Condensed Matter Journal Club, 05.11.2013, Stefan Walter

1. **Measuring topological invariants in photonic systems**
   Mohammad Hafezi
   arXiv:1310.7946
   Motivated by the recent theoretical and experimental progress in implementing topological orders with photons, we analyze photonic systems with different topologies and present a scheme to probe their topological features. Specifically, we propose a scheme to modify the boundary phases to manipulate edge state dynamics. Such a scheme allows one to measure the winding number of the edge states. Furthermore, we discuss the effect of loss and disorder on the validity of our approach.

2. **Tunable polarization in beam-splitter based on 2D topological insulators**
   Dietrich G. Rothe, Ewelina M. Hankiewicz
   arXiv:1310.7213
   The typical bulk model describing 2D topological insulators (TI) consists of two types of spin-orbit terms, the so-called Dirac term which induces out-of plane spin polarization and the Rashba term which induces in-plane spin polarization. We show that for some parameters of the Fermi energy, the beam splitter device built on 2D TIs can achieve higher in-plane spin polarization than one built on materials described by the Rashba model itself. Further, due to high tunability of the electron density and the asymmetry of the quantum well, spin polarization in different directions can be obtained. While in the normal (topologically trivial) regime the in-plane spin polarization would dominate, in the inverted regime the out-of-plane polarization is more significant not only in the band gap but also for small Fermi energies above the gap. Further, we suggest a double beam splitter scheme, to measure in-plane spin current all electrically. Although we consider here as an example HgTe/CdTe quantum wells, this scheme could be also promising for InAs/GaSb QWs where the in- and out-of-plane polarization could be achieved in a single device.

3. **Fragility of the fractional quantum spin Hall effect in quantum gases**
   O. Fialko, J. Brand, U. Zuelicke
   arXiv:1310.7283
   We consider the effect of contact interaction in a prototypical quantum spin Hall system of pseudo-spin-1/2 particles. A strong effective magnetic field with opposite directions for the two spin states restricts two-dimensional particle motion to the lowest Landau level. While interaction between same-spin particles leads to incompressible correlated states at fractional filling factors as known from the fractional quantum Hall effect, these states are destabilized by interactions between opposite spin particles. Exact results for two particles with opposite spin reveal a quasi-continuous spectrum of extended states with a large density of states at low energy. This has implications for the prospects of realizing the fractional quantum spin Hall effect in electronic or ultra-cold atom systems. Numerical diagonalization is used to extend the two-particle results to many bosonic particles and trapped systems. The interplay between an external trapping potential and spin-dependent interactions is shown to open up new possibilities for engineering exotic correlated many-particle states with ultra-cold atoms.

4. **Cold Rydberg atoms for quantum simulation of exotic condensed matter interactions**
   J.P. Hague, S. Downes, C. MacCormick, P.E. Kornilovitch
   arXiv:1310.7360
   We study the magnetization dynamics in a ferromagnet-insulator-superconductor tunnel junction and the associated buildup of the electrical polarization. We show that for an open circuit, the induced voltage varies strongly and nonmonotonically with the precessional frequency, and can be enhanced significantly by the superconducting correlations. For frequencies much smaller or much larger than the superconducting gap, the voltage drops to zero, while when these two energy scales are comparable, the voltage is peaked at a value determined by the driving frequency. We comment on the potential utilization of the effect for the low-temperature spatially-resolved spectroscopy of magnetic dynamics.

5. **Majorana fermions in three dimensional ultracold fermionic optical lattices**
   Chunlei Qu, Ming Gong, Yong Xu, Sumanta Tewari, Chuanwei Zhang
   arXiv:1310.7557
   The realization of spin-orbit coupling (SOC) in ultracold atomic gases has opened the door for observing Majorana fermions (MFs) in cold atom systems. We show that MFs exist in three dimensional (3D) fermionic optical lattices with strictly one dimensional (1D) SOC which has already been realized in experiments. The presence of an in-plane Zeeman field drives the system from a Bardeen-Cooper-Schrieffer (BCS) superfluid to a Fulde-Ferrell (FF) superfluid phase. We find that both phases support multiple MFs at each end of quasi-one dimensional (quasi-1D)

optical lattices with a weak transverse tunneling. In the generalization to 3D, the multiple MFs form a zero energy flat band. Our results are useful to guide the experimentalists on searching for MFs in the context of ultracold fermionic atoms.

