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ABSTRACTS

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Compactons in BEC with periodically modulated interactions in deep optical lattices

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Compacton matter waves in one- and two-dimensional Bose-Einstein condensates (BEC) and in binary BEC mixtures, trapped in deep optical lattices in the presence of strong and rapid periodic time modulations of the atomic scattering length, are considered. For this, we derive vector averaged discrete nonlinear Schroedinger equations (DNLSE) and show that compacton solutions of different types can exist as stable excitations. Stability properties are studied by linear analysis and by direct numerical integrations of the DNLSE system.

Development of high-vorticity structures in incompressible 3D Euler equations: vortex lines representation

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The incompressible three-dimensional ideal flows develop very thin pancake-like regions of increasing vorticity, which evolve with the scaling $\omega_{\max} \propto \ell^{-2/3}$ between the vorticity maximum and pancake thickness. In this work we describe this process from the point of view of vortex lines representation (VLR). Based on two numerical simulations in anisotropic grids with 1536^3 total number of nodes, we examine the structure of characteristic matrices for the VLR (the Jacobi matrix and the Hessian matrix of the Jacobian), and link these matrices with the emergence of the scaling law $\omega_{\max} \propto \ell^{-2/3}$.

Collision of gravitational and electromagnetic solitons with strong electromagnetic waves of arbitrary amplitudes and profiles in the expanding background space-time

Alekseev GA

Steklov Mathematical Institute

A class of exact solutions of Einstein - Maxwell equations which describe the collision and nonlinear interaction of gravitational and electromagnetic soliton waves with strong non-soliton electromagnetic traveling waves of arbitrary amplitudes and profiles propagating in the expanding background space-time is presented. In contrast to intuitive expectations that rather strong traveling waves can destroy the soliton, it occurs that the soliton survives during its interaction with electromagnetic waves of arbitrary amplitude and profile, but its parameters begin to evolve under the influence of this interaction. If a traveling electromagnetic wave possesses a finite duration, the soliton parameters after interaction take constant values again, but these values in general are different from those before the interaction. These solutions of the Einstein-Maxwell equations demonstrate a series of nonlinear phenomena, such as (a) creation of gravitational waves in the collision of two electromagnetic waves, (b) creation of electromagnetic soliton waves in the collision of a gravitational soliton with traveling electromagnetic waves, (c) scattering of a part of a soliton wave in the direction of propagation of a traveling electromagnetic wave, and (d) quasi-periodic oscillating character of fields in the wave interaction region and multiple mutual transformations of gravitational and electromagnetic waves in this region.

An algorithm for demonstrative computation of solitons in NLS-type models

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We address the problem of description and numerical computation of localized modes in NLS-type scalar and vector models, the defocusing case. Such modes are described by a system of ODE's that in eneral case are nonautonomous. The main idea of the approach is to make use of the fact that "the most part" of solutions for Cauchy problem for such ODE systems collapses, i.e. tend to infinity at some point of the real axis. In some cases this allows for complete description of the set of the localized modes. In the talk this approach is illustrated by (i) the Lugiato-Lefever equation; (ii) coupled Gross-Pitaevskii equations for mixture of ultracold gases.

On universality of spectral distributions of sea swell: estimates and numerical simulations

Badulin SI, Zakharov VE

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On stability of multi-soliton bound states in dispersion-managed optical fibers

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To date the existence of robust two- and three-soliton bound states in dispersion-managed (DM) optical fibers has been experimentally demonstrated [1,2]. These soliton compounds, also known as soliton molecules, may find important applications in fiber optic communication systems to enhance their data carrying capacity [3]. So far the binding mechanism of DM solitons was proposed [4] and some stability issues were addressed [5].
In this contribution we develop a collective coordinate approach for multi-soliton compounds in DM fibers and explore their stability both analytically and numerically. In particular, we have revealed the dependence of the binding energy of a multi-soliton compound on the number of constituent solitons. Disintegration of soliton molecules due to wave tunneling effect [5] and under different perturbations, originating from imperfections of DM fiber links [6,7], has been investigated.

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Collapse of the wave field in a system of weakly coupled light guides

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The analytical and numerical study of the radiation self-action in a system of coupled light guides is fulfilled on the basis of discrete nonlinear Schrödinger equation (DNSE). We develop a variational method for qualitative study of DNSE and make classification of self-action modes. We show that the diffraction of narrow (in grating scale) wave beams weakens in discrete media and, consequently, the “collapse” of one-dimensional wave field with power exceeding the critical value appears. This results in the ability to self-channeling radiation in the central fiber. Qualitative analytical results were confirmed by numerical simulation of DNSE, which also show the stability of the collapse mode.

Self-similar solution for the strong shock in a uniformly expanding universe

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Institute of Space Research

Exact analytic solution of self-similar equations is obtained for propagation of a strong shock in a flat expanding Friedman universe. Dependence of the density, and velocity of the polytropic gas behind the shock wave on time and radius are obtained. The velocity of the shock in the expanding medium decreases as $\sim t^{-1/5}$, slower than the shock velocity in the static uniform medium $\sim t^{-3/5}$, and its radius increases $\sim t^{4/5}$, more rapidly than in the uniform non-gravitating medium $\sim t^{2/5}$. So, the shock propagates in the direction of decreasing density with larger speed, than in the static medium, due to accelerating action of the decreasing density, even in presence of a self-gravitation.

SDYM equations on the self-dual background

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We introduce the technique combining the features of integration schemes for SDYM equations and multidimensional dispersionless integrable equations to get SDYM equations on the conformally self-dual background. Generating differential form is defined, the dressing scheme is developed. Some special cases and reductions are considered.

Energy flux enhancement, intermittency and turbulence via triad Fourier phase dynamics in dispersive and non-dispersive PDEs

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In this work we present a study of Fourier-space phase dynamics in fluid dynamical PDEs with quadratic nonlinearity where triadic wavevector interactions are responsible for energy transport across scales. We examine in detail the dynamics of the triad Fourier phases, defined as triadic linear combinations of individual Fourier phases. These 'dynamical' triad phase variables play an explicit role in governing the time evolution of the Fourier amplitude and phase variables and thus help regulate the global dynamics of such fluid systems. Our study examines the influence of these triad phase variables on energy/enstrophy transfers in forced and dissipative one-dimensional systems such as Burgers and Korteweg-de Vries/Burgers equation [M. Buzzicotti, B. P. Murray, L. Biferale & M. D. Bustamante, EPJE 39: 34 (2016)] and the two-dimensional Charney-Hasegawa-Mima equation [M. D. Bustamante, B. Quinn & D. Lucas, PRL 113: 084502 (2014)], relevant in atmospheric and plasma physics. In these systems we see and quantify strong correlations between the triad phase dynamics and the evolution of the amplitudes of Fourier modes in the triads, with intermittent (in time) collective alignment of triad phases leading to maximally efficient energy/enstrophy fluxes throughout the inertial range modes of the system. In scenarios where intermittent alignment is present, all triad phases across 'inertial-range' spatial scales display a characteristic probability density function (PDF), with a marked peak at the 'perfect alignment' value of $\pi/2$; remarkably, the so-called 'degenerate' triads (where one mode is repeated) display a PDF with a less marked peak at the alignment value.

Following [Y. Kuramoto. Chemical oscillations, waves and turbulence, Springer (1984)] we define a complex order parameter that allows us to measure the level of synchronisation across many triads at different spatial scales. The intermittent events of collective alignment mentioned above resemble 'phase transitions' from disorder to order, with a time scale that is faster than the typical frequencies in the system. We hypothesise that these transitions are mainly due to the triad phase dynamics; to verify this hypothesis we investigate models where the Fourier modes' energies (the moduli squared of the amplitudes) are kept constant or prescribed in time, letting the triad phases evolve according to the governing PDE, and studying how alignments occur in these simplified models.

