Abstracts / Talks

Yasuhiro Hatsugai, Department of physics, University of Tsukuba
Bulk-edge correspondence revisited

Although the theoretical proposal of an adiabatic pump due to Thouless [1] is old that was right after the celebrated paper of the quantum Hall effect by TKNN [2], it has been realized experimentally just recently in 2015 [3,4]. The phenomenon is topological and the pumped charge is given by the Chern number. It can be understood as a reinterpretation of the quantum Hall effect with periodic potential by the time as a synthetic dimension. Then it is natural to believe that edge states in the pumping also play a fundamental role according to the bulk-edge correspondence [5]. However, the role of the edge states in the topological pumping was not focused seriously before. We have discussed this problem and defined a new topological invariant by the discontinuities of the center of mass motion, which establishes the bulk-edge correspondence in the topological pumping [5]. Although the two bulk-edge correspondences [5,6] describe the same model, their physical meanings are quite different. In most cases of topological phases, the edges are the physical observables and the bulk is hidden. In the topological pumping, however, the bulk is the physical observable and the edges are hidden. The edges never appear in an experiment of finite speed pumping due to the breakdown of the adiabaticity. Still the edge states topologically guarantee quantization of the pumped charge by the bulk. Effects of randomness in the adiabatic pumping are also discussed [7].

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[3] S. Nakajima, T. Tomita, S. Taie, T. Ichinose, H. Ozawa, L.Wang, M. Troyer, and Y. Takahashi, Nat. Phys. 12, 296 (2016).
[4] M. Lohse, C. Schweizer, O. Zilberberg, M. Aidelsburger, and I. Bloch, Nat. Phys. 12, 350 (2016).
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Mathai Varghese, University of Adelaide
Spectral gap-labelling conjecture for magnetic Schrödinger operators and recent progress

Given a constant magnetic field on Euclidean space R^p determined by a skew-symmetric p x p matrix Θ, and a Z^p-invariant probability measure μ on the disorder set Σ which is by hypothesis a Cantor set, where the action is assumed to be minimal, the corresponding Integrated Density of States of any self-adjoint operator affiliated to the twisted crossed product algebra \$C(Σ) α_σ Z^p, where σ is the multiplier on Z^p associated to Θ, takes on values on spectral gaps in the magnetic gap-labelling group. The magnetic frequency group is defined as an explicit countable subgroup of R involving Pfaffians of Θ and its sub-matrices. We conjecture that the magnetic gap labelling group is a subgroup of the magnetic frequency group. We give evidence for the validity of our conjecture in 2D, 3D, the Jordan block diagonal case, the periodic

case in all dimensions and most recently, the case of principal solenoidal tori in all dimensions.

Gianluca Panati, "La Sapienza" Università di Roma
The Localization-Topology Correspondence in gapped (periodic) systems: ordinary, Chern and Z_2 topological insulators

As realized in a breakthrough paper by Thouless et al. [TKNN], for gapped (periodic) 2D systems a relevant Transport-Topology Correspondence holds true, in the sense that a non-vanishing Hall conductivity corresponds to a non-trivial topology of the space of occupied states, decomposed with respect to the crystal momentum – a space which is called *Bloch bundle* in the recent literature.

More recently, a related Localization-Topology Correspondence has been noticed and mathematically proved for 2D and 3D gapped periodic quantum systems [MPPT].
The result states that the Bloch bundle is trivial if and only if there exixts a system of composite Wannier functions on which the expectation value of the squared position operator is finite. In other words, whenever the system is in a Chern-non-trivial phase, the composite Wannier functions are very delocalized, while in the Chern-trivial phase they can be chosen exponentially localized.

During my talk, I will report on this result and the essential ideas of its proof, as well as on the ongoing attempt to generalize this correspondence to non-periodic gapped quantum systems (work in progress with G. Marcelli and M. Moscolari).

If time permits, I will also discuss how similar ideas can be adapted to deal with time-reversal-symmetric topological insulators, and how the related Z_2 index can be connected with localization properties of the composite Wannier functions.

