CAMTP

"Let's Face Chaos through Nonlinear Dynamics"

6th International Summer School/Conference

at the University of Maribor

26 June - 10 July 2005

Dedicated to the 75th Birthday of Professor Siegfried Großmann

Maribor **Slovenia**

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Foreword

The series of by now traditional international Summer Schools/Conferences "Let's Face Chaos through Nonlinear Dynamics" began in the year 1993 on the initiative of a group of undergraduate students of the various faculties at the University of Ljubljana, under the leadership of Mrs. Maja Malus, a student of electrical engineering at the time (now a medical doctor at Harvard), under the scientific guidance of Professors Marko Robnik, Aneta Stefanovska and Igor Grabec. Since 1996 the Schools/Conferences are held exclusively at the University of Maribor, under the organization of CAMTP - Center for Applied Mathematics and Theoretical Physics, every three years. The 6th School/Conference is the largest, according to the number of invited lecturers (46), whilst it is second largest as to the number of other participants (about 62), and also according to the richness of the scientific and cultural programme, which you can see in the following pages of this Book of Programme.

The character of our Schools/Conferences is strongly international, we have invited lecturers and participants from all over the world, from all continents, and the national component of the Slovenian participants in total (invitees and others) does not exceed 10%. They are strongly interdisciplinary, with the focus on the rich variety of problems in nonlinear science, in mathematics, natural sciences and engineering in the field of chaos, synergetics and theory of complex systems. As for the scientific level we believe that we are gathering the worldwide leadership and elite, not only among the invited speakers, but also quite pronounced in the other participants, most of them are very talented and productive young scientists from some of the best research groups in the world. So, our gatherings in Maribor have the following dimensions: High level science, internationality, interdisciplinarity, special attention to young students and scientists, promoting them and also helping them financially (especially for those coming from financially weak countries), and finally the cultural dimension which ties together science and life, in a cosmopolitan spirit, without any nationalisms, but rather in mutual respect of all cultures of the world. In fact, it is one of my by now quite popular sayings, that "The Science is the Culture of the World", it is a universal culture indeed, like music.

As the main organizer of the Schools/Conferences, I have made every effort to make your stay in Maribor scientifically as profitable as possible, also to make it culturally as much enjoyable as possible, hoping that you will not only obtain new knowledge, but also successfully present your own research work, and make new scientific collaborative links and creative friendships. This is the most important face of the Maribor gatherings, highly successful and appreciated so far.

Finally, I should like to emphasize the personal component of the 6th School/Conference, namely the fact that it is dedicated to the 75th Birthday of Professor Siegfried Grossmann, the spiritual father and scientific founder and leader in the field of nonlinear science, especially in nonlinear dynamics, fluid dynamics and turbulence, phase transitions, laser physics, nuclear fission, transport theory, Bose-Einstein condensation, and general statistical physics. We are all very much honoured by his presence in Maribor, he is visiting our Schools/Conferences in Maribor already for the fifth time (and this is his fifth visit to Slovenia), and it is a privilege for all of us to attend his brilliant lectures offering a pedagogical introduction to - as well as an account of - the current research work on fluid dynamics and turbulence. It is on Tuesday 5 July 2005, at 21:00 hours, that we shall start the official celebration of his 75th Birthday by a chamber music concert, performed by the young Slovenian violinist Anja Bukovec, followed by a celebration and reception in the Kazinska dvorana of the Slovenian National Theatre in Maribor.

Last but not least, I should thank all the Members of the international Organizing Committee for their support and help: The Honorary Directors Giulio Casati, Predrag Cvitanović, Siegfried Grossmann and Hermann Haken, and the Members: Yoji Aizawa, Tokyo, Tassos Bountis, Patras, Tomaž Prosen, Ljubljana, Andreas Ruffing, Munich and Aneta Stefanovska, Ljubljana. Among the local organizers my very special thanks go again to Dr. Igor Mozetič, from CAMTP, for his help in setting up the home pages, and to Mr. Gregor Vidmar, also from CAMTP, for his kind, reliable and perfect help in many important technical dimensions in the organizational work.

Our special gratitude must be acknowledged to our co-organizer University of Maribor represented by the Rector of the University of Maribor, Professor Dr. Ivan Rozman, for providing the lecture halls and the facilities in the University Main Building, and to our respected general sponsors: Ministry of Higher Education, Science and Technology of the Republic of Slovenia, The City of Maribor, represented by the Mayor of the Town, Mr. Boris Sovič, The Nova Kreditna Banka Maribor, TELEKOM Slovenije, Slovenian National Theatre Maribor, VINAG Wine Company, and Festival Lent.

At the very end, thanks go to all participants for coming to Maribor and contributing to a productive and enjoyable friendly scientific atmosphere. Without the financial and intellectual contribution by the participants, this event would be absolutely impossible.

Here I just would like to give you some statistics, some numbers: We have about 20 participants from Japan, about 6 from USA, 1 from Mexico, 2 from Israel, about 27 from Germany, 3 from Greece, 7 from The Netherlands, 1 from France, 4 from Italy, 4 from South Korea, 1 from Ukraine, 2 from Belarus, 1 from Serbia, 2 from Austria, 3 from Greece, 2 from Denmark, 1 from Iran, 1 from Kazakhstan, 2 from Sweden, 1 from Portugal, 2 from United Kingdom, and about 10 from Slovenia. Therefore, we are indeed quite an international gathering.

I wish you all a scientifically successful and culturally pleasant stay in Maribor, and of course, please enjoy the Maribor Festival Lent 2005, the fireworks, and all the cultural programme, the mountains, the excursions and trips, the Slovenian cuisine and wines, the concerts, and the art exhibition, authored by Mrs. Edita Mileta, in the Saloon of the Hotel PIRAMIDA.

Professor Dr. Marko Robnik
— Director of **CAMTP** —
— Director General of the Summer School/Conference —

Maribor, 6 June 2005

1st Week: 27 June - 2 July

	MONDAY 27 June	TUESDAY 28 June	WEDNESDAY 29 June	THURSDAY 30 June	FRIDAY 1 July	SATURDAY 2 July
Chairman	*Robnik*	*Casati*	*Harayama*	*Stöckmann*	*Takatsuka*	*Chairman: Bountis*
09:00 - 10:00	**Großmann**	**Umeno**	**Großmann**	**Prosen**	**Großmann**	Bartsch 09:00-09:20 Cherkaskiy 09:20-09:40
10:00 - 11:00	**Haken**	**Haken**	**Haken**	**Haken**	**van der Weele**	Čubrović 09:40-10:00 Eshuis 10:00-10:20
11:00 - 11:30			– COFFEE & TEA –			Horvat 10:20-10:40 Korošak 10:40-11:00
11:30 - 12:30	**Cvitanović**	**Cvitanović**	**Cvitanović**	**Cvitanović**	**Cvitanović**	- COFFEE & TEA - 11:00-11:30
12:30 - 13:30	**Bunimovich**	**Shudo**	**Shudo**	**Bunimovich**	**Rosenblum**	*Chairman: Izrailev*
13:30 - 15:15			– LUNCH –			Kuhl 11:30-11:50 Lee 11:50-12:10
Chairman	*Aizawa*	*Prosen*	*Guhr*	*Wilkinson*	*McClintock*	Macor 12:10-12:30
15:15 - 16:15	**Robnik**	**Harayama**	**Aizawa**	**Geisel**	**Takatsuka**	Mencinger 12:30-12:50 Salasnich 12:50-13:10
16:15 - 16:45			– COFFEE & TEA –			13:10-15:00 - LUNCH -
16:45 - 17:45	**Casati**	**Izrailev**	**Geisel**	**Matsushita**	**Stöckmann**	
17:45 - 18:45	**Prosen**	**Hasegawa**	**Marhl**	**Stöckmann**	**Stefanovska**	15:00-16:30 **Exc. City of Maribor**
	18:45-20:30 - DINNER -	18:45-20:30 - DINNER -	Sugita 18:45-19:05	Veble 18:45-19:05	**van der Weele** 18:45-19:15	16:30-18:00 **Wine**
	20:30 **Welcome Art Exibition**	21:00 **Concert**	19:05-20:30 - DINNER -	19:05-20:30 - DINNER -	19:15-20:30 - DINNER -	20:00 **Concert&Banquet**
		22:00 **Reception**				23:45 **Fireworks**

2nd Week: 4 July - 9 July

	MONDAY 4 July	TUESDAY 5 July	WEDNESDAY 6 July	THURSDAY 7 July	FRIDAY 8 July	SATURDAY 9 July
Chairman	*Flach*	*Bunimovich*	*Nakamura*	*Elaydi*	*Haake*	*Großmann*
09:00 - 10:00	**Nakamura**	**Nakamura**	**Haake**	**Haake**	**Tass**	**Fujisaka**
10:00 - 11:00	**McClintock**	**Flach**	**Elaydi**	**Guhr**	**Tass**	**Cvetič**
11:00 - 11:30	– COFFEE & TEA –					
11:30 - 12:30	**van der Weele**	**Ruffing**	**McClintock**	**Procaccia**	**Popovych** 11:30-12:00 **Žnidarič** 12:00-12:30	**Bountis**
12:30 - 13:30	**Kuvshinov**	**Großmann**	**Dvorak**	**Daido**	**Main**	**Prosen**
13:30 - 15:15	– LUNCH –					
Chairman	*Daido*	*Fujisaka*	*Procaccia*	*Main*	*Robnik*	
15:15 - 16:15	**Stefanovska**	**Richter**	**Wilkinson**	**Mehlig**	**Dvorak**	
16:15 - 16:45	– COFFEE & TEA –					
16:45 - 17:45	**Stöckmann**	**Lohse**	**Wilkinson**	**Guhr**	**Bountis**	
17:45 - 18:45	**Mendonça**	**Lohse**	**Mehlig**	**Romanovsky**	**Fujisaka**	
	18:45-20:30 - DINNER -	18:45-20:30 - DINNER -	20:00 **Concert** **and festive Dinner**	Skokos 18:45-19:05	Behnia 18:45-19:05	20:00 - LAST DINNER -
	21:00-22:00 **Petrač**	21:00 **Concert**		19:05-20:30 - DINNER -	Somsikov 19:05-19:25	**Fireworks** 23:45
		22:00 **Reception**			19:25-21:00 - DINNER -	

Cultural, Social and Touristic Events

LENT FESTIVAL 2005

During the entire period of our School and Conference there will be the international Festival Lent, offering a very rich variety of performances every evening and every night in the Lent area of Maribor, on the banks by the river Drava (medieval part of the old town). Each participant receives upon his or her arrival a programme brochure and the entrance pass for all performances, free of charge.

MONDAY 27 JUNE 20:30: WELCOME PARTY AND OPENING OF THE ART EXHIBITION

On Monday 27 June 2005 at 20:30 (thus after the dinner) we shall gather in the "Art Saloon" (Art Kavarna) in the Hotel PIRAMIDA, to get together and to enjoy a glass of fine Slovenian wine. There will be the official opening of an art exhibition with works of a few best Slovenian artists on display, painters and sculpturers. The exhibition is authored by Mrs. Edita Mileta from Maribor, who has recently opened a private art gallery in Maribor. All works exhibited can be actually bought.

TUESDAY 28 JUNE 2005 21:00: OFFICIAL OPENING OF THE SCHOOL AND CONFERENCE WITH A CONCERT

The official opening of our 6th School and Conference will take place on Tuesday 28 June 2005 at 21:00 in the Kazinska dvorana of the Slovenian National Theatre in Maribor, at Slomškov trg, just next to the Main University Building and the cathedral.

We begin with a chamber music concert (cellist Niko Sajko and pianist Ivan Marinovič, about 60 minutes) followed by the addresses of the Mayor of the Town of Maribor, Mr. Boris Sovič, the Rector of the University of Maribor, Prof.Dr. Ivan Rozman, and a few participants of the School and Conference.

After the speeches there will be a reception with some good Slovenian wines.

SATURDAY 2 JULY 2005: MARIBOR, WINE TASTING, CONCERT, BANQUET AND FIREWORKS

15:00-16:30 There will be a guided tour through the town of Maribor, starting at Grajski trg, just next to Hotel OREL and the City Castle

16:30-18:00 Visit of the (huge) wine cellar of the VINAG Wine Company at Trg svobode 3 (100 meters from Grajski trg) and wine tasting programme

20:00 We gather at the "Art Saloon" (Art Kavarna) of the Hotel PIRAMIDA enjoying a glass of champaign

20:00-20:20 Chamber music concert (Barbara Novak, piano and Mojca Sok, flute)

20:20-23:35 Banquet

23:45-00:15 Fireworks of the festival Lent

SUNDAY 3 JULY 2005: THREE DIFFERENT TRIPS

On this day we organize three different trips/excursions, in parallel, so you can choose which one you want to join. Each one starts at 08:30 and we return to the residences in Maribor in the evening.

Trip No.1: Lake Bled (in the Alps), Cave of Postojna, old town of Ljubljana, capital of Slovenia. The price is about 100.-EUR per person, which includes everything, also high level lunch and dinner, except for the drinks. This trip is strongly recommended to participants who are visiting Slovenia for the first time. We return to Maribor at about 23:30.

Trip No.2: Hiking tour over Pohorje, from Ribniška koča to Rogla, visiting also Lovrenška jezera. This is strongly recommended to participants who prefer beautiful nature, the forests, and physical activity. We return to Maribor at about 21:00 - 22:00. Price is about 60.-EUR per person, which includes everything, also lunch and dinner (except for the drinks).

Trip No.3: Prlekija: visiting the beautiful countryside around Ljutomer, river Mura area and Jeruzalem (about 80 Km to the East of Maribor). It includes a visit to a local bee-keepers museum, a blacksmith museum, a floating mill on the river Mura, wine tasting at Jeruzalem and video show of grape gathering, and much more. Price is about 70.-EUR per person and it includes everything, also lunch and dinner (except for the drinks). We return to Maribor at about 21:00-22:00.

Please register for the trip and pay in cash to Mr. Gregor Vidmar at latest on Wednesday 29 June.

MONDAY 4 JULY 2005 21:00: PUBLIC EVENING LECTURE

At 21:00-22:00 there will be a Public Evening Lecture by Professor Dušan Petrač from Jet Propulsion Laboratory, NASA, Caltech, about the current and future projects of space exploration by NASA.

The lecture will be given in the Lecture Hall of Hotel PIRAMIDA (amphitheatre at the underground level).

TUESDAY 5 JULY 2005: DEDICATED TO THE 75TH BIRTHDAY OF PROFESSOR SIEGFRIED GROSSMANN FROM MARBURG, GERMANY

This day is dedicated to the celebration of the 75th birthday of Professor Siegfried Grossmann.

12:30-13:30 A Festive Public Lecture by Professor Siegfried Grossmann in the Large Lecture Hall (Velika dvorana, just the same where we shall have all other lectures).

21:00-22:00 A chamber music concert by a young Slovenian violin virtuous Anja Bukovec (accompanied by Janez Dovč and Mateja Urbanč) at Kazinska Dvorana of the Slovenian National Theatre in Maribor, at Slomškov trg, just next to the Main University Building and the cathedral. After the concert there will be addresses and speeches, followed by a reception with good Slovenian wines.

WEDNESDAY 6 JULY 2005 20:00: CONCERT AND FESTIVE DINNER

20:00 We gather at the "Art Saloon" (Art Kavarna) of the Hotel PIRAMIDA enjoying a glass of champaign

20:00-20:20 Chamber music concert (Feguš String Quartet)

20:20-24:00 Festive dinner

SATURDAY 9 JULY 2005: LAST DINNER AND FIREWORKS

We shall gather at 20:00 to enjoy the last common informal dinner with some good wines in good atmosphere and shall admire the closing fireworks of the Festival Lent at 23:45-00:15 in the Lent area. Good bye MARIBOR 2005! See you at MARIBOR 2008.

All events except for the trips on Sunday 3 July are free of charge for all invited lecturers and for other participants of the School and Conference, as they are covered by the conference budget for the local expenses and by the participation fees.

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Marko Robnik (CAMTP, University of Maribor, Slovenia)

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Giulio Casati (University of Insubria, Italy)

Predrag Cvitanović (Georgia Institute of Technology, USA)

Siegfried Großmann (Philipps-Universität Marburg, Germany)

Hermann Haken (University of Stuttgart, Germany)

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Public Evening Lecture:
About some current and future NASA projects

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Abstracts of Invited Lectures

Coherence and Complexity in the Refractory-Activation System - Toward a model of muscle contraction -

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Contractile motion of muscle fibers arises from the microscopic process of chemo-mechanical energy transformation through the cross-bridge formation between actin and myosin filaments. A large number of cross-bridges work cooperatively and create the coherent macro-motion of the filaments. It is worth of notice that the macro-motion induces the feedback effect to the energy transformation and regulates the micro-dynamics of the internal degrees of freedom in each cross-bridge. In general, such kind of feedback loop between micro- and macro- dynamics plays a significant role in active element systems with internal degrees of freedom in order to organize global functions as a whole body; the sliding motion of acto-myosin filaments is a typical example of the active element system. Here we propose a simplified model of the cross-bridge formation, and simulate the complex behaviors which link both the microscopic level and the macroscopic one. The basic assumptions of our model are the following: the cross-bridge formation occurs within very narrow active regions distributed periodically on the actin filament, and that the state of the cross-bridge is inactive for a certain refractory period. This is called the Refractory-Activation Model in what follows. The detailed bifurcation and the onset of coherent behaviors in the many-site model are discussed, where the breakdown of the law of large number is demonstrated. The comparison with experimental results is discussed.

