The Science of Nanostructures:

New Frontiers in the Physics of Quantum Dots

Chernogolovka, Russia, September 10-14, 2012

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Program and Abstracts

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Igor Burmistrov (Landau Institute for Theoretical Physics)

Yuval Gefen (Weizmann Institute of Science)

Yuri Makhlin (Landau Institute for Theoretical Physics)

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Program	3
Abstracts	6
List of Speakers	21
Chernogolovka map	22

CONFERENCE PROGRAM

September 10, Monday

9:00 - 9:30	Registration		
9:30 - 9:40	Workshop opening		
9:40 - 10:10	Harold Baranger	Waveguide QED: quantum transport of strongly-correlated photons	6
10:10 - 10:20	Discussions		
10:20 - 10:50	**COFFEE BREAK**		
10:50 - 11:20	Julien Basset	Dipole coupling a double quantum dot to a microwave resonator	6
11:20 - 11:30	Discussions		
11:30 - 12:00	Moshe Goldstein	Quantum impurity physics with microwave photons	6
12:00 - 12:10	Discussions		
12:10 - 12:40	Gergely Zarand	Non-equilibrium time dependent current correlations and dynamical response through a biased quantum dot	7
12:40 - 12:50	Discussions		
13:00 - 15:00	**LUNCH**		
15:00 - 15:30	Christophe Mora	Dynamical response of nanoconductors: the example of the quantum RC circuit	7
15:30 - 15:40	Discussions		
15:40 - 16:10	Jeroen Elzerman	Coherence between two-electron spin singlet and triplet states in a coupled quantum dot	8
16:10 - 16:20	Discussions		
16:20 - 16:50	**COFFEE BREAK**		
16:50 - 17:20	Dmitry Gutman	Dynamics of fermionic fluid with inverse population	9
17:20 - 17:30	Discussions		

September 11, Tuesday

9:00 - 9:30	Thomas Ihn	Nanostructures on ultra-clean two-dimensional electron gases	10
9:30 - 9:40	Discussions		
9:40 - 10:10	Richard Berkovits	Entanglement entropy of excited states in disordered interacting finite 1D quantum dots: signs of many-body delocalization?	10
10:10 - 10:20	Discussions		
10:40 - 24:00	**EXCURSION and CONFERENCE DINNER**		

September 12, Wednesday

9:40 - 10:10	Igor Burmistrov	An exact solution for spin and charge correlations in quantum dots	11
10:10 - 10:20	Discussions		
10:20 - 10:50	**COFFEE BREAK**		
10:50 - 11:20	Alexander Shnirman	A quantum dot close to Stoner instability: the role of Berry's phase	11
11:20 - 11:30	Discussions		
11:30 - 12:00	Jürgen König	Mesoscopic Stoner instability in metallic nanoparticles revealed by shot noise	11
12:00 - 12:10	Discussions		
12:10 - 12:40	Vasiliy Glazkov	Quest for the Stoner instability in Pd quantum dots	12
12:40 - 12:50	Discussions		
13:00 - 15:00	**LUNCH**		
15:00 - 15:30	Akira Oiwa	Interplay between proximity effect and Kondo effect in InAs self-assembled quantum dot Josephson junctions	13
15:30 - 15:40	Discussions		
15:40 - 16:10	Mikhail Kiselev	Kondo force in nanoelectromechanical devices: dynamical probe for a Kondo cloud	13
16:10 - 16:20	Discussions		
16:20 - 16:50	**COFFEE BREAK**		
16:50 - 17:20	Kentsuke Kobayashi	Evolution of the Kondo effect in a quantum dot probed by shot noise	14
17:20 - 17:30	Discussions		

September 13, Thursday

9:00 - 9:30	Alex Kamenev	Composite fermion groundstate of Rashba spin-orbit bosons	15
9:30 - 9:40	Discussions		
9:40 - 10:10	Alfredo Levy Yeyati	Andreev and Majorana bound states in quantum dots	15
10:10 - 10:20	Discussions		
10:20 - 10:50	**COFFEE BREAK**		
10:50 - 11:20	Karsten Flensberg	Quantum dots and Majorana fermions	15
11:20 - 11:30	Discussions		
11:30 - 12:00	Alex Altland	Class D spectral peak in Majorana quantum wires	16
12:00 - 12:10	Discussions		
12:10 - 12:40	Ganpathy Murthy	Hamiltonian theory of fractionally filled topological insulators	16
12:40 - 12:50	Discussions		
13:00 -15:00	**LUNCH**		
15:00 - 15:30	Pavel Ioselevich	Majorana state on the surface of a disordered three-dimensional topological insulator	16
15:30 - 15:40	Discussions		
15:40 - 16:10	Bernd Rosenow	Dephasing by a zero temperature detector and the Friedel sum rule	17
16:10 - 16:20	Discussions		
16:20 - 16:50	**COFFEE BREAK**		
16:50 - 17:20	Oded Zilberberg	Null weak values in superconducting quantum dots and beyond	17
17:20 - 17:30	Discussions		

September 14, Friday

9:00 - 9:30	Jukka Pekola	Quasiparticle dynamics in a superconducting island and lead	19
9:30 - 9:40	Discussions		
9:40 - 10:10	Alexander Mirlin	Multifractality of wave functions: Interplay with interaction, classification, and symmetries	19
10:10 - 10:20	Discussions		
10:20 - 10:50	**COFFEE BREAK**		
10:50 - 11:20	Igor Gornyi	Coulomb drag in graphene	19
11:20 - 11:30	Discussions		
11:30 - 12:00	Aleksey Kozikov	Imaging the transmission of nanostructures in a high-mobility heterostructure	20
12:00 - 12:10	Discussions		
12:10 - 12:20	Workshop closing		
12:30 -13:30	**LUNCH**		

September 10, Monday

Waveguide QED: Quantum Transport of Strongly-Correlated Photons

Harold Baranger,[1] Huaixiu Zheng,[1] and Daniel Gauthier[1]

[1] *Department of Physics, Duke University, Durham, North Carolina 27708-0305, USA*

Strong coupling between a local quantum system and extended bosonic states has recently become experimentally feasible in a variety of plasmonic, photonic, circuit-QED, and cold-atom contexts. This has opened up a new field dubbed “waveguide QED”. I first introduce several of the experimental systems and the basic quantum non-linear optics problems they can address. Then, turning to our own results, I present an exact solution of the quantum transport problem of photons in a waveguide strongly coupled to a two-, three-, or four- level system [1–4].