[MPPT] Monaco, D.; Panati, G.; Pisante, A.; Teufel, S.: Optimal decay of Wannier functions in Chern and Quantum Hall insulators, *Commun. Math. Phys.* 359, 61-100 (2018).

[TKNN] Thouless, D.J.; Kohmoto, M.; Nightingale, M.P.; den Nijs, M.: Quantized Hall conductance in a two-dimensional periodic potential. *Phys. Rev. Lett.* 49, 405–408 (1982).

Alain Joye, Institut Fourier, Université Grenoble Alpes
Chirality induced Interface Currents in the Chalker Coddington Model

Chalker & Coddington provided in 1988 a simplified description of the quantum dynamics of electrons in a plane, submitted to an electric potential and a strong perpendicular magnetic field, in a model that now bears their names. The one time step electronic motion is given by a unitary operator on $l^2(Z^2)$ constructed in terms of scattering matrices attached to the sites of Z^2 that contain the main physical characteristics of the potential and magnetic field at these sites. The transport properties of the electrons are then encoded in the spectral properties of the unitary operator, which is our main concern. We consider the situation where the model presents asymptotically pure anti-clockwise rotation of the electrons on the left and

clockwise rotation of the electrons on the right and we investigate the presence of induced currents at the interface between these two different localised phases. We also discuss situations where currents develop due to peculiarities of the scattering matrices along certain paths in Z^2. The existence of currents is shown by proving that the absolutely continuous spectrum of the Chalker Coddington unitary operator covers the whole unit circle. The result is independent of the details of the model within the interface and possesses some topological features.
This is joint work with J.Asch and O.Bourget

Christopher Mudry, Paul Scherrer Institute, Villigen
Hierarchical Majoranas in a Programmable Nanowire Network

We propose a hierarchical architecture for building "logical" Majorana zero modes using "physical" Majorana zero modes at the Y-junctions of a hexagonal network of semiconductor nanowires. Each Y-junction contains three "physical" Majoranas, which hybridize when placed in close proximity, yielding a single effective Majorana mode near zero energy. The hybridization of effective Majorana modes on neighboring Y-junctions is controlled by applied gate voltages on the links of the honeycomb network. This gives rise to a tunable tight-binding model of effective Majorana modes. We show that selecting the gate voltages that generate a Kekul\'e vortex pattern in the set of hybridization amplitudes yields an emergent "logical" Majorana zero mode bound to the vortex core. The position of a logical Majorana can be tuned adiabatically, *without* moving any of the "physical" Majoranas or closing any energy gaps, by programming the values of the gate voltages to change as functions of time. A nanowire network supporting multiple such "logical" Majorana zero modes provides a physical platform for performing adiabatic non-Abelian braiding operations in a fully controllable manner.

Krzysztof Gawedzki, Laboratoire de Physique, ENS de Lyon
Heat waves in Conformal Field Theory

I shall discuss a class of nonequilibrium states in CFT in one space dimension and how heat transport in such states connects to the representation theory of the group of circle diffeomorphisms.

Max Lein, Tohoku University, AIMR
Towards A Rigorous Proof of Haldane's Photonic Bulk-Edge Correspondence (joint work with Giuseppe De Nittis)

In 2005 Raghu and Haldane predicted an analog of the Integer Quantum Hall Effect in quasi-2d gyrotropic photonic crystals, thereby conjecturing that topological effects are *wave* rather than quantum *phenomena*. These unidirectional, backscattering-free edge modes were indeed observed in a number of beautiful experiments with microwaves, light at optical frequencies, coupled oscillators and other classical waves. Haldane proposed to explain this phenomenon via a *photonic bulk-edge correspondence*: the net number of edge modes that traverse a photonic bulk band gap are given by the bulk Chern number associated to the corresponding “Fermi projection”.

Proving Haldane's conjecture turns out to be significantly harder than expected, because of a number of conceptual and technical difficulties. This talk will explore four of them: (1) Establishing rigorous *quantum-wave analogies* that allow us to systematically adapt tools from quantum mechanics to electromagnetism. (2) Identify the physically *relevant symmetries* and understand their nature. (3) Classify periodic operators with "half a conical crossing". (4) Further develop tools to prove bulk-boundary correspondences for *operators on the continuum*.

