Abstracts of Short Reports

Geometric Correlations and Breakdown of Mesoscopic Universality in Spin Transport: From Spin Hall Effect to Topological Insulators

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In this talk I will discuss recent developments in semiclassical theory of spin transport. In particular, I will show how conventional theory of semiclassical transport is not able to describe spin transport phenomena in which charge currents generate pure spin currents or spin accumulations, namely spin Hall and Edelstein effects. I will then show how to construct a unified semiclassical theory of charge and spin transport in chaotic ballistic and disordered diffusive mesoscopic systems with spin-orbit interaction. Within the unified theory, the random matrix theory prediction that the spin conductance fluctuates universally around zero average, can be produced only by disregarding dynamic effects of spin-orbit interaction. However, these dynamic effects conspire together with geometric Hall correlations to generate finite average spin conductances, thus generating mesoscopic version of the spin Hall and Edelstein effects. The theory, which is confirmed by numerical transport calculations, allows the investigation of the entire range from the weak to the previously unexplored strong spin-orbit regime (i.e. the regime in which the spin rotation time is shorter than the momentum relaxation time). I will also discuss how these geometric correlations can be utilized to search for signs of Berry curvature of the underlying band structure in phase coherent transport. As an example I will focus on an n-doped 2d topological insulator mesoscopic structure, and show how geometric correlations can be utilized to obtain the Berry curvature from the weak spin-localization signal. Finally, I will discuss how spin currents generated with geometric Hall correlations interact with the topological insulator edge states thus generating observable signals in charge conductance.

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Transport properties of one-dimensional quantum chains –Lindblad approach, and C* algebraic approach –

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Despite recent developments of frameworks to study nonequilibrium systems, there is no consensus on which gives the appropriate way to deal with nonequilibrium states. Unfortunately, inconsistent results for the same systems due to different frameworks have been reported, and there is no consensus among them.
Therefore, it is of great importance to study simple systems, and to see the differences among the existing frameworks. As one of the simplest examples, we study a one dimensional fermionic chain. We mainly present the following two aspects.

1 Comparison among different methods.
We study transport properties of one dimensional periodic chains by using C* algebra and Lindblad equation. In the study of C*algebra, we study NESS (nonequilibrium steady state) of (1) infinite chain, and (2) finite chain coupled to infinite reservoirs at the edge of the chain.
For the system (2), we also discuss condition under which unique steady state exists.
In the study of Lindblad equation, we study a finite chain coupled to *infinite reservoirs* which are forced to different equilibria by a Lindblad operator. We use the technique of canonical quantization in the Fock space of operators, and discuss properties of NESS and relaxation to this NESS.

2 Transport properties of quasi-periodic and disordered chains
Using the Lindblad approach explained, we have studied quasi-periodic and disordered chains.

Microwave Measurements on Graphene-like Structures

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An experimental realization of finite tight binding graphene-like structures in a microwave setup is presented. The structures are realized using cylindric discs with a high index of refraction which are placed on a metallic surface. A second surface is adjusted atop the discs, such that the waves coupling the discs in the air are evanescent. In 2, 3 and 6 discs measurements we assured the validity ot the tight binding approximation. In reflection measurements performed in the centre of hexagonal lattices including 200 discs reminiscences of the Dirac point are observed, whereas resonances close to the Dirac points are found if the measurements are performed at the zigzag-edges or at the corner in case of a broken benzene ring.

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Velocity dynamics in conformally breathing billiards

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A point particle is moving freely inside a time varying domain while experiencing elastic reflections on its boundary. The energy is not conserved and can reach arbitrarily large value (Fermi acceleration). According to many numerical simulations in various billiard systems where Fermi acceleration is observed the mean velocity of an ensemble of particles follows the power law $\langle v \rangle = n^{\beta}$, where n is the number of collisions and β is the system dependent acceleration exponent. We shall present the first theoretical derivation [1] of $\beta = 1/6$ for important class of conformally breathing fully chaotic billiards. We shall also analyze the velocity dynamics of a single trajectory, independent of the properties of the underlying static billiard.

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DISOREDERED QUANTUM WIRE SWITCHING CAPABILITIES

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Development and miniaturization in the field of electronic components has achieved the stage, when devices make use of quantum coherent effects. Materials with anomalously high Fermi surface anisotropy are common in nanoscale. Transport characteristics of these systems are highly anisotropic, so while conductivity in chosen directions has typical metallic behavior, in localized dimensions we deal with jumps between layers, or even transport is denied. We give numerical analysis of controlling electric field effect on one-dimensional atom chain represented with a curve. Curve shape corresponds topology of several real systems; gaussian and angular shapes are used. In one-dimensional case we exploit Kronig-Penney model with atom potential disorder to calculate conductivity: time-independent Schrodinger equation is represented as recurrent equation [1]. Due to the absence of non-coherent scattering in the system we observe nonlinear field intensitiy. The dependence of transparencyversus field intensity can render a possible use in high-frequency switches. The second model represents a planar nanoscale curved channel of a finite width and previously defined shape with one electron passing through. We used Split-Step Fourier method. High amount of calculations required supercomputer usage. We compared results both model results. In every case transparency can be controlled by transverse field.

