International conference
dedicated to the 100th anniversary of
I. M. Khalatnikov

Quantum Fluids, Quantum Field Theory, and Gravity

PROGRAM BOOK

Landau Institute
October 17-20, 2019, Chernogolovka

Academician I.M. Khalatnikov

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Chernogolovka
Landau Institute
2019

ББК 22.31:22.317;26.21
К 32
УДК 530.145:538.94:544.18:550.831.01

К 32 **Quantum** fluids, quantum field theory, and gravity: International Conference Dedicated to the 100th Anniversary of I. M. Khalatnikov Program Book. — Moscow: TORUS PRESS, 2019. — 60 p.

ISBN 978-5-94588-262-1

On October 17, 2019, the outstanding theoretical physicist Isaak Khalatnikov will turn one hundred years old. His works are devoted to the theoretical problems of quantum physics, superfluidity and superconductivity, quantum electrodynamics and cosmology. In all these areas of physics, Khalatnikov's papers were an outstanding phenomenon and rightfully entered the treasury of science. We are proud of the fact that Khalatnikov is the founder of the Landau Institute for Theoretical Physics and its first director from 1965 till 1992. The broad scope of his scientific interests is manifested in the variety of areas in which the scientific staff of the Landau Institute is still working. In honour of the 100th anniversary of Isaak Khalatnikov, the Landau Institute organizes the international conference. In accordance with Khalatnikov's broad interests, the conference will be devoted to the modern frontiers of theoretical physics from the kinetics of quantum systems to cosmology.

ББК 22.31:22.317;26.21

ISBN 978-5-94588-262-1

Printed in Russian Federation

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Sponsors:
Russian Foundation for Basic Research, grant No 17-02-20240
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Program

Thursday, 17 October

08:50-09:00 Opening	
09:00-09:40	**Alexei Starobinsky** *Inflation in the early Universe and its present artifacts*
09:40-10:20	**Thibault Damour** *Hidden symmetries near cosmological singularities*
10:20-11:00	**Vladimir Lebedev** *Coherent structures in turbulence*
11:00-11:30 Coffee break	
11:30-12:10	**John Chalker** *Minimal models for chaotic quantum dynamics in spatially rextended many-body systems*
12:10-12:50	**Paul Wiegmann** *Quantisation of 2D hydrodynamics and gravitational anomaly*
12:50-13:30	**Alexander Mil'stein** *Diving into the depths of theoretical physics*
13:30-15:00 Lunch	
15:00-19:00	**Celebration of the 100th anniversary of I.M. Khalatnikov**

Friday, 18 October

09:00-09:40 **Grigory Volovik**
From synthetic gravity to general relativity

09:40-10:20 **Igor Krichever**
The Bethe ansatz equations and integrable systems of particles

10:20-11:00 **Nikita Nekrasov**
BPS/CFT correspondence

11:00-11:30 Coffee break

11:30-12:10 **Alexander Mirlin**
Anderson localization on random regular graphs: Toy-model of many body localization

12:10-12:50 **Vladimir Kravtsov**
Anderson localization and ergodic transitions in the log-normal Rosenzweig-PorterBa random matrix ensemble

13:00-14:30 Lunch

14:30-15:10 **Valery Pokrovsky**
Superfluidity in condensate of magnons: experiment and theory

15:10-15:50 **Lev Ioffe**
Problems for quantum simulations by NISQ devices

15:50-16:20 Coffee break

16:20-17:00 **Alexander Zamolodchikov**
"Moscow zero" and solvable deformations of 2D quantum field theories

17:00-17:40 **Pavel Lushnikov**
Motion of complex singularities and integrability of fully nonlinear free surface dynamics of superfluid Helium vs. single ideal fluid

17:40-18:20 **Efim Kats**
Inexhaustibility of colloidal dispersions

18:20-20:00 Poster session

Saturday, 19 October

09:00-09:40 **Hermann Nicolai**
Ultra-high energy cosmic rays: a hint of K(E10) in the sky?

09:40-10:20 **Igor Klebanov**
Dynamics of tensor and SYK models

10:20-11:00 **Vladimir Mineev**
Low-temperature transport in metals without inversion centre

11:00-11:30 Coffee break

11:30-12:10 **Boris Spivak**
Debye mechanism of giant microwave absorption in superconductors

12:10-12:50 **Mikhail Feigel'man**
Strange metal state near quantum superconductor-metal transition in thin films

13:00-14:30 Lunch

14:30-15:10 **Alexander Kamenshchik**
Exact solutions in general relativity, Kasner universes and singularities

15:10-15:50 **Mikhail Skvortsov**
Inverted pendulum driven by a random force: statistics of the non-falling trajectory and supersymmetry

15:50-16:20 Coffee break

16:20-17:00 **Konstantin Postnov**
Binary black holes: formation and observations

17:00-17:40 **Dmitri Ivanov**
Computational complexity of full counting statistics of quantum particles in product states

17:40-18:20 **Robert Suris**
Exciton Bose-Einstein condensation in 2D heterostructures with disorder

Sunday, 20 October

09:00-09:40	**Benoit Douçot** *The Floquet spectrum of superconducting multiterminal quantum dots*
09:40-10:20	**Alexander Abanov** *Odd fluids in action*
10:20-11:00	**Lavinia Heisenberg** *Spacetime Trinity*
	11:00-11:30 Coffee break
11:30-12:10	**Igor Fomin** *Multiple functions of aerogels in liquid 3He at ultralow temperatures*
12:10-12:50	**Igor Kolokolov** *Kinematic dynamo in three - and two-dimensional chaotic*
	13:00-14:30 Lunch
14:30-15:10	**Pavel Ostrovsky** *Anomalous Hall effect in Weyl semimetals*
15:10-15:50	**Evgenii Kuznetsov** *Expansion of the strongly interacting superfluid Fermi gas: symmetry and self-similar regimes*
	15:50-16:20 Coffee break
16:20-17:00	**Serguei Brazovskii** *Multi-fluid hydrodynamics in charge density waves with collective, electronic, and solitonic densities and currents*
17:00-17:40	**Igor Burmistrov** *Mesoscopic Stoner instability in open quantum dots*
	17:40-17:50 Closing

Oral Talks

Odd fluids in action

Alexander Abanov

Department of Physics and Astronomy, Stony Brook University, Stony Brook, NY 11794, USA

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Two-dimensional isotropic fluids can possess an anomalous part of the viscous stress tensor known as odd or Hall viscosity. This peculiar viscosity does not lead to any dissipation in the fluid. Examples of fluids with odd viscosity include rotating superfluids, plasmas in magnetic fields, quantum Hall fluids, and chiral active fluids. I will describe some manifestations of the odd viscosity. In particular, I will focus on surface waves propagating along the boundaries of such fluids. I will also present a variational principle and the corresponding Hamiltonian structure for fluid dynamics with odd viscosity.

