Rapport d'activité

Scientific Research Activity

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Contents

1. Curriculum Vitae

1.1. General description

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1.2. Scientific degrees

- Candidate (Ph D) degree of phys-math. sciences Novosibirsk 1982
- Doctor (habilitation) degree of phys.-math. sciences, Novosibirsk/Moscow 1989

1.3. Brief scientific biography

1973-1978: student of Physical Department of Novosibirsk University, Novosibirsk, USSR.

1978, graduated from Novosibirsk University with distinction

1978, PhD position in the group of Boris Chirikov at Institute of Nuclear Physics, Novosibirsk

1981, researcher in Theoretical Division of Institute of Nuclear Physics, group of Boris Chirikov

1982, candidate degree of phys.-math. sciences (PhD),
Institute of Nuclear Physics, Novosibirsk
PhD thesis title: ”Investigations of a Dynamics of Quantum Systems
Stochastic in the Classical Limit”,
supervisor Boris Chirikov, referees Ya.A.Smorodinsky, V.V.Sokolov

1983, senior researcher (Institute of Nuclear Physics)

1989, doctor degree of phys.-math. sciences (analog of habilitation),
Institute of Nuclear Physics, Novosibirsk
doctorant (habilitation) thesis title
"The Theory of Diffusive Photoelectric Effect in Hydrogen Atom",
referees A.M.Dykhne, A.P.Kazantsev, A.V.Chaplik, V.V.Serebryakov.

1989, leading senior researcher (Institute of Nuclear Physics, Novosibirsk)

1978 - 1991: I gave practical exercises for 2d, 3d, 4th year students at the Physical Department of Novosibirsk University in analytical, quantum and statistical mechanics

1991, one year invited position as researcher 1 class at CNRS, Laboratoire de Physique Quantique, URA 505, Toulouse, France

1992 - 1994, researcher 1 class at CNRS, Laboratoire de Physique Quantique, URA 505, Toulouse, France

October 1994 - Sept 2004, director of research 2 class at CNRS (DR2), Laboratoire de Physique Quantique, UMR 5626 du CNRS (now it is Laboratoire de Physique Théorique, UMR 5152 du CNRS) Toulouse, France

from 1 October 2004 director of research 1 class at CNRS (DR1), same Lab

1995 - 2000: I give a special course "Classical and Quantum Chaos" for DEA students at University Paul Sabatier, Toulouse, France

2. Subject of Scientific Research

2.1. Introduction

Starting from my 4th year at the Novosibirsk University (1976) I entered in the group of Professor B.V.Chirikov in the Institute of Nuclear Physics. After the University I continued the researches of classical and quantum chaos in this group in collaboration with B.V.Chirikov and F.M.Izrailev. The main directions of my scientific researches are: classical chaos, quantum chaos, ionization of Rydberg atoms and molecules, applications of quantum chaos to solid state problems. In last 10 years the new directions of research were developed with application of quantum chaos to mesoscopics, many-body interacting systems, problems of transport in disordered fermionic systems with interaction, quantum spin glass clusters, quantum chaos in quantum computers.

Many of the results were obtained in collaboration with the scientists from different countries. The most close collaborations are with the group of G.Casati and I.Guarneri (Milan-Como-Pavia, Italy), the group of R.Graham and F.Haake (Essen, Germany), the groups of S.Fishman and U.Smilansky (Haifa-Rehovot, Israel), the group of A.D.Stone (Yale Univ., CT, USA), the group of V.Flambaum and O.Sushkov (UNSW, Sydney, AU), with O.V.Zhirov at Budker Inst. of Nuclear Physics, Novosibirsk, Russia. The problems of interaction and disorder are intensively discussed with Y.Imry (Weizmann Inst., Israel) and J.-L.Pichard (Saclay).

At present I coordinate in Toulouse the activity of "Quantware MIPS Center" which includes 5 permanent researchers: Klaus Frahm (Professor UPS), Bertrand Geogreot (DR1), Ion Nechita (CR1), Gabriel Lemarie (CR1) and Dima Shepelyansky (DR1). Daniel Braun joined the group from September 2004 (left in 2013), Ion Nechita joined the group in October 2010, Gabriel Lemarie in Feb 2012. Former group members: Robert Fleckinger (from beginning till retirement in July 2010); Olivier Giraud (from Oct 2005 till Jan 2010, moved to LPTMS, Orsay), Daniel Braun (Professor UPS, joined the group from September 2004, left in 2013). The list of PhD students and post-docs is given in Section 7. The research program includes classical and quantum chaos, quantum many-body physics, quantum information and quantum computers. The research finds applications to the problems of atoms and molecules in external fields, mesoscopic systems, quantum spin glasses, interaction, disorder, Anderson localization and quantum transport in presence of disorder and interactions, ratchets and directed transport, realistic quantum computations in presence of imperfections, dynamics and chaos in astronomy. There was a close collaboration with a member of quantum chemistry group Bhargavi Srinivasan from Lab. de Phys. Quantique, UMR 5626 du CNRS (she moved to Paris in 2005). In 2009 a new direction was started with studies of Google matrix of various directed networks including the world trade network from United Nations COMTRADE database.

2.2. Classical Chaos

As the main results obtained in the field of classical chaos I would like to mention: the discovery of slow power law decay of correlations and Poincaré recurrences in the system with divided phase space (with Chirikov, refs. [5,18,30,34]), numerical observation of the modulational diffusion and the development of the theory of this phenomenon (refs.[4,6,19]), investigation of the dynamics of the classical homogeneous Yang-Mills fields which for the first time showed that the dynamics of Yang-Mills fields has a positive Lyapunov exponent and is chaotic (refs.[7,8]), observation of breakdown of universality in renormalization dynamics for critical invariant torus with two frequencies (refs. [47, 56]).

2.2.1. Poincaré recurrences and correlations decay in the systems with divided phase space

The investigations of the Poincaré recurrences in the systems with the divided phase space (for example, Chirikov standard map) showed that the probability P to stay in some part of phase space during time larger than τ decay in a power law $P(\tau) \sim 1/\tau^p$ with the exponent $p < 2$. The average value of p is 1.5 but in some cases its value can be 1.3 or even very close (but larger) to 1 (refs.[18,30]). Such slow power decay is quite different from exponential decay typical for completely chaotic systems (for example, Anosov systems). The decay of correlations C is connected with the decay of P in the way: $C(\tau) \sim P(\tau)\tau \sim 1/\tau^{p-1}$. Since $p < 2$ this mean that such slow correlations decay can lead to a divergence of integral of correlations giving in some cases infinite diffusion rate (streaming). Such divergence indeed exists in the standard map for parameter values when there exist accelerating modes (however, the dynamics is considered for trajectories in the chaotic component). For the first time such anomalously slow decay of $P(\tau)$ was observed in [5]. Later it was investigated also by Karney and many others. It was shown that this slow decay is originated by the hierarchical renormgroup structure of the phase space [5,18,30]. The investigations of refs. [18,30] showed that the value of p becomes closer to 1 if the chaotic component is restricted by critical golden invariant curve. However, in such case for different maps different values of $p \approx 1; 1.3$ appear that looks to be in some contradiction with the universal structure of critical golden curve. The theory developed by Ott and Meiss was not able to explain the numerical values of p close to 1. Further investigations are required for a better understanding of Poincaré recurrences. However, the results obtained in [101] gave arguments that for asymptotically large times the exponent p approaches to the value $p = 3$ (see more details in the section 2.6.1). More recent and more extended analysis show that many islands of stability with their boundary critical KAM curves contribute to the power law decay of recurences with the average exponent value $p \approx 1.5$ [188,213].

For Poincaré recurrences in Hamiltonian systems with a few degrees of freedom it was found that the exponent is $p \approx 1.3$ [192].

2.2.2. Modulational diffusion

In the series of works (refs.[4,6,19]) the diffusion created by a chaotic motion in a chaotic layer was studied numerically and theoretically. It was shown that the diffusion rate in a coupled degree of freedom with frequency ω decays with ω in the exponential way $D(\omega) \sim \exp(-C\omega/\Delta\omega)$ where $\Delta\omega$ is the width of the chaotic layer and C is some weak function of the parameters of the layer. This result shows that the modulational diffusion is in some sense similar to the Arnold diffusion but on the other side it gives much stronger diffusion rate due to large values of $\Delta\omega$.

2.2.3. Chaos of color dynamics of classical Yang-Mills fields

The investigations of the color dynamics of Yang-Mills fields was carried out in refs. [7, 8]. It was found by Matinyan and Savidy (1981) that for homogeneous Yang-Mills fields the color dynamics is described by simple Hamiltonian models with few degrees of freedom. The first analysis of these models was done in numerical experiments [7]. There it was shown for the first time that the dynamics of these models has positive Lyapunov exponent and that it is chaotic. In this sense ref. [7] closed the long debates about complete integrability of classical Yang-Mills equations. For the models with Higgs [8] it was shown that due to degeneracy the Kolmogorov-Arnold-Moser theorem cannot be applied and the classical chaos exists for arbitrary small energy (small nonlinearity).

2.2.4. Breakdown of universality in renormalization dynamics for critical invariant torus with two frequencies

The concept of renormalization chaos was developed in ref. [30] where its application to boundary invariant curves and Poincaré recurrences had been discussed. However, this chaos is connected with the random continuous fraction expansion for the rotation number of critical boundary invariant curve. This renormalization chaos is universal since the renormalization dynamics on the critical curve asymptotically is the same for all smooth 2-dimensional canonical maps. In some sense randomness in renormdynamics is external and reproducible (like external fixed random noise). In refs. [47, 56] for the first time it was shown that for a critical invariant torus with two frequencies and fixed rotation numbers (as example the spiral mean had been chosen) the renormalization dynamics is irregular and not universal. Indeed, different similar maps give different renormdynamics for the same fixed rotation numbers. This situation is analogous to a strange attractor for which the number of renormalization step plays the role of time. The above problem of two-frequencies torus is related to the analyticity breaking in two coupled Frenkel-Kontorova chains studied in [61].

2.3. Quantum Chaos

In the field of quantum chaos the main results are the following: derivation of the connection between the localization length of quantum chaos and classical diffusion rate $l = D/2$ (refs.[4,14,20,24,27]), analytical estimate for the time of applicability of quasiclassical expansion over classical trajectories for wave function in the chaotic regime (refs. [2,4]); establishment of the absence of local instability and of practical time reversibility of the quantum dynamics of the systems chaotic in the classical limit (refs. [3,14,21]), sharp increase of the localization length, or delocalization, for the 1d systems with time perturbation containing two or tree incommensurable frequencies and the connection of this phenomenon with Anderson localization in 2 and 3-dimensional solid state (refs. [14,27,37]), quantum delocalization of chaos in the kicked Harper model (ref.[51,52,57]), a quantum transition from localized to extended states for a ping-pong ball on an oscillating wall (ref. [46]).

2.3.1. Kicked rotator and dynamical localization

The model of kicked rotator was introduced by Casati, Chirikov, Ford and Izrailev in 1979 and became one of the basic model of quantum chaos. In fact this model is obtained by quantization of the Chirikov standard map. The numerical simulations 1979 showed that the classical chaotic diffusion is completely suppressed by quantum effects.

For a better understanding of quantum dynamics of classically chaotic systems the concept of two principal time scales was introduced in [4]. The first (Ehrenfest) time scale t_E is proportional to the logarithm of a typical quantum number $q \sim 1/\hbar$ ($t_E \sim \ln q$). For times shorter than this scale the minimal coherent wave packet completely follows a chaotic classical trajectory and according to the Ehrenfest theorem there is complete agreement between classical and quantum mechanics. However, due to local exponential instability of classical motion the packet is fastly destroyed. However, the classical diffusion goes on on a much larger diffusive time scale t_D. The estimate for this time scale (break time) was obtained in [4] ($t_D \sim q^2$). After this time the classical diffusion is localized by quantum interference.

The Ehrenfest time scale is very short and after this scale there is no instability in quantum dynamics. Due to that the exponential decay of correlations which existed in the classical system with hard chaos (no islands of stability) is replaced by a very slow power decay or some residual constant level of correlations in the quantum system (refs. [3, 14]). This leads to the practical reversibility of quantum motion in time. Indeed, after time reversal the quantum system returns back to the initial state with computer accuracy, while the classical system due to exponential instability and computer round off errors continues to diffuse [14,21].

The analogy established by Fishman, Grempel and Prange tells that the localization of chaotic classical diffusion is analogous to the Anderson localization in one-dimensional random potential. However, in the kicked rotator the localization is of dynamical origin since the model is completely deterministic and it has no random parameters. The more detailed further investigations of this dynamical localization were carried out in [14,20,24,27]. In [20] the transfer matrix technique was for the first time applied to the problem of dynamical localization (later it was also used by Blumel and Smilansky). On the basis of this technique and analytical theory for simple models it was shown that the localization length for quasienergy eigenstates is given by the classical diffusion rate $l = D/2 \sim t_D$ [20,27]. Recently, this result was confirmed by Altland and Zirnbauer, and Frahm on the basis of supersymmetry approach to the kicked rotator with random phases.

The estimate for the diffusive time scale t_D was also obtained on the basis of Maslov formula for quasiclassical expansion of wave function over classical trajectories. The main term in the sum contains exponentially many terms due to local instability of classical motion. In his formula Maslov also gave a general expression for corrections to this term which are proportional to higher powers of $\hbar$. The analysis of these corrections [2,4] for chaotic systems shows that these corrections grow only as a power of time and gives the estimate $t_D \sim q^2$ in the case of kicked rotator.

The kicked rotator model was recently realized in experiments with cold atoms by M.Raizen et al.. (see also section 2.5.3).

2.3.2. 2d and 3d Anderson localization in one-dimesional system with 2 and 3 incommensurate frequencies

The analysis of models like kicked rotator in the case when one of the parameters of the model is varied with a frequency incommensurate with the frequency of the kicks showed that the diffusive time scale increases exponentially with the classical diffusion rate D [14]. This case corresponds to Anderson localization in 2-dimensional random potential. In the case when modulation is done with 2 frequencies the transition from localization to diffusion takes place in analogy with Anderson transition in 3d [37]. However, here all computations are done with one-dimensional system, instead of 3-dimensional. This makes such approach very efficient numerically and allows to observe indeed the transition without renormgroup assumptions and also to determine the scaling exponents near transition. More recent investigations [86] of the case with larger number of frequencies allowed to study the Anderson transition in this model for effective dimension $d \geq 4$. The numerically obtained critical exponents were found to be different from the standard scaling relation ($s = (d-2)\nu$) that can be related to a quasiperiodic nature of effective potential in $d-1$ directions.

2.3.3. Kicked Harper model

Another homogeneous model but periodic in time in which delocalization takes place was considered in [51]. It is the first example of a model which is classically quite similar to the Chirikov standard map but where in the quantum case the excitation is unlimited in a striking difference from the kicked rotator. Moreover, the results of [51,52] show that the quantum excitation can be even ballistic when the classical motion is completely chaotic and diffusive. Generally, the excitation for the number of levels Δn^2 can be characterized by anomalous diffusion with the exponent dependent on the parameters and changing between 0 and 2 [51,52,57]. In the delocalized phase the quasienergy spectrum is fractal and its Hausdorff dimension changes with the parameter. In the localized phase eigenstates are exponentially decaying. Another interesting feature of the model is that in the delocalized phase some part of eigenstates are localized that is in some sense analogous to existence of discrete states in the continuum. More recently, it was found that at the same time the spectrum of the Harper model may have pure point, multifractal and continuous components [72].

For the small amplitudes of kicks the kicked Harper model is reduced to the well known Harper model which describes also the electron dynamics of a square lattice in magnetic field. In the Harper model electron is moving in an effective potential incommensurate with the lattice size. However, the underlying classical Hamiltonian is integrable. The kicked Harper model was considered as the first example[51] of motion in incommensurate potential when the underlying classical dynamics is chaotic. The localization and delocalization, for the kicked rotator and the kicked Harper model correspondingly, clearly demonstrate that the systems with quite similar classical chaotic dynamics may have rather different quantum behaviour. Some similar type of behaviour was observed also in the dynamical model of quasicrystal [58].

2.3.4. Quantum ping-pong model

A dynamics of quantum particle in a triangular well in a presence of monochromatic driving field was studied in [46]. After a canonical transformation the model becomes equivalent to a ball jumping on oscillating plate in a gravitational field. The classical dynamics is described by the Chirikov standard map, which gives the ball velocity change after each elastic collision with the wall. In spite the fact that the classical dynamics is as for the kicked rotor the quantum behaviour is different. The physical reason is due to a proportionality of the diffusion rate D , measured in the number of photons, to the photon number N ($D \sim \epsilon^2 N/\omega^3$ where ϵ, ω are the field strength and frequency, and mass $m = 1$, $\hbar = 1$). As the result the quantum dynamics is diffusive only for $l \sim D > N$, namely $\epsilon > \omega^{3/2}/2$. Below this delocalization border eigenstates are algebraically localized. This research together with results of [49] formed the basis of thesis of F.Benvenuto (Milano Univ., 1992). Recently this model was studied in more detail by N.Brenner and S.Fishman (1996).

2.4. Diffusive Photoelectric Effect in Hydrogen Atom

The investigations of the properties of quantum chaos in the simple models, such as kicked rotator, allowed to understand the quantum picture of microwave ionization of highly excited hydrogen atoms. The predicted effect of quantum localization of chaos for hydrogen atom in a microwave field was observed in the experiments of Bayfield and Koch. The phenomenon of such unusual diffusive photoelectric effect, in which direct one-photon ionization is much less effective than the ionization at much smaller frequency, was explained on the grounds of the theory of quantum localization of classical chaos and Kepler map (main refs.[13,15,17,26,33]). This problem is the first real physical system in which dynamical localization of quantum chaos has been observed in a laboratory. Recently, dynamical localization was observed in experiments with cold atoms by Raizen et al. (see section 2.5.3).

2.4.1. History of the problem

The researches in this field were initiated by the pioneer experiment of Bayfield and Koch (1974) in which they had observed a strong ionization of an atom with principal quantum number $n \approx 66$ in a linearly polarized microwave field with a field $\epsilon \sim 10V/cm$ and a frequency $\omega/2\pi = 9.9GHz$. In this case the value of ϵ was much less than the value at which ionization takes place in the static electric field, $\epsilon_{st} = 0.13/n^4$. Also for ionization it was necessary to absorb approximately 100 photons (here and below we use atomic units).

It happened that this system with quite simple equations of motion lies on the intersection of few modern lines of development in physics being the following: classical and quantum chaos, Anderson localization, multiphoton ionization, Rydberg atoms. Only the knowledge of the physics of these fields allowed to understand the origin of the fast ionization observed in the experiment.

For an explanation of the results of these experiments Delone, Zon and Krainov (1978) put forward a hypothesis about a diffusive mechanism of ionization. On those grounds the diffusion rate in energy and the estimate for a ionization time were obtained. However, the suggested border for the appearance of diffusive ionization $\epsilon \approx 1/n^5$ was based on the quantum perturbation theory and was not correct. Leopold and Percival (1978), on the basis that the principal quantum number $n >> 1$, applied for the description of ionization the method of numerical simulation of the classical electron dynamics. As the result they obtained a satisfactory agreement between the ionization probability of the classical atom and its experimental value. The explanation of the physical reason for the appearance of the diffusion and ionization in the classical system was given by Meerson, Oks and Sasorov (1979). They showed that for a field strength above some critical value the overlapping of the resonances took place and the motion of the electron became chaotic leading to its ionization. It is necessary to stress here that the field is strictly monochromatic and there are no random forces acting on the atom. Further laboratory and numerical experiments were made for different values of the initially excited level n and for different values of the field strength by Jensen, Koch, Leopold and Richards (1985). They showed that the ionization probability obtained in the experiment was close to its classical value and in such a way confirmed the classical picture of the ionization process. These results led these authors to the conclusion that the ionization process, except some fine details, is excellently described by classical mechanics and that the quantum effects had unimportant influence.

The first quantum investigations of microwave ionization of hydrogen atom were done in ref. [15]. The numerical simulations carried out there showed that quantum interference can suppress under certain conditions the chaotic diffusion giving ionization probability much smaller than in the classical case. Further detailed investigations allowed to understand the properties of the quantum system [13,15,17,26,33]. These researches indicated the optimal parameter region in which the effect of the quantum localization of chaos was finally observed in the laboratory experiments of Koch (1988) and Bayfield (1989).

2.4.2. Chaos, photonic localization and Kepler map

The classical chaos border ($\epsilon \approx 1/50\omega^{1/3}n^5$) for the electron motion in the atom under the action of microwave monochromatic field was obtained in [13] for arbitrary field frequency ω basing on the Chirikov criterion of overlapping resonances. This approach also allowed to obtain expression for the diffusion rate and ionization times at different ω. Before that there were only estimates of Meerson, Oks and Sasorov for $\omega \approx 1/n^3$ while the estimates given independently by Jensen (1982) for arbitrary ω were not correct. These results [13] allowed to make comparison of diffusive ionization rate with one-photon ionization rate. This comparison showed that here we have matter with unusual photoelectric effect when ionization rate by direct one-photon transition is much smaller then diffusive ionization at lower frequencies when it is necessary to absorb about 100 photons to ionize the atom [22].

The understanding of the properties of quantum chaos and localization of chaos obtained from the analysis of simple models like kicked rotator allowed to understand the quantum process of microwave ionization. According to the relation $l \sim D$ the localization length is determined by the classical diffusion rate. It is convenient to express the localization length in photonic basis where the probability distribution is exponentially localized with the localization length $l \approx 3.3\epsilon^2/\omega^{10/3}$ [17,26,28,33]. If this length is much less than the number of photons required for ionization $N_I = 1/2n^2\omega$ then the quantum ionization probability is exponentially small in comparison with the classical one. The condition $l \approx N_I$ determines the quantum delocalization border ϵ_q above which the quantum ionization process is close to the classical diffusive ionization. It is interesting to note that for fixed ω the border ϵ_q grows with the initial value of the principal quantum number n and becomes higher than the classical chaos border [33].

The ionization process is also well described by the simple Kepler map [28,33] which gives the change of photon number N and field phase ωt after one orbital period of the electron. This map is quite close to the Chirikov standard map and it gives very simple picture of ionization. In the quantum case its close connection with the kicked rotator allows to understand the peculiarity of the quantum ionization. The numerical simulations of the quantum Kepler map give very good agreement with the ionization border obtained in the laboratory experiments [40].

The existence of the quantum delocalization border explains why in the first experiments of Bayfield and Koch (1974-1987) the quantum suppression of chaos was not observed: the experimental conditions were above delocalization border [26,33]. After theoretical explanation of this fact and intensive numerical simulations started in [15] the experiments had been done in the localization regime and the quantum suppression of chaos had been clearly observed for hydrogen atom by Koch (1988), Bayfield (1989) and also for alkali atoms by Walther (1991).

2.5. Other Directions of Research

Here I give short description of other directions of my researches.

2.5.1. Quantum optics

In the paper [23] I studied a generalized 3-level Janes-Cummings model for atoms interacting with radiation in a resonator. In such kind of models the self-consistent field in the resonator is classical while the atom is quantum. It was shown that if the atom levels are equidistant and dipole transitions are possible between all levels then the exchange of energy between the 2-mode resonant field and atoms is chaotic. This model gives the first example of such quantum optical system where the chaos appears in the rotating wave approximation and can take place for arbitrary small coupling constant $\Lambda = (16\pi\rho d^2/\hbar\omega)^{1/2} << 1$ between atoms and the the resonator field. Such unusual situation appears due to degeneracy of unperturbed system and inapplicability of the Kolmogorov-Arnold-Moser theorem in this case. The investigation of such kind of models but with quantized field showed that in the chaotic regime the statistics of levels is described by Wigner-Dyson distribution [35].

2.5.2. Quantum Frenkel-Kontorova model

The structure of the ground state of the quantum discrete Frenkel-Kontorova model was numerically analyzed by means of the Metropolis algorithm in [38,41]. Special attention was given to the effects of quantization on the Cantori structure of the classical ground state. It was shown that these quantum effects produce a new structure which is described by using a sawtooth map instead of the Chirikov standard map. At sufficiently large values of $\hbar$ the Cantori is destroyed. These results formed the basis of thesis of F.Borgonovi (Pavia Univ., 1990). The recent results related this model are described in Sections 2.9 and 4.4.

2.5.3. Dynamical localization for Josephson junctions and cold atoms

In [44] the dynamical localization is predicted for periodically current-driven Josephson junctions: the quantum-mechanical decrease, as opposite to the classical increase, of the intensity of voltage fluctuations with increasing driving amplitude. Classically, this intensity is predicted to rise linearly with the current amplitude. The effect of dynamical localization of chaos gives the decrease of this intensity in inverse proportionality to the current amplitude, above a certain current threshold. In 2002 the group of Devoret and Esteve at Saclay obtained a superconducting qubit with a quality factor about 20000 that makes possible to observe the effect described in [44] experimentally.