We further investigate how the synchronisation and alignments are disrupted via Fractal Fourier decimation or alternatively through the fine-tuning of dispersion in the Korteweg-de Vries/Burgers equation. The effect of these additions on the energy/enstrophy flux is discussed in detail. Finally, the careful analysis of these systems naturally leads us to a discussion as to how the distribution and dynamics of these Fourier triad phases may offer insight into energy/enstrophy transport in the case of isotropic Navier-Stokes turbulence.

Zeros of polynomials and solvable nonlinear evolution equations

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There exist convenient *explicit* formulas expressing the time-derivative (of any order k) of each of the N *zeros* of a (monic) time-dependent polynomial of degree N in terms of: (i) the derivatives of the same order k of the N *coefficients* of that polynomial; and (ii) the N *zeros* (and their time-derivatives of order less than k) of that polynomial. This allows the identification of many *new* N-body problems—*solvable/integrable* by *algebraic* operations—characterized by Newtonian ("accelerations equal forces") equations describing N, nonlinearly interacting, point-particles moving in the *complex* plane, or equivalently in the *real* Cartesian plane. The same approach can also be used to identify *new solvable* systems of *nonlinear* PDEs; as well as a new *differential algorithm* to compute *all* the *zeros* of *generic* polynomials of *arbitrary* degree N. This approach moreover yields *infinite* hierarchies of all these *solvable nonlinear* evolution equations, via the introduction of the notion—of mathematical interest in its own right—of *generations* of monic polynomials, all of the same *arbitrary* degree N, with the N coefficients of the polynomials of the *next generation* coinciding with every one of the $N!$ permutations of the N *zeros* of each polynomial of the *current generation*. In this talk I plan to outline these recent developments, which have been reported in several papers published in the last 1-2 years—some authored by myself alone and some co-authored with **Oksana Bihun** and with **Mario Bruschi**—and which shall be reviewed in a book I am now writing.

Observation of Hydrodynamic Solitons and Breathers

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The nonlinear Schrödinger equation (NLSE) is one of the key equations in physics. It describes the evolution in time and space of wave packets and it applies to several nonlinear dispersive media, such as Bose-Einstein condensates, plasma, optics and hydrodynamics. An important feature of the NLSE is its integrability. Exact solutions and their experimental observations, ranging from solitons to breathers in various physical media, confirmed the validity of the NLSE in accurately describing the wave motion. The accuracy is surprisingly high even for the cases of severe wave focusing in a wide range of nonlinear dispersive media. In this Chapter, we will briefly discuss the physical relevance of exact NLSE solutions as well as review past and recent progress of experimental studies of dark and bright NLSE solutions in hydrodynamics. Validity and limitations of such weakly nonlinear models will be discussed in detail. Related promising engineering applications will be also emphasized.

Real world ocean rogue waves explained without the modulational instability

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Since the 1990s, the modulational instability has commonly been used to explain the occurrence of rogue waves that appear from nowhere in the open ocean. However, the importance of this instability in the context of ocean waves is not well established. This mechanism has been successfully studied in laboratory experiments and in mathematical studies, but there is no consensus on what actually takes place in the ocean. In this talk, we question the oceanic relevance of this paradigm. In particular, we analyze several sets of field data in various European locations with various tools, and find that the main generation mechanism for rogue waves is the constructive interference of elementary waves enhanced by second-order bound nonlinearities and not the modulational instability. This implies that rogue waves are likely to be rare occurrences of weakly nonlinear random seas.

Fock quantization of singular trajectories, Carrier-Greenspan transformation, and the run-up problem in the framework of shallow water models

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First, we consider the Cauchy problem with localized initial data for the two-dimensional wave equation with variable velocity in a domain D, which describes long linear waves in shallow water. We assume that the velocity C(x,y) =0 and grad C(x,y) does not vanish on the boundary (shore) of D. We construct asymptotic solutions of this problem using a modified semiclassical approximation and the Maslov canonical operator. It is determined by the fronts, which are formed by the trajectories of the Hamiltonian system with Hamiltonian H(p,x)=C(x,y)|p|. When the trajectories reach the boundary of the domain D, the momentum p of the trajectories goes to infinity; in some sense one can view the boundary of D as a caustic of a special kind. We define a canonical transformation that leads to the compactification of the trajectories and allows one to continue the trajectories through this singularity. Near this boundary-caustic, the standard semiclassical approximation does not work, and we use the Fock quantization formulas for the canonical transformation, which results in the use of the Hankel transform in a neighborhood of this type, caustic, and gives an asymptotic solution to the original linear problem. It turns out that the solution on the boundary of D has the standard form for the canonical operator on some special curve in the two-dimensional phase space. Next, we consider the nonlinear shallow water equations. Using Pelinovskii-Masova ideas and the Carrier-Greenspan transformation, we derive formulas for the the run-up on the shore of long waves (e.g. tsunami waves) generated by localized sources. As a result, we obtain simple analytical formulas relating the magnitude of the uprush of long waves with the parameters of the generating source. This work was supported by the Russian Science Foundation (project no. 16-11-10282).

Spin-polarized plasmons in magnetic nanoparticles

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Understanding the effect of spin polarization on plasmon oscillations of the free electrons is, essentially, unexplored and crucial in many envisioned applications at the cross road of magnetism and plasmonics. It is a common belief that the quality of the plasmon resonance of magnetic nanoparticles such as Co is quite low, which follows, in particular, from the experimental data for permittivity of bulk cobalt by Johnson and Christy [1]. Our results show that Co nanoparticles with a single-domain crystal structure support an excellent plasmon resonance at about 280 nm with the quality comparable to gold nanoparticles. This type of plasmons is unusual in a way that two plasmons coexist in a particle at the same frequency and polarizations of excitation, but for electrons of opposite spin. Inter-nanoparticle interactions completely demolish plasmon quality resonance, which is the probable reason why it was not observed previously and why the results for bulk films [1] cannot be used for single domain nanoparticles evaluations. It is known that the exchange interaction of electrons splits the energy bands between spin-up (majority) electrons and spin-down (minority) electrons. We suggest that minority electrons with a partially populated d-band increase the relaxation rate of the conduction electrons and consequently reduce the plasmon resonance quality, while majority electrons with a completely filled d-band does not affect the plasmon resonance of the conduction spin-up electrons within magnetic nanoparticles. To address the mechanism of new type of plasmons specific for magnetic nanoparticles our work involves an advanced fabrication, structural microscopy, SQUID magnetometry, and spectroscopy of Co nanoparticles. We show a correlation of magnetic and optical properties of magnetic nanoparticles, which have not received adequate attention so far. In this talk we will discuss also our experiments on the effect of aggregation on collective electron oscillations in spin-polarized single-domain nanoparticles. The main goal of the work is to explain the physical origins of the high quality plasmon resonance observed in the experiments. Note that the plasmon resonance of Co is in the ultraviolet spectral range, which is the range for bio-molecule resonances and therefore attractive for bio-medical applications.

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Nonlinear Nonlocal Equation for Envelope of Water Waves

Dyachenko AI

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TUNING FORKS AS A GENERATOR OF QUANTUM TURBULENCE IN SUPERFLUID HELIUM

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Superfluid helium is the simplest medium for study bulk turbulent processes and energy flux through the frequency range. Very low viscosity of superfluid helium and formatting turbulent system consisting from quantized vortexes allowed studying processes of vortexes formation and its decay. A vibration of bodies is the most common way to produce a turbulent state in superfluid helium. The most convenient devices for this purpose are tuning forks – rigid, stable, and cheap elements of modern electronics. In the report we'd like to review the last experimental results for using the tuning forks as a generator of the quantum turbulence and as a vortex detector, peculiarities of using a new type of tuning forks, which have bending and twisting modes of vibration. The last experiments indicated the drastical reduction of the critical velocity at which the transition into a turbulent state began for the twisting mode of the fork vibration.

Triadic instability in internal wave attractors: scale effect

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Lavrentyev Institute of Hydrodynamics

One of the pivotal questions in the dynamics of the oceans is related to the cascade of mechanical energy in the abyss and its contribution to mixing. In the present talk we discuss a unique self-consistent experimental and numerical setup that models a cascade of triadic interactions transferring energy from large-scale monochromatic input to multiscale internal wave motion. This setup represents a trapezoidal fluid domain filled with a linearly stratified fluid. The energy is injected into the system by oscillation of a vertical wall in form of a standing half-wave of a cosine function. The velocity field in the domain is measured with the standard PIV technique and analysed by using Fourier and Hilbert transforms, bispectra, and vorticity PDFs. The numerical simulation has been performed with the help of the spectral element method.

