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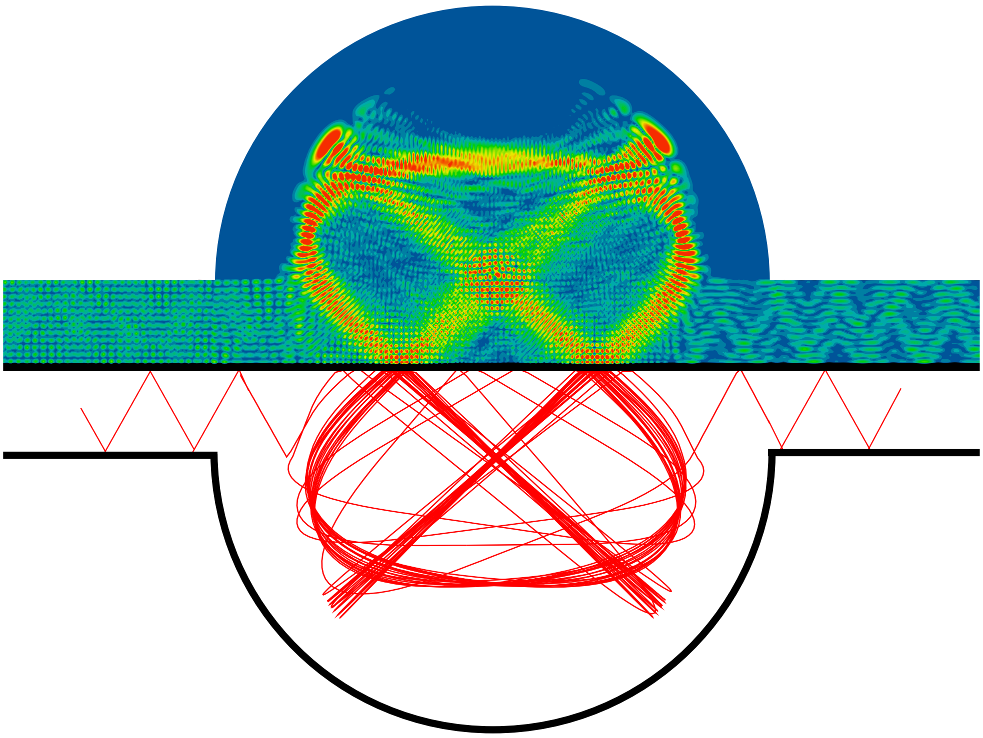
INSTITUTE FOR THEORETICAL PHYSICS

Institute for Theoretical Physics
Vienna University of Technology
Annual Report 2004



Institute for Theoretical Physics
Vienna University of Technology
Annual Report 2004

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The image on the cover shows the density of a quantum state (top) and a corresponding classical trajectory (bottom, mirror image) in a "quantum dot". The electron is injected from the left and gets trapped in the vicinity of a periodic orbit. This phenomenon is reflected in the quantum wavefunction in terms of a pronounced density enhancement around this "pretzel"-shaped trajectory. Numerical calculations allow to study in detail the quantum-to-classical correspondence in such mesoscopic devices which have been realized experimentally. For details see B. Weingartner et al., Phys. Rev. B 72, 115342 (2005).

Institute for Theoretical Physics, Vienna, October 2005

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Chapter 1

Executive Summary: Key data 2004

• **Positions:**	Faculty positions: [a]		**14,5**
	Externally funded scientific staff:		**34**
• **Budget:**	Operating budget available to the institute:	EUR	**48.000,–**
	External funds attracted in 2004:	EUR	**368.700,–**
• **Research:**	Publications in peer-reviewed journals:		**55**
	Presentations:		**105**
	Invited talks:		**23**
• **Teaching:**	Course hours/week taught by faculty during the academic year 2003/04:		
	Mandatory core courses:		**30**
	Special lectures:		**416**
	Total:		**446**
• **Degree Awarded:**	Diploma:	2004:	**12**
	Ph. D.:	2004:	**5**

(a) 2 of which are vacant

Foreword by the Institute Director

Joachim Burgdörfer

The year 2004 was undoubtedly in many ways a year of change.

As a result of the implementation of the new Austrian University legislation (UG2002), 2004 has seen dramatic changes of our University of Technology and of our Institute for Theoretical Physics along with it. The newly conferred increased autonomy, as much welcome as this step might have been, came at the price of a grossly inadequate budget allocation that translated into Draconian cuts of expenditures at all levels. The switch to a new organization and business model of operation without well-planned implementation and with a poorly designed business software lead to a state which could be politely described as less than creative chaos. It placed a heavy burden on our administrative staff, Mrs. Mössmer and Mrs. Unden, who handled this challenge with great fortitude and proficiency.

It is all the more remarkable that despite these adverse circumstances the core mission of our institute, excellence in research and teaching, did not suffer a major setback. The key data summarized in the executive summary attests to the high quality and productivity of the institute. 55 publications in international scientific journals (i.e. 4.5 publications per faculty member and year), a significant presence at international conferences with more than 100 contributions, many of which invited, and the award of 17 academic degrees under the supervision of our faculty members document these efforts impressively. Last but not least, the fact that externally attracted funding exceeded our basic operating budget by a factor 8 is not only a noteworthy achievement for a theory institute but testifies to the level of recognition our work enjoys with funding agencies and international peer reviewers. I would like to express my thanks to all staff members for their important contributions and their enthusiasm that helped to keep up this level of productivity.

The year 2004 brought another profound change to our institute. After 36 years of outstanding service as a full professor at this institute and the university at large, Prof. Wolfgang Kummer was promoted to Professor Emeritus effective October 1, 2004. Prof. Kummer, together with the late Prof. Hittmair, formed the nucleus around which the Institute for Theoretical Physics expanded and rose to its current status. The importance of his contributions to the growth and visibility of theoretical physics at our university as well as in Austria can hardly be overrated. The institute wishes him well for his new career as an emeritus and continues to count on his wise counsel and on his further contributions to research and teaching.

As a consequence of this change another change came along: I have been appointed director of our institute by our Dean, Prof. G. Badurek, effective January 1,2004.

Finally, also the layout of our annual report underwent a change long overdue. In line with the strong international connections our institute has developed over the years, it is now published in English. Moreover, we have attempted to shift the focus to physics highlights and relegate the inevitable statistical data to an appendix. I would like to thank Rainer Dirl and Elfriede Mössmer for their efforts to make this happen.

Chapter 2

Research

The purpose of this report section is to feature a few research highlights during the year 2004. It is meant as an "appetizer" and is, by no means, complete. A complete listing of published and presented research results are given in the appendix. Interested readers are referred to the web page of the institute (http://tph.tuwien.ac.at/) where more information can be found.
The research program at our institute is characterized by a remarkable diversity covering a broad spectrum of topics ranging from high-energy physics and quantum field theory to atomic and condensed matter physics. As a focus area, non-linear dynamics of complex systems including aspects of quantum cryptography and quantum information plays an important role. Many of the research topics make use of and belong to the subdiscipline "computational physics". Keeping the available and accessible computer infrastructure competitive remains, in view of budgetary constraints, a constant challenge.

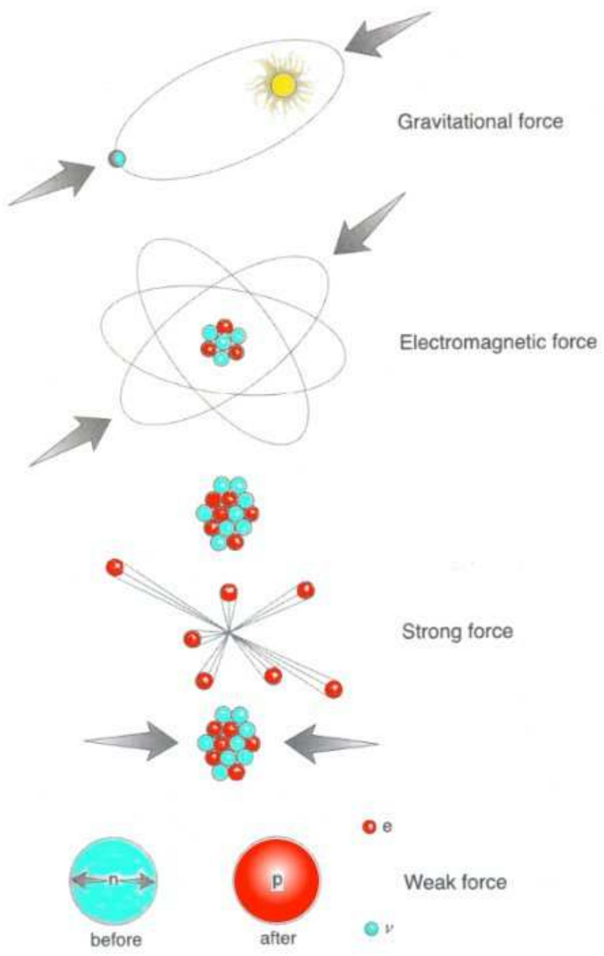
The breadth of activities at our institute provides advanced students as well as young researchers with the opportunity to be exposed to a multitude of state-of the art research directions and to receive a broad-based academic training. It is our intention to maintain and further develop our institute as an attractive place of choice for aspiring students and post-docs. The few highlights featured below may convey this message.

Vienna, October 2005

Joachim Burgdörfer
(Head of Institute)

2.1 Fundamental Interactions

According to our present knowledge there are four fundamental interactions in nature: gravity, electromagnetism, weak and strong interaction with electromagnetism and weak interaction unified in the electroweak theory. Gravity as well as electromagnetism are macroscopic phenomena, immediately present in our everyday life, like falling objects and static electricity. Weak and strong nuclear interactions, on the other hand, become only important on the microscopic, atomic and subatomic level.



Schematic presentation of fundamental interactions

The most important aspect of the strong interaction is that it provides stability to the nucleus overcoming electric repulsion, whereas the transmutation of neutrons into protons is the most well-known weak phenomenon. The aim of fundamental physics may be described as obtaining a deeper understanding of these interactions, and penultimately finding a unified framework, which understands the different interactions as different aspects of a single truly fundamental interaction.

2.1.1 Quantum field theory and non-commutative geometry

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Describing the interactions on a more fundamental level the concepts of relativistic quantum field theories are employed. With the advent of quantum mechanics in the first decades of the 20th century it was realized that the electromagnetic field, including light, is quantized and can be seen as a stream of particles, the photons. This implies that the interaction between matter is mediated by the exchange of photons. The concept of relativistic quantum field theory is very simple, unifying a classical field theory with the concepts of quantum theory and special relativity.