Later, Graham et al. noted that the quantum model introduced and studied in [44] describes also the dynamics of atoms in a resonator with modulated boundary. Here the momentum of atom is analogous to the voltage in the case of Josephson junction. This model was realized in the laboratory experiments with laser cooled atoms by group of Raizen (Austin, TX) in 1994 - 1995. This group worked in the dimensionless parameter regime proposed in [44] and clearly observed quantum localization of chaos. Later, the Raizen group introduced sharp modulation of the boundary and in this way directly realized the kicked rotator model with dynamical localization of chaos.

2.5.4. Rydberg stabilization of atoms in a strong monochromatic field

During the last years the phenomenon of stabilization of atom in a strong laser field attracted a great deal of attention (Gavrila, Eberly, Shakeshaft, Kulander 1988-1993). While the existence of the stabilization of atom has been clearly demonstrated in the numerical experiments the clear analytical criterion of stabilization is still absent. Usually it is assumed that stabilization condition is satisfied if the energy of the laser photon is larger than the electron coupling energy and the amplitude of electron oscillations in the field is large in comparison with Bohr radius. However, the investigations of the corresponding classical problem [59,60,63,65] demonstrated that stabilization remains also in the classical atom, where the above conditions are violated. According to these results the Rydberg atom becomes stable if the field strength of the linearly polarized field exceeds the stabilization border $\epsilon > \epsilon_{stab} \approx 10\omega/(m+1)$ where m is the magnetic quantum number. A simple description of this effect is achieved on the basis of the derived Kramers map which is very similar to the Kepler map [63]. This map allows to give an estimate for one-photon ionization rate and to show that this rate decreases exponentially with the field strength for $\epsilon > \epsilon_{stab}$. The interesting new property of Rydberg stabilization is that the stabilized Rydberg electron can have enormous kinetic energy (about hundreds eV) which can be radiated during a transition to the ground state. The energy of it is as in a usual hydrogen atom since in the ground state the field is very small $\epsilon_{stab} << 1$. Further investigations are required for this interesting phenomenon.

2.5.5. Nonlinear wave propagation in a random media and delocalization of quantum chaos by weak nonlinearity

The manifestation of dynamical localization can take place also in the propagation of linear waves in wave guides or fibers (Fishman, Prange 1989). For propagating waves the localization suppresses the growth of aperture angle with the wave guide length and leads to effective intensity transmission. Here a new and interesting type of problem arises if the waves propagate in a nonlinear media. This problem puts the question of general interest: how the localization, appearing as the result of linear wave interference, is modified by the introduction of small nonlinear wave interaction? It is shown [62] that there is a critical strength of nonlinear coupling below which the localization remains. Above this border a delocalization takes place and the number of excited linear modes grows according to the derived anomalous subdiffusion law ($(\Delta n)^2 \sim t^{2/5}$). This excitation is much slower than the chaotic diffusion of classical rays so that the suppression of classical chaos by quantum (or linear waves) interference is not completely destroyed. The obtained subdiffusion law is of universal nature since it always takes place in the limit of weak nonlinearity when the energy of nonlinear four-waves interaction ($\mid \psi \mid^4$) is much less than the energy of linear modes. The obtained results [62,68,49] show that the penetration of nonlinear waves through a one-dimensional disordered media decays exponentially with the length of the layer if a constant of nonlinear interaction is less than some critical value. Above this threshold subdiffusional propagation through the layer takes place and after some time the wave crosses the layer without any significant loss of the amplitude. The presented picture is quite different from the picture of Souillard and Doucot and Rammal obtained in stationary approximation according to which there is no critical value of nonlinearity. These studies initiated further researches of two interacting particles in a random potential [69].

2.5.6. Chaotic autoionization of molecular Rydberg states

In ref. [64] an energy exchange between a Rydberg electron and a molecular core is investigated in the regime where the Born-Oppenheimer approximation is violated. The theory developed allows the possibility for a strong energy exchange even for high orbital momentum of the electron when quantum defects are small. This regime is completely different from the regime studied by Labasti, Lombardi and Seligman when electron is colliding with the core and only small orbital momenta are mixed. Basing on Kramers-Henneberger transformation it is possible to connect Rydberg molecule problem with the problem of microwave ionization. Here the frequency of molecular rotation ω plays the role of microwave frequency while the effective electric field is given by the dipole moment of the molecule ($\epsilon = d\omega^2$). This connection of two problems allows to find a classical border of chaotic ionization and a quantum delocalization border above which strong autoionization takes place. Similar effects, as discussed in [77], can take place in atomcule (helium atom in which one electron is replaced by antiproton) where antiproton has high quantum numbers and moves quasiclassically. It is interesting to note that this system gives a physical example of conservative model in which eigenstates can be localized on energy surface while a classical trajectory diffusively cover the whole energy surface. This should lead to Poisson statistics of levels instead of Wigner-Dyson distribution. A similar situation happens in rough billiards studied in [89,92] (see discussion in the next Section). It is interesting to note that the classical energy exchange between rotating core and electron is very similar to the energy variation of Halley's comet produced by Jupiter. Indeed, as had been shown by Chirikov and Vecheslavov the dynamics of Halley's comet is described by a map very similar to the Kepler map. In this sense the autoionization of molecular Rydberg states simulates ionization of a quantum comet.

2.6. Recent Results

This and following sections review the results obtained in the field of classical and quantum chaos after 1 October 1994. The description starts from classical models and then goes to the quantum results.

2.6.1. Universal diffusion near the golden chaos border and asymptotic statistics of Poincaré recurrences

The investigation of local diffusion rate near the critical golden curve in the Chirikov standard map was done in [77]. In agreement with the heuristic Chirikov's prediction it is found that the diffusion rate scales as $D \sim |r_n - r_g|^{5/2}$ where r_n is the local rotation number converging to its limiting golden value r_g via the principal rational approximates. The results demonstrate the universal self-similar structure of the local diffusion rate near the critical golden curve. The diffusion rate drops rapidly when an orbit approaches to the critical invariant curve. This should give the exponent $p = 3$ for the decay of the Poincaré recurrences $P(\tau)$. However, this value of p is in the contradiction with the values obtained from the numerical simulations of $P(\tau)$ (see section 2.2.1).

This contradiction is resolved in the recent paper [101]. There, the new numerical method was developed which allowed to study $P(\tau)$ up to very large $\tau \approx 10^9$. This allowed to establish that asymptotically in time $P(\tau) \sim 1/\tau^p$ with $p = 3$. However, this behavior starts only after extremely large times $\tau > \tau_g \sim 10^7$. For $\tau < \tau_g$ the exponent is different $p \sim 1.5$. The physical reason of this late asymptotic decay is explained on the basis of slow diffusion rate in the chaotic separatrix layer. The results obtained in [101] establish the universal law for Poincaré recurrences decay in hamiltonian systems with divided phase space. As the result, at $\tau \to \infty$ the correlation functions decay as $C(\tau) \sim 1/\tau^2$ and the diffusion rate remains finite ($D \sim \int C d\tau < \infty$). However, still it remains an interesting problem to see numerically the asymptotic decay with $p = 3$ [101].

2.6.2. Chaos and long wave equipartition in the Fermi-Pasta-Ulam problem at low energy limit

The Fermi-Pasta-Ulam problem at very low energies was studied in [88]. It is found that there is a new energy threshold above which the Chirikov criteria of overlapping resonances is satisfied. In this regime the equipartition in energy takes place for some number of low energy modes. This new threshold is much below the conventional border of Chirikov and Izrailev (1966, 1973) and the critical energy per particle goes to zero with the increase of the number of particles. The mechanism of chaos in this regime is related to the resonances between sound waves with almost a linear dispersion law due to which even weak nonlinearity can strongly affect the long time dynamics (similar effects were discussed in section 2.5.1). At the same time the results obtained in [88] show that a proximity to completely integrable models such as Toda lattice can strongly affect dynamics as it happens for the case of cubic nonlinearity. Similar results were independently obtained by De Luca, Lichtenberg and Lieberman at Berkeley.

2.6.3. Adiabatic destruction of Anderson localization

The effect of slow parameter variation on the Anderson localization in one-dimensional case was studied in [71]. It is shown that when the typical frequency of this variation ω (the signal assumed to be non monochromatic) goes to zero then the diffusion rate of propagation along the chain, produced by such adiabatic noise, is proportional to $\omega^{2/3}$. This dependence is explained on the basis of Mott mechanism of low frequency conductivity. The result differs from earlier predictions of M.Wilkinson. A similar type of diffusion was seen by D.Cohen for the model of kicked particle.

2.6.3. Chaotic Landau level mixing in classical and quantun wells

Several recent experiments in semiconductor heterostructures have studied the tunneling current of electrons through planar potential barriers in a magnetic field which is tilted at an angle θ with respect to the normal to the barriers (L.Eaves et al. at Nottingham and G.Boebinger et al. at Bell Labs). When a variable voltage is applied across the barriers these systems exhibit oscillations in the I-V characteristic which were found to have a strong sensitivity to the tilt angle, θ, magnetic field, B and driving voltage, ΔV. Theoretical analysis has shown that tilting the field induces a classical transition from integrability (for $\theta = 0$) to chaos; Fromhold et al. showed that Gutzwiller periodic orbit theory of the density of states oscillations could account for the dominant features of resonances in the I-V curve in the strongly chaotic regime. This work has drawn attention to a new dynamical system for the study of classical and quantum chaos which should have other experimental signatures in semiconductor quantum wells and experimental realizations outside of solid-state physics. It therefore seemed worthwhile to analyze the dynamics of this system from the point of view of the global phase space structure and obtain the relevant parametric criteria for the onset of chaos in different regimes [73]. Since the real-space motion is three-dimensional and depends on a large number of parameters ($\theta, B, \Delta V, E_i$, the initial kinetic energy, and d, the distance between the barriers) it is not obvious that this system can be reduced to familiar models which have been previously analyzed. The results obtained in [73] show that in fact the transition to chaos in this system can be described by a two-dimensional map with strong similarities to the Fermi acceleration model in the limit $\Delta V \to 0$, and the Haake "kicked top" (see [32]) and the Chirikov standard map for $\Delta V \gg E_i$. In both limits the parametric conditions for the onset of chaos are obtained being in agreement with numerical simulations and experimental results of the above experimental groups. The onset of chaos allows effective energy exchange between Landau levels and longitudinal motion. However, quantum effects suppress energy exchange up to a critical angle determined by the localization transition. The theoretical analysis pointed out many similarities of the above problem with the quantum ping-pong model discussed in section 2.3.4. The problem of dynamics in a tilted magnetic field is still actively studied by different theoretical and experimental groups.

2.6.4. Emergence of quantum ergodicity in rough billiards

In 1974, Shnirelman proved a theorem according to which quantum eigenstates in chaotic billiards become ergodic for sufficiently high level numbers. Later it was demonstrated by Bohigas, Giannoni and Schmidt that in this regime the level spacing statistics $P(s)$ is well described by random matrix theory. However, one can ask the question how this quantum ergodicity emerges with increasing level number N? This question becomes especially important for diffusive billiards with weakly rough elastic boundary where the time of classical ergodicity τ_D due to diffusion on the energy surface in the angular momentum l-space is much larger than the collision time with the boundary τ_b. As is shown in [89,92] in such a situation quantum localization on the energy surface may break classical ergodicity eliminating the level repulsion in $P(s)$. The investigation of rough billiards [89,92] showed that this change of $P(s)$ happens when the localization length ℓ in l-space becomes smaller than the size of the energy surface characterized by the maximal $l = l_{max}$ at given energy ($\ell < l_{max}$). The localization length $\ell = D \approx 4 l_{max}^2 \tilde{\kappa}^2$ is determined by diffusion rate in l being proportional to the billiard roughness $\tilde{\kappa}^2 =< (dR/d\theta/R_0)^2 >$. In the localized regime $P(s)$ has a large Shnirelman peak at small spacings which contains about 30-40% of all spacings. The appearance of quasidegeneracy in integrable billiards was proved by Shnirelman in 1975. Its physical origin was explained in [70] on the basis of tunneling between states rotating in different directions. In some sense the degeneracy between the states connected by time-reversal symmetry is destroyed by *tunneling between the future and the past.*

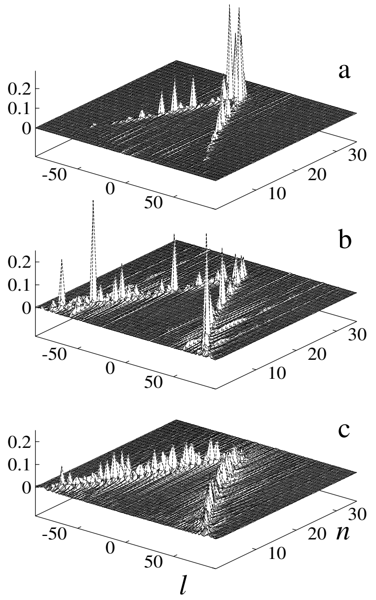

Fig.1 (see text)

For $\ell > l_{max}$ the eigenfunctions are extended over the whole energy surface but surprisingly they are not necessarily ergodic. The usual scenario of ergodicity breaking was based on an image of transition from the quantum eigenstates ergodic on this surface (*Shnirelman ergodicity*) to the exponential localized states. In [92] it is shown that this transition between localized and Shnirelman ergodic states can pass through an intermediate phase of *Wigner ergodicity*. In this Wigner phase the eigenstates are nonergodic and composed of rare strong peaks distributed on the *whole* energy surface (Fig.1: Transition from localization to Shnirelman ergodicity on energy surface for level number $N \approx 2250$; a)localization at small roughness, b) Wigner ergodicity for medium roughness, c)Shnirelman ergodicity for large roughness).

The description and understanding of this case is based on the mapping of the billiard problem with weakly rough (random) boundary on to a superimposed band random matrix (SBRM). This model is characterized by strongly fluctuating diagonal elements corresponding to a preferential basis of the unperturbed problem. Such type of matrices was studied recently in the context of the problem of particle interaction in disordered systems (see [69,75] and papers of Fyodorov and Mirlin and Frahm and Müller–Groeling). There it was found that the eigenstates can be extended over the whole matrix size while having a very peaked structure. The origin of this behavior is due to the Breit-Wigner form of the local density of states according to which only unperturbed states in a small energy interval Γ_E contribute to the final eigenstate. The condition for Wigner ergodicity in rough billiards are determined in [92].

The physical realizations of rough billiards can be quite different. As examples, it is possible to mention surface waves in the droplets which are practically static for the light, nonideal surfaces in microdisk lasers, and capillary waves on a surface of small metallic clusters (see refs. [7, 8, 10] in [89]). Recently, the above theoretical results have been studied and confirmed in experiments with microwave rough billiards realized by Stöckmann et al. at Marburg and Sirko et al. at Warsaw (see e.g. Phys. Rev. E v.63 (2001) 046208).

The results of this section were obtained with Klaus Frahm who also developed a supersymmetry approach to rough billiards in separate publications. This direction of research is represented in his habilitation.

2.6.5. Chaotic enhancement of microwave excitation for chaotic Rydberg atoms

In 1982 Shushkov and Flambaum discussed the effect of weak interaction enhancement due to a complex structure of ergodic eigenfunctions in nuclei. The basic idea of this effect is that in complex systems an eigenfunction, represented in some basis, has a large number M of randomly fluctuating components so that their typical value is $1/\sqrt{M}$. Due to this, the matrix elements for inter-particle interaction are $V_{int} \sim 1/\sqrt{M}$ while the distance between mixed levels is $\Delta E \sim 1/M$. As a result, according to the perturbation theory, the admixture factor η is strongly enhanced: $\eta \sim V_{int}/\Delta E \sim \sqrt{M}$ as compared to the case in which eigenfunctions have only few components ($M \sim 1$). This effect was investigated and well confirmed in experiments with weak interaction enhancement for scattering of polarized neutrons on nuclei. Recently a similar effect of inter-particle interaction enhancement was discussed for two interacting particles in disordered solid state systems [69]. Here, a short range interaction produces a strong enhancement of the localization length leading to a qualitative change of physical properties (see section 2.7). This shows that the effect is quite general and can take place in different systems.

In [82,91,93,98] such an enhancement in atomic physics is studied for atoms interacting with electromagnetic fields. Such process becomes especially interesting for highly excited atoms (hydrogen or Rydberg atoms) in microwave fields where absorption of many photons is necessary in order to ionize electrons. Until now this problem was studied only in the case in which the electron dynamics, in absence of microwave field, is integrable (see section 2.4). A quite different situation, investigated in [82,91,93,98], appears when the electron's motion in the atom is already chaotic in the absence of microwave field. An interesting example of such situation is an hydrogen atom in a strong static magnetic field or alkali atoms in a static electric field. The properties of such atoms have been extensively studied in the last decade and it has been shown that the eigenfunctions are chaotic, and that several properties of the system can be described by Random Matrix Theory. Due to that the interaction of such an atom with a microwave field is strongly enhanced so that the localization length becomes much larger, approximately by factor n_0, than the corresponding one in the absence of magnetic fields (or static electric filed). As a result, the quantum delocalization border, which determines the ionization threshold, drops by factor $\sqrt{n_0}$. In addition, due to internal chaos the microwave ionization can be studied in a regime when the microwave frequency is much smaller than the Kepler frequency ($\omega \ll 1/n_0^3$). In such a case up to 1000 photons are required to ionize an atom at $n_0 = 60, \omega n_0^3 = 0.03$ and only the theory of dynamical localization can describe ionization process in this situation. The drop in the quantum delocalization border for alkali atoms in a static field is in a qualitative agreement with the experimental results of Gallagher (Univ. of Virginia, USA) and Beterov (Inst. of Semiconductor Physics, Novosibirsk). Also the group of Kleppner (MIT, USA) works in a very similar regime. Therefore, the above theory can be tested experimentally. The results obtained in [91,93,98] form the basis of thesis of G.Benenti (hold at Milano Univ. in February 1998).

2.6.6. Quantum chaos in open systems

It is show that the quantum relaxation process in a classically chaotic open dynamical system is characterized by a quantum relaxation time scale t_q [95]. This scale is much shorter than the Heisenberg time and much larger than the Ehrenfest time: $t_q \propto g^{\alpha}$ where g is the conductance of the system and the exponent α is close to $1/2$. As a result, quantum and classical decay probabilities remain close up to values $P \sim \exp\left(-\sqrt{g}\right)$ similarly to the case of open disordered systems. The analysis of this behaviour was done for the kicked rotator model with absorption which was introduced in [50]. Later this result was confirmed by methods of random matrix theory (D.Savin and V.Sokolov) and by supersymmetry approach (K.Frahm). This result can be also understand on the basis of weak localization correction to diffusion in disordered systems (A.Mirlin, B.Muzikantskii and D.Khmelnitskii).

In the chaotic regime the quantum eigenstates of nonunitary evolution operator reveal a fractal structure in the phase space [97] corresponding to a underlying classical strange repeller. An example of such fractal quantum eigenstate in Husimi representation is shown in Ref. [97]. It is conjectured that quantum strange attractors, once identified, should have a similar structure.

The quantum effects for Poincaré recurrences in divided phase space (see sections 2.2.1 and 2.6.1) are investigated in [100]. It is shown that quantum effects modify the decay rate of Poincaré recurrences $P(\tau)$ in classical chaotic systems with hierarchical structure of phase space. The exponent p of the algebraic decay $P(\tau) \propto 1/\tau^p$ is shown to have the universal value $p = 1$ due to tunneling and localization effects. Experimental evidence of such decay should be observable in mesoscopic systems, Rydberg and cold atoms.

This direction of research forms the basis of the thesis "Quantum chaos in open systems" of G.Maspero (Univ. of Milano at Como) finished in January 1999.

2.7. Interaction, disorder and Anderson localization

This section reviews the new direction of research developed from 1994 which is based on the effect of chaotic enhancement of interaction for complex eigenfunctions. This effect was discussed by Sushkov and Flambaum for weak interaction in nuclei (see some details in section 2.6.6). It was shown in my works [69,74,76,80] that the enhancement of interaction can qualitatively change transport properties and destroy Anderson localization. In the phase where all one-particle states are localized the pairs of two repulsive/attractive particles can propagates together on a distance much larger than their size or even be delocalized. This gives the positive answer to the Bible question "Can two walk together, except they be agreed?" (Amos, (III.3)).

In the metallic phase a critical strength of two-body interaction is defined at which a crossover to quantum chaos and thermalization takes place in Landau Fermi liquid of finite systems [94,96]. These ideas are recently applied to the quantum spin glass shards (clusters). Later they find applications for the stability of quantum computer hardware (see Sec. 3.1).

2.7.1. Two interacting particles effect

The investigation of effects of short range repulsive/attractive interaction between two particles in a random potential with localized one-particle states was started in [69]. It gave a striking result according to which there are states of a new type in which the particles are located from each other on a distance of one-particle localization length l_1 and propagate together coherently on a much larger distance $l_c \gg l_1$. Such coherent propagation takes place even in the case of repulsive interaction. The physical reason for appearance of such effective pairing for repulsing particles can be understood in the following way. In the random potential two repulsing particles which were originally close to one another cannot diverge on a distance much larger than l_1 due to exponential decrease of transition matrix elements for a distance between particles $R \gg l_1$. In some sense the localization forces the particles to stay together. In such coupled state the particles can move one with respect to the other. This destroys quantum interference and localization and strongly increases the distance l_c on which they propagate together, if compared to l_1.

This research started in [69] was then continued in papers [74-76,79-81,83,90]. The two interacting particles (TIP) effect attracted the interest of other groups who obtained a number of interesting results: Y.Imry (Weizmann); K.Frahm, A.Müller-Groeling, J.-L.Pichard and D.Weinmann (Saclay); F. von Oppen, T.Wetting and J.Müller (Heidelberg); P.Silvestrov (Novosibirsk). The case of two particles with strong long range attraction was first studied by O.Dorokhov (1990) who found that the pairs of strongly attractive particles can propagate on a larger distance.

The results for TIP can be summarized in a following way. There is an important parameter κ which determines how many noninteracting levels are mixed by interaction. Generally, $\kappa \sim \Gamma_2 \rho_2$, where $\Gamma_2 \sim U^2/V{l_1}^d$ is interaction induced transition rate and $\rho_2 \sim {l_1}^{2d}/V$ is the density of two-particle states (here U is a strength of on site/nearby site interaction, $V > U$ is inter-site hopping and d is a system dimension). The rate Γ_2 has a meaning of Breit-Wigner width which determines the shape of local density of states and a number of unperturbed states contributing to an eigenstate in the present of interaction, which can be defined via inverse participation ratio [75]. For $d = 1$ the localization length for pairs is enhanced by factor $l_c/l_1 \sim \kappa > 1$; for $d = 2$ the enhancement is exponentially strong $\ln(l_c/l_1) \sim \kappa > 1$ and for $d = 3$ the pairs are delocalized for $\kappa > 1$ while all one-particle states are localized [80]. In $d = 3$ there is a logarithmically slow growth of pair size that slightly decreases the diffusion rate of pair propagation. The above picture was confirmed by extensive numerical simulations for different models which are discussed in [69,74,76,81] and by results of other groups. However, due to the fact that particles are moving in the same random potential further studies are still desirable to understand in a better way the effects of correlations and approximate selection rules (see e.g. [80,83] and Refs. therein).

However, the most interesting questions are related to the TIP effect at a constant density of particles. Following the suggestion of Y.Imry it was studied in [90] in the Cooper approximation for quasiparticles above the frozen Fermi sea. Indeed, due to the proximity to the Fermi level a density of two-particle states is reduced: $\rho_2 \sim \epsilon/\Delta$, where ϵ is the TIP energy counted from the Fermi level and Δ is one-particle level spacing in a block of size l_1. At a first glance this should also reduce the Breit-Wigner width $\Gamma_2 \propto \rho_2$. However, in a localized regime with $d = 2, 3$ a return probability is enhanced comparing to a ballistic motion of particles that finally does not lead to a strong reduction in Γ_2 at small ϵ. As a result for $U \sim V$ the enhancement parameter becomes $\kappa > 1$ for $\epsilon > \Delta$ [90]. This indicates that delocalization of pairs can take place quite close to the Fermi level. In this situation the effects of interaction between larger number of particles should be taken into account to model a real situation in which the Fermi sea is not frozen.

This direction of research becomes especially interesting in a light of recent experiments of Kravchenko et al. who definitely demonstrated the existence of metal-insulator transition for strongly interacting electrons in two-dimensional random potential. It is possible that this transition can be related to the TIP effect. Recent results obtained from extensive quantum Monte Carlo simulations show that the repulsive Hubbard interaction between spin halves fermions on a lattice with disorder enhances delocalization even if they do not allow to make a definite conclusion on the delocalization in the large system size limit (see [139]).

The results obtained in [75,83,85,86,90] form the basis of the thesis of Ph.Jacquod (Univ. de Neuchâtel, 1997).

