TT 82: Low-Dimensional Systems: Topological Order (organized by TT)

Time: Thursday 9:30–13:15 Location: HSZ 204

TT 82.1 Thu 9:30 HSZ 204

Silicene and germanene as topological insulators: ab-initio approach — •Lars Matthes and Friedhelm Bechstedt — Institut für Festkörpertheorie und -optik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany

Silicene is a two-dimensional honeycomb lattice formed by silicon atoms and shares many properties of graphene, e.g. massless Dirac electrons at the Fermi level. In silicene the effect of spin-orbit interaction (SOI) is enhanced due to its buckled structure. Furthermore, by means of tight-binding calculations including SOI the emergence of topologically protected edge states has been predicted in silicene (and also germanene) nanoribbons [1] for zigzag and armchair edges, turning these crystals into topological insulators.

In this talk we study, whether or not silicene and germanene are topological insulators in a real simulation. We employ density-functional theory for the simulation of germanene nanoribbons. The band structures of ribbons of several widths as well as zigzag and armchair edges with hydrogen passivation are presented. The presence of topologically protected states is discussed versus edge shape, edge magnetization, ribbon width, and strength of spin-orbit interaction. The validity of results of the tight-binding model is critically discussed.

[1] M. Ezawa and N. Nagaosa, Phys. Rev. B 88, 121401(R) (2013)

TT 82.2 Thu 9:45 HSZ 204

First-principles Fermi surface characterization of doped PbTe — •Boris Sangiorgio, Michael Fechner, and Nicola Spaldin — ETH Zürich, Department of Materials, CH-8093 Zürich, Switzerland

Doped PbTe has raised increased interest because of its peculiar properties. In particular, it shows enhanced thermoelectricity, topological insulator behaviour and a charge Kondo effect, depending on the dopant atom. Here we investigate the nature of the Fermi surface in hole-doped PbTe using first-principles calculations. We begin by comparing recent experimental characterizations of the Fermi surface by means of effective masses, band offsets and de Haas-van Alphen frequencies with results from density functional theory (DFT). We find that the values of these properties depend strongly on the choice of exchange-correlation functional and identify functionals that give good agreement with experiment. Our results indicate appropriate methodologies for first-principles studies of doped-PbTe, and give insights into the origin of the charge Kondo effect.

TT 82.3 Thu 10:00 HSZ 204

Conductance of flat bands with long range Coulomb interactions — •Wolfgang Häusler — Institut für Physik, Universität Augsburg, D-86135 Augsburg

Dispersionless ("flat") electronic bands can arise throughout the Brillouin zone in certain multipartite lattices, besides ordinary dispersing bands. In such a flat band, hoppings between atomic orbitals interfere destructively which then leads to localization, a phenomenon denoted as "caging" of carriers. As a consequence, the system is insulating at zero temperature even when this band is partly filled, provided all other bands are either empty or completely filled.

One may ask whether long range Coulomb interactions can alter this situation and cause finite conductivity. In the absence of kinetic energy, flat band carriers tend to Wigner crystallize. Here, this general observation is analyzed for the two-dimensional case specifically for the Sutherland or $\mathcal{T}_3$–lattice where a conductivity is found, depending non-trivially on the carrier density at small flat band fillings.

TT 82.4 Thu 10:15 HSZ 204

Fluctuation-Induced Topological Insulators — •Sebastian Riese and Stephan Rachel — Institut für Theoretische Physik, TU Dresden

We consider interaction-induced topological insulators as paradigms for systems which are dominated by the interplay of a topological band structure and electron-electron correlations. In particular, we extend the previous work about fluctuation-induced topological phases. We show that the fluctuation-induced Chern insulator phase can be reduced to the non-interacting model with an additional mass-term which depends on the parameters of the self-energy. Then we generalize this idea to the spinfull case of time-reversal invariant topological insulators. We show that his phase is stable with respect to spin-mixing in the band structure and in the self-energy. Implications for realistic interacting Hamiltonians are discussed.

