Classical Chaos and its Quantum Manifestations

Guest Editors

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Abstract

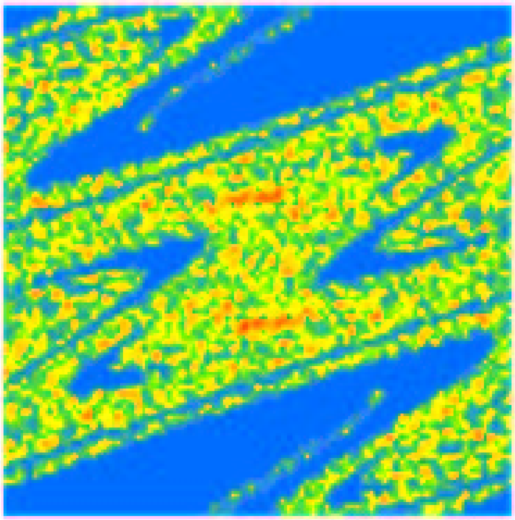
We present here the special issue of Physica D in honor of Boris Chirikov. It is based on the proceedings of the Conference *Classical Chaos and its Quantum Manifestations* held in Toulouse in July 1998. This electronic version contains the list of contributions, the introduction and the unformal conclusion. The introduction represents *X Chirikov Chaos Commandments* and reviews Chirikov's pioneering results in the field of classical and quantum chaos. The conclusion, written by P.M.Koch, gives an outlook on the development of the field of chaos associated with Chirikov, including the personal reminiscences of Professor Andy Sessler. This electronic version of the special issue has certain differences and extentions comparing to the journal.

Classical Chaos and its Quantum Manifestations

Sputnik Conference of STATPHYS 20

In honor of Boris Chirikov

Toulouse, France • July 16 – 18, 1998



Organizers:

Jean Bellissard, Dima Shepelyansky
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During the last decades, important mathematical progress in dynamical chaos has found applications to a broad range of physical systems. Recently, the manifestations of classical chaos have also become important in quantum systems, due to a rapid technological progress in nanostructures and laser physics. The quantum and classical theory of chaos is developing rapidly with applications to Rydberg atoms in external fields, cold atoms, mesoscopic systems, plasma physics, accelerators and planetary motion. The aim of the conference is to invite specialists from different fields to discuss the modern problems of classical and quantum chaos. The conference is dedicated to the 70th birthday of Boris Chirikov, who has contributed pioneering results in this area since 1959.

Invited speakers:

V.Akulin (Paris)
S.Aubry (Saclay)
E.Bogomolny (Orsay)
O.Bohigas (Orsay)
A.Buchleitner (Munich)
L.Bunimovich (Atlanta)
G.Casati (Como)
B.Chirikov (Novosibirsk)
S.Fishman (Haifa)
V.Flambaum (Sydney)
Y.Fyodorov (St. Petersburg)
T.Geisel (Göttingen)
I.Guarneri (Como)
F.Haake (Essen)
F.Izrailev (Novosibirsk)
P.Koch (Stony Brook)
J.Laskar (Paris)
A.Lichtenberg (Berkeley)
R.MacKay (Cambridge)
A.Pikovsky (Potsdam)
M.Raizen (Austin)
S.Ruffo (Florence)
T.Seligman (Cuernavaca)
E.Shuryak (Stony Brook)
Y.Sinai (Princeton)
A.D.Stone (Yale)
F.Vivaldi (London)
G.Zaslavsky (New York)

(participation confirmed)

A poster session will be organized for other participants.

Sponsors: CNRS, Université Paul Sabatier, Institut Universitaire de France, IRSAMC, Région Midi–Pyrénées, Physica D

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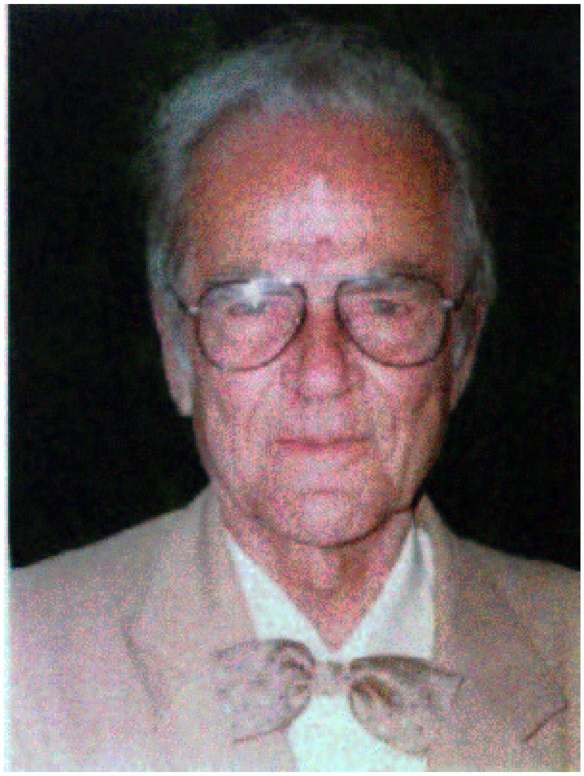


Boris Chirikov

6 June, 1998

Sputnik of Chaos

This special issue of Physica D represents selected proceedings of the Sputnik Conference of STATPHYS 20 “Classical Chaos and its Quantum Manifestations” organized in honor of Boris Chirikov, on the occasion of his 70th birthday on June 6th, and held in Toulouse, France on 16–18 July, 1998.