Lecture 1:
Order and Chaos in N-Degree of Freedom Hamiltonian Systems

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We investigate the connection between local and global dynamics of two N–degree of freedom (dof) Hamiltonian systems, describing one–dimensional (1D) nonlinear lattices: The Fermi–Pasta–Ulam (FPU) model and a discretized version of the nonlinear Schrödinger equation related to Bose–Einstein Condensation (BEC). We study solutions in the vicinity of a family of simple periodic orbits (SPOs), among which are the in–phase mode (IPM) and out–of–phase mode (OPM), which are known in closed form. Our results demonstrate that, in some cases, the local structure of the unstable manifold seriously affects the behavior of the Lyapunov exponents, $L_k, k = 1, 2, ..., N - 1$, nearby, while in others, the dependence of the L_k on E follows the expected power laws. The destabilization energy per particle goes to zero following a simple power law, $E_c/N \propto N^{-\alpha}$, $\alpha = 1, 2$ as $N \to \infty$. However, the two Hamiltonians have very different local dynamics around the SPOs, as the energy increases at fixed N: For the FPU system, the islands about the OPM orbit decrease before its destabilization which occurs through period-doubling, while the OPM motion of the BEC system bifurcates through symmetry breaking and its islands *grow* before destabilization! In fact, the IPM of the BEC Hamiltonian is always stable with finitely sized islands around it, for all the values of N and E we studied. Still, when calculating Lyapunov spectra, we find for both Hamiltonians that the L_k decay following an exponential law and yield extensive Kolmogorov–Sinai entropies per particle $h_{KS}/N \propto$ const., as E and N increase indefinitely at energy density E/N fixed.

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Lecture 2:
Quasiperiodic and Chaotic Breathers in a Class of 1-Dimensional Lattices

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Discrete breathers (DBs) are simple periodic solutions of nonlinear lattices, which are exponentially localized and frequently stable under small perturbations. They were first observed in the late 1980's in numerical simulations by Sievers and Takeno and their existence was proved in the early 1990's by MacKay and Aubry. In recent years their importance has been amply demonstrated by a wealth of experimental evidence in arrays of optical wave guides, Josephson junctions and micromechanical oscillators. Bountis and Bergamin, following earlier work by Flach, discovered highly efficient ways of constructing breathers and multi-breathers in 1- and 2-dimensional Hamiltonian lattices, using the theory of homoclinic orbits of invertible maps. In this lecture, I will present new results on a 1-dimensional lattice of anharmonic oscillators with only quartic nearest neighbor interactions (i.e no linear dispersion), in which discrete breathers can be explicitly constructed by an exact separation of time and space dependence. Introducing parametric periodic driving, we first show how a variety of such DBs can be selected from the Poincare surface of section of a Duffing's equation: At the center of the islands of a resonance, the breathers are exactly periodic. When they are stable, we find a large region around them of *quasiperiodic* DBs which remain localized for very long times. Moreover, near the main chaotic layer of Duffing's surface of section, we have also discovered *chaotic* DBs, with broad banded Fourier spectrum in time and irregular energy exchanges between very few particles. Our results demonstrate, therefore, the importance of phonons, as it is most probably their absence that explains this remarkable localization of quasiperiodic and chaotic DBs in our system.

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Billiards: A Favorite Game in Nonlinear Science

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Billiard is a dynamical system generated by the inertial motion of a point particle within a region that has a piecewise smooth boundary. Upon reaching the boundary the particle gets elastically reflected, i.e. the angle of reflection equals the angle of incidence. Such models arise naturally in optics, acoustics and classical and statistical mechanics. The billiards occupy a central place in nonlinear dynamics as the most visual and natural models that demonstrate a surprisingly rich variety of possible behaviors. The classical examples of integrable Hamiltonian systems are provided by billiards in circles and ellipses. Configuration spaces of these billiards are foliated by caustics. If a boundary of a billiard is strictly convex then in 2D there exists an infinite series of caustics convergent to the boundary of a billiard "table." Therefore such billiards are non-ergodic. An opposite situation occurs when the boundary of a billiard is everywhere dispersing. Such billiards are called Sinai billiards. Singularities in dispersing billiards may cause some problems with more delicate chaotic properties but all dispersing billiards are ergodic, mixing and have a positive entropy. If a narrow parallel beam of rays is fallen onto a dispersing boundary, then after reflection it becomes divergent and therefore the distance between the rays increases with time. It is this mechanism of dispersing that generates sensitive dependence on initial conditions (hyperbolicity) and is responsible for strong chaotic properties of dispersing billiards. On the other hand, focusing boundaries produce the opposite effect. In fact, a narrow parallel beam of rays after reflection from the focusing boundary becomes convergent that results in decreasing of distances between rays. Still, there exists another mechanism of chaos (hyperbolicity), called the mechanism of defocusing, which can generate strong chaotic behavior of billiards with focusing components. In fact, the mechanism of dispersing is a special (extremal) case of the mechanism of defocusing. There are no other mechanisms of chaos in billiards because billiards with flat boundaries have zero entropy. Clearly, focusing chaotic billiards are much closer to integrable billiards than dispersing billiards. A better understanding of the mechanism of defocusing allowed to construct many new examples of billiards that demonstrate coexistence of regular and chaotic regions and some other new types of behavior. Moreover, the mechanism of defocusing generates chaos in higher dimensions as well ($d > 2$) despite of the astigmatism. I'll discuss these various simple examples and explain why they behave like they do.

Deterministic Walks in Random Environments

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Deterministic walks in random environments (DWRE) form a class of models generated by the motion of some object (e.g. a particle, wave, signal, virtual ant, read/write head of a Turing machine, etc) on some graph. At each time step, the object hops from a vertex to one of its neighboring vertices. The choice of neighbor is completely determined by the type of deterministic scattering rule or scatterer, located at the vertex. A random environment is formed by the scatterers that are assumed to be initially randomly distributed among the vertices. The simplest models of DWRE were introduced and independently studied numerically (under different other names) in material science, communication theory, chemical kinetics, statistical physics, computer science, etc. In early numerical studies graphs always were regular lattices and two types of scatterers were considered in each model. The most studied case was that of the regular quadratic lattice with left and right rotators, which rotate the particle to the left or to the right by a right angle. Two classes of such models were studied numerically. The first class corresponds to the case when there is no feedback of the moving object to the environment; that is, a particular type of scatterer is fixed at each site of the lattice forever. Another class is formed by models with flipping scatterers, when a scatterer at a site changes (deterministically!) after every visit to this site. In statistical physics these models naturally appear as deterministic lattice Lorentz gases with random distribution of scatterers. Although DWRE look somewhat similar to random walks, these systems are essentially different. In fact instead of carrying out a random experiment (like flipping a coin) the particle chooses each step deterministically. Dynamics (evolution) of DWRE is often counterintuitive, demonstrating a mixture of deterministic and probabilistic properties. I will describe some exactly solvable rich classes of DWRE with "unusual" behavior including the simplest deterministic systems with sub-, super- and "normal" diffusion. Some general principal differences in behavior of DWRE and of random walks will be discussed as well.

Classical and quantum chaos and understanding and control of heat flow

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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. Recent years have witnessed some important progress in this direction even though a satisfactory understanding is, so far, unavailable. For example, after two decades of debates, it is now clear that exponential local instability is not a necessary condition for the validity of Fourier law.

A better understanding of the mechanism of heat conduction 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. Although this model is far away from a prototype realization, it is based on a mechanism of very general nature and, as such, is suitable of improvement and may eventually lead to real applications. More recently, a different thermal diode model has been proposed in which, even though the underlying physical mechanism is similar to the previous model, there is a new crucial element which allows to improve the efficiency by more than two orders of magnitude. Finally we briefly discuss the possibility to build a thermal transistor.

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.

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String Theory, M-Theory and Particle Physics

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We review developments leading to the unification of string theories (M-theory), with an emphasis on particle physics implications. We introduce extended objects - Dirichlet branes - and highlight a novel role that these objects play in deriving particle physics from string theory. Progress in finding solutions of string theory with Dirichlet branes, that have the structure of the standard model and three families of quarks and leptons, is reviewed.

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Turbulence and what to do about it

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A 5-lecture graduate-level course that starts with a recapitulation of basic notions of dynamics; flows, maps, local linear stability, periodic orbit stability, density transport, natural measure, chaotic averages of observables, evolution operators, qualitative dynamics of stretching and mixing, Smale horseshoes and symbolic dynamics - all of this in order to set the stage for

Dynamical theory of turbulence, illustrated by Kuramoto-Sivashinsky system: As a turbulent flow evolves, every so often we catch a glimpse of a familiar pattern. For any finite spatial resolution, the system follows approximately for a finite time a pattern belonging to a finite alphabet of admissible patterns. The long term dynamics is a walk through the space of such unstable patterns.

Prospective student is urged to consult the course website ahead of the course, and download the relevant chapters and overheads.

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Cooperative entrainment and aging in populations of coupled oscillators

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Coupled nonlinear oscillators appear in a variety of areas in science and technology, playing a crucial role in understanding the behavior of simple as well as complex systems operating in nature, laboratories, and human societies. In this presentation, I will talk about two important topics in the theory of coupled nonlinear oscillators, namely, *cooperative entrainment* and *aging*, as expanded below. Oscillators treated here are of dissipative nature (limit cycle oscillators) and assumed to be under uniform all-to-all coupling.

(1) Cooperative entrainment
This is a phenomenon such that a macroscopic number of oscillators with random natural frequencies run with a common average frequency. In his seminal paper, Winfree argued its relevance to diverse biological rhythms and performed an inspiring theoretical analysis. Here I briefly describe a theory of this phenomenon, which is based on phase reduction and generalizes Kuramoto's self-consistent theory. The key of this theory is a function which I call the *order function*.

(2) Aging
Coupled oscillators may "age" with some of them inactivated due to some kind of deterioration. Then, how will their behavior as a whole change ? Motivated by such a question, I here discuss the effect of increasing the ratio of inactive oscillators (damped oscillators) within a population, showing that under some conditions, there is a transition, *aging transition*, accompanied by a universal scaling of an order parameter.

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The Role of Resonances in Planetary systems

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The paper reviews the important role of resonances for the structure of planetary systems. After a short introduction into the basics of the orbital dynamics of motion in resonances we describe the dynamics of our planetary systems and also of extrasolar planetary systems, where up to now more than 100 are known. In our planetary system the planets move on quite regular orbits with small eccentricities although it was found that the motion is chaotic on very large time scales, which surpasses the age of the Solar system. This quasi regularity (close to so-called quasi-periodic motion on a torus) is not true for the small bodies: the main belt of asteroids between Mars and Jupiter with gaps for special values of the semimajor axes on one hand and on the other hand with families of many small bodies, is sculpted due to the presence of 1^{st} mean motion resonances with Jupiter and 2^{nd} secular resonances with long-periodic motions of the nodes and perihelia of Jupiter and Saturn. In extrasolar systems the planets are – rather surprisingly – found to move sometimes on very high eccentric orbits when they are in distances comparable to the size of our planets. Because of our still limited observational techniques using indirect methods we only discovered massive planets comparable to the size of Jupiter. When these planets are orbiting alone around their host star our research is aimed to the possibility of additional terrestrial planets moving in such a system. Because of the mostly large eccentricities here the resonances are, in contrary to our planets, essential for the stability of the orbits, and may protect or destroy an orbit. On the other hand in multiple planetary systems we concentrate on the stability of their orbits as they are observed: a very interesting new result is that most of these multiple planetary systems with high eccentric orbits move in resonances with a special configuration which protects them from close encounters although there orbits are crossing.

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Numerical Integration with Lie series

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In this lecture we introduce a fast and precise numerical integration method with an adaptive step size for the solution of ODEs.

We define the Lie-operator D as follows:

$$D = \theta_1(z)\frac{\partial}{\partial z_1} + \theta_2(z)\frac{\partial}{\partial z_2} + \ldots + \theta_n(z)\frac{\partial}{\partial z_n} \tag{1}$$

D is a linear differential operator; the point $z = (z_1, z_2, \ldots, z_n)$ lies in the n-dimensional z-space, the functions $\theta_i(z)$ are holomorphic within a certain domain G, e.g. they can be expanded in converging power series. Let the function $f(z)$ be holomorphic in the same region as $\theta_i(z)$. Then D can be applied easily to $f(z)$. The **Lie-series** is defined in the following way;

$$L(z,t) = \sum_{\nu=0}^{\infty} \frac{t^\nu}{\nu!} D^\nu f(z) = f(z) + tDf(z) + \frac{t^2}{2!}D^2 f(z) + \ldots.$$

We can then solve the the system of ODEs:

$$\frac{dz_i}{dt} = \theta_i(z), z_i = e^{tD}\xi_i \tag{2}$$

where the ξ_i are the initial conditions $z_i(t=0)$ and D is the Lie-operator as defined before.

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Nonautonomous dynamical systems: the periodic case

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The dynamics of nonautonomous discrete dynamical systems or difference equations can be better understood in the setting of skew-product dynamical systems (Elaydi and sacker 2005). We will survey the recent developments in the theory of periodic discrete dynamical systems from stability to chaos (Elaydi 2000). This includes, among other things, the various extensions of Sharkovsky's theorem (Alsharawi et al, Der Heiden and Liang 2004), Singer's theorem, and Elaydi-Yakubu-Sacker theorem (Elaydi and Yakubu 2002). Open problems and conjectures will be presenteed. The theory will then be applied to models in biology (Cushing and Henson 2002).

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From discrete breathers to q-breathers

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I will introduce the concept of discrete breathers - time-periodic and spatially localized excitations in nonlinear lattice dynamics. I will review their main mathematical properties including existence, stability, influence of lattice dimensionality, their impact on transient processes and thermal equilibrium. I will also discuss the issue of resonant wave scattering by discrete breathers. If time permits, I will also review recent experimental observations of these excitations in such different systems as bond excitations in molecules, lattice dynamics of crystals, light propagation in coupled nonlinear optical waveguides, excitations in networks of Josephson junctions, localized excitations in Bose-Einstein condensates loaded on optical lattices, among others.

Then I will turn to the famous fifty years old FPU paradox. I will apply the discrete breather concept in order to show that the FPU lattice allows for time-periodic orbits which are localized in q-space - the space of eigenmodes of the linear atomic chain. These solutions are called q-breathers. I will discuss some of their properties including the degree of localization and their stability. The trajectories computed by Fermi, Pasta and Ulam (and which lead to the surprising observation on nonequipartition of mode energies in reciprocal space) are perturbations of q-breathers. Since q-breathers are linearly stable (for the FPU case), we arrive at a simple interpretation of the famous paradox in terms of persistence of simple periodic orbits.

Chaotic phase synchronization and its breakdown - Mapping model and critical behaviors -

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Coupled chaos systems are not only theoretically interesting but also important from the viewpoint of the application to engineering and biology. Dynamical behaviors observed in coupled oscillator systems depend on the number of chaotic oscillators as well as the coupling form. As the number of oscillators is increased, the variety and the complexity of dynamical behaviors increase.

For a coupled system consisted of identical chaotic oscillators, the oscillators can completely synchronize under certain conditions (**chaotic complete synchronization**). On the other hand, even when two oscillators have a mismatch in characteristics, they can show the so called **chaotic phase synchronization** for a certain region of coupling strength.

It is well known that the coupled map system played a significant role in the study of complete synchronization. In contrast to the complete synchronization, coupled mapping model for chaotic phase synchronization-desynchronization phenomenon is not studied so much because of the lack of suitable mapping model for coupled phase synchronization.

In my talk, I first propose a coupled mapping model for chaotic phase synchronization and then to examine the universality of the breakdown of synchronization so far mainly studied for the coupled Rössler system.

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Dynamic phase transitions in oscillating and random fields

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Recently many studies have been carried out for phase transitions observed particularly in ferromagnetic systems under their critical temperatures in oscillating magnetic fields by changing either magnitude or frequency. An eminent difference of these transitions called the **dynamic phase transitions** (DPT) from the thermal ones is that the control parameter is not the temperature but the dynamical quantities. So the DPT is a kind of bifurcation phenomena in dynamical systems.

Experimentally it is possible to apply the external noise such as a dichotomous noise (DN) instead of oscillating magnetic field. The DN has a characteristic quite different from the Gaussian noise. It is quite natural to ask the possibility of the existence of a DPT-type transition and its characteristics if it exists.

In my talk, first reviewing dynamic phase transitions in magnetic systems described by Ginzburg-Landau equations either without or with anisotropic term in an oscillating external field, we propose a dynamical model of ferromagnetic systems subject to an external dichotomous noise. It is shown that the system under the DN shows a clear phase transition between symmetry-restoring and symmetry-breaking motions. Then I will talk about several statistical characteristics associated with the phase transition.

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Synchronization in Complex Networks - A Paradigm for Neuroscience*

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In the past decade, theoretical neuroscience has developed into a very fruitful branch of research in neurosciences. As one finds complex dynamical phenomena from very short to very long time scales, i.e. from the fast firing and synchronisation dynamics of nerve cells to slow learning processes of neural networks, nonlinear dynamics has played a major role as a tool besides statistical physics etc.

Neuronal synchronisation has been found e.g. in visual areas and has been hypothesized to be involved in the so-called feature binding in visual perception. Numerous articles have been devoted to numerical simulations of more or less realistic and detailed models of complex neurons. Such simulations, however, fall short of rigorously answering questions as e.g. on the stability of synchronization, or on the speed of synchronization as a function of the network topology.

