Journal Club 17.02.2015 (Paweł Szumniak)

"Majorana Fermion Rides on a Magnetic Domain Wall"
Se Kwon Kim, Sumanta Tewari, Yaroslav Tserkovnyak
arXiv:1502.02088

“**From quantum matter to high-temperature superconductivity in copper oxides**”
B. Keimer, S. A. Kivelson, M. R. Norman, S. Uchida, and J. Zaanen
Nature 518, 179–186 (12 February 2015)

The discovery of high-temperature superconductivity in the copper oxides in 1986 triggered a huge amount of innovative scientific inquiry. In the almost three decades since, much has been learned about the novel forms of quantum matter that are exhibited in these strongly correlated electron systems. A qualitative understanding of the nature of the superconducting state itself has been achieved. However, unresolved issues include the astonishing complexity of the phase diagram, the unprecedented prominence of various forms of collective fluctuations, and the simplicity and insensitivity to material details of the ‘normal’ state at elevated temperatures.

“Quantum spin Hall effect in two-dimensional transition metal dichalcogenides”
Xiaofeng Qian, Junwei Liu, Liang Fu, and Ju Li
Science 346, 6215, 1344-1347 (12 December 2014)

Quantum spin Hall (QSH) effect materials feature edge states that are topologically protected from backscattering. However, the small band gap in materials that have been identified as QSH insulators limits applications. We use first-principles calculations to predict a class of large-gap QSH insulators in two-dimensional transition metal dichalcogenides with 1T¤ structure, namely, 1T¤-MX2 with M = (tungsten or molybdenum) and X = (tellurium, selenium, or sulfur). A structural distortion causes an intrinsic band inversion between chalcogenide-p and metal-d bands. Additionally, spin-orbit coupling opens a gap that is tunable by vertical electric field and strain. We propose a topological field effect transistor made of van der Waals heterostructures of 1T¤-MX2 and two-dimensional dielectric layers that can be rapidly switched off by electric field through a topological phase transition instead of carrier depletion.

“Imprint of topological degeneracy in quasi-one-dimensional fractional quantum Hall states”
Eran Sagi, Yuval Oreg, Ady Stern, Bertrand I. Halperin
arXiv:1502.01665

We consider an annular superconductor-insulator-superconductor Josephson-junction, with the insulator being a double layer of electron and holes at Abelian fractional quantum Hall states of identical fillings. When the two superconductors gap out the edge modes, the system has a topological ground state degeneracy in the thermodynamic limit akin to the fractional quantum Hall degeneracy on a torus. In the quasi-one-dimensional limit, where the width of the insulator becomes small, the ground state energies are split. We discuss several implications of the topological degeneracy that survive the crossover to the quasi-one-dimensional limit. In particular, the Josephson effect shows a $2\pi d$-periodicity, where d is the ground state degeneracy in the 2 dimensional limit. We find that at special values of the relative phase between the two superconductors there are protected crossing points in which the degeneracy is not completely lifted. These features occur also if the insulator is a time-reversal-invariant fractional topological insulator. We describe the latter using a construction based on coupled wires. Furthermore, when the superconductors are replaced by systems with an appropriate magnetic order that gap the edges via a spin-flipping backscattering, the Josephson effect is replaced by a spin Josephson effect.

“Quantum Gross-Pitaevskii Equation”
Jutho Haegeman, Damian Draxler, Vid Stojevic, J. Ignacio Cirac, Tobias J. Osborne, Frank Verstraete
arXiv:1501.06575

We introduce a non-commutative generalization of the Gross-Pitaevskii equation for one-dimensional quantum field theories. This generalization is obtained by applying the Dirac-Frenkel time-dependent variational principle to the variational manifold of continuous matrix product states. This allows for a full quantum description of the many body system including entanglement and correlations and thus extends significantly beyond the usual mean-field description of the Gross-Pitaevskii equation, which is known to fail for one-dimensional systems.

“The second laws of quantum thermodynamics”
Fernando Brandãoa, Michał Horodecki, Nelly Ng, Jonathan Oppenheim, and Stephanie Wehner
10.1073/pnas.1411728112 PNAS, (2015)

In ordinary thermodynamics, transitions are governed by a single quantity–the free energy. Its monotonicity is a formulation of the second law. Here, we find that the second law for microscopic or highly correlated systems takes on a very different form than it does at the macroscopic scale, imposing not just one constraint on state transformations, but many. We find a family of quantum free energies which generalize the standard free energy, and can never increase. The ordinary second law corresponds to the nonincreasing of one of these free energies, with the remainder imposing additional constraints on thermodynamic transitions. In the thermodynamic limit, these additional second laws become equivalent to the standard one. We also prove a strengthened version of the zeroth law of thermodynamics, allowing a definition of temperature.