We show that strong coupling produces dramatic quantum optics effects. In particular, multi-photon correlated states emerge in the scattering of two or more photons, which then have a large impact on the transport of coherent-state wave-packets. These correlated states cause photon blockade [2, 3] which regulates the flow of photons and can generate a sub-Poissonian single photon source on demand. Such nonlinear phenomena in open systems can play a critical role in the manipulation of individual, mobile quanta, which is a key goal of quantum information processing and communication.

In a two qubit system, we study photon-photon correlations and entanglement generation for arbitrary spatial separation of the qubits [4]. A novel Green function method is used to study vacuum-mediated qubit-qubit interactions, including both spontaneous and coherent couplings. As a result of these interactions, quantum beats appear in the second-order correlation function. Non-Markovian processes generate a high degree of long-distance entanglement.

[1] H. Zheng, D.J. Gauthier, and H.U. Baranger, PRA 82, 063816 (2010).
[2] H. Zheng, D.J. Gauthier, and H.U. Baranger, PRL 107, 223601 (2011).
[3] H. Zheng, D.J. Gauthier, and H.U. Baranger, PRA 85, 043832 (2012).
[4] H. Zheng and H.U. Baranger, arXiv:1206.4442 (2012).

Dipole coupling of a double quantum dot to a microwave resonator

J. Basset,[1] T. Frey,[1] P.J. Leek,[1] M. Beck,[1] A. Blais,[2] T. Ihn,[1] K. Ensslin,[1] and A. Wallraff[1]

[1] *Department of Physics, ETH Zurich, CH-8093, Zurich, Switzerland*
[2] *Département de Physique, Université de Sherbrooke, Sherbrooke, Québec, J1K 2R1 Canada*

We have realized a hybrid solid-state quantum device, in which a semiconductor double quantum dot is dipole coupled to the microwave field of a superconducting coplanar waveguide resonator. The double dot charge stability diagram extracted from measurements of the amplitude and phase of a microwave tone transmitted through the resonator is in good agreement with that obtained from transport measurements. Both the observed frequency shift and linewidth broadening of the resonator are explained considering the double dot as a charge qubit coupled with a strength of several tens of MHz to the resonator[1].

[1] T.Frey et al. Phys. Rev. Lett. **108**, 046807 (2012)

Quantum Impurity Physics with Microwave Photons

Moshe Goldstein,[1] Michel Devoret,[1,2] Manuel Houzet,[3] and Leonid Glazman[1,2]
[1]*Department of Physics, Yale University, New Haven, CT 06520, USA*
[2]*Departments of Applied Physics, Yale University, New Haven, CT 06520, USA*
[3]*SPSMS, UMR-E 9001, CEA-INAC/UJF-Grenoble 1, F-38054 Grenoble, France*

We consider the propagation of microwave photons along an array of superconducting islands with a set of weakly-coupled islands at its center. Quantum fluctuations of charge on the weakly-coupled islands make the process of “photon splitting” effective. In such a process an incoming photon may be split into a number of photons of lower energy. The minimal number of photons so created depends on the symmetry properties of the corresponding quantum impurity model. As an example, we consider a specific circuit allowing quantum fluctuations between two charge configurations of two weakly-coupled islands, thus mimicking the behavior of an anisotropic Kondo impurity. We evaluate the inelastic photon scattering cross-sections, and show that these cross-sections reveal many-body properties of the Kondo problem, which are hard to access in its traditional fermionic version.

Non-equilibrium time dependent current correlations and dynamical response through a biased quantum dot

Gergely Zarand[1]
[1]*BME-MTA Exotic Quantum Phase Group, Institute of Physics, Budapest University of Technology and Economics, H-1521 Budapest, Hungary.*

We construct a real time current-conserving functional renormalization group (FRG) scheme on the Keldysh contour to study frequency-dependent transport and noise through a quantum dot in the local moment regime [1]. We find that the current vertex develops a non-trivial non-local structure in time, governed by a new set of RG equations. Solving these RG equations, we compute the complete frequency and temperature-dependence of the noise spectrum. For voltages large compared to the Kondo temperature, $eV \gg k_B T_K$, two sharp anti-resonances are found in the noise spectrum at frequencies $\hbar\omega = \pm eV$, and correspondingly, two peaks in the ac conductance through the dot. The effects of magnetic field are also discussed.

The results of the FRG calculations are then compared to the results of current emission noise measurements on a carbon nanotube quantum dot in the Kondo regime, measured at at frequencies ν of the order or higher than the frequency associated with the Kondo effect $k_B T_K/h$, with T_K the Kondo temperature [2]. The carbon nanotube is coupled via an on-chip resonant circuit to a quantum noise detector, a superconductor-insulator-superconductor junction. For $h\nu \approx k_B T_K$ a Kondo effect related singularity is found at a voltage bias $eV \approx h\nu$, and a strong reduction of this singularity for $h\nu \approx 3k_B T_K$, in good agreement with theory.

[1] C. P. Moca, P. Simon, C. H. Chung, and G. Zarand, Phys. Rev. B **83**, 201303(R) (2011).
[2] J. Basset, A. Yu. Kasumov, C. P. Moca, G. Zaránd, P. Simon, H. Bouchiat, and R. Deblock, Phys. Rev. Lett. 108, 046802 (2012).

Dynamical response of nanoconductors: the example of the quantum RC circuit

Christophe Mora,[1] Michele Filippone,[1] and Karyn Le Hur[2]

[1] *Laboratoire Pierre Aigrain, École Normale Supérieure, Université Paris 7 Diderot, CNRS; 24 rue Lhomond, 75005 Paris, France*
[2] *Departments of Physics and Applied Physics, Yale University, New Haven, Connecticut 06520, USA*

The ability to probe and manipulate electrons in real time constitutes one of the main challenges of transport in quantum dots. One paradigmic experiment in the topic of high frequency is the quantum RC circuit, its behavior being governed by the interplay between quantum coherence and interaction effects. This circuit is the quantum analogue of the classical RC circuit: it comprises a dot capacitively coupled to a nearby gate and connected to a single reservoir lead. In this talk, I will discuss the emergence of universal and quantized expressions [1] for the AC resistance of this circuit, and derive an effective low energy model for this problem [2]. In the case of the Anderson model, I will show that a giant peak develops in the AC resistance as the magnetic field is varied [3].

[1] C. Mora and K. Le Hur, Nature Phys. **6**, 697 (2010).
[2] M. Filippone and C. Mora, arXiv:1205.2213.
[3] M. Filippone, K. Le Hur and C. Mora, Phys. Rev. Lett. **107**, 176601 (2011).