Sputnik is the name of the very first artificial satellite, launched back in 1957. In russian, this word means companion, but it is also a metaphor for a pioneering, outstanding achievement. These meanings seem appropriate for a portrait of Boris Chirikov. Back in 1959, he published a seminal article [1], where he introduced the very first physical criterion for the onset of chaotic motion in deterministic Hamiltonian systems. He then applied such criterion — now known as the *Chirikov resonance-overlap criterion*— to explain puzzling experimental results on plasma confinement in magnetic bottles. As in an old oriental tale, Boris opened such a bottle, and freed the genie of Chaos, which spread the world over.

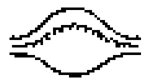
Boris Chirikov’s research on chaos begun in a laboratory at the Kurchatov Institute for Atomic Energy (Moscow). In September 1959, he moved to Novosibirsk, at the Institute of Nuclear Physics founded by G. I. Budker, where he still continues to work. He became a correspondent member of the Russian Academy of Sciences in 1983, and a full member in 1992. (Further biographical details can be be found in [2].)

Giving a fair account of Chirikov’s scientific output is an arduous task. Below we shall list ten prominent achievements of his, selected among those which are closer to the theme of this Conference, but we do so aware that much will be necessarily left out. What is more difficult to convey is a flavour of his personal qualities, his warmth and kindness, his attitude on life and science, and the influence these had on our scientific community. An event in his life paints some traits of his character: as a young researcher, he left Russia’s capital city, the hectic rush for career and influence, and chose a simpler way of life, in a remote Siberian forest.

X CHIRIKOV CHAOS COMMANDMENTS

I

$K \sim S^2 = \left(\frac{\Delta\omega_r}{\Omega_d}\right)^2 > 1$



(1959)

II

$\beta E_0 > N/k$ /FPU/ (1968/73)

III

$\bar{I} = I + K\sin\theta, \quad \bar{\theta} = \theta + \bar{I}$

$K > K_c \approx \frac{\pi^2}{4}S^2 \approx 1; \quad h = \ln(K/2) > 0$

/KAM/ /KS/ (1969/79)

IV

$\omega_s \approx 4\pi\varepsilon\lambda^3 \exp(-\pi\lambda/2), \quad \lambda = \Omega/\omega_0$

$D_A \approx D_0 \exp(-\pi\lambda) \sim \omega_s^2$ (1969/79)

V

$\bar{\psi} = \exp(-i\frac{T\hat{n}^2}{2})\exp(-ik\cos\hat{\theta})\psi$

$(\Delta n)^2 \sim k^2 t^* < \infty$ /KR/ (1979)

VI

$h > \Lambda_m \approx 0.38H^{1/4} > 0$

/YM/ (1981)

VII

$P(\tau) \sim 1/\tau^p, \quad p \approx 1.5$ (1981)

$p = 3 \quad (\tau \to \infty)$ (1998)

VIII

$t^* \sim \Delta n \sim D \sim k^2 \gg t_E \sim \ln k/h$ (1981)

IX

$\varepsilon_q \approx 0.5\omega_0^{7/6}/\sqrt{n_0}$ /H/ (1984)

X

$\bar{w} = w + F(x), \quad \bar{x} = x + \bar{w}^{-3/2}$

$h > 0, \quad t_D \approx 4 \times 10^6$ yrs

/CH/ (1989)

1998, Toulouse

X Chirikov Chaos "Commandments" [1]

I. The first rule represents the Chirikov resonance-overlap criterion introduced in [1] and then successfully applied to the determination of the confinement border for Rodionov experiments [3] with plasma in open mirror traps (the shape of magnetic lines is shown in the Figure). According to this criterion, a deterministic trajectory will begin to move between two nonlinear resonances in a chaotic and unpredictable manner, in the parameter range $K \sim S^2 > 1$. Here K is the perturbation parameter, while $S = \Delta\omega_r/\Omega_d$ is the resonance-overlap parameter, given by the ratio of the unperturbed resonance width in frequency $\Delta\omega_r$ (often computed in the pendulum approximation and proportional to the square-root of perturbation), and the frequency difference Ω_d between two unperturbed resonances. Since its introduction, the Chirikov criterion has become an important analytical tool for the determination of the chaos border [4]. The accuracy of the criterion can be improved on the basis of a renormalization approach to resonances on smaller and smaller scales [5]. For an up-to-date account of the status of particle confinement in magnetic traps, see [6–8].

II. This result [9] determines the energy border for strong chaos in the Fermi-Pasta-Ulam problem (FPU) [10], which became a cornerstone in modern statistical mechanics (see the historical review in [11]). The system represents a chain of N weakly coupled nonlinear oscillators with the Hamiltonian $H = \sum_n [p_n^2/2 + (x_{n+1} - x_n)^2/2 + \beta(x_{n+1} - x_n)^4/4]$; initially only few long wave modes with wave vector k and energy E_0 are excited. The chaos border is obtained from the Chirikov resonance-overlap criterion. New insights on this problem can be found in [12,13].