In the appropriate parameter range, the energy injected into the domain is focused at a closed loop, the internal wave attractor (Maas et al., Nature 1997). The linear viscous dynamics of wave attractors is governed by a balance between geometric focusing and viscous broadening (Ogilvie, JFM 2005; Grisouard et al., JFM 2008).

We have shown that at high level of the input forcing the attractor becomes unstable due to triadic resonance (Scolan et al., PRL 2013). We also provided explicit evidence of a wave turbulence framework for internal waves (Brouzet et al., EPL 2016), and demonstrated the robustness of the spectral element method in numerical simulations (Brouzet et al., JFM 2016) and complexity of observed instability scenarios (Brouzet et al., JFM 2017).

In the present talk we focus our attention on the scale effect in internal wave attractors. The experiments have been conducted in two wave tanks, with depth of 30 and 90 cm. We show explicitly how the linear viscous scaling for the width of the attractor branches in a stable regime is replaced by a non-linear scaling in the unstable regime. The width of the attractor branch (which serves as a primary wave of a resonant triad) is measured by decomposing the complex wave field using the Hilbert transform. Numerical simulations performed for geometrically similar setups of different scale suggest a universal behavior: under appropriate scaling the data for the width of the attractor branch as function of the forcing amplitude collapse onto a universal curve. The results have a strong consequence in geophysical problems since the linear viscous scaling predicts unrealistically thin attractor branches. There are reasons to believe that non-linear scaling is relevant to the natural-scale phenomena.

Resonance tunneling of electromagnetic waves through inhomogeneous plasma with small scales structures

Erokhin NS, **Zolnikova NN**, **Mikhailovskaya LA**

Institute of Space Research

It is described the exactly solvable analytical model of the resonance tunnelling of electromagnetic waves in the inhomogeneous plasma with small scale structures of large amplitude by the solution of Helmholtz equation. It is shown that plasma layer of large thickness may be transilluminated by the electromagnetic wave (nonreflection wave propagation). The wave amplitude may has the big splashes in the inhomogeneous plasma layer. The nonlocal connexion of wave vector with the effective dielectric permetivity is described. The results obtained are important ones for a number of applications both in laboratory plasma and in space ones.

Wonders of viscous electronics

Falkovich G

Weizmann Institute of Science

Quantum-critical strongly correlated systems feature universal collision-dominated collective transport. Viscous electronics is an emerging field dealing with systems in which strongly interacting electrons flow like a fluid. We identified vorticity as a macroscopic signature of electron viscosity and linked it with a striking macroscopic DC transport behavior: viscous friction can drive electric current against an applied field, resulting in a negative resistance, recently measured experimentally in graphene. I shall also describe current vortices, expulsion of electric field, conductance exceeding the fundamental quantum-ballistic limit and other wonders of viscous electronics. Strongly interacting electron-hole plasma in high-mobility graphene affords a unique link between quantum-critical electron transport and the wealth of fluid mechanics phenomena. Nature Physics 2016, 12 : 672-676; PRL 2017 and Arxiv:1607.00986; PNAS 2017 and 1607.07269 1612.09239

Experimental observation of nonlinear generation of vorticity by gravity surface waves.

Aliev SA, **Levchenko AA**, **Khramov DA**, **Filatov SV**

ISSP RAS

We experimentally study generation of the vortex motion on the surface of water by gravitational waves(frequencies are 3 and 4 Hz with a wavelength of 17 and 9.7 cm). It was shown that the obtained results can be described in the framework of the vorticity formation model by nonlinear waves. The first time it was shown that the vorticity amplitude on the water surface depends on the phase difference between waves propagating at an angle of 90° to each other with a period equal to 360°. We observe a quadratic dependence of the vorticity amplitude on the surface on the angular amplitude of the waves. The energy transfer of the vortex motion from the pumping region to large scales is disrupted.

Surface Waves on the Interface of Hybrid Metamaterials

Gabitov IR, **Maimistov A**

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We studied propagation of the electromagnetic waves in a hybrid planar structures containing uniaxial hyperbolic material. For structures, satisfying to the set of special requirements, our analysis showed existence of surface waves. This result is different from several well-known cases when hybrid stricture contains conventional dielectric instead of hyperbolic material. Using derived dispersion relations, we also conducted comparative analysis of the discovered surface waves with the characteristics of surface plasmons. We evaluated relevance of obtained results to the experimental situation for hybrid structures based on currently available materials.

Statistic of strongly interacting soliton gas and formation of rogue waves

Gelash AA, **Agafontsev DS**

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We study numerically the statistical properties of high-density soliton gas, in the framework of the focusing nonlinear Schrödinger equation (NLSE). Multi-soliton solutions containing of up to 128 solitons are generated with the new recursive numerical scheme for the Zakharov-Mikhailov variant of the dressing method. The statistical properties of these solutions are then studied with repsect to soliton gas density and velocity distribution. Special attention is paid to examination of rogue waves that appear as a result of multi-soliton collisions.

Numerically solving the kinetic equation for deep water gravity waves: the new approach

Geogjaev VV

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The new numeric algorithm for solving of the kinetic equation for deep water gravity waves was constructed. The algorithm is based on the detail study and classification of 4-wave nonlinear interaction. Test calculations of the developing of wind waves were done with several types of pumping. Comparison with existing algorithms was performed. Different grid densities were tested. New quadruplet grid was developed, which allows the increase in calculation speed up to several times while maintaining adequate precision.

Direct problem for the defocusing NLS equation

Grinevich PG, Santini PM

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We study the direct spectral transform for the self-focusing NLS equation with periodic boundary conditions assuming that the potential is a small perturbation of the constant solution and the number of unstable modes is much smaller than inverse value of the perturbation. This admits to predict the behaviour of solutions in terms of the Cauchy data.

Nonlinear localized flat-band modes in pseudo-spinor diamond chain

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Wave dynamics can be tailored by symmetries and topologies imprinted by underlying periodic potentials. In particular, using potential with specific local symmetries, flat-band (FB) lattices with completely dispersionless bands in the system's spectrum can be realized. These lattices are characterized by existence of compact localized states (CLSs)-FB eigenstates, which have nonzero amplitude only on finite number of sites [1]. FB lattices have been realized in photonic waveguide arrays [2], exciton-polariton condensates [3], and atomic Bose-Einstein condensates (BECs) [4]. Also, recently, studies of spin-orbit coupling (SOC) in BEC, as well as fermionic gases, have become a vast research area [5].

Here, we study the existence and stability of nonlinear localized modes in pseudo-spinor (two-component) diamond chain with components mixed due to SOC. This system can be implemented using a binary BEC loaded in the corresponding optical lattice with geometry of diamond chain. The characteristic symmetries of diamond chain provide the framework of the FB lattice with disperionless (flat) bands in the system's spectrum. The different states of the same atomic species allow that SOC between them can be induced by properly applied external magnetic and optical fields. Considering discrete model of such system, we found that in the linear limit, SOC opens mini-gaps between flat and dispersive bands. It is shown that the CLSs in the presence of SOC occupy two unit cells instead one. In the presence of on-site cubic nonlinearity, the CLSs remain with frequencies that are smoothly tuned into mini-gap. In addition, discrete solitons with exponentially decaying tails are found, too [6].

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Dissipation of water waves due to wave breaking

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We applied canonical transformation to water wave equation not only to remove cubic nonlinear terms but to simplify drastically fourth order terms in Hamiltonian. After the transformation the well-known but cumbersome Zakharov equation is drastically simplified and can be written in terms of envelope of wave surface in compact way. A numerical simulations of nonlinear stage of modulational instability of Stockes waves in the framework of this equation were performed. The numerical results of dissipation of water waves due to wave breaking were obtained.