Coherence between two-electron spin singlet and triplet states in a coupled quantum dot

Jeroen Elzerman[1]

[1] *Institute of Quantum Electronics, ETH Zurich, CH-8093 Zurich, Switzerland*

Single electron or hole spins confined in self-assembled InGaAs quantum dots can be initialized, manipulated and read out using fast optical techniques. In recent years it has been established that the electron spin's T_2^* coherence time is limited by fluctuations in the nuclear spin bath that couple to the electron spin via the hyperfine interaction. The hole spin coherence, on the other hand, appears to suffer from electrical fluctuations due to the holeŠs larger spin-orbit interaction. Although techniques are being developed to reduce these sources of noise in the electric and magnetic environment, it is probably not feasible to suppress them completely. Fortunately it is possible to design a system of two tunnel-coupled quantum dots that can be robust against both electric and magnetic fluctuations simultaneously.

We study a single pair of two vertically stacked self-assembled quantum dots, each filled with a single electron spin [1]. The two-electron spin singlet (S) and triplet (T) eigenstates are split by the exchange energy of around 100 μeV, due to the strong tunnel coupling between the dots. In addition, a modest magnetic field of 200 mT along the sample's growth direction splits the three T states by the Zeeman energy. Thus, we are able to isolate an optical lambda system consisting of the S and middle T state both coupled to a shared optically excited state. We then study the coherence properties of the S and T ground states in the frequency domain, by performing coherent population trapping experiments. We find that at the optimal value of the gate voltage (a point we refer to as the "sweet spot"), the T_2^* coherence time may exceed 200 ns.

[1] K. M. Weiss, J. M. Elzerman, Y. L. Delley, J. Miguel-Sanchez, A. Imamoglu, *Coherent two-electron spin qubits in an optically active pair of coupled InGaAs quantum dots*, Phys. Rev. Lett. (in print)

Dynamics of fermionic fluid with inverse population

Dmitry Gutman[1]

[1] *Department of Physics, Bar-Ilan University, Ramat-Gan 52900, Israel*

We explore dynamics of a density pulse induced by a local quench in a one-dimensional electron system. The spectral curvature leads to an “overturn” (population inversion) of the wave. We show that beyond this time the density profile develops strong oscillations with a period much larger than the Fermi wave length. The effect is studied first for the case of free fermions by means of the analysis of the evolution of Wigner function. We demonstrate then that the period of oscillations is correctly reproduced by a hydrodynamic theory with an appropriate dispersive term. Finally, we explore the effect of different types of electron-electron interaction on the phenomenon.

September 11, Tuesday

Nanostructures on ultra-clean two-dimensional electron gases

T. Ihn,[1] C. Rössler,[1] S. Baer,[1] K. Ensslin,[1] C. Reichl,[1] and W. Wegscheider[1]
[1] *Solid State Physics Laboratory, ETH Zürich, CH-8093 Zürich, Switzerland*

Two-dimensional electron gases with ultra-high mobilities reaching above 10^7 cm^2/Vs at low temperatures enable the observation of phenomena such as the microwave-induced zero-resistance state, the filling factor $\nu = 5/2$ fractional quantum Hall state, and interaction effects between composite fermions. However, fabricating nanostructures on the basis of such electron gases, preserving the fragile phenomena of interest, is challenging [1].

We have experimentally investigated the transport properties of nanostructures fabricated from high-mobility electron gases. Quantum point contacts [2] benefit from the weakness of the disorder potential and therefore show many-body phenomena, such as the 0.7-anomaly and exchange-enhanced g-factors, and geometry-induced quantum interference of edge channels. We also investigate quantum dots and Fabry-Perot interferometers, which are investigated in the (fractional) quantum Hall regime. For example, using direct transport and single-electron counting we measure the charge-stability diagram of two capacitively and tunnel coupled edge channels.

[1] C. Rössler, T. Feil, P. Mensch, T. Ihn, K. Ensslin, D. Schuh, and W. Wegscheider, New J. Phys. **12**, 043007 (2010).
[2] C. Rössler, S. Baer, E. de Wiljes, P.-L. Ardelt, T. Ihn, K. Ensslin, C. Reichl, and W. Wegscheider, New J. Phys. **13**, 113006 (2011).

Entanglement entropy of excited states in disordered interacting finite 1D quantum dots: signs of many-body delocalization?

Richard Berkovits[1]
[1] *Department of Physics, Bar-Ilan University, Ramat-Gan 52900, Israel*

It is well known that the ground state of a disordered 1D systems is localized even in the presence of electron-electron interactions. Excited states of non-interacting electrons will remain localized, while according to the ideas of many particle localization [1–3] there should be a critical excitation energy above which the many-particle states are delocalized. The entanglement entropy is a convenient quantity for numerical evaluation using the density matrix renormalization method, and behaves differently for localized and delocalized states. We shall show that for finite 1D dots, in which the ground-state localization length ξ is smaller than the dot length L, there are signs of many-body delocalization ($\xi \gg L$) as function of interaction strength in the entanglement entropy of low-lying excited states.

[1] B. L. Altshuler, Y. Gefen, A. Kamenev, and L. S. Levitov, Phys. Rev. Lett. **78**, 2803 (1997).
[2] I. V. Gornyi, A. D. Mirlin, and D. G. Polyakov Phys. Rev. Lett. **95**, 206603 (2005).
[3] D. M. Basko, I. L. Aleiner, and B. L. Altshuler, Ann. Phys. (N.Y.) **321**, 1126 (2006).

September 12, Wednesday

An Exact Solution for Spin and Charge Correlations in Quantum Dots

I.S. Burmistrov,[1] Yuval Gefen,[2] and M.N. Kiselev[3]

[1] *L.D. Landau Institute for Theoretical Physics RAS, Kosygina street 2, 119334 Moscow, Russia*
[2] *Department of Condensed Matter Physics, The Weizmann Institute of Science, Rehovot 76100, Israel*
[3] *International Center for Theoretical Physics, Strada Costiera 11, 34014 Trieste, Italy*

The inclusion of charging and spin-exchange interactions within the Universal Hamiltonian description of quantum dots is challenging as it leads to a non-Abelian action. In the talk we present an *exact* analytical solution of the probem, in particular, in the vicinity of the Stoner instabilty. We calculate the tunneling density of states and the spin susceptibility. We demonstrate that near the Stoner instability the spin susceptibility follows a Curie law with an effective spin. The latter depends logarithmically on temperature due to the statistical fluctuations of the single-particle levels. Near the Stoner instability the tunneling density of states exhibits a non-monotonous behavior as function of the tunneling energy, even at temperatures higher than the exchange energy. This is due to ehnanced spin correlations. Our results could be tested in quantum dots made of nearly ferromagnetic materials [1, 2].

[1] I. S. Burmisrov, Y. Gefen, M. N. Kiselev, JETP Letters **92**, 179 (2010).
[2] I. S. Burmisrov, Y. Gefen, M. N. Kiselev, Phys. Rev. B **85**, 155311 (2012).

