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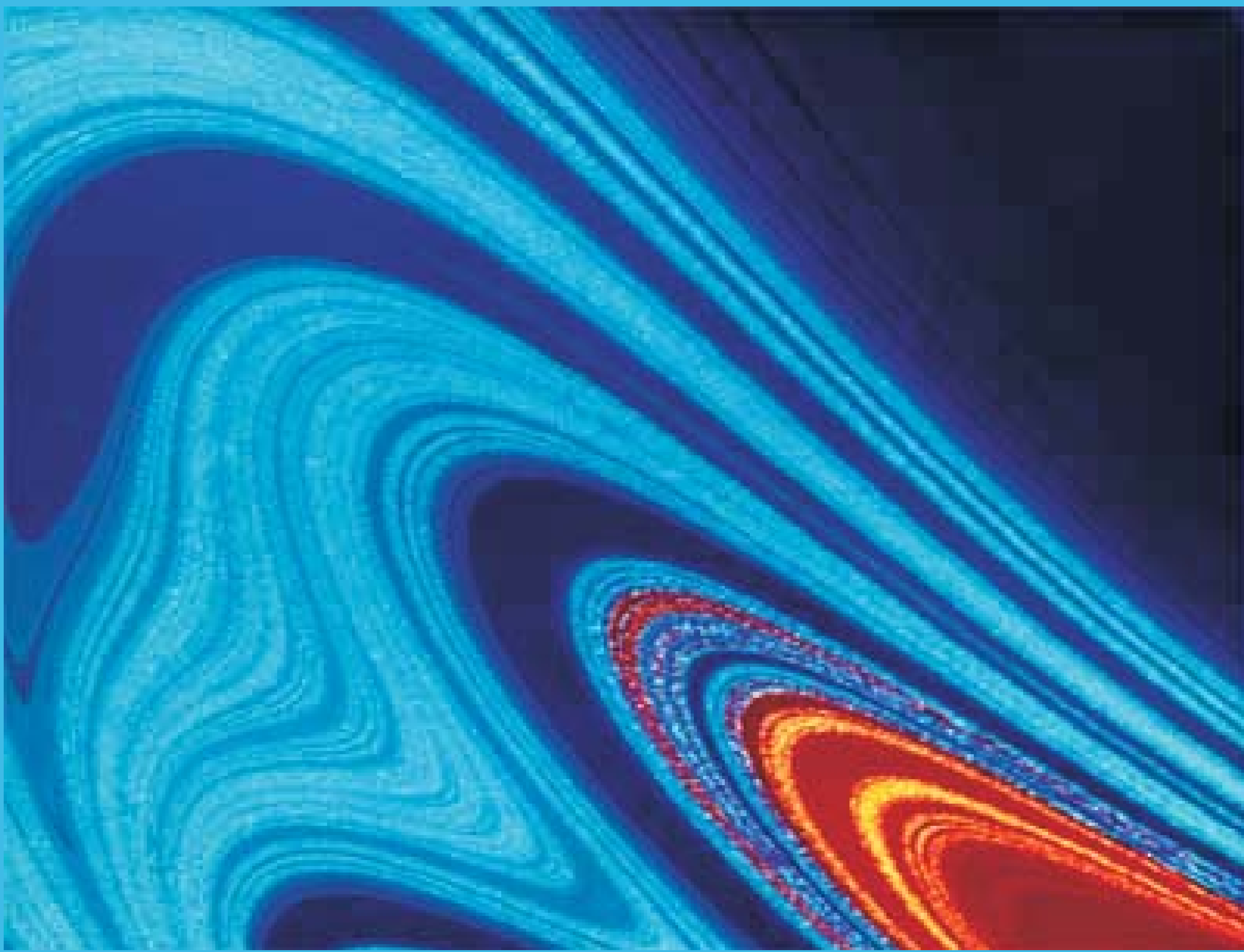

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Nanophysics

Modelling of quantum sized wires in the interface layer of the semiconductor-oxide structures with charge built in oxide

A.E. Atamuratov
Urganch State University, Urganch, Uzbekistan

Abstract: In these work one of the long-lived, reconfigurable, nanoscale electronic systems of a low dimension - quantum wires in a semiconductor is modelled. This approach consists of creating a regular charge distribution in an adjacent dielectric, so that a two-dimensional potential distribution is induced in the interface layer of the semiconductor. Parameters of quantum wires arising in a potential well dependence on distribution and density of the built in charge is analyzed.

Potential distribution of these desired charge in the semiconductor is defined by solving of Poussion equation in a cylindrical coordinates. The equation is solved numerically by application of finit difference method. The considered structure represents a semiconductor substrate of the cylindrical form covered by a coaxial oxide layer. The charge is built in oxide layer as one and two round parallel rings with finit thickness located at some distance from each other on planes which is parallel to the basis of the cylinder. Results show, that in the interface layer of the semiconductor of oxide-semiconductor structures it is possible to generate two-dimensional potential well at the certain distribution of a charge in a oxide layer. The potential well created in this way can be reconstructed by changing the position, size and density of the charged areas. Depth of the well basically is defined by charge density, and his width depends on distribution of a charge in an oxide layer.

The influence of the potential well to lateral capacitance of semiconductor-oxide structure also is explored.

Pattern formation process in the intermediate state of mesoscopic type-I superconductors

G. R. Berdiyorov

Departement Fysica, Universiteit Antwerpen, Belgium

Abstract: The intermediate state (IS) of type-I superconductors has recently become a topic of increasing interest [1-3]. Type-I superconductors in their IS belong to the wide variety of systems like magnetic fluids, Langmuir monolayers, ferromagnetic layers and self-assembled atoms on solid surfaces, where competing interactions lead to the formation of spatially modulated structures. Analogies to type-I superconductors extend even to astrophysics in studying nuclear matter in neutron stars [4]. Direct imaging of type-I superconductors reveals that, while in some cases its structure is periodic with alternating strips of normal and superconducting phases, most often very complex patterns and history dependence are seen, e.g. flux tubes are formed upon magnetic field penetration and laminar patterns appear upon flux exit [1]. However, spheres and cones show no hysteresis with flux tubes dominating the IS [2,3].

In this work we investigate the effect of the sample topology on the formation of the flux patterns in mesoscopic type-I superconductors within the Ginzburg-Landau theory. We show that

regardless of the shape of the SC the IS consists of flux tubes at small magnetic fields, laminar structures at larger magnetic fields and combination of these two states at intermediate values of the magnetic field. However, the sample boundary plays an important role in the formation of the flux patterns in the intermediate state. For example, in samples with sharp boundaries (cubes and disks) laminar structures are mostly located along the boundary, whereas radial distribution of the flux patterns is obtained for cones and spheres.

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Diffractive paths in the semiclassical and quantum mechanics of billiards

Joachim Burgdörfer
Institute for Theoretical Physics, Vienna University of Technology, Vienna, Austria

Abstract: Quantum billiards, experimentally realized over a wide range of length scales from nanoscale graphene flakes, via micrometer-size quantum dots in semiconductor heterostructures to macroscopic microwave cavities continues to challenge semiclassical theory. The quantum-to-classical transition in clean two-dimensional (2D) ballistic systems has remained a widely open question. Quantum interference and quantum correlations are key to the understanding of transport through open billiards. Yet, path interference built into standard semiclassical theory is not sufficient to adequately account for several quantum properties of ballistic phase-coherent transport. They include the quantum suppression of shot noise at zero temperature, the weak localization dip in conductance, and (non) universal conductance fluctuations in regular and chaotic structures. We have recently developed a pseudo-path semiclassical approximation (PSCA) that explicit accounts for contributions to the S matrix not included in standard semiclassics. These diffractive contributions are key to restore the unitarity of the S matrix and to represent quantum correlation between paths. Applications show quantitative agreement with ab initio quantum simulations for the Fano factor of quantum shot noise, weak localization and quantum fluctuations. In this talk we will also give an overview over recent extensions to disordered graphene quantum dots and Andreev billiards consisting of hybrid superconducting-normalconducting heterostructures.

