Collection of abstracts of the international conference

“Modern Trends in Condensed Matter Physics”
(Lev Gor'kov Memorial Conference)

June, 24-27, 2019, Chernogolovka, Russia

Сборник тезисов международной конференции

«Современные тенденции в физике конденсированных сред»
(Мемориальная конференция памяти академика Льва Петровича Горькова)

24-27 июня 2019, г. Черноголовка, Россия

Тезисы отсортированы в алфавитном порядке фамилий авторов, отдельно в каждой из двух секций: устные и стендовые доклады.

Abstracts are sorted in alphabetical order of the names of authors, separately in each of the two sections: oral and poster presentations.

Between localization and ergodicity in many-body quantum systems

Altshuler Boris

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Strictly speaking the laws of the conventional Statistical Physics, in particular the Equipartition Postulate, apply only in the presence of a thermostat. For a long time this restriction did not look crucial for realistic systems. Recently there appeared two classes of quantum many-body systems with the coupling to the outside world that is (or is hoped to be) negligible: (1) cold quantum gases and (2) systems of qubits, which enjoy a continuous progress in their disentanglement from the environment. To describe such systems properly one should revisit the very foundations of the Statistical Mechanics. The first step in this direction was the development of the concept of Many-Body Localization (MBL) [1]: the states of a many-body system can be localized in the Hilbert space resembling the celebrated Anderson Localization of single particle states in a random potential. Moreover, one-particle localization of the eigenfunctions of the Anderson tight-binding model (on-site disorder) on regular random graphs (RRG) strongly resembles a generic MBL.

MBL implies that the state of the system decoupled from the thermostat depends on the initial conditions: the time averaging does not result in equipartition distribution, the entropy never reaches its thermodynamic value i.e. the ergodicity is violated. Variations of e.g. temperature can delocalize many body states. However, the recovery of the equipartition is not likely to follow the delocalization immediately: numerical analysis of the RRG problem suggests that the extended states are multi-fractal at any finite disorder [2]. Moreover, regular (no disorder!) Josephson junction arrays (JJA) under the conditions that are feasible to implement and control experimentally demonstrate both MBL and non-ergodic behavior [3].

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Debye mechanism of microwave absorption in superconductors

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We discuss a mechanism of microwave absorption in conventional superconductors which is similar to the Debye absorption mechanism in molecular gases. The contribution of this mechanism to the *ac* conductivity is proportional to the inelastic quasiparticle relaxation time τ_{in} rather than the elastic one $\tau_{el,}$ and therefore can be much larger than the conventional one. The Debye contribution to the linear conductivity arises only in the presence of a *dc* supercurrent in the system, and its magnitude depends strongly on the orientation of the microwave field relative to the supercurrent. The Debye contribution to the nonlinear conductivity exists even in the absence of *dc* supercurrent. It provides an anomalously low nonlinear threshold. Microwave absorption measurements may provide direct information about τ_{in} in superconductors.

Superconductivity of strontium titanate

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Long-range ferroelectric order is aborted in strontium titanate because of quantum fluctuations. The extremely large low-temperature dielectric constant elongates the effective Bohr radius to a micron. Consequently, removing one oxygen atom out of several tens of thousands suffices to turn the insulator to a metal with a sharp Fermi surface and a superconducting instability and intriguing features in charge transport below and above the degeneracy temperature.
Substituting a tiny fraction of strontium atoms with calcium stabilizes long-range ferroelectric order. Remarkably, dilute superconductivity and dilute ferroelectricity coexist in a narrow window of doping in $Sr_{1-x}Ca_xTiO_{3-}$. With increasing carrier concentration, the ferroelectric order is destroyed, and the superconducting critical temperature is enhanced near this quantum phase transition, confirming the suspected intimate link between dilute superconductivity and ferroelectric fluctuations.

Using high magnetic fields to reveal critical behavior near optimum doping in high-temperature superconductivity

Greg Boebinger

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We measure the electronic specific heat in a series of Ba122 high-temperature superconductors. High magnetic fields are used to suppress the superconducting state, providing a direct experimental determination of the density of electronic states that take part in superconductivity in these samples. We find that this density of states is greatly enhanced as one approaches optimum doping, evidencing increased electronic correlations in more strongly superconducting samples. Indeed, the data extrapolate to imply a divergence precisely at optimum doping.

Dissipative and Hall viscosity of a disordered 2D electron gas

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Hydrodynamic charge transport is at the center of recent research efforts. Of particular interest is the non-dissipative Hall viscosity, which conveys topological information in clean gapped systems. The prevalence of disorder in the real world calls for a study of its effect on viscosity. Here we address this question, both analytically and numerically, in the context of a disordered noninteracting 2D electrons. Analytically, we employ the self-consistent Born approximation, explicitly taking into account the modification of the single-particle density of states and the elastic transport time due to the Landau quantization. The reported results interpolate smoothly between the limiting cases of weak (strong) magnetic field and strong (weak) disorder. In the regime of weak magnetic field our results describes the quantum (Shubnikov-de Haas type) oscillations of the dissipative and Hall viscosity. For strong magnetic fields we characterize the effects of the disorder-induced broadening of the Landau levels on the viscosity coefficients. This is supplemented by numerical calculations for a few filled Landau levels. Our results show that the Hall viscosity is surprisingly robust to disorder.

The results are published in
I.S. Burmistrov, M. Goldstein, M. Kot, V.D. Kurilovich, P.D. Kurilovich, "Dissipative and Hall viscosity of a disordered 2D electron gas", arxiv:1901.03561 (to appear in Physical Review Letters)

Bound state of electrons in 2d structures due to the spin-orbit interaction

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Electrons in a quantum well placed nearby a metal plate (gate electrode) are subjected to the direct Coulomb forces and those of image charges. Spin-orbit interaction (SOI)of the Bychkov-Rashba type (the so called Rashba term) depends on the normal component of the electric field in the structure and the image charge contribution to this field increases with decrease in interelectron separation. We show that this results in effective attraction between electrons which, under cetain conditions, exceeds the Coulomb repulsion and bound state of the e-e pair becomes possible. Additional gate voltage of the proper polarity increases the effective attraction and the binding energy of the electron pair becomes easily controllable in experiments.

Interplay between superconductivity and non-Fermi liquid above a quantum critical point in a metal

Andrey V Chubukov

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I discuss the interplay between non-Fermi liquid behaviour and superconductivity near a quantum-critical point (QCP) in a metal. It is widely thought that the tendency towards superconductivity and towards non-Fermi liquid behaviour compete, such that when the pairing interaction is reduced below a certain threshold, the system displays a naked non-Fermi liquid QC behaviour. I show that the situation is more complex as there are multiple solutions for Tc at a QCP. For all solutions, except one, Tc vanishes when the pairing interaction drops below the threshold. However, for one solution Tc remains finite even at arbitrary small pairing interaction, despite that there is no Cooper logarithm. I argue that superconductivity between this Tc and a lower T, when other solutions appear, is special, as it is entirely induced by fermions with the first Matsubara frequency. I discuss the implications for the density of states and the spectral function. I argue that there are two qualitatively different regimes of system behaviour below the onset of pairing – at low T the pairing gap closes with increasing T, while at higher T it gets filled in, but remains finite. I discuss pairing fluctuations and argue that in the "gap filling" regime long-range superconducting order is destroyed, and the system displays a pseudogap behaviour.

Landau theory of disorder-driven metal-insulator transitions

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Disorder driven metal-insulator transitions have long defied proper understanding, despite representing one of the basic phenomena in solid state physics. Here we provide a broad overview of the available theoretical ideas and methods, as well as the experimental results providing guidance. We then present a new theoretical approach that makes it possible to formulate Landau-like order parameter theory at the saddle-point level, capturing most experimental puzzles. It also allows an investigation of systematic fluctuation corrections, suggesting a finite upper critical dimension, and a formulation of an appropriate Landau-Ginzburg description of spatial correlations currently studied by scanning probes.

Thermodynamic properties of disordered unconventional superconductors with competing interactions

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Abstract: A topic of interplay between disorder and competing electronic phases in multiband superconductors have recently got renewed interest in the context of iron-based superconductors. In my talk I will present a theory of disordered unconventional superconductor with competing magnetic order. My discussion will be based on the results obtained for on a two-band model with quasi-two-dimensional Fermi surfaces, which allows for the coexistence region in the phase diagram between magnetic and superconducting states in the presence of intraband and interband scattering induced by doping. Within the quasi-classical approximation I will present the analysis of the quasi-classical Eilenberger's equations which include weak external magnetic field. I will demonstrate that disorder has a crucial effect on the temperature dependence of the magnetic penetration depth as well as critical current, which is especially pronounced in the coexistence phase.

