TT 18: Focused Session: Correlations in Topological Bands (jointly with DS, HL, MA, and O)

Topological ideas have been among the most profound recent additions to the field of condensed matter physics, and they have provided some of the most unexpected new developments, most recently through the proposed existence of fractional Chern insulators: these are lattice systems in which fractional quantum Hall physics occurs in partially filled non-dispersive topological "Chern" bands. Our ability to create such environments is central to advancing the understanding of correlated electron physics.

This session focuses on the twin aspects of the new physics that can be found in such settings on one hand, and recent progress towards realizing such settings on the other. It contains theoretical and experimental contributions, from nano-, semiconductor and cold atomic physics.

Organizer: Roderich Moessner (MPI PKS, Dresden)

Time: Monday 15:00–17:45 Location: H20

Invited Talk TT 18.1 Mon 15:00 H20

Designer Dirac Fermions, Topological Phases, and Gauge Fields in Molecular Graphene — •Hari C. Manoharan — Dept. of Physics, Stanford University, Stanford, California 94305, USA

Using low-temperature scanning tunneling microscopy and spectroscopy, we show the emergence of Dirac fermions in a fully tunable condensed-matter system—molecular graphene—assembled via atomic manipulation of a conventional two-dimensional electron system in a surface state. We embed, image, and tune the symmetries underlying the two-dimensional Dirac equation into these electrons by sculpting the surface potential with manipulated molecules. By distorting the effective electron hopping parameters into a Kekulé pattern, we find that these natively massless Dirac particles can be endowed with a tunable mass engendered by the associated scalar gauge field, in analogy to the Higgs field. With altered symmetry and texturing of the assembled lattices, the Dirac fermions can be dressed with gauge electric or magnetic fields such that the carriers believe they are in real fields and condense into the corresponding ground state, as confirmed by tunneling spectroscopy. Using these techniques we ultimately fabricate a quantum Hall state without breaking time-reversal symmetry, in which electrons quantize in a gauge magnetic field ramped to 60 Tesla with zero applied laboratory field. We show that these and other chiral states now possible to realize have direct analogues in topological insulators, and can be used to guide or confine charge in nontrivial ways [1].

[1] Gomes et al., Nature **483**, 306–310 (2012).

Invited Talk TT 18.2 Mon 15:30 H20

Fractional Topological Insulators — •Claudio Chamon[1], Christopher Mudry[2], Titus Neupert[2], and Luiz Santos[3] — [1]Boston University — [2]Paul Scherrer Institute — [3]Perimeter Institute

The prediction and experimental discovery of topological band insulators and topological superconductors are recent examples of how topology can characterize phases of matter. In these examples, electronic interactions do not play a fundamental role. In this talk we shall discuss cases where interactions lead to new phases of matter of topological character. Specifically, we shall discuss fractional topological states in lattice models which occur when interacting electrons propagate on flattened Bloch bands with non-zero Chern number. Topologically ordered many-particle states can emerge when these bands are partially filled, including a possible realization of the fractional quantum Hall effect without external magnetic fields. We also discuss the importance of geometric band attributes to stabilize certain fractional states, highlighting the importance of geometry and not just topology for reaching fractional states of matter.

Topical Talk TT 18.3 Mon 16:00 H20

Hierarchy of Fractional Chern Insulators and Competing Compressible States — •Andreas Läuchli — Institut für Theoretische Physik, Universität Innsbruck, A-6020 Innsbruck, Österreich

The recent engineering of simple tight binding models harboring flat bands with non-zero Chern number calls for a detailed study of the possible many-body phases occurring in partially filled Chern bands and their analogies and differences compared to the continuum Landau level problem. We first report the numerical phase diagram for a flat Chern band with $C = 1$ on the checkerboard lattice, where we find hierarchy multiplets of incompressible states at various fillings ν These are accounted for by an analogy to Haldane pseudopotentials extracted from an analysis of the two-particle problem. Important distinctions to standard fractional quantum Hall physics are striking: absent particle-hole symmetry in a single band, an interaction-induced single-hole dispersion appears, which perturbs and eventually destabilizes incompressible states as ν increases [1]. In second study we investigate the occurrence of fractional Chern insulating phases in a series of bands with higher Chern numbers $C = N > 1$. We find compelling evidence for a series of stable states at $\nu = 1/(2N + 1)$ for fermions as well as bosonic states at $\nu = 1/(N + 1)$. By examining the topological ground state degeneracies and the excitation structure as well as the entanglement spectrum, we conclude that these states are Abelian [2].

[1] A. M. Läuchli, Z. Liu, E.J . Bergholtz, and R. Moessner, arxiv:1207.6094 (2012)
[2] Z. Liu, E. J. Bergholtz, H. Fan, and A. M. Läuchli, Phys. Rev. Lett. **109**, 186805 (2012)

15 min. break

Topical Talk TT 18.4 Mon 16:45 H20

Designing Topological Bands for Ultracold Atomic Gases — •Nigel Cooper — Cavendish Laboratory, University of Cambridge, UK

One of the most important techniques in the ultracold atom toolbox is the optical lattice: a periodic scalar potential formed from standing waves of light. Optical lattices are central to the use of atomic gases as quantum simulators, and allow the exploration of strong-correlation phenomena related to condensed matter systems. I shall describe how to design new forms of optical lattice - so-called "optical flux lattices" - in which optically dressed atoms experience a periodic effective magnetic flux with high mean density. Optical flux lattices have narrow energy bands with nonzero Chern numbers, analogous to the Landau levels of a charged particle in a uniform magnetic field. These lattices will greatly facilitate the achievement of the quantum Hall regime for ultracold atomic gases.

Topical Talk TT 18.5 Mon 17:15 H20

Probing Topological Bloch Bands Using Ultracold Quantum Gases — •Immanuel Bloch — Max-Planck Institut für Quantenoptik, Garching, Germany — Ludwig-Maximilians Universität, München, Germany

Over the past years, ultracold quantum gases have emerged as highly controllable testbeds for probing fundamental condensed matter phenomena. In my talk, I will show how strong effective magnetic fields can be realized for neutral atoms held in an especially engineered optical lattice potential. The effective field strengths that can be reached, are 10-100 times larger than what can be achieved even with the strongest magnets in real material systems, allowing one to take the artificial quantum matter into a new parameter regime. Furthermore, I will show how by carrying out matter wave interferometry within the Bloch bands, we have been able to measure the Zak phase - the Berry phase in one dimension - and to directly determine topological invariants. As an example, I will present results for the celebrated Su-Schrieffer-Heeger model of polyacetylene that can be modelled by using optical superlattice potentials.