PREFACE

In 2008 the anniversary of Lev Landau was celebrated. Landau was born 22 January 1908 and died 1 April 1968. Lev Landau was one of the greatest physicists of the XX-th Century, Nobel Prize Winner (1962). His pioneering results advanced various major fields of theoretical physics: Quantum theory of metals, Superfluidity, Superconductivity, Plasma Physics, Theory of Phase Transitions, Quantum Electrodynamics, etc. The fundamental Course in Theoretical Physics, written by Lev Landau and Evgeny Lifshitz, is internationally recognized for about 50 years as the major general textbook for theoretical physicists of all specializations. Lev Landau is the founder of the most influential scientific school of the Soviet Union, which is currently active both in Russia and world-wide.

One of events of the anniversary celebration was International Conference "Advances in Theoretical Physics", held in Chernogolovka (Moscow region, Russia) June 22-26. The conference was organized by Landau Institute for Theoretical Physics that was established by Landau pupils and carries his traditions. The idea of the conference was to review current progress in the main branches of theoretical physics, in the spirit of Landau's universality. The talks covered solid state physics and cosmology, low temperature physics and optics, quantum field theory and statistical physics, physics of low-dimensional systems and hydrodynamics.

The conference was organized in the thematic mode, that is, collecting together talks on similar topics. Certainly, this principle was not realized rigorously, but served to define a useful general framework. We follow in this Volume the same approach: the papers corresponding to the reports given at the Conference are ordered according to the Conference schedule. Unfortunately, just about one half of all speakers were able to present their manuscripts for the Proceedings; in order to provide the reader with a broader view of the event, we listed all the talks of the Conference below, together with the corresponding abstracts. Almost all presentations of the talks are available in the PDF form at the site http://landau100.itp.ac.ru/program.shtml

Mikhail Feigel'man and Vladimir Lebedev,
15 March 2009, Moscow.

Talks

- V.L. Pokrovsky,
  Weakly interacting Bose gas in a disordered environment
- S. Stringari,
  Superfluidity of trapped atomic gases
  Abstract
  I will present recent advances in the theoretical and experimental studies of superfluidity in trapped quantum gases, including both Bose and Fermi gases. Emphasis will be given on the T=0 hydrodynamic behavior of these quantum systems (propagation of sound, collective oscillations, expansion), on the rotational properties (quenching of moment of inertia and quantized vortices) and on the Josephson oscillations in the presence of optical lattices.
  Special attention will be also given to Fermi superfluidity, including the BEC-BCS crossover, the universal behavior at unitarity, the behavior of Landau's critical velocity and the superfluid-normal phase separation caused by the polarization of the gas.
- E.A. Demler,
  Nonequilibrium spin dynamics in systems of ultracold atoms
  Abstract
  I will discuss two examples of theoretical and experimental progress in understanding non-equilibrium quantum spin dynamics in systems of ultracold atoms. I will revew theoretical prediction and experimental observation of superexchange interactions in the Mott state of ultracold atoms. I will also discuss recent experiments with spinor ^{87}Rb condensates which observed spin fragmentation. I will show that this instability results from dipolar interactions averaged over fast Larmor precession of the spins. I will argue that this system has the Landau type spectrum of collective excitations with a spin-wave and roton branches. The instability develops when the roton branch softens to zero frequency suggesting a formation of the supersolid phase.
- A.W.W. Ludwig,
  Anderson Localization at Boundaries, and Topological Insulators
- N. Andrei,
  Quantum Impurities out of Equilibrium
  Abstract
  We develop an exact non-perturbative framework to compute steady state properties of quantum-impurities connected to leads subject to finite bias. We show that the steady-state physics of these systems is captured by non-equilibrium scattering eigenstates defined on the infinite open line with boundary conditions set by the leads (open system limit). Introducing the Scattering Bethe Ansatz (SBA), a generalization of the traditional Bethe Ansatz to open systems, we show how to explicitly construct the fully interacting, current-carrying and entropy producing scattering eigenstates. As exam-

ples we derive exact results for the non-equilibrium steady state properties of the Interacting Resonance Level model and the Anderson model.