Multi-fluid hydrodynamics in charge density waves with collective, electronic, and solitonic densities and currents

Serguei Brazovskii

LPTMS, UMR 8626, CNRS & University Paris-sud, Univ. Paris-Saclay, Orsay, cedex, France

We present a general scheme to approach the space - time evolution of deformations, currents, and the electric field in charge density waves related to appearance of intrinsic topological defects: dislocations, their loops or pairs, and solitons. We derive general equations for the multi-fluid hydrodynamics taking into account the collective mode, electric field, normal electrons, and the intrinsic defects. These equations may allow to study the transformation of injected carriers from normal electrons to new periods of the charge density wave, the collective motion in constrained geometry, and the plastic states and flows. As an application, we present analytical and numerical solutions for distributions of fields around an isolated dislocation line in the regime of nonlinear screening by the gas of phase solitons.

Mesoscopic Stoner instability in open quantum dots

Igor Burmistrov

L.D. Landau Institute for Theoretical Physics, Chernogolovka, Russia

The mesoscopic Stoner instability is interesting phenomenon of symmetry breaking in isolated metallic quantum dots which exists due to competition between the single-particle energy and Heisenberg exchange interaction. To study this phenomenon in the presence of coupling to a reservoir we compute the spin susceptibility of electrons on the quantum dot for different values of tunnel coupling and temperature. Our results suggest the existence of *the quantum phase transition* at the critical value of the tunneling coupling which is determined by the Stoner-enhanced exchange interaction. This quantum phase transition is manifestation of suppression of the Coleman-Weinberg mechanism of symmetry breaking by tunneling to the reservoir.

Minimal models for chaotic quantum dynamics in spatially extended many-body systems

John Chalker

Theoretical Physics, University of Oxford, Parks Road, Oxford OX1 3PU, United Kingdom

I will give an overview of recent work on minimal models for quantum chaos in spatially extended many-body quantum systems, describing simple, solvable models. The detailed study of generic quantum systems – ones without exact or approximate conservation laws – goes back at least as far as investigations of highly-excited states in nuclei in the 1950s. It saw revivals in the 1980s with work on systems such as quantum billiards, that have only a few degrees of freedom, and also in the context of mesoscopic conductors. It is attracting renewed current interest with a focus on many-body systems that are spatially extended. Part of the motivation for this comes from experiments on cold atom systems, and part comes from development on the theoretical understanding of eigenstates of many-body systems. The study of dynamics in spatially many-body systems introduces new questions that do not arise in finite systems such as quantum billiards, or in extended single particle systems, such as mesoscopic conductors. The questions concern the dynamics of quantum information and the approach to equilibrium. I will discuss how these can be answered in the context of minimal models.

A. Chan, A. De Luca, and J. T. Chalker, Phys. Rev. Lett. 121, 060601 (2018) and Phys. Rev. X 8, 041019 (2018)

Hidden symmetries near cosmological singularities

Thibault Damour

Institut des Hautes Etudes Scientifiques, 91440 Bures-sur-Yvette, France

We shall review the evidence for the presence of a hidden hyperbolic Kac-Moody symmetry in the chaotic dynamics of cosmological singularitiesdiscovered by Belinsky, Khalatnikov and Lifshitz. This hidden symmetry was first noticed in the dynamics of bosonic fields, but, remarkably, it is also present in the dynamics of fermionic fields. Terms quartic in the gravitino of supergravity might lead to an avoidance of the zero-volume singularity, i.e. to a cosmological bounce.

The Floquet spectrum of superconducting multiterminal quantum dots

Benoit Douçot

Laboratoire de Physique Theorique et Hautes Energies, Sorbonne Universite CNRS UMR 7589, 4 place Jussieu, 75252 Paris Cedex 05, France

I will present a theoretical investigation of the Floquet spectrum in multiterminal quantum dot Josephson junctions biased with commensurate voltages, so that the corresponding Bogoliubov-De Gennes Hamiltonian is periodic in time. We show that the finite voltage bias turns the equilibrium Andreev bound-states into narrow resonances forming a pattern of coupled Floquet-Wannier-Stark ladders, which can be probed experimentally by measuring finite frequency noise fluctuations. A semi-classical treatment shows that the location of these ladders of resonances is controlled by a Berry phase which can take the values 0 or π depending on the values of control parameters such as contact transparencies and static linear combinations of superconducting phases. We demonstrate that such Berry phase shifts can be observed by measuring the tunneling density of states on the dot. Our results suggest that the Floquet spectrum for this class of periodically driven systems presents rich behaviors, whose experimental investigation is likely to begin in the near future.

Strange metal state near quantum superconductor-metal transition in thin films

Mikhail Feigel'man

L.D. Landau Institute for Theoretical Physics, Chernogolovka, Russia

We develop a theory of quantum $T = 0$ phase transition between metal and superconducting (q-SMT) ground states in a two-dimensional metal with frozen-in spatial fluctuations $\delta\lambda(r)$ of the Cooper attraction constant. We show that if the strength of fluctuations $\delta\lambda(r)$ exceeds some critical value, usual mean-field-like scenario of the q-SMT breaks down due to spontaneous formation of rare local droplets of superconducting phase. We account for the interaction between these droplets by means of a real-space renormalization group (RG) and find that the RG flow near q-SMT is the dual equivalent of the Kosterlitz-Thouless RG. We find that relevant energy/temperature scale drops exponentially upon approach to the q-SMT point. Close to the quantum critical point, in a broad range of low temperatures fluctuations-induced conductivity σ_{fl} is nearly T-independent. This behaviour reminds a "strange metal" phase, frequently observed near SMT.

Multiple functions of aerogels in liquid 3He at ultra-low temperatures

Igor Fomin

Kapitza Institute of Physical Problems, Moscow, Russia

Some recent results of experimental and theoretical investigations of the effect of different high porosity aerogels immersed in the liquid ^{3}He at millikelvin temperatures are reviewed. Most of the results were obtained in the P.L. Kapitza Institute for Physical Problems in Moscow. A difference with respect to conventional impurities in metals is discussed.