I will review our recent work on abstract mathematical models of complex networks of pulse-coupled units, where analytic approaches are feasible. We have shown e.g. that the dynamics of synchronization is governed by unstable attractors (i. e. unstable sets with basin of attraction) in the case of excitatory all-to-all coupling. This property gives the network an ability of switching swiftly among the attractors. On the other hand synchronization is stable for inhibitory coupling. In random networks there exists a rigorous upper limit for the speed of synchronization, which can be calculated in dependence on the network topology.

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∗ work in collaboration with M. Timme and F. Wolf

Forecasting Epidemics: The Dynamics of Human Dispersal*

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An accurate understanding of human dispersal, i.e. the question how people travel in space and time is of paramount importance e.g. for the mathematical description and forecast of modern epidemics. So far these properties could only be conjectured and the opinion that humans move diffusively still prevails in models. We have analyzed a comprehensive dataset of over a million individual displacements and found that human dispersal is anomalous in two ways. The probability of finding a displacement of length x decays as power law, indicating that trajectories of humans are reminiscent of Lévy flights characterized by a Lévy exponent $\mu \approx 1/2$. On the other hand the waiting time distribution also exhibits a heavy tail implying a subdiffusive influence. Effectively, the scaling behavior of distance with time, $X(t) \sim t^p$ is superdiffusive with an exponent p near unity.

These results represent the first solid and quantitative assessment of human dispersal on geographical scales. We show how standard epidemiological models must be extended in order to account for the anomalous dynamics.

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$*$ work in collaboration with D. Brockmann and L. Hufnagel

Her Majesty, Queen BL
A mysterious dynamical system
Four lectures on boundary layers in fluid flow

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1. The basic physics of boundary layers

It is generally accepted that small Reynolds number flow of fluids is dominated by viscosity, while for large Reynolds numbers the flow is expected to be nearly inviscid, ideal. But, in real flow, also for large Reynolds numbers viscosity has significant influence, due to the always present effects of the boundary layers in the vicinity of all solid surfaces in contact with the fluid. Because of the usually unavoidable separation of the boundary layers from the surface, vortices and turbulent structures also penetrate into the interior of the flow volume and introduce fluctuations and viscous energy loss into (at least) parts of the bulk.

The scaling properties of boundary layers, the Prandtl equations describing them and the range of their validity, and also the mechanism leading to separation are discussed. There are still considerable problems to describe the flow in the vicinity of separation. Of particular interest are time dependencies even in scaling wise laminar boundary layers.

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2. Why do airplanes fly ?

Boundary layers are responsible for the flow resistance of a solid body in the flow field and for the dynamical lift forces felt by the body. The physical mechanism for both characteristic phenomena is mainly the formation of a wake behind the body. The origin of the wake is the separation of the boundary layer near the body's surface. Within the wake the flow is nonideal however large the Reynolds number might be.

The properties of wakes, in particular their width and length together with their scaling behavior with the distance from the body are discussed. The drag and the lift (or dynamical buoyancy) can be calculated from the global balance of all forces on the body included in the Navier-Stokes equation, in particular the nonlinear inertia term. The drag and the lift coefficients are introduced, which significantly depend on the geometry of the body. Typical geometries are considered, in particular the differences between streamlike and normal profiles. Fairy-tales and arguments are given why airplanes do what they are expected to do, namely to fly.

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3. The role of boundary layers in thermal convection

Convective heat transport depends significantly on the boundary layers near the top and bottom plates and the walls. In particular by repeated separation of boundary layers plumes are injected into the bulk, which contribute to the convective heat transport. Their scaling behavior with Rayleigh and Prandtl numbers is different from that of the turbulent fluctuations. Both contributions are superimposed and together design the phase diagram of Rayleigh-Bénard thermal convection as a function of the Rayleigh and the Prandtl number.

The heat transport, described by the Nusselt number, and the large scale coherent flow, described by the socalled wind which is characterized by a Reynolds number, are calculated. The physical idea is to express them in terms of the bulk and the boundary layer properties. Recent experiments gave surprisingly good agreement with the theory, to high precision. This in turn now allows to identify unexpected deviations observed in experiment for large enough Rayleigh numbers, which wait for explanation.

The formation of the boundary layer is intimately related with the large scale coherent circulation (wind). Its scaling with the Rayleigh and the Prandtl numbers can be derived before the transition to turbulence in terms of the Prandtl scaling. Transition to turbulence in the boundary layer only comes at rather large Rayleigh numbers.

The fluctuations of the temperature and the velocity field in turbulent thermal convection can be based on the large scale coherent flow properties as a source of driving. Their scaling properties are mostly consistent with the data but in some cases there are still open questions.

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4. Pipe and Taylor-Couette flow: News on skin friction and torque scaling

Boundary layer formation is also the key for understanding the flow resistance and skin friction in fluid flow through pipes and the torque in Taylor-Couette flow between independently rotating concentric cylinders. The scaling properties of both, the skin friction in pipe flow as well as the torque in Taylor-Couette flow, are discussed on the basis of a surprisingly close similarity to Rayleigh-Bénard thermal convection. The main physical quantities are the momentum current density and the dissipation rate.

In all these flows boundary layers develop, steepening the profile near the walls and flatening it in the interior. The analog of the plumes seem to be the hairpin vortices. The different but characteristic scaling dependences on the Reynolds number which hold for the contributions from the boundary layers in contrast to that from the bulk imply a Reynolds number dependence of the local scaling exponent of skin friction and of torque to the momentum transport between the walls of the pipe or the cylinders. These deviations from a global scaling law are measured and can be explained now.

Comparison of the new theory with existing data is promising. This new understanding is at variance to the description with a logarithmic profile. Further experiments of higher precision are desirable in order to confirm this new theory or to ask for its corrections or extension.

Ackowledgments: The work on Rayleigh-Bénard convection has been done in close collaboration with Detlef Lohse, that on Taylor-Couette and pipe flow with him and also with Bruno Eckhardt. I wish to cordially thank them both for many exciting and stimulating hours, when we were hunting the truth, a wonderful experience.

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Econophysics: Brief Introduction

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The economy clearly qualifies as a *complex system*. In the last ten to fifteen years, a wealth of empirical data became available. This makes it possible to construct *mathematical models based on empirical information* by applying concepts developed in statistical physics. A much deeper theoretical understanding of the structures and the mechanisms in the economy is highly desirable. There is hope that the new field of *econophysics* [1,2,3] contributes to this by employing the expertise gained in studying complex systems.

I give a brief introduction to econophysics by focusing on *financial risk management* and *portfolio optimization*. The usefulness of physics approaches in these areas is also reflected in the fact that the *job market* for physicists keeps widely expanding in the financial industry and in consulting firms.

In the first lecture, some basics on *Brownian motion* and *stochastic processes* are reviewed. It is shown how this is used to model *stock prices*. Empirical *price distributions* are critically compared with the model predictions. A brief discussion of *financial derivatives*, in particular of *options*, follows. *Hedging*, a major concept in financial risk management is demonstrated by studying a portfolio containing stocks and options. The importance of *financial correlations* is explained, leading to *diversification*, another key concept in financial risk management.

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Econophysics: Measuring and Removing Noise in Financial Correlations

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The second lecture on econophysics is devoted to a more detailed discussion of financial correlations, as introduced in the first lecture. The correlation coefficients measured from the recorded time series of the stock prices are often unreliable, because the *true* correlations are *noise–dressed*. A major reason for the noise is the *finiteness* of the time series. This effect was known to practitioners in the financial industry. Nevertheless, it was a big step forward when physicists [1,2] considerably improved the estimation of this noise by relating it to *random matrix theory*, a powerful concept in the theory of *chaos* and other *complex systems*. It turned out that the noise–dressing can be so serious that new methods to *reduce* the noise are urgently needed for portfolio optimization. Several such methods have been proposed, see brief accounts of the literature in Refs. [3,4]. I focus on two conceptually very different methods the *filtering* [5,3] and the *power mapping* [4].

The *Markowitz theory* for portfolio optimization [6] is sketched. It can be viewed as an Euler–Lagrange optimization problem. Real market data for Swedish and US stocks are used to show how the noise reduction improves the portfolios.

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Semiclassical Foundation of Spectral Universality

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According to a conjecture of Bohigas, Giannoni and Schmit (BGS), quantum energy spectra of fully chaotic dynamics bear universal fluctuations, in agreement with fluctuations known from the theory of random matrices of Wigner and Dyson. The BGS conjecture is supported by experimental and numerical data, but a proof has been in search for by now two decades.

I report semiclassical evidence for spectral universality: The families of (pairs of) classical periodic orbits which build up, within Gutzwiller's periodic-orbit theory, all orders of the small time-expansion of the so called spectral form factor (the Fourier transform of the two-point correlator of the level density). Universal properties of classical chaos (ergodicity) and of quantum chaos (spectral statistics) are thus revealed as intimately related. Likewise, deep connections to the so-called non-linear sigma model of quantum field theory are uncovered.

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Lecture I
Pulse-coupled neural nets I. A reminder of the synergetic computer for pattern recognition

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Pattern recognition is understood as the action of an associative memory by which incomplete patterns are complemented according to specific rules. This is achieved by a dynamical system. The key to its construction is provided by the insight that pattern recognition is nothing but pattern formation as treated in synergetics. According to this approach an initially partly ordered pattern calls upon order parameters that compete with each other whereby one order parameter wins and enslaves the total system so to bring it in the fully ordered state. In analogy to that, in pattern recognition incomplete features call upon their order parameters that compete with each other and finally via the slaving principle call upon the rest of the corresponding features. Several methods are treated to make the recognition process invariant against displacements in space, rotations, and scaling. Also deformations will be treated so that contact with the Gestalt problem can be made. Finally oscillations and hysteresis in the perception of ambiguous figures will be treated.

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Lecture II
Pulse-coupled neural nets II. Synchronization

As was experimentally found by several authors, under specific conditions neurons of the visual cortex of cats, monkeys and other animals can fire synchronously. A theoretical modelling requires the treatment of a pulse-coupled neural network. Starting from a typical neuronal model with its dendrites, soma and axon, equations are established for the dendritic currents and the generation of the axonal pulses. Using a Green's function method the dendritic currents can be eliminated so that equations for the pulse variables alone result. The pulse variables can be interpreted either as phases (the light house model) or as generation times. I study the conditions on the external signals as well as on the connectivities so that either synchronization or at least phase locking becomes possible. The study of the stability of the phase locked state is rather intricate and I treat a number of typical cases. If time is left, I also treat some general approaches to calculate phases from experiments such as the Hilbert transform and correlation functions.

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Lecture III
Pulse-coupled neural nets III. The high pulse density limit

In order to make contact with the attractor network of the synergetic computer or a related network, I consider the case of short time intervals between pulses. This allows me to derive equations that are reminiscent of those of the synergetic computer where, however, the coupling coefficients become time dependent. I discuss the impact of this time dependence on the recognition process.

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Haken H 2005 to appear*Progress of theoretical Physics*

Lecture IV
Pulse-coupled neural nets IV. The role of attention and the finite present

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I first discuss the insufficiency of attractor neural networks because the system (brain) gets stuck after the recognition of one pattern. This is remedied by the concept of quasi-attractors in which an attractor is closed via saturation of attention after a pattern has been recognized. I discuss the details of the opening and closing process and its implication for the subjective present. In this approach the dynamical system "brain" wanders from one quasi-attractor to another one. The impact of various time constants on this process is studied and some speculative comments on consciousness will be made.

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Theory and Application of 2D Microcavity Lasers

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Various kinds of devices such as lasers and musical instruments utilize stationary wave oscillations in resonant cavities. In order to maintain the stationary oscillation in these devices, nonlinearity is essential in the mechanism for balancing the pumping of the external energy and the decay of the wave of the quasi-stable resonance in the resonant cavity. Besides, the interaction between nonlinearities and the morphology of the boundary condition imposed on a resonating wave system by the shape of the cavity is also very important for determining the modes of oscillation.

1D simple shapes have been used for laser cavities because they are suitable for fabrication as well as application of directional emission. However, recent advances in processing technology of dry-etching for semiconductor laser diodes have made it possible to fabricate 2D microcavity lasers of arbirary 2D shapes with potential applications of 2D emission of laser light in optical communications and optical integrated circuits.

We will review the theoretical models of 2D microcavity lasers and discuss their applications.

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Entropy Production of Nonequilibrium Systems

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Physical concept of *entropy production* formulated in the last century as statistical dynamics, which has been newly developed recently, is reviewed with emphasis of the role of *detailed balance*.

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Regular and irregular dynamics in quantum systems of interacting particles

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We discuss the mechanisms of a statistical behavior of classical and quantum Hamiltonian systems, both integrable and chaotic ones. As is known since the early works on the classical statistical mechanics, the conventional mechanism leading to a statistical relaxation in closed many-body systems is the thermodynamical limit which practically means a very large number of particles participating in the evolution of a system. Remarkably, in this approach there is no room for the notion of the chaos or integrability. Two famous examples are the chain of linear oscillators with linear couplings, and the nonlinear Toda-lattice. Being completely integrable, both systems in the thermodynamical limit manifest generic statistical properties for almost any initial conditions.

Another mechanism which nowadays is considered as the basic one, is the local instability of close trajectories in the phase space of classical systems. Due to this instability, the motion turns out to be chaotic even in the case of a small number of degrees of freedom. In the quantum mechanics this mechanism is absent, however, in a deep semiclassical limit the correspondence principle provides a close similarity of a quantum dynamics to the classical one.

In this lecture we discuss the occurrence of global statistical properties in closed many-body quantum systems, in the connection with two above mechanisms. As an example, we consider a system of interacting Bose-particles for which.

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Gauge Fields in Chaos Theory

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The structure of the lecture:

1. Gauge fields as connections in charge space. Curvature tensor. Gauge invariance and interactions. Path-ordered integrals. Wilson operator and Wilson loop. Non-abelian Stocks theorem (NAST).

2. Stochastic processes. Cumulants. Path ordered structures with Random variable. Van-Kampen expansion. Length of correlations. Gaussian dominance.

3. Gauge fields and curvature in holonomic quantum computations (HQC). Stability of HQC. Fidelity (1). Instability induced by perturbations. Fidelity (2). Instability and decoherence induced by interaction with environment. Fidelity and Wilson loop. Calculation of fidelity with the helps of (NAST) (exact formula and small errors approximation).

4. Confinement of colour quarks in Quantum Chomodynamics (QCD). Stochastic vacuum environment interaction of quarks. Wilson loop exponential decay (string tension) corresponds to fidelity (1) exponential decay (instability, chaos) corresponds to fidelity (2) (which is equal purity) exponential decay (decoherence, entangled state of pair of quarks with environment, loose information about colour, loose of colour objects, measurement of white object).

5. Instanton approach in chaos assisted tunneling (CAT). Instantons in quantum mechanics and in QCD. Space periodic perturbed potential as a model of CAT. Chaotic instanton solutions. Increasing of tunneling probability in terms of chaotic instantons. Plots.

6. Chaos in reduced gauge models. Analytical and numerical approaches. Toda instability criterion. Quantum chaos definition in terms of propagations. Chaos and spontaneous symmetry breakdown. Quantum loop corrections and order-chaos transition.

7. Conclusions.

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Impact: Void collapse and jet formation

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A lot of information on impacts of solid bodies on planets has been extracted from remote observations of impact craters on planetary surfaces; experiments however with large enough impact energies as compared to the energy stored in the ground are difficult. We approach this problem by downscaled experiments and by corresponding discrete particle numerical simulations: The idea is to fully decompactify very fine sand which then at impact of a steel ball behaves fluid-like. This prepared sand does not support weight: Balls carefully put on the surface sink into the sand up to five diameters deep. We call this state of sand dry quick sand. The final depth of the ball scales linearly with its mass. Now on impact of the ball, the series of events is as follows: sand is blown away in all directions ("splash") and an impact crater forms. When this cavity collapses, a granular jet emerges and is driven straight into the air. A second jet goes downwards into the air bubble entrained during the process, thus pushing surface material deep into the ground. The entrained air bubble rises slowly towards the surface, causing a granular eruption. In addition to the experiments and discrete particle simulations, we present a simple continuum theory to account for the void collapse leading to the formation of the upward and downward jets. We show that the phenomenon is robust and even works for oblique impacts: the upward jet is then shooting backwards, in the direction where the projectile came from.

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Turbulent bubbly flow

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The effect of bubbles on fully developed turbulent flow is investigated numerically and experimentally [1-4]. On the numerical side we simulate Navier-Stokes turbulence with a Taylor-Reynolds number of $Re_\lambda \approx 60$, a large scale forcing, and periodic boundary conditions. The point like bubbles follow their Lagrangian pathes and act as point forces on the flow. As a consequence, the spectral slope is less steep as compared to the Kolmogorov case. The slope decrease is identified as a lift force effect. On the experimental side we do hot-film anemometry in a turbulent water channel with $Re_\lambda \approx 200$ in which we have injected small bubbles up to a volume percentage of 3%. Here the challenge is to disentangle the bubble spikes from the hot-film velocity signal. To achieve this goal we have developed a pattern recognition scheme. Furthermore, we injected microbubbles up to a volume percentage of 0.3%. Both in the counter flowing situation with small bubbles and in the co-flow situation with microbubbles we obtain a less spectral slope, in agreement with the numerical result. - Finally, we address the issue of turbulent drag reduction in Taylor-Couette flow [5].