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Air Entrainment by Advancing Contact Lines

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The entrainment of air by a liquid jet plunging into a liquid reservoir has been studied in great detail. By contrast, the situation of a plunging solid, for which there is a moving contact line, is much less understood. We investigate this phenomenon experimentally by plunging a smooth solid plate into a reservoir of viscous silicone oil of different viscosities. When the plate speed is above a critical value, the surrounding air will be entrained to the liquid phase and form a thin air film. The air film is not stable but breaks up into small air bubbles quickly. We found that the critical speed for air entrainment depends on the oil viscosity in power law with scaling -1/3.

Semiclassics of Andreev Billards

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When coupling a superconductor to a normal conducting region the physical properties of the system are highly affected by the superconductor. One of the best known phenomena of such heterostructures is the induction of Cooper pairs into the normal region also known as the proximity effect. This proximity effect is also highlighted by Andreev reflection where an electron hitting the superconductor is retro-reflected as a hole and vice versa. The resulting behaviour enables one to decide whether the classical counterpart of the system is chaotic or not. While for integrable systems the density of states is suppressed exponentially for energies close to the Fermi energy, for chaotic systems a gap opens.

We combine a trajectory based semiclassical approach with Andreev reflection to show how subtle correlations between classical paths lead to a formation of the gap in the density of states for chaotic systems. We also include a phase difference between two superconductors and see how the phase difference reduces the effect of the superconductors due to the decoherence induced by the Andreev reflection. This approach can also be extended to the conductance and the thermopower of Andreev billards. We will see that the proximity of the superconductor leads to a quantum increase or decrease of the conductance of the same order as the classical conductance, depending on the size and the phase of the superconductor. Moreover we see how the correlations of the classical paths give rise to a finite antisymmetric thermopower showing that for Andreev billiards this is a purely quantum mechanical property.

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INTEGRABILITY CONDITIONS OF SOME COMPLEX SYSTEMS WITH HOMOGENEOUS NONLINEARITIES

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The problem of integrability of systems of differential equations is one of central problems in the theory of ODE's. Integrable systems are important in studying various mathematical models, since often perturbations of integrable systems exhibit rich picture of bifurcations.

Consider the center problem of system

$$\begin{aligned} \dot{x} &= x - a_{40}x^5 - a_{31}x^4y - a_{22}x^3y^2 - a_{13}x^2y^3 - a_{04}xy^4 - a_{-15}y^5, \\ \dot{y} &= -y + b_{5,-1}x^5 + b_{40}x^4y + b_{31}x^3y^2 + b_{22}x^2y^3 + b_{13}xy^4 + b_{04}y^5, \end{aligned} \tag{1}$$

where x, y, a_{ij}, b_{ji} are complex variables. It turns out the computations involved to the determination of the necessary conditions of integrability for the full family (2) are so heavy that they cannot be completed even using powerful computers and modern algebra systems. Thus, it is reasonable to study some subfamilies of system (2). Recently, the integrability conditions for the subfamily of (2), with $a_{-15} = b_{5,-1} = 0$, called Lotka-Volterra system, have been obtained in [1]. We study the integrability of system (2) with $a_{-15} = b_{5,-1} \neq 0$ and we found necessary conditions for existence of the local first integral for four subfamilies of this system. For the most cases we show that the obtained conditions are also sufficient conditions for existence of the local first integral.

We study also the integrability of the quartic system

$$\begin{aligned} \dot{x} &= x - a_{30}x^4 - a_{21}x^3y - a_{12}x^2y^2 - a_{03}xy^3 - a_{-1,4}y^4, \\ \dot{y} &= -y + b_{4,-1}x^4 + b_{30}x^3y + b_{21}x^2y^2 + b_{12}xy^3 + b_{03}y^4. \end{aligned} \tag{2}$$

For the particular subfamily of (2), where $a_{-1,4} = b_{4,-1} = 0$, we first find necessary conditions for integrability. Then we construct first integrals of the corresponding systems or at least show, that under the obtained conditions such integrals exist.