Within quantum electrodynamics (QED) - a unified quantum theory of Dirac particles (fermions) and photons (bosons) - the forces between fermions are realized by the exchange of massless photons. Additionally, QED is characterized by gauge invariance. It turns out that also the strong and weak forces can be formulated in terms of quantized gauge fields. This implies the existence of quantized non-Abelian gauge theories - a generalization of the quantized Maxwell theory containing self-interactions of the gauge bosons. The quantum field theory for the strong interaction is quantum chromodynamics (QCD) which also allows to form strongly bound states. The weak interactions are mediated by the exchange of massive gauge bosons with very short ranges.

The second half of the last century was dominated by the quest for a unified quantum gauge field theories leading to the Glashow-Weinberg-Salam model, the Standard Model. In the realm of string theories and with the concepts of supersymmetry also gravity may be included in the unification. An important concept in any quantized field theory is its perturbative realization with quantum corrections described in terms of Feynman-graphs. The Figure below contains all one-loop corrections of the propagation of a nonabelian gauge boson (vacuum polarization). The wavy line represents the gauge field propagator which describes the free propagation.

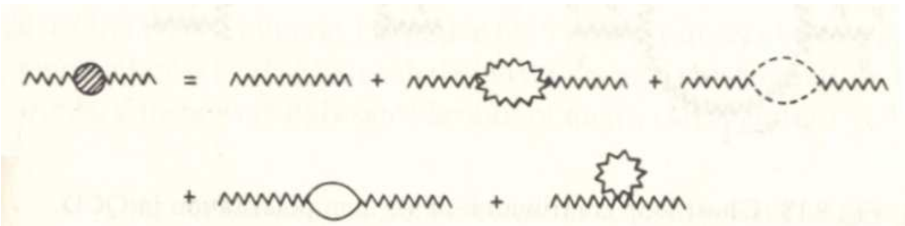

Fig. 1: Full propagator in terms of free propagation and self-energy corrections

The one-loop corrections contain products of propagators, i.e. products of distributions. Since such products are ill-defined also the corresponding Feynman-integrals in the momentum representation are divergent for high internal loop-momenta leading to the so-called ultraviolet (UV) divergences. These UV infinities demand a regularization scheme characterized by cutoffs in order to make the Feynman integrals meaningful and a corresponding renormalization program for the definition of physical quantities (physical masses, wave-functions renormalization and renormalized couplings) is needed.

The appearance of the UV singularities is caused by the fact that the interactions vertices are described by local field products if the underlying geometry is commutative. It was suggested very early by Snyder [1] in the pioneering days of quantum field theory that one could use a noncommutative structure for space-time coordinates at very small length scale to introduce an effective UV cutoff. This was motivated by the need to control the divergences of quantum loop-corrections.

Noncommutative Quantum Field Theory (NCQFT)

In describing fundamental physics space and time are unified by the principle of Special Relativity into a four-dimensional space-time: $x^\mu = (ct, \vec{x})$. Usually, one assumes that the x^μ are ordinary commuting 4-dimensional coordinates leading to the concepts of commutative geometry. In the context of commutative geometry one can discuss the fundamental interactions.

However there are many hints that the concepts of space-time as a differentiable manifold cannot be extrapolated to the physics at short distances. Simple heuristic arguments forbid a naive unification of the principles of General Relativity with local quantum theory. It is impossible to locate a particle with an arbitrary small uncertainty. On the other hand, our understanding of the theories of fundamental interactions and General Relativity is strongly related to standard commutative differential geometry. The failure of standard commutative differential geometry demands a replacement. Following Filk [2], the commuting space-time coordinates x^μ of flat space are replaced by Hermitian operators $\widehat{\mathbf{x}}^\mu$ respecting in the simplest case the following algebra

$$\begin{aligned} [\widehat{\mathbf{x}}^\mu, \widehat{\mathbf{x}}^\nu] &= i\theta^{\mu\nu}, \\ [\theta^{\mu\nu}, \widehat{\mathbf{x}}^\sigma] &= 0, \end{aligned}$$

where the entry $\theta^{\mu\nu}$ is a real, constant and antisymmetric matrix – the deformation parameter. In natural units, where $\hbar = c = 1$, its mass dimension is -2, where the relevant scale is expected to be the Planck mass. We call a space with the above commutation relations as a noncommutative space.

The construction of the perturbative NCQFT leads to new types of infrared (IR) singularities which represent a severe obstacle for the renormalization program at higher order and therefore lead to inconsistencies. The IR singularities are produced by the so-called UV finite nonplanar one-loop graphs (which are expected to be UV divergent by naive power counting) in $U(N)$ gauge models and also in scalar field theories. The interplay between expected UV divergencies and the existence of the IR singularities is the so-called UV/IR mixing problem of NCQFT. One also has to stress that the usual UV divergences may be removed by the standard renormalization procedure.

The present research activities are devoted to find solutions for the UV/IR mixing problem of noncommutative gauge field models. In order to respect the effects of noncommutativity implied by the non-abelian structure a consistent treatment requires the use of the BRS quantization procedure even for a $U(1)$ deformed Maxwell theory.

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2.1.2 Gravitation

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External: **Peter Aichelburg** (Uni Wien), **Daniel Grumiller** (Uni Leipzig), **Dimitri Vassilevich** (Uni Leipzig)

Since the groundbreaking work of Einstein, gravitation is conceived as defining the geometry of spacetime – even defining the very concepts of time and space itself. Planetary motion as well as the motion of massless particles, that is to say light, become the straightest possible paths in a non-Euclidean geometry.

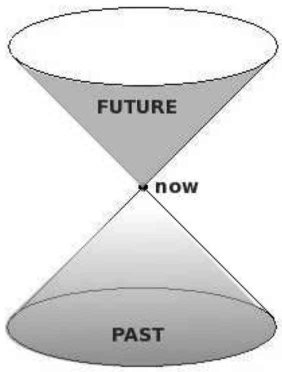

Fig. 1: Light-cone of an event representing its causal past and future

Not only geometry and curvature rely on the gravitational field. The causal structure is completely determined by the so called light-cone that separates events that can be influenced from those that cannot, thus embodying the principle of a finite maximum speed. In contrast to the usual (quantum) field theories this structure is no longer fixed, i.e. given a priori, but in Einstein's General Theory becomes a dynamical entity of its own device which is responsive to the distribution of other matter fields, resulting in the curvature of spacetime.

General relativity is a very successful theory. Its predictions range from the deflection of light by massive bodies which distort spacetime (Einstein-lensing) to that of gravitational radiation carrying away energy in the form of "ripples" in spacetime (Hulse-Taylor binary pulsar), as well as to the expansion of the universe (microwave background radiation). Still, the geometric theory of gravity suffers also from severe problems. Namely the inevitable occurrence of spacetime singularities, which was proven by Penrose and Hawking in their famous singularity theorems. Physically this means that spacetime contains regions where the curvature grows without a bound. The most prominent examples are the singularities at the "center" of black holes, where time itself comes to an end as well as the so-called initial singularity that occurs at the "Big Bang" the beginning of time. Other difficulties arise from the unification of gravity with quantum theory which governs the atomic and subatomic regime. Although several promising proposals for such a unification have been promoted, like Ashtekar's Loop Quantum Gravity and String Theory, to name just the most prominent ones, many problems have so far remained unresolved. It is therefore useful to focus on these central problematic aspects of gravity.

Distributions and General Relativity

Spacetime singularities belong to the big stumbling blocks of the classical theory and are therefore usually excluded from the definition of spacetime itself. From the point of view of quantum theory, which considers not only the classical evolution between a given initial and final three-geometry, they may just be the sheet-lightning of a change in topology of spacetime [1]. Due to their strong localization the concept of distributions (generalized functions)

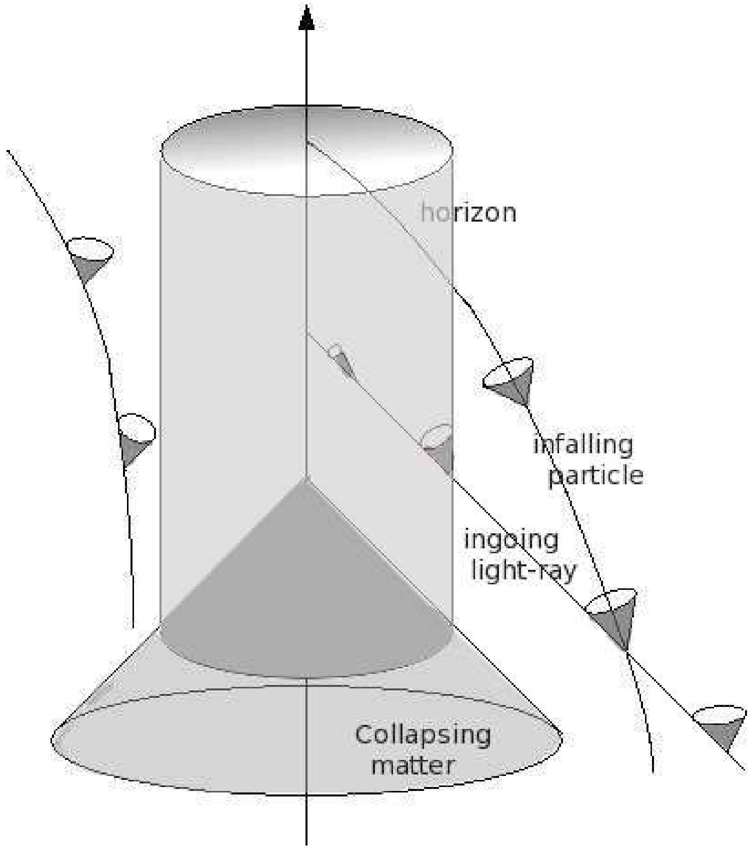

Fig. 2: Geometry of a black hole formed by a collapsing pulse of radiation.

suggests itself as the mathematical structure being able to handle these singular regions. The simplemost example of a geometry with distributional curvature may be derived from the image of a cone taken to be the limit of a hyperbolic shell whose curvature concentrates more and more on the tip. The limit geometry is flat with all its curvature concentrated in a Dirac delta-function at the location of the tip. In spite of the non-linear structure of general relativity, it is still possible to construct distributional curvature quantities associated with the singular regions and beyond of all the known stationary black-holes [2]. The discussion of a continuation of the geometry of a black hole beyond its curvature singularity has to transgress the boundaries of "classical" distribution theory and make use of the so-called Colombeau-algebra of new generalized functions [3] which allows for a systematic multiplication of distributional objects. It is therefore important, both from the quantum as well as the classical point of view, to get a better understanding of these structures.

Two-dimensional Quantum Gravity

Deeper insights into the structure of physical systems have often been achieved by the imposition of symmetries.

