Abstracts of Talks

Visualization of the hierarchy of regular tori in 4d maps

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For a generic 4D symplectic map we visualize the global organization of regular tori using 3D phase-space slices. The regular 2-tori are shown to be arranged around a skeleton of elliptic 1-tori. The 1-tori occur in two types of one-parameter families: (so-called) Lyapunov families emanating from elliptic-elliptic periodic orbits and families originating from rank-1 resonances. At resonance gaps of both types of families periodic orbits may occur, similar to the Poincaré-Birkhoff theorem for 2D maps. Based on this we describe the hierarchical structure of regular tori in the 4D phase space. Each level of the hierarchy can result from three types of structures which generalizes the islands-around-islands hierarchy in 2D maps. As an application we consider the representation of eigenstates of the corresponding quantum map to investigate the semiclassical eigenfunction hypothesis.

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Complexity Aspects of Hamiltonian Dynamics and Statistics

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As is well known, many problems of classical mechanics, celestial mechanics and solid state physics, when dissipation is neglected, are expressed in Hamiltonian form and deal with multi-dimensional systems of interacting mass particles. These typically execute oscillatory motions near stable equilibria and the most frequently asked questions concern the amplitudes and frequencies of these oscillations. However, since the interactions are fundamentally nonlinear, unstable equilibria become important as the total energy increases, causing the motion to drift into chaotic domains where the oscillations become unpredictable and statistical mechanics is expected to take over. In this presentation, I will first mention some very efficient techniques for distinguishing regular from chaotic domains in Hamiltonian systems of many degrees of freedom. More importantly, I will describe some complex aspects of Hamiltonian dynamics and statistics, demonstrating "hierarchies" of order, weak and strong chaos and discuss the role of long vs. short range interactions.

Dedication: *This lecture is dedicated to Professor Marko Robnik, with affection for his 60th birthday and appreciation for his contributions to the field of Hamiltonian systems, classical and quantum.*

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Conservation laws, symmetry breaking and control of the heat current

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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. Indeed, a model of thermal rectifier has been recently proposed in which heat can flow preferentially in one direction. The proposed rectifying mechanism is of very general nature and theoretical and experimental work is currently undergoing.

In particular we discuss here the possibility to increase the rectifying factor by orders of magnitude. We then discuss a new approach, which is rooted in nonlinear dynamical systems, for increasing the efficiency of thermoelectric machines. The main focus will be on the physical mechanisms, unveiled by these dynamical models, which lead to high thermoelectric efficiency, approaching the Carnot limit. The role of conservation laws and symmetry breaking will be emphasized.

String Theory Confronts Particle Physics and Black Holes

Mirjam Cvetic

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String theory, as the prime candidate for quantum unification of particle physics and gravity, sheds light on important fundamental questions such as the microscopic structure of black holes and the geometric origin of particle physics. We review these developments such as the introduction of extended objects - Dirichlet branes - and highlight the important geometric role of these objects in deriving particle physics from string theory, including recent progress within string theory at finite coupling (F-theory), as well as their role in deriving the black hole microscopics, including recent progress for non-extremal black holes.

Planetary systems and the formation of habitable planets

Rudolf Dvorak

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Since the last 20 years many planets around other system were detected either from the ground or by space missions. More than 1100 planetary systems with more than one discovered planet are known but for planets being habitable many conditions need to be fulfilled: e.g. the spectral type and age of the hosting star, the location in our galaxy and also the orbit of a planet and its physical nature. Different estimates lead to quite different results especially for planet which host in fact life. In this talk different results and aspects concerning this question will be addressed.

Quantum chaotic subdiffusion in random potentials

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Two interacting particles (TIP) in a disordered chain propagate beyond the single particle localization length ξ_1 up to a scale $\xi_2 > \xi_1$. An initially strongly localized TIP state expands almost ballistically up to ξ_1. The expansion of the TIP wave function beyond the distance $\xi_1 >> 1$ is governed by highly connected Fock states in the space of noninteracting eigenfunctions. The resulting dynamics is subdiffusive, and the second moment grows as $m_2 \sim t^{1/2}$ [1], precisely as in the strong chaos regime for corresponding nonlinear wave equations [2-7]. This surprising outcome stems from the huge Fock connectivity and resulting quantum chaos. The TIP expansion finally slows down towards a complete halt - in contrast to the nonlinear case.

