Titles/Abstracts

Alexander Abanov (Stony Brook)

Chiral anomaly in fluid dynamics: coupling axial gauge field to Euler fluid

An ideal barotropic fluid in three spatial dimensions has an additional conservation law - the conservation of the fluid helicity. We couple the helicity density to a background axial gauge field. Using the variational principle, we show that the fluid dynamics in the presence of an axial and vector gauge fields have a mixed vector-axial anomaly known in quantum field theories with Dirac fermions.

Yacin Ameur (Lund):

The two-dimensional Coulomb gas with spectral gaps

The talk will focus around some new results relating to fuctuations of smooth linear statistics of two-dimensional Coulomb gas ensembles, where the droplet is disconnected, i.e., it has some "spectral gaps". The particles which fall near the boundary of the gap come with an additional uncertainty, since there are several disjoint boundary components to choose from. For a class of centrosymmetric model ensembles, we quantify this uncertainty in terms of the Jacobi theta function as well as a discrete Gaussian distribution. If time permits, I will also discuss a related large N expansion of the partition function. Joint work with Christophe Charlier and Joakim Cronvall (both from Lund University).

Simon Becker (ETH, Zurich)

Mathematics of magic angles

Magic angles are a hot topic in condensed matter physics: when two sheets of graphene are twisted by those angles the resulting material is superconducting. I will present a very simple operator whose spectral properties are thought to determine which angles are magical. It comes from a 2019 PR Letter by Tarnopolsky--Kruchkov--Vishwanath. The mathematics behind this is an elementary blend of representation theory (of the Heisenberg group in characteristic three), Jacobi theta functions and spectral instability of non-self-adjoint operators (involving Hörmander's bracket condition in a very simple setting). Recent mathematical progress also includes the proof of existence of generalized magic angles and computer assisted proofs of existence of real ones (Luskin--Watson, 2021). The results will be illustrated by colourful *numerics which suggest many open problems (joint work with M Embree, J Wittsten, M Zworski in 2020 and T Humbert and M Zworski in 2022)*

Igor Burban (Paderborn):

Magnetic bundle in the multilayer model of the fractional quantum Hall effect on a torus

In 1993 and Keski-Vakkuri and Wen introduced a model for the fractional quantum Hall effect based on multilayer two-dimensional electron systems satisfying quasi-periodic boundary conditions. Such a model is specified by a choice of a complex torus E and a symmetric positively definite matrix K of size g with integer coefficients. The space of the corresponding wave functions turns out to be d-dimensional, where d is the determinant of K. I am going to explain a construction of a hermitian holomorphic bundle of rank d on the abelian variety A (which is the g-fold product of the torus E with itself), whose fibres can be identified with the space of wave function of Keski-Vakkuri and Wen . A rigorous construction of this "magnetic bundle" involves the technique of Fourier-Mukai transforms on abelian varieties. This bundle turns out to be simple and semi-homogeneous and it carries a projectively flat hermitian connection. Moreover, for special classes of the matrix K, the canonical Chern-Weil connection of the magnetic bundle is shown to be projectively flat.
This is a joint work with Semyon Klevtsov.

Andrea Cappelli (INFN and Physics Dept., Florence, Italy)

W-Infinity Symmetry in the Quantum Hall Effect

I review the description of quantum incompressible fluids by the W-infinity symmetry. I discuss how it encompasses the conformal symmetry of edge excitations and characterizes the observed Jain states. Next, I show how it extends to the non-conformal bulk in the disk geometry. Bulk excitations have larger sizes, energies and momenta as compared to edge modes, and stay finite for large droplets. I present analytic results for the radial shape of excitations, the edge reconstruction phenomenon and the spectrum of large density fluctuations near the edge.

Valentin Crepel (Flatiron Institute, New York City)

Ideal bands as Landau levels in curved space, and magic in twisted TMDs

We show that all the criteria proposed in the literature to identify Chern bands hosting fractional Chern insulating ground states, in fact, describe an equivalence with lowest Landau levels defined in curved space. Our work clarifies the common origin of various Chern-idealness criteria, proves that these criteria exhaust all possible lowest Landau levels, and hints at classes of Chern bands that may posses interesting phases beyond Landau level physics. Finally, we describe how such ideal bands may appear in the moire transition metal dichalcogenide heterostructures, and highlight experimental consequences concerning the possibility of observing fractional Chern insulators at zero field.