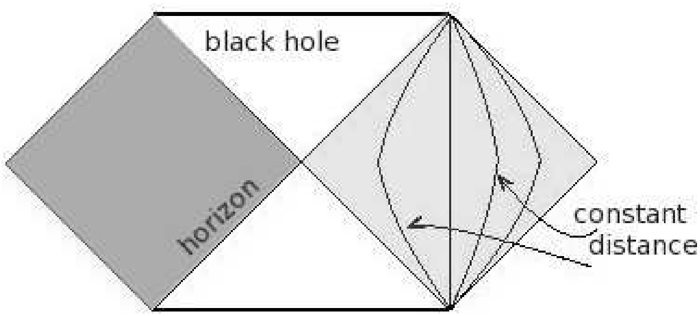

Fig. 3: Spherically symmetric black hole.

This usually breaks the problem down into simpler building blocks which ideally allow a complete solution. Gravity is no exception to this rule since the prototypic black-hole solution, the Schwarzschild geometry (actually the first exact non-trivial solution of the Einstein-equations), has been found precisely along theses lines, i.e. upon imposing spherical symmetry.

It is therefore natural to pursue a similar plan of attack for the quantization of gravity. The corresponding models become gravitational theories in a 1+1 dimensional spacetime coupled to the area of the two-sphere which becomes a dynamical variable in the reduced theory. As shown by work in our group in the absence of additional matter all such models turn out to be exactly soluble classically and allow even a background independent ("exact") quantization in terms of the so-called first order formalism, which takes the normalized dyad and its parallel displacement as fundamental variables [4]. Coupling to matter allows the description of scattering within an exactly soluble gravitational sector thereby leading to the concept of virtual black holes, as intermediate states, which hopefully sheds some light on the process of Hawking-evaporation of four-dimensional black holes [5]. The richness of the two-dimensional structure allows also the discussion of a supersymmetric extension of the original dilaton model thereby incorporating fermionic degrees of freedom in a particularly natural form. Here new insights regarding closely related problems in String Theory have been gained [6].

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2.1.3 Quark-Gluon plasma

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Quantum chromodynamics (QCD) is the accepted theory of the strong interactions responsible for the binding of quarks into hadrons such as protons and neutrons, and the binding of protons and neutrons into atomic nuclei. The fundamental particles of QCD, the quarks and gluons, carry a new form of charge, which is called color because of its triplet nature in the case of the quarks (e.g. red, green, blue); gluons come in eight different colors which are composites of color and anticolor charges. However, quarks and gluons have never been observed as free particles. Nevertheless, because quarks have also electrical charge, they can literally be seen as constituents of hadrons by deep inelastic scattering using virtual photons. The higher the energy of the probing photon, the more do the quarks appear as particles propagating freely within a hadron. This feature is called "asymptotic freedom". It arises from so-called nonabelian gauge field dynamics, with gluons being the excitations of the nonabelian gauge fields similarly to photons being the excitations of the electromagnetic fields, except that gluons also carry color charges. Asymptotic freedom is well understood, and the Nobel prize was awarded to its main discoverers Gross, Politzer, and Wilczek in 2004.

Much less understood is the phenomenon of "confinement", which means that only color-neutral bound states of quarks and gluons exist. This confinement can in fact be broken in a medium if the density exceeds significantly that of nuclear matter. When hadrons overlap so strongly that they loose their individuality, quarks and gluons come into their own as the elementary degrees of freedom. It is conceivable that such conditions are realized in the cores of certain neutron stars.

Moreover, lattice gauge theory simulations have demonstrated that deconfinement also occurs at small baryon densities for temperatures above approximately 2×10^{12} Kelvin, corresponding to mean energies of about 200 MeV. According to the Big Bang model of the early universe, such temperatures have prevailed during the first few microseconds after the Big Bang as shown in Fig. 1.

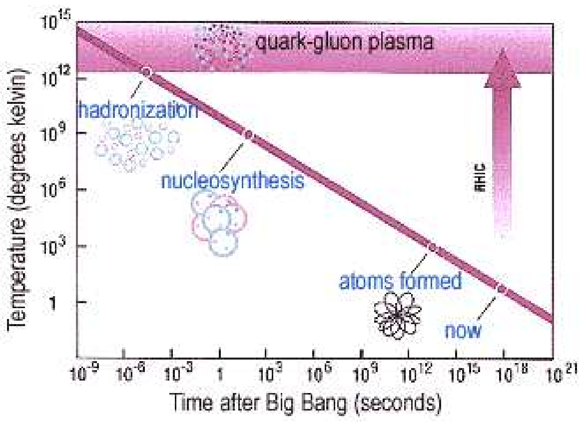

Fig. 1: Thermal history of the Universe from the time when it was filled by a quark-gluon plasma until now.

At present there are experiments being carried out in the Relativistic Heavy Ion Collider (RHIC) at the Brookhaven National Laboratory, where a tiny fire-ball with temperatures larger than the deconfinement temperature can be produced and the resulting "quark-gluon plasma" [1] can be investigated. Starting in 2007, similar experiments at even larger energies and thus higher temperatures will be carried out at the European collider center CERN in Geneva. There is now ample evidence for the generation of a new state of matter in these experiments, although much remains to be understood.

One recent problem is the surprisingly fast apparent thermalization of the quark-gluon plasma. This seems to be much faster than can be accounted for by calculations of elastic and inelastic scattering events. A possible explanation is that what is being observed experimentally is just early isotropization. The latter could be due to nonabelian variants of plasma instabilities that are familiar from ordinary plasma physics [2]. First results from our group which support this picture have already appeared in the 18 March 2005 issue of Physical Review Letters [3]: Numerical simulations of collective chromomagnetic and -electric fields in an anisotropic quark-gluon plasma show exponential growth of unstable modes which in the nonlinear regime lead to complicated dynamics, eventually leading to fast isotropization of the plasma. Fig. 2 visualizes the color degrees of freedom in collective fields as they evolve from initial fluctuations. The horizontal axis is the spatial direction in which there is momentum-space anisotropy in the plasma. Time flows from bottom to top, with initial conditions (at the bottom) corresponding to random color fluctuations in initially tiny collective fields.

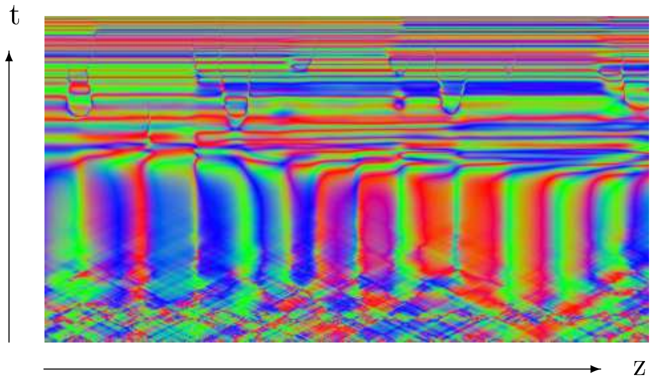

Fig. 2: The time evolution of the color degrees of freedom in the chromomagnetic field associated with instabilities in an anisotropic quark-gluon plasma. The horizontal axis is the spatial direction (z) in which there is a momentum-space anisotropy in the quark-gluon plasma.

In this plot one can see how the initial random fluctuations are swamped by the exponentially growing collective modes which involve a characteristic wavelength and locally fixed color charges (the amplitudes of the fields are not shown). After these perturbations have grown such that nonabelian self-interactions come into the play, there is rapid color precession in time (upper half of the plot), and a certain amount of spatial "abelianization" (i.e. finite domains of fixed color). The crucial finding, which cannot be read from this plot, is that exponential growth of these intrinsically nonabelian plasma instabilities continues until the collective fields give significant backreaction on the plasma constituents, rapidly eliminating their momentum-space anisotropies. This isotropization is much faster than the processes leading to thermalization, which occur somewhat later in the evolution of the fireball created in relativistic heavy-ion collisions.

After local thermalization has taken place, the physics of hot and dense quark-gluon matter can be described by the following sketch of a phase diagram,

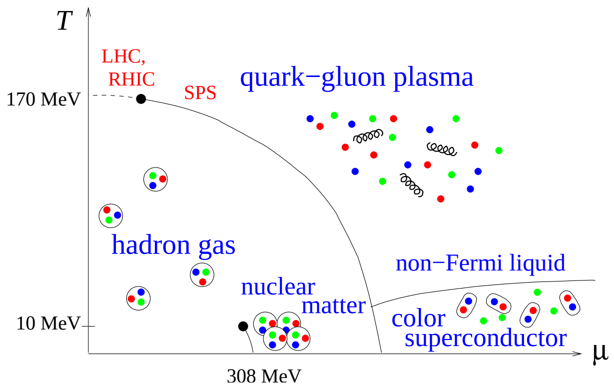

Fig. 3: Qualitative sketch of the phase diagram of quark-gluon matter as a function of temperature T and quark chemical potential μ. Solid lines denote first-order phase transitions, the dashed line a rapid crossover.

where T is the temperature in MeV (1 MeV $\approx 10^{10}$ K), and μ is the quark chemical potential characterizing the density of net baryon number. (Nuclear densities correspond to about 308 MeV quark chemical potential.) “SPS, RHIC, and LHC” mark the regions of this phase diagram accessible by the older CERN experiment SPS, the present RHIC collider in Brookhaven, and the future LHC collider at CERN.

A main activity of our group is the development of improved analytical techniques to calculate the thermodynamical properties of the quark-gluon plasma [4]. One focus is on properties at small μ and high temperatures, which are relevant for relativistic heavy ion colliders and the physics of the early universe. Another case of interest is high μ and smaller temperatures, which is of relevance to the physics of neutron stars and proto-neutron stars.

At comparatively low temperatures, quark matter is known to form Cooper pairs and turns into a color superconductor [5]. Also at temperatures just above the superconductivity phase new phenomena appear, which reflect that quark matter has strong deviations from an ideal Fermi liquid. In particular, there is anomalous behaviour in the low-temperature specific heat, which has been calculated for the first time systematically by our group [6]. This has already found application in revised calculations of the cooling behavior of young neutron stars [7].

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2.1.4 String theory

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The names of the fundamental forces are related to their strength. The strong force is much stronger than electromagnetism and is thus able to overcome the repulsive force between objects with the same electrical charge (protons or quarks). The weak force is weaker than electromagnetism but still much stronger than gravity. The reason that we almost only recognize gravity in everyday life is that the macroscopic objects are neutral. They don't carry an effective color charge and they carry - if at all - only very small electric charges. For gravity there is no negative charge (negative mass), so that all the small gravitational effects add up to something which is strong enough to move galaxies and build black holes. The seperate description of the forces is quite accurate by now. This is summarized in the standard model of particle physics.