Acoustic Black Hole in a Stationary Hydrodynamic Flow of Microcavity Polaritons
H.□S. Nguyen, D. Gerace, I. Carusotto, D. Sanvitto, E. Galopin, A. Lemaître, I. Sagnes, J. Bloch, and A. Amo
Phys. Rev. Lett. 114, 036402 – (22 January 2015)
We report an experimental study of superfluid hydrodynamic effects in a one-dimensional polariton fluid flowing along a laterally patterned semiconductor microcavity and hitting a micron-sized engineered defect. At high excitation power, superfluid propagation effects are observed in the polariton dynamics; in particular, a sharp acoustic horizon is formed at the defect position, separating regions of sub- and supersonic flow. Our experimental findings are quantitatively reproduced by theoretical calculations based on a generalized Gross-Pitaevskii equation. Promising perspectives to observe Hawking radiation via photon correlation measurements are illustrated.

Controlled Population of Floquet-Bloch States via Coupling to Bose and Fermi Baths
Karthik I. Seetharam, Charles-Edouard Bardyn, Netanel H. Lindner, Mark S. Rudner, Gil Refael
arXiv:1502.02664

External driving is emerging as a promising tool for exploring new phases in quantum systems. The intrinsically non-equilibrium states that result, however, are challenging to describe and control. We study the steady states of a periodically driven one-dimensional electronic system, including the effects of radiative recombination, electron-phonon interactions, and the coupling to an external fermionic reservoir. Using a kinetic equation for the populations of the Floquet eigenstates, we show that the steady-state distribution can be controlled using the momentum and energy relaxation pathways provided by the coupling to phonon and Fermi reservoirs. In order to utilize the latter, we propose to couple the system and reservoir via an energy filter which suppresses photon-assisted tunneling. Importantly, coupling to these reservoirs yields a steady state resembling a band insulator in the Floquet basis. The system exhibits incompressible behavior, while hosting a small density of excitations. We discuss transport signatures, and describe the regimes where insulating behavior is obtained. Our results give promise for realizing Floquet topological insulators.

“Soliton-induced Majorana fermions in a one-dimensional atomic topological superfluid”
Xia-Ji Liu
Phys. Rev. A 91, 023610 – Published 12 February 2015

We theoretically investigate the behavior of dark solitons in a one-dimensional spin-orbit coupled atomic Fermi gas in harmonic traps by solving self-consistently the Bogoliubov–de Gennes equations. The dark soliton—to be created by phase imprinting in future experiments—is characterized by a real order parameter, which changes sign at a point node and hosts localized Andreev bound states near the node. By considering both cases of a single soliton and multiple solitons, we find that the energy of these bound states decreases to zero when the system is tuned to enter the topological superfluid phase by increasing an external Zeeman field. As a result, two Majorana fermions emerge in the vicinity of each soliton, in addition to the well-known Majorana fermions at the trap edges associated with the nontrivial topology of the superfluid. We propose that the soliton-induced Majorana fermions can be directly observed by using spatially resolved radio-frequency spectroscopy or indirectly probed by measuring the density profile at the point node. For the latter, the deep minimum in the density profile will disappear due to the occupation of the soliton-induced zero-energy Majorana fermion modes. Our prediction could be tested in a resonantly interacting spin-orbit coupled 40K Fermi gas confined in a two-dimensional optical lattice.

“Electron counting in a silicon single-electron pump”
Tuomo Tanttu, Alessandro Rossi, Kuan Yen Tan, Kukka-Emilia Huhtinen, Kok Wai Chan, Mikko Möttönen, Andrew S. Dzurak
arXiv:1502.04446

We report electron counting experiments in a silicon metal-oxide-semiconductor quantum dot architecture which has been demonstrated to generate a quantized current in excess of 80 pA with uncertainty below 30 parts per million. Single-shot detection of electrons pumped into a mesoscopic reservoir is performed using a capacitively coupled single-electron transistor. We extract the full probability distribution of the transfer of n electrons per pumping cycle for n = 0, 1, 2, 3, and 4. We find that the probabilities extracted from the counting experiment are in excellent agreement with direct current measurements in a broad range of dc electrochemical potentials of the pump. The electron counting technique is also used to confirm the improving robustness of the pumping mechanism with increasing electrostatic confinement of the quantum dot.