Journal Club, 17. April 2012, Robert Zielke

Cooling by Heating: Very Hot Thermal Light Can Significantly Cool Quantum Systems
A. Mari and J. Eisert,Phys. Rev. Lett. 108, 120602 (2012)

We introduce the idea of actually cooling quantum systems by means of incoherent thermal light, hence giving rise to a counterintuitive mechanism of cooling by heating. In this effect, the mere incoherent occupation of a quantum mechanical mode serves as a trigger to enhance the coupling between other modes. This notion of effectively rendering states more coherent by driving with incoherent thermal quantum noise is applied here to the optomechanical setting, where this effect occurs most naturally. We discuss two ways of describing this situation, one of them making use of stochastic sampling of Gaussian quantum states with respect to stationary classical stochastic processes. The potential of experimentally demonstrating this counterintuitive effect in optomechanical systems with present technology is sketched.

Adiabatic manipulations of Majorana fermions in a three-dimensional network of quantum wires
Bertrand I. Halperin, Yuval Oreg, Ady Stern, Gil Refael, Jason Alicea, and Felix von Oppen, Phys. Rev. B 85, 144501 (2012)

It has been proposed that localized zero-energy Majorana states can be realized in a two-dimensional network of quasi-one-dimensional semiconductor wires that are proximity coupled to a bulk superconductor. The wires should have strong spin-orbit coupling with appropriate symmetry, and their electrons should be partially polarized by a strong Zeeman field. Then, if the Fermi level is in an appropriate range, the wire can be in a topological superconducting phase, with Majorana states that occur at wire ends and at Y junctions, where three topological superconductor segments may be joined. Here we generalize these ideas to consider a three-dimensional network. The positions of Majorana states can be manipulated, and their non-Abelian properties made visible, by using external gates to selectively deplete portions of the network or by physically connecting and redividing wire segments. Majorana states can also be manipulated by reorientations of the Zeeman field on a wire segment, by physically rotating the wire about almost any axis, or by evolution of the phase of the order parameter in the proximity-coupled superconductor. We show how to keep track of sign changes in the zero-energy Hilbert space during adiabatic manipulations by monitoring the evolution of each Majorana state separately, rather than keeping track of the braiding of all possible pairs. This has conceptual advantages in the case of a three-dimensional network, and may be computationally useful even in two dimensions, if large numbers of Majorana sites are involved.

Coherent superconducting quantum pump
Felix Hoehne, Yuri A. Pashkin, Oleg V. Astafiev, Mikko Möttönen, Jukka P. Pekola, and JawShen Tsai, Phys. Rev. B 85, 140504(R) (2012)

We demonstrate nonadiabatic charge pumping utilizing a sequence of coherent oscillations between a superconducting island and two reservoirs. The pumping rate for each elementary cycle is limited by the coupling between the island and the reservoirs given by the Josephson energy. Our experimental and theoretical studies show that relaxation can be employed to reset the pump in order to avoid accumulation of errors due to nonideal control pulses. Thus our results demonstrate the effects of nonadiabatic quantum pumping and dissipation.

Quantum speeding-up of computation demonstrated in a superconducting two-qubit processor
Andreas Dewes, Romain Lauro, Florian R. Ong, Vivient Schmitt, Perola Milman, Patrice Bertet, Denis Vion, and Daniel Esteve, Phys. Rev. B 85, 140503(R) (2012)

We operate a superconducting quantum processor consisting of two tunable transmon qubits coupled by a swapping interaction, and equipped with nondestructive single-shot readout of the two qubits. With this processor, we run the Grover search algorithm among four objects and find that the correct answer is retrieved after a single run with a success probability between 0.52 and 0.67, which is significantly larger than the 0.25 achieved with a classical algorithm. This constitutes a proof of concept for the quantum speed-up of electrical quantum processors.

Conductance beyond the Landauer limit and charge pumping in quantum wires
Jay D. Sau, Takuya Kitagawa, and Bertrand I. Halperin, Phys. Rev. B 85, 155425 (2012)

Periodically driven systems, which can be described by Floquet theory, have been proposed to show characteristic behavior that is distinct from static Hamiltonians. Floquet theory proposes to describe such periodically driven systems in terms of states that are indexed by a photon number in addition to the usual Hilbert space of the system. We propose a way to measure directly this additional Floquet degree of freedom by the measurement of the DC conductance of a single channel quantum point contact. Specifically, we show that a single channel wire augmented with a grating structure when irradiated with microwave radiation can show a DC conductance above the limit of one conductance quantum set by the Landauer formula. Another interesting feature of the proposed system is that being nonadiabatic in character, it can be used to pump a strong gate-voltage-dependent photocurrent even with linearly polarized radiation.