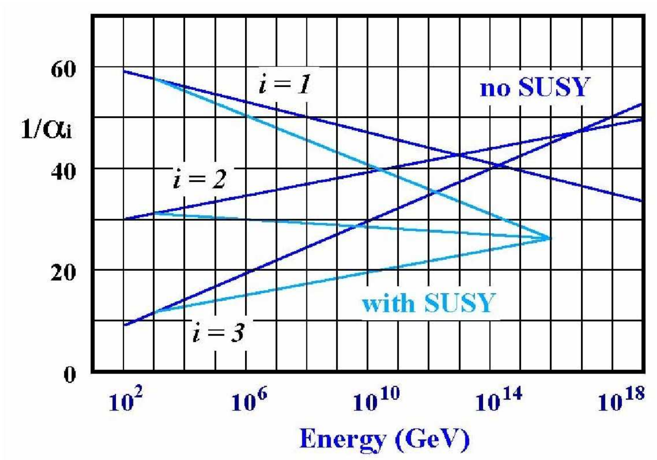

Fig. 1: Grand unification. i=1: Electromagnetism, i=2: weak interactions, i=3: strong interactions

There is only one particle (the Higgs boson), which is predicted by the standard model and has not yet been found. A measure for the strength of a force are the coupling constants of the corresponding theory. They are, however, not constant, but depend on the energy level one is dealing with. If one extrapolates their values to high energies, one discovers that the couplings of electromagnetism, strong and weak force meet at a certain energy level almost in one single point (see Figure 1). This supports the idea that those three forces could be just different aspects of one and the same universal force. There are several theories which try to describe this unification. They are called GUTs, 'grand unified theories'. However, to be really 'grand', such a unification should also include gravity, whose coupling constant is far weaker still at this high energies. The theory, which will manage to unify all forces, including gravity, is sometimes called TOE, "theory of everything". String theory is one candidate, and at present actually the only one for this TOE.

Before going to explain a little bit what string theory roughly is, let us have a second look at Figure 1, where it is shown that with 'SUSY', the lines not only almost meet in one point, but they meet exactly (within present precision) in one point [1]. 'SUSY' stands for supersymmetry and means that there is an exchange symmetry between fermionic particles (like quarks and electrons) and bosonic ones (like photons and even gravitons, if one includes gravity into the considerations). It does, however, not relate the already known particles, but it predicts new supersymmetric partners to the known particles (called e.g. squarks, selectrons, photinos and gravitinos). So far none of those superparticles has been discovered, but there are a lot of theoretical reasons for believing in supersymmetry, one of them being Figure 1. Supersymmetry is an integral part of string theory, or more precisely 'superstring theory'. In about two years, the new accelerator LHC (large hadron collider) at CERN will start and try to produce the Higgs boson and the superparticles mentioned above and will therefore also be a first test for string theory.

Gravity is described by Einsteins General Relativity which explains the gravitational force as being an effect of curved space-time. It is an extremely beautiful, successful and revolutionary theory, but it is classical in the following sense: the gravitational field is smooth and one can in principle measure arbitrarily small distances. However, time evolution of the gravitational field is governed by the matter content - or more specifically - by the fields that are described by the Standard Model. The Standard Model, on the other hand, describes quantum fields, i.e. the fields consist of quanta - the particles - whose position and momenta underly Heisenbergs uncertainty relation. In a macroscopic limit, one can still think of the fields being classical smooth fields and for this reason General Relativity is extremely successful in describing large scale physics. But to avoid inconsistencies, one needs - in order to consider extreme situations like black holes correctly - to treat the gravitational field as a quantum field as well as described earlier. There is a standard procedure how to make quantum fields out of classical ones. This procedure, called quantization, unfortunately fails for gravity. The reason is that interactions of point particles produce singularities (infinite values in at least intermediate steps on the way to compute probabilities of particle collisions). Those singularities can be dealt with in the standard model, but the standard (perturbative) approach fails for 'quantum gravity'.

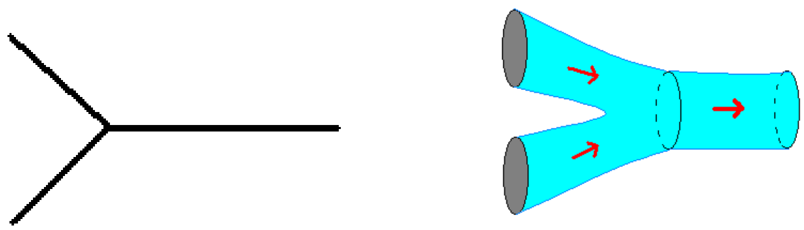

Fig. 2: Left: Point particle interaction, Right: Closed string interaction, note the smooth interaction surface

It is thus reasonable to avoid those singularities from the beginning by treating the elementary objects not as point particles, but as extended objects, which are called strings [2]. In Figure 2 one can see that the collision of two strings - joining to a single one - produces a smooth surface, while the same process for point particles is not smooth and therefore produces singularities. Considering a string instead of a point particle is a simple idea, but it has extremely far-reaching consequences. The first consequence is that a string has more degrees of freedom. It can oscillate in different modes like a guitar string. The different tones then correspond to different particles which makes it possible to describe the complete spectrum of particles by one fundamental object! While taking open or closed strings as starting point apparently leads to different string theories with different particle spectra, the very same string can start as an open one and become a closed one during some scattering processes.

According to an old idea of Kaluza and Klein (KK) it should be possible to describe also the other forces in a purely geometrical way, as it was done for gravity. Indeed they managed to produce electromagnetism by starting with a five dimensional gravity and then curling up one dimension on a very small radius, so that gravity effectively becomes four-dimensional. Components of the gravitational field belonging to the fifth dimension then show up as an electromagnetic field. The KK method needs 11 dimensions in order to describe all the fundamental forces but it never worked out to give the correct matter content. Superstring theory, on the other hand, *predicts* ten dimensions. Hence one has to curl up six dimensions in order to end up with a four-dimensional observable space-time. In contrast to point particles, strings have the new feature that they can wind around the curled up dimensions, thus extending the spectrum of physical states. When string theory is compactified on a circle there is a 'dual' inverse radius for which we obtain exactly the same spectrum of particles, so that the full quantum theory is indistinguishable from the first one. This implies a smallest observable scale, a feature that should be expected from any consistent quantum theory of gravity. Going below that scale would mean that one ends up with something that is actually bigger!

This is only one example of a number of dualities connecting string theories that are at first sight completely different. The above radius duality led to the discovery of other extended objects, which are not just strings but can have more dimensions and are called D-branes. They are dynamical objects on which open strings end. Gauge fields, the fields that also appear in the standard model, are restricted to those D-branes, while gravity is diluted because it can spread out into ten dimensions. This would explain the large difference between the values of the coupling constants of the standard model and of gravity, respectively: we are just living on a brane!

The duality mentioned above, relating big and small radii, can be generalized to curved spaces and is then called mirror symmetry. The curled up six-dimensional spaces have to fulfill certain properties and are mathematically called Calabi-Yau spaces. A major work of our group goes into examining and classifying those Calabi-Yau spaces [3], exploring the consequences of dualities [4], and physical properties of D-branes [5] in there.

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2.2 Nonlinear Dynamics, Physics of Complex Systems

2.2.1 Quantum information

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Suppose we would be able to unleash the power of the quantum world in ways which would have been unthinkable only a few years ago. For instance, we could use quantum superposition, the possibility for a quantum bit to contain all conceivable and mutually excluding classical states in itself. Then, in a single computational step, we could realize the parallel processing of all these classical states, whose number grows exponentially with the number of classical bits involved, through the quantum state evolution of this single state. That is the vision of quantum parallelism, which is one of the driving forces of quantum computing, and at the same time one of the fastest growing areas of research in the last decade or so. These strategies have all been made possible with new techniques capable to produce, manipulate, and detect single quanta, such as photons, neutrons and electrons.

There are other prospects as well. Quantum processes and in particular the quantum state evolution in-between irreversible measurements are one-to-one, i.e., reversible. The "message" encoded into a quantum state merely gets permuted and transformed such that nothing gets lost. Thus, processes such as state copy or state deletion, which appear so familiar from classical computing, are not allowed in quantum information theory. Copy, for instance, is one-to-two, or one-to-many. Deletion is many-to-one. As a consequence, information transmission has to rely on processes which are strictly one-to-one. This elementary, innocently looking fact of quantum state evolution, can be put to practical use in areas such as cryptography, where it is tantamount to keep a secret secret; i.e., by not allowing potential eavesdroppers to divert, copy, and resubmit messages. Actually, quantum cryptography uses another mind-boggling quantum feature: complementarity; the impossibility to measure all classical observables of a state at once with arbitrary accuracy. So it is the scarcity of the quantum processes which could be harvested for new technologies. Even potential cryptanalytic techniques – such as man-in-the-middle attacks on quantum cryptography – could be perceived as a challenge to cope with the structure of the quantum world in detail.

The basis of these potential exciting new technologies is the quantum world and its relation to the performance of classical systems. Already George Boole, one hundred and fifty years ago, mused over issues which became most important today. He figured out that there are some constraints on the joint frequency of classical events which come from the requirement of consistency.

Suppose someone claims that the chances of rain in Vienna and Budapest are 0.1 in each one of the cities alone, and the joint probability of rainfall in both cities is 0.99. Would such a proposition appear reasonable? Certainly not, for even intuitively it does not make much sense to claim that it rains almost never in one of the cities, yet almost always in both of them. The worrying question remains: which numbers could be considered reasonable and consistent? Surely, the joint probability should not exceed any single probability. This certainly appears to be a necessary condition, but is it a sufficient one? Boole, and much later Bell – already in the quantum mechanical context and with a specific class of experiment in mind – derived constraints on the classical probabilities from the formalization of such considerations. In a way, these bounds originate from the conception that all classical probability distributions are just convex sums of extreme ones, which can be characterized by two-valued measures interpretable as classical truth values. They form a convex polytope bounded by Boole-Bell-type inequalities.

Remarkable, quantum probability theory is entirely different from classical probability theory, as it allows a statistics of the joint occurrence of events which extends and violates Boole's and Bell's classical constraints. Alas, quantum mechanics does not violate the constraints maximally, quantum bounds fall just "in-between" the classical and maximal bounds.

The question is: how much exactly and quantitatively does quantum mechanics violate these bounds? We have derived numerical as well as analytical bounds on the norm of quantum operators associated with classical Bell-type inequalities can be derived from their maximal eigenvalues. This quantitative method enables detailed predictions of the maximal violations of Bell-type inequalities, and generalizes Tsirelson's result $2\sqrt{2}$ for the maximal violation of the Clauser-Horn-Shimony-Holt inequality.