TT 82.5 Thu 10:30 HSZ 204

Topological phase transition in the Kitaev-Ising ladder — Amir Mohammad-Aghaie[1], Reza Haghshenas[1], and •Abdollah Langari[1,2] — [1]Department of Physics, Sharif University of Technology, P.O.Box 11155-9161, Tehran, Iran — [2]Max-Planck-Institut fuer Physik komplexer Systeme, 01187 Dresden, Germany

We have studied the Kitaev-Ising model on a ladder geometry using iDMRG algorithm. We find a quantum phase transition between the Kitaev and Ising phases whenever the ratio of Ising to Kitaev coupling is exactly equal to 1/2. The divergence in the von-Neumann entropy and the change of degeneracy in the entanglement spectrum justifies the symmetry protected topological phase (SPT) transition. We investigate the robustness of the SPT phase in the presence of cluster terms which preserve/break the symmetry of the model. We also discuss the effect of Ising terms on the legs of ladder in addition to the rhombic interaction, which leads to frustration for the antiferromagnetic interactions.

TT 82.6 Thu 10:45 HSZ 204

Entanglement Spectra of Interacting Fermions in Quantum Monte Carlo Simulations — Fakher F. Assaad[1], Thomas C. Lang[2], and •Francesco Parisen Toldin[1] — [1]Institut für Theoretische Physik und Astrophysik, Universität Würzburg, Germany — [2]Department of Physics, Boston University, U.S.A.

In a recent article T. Grover introduced a simple method to compute Renyi entanglement entropies in the realm of the auxiliary field quantum Monte Carlo algorithm [1]. Here, we further develop this approach and provide a stabilization scheme to compute higher order Renyi entropies and an extension to access the entanglement spectrum [2]. The method is tested on systems of correlated topological insulators.

[1] T. Grover, Phys. Rev. Lett. 111, 130402 (2013)

[2] F. F. Assaad, T. C. Lang, F. P. Toldin, arXiv:1311.5851

TT 82.7 Thu 11:00 HSZ 204

Topological insulators with arbitrarily tunable entanglement scaling — •Jan Carl Budich[1], Jens Eisert[2], and Emil Johansson Bergholtz[2] — [1]Department of Physics, Stockholm University, SE-106 91 Stockholm, Sweden — [2]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany

We elucidate how Chern and topological insulators fulfill an area law for the entanglement entropy. By ex- plicit construction of a family of lattice Hamiltonians, we are able to demonstrate that the area law contribution can be tuned to an arbitrarily small value, but is topologically protected from vanishing exactly. We prove this by introducing novel methods to bound entanglement entropies from correlations using perturbation bounds and complement this approach by an intuitive understanding. These insights have a number of important consequences. The non-universality implies that the entanglement scaling cannot be used as a faithful diagnostic of topological insulators. The existence of arbitrarily weakly entangled topological insulators opens up possibili- ties of devising correlated topological phases in which the entanglement entropy is small and which are thereby numerically tractable, specifically in tensor network approaches.

15 min. break.

Topical Talk TT 82.8 Thu 11:30 HSZ 204

Density Matrix Renormalization Group: Probing the Topology of Quantum States — •Frank Pollmann — Max-Planck-Institute for the Physics of Complex Systems, Dresden, Germany

Matter occurs in various phases with different properties. Usually these phases are characterized in terms of symmetry breaking. A major discovery in the 1980s was the quantum Hall effect which forms a new kind of "topological" order. This order represents exotic phases with unusual properties and cannot be understood in terms of symmetry breaking. Since then, a growing number of instances of topological phases has accumulated, and important applications – not least topological quantum computers – have been proposed, but a characterization and classification of these new phenomena has been slow to emerge. In parallel, DMRG has arrived as a powerful numerical method with extensions to two dimensional systems and time-dependent phenomena. I will show how to use DMRG to develop new frameworks that help to understand topologically ordered systems. For example, it is now possible to extract characterizing properties of the anyonic excitations directly from the ground state of fractional quantum Hall systems. This approach further makes contact with "measurable" quantities (Hall viscosity) and field theories (central charge at critical points). Other remarkable examples are symmetry protected topological phases in one-dimensional systems for which DMRG provides a complete characterization.

TT 82.9 Thu 12:00 HSZ 204

Excitation statistics distinguish topologically ordered phases — •Siddhardh Morampudi[1], Curt von Keyserlingk[2], and Frank Pollmann[1] — [1]Affiliation: Max-Planck-Institut für Physik komplexer Systeme, Dresden, Germany — [2]Affiliation: Rudolf Peierls Centre for Theoretical Physics, 1 Keble Road, Oxford, OX1 3NP, United Kingdom

We investigate the characterization of topologically ordered phases and phase transitions between them. Topological order is a kind of order which cannot be characterized by the traditional approach of Landau's symmetry breaking theory and local order parameters. It is known to arise in diverse systems ranging from the well known fractional quantum hall systems to highly frustrated systems like the Heisenberg antiferromagnet on the Kagome lattice. The lack of local order parameters makes it difficult to uniquely identify a topologically ordered phase and to investigate phase transitions between them.