Classical and quantum transport: from Fourier law to thermoelectric efficiency

Giulio Casati
Center for nonlinear and complex systems, Universita' della Insubria, Como, Italy

Abstract: The understanding of the underlying dynamical mechanisms which determines the macroscopic laws of heat conduction is a long standing task of non-equilibrium statistical mechanics. A better understanding of such mechanism may also lead to potentially interesting applications based on the possibility to control the heat flow. Of particular interest is the problem, almost completely unexplored, of the derivation of Fourier law from quantum dynamics. To this end

we discuss heat transport in a model of a quantum interacting spin chain and we provide clear numerical evidence that Fourier law sets in above the transition to quantum chaos. In particular a new phenomenon of negative differential conductivity is illustrated.

Finally we consider the transport of particles and heat in models of elastically colliding particles and we discuss the conditions under which thermoelectric efficiency can approach the Carnot limit.

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Controlling Bose-Einstein condensates with semiconductor surfaces and devices

Mark Fromhold
School of Physics and Astronomy, University of Nottingham, Nottingham, UK

Abstract: We will consider how room-temperature semiconductor surfaces can be used to manipulate atoms cooled to nK temperatures. At such low temperatures, quantum-mechanical reflection can shield the atoms from the disruptive influence of the surface [1-3]. By considering experiments performed at MIT on Bose-Einstein condensates [1, 2], we will show that inter-atomic interactions and the aspect ratio of the condensate both strongly affect the reflection process when the incident velocity is very low (below approximately 2 mm/s) [3]. We will also consider how surfaces that are patterned on nanometre and micrometre scales can be used to increase the reflection probability, as in recent experiments [2], control the shape and excitations of the condensate [4, 5]. In particular, we show that Fresnel zone plates, fabricated in a solid surface, can sharply focus Bose-Einstein condensates, so reducing their volume by orders of magnitude despite inter-atomic repulsion. The focusing is insensitive to quantum fluctuations of the atom cloud and largely preserves the condensates' coherence. We also study modified zone plates, designed to focus atom clouds into arbitrary shapes. Such devices may enable matter-wave lithography of hybrid atom-electron chips, which can both monitor the fabrication process and couple electrons within the chip to ultracold atoms held above it.

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Quantum Chaos and Non-Hamiltonian Dynamics in Optical Microcavities

Martina Hentschel
Max Planck Institute for the Physics of complex Systems, Dresden, Germany

Abstract: Optical microcavities are open billiards for light in which electromagnetic waves can, however, be confined by total internal reflection at dielectric boundaries. These resonators enrich the class of model systems in the field of quantum chaos and are an ideal testing ground for the correspondence of ray and wave dynamics that, typically, is taken for granted. Using phase-space methods we show that this assumption has to be corrected towards the long-wavelength limit. Here, corrections to the specular reflection of rays occur in the form of the Goos-Hänchen shift and the so-called Fresnel filtering. Both are especially important around the critical angle. Adjusting the ray picture by taking these wave-picture inpsired corrections into account results in a non-Hamiltonian dynamics. It explains the existence of regular modes in classically chaotic cavities such as the spiral as well as the loss of time-reversal symmetry observed previously in Husimi functions.

We also discuss the issue of achieving directional emission from optical microcavity lasers, highly desired concerning applications in photonic devices, with a focus on cavities of Limacon and spiral shape.

Time reversal of quantum states and classical waves: a semiclassical approach

Rodolfo A. Jalabert
Université Louis Pasteur, Strasbourg, France

Abstract: Time reversal has been the subject of theoretical discussions among physicists for a long time. Recently a few experimental realizations have made it possible to address such discussions on a solid basis. On one hand, the revival of a localized density upon reversal of its time evolution, referred as Loschmidt echo, has been obtained on relatively complex spin systems. On the other hand, time reversal mirrors have been achieved for acoustic waves, where an initially localized pulse is accurately reconstructed by an array of receiver-emitter transducers that re-inject the recorded signal. We develop a semiclassical approach to describe these kinds of processes and give quantitative predictions on the quality of the reconstruction. The nature of the underlying classical dynamics appears in both cases as a critical issue for the reconstruction. For the Loschmidt echo a small perturbation between the forward and backward evolutions results in a decay of the revival with a rate that becomes independent of the perturbation strength after a critical value. For the time reversal mirror in a chaotic cavity it can be shown that a single transducer is enough to obtain the re-

focalization of an initial pulse, and that such reconstruction is quite robust against variations of the environment between the recording and re-emission processes.

Phonons and electron-phonon interactions in single-walled achiral carbon nanotubes

B. S. Kandemir
Department of Physics, Faculty of Sciences, Ankara University, Ankara, Turkey

Abstract: Exact analytical expressions for the entire phonon spectra in single walled carbon nanotubes with achiral geometries are presented by using an approach, which mainly includes the construction of classical lattice Hamiltonian of single walled carbon nanotubes, then its quantization and finally diagonalization of the resulting second quantized Hamiltonian.

Furthermore, within this context, analytical formulas for the relevant electron-phonon interaction coefficients are also obtained for single walled carbon nanotubes having these geometries, by the phonon modulation of the hopping interaction.

Fermi acceleration in the driven elliptical billiard

Florian Lenz
Theoretische Chemie, University of Heidelberg, Heidelberg, Germany

Abstract: We explore the dynamical evolution of an ensemble of non-interacting particles propagating freely in an elliptical billiard with harmonically driven boundaries. The existence of Fermi acceleration is shown, thereby refuting the established assumption that smoothly driven billiards whose static counterparts are integrable do not exhibit acceleration dynamics.

The underlying mechanism based on intermittent phases of laminar and stochastic behavior of the strongly correlated angular momentum and velocity motion is identified and studied with varying parameters. This intermittent behavior leads to anomalous diffusion in momentum space.

Optimized ion force fields based on thermodynamic properties

Shavkat I. Mamatkulov
Heat Physics Department, Tashkent, Uzbekistan

Many systems, which are studied by molecular dynamics simulations, contain solvated ions. Such simulations of ionic solutions are strongly influenced by the ionic force field, which has two adjustable parameters in the most commonly used force fields: the Lennard-Jones diameter and interaction strength. Along this line, the plethora of parameters one finds for one and the same ion type is surprising. Usually, ion parameters are chosen such that they reproduce the free energy of solvation of an ion when used in conjunction with a certain water model and a certain simulation protocol. For the unique determination of the two adjustable Lennard-Jones parameters, a second quantity has to be considered. In the present work we use the entropy of solvation and the ion-water radial distribution function as additional properties. There appear two difficulties during the parameter optimization: first, solvation of single ions is thermodynamically not defined, which leads to undetermined surface terms. This problem, can be avoided using ion pair thermodynamic data for the fitting. Second, there is a near-degeneracy of the three quantities under consideration with respect to the Lennard-Jones parameters. There is a manifold of parameters combinations that is compatible with all studied quantities.