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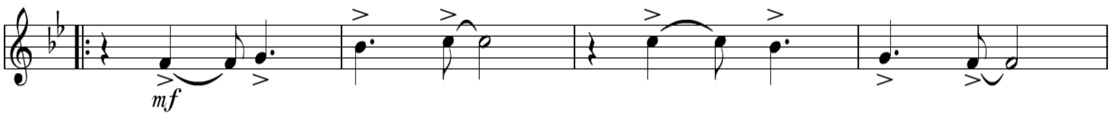

Rhythms, Algorithms, and Self-Similarity in Music

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Even the best musicians do not play rhythms with perfect precision. Slight deviations from an ideal beat pattern are a fundamental characteristic of music played by humans. This talk investigates the statistical laws underlying rhythmic fluctuations and their role in musical perception. Based on these findings one can make computer generated music sound more human. Audio examples from the Art of Fugue to stochastic music highlight the general role of long range correlations and self-similarity in music for its perception by the information processing in our brains.

Different paths to spectral universality

Fritz Haake

Universität Duisburg-Essen

Numerical case studies reveal that dynamics with full chaos in their classical limit show universal fluctuations in their two-point function of the quantum level density, at least within the window(s) of (quasi-)energies where correlations persist above some small noise level. Good understanding of such universality has by now been reached by four different methods:

> (i) Random matrix theory provides ensembles of (Hermitian and unitary) matrices phenomenologically describing symmetry classes of Hamiltonians of Floquet maps and predicts closed-form expressions for the two-point function within certain symmetry classes; moreover, the variances of that function are shown to be inversely proportional to the matrix size N such that for $N \rightarrow \infty$ all matrices have the same (universal) spectral fluctuations.
>
> (ii) 'Level dynamics' maps the dependence of quantum levels on some control parameter to the time evolution of some fictitious classical many-particle system whose equilibrium statistics is equivalent to random-matrix theory.
>
> (iii) Gutzwiller's periodic-orbit theory allows to calculate spectral characteristics like the two-point function as the sum of contributions from bunches of near action degenerate orbits, thus recovering the RMT results for individual quantum systems.
>
> (iv) The field theoretic method known as supersymmetric sigma model reveals the periodic-orbit sums as perturbation expansions and even comes with more powerful non-perturbative procedures.

I shall briefly describe the relative status of the four approaches.

Random Matrix Theory approach to Thermal Transport in Complex Lattices

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Using random matrix theory modeling we investigate the thermal transport in networks of N oscillators coupled harmonically with random springs. When the network is assumed to be fully connected we show, that both the average phonon heat current and its variance are scale invariant and take universal values in the large N limit. These anomalous mesoscopic fluctuations are the hallmark of strong correlations between normal modes. In the case of quasi-one dimensional networks with finite connectivity between nearby oscillators, we show that the heat current obeys a one-parameter scaling law. The resulting β function indicates that an anomalous Fourier law is applicable in the diffusive regime, while in the localization regime the heat current decays exponentially with the sample size. Our approach opens a new way to investigate the effects of Anderson localization in heat conduction based on the powerful ideas of scaling theory and random matrix theory modeling.

Charge transport in single layer graphene: beyond massless Dirac fermion approach

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Approaches to theoretical description of change transport in single layer graphene are discussed. Consequent quantum field theory approach has been proposed. It generalizes known massless Dirac fermion model and is based on the Dirac – Hartree – Fock self-consistent field approximation and assumption on antiferromagnetic ordering of graphene lattice. The developed approach allows asymmetric charged carriers in single layer graphene with partially degenerated Dirac cones. Some open problems of graphene physics are also discussed.

Chaotic and Unstable Behaviour of Quantum Colour Particles in QCD Vacuum

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Quantum colour particles are considered in stochastic vacuum of Quantum Chromodynamics (QCD) as environment, with density matrix averaged over external QCD vacuum degrees of freedom. Density matrices decoherence rates, purities, Von Neumann entropies, fidelities are calculated for different pure, mixed, separable, entangled colour states. It is shown that in confinement region (Wilson loop decays exponentially) colour particle movement is chaotic and unstable, order-chaos transition appears with critical energy depended on Higgs mass and coupling constant, density matrixes lose nondiagonal elements, final states become mixed and colourless, quantum squeezing and entanglement of colour particles appear.