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Semiclassical quantization of chaotic systems

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How are quantum spectra related to the dynamics of the underlying classical Hamiltonian system? Integrable systems can be quantized using simple quantization rules, such as the Bohr-Sommerfeld quantization conditions. However, as already pointed out by Einstein (1917), the torus quantization fails for nonintegrable systems, where the classical dynamics is chaotic. For chaotic systems the link between the quantum and classical dynamics is given by Gutzwiller's (1990) periodic orbit theory, where the quantum density of states is expressed as a superposition of sinusoidal oscillations in terms of parameters of the periodic orbits.

Gutzwiller's trace formula suffers from convergence problems of the periodic orbit sum. Various regularization techniques have been developed to overcome those problems and to calculate individual semiclassical eigenenergies. For systems with complete hyperbolic dynamics Cvitanović and Eckhardt (1989) use a cycle expansion of the Gutzwiller-Voros zeta function. The cycle expansion requires the existence and knowledge of a symbolic code and is most successful for open systems. For bound systems Berry and Keating (1990) suggested pseudo-orbit expansions of Riemann-Siegel look-alike formulae as a rule for quantizing chaos. Main and Wunner (1999 and 2001) introduced harmonic inversion, i.e. high-resolution signal processing methods to extract individual semiclassical eigenenergies or resonances from a periodic-orbit time signal of finite length. The advantage of the harmonic inversion technique is its wide applicability, which allows periodic orbit quantization of bound and open systems with an underlying regular, mixed, or chaotic classical dynamics.

We shall review Gutzwiller's periodic orbit theory and various refinements to overcome the convergence problems of the trace formula. We shall then present results for systems with chaotic and mixed regular-chaotic dynamics including challenging problems, which so far have resisted any attempts for semiclassical quantization.

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Flexibility of dynamical systems and its importance for chaos control

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Flexibility of dynamical systems is studied in response to external perturbations, such as singular pulses, periodic signals, and noise. In particular, we are interested in the response ability of biophysical models for intra- and intercellular signal transduction. We propose the divergence as a simple mathematical measure for estimating the flexibility of dynamical systems [1,2]. The flexibility plays important role in determining coupling properties of dynamical systems. Flexible systems, characterised by close to zero local divergence, can be more easily coupled [3,4]. In case of stochastic resonance, constructive and destructive role of noise can be explained by the flexibility of the system [5,6,7]. Furthermore, the flexibility of dynamical systems also plays a role in chaos control. A deficiency of the existing algorithms for chaos control [8-10] is that the chaos control is limited to the control of UPOs that are part of chaotic attractors. Although every chaotic attractor consists of infinity number of UPOs, their diversity and, hence, their practical experimental applicability is usually moderate. We propose a new algorithm for detecting and controlling additional UPOs that are not part of the original chaotic attractor [11], and herewith enhance the applicability of chaos control methods also to those systems that are not characterised by numerous qualitatively different oscillatory regimes. The chaos control methods can also be applied to the temporarily destabilised regular systems characterised by a high degree of flexibility [12].

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Long-tailed distributions of the duration of life for disability in aged people

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Disability and the resulting lowered quality of life are serious issues accompanying increased longevity. Curiously, despite its potential contribution to aging theory, complete statistical and etiological structures of this common and unwelcome aging phenotype before death have not been well identified.

Here we analyze characteristic long tails of the duration distributions for disabilities in the aged. Log-normal distribution (LND) shows excellent fit with various data on the durations of disabilities, irrespective of their severity. For approximately 60 percent of the patients, the duration distributions are also mimicked by the first passage time distribution (FPTD) of one-dimensional Brownian motion. The robust long-tailed LND for various phases of disability validates the fact that patients in disability undergo series of stochastic subprocesses of many independent endogenous diseases, i.e., multiple pathology, until death. Diseases of core organs are found to be major causes of the long tails. A declining force of natural selection after reproduction and trade-off of life history through pleiotropy of the genes are considered to be the roots of aging. The attenuated selection pressure and the resulting decrease of genetic constraints produce an increased opportunity for chance and stochastics.

One of the lessons from this study is that any hospital for the aged must be a polyclinic which can cope with various diseases simultaneously in a coordinated fashion. We also believe that the present argument may apply to some problems in econophysics. One plausible example is bankruptcy of companies, which is often caused by multiple failures in management and circumstances.

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Nonlinear dynamics of anæsthesia

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The cardiovascular system behaves in many respects like a collection of noisy nonlinear oscillators whose mutual interactions give rise to a variety of classical coupled oscillator phenomena. Cardio-respiratory synchronization is especially pronounced during the state of anæsthesia in rats; recent work has shown that the directionality of the inter-oscillator interaction *reverses* as deep anæsthesia gives way to light anæsthesia. It seems that comparable synchronization phenomena occur in humans.

In the results to be discussed, we have found that cortical (EEG) waves can also become synchronized with the cardiac or respiratory oscillations, and that directionality of some interactions change in anæsthesia. We hope in the long run to develop a system for the routine monitoring of clinical anæsthesia based on such phenomena.

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Nonlinear dynamics of congestive heart failure

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Following on the anaesthesia lecture, we consider another distinct state of the cardiovascular system: that of the chronically failing heart. There is evidence that the lowest spectral peak in blood flow oscillations is related to endothelial function and we show that it is affected in congestive heart failure (CHF).

To do so, skin blood flow oscillations were measured by laser Doppler flowmetry (LDF) in 17 patients newly diagnosed with CHF, using the iontophoretically-administered vasodilators acetylcholine (ACh) and sodium nitroprusside (SNP). After treatment with a β-blocker (Bisoprolol), the measurements were repeated. Similar measurements were made on an age- and sex-matched control group of heathy volunteers. The resultant time series were analysed by use of the wavelet transform. In addition to the 5 spectral peaks seen in earlier studies, an additional peak was clearly resolved near 0.007 Hz. In healthy controls it is more strongly enhanced by ACh than SNP, whereas in CHF patients there is little difference. After treatment, however, the differential effect of ACh and SNP on the peak was more pronounced, demonstrating that the β-blocker treatment moved the response closer to that of the healthy controls. The results presented show clearly that oscillatory components can give non-invasively an insight into endothelial function in health and disease.

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Clustering of inertial particles in random flows

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We describe the dynamics of particles suspended in a randomly moving incompressible fluid which we assume to be mixing. At first sight, it seems as if the particles suspended in an incompressible mixing flow should become evenly distributed. This is indeed what happens if the particles are simply advected by the fluid. However, it has been noted [Maxey (1987)] that when the finite inertia of the suspended particles are significant, the particles can show a tendency to cluster.

The current theoretical understanding of this remarkable phenomenon refers to a dimensionless parameter termed the Stokes number, $\mathrm{St} = 1/(\gamma\tau)$, where γ is the rate at which the particle velocity is damped relative to that of the fluid due to viscous drag, and τ is the correlation time of the velocity field of the fluid. There is a consensus that clustering is pronounced when the Stokes number is of order unity.

In our lectures we show however that strong clustering can occur when the Stokes number is large. We show that different clustering mechanisms compete at large values of the Stokes number and quantify under which circumstances clustering occurs. To this end it is necessary to consider an additional dimensionless parameter, the so-called Kubo number Ku. We determine the phase diagram in the St-Ku plane.

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Extreme states of matter

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The violent processes of matter in extreme conditions are intrinsically associated strong with nonlinearity and chaos, where a theoretical description based on perturbation analysis usually brakes down. We review here several aspects of the nonlinear physics relevant to extreme states of matter, in terms of field intensity, particle density, pressure and temperature, that can be found in astronomical objects as well as in ultra-intense laser experiments. These two areas are closely related, not only in terms of the most relevant physical phenomena, such as relativistic particle beam instabilities, but also in terms of theoretical models and techniques, as for instance the wave kinetic theory. The connections and similarities between observed phenomena in the laboratory and in the universe will be stressed.

Present state of the art ultra-intense laser systems can deliver pulses in the Peta-Watt range ($1PW = 10^{15}W$) and intensities above $10^{20}W/cm^2$. At such high intensities the neutral atoms are completely ionized, and the solid targets vaporized. In the resulting dense plasma medium dramatic processes can occur, such as acceleration of electrons and protons to hundreds of MeV energies, novel types of nuclear processes, emission of sub-picosecond γ-ray bursts, high harmonic generation and Giga-Gauss magnetic fields. The more recent results are reviewed, including ion heating mechanisms that can be relevant to laser fusion. The astrophysical implications of this laboratory work, which is currently included in the new branch of laboratory astrophysics, will also be discussed.

The second part of the talk will be devoted to the astrophysical processes that can be tackled with similar nonlinear theoretical methods. In particular, the theory of photon kinetics and its generalized version called wave kinetics will be mentioned. As specific examples, we will discuss the supernova explosions, the neutrino beam instabilities and other collective neutrino processes. And, as a final illustration, we will describe a recent theoretical model for photon and neutrino acceleration by gravitational waves, and its implications to the γ-ray bursts of extra-galactic origin that are observed on Earth almost every day.

Role of nonlinearity in wave packet dynamics of Bose-Einstein condensates: soliton molecules versus wave interference

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We consider a role of nonlinearity in the dual (wave and particle) aspect of wave packet dynamics in Bose-Einstein condensates. The analysis is based on 2-d nonlinear Schrödinger equation (NSE) or Gross-Pitaevskii equation (GPE). Firstly we are concerned with the particle aspect of interacting wave packets and explore the emergence of chaos in soliton molecules. We choose the multi-component repulsive BEC in a 2-d harmonic trap. In the absence of the inter-component interaction (ICI), the wave packet(WP) breathing and the motion of relative distance between WPs have oscillation frequencies always degenerate for any set of the angular momentum and intra-component interaction. The non-zero ICI removes the degeneracy and induces the fat mode that breaks a picture of soliton molecules. We therefore propose a new model with a time-periodic ICI with zero time-average. This model elongates the time interval without any blowup of WPs and stabilizes high-dimensional WPs, provided that the frequency is larger than the characteristic breathing frequency. In case of the molecule of three wave packets for a three-component BEC, the increase of ICI amplitude yields a transition from regular to chaotic oscillations in the wave packet breathing (Yamasaki *et al* (2005)) .

Secondly we investigate the wave aspect of a single wave packet and the formation of fringe patterns. By using a single component NSE, dynamics of a macroscopic wave packet falling through the double slits is analyzed. We explore the splitting of the wave packet and its reorganization leading to the interference pattern. Particular attention is paid to the role of gravity and nonlinearity on the fringe pattern. Increase of gravity shortens de Broglie wavelength and thereby narrows the peak-to-peak distance in the fringe pattern and the repulsive nonlinearity elongates the wave packet width and thereby increases the number of interference peaks. Control of gravity and nonlinearity is suggested to design the experiments to verify the present result (Nakamura *et al* (2005)) .

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Quantum transport in quantum dots: from Lord Kelvin through orbit bifurcations

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The dynamics of billiard balls and its role in physics have received wide attention since the monumental lecture by Lord Kelvin at the turn of the 19th century, entitled "The 19th century clouds over the dynamical theory of heat and light. " The first cloud was the question of the existence of the **ether** propagating light. He disapproved of the possibility of the Earth moving through the ether. The second cloud was the question of the validity of the Maxwell–Boltzmann (MB) distribution leading to the equipartition of energy and he ultimately doubted the **ergodicity hypothesis** behind the MB distribution. Five years later after Kelvin's lecture, the first cloud was swept away by Einstein's special theory of relativity. But, how did the second cloud disappear? In order to sweep away the 19th century cloud over the ergodicity hypothesis, it had become indispensable to envisage complex features of nonlinear dynamics of a particle in billiards, leading ultimately to today's prosperity of physics of classical and quantal billiards.

We shall here focus on the billiards with mixed phase space rather than fully ergodic billiards and investigate a role of orbit bifurcations in magnetic billiards. The Gutzwiller-type semiclassical trace formula and the semiclassical Kubo formula work only when there is no overlapping among saddle points, namely, when periodic orbits are isolated from each other. However, periodic orbits can show bifurcations when the system's parameters (e.g., magnetic or electric fields or billiard table shapes) are varied. At the point of bifurcations, the improved semiclassical formulas should be used. The triangular antidot lattice in semiconductor interfaces, is a realization of Sinai billiards. The anomalously large fluctuations in magneto-resistivity observed in experiments on the lower-magnetic-field side of Weiss *et al*'s commensurability peak, can be interpreted on the basis of orbit bifurcations. We review the existing works (Nakamura and Harayama (2004)) and show the more interesting role of orbit bifurcation in quantum transport (Miyamoto *et al* (2005)).

About some current and future NASA projects

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NASA keeps its program humming along in spite of the Shuttle tragedies. Many programs are with international cooperation with classical example of Cassini and International Space Station . The Martian geological robots Spirit and Opportunity are continuing the exploration of the Martian surface. With additional funding they can continue - if healthy - until the fall of 2006. This summer a new martian orbiter, Mars Reconaissance Orbiter, will be launched. Martian orbital surveyor is still very much active since 1997. In preparation is also Mars Sample Return Mission. Landing on Mars is on the books, but not yet on firm footing. Sonda Stardust is on the way back to Earth landing in Jan of 2006 after successful passage through the tail of comet Wild 2. The spacecraft Cassini is since January in the orbit around Saturn. It will approach a number of Saturn's moons, especially Titan on which landed European probe named Huygens. Space telescope Hubble is still alive and continues sending us unbelievable snapshots from space and so far got us views furthest into the vastness of space over 13 billions light years away. The maintenance with upgrades of the gyros is not funded. As an advanced replacement will be James Webb Space telescope around 2011. Spitzer Space Telescope is unveiling many sights of the universe visible only in infrared part of the electromagnetic spectrum. The construction of the International Space Station continuous with the restart of Shuttle flights in July 2005. Russian vehicles Soyuz and Vostok proved to be of extreme value with their proven reliability to dock at the station and bringing the material and cosmonauts-astronauts to and back from the station. Another exciting area is search for the extrasolar planets. There are over 150 planets identified around nearby stars, but only indirectly through wobbling of the stars. Project Kepler 2006/7 will look for the planets with the transit method. Project SIM space interferometry mission and planned Terrestrial planet finder around 2015 will look for the terrestrial type planets directly through the detection of planets light. We discussed a few most prominent projects but there are more of them. Discussion and comments are welcome.

Effective desynchronization of coupled oscillators by nonlinear delayed feedback

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Synchronization of coupled oscillators is a universal phenomenon, which has been observed and studied in many fields. However, synchronization is not always desirable. In fact, pathological synchronization is a hallmark of several neurological diseases like Parkinson's disease (PD) or essential tremor, where the resting tremor is caused by a pacemaker-like population of neurons which fire in a synchronized and periodical manner. There is a significant clinical need for mild deep brain stimulation techniques which restore desynchronized (i.e., normal) dynamics in networks of oscillatory neurons.

We propose an effective method for desynchronization of strongly interacting oscillators. The method is based on the nonlinear delayed feedback, where a synchronized population of oscillators is stimulated with a signal constructed by nonlinear combination of the delayed and instantaneous mean fields of the ensemble. The stimulation results in complete desynchronization of the oscillators and restores their natural frequencies, so that the oscillators rotate as if they were uncoupled. Even in the case of strong coupling, the amplitude of the stimulation signal practically vanishes when a desynchronized state is achieved. This naturally realizes a demand-controlled character of the proposed desynchronization technique.

We study the impact of nonlinear delayed feedback on stimulated ensembles and illustrate the method on the ensembles of coupled phase, limit-cycle, relaxation van der Pol, and chaotic Rössler oscillators. We discuss the phenomenon of multistability of stimulation-induced desynchronized states, where the mean frequency of macroscopic oscillations can be adjusted by properly chosen values of stimulation parameters. We also discuss a variety of application protocols of the proposed method, where the number of stimulation sites can vary from multiple to a single one as desired by a particular application. Our method may be suitable for both technical and medical applications requiring robust desynchronization by mild stimulation.

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Drag reduction by polymers in turbulent wall-bounded flows

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Drag reduction in turbulent flows by a small concentration of polymers is an important phenomenon utilized in a number of technological applications including the Alaska pipeline. The efficacy of drag reduction by polymers is bounded by the so-called "maximum drag reduction asymptote" which was discovered and fully characterized experimentally more than thirty years ago. The asymptote appears universal, and the parameters characterizing it were carefully measured, but to date not understood. In this lecture I will offer a way to understand the nature of this asymptote and to calculate theoretically the parameters involved. The theory provides understanding of the intrinsic limit to how much the drag can be reduced by polymeric agents, and offers predictions for the non-universal cross-overs back to the Newtonian plug when the concentration of polymers or the Reynolds numbers are too small.

Quantum and Classical Loschmidt Echoes

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We shall review some recent developments on the question of stability of quantum [1,2] and classical mechanics [3] under external static perturbations of the Hamiltonian. Understanding different types of stability of quantum dynamics should be particularly useful for a design of efficient and robust protocols of quantum computation [4]. Furthermore, as a consequence of unitarity of quantum and classical time evolutions the problem is equivalent to the old problem of Loschmidt echoes in statistical mechanics and may shed a new light on the question about the origin of macroscopic irreversibility of microscopically reversible mechanics.

In the first part of the lecture I shall introduce the basic concepts and outline the main semiclassical and heuristic theories for a description of the decay of Loschmidt echoes [1]. In the second part I will focus on a very simple and useful description [2] of Loschmidt echo decay in terms of temporal correlation functions of the perturbation operator.