2.7.2. Two interacting particles in the Harper model

Dynamics, the spectral and eigenstate properties of two particles with short range repulsive or attractive interaction was studied in the Harper model with incommensurate potential [84,85,87]. It is shown that interaction leads to appearance of localized states and pure-point spectrum component in the case when noninteractive system is quasi-diffusive or ballistic. In the localized phase interaction gives only stronger localization contrary to the case of two interacting particles in a random potential. These results were qualitatively understood on the basis of Aubry duality breaking.

2.7.3. Emergence of quantum chaos and thermalization in finite Fermi systems

The Random Matrix Theory (RMT) was developed to explain the general properties of complex energy spectra in many-body interacting systems such as heavy nuclei, many electron atoms and molecules. Later, it has found many other successful applications in different physical systems. Among the most recent of them we can quote models of quantum chaos where RMT appears due to the classically chaotic but deterministic underlying dynamics. One of the most direct indications of the emergence of quantum chaos is the transition of the level spacing statistics $P(s)$ from Poisson to Wigner-Dyson (WD) distribution. This property has been widely used to detect the transition from integrability to chaos not only in systems with few degrees of freedom (O.Bohigas et al.) but also in solid-state models with many interacting electrons. It was also applied to determine the Anderson delocalization threshold in noninteracting disordered systems .

While the conditions for the appearance of the WD distribution in noninteracting systems is qualitatively well understood the situation is more intricate in presence of interaction. Indeed, in this case the size of the total Hamiltonian matrix grows exponentially with the number of particles and it becomes very sparse as a result of the two-body nature of the interaction. According the common lore in nuclear physics the level density grows exponentially with the number of particles and therefore an exponentially small interaction is sufficient to mix nearby levels. However recent estimates on few-particle models ($n = 2, 3, 4$) showed that in spite of the high many-body density of states, only an interaction strength comparable to the two-particle level spacings can give a level mixing and WD distribution for $P(s)$ [79]. This result was confirmed later by Weinmann, Pichard and Imry. The generalization to the case of large number of particles was done in [94]. There, for a model with a random two-body interaction it was shown that there is a smooth crossover from Poisson to WD distribution for interaction $U > U_c \approx 1/\rho_c \sim 1/(\rho_2 n^2)$ where ρ_2 is the density of two-particle states and n is the number of effectively interacting particles. For fixed interaction being small comparing to one-particle level spacing $\Delta \gg U$ the number of effectively interacting particles depends on excitation energy δE above the Fermi level: $\delta n \sim T/\Delta \sim \sqrt{\delta E/\Delta}$, where T is the temperature of this finite closed Fermi system. Due to that as it is found in [94] the crossover to WD distribution takes place only for $\delta E > \delta E_{ch} \approx \Delta(\Delta/U)^{2/3}$. Since without random matrix properties thermalization cannot set in the result of [94] implies that the system is thermalized only for $T > T_{ch} \approx \Delta(\Delta/U)^{1/3}$ (or $\delta E > \delta E_{ch}$).

The obtained estimates for the quantum chaos border can be applied to different finite interacting Fermi systems such as complex nuclei with residual interaction, atoms and molecules, clusters and quantum dots. Here we briefly discuss the case of metallic quantum dots studied in the experiments of Sivan et al.. In this case the inter-particle interaction is relatively weak so that $U/\Delta \sim 1/g$ with $g = E_c/\Delta \gg 1$ being the conductance of the dot and E_c the Thouless energy. According to above estimates the thermalization will take place above the excitation energy $\delta E_{ch} \sim \Delta g^{2/3}$. This is in a satisfactory agreement with the experimental results where a dense spectrum of excitations in dots with $g \sim 100$ appears at excitation energies $\delta E_{ch} \sim 10\Delta$. The above border for thermalization and chaos δE_{ch} is higher than the border for quasiparticle disintegration on many modes $\delta E_D \sim \Delta g^{1/2}$ proposed by Altshuler, Gefen, Kamenev and Levitov. The parametrically different dependence on g suggested there appears because the effect of energy redistribution between many excited modes was neglected while the results of [94,96] show that it plays an important role.

The investigation of the eigenstate properties was done in [96]. It was shown that for $U > U_c$ the number of noninteracting states contributing to one eigenstate, which is proportional to the inverse participation ratio, is $\xi \approx \Gamma\rho_n$. Here $\Gamma \sim U^2\rho_c$ is the Briet-Wigner width of the local density of states and ρ_n is the multi-particle density of states. As the result for $U \sim U_c$ interaction mix exponentially many states ($\xi_c \sim \rho_n/\rho_c$). Near the Fermi level $\Gamma \sim (\delta E/\Delta)^{3/2}\ (U^2/\Delta)$. The last expression for Γ has a simple meaning. Indeed, Γ is the total Breit-Wigner width for δn effectively interacting particles.

Therefore, the partial width $\Gamma_D \sim \Gamma/\delta n$ is the usual quasi-particle decay rate which in agreement with the theory of Landau Fermi liquid is proportional to T^2. At the quantum chaos border $\delta E = \delta E_{ch}$, when the crossover to the Wigner-Dyson statistics takes place, the IPR becomes exponentially large $\xi_c \sim (T_{ch}/\Delta)\exp(2.6T_{ch}/\Delta)$. We note that in the Landau Fermi liquid theory quasiparticles are well defined if $\Gamma_D < T (T < T_L = \Delta(\Delta/U)^2)$. In this regime the level statistics $P(s)$ can be as in chaotic ($P(s) = P_{WD}(s)$ for $T_{ch} < T < T_L$) or integrable ($P(s) = P_P(s)$ for $T < T_{ch} < T_L$) systems.

As a result, the Landau Fermi liquid in finite systems can be integrable or chaotic depending on temperature (or excitation energy) and interaction strength.

2.7.4. Integrability and quantum chaos in spin glass shards

The ideas developed above for interaction induced thermalisation in finite Fermi systems were applied to quantum spin glass shards [99]. The studies are done for spin glass clusters ("shards") in a random transverse magnetic field. All spins are coupled so that at zero magnetic field the system represents the classical Sherrington-Kirkpatrick spin glass model. It is shown that for a weak or strong transverse magnetic field the dynamics remains integrable and the level spacing statistics is Poissonian. The regime where quantum chaos and random matrix level statistics emerge from the integrable limits of weak and strong field is determined. Relations with quantum phase transitions are also analyzed [99].

2.7.4. 3d Anderson transition for two electrons in 2d

It is shown that the Coulomb interaction can lead to delocalization of two electron states in two-dimensional disordered potential in a way similar to the Anderson transition in three dimensions [102,105]. At fixed disorder strength the localized phase corresponds to low electron density and large value of parameter r_s. The analytical results are supported by numerical study of level spacing statistics.

2.7.5. Quantum ergodicity for electrons in 2d

The results obtained [102,105] show that the Coulomb interaction between two electrons in excited states leads to their delocalization for $1 < r_s < r_L^{4/3}$ while for $r_s > r_L^{4/3}$ they remain localized. Here the parameter r_s is the ration of the Coulomb interaction to the Fermi energy and r_L is the r_s-value taken at such a density when one electron is located in a box of one-electron localization length size. The transition between these phases is similar to the Anderson transition in an effective dimension $d_{eff} = 3$. The numerical studies of the spectral statistics for many polarized electrons in the 2D Anderson model [104,106] show that for $3 < r_s < 9$ and $5 \leq W/V \leq 15$ the ground state is nonergodic (localized) and is characterized by the Poisson statistics for the total energy $E < E_c$ (here W, V are the disorder and hopping strengths, respectively). However, the transition to quantum ergodicity and the Wigner-Dyson statistics takes place at a fixed total energy E_c independent of system size (for $r_s \approx 3.2$, $5 \leq W/V \leq 10$ and fixed filling $\nu \approx 1/32$). This implies a delocalization at zero temperature T. At the critical point E_c the critical statistics approaches to the Poisson limit with the increase of disorder strength. In a certain sense the situation is similar to the Anderson transition in high dimensions $d > 3$ where a similar tendency had been observed. In analogy with this result and the case of two electrons in 2D we make a conjecture that the transition at E_c is similar to a transition in some effective dimension $3 \leq d_{eff}$. This d_{eff} is growing with the disorder strength W.

The interaction induced ergodicity at $T = 0$ is in favor of the metal-insulator transition observed experimentally by Kravchenko et al.. However, the data are not yet sufficient to determine the behavior of resistivity on temperature in the ergodic phase at $E > E_c$. Therefore, it is not excluded that at strong disorder this ergodic phase will show a resistivity growth at low T. In this case one can suppose that the ergodicity induced by the Coulomb interaction is responsible for the phononless VRH conductivity as it was argued by Shklovskii and indicated by the experiments of Shlimak, Pepper et al.. More detailed investigations are required to understand the properties of the Coulomb ergodic phase at $E > E_c$.

In Ref. [139], with Srinivasan and Benenti, we study numerically the ground-state properties of the repulsive Hubbard model for spin-1/2 electrons on two-dimensional lattices with disordered on-site energies. The projector quantum Monte Carlo method is used to obtain very accurate values of the ground-state charge density distributions with N_p and $N_p + 1$ particles. The difference in these charge densities allows us to study the localization properties of an added particle. The results obtained at quarter-filling on finite clusters show that the Hubbard repulsion has a strong delocalizing effect on the electrons in disordered 2D lattices. These numerical findings are in a qualitative agreement with the experimental results obtained by Kravchenko and others on metalic behaviour in 2d. However, numerical restrictions do not allow to reach a definite conclusion about the existence of a metal-insulator transition in the thermodynamic limit in two-dimensions.

In Ref.[125] the ground state magnetization properties are studied numerically for clusters of interacting electrons in two dimensions in the regime where the single particle wavefunctions are localized by disorder. It is found that the Coulomb interaction leads to a spontaneous ground state magnetization. For a constant electronic density, the total spin increases linearly with the number of particles, suggesting a ferromagnetic ground state in the thermodynamic limit. The magnetization is suppressed when the single particle states become delocalized. The possibility of a ferromagnetic phase in strongly correlated two-dimensional (2D) systems has recently received experimental support in dilute 2D electron gases as reported in the experiments of Vitkalov, Sarachik and others. The results obtained in [111,125] form the basis of the thesis of G.Caldara defended in Dec. 2002.

2.8. Disorder and superconductivity: a new phase of bi-particle localized states

The Cooper problem is studied numerically for the Anderson model with disorder in two-dimensions. It is shown that the attractive Hubbard interaction creates a phase of bi-particle localized states in the regime where non-interacting states are delocalized. This phase cannot be obtained in the mean-field approximation and the pair coupling energy is strongly enhanced in this regime. The effects of magnetic field are studied and it is shown that under certain conditions they lead to delocalization. The coupling energy of these pairs is much larger than the coupling energy given by the mean field solution (Cooper ansatz). Therefore energetically it is more favorable to have an insulator with localized pairs instead of usual weakly coupled delocalized Cooper pairs. This result indicates the appearance of a new phase of bi-particle localized states (BLS phase) which appears in the regime when non-interacting states are extended (metallic). It is in a qualitative agreement with the quantum Monte Carlo studies obtained recently in our group in Toulouse [123]. This BLS phase is qualitatively different from BCS solution which corresponds to weakly coupled delocalized pairs. The obtained results are published in [109,110,122,123,126]. They form the basis of the thesis of J.Lages defended 19 Oct 2001 in Toulouse.

The recent extensive quantum Monte Carlo simulations for attractive Hubbard model on a disordered 3d lattice are performed with up to 110 fermions in [133]. They showed the appearance of localized paires in noninteracting metallic phase. These results give a scenario explaining the unusual experimental results of Gantmakher group in Chenogolovka on superconducting thin films in a strong magnetic field.

In [195] we propose a physical picture of superinsulator observed recently in experiments with superconducting films in a magnetic field. On the basis of previous numerical studies we argue that a moderate attraction creates bi-particle localized states at intermediate disorder strength when noninteracting electron states are delocalized and metallic. Our present numerical study show that such localized pairs are broken by a static electric field which strength is above a certain threshold. We argue that such a breaking of localized pairs by a static field is at the origin of superinsulator breaking with a current jump observed experimentally above a certain critical voltage.

2.9. Quantum phase transition in the Frenkel-Kontorova model

The research started in Sec. 2.5.2 is continued in [128,136]. With Zhirov and Casati we study analytically and numerically the one-dimensional quantum Frenkel-Kontorova chain in the regime when the classical model is located in the pinned phase characterized by the gaped phonon excitations and devil's staircase. By extensive quantum Monte Carlo simulations with up to a few hundreds of atoms we show that for the effective Planck constant $\hbar$ smaller than the critical value $\hbar_c$ the quantum chain is in the pinned instanton glass phase. In this phase the elementary excitations have two branches: *phonons*, separated from zero energy by a finite gap, and *instantons* which have an exponentially small excitation energy. At $\hbar = \hbar_c$ the quantum phase transition takes place and for $\hbar > \hbar_c$ the pinned instanton glass is transformed into the sliding phonon gas with gapless phonon excitations. This transition is accompanied by the divergence of the spatial correlation length and appearance of sliding modes at $\hbar > \hbar_c$.

2.10. Dynamical turbulent flow on the Galton board with friction, directed transport and ratchets

It is well known that dissipation can lead to the appearance of strange chaotic attractors in nonlinear nonautonomous dynamical systems. In this case the energy dissipation is compensated by an external energy flow so that stationary chaotic oscillations set in on the attractor. Such an energy flow is absent in the Hamiltonian conservative systems and therefore the introduction of dissipation or friction is expected to drive the system to simple fixed points in the phase space. This rather general expectation is surly true if the system phase space is bounded. However a much richer situation appears in the case of unbounded space, where unexpectedly a strange attractor can be induced by dissipation in an originally conservative system. To investigate this situation with Alexei Chepelianskii we study the dynamics of particles on the Galton board in the presence of constant external fields and friction. This board, introduced by Galton in 1889, represents a triangular lattice of rigid discs with which particles collide elastically. For the case of free particle motion, the collisions with discs make the dynamics completely chaotic on the energy surface as it was shown by Sinai. In the paper [120] we study how the dynamics of a charged particle in a presence of electric and magnetic fields is affected by a friction force $\mathbf{F}_f = -\gamma \mathbf{v}$ directed against particle velocity $\mathbf{v}$ (see Fig. 2). Without discs an external in-plane electric field $\mathbf{E}$ and a perpendicular magnetic field $\mathbf{B}$ create a stationary particle flow with the velocity $\mathbf{v}_f = (\mathbf{f} + F_L)/\gamma$. Here $\mathbf{f} = e\mathbf{E}$ is the effective force, $\mathbf{F}_L = e\mathbf{v_f}\times\mathbf{B}$ is the Lorentz force and e, m are the particle charge and mass. All perturbations decay to this flow with a rate proportional to γ so that this laminar flow can be considered as a simple attractor. The effects of friction inside one cell of the Galton board at $\mathbf{B} = 0$ have been studied by Hoover and it has been found that friction leads to the appearance of a nontrivial strange attractor. At present the effects of energy dissipation are actively investigated with the aim to construct equilibrium and nonequilibrium steady states in a deterministic way. Here the Nosé-Hoover and Gaussian thermostats with variable friction coefficients lead to a number of interesting results with applications to molecular dynamics and nonequilibrium liquids. In our studies, contrary to results of Hoover, we concentrate mainly on the spatial structure of the turbulent chaotic particle flow appearing in the presence of friction. We show that the flow direction can be efficiently affected by a magnetic field. The obtained results describe the electron dynamics in antidot superlattice which has been experimentally realized in semiconductor heterostructures (experiments of Weiss). In such structures the effects of classical chaos play an important role and the effects of friction we discuss here can appear for relatively strong electric fields. The same model describes the motion of small particles in a viscous liquid flow which laminarly streams through large scatters that in this case have the form of discs.

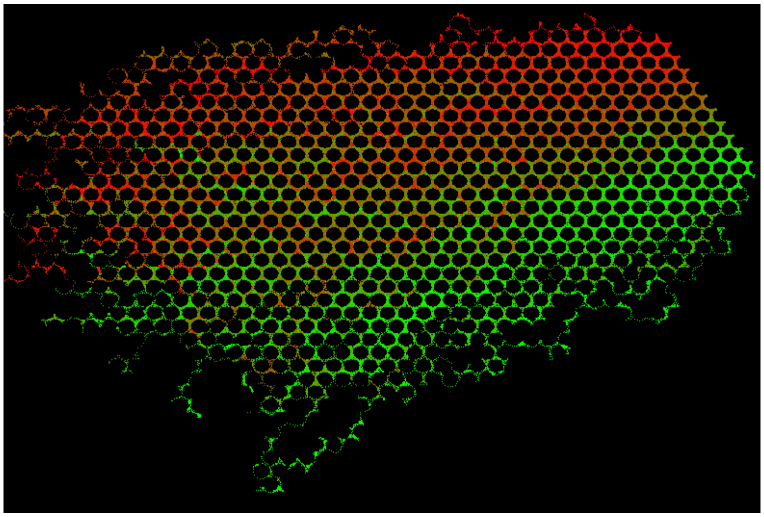

Fig.2 (see text)

A chaotic flow on the Galton board is shown in Fig.2 from [120]. Here the distance between discs is $R = 2.24$, $\mathbf{f}$ = (-0.5, -0.5), $B = 2$ and $\gamma = 0.1$. Initially 200 particles are distributed homogeneously along a straight line segment in the upper right corner, their color homogeneously changes from red to green along this segment. (color animated version is available at http://w3-phystheo.ups-tlse.fr/∼dima/galton)

This research line is continued in [145] with the investigation of directed transport and ratchets. A numerical study of the dynamics of particles on the Galton board of semi-disk scatters in presence of monochromatic radiation and dissipation is done in this work. It is shown that under certain conditions the radiation, which does not give any preferable direction, leads to appearance of directed transport (ratchet) linked to an underlining strange attractor. The direction of transport can be efficiently changed by radiation polarization. The experimental realization of this effect in asymmetric antidot superlattices with microwave radiation is discussed. At present an experimental realization of this ratchet effect in mesoscopic heterostructures with anti-dots semi-disk lattice is prepared by Prof. Kvon Ze Don at Inst. of Semicondactor Physics, Russian Academy of Science, Novosibirsk.

3. Research on quantum information and computation

In 1999 I initiated in Toulouse a new research line linked to quantum information and quantum computation. At present this research line is developed in the Quantware MIPS Center (http://www.quantware.ups-tlse.fr) which represents an informal group of researchers at the Lab. de Phys. Théorique (10 researchers including 4 permanents, 3 post-docs, 2 PhDs and 1 undergraduate). This research is supported by three international grants (two from EC and one from USA) which allow to give temporary jobs to 4 researcher (see details in Sec. 7).

3.1. Quantum chaos & quantum computers

The investigation of stability of quantum computer hardware in respect to static imperfections and residual inter-qubit couplings was started with Georgeot in [107]. There we study a generic model of a quantum computer, composed of many qubits coupled by short-range interaction. Above a critical inter-qubit coupling strength, quantum chaos sets in, leading to quantum ergodicity of the computer eigenstates. In this regime the noninteracting qubit structure disappears, the eigenstates become complex and the operability of the computer is destroyed. Despite the fact that the spacing between multi-qubit states drops exponentially with the number of qubits n, we show that the quantum chaos border decreases only linearly with n. This opens a broad parameter region where the efficient operation of a quantum computer remains possible.

The obtained chaos border for the quantum computer melting induced by inter-qubit couplings is of principal importance. Indeed, for $n = 1000$, the minimum number of qubits for which Shor's algorithm becomes useful, the multi-qubit spacing becomes $\Delta_n \sim 10^3 \times 2^{-10^3} \Delta_0 \sim 10^{-298}$ K, where we used $\Delta_0 \sim 1$ K that corresponds to the typical one-qubit spacing in the experimental proposal of Kane. It is clear that the residual interaction J between qubits in any experimental realization of the quantum computer will be larger than this. For example, in the proposal of Kane, the increase of effective electron mass by a factor of two, induced by the electrostatic gate potential, means that the spin-spin interaction is changed from $J \sim \Delta_0 \sim 1$ K (corresponding to a distance between donors of 200 Å and an effective Bohr radius of 30 Å) to the residual interaction $J \sim 10^{-5}$ K $\gg \Delta_n$. However, the quantum chaos border found in [107] is $J_c \approx 0.4\Delta_0/n \gg \Delta_n$. Only for $J > J_{cs}$ the multi-qubit states start to be mixed while for $\Delta_n \ll J < J_c$ noninteracting multi-qubit states are well defined and the quantum computer can operate successfully. If one-qubit level spacing changes from one qubit to another in a smaller energy interval $\delta \ll \Delta$ then the quantum chaos border is $J_c \sim \delta/n$ [107].

A pictorial image of the quantum computer melting induced by the coupling between qubits is shown in Fig.3 (from [107]). Color represents the level of quantum eigenstate entropy S_q, with bright red for the maximum values ($S_q \approx 11$) and blue for the minimal ones ($S_q = 0$). For $S_q = 0$ the quantum computer eigenstate is represented by one noninteracting multi-qubit state, for $S_q = 1$ it is composed from 2 multiqubit states and for $S_q = n$ its is composed from approximately 2^n states. Horizontal axis is the energy of the computer eigenstates counted from the ground state to the maximal energy ($\approx 2n\Delta_0$). Vertical axis is the scaled value of the inter-qubit coupling J/Δ_0, varying from 0 to 0.5. Here $n = 12$ and one random realization of inter-qubit coupling is chosen [107]. This result shows that coupling between qubits can completely destroy the quantum computer hardware.

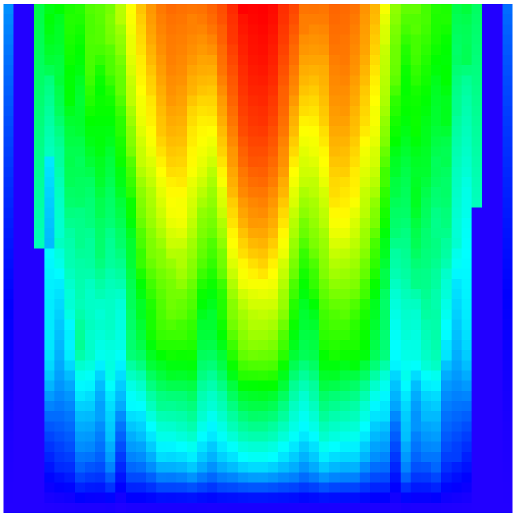

Fig.3 (see text)

The results on static quantum hardware properties are described in the papers [107,112,116]. They were presented in my invited lecture at Nobel Symposium on Quantum chaos in June 2000 in Sweden (see [113]).

3.2. Quantum algorithms for complex dynamics

A number of efficient quantum algorithms were developed and their stability was tested in respect to imperfections described in Sec. 3.1 and noise in the quantum gates. These results are presented in [115,117,121,124,129,130,131,132,134, 135,137,138,140].

Here I review a few results obtained there. Thus, in [121] with Georgeot we show on the example of the Arnold cat map that classical chaotic systems can be simulated with exponential efficiency on a quantum computer. Although the classical computer errors grow exponentially with time, a quantum algorithm in presence of moderate imperfections is able to simulate accurately the unstable chaotic classical nonlinear dynamics for long times. The algorithm can be easily implemented on systems of a few qubits. An example of such a dynamics is shown in Fig.4 (from [121]). Here, the dynamics of the Arnold cat map is simulated on a classical (left) and quantum computer (right), on a 128×128 lattice. Upper row: initial distribution; second row: distributions after 10 iterations; third row: distributions at $t_{2r} = 20$, with time inversion made at $t_r = 10$; bottom row: distributions at $t_{2r} = 400$, with time inversion made at $t_r = 200$. Left: inversion is done with classical error of one cell size ($\epsilon = 1/128$) at $t = t_r$ only; right: all quantum gates operate with random quantum errors of amplitude $\epsilon = 0.01$ in angles of unitary rotations; color from blue to red gives the probability $|a_{ij}|^2$; $n_q = 7$. In total 20 qubits with noisy gates are simulated for Quantium I (right). In this algorithm proposed in [121] an exponential number of classical orbits $O(2^{2n_q})$ is simulated by a quantum computer in $O(n_q)$ quantum gates. The obtained results show that despite the common lore that quantum computers are very vulnerable to noise, our study of the Arnold cat dynamics shows that classical unstable motion, for which classical computers display exponential sensibility to errors, can be simulated accurately with exponential efficiency by a realistic quantum computer. The quantum computation remains accurate on a time scale $t_f \sim 1/(\epsilon^2 n_q)$ which is much larger than the logarithmic time scale related to the Lyapunov exponential instability.