Spacetime Trinity

Lavinia Heisenberg

Institute for Theoretical Physics, ETH Zurich, Wolfgang-Pauli-Strasse 27, 8093, Zurich, Switzerland

I will give a detailed introduction into the successful construction of General Relativity from a geometrical perspective. I will introduce the geometrical trinity of gravity, in which the same theory of General Relativity can be constructed a la Einstein based on curvature, a la TEGR based on torsion and a la CGR based on non-metricity, which represents a simpler formulation of General Relativity. Starting from the defining key properties of General Relativity I will explain in which consistent ways these properties can be altered and generalizations beyond General Relativity can be constructed.

Problems for quantum simulations by NISQ devices

Lev Ioffe

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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 as well as the diffusion (or the absence of it) in the non-integrable one dimensional quantum systems. I review the parameters of the existing qubit devices and argue that these problems can be simulated by these devices that can be represent spin ladders or chains at high and low temperatures. I show that the available sizes already exceed those for which direct simulation by classical computer is possible.

Computational complexity of full counting statistics of quantum particles in product states

Dmitri Ivanov

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We study the computational complexity of quantum-mechanical expectation values of single-particle operators in bosonic and fermionic multi-particle product states. Such expectation values appear, in particular, in full-counting-statistics problems. Depending on the initial multi-particle product state, the expectation values may be either easy to compute (the required number of operations scales polynomially with the number of particles) or hard to compute (at least as hard as a permanent of a matrix). We conjecture that in general such expectation values are "hard", with the exception of Gaussian states. We support this conjecture with several examples. Further, we consider a more restricted class of single-particle operators of the form $1 + V$, where V is an operator of a small finite rank k. This corresponds to projecting full counting statistics on k single-particle states. For such a restricted class of operators, the complexity of the expectation values is only polynomial in the number of particles N. We prove this for the general fermionic case and for the single-boson product state (the same as used in the boson-sampling proposal). We also obtain the bounds on the number of operations $O(N^{2k})$ in the fermionic case and $O(N^{2k+1})$ in the bosonic case. This study may be relevant for using multi-particle product states as a resource for quantum computing.

[1] D.A.Ivanov, arXiv:1603.02724, Phys. Rev. A 96, 012322 (2017).
[2] D.A.Ivanov and L.Gurvits, arXiv:1904.06069.

Exact solutions in general relativity, Kasner universes and singularities

Alexander Kamenshchik

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and INFN, Via Irnerio 46, 40126 Bologna, Italy
L.D. Landau Institute for Theoretical Physics, Chernogolovka, Russia

We find exact static solutions of the Einstein equations in the spacetime with plane symmetry, where an infinite slab with finite thickness and homogeneous energy (mass) density is present. In the first solution the pressure is isotropic, while in the second solution the tangential components of the pressure are equal to zero. In both cases the pressure vanishes at the boundaries of the slab. Outside the slab these solutions are matched with the Rindler spacetime and with the Weyl-Levi-Civita spacetime, which represent special cases of the Kasner solution. We also discuss general problems of interpretation of singularities in General Relativity and Cosmology.

Inexhaustibility of colloidal dispersions

Efim Kats

L.D. Landau Institute for Theoretical Physics, Chernogolovka, Russia

In this work we propose and explore a method of analysis of the scattering experimental data for uniform liquid-like systems. In our pragmatic approach we are not trying to introduce by hands an artificial small parameter to work out a perturbation theory with respect to the known results e.g., for hard spheres or sticky-hard spheres (all the more that in the agreement with the notorious Landau statement, there is no any physical small parameter for liquids). Instead of it guided by the experimental data we are solving the Ornstein-Zernike equation with a trial (variational) form of the inter-particle interaction potential. To find all needed correlation functions this variational input is iterated numerically to satisfy the Ornstein-Zernike equation supplemented by a closure relation. We illustrate by a few of model and real experimental examples of the X-ray and neutron scattering data how the approach works.

Dynamics of tensor and SYK models

Igor Klebanov

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Princeton Center for Theoretical Science, Princeton University, Princeton, NJ 08544

I review the combinatorics of models where the degrees of freedom are tensors of rank three or higher. For specially chosen interactions, the Feynman graph expansion is dominated by the so-called melonic graphs in the large N limit. I present the simplest tensor quantum mechanical model for Majorana fermions with a quartic Hamiltonian, which was introduced in my work with G. Tarnopolsky, and compare it with the Sachdev-Ye-Kitaev model. When two tensor or SYK models are coupled by a quartic interaction, a gap can open up for sufficiently large N between two nearby lowest energy states and the rest of the spectrum. This suggests spontaneous breaking of a Z_2 symmetry. Analysis of the large-N Schwinger-Dyson equations shows that a symmetry-breaking operator indeed acquires an expectation value, demonstrating a pairing mechanism in melonic theories.

Kinematic dynamo in three - and two-dimensional chaotic

Igor Kolokolov

L.D. Landau Institute for Theoretical Physics, Chernogolovka, Russia

The growth of small-scale magnetic field fluctuations in chaotic flow of conducting fluid is studied. It is shown that this enhancement terminates in three dimensional case by back reaction of the magnetic field on the flow, but in two-dimensional case it could be stopped by purely kinematic anti-correlation mechanism. In both situations the statistics of the field fluctuations demonstrates strong spatial and temporal intermittency on the growth stage.

Anderson localization and ergodic transitions in the log-normal Rosenzweig-Porter random matrix ensemble

Vladimir Kravtsov

International Center for Theoretical Physics, Trieste, Italy

It has been recently shown [1] that the $N * N$ generalized Rosenzweig-Porter random matrix model [2] can be in three distinctly different phases: ergodic, fractal and localized, depending on the scaling parameter γ in the variance $N^{-\gamma}$ of the i.i.d. Gaussian off-diagonal matrix elements. Several models of disordered systems can be reduced to the logarithmically-normal Rosenzweig-Porter ensemble in which i.i.d. off-diagonal matrix elements have a log-normal distribution with the variance proportional to $\ln N$, while the diagonal matrix elements remain Gaussian distributed with the variance 1. In this case the typical and the averaged values of off-diagonal matrix elements have different scaling with N. In the present work we address the question how the tailed distributions of this type alter the phases and phase transitions in the eigenvector statistics.