Polarization waves in a two-component Bose-Einstein condensate

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If intra-species nonlinear interaction constants in a two-component Bose-Einstein condensate have close values, then dynamics of the condensate reduces to the so-called polarization modes with preservation of the total density of two components. In dispersionless limit this dynamics coincides with Ovsyannikov's "model III" for dynamics of a two-layer fluid. We derive nonlinear wave equations for these polarization waves in BEC with account of dispersion and show that the resulting equations coincide with the Landau-Lifshitz equations for magnetics with easy-plane anisotropy. Periodic solutions and corresponding Whitham modulation equations are obtained. They are applied to the problem of evolution of initial discontinuities in distributions of densities and relative velocities of the condensate components. Relations of the theory to the current experiments are discussed.

Dynamical field patterns of superradiant lasing and empirical modes with a variable spatial-temporal structure

Kocharovskaya ER, Gavrilov AS, Loskutov EM, Mukhin DM, Feigin AM, Kocharovsky VV

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An approach of the empirical modes with a variable spatial-temporal structure is proposed and developed for the analysis of non-stationary nonlinear dynamics of the multimode superradiant lasers with a low-Q cavity and a strong inhomogeneous broadening of lasing transition in an active medium. It is shown that the approach makes it possible to analyze a number of complicated dynamical phenomena in an ensemble of the strongly interacting centers which constitute the active medium and are exposed to CW pumping.

Usually, a spatial-temporal evolution of a laser field is described by a superposition of the cavity modes with the time-dependent amplitudes and the spatial profiles, which are fixed and known beforehand. A laser dynamics becomes essentially different in the case of lasers with low-Q (bad) cavities where a photon lifetime is less than a polarization relaxation time (a lifetime of the optical dipole oscillations) of the individual active centers excited by pumping. A theoretical analysis of the spatial-temporal dynamics of the field and its spectral and correlation features in such lasers, known as the superradiant lasers, cannot be based on the above-mentioned standard decomposition on neither 'cold' no 'hot' modes which are defined, respectively, by a cavity without or with taking into account the active medium. The point is that the polarization of active centers in the superradiant lasers does not follow adiabatically a value of the local electric field and plays a part of an independent dynamical variable. The field itself flows out of a cavity rapidly and changes in time and space strongly. These effects result in a complicated spatial-temporal dynamics of the population inversion and lead to an efficient non-adiabatic coupling of cold and/or hot modes what makes those modes useless for the interpretation of collective emission phenomena and quasi-chaotic field patters, even in the case of a steady time-dependent lasing under CW pumping.

A progress in modern technologies, especially in the field of semiconductor heterostructures, leaves no doubts about near fabrication of the dense (in space and spectrum) ensembles of active centers needed for such dynamically rich lasing in the low-Q cavities under CW pumping. In order to understand the time-dependent space-inhomogeneous configurations of a lasing field in various steady-superradiant regimes and to interpret them properly, we suggest to use a well-known approach of empirical orthogonal functions (EOFs) which is based on a method of the main components and have been widely employed in the analysis of observed space-distributed time series, including the correlation analysis of data. For the laser problem under consideration, this approach should be generalized and then may be called as an approach of Space-Time Empirical Modes (STEMs). The definition and applications of the newly suggested modes are illustrated below on the basis of a numerical solution to the integral-differential Maxwell-Bloch equations for a 1D model of a cavity and an active medium with strong inhomogeneous broadening of a spectral line. Namely, we consider a low-Q hybrid Fabry-Perot cavity with a distribute feedback (DFB) of the counter-propagating waves, where a generation of the superradiant pulses may be accompanied by a partial self-locking of the longitudinal modes without use of any additional technique of mode locking. The presented examples of the space-time empirical modes (STEMs) prove that these modes are useful for the analysis of complicated features of a strongly non-stationary field which are typical for the superradiant lasing in the low-Q cavity. Thus, the suggested STEM approach is an efficient tool in the dynamical theory and interpretation of various regimes of the superradiant lasers as well as in the development of their applications in the optical information processing, the wideband dynamical spectroscopy, and the diagnostics of the many-particle processes in condensed active media.

Nonlinear waves on the boundary of finite depth dielectric liquid in a strong tangential electric field

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Nonlinear dynamics of the free surface of finite depth non-conducting fluid with high dielectric constant under the action of strong tangential electric field is investigated in the present work. The equations of boundary motion admit an exact solution in the form of nonlinear waves of arbitrary shape propagating without distortion along the surface of liquid in the direction of (or against the direction of) the external field. The velocity of periodic waves is greater than velocity of linear one and depends on problem parameters: fluid depth, wave amplitude and wavelength. It is obtained an explicit solution of the problem for the weakly nonlinear waves; in accordance with it, the rise to velocity is proportional to square of wave amplitude. Numerical analysis of exact expression for strongly nonlinear waves has shown that speed of waves propagation increases unlimitedly in the situation where amplitude is close to the fluid depth, i.e. when the surface touches the bottom. Despite the fact that nonlinear waves can separately propagate without distortion, the interaction of counter-propagating waves can result in deformation of the boundary. Numerical modeling methods based on using of dynamic conformal transforms of the region occupied by the fluid into parametric strip of auxiliary variables were chosen for the study of interaction of the oppositely traveling waves. The simulations show that nonlinear waves are actually deformed in result of their collisions; herewith the effect of nonlinearity is inversely proportional to the liquid depth, i.e. deformation increases with depth decreasing.

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Evolution of magnetic field fluctuations in two-dimensional chaotic flow

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Discrete integrable systems and lifts to Yang-Baxter maps: Grassmann extension scheme

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In this talk, we present a simple scheme for constructing noncommutative extensions–in a Grassmann setting–of discrete integrable systems together with their associated Yang-Baxter maps. The scheme is a combination of the schemes introduced in [2, 3].
We apply this scheme to the case of the discrete potential KdV equation. In particular, we construct its associated Grassmann-extended Yang-Baxter lift, which can be squeezed down to a novel, integrable, noncommutative discrete potential KdV system. We discuss the integrability of some commutative analogues of the associated Yang-Baxter maps.

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Stimulated scattering on surface waves and pulsar radiation

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Neutron stars were predicted by Landau, related to supernovae by Baade and Zwicky, and discovered a quarter century later fifty years ago in the form of pulsars by Hewish et al. Produced by collapse in supernova explosions, these stars have very high magnetic fields of 1012 G, rotate rapidly (with periods ranging from seconds to milliseconds), and are blanketed in a magnetosphere of electron-positron pairs which mostly co-rotates with the star but contains a beam of open lines of force over the magnetic poles, along which particles are accelerated and emit electromagnetic radiation. Particles are accelerated in the gap above the region of the open lines of force, which contains a strong accelerating electric field generated by the magnetic field and the rotation. Stimulated scattering (SS) is an effect as common as a nonlinear frequency shift. In contrast to the frequency shift, at SS the coefficient at a squared module of the amplitude of strong incident wave contains an imaginary part, which is responsible for the arising instability. Each type of stimulated scattering corresponds to its spontaneous analogue. Including as to a surface waves scattering, there has to be the stimulated scattering on them (SS on SW).

All kinds of SS had observed in special experiments using powerful sources of radiation (lasers). SS on SW unlike the rest of SS has not been observed in its pure form, although it indirectly manifested itself in the appearance of the surface structures. In nature, any type of SS of the natural origin is still nowhere to be registered. We point out that the SS probably responsible for some forms of radiation in pulsars. The powerful radiation of returned relativistic positrons, extracted from the electron-positron plasma magnetosphere by accelerating electric field and flying toward the star, serves in this case as a source. A specular (mirror) reflection of this radiation in a tilted magnetic field leads to shifts the inter pulses in the Crab Nebula pulsar, detected 20 years ago by Moffet & Hankins [1.2] in the centimeter range, that did not receive any explanation other than that, proposed by S.V.Trofymenko and myself [3] a year ago. Two additional pulse components arise on the same frequencies, and, as well as the shift of the inter pulses, they could be associated with the non-linear reflection in the direction of the diffraction peak on a periodic surface structure excited by the SS [4]. The same mechanism could explain the frequency drift component detected by Hankins, Jones and Eilek [2], which is analyzed in this report. Thus, this is the first case, indicating on the realization of SS in nature. The discussed instability it is a stimulated scattering by the surface waves predicted more than forty years ago (see Refs in [4]) and still nowhere and by no one had been observed. With its help one can hope to obtain information about the surface of the neutron star.