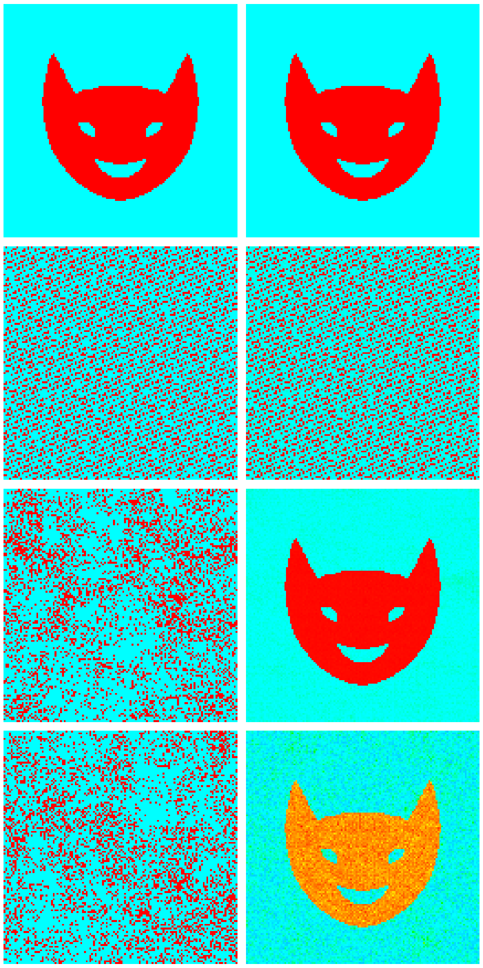

Fig.4 (see text)

The paper [117] presents a quantum algorithm which simulates the quantum kicked rotator model (see Sec. 2.3.1) exponentially faster than classical algorithms. This shows that important physical problems of quantum chaos, localization and Anderson transition can be modeled efficiently on a quantum computer. It also shows that a similar algorithm simulates efficiently classical chaos in certain area-preserving maps. The examples of such algorithms are tested in numerical simulations in [129,130,131,138] and [127,132]. An example of the Schrödinger cat oscillations (in the regime of chaos-assisted tunneling) simulated on a quantum computer with noisy quantum gates is discussed in [131]. The algorithm developed there opens new possibilities for investigation of macroscopic quantum tunneling and realization of semiclassical Schrödinger cat oscillations. The numerical studies determine the decoherence rate induced by noisy gates for these oscillations and propose a suitable parameter regime for their experimental implementation in

NMR based quantum computers. Fig.5 shows the time evolution of the Schrödinger cat in the double-well map animated on a quantum computer: probability distribution $W(x)$ over horizontal x-axis for $-\pi \leq x \leq \pi$ is shown for different number of map iterations t, changing along vertical y-axis from $t = 0$ (top) to $t = 180$ (bottom). Quantum computation is done with $n_q = 6$ qubits, ideal perfect gates give probability oscillations from left to right (not shown). For noisy gates of strength $\epsilon = 0.02$, and $n_g = 2090$ gates per one map iteration these oscillations stats to decay with time. At $t = 0$ initial coherent packet is located on the left. The color is proportional to the density: blue for zero and red for maximal density; axes are dimensionless. The effective decoherence rate is shown to scale as $\Gamma \sim \epsilon^2 n_q^4$. Thus the decay rate is polynomial in ϵ and n_q even if the exponentially large vector of size 2_q^n is simulated by the algorithm constructed in [131].

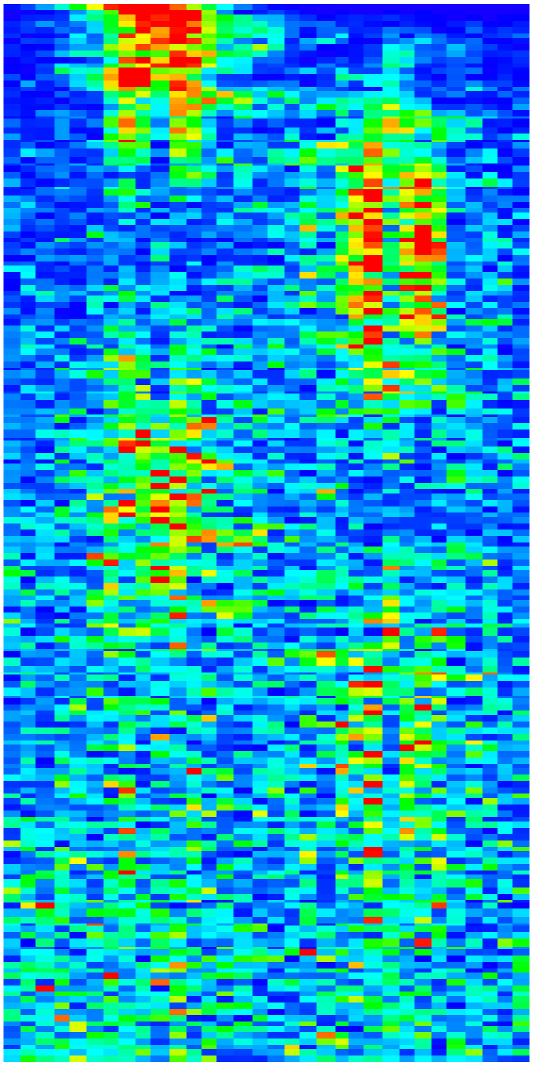

Fig.5 (see text)

The quantum algorithms for simulation of a strange attractor and dynamics in the quantum saw-tooth map are described in [132] and [129,130]. The numerical studies for the quantum saw-tooth map with 16 qubits show that the static imperfections act in a very different way comparing to classical round-off errors and lead to direct transitions inside classically integrable islands of stability (see Fig.6 from [129] as an example of the Husimi wavefunction in the phase-space of the map $n_{t+1} = n_t + kx_t, x_{t+1} = x_t + Tn_t$ at $T = 2\pi/N, N = 2^{n_q}, K = kT = -0.1, n_q = 16$, probability changes from zero (blue) to maximum (red)). The investigation of the quantum algorithm for the saw-tooth map and the effects of imperfections in this quantum computation formed the basis of the PhD thesis of Simone Montangero defended in March 2003 at Univ. of Milano (it is based on the papers [129,130,134,135]).

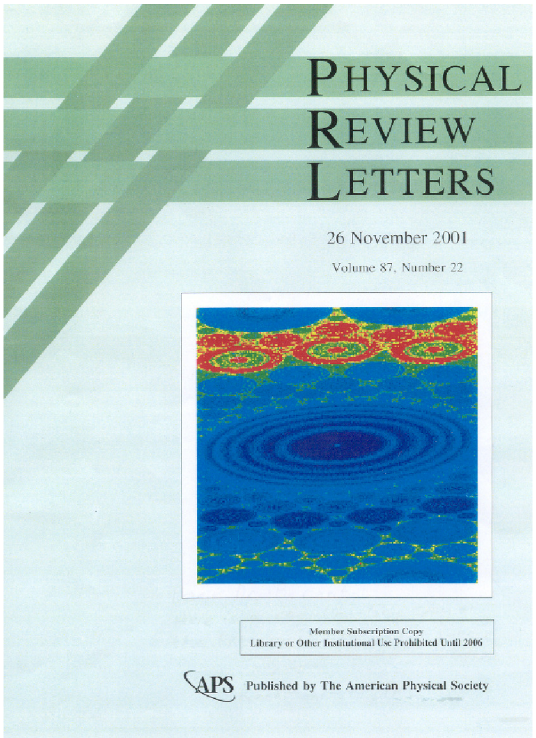

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Fig.6 (see text)

The accuracy of quantum wavelet transform is studied in [140]. The obtained relations give a significant decrease of the threshold of the fault-tolerant quantum computation for the case of static imperfections. This result shows that new strategies of quantum error correction codes should be developed to significantly suppress phase shifts induced by static imperfections. The spin echo techniques used in NMR may play here an important role.

In [144] we determine the universal law for fidelity decay in quantum computations of complex dynamics in presence of internal static imperfections in a quantum computer. Our approach is based on random matrix theory (RMT) applied to quantum computations in presence of imperfections. The theoretical predictions are tested and confirmed in extensive numerical simulations of a quantum algorithm for quantum chaos in the dynamical tent map with up to 18 qubits. The theory developed determines the time scales for reliable quantum computations in absence of the quantum error correction codes. These time scales are related to the Heisenberg time, the Thouless time, and the decay time given by Fermi's golden rule which are well known in the context of mesoscopic systems. The comparison is presented for static imperfection effects and random errors in quantum gates. A new convenient method for the quantum computation of the coarse-grained Wigner function is also proposed. This work gives a unified RMT approach to effects of static imperfections for quantum computations of complex dynamics.

In a case of integrable dynamics the imperfectioons should be treated in a different way. Thus in [146] we study effects of static inter-qubit interactions on the stability of the Grover quantum search algorithm. Our numerical and analytical results show existence of regular and chaotic phases depending on the imperfection strength ε. The critical border ε_c between two phases drops polynomially with the number of qubits n_q as $\varepsilon_c \sim n_q^{-3/2}$. In the regular phase ($\varepsilon < \varepsilon_c$) the algorithm remains robust against imperfections showing the efficiency gain $\varepsilon_c/\varepsilon$ for $\varepsilon \geq 2^{-n_q/2}$. In the chaotic phase ($\varepsilon > \varepsilon_c$) the algorithm is completely destroyed.

At present the world largest quantum computer (Quantum I) operating an efficient algorithm for a strange attractor was tested in Toulouse in numerical simulations in presence of realistic imperfections with up to 28 qubits (see the description of work in [132]).

4. Results obtained from 2004 till present

4.1. Quantum computing continued

Research of quantum computing in presence of realistic imperfections have been continued in [146,148,151,152,153,155,157,158,162].

Thus the stability range for the Grover algorithm in respect to static couplings between qubits (or static imperfections) is determined in [146]. The effects of dissipative decoherence are studied with the method of quantum trajectories in [152,158]. In [152], using the methods of quantum trajectories we investigate the effects of dissipative decoherence in a quantum computer algorithm simulating dynamics in various regimes of quantum chaos including dynamical localization, quantum ergodic regime and quasi-integrable motion. As an example we use the quantum sawtooth algorithm which can be implemented in a polynomial number of quantum gates. It is shown that the fidelity of quantum computation decays exponentially with time and that the decay rate is proportional to the number of qubits, number of quantum gates and per gate dissipation rate induced by external decoherence. In the limit of strong dissipation the quantum algorithm generates a quantum attractor which may have complex or simple structure. We also compare the effects of dissipative decoherence with the effects of static imperfections. The quantum algorithm studied in [152] has been experimentaly implemented on a 3-qubit NMR-based quantum computer by the group of D.Cory at MIT, USA (see "Localization in the quantum sawtooth map emulated on a quantum-information processor" M.K. Henry, J.Emerson, R.Martinez, and D.G.Cory, Phys. Rev. A v.74, p.062317 (2006)). The experiment showed first signs of quantum localization even if decoherence has been significantly strong inducing wave packet spreading in time. The effects of dissipative decoherence for the Grover algorithm have been analyzed in [158].

In [157], we present numerical and analytical studies of a quantum computer proposed by the Yamamoto group in Phys. Rev. Lett. v.89, p.017901 (2002). The stable and quantum chaos regimes in the quantum computer hardware are identified as a function of magnetic field gradient and dipole-dipole couplings between qubits on a square lattice. It is shown that a strong magnetic field gradient leads to suppression of quantum chaos.

In [155] we study a quantum small-world network with disorder and show that the system exhibits a delocalization transition. A quantum algorithm is built up which simulates the evolution operator of the model in a polynomial number of gates for exponential number of vertices in the network. The total computational gain is shown to depend on the parameters of the network and a larger than quadratic speed-up can be reached. We also investigate the robustness of the algorithm in presence of imperfections.

In [148], a general error correction method is presented which is capable of correcting coherent errors originating from static residual inter-qubit couplings in a quantum computer. It is based on a randomization of static imperfections in a many-qubit system by the repeated application of Pauli operators which change the computational basis. This Pauli-Random-Error-Correction (PAREC)-method eliminates coherent errors produced by static imperfections and increases significantly the maximum time over which realistic quantum computations can be performed reliably. Furthermore, it does not require redundancy so that all physical qubits involved can be used for logical purposes.

We study effects of imperfections induced by residual couplings between qubits on the accuracy of Shor's algorithm [162] using numerical simulations of realistic quantum computations with up to 30 qubits. The factoring of numbers up to N=943 show that the width of peaks, which frequencies allow to determine the factors, grow exponentially with the number of qubits. However, the algorithm remains operational up to a critical coupling strength ϵ_c which drops only polynomially with $\log_2 N$. The numerical dependence of ϵ_c on $\log_2 N$ is explained by analytical estimates that allows to obtain the scaling for functionality of Shor's algorithm on realistic quantum computers with a large number of qubits.

In [172] we formulate and numerically simulate the single control qubit Shor algorithm for the case of static imperfections induced by residual couplings between qubits. This allows us to study the accuracy of Shor's algorithm with respect to these imperfections using numerical simulations of realistic quantum computations with up to $n_q = 18$ computational qubits allowing to factor numbers up to N=205193. We confirm that the algorithm remains operational up to a critical coupling strength ϵ_c which drops only polynomially with $\log_2 N$. The obtained numerical dependence of ϵ_c on $\log_2 N$ is in a good agreement with the analytical estimates that allows to obtain the scaling for functionality of Shor's algorithm on realistic quantum computers with a large number of qubits.

In [168] we study numerically the effects of static imperfections and residual couplings between qubits for the quantum phase estimation algorithm with two qubits. We show that the success probability of the algorithm is affected significantly more by static imperfections than by random noise errors in quantum gates. An improvement of the algorithm accuracy can be reached by application of the Pauli-random-error-correction method (PAREC).

The results listed above are supported by USA ARO-NSA grant, EU EDIQIP and EuroSQIP grants.

4.2. Deterministic ratchets in asymmetric nanostructures

The research line on ratchet started in [145] and described partially in Sec.2.10 is further developed in [149,160,161] and [147]. This research is supported by the ANR PNANO project MICONANO.

For the semidisk Galton board in presence of Maxwell thermostat the dependence of the ratchet velocity on temperature is determined in [149]. The case of the Fermi-Dirac thermostat in investigated in [161]. We develop a theoretic description of the photogalvanic current (or ratchet) induced by a high frequency radiation in asymmetric nanostructures and show that it describes well the results of numerical simulations. Our studies allow to understand the origin of the electronic ratchet transport in such systems and show that they can be used for creation of new types of detectors operating at room temperature in a terahertz radiation range. The theoretical results are in qualitative agreement with the room temperature ratchet observed experimentally by the Lund group (A.M.Song et al. Appl. Phys. Lett. v.79, p.1357 (2001)). The experiments presently performed by the group of J.-C.Portal at Grenoble also indicate existence of strong ratchet transport on the semidisk Galton board implemented on nanoscale (work in progress in the frame of MICONANO project, see recent publications at Physica E v.40, p.2043 (2008)) and Phys. Rev. B v.78, 045431 (2008). This research line was continued in the frame of the approved ANR PNANO project NANOTERRA (coordinated by J.-C.Portal; Jan 2009 - Dec 2012).

In [160], on a basis of extensive analytical and numerical studies we show that a linear-polarized microwave field creates a stationary magnetization in mesoscopic ballistic quantum dots with two-dimensional electron gas being at a thermal equilibrium. The magnetization is proportional to a number of electrons in a dot and to a microwave power. Microwave fields of moderate strength create in a one dot of few micron size a magnetization which is by few orders of magnitude larger than a magnetization produced by persistent currents. The effect is weakly dependent on temperature and can be observed with existing experimental techniques. The parallels between this effect and ratchets in asymmetric nanostructures are also discussed.

In [171] we study analytically and numerically the ratchet transport of interacting particles induced by a monochromatic driving in asymmetric two-dimensional structures. The ratchet flow is preserved in the limit of strong interactions and can become even stronger compared to the non-interacting case. The developed kinetic theory gives a good description of these two limiting regimes. The numerical data show emergence of turbulence in the ratchet flow under certain conditions.

The quantum ratchets are studied in [147]. Using the method of quantum trajectories we study a quantum chaotic dissipative ratchet appearing for particles in a pulsed asymmetric potential in the presence of a dissipative environment. The system is characterized by directed transport emerging from a quantum strange attractor. This model exhibits, in the limit of small effective Planck constant, a transition from quantum to classical behavior, in agreement with the correspondence principle. We also discuss parameter values suitable for implementation of the quantum ratchet effect with cold atoms in optical lattices. At present experiments with a kicked Bose-Einstein condensate comes close to experimental implementations of the nontrivial effects considered in [147] (see recent M.Sadgrove et al Phys. Rev. Lett. v.99, p.043002 (2007)).

Other type of microwave control of transport through quantum dots is considered in [150] where we establish analogy between a microwave ionization of Rydberg atoms and a charge transport through a chaotic quantum dot induced by a monochromatic field in a regime with a potential barrier between dot contacts. We show that the quantum coherence leads to dynamical localization of electron excitation in number of photons absorbed inside the dot. The theory developed determines the dependence of localization length on dot and microwave parameters showing that the microwave power can switch the dot between metallic and insulating regimes.

In [185] photon drag current in monolayer graphene with degenerate electron gas is studied under interband excitation near the threshold of fundamental transitions. Two main mechanisms generate an emergence of electron current. Non-resonant drag effect (NDE) results from direct transfer of in-plane photon momentum $\mathbf{q}$ to electron and dependence of matrix elements of transitions on $\mathbf{q}$. Resonant drag effect (RDE) originates from $\mathbf{q}$-dependent selection of transitions due to a sharp form of the Fermi distribution in energy. The drag current essentially depends on the polarization of radiation and, in general, is not parallel to $\mathbf{q}$. The perpendicular current component appears if the in-plain electric field is tilted towards $\mathbf{q}$. The RDE has no smallness connected with q and exists in a narrow region of photon frequency ω: $|\hbar\omega - 2\epsilon_F| < \hbar sq$, where s is the electron velocity.

In [194], using extensive Monte Carlo simulations, we study numerically and analytically a photogalvanic effect, or ratchet, of directed electron transport induced by a microwave radiation on a semidisk Galton board of antidots in graphene. A comparison between usual two-dimensional electron gas (2DEG) and electrons in graphene shows that ratchet currents are comparable at very low temperatures. However, a large mean free path in graphene should allow to have a strong ratchet transport at room temperatures. Also in graphene the ratchet transport emerges even for unpolarized radiation. These properties open promising possibilities for room temperature graphene based sensitive photogalvanic detectors of microwave and terahertz radiation. The effects of interactions and magnetic field on ratchet transport are analyzed in [210].

Ratchet transport in SiGe 2DEG has been observed by Portal group [Appl. Phys. Lett. v.98, p.193505 (2011)].

4.3. Quantum synchronization

The synchronization discovered by Ch.Huygens in 1665 is a universal nonlinear phenomenon which has abundant manifestations in science, nature, engineering and social life as it is described in the book of A.S.Pikovsky et al. "Synchronization: A Universal Concept in Nonlinear Sciences", Cambridge Univ. Press, Cambridge (2001). Nowadays this research line is getting more and more importance since technology goes on smaller and smaller scales where an interplay of dissipative and quantum effects becomes dominant. A typical example is given by small size JJs. Here dissipative effects are always present even if in certain cases skillful manipulations allow to realize long term coherent Rabi oscillations. In [156], using the methods of quantum trajectories we study numerically the phenomenon of quantum synchronization in a quantum dissipative system with periodic driving. Our results show that at small values of Planck constant $\hbar$ the classical devil's staircase remains robust with respect to quantum fluctuations while at large $\hbar$ values synchronization plateaus are destroyed. Quantum synchronization in our model has close similarities with Shapiro steps in Josephson junctions and it can be also realized in experiments with cold atoms (see recent M.Sadgrove et al Phys. Rev. Lett. v.99, p.043002 (2007)).

It is interesting to note that at weak dissipation a dissipative chaotic dynamics may lead to an explosion of quantum wave packet. This effect is discussed in [154] where by the quantum trajectories approach we study the quantum dynamics of a dissipative chaotic system described by the Zaslavsky map. For strong dissipation the quantum wave function in the phase space collapses onto a compact packet which follows classical chaotic dynamics and whose area is proportional to the Planck constant. At weak dissipation the exponential instability of quantum dynamics on the Ehrenfest time scale dominates and leads to wave packet explosion. The transition from collapse to explosion takes place when the dissipation time scale exceeds the Ehrenfest time. For integrable nonlinear dynamics the explosion practically disappears leaving place to collapse.

In [166] we study numerically the behavior of qubit coupled to a quantum dissipative driven oscillator (resonator). Above a critical coupling strength the qubit rotations become synchronized with the oscillator phase. In the synchronized regime, at certain parameters, the qubit exhibits tunneling between two orientations with a macroscopic change of number of photons in the resonator. The life times in these metastable states can be enormously large. The synchronization leads to a drastic change of qubit radiation spectrum with appearance of narrow lines corresponding to recently observed single artificial-atom lasing [O. Astafiev *et al.* Nature **449**, 588 (2007)].

In [178] using method of quantum trajectories we study the behavior of two identical or different superconducting qubits coupled to a quantum dissipative driven resonator. Above a critical coupling strength the qubit rotations become synchronized with the driving field phase and their evolution becomes entangled even if two qubits may significantly differ from one another. Such entangled qubits can radiate entangled photons that opens new opportunities for entangled wireless communication in a microwave range.

4.4. Wigner crystal in a periodic potential

In [159] we study analytically and numerically the properties of one-dimensional chain of cold ions placed in a periodic potential of optical lattice and global harmonic potential of a trap. In close similarity with the Frenkel-Kontorova model (see [38,41,128,136]), a transition from sliding to pinned phase takes place with the increase of the optical lattice potential for the density of ions incommensurate with the lattice period. Quantum fluctuations lead to a quantum phase transition and melting of pinned instanton glass phase at large values of dimensional Planck constant. The obtained results describe the properties of a Wigner crystal placed in a periodic potential.

In [196,203] we study the properties of a Wigner crystal in snaked nanochannels and show that they are characterized by a conducting sliding phase at low charge densities and an insulating pinned phase above a critical charge density. The transition between these phases has a devil's staircase structure typical for the Aubry transition in dynamical maps and the Frenkel-Kontorova model. We discuss the implications of this phenomenon for charge density waves in quasi-one-dimensional organic conductors and for supercapacitors in nanopore materials.

In [219] we study numerically the thermoelectricity of the classical Wigner crystal placed in a periodic potential and being in contact with a thermal bath modeled by the Langevin dynamics. At low temperatures the system has sliding and pinned phases with the Aubry transition between them. We show that in the Aubry pinned phase the dimensionless Seebeck coefficient can reach very high values of several hundreds. At the same time the charge and thermal conductivity of crystal drop significantly inside this phase. Still we find that the largest values of ZT factor are reached in the Aubry phase even if for the studied parameter range we obtain $ZT < 2$. We argue that this system provides an optimal regime for reaching high ZT factors and realistic modeling of thermoelecriticy. Possible experimental realizations of this model are discussed.

4.5. Synchnonization, zero-resistance states and rotating Wigner crystal

The discovery of microwave-induced resistance oscillations and of striking zero-resistance states of a 2DEG in a magnetic field (see R.Mani et al. Nature v.420, p.646 (2002) and M.A.Zudov et al. Phys. Rev. Lett. v.90, p.046807 (2003)) attracted a great interest of the community. A variety of theoretical explanations has been pushed forward to explain the appearance of ZRS. These approaches provide certain MIRO which at large microwave power even produce a current inversion. However, these theories do not give zero resistance, and it is usually argued that ZRS are created as a result of some additional instabilities which mysteriously compensate currents to zero. Hence, a physical origin of ZRS still remains a puzzling problem.

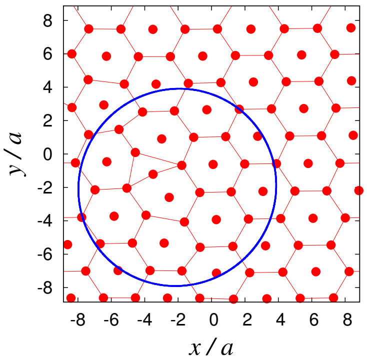

Fig.7 (see text)

In [163], we show that rotational angles of electrons moving in two dimensions (2D) in a perpendicular magnetic field can be synchronized by an external microwave field which frequency is close to the Larmor frequency. The synchronization eliminates collisions between electrons and thus creates a regime with zero diffusion corresponding to the zero-resistance states observed in experiments with high mobility 2D electron gas (2DEG). For long range Coulomb interactions electrons form a rotating hexagonal Wigner crystal. An instant image of the rotating Wigner crystal formed by $N = 100$ electrons (points) in a periodic cell is shown in Fig.7; the circle shows an orbit of one electron, lines are drawn to adapt an eye showing a hexagonal crystal with a defect.

Possible relevance of this effect for planetary rings is discussed. Namely, we make a conjecture that the mechanism described in [163] may be responsible for enormously long life time ($\sim 10^{12}$ rotations) and sharp edges of planetary rings (e.g. $\sim 10m$ for Saturn) (see e.g. A.M. Fridman, and N.N. Gorkavyi, *Physics of Planetary Rings*, Springer, Berlin (1999)). Indeed, a temperature there is very low and in the rotational frame the 2D dynamics of particles is similar to motion of electrons in a magnetic field. Hence, moons inside a ring and near to a resonance may produce synchronization and diffusion suppression with emergence of ZRS in space.