- F.D.M. Haldane,
  Berry Phases and Fermi Liquid theory in the anomalous Hall effect and in the lowest Landau level
  Abstract
  The Karplus-Luttinger intrinsic contribution to the anomalous Hall effect in ferromagnetic metals can be expressed in terms of Berry curvature of quasiparticles at the Fermi surface, and is a magnetic-field-induced correction to the Luttinger theorem relating the electron density to the volume of the Fermi surface. It is therefore a fundamental Fermi-liquid property of metals with broken time-reversal symmetry. I will also describe its application to "composite fermion" Fermi-liquid-like states in the partially-filled Landau level. Finally, I will discuss aspects of Luttinger's theorem and Fermi-liquid theory in metals with both broken time-reversal symmetry and spatial inversion symmetry. In this case, the Kohn-Luttinger effect (that a BCS instability must always destroy the Fermi surface of an interacting system at low-enough temperatures) is defeated, and a true Fermi-liquid ground state is possible.
- A.Yu. Kitaev,
  Periodic table for topological insulators and superconductors
- M.P.A. Fisher,
  Critical Quantum Spin Liquids in Two Dimensions
- M.R. Zirnbauer,
  Energy correlations for a random matrix model of disordered bosons
  Abstract
  Linearizing the Heisenberg equations of motion around the ground state of an interacting quantum many-body system, one gets a time-evolution generator in the positive cone of elliptic elements of a real symplectic Lie algebra. The presence of disorder in the physical system determines a probability measure with support on this cone. In this talk I discuss a family of such measures of exponential type, and do so in an attempt to capture, by a simple random matrix model, some generic statistical features of the characteristic frequencies of disordered bosonic quasi-particle systems. The level correlation functions of the said measures are shown to be those of a determinantal process, and the kernel of the process is expressed as a sum of bi-orthogonal polynomials. While the correlations in the bulk scaling limit are in accord with GUE (or sine kernel) universality, at the low-frequency end of the spectrum an unusual type of scaling behavior is found.
- V.E. Kravtsov,
  One-dimensional localization: devil's staircase of statistical anomalies
- L.S. Levitov,
  Quantum Noise as an Entanglement Meter
- T. Damour,
  Chaos and Symmetry in Gravity and Supergravity
  Abstract
  We shall review the intriguing connection between the Belinsky-Khalatnikov-Lifshitz-type 'chaotic' behaviour of spacelike singularities in gravity and supergravity, and certain hyperbolic Kac-Moody algebras (notably E_10). This leads to studying a one-dimensional E_10 coset model. This study hints at an 'hyperbolic' generalization of the usual (affine Kac-Moody) Sugawara construction.
- A.Yu. Kamenshchik,
  The problem of initial conditions in cosmology
- L. Kofman,
  Very early universe
  Abstract
  According to the modern cosmological theory, the universe in its very early stages underwent an exponentially rapid expansion, inflation. Inflation predicts homogeneity and flatness of observable universe as well as small cosmological fluctuations around it. Another prediction of inflation is the creation of matter from vacuum in the process of preheating after inflation. We will review the status of the inflationary theory including preheating after inflation, and discuss potential observational tests of their signatures.
- M. Sasaki,
  δN formalism and nonlinear curvature perturbations from inflation
  Abstract
  The δN formalism is a useful tool for computing cosmological curvature perturbations. In this formalism, the final amplitude of the curvature perturbation at $t = t_f$ is given by δN, where δN is the perturbation of the number of e-folds between an initial time $t = t_i$ and the final time $t = t_f$. It was originally advocated by Starobinsky. Then it was formulated geometrically, and it was recently proven to be applicable to fully nonlinear cosmological perturbations. In particular, the δN formalism has been applied to the curvature perturbations from inflation with great success. In this talk, I will review the delta N formalism and discuss its applications to the evaluation of non-Gaussian perturbations from inflation, which has been recently a topic of great interest in cosmology.
- A.A. Starobinsky,