We have also developed new protocols for quantum cryptography using interferometers. Thereby, we have considered sets of quantum observables corresponding to *eutactic stars*. Eutactic stars are systems of vectors which are the lower-dimensional "shadow" image, the orthogonal view, of higher-dimensional orthonormal bases. Although these vector systems are not comeasurable, they represent redundant coordinate bases with remarkable properties. One application is quantum secret sharing. The Figure below depicts a typical configuration.

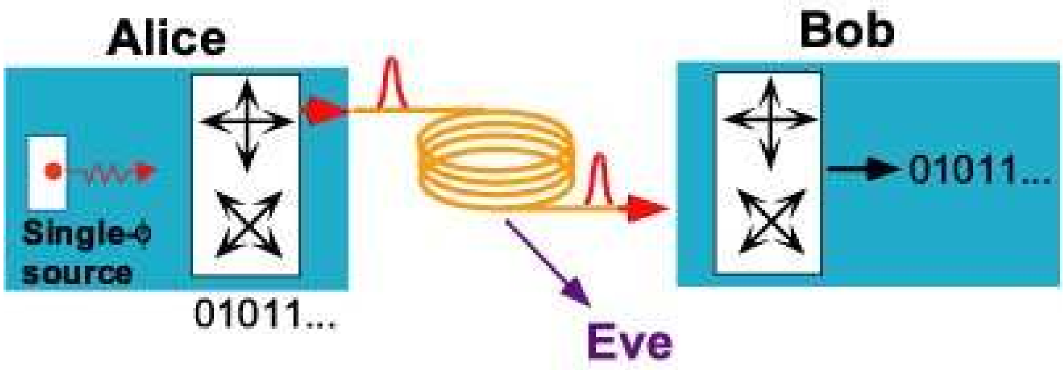

Fig. 1: Quantum cryptography using single-photon sources.
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2.2.2 Steering Rydberg wave packets with ultrashort pulses

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In recent years there has been increasing interest in the control and manipulation of atomic wave functions. The engineering of wave functions promises applications in many areas of physics, such as quantum computing [1], promotion of chemical reactions towards any preferable direction [2], or optimization of high harmonic generation [3]. Theoretically any wave function can be formed as a coherent superposition of energy eigenstates. In practice, however, it is not an easy task to prepare a preselected target state experimentally. Thus there are increasing demands for establishing protocols to produce any preferable designer state starting from the states which are experimentally accessible. Recently a few protocols have been suggested to create and manipulate a wave packet. A Rydberg wave packet is a coherent superposition of highly excited atomic states, localized in phase space [4]. Due to the relatively large time and spatial scale ($t \sim n^3$ and $r \sim n^2$) of Rydberg atoms with quantum number n, Rydberg wave packets are known to be among the best explored quantum objects which approximately follow the dynamics of the corresponding classical particle and serve as benchmark for probing the crossover between classical and quantum dynamics. With recent advances in ultrashort pulse generation it has become possible to engineer wave packets using Rydberg atoms [5]. Using such a Rydberg wave packet as the initial state, we have demonstrated a few protocols to steer such a Rydberg wave packet towards any preferable location in phase space [6] or to manipulate the size of a wave packet using a train of short pulses, so-called half-cycle pulses (HCPs) [7].

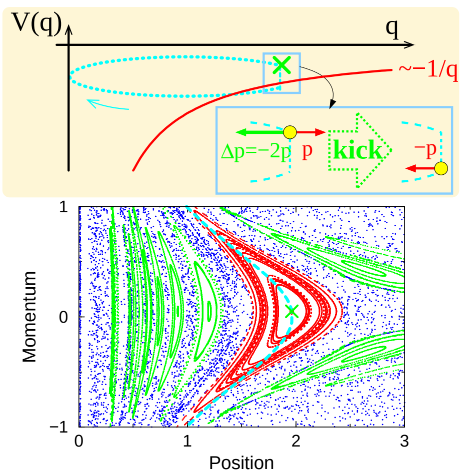

Fig. 1: Poincaré surface of section for the periodically kicked atom by a train of kicks with $\nu = 1.095/(2\pi)$ and $\Delta p = -0.1$. A periodic orbit (blue dashed line) is located at the center (green cross) of main stable island (red) in the Poincaré surface. The upper frame explains graphically how the periodic orbit can be stabilized.

Our first strategies for wave packet control are thus based on the analysis of the classical dynamics. When a Rydberg atom is subject to a half-cycle pulse (HCP) [8] whose duration is much shorter than the Kepler period of the Rydberg electron, the atom experiences an impulsive momentum transfer or "kick" given by

$$\Delta p = -\int F_{\mathrm{HCP}}(t)dt \tag{2.1}$$

and the corresponding energy transfer follows as

$$\Delta E = \frac{(p+\Delta p)^2}{2} - \frac{p^2}{2} = p\Delta p + \frac{\Delta p^2}{2} \ . \tag{2.2}$$

The response of Rydberg atoms to a train of identical HCPs equispaced in time has been studied extensively revealing a wide variety of dynamical behaviors. Under the influence of a periodical train of kicks, the electron experiences a random sequence of energy transfers ΔE leading to a random-walk behavior in energy space. On the other hand, by tuning the frequency of a train of kicks near the Kepler orbital frequency and setting the kick strength $\Delta p = -2p$ to satisfy $\Delta E = 0$ [Eq. (2.2)], the motion of the electron can be synchronized with the periodic train and stabilized without any energy transfer. This motion is analogous to a tennis ball (electron) hitting a wall (nucleus as a scatterer). At each hit (kick) by a racket the tennis ball changes only its direction of motion i.e. $p_{\mathrm{after}} = p_{\mathrm{before}} + \Delta p = -p_{\mathrm{before}}$ when $\Delta p = -2p_{\mathrm{before}}$ (see Fig. 1). By hitting a ball with a proper frequency a periodic motion can be established. This idea of dynamical stabilization has been used to create a wave packet localized in phase space [9]. The main stable island (red) seen in the Poincaré surface of section (Fig. 1) is a manifestation of a periodic motion and quasi-periodic trajectories surrounding it. Classical trajectories inside the island are kept trapped as long as a train of kicks is applied and the trajectories outside are spread out over whole phase space and eventually this unbounded motion (blue chaotic sea) leads to ionization. Another consequence of the island structure is that parts of the quantum wave function outside the islands get trimmed off by the periodic pulse and consequently the wave packet will be well localized inside the island.

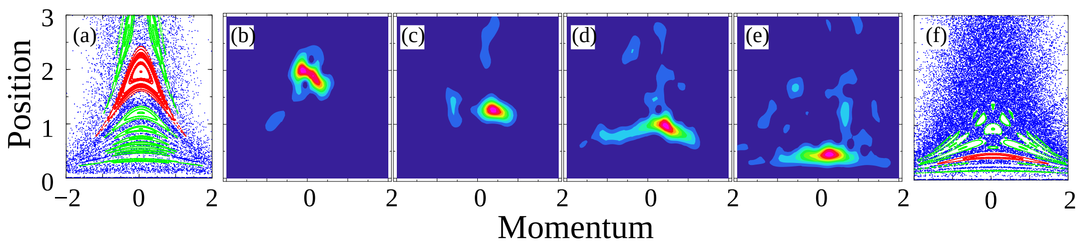

Fig. 2: Poincaré surfaces of section for the periodically kicked atom with $\Delta p = -0.1/n_i$ and (a) $\nu = 1.095/(2\pi n_i^3)$, and (f) $\nu = 10/(2\pi n_i^3)$. (b) is a Husimi distribution of the wave function when the initial Rydberg state ($n_i = 50$) is subject to a periodic train of 14 kicks with the same parameters as for (a). (c), (d) and (e) show snapshots of the time development when the wave function in (b) is subject to a chirped train of pulses whose frequency is accelerated upto the value as in (f).

Figure 2(b) shows the quantum wave function projected onto phase space (Husimi projection [10]) when the initial Rydberg state with $n_i = 50$ is exposed to a train of 14 kicks with $\nu = 1.095/(2\pi n_i^3)$ and $\Delta p = -0.1/n_i$. The corresponding classical system (Fig. 2 (a)) is invariant under variation of the action n_i and therefore the results from quantum simulations using different n_i can be compared with a single classical Poincaré surface. Obviously the wave function is trapped and localized at the position where the classical phase space shows the main stable island [depicted in red in Fig. 2 (a)]. This basic idea demonstrated here for a one-dimensional atom has been confirmed in the pump-probe experiments [9]. The efficiency for creating a localized wave packet depends on which fraction of the initial Rydberg state concentrated inside the island. Since the Rydberg states are prepared by one- or two-photon laser excitation from the ground state, their scaled angular quantum numbers are small ($l/n \sim 0$). Therefore the Husimi distribution peaks near the outer turning point of the classical Kepler orbit at $(q, p) = (2n^2, 0)$ where n is the main quantum number of the Rydberg state. When the island is located around the turning point a wave packet can be most effectively created.

A more interesting and challenging task is to steer the wave packet towards any other location. When the frequency of periodical kicks is increased, the position of stable islands in classical phase space is shifted towards small position coordinates q , i.e. towards the nucleus. Exploiting the analogy to the tennis ball hitting a wall, the players position must come closer to the wall when he tries to hit the ball with the same strength but a higher frequency. Figure 2 (f) shows a Poincaré surface for a higher frequency $\nu = 10/(2\pi n_i^3)$ and the shift of the positions of the islands (both read and green ones) compared to Fig. 2 (a) can be clearly seen. This observation can be profitably exploited to steer a wave packet along the q-axis. When the frequency of a train of pulses is adiabatically increased ("chirped"), the island gradually shifts its position towards the nucleus. Correspondingly, the wave packet initially localized inside the main island [red one in Fig. 2 (a)] is kept trapped inside the island and moves together with it. Figures 2 (b) to (e) show the snap shots of the wave packet evolving in time. The wave packet is steered gradually towards the nucleus and at the end when the frequency reaches the values of $\nu = 10/(2\pi n_i^3)$, the wave packet is localized exactly at the classical stable island (depicted in red) in Fig. 2 (f). The wave packet subject to a chirped train of pulses is confirmed to follow the adiabatic change of the phase space structure. Alternatively the position of a wave packet along momentum (p) axis shifted by adiabatically modulating the kick strength instead of the frequency. With increasing kick strength the islands become less and less stable and therefore their sizes shrink, just as it becomes more difficult to keep hitting a ball against a wall periodically as the hitting power is increased. Therefore, the kick strength modulation not only shifts the position of the wave packet but also changes its size by trimming off its edge. This technique can be applied to a creation of a minimum uncertainty wave packet [7]. The protocols for shaping and steering wave packets with an unprecedented control developed in our group are currently being implemented experimentally [11].