Dispersive optomechanics: a membrane inside a cavity

Florian Marquardt
Center for NanoScience, Arnold Sommerfeld Center
for Theoretical Physics, and Department of Physics, Ludwig-Maximilians- University Munich, Germany

Abstract: In this talk I will review recent progress in the physics of the interaction between radiation and mechanical motion. The paradigmatic system in this field of 'optomechanics' consists of an optical cavity with a movable mirror attached to a cantilever. I will discuss how the coupled dynamics of the light field inside the cavity and the cantilever motion gives rise to a series of interesting effects. On the level of classical dynamics, I will present the theory of nonlinear oscillations and the corresponding attractor diagram. Furthermore, it is possible to cool the cantilever by irradiating the cavity with a red-detuned laser beam. I will present the quantum theory of optomechanical cooling and discuss the prospects for reaching the ground state of the cantilever's center-of-mass motion. This could open the door to the observation of quantum jumps between Fock states of a macroscopic object, and I will illustrate this by presenting a setup where a quantum-non-demolition measurement of the cantilever's phonon number could be achieved.

Quantum time-dependent billiards

D.U. Matrasulov
Heat Physics Department, Tashkent, Uzbekistan

Abstract: In this talk we discuss quantum dynamics of a particle in billiard geometries with time-dependent boundaries. In particular, the cases when the exact analytical solution of the problem can be obtained are explored for circular, square and right triangular billiards. The case of “breathing” boundaries is treated by solving the Schrödinger equation with time-dependent boundary conditions. The comparison is made with the corresponding classical systems.

Light and anti-light in a nonlinear liquid of photons

H. Michinel
University of Vigo, Vigo, Spain

Abstract: In this talk I will discuss some new properties of the so called “liquid of light”: a new state of matter which can be produced in self-trapped laser beams propagating in highly

nonlinear optical materials. Surface tension effects of the “liquid of photons” will be shown and compared with usual liquids. Finally, a study of vortices and vortex dipoles production by interference of liquid light condensates will be developed which yield interesting analogies with particle-antiparticle pair production in vacuum.

Nonlinear responses in Hard disk gases

Tomoshige Miyaguchi
Osaka City University, Osaka, Japan

Abstract: The hard disk gases in contact with two heat reservoirs at different temperatures are numerically studied, especially for the case of far from equilibrium. The fluctuation relation and a nonlinear response formula are numerically confirmed in a good accuracy. Similar results are obtained for time periodic perterbations-periodically driven shear flow. In this case, the amplitude of each mode follows a similar relation as the static case.

Tuning the superconducting properties of nanomaterials

François Peeters*
Departement Fysica, Universiteit Antwerpen, Antwerpen, Belgium

Abstract: Quantum confinement of electrons in metallic clean nanowires results in the formation of a series of subbands that move in energy with changing wire thickness. When the bottom of such a subband moves throught the Fermi surface, the density of states changes and a shape resonance appears leading to oscillations in the critical temperature and the critical magnetic field as function of the wire width. Our theoretical formulation is based on a numerical solution of the Bogoliubov-de Gennes equations. A quantitative description is given of recent experimental data on the thickness dependence of T_c in Al and Sn nanowires [1].

At a shape resonance the density of the superconducting condensate is very inhomogeneous, leading to new Andreev-type of states [2].

In the presence of a parallel magnetic field we predict that the superconductor-to-normal transition at zero temperature occurs as a cascade of subsequent jumps in the order parameter (this is opposed to the smooth second-order phase transition in the mesoscopic regime). Each jump is associated with the depairing of electrons in one of the single-electron subbands. Pronounced quantum-size oscillations of the critical magnetic field with giant resonant enhancements are predicted for narrow nanowires.

* Work done in collaboration with A. Shanenko and M. Croitoru.

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Mesoscopic interplay of superconductivity and ferromagnetism in ultrasmall metallic grains

Sebastian Schmidt
ETH Zürich, Switzerland

Abstract: We investigate the competition between superconductivity and ferromagnetism in chaotic ultrasmall metallic grains in a regime where both phases can coexist. An effective Hamiltonian is used which combines a BCS-like pairing term and a ferromagnetic Stoner-like spin exchange term. We study the transport properties of the grain in the Coulomb blockade regime and identify signatures of the coexistence between pairing and exchange correlations in the mesoscopic fluctuations of the conductance peak spacings and peak heights.

Thermal conduction in a quantum system: universality and it origins

Ayumu Sugita
Department of Applied Physics, Osaka City University, Osaka, Japan.

Abstract: We study a quantum spin chain coupled to two phonon heat baths with different temperatures. Although the non-equilibrium steady state (NESS) of the system depends on the details of the reservoirs (spectral densities and coupling operators), it is known that local properties of the NESS (e.g., local temperature and energy flow) are insensitive to the details of the reservoirs, and determined almost only by their temperatures.

We investigate microscopic origins of this universal behavior.

Statistic theory of MEG in quantum dots based solar cells

N.N. Turaeva
Institute of Polymer Chemistry and Physics, Tashkent, Uzbekistan

Abstract: Quantum dots (QDs) based solar cells attract a big attention of researchers involved in creation of 3rd generation solar cells with increased power efficiency [1]. The high efficiency of such solar cells is conditioned by the multiple exciton generation (MEG) effect in quantum dots [2-5] at single photon absorption. A usual assumption in conventional photovoltaics is that the single photon absorbed by a semiconductor (such as Si) produces a single electron-hole pair, which is then separated by the internal electric field of p/n junction of a solar cell. The photon energy in excess of the energy gap Eg is dissipated as heat by exciting lattice vibrations (phonons), and therefore the power efficiency of solar cells is limited by so called Shottky-Quiser limit [1]. In this work the statistic theory of MEG in quantum dots is presented on the base of Fermi approach to the problem of multiple generation of elementary particles [6]. Our calculations on the base of Fermi approach show that the quantum efficiency of multiple excitons generation in PbSe quantum dots at absorption of single photon is in a good agreement with experimental data [7].

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Stochastic Landau-Lifshitz-Gilbert equation with delayed feedback field: Efficiency for maintaining a UPO

Hiroki TUTU

Dept. of Applied Analysis and Complex Dynamical Systems, Kyoto University, Japan

Abstract: As a model-based study for controlling nano-scale magnetic systems, we investigate a time-delayed feedback control to stabilize a swinging motion of a magnetic moment in a single-domain magnetic system under AC field. The system has a uniaxial anisotropy, and the AC field is applied parallel to this. Without control, it prefers the Ising state which is (anti)parallel to the anisotropy axis. Then, the control stabilizes an oscillation of the magnetization across the equatorial plane perpendicular to the anisotropy axis (swinging motion). This motion possesses the XY-spin-like symmetry, thus the control method provides a method to causes a switching between the Ising and XY-like states. Employing a stochastic Landau-Lifshitz-Gilbert equation, we study effects of thermal fluctuation on the controlled state. Linear fluctuation, in which a variance linearly depends on the noise intensity, around the controlled state is analyzed, and a stability criterion of the controlled state is obtained. We also discuss an efficiency of the control in terms of energy consumption. A comparison with another method suggests that the method of the delayed feedback control can maintain the controlled state with a low energy consumption.

Many-body physics and quantum chaos in mesoscopic systems

Denis Ullmo

LPTMS University Paris Sud, Orsay, France

Abstract: Experimental advances in the miniaturization of electronic devices have made nanoscale electronic systems routinely available in the laboratory, which at low temperatures are suffiently well isolated from their environment to be considered as fully coherent.

Some of their most important properties are dominated by the interactions between electrons. Understanding their behavior therefore requires a description of the interplay between interference effects and interactions.

In this talk I will address this relatively broad issue, and more specifically discuss it from the perspective of the quantum chaos community. I will therefore present some of the concepts

developed in the field of quantum chaos which have application to the study of many-body effects in mesoscopic and nanoscale systems.