Scalar-tensor and f(R) models of dark energy in the Universe
Abstract
Recent numerous observational data obtained from angular anisotropies of the cosmic microwave background radiation, large-scale gravitational clustering of galaxies and observations of supernovae explosions at high redshifts prove convincingly that the Universe expands with acceleration at the present time while it was decelerating in the past for redshifts larger than about 0.7. If interpreted in terms of the Einstein general theory of relativity, this means that about 0.7 of the total energy density of matter in the present Universe is due to a new (effective) kind of matter - 'dark energy' - which is non-baryonic, has a negative pressure which modulus is very close to its energy density, and remains unclustered at all scales where clustering of baryons and dust-like cold dark matter is seen. The simplest possibility of dark energy being a cosmological constant provides a good fit to all existing observational data. However, a more complicated situation including 'phantom behaviour' of dark energy (breaking of the weak energy condition for it) for redshifts $z < 0.5$ combined with some increase of its energy density with redshift for larger z is possible, too. The simplest dark energy model admitting such a non-trivial behaviour which does not have ghosts and instabilities is based on scalar-tensor gravity. Recent progress in construction of viable dark energy models in scalar-tensor gravity and its particular case - f(R) gravity - which satisfy laboratory, Solar system and cosmological tests is discussed. Further problems and most critical tests of these models are outlined.

- R.A. Sunyaev,
Clusters of galaxies, cosmic microwave background and cosmology
Abstract
Clusters of galaxies are most massive gravitationally bound objects in the Universe. They contain hot rarefied intercluster gas having temperature 1-10 KeV and making them bright in X-Rays. Thomson scattering of CMB photons on the hot electrons results in the diminution of observed CMB brightness toward clusters of galaxies. New ground based radiotelescopes on South Pole and 5 km elevation in Chile and Planck Surveyor spacecraft are planning to detect tens of thousands of clusters using this effect and to measure the peculiar velocities of clusters in a unique coordinate frame where CMB is isotropic. Russian Space Agency and IKI in collaboration with Germany, Holland, Japan and USA are planning to launch SPECTR-RG spacecraft able to map all reach clusters of galaxies in observable Universe. These two samples of clusters will open a possibility to measure with very high precision the key parameters of our Universe including the dark energy equation of state.
- V.E. Zakharov,
Theory of Freak Waves and Possible Integrability of the Hydrodynamics with Free Surface
- S.E. Korshunov,
Universal and non-universal tails of distribution functions in the directed polymer and KPZ problems
Abstract
The optimal fluctuation approach is applied to study the most distant (non-universal) tails of the free-energy distribution function $P_L(F)$ for an elastic string (of a large but finite length L) interacting with a quenched random potential. A further modification of this approach is proposed which takes into account the renormalization effects and allows one to investigate the most close parts of the tails in the strong-coupling phase where they have to be universal (in particular, independent of the details of a disorder distribution).
- G.E. Falkovich,
Emerging symmetries and condensates in turbulent inverse cascades
Abstract
I shall briefly review an empiric knowledge on turbulent inverse cascades with a focus on most fundamental physical aspects, symmetries and anomalies. Some surprising findings relating turbulence to critical phenomena and conformal field theory will be presented. I shall describe then the phenomenon of spectral condensation which is an appearance of large vortices coherent across the whole system for many rotation periods. I shall describe some new data on how condensates renormalize the statistics of turbulence with a possible application to a controversy on an energy source of mesoscale atmospheric turbulence.
- C.L. Henley,
Mechanisms for macroscopic chirality in organisms
- V.B. Geshkenbein,
Munchhausen effect, tunneling in an asymmetric SQUID
- V.P. Mineev,
Pressure-temperature phase diagram of ferromagnetic superconductors
- E.I. Kats,
Electromagnon excitations in modulated multiferroics
Abstract

The phenomenological theory of ferroelectricity in spiral magnets is generalized to describe consistently states with both uniform and modulated-in-space ferroelectric polarizations. A key point in this description is the symmetric part of the magnetoelectric coupling since, although being irrelevant for the uniform component, it plays an essential role for the non-uniform part of the polarization. We illustrate this importance in generic examples of modulated magnetic systems: longitudinal and transverse spin-density wave states and planar cycloidal phase. We show that even in the cases with no uniform ferroelectricity induced, polarization correlation functions follow to the soft magnetic behavior of the system due to the magnetoelectric effect. Our results can be easily generalized for more complicated types of magnetic ordering, and the applications may concern various natural and artificial systems in condensed matter physics (e.g., magnon properties could be extracted from dynamic dielectric response measurements).