III. Here the first line represents the Chirikov standard map [14,15]. It is an area-preserving map with action variable I and phase θ. The bars denote the new values of the variables, while K is the perturbation parameter. The dynamics becomes unbounded and diffusive in I for $K > K_c \approx 1$, when all Kolmogorov-Arnold-Moser (KAM) invariant curves are destroyed. This value is obtained from the overlap criterion of first and higher order resonances [14,15]. For large $K > 4$ the Kolmogorov-Sinai (KS) entropy h, related to the exponential local instability of motion, is well-described by the given analytical formula. The Chirikov standard map provides a local description of the interaction between resonances, which finds applications in such diverse physical systems as particles in magnetic traps [15], accelerator physics [16], highly excited hydrogen atoms in a microwave field [17], mesoscopic resonance tunnelling diode in a tilted magnetic field [18]. Later, a refined analysis [19,20] gave the more precise value $K_c = 0.9716...$, related to the destruction of the KAM curve with the golden rotation number. For $K > K_c$ invariant curves are replaced by "cantori". Rigorous results were obtained in [21–23] (see also [24]). However, in spite of fundamental advances in ergodic theory [25], a rigorous proof of the existence of a set of positive measure of orbits with positive entropy is still missing, even for specific values of K.

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[1]) According to the Merriam-Webster dictionary the word *"commandment"* means command, order. We use this word as an equivalent of order, law, rule, result, postulate, principle etc. Nevertheless, a reader can note that even a strict rule (law) can lead to chaotic unpredictable behavior in agreement with the theory of deterministic chaos (see [32] for details).

IV. Here the first line represents the width w_s of chaotic layer appearing around a separatrix of a nonlinear resonance [14,15]. This answers a question first addressed by Poincaré [27], who estimated the angle of separatrix splitting, but not the width of the layer. The above equation is written for the Hamiltonian $H(I, \theta, t) = H_0 + \epsilon\omega_0^2 \cos\theta \cos\Omega t$, where the unperturbed system is a pendulum with $H_0 = I^2/2 - \omega_0^2 \cos\theta$ and $w = H_0/\omega_0^2 - 1$ is the relative variation of the unperturbed pendulum energy. The second line describes the very slow rate of Arnold diffusion [26], a universally feature of such chaotic separatrix layers in systems with more than two degrees of freedom [14,28,15]. More recent results on chaos in separatrix layers and Arnold diffusion can be found in [29–31], see also the book [32].

V. Here the first equation describes the quantum kicked rotator, introduced [33], which is the quantized version of the Chirikov standard map (see *III*). The classical limit corresponds to $T \propto \hbar \to 0$, $k \propto 1/\hbar \to \infty$ and $K = kT = const$ with $I = Tn$. The map gives the evolution of the wave function after one period of the perturbation ($\hat{n} = -i\partial/\partial\theta, \hbar = 1$). The numerical results obtained in [33] showed that in the regime of strong chaos ($K \gg 1$) the rotator energy, or the squared number of excited quantum levels $(\Delta n)^2$, grows diffusively in time as in the corresponding classical system, but only up to a break time t^*. After this time, the quantum energy excitation is suppressed while the classical one continues to diffuse. It was shown that t^* grows with k, but an explanation of this phenomenon was found only later (see *VIII*).

VI. The result obtained in [34] showed that in general the dynamics of classical Yang-Mills fields is not completely integrable and can be chaotic. These studies were done for spatially homogeneous models of Yang-Mills fields introduced in [35], which can be described by an effective Hamiltonian with few degrees of freedom N. For a concrete case with $N = 3$ it was found that the dynamics of color fields with energy H is characterized by a maximal Lyapunov exponent $\Lambda_m \approx 0.38 H^{1/4} > 0$. As a result, the Kolmogorov-Sinai entropy h is also positive, and the color field oscillations are chaotic. Later, low-energy chaos was also found for massive Yang-Mills fields [36].

VII. The results [37] showed that the statistics of Poincaré recurrences $P(\tau)$ in Hamiltonian systems with divided phase spaces decays as a power of time τ with the exponent $p \approx 1.5$. This algebraic decay originates from the long sticking of a trajectory near stability islands and the consequent slow diffusion on smaller and smaller scales of the phase space. This result also implies a slow decay of the correlation functions $C(\tau)$ related to recurrences as $C(\tau) \sim \tau P(\tau)$ [38–40]. The same exponent $p \approx 1.5$ was observed in other maps and Hamiltonian flows (e.g., the separatrix map, the Chirikov standard map etc.), up to times that are about 10^6 times longer than an average return time [39–41]. For larger times the exponent reaches its asymptotic value $p = 3$ [42] determined by the scaling properties of the diffusion rate near a critical KAM curve [38,41]. Since asymptotically $p > 2$, the diffusion rate D_c determined by such dynamics remains finite ($D_c \sim \int C(\tau) d\tau < \infty$) .

VIII. In [43] it is shown that the break time t^*, at which the quantum suppression of classical chaos takes place, is proportional to the classical diffusion rate D. For the kicked rotator, this time scale determines also the number of excited unperturbed states $\Delta n \sim t^* \sim D \sim k^2 \propto 1/\hbar^2$. The time scale t^* is much longer than the short Ehrenfest time t_E on which a minimal coherent wave packet spreads over a large part of the phase space, due to the exponential local instability determined by the Kolmogorov-Sinai entropy h [44,43].

The analogy between the quantum suppression of chaos and the Anderson localization in a disordered one-dimensional potential was established in [45]. In this sense the kicked rotator represents the first example of dynamical localization of chaos in a deterministic system without any randomness. The localization length is given by $l \sim \Delta n \sim D$. Recently the dynamical localization in kicked rotator was observed in the experiments with cold atoms in a laser field [46]. More details on the kicked rotator can be find in [47,48].

