Kevin van Hoogdalem **Journal Club** 17/01/2012

Frank Gaitan and Lane Clark
Ramsey Numbers and Adiabatic Quantum Computing
Phys. Rev. Lett. ***108****, 010501 (2012)*
The graph-theoretic Ramsey numbers are notoriously difficult to calculate. In fact, for the two-color Ramsey numbers $R(m,n)$ with $m,n\geq 3$, only nine are currently known. We present a quantum algorithm for the computation of the Ramsey numbers $R(m,n)$. We show how the computation of $R(m,n)$ can be mapped to a combinatorial optimization problem whose solution can be found using adiabatic quantum evolution. We numerically simulate this adiabatic quantum algorithm and show that it correctly determines the Ramsey numbers $R(3,3)$ and $R(2,s)$ for $5\leq s\leq 7$. We then discuss the algorithm's experimental implementation, and close by showing that Ramsey number computation belongs to the quantum complexity class quantum Merlin Arthur.

Sebastian Loth, Susanne Baumann, Christopher P. Lutz, D. M. Eigler, Andreas J. Heinrich
Bistability in Atomic-Scale Antiferromagnets
Science ***335****, 196 (2012)*
Control of magnetism on the atomic scale is becoming essential as data storage devices are miniaturized. We show that antiferromagnetic nanostructures, composed of just a few Fe atoms on a surface, exhibit two magnetic states, the Néel states, that are stable for hours at low temperature. For the smallest structures, we observed transitions between Néel states due to quantum tunneling of magnetization. We sensed the magnetic states of the designed structures using spin-polarized tunneling and switched between them electrically with nanosecond speed. Tailoring the properties of neighboring antiferromagnetic nanostructures enables a low-temperature demonstration of dense nonvolatile storage of information.

Morten Kjaergaard, Konrad Wölms, and Karsten Flensberg
Majorana fermions in superconducting nanowires without spin-orbit coupling
Phys. Rev. B ***85****, 020503(R) (2012)*
We study nanowires with proximity-induced *s*-wave superconducting pairing in an external magnetic field that rotates along the wire. Such a system is equivalent to nanowires with Rashba-type spin-orbit coupling, with strength proportional to the derivative of the field angle. For realistic parameters, we demonstrate that a set of permanent magnets can bring a nearby nanowire into the topologically nontrivial phase with localized Majorana modes at its ends. This occurs even for a magnetic field configuration with nodes along the wire and alternating sign of the effective Rashba coupling.

Vladimir E. Manucharyan, Nicholas A. Masluk, Archana Kamal, Jens Koch, Leonid I. Glazman, and Michel H. Devoret
Evidence for coherent quantum phase slips across a Josephson junction array
Phys. Rev. B ***85****, 024521 (2012)*
Superconducting order in a sufficiently narrow and infinitely long wire is destroyed at zero temperature by quantum fluctuations, which induce 2π slips of the phase of the order parameter. However, in a finite-length wire, coherent quantum phase slips would manifest themselves simply as shifts of energy levels in the excitation spectrum of an electrical circuit incorporating this wire. The higher the phase slips' probability amplitude, the larger are the shifts. Phase slips occurring at different locations along the wire interfere with each other. Due to the Aharonov-Casher effect, the resulting full amplitude of a phase slip depends on the offset charges surrounding the wire. Slow temporal fluctuations of the offset charges make the phase-slip amplitudes random functions of time, and therefore turn energy level shifts into linewidths. We experimentally observed this effect on a long Josephson junction array acting as a "slippery" wire. The slip-induced linewidths, despite being only of order 100 kHz, were resolved from the flux-dependent dephasing of the fluxonium qubit.

Yuezhen Niu, Suk Bum Chung, Chen-Hsuan Hsu, Ipsita Mandal, S. Raghu, and Sudip Chakravarty
Majorana zero modes in a quantum Ising chain with longer-ranged interactions
Phys. Rev. B ***85****, 035110 (2012)*
A one-dimensional Ising model in a transverse field can be mapped onto a system of spinless fermions with *p*-wave superconductivity. In the weak-coupling BCS regime, it exhibits a zero-energy Majorana mode at each end of the chain. Here, we consider a variation of the model, which represents a