Their implementation is illustrated by a few examples of experimental relevance such as persistent currents, and Coulomb blockade.

Cold Atom Physics

Soliton dynamics at interface between uniform medium and nonlinear optical lattice

R. Galimzyanov
Physical-Technical Institute of the Academy of Sciences, Tashkent, Uzbekistan

Abstract: The work is devoted to the fundamental processes of reflection, transmission and trapping of a nonlinear wave packet ingoing onto the interface between uniform nonlinear media and one with periodically modulated nonlinearity [1–4]. Existence of a stable soliton solution in a nonlinear optical lattice (medium with periodically modulated in space nonlinearity) was shown in [5]. We study dynamics of a matter wave soliton in an elongated condensate with attractive interaction described by the 1D Gross-Pitaevskii equation for the wave function function.

Two cases are considered, dynamics of a broad soliton and dynamics of a narrow one. Description of a broad soliton is based on averaging of the governing GP equation over rapid oscillations of the nonlinearity in space. In this case the problem is reduced to the dynamics of a soliton at the interface between cubic and effective cubic-quintic nonlinear media.

In description of the dynamics of a narrow soliton solution a variational approach is used. Different regimes for trapping of a narrow soliton are investigated. Predictions obtained from the averaged Gross-Pitaevskii(GP) equation and a variational approach are confirmed by numerical simulations of the original GP equation with a nonlinear periodic potential, i.e. with the nonlinearity coefficient varying in space.

For both cases the characteristics have been found of a soliton trapped by the interface.

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Generation of Sound Waves in Two-Component Bose-Einstein Condensates

B.B. Baizakov
Physical - Technical Institute, Uzbek Academy of Sciences, Tashkent, Uzbekistan

Abstract: In this work we propose a new approach to generation of waves in two - component Bose-Einstein condensates (BEC) which is based on a fast change of the interspecies interaction constant. Two settings are considered: in one case the system represents a homogeneous mixture of two repulsive BEC's, in the other case one component is a drop-like condensate immersed into the second large repulsive condensate. To create density waves, on the first step the interaction between a drop-like condensate and surrounding condensate is adiabatically turned on, which leads to emergence of a density hump or hole in the surrounding condensate, depending on the sign of the interaction constant. On the second step, the inter-species interaction is rapidly turned off. Decaying hump/hole induces density waves in the background condensate. Alternatively, density disturbance in a homogeneous mixture of two repulsive condensates can be created by a tightly focused laser beam capable to change the intra- or inter-species interaction constant via optically induced Feshbach resonance. To illustrate the proposed method we numerically simulate the creation and evolution of matter density waves in a two component BEC. A mathematical model based on the linearized Gross- Pitaevskii equation has been developed which provided explicit formulae for the space-time dependence of matter density waves. Comparison of analytic results with numerical data shows good agreement. The proposed method may open up new perspectives in investigation of different wave phenomena in coupled BECs, especially in higher dimensional settings. Obtained results can be of interest for the physics of interacting two-component superfluid systems.

Experimental observation of the Anderson transition with atomic matter waves

D. Delande
Pierre and Marie Curie University, Paris, France

Abstract: The metal-insulator Anderson transition plays a central role in the study of quantum disordered systems. An insulator is associated with localized states of the system, while a metal generally displays diffusive transport associated with delocalized states. The Anderson model describes such a metal-insulator transition, due to quantum interference effects driven by the amount of disorder in the system. We realize experimentally an atom-optics quantum chaotic system, the quasiperiodic kicked rotor, which is equivalent to a 3D disordered system, that allow us to demonstrate the Anderson metal-insulator transition. Sensitive measurements of the atomic wave function dynamics and the use of finite-size scaling techniques make it possible to extract both the critical parameters and the critical exponent of the transition, which is in good agreement with the value obtained in numerical simulations of the 3D Anderson model.

Dissipative Bose Einstein condensate under vibration of harmonic trap position

Kh. N. Ismatullaev

Physical-Technical Institute of the Academy of Sciences, Tashkent, Uzbekistan

Abstract: Based on the phenomenological damping approach [L.P. Pitaevskii, Sov. Phys. JETP 35 (1958) 282] developed by Pitaevskii collective oscillations of a quasi-one-dimensional trapped Bose gas has been studied. Ordinary differential equations for the parameters of the condensate wave function have been derived using a moment method. Analytic expressions show that due to dissipation the motion of the centre of mass and oscillation of the width becomes coupled. It gives rise to the possibility to control internal modes by manipulating the position of the trap. It has been shown that in the dissipative systems periodical variations of the trap position result in changing the asymptotical behaviour of the driven norm oscillations.

Fast-Forward Problem in Quantum Mechanics

Shumpei Masuda
Department of Applied Mathematics and Physics, Graduate School of Informatics, Kyoto University, Kyoto, Japan

Abstract: We show the way to speed up the time-evolution of wave functions (WFs) in quantum mechanics by controlling the potential together with resultant tuning of the additional phase of WF, so that a target state is obtained in a shorter time. We present some examples of the fast-forwarding of an electron motion together with numerical and analytical results. The framework of the fast-forward is also applicable to the nonlinear Schrödinger equation. We show the fast-forward of the transport of Bose Einstein condensates trapped by a harmonic potential and propagation of solitons.

Quantum kicked rotors with cold atoms and spin chains

T.S. Monteiro
Department of Physics and Astronomy, University College London, University of London, UK

Abstract: The Quantum Kicked Rotor is one of the best-known paradigms of quantum chaos. For theorists, an attractive feature is the extremely simple quantum map which fully determines its dynamics and clarifies the interesting phenomenology. For experimentalists, it is the very clean realisation permitted by cold atoms: the QKR has since 1995, been the subject of dozens of published experimental studies by 10 different cold atom groups. Some studies probed phenomena such as dynamical localization (the quantum suppression of chaotic diffusion). Others probed resonant effects such as, for example, accelerator modes. In future, many-body dynamics may be increasingly relevant. Spin-chain systems of potential interest to quantum information have maps very similar to those of the QKR. And the most recent QKR experiments have used a Bose Einstein Condensate (BEC); here, atomic densities have to date been slightly too low to probe atomic interactions and collective effects, but only by a factor of 2-3 -and the gap is closing.

In this talk I will discuss new possibilities for quantum dynamics of kicked rotors using BECs and spin chains, arising from their many-body nature. For the BECs, resonant behaviour and the onset of exponential instabilities is investigated. For the spin chains, the potential of quantum chaotic dynamics for quantum state transfer in quantum information is considered.

Nonlinear Dynamics and Chaos of Wave Packets and Vortices in Multi-Component Bose-Einstein Condensates

Katsuhiro Nakamura
Heat Physics Department, Tashkent, Uzbekistan

Abstract: Bose-Einstein condensates (BECs) provides a nice stage where nonlinear dynamics of wave packets (WPs) and vortices plays a vital role. We study the dynamics of single and multi-component BEC in 2 dimensions with and without a harmonic trap by using various variants of nonlinear Schrödinger (or Gross-Pitaevskii) equation.

Firstly, we examine the three-component repulsive BEC with cubic nonlinearity in 2 dimensions in a harmonic trap in the absence of magnetic field, and see the conservative chaos based on a picture of vortex molecules. We obtain an effective nonlinear dynamics for three vortex cores, which are equivalent to three charged particles under the uniform magnetic field with the repulsive inter-particle potential quadratic in the inter-vortex distance r_{ij} on short length scale and logarithmic in r_{ij} on large length scale. The vortices here acquire the inertia in marked contrast to the standard theory of point vortices since Onsager. We then explore "chaos (shown by power spectra and Poincare surface of section) in the three-body problem" in the context of vortices with inertia.