Benoit Estienne (Jussieu, Paris)

Charge fluctuations and symmetry-resolved entanglement entropy for quantum Hall states

We study the full counting statistics (FCS) and symmetry-resolved entanglement entropies of integer and fractional quantum Hall states. For the filled lowest Landau level of spin-polarized electrons on an infinite cylinder, we compute exactly the charged moments associated with a cut orthogonal to the cylinder's axis. This yields the behavior of FCS and entropies in the limit of large perimeters: in a suitable range of fluctuations, FCS is Gaussian and entanglement spreads evenly among different charge sectors. Subleading charge-dependent corrections to equipartition are also derived. We then extend the analysis to Laughlin wavefunctions, where entanglement spectroscopy is carried out assuming the Li-Haldane conjecture. The results confirm equipartition up to small charge-dependent terms, and are then matched with numerical computations based on exact matrix product states.

Jürg Fröhlich (ETH Zurich)

Chiral Anomaly, Topological Field Theory, and Topological States of Matter

Starting with a description of the goals of the analysis and a brief survey of the chiral anomaly, I will review some basic elements of the theory of the quantum Hall effect in 2D electron gases. I will discuss the role of anomalous chiral edge currents and of anomaly inflow in 2D insulators with explicitly or spontaneously broken parity and time reversal, i.e., in incompressible Hall fluids and Chern insulators, respectively. The topological Chern-Simons actions yielding the correct response equations for the 2D bulk of such materials will be exhibited. I will then analyse chiral edge spin-currents and the bulk response equations in time-reversal invariant 2D topological insulators. To conclude some open problems and an outlook towards other related areas of theoretical physics will be presented.

Gian Michele Graf (ETH Zurich)

Adiabatic charge pumps and Galilei covariance

The Thouless theory of quantum pumps establishes quantized transport per cycle and determines the conditions for that. When the description is shifted to a moving frame, transported and residing charges mix. That transformation is encoded in Galilean space and time, but underlying it is one of vector bundles that may be described in a number of ways, that may or may not rely on Bloch theory. In one of them, the transformation mixes strong and weak indices of a bundle on a 2-torus; in another one, a 3-torus is at center stage.

Alex Kruchkov (EPF Lausanne)

Quantum geometry: a new paradigm in anomalous electronic transport and unconventional superconductivity

Quantum geometry — the metric of quantum states in Hilbert space — determines the distance between two neighbouring quantum states. The concept of quantum geometry, represented by Fubini-Study metric, had been used in the quantum information theory, however, had been mainly overlooked in the condensed matter environment. This situation has changed after discovery of twisted bilayer graphene (TBG) and twisted transition metal dichalcogenides, which host nearly dispersionless quantum states ("flat bands") characterized by nontrivial topology and quantum geometry. Despite the conventional expectation of vanishing conductivity and absent superconductivity, the dispersionless electrons in moiré materials demonstrate a plethora of anomalies ranging from unconventional superconductivity to giant thermopower, strange metal behaviour, Fractional Chern Insulator states, among others. A new paradigm featuring the quantum geometry of dispersionless quantum states is getting momentum towards understanding these anomalies. In this talk, we will discuss quantum transport — thermal conductance, thermoelectric response, and superfluid weight — from the old perspective and from the new quantum-geometric perspective. Time permitting, we discuss recent experimental evidence of significant quantum-geometric effects on the transport anomalies in flat bands of twisted bilayer graphene, and outline new perspectives and challenges.

References:

[1] A. Kruchkov, Physical Review B (Letter), vol. 105, p. L241102, Jun 2022.
[2] A. Kruchkov, arXiv:2210.00351, under review in PRL (2023).
[3] Y. Guan, O. V. Yazyev, and A. Kruchkov, Physical Review B (Letter), vol. 106, p. L121115, Sep 2022.