The frequency drift of the components is very important in choosing the right theoretical model. Particularly, the coincidence of its directions for both components is an argument in favor of the birefringence of the scattered wave in anisotropic magnetized pulsar plasma. Returned motion of positrons, arising at penetration of accelerating electric field of the gap in the pair plasma, was considered in literature in a connection with heating of the surface by the reverse current. The difference of magnetic field from dipole one, leading in particular to its slope, also was discussed, including with regard to its toroidal component. However, the low-frequency radiation of backflow positrons and reflected radiation from the surface of the pulsar were not considered anywhere until our works.

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Beam plasma interaction in strongly randomly inhomogeneous plasma

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Transition to Kolmogorov turbulence

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Coherent structures in 2d turbulence

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Dynamics of singularities in 2D hydrodynamics with free surface throut time dependent conformal maps

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2D hydrodynamics of ideal fluid with free surface is addressed. A time-dependent conformal transformation is used which maps a free fluid surface into the real line with fluid domain mapped into the lower complex half-plane. The fluid dynamics is fully characterized by the complex singularities in the upper complex half-plane of the conformal map and the complex velocity. The initially flat surface with the pole in the complex velocity turns over arbitrary small time into the branch cut connecting two square root branch points. Without gravity one of these branch points approaches the fluid surface with the approximate exponential law corresponding to the formation of the fluid jet. The addition of gravity results in wavebreaking in the form of plunging of the jet into the water surface. The use of the additional conformal transformation to resolve the dynamics near branch points allows to analyze wavebreaking in details. The formation of multiple Crapper capillary solutions is observed during overturning of the wave contributing to the turbulence of surface wave. Another possible way for the wavebreaking is the slow increase of Stokes wave amplitude through nonlinear interactions until the limiting Stokes wave forms with subsequent wavebreaking. For non-limiting Stokes wave the only singularity in the physical sheet of Riemann surface is the square-root branch point located. The corresponding branch cut defines the second sheet of the Riemann surface if one crosses the branch cut.
The infinite number of pairs of square root singularities is found corresponding to infinite number of non-physical sheets of Riemann surface. Each pair belongs to its own non-physical sheet of Riemann surface. Increase of the steepness of the Stokes wave means that all these singularities simultaneously approach the real line from different sheets of Riemann surface and merge together forming 2/3 power law singularity of the limiting Stokes wave. We found that that non-limiting Stokes wave at the leading order consists of the infinite product of nested square root singularities which form the infinite number of sheets of Riemann surface [1,2].

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Instability of an oscillating scalar field in expanding Universe

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We study instability of the scalar field oscillating around a minimum of inflaton potential in the Friedmann-Robertson-Walker universe. It is shown that the evolution of the k-modes of the scalar field perturbations is governed by the Hill equation involving the field energy density as a parameter that changes slowly as the Universe expands. The general perturbative approach to the Hill equation with a slowly varying parameter is developed. As an application we consider slow passage through the resonance in the Lame equation describing the scalar field modes in the case of $\varphi^2 - \varphi^4$ potential. The asymptotic solutions obtained by the perturbative approach are compared with the results of the direct numerical integration. The nonlinear stage of instability and formation of the oscillating field lumps are briefly discussed.

Genuine low latency pipeline parallel algorithm for numerical modelling of 1D evolution equations.

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We present a novel algorithm for numerical integration of 1D evolutional Partial Differential Equations (PDE). This work is primarily motivated by applications in nonlinear optical fiber communications where generalized Non-Linear Schrödinger Equation (NLSE) is used for modelling. A conventional Split-Step Fourier Method (SSFM) is a proven and most efficient numerical technique widely adopted in numerical modelling. Recently, SSFM has been used as an impressive facilitator of digital reconstruction of initial signal by virtue of a Digital Back Propagation (DBP) from a receiver to a er end of a communication line as the most natural and comprehensive compensation of adverse dispersion and nonlinear effects. However, inherent complexity of Discrete Fourier Transform (DFT) for extremely large volumes of sampled data where the number of floating point operations scales as $N \log(N)$ and, most importantly, the global coupling of meshpoints in DFT algorithm which dictates a relatively large frame data buffers hindered prevented the SSFM-based DBP from becoming a practical real time reconstruction technique with low latency.

Our approach is essentially based on an explicit finite difference discretization of the PDE in question, where an algorithm is distilled to an explicit calculation of the unknown field(s) on the next evolution level (tier). Traditionally, evolution tiers are evaluated sequentially. Explicit methods are perfectly suitable for parallel implementation since a meshpoint in the next tier is based on a finite number of neighbors of its predecessor at previous evolution tier(s). Naturally, parallel implementation is trivial when the complete dataset is treated by a parallel unit, e.g. GPU, and a complete evolution tier can be treated simultaneously. Alternatively, a domain decomposition is required and it is often a bottleneck since usually data exchange between specialist units and main computer memory is limited.

Our innovation is in reorganizing tier-to-tier explicit calculations in such a way that the way up is made as steep as possible and the evolution advance is performed not in a complete tier-to-tier fashion but in a slanted ant hill fashion when the top meshpoints at higher tiers are built on the narrowest possible base on the ancestor tiers. This approach reduces the need of data exchange between the storage and processing units to barely a few numbers per calculation cycle. Hence, the proposed algorithm requires no intrinsic latency in dealing with frames or data domains.

Quantum analog of the Kelvin-Helmholtz instability on the surface of superfluid He-II

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In this paper, we present the results of our experimental study of dynamic instability on the surface of superfluid He-II, induced by the relative motion (counterflow) of the normal and superfluid components, which arises under the action of a stationary heat flux in the volume of liquid. This instability is similar to the well-known Kelvin-Helmholtz instability, which arises at the boundary of two ordinary immiscible liquids or dense gases moving with different velocities. The theory of the KH instability on the surface of He-II was first considered in detail by S.E.Korshunov. An analogous approach was used by Andersson et al., in studies of the instability of a superfluid neutron liquid on the surface of neutron stars. Our experimental data are qualitatively consistent with the theoretical predictions taking into account the finite viscosity of He-II. The work was supported by the Russian Science Foundation, Grant No.14-22-00259.

Wave fronts and cascades of soliton interactions in the periodic two dimensional Volterra system

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We develop the dressing method for the solution of the two-dimensional periodic Volterra system with a period N. We derive soliton solutions of arbitrary rank k and give a full classification of rank 1 solutions. We have found a new class of exact solutions corresponding to wave fronts which represent smooth interfaces between two nonlinear periodic waves or a periodic wave and a trivial (zero) solution. The wave fronts are non-stationary and they propagate with a constant average velocity. The system also has soliton solutions similar to breathers, which resembles soliton webs in the KP theory. We associate the classification of soliton solutions with the Schubert decomposition of the Grassmannians $Gr_{\mathbb{R}}(k,N)$ and $Gr_{\mathbb{C}}(k,N)$. We proved the regularity of all solutions obtained.

Propagation Velocity of Flame Balls Array in Low Lewis Number Gas Premixture

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The most distinctive feature of combustion waves is its ability to assume the form of a self-sustained reaction wave propagating at a well-defined speed. A flame front or surface with maximal heat liberation located within zone of chemical reaction of combustion wave is considered generally as continuous surface although it can possesses cellular structure in some cases. Formation of non-planar cellular structure of flame front is result of development of thermo-diffusive instability. The instability is most prominent in weak near-limit low-Lewis-number premixtures sensitive to radiative heat losses. In such systems, the cellular flames often break up into separate cap-like fragments which sometimes close upon themselves to form seemingly spherical structures called flame-balls.