Thermodynamic quantum time-space crystal

Konstantin Efetov

Ruhr University Bochum, Germany

Although quantum time crystals have been proposed initially as macroscopic and thermodynamically stable states, results of subsequent study seemed to indicate that they could be realized only in systems out of equilibrium. Here, investigating a rather general microscopic model we show that, in contrast to the general belief, thermodynamically stable macroscopic quantum time crystals can exist. The order parameter of this new state of matter is periodic in both real and imaginary time but its average over the phase of the oscillations equals zero. At the same time, correlation functions of physical quantities oscillate periodically in time without any decay, and this behavior can in principle be observed experimentally.

Gorkov and modern hydrodynamics

G Falkovich

Weizmann Institute, Israel

I shall start from reviewing the seminal work of Gorkov on thermal convection and the role it played in uniting stability treatment in phase transitions and fluid mechanics. I then shall describe modern applications.

Odd-frequency pairing in disordered conductors

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Texas A&M University & Weizmann Institute

We studied the possibility of the odd frequency pairing, proposed by Berezinskii, in disordered conductors. We considered the case of a very disordered system near an insulating state. Then, an interplay of the Coulomb interaction with strong disorder could be the source of the Cooper pairing in the triplet channel, which in turn may lead to the odd-frequency pairing. The other case where such an instability may develop is near a boarder-line of the transition into superconducting state. We discussed the existing experimental data in view of the considered exotic pairing. A hypothesis has been put forward that the odd frequency pairing, unlike the even frequency pairing, leads to an insulating behavior.

Cavity Quantum Enhancement of Superconductivity

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Driving a conventional superconductor with an appropriately tuned classical electromagnetic field can lead to an enhancement of superconductivity via a redistribution of the quasiparticles into a more favorable non-equilibrium distribution – a phenomenon known as the Eliashberg effect. In the first part of the talk, I will discuss coupling a two-dimensional superconducting film to the quantized electromagnetic modes of a microwave resonator cavity, which leads to a quantum version of the Eliashberg effect. We find [1] that when the photon and quasiparticle systems are out of thermal equilibrium, a redistribution of quasiparticles into a more favorable non-equilibrium steady-state occurs, thereby enhancing superconductivity in the sample. We predict that by tailoring the cavity environment (e.g. the photon occupation and spectral functions), enhancement can be observed in a variety of parameter regimes, offering a large degree of tunability.

In the second part of the talk, I will focus on generalizing polaritonic states to a variety of hybrid modes possible in superconducting systems interacting with cavity photons. Following the recent success of realizing exciton-polariton condensates in cavities, the hybridization of cavity photons with the closest analog of excitons within a superconductor – states called Bardasis-Schrieffer modes – will be discussed. Though Bardasis-Schrieffer modes do not typically couple directly to light, one can engineer a coupling with an externally imposed supercurrent, leading to the formation of hybridized Bardasis-Schrieffer-polariton states. These new excitations have nontrivial overlap with both the original photon states and d-wave superconducting fluctuations, implying that their condensation could produce a finite d-wave component of the superconducting order parameter – an exotic s±id superconducting state.

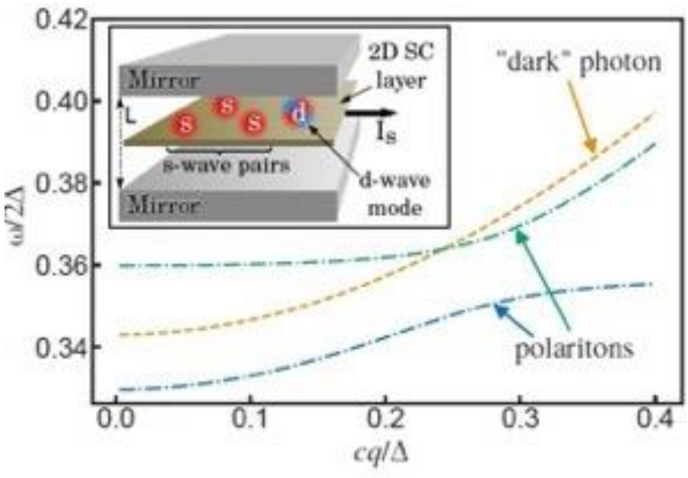

Fig. 1. Bardasis-Schrieffer polaritons.

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Superinductors and superinductor-based qubits

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Superinductors are superconducting (dissipationless) elements with microwave impedance greatly exceeding the resistance quantum $R_Q = \frac{h}{(2e)^2}$. These elements can be implemented as either specially designed chains of Josephson junctions (see, e.g., [1]), or narrow films made of strongly disordered superconductors [2]. There is a wide range of potential applications of superinductors, from protected qubits [3] to parametric amplifiers [4] and Bloch-oscillation-based current standards. In the talk I will briefly discuss the implementation of superinductors and the fluxon-parity-protected qubits [3] based on these elements.

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Topology of the Fermi surface wavefunctions and magnetic oscillations in metals

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In the traditional Fermiology, the size and shape of the Fermi surface in a metal is often deduced from the period of magnetic oscillations of transport or thermodynamic characteristics, *e.g.*, from the de Haas – van Alphen effect. We find that the intercept □ of the infinite-field asymptote of the oscillations yields information about the topology of the Fermi surface wave functions. The topological invariance of □ originates from the symmetry of extremal orbits, which depends not only on the space group but also on the field orientation with respect to the crystal axes.
The wavefunctions fall into 10 distinct classes stemming from the crystalline symmetry; transitions between the classes occur via magnetic breakdown.

On the origin of magnetic quantum oscillations in YBCO high-Tc superconductors

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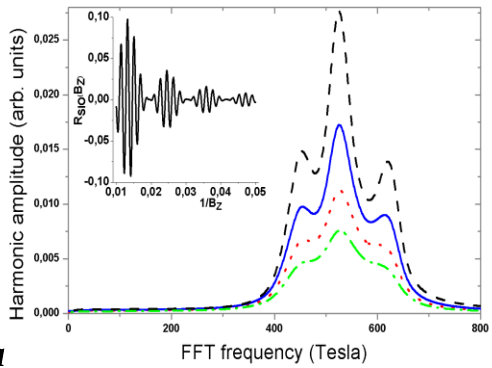
The Fourier transform of the observed magnetic quantum oscillations (MQO) in YBaCuO high-temperature superconductors has a prominent low-frequency peak with two smaller neighbouring peaks [1,2]. The separation and even the position of these three peaks is almost independent of doping. This pattern has been explained previously by rather special, exquisitely detailed, Fermi-surface reconstruction, formed by electron scattering on two charge-density waves. We propose [3-5] that these MQO may have a different origin, and their frequencies are related to the bilayer and inter-bilayer electron hopping rather than directly to the areas of tiny Fermi-surface pockets. Such so-called "slow" or "differential" oscillations explain more naturally many features of the observed oscillations, especially their frequency content, and allow us to estimate the inter-layer transfer integrals and even the in-plane Fermi momentum of true closed orbits. Similar slow oscillations have been proposed first in organic metals [5] and also observed in rare-earth tritelluride compounds [6]. We expect them to be a general phenomenon in layered metals.



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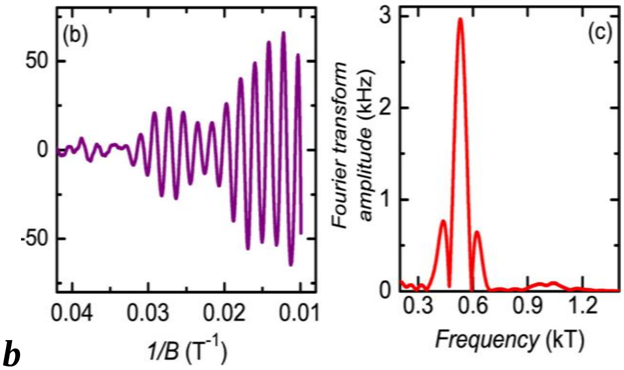

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Fig.1. (a) The Fourier transform of theoretically calculated slow oscillations of magnetoresistance, coming from the interplay of bilayer splitting and of interlayer electron dispersion at four different Dingle temperatures $\pi T_D/\ \hbar\omega_c(B_z{=}1T)=1$ (dashed black line), 3 (solid blue line), 5 (dotted red line) and 7 (dash-dotted green line). Insert shows the conductivity as a function of inverse magnetic field at $\pi T_D/\hbar\omega_c(B_z{=}1T)=3$. (b) The corresponding experimental data from Refs. [1,2].

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Van der Waals interfaces of high-Tc crystalline Bi-2212 with semiconductor *n*-GaAs for teasing out superconductor electric field screening lengths

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The crystalline layered high-Tc superconductor Bi-2212 can be easily cleaved into smoothly faceted flakes which, when placed into intimate physical contact with a variety of layered materials or bulk semiconductors, form heterogeneous junctions. For the Bi-2212/*n*-GaAs Schottky barrier junctions, modifications to the thermionic emission equation provide an excellent description of the I-V characteristics even at low temperatures where tunneling is found by differential conductance spectroscopy measurements to be important. Capacitance measurements under reverse bias suggest an unexpectedly long electric field screening length in the superconductor.