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STATISTICAL PROPERTIES OF TIME-DEPENDENT SYSTEMS

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We study some dynamical properties of time dependent systems. It is well known that the structure of the phase space depends on the individual characteristics of each system. Here, we consider the two types, namely, one integrable (elliptical billiard [1,2]) and one mixed (Standard map [3]). Our main goal is to understand and describe the behaviour of the particle's average velocity (and hence its energy) as a function of the number of collisions considering both, the conservative as well as the dissipative dynamics. For the dissipative case we consider two kinds of dissipation, namely, collisional dissipation and in-flight dissipation. Our results confirm that unlimited energy growth is observed for the non-dissipative case in the three cases. However, when dissipation is introduced via inelastic collisions or in-flight dissipation, the scenario changes and the unlimited energy growth is suppressed, thus leading to a phase transition from unlimited to limited energy growth. The behaviour of the average velocity is described using scaling arguments. Finally, we propose a new universal empirical function to describe this scaling behavior with only one parameter left, namely the acceleration exponent.

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Probing decoherence through Fano resonances

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We investigate the effect of decoherence on Fano resonances in wave transmission through resonant scattering structures. We show that the Fano asymmetry parameter q follows, as a function of the strength of decoherence, trajectories in the complex plane that reveal detailed information on the underlying decoherence process. Dissipation and unitary dephasing give rise to manifestly different trajectories. Our predictions are successfully tested against microwave experiments using metal cavities with different absorption coefficients and against previously published data on the temperature dependence of transport through quantum dots.

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DELOCALIZATION IN A NONLINEAR GENERALIZATION OF THE QUANTUM KICKED ROTOR

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One of the most interesting effects discovered in the domain of quantum chaos is the quantum suppression of classical chaotic diffusion. It was first observed numerically in the quantum kicked rotor model. This phenomenon in many aspects can be considered as the dynamical version of Anderson localization in the tight-binding disordered models. However, in the case of quantum chaos there is no randomness and transient diffusion in the corresponding classical system. Namely, the dynamical localization in a quantum kicked rotor occurs in a completely deterministic system. The realization of the Bose-Einstein condensates in dilute gases has opened a new opportunity for investigating dynamics of the many-body systems in the presence of interactions between their constituents. In the mean field approximation, the interactions can be modeled by adding a cubic nonlinear term in the corresponding Schrödinger equation. This approach can be extended to the quantum kicked rotor model resulting in its nonlinear generalization. Our aim is to utilize such model, which was introduced by Shepelyansky, in order to understand how the nonlinearity generally affects the kicked rotor model. Particularly, we aim to understand the influence of nonlinearity on dynamical localization. The special concerns are to identify a critical nonlinear strength above which localization is destroyed, and mechanism of the localization destruction. Finally, we consider the corresponding anomalous subdiffusion law in the destruction regime, compare it with the subdiffusion laws derived in other nonlinear system with disorder, and test its universality.

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Non-equilibrium phase transition in a periodically driven XY spin chain

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We present a general formulation of Floquet states of periodically time-dependent open Markovian quasi-free fermionic many-body systems in terms of a discrete Lyapunov equation. Illustrating the technique, we analyze periodically kicekd XY spin 1/2 chain which is coupled to a pair of Lindblad reservoirs at its ends. A complex phase diagram is reported with re-entrant phases of long range and exponentially decaying spin-spin correlations as some of the systems parameters are varied. The structure of phase diagram is reproduced in terms of counting non-trivial stationary points of Floquet quasi-particle dispersion relation.

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Covariant Lyapunov Analysis of Chaotic Kolmogorov Flows and Time-correlation Functions

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We study a hyperbolic/non-hyperbolic transition of the flows on two-dimensional torus governed by the incompressible Navier-Stokes equation (Kolmogorov flows) using the method of covariant Lyapunov analysis developed by Ginelli et al.(2007). As the Reynolds number is increased, chaotic Kolmogorov flows become non-hyperbolic at a certain Reynolds number, where some new physical property is expected to appear in the long-time statistics of the fluid motion. Here we focus our attention on behaviors of the time-correlation function of vorticity across the transition point, and find that the long-time asymptotic form of the correlation function changes at the Reynolds number close to that of the hyperbolic/non-hyperbolic transition, which suggests that the time-correlation function reflects the transition to non-hyperbolicity.

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Manifold structures of unstable periodic orbits and the appearance of periodic windows in chaotic dynamical systems

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It is known that properties of chaos can be characterized in terms of unstable periodic orbits. In this presentation, manifold structures of the Lorenz system and the Kuramoto-Sivashinsky system are investigated in terms of unstable periodic orbits embedded in the attractor. Especially, the change of manifold structures are focused on when some parameter values are varied.

It is found that the angle between a stable manifold and an unstable manifold (manifold angle) at sample points on an unstable periodic orbit, which is measured by using the covariant Lyapunov vectors, characterizes the parameter at which the periodic window corresponding to the unstable periodic orbit finishes, that is a saddle-node bifurcation point. In particular, when the minimum value of the manifold angle along an unstable periodic orbit is small (large), the corresponding periodic window exists near (away from) the parameter. It is concluded that the window sequence in a parameter space can be predicted from the manifold angles of unstable periodic orbits at some parameter. This approach helps us find periodic windows including quite small ones.