IX. On the basis of the results obtained for the kicked rotator (see *V, VIII*) the dynamical localization length was found for highly excited hydrogen atoms in a microwave field, that afforded a determination of the quantum delocalization border ϵ_q above which ($\epsilon_0 > \epsilon_q$) ionization takes place [49]. Here the microwave field strength ϵ and frequency ω are measured in rescaled atomic units so that $\epsilon_0 = \epsilon n_0^4, \quad \omega_0 = \omega n_0^3$, where n_0 is the principal quantum number. For $\omega_0 > 1$ the border ϵ_q can be larger than the classical chaos border $\epsilon_c = 1/49\omega_0^{1/3}$ [50]. As a result, for $\epsilon_q > \epsilon_0 > \epsilon_c$ the classical atom is completely ionized while the quantum is not. Moreover, if in the experiment the frequency $\omega = const$, then the quantum border *grows* with the level number n_0. This behavior, predicted in [49], was observed in laboratory experiments with hydrogen and Rydberg atoms [51–53]. As shown in [17], the dynamical localization for hydrogen atoms in a microwave field can be locally described by the kicked rotator. More details about quantum chaos in the microwave ionization of atoms can be found in [54,17,55].

X. This result [56] shows that the dynamics of the Halley comet can be modelled by a simple map (see the Figure): the comet energy change $(\bar{w}-w)/2$ is a periodic function of perihelion passage time x, measured in periods of Jupiter (first equation); the successive passage time $\bar{x}$ is given by the Kepler law (second equation) [in principle, Saturn also influences the comet's motion [56]]. This map is approximate but it describes the comet dynamics with very high accuracy [56]. Studies of this map showed that the Halley comet moves chaotically (the KS entropy is positive), and that the time of its diffusive escape from the solar system (both forward and backward in time) is rather short $t_D \approx 4 \times 10^6 years$. All this information was obtained from only 46 numbers, the perihelion passage times, found by extensive numerical simulations of other groups and astronomy observations found in historical records.

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These Chirikov Chaos "Commandments"*, as well as his other results (e.g. [57–59]), are directly related to the modern physical developments of chaos presented at the Conference.

This Conference attracted more than one hundred participants. The majority were young researchers from all over the world, showing that this branch of science continues to generate enormous interest. The Conference logo, representing an eigenstate of the kicked rotator (see [60] for details), was chosen to emphasize the beauty and complexity of chaotic behavior. The following topics were in the center of discussions of participants:

Nonlinear systems and classical chaos. This topic was mainly addressed on the first day of the Conference. The problem of interaction of nonlinear resonances and their overlap in maps with quadratic nonlinearity was discussed by Chirikov and Lichtenberg (related to I, III). The properties of transport in quasi-periodic media were discussed by Sinai. The recent mathematical results for discrete breathers in nonlinear lattices were presented by Aubry and MacKay. The problems of space-time chaos, chaotic patterns and dynamical phase transitions in extended dynamical systems were analyzed by Bunimovich, Pikovsky and Ruffo (partially related to II). The properties of chaos borders and the statistics of Poincaré recurrences in area-preserving maps were discussed by Laskar, Artuso and Zaslavsky (see also III, IV, VII). The special role of symmetric periodic orbits and chaotic dynamics of classical wave fields were discussed by Seligman and Guarneri. The chaotic properties of billiards were analyzed by Bunimovich and Mantica. The problem of hamiltonian round-off errors and discretization in dynamical systems was highlighted by Vivaldi.

Spectrum, eigenstate properties, quantum ergodicity and localization. This topic was represented by investigations of a variety of models. Multifractal properties in models of quantum chaos and their relation to wave packet spreading were addressed by Geisel and Guarneri. The problem of emergence of quantum ergodicity in billiards was discussed by Borgonovi, Casati, Frahm, Prange, Prosen, and Ree. Fractal conductance fluctuations in billiards were studied by Ketzmerick. The localization of eigenstates in dynamical models and band random matrices was studied by Fishman, and Izrailev (related to V, VIII). The appearance of deviations from the random matrix theory and intermediate level statistics was discussed by Bogomolny. Quantum chaos in open systems, non-hermitian matrices and chaotic scattering was addressed by Casati, Maspero, and Fyodorov. The results of these studies found their applications in experiments with multimode optical fibers as discussed by Doya, Legrand, and Mortessagne. The theory of wave-chaotic optical resonators was developed and applied to droplet lasing experiments by Stone.

Periodic orbits and quantum chaos. New results on periodic-orbit theory for dissipative quantum dynamics were presented by Haake. Periodic orbits and their signatures in tunnelling, diffusion and scars were discussed by Creagh, Tanner and Borondo. Manifestations of periodic orbit quantization in such mesoscopic systems as a resonance tunneling diode in a tilted magnetic field were highlighted by Stone.

Quantum chaos in atomic physics. An experimental study of dynamical localization in the kicked rotator realized with ultra-cold cesium atoms in a laser field was presented by Raizen, who also discussed the effects of noise (related to V, VIII). Experimental investigations of quantum resonances in hydrogen atoms in a microwave field and effects beyond one dimension were presented by Koch (related to I, IX). A theory of microwave excitation of chaotic Rydberg atoms in a magnetic (or static electric) field, where more then 1000 photons are required to ionize one atom, was presented by Benenti (see IX). The chaotic dynamics of quasiparticles in trapped Bose condensates was studied by Fliesser and Graham. Properties of stable two electron configurations in strongly driven helium were discussed by Buchleitner. The statistical theory of dynamical thermalization and quantum chaos in complex atoms was presented by Flambaum (related to [59]). A theory of line broadering in recent experiments with a gas of interacting cold Rydberg atoms was developed by Akulin.

