiO_{3-x}$ and show that the reduction process can be applied to other nickelate systems.

**Patrick J. Wong – Appearance of odd-frequency superconductivity in a relativistic scenario**
University of Connecticut – Storrs, Connecticut – USA

Nordic Institute for Theoretical Physics – Stockholm – Sweden

Odd-frequency superconductivity is an exotic superconducting state in which the symmetry of the gap function is odd in frequency. Here we show that an inherent odd-frequency mode emerges dynamically under application of a Lorentz transformation of the anomalous Green function with the general frequency-dependent gap function. To see this, we consider a Dirac model with quartic potential and perform a mean-field analysis to obtain a relativistic Bogoliubov-de Gennes system. Solving the resulting Gor'kov equations yields expressions for relativistic normal and anomalous Green functions. The form of the relativistically invariant pairing term is chosen such that it reduces to BCS form in the non-relativistic limit. We choose an ansatz for the gap function in a particular frame which is even-frequency and analyze the effects on the anomalous Green function under a boost into a relativistic frame. The odd-frequency pairing emerges dynamically as a result of the boost. In the boosted frame the order parameter contains terms which are both even and odd in frequency. The relativistic correction to the anomalous Green function to first order in the boost parameter is completely odd in frequency. This work provides evidence that odd-frequency pairing may form intrinsically within relativistic superconductors.

## List of Participants

| First Name | Last Name | Affiliation |
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## Break Time Puzzles

Keep your brain going!

### Quantum Matter Word Search

Find these words in the puzzle!

| | | |
|---|---|---|
| Anderson | Fermion | Materials |
| Boson | Heisenberg | Matter |
| Coupling | Kagome | Quantum |
| Dark | Kondo | Superconductivity |
| Dirac | Magnetism | Topological |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M | Q | Y | H | X | R | L | A | C | N | V | O | V | W | Q | K | V | M | M | T | A | D | V | A | T | E | L | G | T | M |
| I | S | D | L | E | M | D | F | Z | G | T | D | C | S | S | E | R | A | W | F | M | I | L | D | D | R | A | U | C | V |
| P | E | I | T | A | G | F | O | P | K | B | P | L | K | R | M | H | E | B | T | F | U | L | N | A | K | D | O | K | T |
| R | F | T | T | A | A | Q | U | S | H | N | R | F | D | N | F | D | M | K | E | Y | B | H | Y | W | C | L | Q | F | B |
| E | A | V | W | E | O | B | T | S | E | L | P | I | G | A | A | G | C | S | Y | E | I | R | C | G | A | Q | V | X | N |
| M | X | Z | O | H | N | M | B | I | X | C | P | C | H | T | F | M | O | K | M | U | T | W | Q | W | K | D | W | Q | R |
| X | N | P | Y | V | C | G | A | S | Z | R | X | X | C | G | Z | W | M | T | W | O | G | C | K | T | S | K | C | T | M |
| D | X | N | L | V | O | S | A | M | Y | E | E | D | B | I | K | E | Q | C | A | Z | X | Q | S | F | D | H | H | L | H |
| P | L | D | G | K | D | N | C | M | C | G | E | B | S | H | A | M | Z | S | L | A | I | R | E | T | A | M | P | W | R |
| U | F | S | A | X | V | D | G | X | R | N | B | R | W | S | F | U | O | G | G | W | V | R | I | D | O | C | K | S | H |
| W | D | I | V | Z | B | Q | Q | C | Y | U | E | V | W | Y | J | T | Q | T | N | M | O | F | F | G | S | R | P | K | E |
| N | R | V | C | P | C | M | A | S | H | N | M | E | K | P | J | N | K | I | C | O | B | F | Y | U | O | O | S | I | I |
| T | B | D | J | R | D | L | Z | N | T | T | E | X | H | T | O | A | C | R | X | J | O | U | P | O | F | M | X | C | S |
| Q | Z | P | Y | J | V | K | C | R | D | J | B | V | Y | D | R | U | P | D | O | F | X | E | U | I | Y | Q | A | S | E |
| N | M | U | Q | W | Q | J | K | I | R | E | M | E | L | N | D | Q | K | Q | U | H | R | D | L | E | Q | R | L | K | N |
| F | T | D | A | L | E | E | B | I | O | K | R | G | P | A | I | U | R | D | O | C | D | U | N | N | I | H | U | W | B |
| J | S | L | B | Y | F | E | R | M | I | O | N | S | S | L | A | N | A | X | O | Q | A | D | X | D | O | U | R | L | E |
| P | J | U | M | S | N | K | Z | B | B | Y | H | X | O | H | F | X | D | N | E | X | V | H | E | A | M | L | N | C | R |
| L | I | V | K | A | V | S | E | D | C | L | O | H | D | N | W | K | D | K | J | K | S | M | L | U | L | D | W | J | G |
| X | O | J | K | M | S | O | O | C | W | E | I | R | M | W | Q | U | I | N | G | H | S | B | H | N | M | Z | X | E | O |
| J | A | L | L | Y | C | C | Q | P | Z | I | J | D | J | G | C | T | X | V | Q | P | U | W | L | M | Q | U | Z | X | E |
| X | G | O | G | Q | K | G | T | A | K | H | F | F | W | T | T | S | F | Y | U | G | X | B | V | X | O | Y | V | W | Y |
| I | J | Q | W | E | C | I | L | W | C | E | B | S | I | G | X | N | D | H | O | D | L | W | O | W | I | O | I | K | C |
| J | I | G | B | T | O | I | L | G | K | S | S | V | L | V | N | V | C | Z | Z | T | M | K | Q | S | H | K | T | D | Z |
| Q | W | G | Y | K | U | D | U | J | Q | H | I | L | O | A | M | C | V | R | E | V | Y | M | X | J | O | K | W | B | E |
| O | T | U | Q | N | P | Q | V | Y | S | T | L | T | X | T | O | P | O | L | O | G | I | C | A | L | O | N | E | P | P |
| I | A | Y | N | W | L | X | G | B | Y | W | F | N | X | J | Q | X | Y | C | L | I | C | G | O | N | J | G | A | X | M |
| Y | Y | H | K | L | I | J | P | H | R | E | O | V | G | J | J | H | N | F | S | V | T | I | D | W | V | A | I | A | Q |
| O | Y | S | I | L | N | D | V | P | P | I | J | C | C | T | V | P | N | X | P | O | D | O | Z | Y | H | A | G | R | J |
| C | Z | I | S | F | G | Z | C | R | Z | F | H | D | D | H | W | D | I | W | E | M | O | G | A | K | U | L | B | M | A |

