Adrian Hutter **Journal Club** 05 May 2015

Demonstration of a quantum error detection code using a square lattice of four superconducting qubits
A.D. Corcoles, Easwar Magesan, Srikanth J. Srinivasan, Andrew W. Cross, M. Steffen, Jay M. Gambetta, and Jerry M. Chow
Nat. Commun. **6**, 6979

The ability to detect and deal with errors when manipulating quantum systems is a fundamental requirement for fault-tolerant quantum computing. Unlike classical bits that are subject to only digital bit-flip errors, quantum bits are susceptible to a much larger spectrum of errors, for which any complete quantum error-correcting code must account. Whilst classical bit-flip detection can be realized via a linear array of qubits, a general fault-tolerant quantum error-correcting code requires extending into a higher-dimensional lattice. Here we present a quantum error detection protocol on a two-by-two planar lattice of superconducting qubits. The protocol detects an arbitrary quantum error on an encoded two-qubit entangled state via quantum non-demolition parity measurements on another pair of error syndrome qubits. This result represents a building block towards larger lattices amenable to fault-tolerant quantum error correction architectures such as the surface code.

Fractionalized topological insulators
Joseph Maciejko and Gregory A. Fiete
Nat. Phys. **11**, 385–388

Topological insulators have emerged as a major topic of condensed matter physics research, with several novel applications proposed. Although there are now a number of established experimental examples of materials in this class, all of them can be described by theories based on electronic band structure, which implies that they do not possess electronic correlations strong enough to fundamentally change this theoretical description. Here, we review recent theoretical progress in the description of a class of strongly correlated topological insulatorsfractionalized topological insulatorswhere band theory fails owing to the fractionalization of the electron into other degrees of freedom.

Quantum optics of chiral spin networks
Hannes Pichler, Tomas Ramos, Andrew J. Daley, and Peter Zoller
Phys. Rev. A **91**, 042116

We study the driven-dissipative dynamics of a network of spin-1/2 systems coupled to one or more chiral 1D bosonic waveguides within the framework of a Markovian master equation. We determine how the interplay between a coherent drive and collective decay processes can lead to the formation of pure multipartite entangled steady states. The key ingredient for the emergence of these many-body dark states is an asymmetric coupling of the spins to left and right propagating guided modes. Such systems are motivated by experimental possibilities with internal states of atoms coupled to optical fibers, or motional states of trapped atoms coupled to a spin-orbit coupled Bose-Einstein condensate. We discuss the characterization of the emerging multipartite entanglement in this system in terms of the Fisher information.

Quantum information: Good causes
Giulio Chiribella
Nat. Phys. **11**, 379–380

Classically, it is impossible to infer causal dependencies from the correlations between two variables alone, but in the quantum world causal relationships exist that can be completely characterized by observing the correlations between two systems.

Topology of density matrices
Jan Carl Budich and Sebastian Diehl
Phys. Rev. B **91**, 165140

We investigate the topological properties of density matrices, motivated by the question to what extent phenomena such as topological insulators and superconductors can be generalized to mixed states in the framework of open quantum systems. The notion of geometric phases has been extended from pure to mixed states by Uhlmann [Rep. Math. Phys. 24, 229 (1986)], who discovered an emergent gauge theory over the density matrices based on their pure state representation in a larger Hilbert space. However, since the uniquely defined square root of a density matrix provides a global gauge, this construction is always topologically trivial. Here, we study a more restrictive gauge structure which can be topologically nontrivial and is capable of resolving homotopically distinct mappings of density matrices subject to various spectral constraints. Remarkably, in this framework, topological invariants can be directly defined and calculated for mixed states. In the limit of pure states, the well-known system of topological invariants for gapped band structures at zero temperature is reproduced. We compare our construction with recent approaches to Chern insulators at finite temperature.

Quantum speedup of Monte Carlo methods
Ashley Montanara
arXiv:1504.06987

Monte Carlo methods use random sampling to estimate numerical quantities which are hard to compute deterministically. One important example is the use in statistical physics of rapidly mixing Markov chains to approximately compute partition functions. In this work we describe a quantum algorithm which can accelerate Monte Carlo methods in a very general setting. The algorithm estimates the expected output value of an arbitrary randomised or quantum subroutine with bounded variance, achieving a near-quadratic speedup over the best possible classical algorithm. Combining the algorithm with the use of quantum walks gives a quantum speedup of the fastest known classical algorithms with rigorous performance bounds for computing partition functions, which use multiple-stage Markov chain Monte Carlo techniques. The quantum algorithm can also be used to estimate the total variation distance between probability distributions efficiently..

Precise Quantization of the Anomalous Hall Effect near Zero Magnetic Field
A.J. Bestwick, E.J. Fox, Xufeng Kou, Lei Pan, Kang L. Wang, and D. Goldhaber-Gordon
Phys. Rev. B **114**, 187201

We report a nearly ideal quantum anomalous Hall effect in a three-dimensional topological insulator thin film with ferromagnetic doping. Near zero applied magnetic field we measure exact quantization in the Hall resistance to within a part per 10000 and a longitudinal resistivity under 1Ω per square, with chiral edge transport explicitly confirmed by nonlocal measurements. Deviations from this behavior are found to be caused by thermally activated carriers, as indicated by an Arrhenius law temperature dependence. Using the deviations as a thermometer, we demonstrate an unexpected magnetocaloric effect and use it to reach near-perfect quantization by cooling the sample below the dilution refrigerator base temperature in a process approximating adiabatic demagnetization refrigeration.

Field-Dependent Size and Shape of Single Magnetic Skyrmions
Niklas Romming, Andr Kubetzka, Christian Hanneken, Kirsten von Bergmann, and Roland Wiesendanger
Phys. Rev. Lett. **114**, 177203

The atomic-scale spin structure of individual isolated Skyrmions in an ultrathin film is investigated in real space by spin-polarized scanning tunneling microscopy. Their axial symmetry as well as their unique rotational sense is revealed by using both out-of-plane and in-plane sensitive tips. The size and shape of Skyrmions change as a function of the magnetic field. An analytical expression for the description of Skyrmions is proposed and applied to connect the experimental data to the original theoretical model describing chiral Skyrmions. Thereby, the relevant material parameters responsible for Skyrmion formation can be obtained.

Role of transparency of platinumferromagnet interfaces in determining the intrinsic magnitude of the spin Hall effect
Weifeng Zhang, Wei Han, Xin Jiang, See-Hun Yang, and Stuart S. P. Parkin
Nat. Phys., doi:10.1038/nphys3304