Secondly, we investigate the single and multi-component WP dynamics within the hard-walled square billiards with neither a harmonic trap nor driving field. We study the stability of WPs in the attractive cubic-repulsive quintic nonlinear systems. The stability of WPs can be analyzed by using the variational (collective-coordinate) method. As the velocity increases, WPs tend to be stable against many collisions. WP in the saturable nonlinear system is found more stable than in the cubic-quintic one. In the two-component saturable nonlinear system, there exist interesting three types of collisions between WPs (transmission, reflection, and formation of a molecule) depending on the initial relative velocity. The critical velocities can also be estimated.

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Supersolitons, a novel kind of solitonic excitations in atomic soliton chains

David Novoa
University of Vigo, Spain

Abstract: We show through both analytical calculations and numerical simulations that by appropiately tunning physically relevant interactions in a non-integrable system governed by two-component coupled nonlinear Schrödinger equations, it is possible to achieve a parameter regime where real particle-like elastic collisions between adjacent solitons can occur.

This fact allows to construct an analog of the Newton's cradle with matter-wave solitons. Furthermore, in this system it is possible to create localised collective excitations in solitary wave trains, which are called "supersolitons". As a result, the emergence of quasi-integrable dynamics within a strongly non-integrable model is observed. We propose the realization of this nonlinear model in the framework of recent experiments with two-component Bose-Einstein condensates with intracomponent attraction and intercomponent repulsive interactions.

Nonlinear dynamics of atoms in a cavity: The role of finite temperature effects

D.M. Otajanov
Heat Physics Department, Tashkent, Uzbekistan

Abstract: Cavity quantum electrodynamics is an area of physics studying the interaction of atoms with photons in high-finesse cavities in a wide range of the electromagnetic spectrum from

microwaves to visible light. The fact that the system "atom + cavity mode" is a quantum system makes cavity quantum electrodynamics (QED) an excellent testing ground for such important issues of modern quantum physics as quantum measurement theory, entanglement, quantum computation, quantum interference and at the same time provides a unique possibility for trapping, cooling and manipulating of atoms. Practical importance of cavity QED is mainly related to potential possibility for manipulating atoms and photons in mesoscopic scales. Therefore, in recent years cavity QED has become one of the hot topics both in theoretical and experimental physics [1 - 3]. Since the dynamics of a single atom trapped in a microcavity is governed by quantum electrodynamics, the cavity QED can be considered as an interdisciplinary area. Many subfield of physics, such as quantum and atomic optics, cold atom physics, physics of nanosized systems and quantum information, may use important results of the cavity QED. Recently cavity QED is considered in the context of nonlinear dynamics [3]. Mapping quantum equations of motion onto classical ones, for the Jaynes-Cummings Hamiltonian, which includes recoil motion of the atom, Prants et. al., explored phase-space dynamics of the atom interacting with a single cavity mode by analyzing Poincare surface sections and calculating Lyapunov exponents [3]. In this work we explore finite-temperature nonlinear dynamics of an atom coupled to a single mode of the cavity field. Applying the formalism of a real-time finite-temperature field theory to the Jaynes-Cummings Hamiltonian and using the same approach as that used in we have studied classical dynamics of the "atom + cavity mode" system in the presence of coupling to a thermal bath. Using the temperature-dependence of the equations of motion, dependence of the dynamics on heat-bath effects or finite temperature effects are considered. The results show that the dynamics is quite sensitive to the small changes of temperature. This implies that temperature of a thermal bath can be considered as an additional control parameter for the dynamics of an atom coupling to cavity modes.

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Instability of homogeneous Bose – Einstein condensate at zero temperature: HFB approximation

Abdulla Rakhimov
Institute of Nuclear Physics, Tashkent, Uzbekistan

Abstract: The properties of the uniform Bose gas at zero temperature are studied within Hartree – Fock –Bogoliubov approximation taking into account all imposed conditions that uniquely define the given statistical system. It is shown that the pressure of the atomic BEC is negative (P<0) when the gas parameter gamma=rho a^3 exceeds a critical value gamma_{crit} ~ 0.01 and hence the condensate with a repulsive interaction becomes unstable.

Vortices in ground state of spinor Bose-Einstein condensates

Almas F. Sadreev
Kirensky Institute of Physics, Krasnoyarsk, Russia

Abstract: The second order superconductor in external magnetic field is the most famous and remarkable example of existence of vortices in the ground quantum state (Abrikosov vortices). One of the recent developments in Bose-Einstein condensates (BEC) in atomic gases is the study of dilute Bose gases with spin degrees of freedom. The first realization of such a system is found in optically trapped ^{23}Na, which is a spin-1 Bose gas. Further, theoretical proposals of the possible vortex states in the ground state of the spin-1 BEC are suggested [1-3]. Here we consider the effects of the quadratic Zeeman energy on the vortex states. This energy is a result of trapping of BEC in harmonical potential of an applied Ioffe-Pitchard magnetic field. The total energy is

$$H = \Psi_i^* \left(-\frac{\hbar^2}{2m}\nabla^2 + U(r) - \mu \right)\Psi_i + \frac{1}{2} g_1 (\Psi_i^* \Psi_i)^2 + \frac{1}{2} g_2 (\Psi_i^* \Psi_i^*)(\Psi_j \Psi_j) + i\gamma_\mu \varepsilon_{ijk} B_k \Psi_i^* \Psi_j,$$

where $B_k(r)$ are components of the magnetic _eld of the Ioffe-Pitchard trap. In the spinor BEC, a vortex state is inseparably related to the spin texture. By utilizing this relation, it is possible to imprint the vorticity without rotating the cloud, as proved experimentally. By applying a quadrupole (nonuniform) magnetic field, the spin texture of the BEC is forced, resulting in the nucleation of the vortex. The vortex phase diagram is found in the plane spanned by perpendicular and longitudinal magnetic fields. The ferromagnetic condensate has two vortex phases which differ by winding number in the spinor components. The two vortices for the $F_z = \pm 1$ antiferromagnetic condensate are separated in space.

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Mesoscopic Physics with Ultracold Atoms: From Confined-Induced Transparency to One-Dimensional Rydberg Gases

P. Schmelcher
Theoretische Chemie, University of Heidelberg, Heidelberg, Germany

Abstract: We explore three examples of mesocopic physics with ultracold atoms indicative for very different regimes of interactions. First the few-boson tunneling in a one-dimensional double well, covering the full crossover from weak interactions to the fermionization limit of strong correlations is investigated. It is found that the tunneling dynamics of two atoms evolves from Rabi oscillations to correlated pair tunneling as we increase the interaction strength. Near the fermionization limit, fragmented-pair tunneling is observed.

As a second example we demonstrate that scattering of particles strongly interacting in three dimensions (3D) can be suppressed at low energies in a quasi-one dimensional (1D) confinement. The underlying mechanism is the interference of the s- and p-wave scattering contributions with large s- and p-wave 3D scattering lengths being a necessary prerequisite. This low-dimensional quantum scattering effect might not only be important for “interacting” quasi-1D ultracold atomic gases and guided atom interferometry but also for impurity scattering in strongly confined quantum wire-based electronic devices. Finally we study the quantum properties of Rydberg atoms in a magnetic Ioffe-Pritchard trap which is superimposed by a homogeneous electric field. Trapped Rydberg atoms can be created in long-lived electronic states exhibiting a *permanent* electric dipole moment of several hundred Debye. The resulting dipole-dipole interaction in conjunction with the radial confinement is demonstrated to give rise to an effectively one-dimensional ultracold quantum Rydberg gas with a macroscopic interparticle distance. We derive analytical expressions for the electric dipole moment and the required linear density of Rydberg atoms.