Quantum chaos in many-body systems. This is a relatively recent topic in the field of quantum chaos. New results for various systems were presented. The statistics of energy fluctuations of non-interacting fermions was discussed by Bohigas. Effects of interaction in finite Fermi systems were analyzed by Flambaum. Georgeot presented the conditions for applicability of random matrix theory to quantum spin glass clusters. The problem of two interacting particles propagating in a random potential was investigated numerically by

Diaz-Sanchez. A transition from integrable to ergodic dynamics in many-body systems was investigated by Prosen. A review on quantum chaos in QCD vacuum was given by Shuryak.

The Conference demonstrated how varied are the physical applications of the ideas of classical and quantum chaos, ranging from QCD [61], cold [46], Rydberg [51] and complex [62] atoms to mesoscopic physics and chaotic light in droplets and microdisk lasers [63]. The achievments of physicists are complementary to the impressive mathematical developments of many twentieth-century mathematicians which are part of the legacy of Henri Poincaré, who discovered the first manifestations of what is now called deterministic chaos. Further mathematical results in this area can be found in the parallel special issue of the Annales de l'Institut Henri Poincaré on "Classical and Quantum Chaos", also dedicated to Boris Chirikov on the occasion of his 70th birthday [64].

In closing, we would like to thank the Conference sponsors, who helped to make this event possible: CNRS, Université Paul Sabatier, Institut Universitaire de France, IRSAMC, Région Midi-Pyrénées. We owe special thanks to Physica D, the journal where Boris Chirikov and his friend Joe Ford collaborated during many years. Our warmest thanks go to Sylvia Scaldaferro and Robert Fleckinger, for their day-by-day assistance in the organization; we also thank Armelle Barelli, Klaus Frahm and Bertrand Georgeot. We are thankful to F.M.Izrailev, V.V.Vecheslavov and F.Vivaldi for their friendly remarks we used here. Finally, we express our gratitude to the invited speakers and to the authors of the contributions to this volume, who enthusiastically accepted the invitation to participate.

J. Bellissard, O. Bohigas, G. Casati and D. L. Shepelyansky

Toulouse, 21 September, 1998

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Remarks on Boris (a Russian) by Peter (an American) in Toulouse (France): Yes, physics is international !

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Abstract

The author was deeply honored to be requested to give the after-dinner speech at the banquet held on 17 July 1998 as part of the conference "Classical Chaos and its Quantum Manifestations" in honor of the 70th birthday of Boris Chirikov. An unusual aspect of this after-dinner speech was its being given before dinner. The text has been edited to conform, as closely as possible, to the words that were actually spoken.

A reporter once asked the elderly Winston Churchill of Great Britain what in life was the most difficult test. Churchill replied, "To climb a ladder leaning towards you, to kiss a girl leaning away from you and third, to give an after dinner speech."

I avoid ladders leaning toward me. So far this evening, the opportunity to kiss a girl, leaning whatever way, has not presented itself. So my test is the third. It was an honor to be asked to address you after tonight's lovely banquet, though the organizers have just requested that I do so before dinner. Throughout the meeting, and especially tonight we join in celebrating the 70th birthday and science of our dear colleague and friend Boris Chirikov.

Most of you, as Boris's former students, collaborators, or friends could have been asked to speak tonight and, I'm sure, would have gladly agreed. Perhaps it's a bit strange that I, an American, have been recruited to celebrate here, in France, Boris, a Russian, before you all, who come from various corners of the world.

Ya na gaviru parruski, so I cannot honor Boris in his native language...

which reminds me of the story of two sheep who were grazing in a pasture. The first sheep said, "BAAAA." His companion looked up and replied, "MOOOO." The first sheep was rather surprised by this and asked, "What are you doing? Sheep don't say MOOOO; they say BAAAAA." "I know," replied his friend. "I was just practicing a foreign language."

So if I'm saying "MOOOO" where many of you would expect to hear "BAAAA", please bear with me.

For many people, birthdays are like glasses of wine: after you've had a few, you don't bother to count them.

But Boris gives us a way to measure his years: by his scientific development as a young researcher and later professor and mentor to his students and colleagues, by the productivity marked by his many important papers, and by the rich stories of his life. If I don't get them all without small errors, please forgive me.

Just a few facts. His birth was in Orel on the 6th of June 1928, so his boyhood came in the internal turbulence of the Soviet Union of the 1930's. With the father absent from their small family, he and his mother fled famine and went around 1936-7 to relatives in Leningrad, where they, of course, found more difficult times after the outbreak of war in Europe. In 1941 or 42 they were evacuated from Leningrad to the northern Caucasus, a region that about 4 months later was conquered and occupied by the German Army.

How many of you in the audience now have teen-aged children? (A show of hands indicated that many did.) My son Nathan is 13, the same age as Boris in 1941-2. Despite the trials of adolescent life in America, I know that my Nathan at 13 faces nothing like the wartime dislocations that came to Boris and so many others during the terrible wartime. Children should never have to face such things, but we still see around the world that they do. Let us all pray that human beings can learn to put such behavior behind them.

Less than a year later, the counter offensive of the Soviet Army moved the frontier westward again and liberated the region, but Boris soon faced sadness again. After a protracted illness, Boris's mother died around 1944. He was now an orphan. Fortunately for his future and ours, a teacher at his school took him into her home and life went on.

