Quantum Accelerator Modes
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Methods of cold atom optics allow for experimental realization of some theoretical models, which play a paradigmatic role in the analysis of quantum dynamical implications of classical chaotic behavior. The new phenomenon of Quantum Accelerator Modes (QAMs) was brought to light by experiments of this kind [1,3], when a unexplored variant of the Kicked Rotor Model was introduced, by giving room to effects of gravity. Although QAMs are a purely quantal phenomenon, they are accounted for by trajectories of certain formally classical dynamical systems [2], and their theory calls into play a repertory of classic items of nonlinear dynamics [4,5]. In this talk, a survey of these issues will be given and some new results will be presented, which significantly generalize the original theory.


The Versatile Quantum Delta-Kicked Rotor: From Accelerators to Ratchets
Gil S. Summy

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The quantum delta-kicked rotor (QDKR) has been one of the mainstays of both theoretical and experimental studies of quantum chaos in recent years. Much of this interest was motivated by the development of a simple experimental model of the QDKR: laser cooled atoms exposed to the potential generated by pulses (kicks) of an off-resonant standing wave of laser light [1]. In this talk, I will describe recent experiments carried out on variants of the QDKR, in which a Bose-Einstein condensate (BEC) is subjected to standing-wave laser pulses. Such experiments have a much greater momentum resolution compared to those using uncondensed cold atoms and allow for the preparation...
of interesting initial states. Two main experiments will be discussed: quantum accelerator modes (QAMs) and quantum ratchets. In the case of QAMs, a linear potential is added to the normal QDKR and the kicking period is near a quantum resonance. The modes are then characterized by atoms which receive a fixed amount of momentum each time a kick occurs. The use of a BEC has allowed us to determine the previously unseen internal structure of QAMs [2], much of which can be understood in a manner which is reminiscent of the fractional Talbot effect in optics [3]. In the second set of experiments, I will show that by preparing a BEC in a superposition of momentum states with an adjustable relative phase, it is possible to produce a ratchet current at a quantum resonance [4]. One of the surprising aspects of this system is that such a current exists even though the kicking potential and atomic wavefunction both have a point-like symmetry. Additionally, the current is very sensitive to the quasimomentum of the initial state and is easily suppressed if the state has some width in quasimomentum. I will conclude by discussing the future possibilities for this work, particularly the interesting properties of ratchets in the presence of an additional linear potential such as gravity [5].


Controlled Decoherence in a Lévy Kicked Rotator
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We investigate decoherence in the quantum kicked rotator (modelling cold atoms in a pulsed optical field) subjected to noise with power-law tail waiting-time distributions of variable exponent (Lévy noise). We demonstrate the existence of a regime of nonexponential decoherence where the notion of a decoherence rate is ill-defined. In this regime, dynamical localization is never fully destroyed, indicating that the dynamics of the quantum system never reaches the classical limit. We show that this leads to quantum subdiffusion of the momentum, which should be observable in an experiment.

The Topography of Random Waves
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Random waves have been investigated since the 1940’s in connection with modeling telephone signals (Rice), to model sea waves (Longuet-Higgins), and since the 1970’s by Berry and others to model quantum wave functions of classically chaotic systems.

One particular characteristic of wave functions is the structure of their nodal sets, for which numerical and experimental findings reveal several intricate structures, most of which are poorly understood. Thus one would like to understand the corresponding questions for nodal sets of random waves. For instance, one may investigate statistics of quantities such as the number of nodal domains or the length of nodal lines, as has been done by Berry, Biswas and Heller, Bogomolny and Schmit, Nazarov and Sodin, and others.

After surveying these topics, I will briefly discuss recent work with Igor Wigman, which uses random wave functions of integrable systems to gain understanding of chaotic systems. Contrary to what is sometimes stated in the literature, we find that generic wave functions of integrable systems such as the square billiard share much in common with those of chaotic systems.

Perturbation-Dependent Dephasing in Atom-Optics Billiards
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Atoms trapped in atom-optics billiards can be considered to be an ensemble of independent trapped atoms, thermally distributed over some $10^6$ levels of the billiard. We consider each of our trapped atoms as an independent two-level system. The internal (hyperfine) and external (billiard) degrees of freedom of our atoms are coupled, which enables us to study the dynamics of the trapped atoms by spectroscopic microwave techniques. We recently demonstrated that the use of coherence echoes and compensating techniques suppress dephasing of the internal state of the atoms induced by inhomogeneous broadening of the atomic ensemble by the trap. Residual dephasing is measured by microwave echo spectroscopy and is related to the Loschmidt echo. First, we show that perturbation to the internal state of the atoms caused by the trap itself results in perturbation-independent regime and distinct revival of the echo coherence even for classically chaotic atom-optics billiards, reflecting symmetry properties of this perturbation. Then we investigate two extreme examples of a broader class of so-called generic perturbations. First, we consider a weak speckle perturbation beam, which breaks the billiards spatial symmetry. The resulting monotonic decay of echo coherence is shown to have no perturbation-independent regime. As a second perturbation, we consider a point probe in
a mixed phase-space billiard. By controlling the point’s position, we apply a localized perturbation to either an island of stable trajectories or to the chaotic sea. The qualitatively different echo signal identifies different regimes of phase space in the atom-optics billiard.


Deterministic Chaos and Diffusion:
From One-Dimensional Maps to Hamiltonian Particle Billiards
Rainer Klages
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A fundamental problem of statistical mechanics and dynamical systems theory is to understand diffusion on the basis of deterministic chaos. In my talk, I will outline an approach by which diffusion coefficients can be calculated exactly starting from the microscopic equations of motion of certain classes of dynamical systems. Applying this theory to a piecewise linear map lifted periodically onto the real line, the diffusion coefficient is found to be a fractal function of a control parameter. This fractality can be understood by analyzing the invariant probability density of the map and de Rham-type functional equations. Similar results are obtained numerically for deterministic diffusion in Hamiltonian particle billiards, leading to the prediction that traces of such properties should be seen in experiments.


Mutual Synchronization of Chaotic Semiconductor Lasers - Theory and Experiment
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Semiconductor laser subjected to external time-delayed optical feedback displays chaotic behavior. As for most time-delayed nonlinear oscillators, such a system demonstrates hyperchaotic dynamics with typical Lyapunov dimension of its attractor being more than a hundred.

The chaotic behavior of a laser consists of very short and random spiking of the laser intensity with the time interval between spikes depending on how far above lasing threshold the laser is. Two chaotic lasers can be synchronized with each other when they are coupled as any other coupled chaotic oscillators can do.

We will show two main points. First, we analyze the time resolved spike statistics of a solitary and
two mutually interacting chaotic lasers [1]. Repulsion between two successive spikes is observed, resulting in a refractory period, which is largest at laser threshold. For time intervals between spikes greater than the refractory period, the distribution of the intervals follows a Poisson distribution. When zero-lag synchronization between two lasers is established, the statistics of the nearly perfectly matched spikes are not altered.

Second, we analyze the behavior of two chaotic lasers when the mutual coupling is suddenly switched off or on. Intuitively one can expect that when the coupling is switched off between the synchronized chaotic oscillators, the separation of trajectories will be fast, effectively described by the largest Lyapunov exponents of a single oscillator. We show that the trajectory dynamics of the decoupled chaotic oscillators (two decoupled lasers), which also poses time-delayed self-feedback, is different [2]. In such system, the time scale for the separation of the trajectories is found to be much longer than the coupling time. On the other hand, when the coupling is switched on, resynchronization occurs on a faster time scale.