Quantum Information

Statistical mechanics of multipartite entanglement

Saverio PASCAZIO
Dipartimento di Fisica Universita di Bari, Bari, Italy

Abstract: Entanglement is one of the most intriguing features of quantum mechanics. It is widely used in quantum communication and information processing and plays a key role in quantum computation. At the same time, entanglement is not fully understood. It is deeply rooted into the linearity of quantum theory and in the superposition principle and (for pure states) is essentially and intuitively related to the impossibility of factorizing the state of the total system in terms of states of its constituents.

The characterization and quantification of entanglement is an open and challenging problem. It is possible to give a good definition of bipartite entanglement in terms of the von Neumann entropy and the entanglement of formation. The problem of defining multipartite entanglement is more difficult and no unique definition exists.

I introduce the notion of maximally multipartite entangled states (MMES) of n qubits as a generalization of the bipartite case. Their bipartite entanglement does not depend on the bipartition and is maximal for all possible bipartitions. Some examples of MMES for $n = 3,\ 4,\ 6$ and 7 are investigated. These states are the solutions of an optimization problem, that can be recast in terms of statistical mechanics.

We focus on fundamental issues and possible applications.

Quantum chaos in quantum information and cold atoms physics: from entanglement of random vectors to time reversal of matter waves

Bertrand Georgeot
Laboratoire de Physique Thèorique, Universitè Toulouse III & CNRS, Toulouse, France

Abstract: In this talk, I will present results which use quantum chaos techniques in the context of quantum information and cold atom physics. First, I will discuss entanglement of random vectors. Random Matrix Theory has been very successful in modelizing the properties of complex quantum systems in a regime of quantum chaos. Quantum information has put forward the notion of entanglement as one of its key resources. It is especially important since the amount of entanglement generated during a quantum process can be linked to the difficulty of simulating it by classical means. Results on the mean entanglement for certain classes of random vectors will be presented. In particular, it will be shown that assuming certain natural hypotheses entanglement is linked at first order to the localization of the state. The next order involves the multifractal exponents of the wave function [1]. These results shed light on the properties of random vectors, which are an interesting resource in quantum information, akin to random numbers in classical computation. They also enable to modelize certain types of wave functions of physical systems, and therefore can give information on the entanglement present in several physical processes, such as the Anderson transition.

I will also discuss a new method to perform approximate time reversal of matter waves. Time reversal is a fundamental question of statistical mechanics since the famous Boltzmann-Loschmidt controversy; time reversal of spin systems, acoustic and electromagnetic waves have already been experimentally realized. However, time reversal of matter waves has not been performed so far. I will discuss the experimental scheme proposed in [2] to realize approximately the time reversal of matter waves of ultracold atoms in optical lattices. The atoms undergo the dynamics of the quantum kicked rotator, which is exactly reversed for states of zero quasimomentum. Numerical simulations show that a significant fraction of the atoms return back to their original state, and are at the same time cooled down by several orders of magnitude. The proposal was also more recently extended to Bose-Einstein condensates [3]. Bose-Einstein condensates have very narrow quasimomentum distributions, but also correspond to a regime where interaction between the atoms is not negligible. Simulations using Gross-Pitaevskii equation show that the preceding scheme can be implemented for weak interaction. The accuracy of time reversal decreases with the increase of atom interactions inside the condensate, but surprisingly, quantum chaos helps to restore time reversibility. These predictions can be tested with existing experimental setups.

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Spin dynamics and quantum transport in quantum spin chainsunder an oscillating field

Kazue Kudo
Ochanomizu University, Tokyo, Japan

Abstract: Quantum spin chains under an oscillating field show various kinds of dynamics depending on the strength and frequency of the field. In a one-spin-flip case, spin dynamics can dive remarkable transfer of quantum information under some conditions. When a wave packet is initially located at an appropriate position in the spin chain, the wave packet travels for a quite long time without broadening.

The quantum spin model describing the dynamics can be transformed into the tight-binding model with an oscillating field, and it is equivalent to the driven Harper model, which is similar to the kicked Harper model. The behavior of the dynamics if explained by the corresponding classical phase space. In the case corresponding to the remarkable spin dynamics, two channels of regular motion appear. The channels, which include shearless tori, are responsible for the remarkable transfer of quantum information.

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Quantum interface between light and matter

Eugene S. Polzik
The Niels Bohr Institute, Copenhagen University, Copenhagen, Denmark

Abstract: Quantum interface between light and matter is a necessary ingredient of quantum networks of the future. One particular implementation of it is teleportation of quantum states between light – the carrier of information – and atoms – the storage medium of information. Teleportation is not exactly the Star Trek trick but it may be even more exciting. Information about physical objects is hidden in non-commuting quantum variables, like position and momentum of a particle, or amplitude and phase of light, or components of an atomic spin. The challenge of teleportation expressed in the physics language is in a transfer of such quantum variables from one system to another. A pair of non-commuting, complementary variables cannot be measured simultaneously without additional noise and hence cannot be faithfully transferred by classical signals. There is, however, a way, called quantum teleportation which allows to transfer – teleport – complementary variables, with the help of entangled quantum systems. In the lecture I will describe a recent experiment performed at the Niels Bohr Institute in Copenhagen in which quantum teleportation was for the first time demonstrated between a pulse of light and a collection of atoms – a flying and a stationary object.

Another application of the quantum interface is generation of entangled states for measurements beyond quantum limits. I will describe a recent experiment where entanglement has been used to improve the performance of an atom clock.

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See also the Scientific American article
http://www.sciam.com/article.cfm?chanID=sa003&articleID=000E9691-0261-1524-826183414B7F0000

Algorithms for Quantum Simulation

Barry C. Sanders
University of Calgary, Alberta, Canada

Abstract: One of the most important applications of quantum computation will be to simulate quantum systems efficiently in cases where classical simulations are intractable, as Feynman proposed when he first started investigating quantum computing. I will present algorithms for simulating Hamiltonian evolution and show that, in the case that the Hamiltonian is provided to an oracle, the cost of the simulation is nearly constant in space and nearly linear in time. The cost is quantified as the number of queries to the oracle, and this low cost is advantageous for quantum simulation implementations.

Classical and Quantum Nonequilibrium Systems

Operator algebras and quantum dynamics

Sh. A. Ayupov
Institute of Mathematics And Information Technologies
Uzbekistan Academy of Sciences, Tashkent, Uzbekistan

Abstract: Given an algebra A, a linear mapping $d : A \to A$ is called a derivation if it satisfies the condition $d(xy) = d(x)\, y + x\, d(y)$ for all $x, y \in A$. In this talk we study derivations on algebras of bounded and unbounded operators on a Hilbert space, emphasizing their properties such as innerness and spatialness. These notions are very important in the structure theory and cohomology of abstract ring and algebras and at the same time they have deep applications in quantum dynamics. Therefore we also discuss a physical background for derivations and automorphism of operator algebras. After exposition of some well-known result on bounded derivations on C^* - algebras and von Neumann algebras we consider open problems concerning derivations on unbounded operator algebras, namely algebra of measurable operators affiliated with von Neumann algebras and faithful normal semi-finite traces. Finally we give solutions of the mentioned problems for algebras of measurable operators affiliated with type I von Neumann algebras.