- S.A. Brazovskii,
  Solitonic quasi-particles in electronic systems with a long range order
- K.B. Efetov,
  Effect of magnetic field on transport in granular materials
- B.Z. Spivak,
  Theory of disordered d-wave superconductors
- I.R. Gabitov,
  Transient phenomena on the interface of optical materials with negative index of refraction
  Abstract
  Nanostructured metamaterials with negative index of refraction have been recently fabricated in several research groups. The left handed orientation of the ($\vec{\mathbf{k}},\vec{\mathbf{E}},\vec{\mathbf{H}}$) triplet and opposite directionality of the phase velocity $\vec{\mathbf{v}}_{ph}$ and Poynting vector $\vec{\mathbf{S}}$ are the most distinctive features of these optical materials. When an electromagnetic wave enters a negative refractive index material the right-handed orientation of the ($\vec{\mathbf{k}},\vec{\mathbf{E}},\vec{\mathbf{H}}$) triplet and parallel orientation of $\vec{\mathbf{v}}_{ph}$ and $\vec{\mathbf{S}}$ can not be changed to a left-hand orientation of the ($\vec{\mathbf{k}},\vec{\mathbf{E}},\vec{\mathbf{H}}$) triplet and opposite directionality of $\vec{\mathbf{v}}_{ph}$ and $\vec{\mathbf{S}}$ in a continuous way, while the value of refractive index can change sign continuously. We study transient characteristics of the incident electromagnetic field. The problem of continuous change of the value dielectric permittivity was considered in plasma physics. We obtained an analytic expression describing the phase velocity as a function of distance along the normal to the interface surface. We have demonstrated that the transition is through a pole for magnitude of the phase velocity located where $n = 0$. In the case of normal incidence the reflection coefficient is zero and the electromagnetic field is regular. In the case of oblique incidence we predict singular behavior of the electromagnetic field at the point of zero refractive index and an exact formula for the energy dissipation in the limit where absorption vanishes. As the absorption coefficient decreases, there is compensation because the field is growing. The limit is a universal value depending on the angle of incidence.
- D.A. Ivanov,
  Resonating-valence-bond physics and topological order in two dimensions: from dimer models to high-temperature superconductivity
- J.T. Chalker,
  Phase transitions in highly constrained systems
  Abstract
  There is a class of statistical mechanical systems in which local constraints are combined with macroscopic ground state degeneracy. Examples include models for geometrically frustrated antiferromagnets, and for proton disorder in ice, and dimer covering problems on various lattices. In three dimensions the constraints may give rise to a Coulomb phase, which is disordered but has power-law correlations, with long-distance properties described by Gaussian fluctuations of a solenoidal field. The Coulomb phase is stable against small perturbations, but large ones may induce a phase transition. I will give an overview of recent work on ordering transitions from this Coulomb phase. These ordering transitions are of interest partly because they evade a straightforward application of the Landau approach to critical phenomena, since a theory constructed in the conventional way from the order parameter characterising symmetry-breaking in the ordered phase will not reproduce the power-law correlations of the disordered phase. I will discuss ways around this difficulty, and will describe links between these classical ordering transitions and quantum phase transitions.
- A.F. Andreev,
  Non-classical rotation of quantum glasses
  Abstract
  Supersolidity of glasses is explained as a property of an unusual state of condensed matter. This state is essentially different from both normal and superfluid solid states. The mechanism of the phenomenon is the transfer of mass by tunneling two level systems.
- V.V. Cheianov,
  Spin dynamics in a one-dimensional Bose ferro-

magnet
Abstract
We investigate the propagation of spin excitations in a one-dimensional ferromagnetic Bose gas. While the spectrum of longitudinal spin waves in this system is soundlike, the dispersion of transverse spin excitations is quadratic, making a direct application of the Luttinger liquid theory impossible. By using a combination of different analytic methods we derive the large time asymptotic behavior of the spin-spin dynamical correlation function for strong interparticle repulsion. The result has an unusual structure associated with a crossover from the regime of trapped spin wave to an open regime.