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Decoherence in regular and chaotic systems

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In this second lecture, which shall be a natural continuation of the first lecture on Loschmidt echoes, we shall relate the problem of fidelity decay and Loschmidt echoes to the unitary description of decoherence in a weakly coupled composite system (central system plus environment) [1,2]. We will demonstrate a simple and useful inequality between the purity of the reduced density matrix (traced over the environmental degrees of freedom) and the square of fidelity of a weakly coupled composite system [2,3]. For a particular form of a coupling one can even find exact relationship between off-diagonal matrix element of the reduced density matrix - the main indicator of decoherence - and fidelity decay in the environment [4].

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Quantum chaos and transport in many-body systems

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The problem of quantum chaos in many-body systems is still largely unexplored area. In this lecture we shall present one important set of questions in this context, namely on the relation between (non)integrability, quantum chaos as defined for example in terms of level statistics, and relaxation - decay of time-correlation functions which are direcly related to transport coefficients such as conductivities. Even the complementary question on the connection between integrability and anomalous (ballistic) transport largely puzzled condensed matter community in recent years [1].

As there is so far no rigorous theoretical description of non-integrable quantum many-body systems, our approach and presentation are mainly based on numerical investigations in simple but generic toy models of interacting one-dimensional many-body systems, e.g. quantum spin chains [2] or spinless fermion chains [3]. These results show quite clearly the connection between quantum chaos and normal (diffusive) transport properties of these models.

Recently it has been shown [4] that one can use a concept of maximal eigenvalues of certain effective propagator in the space of observables, similar to the notion of Ruelle resonances in classical chaotic systems, in order to describe decay of time-correlations of typical observable.

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Rigid Body Dynamics

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The standard rigid body problem as defined by the Euler-Poisson equations has four essential parameters (two moments of inertia and two angles for the location of the center of gravity) and a six-dimensional phase space. The existence of two Casimir functions implies that the system may be decomposed into Hamiltonian systems with four-dimensional phase spaces and three-dimensional iso-energy surfaces.

We shall review the topological nature of these energy surfaces and their projections into configuration and momentum spaces. The richness of their bifurcation diagrams is impressive.

The well known integrable cases correspond to small subsets of the 4D parameter set: 2D in Euler's case, 1D in Lagrange's and Kovalevskaya's. These systems have been fully analyzed: the energy surfaces will be shown in action variable representation (Dullin et al 1994, 1998); the topology of Liouville foliations was completely elucidated in Bolsinov et al (1999).

Much less is known about non-integrable cases. Bifurcation diagrams of a 2D subset first studied by Katok (1972) will be presented, including the bifurcation scheme of the envelopes of the projections into the space of angular velocities (Gashenenko and Richter 2004). A 3D subset was recently analyzed by Gashenenko (2003).

The last part will be devoted to a discussion of convenient Poincaré surfaces of section for the study of non-integrable dynamics. For a one-parameter family connecting a Lagrange case to the Kovalevskaya system, the bifurcation scheme for the dominant periodic orbits will be shown (Schmidt et al, in preparation).

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Quantum chaos in mixed type Hamiltonian systems

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We shall review the basic aspects of complete integrability and complete chaos (ergodicity) in classical Hamiltonian systems, as well as all the cases in between, the generic, mixed type systems, where KAM Theory is applicable, and shall illustrate it using the billiard model systems.

Then we shall proceed to the quantum chaos and its stationary properties, that is the structure and the morphology of the solutions of the underlying Schroedinger equation which in case of 2-dim billiards is just the 2-dim Helmholtz equation. We shall discuss the statistical properties of chaotic eigenfunctions, the statistical properties of the energy spectra, and show arguments and results in support of the so-called universality classes of spectral fluctuations, where in the fully chaotic case the Random Matrix Theory (RMT) is applicable. First we discuss the universality classes of spectral fluctuations (GOE/GUE for ergodic systems, and Poissonian for integrable systems). We explain the problems in the calculation of the invariant (Liouville) measure of classically chaotic components, which has recently been studied by Robnik et al (1997) and by Prosen and Robnik (1998). Then we describe the Berry-Robnik (1984) picture, based on The Principle of Uniform Semiclassical Condensation of Wigner functions (PUSC; Robnik 1998), which is claimed to become exact in the strict semiclassical limit $\hbar \to 0$. However, at not sufficiently small values of $\hbar$ we see a crossover regime due to the localization properties of stationary quantum states where Brody-like behaviour with the fractional power law level repulsion is observed in the corresponding quantal energy spectra. We shall discuss some very recent results on this topic.

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Computational algebra and invariants of differential equations

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First, we explain very briefly the notion of Groebner basis which is a cornerstone of numerous algorithms of computational algebra.

Then, we consider applications of the Groebner bases algorithm to the following problems of the theory of ordinary differential equations.

(a) The description problem for normal forms of local dynamical systems. Any autonomous system of ODE of the form

$$\dot{x} = Ax + h.o.t., \tag{1}$$

where x is a n-dim vector and A is a $n \times n$ matrix. can be transformed to a simpler form, called a normal form of system (1). The normal form is characterized by:
(1) a collection of functions $I_1, \ldots, I_p$ of the coordinates called the basic invariants;
(2) a collection of vector fields $v_1, \ldots, v_q$ called the basic equivariants.

We present simple algorithms for computing the invariants and equivariants of a given system of the form (1).

(b) Consider 2-dim system (1), where the right-hand sides are polynomials. Let Q be the group of rotation of the phase space of (1). We give an algorithm to compute a finite basis of invariants of the group Q and show that these invariants determine the set of all time-reversible systems in the family (1). They also determine the number of axes of symmetry of the phase space picture of trajectories of system (1).

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Synchronization of complex systems

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In the classical sense, synchronization of interacting periodic oscillators means appearance of certain relations between their phases and frequencies due to a weak coupling. After giving brief introduction into the classical theory we review its recent extension to the case of chaotic systems; here we distinguish the effects of complete and phase synchronization. First we discuss how the phase and mean frequency of an autonomous chaotic system can be determined and compare phase dynamics of chaotic oscillators with that of noisy limit cycle oscillators, illustrating the deterministic phase diffusion by numerical examples. We discuss the effect of phase diffusion, or oscillator coherence, on the ability of a system to be synchronized. Next, we illustrate synchronization effects in periodically driven and coupled chaotic systems by numerical and experimental examples.

In the second part of the talk we demonstrate that the coherence of a noisy or chaotic self-sustained oscillator can be efficiently controlled by the delayed feedback. We present a theory of this effect and demonstrate its good agreement with the numerics. One of the implications of the coherence control is a possibility to govern synchronization properties of an oscillator. We illustrate this by consideration of the phase synchronization of the Lorenz system by a periodic force. In the absence of the feedback the force is too weak to entrain the system, while the coherent oscillator demonstrates synchronization.

Finally, we consider dynamical systems with multiple time scales where both slow and fast variables possess nontrivial dynamics, and discuss how a separation of slow and fast motions in such systems can be performed. We demonstrate the effect of partial phase and complete synchronization, where slow motions become synchronized while the fast ones do not. The effect is illustrated by examples of coupled bursting neurons and coupled Josephson junctions.

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Report on Basic Partial Difference Equations

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Partial differential equations belong to the natural analytic structures to model processes all over the sciences. In many classically important cases, like standard elliptic equations, standard hyperbolic equations and standard parabolic equations, the assumption that space and time are continuous leads quite far.

In this contribution, we show how well-known partial differential equations from Mathematical Physics can be discretized by means of so-called Basic Fourier Series. We give main properties of these equations in detail and reveal this new discretization technique which is interesting not only from the analytic but also from the numerical point of view.

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Stokes geometry in chaotic systems I, II

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Semiclassical approximation is a widely used technique to study quantum-classical correspondence in chaotic systems, that is, to see how classical chaos influences the corresponding quantum systems in the semiclassical limit. Here, we mean semiclassical approximation as just taking the leading order contribution in evaluating, for example, the quantum time-evolution operator via the stationary phase method. Formally, it looks straightforward to extend it to the complex domain, but one encounters a serious difficulty in developing the complex semiclassical method since the so-called *Stokes phenomenon* occurs between the solutions satisfying the saddle-point condition(Dingle 1973). In particular, the Stokes phenomenon in multidimensional problems has not been well understood until the exact WKB method established mathematical ground of the Stokes phenomenon(Bender & Wu 1969, Voros 1983, Zinn-Justin 1984, Silverstone 1985, Delabaere, Dillinger & Pham 1993, Kawai & Takai 1998).

We shall present a brief review of recently developed ideas to deal with the Stokes phenomenon in higher-order differential equations and to give a concrete recipe to analyze it within the exact WKB framework (Aoki, Kawai & Takai 1994, Aoki *et al* 2005)). We stress that new ingredients appear in multidimensional problems and incorporating them into the standard ones dissolves a paradox first discovered in analyzing a third-order diffrential equation(Berk, Nevins & Roberts 1982). As a direct application of a proposed recipe, we shall discuss the Stokes geometry of the quantum Hénon map(Shudo 2005), and also multi-level non-adiabatic transition problems(Aoki, Kawai & Takai 2002).

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Noisy coupled oscillators: cardiovascular and brain interactions

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Blood flow and blood pressure are governed by dynamical interactions between the cardiac, respiratory and vascular systems. They can be characterized as coupled noisy oscillators acting on distinct time-scales but with time-varying characteristic frequencies (Stefanovska and M Bračič, 1999). The variability results from their mutual frequency and amplitude modulation and partially from the spatial distribution of the underlying physiological systems. It is well known that, in relaxed healthy humans, the cardiac and respiratory instantaneous frequencies fluctuate around 1 Hz and 0.2 Hz respectively.

In our experiments, the wavelet transform, which allows for optimal time and frequency localisation, is being used to reveal the low frequency oscillatory components. Skin blood flows on all four extremities, arterial blood pressure, ECG and respiration are simultaneously recorded and analysed. Although these signals bear complex dynamics we can distinguish the involvement of the myogenic, neurogenic (Söderström *et al*, 2003) and endothelial (Kvernmo *et al* 1999; Kvandal *et al*, 2003) activities. Their instantaneous frequencies fluctuate around 0.1 Hz, 0.04 Hz and 0.01 Hz, respectively. An overview of recent experiments related to their physiological origin will be presented.

The contribution of each of the cardiovascular oscillatory process can be expected to change with age, after exercise (Kvernmo *et al*, 2003) or in diabetes (Urbančič-Rovan *et al*, 2003), congestive heart failure and acute myocardial infarction. Results of large clinical, multi-centre, studies will be presented and potentials of the coupled oscillators approach in gaining clinical and physiological insight will be discussed.

New studies focusing on the interactions between the oscillatory components of the cardiovascular system and the brain activity have recently been initiated. Analyses based on the wavelet transform have shown that the frequency content of the brain waves (John, 2002), δ (0.5–3.5 Hz), θ (3.5–7.5 Hz), α (7.5–12.5 Hz), β (12.5–25 Hz), γ_1 (25–35 Hz), γ_2 (35–50 Hz), and γ_3 (50–100 Hz), also varies in time. New techniques (Rosenblum and Pikovsky 2001; Paluš and Stefanovska 2003; Jamšek *et al*, 2004) allowing fresh insight into the mutual interactions between oscillatory processes will be described. It will be illustrated that the characteristics of the causal relationships between cardiac, respiratory and brain oscillations change dramatically from the waking state to anæsthesia (Stefanovska *et al*, 2000; Entwistle *et al*, 2004; Musizza *et al*, 2005). Again, practical implications of the coupled oscillators approach will be presented and possibilities of detection awareness in anaesthesia, potentially enabling its prevention, will be discussed.

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1/f spectra: noise, chaotic dynamics, or phase coupled oscillators?

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Weakly coupled nonlinear oscillators operating in the presence of noise are widespread in nature. Examples include brain waves and cardiovascular oscillations. They can be amplitude and frequency-coupled, and are characterised by time-varying frequencies of oscillation. The time series related to cardiovascular and brain oscillations have been extensively analysed in the past decades and often associated with 1/f spectra. Their origin has been characterised variously as noise, chaotic dynamics and phase coupled oscillations. The talk will present an extensive review and discuss this yet unanswered question using numerically simulated and real data.

Microwave billiards as scattering systems

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Each measurement unavoidably disturbs the system one is interested in with the consequence that always a combination of system properties and those of the measuring apparatus is obtained. Scattering theory is the method of choice to cope with such a situation. Microwave billiards are particularly well suited to check the theoretical predictions of scattering theory. In quasi-two dimensional systems, with top and bottom plate parallel to each other, there is a one-to-one correspondence to quantum mechanics, as long as a maximum frequency of $\nu_{\max} = c/2h$ (h: height of the resonator) is not exceeded [1]. In microwave billiards the scattering channels are the attached antennas. The diagonal elements of the scattering matrix are the reflection amplitudes, and the off-diagonal elements the transmission amplitudes between the two respective antennas. In contrast e. g. to nuclear or mesoscopic physics all elements of the scattering matrix are available including their phases. In addition the geometry of the billiards is exactly known allowing tests of scattering theory with an hitherto unknown precision.

This is illustrated in a series of three lectures in a number of examples.

Lecture 1: Current and vortex distributions in open systems

By scanning with an antenna through a billiard the field distributions within the system can be determined. Since the phases can be measured, too, the Poynting vector, being equivalent to the quantum-mechanical probability current density, can be reconstructed as well. According to the Berry conjecture in chaotic billiards the wave functions may be looked upon as a random superpositions of plane waves [2]. The model allows the analytical calculation of various current and vortex distributions, vortex distance distributions and spatial correlation functions, which can be tested in the experiment [3, 4]. A number of these correlations, contrary to what one might expect, show surviving long-range correlations [5].

Whereas the Berry conjecture focusses on the *universal* properties of chaotic systems, semiclassical quantum mechanics, based on the works of Gutzwiller [6] gives information on *individual* properties, i. e. on the classical orbits connecting entrance and exit antennas. Experimental studies in microwave "quantum dots" show that the transport is dominated by scarring, i. e. by field distributions showing extra-large amplitudes close to classical orbits [7, 8].

Lecture 2: Distribution of transmission and reflection coefficients

Scattering theory yields a relation between the scattering matrix and the billiard Green function which may be written as

$$S = 1 - 2iW^{\dagger}\frac{1}{E - H - iWW^{\dagger}}W \tag{3}$$

where $H = -\Delta$ is the Hamiltonian of the closed system, and matrix W contains the information on the antenna coupling [9]. For point-like coupling the matrix elements W_{nm} are, up to a factor, just the wave functions $\psi_n(r_m)$ of the closed system at the position at the antenna.

Using random matrix theory, where the matrix elements of H and W are taken as Gaussian random variables, various quantities can be explicitly calculated from Eq. (3), among others distributions of reflection and transmission coefficients. To check the theoretical predictions, transmission studies have been performed in microwave billiards with and without time-reversal symmetry [11]. Ferrites had been inserted to break time-reversal symmetry. For the one-channel case a systematic study of the reflection in dependence of the absorption was performed [10], as well as of the distribution of reflection phases, the so-called Poisson kernel [12]. In all cases a perfect agreement with random matrix predictions was found.

Lecture 3: Scattering fidelities

The concept of fidelity has been proposed by Peres [13] to quantify the quantum-mechanical stability of a system against a perturbation. The fidelity amplitude is defined as the overlap integral of some initial state $\psi(0)$ with itself after the evolution under the influence of two slightly different time evolution operators $U(t)$ and $U'(t)$,

$$f(t) = \langle\psi(0)|\, U^\dagger(t)\, U'(t)\, |\psi(0)\rangle \tag{4}$$

In scattering experiments an equivalent of the the fidelity amplitude can be defined in terms of cross-correlations of scattering matrix elements. In microwave billiards the variation in the time evolution has been realized by shifting one wall. A perfect agreement with predictions of linear-response calculations [14] was obtained [15].

The linear-response calculations break down for strong perturbations. In this regime exact results can be obtained by means of super-symmetry techniques [16]. As a new and completely unexpected result it is found that there is a recovery of the fidelity at the Heisenberg time. A presentation of the calculations is used to provide a short tutorial introduction into the technique.

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Quantum chaos in dynamics of molecules

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Molecular science covers a wide range of material science, ranging from hydrogen molecule to protein, DNA, and even larger molecules. In particular, dynamics of molecules is quite interesting in that you can establish novel concepts, theories, methods, and models to describe new phenomena that come out experimentally. What is more, you can verify your theory in terms of experiments with highly sophisticated techniques. Nevertheless, the importance of chemical dynamics does not seem to be well recognized in physics community.

Spending the first one third of my talk, I explain the basic theoretical framework of dynamics of molecules, with which you can begin your study in this field. Then, I devote the next one third to semiclassical quantization of chaos, which is relevant to highly excited states of molecular vibration. To this aim, we have developed a new powerful method [1-3] that is free of the annoying amplitude factor in the semiclassical Feynman-Van Vleck propagator and the Gutzwiller trace formula, which diverges exponentially in time in classically chaotic systems and thereby destroys the spectrum. Then, in the last one third, I discuss a "quantum chaos" that can occur only in quantum mechanics, the mechanism of which is ascribed to a repetition of bifurcation (branching) and merge of a quantum wave packet due to nonadiabatic transition [4]. This phenomenon is relevant to molecular electron transfer, which is a very fundamental process not only in chemistry but in biological science. I show that this wave packet bifurcation can be observed by means of femto-second time-resolved photoelectron spectroscopy [5].