In fact, it was during this period near and just after the end of the war that Boris became the sweet man we have all come to know.

Sweet, you say? Well many years later, Peter Scherer, a young German physicist, recognized Boris's sweetness and coded it into the caricature he drew of Boris at the Les Houches theoretical summer school in 1989. Though I was not there, I know that a number of you here were. (The only transparency used in the talk was then shown. It was the caricature of Boris appearing in Chaos and Quantum Physics, M.-J. Giannoni, A. Voros, and J. Zinn-Justin, editors (Elsevier, Amsterdam, 1991, page 444).)

We all recognize Boris lecturing. But notice Boris's small listener, buzzing around feverishly. Maybe the question marks mean that this bee is not sufficiently educated, but the bee is certainly not stupid. This bee knows Boris's sweetness, for bees are drawn to sugar.

What does sugar have to do with the picture, you ask? Well, what you may not know is that from about 1944 to 1947 Boris's place in socialist labor was working in a sugar factory. Boris became quite the expert on sugar, and knows good and bad sugar when he tastes it.

(The speaker turned to Boris.) With that the case, Boris, let me present you with a small present. Please accept this small box of American sugar, but I do ask that after you try it, you do make public your referee report.

Let me jump forward tell you the story of how in 1987 I met Boris in his native land. In December 1986 I had been invited by telex (these were the days before widespread email and the Internet) to be a speaker at the IXth Vavilov Conference on Nonlinear Optics in

Novosibirsk in mid June 1987. For this I was to be, for about two weeks, an official guest of the Soviet Academy of Sciences. Around that time it was also arranged that there would be a small workshop about two weeks earlier in Riga, then in the Latvian SSR. Therefore, my invitations to these meetings meant that I would change "status" while in the USSR, from an "ordinary" foreign person for the first week, around the Riga workshop, to an important guest of the Academy, for the last two weeks or so around the Novosibirsk meeting.

Well, Latvia was nice, the workshop hosted by Robert Damburg was small and wonderful, and there I met Boris as well as Dima, our co-host this time around.

After the Riga workshop, I underwent in Moscow the transformation from ordinary American to official guest of the Soviet Academy. A chauffered car was made available to take me from lab to lab. Young scientists were assigned to shepherd me around. Emboldened, I decided to make a firm request. I wanted to travel to Novosibirsk by train, not by the Aeroflot flight already arranged.

No, no, they said. It's too far. Do you know how far it is, they asked? Sure, I said. About the same as from New York City to Denver, which in the USA I would never do. I'm too busy! It takes too long! But I have the time here, and I want to see your big country.

But we've no one to go with you, they said. No problem, I said. I'll be fine.

But you don't speak Russian, they said. True, I said, but I'll be OK.

Finally, my polite firmness won out, and the train travel was booked. On train number 7, the same tracks as the Trans Siberian Railway, I'm told. A soft car, with me alone in the compartment. A kind young Moscow physicist donated a copy of a Russian phrase book prepared in English for the Moscow Olympic Games, which the USA and some other countries had boycotted. I suppose that meant that lots of phrase books were left over.

Anyway, off I went. The view out the window of my train compartment was wonderful, and at mealtimes I did manage to find the dining car, where the kind people really looked after me. 53 hours later (I think it was), on a Sunday evening, I arrived in Novosibirsk. This turned out to be quite an event. First, no one told me that the Soviet trains traveled on Moscow time! According to the time schedule on the wall of the train, I thought I would be arriving in the afternoon in Novosibirsk. Out on the train station platform, I noticed that the sun was suspiciously low in the sky. It was definitely not afternoon. And the big digital clock on the Novosibirsk hotel did not say the time that I expected. It said 20 hours as I recall.

Moreover, as all the passengers leaving the train walked away on the platform, it became clear that no one was at the station to meet me.

What to do?

Well, having been in the USSR already for nearly two weeks, I now recognized the uniforms. I walked up to a blue one, a Militsia officer, cleared my throat, and said, "Amerikanskii. Ya na gaviru paruskii." What a look on his face. I'll never forget it! He started to speak to me in Russian, but then, realizing the futility, he stopped.

I showed him the one piece of official paper I had with Cyrillic letters on it. It was a letter written in English from the conference organizers, but it was on the official letter paper of the Institute of Thermal Physics (Institut Teplofiziki). The Militsia officer took my precious piece of paper, read the Russian top of it, and evidently got his plan. He took me to the head of the taxi queue, spoke to the taxi master, and got me put in a taxi to go to Akademgorodok. The taxi driver had my precious piece of Russian paper.

Just as the sun was nearly setting, we arrived in Akademgorodok. Of course, the taxi man took me to the institute. That was what was printed on the top of my letter. But it was Sunday night. The institute was closed! Which the taxi driver soon discovered after getting out of the taxi and knocking on the front door. He returned to the taxi, looked at me, and shrugged his shoulders, as if to say, "What now, Amerikanskii?"

Something made me think of looking in my American "Fodor's Guide" to the Soviet Union. Listed under Akademgorodok was the name of only one hotel. I said this to the taxi driver. He asked some people walking by where it was, and then quickly drove to it. It was only a block or two away.

On the outside of the hotel, I could see in English a sign that said something like "Welcome to the IXth Vavilov Conference". We had found the right place.

After a good night's sleep in my room, I was in the hotel lobby the next morning when all the Soviet scientists from Moscow showed up after their very early morning flight from Moscow. I don't recall who it was, but when one of them saw me sitting there in the lobby, all the color drained out of his face. He came up to me and said, "You're here! You weren't supposed to arrive until today! How did you get here? No one was here to meet you!"

