Conference on Advances in Topological Condensed Matter | (SMR 3980)

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Signature of Anyonic Statistics in the Integer Quantum Hall Regime

T01

Abstract template for Conference on Advances in Topological Condensed Matter — (smr 3980)

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In this talk, I will focus on fractional charges as well as Majorana zero modes bound to vortices in topological materials that are in proximity to superconductors. I will discuss how these fractional charges evolve into Majorana zero modes as the coupling to the superconductor gets stronger. In particular, I will focus on proximitized (i) Quantum Anomalous Hall insulators, (ii) 3D Topological insulators and (iii) 3D magnetic topological insulators, and present our recent results on how to isolate and manipulate $e/4$ charges [1]. I will also show how fractional charge/Majorana (abelian/nonabelian anyon) physics differs in different dimensions and physical platforms. I will explain how these $e/4$ charges (abelian anyons) can be manipulated to fuse with Majorana zero modes (nonabelian anyons) in proximitized topological materials. The resulting anyon has all the nonabelian exchange properties of Majorana zero modes but with a different abelian exhange phase, which implies the fused anyon has a different topological spin. This opens the way to manipulate the topological spin of Majorana zero modes and, among other things, implement topologically protected phase operations in Majorana platforms that are based on the superconducting proximity effect [1].

[1] S.R. de Wit, E. Duman, A.M. Bozkurt and I. Adagideli, manuscript in prep. (2024).

T02

Title:

GdAlSi: A potential candidate for altermagnetic topological Weyl semimetal

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Abstract:

Spintronics has emerged as a viable alternative to conventional electronics in the past few decades. On one hand, discovery of topological phases of matter with protected spin-polarized states have shown promising applications while on the other hand, new magnetic materials have shown in- triguing phases of collinear antiferromagnets with unconventional spin-splitters. In this work, we report the co-existence of these two interesting phases in a single material: GdAlSi. GdAlSi crys- tallizes in a body-centered tetragonal structure with a non-centrosymmetric space group I41md (109). The magnetization data indicates antiferromagnetic (AFM) ordering with an ordering temperature (TN) 32 K. Ab-initio calculations show GdAlSi to be a collinear antiferromagnetic Weyl semimetal (WSM) with an unconventional momentum-dependent spin splitting (also nomenclature as altermagnetism). Fermi arcs, a characteristic feature of WSMs, have been subsequently observed in angle-resolved photoemission spectroscopy (ARPES) measurements performed on GdAlSi single crystals. Electric and magnetic multipole analysis gives a deeper insight into the symmetry mediated momentum-dependent spin splitting which has a strictly non-relativistic origin. To the best of our knowledge, such coexistence of unconventional AFM order and non-trivial topology is unprecedented and has never been observed before in any material which makes GdAlSi a wonder material. Finally, we propose a device which can leverage this unique coexistence leading to practical and efficient topotronic application

T03

Casimir Effect in Topological Systems

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Topological materials have attracted great attention in the last few decades. The exotic electromagnetic and transport properties of topological materials have been extensively studied, e.g. the gasless surface state and topological magnetoelectric effect in topological insulators, the surface Fermi arc and chiral magnetic effect of Weyl semimetals, etc.

There is actually another routine for the investigation of Casimir effect in topological materials. Repulsive Casimir force in topological insulators, Chern insulators, quantum Hall systems, and Weyl semimetals are widely studied. In 2020, We found that the chiral anomaly in Weyl semimetals can induce a novel Casimir-Lifshitz torque [1]. In this talk, I will give a brief report about our work: the chiral-anomaly-driven Casimir-Lifshitz torque (CLT) in Weyl semimetals, and the sign-reversal of CLT in nodal-line semimetals [2]. We find that the unique dispersion of nodal-line semimetal in different directions provides a general mechanism for the formation of sign-reversal of CLT. For a typical system, $5PCH/Ca_2P_3$ with intervening layer, the CLT has a sign-reversal at about 30 nm, which is very close to the experimental accessible regime. This pave the way for the experimental research of this exotic phenomena. If time permits, I will also talk about our recent work on spin-orbit interaction (SOI) induced CLT in two-dimensional electron gas system [3]. Using path integral method in quantum field theory, we have developed a perturbation theory to study the CLT induced by SOI. We find that the CLT is proportional to the fourth power of SOI, which demonstrates that CLT can be significantly enhanced in strong SOI systems, for example, $LaWN_3$ and $BiInO_3$.