Stability and chaos in multidimensional hamiltonian systems: from local to global dynamics

Tassos Bountis
Department of Mathematics and
Director of Center for Research and Applications of Nonlinear Systems
University of Patras, Patras, Greece

Abstract: The connection between local and global stability of multidimensional Hamiltonian systems will be discussed, in an attempt to understand the presence of varying degrees of order and chaos, as the total energy E and the number of degrees of freedom N are increased. We focus on Simple Periodic Orbits (SPOs) and show how their (linear) stability is related to the breakdown of FPU recurrences and the onset of large scale chaos characterized by invariant spectra of Lyapunov exponents. We analyze SPOs which are either localized in Fourier space (as continuations of linear modes) or in configuration space (as discrete breathers) and find that quasiperiodic orbits in their vicinity lie on low—dimensional tori. Our study of tangent dynamics employs a recently introduced spectrum of indices called $GALI_k$, which for chaotic orbits tend exponentially to zero and for quasiperiodic motion are either nearly constant or decay following power laws that depend on the dimension of the torus . Thus, using the $GALI_k$, we are able to: (a) distinguish regular from chaotic domains much faster than other methods, (b) identify the dimensions of regular motion on quasiperiodic tori and (c) predict slow diffusion away from quasiperiodicity, long before it is actually observed in the oscillations.

Dynamical trapping and chaotic scattering of the harmonically driven barrier

Florian Koch
Theoretische Chemie, University of Heidelberg, Heidelberg, Germany

Abstract: A detailed analysis of the classical nonlinear dynamics of a single driven square potential barrier with harmonically oscillating position is performed. The system exhibits dynamical trapping which is associated with the existence of a stable island in phase space. Due to the unstable periodic orbits of the KAM-structure, the driven barrier is a chaotic scatterer and shows stickiness of scattering trajectories in the vicinity of the stable island. The transmission function of a suitably prepared ensemble yields results which are very similar to tunneling resonances in the quantum mechanical regime. However, the origin of these resonances is different in the classical regime.

Nonequilibrium diffusion induced by an external force and a spatio-temporal correlated noise

Takaaki Monnai
Department of Applied Physics, Waseda University, Tokyo, Japan

Abstract: We shall explore the Brownian motion induced by a deterministic external force and a spatially and temporally short correlated fluctuation. Such a spatio-temporal fluctuation approach can describe the dynamics of the collective coordinate which is not in thermal equilibrium with the environment [1], such as particles in a random flow [2, 3]. Firstly, we show how the potential-induced deterministic motion is radically affected by the spatio-temporal correlation [4. As a typical example, we consider a Langevin dynamics with a short correlated colored noise $f(x,t)$

$$\dot{x}(t) = -U'(x(t)) + f(x(t))$$
$$\langle f(x,t) \rangle = 0, \quad \langle f(x,t)\, f(x',t') \rangle = C(x-x',\ t-t'). \tag{1}$$

Then a Fokker-Planck equation is well-defined in a certain Markovian limit characterized by a balance relation between spatial and temporal noise correlation lengths.

$$\frac{\partial}{\partial t} P(x,t) - \frac{1}{\eta} \frac{\partial}{\partial x} \left(U'(x)(1-\kappa) + \theta \frac{\partial}{\partial x} \right) P(x,t), \tag{2}$$

with a dimensionless parameter $\kappa \in [0,\ 1]$, and a measure of the noise strength θ. It is notable that the drift velocity is reduced by a factor of κ, since the potential-induced systematic motion amounts to the decorrelation of the noise, i.e. the noise fluctuates more rapidly. Our theoretical predictions are numerically confirmed by calculating the escape rate for the double-well potential and also the steady state distribution with use of the stochastic simulations of corresponding Langevin equation. Thermodynamic characterization of the steady state will be also discussed.

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Third quantization: a general method to solve master equations for quadratic open Fermi systems

Thomaz Prosen
University of Ljubljana Slovenia

Abstract: Using the concept of quantization in the Fock space of operators, the Lindblad master equation for an arbitrary quadratic system of n fermions is solved explicitly in terms of diagonalization of a 4n times 4n matrix, provided that all Lindblad bath operators are linear in the fermionic variables. As an example, the method is applied to the explicit construction of non-equilibrium steady states and the calculation of asymptotic relaxation rates in the far from equilibrium problem of heat and spin transport in a nearest neighbor Heisenberg XY spin 1/2 chain in a transverse magnetic field. Furthermore, we find and demonstrate a new type of far from equilibrium quantum phase transition with spontaneous emergence of long-range order in spin-spin correlation functions.

Exact analysis of the adiabatic invariants in time-dependent harmonic oscillator

Marko Robnik
Center for Applied Mathematics and Theoretical Physics, University of Maribor, Maribor, Slovenia

Abstract: The theory of adiabatic invariants has a long history, and very important implications and applications in many different branches of physics, classically and quantally, but is rarely founded on rigorous results. It began with the classical paper by Einstein in 1911, following a suggestion by Lorentz in the same year. We treat the general one-dimensional harmonic (linear) oscillator with time-dependent frequency whose energy is generally not conserved, and analyse the evolution of the energy and its statistical properties, like the distribution function of the final energies evolved from an initial microcanonical ensemble. This distribution function turns out to be universal, i.e. independent of the nature of the frequency as a function of time. The theory is interesting from the mathematical point of view as it comprises elements of the theory of dynamical systems, the probability theory and discrete mathematics, and sheds new light on the understanding of the adiabatic invariants in nonautonomous dynamical systems.

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Econophysics, Self-organized Criticality

Simplified stock markets modelled through bosonic operators

Fabio Bagarello
Dipartimento di Metodi e Modelli
Matematici, Facoltà di Ingegneri, Palermo, Italy

Abstract: We discuss how simplified stock markets can be modelled in terms of some non commuting operators which are used to describe, in particular, the portfolios of the various traders and other "observable" quantities. After few introductory considerations, we discuss a model of closed market with an arbitrary number of traders and in which a single kind of share is exchanged. We discuss approximated solutions for the time evolution of the portfolio of each trader and possible extensions of the model.

Detrending Moving Average Algorithm (DMA)

Anna Carbone
Physics Department, Politecnico di Torino, Torino, Italy

Abstract: We discuss properties and applications of a recently proposed method, the Detrending Moving Average (DMA), to investigate long-range correlated signals at varying scales. The extension of the DMA algorithm to higher dimensional fractals will be also presented. The DMA algorithm extracts information and statistical properties from long-range correlated signals related to general aspects of complex systems. In this talk, we will in particular address the problem to quantify some well-known "stylized facts" observed in financial series as the leverage effect, the volatility clustering and asymmetry by showing results obtained from 4 years of tick-by-tick data of the European Market (DAX, EuroStoxx, FIB30).

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Detecting special patterns in financial series via a universal data compression algorithm

Armin Shmilovici
Ben-Gurion University, Israel

Abstract: Universal compression algorithms can detect recurring patterns in any type of temporal data "including financial data" for the purpose of compression. The universal algorithms actually find a model of the data that can be used for either compression or prediction. We present a universal Variable Order Markov (VOM) model and use it to test of the weak form of the Efficient Market Hypothesis (EMH).

The EMH is tested for 12 pairs of international intra-day currency exchange rates for one year series of 1,5,10,15,20,25 and 30 minutes. Statistically significant compression is detected in all the time-series and the high frequency series are also predictable above random. However, the predictability of the model is not sufficient to generate a profitable trading strategy, thus, Forex market turns out to be efficient, at least most of the time.