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Adaptive neuromodulation: a novel approach to electrical brain stimulation

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In several neurological diseases like Parkinson's disease (PD), essential tremor or multiple sclerosis (MS) brain function in severely impaired by synchronization processes. To overcome limitations and drawbacks of conventional DBS (Benabid et al. 1991, McIntyre et al. 2004), we propose a novel method which selectively disrupts pathological synchronization and restores desynchronization in a mild but effective manner (Tass 1999). Effective transient desynchronization is achieved by a multisite coordinated reset (CR) stimulation, where mild resetting stimulus trains are sequentially administered via several sites (Tass 2003a, Tass 2003b). After a CR stimulus the target population splits into several sub-populations, quickly runs into a pronounced transient desynchronized state, and then reverts to synchrony if left unperturbed. To maintain a desynchronized firing, CR stimuli have to be administered repitively, e.g., strictly periodically or on demand. We have successfully tested multisite CR stimulation during stereotaxic electrode implantation in patients with tremor caused by PD and MS. CR stimulation turned out to be superior compared to conventional DBS with respect to tremor suppression and energy consumption. Multisite CR stimulation may also be a promising therapeutic option for other neurological diseases characterized by pathological neuronal synchronization, e.g. epilepsies. As shown theoretically, desyncronizing brain stimulation may even have long-lasting curative effects in terms of therapeutic rewiring (Tass and Majtanik 2005).

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Complex transient dynamics underlying visual evoked responses

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The role of ongoing rhythmic activity in the generation of evoked responses is still a matter of debate (see e.g. Makeig et al. 2002, Mäkinen et al. 2005). Theoretical studies in coupled oscillators predict: (i) Apart from phase resets stimuli may cause a response clustering, i.e. a switching between qualitatively different responses across trials, which is typically averaged out with standard analysis (Tass 2003). (ii) Latencies of resets provide reliable estimates of the transmission of stimulus effects and are typically different from latencies of averaged responses (Tass 2004). A full-field pattern reversal task was performed in 7 healthy male right handed subjects. Stimulus-locked single run responses of the alpha rhythm were analyzed with a stochastic phase resetting analysis (Tass 2003, Tass 2004), magnetic field tomography (Ioannides et al. 1990), and probabilistic cytoarchitectonic maps (Amunts et al. 2000, Zilles et al. 2002). In all 7 subjects visual areas V1/V2 and V5 are generators of averaged broadband responses. Resets of the alpha rhythm occur at 149 +/- 27 ms (V1/V2) and 146 +/- 39 ms (V5) and are followed by long-lasting epochs of synchronized response clustering in V1/V2 (mean duration in a 2-s poststimulus window: 859 +/- 308 ms) and V5 (772 +/- 540 ms). Peaks of averaged alpha responses occur at 97 +/- 26 ms (V1/V2) and 129 +/- 55 ms (V5). Reset latency and latency of averaged response in V1 are significantly different ($p < 0.0032$, T-test). We verify predictions (i) and (ii) and observe long-lasting complex alpha responses. Averaged responses may be misleading when used for the detection of latencies of responses of brain rhythms.

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Chaos and Code in Communications

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It is recently found that chaos has many interesting roles in communication systems. I shall review the following topics including basic theory and experiments of Chaos-CDMA in wireless communication systems, digital chaotic cipher, independent component analysis of chaotic communication signals, and chaotic public key encryption.

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Granular Gas Dynamics I: Clustering, Coarsening, and Traffic Jams

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Granular gases are of great scientific *and* economic relevance. Scientific, because of their tendency to spontaneously separate into dense and dilute regions, which makes them fundamentally different from any textbook molecular gas. Economic, because no less than 5 per cent of the global energy budget is wasted due to problems with granular matter in conveyor belts, sorting machines, mixers, and other industrial machinery (Jaeger et al., 1996).

Here we study - experimentally, numerically, and theoretically - the clustering of particles in a vertically vibrated array of N connected compartments. For strong shaking, the particles spread evenly over the compartments, but if the shaking strength is lowered beneath a critical level this uniform distribution gives way to a clustered state, consisting of a few well-filled compartments and a lot of diluted ones (Eggers, 1999; Van der Weele et al., 2001, 2004; Van der Meer et al., 2001, 2002, 2003; Mikkelsen et al., 2002, 2003, 2004, 2005). In the course of time, this state *coarsens*: The smaller clusters are eaten by the larger ones, until finally only one big cluster remains. This coarsening process is exceptionally slow, with the mass of the surviving cluster growing only as $(\log t)^{1/2}$ (Van der Meer et al., 2004).

A related problem of prime importance in modern society is the clustering of cars on the highway (Helbing, 2001). We show how the formation of traffic jams on the Dutch highway A58 is well described - and predicted! - by a flux model similar to the one we use for the clustering of granular particles (Van der Weele et al., 2005).

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Granular Gas Dynamics II:
a. The granular Leidenfrost effect
b. Fountains and Ratchets

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The granular *Leidenfrost effect* is observed when a container with beads is vibrated vertically. Above a critical shaking strength, and for a sufficient number of particle layers, a dense cluster of beads with a near-perfect crystalline packing is elevated and supported by a dilute layer of fast particles underneath. This is just as in the original Leidenfrost effect, described in 1756 by Johann Gottlob Leidenfrost, in which a water droplet hovers over a hot plate, floating on its own vapor layer. The experimental observations are accounted for using a hydrodynamic-like model (Meerson et al. 2003; Eshuis et al., 2005).

Next we turn to the wonderful world of *ratchets*, which have become a hot topic in recent years. In order to extract mechanical work on a molecular scale (e.g., to make a muscle move), nature uses the concept of a Brownian ratchet: The stochastic forces from a noisy environment are converted into a directed motion. Here we create a "granular ratchet", exploiting the clustering phenomenon from the previous lecture in a slightly adapted array of N connected compartments: The stochastically colliding particles spontaneously generate a particle current perpendicular to the direction of energy input. This is the first practical realization of the theoretically predicted concept of a stochastic ratchet as a collective effect in a symmetric geometry (Van der Meer et al., 2004).

Closely related to this is the "granular fountain", being a two-compartment system in which the directed motion of the particles takes the form of a spectacular convection roll. All the experimental observations are explained quantitatively by a dynamical flux model (Van der Meer et al., 2004).

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Reviewing the relativistic pole-barn paradox: How the pole is caught

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Hundred years after Einstein formulated the special theory of relativity, we review one of its famous paradoxes: the length contraction paradox, about a farmer who wants to catch a pole-vaulter in a short barn. The original paradox only describes the situation in which the velocity of the pole with respect to the barn is constant, but we go beyond that and also analyze the actual catch in which the pole is brought to a standstill. This natural follow-up question, rarely addressed in textbooks, turns out to have a very surprising outcome (Van der Weele and Snoeijer, 2005).

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Clustering of inertial particles in random flows

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We describe the dynamics of particles suspended in a randomly moving incompressible fluid which we assume to be mixing. At first sight, it seems as if the particles suspended in an incompressible mixing flow should become evenly distributed. This is indeed what happens if the particles are simply advected by the fluid. However, it has been noted [Maxey (1987)] that when the finite inertia of the suspended particles are significant, the particles can show a tendency to cluster.

The current theoretical understanding of this remarkable phenomenon refers to a dimensionless parameter termed the Stokes number, $\mathrm{St} = 1/(\gamma\tau)$, where γ is the rate at which the particle velocity is damped relative to that of the fluid due to viscous drag, and τ is the correlation time of the velocity field of the fluid. There is a consensus that clustering is pronounced when the Stokes number is of order unity.

In our lectures we show however that strong clustering can occur when the Stokes number is large. We show that different clustering mechanisms compete at large values of the Stokes number and quantify under which circumstances clustering occurs. To this end it is necessary to consider an additional dimensionless parameter, the so-called Kubo number Ku. We determine the phase diagram in the St-Ku plane.

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Quantum Adiabatic Computation and NP-Complete problems

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According to the algorithmic complexity computational problems can be divided into several classes, two most important are: (i) problems for which *finding* the solution demands a number of steps that grows polynomially with the size of the problem, this group is denoted shortly by P, and (ii) problems for which *verifying* if a given solution really solves the problem needs polynomial number of steps, this group is denoted by NP (non-deterministic polynomial). Especially important class of NP problems are the so-called NP-complete problems (NPC). Vaguely speaking, NPC problems are the hardest problems in NP. If we find a polynomial algorithm for a single NPC problem, we automatically have a polynomial algorithm for *all* NP problems. At present, all known algorithms for NPC require exponentially many steps, but there is no proof that none exists. Actually, the problem whether P=NP is the main problem of theoretical computer science. Opinion is that P≠NP, proof of the contrary would be a great shock and would have many practical consequences.

A few years ago a new quantum algorithms appeared. Quantum computation has received great attention after Shor's discovery of factorization algorithm. This algorithm is polynomial and is faster than any known classical algorithm. Quantum algorithms therefore seem to be better than the classical ones. The question is, are they able to solve also NPC problems in polynomial time? In 2001 a group from MIT described a new type of algorithm, namely quantum adiabatic algorithm [1]. Their numerical data for NPC problem of small size suggested polynomial time dependence, which would imply P=NP!

I will present the analysis of running time of quantum adiabatic algorithm for an NPC problem called 3-SAT. Numerical data show that the running time is exponential for a certain type of "hard" instances not know previously [2]. These new hard instances also seem to be harder for classical solving algorithms [3].

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Abstracts of Short Reports

The Transition State in a Noisy Environment

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Classical Transition State Theory is the cornerstone of reaction rate theory. It postulates a partition of phase space into reactant and product regions, which are separated by a dividing surface that reactive trajectories must cross. In order not to overestimate the reaction rate, the dividing surface must be chosen so that no reactive trajectory crosses back into the product region. Whereas most chemical reactions take place in a randomly fluctuating environment, as, e.g., a liquid, conventional Transition State Theory is not well equipped to handle this case because the no-recrossing condition is hard to enforce in the presence of noise. To generalize the formalism of Transition State Theory to reactive systems driven by noise, we introduce a time-dependent dividing surface that is randomly moving in phase space so that it is crossed once and only once by each reactive trajectory.

Study of features based on nonlinear dynamical modeling in ECG Arrhythmia detection and classification

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The analysis of ECG signals with methods derived from chaos theory is a potential tool to classify different heart behaviors and can help to get insights on the heart dynamics. The main purpose of the present work are to implement and validate the correlation dimension (CD) method for HRV-analysis and to investigate whether it is possible to distinguish between the HRV-signals of healthy subjects and heart diseases subjects only based on the CD or whether the Largest Lyapunov Exponent (LLE) can be used for this aim. We used CD and LLE methods from nonlinear time series analysis to characterize human ECG of normal (sinus) rhythm, atrial fibrillation (AF) and ventricular fibrillation (VF) and others. The correlation dimension (CD) method is related to chaos theory and is used to quantify heart rate variability (HRV). The CD is a measure for the amount of correlations present in the signal and as a feature describing character of signals is also often used for classification of signals (ECG). The correlation function C(r) is given by:

$$C(r) = \lim_{N\to\infty} \frac{2}{N(N-1)} \sum_{i,j=1}^{N} H(r - |Y_i - Y_j|), \tag{5}$$

where H is the Heaviside step function, with $H(u) = 1$ for $u > 0$, and $H(u) = 0$ for $u < 0$, where, N is the number of points on the reconstructed attractor, r is the radius of the sphere centered on Y_i or Y_j, and D_2 is given by:

$$D_2 = \lim_{r\to 0} \frac{\log C(r)}{\log r}. \tag{6}$$

Lyapunov exponents measure the average local rate of divergence of neighboring trajectories in phase space embedding and quantify the sensitivity of the system to initial conditions, which is an important feature of chaotic systems. A positive Lyapunov Exponent can be taken as a definition of chaos, provided the system is known to be deterministic.

$$\lambda_1(i,k) = \frac{1}{k.\triangle t}.\frac{1}{M-k} \sum_{j=1}^{M-k} \ln \frac{d_j(i+k)}{d_j(i)} \tag{7}$$

CD and Largest Lyapunov exponent (LLE) are increasingly used to classify systems (say for diagnostics purposes). ECG time series were classified according to results obtained from computation of CD and LLE. Our results confirm the previous studies, which indicate that technique from nonlinear dynamical systems theory should help us understand the mechanism underlying cardiac diseases and allow one to distinguish between different groups of patients with more confidence than the standard methods for time series processing accepted in cardiology. The statistical analysis of the results suggests that the use of such features can be advantageous to ECG arrhythmia detection and classifying the type of ECG abnormality.

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Quantum chaos in two-dimensional potentials with non-trivial topology

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We summarize our recent investigations of quantum chaos in smooth 2D-potentials with two and more local minima and discuss our numerical results obtained for the potential of lower umbillic catastrophe D_5 (with two local minima) and the potential of quadrupole surface oscillations of atomic nuclei (with four local minima). We stress some new specific features of the systems under consideration in comparison with more usual objects of quantum chaos investigations: two-dimensional billiards and trivial topology potential cases — homogeneous and one-well potentials.

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Universality and scaling in nonintegrable Hamiltonian systems: escape times, Lyapunov exponents and inverse chaotic scattering

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We describe our fractional kinetic model of transport in Hamiltonian systems which allows one to obtain and solve approximately the fractional diffusion equation in the action space. In addition to the derivation of kinetic equations from the optimal normal forms (1), we give two additional ways of obtaining them, from a non-Gaussian Langevin equation and as a hydrodynamic limit of continous time random walk. The model predicts approximate scaling relations for the diffusion times with respect to the Lyapunov times, and for the rates and probabilities of the escape to infinity in open Hamiltonian systems (inverse chaotic scattering). The scalings appear in two distinct regimes, thus resembling a phase transition. As an example, we present analytical and numerical results for a number of Hamiltonians (1, 2) and discuss the relation to some results of other authors.

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The granular Leidenfrost effect

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See the abstract of the second lecture (2a) by Van der Weele.

Uni-directional transport properties of a serpent billiard

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We discuss classical and quantum dynamics in a *billiard chain – channel* with hard parallel semi-circular walls, which can be viewed as a model for optical fibers. In this billiard the classical particles – rays do not change the direction of motion, resulting is the splitting of the classical phase space into two disjoint invariant components corresponding to the left and right uni-directional motions (UM).

In the classical mechanics the dynamics is decomposed into the *jump map* – a Poincare map between the two ends of a basic cell, and the *time function* – traveling time across a basic cell of a point on a surface of section.

The jump map has a mixed phase space where the relative sizes of the regular and chaotic components depend on the width of the channel. For a suitable value of this parameter we can have almost fully chaotic phase space. We have studied numerically the Lyapunov exponents, time auto-correlation functions and diffusion of particles along the chain. As a result of a singularity of the time function we obtain marginally-normal diffusion after we subtract the average drift. The last result is also supported by some analytical arguments.

In the quantum description of a particle in our billiard, the UM is violated due to tunneling between classically invariant components of phase space. Changing of directionality can be observed already in a single cell, which we discuss in more detail by studying its *scattering matrices* – the analog of the classical jump map. We calculate scattering matrices in the *modal approach* for which we developed a stable algorithm incorporating gathered knowledge about the modes in the cell. We are especially interested in the strength of the reflection, which serves as a measure of violation of classical UM, and its effects on the particle dynamics along the chain.

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Applications of fractional calculus in the analysis of dielectric response of porous media

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Fractional calculus based on generalized Reimann-Liouville derivatives has been recently used to describe the variety of observed phenomena: the slow relaxation near phase transition in supercooled liquids, memory effects in financial time series, anomalus diffusion processes in porous glasses, two-dimensional rotating flows and intracellular transport, to name a few. Recently, the systems with Hamiltonian chaos were analyzed in perspective of fractional kinetics.

In this work we present the application of fractional calculus in the analysis of the measured dielectric response of the clay-water system which exhibits anomalus features in the low frequency part. It is shown that the motion of the ions in the pore electrolyte of the clay-water system can be described by anomalous diffusion yielding the nonexponential spectrum of the dielectric response. The theoretical expression for the generalized conductivity is given based on the properties of the velocity autocorrelation function for the particles in complex systems. The dynamics of the ions near the surface of the solid matrix is in this system found to be governed by anomalous diffusion, and the analysis of the results yielded the approximate expressions for the scaling law of the effective diffusion constant. In the limit of low water content the theoretical model yielded the power-law frequency dependence of the conductivity in accordance with the results typical for the disordered solids.

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Softwall Quantum Dots modelled with Microwave Cavities

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We investigate the signatures of dynamical tunneling in open quantum dots, by implementing a soft-walled microwave cavity [1] as a novel analogue system. We explore the evidence for dynamical tunneling by studying the evolution of the wave function phase as a function of frequency and show evidence for evanescent coupling to isolated orbits, including the existence of 'dirty' states in the wave function that are generated from a degenerate pair of 'clean' states when they are degraded by their tunneling interaction [2]. Our investigations provide a useful analogue of quantum transport in open quantum dots, and demonstrate the importance of dynamical tunneling that arises from the mixed classical dynamics that is inherent to these structures.

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Chaos and Fractal Basin Boundaries of a Perfect Circular Plate

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The nonlinear dynamics of a perfect circular plate with one-to-one internal resonance is analyzed. The case of primary resonance, in which an excitation frequency is near one of natural frequencies, is considered. Via the method of multiple scales, the equations governing non-linear oscillations of the circular plate are reduced to a system of autonomous ordinary differential equations with dimension four. The steady-state responses and their stability are determined by using this system.