Microwave spectroscopy of a weakly-pinned charge density wave in a superinductor

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A chain of small Josephson junctions (aka superinductor) emerged recently as a high-inductance, low-loss element of superconducting quantum devices. We notice that the intrinsic parameters of a typical superinductor in fact place it into the Bose glass universality class for which the propagation of waves in a sufficiently long chain is hindered by pinning. Its weakness provides for a broad crossover from the spectrum of well-resolved plasmon standing waves at high frequencies to the low-frequency excitation spectrum of a pinned charge density wave. We relate the scattering amplitude of microwave photons reflected off a superinductor to the dynamics of a Bose glass. The dynamics at long and short scales compared to the Larkin pinning length determines the low- and high-frequency asymptotes of the reflection amplitude.

Multiband superconductivity and quantum criticality in the heavily hole-doped iron arsenides $A\mathrm{Fe_2As_2}$ with A = K, Rb, and Cs

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In this talk, I present some recent results of my group in Karlsruhe. Besides the discussion of multiband superconductivity in heavily hole-doped iron arsenide superconductors [1], I will report on the multidimensional entropy landscape in the canonical quantum-critical heavy-fermion metal $\mathrm{CeCu_{6\text{-}x}Au_x}$ as determined from thermal-expansion measurements [2], and will discuss novel type of two-band proximity-induced superconductivity in silver on Nb [3].

The iron-based superconductors $A\mathrm{Fe_2As_2}$ with A = K, Rb, Cs exhibit large Sommerfeld coefficients approaching those of heavy-fermion systems. Quantum oscillations of the magnetostriction allow identifying the band-specific quasiparticle masses which by far exceed the band-structure derived masses. The divergence of the Grüneisen ratio derived from thermal expansion indicates that with increasing volume along the series a quantum critical point (QCP) is approached. Critical fluctuations responsible for the enhancement of the quasiparticle masses appear to weaken the superconducting state. This might be due to the fact that the heaviest band (of d_{xy} character) does not significantly contribute to superconductivity in $\mathrm{CsFe_2As_2}$, in line with previous laser-ARPES results for $\mathrm{KFe_2As_2}$ [4].

The third law of thermodynamics states that the entropy of any system in equilibrium has to vanish at absolute zero temperature. At nonzero temperatures, on the other hand, matter is expected to accumulate entropy near a quantum-critical point, where it undergoes a continuous transition from one ground state to another. Based on general thermodynamic principles, the spatial-dimensional profile of the entropy S near a quantum critical point and its steepest descent in the corresponding multidimensional stress space can be determined [2]. Applying this approach for the canonical-quantum critical compound $\mathrm{CeCu_{6\text{-}x}Au_x}$ near its onset of antiferromagnetic order, we are able to link the directional stress dependence of S to the previously determined anisotropy of quantum-critical fluctuations.

We use epitaxial strain to spatially tune the bottom of the surface-state band E_{SS} of Ag(111) islands on Nb(110). Bulk and surface-state contributions to the Ag(111) local density of states (LDOS) can be separated with scanning tunneling spectroscopy. For thick islands (≈ 20 nm), the Ag surface states are decoupled from the Ag bulk states and the superconductive gap induced by proximity to Nb is due to bulk states only. However, for thin islands (3–4 nm), surface-state electrons develop superconducting correlations as identified by a complete energy gap in the LDOS when E_{SS} is smaller than but close to the Fermi level. The induced superconductivity in this case is of a two-band nature and appears to occur when the surface-state wave function reaches down to the Ag/Nb interface.

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Problems for quantum simulations

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I discuss old unresolved problems in theoretical physics that can be simulated by NISQ (noisy intermediate scate quantum) devices, in particular, the puzzle of normal state of bose liquids at large densities and low temperatures. I argue that the physics of these problems should be similar to that of frustrated spin ladders. I review the parameters of the currently available quantum coherent devices and restrictions imposed by them on the simulated problems. I conclude that the frustrated spin ladders relevant for dense bose liquid problem can be directly simulated by NISQ devices.

Non-Born effects in scattering of electrons in a conducting tube with a low concentration of impurities

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Quasi-one-dimensional systems demonstrate Van Hove singularities in the density of states νF and the resistivity ρ, occurring when the Fermi level E crosses a bottom EN of some subband of transverse quantization. We demonstrate that the character of smearing of the singularities crucially depends on the concentration of impurities. There is a crossover concentration nc∝|λ|, λ≪1 being the dimensionless amplitude of scattering. For n≫nc, the singularities are simply rounded at ε≡E−EN∼τ−1—the Born scattering rate. For n≪nc, the single-impurity non-Born effects in scattering become essential despite λ≪1. The peak of the resistivity is asymmetrically split in a Fano-resonance manner (however, with a more complex structure). Namely, for ε>0, there is a broad maximum at ε∝λ2, while for ε<0, there is a deep minimum at ||ε||∝n2≪λ2. The behavior of ρ below the minimum depends on the sign of λ. In case of repulsion, ρ monotonically grows with ||ε|| and saturates for ||ε||≫λ2. In case of attraction, ρ has a sharp maximum at ||ε||∝λ2. The latter feature is due to resonant scattering at quasistationary bound states that inevitably arise just below the bottom of each subband for any attracting impurity.

TIME REVERSAL SYMMETRY BREAKING IN UNCONVENTIONAL SUPERCONDUCTORS

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Abstract:

It is common to describe unconventional superconductors as materials that display superconductivity but that do not conform to BCS or Migdal-Eliashberg theories. BCS theory of conventional superconductivity describes pairing of spin-singlet time-reversed states, and is characterized by an order parameter which breaks U(1)-gauge symmetry leading to basic superconducting properties, such as the Meissner effect, persistent current and flux quantization. By contrast, unconventional superconductors exhibit internal degrees of freedom within the pair-wavefunction, which often lead to additional broken symmetries, and thus distinct superconducting phases with unique properties. In this talk we discuss specifically the role of time reversal symmetry (TRS) breaking, as probed by polar Kerr effect (PKE) measurements [1], in the heavy fermion superconductor UPt_3. Our measurements follow the previously studied triplet superconductor Sr_2RuO_4 [2], and thus we will discuss the theory behind the possible observation of a Kerr effect in a TRSB superconductor [3].

Focusing on UPt_3 [4], we observe the onset of PKE below a temperature T_{Kerr} that coincides with the low temperature B-phase superconducting transition temperature T_{c-}~480mK. In contrast, no change in Kerr effect is observed through either the high temperature A-phase superconducting transition at $T_{c+}\approx$550mK or the small-moment antiferromagnetic (AF) transition at $T_N\approx$5K. These results indicate that TRS is broken only in the B-phase, independently of the higher temperature AF order, thus placing strong restrictions on the theory of superconductivity in this system.

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Chaos and out-of-time-order correlators in large-N systems

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Out-of-time-order correlators (OTOCs) are a mathematical tool for the study of quantum chaos. Interesting questions about chaos involve asymptotic behavior. For example, the divergence of phase space trajectories is described by OTOCs in the semiclassical limit. In this talk, I discuss a different limit, where a large number of quantum degrees of freedom (such as spins of fermionic modes) are coupled all-to-all. OTOCs in such systems exhibit exponential growth in a certain time window. The more technical part of the talk is based on the paper [Yingfei Gu, Alexei Kitaev, arXiv:1812.00120]. OTOCs for the SYK and similar models are studied using the dynamical mean-field method and a kinetic equation on the double Keldysh contour. A relation between the growth exponent and the overall factor is derived; its corollaries are examined.

Gor'kov-theory used for superconducting devices in astronomical instruments

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Lev Gor'kov's Master's diploma citation reads ''engineer-physicist proficient in build-up experimental equipment and exploitation". Therefore, it is appropriate to ask the question what contribution his work made to the functional use of superconductivity, in particular in superconducting electronics. One clear example is in astronomical instruments such as the Herschel Space telescope and the Atacama large millimeter array. Both are equipped with superconducting tunnel-junctions based on niobium, which came to practical use only in 1983. In order to overcome the ill-defined properties of niobium-oxide as a tunnel-barrier a base-electrode consisting of a bilayer of Nb-Al was introduced, which allows the use of AlO_x as a tunnel-barrier. To harvest the full properties of the superconducting gap of niobium one has to rely on the proximity-effect to make the Al a superconductor with a large enough energy-gap, needed for the THz frequencies to be detected. Despite of a number of skillful ways to avoid the use of Gor'kov's equations, ultimately the conclusion was that in order to do the superconducting engineering right, on has to use Gor'kov's equations, to understand the properties of the tunnel-junctions used for astronomical detection, including the recent observations of the edge of a black hole with the Event Horizon Telescope.