(For solutions, talk to Jason Haraldsen)

**Symmetry Point Sudoku**

Complete the Sudoku Puzzle using these electronic structure symmetry points!

G, K, M, L, A, H, X, U, W

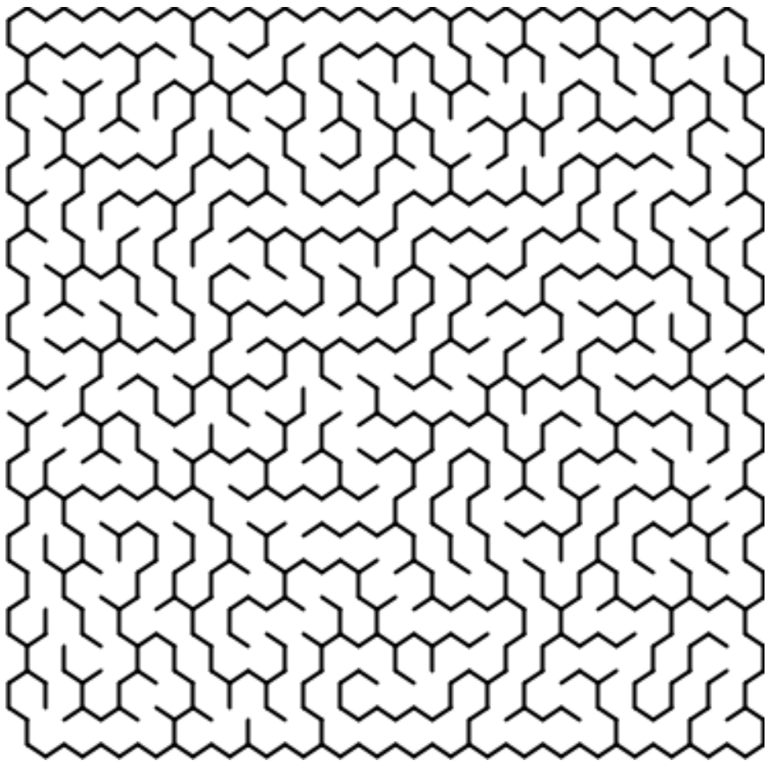
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | W | | | | | G | |
| | | | | | X | | | |
| M | | | K | | G | X | | |
| | U | A | | | | | | |
| K | | | | H | | | W | |
| | H | G | | | L | U | | |
| | | | | | H | W | | |
| A | | | U | | | | X | L |
| | L | M | | | | | | |

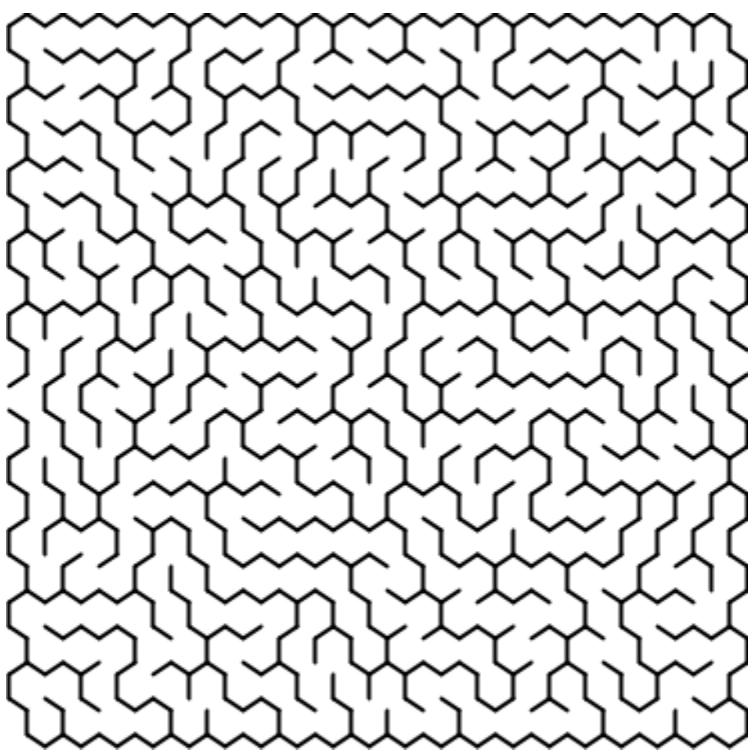
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | A | L | | | K |
| | | | | | X | | M | |
| | | | | K | | G | | |
| | A | K | L | | | | U | G |
| | | | U | | | | | |
| | | | H | | | | W | |
| | | | A | U | H | M | | |
| | | U | | | | | | |
| | | A | | | G | U | | |

(For solutions, talk to Jason Haraldsen)

**Honeycomb Lattice Maze**

Navigate the vacancies in the honeycomb lattices!





# Note Pages