- I.S. Burmistrov,
  The Problem of True Macroscopic Charge Quantization in Coulomb Blockade
- S.M. Girvin,
  'Circuit QED': Quantum Optics and Quantum Computation with Josephson Junctions
  Abstract
  'Circuit QED' explores quantum optics and cavity quantum electrodynamics in electrical circuits. Josephson junction 'atoms' placed inside an on-chip resonant cavity can strongly interact with microwaves. In addition to being a new test bed for quantum mechanics and quantum optics in the ultra-strong coupling regime, this system has many promising features for quantum computation.
  The large transition dipole moment of the 'atom' combined with a novel cavity geometry with mode volume of only 10^{-6} cubic wavelengths gives an atom/photon coupling which reaches the theoretical limit set by the fine structure constant. This ultra-strong coupling can be used to detect and generate individual microwave quanta, transfer quantum information between distant qubits via virtual photon exchange along the cavity 'bus', and transfer quantum information from qubits to 'flying qubits' (coherent superpositions of zero and one photon). This technology can also be used to construct ultra-low noise quantum limited parametric amplifiers.
  Charge based qubits have traditionally suffered from strong decoherence due to environmental fluctuations. The Yale group has developed a new design which is exponentially insensitive to charge noise and exhibits long coherence times T_2^* approaching 3 μs and homogeneous broadening $1/T_2^* \sim 1/2T_1$.
  This talk will give an introduction to the recent remarkable experiments in the Schoelkopf and Devoret lab at Yale.
- Yu.V. Nazarov,
  Statistics of Measurement of Non-commuting Quantum Variables
- G. Blatter,
  Wave-packet Formalism of Full Counting Statistics
- G.B. Lesovik,
  Entanglement and noise in quantum conductors
- B. Doucot,
  Residual decoherence in protected qubits
- L.B. Ioffe,
  Low frequency dynamics of quantum spins at high temperatures in the absence of dissipation
  Abstract
  I discuss the noise generation by a purely quantum system of spins on a surface of a superconductor interacting via screened RKKY interaction. I show that this noise has a low frequency part which is due to the rare pairs of close and strongly coupled spins which switch rarely from the triplet to singlet state. The rate of this process is due to the high frequency part of the noise generated by the surrounding spins. I develop the analytical technique to evaluate the high frequency asympotics of the spin-spin correlator responsible for this process. I conclude that this physics leads to the 1/f spectrum of the low frequency noise. I discuss the implications of this result to the flux noise in small superconducting devices.
- M.A. Skvortsov,
  Giant Nernst effect due to fluctuating Cooper pairs in superconductors
- A.M. Finkelstein,
  Metal-Insulator Transition in Disordered Two-Dimensional Electron Systems
  Abstract
  I will discuss the current status of the Metal-Insulator Transition (MIT) observed in a two-dimensional electron gas. I will demonstrate that the theory which takes into account the interplay of electron-electron interactions and disorder can comprehensively explain the observed properties of the MIT. Recent measurements provide experimental evidence supporting our theory. The experimentally obtained flow diagram clearly reveals the existence of a quantum critical point that separates the metallic phase from the insulating phase. Moreover, the metallic side of this diagram is accurately described by the renormalization-group theory without any fitting parameters.
- L.N. Lipatov,
  Integrability at high energy QCD and N=4 SUSY
- N.A. Nekrasov,
  Quantum integrability, mass puzzle, and gauge theory