Electron-phonon cooling in Anderson insulators

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The electron-phonon relaxation and cooling rate is shown [1] to be dramatically (by 200-500 times) enhanced in a weak insulator close to the metal-insulator transition. This effect is caused by multiplication of enhancement due to (a) multifractality of electron wave functions [2-4] and (b) due to formation of bonding and anti-bonding superposition of resonance localized states which enhances the phase volume of any local matrix element [2]. The latter mechanism also leads to logarithmic enhancement of frequency-dependent conductivity discovered by Berezinskii and Mott. Our theory explains the dramatic enhancement of the electron cooling rate by phonons in experiments on InO amorphous films [5] and on weakly insulating Nb_xSi_{1-x} [6]. It also explains the deviation [7] of the out-cooling rate power law from T^6 predicted for strongly disordered but metallic samples [8].

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Some many-body phenomena due to quantum and quasiclassical effects of electron motion along open trajectories in a magnetic field

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We theoretically study the upper critical magnetic fields at zero temperature in a quasi-two-dimensional (Q2D) superconductor in the parallel and perpendicular fields, $H_{c2}^{\|}(0)$ and $H_{c2}^{\perp}(0)$, respectively. We find that $H_{c2}^{\|}(0) \approx 0.75\ T_c\ |\ dH_{c2}^{\|}/\ dT|_{Tc}$ and $H_{c2}^{\perp}(0) \approx 0.59\ T_c\ |\ dH_{c2}^{\perp}/\ dT|_{Tc}$, where $|\ dH_{c2}^{\|}/\ dT|_{Tc}$ and $|\ dH_{c2}^{\perp}/\ dT|_{Tc}$ are the corresponding Ginzburg-Landau slopes of the upper critical magnetic fields. Our results demonstrate the breakdown of the so-called effective mass model in Q2D case and may be partially responsible for the experimentally observed deviations from the effective mass model in a number of layered superconductors, including MgB_2.

Anomalous quantum transport in superconductors: examples from Nernst and Hall effects

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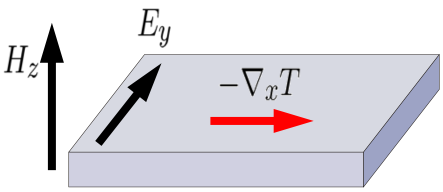
We study anomalous and mesoscopic transport effects at the onset of the superconducting transition focusing on the observed large Nernst-Ettinghausen signal in disordered thin films. In the vicinity of the transition, as the Ginzburg-Landau coherence length of preformed Cooper pairs diverges, short-range mesoscopic fluctuations are equivalent to local fluctuations of the critical temperature. As a result, the dynamical susceptibility function of pair propagation acquires a singular mesoscopic component, and consequently, superconducting correlations give rise to enhanced mesoscopic fluctuations of thermodynamic and transport characteristics. In contrast to disordered normal metals, the rms value of mesoscopic conductivity fluctuations ceases to be universal and displays strong dependence on dimensionality and temperature and under certain conditions can exceed its quantum normal-state value by a large factor. Interestingly, we find different universality as magnetic susceptibility, conductivity, and transverse magnetic thermopower coefficients all display the same temperature dependence. Additionally, we discuss an extrinsic skew-scattering and side-jump mechanisms of Hall and Nernst effects as mediated by emergent superconducting fluctuations near T_c.



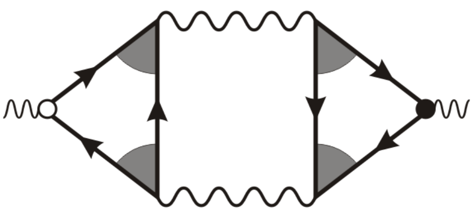


Fig. 1. Left panel represents the schematic of the Nernst effect measurement setup, namely electric field E_y generated by a temperature gradient $\nabla_x T$ in the presence of magnetic field H_z. Right panel represents Aslamazov-Larkin diagram that gives largest contribution to transverse thermomagnetic Nernst coefficient in superconductors near T_c.

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Majorana degrees of freedom with Josephson qubits

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We discuss possibilities to implement braiding of effective Majorana zero modes in chain structures of ordinary (non-topological) qubits, spins, or pseudospins. A generalization of the Jordan-Wigner transformation allows to analyze networks with non-trivial branching. We study realization and stability with respect to relevant perturbations of single- and two-qubit logical gates using symmetries of the system and demonstrate partial topological stability in the absence of full topological protection. Implementation in Josephson-qubit circuits is proposed.

Normal and superfluid ^{3}He in anisotropic aerogel: phase diagram and spin current

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The superfluid state in bulk liquid ^{3}He is realized in the form of A or B phases. Uniaxially anisotropic aerogel (nafen) stabilizes transition from the normal to the polar superfluid state which on further cooling transitions to the axipolar orbital glass state [1]. This is the case in nafen aerogel preplated by several atomic layers of ^{4}He. When pure liquid ^{3}He fills the same nafen aerogel a solid-like layer of ^{3}He atoms coats the aerogel structure. The polar state is not formed anymore and a phase transition occurs directly to the axipolar phase [2]. The substitution of ^{4}He by ^{3}He atoms at the aerogel surface changes the potential and adds the exchange scattering of quasiparticles on the aerogel strands. A calculation shows that both of these effects can decrease the degree of anisotropy of scattering and suppress the polar phase formation. The derived anisotropy of the spin diffusion coefficient in globally anisotropic aerogel is determined by the same parameter which controls the polar state emergence which allows one to check the effect of anisotropy change for different types of covering [3].

The contribution of pair fluctuations to the spin current in liquid ^{3}He in aerogel near the critical temperature of transition to superfluid state is calculated [4].

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Spin liquids from Majorana Zero Modes in a network of Cooper Boxes

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The charging energy U of a small superconducting island containing Majorana zero modes -- a Majorana Cooper-pair box -- induces interactions between the Majorana zero modes. Considering a chain of many such boxes, a topological superconductor-insulator transition occurs when U is much larger than the transfer matrix element t between the boxes. In this Letter, we focus on the insulting phases occurring in this regime. We show that there are several competing insulating phases, and that the transition between them is described by a supersymmetric field theory with a central charge c=7/10. We obtain this result by mapping the model to a spin-1 system and through a field theoretical approach. The microscopic model we propose consists of a chain of Majorana Cooper-pair boxes with *local* tunneling between Majorana zero modes and *local* charging energy terms, which can be controlled by gate potentials, thus making its realization more feasible

Interplay between Anderson localization and proximity effect

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We consider the interplay between proximity effect and Anderson localization in quasi-one-dimensional disordered metallic wires. Proximity effect implies suppression of the local density of states in the normal metal in the vicinity of the contact with a superconductor. The amount of suppression depends both on the energy and on the distance from the contact. Within quasiclassical theory based on the Usadel equation, proximity effect extends into the normal metal up to the distances inverse proportional to the square root of energy. At the lowest energies, when the extent of proximity effect becomes comparable to the localization length, quasiclassical approximation breaks down. In order to simultaneously describe proximity effect and localization, we apply a more general approach of the nonlinear sigma model. In the quasi-one-dimensional case the nonlinear sigma model can be represented as an effective quantum theory in imaginary time. Using perturbative expansion in small energies, we calculate spectral properties and matrix elements within this effective quantum model and obtain exact expressions for the local density of states at low energies and arbitrary distances. Our results show that in the strongly localized regime the proximity effect extends to a distance that grows logarithmically with decreasing energy.

Non-topological domain walls and other singularities in helical magnets.

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Recent experiments of a Norway-German-Japanese team of experimenters and theorists [1] demonstrated the appearance of domain walls between domains with different direction of helix axes on crystal faces (100) and (110) of helical magnets FeGe. It occurred that in a range of temperature between Curie point and orientational transition studied in this research, the direction of helical axis was confined in the plane of face, but there is no anisotropy in this plane. They have found domain walls whose central line is a bisector between directions of helix axes in the two domains. They observed that domain walls whose central line deviates from bisector direction are supplied with a periodic chain of vortexlike singularities called plus and minus pi disclinations. These observations confirmed predictions made in our work [2] imade in cooperation with Dr.. Fuxiang LI. We considered domain walls in the bulk helical magnets. However, the principal problem is why domain wall appear in systems with no anisotropy? We have shown that it happens because the smooth transition from one orientation of helix to another fixed by some pinning centers or edges of face is impossible without changing the pitch of helix somewhere. Such a change violates the balance between exchange and Dzyaloshinskii-Moria interaction. These two forces tend to confine such a violation in a narrowest possible band separating the fixed orientations of axis and thus form a domain wall. This work was published in JETP [3].

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Advantures in synthetic dimensions: New schemes for quantum control

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In my talk I will explore new paradigms for controlling dymaical systems which are inspired by topological physics. First, I'll recount the principles of topological energy pumping [1]/ Next, I will show how states that exhibit topological behavior in synthetic dimension corresponding to photon numbers can exhibit edge states in the synthetic dimension [2]. Lastly, I will show that dynamical majorana states can emerge in multiply driven system even when no gap exists due to the incommensurate drives [3].