4.6. Fractal Weyl law for quantum fractal eigenstates

The properties of the resonant Gamow states are studied numerically in the semiclassical limit for the quantum Chirikov standard map with absorption. It is shown that the number of such states is described by the fractal Weyl law and their Husimi distributions closely follow the strange repeller set formed by classical orbits nonescaping in future times [165]. For large matrices the distribution of escape rates converges to a fixed shape profile characterized by a spectral gap related to the classical escape rate.

In [184] using the Ulan method we show that the fractal Weyl law is valid for the Perron-Frobenius operators of dynamical maps with dissipation or absorption. The application of this result to the Linux Kernel network [190] generated by procedure calls in the code shows that the fractal dimension of Linux is approximately 1.3 and is also described by the fractal Weyl law.

4.7. Loschmidt cooling and time revesal of Bose-Einstein condensates

In [167] we propose an experimental scheme which allows to realize approximate time reversal of matter waves for ultracold atoms in the regime of quantum chaos. We show that a significant fraction of the atoms return back to their original state, being at the same time cooled down by several orders of magnitude. We give a theoretical description of this effect supported by extensive numerical simulations. The proposed scheme can be implemented with existing experimental setups.

In [169] using Gross-Pitaevskii equation, we study the time reversibility of Bose-Einstein condensates (BEC) in kicked optical lattices, showing that inside the regime of quantum chaos the dynamics can be inverted from explosion to collapse. The accuracy of time reversal decreases with the increase of atom interactions inside BEC, until it is completely lost. Surprisingly, quantum chaos helps to restore time reversibility. These predictions can be tested with existing experimental setups. A coupling between BEC and a qubit is analyzed in [174].

Effects of interactions between BEC and qubit are analyzed in [174].

Following our proposal [167,169], the time reversal of atomic matter waves in kicked optical lattices in the regime of quantum chaos has been experimentally demonstrated by the group of Hoogerland at Auckland [Phys. Rev. E v.83, p.046218 (2011)].

4.8. Destruction of Anderson localization by a weak nonlinearity and dynamical thermalization

In [164] we study numerically a spreading of an initially localized wave packet in a one-dimensional discrete nonlinear Schrödinger lattice with disorder. We demonstrate that above a certain critical strength of nonlinearity the Anderson localization is destroyed and an unlimited subdiffusive spreading of the field along the lattice occurs. The second moment grows with time $\propto t^{\alpha}$, with the exponent α being in the range $0.3 - 0.4$. For small nonlinearities the distribution remains localized in a way similar to the linear case.

In [170] we study numerically the effects of nonlinearity on the Anderson localization in lattices with disorder in one and two dimensions. The obtained results show that at moderate strength of nonlinearity an unlimited spreading over the lattice in time takes place with an algebraic growth of number of populated sites $\Delta n \propto t^{\nu}$. The numerical values of ν are found to be approximately $0.15 - 0.2$ and 0.25 for the dimension $d = 1$ and 2 respectively being in a satisfactory agreement with the theoretical value $d/(3d+2)$. The localization is preserved below a certain critical value of nonlinearity. We also discuss the properties of the fidelity decay induced by a perturbation of nonlinear field.

In [205] the conditions for emergence of Kolmogorov turbulence, and related weak wave turbulence, in finite size systems are analyzed by analytical methods and numerical simulations of simple models. The analogy between Kolmogorov energy flow from large to small spacial scales and conductivity in disordered solid state systems is proposed. It is argued that the Anderson localization can stop such an energy flow. The effects of nonlinear wave interactions on such a localization are analyzed. The results obtained for finite size system models show the existence of an effective chaos border between the Kolmogorov-Arnold-Moser (KAM) integrability at weak nonlinearity, when energy does not flow to small scales, and developed chaos regime emerging above this border with the Kolmogorov turbulent energy flow from large to small scales.

The research along these lines is continued in [175,176,197].

In [218] we study numerically time evolution in classical lattices with weak or moderate nonlinearity which leads to interactions between linear modes. Our results show that in a certain strength range a moderate nonlinearity generates a dynamical thermalization process which drives the system to the quantum Gibbs distribution of probabilities, or average oscillation amplitudes. The effective dynamical temperature of the lattice varies from large positive to large negative values depending on energy of initially excited modes. This quantum Gibbs distribution is drastically different from usually expected energy equipartition over linear modes corresponding to a regime of classical thermalization. Possible experimental observations of this dynamical thermalization are discussed for cold atoms in optical lattices, nonlinear photonic lattices and optical fiber arrays.

In [224] we study numerically the frequency modulated kicked nonlinear rotator with effective dimension $d = 1, 2, 3, 4$. We follow the time evolution of the model up to 10^9 kicks and determine the exponent α of subdiffusive spreading which changes from 0.35 to 0.5 when the dimension changes from $d = 1$ to 4. All results are obtained in a regime of relatively strong Anderson localization well below the Anderson transition point existing for $d = 3, 4$. We explain that this variation of the exponent is different from the usual $d-$dimensional Anderson models with local nonlinearity where α drops with increasing d. We also argue that the renormalization arguments proposed by *Cherroret N et al. arXiv:1401.1038* are not valid for this model and the Anderson model with local nonlinearity in $d = 3$.

In [232] we study numerically the wavefunction evolution of a Bose-Einstein condensate in a Bunimovich stadium billiard being governed by the Gross-Pitaevskii equation. We show that for a moderate nonlinearity, above a certain threshold, there is emergence of dynamical thermalization which leads to the Bose-Einstein probability distribution over the linear eigenmodes of the stadium. This distribution is drastically different from the energy equipartition over oscillator degrees of freedom which would lead to the ultraviolet catastrophe. We argue that this interesting phenomenon can be studied in cold atom experiments.

This line is continued in [241] for BEC in the Sinai oscillator trap. We study numerically the evolution of Bose-Einstein condensate in the Sinai oscillator trap described by the Gross-Pitaevskii equation in two dimensions. In the absence of interactions this trap mimics the properties of Sinai billiards where the classical dynamics is chaotic and the quantum evolution is described by generic properties of quantum chaos and random matrix theory. We show that, above a certain border, the nonlinear interactions between atoms lead to the emergence of dynamical thermalization which generates the statistical Bose-Einstein distribution over eigenmodes of the system without interactions. Below the thermalization border the evolution remains quasi-integrable. Such a Sinai oscillator trap, formed by the oscillator potential and a repulsive disk located in the vicinity of the center, had been already realized in first experiments with the Bose-Einstein condensate formation by Ketterle group in 1995 and we argue that it can form a convenient test bed for experimental investigations of dynamical of thermalization. Possible links and implications for Kolmogorov turbulence in absence of noise are also discussed.

In [237] we numerically study a Bose-Hubbard ring of finite size with disorder containing a finite number of bosons that are subject to an on-site two-body interaction. Our results show that moderate interactions induce dynamical thermalization in this isolated system. In this regime the individual many-body eigenstates are well described by the standard thermal Bose-Einstein distribution for well-defined values of the temperature and the chemical potential which depend on the eigenstate under consideration. We show that the dynamical thermalization conjecture works well both at positive and negative temperatures. The relations to quantum chaos, quantum ergodicity and to the Åberg criterion are also discussed.

4.9. Synchronization mechanism of sharp edges in rings of Saturn

In [173] we propose a new mechanism which explains the existence of enormously sharp edges in the rings of Saturn. This mechanism is based on the synchronization phenomenon due to which the epicycle rotational phases of particles in the ring, under certain conditions, become synchronized with the phase of external satellite, e.g. with the phase of Mimas in the case of the outer B ring edge. This synchronization eliminates collisions between particles and suppress the diffusion induced by collisions by orders of magnitude. The minimum of the diffusion is reached at the center of the synchronization regime corresponding to the ratio 2:1 between the orbital frequency at the edge of B ring and the orbital frequency of Mimas. The synchronization theory gives the sharpness of the edge in few tens of meters that is in agreement with available observations. These results are highlighted by Lenta.ru and Gazeta.ru.

4.10. Microwave stabilization of edge transport and zero-resistance states

In [179] we develop a new theory for ZRS experiment of Mani-Zudov. It explains the main features of the experiment. Edge channels play a crucial role for electron transport in two dimensional electron gas under magnetic field. It is usually thought that ballistic transport along edges occurs only in the quantum regime with low filling factors. We show that a microwave field can stabilize edge trajectories even in the semiclassical regime leading to a vanishing longitudinal resistance. This mechanism gives a clear physical interpretation for observed zero-resistance states.

Recent experiments of Kono group at RIKEN, Tokyo with electrons on a surface of liquid helium give first confirms of the theoretical predictions [179] of microwave stabilization of edge transport [arXiv:1101.5667 (2011)].

In [214] we develop a synchronization theory for the dynamics of two dimensional electrons under a perpendicular magnetic field and microwave irradiation showing that dissipative effects can lead to the synchronization of the cyclotron phase with the driving microwave phase at certain resonant ratios between microwave and cyclotron frequencies. We demonstrate two important consequences of this effect: the stabilization of skipping orbits along the sample edges and the trapping of the electrons on localized short ranged impurities. We then discuss how these effects influence the transport properties of ultra high mobility two dimensional electron gas and propose mechanisms by which they lead to microwave induced zero resistance states. Our theoretical analysis shows that the classical electron dynamics along edge and around circular disk impurities is well described by the Chirikov standard map providing an unified formalism for those two rather different cases. We argue that this work will provide the foundations for a full quantum synchronization theory of zero-resistance states for which a fully microscopic detailed theory still should be developed.

4.11. Google Matrix of directed networks

In [177,181] we study the eigenvalue and eigenvector properties of the Google matrix. We study the localization properties of eigenvectors of the Google matrix, generated both from the World Wide Web and from the Albert-Barabasi model of networks [177]. We establish the emergence of a delocalization phase for the PageRank vector when network parameters are changed. In the phase of localized PageRank, a delocalization takes place in the complex plane of eigenvalues of the matrix, leading to delocalized relaxation modes. We argue that the efficiency of information retrieval by Google-type search is strongly affected in the phase of delocalized PageRank.

In [181] we study the properties of the Google matrix generated by a coarse-grained Perron-Frobenius operator of the Chirikov typical map [180] with dissipation. The finite size matrix approximant of this operator is constructed by the Ulam method. This method applied to the simple dynamical model creates the directed Ulam networks with approximate scale-free scaling and characteristics being rather similar to those of the World Wide Web. The simple dynamical attractors play here the role of popular web sites with a strong concentration of PageRank. A variation of the Google parameter α or other parameters of the dynamical map can drive the PageRank of the Google matrix to a delocalized phase with a strange attractor where the Google search becomes inefficient. The propeties of Ulam networks generated by dynamical maps are analyzed for the Chirikov standard map [188], the Arnold cat map [201].

The research on the Google matrix is continued extentively with the related publications in [183,184,186,187,187,190,191] and pllications to the dissipative and symplectiv maps, Perron-Frobenius operators, neironal networks in brain, procedure call network of Linuc kernel, network of hyperlinks of Wikipedia articles in English. Two-diemnsial ranking method is applied to Wikipedia that allowed to rank reliably counties, universities, personalities, physicists and Nobel laureates in physics [191]. This work is highlighted by the web site Atelier.fr.

This research line is continued in [193,198,199,200]. Universal properties of emergence of PageRank are established in [199].

In [198] Using the United Nations Commodity Trade Statistics Database we construct the Google matrix of the world trade network and analyze its properties for various trade commodities for all countries and all available years from 1962 to 2009. The trade flows on this network are classified with the help of PageRank and CheiRank algorithms developed for the World Wide Web and other large scale directed networks. For the world trade this ranking treats all countries on equal democratic grounds independent of country richness. Still this method puts at the top a group of industrially developed countries for trade in *all commodities*. Our study establishes the existence of two solid state like domains of rich and poor countries which remain stable in time, while the majority of countries are shown to be in a gas like phase with strong rank fluctuations. A simple random matrix model provides a good description of statistical distribution of countries in two-dimensional rank plane. The comparison with usual ranking by export and import highlights new features and possibilities of our approach.

In [204] the world trade is analyzed in the frame of eclogical systems approach. Ecological systems have a high level of complexity combined with stability and rich biodiversity. Recently, the analysis of their properties and evolution has been pushed forward on a basis of concept of mutualistic networks that provides a detailed understanding of their features being linked to a high nestedness of these networks. It was shown that the nestedness architecture of mutualistic networks of plants and their pollinators minimizes competition and increases biodiversity. Here, using the United Nations COMTRADE database for years 1962 - 2009, we show that a similar ecological analysis gives a valuable description of the world trade. In fact the countries and trade products are analogous to plants and pollinators, and the whole trade network is characterized by a low nestedness temperature which is typical for the ecological networks. This approach provides new mutualistic features of the world trade highlighting new significance of countries and trade products for the world trade.

In [200] we study the statistical properties of various directed networks using ranking of their nodes based on the dominant vectors of the Google matrix known as PageRank and CheiRank. On average PageRank orders nodes proportionally to a number of ingoing links, while CheiRank orders nodes proportionally to a number of outgoing links. In this way the ranking of nodes becomes two-dimensional that paves the way for development of two-dimensional search engines of new type. Information flow properties on PageRank-CheiRank plane are analyzed for networks of British, French and Italian Universities, Wikipedia, Linux Kernel, gene regulation and other networks. Methods of spam links control are also analyzed.

The Google matrix analysis described above is also applied [208] to the entier Twitter network of 2008 with 41 millions of users. We construct the Google matrix of the entire Twitter network, dated by July 2009, and analyze its spectrum and eigenstate properties including the PageRank and CheiRank vectors and 2DRanking of all nodes. Our studies show much stronger inter-connectivity between top PageRank nodes for the Twitter network compared to the networks of Wikipedia and British Universities studied previously. Our analysis allows to locate the top Twitter users which control the information flow on the network. We argue that this small fraction of the whole number of users, which can be viewed as the social network elite, plays the dominant role in the process of opinion formation on the network.

The PageRank of integers is analyzed in [207].

The PageRank model of opinion formation on social networks is proposed in [206]. We propose the PageRank model of opinion formation and investigate its rich properties on real directed networks of Universities of Cambridge and Oxford, LiveJournal and Twitter. In this model the opinion formation of linked electors is weighted with their PageRank probability. We find that the society elite, corresponding to the top PageRank nodes, can impose its opinion to a significant fraction of the society. However, for a homogeneous distribution of two opinions there exists a bistability range of opinions which depends on a conformist parameter characterizing the opinion formation. We find that LiveJournal and Twitter networks have a stronger tendency to a totalitar opinion formation. We also analyze the Sznajd model generalized for scale-free networks with the weighted PageRank vote of electors. These results are extended in [229].

The Google matrix of entier Twitter 2009 is analyzed in [208]. For Wikipedia the spectrum and eigenstate properties of Google matrix are studied in [211]. The Google matrix from various DNA sequencies is analyzed in [212]. Time evolution of Wikipedia network is considered in [215], network of interactions of cultures is constructed from rank positions of persons in 9 language editions of Wikipedia [217].

In [220] we study the statistical properties of spectrum and eigenstates of the Google matrix of the citation network of Physical Review for the period 1893 - 2009. The main fraction of complex eigenvalues with largest modulus is determined numerically by different methods based on high precision computations with up to $p = 16384$ binary digits that allows to resolve hard numerical problems for small eigenvalues. The nearly nilpotent matrix structure allows to obtain a semi-analytical computation of eigenvalues. We find that the spectrum is characterized by the fractal Weyl law with a fractal dimension $d_f \approx 1$. It is found that the majority of eigenvectors are located in a localized phase. The statistical distribution of articles in the PageRank-CheiRank plane is established providing a better understanding of information flows on the network. The concept of

ImpactRank is proposed to determine an influence domain of a given article. We also discuss the properties of random matrix models of Perron-Frobenius operators.

We also study the structural properties of the neural network of the C.elegans (worm) from a directed graph point of view [221]. The Google matrix analysis is used to characterize the neuron connectivity structure and node classifications are discussed and compared with physiological properties of the cells. Our results are obtained by a proper definition of neural directed network and subsequent eigenvector analysis which recovers some results of previous studies. Our analysis highlights particular sets of important neurons constituting the core of the neural system. The applications of PageRank, CheiRank and ImpactRank to characterization of interdependency of neurons are discussed.

In [222] we use the methods of quantum chaos and Random Matrix Theory for analysis of statistical fluctuations of PageRank probabilities in directed networks. In this approach the effective energy levels are given by a logarithm of PageRank probability at a given node. After the standard energy level unfolding procedure we establish that the nearest spacing distribution of PageRank probabilities is described by the Poisson law typical for integrable quantum systems. Our studies are done for the Twitter network and three networks of Wikipedia editions in English, French and German. We argue that due to absence of level repulsion the PageRank order of nearby nodes can be easily interchanged. The obtained Poisson law implies that the nearby PageRank probabilities fluctuate as random independent variables.

In [225] we apply two methods, Markov chains and Google matrix, for the analysis of the hyperlink networks of 24 Wikipedia language editions, and rank all their articles by PageRank, 2DRank, and CheiRank algorithms. Using automatic extraction of people names we obtain the top 100 historical figures for each edition and for each algorithm. We investigate their spatial, temporal, and gender distributions in dependence of their cultural origins. Our study demonstrates not only the existence of skewness with local figures, mainly recognized only in their own culture, but also the existence of global historical figures appearing in a large number of editions. By determining the birth time and place of these persons, we perform an analysis of the evolution of such figures through 35 centuries of human history for each language, thus recovering interactions and entanglement of cultures over time. We also obtain the distributions of historical figures over world countries, highlighting geographical aspects of cross-cultural links. Considering historical figures who appear in multiple editions as interactions between cultures, we construct a network of cultures and identify the most influential cultures according to such network. This work has been highlighted by press of about 20 countries including “The Guardian”, “The Independent”, “The Washington Post”, France24 etc. (see also “Top 100 historical figures of Wikipedia” in [21] of Sec.2).

The review about Google matrix properties [226] is accepted to Rev. Mod. Phys.

In [227,230] the multi-product network of the world trade with 61 products (UN COMTRADE) and the world economic activities with 37 sectors (World Trade Organization Geneve) are analyzed by the Google matrix methods.

In [228] we introduce a number of random matrix models describing the Google matrix G of directed networks. The properties of their spectra and eigenstates are analyzed by numerical matrix diagonalization. We show that for certain models it is possible to have an algebraic decay of PageRank vector with the exponent similar to real directed networks. At the same time the spectrum has no spectral gap and a broad distribution of eigenvalues in the complex plain. The eigenstates of G are characterized by the Anderson transition from localized to delocalized states and a mobility edge curve in the complex plane of eigenvalues.

In [231] we investigate the statistical properties of votes of customers for spots of France collected by the startup company NOMAO. The frequencies of votes per spot and per customer are characterized by a power law distributions which remain stable on a time scale of a decade when the number of votes is varied by almost two orders of magnitude. Using the computer science methods we explore the spectrum and the eigenvalues of a matrix containing user ratings to geolocalized items. Eigenvalues nicely map to large towns and regions but show certain level of instability as we modify the interpretation of the underlying matrix. We evaluate imputation strategies that provide improved prediction performance by reaching geographically smooth eigenvectors. We point on possible links between distribution of votes and the phenomenon of self-organized criticality.

In [238] we use the directed networks between articles of 24 Wikipedia language editions for producing the Wikipedia Ranking of World Universities (WRWU) using PageRank, 2DRank and CheiRank algorithms. This approach allows to incorporate various cultural views on world universities using the mathematical statistical analysis independent of cultural preferences. The Wikipedia ranking of top 100 universities provides about 60 percent overlap with the Shanghai university ranking demonstrating the reliable features of this approach. At the same time WRWU incorporates all knowledge accumulated at 24 Wikipedia editions giving stronger highlights for historically important universities leading to a different estimation of efficiency of world countries in university education. The historical development of university ranking is analyzed during ten centuries of their history. The WRWU results have been highlighted by *Le Monde, MIT Tech Rev* and other press of about 20 countries (see http://perso.utinam.cnrs.fr/ lages/datasets/WRWU/).

The concept of reduced Google matrix is introduced in [236] that allows to analyze hidden links between selected subsets of nodes of large firected network.

4.12. Capture of dark matter by the Solar System

In [182] ee study the capture of galactic dark matter by the Solar System. The effect is due to the gravitational three-body interaction between the Sun, one of the planets, and a dark matter particle. The analytical estimate for the capture cross-section is derived and the upper and lower bounds for the total mass of the captured dark matter particles are found. The estimates for their density are less reliable. The most optimistic of them give an enhancement of dark matter density by about three orders of magnitudes compared to its value in our Galaxy. However, even this optimistic value remains below the best present observational upper limits by about two orders of magnitude.

In [209] we study the capture of galactic dark matter particles in the Solar System produced by rotation of Jupiter. It is shown that the capture cross-section is much larger than the area of Jupiter orbit being inversely diverging at small particle energy. We show that the dynamics of captured particles is chaotic and is well described by a simple symplectic dark map. This dark map description allows to simulate the scattering and dynamics of 10^{14} dark matter particles during the life time of the Solar System and to determine dark matter density profile as a function of distance from the Sun. The mass of captured dark matter in the radius of Neptune orbit is estimated to be $2 \cdot 10^{15} g$. The radial density of captured dark matter is found to be approximately constant behind Jupiter orbit being similar to the density profile found in galaxies.

In [223] using symplectic map description, we study the capture of galactic dark matter particles (DMP) in two-body and few-body galaxies. This approach allows to model scattering of 10^{16} DMP following time evolution of captured particle on about 10^9 orbital periods. We obtain DMP density distribution inside such galaxies and determine the enhancement factor of their density in galactic center compared to its inter-galactic value as a function of mass ratio of galactic bodies and a ratio of body velocity to velocity of galactic DMP wind. We find that the enhancement factor can be of the order of ten thousands.

In [235] we study the dynamical chaos and integrable motion in the planar circular restricted three-body problem and determine the fractal dimension of the spiral strange repeller set of non-escaping orbits at different values of mass ratio of binary bodies and of Jacobi integral of motion. We find that the spiral fractal structure of the Poincaré section leads to a spiral density distribution of particles remaining in the system. We also show that the initial exponential drop of survival probability with time is followed by the algebraic decay related to the universal algebraic statistics of Poincaré recurrences in generic symplectic maps.

4.13. Poincaré recurrences of DNA sequences and molecule

In [202] we analyze the statistical properties of Poincaré recurrences of Homo sapiens, mammalian and other DNA sequences taken from Ensembl Genome data base with up to fifteen billions base pairs. We show that the probability of Poincaré recurrences decays in an algebraic way with the Poincaré exponent $\beta \approx 4$ even if oscillatory dependence is well pronounced. The correlations between recurrences decay with an exponent $\nu \approx 0.6$ that leads to an anomalous super-diffusive walk. However, for Homo sapiens sequences, with the largest available statistics, the diffusion coefficient converges to a finite value on distances larger than million base pairs. We argue that the approach based on Poncaré recurrences determines new proximity features between different species and shed a new light on their evolution history.

Also in a different line the algebraic statistics of Poincaré recurences in a dynamics of DNA molecule is established in [233].

4.14. Two interacting particles effect again

In [234,236,240[it was shown that delocalized states appear for two interacting particles in the Harper model (incommensurate potential) in 1d and 2d.

4.15. Results during Sept 2016 till Sept 2017

These results are reported in Refs.[242-247].

The method of the reduced Google matrix, invented in [239]. is applied to the Wikipedia networks determining hidden relations between political leades of different countries [242], and geopolitical interactions between world countries [243]. This approach is also used to establish hidden interactions in the cancer protein-protein interaction networks [246].

Small bodies of the solar system, like asteroids, trans-Neptunian objects, cometary nuclei, and planetary satellites, with diameters smaller than 1000 km usually have irregular shapes, often resembling dumb-bells or contact binaries. The spinning of such a gravitating dumb-bell creates around it a zone of chaotic orbits. We determine its extent analytically and numerically. We find that the chaotic zone swells significantly if the rotation rate is decreased; in particular, the zone swells more than twice if the rotation rate is decreased 10 times with respect to the centrifugal breakup threshold. We illustrate the properties of the chaotic orbital zones in examples of the global orbital dynamics about asteroid 243 Ida (which has a moon, Dactyl, orbiting near the edge of the chaotic zone) and asteroid 25143 Itokawa. These results are reported in [244].

In [245] We study numerically a model of quantum dot with interacting fermions. At strong interactions with small conductance the model is reduced to the Sachdev-Ye-Kitaev black-hole model while at weak interactions and large conductance it describes a Landau-Fermi liquid in a regime of quantum chaos. We show that above the Aberg threshold for interactions there is an onset of dynamical themalization with the Fermi-Dirac distri bution describing the eigenstates of an isolated dot. At strong interactions in the isolated black-hole regime there is also the onset of dynamical thermalization with the entropy described by the quantum Gibbs distribution. This dynamical thermalization takes place in an isolated system without any contact with a thermostat. We discuss the possible realization of these regimes with quantum dots of 2D electrons and cold ions in optical lattices.