[1] V. E. Kravtsov, I. M. Khaymovich, E. Cuevas and M. Amini, A random matrix model with localization and ergodic transitions, New J. Phys. 17, 122002 (2015)

[2] N. Rosenzweig and C. E. Porter, "Repulsion of energy levels" in complex atomic spectra, Phys. Rev. 120, 1698 (1960)

The Bethe ansatz equations and integrable systems of particles

Igor Krichever

Skolkovo Institute of Science and Technology, 3 Nobelya, Moscow, 121205, Russia

A family of commuting flows on the space of solutions of the Bethe ansatz equations of the $\widehat{\mathfrak{sl}_N}$ XXX quantum integrable model, associated with the trivial representation of $\widehat{\mathfrak{sl}_N}$ is constructed. The family is identified with the flows of N-tuple of coherent rational Ruijesenaars-Schneider systems. For that we develop in full generality the spectral transform for the rational Ruijesenaars-Schneider system.

Expansion of the strongly interacting superfluid Fermi gas: symmetry and self-similar regimes

Evgenii Kuznetsov

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L.D. Landau Institute for Theoretical Physics, Chernogolovka, Russia
Skolkovo Institute of Science and Technology, Skolkovo, Moscow region, Russia

We consider an expansion of the strongly interacting superfluid Fermi gas in the vacuum in the so-called unitary regime when the chemical potential $\mu \propto \hbar^2 n^{2/3}/m$ where n is the density of the Bose-Einstein condensate of Cooper pairs of fermionic atoms. Such expansion can be described in the framework of the Gross-Pitaevskii equation (GPE) [1]. Because of the chemical potential dependence on the density $\sim n^{2/3}$ the GPE has additional symmetries resulting in existence of the virial theorem connected the mean size of the gas cloud and its Hamiltonian. It leads asymptotically at $t \to \infty$ to the ballistic expansion of the gas. We carefully study such asymptotics and reveal a perfect matching between the quasi-classical self-similar solution and the ballistic expansion of the non-interacting gas [2]. This matching is governed by the virial theorem derived in [3] utilizing the Talanov transformation [4] which was first obtained for the stationary self-focusing of light in the media with cubic nonlinearity due to the Kerr effect. In the quasi-classical limit the equations of motion coincide with 3D hydrodynamics for the perfect gas with $\gamma = 5/3$ which, as it was demonstrated by S.I. Anisimov and Yu.I. Lysikov [5], have additional symmetry. Just this symmetry provides one to find self-similar solution which describes, on the background of the gas expansion, the angular deformations of the gas shape in the framework of the Ermakov-Ray-Reid type system.
The work of E.K. was performed under support of the Russian Science Foundation (grant 19-72-30028).

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[2] E.A. Kuznetsov, M.Yu. Kagan and A.V. Turlapov, Expansion of the strongly interacting superfluid Fermi gas: symmetries and self-similar regimes, arXiv:1903.04245 (2019), Phys. Rev. A (submitted).
[3] E.A. Kuznetsov, S.K. Turitsyn, Talanov transformation in self-focusing problems and instability of stationary waveguides, Phys.Lett., 112 A, 273, (1985).
[4] V.I. Talanov, On the self-focusing of light in the cubic media, Pis'ma Zh.Eksp.Teor.Fiz., 11, 303, (1970).
[5] S.I. Anisimov and Yu.I. Lysikov. Expansion of a gas cloud in vacuum, Journal of Applied Mathematics and Mechanics, 34, 882, (1970).

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

Mikhail Skvortsov

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L.D. Landau Institute for Theoretical Physics, Russia

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.

Coherent structures in turbulence

Vladimir Lebedev

L.D. Landau Institute for Theoretical Physics, Chernogolovka, Russia

Hydrodynamic turbulence is a highly non-equilibrium system characterized by strong fluctuations of velocity. The fluctuations are chaotic and should be characterized by their correlation functions. Besides, at some conditions turbulent state contains coherent structures that are in dynamic equilibrium with chaotic motion. Such structures appear in two-dimensional or quasi-two-dimensional cases due to the inverse energy cascade. We analyze structure of coherent vortices that are stable structures in a finite two-dimensional box where turbulence is excited at scales smaller than the box size.

Motion of complex singularities and integrability of fully nonlinear free surface dynamics of superfluid Helium vs. single ideal fluid

Pavel Lushnikov

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L.D. Landau Institute for Theoretical Physics, Chernogolovka, Russia

A motion of fluid's free surface is considered in two dimensional (2D) geometry. A time-dependent conformal transformation maps a fluid domain into the lower complex half-plane of a new spatial variable. The fluid dynamics is fully characterized by the motion of complex singularities outside of fluid, i.e. in the upper complex half-plane, for the analytical continuation of the conformal map and the complex velocity. Both a single ideal fluid dynamics (corresponds e.g. to oceanic waves dynamics) and a dynamics of superfluid Helium 4 with two fluid components are considered. Both systems share the same type of the non-canonical Hamiltonian structure. A superfluid Helium case is shown to be completely integrable for the zero gravity and surface tension limit with the exact reduction to the Laplace growth equation which is completely integrable through the connection to the dispersionless limit of the integrable Toda hierarchy and existence of the infinite set of complex pole solutions. A single fluid case with nonzero gravity and surface tension turns more complicated with the infinite set of new moving poles solutions found which are however unavoidably coupled with the emerging moving branch points in the upper half-plane. Residues of poles are the constants of motion. These constants commute with each other in the sense of underlying non-canonical Hamiltonian dynamics. It suggests that the existence of these extra constants of motion provides an argument in support of the conjecture of complete Hamiltonian integrability of 2D free surface hydrodynamics.

Diving into the depths of theoretical physics

Alexander Mil'stein

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In my talk I discuss a few examples which clearly demonstrate that without deep diving into basics of theoretical physics the results of efforts of large collaborations may be either misleading or useless.