A quantum dot close to Stoner instability: the role of Berry's Phase

Alexander Shnirman,[1] Arijit Saha,[2] Yuval Gefen,[2] Igor Burmistrov,[3] and Alexander Altland[4]

[1] *Institut für Theorie der Kondensierten Materie, Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany*
[2] *Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot 76100, Israel*
[3] *Landau Institute for Theoretical Physics, 119334 Moscow, Russia*
[4] *Institut für Theoretische Physik, Universität zu Köln, D-50973 Köln, Germany*

Physics of a quantum dot with electron-electron interactions is well captured by the so called "Universal Hamiltonian" if the dimensionless conductance of the dot is much higher than unity [1]. Within this scheme interactions are represented by three spatially independent terms which describe the charging energy, the spin-exchange and the interaction in the Cooper channel. In this paper we concentrate on the exchange interaction and generalize the functional bosonization formalism developed earlier for the charging energy [2]. This turned out to be challenging as the effective bosonic action is formulated in terms of a vector field and is non-abelian due to the non-commutativity of the spin operators. Here we develop a geometric approach which is particularly useful in the mesoscopic Stoner regime, i.e., when the strong exchange interaction renders the system close the the Stoner instability. We show that it is sufficient to sum over the adiabatic paths of the bosonic vector field and, for these paths, the crucial role is played by the Berry phase. Using these results we were able to calculate the magnetic susceptibility of the dot. The latter, in close vicinity of the Stoner instability point, matches very well with the exact solution [3, 4].

[1] I. L. Kurland, I. L. Aleiner, and B. L. Altshuler, Phys. Rev. B **62**, 14886 (2000).
[2] A. Kamenev and Y. Gefen, Phys. Rev. B **54**, 5428 (1996).
[3] I.S. Burmistrov, Y. Gefen, and M.N. Kiselev, Pis'ma v ZhETF **92**, 202 (2010).
[4] I.S. Burmistrov, Y. Gefen, and M.N. Kiselev, Phys. Rev. B **85**, 155311 (2012).

Mesoscopic Stoner Instability in Metallic Nanoparticles Revealed by Shot Noise

Jürgen König,[1] Björn Sothmann,[2] Philipp Stegmann,[1] and Yuval Gefen[3]

[1] *Theoretische Physik, Universität Duisburg-Essen and CENIDE, 47048 Duisburg, Germany*
[2] *Département de Physique Théorique, Université de Genève, CH-1211 Genève 4, Switzerland*
[3] *Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot 76100, Israel*

We study sequential tunneling through a metallic nanoparticle close to the Stoner instability coupled to parallel magnetized electrodes. Increasing the bias voltage successively opens transport channels associated with excitations of the nanoparticleÕs total spin. For the current this leads just to a steplike increase. The Fano factor, in contrast, shows oscillations between large super-Poissonian and sub-Poissonian values as a function of bias voltage. We explain the enhanced Fano factor in terms of generalized random-telegraph noise and propose the shot noise as a convenient tool to probe the mesoscopic Stoner instability [1].

In order to further investigate the spin dynamics in a metallic nanoparticle close to the Stoner instability, we analyze the full spectrum of relaxation times and relate the corresponding eigenvectors to magnetic multipole moments. Finally, we propose time-dependent biasing schemes to generate states with magnetic quadrupole moments that dominate over a negligible dipole moment [2].

[1] B. Sothmann, J. König, and Y. Gefen, Phys. Rev. Lett. **108**, 166603 (2012).
[2] P. Stegmann, B. Sothmann, J. König, and Y. Gefen, in preparation.

Quest for the Stoner instability in Pd quantum dots

V. N. Glazkov,[1,2] I. S. Burmistrov,[3] A. A. Khokhlov,[4] G. A.Tsirlina,[4] and A. Zheludev[2]

[1] *Kapitza Institute RAS, Kosygina str. 2, 119334 Moscow, Russia*
[2] *Neutron Scattering and Magnetism, Institute for Solid State Physics, ETH Zurich, Switzerland, 8093 Zürich, Switzerland*
[3] *L.D. Landau Institute for Theoretical Physics RAS, Chernogolovka, Russia*
[4] *Chemical Department, M.V.Lomonosov Moscow State University, Moscow, Russia*

One of intriguing phenomena of nanoscale physics is the appearance of net (ferro)magnetic moment on the small particles of diamagnetic metals (e.g. Au, Ag, Pd). This effect was usually discussed in connection with surface magnetism [1]. Recently, a new theoretical approach was developed [2] that predicts new effects related to the nanoparticle bulk. Namely, it predicts that at sufficiently low temperatures (~ 1 K), due to the effect of space quantization of electron energy levels, balance between kinetic and exchange energy in the bulk of the nanoparticle would be shifted in favor of exchange interaction. Hence, at low temperatures bulk of nanoparticle would make a crossover through the Stoner instability to the ferromagnetic state.

To check this prediction we have performed analysis of the magnetization of Pd nanoparticles samples with different size of nanoparticles (typically ~ 5 nm) at temperatures down to 0.5 K. Pd nanoparticles stabilized by dodecyl sulphate molecules were fabricated by wet technique [3]. We have found that at low temperatures magnetization process is history-dependent and low temperature asymptote of the $M(T)$ deviates from the Curie law. Hysteresis loops $M(H)$ does not revealed strong hysteresis, width of the loops was within $10\dots20$ Oe at lowest temperatures. To check that the observed magnetization is due to the bulk we have saturated our samples with hydrogen, which is known to easily penetrate into Pd crystal lattice. In hydrogen atmosphere, palladium hydride formation in the bulk resulted in the suppression of the magnetization for all samples. This magnetization was partially recovered after hydrogen extraction proving that it indeed originates from the bulk. No evidence for the systematic nanoparticle size dependence of the magnetization curves was observed.

Absence of the nanoparticle size dependence suggests that Stoner instability is not a reason for the observed magnetization. Low temperature behavior of magnetization can be explained assuming presence of $\sim 10^{-3} \ldots 10^{-4}$ of Fe impurities, which causes additional magnetization through the polarization of the Pd electrons [4].

Authors thank University of Geneve for the support of this study through the Scientific&Technological Cooperation Programme Switzerland-Russia.