I just smiled and said, "It's a long story, but I got here just fine last evening."

A couple of other Moscow scientists recognized me and came over to talk. I remember clearly one asked me, "You took the train all the way from Moscow. How was it?" I said, "It was wonderful." He said, "Really? I've always wanted to do this!"

That is how I got to Novosibirsk in the early days of glasnost and perestroika.

Now two short stories from the Vavilov Conference, one about Dima and one about Boris.

The Plenary Talks were held in the Large Auditorium, where earphones were supplied at every seat for simultaneous translation (just like the United Nations). If you spoke in Russian, it was translated to English, and vice versa. Well done, too. The translators must have known some science because they seemed very good to me.

The Seminar talks that were held in the evening, upstairs in smaller rooms, were different. I still have the conference program, and the following occured on Thursday evening in the seminar "Rydberg states and strong field". The session chairman, listed in the program as I.M. Beterov, opened the session in English and asked all speakers to give their talks in English because of the Americans and other foreign scientists present, even though we were fractionally small in number. Well over 90% of those in the room were Russian speakers! In the middle of Siberia, I was surprised.

The first speaker was Dima Shepelyansky, and as always, he did very well, both with the science and with the English. The second speaker was Nikolai Delone, from Moscow, who speaks French well but not English. He said a few words in Russian to Dima, and Dima announced, in English, that the speaker, Delone, would speak in Russian but had asked Dima to translate into English. Dima had evidently not expected this, but he agreed to do so.

I remember Nikolai's talk well. He used lots of words but only one transparency. After every minute or so of talking, he would stop for Dima to translate. Dima would say, "The speaks says blah blah blah ... ." Dima was evidently struggling, not with the English but to understand just what the science was he was supposed to be translating. During the third or fourth chunk of Russian that Nikolai presented, I saw a pained look come on Dima's face. It was clear why Dima looked this way, because he opened the translation of this part by saying, "The speaker says, but I do not agree with this part! ... ." The words coming out of Dima's mouth were Nikolai's, but Dima could not agree with them and wanted to make sure that the audience knew this.

As I recall, it was the next Russian speaker who started his talk with a few words of English that said, "I am Russian. I do not speak English well. I will not give my talk in English. I will give my talk in Russian!" He must have said this in Russian immediately after this, because these words brought a cheer from the audience. Another Russian Revolution! But this time, no fighting nor bloodshed.

As it happened, I was sitting next to Boris at this seminar, so Boris just leaned over to me and whispered in my ear, "I will translate for you." And so he did, most skillfully summarizing in a few words the important point after each few sentences of the speaker.

I don't recall if it was our revolutionary speaker or the next Russian one when the following happened. The speaker began, in Russian, and Boris started translating for me. After a few minutes into the talk, Boris leaned over especially close and whispered to me something like, "The speaker is very confused and doesn't understand what he is talking about, so I will stop translating what he is saying."

Now, let me tell you, this is an efficient way to attend a seminar: not only simultaneous translation, you also get an analog filter on the science! Boris is not one to avoid voicing his opinions.

Nor is Boris one to avoid making insightful decisions, as the early part of his career shows. We know Boris as a theorist, indeed the Director of the Theoretical Division of the Institute of Nuclear Physics. But I find it fascinating that he started his career as an experimenter!

In his 5th year of studies in what became the Moscow Physicotechnical Institute, he was a student-apprentice researcher in the Heat Engineering Lab, now called the Institute of Theoretical and Experimental Physics. After graduation around 1952, he was invited to remain there. His project involved a Wilson cloud chamber for high energy particle tracking and identification. You recall, photographs were taken of tracks of droplets that formed in the supersaturated vapor after the passage of ionizing radiation. The photographs had to "scanned", work that was tedious and time-consuming for the girl technicians. Boris's simple, time-saving proposal was they should count the number of gaps. This was statistically related to the number of drops, but it could be done more quickly.

As Boris told us yesterday, he agreed to transfer in 1954 to what was later called the Kurchatov Institute of Atomic Energy. Actually, he was recruited there by the theorist Andrei Mikhailovich Budker, who had earlier taught the student Boris.

With his first research student Volosov, Chirikov did crucial experiments on the limiting current of electron beams. It was here that Boris's interests in nonlinear phenomena and stochastic processes began.

In 1958 Budker was selected to form the new Institute of Nuclear Physics at the new Akademgorodok (Academy City) being constructed outside Novosibirsk, and the actual move there two years later took the team, including Chirikov, to Siberia.

Boris first presented his results on the stochastic instability of magnetically confined plasma at the Kurchatov seminar in Moscow in 1958, when the plasma research was classified secret. Only after the London plasma conference of 1958 did the results become public, and Kurchatov ordered the plasma results to be published quickly. This led to Boris's celebrated 1959 theoretical paper in a special issue of the journal Atomic Energy. Boris had started his career as an experimenter, but the world would now know him as the theorist who invented the resonance overlap criterion.

What you may not know is the story of the writing of the paper in the same journal issue that describes the related plasma experiments of S. Rodionov. Though Rodionov's name appears as the sole author, the paper was written by Chirikov.