Low-temperature transport in metals without inversion centre

Vladimir Mineev

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Univ. Grenoble Alpes, CEA, IRIG, PHELIQS, F-38000 Grenoble, France

Theory of low temperature kinetic phenomena in metals without inversion center is developed. Kinetic properties of a metal without inversion centerare described by four kinetic equations for the diagonal (intra-band) and the off-diagonal (inter-band) elements of matrix distribution function of electrons occupying the states in two bands split by the spin-orbit interaction. The derivation of collision integrals for electron-impurity scatterings and for electron-electron scatterings in a non-centrosymmetric medium is given. Charge, spin and heat transport in the ballistic and the weak impurity scattering regimes is discussed. It is shown that in 3D media the off-diagonal terms give rise the contribution in charge, spin and heat flows not only due to the interband scattering but alsoin the collisionless case where they bring to birth the unusual dissipative currents. The zero-temperature residual resistivity and the residual thermal resistivity are determined by scattering on impurities as well as by the electron-electron scattering.

Anderson localization on random regular graphs: Toy-model of many body localization

Alexander Mirlin

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L.D. Landau Institute for Theoretical Physics, Chernogolovka, Russia

I will discuss Anderson (de-)localization on random regular graphs (RRG), which have locally the structure of a tree but do not have boundary (and thus possess large-scale loops). Our analytical treatment of the RRG model uses a field-theoretical supersymmetry approach and the saddle-point analysis justified by large volume (number of sites) N. The resulting saddle-point equation can be efficiently solved numerically by population dynamics, and also analyzed analytically [1]. The obtained results are in perfect agreement with those of exact diagonalization. In the delocalized phase on RRG, eigenfunctions are ergodic in the sense that their inverse participation ratio scales as $1/N$ and the spectral statistics is Wigner-Dyson in the large-N limit. This limit is reached via a finite-size crossover from small ($N \ll N_c$) to large ($N \gg N_c$) system, where N_c is the correlation volume diverging exponentially at the transition, $\ln N_c\ \xi_c$, where ξ_c is the correlation length. A distinct feature of this crossover is a non-monotonicity of the spectral and wave-function statistics, which is related to properties of the critical phase in the RRG model [2]. We have also peformed a detailed study of eigenfunction and energy level correlations, fully confirming the ergodicity of the delocalized phase in the large-N limit [1]. We further demonstrate numerically that the correlation length on the delocalized side, ξ_c, diverges with the critical index $\nu_d = 1/2$, in agreement with analytical result [3]. Importantly, properties of the RRG model differ crucially from those of a model on a finite Cayley tree, where wave function moments exhibit multifractal scaling with N in the limit of large N. The multifractality spectrum depends on disorder strength and on the position of the lattice, as we show both analytically and numerically [4, 5]. Finally, I will briefly discuss connections between the (de-)localization on RRG and the many-body localization [1, 6].

[1] K. S. Tikhonov and A. D. Mirlin, Phys. Rev. B 99, 024202 (2019)
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BPS/CFT correspondence

Nikita Nekrasov

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In 2004 we introduced correspondence between the correlation functions of supersymmetric gauge theories in four dimensions and holomorphic blocks of two dimensional conformal theories (also between higher dimensional gauge theories and q-analogues of CFTs). I will review some of the recent developments and applications.

Ultra-high energy cosmic rays: a hint of K(E10) in the sky?

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It is argued that the superheavy gravitinos that we had previously proposed as candidates for Dark Matter can offer a possible explanation for the ultra-high energy cosmic ray (UHECR) events observed at the Pierre Auger Observatory, via gravitino anti-gravitino annihilation in the 'skin' of neutron stars. The large mass and strong interactions of these particles, together with their stability against decays into standard matter are essential for the proposed explanation to work. In particular, it ensues that UHECR events can be understood to originate from neutron stars inside a GKZ horizon of ~ 50 Mpc. The composition of neutron stars near their surface could play a crucial role in explaining the presence of heavy ions in these events. If confirmed, this new mechanism can be taken as evidence for the fundamental ansatz towards unification on which it is based.

Anomalous Hall effect in Weyl semimetals

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Weyl semimetals are 3D materials with a unique type of spectrum featuring isolated nodal points in the momentum space. To a certain extent, they can be regarded as solid-state matter hosting massless relativistic fermions. In this respect Weyl semimetals bear some analogy with 2D graphene. A minimal model of a Weyl semimetal implies two Weyl points of opposite chirality within the Brillouin zone with a Hamiltonian breaking time-reversal symmetry. Weyl semimetals bear two very specific topological properties. First, the Weyl points are topologically protected against small perturbations as long as they maintain a finite distance in the momentum space. Second, presence of the Weyl points in the bulk spectrum inevitably leads to the appearance of soft Fermi arc excitations on the 2D surface. With increasing concentration of carriers, a Weyl semimetal develops finite Fermi surfaces around each Weyl point. When chemical potential exceeds a certain threshold value, these Fermi surfaces fuse via a Lifshits transition.

We study the Hall response of the Weyl semimetal. Hall conductivity appears due to inherent breaking of time-reversal symmetry and is fully analogous to anomalous Hall effect in ferromagnets with strong spin-orbit coupling. In the case of Weyl semimetals, both bulk states originating in the vicinity of Weyl points and surface Fermi-arc states contribute to the Hall conductivity. We consider both contributions as a function of energy both below and above Lifshits transition. In addition we find that very special disorder effects related to scattering on closely positioned pairs of impurities provide a significant contribution to the Hall conductivity.

Superfluidity in condensate of magnons: experiment and theory

Valery Pokrovsky

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Recently two groups of researchers [1], [2] presented experimental data in favor of superfluidity in the Bose-Einstein condensate of magnon liquid supported by permanent rf pumping at room temperature. We discuss these experiments. A basic component of theoretical approach is repulsive interaction between condensate magnons induced in the homogeneous stationary condensate state by the rf pumping. We construct simplified and complete theory of such system based on modified Gross-Pitaevskii equation. We discuss the experiment [2] that first displayed the strong repulsion of condensate magnons in an artificially created potential well. We also describe a new phenomenon found in experiment [2]: gigantic condensate response to a weak inhomogeneous magnetic field. Its theoretical explanation is proposed.

[1] D.A. Bozhko et al., Nat. Phys. 12, 1057 (2015).
[2] I. Borisenko et al., Nat. Comm, in press. (2019).

Binary black holes: formation and observations

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The rapidly increasing knowledge about binary black holes is due to LIGO/Virgo gravitational wave observations started in 2015 with the discovery of the first coalescing binary black hole GW 150914. Presently, several dozen more such binaries have been detected, with the registration rate of about ten sources per month in the ongoing O3 LIGO/Virgo observations. A review of the observed properties of the LIGO/Virgo binary black holes will be given. Their possible formation mechanisms will be discussed, including the standard astrophysical scenario from the evolution of massive binary stars, via dynamical captures in dense stellar clusters, and the formation from primordial stellar-mass black holes.