Topological protection of Majorana qubits
Meng Cheng, Roman M. Lutchyn, and S. Das Sarma, Phys. Rev. B 85, 165124 (2012)

We study the stability of the topological quantum computation proposals involving Majorana fermions against thermal fluctuations. We use a minimal realistic model of a spinless px+ipy superconductor and consider the effect of excited midgap states localized in the vortex core as well as of transitions above the bulk superconducting gap on the quasiparticle braiding, interferometry-based qubit readout schemes, and quantum coherence of the topological qubits. We find that thermal occupation of the midgap states does not affect adiabatic braiding operations but leads to a reduction in the visibility of the interferometry measurements. We also consider quantum decoherence of topological qubits at finite temperatures and calculate their decay rate which is associated with the change of the fermion parity and, as such, is exponentially suppressed at temperatures well below the bulk excitation gap. Our conclusion is that the Majorana-based topological quantum computing schemes are indeed protected by virtue of the quantum nonlocality of the stored information and the presence of the bulk superconducting gap.

Signatures of Majorana fermions in hybrid superconductor-semiconductor nanowire devices V. Mourik, K. Zuo, S. M. Frolov, S. R. Plissard, E. P. A. M. Bakkers, and L. P. Kouwenhoven, DOI: 10.1126/science.1222360

Majorana fermions are particles identical to their own antiparticles. They have been theoretically predicted to exist in topological superconductors. We report electrical measurements on InSb nanowires contacted with one normal (Au) and one superconducting electrode (NbTiN). Gate voltages vary electron density and define a tunnel barrier between normal and superconducting contacts. In the presence of magnetic fields of order 100 mT we observe bound, mid-gap states at zero bias voltage. These bound states remain fixed to zero bias even when magnetic fields and gate voltages are changed over considerable ranges. Our observations support the hypothesis of Majorana fermions in nanowires coupled to superconductors.

Zero bias conductance peak in Majorana wires made of semiconductor-superconductor hybrid structures
Chien-Hung Lin, Jay D. Sau, S. Das Sarma, arXiv:1204.3085v1 [cond-mat.mes-hall]

Motivated by a recent experimental report [1] claiming the likely observation of the Majorana mode in a semiconductor-superconductor hybrid structure [2,3,4], we study theoretically the dependence of the zero bias condcutance peak associated with the zero-energy Majorana mode in the topological superconducting phase as a function of temperature, tunnel barrier potential, and a magnetic field tilted from the direction of the wire. We find that higher temperatures and tunnel barriers as well as a large magnetic field in the direction transverse to the wire length could very strongly suppress the zero-bias conductance peak as observed in Ref.[1]. We also show that a strong magnetic field along the wire could eventually lead to the splitting of the zero bias peak into a doublet.

Non-abelian Majoranas and braiding in inhomogeneous spin ladders
Fabio L. Pedrocchi, Suhas Gangadharaiah, Stefano Chesi, Daniel Loss, arXiv:1204.3044v1 [cond-mat.mes-hall]

We propose an inhomogeneous open spin ladder, related to the Kitaev honeycomb model, which can be tuned between topological and non-topological phases. In extension of Lieb's theorem, we show numerically that the ground state of the spin ladder is either vortex-free or vortex-full. At the phase-boundaries single Majorana states emerge which are proven to be robust against local perturbations and to obey non-abelian braiding statistics. We show that a network of such spin ladders provides a promising platform for topological quantum computing.

Electron(hole)-phonon coupling in crystalline organic semiconductors: a microscopic evidence for non-polaronic charge carriers
Nenad Vukmirovic, C. Bruder, and Vladimir M. Stojanovic, arXiv:1204.3207v1 [cond-mat.str-el]

We consider electron(hole)-phonon coupling in crystalline organic semiconductors, using naphthalene for our case study. Employing a first-principles approach, we compute the changes in the self-consistent Kohn-Sham potential corresponding to different phonon modes and go on to obtain the carrier-phonon coupling matrix elements (vertex functions). We then evaluate perturbatively the quasiparticle spectral residues for electrons at the bottom of the lowest-unoccupied- (LUMO) and holes at the top of the highest-occupied (HOMO) band, respectively obtaining $Z_{\mathrm{e}} \approx 0.74$ and $Z_{\mathrm{h}} \approx 0.78$. Along with the widely accepted notion that the carrier-phonon coupling strengths in polyacenes decrease with increasing molecular size, our results provide a strong microscopic evidence for the previously conjectured non-polaronic nature of band-like carriers in these systems.

Majorana qubit decoherence by quasiparticle poisoning
Diego Rainis, Daniel Loss, arXiv:1204.3326v1 [cond-mat.mes-hall]

We consider the problem of quasiparticle poisoning in a nanowire-based realization of a Majorana qubit, where a spin-orbit-coupled semiconducting wire is placed on top of a (bulk) superconductor. By making use of recent experimental data exhibiting evidence of a low-temperature residual non-equilibrium quasiparticle population in superconductors, we show by means of analytical and numerical calculations that the dephasing time due to the tunneling of quasiparticles into the nanowire may be problematically short to allow for qubit manipulation.