Probing the role of accelerator modes on the dynamical localization properties of the quantum kicked rotator and on the anomalous diffusion of its classical analogue

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In the first part of the talk, we study the *N*-dimensional model of the quantum kicked rotator in the classically fully chaotic regime, which in the limit of sufficiently large *N* tends to the quantized kicked rotator. We describe the features of dynamical localization of chaotic eigenstates as a paradigm for other both time-periodic and time-independent (autonomous) fully chaotic or/and mixed type Hamilton systems. We generalize the scaling variable to the case of anomalous diffusion in the classical phase space, by deriving the localization length for the case of generalized classical diffusion. We greatly improve the accuracy and statistical significance of the numerical calculations, giving rise to the following conclusions: (i) The level spacing distribution of the eigenphases is very well described by the Brody distribution, systematically better than by other proposed models. (ii) We study the eigenfunctions of the Floquet operator and characterize their localization properties using the information entropy measure. (iii) We show the existence of a scaling law between the localization parameter and the relative localization length, now including the regimes of anomalous diffusion.

In the second part, we focus on the effect of the anomalous diffusion arising due to the accelerator modes in the classical kicked rotator, exemplified by the standard map. The systematic approach rests upon detecting the regular and chaotic regions and thus to describe in detail the structure of the phase space, the description of the momentum distribution in terms of the Lévy stable distributions, the numerical calculation of the diffusion exponent and of the corresponding diffusion constant. We use this approach to analyze in detail and systematically the standard map at all values of the kick parameter K, up to K=70. All complex features of the anomalous diffusion are well understood in terms of the role of the accelerator modes, mainly of period 1 at large $K \geq 2\pi$, but also of higher periods (2,3,4,...) at smaller values of $K \leq 2\pi$.

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Coulomb blockade dynamics in biological ion channels

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Biological ion channels are natural nanopores that provide for fast and selective permeation of physiologically important ions (e.g. Na^+, K^+ and Ca^{2+}) through cellular membranes. Although a great deal is now known about ion channels, including their detailed atomic structure in some cases, this information has helped surprisingly little in understanding how they actually work: the central conundrum – their ability to conduct almost at the rate of free diffusion while remaining highly selective for particular ions – remains largely unresolved. We show that treating it as a problem in nonlinear dynamics under the influence of electrostatic forces can account for numerous experimental observations.

In particular, we hypothesise that many of the complex permeation and selectivity phenomena of biological ion channels can be described in terms of a much simpler and well-studied system – the quantum dot.[1] We infer that permeation is governed by ionic Coulomb blockade (ICB),[2] a discrete electrostatic phenomenon closely analogous to its quantal counterpart.[1] It immediately explains the conduction bands seen in Brownian dynamics simulations3 as the fixed negative charge Qf at the selectivity filter (SF) is varied. They are Coulomb blockade oscillations[4] between stop bands Z_n (blockade by an ion trapped in the channel, cf. an electron trapped in a dot) and conduction bands M_n corresponding to resonant conduction. Singular points of the ICB oscillations are given by

$$\begin{aligned} Z_n &= zen \pm \delta Z_n, && \text{Coulomb blockade} \\ M_n &= ze(n+1/2) \pm \delta M_n && \text{Resonant conduction} \end{aligned} \qquad (1)$$

where e is the elementary charge, z the valence, $n = 0, 1, 2...$ the number of ions captured at the SF, and δZ_n, δM_n are possible band shifts to account for affinity, ion-ion interactions and hydration.

Equation (1) is similar to its electronic counterpart[1] but the positions M_n, Z_n of the ICB bands are proportional to z, thereby providing an explanation for valence selectivity. The model also enables bands to be identified with particular channels5 and accounts for the shapes of the conduction bands and occupancy transitions.[3,6] The detailed geometry of the SF has little influence on valence selectivity, for which the magnitude of Qf is the dominant factor, but it may be very important for alike charge selectivity: the explicit inclusion of hydration effects[7] in Eqs. (1) promises to pave the way to the first generalised model of selectivity. The specific prediction of the ICB model (1) – the existence of a universal periodic pattern of conduction bands M_n separated by stop bands Z_n – is already well-supported by simulations and by the identification of mutant channels.[3,8]

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Quantum Chaos in Hadron Spectra