It is found that there exist at most five stable responses, one standing wave and four travelling waves. Two of travelling waves lose their stability by Hopf bifurcations and have a sequences of period-doubling bifurcations leading to chaos. The concept of the principal plane, which includes three equilibrium points of the system corresponding to one standing wave and two travelling waves, is used to obtain the basin boundaries of the chaotic motions. The basin boundaries on the plane turn out to be fractal.

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Experimental exploration of chaos for wave-particle interaction with a specially designed traveling wave tube

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We make experiments on chaos with a specially designed Traveling Wave Tube where a test electron beam interacts with electrostatic waves; such a system has paradigmatic Hamiltonian behavior which we describe in our different tests. By recording the beam energy distribution at the output of the tube with a trochoidal analyzer , we observe the resonant domain of a single wave and the overlap of the resonance domains of two waves associated to the destruction of Kolmogorov-Arnold-Moser tori constituting barriers in phase space [1]. Paying attention to small non linear effects we evidence a nonlinear synchronization due to a single wave at the root of Landau Damping an important phenomenon especially in Plasma Physics; The results are explained by second order perturbation theory in the wave amplitude [2]. It is also possible to remark how chaos may appear in simple Hamiltonian system composed by the beam and only one excited frequency: for such a model we recorded the direct signature of fractal structure which rules the diffusion of the beam velocities into the trapping domain of the wave. Reaching higher performance from system based on many-body interactions where diffusion represents a severe obstacle often means working against chaos, e.g., in free electron laser or particle accelerators; recently we tested a general theory to channel chaos by building barriers in phase space and proved how it is possible to achieve control of test beam velocity diffusion by adding small apt modifications with a low additional cost of energy [3].

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On algebraic properties of the stability of a critical point in the homogeneous quadratic ODEs

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The origin in a homogeneous quadratic system of ODEs is the simplest case of a total degenerate (nonhyperbolic) critical point. The Jacobian (linearization matrix) in a total degenerate critical point is the zero matrix and by the center manifold theorem the dimension of the center manifold equals the dimension of the whole space. Therefore this crucial case requires a special treatment when considering the stability properties of the critical point.

In this report we will consider an algebraic approach to the problem of stability in the case of a homogeneous quadratic ODE. In (Markus, 1960) Markus introduced the idea that one can associate a finite dimensional real nonassociative commutative algebra to any finite dimensional system of homogeneous quadratic ODEs. He proved that the correspondence is one-to-one. Thus, the classification of algebras up to an algebra isomorphism gives the classification of ODEs in the sense of linear equivalence. Markus also proved some basic connections between algebras and ODEs. Some of them will be presented in the report. A standard reference book with many references to older papers is the Walcher's monograph (Walcher, 1991).

From the algebraic point of view, the most important is the following: i) the origin is unstable, if the corresponding algebra contains a nontrivial idempotent (Kinyon and Sagle, 1995), ii) every real finite dimensional algebra contains either nilpotents of rank 2 or idempotents (Kaplan and Yorke, 1977).

We will present some original results from (Mencinger, 2003A) (Mencinger, 2003B) and (Mencinger, 2004). In 2D the stability analysis is complete. In 3D case two large classes of ODEs were worked out and the obtained result can easily be generalized to any dimension. So far the generalization is a conjecture, which will also be presented in the report.

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Multi Solitons of a Bose-Einstein Condensate in a Three-Dimensional Ring

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Bose-Einstein Condensates (BECs) made of alkali-metal atoms at ultra-low temperatures are well described by the 3D cubic non-linear Schrödinger equation, the so-called Gross-Pitaevskii equation (GPE) [1]. We consider a BEC in a ring and investigate the quantum phase transition from a uniform attractive BEC to a localized bright soliton [2]. By solving the GPE we find that the soliton undergoes transverse collapse at a critical interaction strength, which depends on the ring dimensions. In addition, we predict the existence of other soliton configurations with many peaks, showing that they have a limited stability domain. Finally, we show that the phase diagram displays several new features when the toroidal trap is set in rotation [3].

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The importance of periodic orbits in three-dimensional galactic bars and modern numerical techniques for tracing them

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Finding the periodic orbits is of great importance for the understanding of the dynamical behavior of galactic models. In our contribution we briefly report some resent results obtained from the orbital study of analytic three-dimensional (3D) models representing barred galaxies, emphasizing on the connection of periodic orbits to observed morphologies in real galaxies. In 3D models, the planar x1 family of periodic orbits has in general large unstable parts and, thus, its orbits are not sufficient in building the bar. However, other families of periodic orbits that bifurcate from x1 have large stable parts that support the bar. These families built the so-called 'x1-tree'. Specific families of the x1-tree are associated with certain morphological features like peanut edge-on profiles and face-on boxy isophotes. Other families, not belonging to the x1-tree, influenced by the 4:1, 6:1 and 8:1 resonances are related to the appearance of various types of inner rings.

We also propose and apply a new numerical technique for locating periodic orbits, based on the Particle Swarm Optimization (PSO) method. PSO belongs to the category of Swarm Intelligence methods, which are closely related to the methods of Evolutionary Computation. We develop an appropriate scheme that transforms the problem of finding periodic orbits into the problem of detecting global minimizers of a function, which is defined on the Poincare Surface of Section (PSS) of a Hamiltonian system. By combining the PSO method with deflection techniques, we succeeded in tracing systematically several periodic orbits in a 3D model of a Ferrers bar, which are reported for the first time. The method succeeded in tracing the initial conditions of periodic orbits in cases where Newton iterative techniques had difficulties. In particular, we found families of 2D and 3D periodic orbits associated with the inner 8:1 to 12:1 resonances, between the radial 4:1 and corotation resonances. The main advantages of the proposed algorithm are its simplicity, as well as its ability to locate many periodic orbits per run at a given Jacobian constant. The method is particular useful for tracing orbits in the corotation region in order to construct self-consistent Schwarzschild-type models of disk galaxies.

Irreversibility and thermodynamic

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The nature of irreversibility and the problem of connection of the laws of thermodynamics with the classic mechanics laws are studied. With this purpose in the mind the evolution of the conservative of a hard disks and potentially of interacting elements systems prepared by the non-equilibrium way are analyzed. The systems are divided into interacting subsystems. The forces of subsystems interaction are considered as an evolution parameter. Dynamics of one of them is studied with the help of generalized Liouville equation. It was obtained that two types of dynamics are possible: reversible and irreversible. The reversible dynamic is possible in equilibrium systems only. The irreversible dynamics exists in non-equilibrium systems when the forces of subsystems interaction depend on velocities of the elements. The existence of this dependence for the nonequilibrium system of the potentially interaction elements is proved. The evidence based on the equation of motion for two interaction subsystems. The mechanism by which these systems equilibrate is offered. The formula, which connected the dynamic parameter of system -generalized field of forces with thermodynamic parameter -entropy, is analyzed. The way of thermodynamic substantiates and the nature of the irreversibility in the frame of classical mechanics laws is discussed.

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On the basis of quantum statistical mechanics

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It seems to be a common belief that a physical system must be ergodic to reach equilibrium. However, a macroscopic system can not be ergodic for realistic time scale because its ”ergodic time” is extremely large. Moreover, a quantum system can not be ergodic in the usual sense because the Schrödinger equation is linear. The problem is that the ergodicity is a statement for all physical quantities, though actually it is impossible, especially in quantum mechanics, to observe all observables of a macroscopic system. We claim that the essential precondition for the statistical mechanics is not time average, but the limitation of observables. We propose a class of observables for macroscopic quantum systems which contains all quantities of practical physical relevance. Then we show, without introducing time average, that macroscopic systems reach equilibrium under some easy conditions if the observables are limited in this class. We also show that non-integrability is not a necessary condition to reach equilibrium.

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Classical Loschmidt echoes

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We show that in the *classical interaction picture* the echo-dynamics, namely the composition of perturbed forward and unperturbed backward hamiltonian evolution, can be treated as a time-dependent hamiltonian system. For strongly chaotic (Anosov) systems we derive a cascade of exponential decays for the classical Loschmidt echo, starting with the leading Lyapunov exponent, followed by a sum of two largest exponents, etc. In the loxodromic case a decay starts with the rate given as twice the largest Lyapunov exponent. For a class of perturbations of symplectic maps the echo-dynamics exhibits a drift resulting in a super-exponential decay of the Loschmidt echo.

Furthermore, we develop a general theoretic approach to classical Loschmidt echoes in chaotic systems with many degrees of freedom. For perturbations which affect essentially all degrees of freedom we find a doubly exponential decay with the rate determined by the largest Lyapunov exponent. The scaling of the decay rate on the perturbation strength depends on whether the initial phase-space density is continuous or not.

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Abstracts of Posters

Reconnection of Stable/Unstable Manifolds of the Harper Map Asymptotics-Beyond-All-Orders Approach

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The Harper map is one of the simplest chaotic system exibiting reconnection of an invariant manifold. The map depends on a real parameter k and is defined on $(v, u) \in [-\pi, \pi]^2$:

$$\begin{aligned} v(t+\sigma) - v(t) &= -\sigma \sin u(t) \\ u(t+\sigma) - u(t) &= k\sigma \sin v(t+\sigma) \end{aligned} \tag{8}$$

where $\sigma(> 0)$ is the time step and plays a role of the small parameter. In the continuous limit, $\sigma \to 0$, the map reduces to a set of differential equations which admit topologically different separatrices depending on the parameter k(critical value of reconnection is $k = 1$). In the poster, we will consider the change of the unstable manifolds for $k \to 1 - 0$, where the solutions of the unstable manifolds are constructed via the scheme of the asymptotics beyond all orders(ABAO). ABAO enables us to capture the exponentially small ($\epsilon \equiv e^{-\frac{A}{\sigma}}$ (Re$[A] > 0$)) terms with respect to σ which induce the splitting of the stable and unstable manifolds (See more details in [2]). In other words, the unstable manifolds (v_u, u_u) are expressed as the doulbe expansions in σ and ϵ:

$$v_u(t) = \sum_{n=0}^{\infty} \sum_{l=0}^{\infty} \sigma^{j_n} \epsilon^n v_{nl}(t) \sigma^l, \quad u_u(t) = \sum_{n=0}^{\infty} \sum_{l=0}^{\infty} \sigma^{j_n} \epsilon^n u_{nl}(t) \sigma^l \tag{9}$$

where j_n and $(v_{nl}(t),\ u_{nl}(t))$ for $n \geq 1$ are uniquely determined by ABAO and those of $n = 0$, are determined by Melnikov perturbation. We get the formula of the stable/unstable manifolds of the Harper map of the form (9). This formula indicates that the stable/unstable manifolds acquire new oscillatory portion in the limit of $k \to 1 - 0$ and wchich corresponds to the heteroclinic tangle after the reconnection.

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The Analysis for the Convergence Process of the Time Average in the Nonstationary Dynamical Systems

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Let T be a conservative ergodic measure preserving transformation of the σ-finite measure space $(X, \mathcal{B}, m)$, then for $g \in L^1(m), g \geq 0$, the growth rate of $S_n(g) = g + g \circ T + g \circ T^2 + ... + g \circ T^n$ is studied in the ergodic theory. When $m(X) = \infty$, there exists no sequence of constants a_n such that $S_n(g)/a_n$ convergences to a constant value. But there exist constants a_n such that $S_n(g)/a_n$ converges to $\mu(g) = \int_X g d\mu$ in weak senses (converge in distribution), i.e.,

$$\textbf{prob}\left(\frac{S_n(g)}{a_n} = x\right) \underset{n\to\infty}{\to} P(\mu(g)x),$$

where $P(x)$ is Mittag-Leffler distribution.

In order to study not only the groth rate but also the convergence process of the time average, we analyse the convergence rate of the ensemble time average using the modified Bernoulli map. We report that the convergence process depends on the initial ensemble.

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Regular and Chaotic Domains in Multi-Dimensional Hamiltonian Systems

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We investigate the connection between local and global dynamics of two N–degree of freedom Hamiltonian systems, describing one–dimensional nonlinear lattices: The Fermi–Pasta–Ulam model (FPU) and a discretized version of the Nonlinear Schroedinger Equation related to Bose Einstein Condensation (BEC). We focus on the vicinity of Simple Periodic Orbits (SPO) representing in–phase (IPM) and out–of–phase motion (OPM), which are known in closed form and whose linear stability can be analyzed exactly. We find that the Lyapunov exponents fall on a curve which increases at constant energy per particle, as N increases, allowing us to compute accurately the K–S entropy, as the sum of the (positive) Lyapunov exponents, which grows linearly with N. The Smaller Alignment Index (SALI), which has been used so far to study low–dimensional chaos, is used to determine approximately the extent of regular regions around stable SPOs of these higher dimensional systems. Thus, we are able to determine how their regular regions vary as N increases and have shown that in the BEC Hamiltonian they occupy an increasing part of phase space as the energy increases.

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The hydrogen molecular ion in a non-axial electric field: Ionization barriers and tunnelling paths

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Quasi-static models of barrier suppression have played a major role in our understanding of the ionization of atoms and molecules in strong laser fields. Despite their success, in the case of diatomic molecules these studies have so far been restricted to fields aligned with the molecular axis. In a non-axial field, the dynamics is far more involved, as is demonstrated on the most elementary level by bifurcations of potential barriers that occur as the field strength and field direction are varied. A semiclassical description of the tunnelling through these barriers sheds new light on the success of a recent theory of molecular tunnelling ionization.

Impact on soft sand: Void collapse and jet formation

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Very fine sand is prepared in a well defined and fully decompactified state by letting air bubble through it. After turning off the air stream, a steel ball is dropped on the sand. The series of events observed in the experiments and corresponding discrete particle simulations is as follows: Upon impact of the ball, sand is blown away in all directions (the "splash") and an impact crater forms. When this cavity collapses, a granular jet emerges and is driven straight into the air. A second jet goes downwards into the air bubble entrained during the process, thus pushing surface material deep into the ground. The air bubble rises slowly towards the surface, causing a granular eruption. We discuss the scaling of the experiments and the discrete particle simulations and compare them to large planetary impacts. This article is adapted from D. Lohse *et al.*

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Stochasticity in non-Abelian gauge theories

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The effect of stochastic fields with random curvature on the stability of motion in gauge fields are investigated. It is demonstrated that order-chaos transition emerges at some finite temperature. The effects of stochasticity are found to be relevant in many physical systems which are described in terms of non-Abelian gauge fields, ranging from Yang-Mills fields and gravity to holonomic quantum computers. Some general geometric methods relevant for studies of chaos and instability are presented.

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Quark confinement as decoherence

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Basing on the model of QCD stochastic vacuum we treat confinement of quarks in fundamental representation of $SU(N_c)$ gauge group as decoherence of pure colour state into a white mixture of states. Decoherence rate is found to be equal to the tension of QCD string. It is shown that conventional criteria of quantum chaos are applicable to the motion of confined quarks in semiclassical approximation, leading to the conjecture that quantum chaos is important in the emergence of confining properties. The fidelity and the purity of colour states are calculated.

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$\hbar$ expansions in semiclassical formulas for systems with smooth potentials and discrete symmetries

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Gutzwiller's trace formula provides a semiclassical approximation of the quantum level density in terms of classical properties for systems whose classical dynamics is chaotic. It represents the leading order of a systematic expansion of the level density in powers of $\hbar$. Higher orders of this expansion have been calculated for billiard systems. In reference [1] a theory was presented that allows of an efficient calculation of the first order $\hbar$ correction to Gutzwiller's trace formula in terms of periodic orbits for systems with smooth potentials. We extend this method to systems with discrete symmetries and apply it to the two-dimensional hydrogen atom in a magnetic field. This system has a discrete C_{4v} symmetry in semiparabolic coordinates. For the first time we exploit this symmetry in the calculation of the first order $\hbar$ correction terms. The harmonic inversion method provides a possibility to extract the correction terms directly from quantum mechanical eigenvalue spectra. This makes it possible to compare the semiclassical and quantum $\hbar$ corrections. The results show an excellent agreement.

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Analytical and numerical methods for quantum chaos problems in 2D potentials

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I present a review of my experience of numerical quantum mechanical computations for quantum chaos problems in 2D potentials and touch the following points:

- solution of Schrödinger equation — matrix diagonalization versus spectral method;
- optimization of numerical computation using the results of semiclassical approach;
- semiclassically obtained density of states g(E) and level number stair-case n(E) functions — control of accuracy of numerical results, different spectrum unfolding methods, analytical predictions for the nearest neighbor distribution function in the mixed dynamics case;
- semiclassical dynamics of Gaussian wave packets — quantum-classical correspondence.

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The granular Leidenfrost effect

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The granular Leidenfrost effect is experimentally observed in a vertically vibrated 2D container filled with glass beads: Above a critical shaking strength, and for a sufficient number of particles, a dense cluster of beads (with a crystalline packing) is elevated and supported by a dilute, gas-like layer of much faster particles. This Leidenfrost state is reached through a second order phase transition. The experimental observations are confirmed by a model based on hydrodynamic-like equations.

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Gaussian wave packet dynamics for the hydrogen atom in strong magnetic fields

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The method of Gaussian wave packets, introduced by Heller [1] in the seventies, reduces the complicated time dependent Schrödinger equation to a set of ordinary first order differential equations for the parameters of the Gaussian wave packet like e.g. phase, width, center and momentum. The method is widely used in molecular physics where the approximation of the potentials by a parabola around the center of the Gaussian is good. For the singular Coulomb potential this is not the case. By using regularized coordinates the method is applied to the nonintegrable problem of the H-atom in external fields. The efficiency of the method is demonstrated.