6. **Observation of Floquet-Bloch states on the surface of a topological insulator**
   Y. H. Wang, H. Steinberg, P. Jarillo-Herrero, N. Gedik
   arXiv:1310.7563
   The unique electronic properties of the surface electrons in a topological insulator are protected by time-reversal symmetry. Circularly polarized light naturally breaks time-reversal symmetry, which may lead to an exotic surface quantum Hall state. Using time- and angle-resolved photoemission spectroscopy, we show that an intense ultrashort mid-infrared pulse with energy below the bulk band gap hybridizes with the surface Dirac fermions of a topological insulator to form Floquet-Bloch bands. These photon dressed surface bands exhibit polarization-dependent band gaps at avoided crossings. Circularly polarized photons induce an additional gap at the Dirac point, which is a signature of broken time-reversal symmetry on the surface. These observations establish the Floquet-Bloch bands in solids and pave the way for optical manipulation of topological quantum states of matter.

7. **Quasi free-standing silicene in a superlattice with hexagonal boron nitride**
   T. P. Kaloni, M. Tahir, U. Schwingenschlögl
   arXiv:1310.7702
   principles calculations and demonstrate that the interaction between the layers of the superlattice is very small. As a consequence, quasi free-standing silicene is realized in this superlattice. In particular, the Dirac cone of silicene is preserved, which has not been possible in any other system so far. Due to the wide band gap of hexagonal boron nitride, the superlattice realizes the characteristic physical phenomena of free-standing silicene. In particular, we address by model calculations the combined effect of the intrinsic spin-orbit coupling and an external electric field, which induces a transition from a metal to a topological insulator and further to a band insulator.

8. **Spin-orbit coupling, quantum dots, and qubits in transition metal dichalcogenides**
   Andor Kormnyos, Viktor Zlyomi, Neil D. Drummond, Guido Burkard
   arXiv:1310.7720
   We derive an effective Hamiltonian which describes the dynamics of electrons in the conduction band of transition metal dichalcogenides (TMDC) in the presence of perpendicular electric and magnetic fields. We discuss in detail both the intrinsic and the Bychkov-Rashba spin-orbit coupling (SOC) induced by an external electric field. We point out interesting differences in the spin-split conduction band between different TMDC compounds. An important consequence of the strong intrinsic SOC is an effective out-of-plane g-factor for the electrons which differs from the free-electron g-factor $g \approx 2$. We identify a new term in the Hamiltonian of the Bychkov-Rashba SOC which does not exist in III-V semiconductors. Using first-principles calculations, we give estimates of the various parameters appearing in the theory. Finally, we consider quantum dots (QDs) formed in TMDC materials and derive an effective Hamiltonian which allows us to calculate the magnetic field dependence of the bound states in the QDs. We find that all states are both valley and spin split, which suggests that these QDs could be used as valley-spin filters. We explore the possibility of using spin and valley states in TMDCs as quantum bits, and conclude that, due to the relatively strong intrinsic spin-orbit splitting in the conduction band, the most realistic option appears to be a combined spin-valley (Kramers) qubit at low magnetic fields.

9. **Quantum-limited amplification via reservoir engineering**
   A. Metelmann, A. A. Clerk
   arXiv:1311.0273
   We describe a new kind of phase-preserving quantum amplifier which utilizes dissipative interactions in a parametrically-coupled three-mode bosonic system. The use of dissipative interactions provides a fundamental advantage over standard cavity-based parametric amplifiers: large photon number gains are possible with quantum-limited added noise, with no limitation on the gain-bandwidth product. We show that the scheme is simple enough to be implemented both in optomechanical systems and in superconducting microwave circuits.

10. **Quantum limit for nuclear spin polarization in semiconductor quantum dots**
    Julia Hildmann, Eleftheria Kavousanaki, Guido Burkard, Hugo Ribeiro
    arXiv:1310.7819

11. **Non-local spectroscopy of Andreev bound states**
    Jens Schindele, Andreas Baumgartner, Romain Maurand, Markus Weiss, Christian Schönenberger
    arXiv:1311.0659