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Quantum-chaotic behaviour has been identified in quantum spectra quite some time ago according to the Bohigas-Giannoni-Schmit conjecture using random matrix theory [1]. We shall discuss the appearance of quantum chaos in relativistically invariant quantum-mechanical spectra of hadrons (mesons and baryons) [2]. They are considered as two- and three-body systems of confined quarks interacting by different hyperfine interactions matching the experimentally measured energy levels [3]. While the spectra of quarks with only confinement – which has been often modelled by harmonic forces and is more realistically described by a linearly rising potential – are found to be regular, they exhibit chaotic behaviour upon the introduction of hyperfine interactions, motivated by quantum chromodynamics [4]. We consider hadron spectroscopy as a laboratory for studying quantum chaos, irrespective of the approach ranging from relativistic constituent-quark models [5] to lattice gauge theory [6].

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Semiclassical Paths to Many-Body Quantum Interference

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Semiclassical methods in Quantum Chaos have been mainly successfully applied to single-particle quantum systems with corresponding low-dimensional chaotic dynamics. The generalization to interacting many-body systems remains to be one of the major challenges in this field. I will review first steps that have been made in my group [1-3] to devise semiclassical many-particle techniques. In particular, I will discuss a many-body representation of the Gutzwiller-Van Fleck propagator and show how this allows for investigating coherent backscattering and echo phenomena in Fock space, arising from many-body quantum interference.

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Statistical properties of one-dimensional time-dependent Hamiltonian oscillators

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Recently the interest in time-dependent dynamical systems has increased a lot. In this talk I shall present most recent results on time-dependent one-dimensional Hamiltonian oscillators. The time-dependence describes the interaction of an oscillator with its neighborhood. While the Liouville theorem still applies (the phase space volume is preserved), the energy of the system changes with time. We are interested in the statistical properties of the energy of an initial microcanonical ensemble with sharply defined initial energy, but uniform distribution of the initial conditions with respect to the canonical angle. We are in particular interested in the change of the action at the average energy, which is also adiabatic invariant, and is conserved in the ideal adiabatic limit, but otherwise changes with time. It will be shown that in the linear oscillator the value of the adiabatic invariant always increases, implying the increase of the Gibbs entropy in the mean (at the average energy). The energy is universally described by the arcsine distribution, independent of the driving law. In nonlinear oscillators things are different. For slow but not yet ideal adiabatic drivings the adiabatic invariant at the mean energy can decrease, just due to the nonlinearity and nonisochronicity, but nevertheless increases at faster drivings, including the limiting fastest possible driving, namely parametric kick (jump of the parameter). This is so-called PR property, following Papamikos and Robnik *J. Phys. A: Math. Theor.* **45** *(2012) 015206*, proven rigorously to be satisfied in a number of model potentials, such as homogeneous power law potential, and many others, giving evidence that the PR property is always sastified in a parametric kick, except if we are too close to a separatrix or if the potential is not smooth enough. The local analysis is possible and the PR property is formulated in terms of a geometrical criterion for the underlying potential. We also study the periodic kicking and the strong (nonadiabatic) linear driving of the quartic oscillator. In the latter case we employ the nonlinear WKB method following Papamikos and Robnik *J. Phys. A: Math. Theor.* **44** *(2012) 315102* and calculate the mean energy and the variance of the energy distribution, and also the adiabatic invariant which is asymptotically constant, but slightly higher than its initial value. The key references for the most recent work are Andresas et al (2014), given below.

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Nonlinear Fourier transform and its inverse - a perturbational approach

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The inverse scattering transform method for solving nonlinear integrable partial differential equations is a nonlinear analogue of the Fourier transform method for solving suitable initial-value problems for linear partial differential equations. Therefore, the scattering transform is often called the nonlinear Fourier transform (NLFT). When considering the inverse scattering transform method as a tool for finding solutions of initial problems, we find that it provides explicit analytic solutions only for certain very special initial conditions. The main difficulty resides in the fact that finding the inverse scattering transform (inverse NLFT) of a function is a difficult inverse problem, equivalent to a suitable Riemann-Hilbert problem. Therefore, it makes sense to resort to a perturbational approach. In the talk we shall describe a perturbational scheme by means of which we can explicitly compute the inverse NLFT of an arbitrary argument to any desired degree of accuracy. The convergence of this perturbational scheme is a consequence of certain analytical properties of the NLFT when defined on suitable function spaces. In the talk these properties will be proved.