Thibaut Lemoine (Lille):

Integer Quantum Hall Effect on complex manifolds: a probabilistic view

It is well-known that the integer Quantum Hall Effect (IQHE) can be related to the Ginibre ensemble, which is the eigenvalue distribution of complex Gaussian random matrices. In this talk, I will discuss a generalization of this relation on a compact complex manifold: the corresponding ensemble is a determinantal point process whose correlation kernel is the Bergman kernel of a high tensor power of a Hermitian line bundle. I will explain how a universality phenomenon naturally emerges from its scaling limit, and describe a large deviation principle for a wider class of processes in the same geometric setting.

Bruno Mera (Tohoku University):

Uniqueness of Landau levels and their analogs with higher Chern numbers

Lowest Landau level wavefunctions are eigenstates of the Hamiltonian of a charged particle in two dimensions under a uniform magnetic field. They are known to be holomorphic both in real and momentum spaces, and also exhibit uniform, translationally invariant, geometrical properties in momentum space. In this talk, using the Stone-von Neumann theorem, we show that lowest Landau level wavefunctions are indeed the only possible states with unit Chern number satisfying these conditions. We also prove the uniqueness of their direct analogs with higher Chern numbers and provide their expressions.
References:
[1] Bruno Mera and Tomoki Ozawa. Uniqueness of Landau levels and their analogs with higher Chern numbers. arXiv:2304.00866, 2023.

Per Moosavi (ETH Zurich)

Anisotropic quantum Hall droplets

I will discuss recent work on 2D droplets of non-interacting electrons in strong magnetic fields, confined by an anisotropic trapping potential. Using semiclassical methods, we obtain the one-particle energy spectrum and wave functions in the lowest Landau level by deriving and solving a transport equation inspired by standard WKB theory. This shows that energy eigenstates are localized on equipotentials of the trap with angle-dependent local widths and heights, generalizing the rotational-symmetric situation for isotropic traps. From these microscopic first-principle considerations, we obtain explicit results for many-body observables for anisotropic quantum Hall droplets in the thermodynamic limit. In particular, we show that correlations along the droplet's edge are long-ranged, in agreement with low-energy edge

modes described by a free chiral conformal field theory in terms of the canonical angle variable of the trapping potential.
Based on work with B. Oblak, B. Lapierre, J.-M. Stéphan, and B. Estienne.

Blagoje Oblak (École Polytechnique, Paris)

Adiabatic Deformations of Quantum Hall Droplets

The study of two-dimensional droplets of electrons in a strong magnetic field lies at the heart of the quantum Hall effect. In this talk, I present recent results on geometric deformations of such droplets, resulting from variations of the underlying spatial metric and/or confining potential. Time-dependent variations give rise to Berry phases that can remarkably be written in closed form despite the fact that the underlying parameter space is infinite-dimensional. In particular, I argue that a large class of deformations that generalize squeezing and shearing probe the edge modes of the system, including their topological central charge.
(Based on 2212.12935 and 2301.01726 + ongoing work)

Cécile Repellin (CNRS, Grenoble)

Fractional Chern insulators in moiré materials

Layered moiré systems are an outstandingly versatile platform for the study of strongly correlated quantum phenomena, due to the possibility to tune the band structure to obtain a flat band. In many cases, this flat band is also topological: for example a non-trivial Chern number is expected in twisted bilayer graphene (TBG) aligned with hexagonal boron nitride, and in some twisted bilayer transition metal dichalcogenides (TMD) such as WSe2 or MoTe2. These ingredients can in principle permit the emergence of a fractional quantum Hall phase in the absence of a magnetic field, or fractional Chern insulator (FCI), provided that the quantum geometry of the band is also favorable. I will show that the stability regime of FCIs may be enhanced in TMDs by applying pressure, thanks to a line of nearly ideal bandwidth and band geometry in the pressure - twist angle plane. In TBG, I will show that different band geometries can lead to FCIs with different spin orders at the same fraction.

Jean-Marie Stephan (Lyon)

Full counting statistics of charge fluctuations in smooth and singular regions

Outcomes of measurements are characterized by an infinite family of cumulants, which provide information beyond the mean and variance of the observable under consideration. In this talk, we investigate such fluctuations when only a (big) subregion of the system can be observed.