The first two problems have been understood, whereas the last two problems are the subjects of active research.

Sebastian Huber, ETH Zürich
Topological Mechanics

The elastic properties of materials are determined by a few material constants such as the Young's modulus. Using super-structures one can effectively change these "constants". In this way we obtain functionalities such as wave-guiding, acoustic lensing or programmable failure. I will show how topological band theory, known from the description of electrons in solids, provides us with a powerful design-principle for such mechanical metamaterials. Moreover, mechanical metamaterials offer a powerful platform for the study of fundamentally new phenomena that are hard to observe in other arenas. Here, I will highlight the first measurement of a quadrupole topological insulator in a silicon based metamaterial and the implementation of an axial gauge field in an acoustic Weyl system.

Giovanna Marcelli, Universität Tübingen
Quantum (spin) Hall conductivity: Kubo-like formula (and beyond)

We study the linear response coefficients of a gapped, periodic and one-particle quantum system to the perturbation of a small electric field, modeled by a potential εX_j with $\varepsilon << 1$, in terms of the conductivity tensor σ_{ij} for both charge and spin transport. The conductivity σ_{ij} is associated with the current operator defined as $i[H_0, S X_i]$, where H_0 is the unperturbed Hamiltonian and S is a self-adjoint operator acting only on the internal degrees of freedom of the system (e.g. spin). This is of relevance for 2-dimensional quantum (spin) Hall systems, where S is the identity operator (resp. S is the third component of the spin operator). The method relies on the characterization of a *non-equilibrium almost-stationary state* (NEASS), defined via space-adiabatic perturbation theory. Whenever S is a conserved quantity, i.e. $[H_0, S] = 0$, we recover the Kubo-like formula for the conductivity, and consequently its quantization in appropriate units. When instead $[H_0, S] != 0$, we show that further correction terms appear in the formula for σ_{ij}. This technique can be applied in both discrete and continuous models. Moreover, in the discrete case we define the Kubo-like spin conductance and prove that it is equal to the Kubo-like spin conductivity.
This talk is based on joint works with D. Monaco (Roma TRE, Rome), G. Panati (La Sapienza, Rome), C. Tauber (ETH Zürich) and S. Teufel (Universität Tübingen).

Kiyonori Gomi, Shinshu University
Band topology and submanifolds of matrices

A quantum system on a lattice which is invariant under translation can be described by the Fourier-transformed Hamiltonian, a function on the Brillouin zone torus with values in the space of Hermitian matrices. Under this description, a classification of the topological phase of the system, such as an insulator and a semimetal, amounts to classifying the homotopy class of the Hamiltonian on the Brillouin zone, and its topological invariant plays a principal role in the classification. My talk relates such topological invariants with cohomology classes on submanifolds in the space of matrices.

Domenico Monaco, Università degli Studi di Roma Tre
A bird's-eye view on Z_2 topology

After the proposal by Fu, Kane and Mele to classify quantum spin Hall phases, and more generally time-reversal symmetric insulators in class AII, by Z_2 indices, the mathematical physics community has come up with a plethora of ways to give rigorous mathematical foundations for this claim. I will review some of these proposals, in particular the one by Graf and Porta expressed in terms of generalized winding numbers of parallel transport unitaries, the one by Gawedzki and collaborators given by a variant of the Wess-Zumino-Witten action, and the one by Fiorenza, Panati and myself formulated in terms of a certain topological obstruction. I will show that these agree (at least numerically) among themselves and with the original proposal from Kane and Mele.
This is based on a series of works joint with H. Cornean, D. Fiorenza, G. Panati, C. Tauber, and S. Teufel.

Johannes Kellendonk, Institut Camille Jordan, Université Claude Bernard
Secondary invariants for real K-theory from cyclic cohomology

The K-theoretical classification of topological phases provides many interesting cases in which there are elements of finite order. For instance, the strong invariant for two- or three-dimensional systems with time reversal symmetry corresponds to the generator of a Z_2. There are various proposals to associate to such abstract K-theory elements numerical values, that is, complex numbers modulo something. We present here a construction which does precisely this on the basis of secondary pairings between K-theory and cyclic cohomology. As a result the numerical invariants will be formulated through integral formulas which are similar to those for the standard chern numbers but involve an extra symmetry operator, either of spin, or of chiral symmetry type.