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Pair-breaking quantum phase transition in superconducting nanowires

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Quantum phase transitions (QPT) between distinct ground states of matter are widespread phenomena, yet there are only few experimentally accessible systems where the microscopic mechanism of the transition can be tested and understood. We have discovered that a magnetic-field driven QPT in MoGe superconducting nanowires can be fully explained by the pair-breaking critical theory with exponents $\nu\approx 1$ and $z\approx 2$. We find that in the quantum critical regime, the electrical conductivity is in agreement with a *theoretically predicted scaling function* and, moreover, that the theory quantitatively describes the dependence of conductivity on the critical temperature, field magnitude and orientation, nanowire cross-sectional area, and microscopic parameters of the nanowire material. Our work uncovers the microscopic processes governing the transition: the pair-breaking effect of the magnetic field on interacting Cooper pairs overdamped by their coupling to electronic degrees of freedom.
In the talk we will also briefly comment on reliability of the finite-size scaling analysis, implication of our finding for QPT in superconducting films and HTSC and problems with QPT in nanowires and films in zero magnetic field.

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Helical quantum Hall phase in graphene on SrTiO3

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The ground state of charge neutral graphene under perpendicular magnetic field was predicted to be a quantum Hall topological insulator with a ferromagnetic order and spin-filtered, helical edge channels. In most experiments, however, an otherwise insulating state is observed and is accounted for by lattice-scale interactions that promote a broken-symmetry state with gapped bulk and edge excitations. In this talk we show that one can tune the ground state of the graphene zeroth Landau level to the topological phase via a suitable screening of the Coulomb interaction with a $SrTiO_3$ high-*k* dielectric substrate. We observed robust helical edge transport emerging at a magnetic field as low as 1 T and withstanding temperatures up to 110 K over micron-long distances. This new and versatile graphene platform opens new avenues for spintronics and topological quantum computation.

Vestigial order due to superconducting fluctuations in doped topological insulators

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If the topological insulator Bi_2Se_3 is doped with electrons, superconductivity with T_c = 3-4 K emerges for a low density of carriers ($n=10^{20}cm^{-3}$) and with a small ratio of the superconducting coherence length and Fermi wave length: ξ/λ_F = 2 - 4. These values make fluctuations of the superconducting order parameter increasingly important, to the extend that the T_c-value is surprisingly large. Strong spin-orbit interaction led to the proposal of an odd-parity pairing state. This begs the question of the nature of the transition in an unconventional superconductor with strong pairing fluctuations. We show that for a multi-component order parameter, these fluctuations give rise to a nematic phase at $T_{nem} > T_c$.[1] Below T_c several experiments demonstrated a rotational symmetry breaking where the Cooper pair wave function is locked to the lattice. Our theory shows that this rotational symmetry breaking, as vestige of the superconducting state, already occurs above T_c. The nematic phase is characterized by vanishing off-diagonal long-range order, yet with anisotropic superconducting fluctuations. It can be identified through direction-dependent para-conductivity, lattice softening, and an enhanced Raman response in the E_g symmetry channel. In addition, nematic order partially avoids the usual fluctuation suppression of T_c. In addition we present experimental results[2] that demonstrate a partially melted superconductor in which pairing fluctuations condense at a separate phase transition and form a nematic state with broken Z_3, i.e. three-state Potts-model symmetry. High-resolution thermal expansion, specific heat and magnetization measurements of the doped topological insulator $Nb_xBi_2Se_3$ reveal that this symmetry breaking occurs at T_{nem}=3.8 K above T_c=3.25 K, along with an onset of superconducting fluctuations. Thus, before Cooper pairs establish long-range coherence at T_c, they fluctuate in a way that breaks the rotational invariance at T_{nem} and induces a distortion of the crystalline lattice, confirming the prediction of [1].

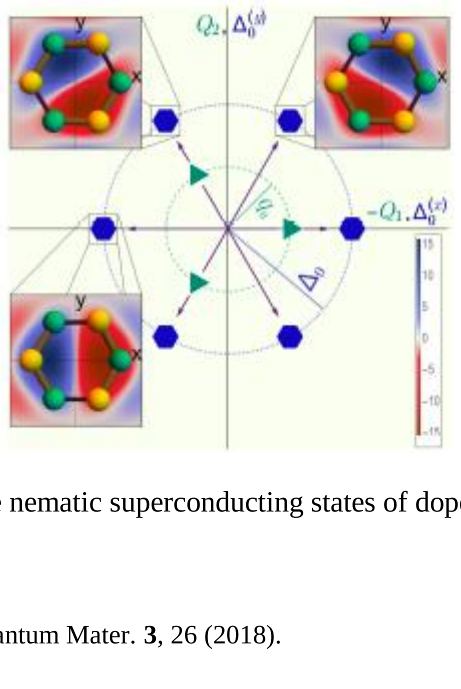

Fig. 1. Three degenerate nematic superconducting states of doped Bi_2Se_3 from Ref.[1].

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Current noise geometrically generated by a driven magnet

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I will review our recent results [1-5] about driven micromagnetic dynamics in small itinerant ferromagnets. We focus on the simplest situation in which only the homogeneous collective mode (Kittel-mode) is excited and the dissipation is dominated by the coupling to the conducting leads. We show that the magnetic dynamics drives the conduction electrons far from equilibrium, which, in turn, strongly influences the trajectory of the magnetization. This requires self-consistency and the emerging dynamics can deviate completely from the expected one. In particular we consider [5] a non-equilibrium cross-response phenomenon, whereby an FMR driven magnetization gives rise to electric shot noise (but no d.c. current). The geometrically generated noise is related to a non-equilibrium distribution in the ferromagnet. Our protocol provides a new channel for detecting and characterizing ferromagnetic resonance.

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Inverted pendulum driven by a random force: statistics of the non-falling trajectory and supersymmetry

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We study stochastic dynamics of an inverted pendulum subject to a random force in the horizontal direction. Considered at the entire time axis, the problem admits a unique solution which always remains in the upper half plane. We develop a new technique for treating statistical properties of this unique non-falling trajectory. In our approach based on the supersymmetric formalism of Parisi and Sourlas, statistics of the non-falling trajectory is expressed in terms of the zero mode of a corresponding transfer-matrix Hamiltonian. The emerging mathematical structure is similar to that of the Fokker-Planck equation, but it is rather written for the ``square root" of the distribution function. Our results for the statistics of the non-falling trajectory are in perfect agreement with direct numerical simulations of the stochastic pendulum equation.

The puzzles of the pseudogap state of high-Tc superconductors

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In the search for mechanisms of High-Tc superconductivity it is critical to know the electronic spectrum in the pseudogap state from which superconductivity evolves. The lack of ARPES data for every cuprate family precludes an agreement as to its structure, doping and temperature dependence and the role of charge ordering. No approach has been developed yet to address the issue theoretically, and we limit ourselves by the phenomenological analysis of the puzzles suggested by the experimental data.

We argue that, in the pseudogap state ubiquitous in underdoped cuprates, the spectrum [1] consists of holes on the Fermi arcs and an electronic pocket in contrast to the idea of the Fermi surface reconstruction via charge ordering. At high temperatures the electrons are dragged by holes while at lower temperatures they get decoupled. The longstanding issue of the origin of the negative Hall coefficient in YBCO and Hg1201 at low temperature is resolved: the electronic contribution prevails as its mobility becomes temperature independent, while the mobility of holes, scattered by the short-wavelength charge density waves, decreases.

To reveal the origin of the electron pocket we analyze the cuprates' energy spectrum in the frames of loop currents picture of pseudogap state [2] using the minimal model Hamiltonian on the basis of interacting *d*, *p* orbitals. We show that for the pseudogap phase, resulting from the time reversal violation by loop currents induced by the strong *d-p* correlations [2], within the certain doping range one should expect an opening of the small electronic pocket at the center of the Brillouin zone. In conclusion we discuss the influence of the lattice structural changes on such transformation of the energy dispersion.

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Quantum metal-superconductor phase transition in 2D disordered materials

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We consider a model of 2-dimensional disordered material with spatial fluctuations of the Cooper attraction constant $\lambda(r) = \lambda_0 + \delta\lambda(r)$. We demonstrate an existence of unusual T=0 quantum phase transition (QPT) as function of relative strength W of $\delta\lambda(r)$ fluctuations. At small enough $W < W_c$ a metal becomes superconducting simultaneously over the whole film at some critical value of λ_0, like in absence of the frozen disorder in $\lambda(r)$.

However, a stronger inhomogeneity with $W > W_c$ leads to formation, with increase of λ_0, of spatially localized superconducting islands which becomes proximity-coupled via normal metal upon further increase of λ_0.We argue that this disorder-dominated type of superconductor-metal QPT is connected with strong critical slowing down and critical fluctuation effects in conductivity.

Freedom of space and time metric:
Solution of the dissipative quantum xy model.