[1] Liang Chen, Kai Chang, Phys. Rev. Lett. **125**, 047402 (2020).
[2] Liang Chen, Xuan Guo, Phys. Rev. B **107**, 115154 (2023).
[3] Jia-Nan Rong, Liang Chen, Kai Chang, Sci. China-Phys. Mech. Astron. 67, 287012 (2024).

T04

Quantum spin Hall insulator in proximity with a superconductor: Transition to the Fulde-Ferrell-Larkin-Ovchinnikov state driven by a Zeeman field

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We investigate the effects of introducing a boost (a Zeeman field parallel to the spin quantization axis) at the proximitized helical edge of a two-dimensional (2D) quantum spin Hall insulator. Our self-consistent analysis[1] finds that a Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) superconducting phase may emerge at the edge when the boost is larger than a critical value tied to the induced pairing gap.

A non-trivial consequence of retaining the 2D bulk in the model is that this boundary FFLO state supports a finite magnetization as well as a finite current (flowing along the edge). This has implications for a proper treatment of the ultra-violet cutoff in analyses employing the effective one-dimensional (1D) helical edge model.

Our results may be contrasted with previous studies of such 1D models, which found that the FFLO phase either does not appear for any value of the boost (in non-self-consistent calculations), or that it self-consistently appears even for infinitesimal boost, but carries no current and magnetization.

[1] Suman Jyoti De, Udit Khanna, Sumathi Rao, Sourin Das, Phys. Rev. B. **108,** L161403 (2023).

T05

Signatures of Majorana bound states in topological Andreev interferometers via electron waiting time distributions

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The signatures of Majorana bound states in an Andreev interferometer where a superconducting loop with a controllable phase difference is connected to a quantum spin Hall edge, are captured via the electron waiting times and the correlation between them. The edge state helicity enables the transfer of electrons and holes into separate leads controlled by the phase difference of the loop. In this setup, the topological phase transition with emerging bound states occurs at $\phi = \pi$ and electron waiting times are sensitive to it. However, the waiting times for the Andreev-reflected holes remain insensitive. These two different waiting times show opposite behaviors when we consider the correlation between them. Some of the cross-distributions also show unique features indicating the appearance of topological Andreev bound states.

[1] P. Dutta, J. Cayao, A. M. Black-Schaffer, and P. Burset, **6**, L012062 (2024).

T06

Local and energy-resolved topological invariants for Floquet systems

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Periodically driven systems offer a perfect breeding ground for out-of-equilibrium engineering of topological boundary states at zero energy (0-mode), as well as finite energy (π-mode), with the latter having no static analog. The Floquet operator and the effective Floquet Hamiltonian, which encapsulate the stroboscopic features of the driven system, capture both spectral and localization properties of the 0- and π-modes but sometimes fail to provide complete topological characterization, especially when 0- and π-modes coexist. In this work [1], we utilize the spectral localizer, a powerful local probe that can provide numerically efficient, spatially local, and energy-resolved topological characterization [2]. In particular, we apply the spectral localizer to the effective Floquet Hamiltonian for driven one- and two-dimensional topological systems with no or limited symmetries and are able to assign topological invariants, or local markers, that characterize the 0- and the π-boundary modes individually and unambiguously. Due to the spatial resolution, we also demonstrate that the extracted topological invariants are suitable for studying driven disordered systems and can even capture disorder-induced phase transitions.

[1] A. K. Ghosh, R. Arouca, and A. M. Black-Schaffer, arXiv:2408.08548.
[2] T. A. Loring, Annals of Physics **356**, 383 (2015).

T07

Quantum phase diagram and topological chiral superconductivity in doped triangular-lattice Mott insulators

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The topological superconducting state is a highly sought-after quantum state hosting topological order and Majorana excitations. We will talk the mechanism to realize the topological superconductivity (TSC) in the doped Mott insulators with time-reversal symmetry (TRS). Through density matrix renormalization group study of an extended triangular-lattice *t*-*J* model, we identify a *d*+i*d*-wave chiral TSC with spontaneous TRS breaking, characterized by a Chern number C=2 and quasi-long-range superconducting order. We map out the quantum phase diagram with by tuning the next-nearest-neighbor (NNN) electron hopping and spin interaction. In the weaker NNN-coupling regime, we identify a pseudogaplike phase with a charge stripe order coexisting with fluctuating superconductivity, which can be tuned into *d*-wave superconductivity by increasing the doping level and system width. The TSC emerges in the intermediate-coupling regime, which has a transition to a *d*-wave superconducting phase with larger NNN couplings. The emergence of the TSC is driven by geometrical frustrations and hole dynamics which suppress spin correlation and charge order, leading to a topological quantum phase transition.

