TT 11: Topology: Quantum Hall Systems

Time: Tuesday 9:30–12:30 Location: H10

TT 11.1 Tue 9:30 H10

Quantum Hall effect induced by chiral Landau levels in topological semimetal films — •Duy-Hoang-Minh Nguyen[1], Koji Kobayashi[2], Jan-Erik Reinhard Wichmann[3], and Kentaro Nomura[2] — [1]Donostia International Physics Center, Donostia-San Sebastian, Spain — [2]Department of Physics, Kyushu University, Fukuoka, Japan — [3]Institute for Materials Research, Tohoku University, Sendai, Japan

Motivated by recent transport experiments, we theoretically study the quantum Hall effect in topological semimetal films. Owing to the confinement effect, the bulk subbands originating from the chiral Landau levels establish energy gaps that have quantized Hall conductance and can be observed in relatively thick films. We find that the quantum Hall state is strongly anisotropic for different confinement directions not only due to the presence of the surface states but also because of the bulk chiral Landau levels. As a result, we re-examine the quantum Hall effect from the surface Fermi arcs and chiral modes in Weyl semimetals and give a more general view into this problem. Also, we find that when a topological Dirac semimetal is confined in its rotational symmetry axis, it hosts both quantum Hall and quantum spin Hall states, in which the helical edge states are protected by the conservation of the spin-z component.

TT 11.2 Tue 9:45 H10

Quantum Hall critical phase at topological insulator surfaces — •Johannes Dieplinger[1], Mateo Moreno-Gonzalez[2], Soumya Bera[3], Martin Puschmann[1], Matthew Foster[4], Ferdinand Evers[1], and Alexander Altland[2] — [1]University of Regensburg, Regensburg, Germany — [2]Universiy of Cologne, Cologne, Germany — [3]IIT Bombay, Mumbai, India — [4]Rice University, Houston, Texas, USA

We show that an AIII three-dimensional topological insulator, when tuned away from the critical point at zero energy, realizes a finite class A critical phase on its surface, i.e. a continuum of quantum Hall critical states, instead of an naively expected quantum Hall insulator. Criticality is characterized numerically via an analysis of the multifractal exponents of the wave functions at the surface of the three dimensional bulk.

This numerical work supports a recently proposed first principle theory explaining the existence of the quantum Hall critical phase. Open questions remain concerning the nature of disordered surface states with higher topological index.

TT 11.3 Tue 10:00 H10

Universal properties of boundary and interface charges in multichannel models of one-dimensional insulators — •Kiryl Piasotski[1], Niklas Muller[1], Dante Kennes[1,2], Herbert Schoeller[1], and Mikhail Pletyukhov[1] — [1]Institut fur Theorie der Statistischen Physik, RWTH Aachen, 52056 Aachen, Germany — [2]Max Planck Institute for the Structure and Dynamics of Matter, Center for Free Electron Laser Science, 22761 Hamburg, Germany

Generalizing our previous results on a one-dimensional single-channel continuum [1] and multichannel tight-binding [2] models, we present novel topological invariants to characterize boundary and interface charges in systems described by one-dimensional Schrödinger operators with periodic non-Abelian vector and scalar potentials. In particular, we prove that the change in boundary charge upon the continuous shift of the system towards the boundary by the distance $x_\varphi \in [0, L]$ (L-period) is given by the sum of the linear function of x_φ and an integer-valued topological index $I(x_\varphi)$ - the boundary invariant, and provide two equivalent representations of $I(x_\varphi)$. In addition, we study translationally invariant systems interrupted by a localized impurity, we show that an excess charge on the impurity is a quantized integer quantity given by a winding number expression.

[1] Phys. Rev. B **104**, 155409 (2021)
[2] Phys. Rev. B **104**, 125447 (2021)

TT 11.4 Tue 10:15 H10

antiferromagnetic chern insulator in a centrosymmetric system — •morad ebrahimkhas[1], mohsen hafez-torbati[2], and walter hofstetter[1] — [1]Institut für Theoretische Physik, Goethe-Universität, 60438 Frankfurt/Main, Germany — [2]Lehrstuhl für Theoretische Physik I, Technische Universität Dortmund, Otto-Hahn-Straße 4, 44221 Dortmund, Germany

An antiferromagnetic Chern insulator (AFCI) can exist if the effect of the time-reversal transformation on the AF state cannot be compensated by a space group operation. Such a state has recently been reported in a noncentrosymmetric Kane-Mele-Hubbard model. We investigate the possible emergence of this phase in a centrosymmetric system. We consider a minimal extension of the time-reversal invariant Harper-Hofstadter- Hatsugai model. The next-nearest-neighbor hopping opens a gap at half-filling and allows for the realization of a quantum spin Hall insulator. We add to the system a staggered potential Δ and the Hubbard interaction U favoring a normal insulator and a Mott insulator, respectively. We map out the phase diagram of the model in the U-Δ plane and show that an AFCI with the Chern number C = 1 appears for (U∼2Δ) ≫ t. We find that for a fixed Δ upon increasing U a spin-flop transition from the C = 1 z-AFCI to a topologically trivial xy-AF phase takes place. Our findings can be used as a guideline in future investigations searching for an AFCI in optical lattices.