Why? The story goes that Rodionov had broken his right hand (probably during skiing) and was in the hospital. Boris was ordered by the KGB to take his secret notes, go to the hospital, and write the paper from the words of Rodionov. The KGB orders included that Boris take a weapon, a revolver, to ensure the security of the secret documents, but Boris refused, arguing that it would be too dangerous to take a revolver on the public buses that, in those days, were always very overcrowded with people. Finally, the KGB agreed that Boris would not have to carry the revolver, but he was oblighed to return all his notes, including the "Rodionov manuscript" back to the secure place.

What we now all know as the "Chirikov resonance overlap criterion" came as a result of Boris's generalizing the theoretical analysis he had first performed for the stochastic instability of confined plasma. Apparently, the first full experimental confirmation of Boris's criterion came at the end of the 1960's, with experiments in Novosibirsk on circulating electron beams.

Chirikov's later widespread and continuing interactions with Western scientists was certainly stimulated by the pioneering results of Chirikov that, fortunately, were published in the open literature and that I have decribed briefly. However, how each of Boris's personal relationships with Western scientitsts began and developed depended, of course in those times of Cold War, on the occasional interruption by more openness.

Boris's long association with Joe Ford of Atlanta, USA, began when Boris and Joe met at a conference in Kiev in 1966. We are all sad that Joe is no longer with us and cannot be here.

Alerted by Ford, Giulio Casati from Milano visited Novosibirsk in 1976 and began a long collaboration with Chirikov and his students that continues up to the present day. As we all know, this circle even widened to the younger associates of Ford in the USA and Casati in Italy.

Let me begin to close by reading some of the reminiscences sent to me on July 3rd by another of Boris's many friends and collaborators, Andy Sessler of the Lawrence Berkeley Laboratory in the USA. As it turns out, Andy is, this year, President of the American Physical Society, but it is clear that his remarks are of a personal nature.

I shall read from Andy Sessler's remarks, a copy of which I have just given to Boris:

I first met Boris in March of 1965 when Budker invited a small number of people (about 12) to Novosibirsk to discuss the technical aspects of storage rings. At that time he told me about his new work, which was unpublished (I believe) at that time and has subsequently become known as the 'Chirikov criteria'.

We 'hit it off together' and ever since then have been good friends. At that time we did a number of 'fun things' like spending evening Under The Integral Sign (a scientific club; really an eating club and night club) and also going cross country skiing. To do that one checked out skis, of course free in those Soviet Days, and that was done one afternoon. Then, the next day, we went to the ski area. The ski area was a small hill (this was Siberia) covered with pine trees. The Soviets could change direction while going down hill, but the Americans were doing their best just to stand up on their skis. That meant that in order not to hit a tree you had to point your skis correctly, before you started down the hill, to about a milliradian. I was doing that fine through most of the afternoon, but then I mis-calculated and hit a tree. I broke the tip of the ski off (and was damn fortunate not to have broken anything else) and remember walking, through deep snow, for what seemed like miles and miles. For many years I had the ski tip as a souvenir of my first meeting of Boris.

Some time later, in 1967, I was spending the year at CERN and Boris visited us. My chance to get even. I suggested that we go to Zermat and do a bit of real (down hill) skiing. So my family (5 of us) and two Soviets, Boris and Ben Sidorov (now deputy director of the Budker Institute), piled into my car and drove from Geneva to where one takes the train to Zermat.

The next day was terribly cold and everyone, except Boris, decided not to try and ski. Boris was not going to miss out on anything and I, as host, felt I must go with him. Me in lots of down and him in a simple sweater. Well, it was really cold. We rode the lift up, skied down and when I took off my gloves my fingers were all white. Boris rushed me to a first aid station and proceeded to rub snow on my hands. Well, he saved my fingers, sent me in for the day, and continued to ski all day, coming in, at the end of the day in fine form.

Through the years we continued to send cards (as well as scientific papers) and I remember one where Boris said it was 40 below and he had stopped skiing. Not to be out done, I sent back a card saying that the Soviets might stop at 40, but Americans certainly kept skiing. He then wrote back saying that I didn't understand: it was the skis that stopped working when it got so cold."

Boris and I, did, once write a paper together. Well, Boris really did all the work, but I do remember a very pleasant day working–for some reason– in his kitchen. Boris had the idea that there hadn't been a paper since World War II co-authored by a Russian, German, and American. (I don't know if this was true or not, but it was an interesting thought.) So, we invited Eberhard Keil into the collaboration."

Once, Boris's wife, Olga, was 'allowed', I think that is the right term, to go on a vacation consisting of a cruise on the Black Sea (and maybe also the Mediterranean). The cruise was for artists (she was a well-known opera singer). The first leg consisted of air to Moscow and it was arranged that she and I went together. In Moscow she escorted me around, including a very lengthy tour–and very special tour led by a friend of hers–to the Tretyahov Gallery. All very good, but she didn't know a word of English and I don't know a word of Russian; we just smiled at each other for a few days."

Boris, I hope you have a great time at this Conference at which your 70th birthday (how can we all be so old so soon?) is properly noted. The honor is richly deserved. I feel touched to have had my life touched by you."

—– Andy Sessler

And now, I will close my talk directly to Boris:

Boris Valerianovich, my vashi druzya zhelaem vam prodolzhat' prodvigatsya po puti resheniya fundamentalnykh problem.

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List of Contributions to the Volume

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18. *Quantum Chaos in Quantum Wells*
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23. *Quantum fractal eigenstates*
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24. *Cantori and dynamical localization in the Bunimovich Stadium*
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25. *Remarks on Boris (a Russian) by Peter (an American) in Toulouse (France): Yes, physics is international ! (unformal Conclusion)*
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