Debye mechanism of giant 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 AC conductivity is proportional to the inelastic quasiparticle relaxation time rather than the elastic one and therefore it 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 non-linear conductivity exists even in the absence of the supercurrent. It provides an anomalously low non-linear threshold. Microwave absorption measurements may provide direct information about the inelastic relaxation times in superconductors.

Inflation in the early Universe and its present artifacts

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I review the present status of the inflationary scenario in the early Universe and the main observational evidence on which it is based. The very possibility to make definite statements and predictions about a new historical stage in the past of our Universe which preceded the hot Big Bang is based on the existence of its artifacts in the present Universe ? those Fourier modes of small scalar and tensor perturbations of the isotropic homogeneous Universe which amplitude is approximately constant in the super-Hubble regime independently of unknown physics at very high energies and curvatures (still assuming that the local Lorentz invariance is not broken). The existence of such modes was first proved by Lifshitz in the perturbation theory long time ago and then generalized to arbitrary amplitudes of metric perturbations in the scope of the Lifshitz-Khalatnikov quasi-isotropic solution (1960). The primordial Fourier spectrum of such scalar perturbations at cosmological scales has been measured by now using temperature anisotropy and polarization of the cosmic microwave background and other methods. Confirming the generic prediction of slow-roll inflationary models, this spectrum appears to be approximately scale-invariant, but its deviation from scale invariance has been reliably measured, too. The numerical value of this deviation $(n_s - 1) \approx -0.035$ leaves viable only a few of slow-roll inflationary models. The simplest of them based either on scalar fields in General Relativity or on modified $f(R)$ gravity, which produce the best fit to all existing astronomical data, require one, maximum two dimensionless parameters taken from observations only. The main discoveries expected for these models in future are discussed. Among them the most fundamental are primordial quantum gravitational waves generated during inflation. In one parametric models, including the original $R + R^2$ one (1980), the definite prediction for the tensor-to-scalar ratio $r = 3(1 - n_s)^2 = 0.004$ follows. In the models considered, the most generic predecessor of inflation is an anisotropic and inhomogeneous space-time near a generic space-like singularity similar to that first studied by Lifshitz and Khalatnikov. Since the transition from such space-time to the generalized quasi-de Sitter regime is generic, too, for inflation to begin inside a patch including the observable part of the Universe, causal connection inside the whole patch is not necessary. However, it becomes obligatory for a graceful exit from inflation in order to have practically the same number of e-folds during inflation inside this patch.

Exciton Bose-Einstein condensation in 2D heterostructures with disorder

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We present the results of the theoretical analysis of the exciton BE-condensation in the 2D heterostructures with disorder. It is shown that the disorder existing in the system makes condensation possible. Besides, the results of the analysis of the finite exciton lifetime are presented. It is shown that the finite exciton lifetime limits the thermalization of excitons in the disordered system and sets an additional limit on the critical temperature of the transition. We present the role of the exciton-exciton interaction and finite lifetime in decay of phase correlation function.

From synthetic gravity to general relativity

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The Khalatnikov lectures on superfluid ^{4}He for students in 1967 at the Kapitza Institute led me to strange connection between superfluid hydrodynamics and general relativity. Later it turned out that in condensed matter it is possible to imitate not only general relativity (in the tetrad form), but also quantum electrodynamics with Weyl and Dirac fermions. The latter follows from the topological properties of the ground state of the system, which are similar in condensed matter and in quantum vacuum. Many different analogies between the condensed matter on one side and relativistic quantum fields and gravity on the other side have been collected in the book [1]. These analogies allowed study the problems of quantum vacuum, such as cosmological constant problem [2] and Hawking radiation [3]. There are several routes to general relativity. In particular, the elasticity theory with the distributed defects can be described in terms of the dimensionful tetrad field [4]. When these dimensionful elasticity tetrads are applied back to general relativity – the so called superplastic vacuum [5] – one obtains that the Ricci curvature scalar R, the gravitational Newton constant G, the cosmological constant Λ and masses of particles M become dimensionless [6]. The reason for that is that in the arbitrarily deformed superplastic vacuum, there is no equilibrium size of the elementary cell. Thus the microscopic length scale (such as Planck scale) is absent, and all the distances are measured in terms of the integer positions of the nodes in the crystal. Because of the suppression of dimensionality of physical parameters, the elasticity tetrads are appropriate for the description of the topological terms responsible for the 3+1 quantum Hall effect [6].

[1] G.E. Volovik, The Universe in a Helium Droplet, Oxford (2003).
[2] F.R. Klinkhamer and G.E. Volovik, Phys. Rev. D 78, 063528 (2008).
[3] G.E. Volovik, JETP Lett. 90, 1 (2009).
[4] I.E. Dzyaloshinskii and G.E. Volovik, Ann. Phys. 125, 67 (1980).
[5] F.R. Klinkhamer and G.E. Volovik, Pis'ma ZhETF 109, 369 (2019).
[6] J. Nissinen and G.E. Volovik, arXiv:1812.03175.

Quantisations of 2D hydrodynamic and gravitational anomaly

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I will present a consistent scheme of quantization of chiral flows (flows with extensive vorticity) in ideal hydrodynamics in two dimensions. Chiral flows occur in rotating superfluid, rotating turbulence and also in electronic systems in the magnetic field in the regime of a fractional Hall effect. The quantization is based on a geometric relation of chiral flows to two-dimensional quantum gravity and is implemented by the gravitational anomaly. The effect of the gravitational anomaly violates the major property of classical hydrodynamics, the Helmholtz law: vortices are no longer frozen into the flow. Effects of quantization could be cast in the form of quantum stress. I show that the quantum stress generates Virasoro algebra, the centrally extended algebra of holomorphic diffeomorphisms.

“Moscow zero” and solvable deformations of 2D quantum field theories

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Posters

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 $G \sim 1/\sqrt{L}$ [1]. In order to calculate the variance of conductance $\operatorname{var} G$ 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 $\operatorname{var} G$ (see Fig. 1) at arbitrary lengths in the diffusive region with the crossover from the weak-localisation regime at $L \ll \xi$ to the regime of a very broad conductance distribution at $L \gg \xi$, 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.