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2.2.3 Atoms in ultrashort laser fields

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Since the first working laser device was built by Maiman in 1960, the progress in laser technology has been tremendous. The intensity of the lasers has been increased by many orders of magnitude. Intensities reach presently well above 10^{20}W/cm^2, where plasma effects as well as relativistic effects are important. In the near future, laser intensities may even reach the critical field strength to directly produce positron-electron pairs.

At the same time, the length of the shortest pulses has decreased by more than 10 orders of magnitude (Fig. 1). While the first lasers had a pulse length of some 100μs, very short pulses can nowadays be produced through mode-locking. In 1990, Zewail et al. [1] managed to generate pulses as short as several femtoseconds, which meant that snapshots of chemical reactions could be directly taken. This opened up the field of femto-chemistry.

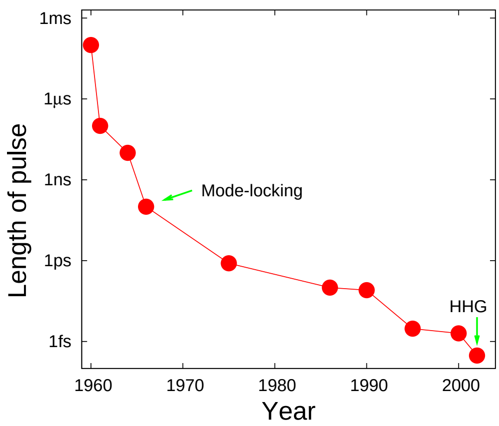

Fig. 1: Decrease of pulse duration as a function of time.

To take time-resolved pictures of atomic processes, even shorter pulses down to the attosecond regime are needed. Such short laser pulses can be produced by the process of high harmonics generation (HHG): the time-dependent field of a strong femtosecond laser may ionize an atom and accelerate the electron in one direction. As the field changes direction, the electron might get accelerated back and emit radiation by "bremsstrahlung" as it hits the nucleus. The frequency of the radiation may be hundreds of times higher than the driving field. By filtering out a narrow region of the highest frequencies produced, pulses as short as some hundreds of attoseconds can be generated.

The possibility of driving an atom by a femtosecond laser as well as the usage of high harmonics generation to producing the shortest pulses presently available challenges our current understanding of the processes taking place in the atom driven by the ultrashort electric field. Two different regimes can be distinguished: the multiphoton regime (high frequency and low intensity) and the tunneling regime (low frequency and high intensity). In the multiphoton regime many experimental (see for example [2]) and theoretical studies have been performed, which have led to a fairly complete understanding of the physical processes involved. In the tunneling regime, on the other hand, recent experiments with linearly polarized lasers have shown novel and previously unexplained structures in the momentum distribution of the photoionized electrons in rare gases. The so-called "double-hump" structure in the longitudinal momentum distribution has been identified as a rescattering process for double-ionization [3] and as the interaction between the electron and the core for single ionization [4].

We study the hydrogen atom driven by a linearly polarized laser field both classically and quantum mechanically. For the first approach we employ the classical trajectory Monte Carlo (CTMC) method including tunnel effects (CTMC-T). The electron is allowed to tunnel through the potential barrier whenever it reaches the outer turning point. Alternatively, the time-dependent Schrödinger equation is solved numerically by means of the generalized pseudo-spectral method. The process of detecting an electron of momentum $\vec{k}$ can then be viewed as a projection of the wave function onto the Coulomb wave functions.

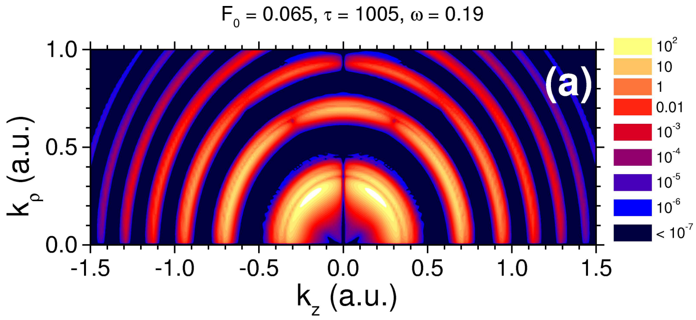

Fig. 2: Doubly differential momentum distribution in multiphoton regime. $I = 1.5 \times 10^{14}\mathrm{W/cm}^2$, $\tau = 0.5$ fs.

New insights can be gained from doubly-differential $(k_z k_\rho)$ momentum distributions. In the multiphoton regime (Fig. 2) the above-threshold ionization peaks are displayed as semicircles of fixed energy. The radius of each semicircle corresponds to an energy given by $U_j = E_0 + j\omega$, where E_0 is the ground state energy of the atom, and j the number of photons absorbed. In the tunneling regime (Fig. 3) the isoenergy circles are strongly distorted in the low momentum region, where novel structures near $k_z = k_\rho = 0$ appear. The latter represent Ramsauer-Townsend minima [5] in the angular distribution experimentally observed for the first time in laser-atom interactions.

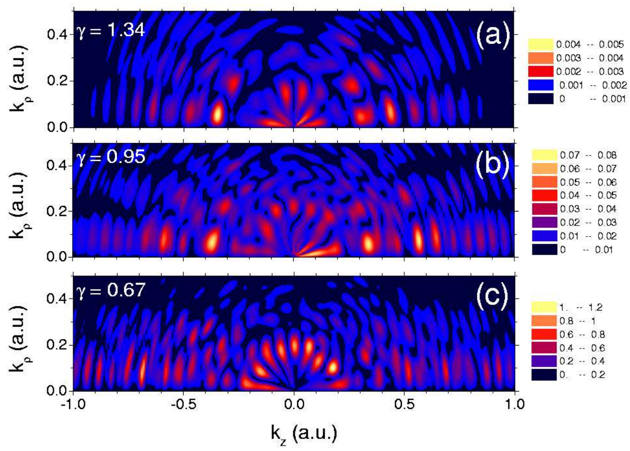

Fig. 3: Doubly differential momentum distributions. $T = 2$ fs, $\tau = 20$ fs, (a) $I = 5 \times 10^{13}\mathrm{W/cm}^2$, (b) $I = 1 \times 10^{14}\mathrm{W/cm}^2$, (c) $I = 2 \times 10^{14}\mathrm{W/cm}^2$.

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2.2.4 Ballistic quantum transport through nanostructures

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A major aim in ballistic transport theory is to simulate and stimulate experiments in the field of phase-coherent electron conductance through nano-scaled semiconductor devices [1]. However, even for two-dimensional quantum dots ("quantum billiards") the numerical solution of the Schrödinger equation has remained a computational challenge. This is partly due to the fact, that many of the most interesting phenomena occur in a parameter regime of either high magnetic field B or small de Broglie wavelength λ_D. Under the influence of a high magnetic field, one can study the Quantum Hall effect [1], de Haas-van Alphen oscillations [2], the "Hofstadter butterfly" [3] and electronic Mach-Zehnder interferometry [4]. In the regime of small λ_D the main interest is focused on the transition from quantum to classical dynamics [5,6] and related topics such as "quantum chaos" [7] and localization [8].

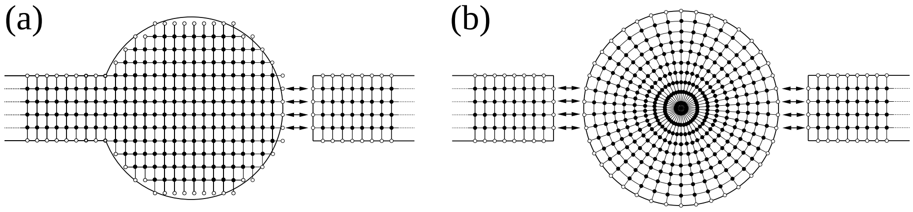

Fig. 1: (a) Illustration of the conventional tight-binding discretization employed in the *Recursive Green's Function Method* for transport through a circular quantum dot with infinite leads. Our modular approach as illustrated in (b) leads to increased efficiency in the numerical calculations.

However interesting they may be, these parameter ranges are difficult to handle from a computational point of view. This is because in the "semi-classical regime" of small λ_D as well as in the "quantum Hall regime" of high magnetic fields B, the proper description of the transport process requires a large number of basis functions. As a result, the theoretical models which are presently being employed eventually become computationally unfeasible or numerically instable.
At the Institute for Theoretical Physics an extension of the widely used *Recursive Green's Function Method* (RGM) [1] was developed which can bypass several of the limitations of conventional techniques. Key ingredient of this approach [9] is the decomposition of the scattering geometry into separable substructures ("modules") for which all the numerical procedures can be performed very effectively. All the modules are eventually connected with each other by means of matrix Dyson equations such that they span the entire scattering region (see Fig. 1). In this way we reach a high degree of computational efficiency. Adapting our *Modular Recursive Green's Function Method* (MRGM) [9] to different scattering scenarios we are able to study a variety of different transport phenomena in previously unexplored parameter regimes. We highlight in the following three areas we focused on in 2004.

Andreev billiards

The interface between a normal-conducting (N), ballistic quantum dot and a superconductor (S) gives rise to the coherent scattering of electrons into holes. This phenomenon is known as Andreev reflection [10]. A N-S hybrid structure consisting of a superconducting lead attached to a normal ballistic cavity (see Fig. 2) is called an Andreev billiard [11]. Such billiard systems attracted much attention recently because of the unusual property that the classical dynamics in these systems features continuous families of periodic orbits, consisting of retracing electron-hole trajectories (see Fig. 2a).

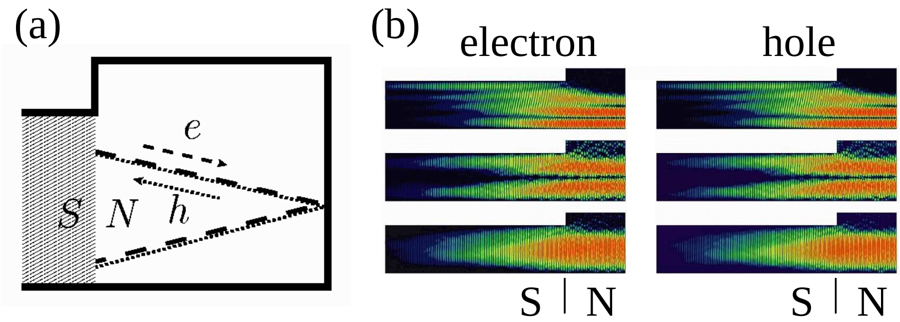

Fig. 2: (a) Retracing electron-hole trajectory in a normal-conducting (N) square billiard with a superconducting (S) lead attached ("Andreev billiard"). (b) Three bound electron-hole wavefunction densities which clearly show signatures of the classical retracing property.