superconductor with longer-ranged kinetic energy and pairing amplitudes, as is likely to occur in more realistic systems. It possesses a richer zero-temperature phase diagram and has several quantum phase transitions. From an exact solution of the model, we find that these phases can be classified according to the number of Majorana zero modes of an open chain: zero, one, or two at each end. The model possesses a multicritical point where phases with zero, one, and two Majorana end modes meet. The number of Majorana modes at each end of the chain is identical to the topological winding number of the Anderson pseudospin vector that describes the BCS Hamiltonian. The topological classification of the phases requires a unitary time-reversal symmetry to be present. When this symmetry is broken, only the number of Majorana end modes modulo 2 can be used to distinguish two phases. In one of the regimes, the wave functions of the two phase-shifted Majorana zero modes decay exponentially in space but in an oscillatory manner. The wavelength of oscillation is identical to that in the asymptotic connected spin-spin correlation of the *XY* model in a transverse field, to which our model is dual.

Alexander A. Tsirlin, Angela Möller, Bernd Lorenz, Yurii Skourski, and Helge Rosner
Superposition of ferromagnetic and antiferromagnetic spin chains in the quantum magnet BaAg2Cu[Vo4]]2
*Phys. Rev. B **85**, 014401 (2012)*
Based on density functional theory band-structure calculations, quantum Monte Carlo simulations, and high-field magnetization measurements, we address the microscopic magnetic model of BaAg2Cu[VO4]2 that was recently proposed as a spin-1/2 anisotropic triangular lattice system. We show that the actual physics of this compound is determined by a peculiar superposition of ferromagnetic and antiferromagnetic uniform spin chains with nearest-neighbor exchange couplings of $Ja(1) \simeq -19$ K and $Ja(2) \simeq 9.5$ K, respectively. The two chains featuring different types of the magnetic exchange perfectly mimic the specific heat of a triangular spin lattice, while leaving a clear imprint on the magnetization curve that is incompatible with the triangular-lattice model. Both ferromagnetic and antiferromagnetic spin chains run along the crystallographic *a* direction, and slightly differ in the mutual arrangement of the magnetic CuO4 plaquettes and nonmagnetic VO4 tetrahedra. These subtle structural details are, therefore, crucial for the ferromagnetic or antiferromagnetic nature of the exchange couplings, and put forward the importance of comprehensive microscopic modeling for a proper understanding of quantum spin systems in transition-metal compounds.

M.M. Glazov, I.A. Yugova, Al.L. Efros
Electron spin synchronization induced by optical nuclear magnetic resonance feedback
arXiv:1103.3249v2 [cond-mat.mes-hall]
We predict a new physical mechanism explaining the electron spin precession frequency focusing effect observed recently in singly charged quantum dots exposed to a periodic train of resonant circularly polarized short optical pulses [A. Greilich et al, Science 317, 1896 (2007), Ref. 1]. We show that electron spin precession in an external magnetic field and a field of nuclei creates a Knight field oscillating at the frequency of nuclear spin resonance. This field drives the projection of the nuclear spin onto magnetic field to the value that makes the electron spin precession frequency a multiple of the train cyclic repetition frequency, which is the condition at which the Knight field vanishes.

T. Ideue, Y. Onose, H. Katsura, Y. Shiomi, S. Ishiwata, N. Nagaosa, Y. Tokura
Effect of lattice geometry on magnon Hall effect in ferromagnetic insulators
arXiv:1201.3002v1 [cond-mat.mtrl-sci]
We have investigated the thermal Hall effect of magnons for various ferromagnetic insulators. For pyrochlore ferromagnetic insulators $Lu_2V_2O_7$, $Ho_2V_2O_7$, and $In_2Mn_2O_7$, finite thermal Hall conductivities have been observed below the Curie temperature T_C . From the temperature and magnetic field dependences, it is concluded that magnons are responsible for the thermal Hall effect. The Hall effect of magnons can be well explained by the theory based on the Berry curvature in momentum space induced by the Dzyaloshinskii-Moriya (DM) interaction. The analysis has been extended to the transition metal (TM) oxides with perovskite structure. Thermal Hall signal was absent or far smaller in La_2NiMnO_6 and $YTiO_3$, which have the distorted perovskite structure with four TM ions in the unit cell. On the other hand, a finite thermal Hall response is discernible below T_C in another ferromagentic perovskite oxide $BiMnO_3$, which shows orbital ordering with a larger unit cell. The presence or absence of the thermal Hall effect in insulating pyrochlore and perovskite systems reflect the geometric and topological aspect of DM-induced magnon Hall effect.