TT 11.5 Tue 10:30 H10

Supercurrent-enabled Andreev reflection in a chiral quantum Hall edge state — Andreas Bock Michelsen[1,2], Patrik Recher[3], Bernd Braunecker[1], and •Thomas L. Schmidt[2] — [1]University of St Andrews, UK — [2]University of Luxembourg, Luxembourg — [3]Technische Universität Braunschweig, Germany

A chiral quantum Hall (QH) edge state placed in proximity to an s-wave superconductor experiences induced superconducting correlations. Recent experiments have observed the effect of proximity-coupling in QH edge states through signatures of the mediating process of Andreev reflection. We present the microscopic theory behind this effect by modeling the system with a many-body Hamiltonian, consisting of an s-wave superconductor, subject to spin-orbit coupling and a magnetic field, which is coupled by electron tunneling to a QH edge state. By integrating out the superconductor we obtain an effective pairing Hamiltonian in the QH edge state. We clarify the qualitative appearance of nonlocal superconducting correlations in a chiral edge state and analytically predict the suppression of electron-hole conversion at low energies (Pauli blocking) and negative resistance as experimental signatures of Andreev reflection in this setup. In particular, we show how two surface phenomena of the superconductor, namely Rashba spin-orbit coupling and a supercurrent due to the Meissner effect, are essential for the Andreev reflection. Our work provides a promising pathway to the realization of Majorana zero-modes and their parafermionic generalizations.

15 min. break

TT 11.6 Tue 11:00 H10

Synthetic gravitational horizons in low-dimensional quantum matter — •Corentin Morice[1], Ali G. Moghaddam[2,3], Dmitry Chernyavsky[2], Jasper van Wezel[1], and Jeroen van den Brink[2,4] — [1]Institute for Theoretical Physics and Delta Institute for Theoretical Physics, University of Amsterdam, 1090 GL Amsterdam, The Netherlands — [2]Institute for Theoretical Solid State Physics, IFW Dresden, Helmholtzstrasse 20, 01069 Dresden, Germany — [3]Department of Physics, Institute for Advanced Studies in Basic Sciences (IASBS), Zanjan 45137-66731, Iran — [4]Institute for Theoretical Physics and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universitt Dresden, 01069 Dresden, German

We propose a class of lattice models realizable in a wide range of setups whose low-energy dynamics exactly reduces to Dirac fields subjected to (1+1)-dimensional gravitational backgrounds, including (anti-)de Sitter spacetime. Wave-packets propagating on the lattice exhibit an eternal slowdown for power-law position-dependent hopping integrals $t(x) \propto x^\gamma$ when $\gamma \geq 1$, signalling the formation of black hole event horizons. For $\gamma < 1$ instead the wave-packets behave radically different and bounce off the horizon. We show that the eternal slowdown relates to a zero-energy spectral singularity of the lattice model and that the semiclassical wave packets trajectories coincide with the geodesics on (1+1)D dilaton gravity, paving the way for new and experimentally feasible routes to mimic black hole horizons and realize (1+1)D spacetimes as they appear in certain gravity theories.

TT 11.7 Tue 11:15 H10

Adiabatic preparation of fractional quantum Hall phases from the thin torus limit — •Benjamin Michen[1], Cécile Repellin[2], and Jan Carl Budich[1] — [1]Institute of Theoretical Physics, Technische Universität Dresden — [2]Univ. Grenoble-Alpes, CNRS, LPMMC, 38000 Grenoble, France

We explore as to what extent reversing the thin torus (TT) limit enables the adiabatic preparation of fractional quantum Hall (FQH) states in quantum simulators. As a novel approach, the TT limit is taken by increasing the hopping amplitude in one direction in order to make the system effectively one-dimensional.

The regime of strongly anisotropic coupling features the expected charge density wave (CDW) ground state. The CDW state can be adiabatically connected to the FQH state by tuning the coupling back to the isotropic regime without closing the many-body excitation gap along the way. This may provide an experimental path to the adiabatic preparation of FQH states from topologically trivial CDW states.

We find that the many-body excitation gap in the TT limit decreases with system size for fully discrete models, which limits the adiabatic preparation. However, there appears to be no such restriction in a semicontinuous setup of coupled wires. In that sense, the proposed protocol could be experimentally relevant for arbitrary system sizes.