The combustion wave in this case represents an array of separate flame-ball like objects in the state of permanent chaotic motion. Such combustion wave may be termed as "sporadic combustion wave" to distinguish its special characteristics differing from conventional continuous flame features. One of the unusual features of sporadic combustion wave is incomplete burning of fuel which remains in the combustion products. This incompleteness is caused by fuel leakage through the gaps among the ball-like flames. The uncertainty in evaluation of total heat release related with incompleteness of combustion as well as complex spatial-temporary structure of reaction zone create difficulties in estimation of sporadic combustion wave propagation velocity. The present study is an attempt to estimate propagation velocity and to distinguish general parameters determining dynamics of sporadic combustion wave and transitions from planar to sporadic flame.

Nonlocal effects in transport: The role of turbulence energy

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Classical approaches to turbulent transport start from the observation that the free energy available in gradients of the plasma pressure or the magnetic field can be relaxed into turbulent field fluctuations. These fluctuations in turn facilitate the reduction of the gradients towards criticality by transporting the driving quantity down the gradient. The transport arising at one point in space is then characterised by the local gradients and values of the plasma parameters. The transport can consequently be expressed in terms of a diffusion coefficient and a turbulent pinch or advection velocity. This picture has been in general very successful, however, we know situations which pose problems to this treatment of turbulence, namely as a cause to local transport.
In situations where the turbulence is strong, significant amounts of energy can be stored in the turbulence field. In addition to facilitating transport, these situations give rise to important feedback mechanisms concerning the turbulence itself [1]. These effects start with the condensation of turbulent energy into zonal, eg. perpendicular to the gradients, flows [2]. Also, as the turbulence energy itself is transported, this introduces an additional transport process. This often "hidden" transport channel can lead to fast signal propagation through the observed medium, which is in classical transport theory heuristically expressed as a nonlocal effect. Finally, in situations with sub- and supercritical gradients the turbulent energy can be transported into the sub-critical region and there perform work by being exhausted on building up the gradient towards the critical one [3].
We will show examples of these situations and argue why the turbulent energy field should be treated as a transported quantity itself. Specifically we discuss up-gradient transport and nonlocality in the context of plasma turbulence.

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Wave Turbulence in Cosmology and Particle Physics

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WARWICK

In field theory, particles are waves or excitations that propagate on the fundamental state. In experiments or cosmological models, one typically wants to compute the out-of-equilibrium evolution of a given initial distribution of such waves. Wave turbulence deals with out-of-equilibrium ensembles of weakly nonlinear waves, and is therefore well suited to address this problem. As an example, we consider the complex Klein-Gordon equation with a Mexican-hat potential, also known as the sigma-model introduced by Gell-Mann as a model for interaction of massive sigma-mesons with light (virtually massless) pions.
This simple equation displays two kinds of excitations around the fundamental state: massive particles and massless Goldstone bosons. The former are waves with a nonzero frequency for vanishing wave number, whereas the latter obey an acoustic dispersion relation. Using wave-turbulence theory, we derive wave kinetic equations that govern the coupled evolution of the spectra of massive and massless waves. We first consider the thermodynamic solutions to these equations and study the wave condensation transition, which is the classical equivalent of Bose-Einstein condensation. We then focus on nonlocal interactions in wave-number space: we study the decay of an ensemble of massive particles into massless ones. Under rather general conditions, these massless particles accumulate at low wave number.
We study the dynamics of waves coexisting with such a strong condensate, and we compute rigorously a nonlocal Kolmogorov-Zakharov solution, where particles are transferred nonlocally to the condensate, while energy cascades towards large wave numbers through local interactions. This nonlocal cascading state constitutes the intermediate asymptotics between the initial distribution of waves and the thermodynamic state reached in the long-time limit.

Elastic sheets, phase surfaces and pattern universes

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Optical emission of graphene due to Landau-Zener transitions in strong THz field

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Nonlinear waves and modulational instability in high-order Korteweg-de Vries equations

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Here we consider the generalized Korteweg-de Vries (gKdV) equation with nonlinear term $su^n\partial u/\partial x$ where $n > 0$ and $s = \pm 1$. Famous kinds of this equation are the Korteweg-de Vries (KdV) equation and modified Korteweg-de Vries (mKdV) equation are integrable and fully investigated. High-order versions of gKdV with $n > 2$ are appeared in hydrodynamics of stratified fluid (Kurkina et al, 2011). Some versions of gKdV contain non-integer values of n, for instance, $n = 1/3$ - the Shamel equation appeared for ion-acoustic waves due to resonant electrons (Schamel, 1973). Also log-KdV equation used for solitary waves in FPU lattices can be mentioned (James and Pelinovsky, 2014). In all papers cited above the main attention is paid to soliton dynamics, its stability and interactions. Dynamics of modulated wave packets in KdV-like systems is less studied. If the wave amplitude is weak (to compare with dispersion) a standard way to investigate the stability of weakly modulated wave train is the deriving the Nonlinear Schrodinger equation (NLS) and determination its type. For the canonic KdV equation the NLS equation has a defocused type and therefore the wave packet is stable (Zakharov and Kuznetsov, 1986).In the case of modified Korteweg-de Vries with $s = +1$ a wave train is modulationally unstable and this leads to generation of rogue waves (Grimshaw et al, 2010). To our knowledge we do not know publications where the NLS equation has been derived from gKdV equation. This task problem is analyzed in our talk.

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Visualization of the Surface Patterns in superfluid He-II

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The low temperature insert into the commercial metal cryostat of inner diameter 200 mm and of the helium bath length 1260 mm for investigation of nonlinear phenomena on the free surface of superfluid He-II has been designed [1]. Frequency of the vertical vibrations of an experimental cell filled with liquid helium can be changed in the range of 5 - 100 Hz while keeping it at a constant temperature down to 1.4 K. Amplitude of the cell vibrations can be varied in a broad range from 0.01 to 1 mm. The images of the liquid surface were recorded by a video camera with pixel array 1920 by 1080 through a window positioned on the upper flange of the insert. In a series of preliminary measurements we have used glass cylindrical cells with an inner diameter up to 100 mm and 18 mm depth, and also plexiglass square cells with the back side 50 mm and up to 20 mm depth.
Later on to visualize the nonlinear phenomena on the He-II surface (Faraday wave instability at high pump amplitudes, attenuation of the fluid rotation in the experimental cell) we used light particles (tracers), particularly 60 μm hollow glass microspheres or 1 mm beads of plastic foam with a density close to the He-II density, that floated beneath the surface. The work was supported by the Russian Science Foundation, Grant No. 14-22-00259.

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Finite size Lyapunov exponent for stochastic flows modeling 2D turbulence

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The finite size Lyapunov exponent (FSLE) is an efficient and widely used measure of mixing in turbulence. We obtained and analyzed asymptotics of FSLE for large and small diffusivity for a class of stochastic velocity fields with a general deterministic component (mean current) and a turbulent component modeled by a white noise. An anisotropic mean is addressed and a particular focus is on the FSLE behavior in vicinity of stagnation points of the mean (such as a saddle or node) in the case of small diffusivity.

Symmetries of the Hirota difference equations

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Continuous symmetries of the Hirota difference equation, both ordinary and auxiliary, are derived by means of the dressing procedure. Resulting partial differential-difference and differential equations are described.

Landau damping in Dirac semimetals and novel collective excitations

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Synchronism conditions play the key role in the theory of collective excitations. We use these process constrains to find the Landau damping regions and the spectrum of collective modes in massless Dirac semimetals placed in a strong magnetic field. In this case, the spectrum of one-particle states has the form $E_n(p_z) = \pm\sqrt{v_F^2 p_z^2 + E_0^2 n}$, where $n \in Z$ is the Landau number, v_F is the Fermi velocity, $E_0 = \sqrt{2} v_F \hbar / l_H$, and $l_H = (c\hbar/eH)^{1/2}$ is the magnetic length. As a result, the energy conservation law $E_i + \hbar\omega_{\mathbf{q}} = E_f$ and the Pauli exclusion principle constraints $E_f > E_F$, if $E_i < E_F$, lead to the Landau damping regions for transverse polarized ($\Delta n \equiv n_f - n_i = +1$) collective excitations. These regions are plotted in Fig. 1. The set of windows in Landau damping in long wavelength regions is the location of new longitudinal ($\Delta n = 0$) and transverse ($\Delta n = +1, -1$) quasi-neutral modes.