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[3] W. L.Wang, Y. Wang, C. C. Wan, C. L. Lee, Colloids & Surfaces A **275**, 11 (2006).
[4] A. I. Larkin and V. I. Melnikov, JETP **61**, 1231 (1971)

Interplay between proximity effect and Kondo effect in InAs self-assembled quantum dot Josephson junctions

A. Oiwa,[1,2] Y. Kanai,[1] R. S. Deacon,[1,2] K. Yoshida,[1] K. Shibata,[3] K. Hirakawa,[3,2,4] and S. Tarucha[1,4]

[1] *Department of Applied Physics, The University of Tokyo*
[2] *CREST, Japan Science and Technology Agency (JST)*
[3] *Institute of Industrial Science, The University of Tokyo*
[4] *Institute for Nano Quantum Information Electronics, The University of Tokyo*

Quantum dot Josephson junctions are of interest not only for device applications such as sensitive superconducting quantum interference devices [1] and non-local entanglement sources [2] but also as a test bed for theoretical predictions for correlated many body effects, namely the interplay between the Kondo effect and superconductivity [3–5, 7]. Uncapped InAs self-assembled quantum dots (QDs) with electrical tuning of several QD parameters [6] can offer a suitable system to tackle on these subjects. Here we repot on the proximity induced superconducting transport and non-equilibrium Andreev conductance in the presence of Kondo correlation through InAs self-assembled quantum dot Josephson junctions [6]. It has been theoretically investigated that the superconducting transport through the junction is affected by the presence of local magnetic moment and the Kondo correlation for a single level case [3–5] and for two level case [7]. When the local magnetic moment exists in the quantum dots, the ground state of the junction is a magnetic doublet, resulting in a strong suppression of non-dissipative supercurrent. In contrast, when the local magnetic moment is zero or screened by the Kondo effect, the supercurrent is restored [3–5]. We have experimentally studied the quantum phase transition between the magnetic doublet and Kondo ground states in an odd electron occupation region [6] and singlet-triplet degeneracy region with electrical controls of Kondo temperature and orbital degeneracy. Furthermore, we discuss the preliminary results of the transport through the Josephson junctions containing a parallel InAs double QD, indicating a Cooper pair splitting and potentially a non-local entanglement.

[1] J.-P. Cleuziou, W. Wernsdorfer, V. Bouchiat, T. Ondarçuhu, and M. Monthioux, Nature Nanotech. **1**, 53 (2006).
[2] P. Recher, E. V. Sukhorukov, and D. Loss, Phys. Rev. Lett. **85**,1962 (2000).
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Kondo Force in Nanoelectromechanical Devices: Dynamical Probe for a Kondo Cloud

M. N. Kiselev,[1] K. A. Kikoin,[2] L. Y. Gorelik,[3] and R. I. Shekhter[4]

[1] *The Abdus Salam International Centre for Theoretical Physics, Strada Costiera 11, I-34151 Trieste, Italy*
[2] *School of Physics and Astronomy, Tel-Aviv University, Tel-Aviv 69978, Israel*
[3] *Chalmers University of Technology, Department of Applied Physics, SE-412 96 Göteborg, Sweden*
[4] *University of Gothenburg, Department of Physics, SE-412 96 Göteborg, Sweden*

We consider electromechanical properties of a single-electronic device consisting of movable quantum dot attached to a vibrating cantilever, forming a tunnel contact with a non-movable source electrode. We show that the resonance Kondo tunneling of electrons amplify exponentially the strength of nano-electromechanical (NEM) coupling in such device and makes the latter to be insensitive to mesoscopic fluctuations of electronic levels in a nano-dot. It is also shown that the study of Kondo-NEM phenomenon provides an additional (as compared with a standard conductance measurements in a non-mechanical device) information on retardation effects in formation of many-particle cloud accompanied the Kondo tunneling. A possibility for superhigh tunability of mechanical dissipation as well as supersensitive detection of mechanical displacement is demonstrated.

Evolution of the Kondo Effect in a Quantum Dot Probed by Shot Noise

Kensuke Kobayashi[1,2]

[1] *Graduate School of Science, Osaka University, Toyonaka, Osaka, Japan*
[2] *Institute for Chemical Research, Kyoto University, Kyoto, Japan*

As the Kondo effect is a typical many body effect associated with spin, its realization in a quantum dot (QD) offers us an ideal stage to test various theoretical predictions for Kondo physics. Recently, the dynamical aspects of Kondo physics are attracting great interest.

We measure the current and shot noise in a quantum dot in the Kondo regime to address the nonequilibrium properties of the Kondo effect [1]. By systematically tuning the temperature and gate voltages to define the level positions in the quantum dot, we observe an enhancement of the shot noise as temperature decreases below the Kondo temperature, which indicates that the two-particle scattering process grows as the Kondo state evolves. Below the Kondo temperature, the Fano factor defined at finite temperature is found to exceed the expected value of unity from the noninteracting model, reaching 1.8 ± 0.2.

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September 13, Thursday

Composite fermion groundstate of Rashba spin-orbit boson

Alex Kamenev[1]

[1] W.I.Fine Theoretical Physics Institute and Department of Physics, University of Minnesota

Recent experiments with cold atomic gases made it possible to investigate iso-spin 1/2 bosons with spin-orbit (SO) coupling. In case of isotropic 2D Rashba SO the single-particle groundstate is degenerate on a circle in the momentum space. A many-body bosonic groundstate is thus solely selected by inter-particle collisions. We argue that at a small density, it is given by a state of composite fermions placed in a quantized Chern-Simons magnetic field with the filling factor one.

Andreev and Majorana bound states in Quantum Dots

Alfredo Levy Yeyati[1]

[1] Departamento de Física Teórica de la Materia Condensada, Universidad Autónoma de Madrid

Quantum dots coupled to superconducting electrodes have been studied theoretically for many years (for a review see [1]). A central issue which concerns all different studied geometries is the effect of Coulomb interactions on their spectral and transport properties. Recent experimental progress is allowing to test the theoretical predictions in great detail.

In the first part of this presentation I shall discuss the case of Andreev bound states (ABS) in quantum dots coupled to two superconducting leads. Direct observation of ABS in carbon nanotubes quantum dots has been possible through spectroscopic measurements [2]. I shall analyze the validity of simple mean field calculations, which were used to describe the experimental data, by comparison with numerically exact results for the superconducting Anderson model.

In the second part I shall present and discuss a simple model for a topological superconducting wire containing Majorana bound states at both ends. For a sufficiently short wire weakly coupled to normal leads one expects charging effects to be of importance. For this "Single Charge Majorana Transistor" model [3] we find an exact formula expressing the current in terms of certain spectral functions. I shall discuss the crossover from resonant Andreev reflection to the Coulomb blockade regime, where "non-local" effects like electron teleportation are expected.