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In the quantum-critical region of the cuprates as well as heavy-fermion antiferromagnets and Fe-based compounds, remarkably simple singular properties have been found. These results cannot be understood by extensions of the Wilson-Fisher type critical theories to quantum dynamics, such as in the works of Hertz, Moriya, etc. One can make reasonable arguments that these problems belong to the 2 dimensional quantum xy model with dissipation. By a transformation of variables this model can be written in terms of orthogonal topological excitations - vortices, and warps which are quantized jumps in imaginary time of phase. The model can then be solved as well as the Kosterlitz-Thouless solution of the classical 2d xy model. The most important properties of the model are that the correlation functions are products of function of space and of imaginary time. Regarding the fluctuations as irreducible vertices, the measured properties can be precisely calculated. Not only are all the singular temperature, frequency, momentum and magnetic field dependences in various properties obtained, their numerical coefficients can be related to each other in terms of two parameters. The transformed model's analytical solution has also been tested in detail by Montecarlo calculations.

Dirac and Weyl fermions: from Gor'kov equations to Standard Model of particle physics

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Application of the Gor'kov theory of superconductivity to the unconventional superconductors demonstrated that the majority of superconductivity classes contain Dirac or Weyl fermions in the electron spectrum [1]. In particular, the topologically protected chiral Weyl fermions emerge in superconductors of the symmetry class $O(D_2)$ - 4 left-handed and 4 right-handed fermions. The topological invariant responsible for the stability of these Weyl fermions is expressed in terms of the Gor'kov Green's function. Expansion of the Gor'kov Green's function in the vicinity of each Weyl point leads to the effective relativistic quantum field theory with effective gauge fields and the effective tetrad gravity. This provides the hint for possible emergent origin of the "fundamental" Weyl fermions, gauge fields, and general relativity. This also allows us to simulate in Weyl semimetals and Weyl superconductors such phenomena as event horizon, Hawking radiation, and transition to antispacetime [2].
Another important group of unconventional superconductors contain the Dirac nodal lines in the electronic spectrum. The Dirac lines have two important consequences. The formation of the Bogoliubov Fermi surfaces in the presence of the supercurrent leads to the $B^{1/2}$ density of states [3]. Gor'kov called this phenomenon "koreshok" -- the diminutive form of the Russian word koren' (root). The second consequence comes from the bulk-surface correspondence, according to which the topological Dirac nodal line in bulk produces the topologically protected flat band with zero energy in the spectrum of the surface electrons. The projection of the Dirac line to the surface serves as the boundary of the flat band. This is one of several possible scenarios of formation of flat bands in different materials, see e.g. [4]. The flat band has extreme density of states, which may provide the room temperature superconductivity.

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<u>Poster presentations:</u> (pages 30-45)

New Transport Mechanism in Weyl Metals with Tilted Dispersion

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Anomalous transport phenomena in the Weyl semimetal can be induced by the chiral anomaly. The latter is the anomalous nonconservation of a chiral charge. In particular, this can be realized by electromagnetic field in parallel fields geometry (~E B). Using a simple theory, we have shown, that in Weyl metals with tilted dispersion a other anomalous transport mechanism is possible. It is not associated with the chiral anomaly. The induced by this mechanism the electric current is proportional to the pseudoscalar product of the fields (E V B) and directed along the magnetic field, that dimers it from the Hall current (~ E x B). At the same time, the conductivity corresponding to this transport chanel does not depend on the scattering time like the Hall conductivity. The new transport mechanism is based on the relativistic effect of the electric field on Landau levels. The electric field changes the distance between the Landau levels, and also changes the effective velocity along magnetic field. At presence of a tilt in the spectrum, this velocity renormalization is dimer for different Weyl points. This leads to a non-zero resulting drift velocity. As a consequence, a non-zero electrical current arises. Thus, we have proposed a new anomalous transport mechanism in the Weyl semimetal, which is not associated with the chiral anomaly.

This work was supported by grants RFBR 18-02-01022a, 18-32-00205 mol(a), 19-02-01000 A.

Mesoscopic conductance fluctuations of class D superconducting wires

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We study disordered superconducting wires (length L) of class D via supersymmetric sigma-model approach in the critical regime between topological and trivial phases, where delocalization happens and average conductance scales as G ~ 1/√L [1]. In order to calculate the variance of conductance G in the diffusive regime we introduce n=2 sigma-model and apply the method of transfer-matrix Hamiltonian, studying Laplace-Beltrami operator on the rank two symmetric space. We use Iwasawa decomposition to construct eigenbasis on this supermanifold, which appears to consist of three-parametric and one-parametric subsets, with the latter closely related to the eigenfunctions on the n=1 sigma-model manifold. Our approach allows to find G (see Fig. 1) at arbitrary lengths in the diffusive region with the crossover from the weak-localization regime at L << ξ to the regime of a very broad conductance distribution at L >> ξ, where ξ is the correlation length of the wire. Also, we account to the possible imbalance m of right/left movers in the wire, which is described by Wess-Zumino-Witten term in the sigma-model action.

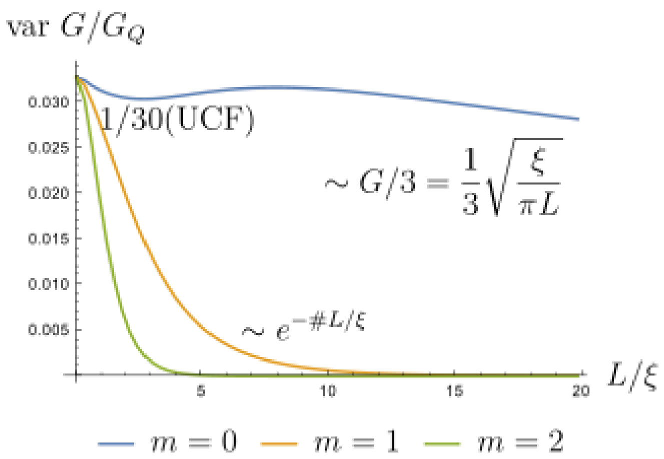

Fig. 1. Variance of conductance due to mesoscopic fluctuations as a function of the wire length. m is the imbalance of right/left movers in the wire.

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Tunneling and Fluctuating Electron-Hole Cooper Pairs in Double Bilayer Graphene

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A strong low-temperature enhancement of the tunnelling conductance between graphene bilayers has been reported recently [G. W. Burg et al. Phys. Rev. Lett. 120, 177702 (2018)], and interpreted as a signature of electron-hole pairing. The pairing in electron-hole double layers was first predicted more than forty years ago but has since avoided observation. In my talk I will present a detailed theory of conductance enhanced by electron-hole Cooper pair fluctuations, which are a precursor to equilibrium pairing, that reflects specific details of double graphene bilayer systems. Above the equilibrium condensation temperature, the pairs have finite temporal coherence and do not support dissipationless tunnelling. Instead they strongly boost the tunnelling conductivity via a fluctuational internal Josephson effect. We find dependences of the zero-bias peak in the differential tunnelling conductance on temperature and electron-hole density imbalance that are in an enough good agreement with experiment.

Reference

D. K. Efimkin, G. W. Burg, E. Tutuc, and A.H. MacDonald - ArXiv: 1903.07739 (2019)

Quantum critical behavior of correlated fermionic systems beyond hertz-moriya-millis theory

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In view of theoretical and experimental interest in quantum phase transitions, we consider the models of strongly correlated fermionic systems, in which quantum critical behavior is different from that described by the Hertz-Moriya-Millis (HMM) theory.

Specifically, we discuss the quantum critical behavior of the doped Hubbard model on a simple cubic lattice with the nearest-neighbor hopping and the half-filled two-dimensional periodic Anderson model. For the former model in the vicinity of quantum phase transition from antiferromagnetic to paramagnetic phase the quantum critical exponents for the correlation length $\xi \propto 1/T^{\nu}$ and the staggered susceptibility $\chi_{\mathbf{Q}} \propto 1/T^{\gamma}$ are $\nu = 1$ and $\gamma = 1/2$ [1], being distinctly different from those in the HMM theory $\gamma = 2\nu = 3/2$. We argue that the difference to HMM theory occurs due to presence of pairs of Kohn lines at the Fermi surface, which are connected by the antiferromagnetic wave vector and characterized by the opposite Fermi velocities. We present an analytical derivation of corresponding exponents within the random phase approximation, confirming the results of the numerical calculations.