Oded Zilberberg, ETH Zürich
Topological pumps and topological quasicrystals

In my talk, I will introduce the quantum Hall effect and demonstrate how it is related to topological pumps. I will, then, present recent realizations of topological pumps using two completely different bosonic systems, namely, using coupled photonic waveguide arrays and with trapped atoms in optical superlattices. In the second part of my talk, I will detail the connection between quasicrystals and topological pumps.

In this context, we have found that quasicrystals inherit topological attributes from their corresponding pumps, i.e., quasicrystals are characterized with topological indices from dimensions higher than their own. I will discuss several 1D quasi-periodic models with nontrivial 1st Chern numbers and topological boundary states, which are inherited from their corresponding topological pumps. Last, I will present how this naturally leads to realizing the 4D and 6D quantum Hall effects, as well as and 2D and 3D topological pumps in the lab.

Giuseppe De Nittis, **Pontificia Universidad Católica de Chile**
Spectral Continuity for Aperiodic Quantum Systems

How does the spectrum of a Schrödinger operator vary if the corresponding geometry and dynamics change? Is it possible to define approximations of the spectrum of such operators by defining approximations of the underlying structures? In this talk a positive answer is provided using the rather general setting of groupoid C*-algebras. A characterization of the convergence of the spectra by the convergence of the underlying structures is proved. In order to do so, the concept of continuous field of groupoids is used. The approximation scheme is expressed through the tautological groupoid, which provides a sort of universal model for fields of groupoids. The use of the Hausdorff topology turns out to be fundamental in understanding why and how these approximations work. The construction presented during the talk is adapted to the case of Schrödinger operator with Delone potential (i.e. quasi-crystals).
The talk is based on a joint work with: S. Beckus and J. Bellissard

Jürg Fröhlich, ETH Zurich - emeritus
Applications of the chiral anomaly to the theory of topological insulators

I review applications of the chiral anomaly to the theory of
(1) 2D Hall- and Chern insulators and 2D time-reversal invariant insulators;
(2) 3D axionic insulators and Weyl semi-metals.

Guo Chuan Thiang, University of Adelaide
Duality methods for topological phases

Bulk topology and edge states are linked by index theory, so that Poincare duality methods come into play. For Weyl semimetals and Kane-Mele invariants, Dirac strings provide the Poincare dual description and they simply project onto the surface Fermi arcs or Dirac cones. Crystallographic T-duality relates the Brillouin torus with the geometric unit cell in position space, preserving topological invariants, and even allows new index theorems to be deduced from the (crystallographic) bulk-edge correspondence heuristic.

Abstracts / Short talks

Jacob Shapiro, ETH Zürich
Strongly Disordered Floquet Topological Systems

We study the strong disorder regime of Floquet topological systems in dimension two, that describe independent electrons on a lattice subject to a periodic driving. In the spectrum of the Floquet propagator we assume the existence of an interval in which all states are localized--a mobility gap. First we generalize the relative construction from spectral to mobility gap, define a bulk index for an infinite sample and an edge index for the half-infinite one and prove the bulk-edge correspondence. Second, we consider completely localized systems where the mobility gap is the whole circle, and define alternative bulk and edge indices that circumvent the relative construction and match with quantized magnetization and pumping observables from the physics literature. Finally, we show that any system with a mobility gap can be reduced to a completely localized one. All the indices defined throughout are equal. (Joint with C. Tauber)

Christopher Max, University of Cologne
Bulk-boundary correspondence of disordered topological insulators and superconductors

We construct explicit topological classes in Real K-theory for the gapped bulk and the gapless boundary of a topological insulator or superconductor with homogeneous disorder. We proof a bulk-boundary correspondence including disorder for all complex and real Altland-Zirnbauer classes. The explicit form of our constructions enables us to derive several properties of the bulk-boundary correspondence using bivariant K-theory. This is joint work with Alexander Alldridge.