[1] Y. Huang, S. S. Gong, D. N. Sheng, Phys. Rev. Lett. **130**, 136003 (2023).

T08

Can quantum topology be exploited in emerging devices?

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Abstract

Two-dimensional (2D)- topological insulators, a class of quantum materials, have been at the forefront of condensed matter physics research. These materials offer symmetry protected ballistic channels that are robust to a large degree against certain forms of ``symmetry permitting'' disorder. Furthermore, quantum phase transitions between a *conducting* topological phase and an *insulating* trivial phase can be engineered via electrical and magnetic means. These two aspects that innately stem from the quantum topology concepts can potentially offer unprecedented possibilities for modern emerging devices, paving the way for ``topological electronics''- translating quantum topology to emerging devices.

Keeping in perspective, the state-of-the-art in computational nanoscale device modeling, this talk aims to explore emerging devices that exploit quantum topological phenomena. Starting from the tenets of quantum transport theory in connection with the current device modeling trends, we will propose device structures using monolayer 2D-Xene materials, which can potentially be engineered to harness quantum topology. We show how device modeling can be adapted to not only model current experiments but also come up with novel device structures that can produce ``on-demand'' symmetry protection [1]. Specifically, we demonstrate as to how edge states possessing a desired symmetry protection, for instance, spin-valley locking, can be achieved via gating strategies. We then depict how to conceptualize realistic device structures [2] that exploit the quantum field-effect transitions and how to navigate the quantum phase space further to ultimately restore the topological robustness of the ON-state while simultaneously surpassing the thermionic limit. We will also explain how device modeling can incorporate ``real-world'' effects which include disorder and relaxation [2-4] present in realistic device structures. We finally close the loop by extending our platform to the field of quantum technologies with our latest developments on machine learning based simulation platforms for qubits in the bilayer graphene platform [5].

We conclude by providing an in-depth outlook on how quantum transport modeling can be seamlessly integrated into circuit models for providing an atom-to-circuit realization [6,7]. In doing so, we also provide our perspectives on what quantum transport-based device modeling needs to incorporate in order to transition toward an all-encompassing platform in the near future.

References

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[7] A. Mukherjee and B. Muralidharan, 2D Materials, 10, 035006, (2023).

Short Bio

Prof. Bhaskaran Muralidharan obtained his Ph. D in Electrical Engineering from Purdue University, West Lafayette, USA in 2003 and 2008 respectively. Between 2008-2012, he was a post-doctoral associate at the Massachusetts Institute of Technology (MIT) and at the Institute for theoretical Physics at the University of Regensburg, Germany. Since 2012, he has been a faculty in the Department of Electrical Engineering at IIT Bombay, where he is currently a Professor. His research output spans diverse areas of emerging nanoscale devices, ultimately built on top of a broad and fundamental foundation of utilizing quantum transport for novel functionalities. He is an Associate Editor in the IEEE Transactions on Nanotechnology, on the Editorial board of Scientific Reports and Materials for Quantum Technology (IOP). He has also been a visiting Professor at the Institute for Quantum Computing (IQC), University of Waterloo, Canada and the InstituteQ in Aalto University, Finland.

T09

Signature of Anyonic Statistics in the Integer Quantum Hall Regime

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Two-dimensional electron gas in the fractional quantum Hall regime hosts exotic anyonic excitations with a fractional charge and exchange statistics that is intermediate between those of fermions and bosons. The fractional quantum Hall regime provides a natural host, with first convincing anyon signatures recently observed through interferometry and cross-correlations of colliding beams. In the latter, anyonic statistics leads to a negative sign of these cross-correlations for two dilute beams. However, fractional regime is rife with experimental complications and exhibits discrepancies with theory, impeding further manipulation of anyons.
In this work [1] we show experimentally that the canonical integer quantum Hall regime can provide a robust anyonic platform. Exploiting the Coulomb interaction between two co-propagating quantum Hall channels, an electron injected into one channel splits into two fractional charges which behave as abelian anyons. Their unconventional statistics is revealed by negative cross-correlations between dilute quasiparticle beams. Similarly to fractional quantum Hall observations, we show that the negative signal stems from a time-domain braiding process, here involving the incident fractional quasiparticles and spontaneously generated electron-hole pairs. Beyond the dilute limit, a theoretical understanding is achieved via the edge magnetoplasmon description of interacting integer quantum Hall channels. Our findings establish that, counter-intuitively, the integer quantum Hall regime provides a platform of choice for exploring and manipulating quasiparticles with fractional quantum statistics.

[1] P. Glidic, *et al*., Nat. Commun. **15**, 6578 (2024).