For the half-filled two-dimensional periodic Anderson model with increasing hybridization V the quantum phase transition from antiferromagnetic to paramagnetic (Kondo insulator) phase occurs; this transition is expected to belong to $z = 1$ universality class, which puts the corresponding effective dimension $D = d + z = 3$ below the upper critical dimension $D_{uc} = 4$. In this case the non-gaussian (i.e. non-HMM-type) quantum critical behavior is expected. Calculations of the temperature dependence of staggered susceptibility [2] show that at small hybridization V and high temperatures the susceptibility is characterized by the exponent $\gamma = 1$ consistent with the free-spin behavior (Curie law). At smaller temperatures a rapid increase of the susceptibility due to strong antiferromagnetic correlations is observed. At the same time, close to quantum phase transition the abovementioned free spin behavior with decreasing temperature is changed to the one with $\gamma = 2$ exponent, identical to that of $z = 1$ Heisenberg model, but different from the HMM critical exponent $\gamma = 1$. In the crossover region the susceptibility shows strong increase due to increase of the antiferromagnetic correlations. The work is supported by the theme Quant AAAA-A18-118020190095-4 of Minobrnauki, Russia and RFBR grant 17-02-00942.

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Conductivity of anisotropic inhomogeneous superconductors above critical temperature

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We propose a general property: if inhomogeneous superconductivity in anisotropic conductors first appears in the form of isolated superconducting islands, it reduces electric resistivity anisotropically with maximal effect along the least conducting axis and minimal effect along the most conducting axis. We derive analytical expressions for conductivity in heterogeneous anisotropic conductors with ellipsoid superconducting inclusions of size greater than the coherence length using the classical Maxwell's approximation generalized to anisotropic case. This model and calculations are useful to analyze the observed temperature dependence of conductivity anisotropy in various anisotropic superconductors, where superconductivity onset happens inhomogeneously in the form of isolated superconducting islands above Tc. The results are applied to analyze the experimental data on resistivity above the transition temperature Tc in high-temperature superconductors FeSe and $YBa_2Cu_4O_8$ and in the organic superconductor b-$(BEDT\text{-}TTF)_2I_3$. Using the anisotropic electron transport and susceptibility measurements we demonstrate the appearance of inhomogeneous superconductivity in FeSe single crystals at ambient pressure and at temperature 5 times higher than its zero-resistance Tc. Usual superconducting fluctuations cannot explain the observed very anisotropic excess conductivity above Tc in FeSe. The comparison of resistivity data and diamagnetic response in FeSe using our model gives an estimate of the typical axes ratio of superconducting inclusions in this compound. Similar comparison in b-$(BEDT\text{-}TTF)_2I_3$ allows estimating the size of superconducting inclusions ~ 600nm, which is much greater than the coherence length, making our classical model applicable.

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Achieving balance of valley occupancy in narrow AlAs quantum wells

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The terahertz photoconductivity of 100μm and 20μm Hall bars fabricated from narrow AlAs quantum wells (QWs) of different widths is investigated in this paper. The photoresponse is dominated by collective magnetoplasmon excitations within the body of the Hall structure. We observed a radical change of the magnetoplasma spectrum measured precisely for AlAs QWs of widths ranging from 4 nm to 15 nm. We have shown that the observed behavior is a vivid manifestation of valley transition taking place in the two-dimensional electron system. Remarkably, we show that the photoresponse for AlAs QWs with a width of 6 nm features two resonances, indicating simultaneous occupation of strongly anisotropic X_{x-y} valleys and isotropic Xz valley in the QW plane. Our results pave the way for realizing valley-selective layered heterostructures, with potential applications in valleytronics.

The scientific result of the present paper has been obtained within the framework of the Russian Science Foundation (Grant No. 18-72-10072).

SYK model with quadratic perturbations: the route to a non-Fermi-liquid

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Модель SYK (Sachedev-Ye-Kitaev) описывает систему случайно взаимодействующих майорановских фермионов без квадратичных членов в гамильтониане. В пределе большого числа фермионов (N) и низких температурах (T « J, где J - характерный масштаб взаимодействия) функция Грина модели, в седловом приближении, имеет не ферми-жидкостное поведение G(t) ~ t^(-1/2). Однако, седловые уравнения обладают высокой симметрией и допускают замену t на произвольную монотонную функцию f(t). Такое решение имеет только SL(2,R) симметрию. Понижение симметрии от полной группы репараметризаций до SL(2,R) приводит к сущестованию мягкой моды, которая становится существенна при NT « J . Функция Грина на самых больших временах меняет свою асимптотику на G(t) ~ t^(-3/2).
В нашей работе мы исследуем влияние квадратичного возмущения на это поведение. Наивное рассмотрение седловых уравнение показывает, что на больших временах ферми-жидкостное поведение должно восстанавливаться. Однако, возникает вопрос: что, произойдёт если эти времена будут столь большими, что нужно учитывать флуктуации мягкой моды? Рассматривая второй порядок теории возмущения мы показываем, что существует ненулевой интервал амплитуд возмущений, когда поведение функции Грина не меняется, сохраняя асимптотику G(t) ~ t^(-3/2). Это позволяет надеяться на использование модели SYK для построения контролируемой теории не-фермижидкостного поведения сильно взаимодействующих фермионов.

Interaction of angular and quantum magnetoresistance oscillations in quasi-2D metals. The effect of real part of electron self-energy.

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We investigate the mutual influence of angular (AMRO) and quantum oscillations (MQO) of interlayer magnetoresistance $R_{zz}(B)$ in quasi-two-dimensional (quasi-2D) layered metals. The MQO and the shape of Landau levels (LL) affect the AMRO amplitude. The influence of AMRO on MQO leads to the new qualitative effect: the angular oscillations of the amplitude of MQO, called "false spin zeros", that could lead to a wrong determination of electron g-factor from experiment. Usually the real part of electron self-energy ReΣ is neglected as it only shifts the electron energy by a constant. However, in magnetic field in quasi-2D metals ReΣ strongly oscillates and cannot be neglected. In weak field it affects the amplitude of the second harmonics of MQO. In strong magnetic field the effect of ReΣ is more important: it strongly affects the shape of MQO and even the non-oscillating part of magnetoresistance.

Tunneling into a Luttinger-liquid coupled to acoustic phonons out of equilibrium

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We consider tunneling from the tip into the Luttinger liquid quantum wire coupled to the acoustic phonons out of equilibrium. Employing the fermionic approach and scattering states formalism for the appearing Y-junction, we calculate the renormalization of the dc conductance of the system. We show that the electron-phonon interaction drastically changes the phase diagram of the system and leads to several distinctive non- equilibrium transport regimes. In addition, the influence of electron-phonon coupling on the phonons transmission coefficients is considered.

Correlation-induced localization

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A new paradigm of Anderson localization caused by correlations in the long-range hopping along with uncorrelated on-site disorder is considered which requires a more precise formulation of the basic localization-delocalization principles. A new class of random Hamiltonians with translation-invariant hopping integrals is suggested and the localization properties of such models are established both in the coordinate and in the momentum spaces alongside with the corresponding level statistics. Duality of translation-invariant models in the momentum and coordinate space is uncovered and exploited to find a full localization-delocalization phase diagram for such models. The crucial role of the spectral properties of hopping matrix is established and a new matrix inversion trick is suggested to generate a one-parameter family of equivalent localization-delocalization problems. Optimization over the free parameter in such a transformation together with the localization-delocalization principles allows us to establish exact bounds for the localized and ergodic states in long-range hopping models. When applied to the random matrix models with deterministic power-law hopping this transformation allows to confirm localization of states at all values of the exponent in power-law hopping and to prove analytically the symmetry of the exponent in the power-law localized wave functions.

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Quasi-two-dimensional turbulence and coherent structures

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We investigate formation of large-scale coherent vortices in thin liquid layers and the velocity distribution in such vortices. The objects of the experiments are electrolytes in a bounded cell. We observe an inverse energy cascade, a coherent vortex drift, and a flat azimuthal velocity profile. Turbulence is excited by ponderomotive forces.

The evolution of a vortex flow excited by an electromagnetic technique in a thin layer of a conducting liquid is studied experimentally. Small-scale vortices, initially excited at the pumping scale, merge with time due to the nonlinear interaction, and large-scale structures are formed. In such a way the inverse energy cascade is formed. The dependence of the energy spectrum in the developed inverse cascade is well described by the Kraichnan law $k^{-5/3}$ [1]. At large scales, the inverse cascade is limited by cell sizes, so a large-scale coherent vortex flow is formed (fig. 1a) due to the spectral condensation [1]. The flow occupies almost the entire area of the experimental cell. The radial profile of the azimuthal velocity in the coherent vortex immediately after the pumping was switched off has been established for the first time (fig. 1b). Inside the vortex core, the azimuthal velocity grows linearly along a radius and reaches a constant value outside the core. It agrees well with the theoretical prediction [2-3]. Details about experimental technique are presented in our article [4].