Assuming translation invariance and rotation symmetry in any dimension, we systematically derive a large subregion expansion for all charge cumulants. The form of the expansion differs for smooth and non-smooth regions, but each term in the expansion can be expressed explicitly in terms of connected correlation functions, which encode the underlying physics. To illustrate those results, we discuss the example of the Quantum Hall effect, where some of these terms turn out to be universal.
References: 2102.06223, 2211.05159

Eugene Sukhorukov (Geneva)

Theory of fractional quantum Hall interferometers

Interference of fractionally charged quasi-particles is expected to lead to Aharonov-Bohm oscillations with periods larger than the flux quantum. However, according to the Byers-Yang theorem, observables of an electronic system are invariant under an adiabatic insertion of a quantum of singular flux. We resolve this seeming paradox by considering a microscopic model of electronic interferometers made from a quantum Hall liquid at filling factor 1/m. An approximate ground state of such interferometers is described by a Laughlin type wave function, and low-energy excitations are incompressible deformations of this state. We construct a low-energy effective theory by restricting the microscopic Hamiltonian of electrons to the space of incompressible deformations and show that the theory of the quantum Hall edge so obtained is a generalization of a chiral conformal field theory. We find that the coherent contribution to the average quasi-particle current through Mach-Zehnder type interferometers does not vanish after summation over quasi-particle degrees of freedom. However, it acquires oscillations with the electronic period, in agreement with the Byers-Yang theorem.

Jie Wang (Harvard):

Universal and Exact Aspects of Ideal Flatbands

Fractional Chern insulators (FCI) are the analogies of fractional quantum Hall effect (FQH) realized in topological flat bands without magnetic field. For a long time, it has been commonly accepted that FCI are less stable than FQH, due to the absence of the closed density-density Girvin-MacDonald-Platzmann algebra (or W-infinity algebra) that is ruined by the non-uniformness of the band geometry of Bloch wavefunctions. In this talk, I will disprove such common lore by showing a large family of flatband systems, called ideal flatbands, which exhibits universal form of single-particle wavefunctions implied from constrained quantum geometries. Moreover, the model FCIs are numerically found and analytically proved to be exact ground states in ideal flatbands when interaction is short-ranged. The underlying reason is the emergent exact Girvin-MacDonald-Platzmann algebra even when Berry curvature itself is *spatially nonuniform. I will comment on the implication to real experiments in moire and related 2D materials in the end.*

Paul Wiegmann (Chicago)

TBA

Amanda Young (Munich):

A bulk gap in the presence of edge states for a truncated Haldane pseudopotential

In this talk, we discuss the bulk gap for a truncated 1/3-filled Haldane pseudopotential for the fractional quantum Hall effect in the cylinder geometry. In the case of open boundary conditions, a lower bound on the spectral gap (which is uniform in the volume and particle number) accurately reflects the presence of edge states, which do not persist into the bulk. A uniform lower bound for the Hamiltonian with periodic boundary conditions is also obtain. Both of these bounds are proved by identifying invariant subspaces to which spectral gap and ground state energy estimating methods originally developed for quantum spin Hamiltonians are applied. Customizing the gap technique to the invariant subspace, however, we are able to avoid the edge states and establish a more precise estimate on the bulk gap in the case of periodic boundary conditions. The same approach can also be applied to prove a bulk gap for the analogously truncated Haldane pseudopotential with maximal half filling, which describes a strongly correlated system of spinless bosons in a cylinder geometry. This is based off joint work with S. Warzel.

Dimitri Zvonkine (CNRS and Paris-Versaille University)

Quantum Hall effect via the Grothendieck-Riemann-Roch formula

We will explain how the fractional quantum Hall effect on a Riemann surface of genus g can be studied using algebraic geometry. The wave functions of charged particles have a semi-phenomenological description by Laughlin states. These states form a holomorphic vector bundle over a Picard group of the Riemann surface. The Chern characters of this vector bundle can be computed by the Grothendieck-Riemann-Roch formula. The mathematical part of the talk involves Grothendieck-Riemann-Roch computations for a universal line bundle on the symmetric power of a smooth curve over its Picard group. This is joint work with Semyon Klevtsov.