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On another concept of Hasselmann equation source terms

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The new ZRP wind input and "implicit" wave-breaking dissipation terms are examined for their consistency via numerical simulation of Hasselmann equation. The results are compared to field experimental data, collected at different sites around the world, and theoretical predictions based on self-similarity analysis. Good agreement is obtained for both limited fetch and time domain statements.

Solitons in spiral structure of magnets and multiferroics

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Many solitons are observed in mediums with spatially inhomogeneous distribution of the order parameter. The solitons against the background of the periodic waves or structures are of special interest. For the first time, the solitons on the nonlinear cnoidal wave background were described in [1] by the inverse spectral transform in the framework of KdV-model. We present the modification of the inverse scattering technique to study the solitons in magnets and multiferroics with a spiral (stripe domain) structure in the framework of sine-Gordon model [2]. We have found new solitons, which are inseparable from the spiral structure. At some conditions they represent the nucleus of magnetization reversal of the material; their formation is accompanied by the macroscopic shifts of the structure [3].

We have found, that the motion of solitons lead to an appearing the extended deformation regions, which can be treated as «precursors» and «tails» of the solitons. The ways of observing and exciting the solitons in the spiral structure of magnets and multiferroics are discussed [3]–[6].

This work is supported by the project of UB RUS no. 15-8-2-7.

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Plasma turbulence and transport barriers

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In magnetically confined hot plasma turbulent transport is the dominating channel for radial density, energy, and momentum transport across the confining magnetic field. However, this transport may be self-regulated by spontaneously generated sheared flows – often referred to as zonal flows – capable of reducing the radial turbulent transport. The transport barriers mediated by these flows appear locally at specific radial positions, but most notably near the plasma edge - the so-called Edge Transport Barriers (ETB's), which are instrumental in the rapid transition to an enhanced confinement state (the H-mode), with suppressed turbulent transport. The transition from low (L-mode) to the high (H-mode) confinement states in magnetically confined plasma is an outstanding issue in magnetic fusion research and is still not understood from first principles. Although the H-mode is routinely achieved in a multitude of magnetic confinement devices, since the first observation more than 30 years ago, the transition still lacks full theoretical explanation and predictive modeling. This is a high priority topic since ITER will rely on operation in H-mode to achieve the goal of ignition.
The self-consistent generation of large scale flows - zonal flows - by the rectification of small scale turbulent fluctuations is not only of relevance in magnetically confined plasmas, but is a generic feature of quasi-2D turbulent flows and also of high importance in, e.g., geophysical flows. The morphology of zonal flows and the basic mechanism for their generation will be discussed.
Particularly, we will present recent investigations of the generation of transport barriers in plasma turbulence and the role of these in the L-H transition by results from both low-dimensional models of the predator-prey type [1] and from first principle simulation applying a four-field, drift-fluid model [2].

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Evolution of the energy flux in a system of nonlinear surface waves in He-II

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The results of experimental studies of turbulent spectra in a wave system on the surface of superfluid He-II in a rectangular cell are presented. It is observed that with intense monochromatic pumping in the non-decay range of the spectrum, the modulation instability of the wave at the pump frequency develops, which can lead to the formation of a flux of wave action directed to the low-frequency range of the spectrum in a discrete wave system.

Topological Bright and Dark 2D and 3D-Dissipative Optical Solitons: Internal Structure, Symmetry, and Motion

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Lasers as a source of high-power and coherent radiation, and new nonlinear-optical materials provide unique possibility for research of complex field structures, one of the most exciting of which are optical solitons. Among these localized structures, the dissipative optical solitons based on the balance of energy input and output in the domain of localization, are characterized by the highest measure of stability and by extremely wide variety of their forms.
Optical solitons are often treated as light particle-like structures. However, they are spatially distributed and have certain internal structure. For dissipative solitons, of special importance is distribution of energy fluxes. In the talk, we present the topological structure of these fluxes in 2D- and 3D-laser (dissipative) solitons found on the basis of analysis of generalized complex Ginzburg-Landau equation and discuss the connection between the structure symmetry and solitons' motion.
The first scheme is a wide-aperture laser with a saturable absorber under conditions of classical bistability that means the possibility of homogeneous lasing and non-lasing regimes for the same parameters of the scheme, depending on the initial conditions [1]. There are various bright and dark, axially symmetric and asymmetric, fundamental and topological 2D-laser solitons and their complexes with weak and strong coupling of solitons. Inside solitons, there are domains with energy source and sinks, depending on the sign of the transverse Poynting vector divergence [2]. The elements of the domains symmetry include lines of symmetry and symmetry of rotation to an angle being a fraction of 2π. The soliton complexes with different symmetry can be motionless, rotating, and moving in the straight line or even curvilinearly.
The second scheme is continuous homogeneous medium with saturable gain and absorption and their frequency and weak angular selectivity. There are also stable symmetric and asymmetric 3D-solitons and their complexes with rectilinear and uniform motion, rotation, and curvilinear motion along a 3D spiral-like trajectory, depending on the symmetry of light intensity and energy fluxes' distributions. Presented is a new type of asymmetric 3D-laser vortex solitons with curved vortex line; the solitons rotate and precess [3]. We demonstrate also 3D-instability of dark quasi-2D solitons with vortex line as a straight line.
N.N.R. is grateful to Prof. E.A. Kuznetsov for numerous and helpful discussions.

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Instability of solitary waves in Zakharov-Kuznetsov equation

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We study solutions behavior in the generalized Zakharov-Kuznetsov equation with various powers of nonlinearity. In particular, we study solitary waves in the 2 dimensional setting (on R^2) and address the question of their stability depending on the power of nonlinearity. Using the fact that this equation can be viewed as a higher-dimensional generalization of the KdV equation, we can partially employ the machinery of Martel-Merle for the generalized KdV equation, and, for instance, show the instability of solitary waves in the 2d Zakharov-Kuznetsov equation in the L^2 critical case (cubic power of nonlinearity), which is a delicate borderline case. This is the first step towards exhibiting the collapse in the generalized Zakharov-Kuznetsov equation.

The dynamics of quantum vortices in a quasi-two-dimensional Bose-Einstein condensate with two "holes"

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The dynamics of interacting quantum vortices in a quasi-2D spatially nonuniform Bose-Einstein condensate is considered in hydrodynamic approximation for the case when equilibrium density of the condensate vanishes at two points of the plane, in each of them the presence of a stationary vortex of several quanta of circulation is possible. A special class of the density profiles is chosen, so that with the help of a conformal mapping of the plane onto a cylinder, analytical calculation becomes possible for the velocity field created by vortices. Equations of motion are presented in a noncanonical Hamiltonian form. The theory is generalized to the case when condensate takes form of a curved quasi-2D shell in the 3D space.

Isotropization of two-dimensional hydrodynamic turbulence

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The direct cascade of two-dimensional hydrodynamic turbulence in a square box with periodic boundary conditions along both coordinates in the frame of the solution of equation for vorticity are numerically investigated in the presence of pumping and viscous-like damping. Equation for vorticity was solved numerically using pseudospectral Fourier method, while integration in time was performed with the use of a hybrid Runge–Kutta/Crank–Nicholson third-order scheme. The initial conditions were chosen as random sets of Gaussian shape vortices with zero mean vorticity and randomly distributed over the entire domain. Simulations were performed at the Computer Center of the Novosibirsk State University (with the use of the NVIDIA CUDA technology). The spatial resolution was up to 16384x16384.