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Quantum dots and Majorana fermions

K. Flensberg[1]

[1] Center for Quantum Devices, Niels Bohr Institute, University of Copenhagen, Universitetsparken 5, DK-2100 Copenhagen, Denmark

In the talk I discuss the coupling of Majorana bound states (MBS) to quantum dots. First, a normal metal-quantum dot-Majorana Fermion (NDF) situation is considered and it is shown that the transport through the discrete dot spectrum coupled to a MBS gives spectroscopic information about the MBS and a way to measure the parity lifetime [1]. Secondly, I discuss a double quantum dot system coupled to a BCS superconductor where a set of "poor man's" Majorana can be engineered [2]. Even without topological protection of the MBS, the system would allow one to verify many of the predicted properties of MBSŠs and parity qubits, including using the dot to perform manipulations of the MBSs [3].

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[2] M. Leijnse and K. Flensberg, arXiv:1207.4299
[3] K. Flensberg, Phys. Rev. Lett. **106**, 090503 (2011)

Class D spectral peak in Majorana quantum wires

Alexander Altland[1]
[1] *Institute for theoretical physics, Zülpicher Str. 77, 50937 Cologne, Germany*

Proximity coupled spin-orbit quantum wires have recently been shown to support midgap Majorana states at critical points. We show that in the presence of disorder these systems are prone to the buildup of a second bandcenter anomaly, which is of different physical origin but shares key characteristics with the Majorana state: it is narrow in width, insensitive to magnetic fields, carries unit spectral weight, and is rigidly tied to the band center. Depending on the parity of the number of subgap quasiparticle states, a Majorana mode does or does not coexist with the impurity generated peak. The strong 'entanglement' between the two phenomena may hinder an unambiguous detection of the Majorana by spectroscopic techniques.

[1] D. Bagrets, A. Altland, *Class D spectral peak in Majorana quantum wires*, arXiv:1206.0434

Hamiltonian Theory of Fractionally Filled Topological Insulators

Ganpathy Murthy[1]
[1] *Department of Physics and Astronomy, University of Kentucky, USA*

A band with a nonzero Chern number is known as a Chern band. When such a band is filled the dimensionless Hall conductance is the Chern number. Recently there has been a lot of interest in what happens when the Chern band is fractionally filled. There is considerable numerical evidence that there are gapped fractional quantum Hall-like states at fractional filling. We all know that the FQHE can be understood by forming composite fermions from electrons by flux attachment. How does one think about flux attachment in the absence of an external magnetic field, as in the Chern bands? I will show that the Hamiltonian theory of the FQHE, which gave predictions accurate to about 10% there, can be generalized to the fractionally filled Chern band. I will talk about the analogues of the liquid FQH states, as well as states which are impossible without a lattice, where the Hall conductance is not the filling.

Majorana state on the surface of a disordered three-dimensional topological insulator

P. A. Ioselevich,[1,2] P. M. Ostrovsky,[3,1] and M. V. Feigel'man[1,2]
[1] *L. D. Landau Institute for Theoretical Physics, Kosygin str. 2, Moscow, 119334 Russia*
[2] *Moscow Institute of Physics and Technology, Institutsky per. 9, Dolgoprudny, 141700 Russia*
[3] *Max Planck Institute for Solid State Research, Heisenbergstr. 1, 70569 Stuttgart, Germany*

We study low-lying electron levels in an "antidot" capturing a coreless vortex on the surface of a three-dimensional topological insulator in the presence of disorder. The surface is covered with a superconductor film with a hole of size R larger than coherence length, which induces superconductivity via proximity effect. Spectrum of electron states inside the hole is sensitive to disorder, however, topological properties of the system give rise to a robust Majorana bound state at zero energy. We calculate the subgap density of states with both energy and spatial resolution using the supersymmetric sigma model method. We identify the presence of the Majorana fermion with symmetry class B. Tunneling into the hole region is sensitive to the Majorana level and exhibits resonant Andreev reflection at zero energy.

[1] P. A. Ioselevich, P. M. Ostrovsky, and M. V. Feigel'man, Majorana state on the surface of a disordered three-dimensional topologicaä insulator, Phys. Rev. B, **86**, 035441 (2012)

Dephasing by a Zero Temperature Detector and the Friedel Sum Rule

Bernd Rosenow[1] and Yuval Gefen[2]

[1] *Institut für Theoretische Physik, Universität Leipzig, D-04103, Leipzig, Germany*

[2] *Department of Condensed Matter Physics, The Weizmann Institute of Science, Rehovot 76100, Israel*

Detecting the passage of an interfering particle through one of the interferometer's arms, known as "which path" measurement, gives rise to interference visibility degradation (dephasing). Here we consider a detector at equilibrium. At finite temperature dephasing is caused by thermal fluctuations of the detector. More interestingly, in the zero temperature limit, equilibrium quantum fluctuations of the detector give rise to dephasing of the out-of-equilibrium interferometer. This dephasing is a manifestation of an orthogonality catastrophe which differs qualitatively from Anderson's. Its magnitude is directly related to the Friedel sum rule.

We condsider an electronic Mach-Zehnder interferometer, one arm of which is coupled electrostatically to a detector. The interferometer is defined by the outer edge channel of a $\nu = 2$ quantum Hall setup while the detector consists of localized electronic state, which is tunnel coupled to the inner edge. Our main findings are (i) Thermal fluctuations of the occupancy of the localized state lead to dephasing through statistical averaging over shifted interference patterns [1]; (ii) In the limit of zero temperature the passage of an electron through the upper arm of the MZI modifies the many-body state of the detector. In similitude to the Anderson orthogonality catastrophy [2, 3], the scalar product of the states before and after this modification has taken place, S_{fi}, plays the role of the visibility suppression factor. However, by contrast to the Anderson orthogonality catastrophy, S_{fi} does NOT scale with the detector's size. Nevertheless, by tuning the gate voltage on the localized impurity, complete dephasing can be achieved. (iii) The degree of dephasing depends on both the magnitude of the system-detector coupling, and the strength of quantum fluctuations in the detector. The former can be expressed through the Friedel sum rule. By changing an external gate voltage, the occupancy of the localized state and the amount of equilibrium charge fluctuations can be tuned. (iv) We briefly discuss the implementation of the Friedel sum rule in the presence of tunnel and/or electrostatic coupling to the localized state whose occupation is varied.

We stress that our dephasing protocol [4] involves energy transfer from the system (MZI) to the detector. The results (ii) and (iii) provide a conceptual and technically workable framework for dealing with tunable zero temperature dephasing.