In [247] we study the dynamics of a Bose-Einstein condensate in a Sinai-oscillator trap under a monochromatic driving force. Such a trap is formed by a harmonic potential and a repulsive disk located in the center vicinity corresponding to the first experiments of condensate formation by Ketterle group in 1995. We argue that the external driving allows to model the regime of weak wave turbulence with the Kolmogorov energy flow from low to high energies. We show that in a certain regime of weak driving and weak nonlinearity such a turbulent energy flow is defeated by the Anderson localization that leads to localization of energy on low energy modes. This is in a drastic contrast to the random phase approximation leading to energy flow to high modes. A critical threshold is determined above which the turbulent flow to high energies becomes possible. We argue that this phenomenon can be studied with ultra cold atoms in magneto-optical traps.

4.16. Results during Sept 2017 till Sept 2019

These results are reported in Refs.[248-272].

The REGOMAX algorithm incented in [239] is applied to various directed networks including Wikipedia networks (painters, worls universities, terror networks, protein-protein interaction networks, infections diseases and cancers, world banks), world trade networks from UN COMTRADE and WTO databases, bitcoin transaction networks and Ulam networks (see [249,252,253,255-258,260,262,265,267-271]). For eaxmple, the influence of gas and petroleum on the trade of EU countries is analyzed with the REGOMAX algorithm applied to UN COMTRADE database [267].

In [250] we investigate the dynamics of a two-dimensional electron gas (2DEG) under circular polarized microwave radiation in the presence of dilute localized impurities. Inspired by recent developments on Floquet topological insulators we obtain the Floquet wave functions of this system which allow us to predict the microwave absorption and charge density responses of the electron gas; we demonstrate how these properties can be understood from the underlying semiclassical dynamics even for impurities with a size of around a magnetic length. The charge density response takes the form of a rotating charge density vortex around the impurity that can lead to a significant renormalization of the external microwave field which becomes strongly inhomogeneous on the scale of a cyclotron radius around the impurity. We show that this inhomogeneity can suppress the circular polarization dependence which is theoretically expected for microwave induced resistance oscillations but which was not observed in experiments on semiconducting 2DEGs. Our explanation for this so far unexplained polarization independence has close similarities with the Azbel'-Kaner effect in metals where the interaction length between the microwave field and conduction electrons is much smaller than the cyclotron radius due to skin effect generating harmonics of the cyclotron resonance.

The properties of Wigner crystal in a periodic potential are investigated in [261,263,266]. It is shown that this system has remarkable thermoelectric properties with the figue of merit $ZT \approx 8$ [263]. In it is proposed to modify the Cirac-Zoller proposal of quantum computer with cold ions in a global oscillator trap potential by adding a periodic potential with an incommensurate average ratio of number of ions to number of periods being order of unity. With the increase of the periodic potential amplitude the system enters in the Aubry pinned phase characterized by quasi-frozen positions of ions and a gap of their first phonon excitations becomes independent of number of ions. This gives hopes that this quantum computer will be really scalable. It is argued that the usual single- and two-qubit gates can be realized between the nearby ions in the Aubry phase. The possibilities of experimental realizations of a periodic potential with microtrap arrays or optical lattices are discussed. It is pointed that the disorder of distances between microtraps with one ion per trap can lead to the Anderson localization of phonon modes with interesting possibilities for ion quantum computing.

The properties of dynamical thermalization induced by interactions in finite isolated many-body systems are studies in [254,264,272]. Thus in [272] we study numerically the problem of dynamical thermalization of interacting cold fermionic atoms placed in an isolated Sinai oscillator trap. This system is characterized by a quantum chaos regime for one-particle dynamics. We show that, for a many-body system of cold atoms, the interactions, with a strength above a certain quantum chaos border given by the Aberg criterion, lead to the FermiDirac distribution and relaxation of many-body initial states to the thermalized state in the absence of any contact with a thermostate. We discuss the properties of this dynamical thermalization and its links with the LoschmidtBoltzmann dispute.

5. Links to experiments

1) The predictions of emergence of dynamical localization for hydgrogen and Rydberg atoms in a microwave field [15,17,26,33] were experimentally confirmed in the experiments of P.Koch *et al.* (PRL v.61, p.2011 (1988)), J.Bayfield *et al.* (PRL v.63, p.364 (1989)) and H.Walther *et al.* (PRL v.67, p.2435 (1991)).

2) Dynamical localization in the kicked rotator predicted theoretically in [4,20,24] was observed in experiments with kicked cold atoms by M.Raizen *et al.* in PRL v.75, p.4598 (1995). Quantum resonance predicted in [1] was also observed there.

3) 3D Anderson transition in the kicked rotator with two incommensurate frequencies has been predicted and studied in [37,76,86] was experimentally observed with cold atoms by J.-C.Garreau (PRL v.101, p.255702 (2008); v.105, p.090601 (2010)). In October 2005 I proposed to J.-C.Garreau to perform such an experiment giving to him my preliminary numerical simulations showing that the transition is reachable at his experimental conditions (see arXiv:1102.4450).

4) Ballistic channels for electrons in a periodic magnetic field predicted theoretically in [66] have been experimentally detected by von Klitzing *et al.* (PRL v.74, p.3013 (1995)).

5) It is argued that the phase of bi-particle localized states numerically found in [109,123,126,195] explains a specific superconductor-insulator transition observed by V.Gantmakher *et al.* (JETP Lett. v.68, p.363 (1998)).

6) Dynamical localization and Wigner ergodicity in rough billiards predicted in [89,92] were observed in microwave rough billiards by L.Sirko *et al.* (Phys. Lett. A v.266, p.331 (2000) and PRE 63, 046208 (2001). Dynamical localization in rough billiards predicted in [89] was observed in microdisk lasers by H.Cao *et al.* (PNAS v.101, p.10498 (2004) and Optics Express v.13, p.5641 (2005)).

7) The quantum algorithm for the quantum saw-tooth map proposed and studied in [117,129,135] was realized with a 3-qubit NMR based quantum computer by D.Cory *et al.* (PRA v.74, p.062317 (2006)).

8) Dynamical ratchet on a semidisk Galton board proposed and analysed in [145,149,161,171] was realized in 2D electron gas by J.-C.Portal *et al.* (PRB v.78, p.045431 (2008); Nanotechnology v.22, p.245401 (2011); APL v.98, p.193505 (2011)).

9) Magnetization of ballistic quantum dots induced by a linear-polarized microwave field predicted in [160] was observed by A.Chepelianskii and H.Bouchiat (PRL v.102, p.086810 (2009)) in a 2D electron billiard with a microwave field.

10) Zero-resistance states experimentally observed for 2D electron gas in a microwave field by R.Mani *et al.* (Nature v.420, 646 (2002)) are theoretically explained in [179]. Similar ZRS effect is observed by D.Konstantinov, A.Chepelianskii and K.Kono for electrons on a surface of liquid helium (arXiv:1101.5667).

11) Loschmidt cooling by time reversal of atomic matter waves proposed in [167,169] is realized with cold atoms by A.Ullah and M.D.Hoogerland (PRE v.83, p.046218 (2011)).

12) The microwave induced stabilization of edge transport in high momility 2DEG, predicted in [179], is observed experimentally by Gusev group at San Paulo (PRB v.89, p.161304(R) (2014))

13) The quantum resonance for kicked rotator explained in [1] is observed in experi-

ments with BEC, cold atoms (PRL v. 96, p.160403 (2006); PRL v.98, p.083004 (2007)) and molecules in kicked laser field (PRL v.115, p.203002 (2015); Phys. Rev. Lett. v.117, p.144104 (2016); Rev. Lett. v.118, p.034101 (2017))

14) The Aubry tranition from sliding to pinned phase for Wigner crystal in a periodic potential, predicted in [159], is observed experimentally with cold ions in optical lattice by Vuletic group at MIT (Nature Mater. v.11, p.915 (2015))

6. Future Perspectives

In the field of quantum information:

The aim of this direction is the investigation of decoherence and error correction in quantum processors solving physical problems for which new and useful results may be achievable using 40–60 qubits. New quantum algorithms will be developed for these problems, which will include complex quantum dynamics, nonlinear classical evolution, electron transport in disordered materials and metal-insulator transitions. A numerical code package will be developed to simulate these new algorithms and to model decoherence and imperfection effects for realistic quantum computers with up to 30 qubits. Using this code package, decoherence time scales and critical thresholds for multi-qubit residual imperfections will be determined. Quantum error-correcting codes will be tested with this package to reduce these decoherence effects in the specific algorithms developed within this project.

Expected results:

- Decoherence time scales for noisy gates and dissipative coupling to the environment
- Universal laws for many-body chaos and fidelity drop induced by static imperfections
- Efficient quantum algorithms for computationally hard physical problems
- Development of a multiple-error correcting jump code
- Numerical code package simulating new algorithms with up to 30 qubits
- Numerical tests of error correcting codes
- Stability bounds for the operability of realistic quantum processors
- Decoherence and imperfections for superconducting qubits

- Synchronization conditions of 1-2 qubits by coupling to a dissipative oscillator

This research program is related to the EU IST-FET project EDIQIP which I am coordinated for EU centers in 2003-2005. The detailed description of the program is given at http://www.quantware.ups-tlse.fr/EDIQIP/ .
Further development continues in the frame of EU IST-FET project EuroSQIP. The detailed description is given at http://mina4-49.mc2.chalmers.se/∼eurosqip/ .

In the field of quantum chaos, transport, interactions and disorder:

It is planned to continue investigations of interaction effects on transport and coherence in systems with disorder including applications to interacting fermions in disordered potential, superconductivity in presence of disorder, properties of the quantum phase transition in the Frenkel-Kontorova model. The new research line on investigation of transport directed by radiation (ratchets) in presence of chaos and dissipation is started. At present it continues in collaboration with experimental groups of J.-C.Portal (Grenoble) and Z.D.Kvon (Novosibirsk) with the support of ANR PNANO projects MICONANO and NANOTERRA. Investigations of the synchronization effects in electron transport and Saturn rings will be continued. The recently proposed theory of microwave stabilization of edge transport explains main features of ZRS experiments of Mani-Zudov, this theory will be refined in future studies. Effects of nonlinearity on Anderson localization will be studied.

In the field of Google Matrix:
Recent results on for the Google matrix [177,181,183,184], [186,187,188,190,191,193], [198,199,200], [201,204,206,207,208] will be extended. The spectral properties of the Google matrix are now studied with the Arnoldi method up to size of 41 millions. The statistical properties of 2Drank will be investigated.

In the field of Astronomy:
The synchronization mechanism of sharp edges of rings of Saturn [173] will be refined. The dynamics and capture of dark matter in the Solar System [182] will be investigated on the basis of symple dynamical maps. Fractals in the Jacobi Hamiltonian of restricted three-body problem will be studied in more detail.

7. International Scientific Activity

7.1. International journals and expertise

In 1992-1996 I was a member of the Editorial Board of "Nonlinearity" publishing by the Institute of Physics Publishing in the United Kingdom.

As the Guest Editor (with Jean Bellissard) I organized the special issues of Annales de l'Institut Henri Poincaré (Phys. Théor. **68** (1998) 378 - 523) and Physica D **131** (1999) N 1-4 (with Guest Editors Bellissard, Bohigas, Casati) dedicated to 70th of Boris Chirikov (see also cond-mat/9903412 which includes unformal conclusion by Peter Koch (Stony Brook) and personal reminiscences of Andy Sessler (President of the American Physical Society)).

From August 2009 I work as Scholarpedia Editor for the Category "Quantum chaos".

For 2011 - 2016 I am a member of Editorial board of Phys. Rev. E.

As a referee I also participate in the work of Nature, Phys. Rev. Lett., Phys. Rev. A,B,E, Europhys. Lett., New J. Phys. In 2008 I was recognized as outstanding referee of American Physical Society.

As an international expert I reviewed proposals for NSF (USA), ESF (EU), DFG (Germany), ANR France, Israel Sci. Foundation. I am also a reviewer for the EU FET Open proposals in 2008-212, ERC EU in 2015.

I am also a member of the commission of specialists at the University P. Sabatier (CS 29) from 1997 till 2008.

7.2. Organization of international conferences

1)I participated in organization of the conference "Random Matrices and Quantum Localization", 29 - 30 January, 1996 Toulouse (with J.Bellissard, E.Bogomolny and O.Bohigas).

2)Jean Bellissard and I organized the Sputnik conference of STATPHYS20 "Classical chaos and its quantum manifestations" dedicated to 70th of Boris Chirikov (16 - 18 July, 1998, Toulouse). This Conferences attracted a hundred participants from all over the world (from Sydney, Siberia, China, USA, Europe etc.).

3)Together with J.Galibert and M.Sanquer I organized a mini-workshop "Transport, localization and interactions" in the frame of Condense-matter days of SFP (Poitier, August 2000).

4)Together with G.Casati and P.Zoller I organized the international conference "Quantum computers and quantum chaos" at Como, Italy, 28 - 30 June 2001 (about 60 participants).

5)I organized the International Quantware workshop at Toulouse, France, 1 - 14 July 2002 (about 20 participants).

6)I participated in the organization of the International Summer School of Enrico Fermi at Varenna, Italy entitled "Quantum Computers, Algorithms and Chaos" hold at July 5-15, 2005 (directors G. Casati (Como), D.L. Shepelyansky (Toulouse), P. Zoller (Innsbruck), scientific secretary G.Benenti)). The event attracted about 90 participants. The web site is http://scienze-como.uninsubria.it/benenti/varenna2005.html

7)I participated in the organization of the program at the Institut Henri Poincaré on "Quantum Computation, Information and Complexity" (Paris, 4 Jan - 7 April 2006) (directors Ph.Grangier, M.Santha, D.Shepelyansky). The program attracted about 130 participants. For the first time in the history of IHP the lectures have been filmed, they are freely available for the public via the program web site http://www.quantware.ups-tlse.fr/IHP2006/ (click on lectures and go to video).

8)With Debora Donato I organized 2 days workshop "PageRank matrix days" in dedicated to 100 Anniversary of S.Ulam in Dec 2009, Toulouse. There were 20 participants.

9)With G.Caldarelli, N.Litvak and T.Guhr I organized a workshop at European Centre for Theoretical Studies in Nuclear Physics and Related Areas, ECT*, Trento, Italy (23 - 27 July, 2012). There were 40 participants.

10)With P.Boldi, M.Santini and S.Vigna I organized the FET NADINE workshop "Directed networks days 2013" at LAW Computer Science Dept. Universita degli studi di Milano, Italy (13 - 14 June, 2013). There were about 20 participants.

11) With E.Kartashova, A.Pikovsky I organized workshop "Weak Chaos and Weak Turbulence", Max Planck Institute for the Physics of Complex Systems Dresden, Germany, 3 - 7 February, 2014 with about 50 participants.

12) With A.Benczur and R.Palovics I organized the FET NADINE workshop "Directed networks day 2014" at MTA SZTAKI, Hungarian Academy of Sciences, Budapest, Hungary (8-10 May 2014) with about 20 participants.

13) With A.Benczur and A.Kaltenbrunner I organized the first summer school "Network Analysis and Applications" at Ecole des Sciences Avances de Luchon 21 June - 5 July 2014 with 50 participants. This ecole de Luchon was initiated by my in collaboration

of Maire of Luchon Louis Ferré.

14) With R.Jalabert and D.Ullmo I organized Luchon Superbagneres Workshop W1 “Quantum chaos: fundamentals and applications”, 14-21 March 2015 with 50 participants.

15) With M.Dyakonov and M.Zudov I organized Luchon Workshop W2 “Quantum transport in 2D systems”, 23-30 May 2015 with 45 participants.

16) With D.Donato and V.Solovyev I organized the summer school “Networks and data mining” at Ecole des Sciences Avances de Luchon 27 June - 11 July 2015 with 40 participants.

17) With J.Lages I organized Luchon workshop ”Applications of Google matrix to directed networks and Big Data (APLIGOOGLE)”, 14 - 18 May, 2016

18) With J.Lages and I.I.Shevchenko I organized Luchon workshop W4 ”Dynamics and chaos in astronomy and physics”, 17 - 24 September, 2016

19) With M.Dyakonov and M.Zudov I organized Luchon Workshop W5 “Quantum transport in 2D systems II”, 20 - 27 May, 2017

20) With A.Benczur and E.Ulmo I organized Workshop 60 years of Institut des Hautes Etudes Scientifiques, Bures-sur-Yvette, France “Google matrix: fundamentals, applications and beyond (GOMAX)”, 15 - 18 October, 2018 (65 subscribed participants)

7.3. International collaboration

The most active collaboration is with the following groups:

- group of Boris Chirikov at Budker Institute of Nuclear Physics, Novosibirsk, Russia, including also F.Izrailev and now O.V.Zhirov (about 35 joint publications);
- dynamic systems group at Univ. of Milano at Como, Italy, including R.Artuso, F.Benvenuto, G,Benenti, F.Borgonovi, G.Casati, I.Guarneri, G.Maspero (about 40 joint publications)
- group of F.Haake and R.Graham at Univ. of Essen, Germany (4 joint publications)
- groups of S.Fishman at Technion, Haifa, Israel and U.Smilansky, Weizmann Institute of Sciences, Rehovot, Israel (1 joint publication)
- group of N.Delone, Inst. of General Physics and V.P.Krainov Moscow Phys.-Tech. Inst, Moscow , Russia (3 joint publications)
- group of A.D.Stone, Yale Univ., USA (1 joint publication)
- group of F.Flambaum and O.Sushkov, Univ. of New South Wales, Sydney, Australia (2 joint publications).
- dynamical system group of A.Pikovsky at Univ. of Potsdam, Germany (4 joint publications)
- collaboration with partners of EC FET NADINE project

Joint papers were also published with:

- J.Ford at Georgia Tech, Atlanta, USA (1 paper)
- M.A.Lieberman, Univ. of California, Berkely, USA (1 paper)
- S.Ruffo, Univ. of Florence, Italy (1 paper)
- P.Schmelcher, Univ. of Heidelberg, Germany (1 paper)
- Pil Hun Song, Seoul National Univ., Korea (3 papers)
- F.Vivaldi, Queen Mary College, London, UK (2 papers)

7.4. International press reports

The scientific results obtained in my group are highlighted in the following press reports:

1)"Computers set for quantum crashes" Nature Science Update (Nature 20 november 2000) by Philip Ball (http://www.nature.com/nsu/001123/001123-3.html)

2)"Quantum simulations of quantum chaos" Nature physics portal-research highlights-april 2001

3)The work on quantum algorithms is highlighted in "Le Monde", 5 mars 2003.

4)The quantum computer language developed by S.Bettelli is highlighted at the print edition of "The Economist" in the article "Dream code" at 3 april 2003.

5)The work on quantum sound [142] is highlighted by Mike Martin (NewsFactor Network, October 9, 2003) (http://www.newsfactor.com/perl/story/22456.html).

6)The Quantware scientific results on quantum computing are reviewed by Storming Media Pentagon Reports: Fast. Definitive. Complete.
(see the web site http://www.stormingmedia.us/04/0496/A049624.html)

7)The work on synchronization in rings of Saturn [173] was highlighted by websites Lenta.ru, Gazeta.ru, Arxivblog.

8)In October 2005 I proposed to Jean-Claude Garreau (CNRS, Lille) to realize with cold atoms the theoretical results on Anderson localization transition in a model of kicked rotator with modulated frequencies as discussed in [14,37,76,86]. This transition was observed in his work on cold atoms in kicked optical latticies in Phys. Rev. Lett. v.101, p.255702 (2008) highlighted in the acticle of Mark Sadgrove physics v.1, p.41 (2008)

9)The work [190]on fractal Weyl law for the Linux Kernel network" was highlighted at http://francisthemulenews.wordpress.com/ and
http://matematicacomputacional.blogspot.com/

10)Two-dimensional ranking of Wikipedia articles [191] is highlighted by Atelier.fr

11) Google matrix of the world trade [198] is highlighted by Atelier.fr

12)The paper [205] on Kolmogorov turbulence and Anderson localization is highlighted by ScienceDaily and EPJB highlights at 27 July 2012.

13) The arXiv [225] has been highlighted by press of about 20 countries including "The Guardian", "The Independent", "The Washington Post", France24, Le Figaro etc..

14) The arXiv [238] has been higlighted by press of about 20 countries including "Le Monde", MIT Tech Rev" etc.

15) The results of article [244] have been higlighted by Nature Astronomy

16) The results of article [246] have been higlighted by INP CNRS

17) The results of article [252] have been higlighted by EPJB journal and 16 other press highlights

18) The results of article [257] have been higlighted by Europhysics News v.50(2), p.6 (2019)

7. PhD theses, post-docs and habilitations

PhD theses

1)PhD thesis of F.Borgonovi ”Analysis and phenomenology of the quantum stochasticity” (Pavia, Italy, 1990) was based on the joint papers [38,41] (see section 2.5.2). At present F.Borgonovi is researcher at Univ. of Brescia, Italy.

2)PhD thesis of F.Benvenuto ”Dynamical localization” (Milano, Italy, 1992) was based on the joint papers [46,49] (see section 2.3.4). At present F.Benvenuto is a system manager at the Suisse National Supercomputer Center, Suisse.

3)PhD thesis of Ph. Jacquod ”Aspects of quantum chaos and disordered interacting systems”, (Neuchâtel, Suisse, 1997) was based on the joint papers [75,83,85,87,90] (see sections 2.7.1 and 2.7.2). Ph.Jacquod was as post-doc at Yale Univ., Leiden Univ. and he is a researcher at Univ. of Geneve (5 years grant). At present he obtained an offer for professor position at Tucson, Arizona and plans to move there.

4)PhD thesis of G.Benenti ”Chaotic enhancement on microwave ionization of Rydberg atoms”, (Milano, Italy, Feb. 1998) was based on the joint papers [91,93,98] (see section 2.6.6). G.Benenti was post-doc in CEA, Saclay in the group of J.-L.Pichard, now he is an assistant professor at Univ. of Insubria, Como, Italy.

5)PhD thesis of G.Maspero ”Quantum chaos in open systems” (Milano-Como, Italy, January 1999) was based on the joint papers [95,97,100] (see section 2.6.7). G.Maspero studies theology and philosophy in Rome and Spain. At present he teaches these subjects at Rome and Vatican.

6)PhD thesis of José Lages (from Univ. Montpellier, DEA at Univ. P. Sabatier, Toulouse) was directed to the problems of interaction, localization and disorder effects. His PhD thesis “Phase of bi-particle localized states induced by attractive interactions in disordered systems” was defended at 19 Oct 2001 at Univ. P. Sabatier, Toulouse. It is based on the joint papers [109,110,122,126]. J.Lages was post-doc in Portugal (2001-2003) and Ames National Lab, Iowa, USA (2003-2004), LPT Toulouse (2004-2005). At present he is the head of Physics Dept. at Univ. of Besancon.

7)PhD thesis of Gaetan Caldara (from ENS, Paris) was started under my supervision at Univ. P. Sabatier in September 1998 and was directed to the investigation of interaction effects in disordered systems. He finished his thesis with K.Frahm in Dec 2002. Left from science. The thesis defended in Dec 2002 is based on the results published in [111,125].

8)PhD thesis of Simone Montangero ”Quantum computing of complex dynamics ” was defended at 4 March 2003, Univ. of Milano, Italy (2003) It is related to simulations of quantum algorithms on realistic quantum computers. It is based on results obtained in [129,130,134,135]. He was post-doc at Univ. of Pisa, Italy with R.Fazio, now at Univ.

Ulm.

9)Oct 2001 till Dec 2004 Benjamin Levi made his thesis in our quantware group directed to investigation of effects of quantum chaos on operability of quantum computers. Joint results are presented in [137]. Support comes from Paris VII. PhD thesis of Univ. Paris VII "Simulation of quantum systems on a realistic quantum computer" defended at Univ. Paul Sabatier, Toulouse at 9 November 2004 After that B.Levi worked as post-doc at MIT, USA at the group of D.Cory then moved to industry in France.

10)From Oct 2001 till Oct 2004 Andrei Pomeransky (from Novosibirsk) made his thesis in our group directed to investigation of inter-qubit interactions on operability of quantum computers (supported by the US army research office grant). Our joint results are presented in [141,146]. PhD thesis "Entanglement and imperfections in quantum computation" was defended at 22 October 2004, Univ. Paul Sabatier, Toulouse At present A.Pomeransky is a resercher at the theory division of the Budker Inst. of Nuclear Physics, Novosibirsk, Russia.

11)Giampaolo Cristadoro (Univ. dell'Insubria, Como, Italy) has spent 4 months in Toulouse during his PhD supervised by Prof. R.Artuso (Univ. dell'Insubria, Como, Italy). The results obtained during this stay on directed transport and ratchets forms a part of the thesis defended in Jan 2005 (joint work [149]). G.Cristadoro was post-doc at MPI Complex Systems, Dresden for 2 years, he was again post-doc at Univ. of Insubria at Como with R.Artuso, now he is working at Bologna Univ., Italy.

