Journal Club, 9th April 2013, James Wootton

Topological Entanglement Entropy with a Twist
Benjamin J. Brown, Stephen D. Bartlett, Andrew C. Doherty, Sean D. Barrett, arXiv:1303.4455

Defects in topologically ordered models have interesting properties that are reminiscent of the anyonic excitations of the models themselves. For example, dislocations in the toric code model are known as twists and possess properties that are analogous to Ising anyons. We strengthen this analogy by using the topological entanglement entropy as a diagnostic tool to identify properties of both defects and excitations in the toric code. Specifically, we show, through explicit calculation, that the toric code model including twists and dyon excitations has the same quantum dimensions, the same total quantum dimension, and the same fusion rules as an Ising anyon model.

Proposal for the detection and braiding of Majorana fermions in a quantum spin Hall insulator
Shuo Mi, D. I. Pikulin, M. Wimmer, C. W. J. Beenakker, arXiv:1304.1685

We show how a quantum dot with a ballistic single-channel point contact to a superconductor can be created by means of a gate electrode at the edge of a quantum spin Hall insulator (such as an InAs/GaSb quantum well). A weak perpendicular magnetic field traps a Majorana zero-mode, so that it can be observed in the gate-voltage-averaged differential conductance $\langle dI/dV \rangle$ as a $4e^2/h$ zero-bias peak above a $(2/3\pi^2 - 4)e^2/h$ background. The one-dimensional edge does not permit the braiding of pairs of Majorana fermions, but this obstacle can be overcome by coupling opposite edges at a constriction, allowing for a demonstration of non-Abelian statistics.

Topological Order from Geometric Entanglement
Roman Orus, Tzu-Chieh Wei, Oliver Buerschaper, Maarten Van den Nest, arXiv:1304.1339

Here we investigate the connection between topological order and the geometric entanglement, as measured by the logarithm of the overlap between a given state and its closest product state of blocks. We do this for a variety of topologically-ordered systems such as the toric code, double semion, color code, and quantum double models. As happens for the entanglement entropy, we find that for large block sizes the geometric entanglement is, up to possible subleading corrections, the sum of two contributions: a non-universal bulk contribution obeying a boundary law times the number of blocks, and a universal contribution quantifying the underlying pattern of long-range entanglement of the topologically-ordered state. This topological contribution is also present in the case of single-spin blocks, and constitutes a novel characterization of topological order based on a multipartite entanglement measure. In particular, we see that the topological term for the 2D color code is twice as much as the one for the toric code, in accordance with recent renormalization group arguments [H. Bombin, G. Duclos-Cianci, D. Poulin, New J. Phys. 14 (2012) 073048]. Motivated by these results, we also derive a general formalism to obtain upper- and lower-bounds to the geometric entanglement of states with a non-Abelian group symmetry, and which we explicitly use to analyze quantum double models. Furthermore, we also provide an analysis of the robustness of the topological contribution in terms of renormalization and perturbation theory arguments. Some of the results in this paper rely on the ability to disentangle single sites from the quantum state, which is always possible for the systems that we consider. Finally, in the Appendix we relate our results to the behavior of the relative entropy of entanglement in topologically-ordered systems.

Vortex states and Majorana fermions in spin-orbit coupled semiconductor-superconductor hybrid structures
Kristofer Bjornson, Annica M. Black-Schaffer, arXiv:1304.0981

We study the energy spectrum of a vortex core in a two-dimensional semiconductor with Rashba spin-orbit interaction and proximity-coupled to a conventional superconductor and a ferromagnetic insulator. We perform self-consistent calculations using the microscopic tight-binding Bogoliubov-de Gennes method on a lattice and confirm the existence of Majorana fermions in the non-trivial topological phase. We also find two different topologically trivial superconducting phases, only differing in the type of vortex core structure they support and separated by a normal fermionic zero-energy excitation. Furthermore, we find an asymmetry in the energy spectrum with respect to both Zeeman splitting and vortex rotation direction and explain its physical origin.

The hidden symmetry-breaking picture of symmetry-protected topological order
Dominic V. Else, Stephen D. Bartlett, Andrew C. Doherty, arXiv:1304.0783

We generalize the hidden symmetry-breaking picture of symmetry-protected topological (SPT) order developed by Kennedy and Tasaki in the context of the Haldane phase. Our generalization applies to a wide class of SPT phases in one-dimensional spin chains, protected by an on-site representation of a finite abelian group. This generalization takes the form of a non-local unitary map that relates local symmetry-respecting Hamiltonians in an SPT phase to local Hamiltonians in a symmetry-broken phase. Using this unitary, we establish a relation between the two-point correlation functions that characterize fully symmetry-broken phases with the string-order correlation functions that characterise the SPT phases, therefore establishing the perspective in these systems that SPT phases are characterised by hidden symmetry-breaking. Our generalization is also applied to systems with continuous symmetries, including SO(2k+1) and SU(k).

Noise-Resistant Control for a Spin Qubit Array

J. P. Kestner, Xin Wang, Lev S. Bishop, Edwin Barnes, and S. Das Sarma, Phys. Rev. Lett. 110, 140502 (2013)

We develop a systematic method of performing corrected gate operations on an array of exchange-coupled singlet-triplet qubits in the presence of both fluctuating nuclear Overhauser field gradients and charge noise. The single-qubit control sequences we present have a simple form, are relatively short, and form the building blocks of a corrected cnot gate when also implemented on the interqubit exchange link. This is a key step towards enabling large-scale quantum computation in a semiconductor-based architecture by facilitating error reduction below the quantum error correction threshold for both single-qubit and multiqubit gate operations.

Majorana Fermions in Superconducting 1D Systems Having Periodic, Quasiperiodic, and Disordered Potentials

Wade DeGottardi, Diptiman Sen, and Smitha Vishveshwara, Phys. Rev. Lett. 110, 146404 (2013)

We present a unified study of the effect of periodic, quasiperiodic, and disordered potentials on topological phases that are characterized by Majorana end modes in one-dimensional p-wave superconducting systems. We define a topological invariant derived from the equations of motion for Majorana modes and, as our first application, employ it to characterize the phase diagram for simple periodic structures. Our general result is a relation between the topological invariant and the normal state localization length. This link allows us to leverage the considerable literature on localization physics and obtain the topological phase diagrams and their salient features for quasiperiodic and disordered systems for the entire region of parameter space.

Spin-dependent trapping of electrons at spinterfaces

Sabine Steil, Nicolas Grossmann, Martin Laux, Andreas Ruffing, Daniel Steil, Martin Wiesenmayer, Stefan Mathias, Oliver L. A. Monti, Mirko Cinchetti & Martin Aeschlimann

Hybrid ferromagnetic metal/organic interfacesalso known as spinterfacescan exhibit highly efficient spin-filtering properties and therefore present a promising class of materials for the future development of new spintronic devices. Advancing the field depends critically on elucidating the fundamental microscopic processes that eventually determine the spin-filtering properties in such hybrid structures. Here, we study the femtosecond spin dynamics at the prototypical interface between cobalt and the metalorganic complex tris(8-hydroxyquinolinato)aluminium. To disentangle the microscopic origin of spin filtering, we optically generate a transient spin polarization in a well-defined hybrid interface state that we follow with a spin-resolved real-time pumpprobe two-photon photoemission experiment. We find that the electrons are trapped at the interface in a spin-dependent manner for a surprisingly long time of the order of 0.51ps. We conclude that ferromagnetic metal/organic interfaces act as spin filters because electrons are trapped in hybrid interface states by spin-dependent confining potentials.