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Null Weak Values in Superconducting Quantum Dots and Beyond

Oded Zilberberg,[1] Alessandro Romito,[2] and Yuval Gefen[3]

[1] *Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot 76100 Israel.*
[2] *Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universität Berlin, 14195 Berlin, Germany*
[3] *Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot 76100, Israel.*

We present a measurement protocol for discriminating between two different quantum states of a qubit with high fidelity. The protocol is comprised of a projective measurement performed on the system with small probability (a.k.a. weak partial-collapse), followed by a second strong measurement (postselection). It is presented in the context of a Josephson phase qubit for which experimental implementation is feasible. We show that our protocol leads to an amplified signal-to-noise ratio (as compared with straightforward strong measurement) when discerning between the two quantum states. We discuss the adverse effect of relaxation and decoherence. Lastly, we report on an optical experimental implementation of the scheme [1].

[1] O. Zilberberg, A. Romito, D. J. Starling, G. A. Howland, J. C. Howell, and Y. Gefen, arXiv:1205.3877 (2012).

<u>*September 14, Friday*</u>

Quasiparticle dynamics in a superconducting island and lead

Ville F. Maisi,[1,2] Olli-Pentti Saira,[1] Sergey V. Lotkhov,[3] Helena S. Knowles,[1,4] Antti Kemppinen,[2] Alexander B. Zorin,[3] and <u>Jukka P. Pekola</u>[1]

[1] *Low Temperature Laboratory (OVLL), Aalto University School of Science, P.O. Box 13500, 00076 Aalto, Finland*
[2] *Centre for Metrology and Accreditation (MIKES), P.O. Box 9, 02151 Espoo, Finland*
[3] *Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany*
[4] *Cavendish Laboratory, University of Cambridge, JJ Thomson Avenue, Cambridge CB3 0HE, United Kingdom*

We discuss experiments at low sub-100 mK bath temperatures where quasiparticles in aluminium superconductor are monitored either under quiescent conditions or when the quasiparticles are injected synchronously by a gate drive one by one. Record low ($0.03\ \mu\mathrm{m}^{-3}$) residual quasiparticle densities have been observed. The energy relaxation rate for a thermal population of quasiparticles, and the recombination rate for a single quasiparticle pair have been measured.

Multifractality of wave functions: Interplay with interaction, classification, and symmetries

Alexander D. Mirlin[1]

[1] *Karlsruhe Institute of Technology*

Multifractality characterizes strong fluctuations of wave functions near Anderson transition and in 2D systems. In this talk recent progress in the field achieved in the framework of the sigma-model formalism will be reviewed. Interplay of multifractality and short-range electron-electron interaction leads to enhancement of superconductivity by Anderson localization [1] and controls dephasing at metal-insulator and quantum Hall transitions [2]. I will further present a symmetry-based classification of observables (composite operators in the field theory language) characterizing wave function correlations [3]. Finally, I will show that the invariance of the sigma-model manifold with respect to a Weyl group leads to numerous exact symmetry relations between the corresponding scaling dimensions [3, 4].

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Coulomb drag in graphene

M. Schütt,[1] <u>I.V. Gornyi</u>,[1,2,3] P.M. Ostrovsky,[4,1,5] M. Titov,[6] B.N. Narozhny,[2] and A.D. Mirlin[1,2,7]

[1] *Institut für Nanotechnologie, Karlsruhe Institute of Technology, 76021 Karlsruhe, Germany*
[2] *Institut für Theorie der Kondensierten Materie and DFG Center for Functional Nanostructures, Karlsruher Institut für Technologie, 76128 Karlsruhe, Germany*
[3] *A.F. Ioffe Physico-Technical Institute, 194021 St. Petersburg, Russia*
[4] *Max-Planck-Institut für Festkörperforschung, Heisenbergstr. 1, 70569, Stuttgart, Germany*
[5] *L.D. Landau Institute for Theoretical Physics RAS, 119334 Moscow, Russia*
[6] *Radboud University Nijmegen, Institute for Molecules and Materials, NL-6525 AJ Nijmegen, The Netherlands*
[7] *Petersburg Nuclear Physics Institute, 188350 St. Petersburg, Russia*

We study [1] Coulomb drag in double-layer graphene [2–4] near the Dirac point. A particular emphasis is put on the case of clean graphene, with transport properties dominated by the electron-electron interaction [1, 5]. Using the quantum kinetic equation framework, we show that the drag becomes T-independent in the clean limit, $T\tau \to \infty$, where T is temperature and $1/\tau$ impurity scattering rate. For stronger disorder (or lower temperature), $T\tau \ll 1/\alpha^2$, where α is the interaction strength, the kinetic equation agrees with the leading-order (α^2) perturbative result [6]. At still lower temperatures, $T\tau \ll 1$ (diffusive regime) this contribution gets suppressed, while the next-order (α^3) contribution becomes important; it yields a peak centered at the Dirac point with a magnitude that grows with lowering $T\tau$. We also discuss the effect of correlations between disorder potentials (of both short-range [7] and long-range [4, 8] types) in the two layers, which also give rise to a finite drag at the neutrality point.

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[3] S. Kim and E. Tutuc, Solid State Commun. **152**, 1283 (2012).
[4] R.V. Gorbachev, A.K. Geim, M.I. Katsnelson, K.S. Novoselov, T. Tudorovskiy, I.V. Grigorieva, A.H. MacDonald, K. Watanabe, T. Taniguchi, and L.A. Ponomarenko, arXiv:1206.6626.
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Imaging the transmission of nanostructures in a high-mobility heterostructure

A. A. Kozikov,[1] C. Rössler,[1] T. Ihn,[1] K. Ensslin,[1] C. Reichl,[1] and W. Wegscheider[1]

[1] *Solid State Physics Laboratory, ETH Zürich, CH-8093 Zürich, Switzerland*

Local electron transport in a high-mobility electron gas formed in a GaAs/AlGaAs heterostructure is studied using scanning gate microscopy. Top gates deposited on top of the GaAs surface are used to electrostatically define nanostructures, such as quantum point contacts (QPC) and a ballistic stadium.

The negatively biased tip of an atomic force microscope depletes the electron gas beneath it and acts as a backscatterer. Electron waves leaving the QPC are backscattered off the tip-induced potential. If the tip is placed in the way of the flow from a QPC mode, the transmission of this mode decreases. This is seen as a change in the conductance across the sample, which is measured as a function of tip position.

Experiments are performed at a base temperature of 300 mK using a home-built atomic force microscope in a He-3 system [1]. We observe branches caused by electron backscattering decorated by interference fringes similar to previous observations by Topinka et al. [2].

We study the behavior of the branches at different experimental conditions defined by the gate and tip voltages, tip-surface distance, magnetic field, temperature and source-drain bias. The tip bias and tip-surface dependences are needed to determine optimal conditions for observing the branches and interference fringes. The importance of backscattering is confirmed in the low magnetic field dependence of the branching behavior.

We extend our studies to a stadium defined by two QPCs. Its opening can be tuned by changing the number of open modes in the constrictions. The measurements are performed at different QPC transmissions, stadium sizes and at high magnetic fields.