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TIME-SPACE DISTRIBUTED MODEL OF DYNAMIC AND POWER CHARACTERISTICS SOLID STATE LASERS

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Solid-state lasers with diode pump are very attractive because of their compactness, high output, high efficiency. The configurations of such lasers are rather different. Geometrical and power parameters optimization issues for this laser type remain actual. However, problems of optimization are being solved still only in the case of steady-state regime. This excludes important issues from consideration such as lasing formation process.In our paper [1], we introduced semi-classical model of one-dimensional distributed laser system. This model makes possible to describe evolution of spatially-distributed laser generation for Er-Yb laser with longitudinal and transversal diode pumping. We generalized model [1] for solid lasers, particularly, for the laser with neodim ions. We did numeric simulation of fiber lasers and short lasers. Optimization characteristics for threshold and pump, slope and geometric parameters of active medium were obtained. Also, evolution of the system was investigated, transitional characteristics were reconsidered via spatially-distributed model. We demonstrated, that optimization is possible not only for fiber lasers, but also for short lasers.

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Newtonian and special-relativistic probability densities for a low-speed system

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The Newtonian and special-relativistic predictions for the position and momentum probability densities of a model low-speed (i.e., much less than the speed of light) dynamical system are compared. The Newtonian and special-relativistic probability densities, which are initially the same Gaussian, are calculated using an ensemble of trajectories. Contrary to expectation, we show that the predictions of the two theories can rapidly disagree completely. This surprising result raises an important fundamental question: which prediction is empirically correct?

Periodic orbits and transport in mixed phase spaces

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Though the transport properties of chaotic systems are computable from periodic orbits, in practice, such computations are easiest to realize in sufficiently hyperbolic systems dominated by short orbits. Phase spaces exhibiting a mixture of chaos and regularity, however, present a greater challenge, owing to the richer topological dynamics in the vicinity of stable islands and the importance of longer orbits. We demonstrate how, using a sufficiently accurate symbolic dynamics, periodic orbit techniques can compute classical decay rates even in a strongly mixed phase space.

SYMMETRY REDUCTIONS OF A FAMILY OF TIME-DEPENDENT ANHARMONIC OSCILLATORS

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Some group theoretic methods for integrating differential equations due to S. Lie and E. Noether are introduced and then applied to a class of time-dependent nonlinear second order differential equations.

In particular, in the first part of this talk some basic concepts will be briefly introduced; namely: continuous groups of transformations and their infinitesimal generators, the concept of a symmetry of a differential equation, simple methods of finding those symmetries (using Lie's algorithm) and how to use them (how to reduce the order of the equation by one, or two in the case of Noether symmetries for equations derived from a variational principle) [1,2,3].

In the second part, Lie's method will be applied to a class of time-dependent, nonlinear oscillators with cubic nonlinearity [4]. A classification of different cases with respect to their Lie point symmetries will be presented and the corresponding reductions of the order of each equation will be given. In some of these cases a second reduction, i.e. integration, is possible due to the special character of the symmetry, namely to preserve also the action integral (that is to be of Noether type). In such cases explicit exact analytic solutions of the underlying systems are given.

This analysis was motivated by the studies of the adiabatic invariants and of the statistical properties of time dependent Hamiltonian systems, the linear and nonlinear oscillators, and finds application in this context, see [5,6] and references there in.

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How horseshoes are destroyed and what comes afterwards

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We investigate the dynamics of strongly dissipative Henon maps at the first bifurcation parameter at which the uniform hyperbolicity is destroyed by the formation of tangencies inside the limit set. In a parameter interval of transition from horseshoes to chaotic attractors, we prove that the relative frequency of chaotic transient tends to one as the Jacobian tends to zero. We also present numerical results which support the conjecture of Grebogi, Kan, Lai & Yorke on the frequency of non-hyperbolic chaotic transient.

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HEAT TRANSPORT IN QUANTUM HARMONIC CHAINS WITH REDFIELD BATHS

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Numerical or analytical investigation of open many-body quantum systems is a demanding task due to the exponential increase of the dimension of the Hilbert space. Consequently, there is a lack of explicit analytical results, which exist mainly for small systems, despite the fact that many simple cases of the effective Redfield and Lindblad master equations have been studied. The Redfield and the Lindblad master equations for general quadratic fermionic or bosonic systems can be solved explicitly by using canonical quantization in the Fock space of operators - third quantization for short. This method was used to find and explain the novel, non-equilibrium quantum phase transition in the one-dimensional XY spin 1/2 chain and to calculate some explicit analytic results for the transport coefficients in the harmonic oscillator chain and the XXZ model.

We will consider the third quantization for bosons on the example of the harmonic oscillator chain and derive some explicit results for the thermal conductance. Possible extensions and applications of the method to interacting models will be discussed.

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