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The Stability of few Body Systems (The Sitnikov Problem, Our solar system, Extrasolar Systems)

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Sitnikov: The Sitnikov Problem is one of the most simple cases of the elliptic restricted three body system. A massless body oscillates along a line (z) perpendicular to a plane (x,y) in which two equally massive bodies perform Keplerian orbits around their common barycentre with a given eccentricity e. In spite of its simple geometrical structure, the system is nonlinear and explicitly time dependent and hence globally non integrable. In the present work a high order perturbation approach to the problem was performed, by using Floquet Theory, the Courant & Snyder transformation and the method of Poincaré-Lindstedt. The enormous amount of necessary computations were performed by extensive use of symbolic programming to master the problem of ordering an increasing number of algebraic terms originating from high order perturbation theory.
Our solar system: The chaotic nature of our solar system leads to one essential question still not answered yet: Is the configuration of our major planets stable or not? In the current study the solar system was integrated over 1 billion years using the Lie - integration Method to obtain the evolution with time of the fundamental frequencies according to windowed Fourier analysis. It has become possible to estimate the size of the chaotic regions in our solar system.
Extrasolar Planets: Today we know more than 150 extrasolar planets, but due to the observational methods all known planets have high masses and most of them are very close to there stars. In our studies we try to find out, if additional, terrestrial planets could survive inside the habitable zone (hz) of known extrasolar planetary systems. Thereby we concentrate on two different types of systems: Multi-body systems (more known planets or planets in binaries) and extrasolar trojan planets (systems in which the known planet moves inside the hz).

Constructing invariant tori for the crossed-fields hydrogen problem

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We analyze the phase space structure of the crossed-fields hydrogen around the saddle point energy using periodic orbit search. With this we identify a system of approximate invariant tori within the large regular regions of phase space. Results in the x-y symmetry plane as well as some preliminary results for the three-dimensional problem are presented.

Harmonic inversion and its application to open billiard systems

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Up to now it is not possible to analyze the poles of scattering matrices experimentally in the regime of strongly overlapping resonances. On the other hand there is a strong interest in width and distance distributions in open systems [1]. The only experimental work up to now is resonance trapping in an open microwave billiard [2], where resonances were however only weakly overlapping. The method of harmonic inversion [3] gives the possibility to obtain resonances in the complex plain for open microwave billiards. The stability of the method especially where resonances strongly overlap is investigated. We show first results for the distribution of resonance widths for regimes of different resonance overlap.

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The quantum-classical correspondence on classical phase space revisited

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We revisit the problem of the dynamical quantum-classical correspondence in classically chaotic systems for pure quantum states. We study time evolution of the deviation between the Wigner function of a quantum state and the corresponding classical density distribution by computing its overlap $F(t)$ – *classical quantum fidelity.* As for the initial states, identical in the quantum and the classical case, we consider Gaussian wave packets.

We find that the quantum-classical fidelity drops exponentially with time $F(t) \sim \exp(-t/t_\mathrm{E})$, where t_E is the well known Ehrenfest time. In the special case of very small or vanishing Lyapunov exponents $F(t)$ decays with the rate of classical correlations. Analytical predictions are verified numerically by using different maps on toroidal geometry.

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The Dynamics of Orientation Preference Maps in the Kohonen Model

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The main project of my present theoretical research is to study a developmental model for the formation of orientation columns in the visual cortex. I am using Kohonen's self-organizing feature map (SOFM) algorithm as a paradigm model based on competitive Hebbian plasticity rule and the dimension reduction framework. Both the analytical and numerical studies of the model demonstrate that the spontaneous emergence of orientation columns can occur only if the size of locally co-activated cortical domains (CCDs) is below a critical value. This critical value is found by linear stability analysis. If only orientation and retinotopy are mapped in the visual cortex, the initial layout of orientation preference maps (OPMs) with singularities (so called 'pinwheels') is only stable for small systems and loses stability when large size systems are considered. In order to test the hypothesis that pinwheels are stabilized by interactions of different feature maps, I first characterized the long term behaviors of OPMs in systems of various sizes. The established method will be used for precisely controlled quantitative numerical studies of the development of OPMs coupled with other feature maps.

Energy diffusion depending on the strength of frustration for XXZ spin chains

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We investigate energy diffusion for frustrated XXZ spin chains with the next-nearest-neighbor coupling (J_2) in the presence of a periodically oscillating magnetic field. The systems are deterministic many-body systems exhibiting Gaussian orthogonal ensemble spectral statistics, which is a hallmark of quantum chaos. Diffusion coefficients (D) are found to obey the power law with respect to both the field strength (B_0) and driving frequency (ω): $D \propto (B_0\omega)^\beta$. We have observed that $\beta = 2$ for the "linear response regime" and $\beta = 1$ for the "non-perturbative regime". The ranges of the linear response and the non-perturbative regimes depend on J_2, which dominates the strength of frustrations. When J_2 is small, we observe large-amplitude oscillations of energy diffusion. We also have a discussion on a mechanisms of the oscillations.

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Hamiltonian chaos in an harmonically excited circular plate

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Global bifurcations and chaos in modal interactions of an imperfect circular plate with one-to-one internal resonance are investigated. The case of primary resonance, in which an excitation frequency is near natural frequencies, is considered. The damping force is not included in the analysis. The method of multiple scales is used to obtain an autonomous system from a non-autonomous system of ordinary differential equations governing non-linear oscillations of an imperfect circular plate. The autonomous system has nearly integrable Hamiltonian form.

The aim of the study is to determine regions in space of system parameters in which motion of system is chaotic. Undamped imperfect circular plates exhibit chaotic motion appearing due to two scenarios: breaking of heteroclinic orbits of the unperturbed system and breaking of invariant tori of the perturbed system. Two methods were used in this study: the Melnikov's method for heteroclinic orbits of the autonomous system and renormalization-group analysis of breaking of KAM-tori. It is shown that the existence of heteroclinic orbits in the unperturbed system implies chaos arising from breaking of heteroclinic orbits under perturbation. Renormalization-group analysis of breaking of KAM-tori gives the threshold for global chaos in the system and fulfills the picture of chaotic phenomenon in the circular plate.

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Experimental exploration of chaos for wave-particle interaction with a specially desighed traveling wave tube

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We make experiments on chaos with a specially designed Traveling Wave Tube where a test electron beam interacts with electrostatic waves; such a system has paradigmatic Hamiltonian behavior which we describe in our different tests. By recording the beam energy distribution at the output of the tube with a trochoidal analyzer , we observe the resonant domain of a single wave and the overlap of the resonance domains of two waves associated to the destruction of Kolmogorov-Arnold-Moser tori constituting barriers in phase space [1]. Paying attention to small non linear effects we evidence a nonlinear synchronization due to a single wave at the root of Landau Damping an important phenomenon especially in Plasma Physics; The results are explained by second order perturbation theory in the wave amplitude [2]. It is also possible to remark how chaos may appear in simple Hamiltonian system composed by the beam and only one excited frequency: for such a model we recorded the direct signature of fractal structure which rules the diffusion of the beam velocities into the trapping domain of the wave. Reaching higher performance from system based on many-body interactions where diffusion represents a severe obstacle often means working against chaos, e.g., in free electron laser or particle accelerators; recently we tested a general theory to channel chaos by building barriers in phase space and proved how it is possible to achieve control of test beam velocity diffusion by adding small apt modifications with a low additional cost of energy [3].

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Asymmetric Quantum Transport in an Open Quantum Dot in the Magnetic Field

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We consider the quantum transport of a billiard in the uniform magnetic field, and explore the role of geometric asymmetry. An symmetry-breaking equilateral triangular, hard-wall potential is introduced at the center of the circular dot. Several remarkable issues will be reported.

Efffects of Non-Stationary processes and Moderate Barrier Height on the Behaviors of On/Off Ratchet

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Brownian motor is the theoretical model that describes the motion of Brownian particles in asymmetric periodic potential. The main consequence is that unidirectional movement is induced in spite of unbiased driving force or potential modulation which is either periodic in time or stochastic process. This phenomenon is called ratchet effect.

In the last decade, Brownian motors have drawn much attention as the model of molecular motors. Recent experimental studies by means of one-molecular measurement technique suggest qualitative agreement with the perspectives according to Brownian motors, although the efficiency of Brownian motors is much smaller than those of actual molecular motors.

In this presentation, we discuss the extension of so-called on-off ratchet On-off ratchet is one of archetypes of Brownian motors, in which periodic potential takes two states alternatively. In on state, potential has non-zero height, whereas potential is flat in off state. Switches from one state to the other take place stochastically. Mean velocity of the Brownian particle depends on the time scale of switching, and it is maximized at a certain switching probability. Bier and Astumian gave an intuitive explanation on how the current induced in on-off ratchet system with two assumptions, stationarity of switching processes and high potential barrier.

First we consider the case that the switching processes are non-stationary. In this case, residence time in each state (on or off) has broad (power law) distribution. We find that mean velocity of the particle becomes independent of mean residence time (time scale of switching) at the stationary/non-stationary transition point. As a result, on-off ratchet driven by non-stationary processes (NS ratchet) shows larger velocity than that of conventional on-off ratchet (S ratchets) at the fast switching regime, although maximum velocity is smaller than that of S ratchet. NS ratchet also shows larger velocity at the low temperature regime than that of S ratchet. We discuss that these behaviors can be explained from the residence time distribution.

Next, we show that the velocity and efficiency of on-off ratchet could be largely enhanced by the introduction of position dependent reaction rate (switching rate), in the case that potential height is moderate.

In the end of the presentation, we shortly discuss the implication of the above results in the study of molecular motors.

On a Similarity Solution of the Basic Discrete Diffusion Equation

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We investigate a discrete version of the diffusion equation on a basic linear grid. A square integrability condition of the solutions is elucidated in detail.

1/f fluctuations of a piecewise linear map and its area-preserving extension

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A new dynamical system which is piecewise linear is introduced. Through numerical simulations, it is found that this system exhibits 1/f fluctuations. Moreover, by calculating the eigenvalues of the Frobenius–Perron operator of the map analytically, it is found that this system exhibits slow relaxations to the equilibrium state for classes of observables and initial densities and that this theoretical prediction is in a good agreement with the numerical results. It is worth noting that this system can be easily extended to a 2-dimensional area-preserving map. Therefore this system may be considered as an abstract dynamical system for generic Hamiltonian systems because power low decay of correlation functions is frequently observed in Hamiltonian systems when tori and chaotic trajectories coexist in their phase spaces.

Quantum Fluctuation Theorem and Jarzynski equality in terms of microscopic reversibility -case study by quasiclassical Langevin system-

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We present a quantum analogue of Fluctuation Theorem(FT) and Jarzynski equality[1]. For classical Markovian stochastic systems, (transient)FT and Jarzynski equality are derived by Crooks in terms of microscopic reversibility[2], as well as the steady state FT for Langevin system by Kurchan[4]. Here microscopic reversibility condition is described as

$$\frac{P[x|\lambda(t)]}{\hat{P}[\hat{x}|\hat{\lambda}(t)]} = e^{-\beta Q}. \qquad (microscopic\ \ reversibility) \tag{10}$$

Here, x, λ, and Q describe path on the state space, control parameter corresponding to the external agent, and heat absorbed by reservoir. $\hat{}$ denotes the time reversal operation. And $P[x|\lambda(t)]$ denotes the probability functional that path $x(t)$ on the state space occurs under the external perturbation represented by $\lambda(t)$. As shown by Crooks[3], this relation results from conditions that dynamics is Markovian and without perturbation dynamics preserves the equilibrium distribution. From Markovian property, $P[x|\lambda(t)]$ is described by the products of transition probabilities. On the other hand, for quantum system since observation does affects to the dynamics, it is not straightforward to derive analogue of the relation above. As a first step, we confirm the microscopic reversibility for so-called quasiclassical Langevin system. This is performed by using the quantum noise theory by Gardiner[5][6]:
Up to the first order of $\hbar$, the dynamics of full quantum system interacting with reservoir reduces to the c-number Langevin equation with Callen-Welton type fluctuation term. Then we can use the results for classical system. Quantum analogues of FT and Jarzynski equality are derived by the microscopic reversibility condition.The steady state FT for quasiclassical Langevin system will obtained as well.

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Effects of additive noise on the spatial dynamics of excitable media

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We study effects of additive spatiotemporal noise on the spatial dynamics of excitable media. In particular, we report the phenomenon of spatial coherence resonance in a two-dimensional model of excitable media with FitzHugh-Nagumo local dynamics. We show that an inherent spatial scale of excitable media is resonantly pronounced for some intermediate level of additive noise. We argue that the observed phenomenon occurs due to existence of a noise robust excursion time that is characteristic for the local dynamics whereby the diffusion constant, representing the rate of diffusive spread, determines the actual resonant spatial frequency. Presented results are discussed in view of their possible biological importance.

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Colored $1/f^\alpha$ Noise and the Order to Chaos Transition in Quantum Mechanics

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The spectral statistic δ_n measures the fluctuations of the number of energy levels with respect to its mean value [1]. It has been shown that chaotic quantum systems display $1/f$ noise in the power spectrum $P(f)$ of δ_n statistic, whereas integrable ones exibit $1/f^2$ noise. These results have been explained on the basis of the random matrix theory [2] and periodic orbit theory [3]. An open problem is the behavior of the power spectrum $P(f)$ for systems in the mixed regime between order and chaos. Recently we have analyzed the order to chaos transition in terms of the power spectrum $P(f)$ by using the Robnik billiard [4]. We have numerically found a net power law $1/f^\alpha$, with $1 \le \alpha \le 2$, at all the transition stages [5]. Similar results have been obtained by Santhanam and Bandyopadhyay [6] analyzing two coupled quartic oscillators and a quantum kicked top. All these numerical results suggest that the exponent α is related to the chaotic component of the classical phase space of the quantum billiard, but a satisfactory theoretical explanation is still lacking.

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Hamiltonian chaos in an harmonically excited circular plate

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Global bifurcations and chaos in modal interactions of an imperfect circular plate with one-to-one internal resonance are investigated. The case of primary resonance, in which an excitation frequency is near natural frequencies, is considered. The damping force is not included in the analysis. The method of multiple scales is used to obtain an autonomous system from a non-autonomous system of ordinary differential equations governing non-linear oscillations of an imperfect circular plate. The autonomous system has nearly integrable Hamiltonian form.

The aim of the study is to determine regions in space of system parameters in which motion of system is chaotic. Undamped imperfect circular plates exhibit chaotic motion appearing due to two scenarios: breaking of heteroclinic orbits of the unperturbed system and breaking of invariant tori of the perturbed system. Two methods were used in this study: the Melnikov's method for heteroclinic orbits of the autonomous system and renormalization-group analysis of breaking of KAM-tori. It is shown that the existence of heteroclinic orbits in the unperturbed system implies chaos arising from breaking of heteroclinic orbits under perturbation. Renormalization-group analysis of breaking of KAM-tori gives the threshold for global chaos in the system and fulfills the picture of chaotic phenomenon in the circular plate.

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Quantum Pumping on a Ring

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Current can be pumped through a closed system by changing parameters in time. Linear response theory (the Kubo formula) allows us to analyze the charge transported (Q) in one pumping cycle. One would expect to get $Q \leq e$, but it is also possible to get the counter intuitive result $Q \gg e$. In our work we analyze a simple closed wire-dot model represented by a ring with two delta function barriers. We estimate the transported charge Q and explain the physical significance of our findings.

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Address by the rector

In the academic year 2005/06 our university is celebrating the 30th Anniversary of its existence and fast development. In this academic year about 23000 full-time and part-time undergraduate students and future graduates and about 2000 postgraduate students are studying at our university. Very important information in the assessment of the success of a university is also the international student and professor exchange. Therefore, we are very satisfied by the fact that 100 international students carried out a part of their studies at our university and 160 of our students studied at other universities for a certain time. These numbers place us among important European universities. In this year for the first time, we are going to carry out Bologna study programs, as well, i. e. the vocational program Trainer in an Optional Sports Discipline and Economic and Technological Logistics. For the first time, the Bologna university study program Logistics of Systems and the doctoral study program Biomedicine Technology are open. The novelties witnessed by us most certainly prove the dedication of our university to steady growth, sustainable development and the following and co-operation in the formation of the events on the European and global level. In the last year, we successfully concluded several tasks, among which the most important one was the establishing of the Faculty of Logistics and the adoption of the renewed rules on habilitation. In this time, the renewal of the study programs in accordance with the Bologna Declaration is actively running, but maybe we could be more successful in this. We are planning tasks to be realized in the near future, such as the establishing of the technological office and the full start of the university incubator. The novelties and the large number of students and new faculties mean a quantitative and qualitative growth of our university. By this, we also take over our task and obligation by Slovenian society: the responsibility for education and the development of expertise in all fields of activities of the faculties of our university. By the Lisbon Strategy, the university obtained another mission that we are very well aware of at our university. Thus, we see the great importance and responsibility of our university in regional development and the country in total.

In the field of higher education, in Europe and in the world, two types of universities are developing, i. e. the research type and the pedagogical type. At our university, we wish to be a research university open to the world and tightly connected to economy. Through this connection and own research, the theoretical and practical knowledge is transferred to the students.

Therefore, I am pleased that we co-operate in the organization of such an important international conference as "Let's face Chaos through Nonlinear Dynamics", which is being organized by CAMTP and its director Prof. Dr. Marko Robnik for the 6th time, already. To the participants of the Conference and the Summer School I wish successful work and nice memories of the university town Maribor, as well as of our university.

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