[1] A. Altland et al., Phys. Rev. B 91, 085429 (2015)

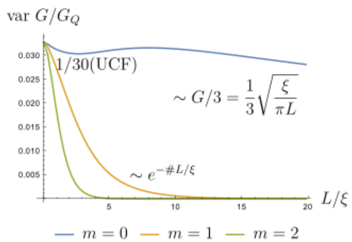

Fig. Variance of conductance due to mesoscopic fluctuations as a function of the wire length. m is the imbalance of right/left movers in the wire.

Randomized benchmarkig of two qubit gates using one qubit Clifford group

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Randomized benchmarking is a widely used technique for estimating average fidelity of a set of quantum gates. To get a well-defined dependence of fidelity from the number of gates in the set it is needed to average the set over the whole Clifford group. Here we propose a method of averaging fidelity over a subgroup of a two qubit Clifford group specifically over tensor product of one qubit Clifford groups.

Theoretical description of Trotter errors in digital quantum simulations of tunneling phenomena

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The phenomenon of tunneling is important both as an observable fundamental process in many body systems and as one of the key parts of quantum optimization algorithms. Therefore, not only the problem of simulating a tunneling event on existing quantum computers is of great fundamental meaning, but it also has particular practical applications. In this work, we investigate the disturbances in a quantum tunneling process when using one of the most widely-used algorithms of quantum simulations based on Suzuki-Trotter product formulas. Using an exactly solvable spin-1/2 XY-model with external Z-field, we apply the discrete analogue of WKB method and provide a quantitative characterization of the discretization error of Suzuki-Trotter decomposition. We compare our analytical answers with existing rigorous bounds on the error and report several settings where these bounds are not saturated. Each of these cases we supply with a certain physical interpretation that provides intuition for the exact form of the correction. Our analysis provides physical insights on the feasibility of simulation of physical quantum systems on existing quantum hardware.

Addressing the sign problem using optimisation of complex integration contours

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The Sign Problem is a computational difficulty one faces when simulating systems whose weight is not positive definite, as in the case of theories, e.g. QCD, with non-zero chemical potential. Such systems lack the simple probabilistic interpretation needed for a Monte Carlo simulation. While this difficulty can be resolved using the method of reweighting, one often faces a new numerical difficulty stemming from very large cancellations that should lead to a relatively small finite result. This is the sign problem. Despite the simple origin of this problem, it turns out that in some cases it is NP-complete. Hence a full solution of the sign problem for all systems would probably never be found. However, specific methods can be used in several particular cases. An important approach is that of using Lefschetz Thimbles, i.e., deforming the original integration contour in C^n to a contour based on downward gradient flow of Re(S) from stationary points in C^n. While successful this method is also not without problems. We propose to consider more general contour deformations and illustrate in a particular model (Bose gas with chemical potential in various dimensions) that it leads to better control over the sign problem.

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

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We study the stability of the SYK_4 model with a large but finite number of fermions N with respect to a perturbation, quadratic in fermionic operators. We develop analytic perturbation theory in the amplitude of the SYK_2 perturbation and demonstrate the stability of the SYK_4 infra-red asymptotic behavior characterized by a Green function $G(\tau) \propto 1/\tau^{3/2}$, with respect to weak perturbation. This result is supported by exact numerical diagonalization.

Nonlinear generation of eddy currents by crossed surface waves

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We study the mass-transport induced by crossed surface waves corresponding to a regular lattice of counter-rotating vortices. In the case of ideal fluid, the flow is described by the Stokes drift mechanism. However, an arbitrarily small viscosity substantially changes the generated flow — an effective force proportional to viscosity and quadratic in wave amplitudes excites an additional slow current in a thin viscous sublayer near the fluid surface. This current spreads into the fluid bulk due to viscosity and, surprisingly, in the stationary regime nothing depends on viscosity. The amplitude of the effective force is sensitive to the surface contamination and we demonstrate that a thin insoluble liquid film presented on the fluid surface can substantially increase the induced mass-transport. The obtained results are in quantitative agreement with recent experiments.

Finite frequency noise at the helical edge in the presence of a magnetic impurity

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We consider the helical edge states of electrons in a 2D topological insulator perturbed by a rare magnetic impurities with spin $\frac{1}{2}$. These magnetic impurities are source for backscattering of edge electrons due to anisotropic exchange interaction. For an arbitrary form of matrix of the exchange interaction, we calculate exactly the current noise at finite but small frequencies at different temperature and applied bias. In paricular, we found that the shot noise has a resonant form as a function of frequency with three resonances which have the Lorentzian form. The corresponding Korringa rates differ by a factor of 2 for central and side resonances.

Finding the resistivity of weakly disordered quasi-1D systems near Van Hove singularities with the help of certain strictly-1D exact results

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Quasi-one-dimensional systems demonstrate Van Hove singularities in the density of states ν_F and the resistivity ρ, occurring when the Fermi level E crosses a bottom E_N of some (resonant) subband of transverse quantization. Taking scattering at short-range impurities into account smears the singularities. However, for energies E close enough to E_N the plane waves does not provide any good approximation for the localized electron wave functions in the resonant band and one has to employ exact 1D-results instead.

We show that the character of smearing crucially depends on the concentration of impurities. Namely, there is a crossover concentration $n_c \propto |\lambda|$, $\lambda \ll 1$ being the dimensionless amplitude of scattering. For $n \gg n_c$ the positions of singularities are shifted by the average impurity potential $\overline{U} \propto \lambda n$ and the singularities are simply rounded at $\varepsilon \equiv E - E_N + \overline{U} \sim \tau^{-1}$ – the Born scattering rate. Below the singularity point, the density of states in the resonant subband is described by Lifshits tail and the overall density of states and resistivity are given by the direct sum of nonresonant and resonant subbands contribution. However, for $n \ll n_c$ the result is more complicated than the direct sum of resonant and nonresonant subband contributions because of the hybridization between resonant and nonresonant subbands.

For $n \ll n_c$ the result for ρ generally depends on the sign of λ. For simplicity, in this work we consider only the case $\lambda > 0$. For this case large mesoscopic fluctuations are expected due to the resonant subband states which for low energies are localized between 2 impurities. All of the scattering processes proceed with compulsory excursions of electron to the resonant subband if the electrons energy happens to be in resonance with the energy of certain localized eigenstate of the corresponding strictly-1D problem.