Pattern Formation

Optimization of synchronization in gradient clustered networks

Lai Choy Heng
Office of the Provost, National University of Singapore, Singapore

Abstract: Complex clustered networks with a gradient structure, where the sizes of the clusters are distributed unevenly, are considered. Such networks describe actual networks in biological systems and in technological applications more closely than previous models. Theoretical analysis predicts that the network synchronizability can be optimized by the strength of the gradient field, but only when the gradient field points from large to small clusters. A remarkable finding is that, if the gradient field is sufficiently strong, synchronizability of the network is mainly determined by the properties of the subnetworks in the two largest clusters. These results are verified by numerical eigenvalue analysis and by direct simulation of synchronization dynamics on coupled-oscillator networks.

Specific features of non-Markovian kinetics of relaxation processes in nonequilibrium systems. Extensions of the continuous-time random walk approach

A.I. Shushin
Institute of Chemical Physics, Russian Academy of Sciences, Moscow, Russia

Abstract: Some specific features of non-Markovian relaxation processes in complex systems are analyzed in detail with the use of the extended continuous time random walk (CTRW) approach [1, 2]. The CTRW extensions are made within the CTRW-based non-Markovian stochastic Liouville equation [3], generalized to take into account the influence of relaxing systems on statistical properties of noise. The generalization is carried out using the Markovian representation of CTRW processes, in which the probability density function (PDF) $W(t)$ of fluctuation renewals is associated with that of reoccurrences in a certain jump state of some Markovian controlling process.

In this work a few applications of the generalized non-Markovian stochastic Liouville equation are discussed. In particular, we have studied two modifications of the CTRW approach corresponding two different "architectures" of kinetic coupling in complex systems.

One of them considers cascaded CTRWs in which the controlling process is actually CTRW-like one controlled by another CTRW process, controlled in turn by the third one, etc. The simple expression for the PDF $W(t)$ of total controlling process is obtained in terms of Markovian variants of controlling PDFs in the cascade. The expression is shown to be especially simple and instructive in the case of anomalous processes determined by long time tailed $W(t)$. The cascaded CTRWs can quite properly describe the effect of complexity of a system on relaxation kinetics (in glasses, fractals, branching media, ultrametric structures, etc. [2]).

Another CTRW-modification describes the kinetics of processes governed by fluctuating $W(t)$ whose fluctuations and correlations are described by some Markovian process. Within the Markovian representation the problem is analyzed in a general form without restrictive assumptions

on correlations of PDFs of consecutive renewals. The analysis shows that fluctuations of $W(t)$ can strongly affect the kinetics of the process. Possible manifestations of this effect are discussed.

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Persistent patterns and multifractality in fluid mixing

Bala Sundaram
Department of Physics, University of Massachusetts, Boston, Massachusetts, USA

Abstract: Stirring a fluid is usually viewed as an effective way to homogenize a mixture. However, in recent years, long term heterogeneities or 'persistent patterns' in periodically driven dynamics have been reported in a wide variety of contexts involving the advection of a passive scalar, which range from table-top to ocean-scale fluid mixing systems. The talk will illustrate a common framework for the emergence of these patterns by considering a simple measure of structure maintenance provided by the average radius of the scalar distribution in transform space. Unlike earlier suggested measures associated with the decay of various norms, this χ^2 measure provides an unambiguous signature for the formation of persistent patterns. Further, it provides insight into the basic mechanism and works well for both maps and flows. In both instances, scaling laws related to the formation and persistence of patterns in phase space are presented. Further, the dependence of the scaling exponents associated with the persistent patterns on the multifractal nature of the advective phase-space geometry will be discussed. Specifically, details in phase space are shown to dramatically alter the effectiveness of diffusion in eliminating concentration gradients in different ranges of values. In this context, the connection between single-period Floquet modes and persistence of patterns will be addressed, with a brief discussion of the small diffusion limit.

Statistical characteristics of the gap soliton dynamics in random media

Eduard N. Tsoy

Physical-Technical Institute of the Uzbek Academy of Sciences, Tashkent, Uzbekistan

Abstract: In this paper we analyze the dynamics of gap solitons in media with spatial disorder. A gap soliton (GS) is a stable pulse that can propagate without distortion in nonlinear periodic medium. The carrier frequency of such pulses is inside the band gap of linear waves. The GSs have been observed in optical systems (Bragg gratings and photonic crystals) and in Bose-Einstein condensates. The propagation of GSs in *regular* structures is well studied theoretically and experimentally [1]. However, the dynamics of GSs in *random* environment is less explored subject.

This problem is related to the more general question, which attracted an attention recently [2], of interplay between nonlinearity and disorder in the wave dynamics.

We show that a GS with a low velocity can be trapped inside the random structure. We demonstrate that the trapping occur between the peaks of an effective potential. The effective potential is obtained as a result of the spectral filtering of disorder by the soliton. The statistical properties of the effective potential are found for the case of δ-correlated disorder. We also relate the problem of the soliton trapping to the problem of the level crossing by a random function. This allows us to estimate a mean value of the interval, where the soliton is trapped, and a probability of trapping on a given propagation length.

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Disaster Modeling and Forecasting

Tsunami asymptotics

Michael Berry
Physics Department, University of Bristol, Bristol, UK

Abstract: For most of their propagation, tsunamis are linear dispersive waves whose speed is limited by the depth of the ocean and which can be regarded as diffraction-decorated caustics in spacetime. For constant depth, uniform asymptotics gives a very accurate compact description of the tsunami profile generated by an arbitrary initial disturbance.

Vartiations in depth can focus tsunamis onto cusped caustics, and this 'singularity on a singularity' constitutes an unusual diffraction problem, whose solution indicates that focusing can amplify the tsunami energy by an order of magnitude.

New Approaches to the Modelling and Forecast of Epidemics in a Globalized World

T. Geisel
Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

Abstract: The efficiency of epidemic modelling and forecasts has suffered in the past from a poor description of the *spatial* dynamics. Accurate models are needed e.g. to test potential strategies to control the spread of an epidemic. While the *local* infection dynamics is well understood for many diseases, little was known about the statistical laws by which humans and their germs disperse. We have simulated the dispersal of pathogens by international air traffic in a comprehensive network model and used it to forcast the spreading of SARS; it can be used to test the efficiency of various control strategies.

To obtain a better spatiotemporal resolution we need the statistical laws governing human travel on all scales, i.e. by all means of transportation. As accurate data were previously not available, we have studied this problem empirically and theoretically using the dispersal of dollar bills as a proxy. The time dependent probability density obtained in this way exhibits pronounced spatiotemporal scaling and superdiffusive spreading, which we model by an ambivalent Lévy random walk. The empirical data can be described very accurately in terms of a bifractional diffusion equation with few parameters.

References

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Theory of Earthquake Recurrence Times

A. Saichev
State University of Nizhni Novgorod, Nizhni Novgorod, Russia

Abstract: The statistics of recurrence times in broad areas have been reported to obey universal scaling law. These unified scaling laws are characterized by intermediate power law asymptotic. We develop the full theory of the statistics of inter-event times in the framework of the ETAS model of triggered seismicity and show that the empirical observations can be fully explained. Our theoretical expression fits well the empirical statistics over the whole range of recurrence times, accounting for different regimes by using only the physics of triggering quantified by Omori law. The description of the statistics of recurrence times over multiple regions requires an additional subtle statistical derivation that maps the fractal geometry of earthquake epicenters onto the distribution of the average seismic rates in multiple regions. This yields a prediction in excellent agreement with the empirical data for reasonable values of the fractal dimension, the average clustering ratio and the productivity exponent. Our predictions are remarkably robust with respect to the magnitude threshold used to select observable events.