To learn more about the classical-to-quantum correspondence of Andreev billiards, it is instructive to study the bound states in these billiards and the form of their wavefunctions. Wavefunctions feature indeed an electron and a hole component that in most cases closely resemble each other (see Fig. 2b) - in analogy to the classical picture of retracing electron-hole orbits. To obtain these quantum results numerically, we calculated the scattering states for the billiard with a normal conducting lead and coupled them to construct the Andreev states [12]. We compare the quantum mechanical solutions with a semiclassical Bohr–Sommerfeld (BS) quantization of periodic orbits and propose an extension of the BS approximation which is well suited to describe Andreev billiards with hard-wall as well as soft-wall boundaries. The underlying classical periodic electron-hole orbits are directly identified in terms of pronounced density enhancements engraved in the quantum wavefunctions of Andreev states [12]. Additionally, we find states which feature very different wavefunctions for electron and hole, indicating the breakdown of the retracing approximation. Work on the inclusion of a disorder potential in the Andreev billiard is in progress.

Shot noise

The electric conductance through a mesoscopic quantum dot features time-dependent fluctuations (noise) which can have different origins. If, e.g., the transport process is measured at finite temperature T, thermal fluctuations will add very strongly to the conductance fluctuations. However, even at $T = 0$ some noise remains. The noisy conductance at zero temperature is due to the fact that an electric current corresponds to the flow of discrete electron charges (as opposed to a smooth fluidlike flow). These noise fluctuations, which are frequency independent ("white noise"), are called *shot noise* and were first theoretically analyzed by Walter Schottky in 1918. Schottky drew an analogy to the metal pellets in the charge of a hunting rifle, which gave the "shot effect" ("Schrotrauschen") its name. The study of shot noise and its universal features has become one of the central issues in the field of mesoscopic transport [13].

In a vacuum tube, as used in many old electronic devices (Fig. 3a), the emission of electrons at the cathode occurs in a random (Poissonian) way. In the presence of this randomness, the shot noise takes on a very large value. By contrast, electrons in ballistic microstructures do not behave nearly as random and independent from each other, but show correlations which reduce the shot noise. This noise suppression is customarily expressed in terms of the Fano factor F, which measures the actual noise power (S), as compared to the Poissonian value of noise (S_P), i.e. $F = S/S_P < 1$.

In ballistic microstructures which feature chaotic dynamics the Fano factor is predicted to take on a universal value $F = 1/4$ [13]. Intensive research has been dedicated to test this prediction and to study different non-universal deviations. These occur e.g. if the electron does not have a long enough dwell time (τ_D) in the microcavity to really "feel" the chaotic dynamics reigning there. Another potential source for a deviation is a reduced or missing chaoticity in the cavity. With the help of our numerical simulations we investigated both of the above features.

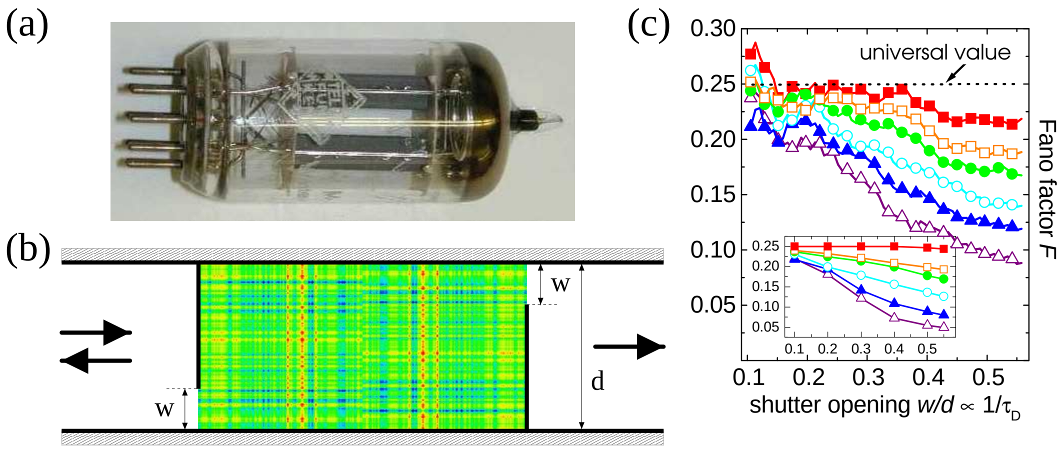

Fig. 3: (a) Vacuum tube which features random emission of electrons. (b) Quantum billiard with tunable shutters and disorder potential (colored area). Tuning the opening of the shutters w, deviations of the Fano factor from the universal limit $F = 1/4$ can be investigated. (c) Fano factor F as as function of the shutter opening w, as calculated numerically. Curves shown correspond to strong ($\blacksquare, \square$), medium ($\bullet, \circ$), weak ($\blacktriangle$), and no ($\triangle$) disorder potential. A decrease from the "random value" $F = 1/4$ for small shutter openings w to $F = 0$ for wide shutter openings w is clearly visible. The inset depicts the theoretical prediction based on a quasiclassical simulation. Note the good agreement with the numerical data from the full quantum simulation.

In analogy to systems which have been studied experimentally [14], we numerically investigate shot noise in cavities with tunable openings that allow to vary the dwell time τ_D [15]. To simulate chaotic dynamics we add a tunable random disorder potential inside the cavity (see Fig. 3b). A remarkable result we find is that for small shutter openings the

Fano factor F is always very close to the universal limit ($F = 1/4$), independent of the strength of the disorder potential (see Fig. 3c). In particular for vanishing disorder, where chaotic dynamics in the cavity is entirely absent, this finding is surprising. We argue that diffraction at the lead openings [16] is the dominant source of shot noise. To quantify this conjecture, we develop a quasi-classical transport model for shot noise suppression which extends previous models [17,18] and agrees with the numerical data (see inset Fig. 3c).

Billiards with a mixed phase space

Most theoretical investigations on quantum billiards focus on the two limiting cases of systems with either purely chaotic or purely regular classical dynamics [7]. However, neither of these cases is generic. For the semiconductor quantum dots that are realized in the experiment a classical phase space structure with mixed regions of chaotic and regular motion is expected. This is due to the fact [1] that the boundaries of such devices are typically not hard walls but feature soft wall profiles for which such a "mixed" phase space is characteristic [6]. For the model system we studied (see Fig. 4a) we indeed find that soft walls give rise to a phase space within which regular and chaotic motion coexists. Characteristic for such “mixed systems” are very long trajectories that get “trapped” in the vicinity of regular islands of motion [6]. A typical example for such a trajectory is depicted in the top part of Fig. 4b. The quantum scattering wavefunction which corresponds to this orbit is shown below [20].

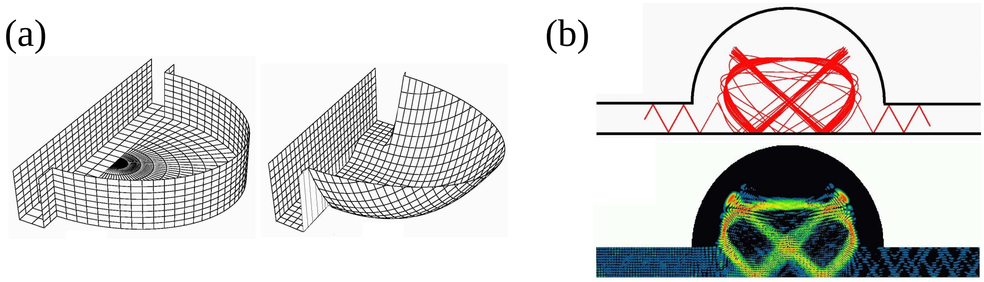

Fig. 4: (a) Billiards with a hard wall vs. soft wall profile. (b) “Trapped” trajectory in a soft wall billiard with a mixed classical phase space and the density of the corresponding quantum wavefunction (a so-called “GWB-scar”).

As was pointed out previously [19] trapped trajectories lead to quasi-bound states in the corresponding quantum transport problem and appear as isolated resonances in the conductance. By analyzing the wave function probability density and the Husimi distribution at the resonance energies we find remarkable similarities between the classical and quantum phase space structures [20]. This enables us to classify resonant scattering states associated with regular, trapped and instable periodic classical trajectories.

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2.3 Condensed Matter Theory

2.3.1 Phase transitions in soft matter

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Introduction

Soft matter physics has become a rapidly developing branch in condensed matter physics. This is certainly due to the fact that soft matter *does* play an important role not only in our daily life, but also in many technological applications.

Despite the fundamental role that soft matter plays in our lives, systematic investigations of its properties have been out of reach over many decades which is due to the intrinsic complexity of these systems. Only in recent years special experimental techniques in combination with new theoretical concepts have brought along – in a fruitful cooperation among soft condensed matter scientists – a deeper insight into the intriguing phenomena of these systems. Since typical soft matter particles are mesoscopic in size, they can be be investigated with experimental methods that are much simpler to handle than, for atomic systems: information is obtained directly in real space and particles can be moved in space nearly arbitrarily with optical squeezers (for an overview see [1]).

The key problem a theoretician is faced with when dealing with soft matter is the huge number degrees of freedom that characterize the particles. Typical soft matter particles (e.g., dendrimers or microgels) are, in turn, complex aggregates of several thousands of atoms or molecules which leaves definitely no hope to describe such a system within the framework of statistical mechanics. Luckily, coarse graining methods have turned out to be a very attractive tool to derive effective interactions between two soft particles [2]: by suitably averaging over the many thousands of degrees of freedom of the constituent particles one arrives at effective potentials, that typically depend on the coordinates of the centers of mass of two interacting aggregates. In contrast to atomic systems, these effective potentials diverge only weakly at the origin or even remain finite at short distances: this reflects the fact that – as a consequence of their loose internal structure – these aggregates are allowed to overlap, to mutually penetrate, or to even intertwine when being compressed. These particular features lead, in turn, to unexpected and surprising effects both in their structural properties as well as in their phase behaviour. Some of these effects have been studied in the present project.

The system and the theory

During the past year we have in particular focused on ionic microgels. They are mesoscopically sized, covalently cross-linked polymer networks, their diameter σ being in the range between 10 nm and 1 μm. Most microgels are based on poly(N-isopropylacrylamide) (PNIPAM) or related co-polymers that are cross-linked during emulsion polymerization, a process that can produce remarkably uniform particles. When the polymer chains comprising the microgels carry ionic groups on their backbones, the latter dissociate upon solution into an aqueous solvent, leading to charged or ionic microgels. Active interest in polyelectrolyte gels (to which microgels belong as a subgroup) remains to date, due to their ability to absorb large amounts of water and act as superabsorbers or drug delivery systems.