Nested environments: Strong decoherence and coherence control

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For a central system weakly coupled to a near environment and uncoupled from a far environment The coupling between near and far environment can have surprising and possibly helpful effects on the conservation of coherence. We shall present analytic and numerical work in an RMT context as well as some numerics in spin networks. Finally we mention some exciting recent results of L. Campos Venuti and P. Zanardi on the use of such effects in coherence control.

Biological cell as a chronotaxic system

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The cell membrane is a lipid bilayer that divides the internal and external environment, thus making the cell the basic functioning unit of living systems. However, the cell is not independent – rather, a living cell continuously exchanges ions, oxygen and other nutrients with its environment known as the extracellular space. Charged ions are continuously crossing the cell membrane, actively and passively, thus resulting in a continuous change in the transmembrane potential. However, the membrane potential is traditionally considered to be in equilibrium. In this talk, based on experimental and theoretical work, we will discuss the origin of the fluctuations that are observed in the membrane potential and their time-dependent deterministic characteristics. In particular, we will argue that the cell can be described as a chronotaxic system (from chronos - time and taxis - order). This is a recently-introduced class of non-autonomous systems with time-dependent point attractors (driven steady states), able to resist external perturbations. The interplay between the production of ATP in mitochondria and due to glycolysis is modelled as a set of coupled chronotaxic systems. We will discuss the role of the oxygen supply and how the chronotaxic properties could change with cancer.

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Microwave experiments in complex systems: From quantum chaos to monster waves

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Most of the phenomena observed in wave propagation are universal and are observed in a large variety of different systems such as matter waves, but also, e.g., in electromagnetic waves and water waves. By means of the microwave measuring technique pioneered in Marburg, it thus becomes possible to study questions extending from the quantum mechanics of chaotic systems to the propagation of waves in the ocean. In this talk recent microwave results are presented, including the study of spectra and periodic orbits in microwave graphs and the study of branched flow in potential landscapes.

Classical and quantum chaos in the dynamics of molecules

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We present the following topics that we have studied and found, in which nonlinearity of dynamics manifests itself as characteristic phenomena of chaos in the dynamics of molecules.

1) Structural isomeization dynamics of atomic clusters: (a) loss of memory in the classical Hamilton chaos [1], (b) many-dimensional geometry behind the chaotic dynamics [2], (c) the concept of inter-basin mixing [3].

2) Bifurcation and merging of quantum wavepacket in consecutive nonadiabatic transitions [4]: (a) complexity arising from quantum entanglement between the dynamics of electrons and nuclei, (b) chaos in molecular double-slit experiments.

3) Chaos induced by quantum tunneling [5]: stationary states and their level statistics on a pair of coupled potential functions [6].

4) Induced photoemission from molecules of intra-molecular electron transfer: Chaotic fingerprints in photo-emission from a driven molecular oscillator (vibrational motion) of nuclear and electronic entanglement [7].

5) Phase-quantization of classical chaos [8]: mechanism of quantizatin of classical chaos.

6) Role of a newly found phase arising from the amplitude of a wavefunction in many-body quantum theory beyond semiclassics [9].

Among these, special emphases will be placed on the items (1), (4) and (6).

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Universal Quantum Graphs

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For completely connected simple graphs with incommensurate bond lengths and with unitary or orthogonal symmetry we prove the Bohigas-Giannoni-Schmit conjecture in its most general form. For graphs that are classically mixing (i.e., for which the spectrum of the classical Perron-Frobenius operator possesses a finite gap), we show that the generating functions for all (P, Q) correlation functions for both closed and open graphs coincide (in the limit of infinite graph size) with the corresponding expressions of random-matrix theory.

Quantum master equations: their power and limitations

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Quantum master equations, frequently called Lindblad equations, have been used to describe physical systems, e.g., in quantum optics or NMR, long before general mathematical theory has been developed in '70 by Kossakowski, Sudarshan, Gorini, and Lindblad. In recent years Lindblad equations have become of interest also in statistical physics, condensed matter, and quantum information. On a practical side, Lindblad equations can be used as an efficient tool to study nonequilibrium physics of many-body systems. Theoretically they can be considered as a resource with which one can prepare quantum states, perform transformations, etc... While Lindblad equations can describe quite a large class of systems, they nevertheless have limitations and an interesting question one may ask is, which operations (or states) are possible to achieve with given resources? I will present some results in this respect as well as point out outstanding problems.