12)Vivek Kandiah from EPFL, Lausanne, CH started his PhD on Google matrix of directed networks in Oct 2011 (supported by CNRS and Region Midi-Pyrenees); PhD defended at 13 Oct 2014 "Application of the Google matrix methods for characterization of directed networks" Joint works are [206,212,221] plus [230[aftre PhD. At present V.Kandiah is post-doc at a Swiss University.

13) Samer El Zant defended his PhD at 6 July 2018 on mobile networks in the frame of IDEX ptoject GOMOBILE (director Katia Jaffres-Runser INPT-ENSEEIHT Toulouse and me).

14) Celestin Coquide started his PhD in Oct 2017 at UTINAM, Besancon directed by Jose Lages (joint works [257,267,270,271].

Post-docs

1)From November 2001 to end October 2003 Marcello Terraneo (PhD from Univ. of Milano - Como, Italy) was a post-doc in my group supported by the EU grant QTRANS. Our joint results are presented in [132,140,143]. Now he works in a bank in Milano.

2)From April 2002 to June 2003 Stefano Bettelli (PhD from Univ. of Trento, Italy) was a post-doc in my group supported by the EU grant QTRANS; from July to October 2003 he was invited researcher at CNRS (post-rose) under my supervision. Now he left to private industry. Our joint results are presented in [138].

3)From January 2003 to January 2005 Jae-Weon Lee (researcher from Korea Advanced Institute of Science and Technology) worked at the post-doc position in my group supported by the EU IST-FET project EDIQIP. Our joint results are presented in [142], [152], [153]. Now J.Lee is government science advisor in Seoul, Korea.

4)I am responsible for the CNRS post-doc position attributed by SPM CNRS to our quantware group on the project of decoherence and imperfections for quantum computations (from Sep 2004 to Aug 2006). O.Giraud was hired as post-doc on this position, after 1 year he got CNRS CR2 position at LPT, Toulouse and now works in LPTMS, Orsay. Joint publication is [155].

5)José Lages was post-doc via EDIQIP grant from Sept 2004 to Sept 2005. After that he became a maitre de conference at Univ. at Besancon. Joint work during this period is at [157]. More recent works are [195,209].

6)Ignacio Garcia-Mata (from Univ. Buenos Aires) started his EuroSQIP post-doc position from April 2006 for 2 years. Now he is permanent researcher at TANDAR Lab. CNEA, Buenos Aires; joint publications are [159], [162], [168], [170].

7)John Martin (from Univ. of Liege, Belgium) is post-doc with B.Georgeot in the frame of French ANR project on quantum information for Sept 2006 to Sept 2008; joint publications are [167], [169]. Now he is permanent researcher at Universite de Liege.

8)Leonardo Ermann (from Univ. Buenos Aires) was ANR NANOTERRA post-doc position from September 1, 2009 till July 2011. Now he is permanent CNEA researcher position at TANDAR, CNEA, Buenos Aires; he is the head of TANDAR Lab; joint works are [183,184,190,194,198,200,201]. More recent publications are [204,210,218].

9)Young-Ho Eom (PhD at KAIST, S.Korea) is EC FET NADINE post-doc from 1 Oct 2012 til 26 Nov 2014. Joint works are [215,217,220,225,229]. At present Y.-H.Eom was EC post-doc at Univ. in Italy, now in Madrid Spain.

Habilitations

The habilitation of Klaus Frahm "Lacalisation and transport in mesoscopic systems: analytical results" (under my supervison) was defended in Dec. 1998 at the Univ. Paul Sabatier, Toulouse. At present Klaus Frahm is professor in our group in Toulouse.

The habilitation of Bertrand Georgeot “Applications du chaos quantique à l'information quantique et aux atomes froids” (under my supervison) was defended at 19 March 2010 at the Univ. Paul Sabatier, Toulouse. At present Bertrand Geoprgeot is directeur de recherche du CNRS (DR2) in our group in Toulouse.

8. Grants, contracts and valorisation of research

International grants

My international grants brought from abroad to France approximately 1 million of euro, the total turnover transfer via France, related to coordination of EC projects and USA ARO/NSA/ARDA grant, is 2 millions and 188 kilo euro (1USD=1euro is taken in this count). These grants allowed to create in France 11 years of young researcher positions on post-doc and PhD level (8 +3 years). Separately, there are 1.5 years from ANR PNANO.

The list of these grands includes:

1) I am the principal investigator for the EU net grant RTN-1999-00400 "Quantum transport on an atomic scale" QTRANS (Toulouse node). This net includes 6 nodes in Toulouse, London, Munich, Frieburg, Como, Palermo.

The grant duration: from Sept 2000 to Aug 2003, extended to Aug 2004.

Two post-docs are supported by this grant (M.Terraneo and S.Bettelli).

Total amount 150000 euro.

2) I am the principal investigator for the 3 years grant for quantum computation and information given by the USA National Security Agency (NSA) and Advanced Research and Development Activity (ARDA) under Army Research Office (ARO) contract No. DAAD19-01-1-0553 . The grant is directed to investigation of imperfection effects and inter-qubit interactions on operability of realistic quantum computers.

The grant duration: from May 2001 to July 2004.

One PhD student is supported by this grant (A.Pomeransky).

Total amount 168000 USD.

3) I am the coordinator of the EC IST-FET project IST-2001-38869 "Effects of decoherence and imperfections on quantum information processing" EDIQIP which includes 4 EU nodes at Como (Univ. of Insubria, Italy), London (Royal Holloway, UK), Darmstadt (Tech. Univ. of Darmstadt, Germany). The grant is directed to investigation of decoherence effects in operating quantum computers. Web site is http://www.quantware.ups-tlse.fr/EDIQIP/

The grant duration: from January 2003 to January 2006.

Three post-docs are supported by the grant in 3 nodes. In Toulouse post-doc Jae-Weon Lee is supported by this grant for 2 years, and Jose Lages for 1 year.

Total amount for EDIQIP: 500000 euro.

Total amount for Toulouse node: 173000 euro.

4) I am responsible for Toulouse part of CNRS partner (other part is at Grenoble) in EuroSQIP "European Superconducting Quantum Information Processor" EC IST FP6-015708 EuroSQIP (November 1, 2005 - October 31, 2009). The grant includes 15 partners all over EU, it is coordinated by Goran Wendin (Sweden). Web site is http://mina4-49.mc2.chalmers.se/∼eurosqip/

I.Garcia-Mata worked as post-doc at this grant for 2 years.

Total grant amout 6.000.000 euro, total amount for Toulouse 150000 euro.

5) I am the coordinator of the EC FET Open project NADINE No 288956 "New tools and algorithms for directed network analysis" The grant is directed to investigation of properties of complex directed networks including WWW, Twitter, Wikipedia, world trade and other networks. Web site is http://www.quantware.ups-tlse.fr/FETNADINE/ Nodes: Univ. Milano, Univ. Twente, and Hungarian Academy of Sciences.

The grant duration: from 1 May 2012 to 30 April 2015.

Three post-docs are supported by the grant in 3 nodes and 1 PhD student in 4th node. In Toulouse post-doc Young-Ho Eom is supported by this grant for 2.5 years.

Total amount for FET-NADINE: 1222000 euro.

Total amount for Toulouse node: 322000 euro.

EC FET gave excellent mark for the results obtained by this grant.

French grants

1)I am responsible for the Toulouse node of the ACI quantum information project which includes J.-M.Raimond (ENS, Paris, ACI coordinator), D.Esteve (CEA, Saclay), R.Mosseri (GPS - Jussieu, Paris).

The grant duration: July 2002 - July 2002. Total amount for Toulouse node: 25000 euro

2)I am responsible for the theory part of PPF on quantum information coordinated by B.Girard (Univ. P. Sabatier, Toulouse). Started in 2003 for a 3 years period. Total amount for quantware group: 13000 euro.

3)Our group in collaboration with quantum chemists from UMR 5626 B. Srinivasan and M.-B. Lepetit obtained also grant for supercomputer facilities at IDRIS, Orsay in the frame of the project 991168 "Chaos quantique, localisation d'Anderson et interactions". This project started in 1999 involved 60000 hours on CRAY T3E and 1000 hours on CCRAY C90 in 2001. I am the responsible for this grant. The project on quantum chaos was also granted by the computer center CICT in Toulouse (ORIGIN computer, 65000 hours in 2000). These projects continued till 2006.

4)I am responsible for Toulouse partner in ANR PNANO project MICONANO via the French goverment grant ANR "Microwave Control of Transport in Nanoscopic Structures" nodes: LPN Paris, LPT Toulouse, CEA and LCMI Greboble (December 1, 2005 - November 30, 2008); project coordinator J.-C.Portal, LCMI Grenoble . Total amount 200000 euro; total amount for Toulouse 42000 euro.

5)I am responsible for LPT, Toulouse partner in ANR PNANO project NANOTERRA via the French goverment grant ANR which for a period Jan 1, 2009 - Dec 31, 2011; extended till Dec 31, 2012. It is coordinated by J.-C.Portal (Grenoble) and includes groups at Toulouse LPT, Toulouse LAAS and Orsay LPS. Its aim is to create detectors of the terahertz radiation based on the ratchet effect in asymmetric fabricated nanostructures similar to those studied in the grant 4. Leodardo Ermann is post-doc of this grant from Sept 1, 2009 for 18 months. Total amount around 850000euro; total amount for Toulouse 110000euro.

L.Ermann was post-doc at LPT in the frame of this grant from Sept to July 2011 (with 3 additional months from CNRS).

6)France-Armenia collaboration "Classical and quantum chaos" grant CNRS/SCS No 24943 (1 Jan 2012 - 31 Dec 2013) I am PI for CNRS Toulouse, France Nerses Ananikyan is PI for Alikhanyan Nat. Sci. Lab., Yerevan, Armenia. Grant amount is 7keuro.

7) IDEX project GOMOBILE (PI Katia JAFFRES-RUNSER, INPT-ENSEEIHT Toulouse, me -Co-PI) includes a PhD position for 3 years from Nov 2015.

8) I coordinate MASTODONS-2016 CNRS project APLIGOOGLE http://www.quantware.ups-tlse.fr/APLIGOOGLE/ on directed networks (March 2016 - Dec 2016, 40000 euro equally distributed between 4 nodes); extented till end 2017 with additional budget 10keuro.

9) I am PI of the LABEX NEXT grant "Thermalization, transport and complexity at nanoscale" (THETRACOM), Pogramme Investissements d'Avenir ANR-11-IDEX-0002-02, reference ANR-10-LABX-0037-NEXT, June 2017 - June 2020 (39keuro)

9. International seminars and visits abroad

Long visits abroad (from October 1994):

1994 - Yale Univ., USA (3 months).
1995 - Univ. of New South Wales, Sydney, Australia (1 month);
Technion and Weizmann Institute, Israel (1 month).
1996 - Workshop at Santa Barbara, USA (1 month).
1997 - Issac Newton Institute, UK (1 month).

1999 - Workshop at MPI, Dresden, Germany (3 weeks).
2000 - Univ. of New South Wales, Sydney, Australia (1 month visit as invited professor)
2001 - Workshop on Quantum information, Univ. of California at Santa Barbara, USA (2 months)
2002 - 2003 - ARO meetings, Yale Univ. in Aug - Sept, USA (1 month per year). 1994 - 2005 regular visits to Univ. of Milano at Como (Univ. of Insubria), Italy.
2005 - SUNY at Stony-Brook, NY and Yale (3 weeks)
2006 - Lewiner Inst. for Theoretical Physics, Technion, Haifa (Nov - Dec, 2 weeks)
2007 - Univ. of Potsdam, Germany (2 months visit as invited scientist, June - Aug)
2008 - Univ. of Potsdam, Germany (1 month visit as invited scientist, July - Aug)
2008; 2013 - Newton Inst., Cambridge, UK, program on Anderson localization 50 years, October 2008, Sept 2012; Cavendish Lab. 2011 - 2013
2009 - 2010 - Univ. of Potsdam, Germany (1-2 month visit as invited scientist, June - Aug)
1992 - 2017 - regular visits to the Budker Inst. of Nuclear Physics, Russian Academy of Sciences, Novosibirsk (about 3-4 weeks per year)

Seminars abroad and in France from 1994:

1. Seminar "Coherent propagation of two interacting particles in a random potential", October 1994, Condensed Matter Seminar, Yale Univ., CT, USA.
2. Seminar "Quantum localization of dynamical chaos", November 1994, Bell Labs., NJ, USA.
3. Seminar "Localization and chaos in Rydberg atoms", November 1994, State Univ. at Stony Brook, NY, USA.
4. Course of Lectures "Classical and Quantum Chaos", October -December 1994, Yale Univ., CT, USA.
5. Seminar "Dynamical localization", December 1994, Univ. of Maryland, MD, USA.
6. Seminar "Quantum chaos", December 1994, Univ. of Texas, Austin, TX, USA.
7. Seminar "Localization and conductance for two interacting particles in a random potential", 10 April 1995, Univ. of New South Wales, Sydney, Australia.
8. Seminar "Localization, diffusion and conductance for two interacting particles in a random potential", 19 May 1995, Max-Planck-Institut fur Kernphysik, Heidelberg, Germany.
9. Seminar "Localization and interaction", 10 August 1995, Budker Institute of Nuclear Physics, Novosibirsk, Russia.
10. Seminar "Localization and interaction", 22 August 1995, Technion, Haifa, Israel.
11. Seminar "Coherent propagation of two interacting particles in a random potential", September 1995, Weizmann Institute of Science, Rehovot, Israel.

12. Seminar "Coherent propagation of two interacting particles in a random potential", September 1995, Ben-Gurion University of the Negev, Beer-Sheva, Israel.

13. Seminar "Coherent propagation of two interacting particles in a random potential", 27 March 1996, Imperial College, London, UK.

14. Seminar "Chaos in the Kepler problem: from Rydberg atoms to Halley's comet", 7 May 1996, Atomic and Molecular Physics Division Harvard-Smithsonian Center for Astrophysics, Harvard Univ., USA.

15. Seminar "Coherent propagation of two interacting particles in a random potential", 9 May 1996, Theoretical Physics Inst., Univ. of Minnesota, USA.

16. Seminar "Interactions and localization: two interacting particles approach", 4 June 1996, Yale Univ., CT, USA.

17. Seminar "Emergence of quantum ergodicity in rough billiards", 14 March 1997, Univ. de Neuchatel, Neuchatel, Switzerland.

18. Seminar "Interaction, disorder and Anderson localization", 18 June 1997, Max-Plank-Institute, Goettingen, Germany.

19. Seminar "Emergence of quantum chaos in finite interacting Fermi systems", 3 July, 1997, Budker Inst. of Nuclear Physics, Novosibirsk, Russia.

20. Seminar "Emergence of quantum chaos in finite interacting Fermi systems", 24 September, 1997, Isaac Newton Institute for Mathematical studies, Cambridge, UK.

21. Seminar "Asymptotic statistics of Poincaré recurrences and correlations in hamiltonian systems", 5 October 1998, Univ. of Potsdam, Germany.

22. Seminar "Metal-insulator transition in 2D: theory, experiment, numerics", 29 April 1999, Budker Institute of Nuclear Physics, Novosibirsk, Russia.

23. Seminar "Quantum chaos & quantum computers", given 8 March 2000 at Yale Univ.; 9 March 2000 at IBM T. J. Watson Research Center, Yorktown Heights; 10 March 2000 at State Univ. at Stony Brook; 17 March at Bell Labs, NJ.

24. Seminar "Quantum ergodicity for electrons in two dimensions", 5 April 2000, Hong Kong Baptist University, Hong Kong.

25. Seminar "Quantum chaos & quantum computers", 5 April 2000, Hong Kong Baptist University, Hong Kong.

26. Seminar "Quantum chaos & quantum computers", 9 May 2000, Univ. of New South Wales, Sydney, Australia.

27. Seminar “Quantum computers: facing chaos”, Univ. of Brussel, Brussel, 9 March 2001.

28. Seminar “Quantum computers: facing chaos”, Univ. of Potsdam, Potsdam, Germany, 7 May 2001.

29. Seminar ”Quantum computers: facing chaos”, Yale Univ., New Haven, CT, USA, 7 August, 2001.

30. Seminar ”Quantum computers: facing chaos”, State Univ. of New York at Stony Brook, USA, 1 October, 2001.

31. Seminar ”Quantum computation and complexity of chaos”, Yale Univ., New Haven, CT, USA, 6 September, 2002.

32. Seminar ”Quantum computation and complexity of chaos”, Institute of Nuclear Physics, Novosibirsk, Russia, 3 October, 2002.

33. Seminar “Interplay between disorder and superconductivity”, Institute of Semiconductor Physics, Novosibirsk, Russia, 9 October, 2002.

34. Seminar “Chirikov’s ten Commandments of chaos”, Yale University, CT, USA, 6 June 2003.

35. Seminar “Introduction to quantum computers” (17 spring highlights), Inst. of Semiconductor Physics, Novosibirsk, Russia, 17 March 2004.

36. Seminar “Quantum errors and quantum computations”, Budker Inst. of Nuclear Physics, Novosibirsk, Russia, 18 March 2004.

37. Seminar “Quantum computations in presence of imperfections”, Center for Theoretical Physics, Institute of Physics, Polish Academy of Sciences, Warsaw, Poland, 19 May 2004.

38. Poster presentation “Effects of decoherence and imperfections for quantum algorithms” at ERATO Conference on Quantum Information Science 2004, Tokyo, Japan, 4 September 2004.

39. Seminar “Microwave control of transport in mesoscopic structures” at Institute of of Semiconductor Physics, Russian Academy of Sciences, Novosibirsk, Russia, 9 March 2005.

40. Seminar “Random matrix theory and error correction for realistic quantum computation”, SUNY at Stony Brook, NY, USA, Condensed matter seminar, 15 April 2005.

41. Seminar “Microwave control of transport in mesoscopic structures”, CUNY, New York City, 25 April 2005.

42. Seminar “Random matrix theory and error correction for realistic quantum computation”, Yale University, 27 April 2005.

43. Seminar “Directed transport born from chaos”, Budker Institute of Nuclear Physics, Novosibirsk, Russia, 27 July 2006.

44. Seminar “Wigner crystal in a periodic potential”, Institute of Semiconductor Physics, Novosibirsk, Russia, 9 August 2006.

45. Seminar “Directed transport born from chaos”, Technion, Haifa, Israel, 3 December 2006.

46. Seminar “Wigner crystal in a periodic potential”, Budker Inst. of Nuclear Physics, Novosibirsk, Russia, 14 March 2007.

47. Seminar “Deterministic ratchets in asymmetric nanostructures” and “Synchronization, zero-resistence states and rotating Wigner crystal”, Freie Univ. Berlin, 12 July 2007.

48. Seminar “Deterministic ratchets in asymmetric nanostructures” and “Synchronization, zero-resistence states and rotating Wigner crystal”, MPI for Complex Systems, Dresden, Germany, 31 July 2007.

49. Seminar “2D Electron transport in a microwave field”, Inst. of Semiconductor Physics, Novosibirsk, Russia, 10 January 2008.

50. Seminar “Chirikov standard map”, Univ. of Potsdam, Germany, 7 June 2008.

51. Seminar “Transport and synchronization for 2D electron gas and other systems”, Univ. of Nottingham, 16 October 2008.

52. Seminar in memory of B.V.Chirikov, “Synchronization in rings of Saturn”, Budker Inst. of Nuclear Physics, Novosibirsk, Russia, 12 February 2009

53. Seminar “Microwave stabilization of edge transport and zero-resistance states”, group of M.Büttiker, Univ. de Geneve, 31 August 2009.

54. Seminar “Microwave stabilization of edge transport and zero-resistance states”, Inst. of Physics of Semiconductors, Russian Academy of Sciencies, Novosibirsk, October 7, 2009.

55. Seminar “Google matrix, dynamical attractors and Ulam networks”, Budker Inst. of Nuclear Physics, Novosibirsk, October 8, 2009.

56. Seminar “Google matrix. delocalization and Ulam networks”, CEA, SPEC, Saclay, 27 January 2010.

57. Seminar “Microwave stabilization of edge transport and zero-resistance states”, Budker Inst. of Nuclear Physics, Novosibirsk, March 4, 2010.

58. Seminar “Wikipedia ranking of human knowledge” Budker Inst. of Nuclear Physics, Novosibirsk, Ovtober 28, 2010.
59. Seminar “Google matrix of business process management” Toulouse School of Economics, November 17, 2010.
60. Seminar “Google matrix of the world trade network” Budker Inst. of Nuclear Physics, Novosibirsk, April 7, 2011.
61. Seminar “Dark matter chaos in the Solar System” Budker Inst. of Nuclear Physics, Novosibirsk, May 10, 2012.
62. Seminar “Google matrix of social and brain networks” at Brain Mapping Unit, Univ. of Cambridge, 18 September 2012.
63. Seminar “Google matrix of social networks” at Alikhanyan National Laboratory, Yerevan, 28 Sept 2012.
64. Seminar “Google matrix of markov chains” Sobolev Institute of Matematics, Russian Academy of Sciencies, Novosibirsk, May 8, 2013.
65. Seminar “Chaotic enhancement of dark matter density in binary systems and galaxies”, Budker Institute of Nuclear Physics, Novosibirsk, March 27, 2014.
66. Seminar “Thermoelectriciy at nanoscale: theoretical models”, Institute of Semiconductor Physics RAS, Novosibirsk, December 10, 2014.
67. Seminar “Google matrix of world trade network”, Budker Institute of Nuclear Physics RAS, Novosibirsk, December 18, 2014.
68. Seminar “Dynamical thermalization in finite interacting systems”, Budker Institute of Nuclear Physics RAS, Novosibirsk, Oct 15, 2015.
69. Seminar “Dynamical thermalization in isolated quantum dots and black holes”, Budker Institute of Nuclear Physics RAS, Novosibirsk, March 9, 2017.
70. Seminar “Google matrix analysis of Markov chains”, LEDAS.COM Novosibirsk, April 18, 2017

10. Reports on International Conferences

These reports were given by author at International Conferences. Reports presented by coauthors at other International Conferences are not included. In total more than 100 talks have been given, more than 40 of them were given at present DR1 position (after 1 October 2004).

1. Invited talk ”Statistics of Poincare Recurrences and the Structure of the Stochastic Layer of a Nonlinear Resonance”, at IX Int. Conf. on Nonlinear Oscillations, 30 August - 6 September 1981, Kiev, USSR

2. Invited talk "Intrinsic chaos in quantum systems" at 6th Int. School of coherent optics, 19-26 September 1985, Ustron, Poland.
3. Talk "Chaos and Ionization of the Hydrogen Atom in a Monochromatic Field", at Int. Conf. "Nonlinear and Turbulent Processes in Physics", April 1986, Kiev, USSR.
4. Invited talk "Hydrogen Atom in Monochromatic Field: Chaos and Dynamical Photonic Localization" at Int. seminar on ionization of highly excited atoms, 3 - 5 June 1987, Riga, USSR.
5. Invited talk "Chaos and Interaction of Atoms with Self-Consistent Field in the Case of Small Coupling Constant" at Soviet-Italian Conference in Statistical Mechanics, 25 June - 5 July 1987, Como, Italy.
6. Invited talk "Diffusive ionization of hydrogen atom in monochromatic field" at Int. conf. Spectroscopy and collisions of few electron ions, 28 August - 2 September 1988, Bucharest, Romania.
7. Invited talk "Quantum localization of chaos for microwave ionization of hydrogen atom" at Int. conf. on the Physics of Electronic and Atomic Collisions, 26 July - 1 August 1989, New-York City, USA.
8. Seminar "Quantum Localization of Dynamical Chaos" at Les Houches Summer School "Chaos and Quantum Physics", August 1989, Les Houches, France.
9. Invited talk "Manifestations of classical and quantum chaos in nonlinear wave propagation" at Int. Vavilov conf. on Nonlinear Optics, June 1990, Novosibirsk, USSR.
10. Invited talk "Statistics of Quantum Lifetimes in a Classically Chaotic System" at Int. conf. during workshop "Quantum aspects of nonlinear systems", July - September 1990, Nordkirkhen , Essen, Germany.
11. Invited talk "Localization of Chaos and Excitation in External fields", at Int. Conf. "Semiclassical methods in Solid State Physics and Quantum Chaos", 17 - 21 December 1990, Marseille, France.
12. Invited talk "Localization and Delocalization of Quantum Chaos" at NATO Advanced Research Workshop "Quantum Chaos - Theory and Experiment", 20 May - 20 June 1991, Nordita - Niels Bohr Inst., Copenhagen, Denmark.
13. Series of lectures "Dynamical Localization in Hydrogen Atom" at Enrico Fermi Summer School "Quantum Chaos", 20 July - 5 August, 1991, Varenna, Italy.
14. Invited talk "Hydrogen in Monochromatic Field: Stabilization and Channeling vs. Chaos" at Int. Conf. on Atomic Physics, 3 - 7 August 1992 Munich, Germany.
15. Invited talk "Classical Stabilization of Hydrogen Atom in Monochromatic Field" at Adriatico Research Conference "Hydrogen atoms in Intense Monochromatic Fields", 18 August - 21 August 1992, Trieste, Italy.