- V.A. Kazakov,
From Classical to Quantum Integrability in the AdS/CFT correspondence
Abstract
I will give an overview of recent advances in solving of the N=4 supersymmetric Yang-Mills (SYM) theory in 4D in the planar limit, and of its dual, the Green-Schwarz-Metsaev-Tseytlin superstring sigma model on AdS5xS5 background. The inspiration comes, on the one hand, from the perturbative quantum integrability of SYM theory, first observed by Minahan and Zarembo, and on the other hand, from the (quasi)classical integrability of the superstring sigma-model. The classical Lax pair found by Bena, Polchinski and Roiban served for the construction of classical "Bethe ansatz equations" found by the finite gap method by Kazakov, Marshakov, Minahan and Zarembo. This development, recently culminated by the work of Beisert, Eden and Staudacher, where the quantum version of these equations finding the anomalous dimensions of all "long" operators of the N=4 SYM theory for any value 'tHooft coupling. I will describe the main ideas of this breakthrough giving us hopes for exact analytical description of the strongly coupled 4D gauge theories.
- M.I. Katsnelson,
Graphene: New bridge between condensed matter and quantum electrodynamics
Abstract
Graphene, which is the first example of truly two-dimensional crystals (it's just one layer of carbon atoms) turns out to be gapless semiconductor with unique electronic properties resulting from the fact that charge carriers in graphene demonstrate charge-conjugation symmetry between electrons and holes and possess an internal degree of freedom similar to "chirality" of ultrarelativistic elementary particles. It provides unexpected bridge between condensed matter physics and quantum electrodynamics. In particular, the Klein paradox of relativistic quantum mechanics is of crucial importance for design of carbon-based transistors; Atiyah-Singer index theorem explains anomalous quantum Hall effect in single- and bilayer graphene; the Zitterbewegung leads to essential quantum corrections to the Boltzmann equation. Some quantum-relativistic effects which are very difficult to probe in high-energy experiments, such as vacuum breakdown near super-heavy nuclei can be rather easily investigated in graphene, due to much higher value of the effective "fine structure constant" in the latter case. Due to thermal fluctuations in two-dimensional systems, as well as an interaction with substrate the graphene membrane turns out to be rippled which leads to an interesting problem of two-dimensional massless Dirac fermions in a curved space.
- M. Müller,
Relativistic magnetotransport in graphene
- P.M. Ostrovsky,
Anomalous localization and quantum Hall effect in disordered graphene
- H. Fritzsch,
Flavor Symmetries, Neutrino Masses and Neutrino Oscillations
- D.I. Diakonov,
Statistical physics of dyons and quark confinement
- A.S. Gorsky,
Amplitudes in N=4 supersymmetric Yang-Mills theory from the geometry of the momentum space
- J. Cardy,
Entanglement in Quantum Field Theory
Abstract
The ground state entanglement between different spatial regions is a useful diagnostic of quantum phase transitions. In 1+1-dimensional relativistic field theories its behavior is remarkably universal, the leading terms depending only on the central charge c of the corresponding UV conformal field theory. Corrections to this can be expressed in terms of the form factors of so-called twist operators, and these are also strongly universal.
- A.B. Zamolodchikov,
On the Ising model criticality in the presense of magnetic field
Abstract
I will discuss the 2D Ising Model in the presence of a magnetic field, in its scaling domain near the critical point: $T_c - T \to 0, \quad H \to 0$ with the ratio $\eta = (T_c - T)/|H|^{8/15}$ fixed. I will demonstrate how going to complex values of η allows one to build analytic interpolation between different physical regimes. I will argue that at complex η the model has infinitely many critical points, the Yang-Lee edge singularity being just the most prominent of them.
- I.B. Khriplovich,
Quantized black holes, their spectrum and radiation
- M.V. Chertkov,
Statistical Inference and Loop Calculus in Physics, Computer and Information Sciences
Abstract
Loop Calculus introduced in [Chertkov, Chernyak '06] constitutes a new theoretical tool that expresses explicitly the symbol Maximum-A-Posteriori solution of a general statistical inference problem via a

solution of the Belief Propagation, or Bethe-Pieirls, equations. This finding brought a new significance to the BP concept, which in the past was thought of as just a loop-free approximation. In this presentation I will explain main concept and feature challenges of the Loop Calculus approach. I will also discuss algorithmic utility of the Loop Calculus for improved decoding of graphical codes, inference on planar graph and matching of particles between two subsequent snapshots of a turbulent flow.