We consider two topologically ordered phases and use exact diagonalization to look at behaviour of various quantities as we move between them. We find that the usual methods of identifying a topologically ordered phase fail to uniquely distinguish these two phases. We then extract the braiding statistics of the excitations in the phases and use it as a non-local order parameter to distinguish the two phases, finding a first-order transition between them. Finally, we discuss how the approach could easily be generalized to other topologically ordered systems.

TT 82.10 Thu 12:15 HSZ 204

Detection of symmetry enriched topological phases — •Ching-Yu Huang[1], Xie Chen[2], and Frank Pollmann[1] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Department of Physics, University of California, Berkeley, California, USA

Topologically ordered systems in the presence of symmetries can exhibit new structures which are referred to as symmetry enriched topological (SET) phases. We introduce simple methods to detect the SET order directly from a complete set of topologically degenerate ground state wave functions. In particular, we first show how to directly determine the characteristic symmetry fractionalization of the quasiparticles from the reduced density matrix of the minimally entangled states. Second, we show how a simple generalization of a string order parameter can be measured to detect SET. The selection rules will get a characterization of SET. This way is more physical, and can be used by other methods, e.g., quantum Monte Carlo methods or potentially measured experimentally. We demonstrated the usefulness of this approach by considering first a spin-1 model on the honeycomb lattice and the resonating valence bond state on a kagome lattice.

TT 82.11 Thu 12:30 HSZ 204

Persisting topological order via geometric frustration — •Kai Phillip Schmidt — Lehrstuhl für Theoretische Physik I, TU Dortmund, Deutschland

We introduce a toric code model on the dice lattice which is exactly solvable and displays topological order at zero temperature. In the presence of a magnetic field, the flux dynamics is mapped to the highly frustrated transverse field Ising model on the kagome lattice. This correspondence suggests an intriguing disorder by disorder phenomenon in a topologically ordered system implying that the topological order is extremely robust due to the geometric frustration. Furthermore, a connection between fully frustrated transverse field Ising models and topologically ordered systems is demonstrated which opens an exciting physical playground due to the interplay of topological quantum order and geometric frustration.

TT 82.12 Thu 12:45 HSZ 204

Kondo holes in topological Kondo insulators — •Pier Paolo Baruselli and Matthias Vojta — Institut für Theoretische Physik, Technische Universität Dresden, 01062 Dresden, Germany

The interplay between strong correlations and topology is a fast-developing and fascinating subject in the field of condensed matter.

Recently, the existence of topological Kondo insulators has been proposed [1]. In these materials the insulating behavior arises from strong correlations, that is from the Kondo screening of localized moments via conduction electrons, while non-trivial topology emerges from the structure of the hybridization between the local-moment and conduction bands.

We present a study of the physics of Kondo holes, i.e., missing local moments, in such topological Kondo insulators, using a self-consistent real-space mean-field theory. Kondo holes induce in-gap states which, for Kondo holes at or near the surface, hybridize with the topological surface state. In particular, we investigate the surface-state quasiparticle interference (QPI) induced by a dilute concentration of surface Kondo holes. We find that most QPI features can be interpreted by taking into account the shape of two-dimensional Fermi surface, together with the absence of backscattering characterizing Dirac cones in topological insulators. However, deviations from this simple picture arise: for example, the real part of the substrate Green's function and of the scattering matrix cannot be neglected in several cases.

[1] M. Dzero, K. Sun, V. Galitski, and P. Coleman, Phys. Rev. Lett. 104, 106408 (2010)

TT 82.13 Thu 13:00 HSZ 204

Topological entanglement entropy at quantum critical points — •Johannes Helmes and Simon Trebst — Institut für Theoretische Physik, Universität zu Köln, Germany

It is increasingly appreciated that a precise determination of the entanglement entropy of an interacting quantum many-body system can be used to identify the fundamental nature of its ground states. In particular, corrections to the prevalent boundary-law can be used to unambiguously identify topological order – a non-local form of order that eludes a standard characterization via correlation functions.

Here we report results for the entanglement entropy at a family of quantum critical points separating a topologically ordered phase from a conventionally ordered one. In technical terms, we employ large-scale quantum Monte Carlo simulations to study various deformations of the paradigmatic toric code model harboring a Z2 topological quantum spin liquid.