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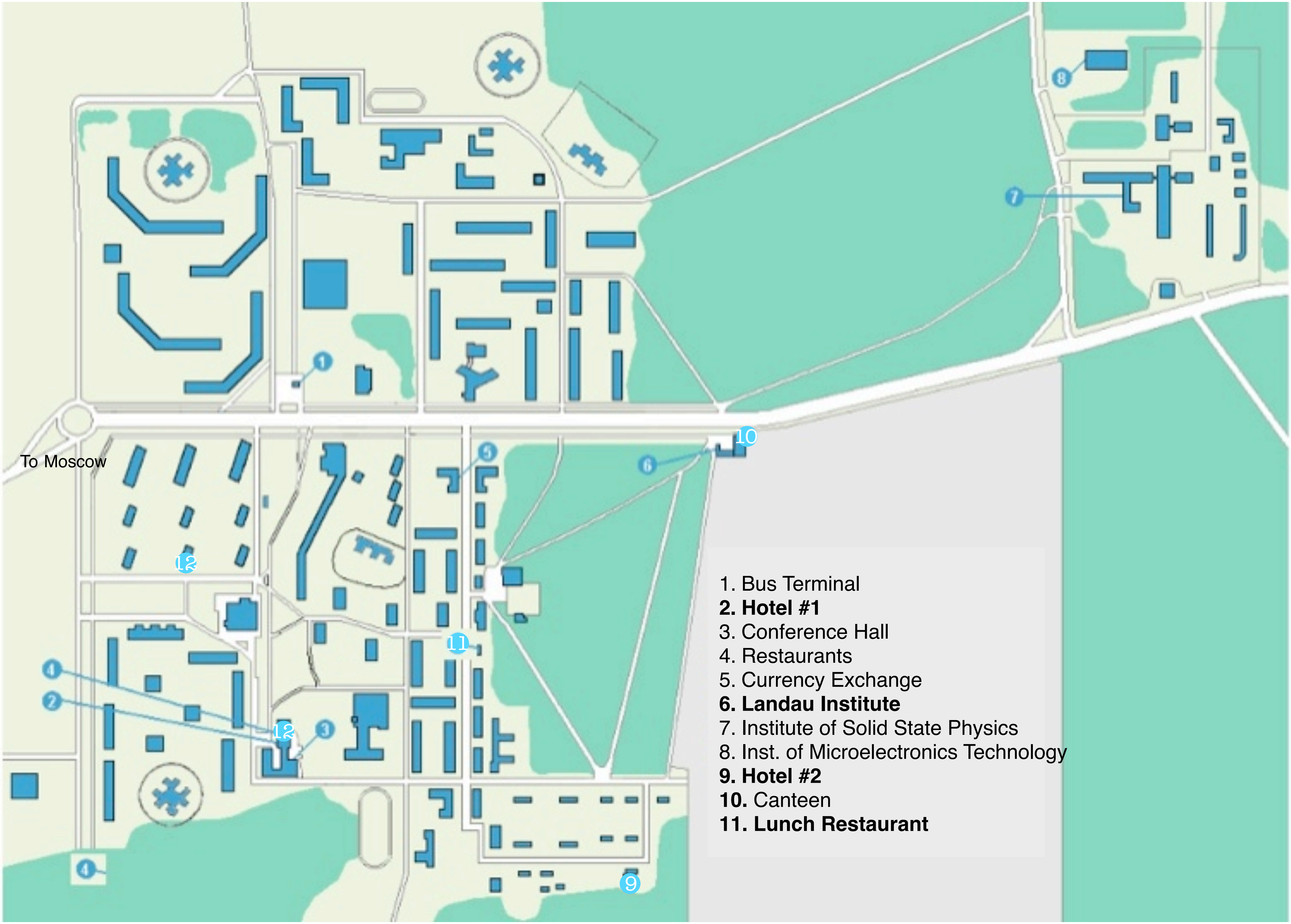
[2] M. A. Topinka et al. Science **289**, 2323 (2000).

List of Speakers

Alexander Altland	University of Köln	alexal@thp.uni-koeln.de	16
Harold Baranger	Duke University	harold.baranger@duke.edu	6
Julien Basset	ETH-Zurich	jbasset@phys.ethz.ch	6
Richard Berkovits	Bar-Ilan University	berkov@mail.biu.ac.il	10
Igor Burmistrov	Landau Institute	burmi@itp.ac.ru	11
Jeroen Elzerman	ETH-Zurich	elzerman@phys.ethz.ch	8
Karsten Flensberg	Niels Bohr Institute	flensberg@fys.ku.dk	15
Vasiliy Glazkov	Kapitza Institute	vglazkov@yandex.ru	12
Moshe Goldstein	Yale University	moshe.goldstein@yale.edu	6
Igor Gornyi	Karlsruhe Institute of Technology	gornyi@tkm.uni-karlsruhe.de	19
Dmitry Gutman	Bar-Ilan University	gutman@biu.ac.il	9
Thomas Ihn	ETH-Zurich	ihn@phys.ethz.ch	10
Pavel Ioselevich	Landau Institute	pioselevich@itp.ac.ru	16
Alex Kamenev	Minnesota University	kamenev@physics.umn.edu	15
Mikhail Kiselev	Intern. Center for Theoretical Physics	mkiselev@ictp.it	13
Kentsuke Kobayashi	Osaka University	kensuke@scl.kyoto-u.ac.jp	14
Jürgen König	University of Duissburg-Essen	koenig@thp.uni-due.de	11
Alexey Kozikov	ETH-Zurich	akozikov@phys.ethz.ch	20
Alfredo Levy Yeyati	Autonoma University of Madrid	a.l.yeyati@uam.es	15
Alexander Mirlin	Kalrsruhe Insitute of Technology	mirlin@tkm.uni-karlsruhe.de	19
Christophe Mora	L.P.A.-ENS	mora@lpa.ens.fr	7
Ganpathy Murthy	University of Kentucky	ganpathy.murthy@uky.edu	16
Akira Oiwa	The University of Tokyo	oiwa@ap.t.u-tokyo.ac.jp	13
Jukka Pekola	Aalto University	jukka.pekola@aalto.fi	19
Bernd Rosenow	University of Leiptzig	rosenow@physik.uni-leipzig.de	17
Alexander Shnirman	Karlsruhe Institute of Technology	alexander.shnirman@kit.edu	11
Gergely Zarand	Budapest Univ. of Technol. and Econ.	zarand@neumann.phy.bme.hu	7
Oded Zilberberg	Weizmann Institute of Science	oded.zilberberg@weizmann.ac.il	17



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