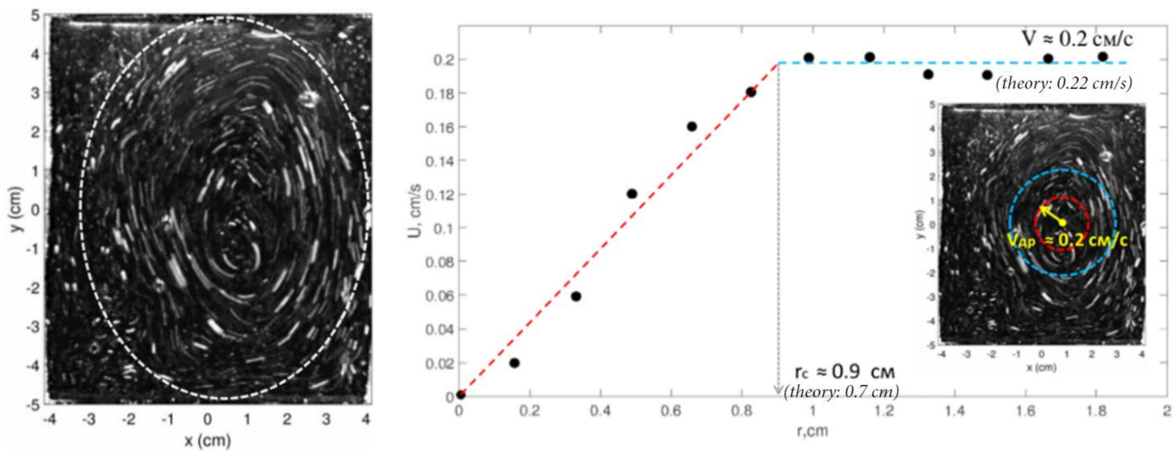

Fig 1. (a) – Polyamide tracers tracks on the liquid surface after the spectral condensation. (b) – Radial profile of the azimuthal velocity in the coherent vortex in this moment. The radius of the outer circumference ≈ 1.8 cm, that of the inner one – $r_c \approx 0.9$ cm. The instant position of the coherent vortex center is indicated by the white small circle

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Paraconductivity of pseudogapped superconductors

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We study the Aslamazov-Larkin (AL) paraconductivity [2] for a model describing a strongly disordered two- or three-dimensional superconductor close to the superconductor-insulator transition (SIT), which exhibit a large pseudogap – a gap in the single-particle excitation spectrum emerging due to localized nature of single-electron wavefunctions and BCS pairing between electrons [3].
We show that the Gaussian fluctuations of the Cooper-pair fluctuations is effectively described by the time-dependent Ginzburg-Landau theory, and the corresponding paraconductivity is twice larger that the classical AL result at the same $\epsilon = (T - T_c) / T_c$.
Upon decreasing the temperature, the Gaussian approximation is violated by the local fluctuations of pairing fields that become relevant at characteristic temperature scale ϵ_1. This scale appears to be parametrically larger than the width ϵ_2 of the thermodynamical critical region determined via the Ginzburg criterion, $\epsilon_2 \approx \epsilon_1^d$. We argue that within the intermediate region $\epsilon_2 \leq \epsilon \leq \epsilon_1$, paraconductivty still follows the AL power law, albeit with another (yet unknown) non-universal numerical prefactor.
At further decrease of the temperature, all kinds of fluctuation corrections become strong at $\epsilon \leq \epsilon_2$; in particular, conductivity occurs to be strongly inhomogeneous in the real space.

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Effective field theory of the Y-junction of Luttinger liquid quantum wires.

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Quantum wires are the application of one dimensional interacting fermions. Fermions in wire are described by the model of Luttinger liquid. For wires without impurity conductance can be obtained by the exact bosonization. Wires with one impurity are described by bosonization or “poor man” renormalization group. Alternative approach constructs effective field theory which yields both perturbative renormalization group results for conductance up to four loops and nonperturbative asymptotics near critical points. The approach was pioneered in [1,2] for two semi-wires connected at the point of junction (one wire with impurity). This theory is consistent with the Bosonization and “poor man” renormalization group in their scope.

Here we extend the method of exact solutions to the case of Y junction of three semi-wires. With the help of functional integration the equivalent 0+1 dimensional field theory is built, in which the fields are the phase jumps of the wave function at the point of junction. Theory contains infinite number of interaction terms due to zero dimension of the fields. In this theory, the conductivity is calculated up to third-order perturbation theory in the small interaction between electrons. Fixed points position, their critical indexes and prefactors of asymptotics are obtained.

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Strong electron-electron interactions and Majorana-like states in superconducting nanowires

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The peculiarities of Majorana polarization [1,2] of an open superconducting nanowire with the strong electron- electron interactions are considered with the use of density matrix renormalization group method. The main attention is paid to the properties of the single particle excitations similar to the Majorana one in the non-interacting quantum wires. It is demonstrated that strong intersite Coulomb repulsion can lead to significant renormalizations of the spin, charge, and spatial characteristics of Majorana-like excitations. Previously, we have shown that Majorana-like states in short superconducting nanowires can be identified using caloric anomalies [3,4]. This work discusses the question of identifying such states in long nanowires with strong electron correlations through a similar study of the magneto and electrocaloric effects.

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Kapitza pendulum under random horizontal driving

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We study stochastic dynamics of an inverted pendulum subject to a random force in the horizontal direction. Consideredat the entire time axis, the problem admits a unique solution which always remains in the upper half-plane We develop a newtechnique for treating statistical properties of this unique non-falling trajectory. In our approach based on the supersymmetricformalism of Parisi and Sourlas [1], statistics of the non-falling trajectory is expressed in terms of the zero mode of a correspondingtransfer-matrix Hamiltonian [2]. The emerging mathematic structure is similar to that of the Fokker-Planck equation, but it is rather written for the “square root” of the distribution function. Our results for the statistics of the non-falling trajectory are inperfect agreement with direct numerical simulations of the stochastic pendulum equation.

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Comparative study of skyrmion crystal and triple helix states in non-centrosymmetric magnets.

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Topological defects in magnets remain an interesting theoretical topic. Vortex-like periodic structures in magnets and multiferroics were found in various experiments [1,2]. The pioneering work by Belavin and Polyakov (BP) [3] discussed baby skyrmions as metastable states in ferromagnetic films.

It is known that the topological defects are stabilized in thin films by additional Dzyaloshinskii-Moria interaction (DMI) and external magnetic field. Following the usual route we rewrite energy in terms of complex function within stereographic projection approach. Poles of this function correspond to unit topological charges and we consider BP-like ansatz for many-skyrmion solution with additional modulating function depending on DMI and magnetic field.

We find numerically that such modulating function for individual skyrmions has nearly universal profile, irrespective of the density of skyrmions. This property allows us to discuss multiple-skyrmion configuration as a direct sum of single skyrmion projections and proper rescaling the solution for one skyrmion. This leads to an effective description of the model in terms of few collective variables. The interaction between skyrmions, which was absent in BP model, is now present. We show the existence of pairwise and triple interactions which favor the formation of hexagonal skyrmion lattice. With this approach we build up solution for skyrmion crystal [4].

It is believed that skyrmion crystal is an equivalent of superposition of tree helices. We showed that it is not quite right, because these two configurations should have different intensities of second satellites in neutron experiments, and actually normalized sum of three helices has higher density of classical energy than skyrmion crystal.

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Competition of band anticrossing and charge-density wave

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We calculated the electron susceptibility of rare-earth tritelluride compounds RTe3 as a function of temperature, wave vector, and electron-dispersion parameters. Comparison of the results obtained with the available experimental data on the transition temperature and on the wave vector of a charge-density wave in these compounds allowed us to predict the values and evolution of electron-dispersion parameters with the variation of the atomic number of rare-earth elements (R).
Our measurements of the Hall coefficient in rare-earth tritelluride compounds reveal a strong hysteresis between cooling and warming in the low temperature range where a second unidirectional charge density wave (CDW) occurs. We show that this effect results from the interplay between two instabilities: band crossing of the Te px and py orbitals at the Fermi level and CDW, which have a close energy gain and compete. Calculation of the electron susceptibility at the CDW wave vector with and without band anticrossing reconstruction of the electron spectrum yields a satisfactory estimation of the temperature range of the hysteresis in Hall effect measurements.

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Nonlinear sigma model approach to many-body quantum chaos: Regularized and unregularized out-of-time-ordered correlators

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The out-of-time-ordered correlator (OTOC) has been widely used as a diagnostic of many-body quantum chaos. To understand the difference between the regularized and unregularized OTOCs which have different arrangements of thermal weight, we study these two types of correlators in a disordered interacting metal. We develop an extended version of Finkel'stein nonlinear sigma model in the augmented Keldysh formalism. Both the regularized and unregularized OTOCs grow exponentially in time but with different growth rates. The regularized exponent satisfies the Maldacena-Shenker-Stanford bound, in agreement with a previous diagrammatic perturbation study. Similar to the dephasing rate, it originates entirely from the real inelastic collisions between electrons. In contrast, the bound does not hold for the unregularized exponent which contains an extra contribution from virtual elastic scattering of electrons off of the disordered-induced Friedel oscillations of charge density. Given that these virtual processes are irrelevant to many-body quantum chaos, we believe the unregularized exponent is not a reliable measure of many-body quantum chaos. These results bring up open questions about the physical meaning behind the regularized and unregularized OTOCs.