16. Talk "Delocalization Transition in Periodically Driven Systems" at International conference "Mathematical Results in Quantum Mechanics", 17-21 May, 1993, Blossin-Berlin, Germany.
17. Invited talk "Stabilization and Chaos for Hydrogen Atom in a Monochromatic Field" at workshop "Classical mechanical methods in Quantum mechanics", 18 June - 15 July 1993, Como, Italy.
18. Invited talk "Delocalization of Quantum Chaos by Weak Nonlinearity" at Adriatico Research Conference "Mesoscopic Systems and Chaos, a Novel Approach", 1 - 6 August 1993, Trieste, Italy.
19. Invited talk "Quantum Localization, Chaos and Nonlinear Interactions" at NATO Conf. The "Gran Finale" (in the frame of NATO Special Programme "Chaos, Order and Patterns: Aspects of Nonlinearity"), 5-10 September 1993, Como, Italy.
20. Invited talk "Coherent propagation of two interacting particles in a random potential" at International Symposium on Chaos and Mesoscopic Systems, 7-10 June 1994, Dresden, Germany.
21. Invited talk "Band random matrices and particles interaction in a random potential" at International conference "Disordered systems, random matrices and quantum chaos", 14-19 May 1995, Bad Honnef, Germany.
22. Invited talk "Dynamical localization and chaos in excited states" at Adriatico Research Conference "Chaos in Atoms and Molecules", 18 - 21 July 1995, Trieste, Italy.
23. Pannel discussion "Localization and interaction" at 6 International Conference "Hopping and Related Phenomena", 26 - 30 August 1995, Jerusalem, Israel.
24. Invited talk "Universal diffusion near the golden chaos border", 3d Meeting on "Statistical Methods in Space-Time chaos", 25 - 27 September 1995, Prato, Italy.
25. Invited talk "Effect of two-particle interactions in disordered systems" at French - Israel meeting "Chaos et Physique Quantique Mesoscopique", 23 - 26 October 1995, Paris.
26. Course of lectures "Classical and quantum chaos" during the semester "Chaos and Quantization" at the Inst. H. Poincare, 1-20 December 1995, Paris, France
27. Invited talk "Interactions and localization: two interacting particles approach" at XXXIst Renconteres de Moriond "Correlated Fermions and Transport in Mesoscopic Systems", 20-27 January 1996, Les Arcs, Savoie, France.
28. Talk at Workshop "Quantum chaos in mesoscopic systems", 12 May - 2 June 1996, Inst. for Theoretical Physics, Univ. of California, Santa Barbara, CA, USA.

29. Invited talk "Interaction and localization of particles in a random potential" at Adriatico Research Conference "Mesoscopic phenomena in complex quantum systems", 11 - 14 June 1996, Trieste, Italy.

30. Invited talk "Particle propagation in a quasiperiodic potential" at International conference "Physics and Dynamics between chaos, order and noise", 26 - 30 August 1996, Berlin, Germany.

31. Invited talk "Two interacting particles effect in disordered systems" at International workshop "Chaotic Dynamics and Quantum Many-Body Systems", 17 - 28 February 1997, Trento, Italy.

32. Invited talk "Emergence of quantum chaos in finite interacting Fermi systems" at Symposium in honor of Martin Gutzwiller "From correlated electrons to the quantum mechanics of complex systems", 23 - 25 June 1997, Dresden, Germany.

33. Invited talk "Chaotic enhancement and suppression of microwave ionization of Rydberg atoms" at XI International Vavilov conference on nonlinear optics, 24 - 28 June 1997, Novosibirsk, Russia.

34. Research programme "Disordered systems and quantum chaos" at the Isaac Newton Institute for Mathematical Sciences, Cambridge, UK, 1 - 30 September, 1997. Invited talk "Relaxation process in a regime of quantum chaos" at NATO Advanced Study Institute "Supersymmetry and trace formulae: chaos and disorder", 8 - 19 September, 1997.

35. Invited talk at Rencontre de Physique Statitistique, l'Ecole Normale Supériure, Paris, "Chaos quantique, interaction et désordre", 22-23 January, 1998.

36. Short communication at the 20th IUPAP International Conference on Statistical Physics, Paris, "Quantum chaos, interaction and disorder", 20 - 25 July, 1998.

37. Invited talk at the WE-Heraeus-Seminar "Percolation, Interaction, Localization: Simulations of Transport in Disordered Systems", Berlin 6 - 9 October 1998, "Integrability and quantum chaos in spin glass shards".

38. Invited talk at the International workshop "Beyond Quasiperiodicity: Complex Structures and Dynamics", Dresden 11 - 15 January 1999, "Renormalization, critical KAM curves and Poincaré recurrences".

39. Invited talk at the International conference XXXIVth Rencontres de Moriond "Quantum physics at mesoscopic scale", Les Arcs, France, 23 - 30 January, 1999, "Two electron view on metal-insulator transition in two dimensions".

40. Workshop "Dynamics of Complex Systems", Max-Plank-Institute, Dresden, 6 - 24 April 1999. Talk "Interplay between disorder and interaction in 2D", 23 April 1999.

41. Invited talk at the International conference ”Localisation 99”, Hamburg, Germany, 29 July - 2 August 1999, ”Quantum ergodicity for electrons in two dimensions”.

42. Invited talk at the workshop ”Complex Systems and Quantum Chaos”, Inst. for Nuclear Theory, Univ. of Washington, Seattle, USA, 13 - 16 March 2000, ”Effects of interaction for disordered systems and localization”.

43. Lecture at Nobel Symposium on Quantum chaos, 13 - 17 June 2000, Sweden, ”Quantum chaos & quantum computers”.

44. Invited talk at the workshop “Coherent Evolution in Noisy Environments”, Max Planck Institute for the Physics of Complex Systems, Dresden, Germany, 7 - 27 May 2001, “Quantum computing of classical and quantum chaos”.

45. Pedagogical seminar ”Quantum chaos: from simple models to quantum computers”, Workshop ”Quantum information: entanglement, decoherence and chaos program”, Inst. for Theoretical Physics, Univ. of California at Santa Barbara, CA, USA, 4 September, 2001 (visiting period 12 Aug - 30 Sept 2001).

46. Invited talk at the International conference “Quantum information”, Inst. for Theoretical Physics, Univ. of California at Santa Barbara, CA, USA, 3 - 7 Dec, 2001.

47. Invited talk at the QTRANS EU Mid-term review “Quantum transport on an atomic scale”, Sicily, 20-22 June 2002, “Quantum transport in many-body systems: from simple models to quantum computers”.

48. Invited presentation of EDIQIP project at EC IST-FET QIPC meeting (European IST-FET program on “Quantum information processing and communications”), 7 June 2002, Brussels, Belgium.

49. Invited talk at Quantum computing program review organized by ARO/NSA/ARDA, 18 - 22 August 2002, Nashville, TN, USA.

50. Invited talk “Quantum computation and complexity of chaos” at Feynman Festival, 22 - 27 August 2002, Univ. of Maryland, College Park, MD, USA.

51. Invited lecture “Quantum computation and complexity of chaos” at Joint ICTP-INFM School/Workshop “Entanglement at the nanoscale”, 28 October - 8 November, 2002, ICTP, Trieste, Italy.

52. Invited lecture “Quantum algorithms for complex dynamics”, at Euroworkshop “Quantum computers: nanoscopic implementation”, 10 - 21 February, 2003, ISI, Villa Gualino, Torino, Italy

53. Invited talk “Les ordinateurs quantiques affrontent le chaos”, Journée de Physique pour l’Istitut de Mathématiques, Calcul et conrôle quantiques, 25 April 2003, Paris.

54. Invited talk “Quantum computation: entanglement, chaos and decoherence”, Workshop on Quantum Chaos and Localisation, 24 - 25 May 2003, Warsaw, Poland.

55. Invited talk “Quantum algorithms in presence of imperfections”, ARO/NSA/ARDA meeting “Theory in Quantum Computing”, Harper’s Ferry, West Virginia, 9 - 10 June 2003.

56. Invited talk “Quantum computation: entanglement and chaos” NATO Advanced Research Workshop “Quantum chaos: theory and applications”, Como, Italy, 17 - 21 June 2003.

57. Invited talk at Quantum computing program review organized by ARO/NSA/ARDA, 18 - 23 August 2002, Nashville, TN, USA.

58. Invited talk “Chaos and quantum computation” at the Conference “Kolmogorov’s legacy in physics: one century of chaos, turbulence and complexity”, ICTP, Trieste, Italy, 15 - 17 September 2003.

59. Invited talk “Chaos and relistic quantum computation” at the workshop “Fundamentals of solid state quantum information processing”, Lorentz Center, Leiden, Netherlands, 8 - 12 December 2003.

60. Invited talk “Quantum computation in presence of imperfections and decoherence”, EU IST-FET QIPC Program Review, Bratislava, SK, 16 - 18 February 2004.

61. Invited talk “Quantum algorithms in presence of imperfections” at the International workshop “Quantum entanglement - from error correction to secure key distribution”, Waldemar-Peterson Haus, Hirschegg, Austria, 30 March - 2 April 2004.

62. Invited talk “Quantum computation of complex dynamics in presence of imperfections” at NATO Advanced Research Workshop “Decoherence, entanglement and information protection in complex quantum systems”, Ecole de Physique Les Houches, France, 25 - 30 April 2004.

63. Invited talk “Applications of quantum chaos to realistic quantum computations and sound treatment on quantum computers”, SPIE Conference 5472 “Noise and information in nanoelectronics”, Maspalamos, Gran Canaria, Spain, 25 - 28 May 2004.

64. Invited talk, “EDIQIP highlights”, IST-FET QIPC Review, Innsbruk, Austria, 14-16 February, 2005.

65. Invited talk “Microwave control of transport in mesoscopic structures”, 2nd Workshop “Quantum chaos and localisation phenomena”, Inst. of Physics, Polish Academy of Sciences, Warsaw, Poland, May 19 - 22, 2005.

66. Invited talk “Quantum chaos and realistic quantum computations”, KIAS-KAIST 2005 Workshp om “Quantum information science”, Seoul, South Korea, August 22 - 24, 2005.

67. Invited talk “Frenkel-Kontorova model with cold trapped ions”, 376 Heraues - Seminar, “At the interface of cold atoms and statistical physics”, Schloss Reisensburg, Gunzburg, Germany, 6-9 Sept 2006.

68. Invited talk “Quantum computation and quantum chaos”, Int. Conference ”Quantum mechanics and chaos”, Osaka City Univ., Osaka, Japan, 19 - 21 Sept 2006.

69. Invited talk “Directed transport born from chaos”, Conference ”Chaos and complex systems 2006”, Monastery of Novacella, Southern Tyrol, Italy, 9 - 12 October, 2006.

70. Invited talk ‘Quantum computation and quantum chaos’, Bar-Ilan Meeting ”Advances in classical and quantum chaos”, Bar-Ilan University, Israel, 12 December, 2006.

71. Invited talk “Directed transport and chaos in asymmetric nanostructures”, International Confernce ‘Chaos, Complexity and Transport: Theory and Applications”, Le Pharo, Marseille, France, 4 - 8 June, 2007.

72. Invited talk ”2D Electron transport in a microwave field”. International Program ”Statistical Physics of Systems out of Equilibrium” at the Institut Henri Poincaré, Paris, Sept 10 - Dec 14 (2007); talk at Dec 10, 2007.

73. Invited talk ”Chirikov standard map”, Chirikov Memorial Seminar, Budker Inst. of Nuclear Physics, Novosibirsk, May 23, 2008

74. Invited talk ”Synchronization of qubits by resonator coupling”, EuroSQIP meeting coordinated by G.Wendin, Hindas, Sweden, May 29-30, 2008

75. Invited talk ”Nonlinearity, localization and quantum chaos”, Workshop ”Anderson Localization for the Nonlinear Schroedinger Equation (NLSE)?”, Lewiner Insitute for Theoretical Physics, Technion, Haifa, Israel, June 22-27, 2008

76. Invited talk “Nonlinearity, interactions and Anderson localization” given at 14 October 2008, Workshop ”Mathematics and Physics of Anderson localization: 50 Years After”, Newton Institute, Cambridge, UK, 14 July - 19 December 2008

77. Invited talk “Interplay of nonlinearity, interactions and Anderson localization” given at 17 March 2009, Workshop “Anderson localization in nonlinear and many-body systems”, Max Planck Institute for the Physics of Complex Systems, Dresden, March 16-20, 2009

78. Invited talk “Delocalization by nonlinearity and interactions in systems with disorder” given at 22 march 2009, DPG Spring Meeting of the Condensed Matter Section, TU Dresden, March 22 - 27, 2009, SYAL 1: Anderson localization in nonlinear and many-body systems

79. Invited talk: ”Delocalization tranzition for the Google Matrix”, SFB Symposium ”Analysis of complex systems”, Fritz Haber Inst. MPG, Berlin, July 3, 2009

80. Invited talk: "Google Matrix, dynamical attractors and Ulam networks", ICPT Workshop "Pseudochaos and Stable-Chaos in Statistical Mechanics and Quantum Physics", Trieste, 21-25 September 2009

81. Invited talk "Spreading and thermalization in disordered nonlinear chains", Workshop "Mesoscopic Physics of Waves for Imaging in Complex Media", Institut Henri Poinracé, Paris, 29-30 Oct 2009.

82. Invited talk "Turbulent flows on complex networks", Advanced Workshop "Anderson localization, Nonlinearity and Turbulence: a Cross-Fertilization", ICTP, Trieste, August 23 - September 3, 2010

83. Invited talk "Wigner crystal in snaked nanochannels" and "Google matrix of the world trade network", Workshop "Quantum chaos and localisation phenomena", IFPAN, Warsaw, 20 - 22 May, 2011

84. Invited talk "CheiRank versus PageRank", Google Krakow (host Wojciech Burkot), 23 May 2011.

85. Invited talk "Wigner crystal in snaked nanochannels", International conference Electronic Crystals, ECRYS-2011 Cargese, Corse, 15 - 27 August, 2011.

86. Lectures "Quantum chaos applications: from simple models to quantum computers and Google matrix" (12 hours); XXVII Graduate Physics Days at Heidelberg University, October 4-7, 2011.

87. Invited talk "Google matrix of the world trade network", 4th Annual Research Conference "Complex systems: Towards a better understanding of financial stability and crises", 3-4 November 2011, De Nedelandsche Bank, Amsterdam

88. Invited talk "Google matrix of social networks", at VII Brunel-Bielefeld Workshop "Random Matrix Theory and Applications in Theoretical Sciences", 15-17 Dec 2011, Bielefeld, Germany

89. Invited talk at Deutsche Bundesbank, Zentrale, Makroprudenzielle Analysen, Frankfurt am main, 6 Feb 2012 (host Barbara Meller) "Google matrix analysis of world trade and financial networks"

90. Invited talk at workshop in honor of Alexander Its "Integrable systems and random matrices" (link), Institut Henri Poincare, Paris 21 - 23 May 2012 (organizer Anne Boutet de Monvel), Invited talk at May 22, 2012: "Google matrix of Markov chains"

91. Invited talk "Kolmogorov turbulence, Anderson localization and KAM integrability" at 19 Sept 2012, at Workshop "Mathematics and Physics of Anderson localization: 50 Years After", follow up meeting, Newton Institute, Cambridge, UK, 17 - 21 Sept 2012

92. Invited talk at International Workshop on Search Computing, Brussels 25-26 September 2012; talk ‘ “NADINE - New tools and Algorithms for DIrected NEtwork analysis” at 25 Sept 2012.

93. Invited talk at International Workshop “MIRO and all that”, Montpellier, France, 13 - 16 May 2013, talk “Synchronization theory of microwave induced zero-resistance states” at 13 May 2013.

94. Invited talk at workshop ”Advances in quantum chaotic scattering: from (non-)linear waves to few-body systems””, 6 - 13 Sept 2013, MPI Complex systems, Dresden, talk at Sept 13, 2013: ”Google matrix and fractal Weyl law”

95. Invited talk at Colloquium in memory of Oriol Bohigas ”Wandering from Nuclei to Chaos”, 13 - 14 March 2014, LPTMS, Orsay, talk at March 14, 2014: ”Spectral properties of Google matrix”

96. Talk at ”Directed networks days 2014”, FET NADINE Workshop, Data Mining Research Group, Informatics Laboratory at the Computer and Automation Research Institute, Hungarian Academy of Sciences, Budapest 8 - 11 May, 2014 : ’Ulam networks and fractal Weyl law’

97. Talk at Luchon summer school “”Network analysis and applications”, July 4, 2014, title ”Google matrix analysis of world trade networks”

98. Talk at Luchon workshop W2 ”Quantum transport in 2D systems”, 28 May, 2015, title ”Poincare sections and zero-resistance states”

99. Invited talk at ”Quantum Correlated Matter and Chaos: A workshop in Honor of the Life and Work of Richard Prange”, MPI Complex Systems, Dresden, 23 June 2015, title ”Anderson transition for Google matrix eigenstates”

100. Talk Luchon summer school ”Networks and data mining”, July 10, 2015, title ”Ulam networks, fractal Weyl law and Anderson localization”

101. Talk Luchon workshop FW3 ”Applications of Google matrix to directed networks and Big Data”, May 17, 2016, title ”Multiproduct world trade network”

102. Talk at NORDITA workshop ”Physics and social network dynamics of the markets”, 30 May - 3 June 2016, Stockholm, Sweeden, title “Introduction to Google matrix and world network of economic activities”

103. Talk at Luchon workshop W4 ”Dynamics and chaos in astronomy and physics”, 17 - 24 Sept 2016, Luchon, France, talk at Sept 19, 2016, title ”Quantum comets”

104. Talk at Luchon workshop W5 “Quantum transport in 2D systems II”, 20 - 27 May 2017, Luchon, France, talk at May 24, 2017, title “Quantum theory of polarization dependence of MIRO in 2DEG”

105. Talk at IHES workshop ”Black holes, quantum information, entanglement and all that”, 29 May - 1 June 2017, Bures-sur-Yvette, France, talk at 1 June 2017, title “Dynamical thermalization in isolated quantum dots and black holes”
106. Invited talk at workshop ”New aspects of localization” LPT, Toulouse, 27 - 29 November 2017, title “Kolmogorov turbulence defeated by Anderson localization”
107. Invited plenary talk at International Conference ”Dynamics in Siberia 2018” dedicated to 90th anniversary of Boris Valerianovich Chirikov, 26 Feb - 4 March 2018, Novosibirsk, Russia; title “Interlinks of dynamical thermalization, Kolmogorov turbulence, KAM and Anderson localization”
108. Talk at 3rd Disease Maps Community Meeting, Inst. Curie, Paris 21 - 22 June 2018, title “Maps of influence and interactions of infectious and cancer diseases from Wikipedia networks”
109. Invited talk at Colloquium in memory of Jean-Louis Pichard, 25-26 June 2018, SPEC, CEA Saclay, France; title “Wigner thermoelectricity and interactions”
110. Invited talk at ”Quantum transport in 2D systems”, 25 May - 1 June 2019, Luchon workshop, France, title “Wigner crystal thermoelectricity, diode and quantum computing”

11. Description of Publications

The list of publications contains 246 papers (published, including 1 submitted) and 23 general public publications including a chapter in a book and a separate edited book. Among them

- 46 papers are in Phys. Rev. Lett. ;
- 1 paper is in Sov. JETP Lett. ;
- 12 papers are in Europhys. Lett;
- 5 review papers are in Sov. Scient. Rev., Sov. Phys. Uspekhy,
  Phys. Rep., IEEE Jour. of Quant. Elect.; Rev. Mod. Phys
- 4 reviews are published as Lectures at School of Nonlinear Waves in Gorky,
  at Enrico Fermi Summer School ”Quantum Chaos” and
  at Rencontres de Moriond, Les Arcs ”Correlated fermions and transport in mesoscopic systems”
  at special issue of Physica D in honor of Boris Chirikov.
- Lecture at Nobel Symposium on Quantum chaos, June 2000, Sweden,
  ”Quantum chaos & quantum computers”.
- 1 in “Images de la Physique”

- a chapter in a book “The Kolmogorov legacy in physics” (Belin, Paris, (2003) (in French) and Lecture Notes in Physics Springer, Berlin (2003) (in English))
- Editor of the book “Quantum Computers, Algorithms and Chaos”, Volume 162 International School of Physics Enrico Fermi, 620pp. IOS Press, Delft, NL (2006) (ISBN: 1-58603-660-2) (Eds. G.Casati, D.L.Shepelyansky, P.Zoller and G.Benenti).
- Scholarpedia article “Chirikov standard map”.
- Scholarpedia article “Chirikov criterion”.
- Scholarpedia Editor of Category “Quantum Chaos”
- Scholarpedia article “Microwave ionization of hydrogen atoms”.
- Scholarpedia article “Google matrix”.
- Book “Boris Valerianovich Chirikov - legislator of chaos”, BINP, Novosibirsk (2014)

At the present DR1 position (from 1 October 2004):

- 128 new papers are published and submitted (Refs. 145-272)
- 8 of them are in Phys. Rev. Lett.
- 1 edited book “Quantum Computers, Algorithms and Chaos” published
- Book “Boris Valerianovich Chirikov - legislator of chaos”, BINP, Novosibirsk (2014)

Citations from ISI web of knowledge (made at Aug 18, 2019, done on “shepel*nsk* d*” to include different translations from Russian):

- TOTAL number of citations (citation report at ISI search): 7016 (5930 without self-citations), H index is 42;
- Google citations (GC) give 11274 citations; H index 52; i10 index is 184 (GC finds in a better way old Russian publications)
- average citation per paper 26.98 for 260 papers visible by ISI
- Most cited papers of GC (top five from GC H-index which is 52): 1)Ref.4 - 512; 2)Ref.26 - 434; 3)Ref.18 - 402; 4)Ref.69 - 363; 5) Ref.164 - 346
- there are 23 articles with more than 100 Google citations, 14 with more than 200 GC citatons, 5 with more than 300 citations

The list of 272 + 24 publications is enclosed in a separate cover.

Scientific Publications

CHEPELIANSKII Dmitrii

(Dima SHEPELYANSKY)

http://www.quantware.ups-tlse.fr/dima

Quantware MIPS Center
Laboratoire de Physique Théorique
UMR 5152 du CNRS
Université Paul Sabatier
31062 Toulouse, France

Contents

1. Publications

1. F.M.Izrailev, D.L.Shepelyansky, "Quantum Resonance for Rotator in Nonlinear Periodic Field", Dok. Akad. Nauk SSSR v.249, p.1103-1107 (1979); Teor. Mat. Fiz. v.43, 417 (1980) (in Russian).

2. D.L.Shepelyansky, "Quasiclassical Approximation for Stochastic Quantum Systems", Dok. Akad. Nauk SSSR v.256, p.586-590 (1981) (in Russian).

3. D.L.Shepelyansky, "About Dynamical Stochasticity in Nonlinear Quantum Systems", Teor. Math. Fiz. v.49, p.117-121 (1981) (in Russian).

4. B.V.Chirikov, F.M.Izrailev, D.L.Shepelyansky, "Dynamical Stochasticity in Classical and Quantum Mechanics", Sov. Scient. Rev. (Gordon & Bridge) v.2C, p.209-267 (1981).

5. B.V.Chirikov, D.L.Shepelyansky, "Statistics of Poincare Recurrences and the Structure of the Stochastic Layer of a Nonlinear Resonance", Preprint INP 81-69, Novosibirsk 1981 (in Russian); English translation available as Preprint PPPL-TRANS-133, Plasma Phys. Lab., Princeton Univ, Princeton, New Jersey, 1983; Proc. IX Int. Conf. on Nonlinear Oscillations (Kiev 1981), Naukova Dumka v.2, p.420-425 (1984) (in Russian).

6. B.V.Chirikov, J.Ford, F.M.Izrailev,D.L.Shepelyansky, F.Vivaldi, "Modulational Diffusion in Nonlinear Oscillating Systems", Proc. IX Int. Conf. on Nonlinear Oscillations (Kiev 1981), Naukova Dumka v.2, p.80-85 (1984) (in Russian).

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8. B.V.Chirikov, D.L.Shepelyansky, "Dynamics of Some Homogeneous Models of Classical Yang-Mills Fields", Yader. Fiz. v.36, p.1563-1576 (1982) [Sov. J.Nucl. Fiz. v.36, p.908 (1982)].

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11. D.L.Shepelyansky, "Stochastic Ionization of Excited Hydrogen Atom in a Field of Electromagnetic Wave", Optic. i Spectr. v.53, p.354-356 (1982) (in Russian).

12. N.B.Delone, V.P.Krainov, D.L.Shepelyansky, "Nonlinear Ionization of Highlyexcited Atoms", Izv. Akad. Nauk SSSR v.47, p.1565-1572 (1983) (in Russian).

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