TT 11.8 Tue 11:30 H10

Non-Hermitian topological signatures in a quantum Hall system — •Raghav Chaturvedi[1], Kyrylo Ochkan[1], Viktor Könye[1], Ewelina Hankiewicz[2], Jeroen van den Brink[1], Joseph Dufouleur[1], and Cosma Fulga[1] — [1]IFW Dresden, Deutschland — [2]Julius Maximilian University of Würzburg

Reflection matrices describing waves reflected from the boundaries of insulators exhibit non-Hermitian topological signatures. Drawing from this, we propose to realize non-Hermitian topology in the quantum regime of a two dimensional condensed-matter system. Our work is based on the insight that, in the limit of maximal non-reciprocity, the Hamiltonian for the simplest topological non-Hermitian system – the Hatano-Nelson chain – effectively describes a one-dimensional, unidirectionally propagating mode. This is analogous to the unidirectional boundary mode of a fully Hermitian topological insulator: the quantum Hall system. We show that the multi-terminal conductance matrix of this system exhibits a topologically protected non-Hermitian skin effect. Moreover, we show that the topological invariant characterizing these features is more robust than the Chern number, as it remains well-quantized even across quantum Hall plateau transitions. Our work shows that the transport properties of Chern insulators may exhibit signatures of non-Hermitian topology, and this paves the way for the first experimental observation of non-Hermitian topology in a quantum condensed-matter system, which will be presented by another author.

TT 11.9 Tue 11:45 H10

Observation of non-Hermitian topology in a multi-terminal quantum Hall device — •Kyrylo Ochkan[1], Raghav Chaturvedi[1], Viktor Könye[1], Ewelina Hankiewicz[2], Jeroen van den Brink[1], Joseph Dufouleur[1], and Cosma Fulga[1] — [1]IFW Dresden, Deutschland — [2]Julius-Maximilians-Universität Würzburg, Deutschland

One of the simplest examples of non-Hermitian topology is encountered in the Hatano-Nelson (HN) model, a one-dimensional chain where the hopping in one direction is larger than in the opposite direction. We present here the first experimental observation of non-Hermitian topology in a quantum condensed-matter system. The measurements are done in a multi-terminal quantum Hall device etched in a high mobility GaAs/AlGaAs two-dimensional electron gas ring. The conductance matrix that connects the currents flowing from the active contacts to the ground with the voltage of the active contacts is topologically equivalent to the HN Hamiltonian.

In our device, we directly measure and evidence the non-Hermitian skin effect. We also compute for our experimental device two topological invariants that are found to be more robust than the Chern number. We finally use the unique properties of our system and continuously tune the system configuration between open and periodic boundary conditions.

We focus here on the experimental results, whereas the theoretical aspects of the non-Hermitian skin effect and the topological invariants will be discussed in another presentation.

TT 11.10 Tue 12:00 H10

Emergent non-Hermitian topology and boundary sensitivity in interacting Su-Schrieffer-Heeger chains — •Tommaso Micallo, Carl Lehmann, and Jan Carl Budich — Institute of Theoretical Physics, Technische Universität Dresden and Würzburg-Dresden Cluster of Excellence ct.qmat, 01062 Dresden, Germany

The exponential sensitivity of effective Non-Hermitian (NH) Hamiltonians with respect to boundary conditions has recently been predicted and observed in a broad range of settings. Here, we discuss as to what extent this remarkable phenomenon may occur in closed correlated fermionic systems that are governed by a Hermitian many-body Hamiltonian. There, an effectively NH quasiparticle description naturally arises in the Green's function formalism due to inter-particle scattering that represents a source of inherent dissipation. Using exact diagonalization, we analyze as a concrete platform extended Su-Schrieffer-Heeger (SSH) chains with interactions subject to varying boundary conditions.

TT 11.11 Tue 12:15 H10

Absent thermal equilibration on fractional quantum Hall edges over macroscopic scale — •Ron Melcer[1], Bivas Dutta[1], Christian Spanslatt[2,3,4], Jinhong Park[5], Alexander Mirlin[3,4], and Vladimir Umansky[1] — [1]Braun Center for Submicron Research, Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot, 761001, Israel — [2]Department of Microtechnology and Nanoscience, Chalmers University of Technology, S-412 96, Göteborg, Sweden — [3]Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology, 76021, Karlsruhe, Germany — [4]Institut für Theorie der Kondensierten Materie, Karlsruhe Institute of Technology, 76128, Karlsruhe, Germany — [5]Institute for Theoretical Physics, University of Cologne, Zülpicher Str. 77, 50937, Köln, Germany

Two-dimensional topological insulators, and in particular quantum Hall states, are characterized by an insulating bulk and a conducting edge. Fractional states may host both downstream (dictated by the magnetic field) and upstream propagating edge modes, which leads to complex transport behavior. Here, we combine two measurement techniques, local noise thermometry and thermal conductance, to study thermal properties of states with counter-propagating edge modes. We find that, while charge equilibration between counter-propagating edge modes is very fast, the equilibration of heat is extremely inefficient, leading to an almost ballistic heat transport over macroscopic distances. Moreover, we observe an emergent quantization of the heat conductance associated with a strong interaction fixed point of the edge modes.