Numerical results are shown that the formation of a power-law dependence on wave number k in the Kraichnan-type spectrum of turbulence formed owing quasi-shocks of vorticity is a very quick process. If at an early stage (at the time of order of the inverse of the pumping increment), the development of turbulence is about the same scenario as in the case of a freely decaying turbulence. Formed quasi-singular distribution of di-vorticity, which in k-space correspond to jets - Fourier transforms of quasi-shocks, leading to a strong turbulence anisotropy. In the next much slower stage, the structure of quasi-shocks lines is complicated. The distances between quasi-shocks lines are reduced, and the spectrum becomes more isotropic. It is also important to note that the probability distribution function of vorticity at these times there is a formation of exponential tail at large arguments, which can be extrapolated as a linear dependence of vorticity in accordance with the theoretical predictions. The probability distribution function for di-vorticity also has two specific areas: the first - the distribution function is close to Poisson PDF, the second (large value of di-vorticity) - distribution function is exponential behavior with more distinct linear dependence than similar for vorticity. Both of these observations suggest that direct cascade of turbulence at large times loses anisotropy due to a tendency to breaking. In our opinion, there are at least two possible reasons of turbulence isotropization. The first reason may be related to the pumping area, where, in spite of the strong dissipation at low k, formed large-scale vortices (it's some remains not killed until the end of inverse cascade), which, due to its rotation, contribute into the system of vorticity quasi-shocks additional stretching of di-vorticity lines, and on the other hand - makes the system of significant lines of the di-vorticity field more complicated. We observed that the isotropic spectrum is carried out by time, more than time of Kraichnan-type enstrophy transferring, when pumping wave reaches the viscous region. As is known, the direct cascade of turbulence is a non-local (or rather - weakly nonlocal), that is accompanied by the appearance of logarithmic corrections to the Kraichnan spectrum. Locality of turbulence means that the main nonlinear interaction is interaction between scale of the same order. Interaction greatly different scales is strongly depressed. In this situation, both boundary to the inertial interval areas - pumping and viscous dissipation, as isotropic sources, in our opinion, are responsible for the turbulence isotropization of direct cascade.

Blowup Dynamics in the Keller-Segel Model of Chemotaxis

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The Keller-Segel equations model chemotaxis of bio-organisms. In a reduced form, considered in this talk, they are related to Vlasov equation for self-gravitating systems and are used in social sciences in descriptions of crime patterns.
It is relatively easy to show that in the critical dimension 2 and for the mass of initial conditions greater than 8π, the solutions break down in finite time. Understanding the mechanism of this breakdown turned out to be a subtle problem defying solution for a long time.
Preliminary results indicate that the solutions 'blowup'. This blowup is supposed to describe the chemotactic aggregation of the organisms and understanding its universal features would allow comparison of theoretical results with experimental observations.
In this talk I discuss recent results on dynamics of solutions of the (reduced) Keller-Segel equations in the critical dimension 2, which include a formal derivation and partial rigorous results on the blowup dynamics of solutions. The talk is based on joint work with S. I. Dejak, D. Egli and P.M. Lushnikov.

Laboratory and numerical study of intense envelope solitons of water waves

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The investigation of dynamics of intense solitary wave groups of collinear surface waves is performed by means of numerical simulations of the Euler equations and laboratory experiments. The processes of solitary wave generation, reflection from a wall and collisions are considered. Steep solitary wave groups with characteristic steepness up to $kA_{cr} \approx 0.3$ (where k is the dominant wavenumber, and $A_{cr}$is the crest amplitude) are concerned. They approximately restore the structure after the interactions. In the course of the interaction with the wall and collisions the maximum amplitude of the wave crests is shown to enhance up to 2.5 times. A standing-wave-like structure occurs in the vicinity of the wall, with certain locations of nodes and antinodes regardless the particular phase of the reflecting wave group. A strong asymmetry of the maximal wave groups due to an anomalous set-up is shown in situations of collisions of solitons with different frequencies of the carrier. In some situations of head-on collisions the amplitude of the highest wave is larger than in overtaking collisions of the same solitons. The discovered effects in interactions of intense wave groups are important in the context of mechanisms and manifestations of oceanic rogue waves.

Search for direct relation between elastic turbulence and turbulent drag reduction

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Elastic turbulence (ET) is a unique chaotic state driven by polymer dynamics alone and occurring in inertia-less flows under certain conditions. Turbulent drag reduction (TDR) is observed at super-critical Reynolds number flows through well-understood flow-turbulence structure interactions. So far, the turbulence community sees ET and TDR as distinct states of turbulence. Neither state enjoys the strong theoretical understanding than Newtonian turbulence has. A recently discovered turbulent state, elasto-inertial turbulence (EIT), occupying the Reynolds number space between ET and TDR, suggests that ET and TDR are linked and this link could be a significant piece missing in the theory of TDR. To search for direct relation between ET and TDR and prove of the aforementioned hypothesis, experiments we focused on a setup of a flow between two cylindrical obstacles in a micro-channel flow. In the same setup we study the dynamics of ET, EIT and TDR in unbounded flow configuration. It allows first to investigate ET in fairly homogeneous vortex flow. Then by using polymer solutions of different viscosities in a wide range of their variations we are able to scan the Wi and Re parameter plane up to several hundred and to study the various turbulent states and transition between them

Solitons in optical communications and fibre lasers: New dawn

Turitsyn SK

Aston University

I will overview recent resurrection of soliton concepts in optical communications and fibre lasers.

Large vortices generation by surface waves excited on a free surface

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We consider different mechanisms of large vortices generation by surface waves, which is ibserved in our experiment. Among the considered mechanisms are: i) Direct energy transmission from the surface waves to the large vortice via viscous nonlinear interaction. This transmission is possible if waves with close wave vectors and coinciding frequencies are excited. ii) We consider possible instability for vortices arising at large enough surface wave amplitude. iii) Finally, we consider possibility of inverse cascade, when surface wave excite small scale wortices with sizes order of wavelength. After that the small scale vortices give kinetic energy to the large scale vortices. We discuss the implementation of each of these scenarious.

Variational approach to the problem of integrability of deep water wave equations

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On another concept of Hasselmann equation source terms

Zakharov VE, **Resio D**, **Pushkarev A**

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The new ZRP wind input source and wave-breaking dissipation terms are examined for their theoretical consistency via numerical simulation of Hasselmann equation. The results are compared to field experimental data, collected at different sites around the world, and theoretical predictions based on self-similarity analysis. Good agreement is obtained for both limited fetch and time domain statements.

On integration of multidimensional system of n-wave type equations.

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IPCP RAS

A version of multidimensional system of n-wave type nonlinear PDEs is proposed. This system is derived both using the spectral representation of its solution via the procedure similar to the dressing method for the ISTM-integrable nonlinear PDEs and using the direct linearization. The proposed system is shown to be completely integrable, a particular solution is represented.

Nonlinear waves at the interface between two ideal fluids in a horizontal electric field in the presence of tangential discontinuity of the velocity

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The nonlinear dynamics of the interface between ideal dielectric fluids in the presence of tangential discontinuity of the velocity at the interface and the stabilizing action of the horizontal electric field is examined. It is shown that the regime of motion of the interface where liquids move along the field lines occurs in the state of neutral equilibrium where electrostatic forces suppress Kelvin–Helmholtz instability. The equations of motion of the interface describing this regime can be reduced to an arbitrary number of ordinary differential equations describing the propagation and interaction of structurally stable solitary waves, viz. rational solitons. It is shown that weakly interacting solitary waves recover their shape and velocity after collision, whereas strongly interacting solitary waves can form a wave packet (breather).

Equilibrium configurations of an uncharged conducting liquid jet in a transverse electric field

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Exact solutions are obtained for the problem of an equilibrium configuration of an uncharged cylindrical jet of a conducting liquid in a transverse electric field. The transverse cross section of the jet moving between two planar electrodes is deformed under the action of electrostatic forces (capillary forces play a stabilizing role). According to the solutions obtained, the initially circular cross section of the jet may be significantly (formally, unboundedly) stretched along the lines of forces of the field, and the boundaries of the jet asymptotically approach the electrodes. The stability of these solutions is discussed.

Singularity in Navier-Stokes equation under an action of non-uniform, random force

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