Paraconductivity in pseudogapped superconductors

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We calculate Aslamazov-Larkin paraconductity $\sigma_{AL}(T)$ for a model of strongly disordered superconductors (dimensions $d = 2, 3$) with a large pseudogap whose magnitude strongly exceeds transition temperature T_c. We show that, within Gaussian approximation over Cooper-pair fluctuations, paraconductivity is just twice larger that the classical AL result at the same $\epsilon = (T - T_c)/T_c$. Upon decreasing ϵ, Gaussian approximation is violated due to local fluctuations of pairing fields that become relevant at $\epsilon \leq \epsilon_1 \ll 1$. Characteristic scale ϵ_1 is much larger than the width ϵ_2 of the thermodynamical critical region, that is determined via the Ginzburg criterion, $\epsilon_2 \approx \epsilon_1^d$. We argue that in the intermediate region $\epsilon_2 \leq \epsilon \leq \epsilon_1$ paraconductivity follows the same AL power law, albeit with another (yet unknown) numerical prefactor. At further decrease of the temperature, all kinds of fluctuational corrections become strong at $\epsilon \leq \epsilon_2$; in particular, conductivity occurs to be strongly inhomogeneous in real space.

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, statistics of the non-falling trajectory is expressed in terms of the zero mode of a corresponding transfer-matrix Hamiltonian. 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.

Index

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Daniil Antonenko (antonenko.daniel@gmail.com), 48

Serguei Brazovskii (serguei.brazovski@u-psud.fr), 13
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Evgenii Kuznetsov (kuznetso@itp.ac.ru), 29

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Alexei Lunkin (lunk112514@gmail.com), 52
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Boris Pashinsky (boris.pashinsky@gmail.com), 54
Nikolai Peshcherenko (peshcherenko@itp.ac.ru), 55
Igor Poboiko (poboiko@itp.ac.ru), 56
Valery Pokrovsky (valery@physics.tamu.edu), 39
Konstantin Postnov (kpostnov@gmail.com), 40

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Научное издание

Квантовые жидкости, квантовая теория поля и гравитация

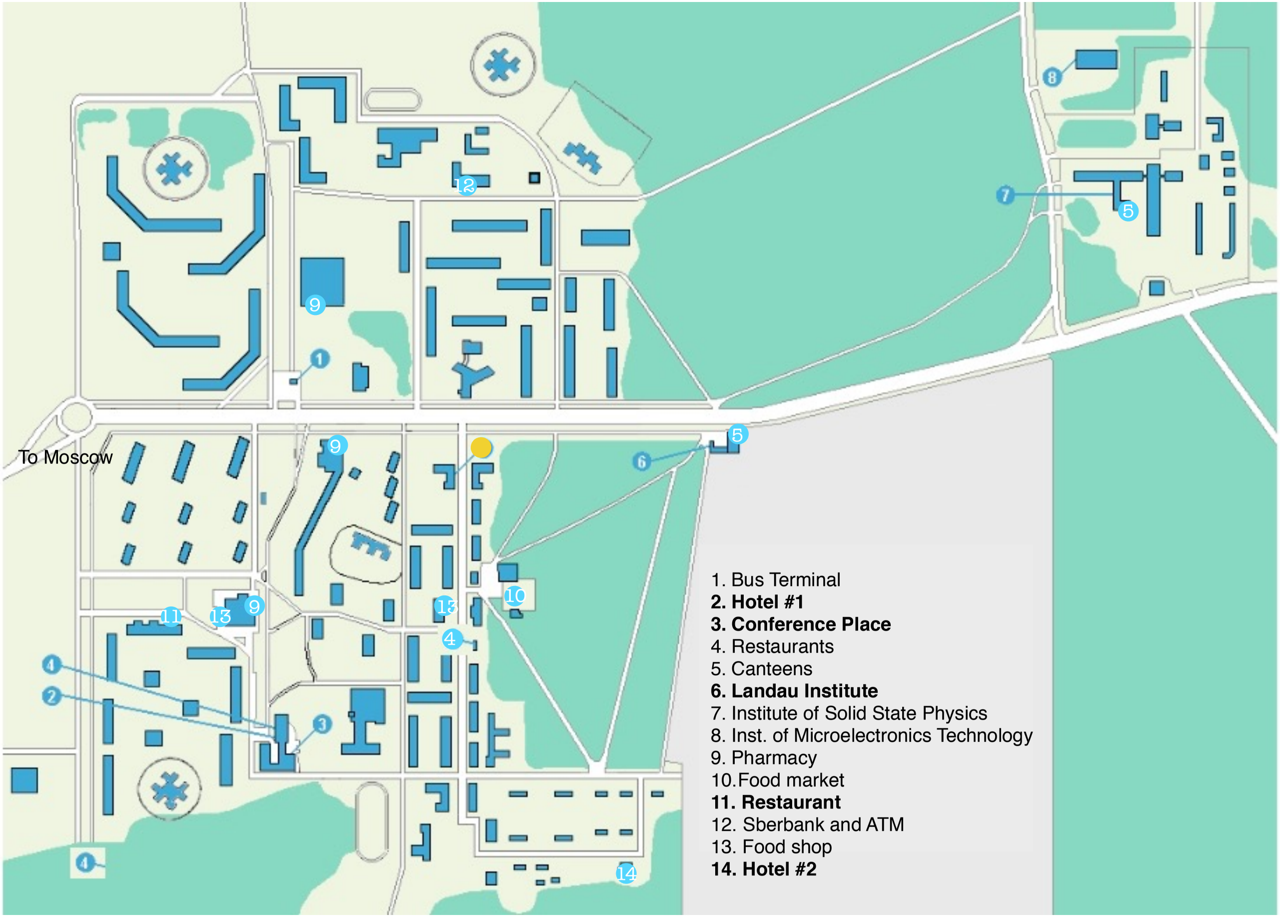
Тезисы Международной конференции, посвященной 100-летию
со дня рождения И.М. Халатникова

Подписано в печать 09.10.19. Формат $60 \times 90/16$.
Бумага офсетная. Печать цифровая.
Усл.-печ. л. 3,75. Уч.-изд. л. 2,0. Тираж 80 экз.

Заказ № 1080.

Издательство «ТОРУС ПРЕСС»
Москва 121614, ул. Крылатская, 29-1-43
torus@torus-press.ru; http://www.torus-press.ru

Отпечатано в НИПКЦ «Восход-А» с готовых файлов
Москва 109052, ул. Смирновская, д. 25, стр. 3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