An effective potential, $\Phi_{\rm eff}(r)$, where r is the center-to-center distance of two microgel particles, can be derived within the framework of linear-response theory [3]: $\Phi_{\rm eff}(r)$ can be split up into a bare interaction between two uniformly charged spheres and a contribution induced by the counterions. This effective potential remains finite at the origin and depends on the net microgel charge Z, the dielectric constant ϵ of the solvent, the counterion density n_c, and valency z. In addition, steric repulsions (that are due to the overlap between the monomer units of two interacting microgels) can be included in a simple model, based on standard Flory-Huggins theory.

Based on this effective two-body potential we can now determine the phase diagram for this system [4, 5]. For the fluid phase we have used a standard liquid state theory, i.e., the thermodynamically self-consistent Rogers-Young (RY) scheme [6], which provides both information on the structure and on the thermodynamic properties. For the solid phases we have applied an Einstein model with Hamiltonian $\mathcal{H}_0$ (characterized by a spring constant) which serves as a reference state for the true Hamiltonian, $\mathcal{H}_{\rm eff}$: the Gibbs-Bogoljubov inequality provides (via minimization with respect to the stiffness of the spring and the cell geometry) a lowest upper bound for the free energy. The set of possible candidate structures for the solid phases was fixed in a preceding step with the help of a genetic algorithm [7] where the following structures were proposed for the density range considered: fcc, bcc, hexagonal, bco, and trigonal.

Results

The first indications of a very peculiar phase behaviour are found from a closer analysis of the structure factor $S(k)$ (Figure 1): as the density ρ becomes larger, the value of the main peak first increases (as expected), but then drops suddenly at $\rho\sigma^3 \sim 2$. This anomalous behaviour is a clear indication that re-entrant melting is to be expected.

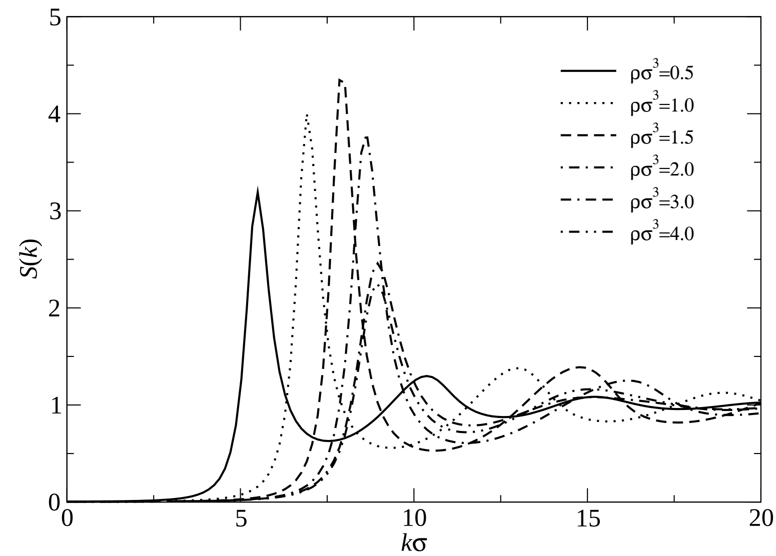

Fig. 1: Anomalous behaviour of the structure factor $S(k)$ for microgels with charge $Z = 250$ and size σ=100 nm for increasing density (as indicated in the inset).

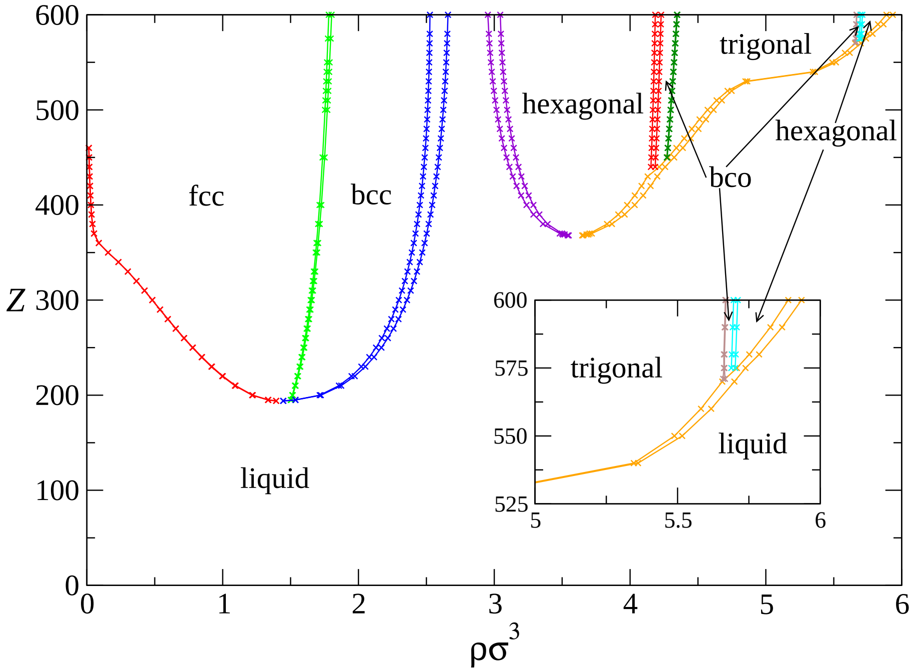

Fig. 2: Phase diagram (Z vs. ρ) of ionic microgels of size σ=100 nm. For the fluid phase the RY approach has been used.

The phase diagram of an ionic microgel (Z vs. ρ) for σ=100 nm is shown in Figure 2. For $Z < 200$ the system remains fluid for the entire density range considered. As we increase the charge, we encounter re-entrant melting: at densities roughly below the overlap value, $\rho_\star$, the system freezes into the fcc lattice, which undergoes a structural phase transformation into a bcc structure at higher densities. Upon further compression the systems remelts again, i.e., the disordered structure is energetically more favourable. For charges larger than $\sim$ 400 the re-entrant melting scenario repeats itself, but the stable crystal lattices are not cubic: instead the system crystallizes into unusual, strongly asymmetric structures with a small number of nearest neighbours such as hexagonal, bco, and trigonal lattices.

Three remarks are in order:

- re-entrant melting represents a freezing scenario that distinguishes itself distinctively from the well-studied freezing behaviour in systems with harshly repulsive potentials (such as atomic systems): in the latter case the fluid freezes typically into an fcc or a bcc structures and then remains solid until no further compression is possible. In soft matter, however, the situation is completely different: as a consequence of the softness of the potentials the particles can now be compressed even beyond their overlap density. Re-entrant melting is one possibility of how soft systems react upon compression; the alternative scenario, i.e., clustering, is currently investigated in our group.

- Based on the experience from atomic systems [8], it was generally believed that only non-spherical potentials could lead to anisotropic (i.e., non-cubic) structures. However, in soft systems with spherical effective potentials fluids can freeze into structures such as hexagonal, bco, or trigonal (see Figure 2).

- traditional rules to estimate the location of the freezing transition (as those due to Hansen and Verlet or to Lindemann), that have been derived for atomic systems clearly fail in soft systems. The broken line in Figure 2 indicates those states where – according to the Hansen-Verlet rule – freezing should set it; it is obvious that this rule is violated for our ionic microgel system.

All these facts demonstrate that soft interactions offer an obviously unexpected rich variety of new physical phenomena and that the conventional views on crystallization gained from hard potentials have to be revisited thoroughly. It is anticipated that not only the equilibrium but also the dynamical behavior of ionic microgel solutions will be highly unusual, opening the way for a wealth of possibilities to manipulate the rheological behavior of microgel solutions that may lead to interesting technological applications.

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2.3.2 Phase behaviour and criticality in simple liquids and their mixtures

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Introduction

Liquid state theories establish a link between the microscopic properties of a liquid (in terms of its pair potential) and its structural and thermodynamic properties. Statistical Mechanics provides the versatile formalism to determine the relevant relations. In practice, however, these expressions cannot be applied directly, not even for the simplest non-ideal system, i.e., to hard spheres: the reason is that they become intractably complex and therefore require simplifying assumptions. These simplifications lead to approximate schemes that can be derived systematically (e.g., via graph-theoretical considerations) [1] from the exact expressions for partition sums and related quantities. One thus arrives at so-called closure relations to the Ornstein-Zernike equation that relate the total and the direct correlation functions which describe the structural properties of the system. In early years of liquid state theory well-known conventional schemes, such as the mean spherical approximation (MSA), the Percus-Yevick (PY), or the hypernetted chain (HNC) approximations have been derived.

The simplifying assumptions lead, however, to a serious drawback: if we calculate the thermodynamic properties of a given system, then we obtain – as a consequence of the approximate character of the closure relations – results that depend on which thermodynamic route has been chosen; an exact theory, on the other hand, would have led to identical data.

These inconsistencies have further consequences: first, the structural data are inaccurate; second, the determination of the phase diagram (in particular the exact location of the phase boundaries as well as a reliable description of the critical region) becomes problematic. Remedies have been searched for to cope with this problem:

- in integral-equations parameters are introduced in the closure relations that interpolate in a functional form between different conventional closure relations. The parameters are adjusted such that thermodynamic self-consistency is enforced for a given state point;

- advanced liquid state theories go beyond this simple interpolation scheme: in the Self-Consistent Ornstein-Zernike Approximation (SCOZA) [2] a partial differential equation can be derived that enforces consistency not only for a single, isolated state point, but for the entire parameter range; the Hierarchical Reference Theory (HRT) [3], on the other hand, successfully merges concepts of classical liquid state theory and ideas of renormalization group theory.

Over many years, our group has accumulated expertise in liquid state theory: this applies both to numerical implementations as well as to the development of new integral-equation schemes. In the following we shall briefly report on a few recent contributions.

Phase behaviour of a binary symmetrical fluid

We have studied the phase diagram of a binary symmetrical mixture of two fluids (labeled '1' and '2'): here the potentials between the like particles are equal, i.e., $\Phi_{11}(r) = \Phi_{22}(r)$, while the interaction between the unlike particles is fixed by $\Phi_{12}(r) = \alpha\Phi_{11}(r)$. α can be identified as the relevant parameter that triggers the phase behaviour of the system (see below). If $\alpha < 1$ then the competition between the liquid-vapour phase transtition and the demixing transition (into a 1- and a 2-rich phase) leads to a very intriguing phase behaviour [4]; some aspects will be presented below.

The system itself is not as academic as it might seem at first sight: it shows – if we consider for the moment only the topology of the phase diagrams – the same behaviour as one-component systems endowed with an additional internal degree of freedom, such as Heisenberg liquids or fluids of particles carrying a dipolar moment. Since a binary symmetric mixture is the simplest representative among these systems it is the obvious candidate to perform detailed investigations of its phase behaviour.

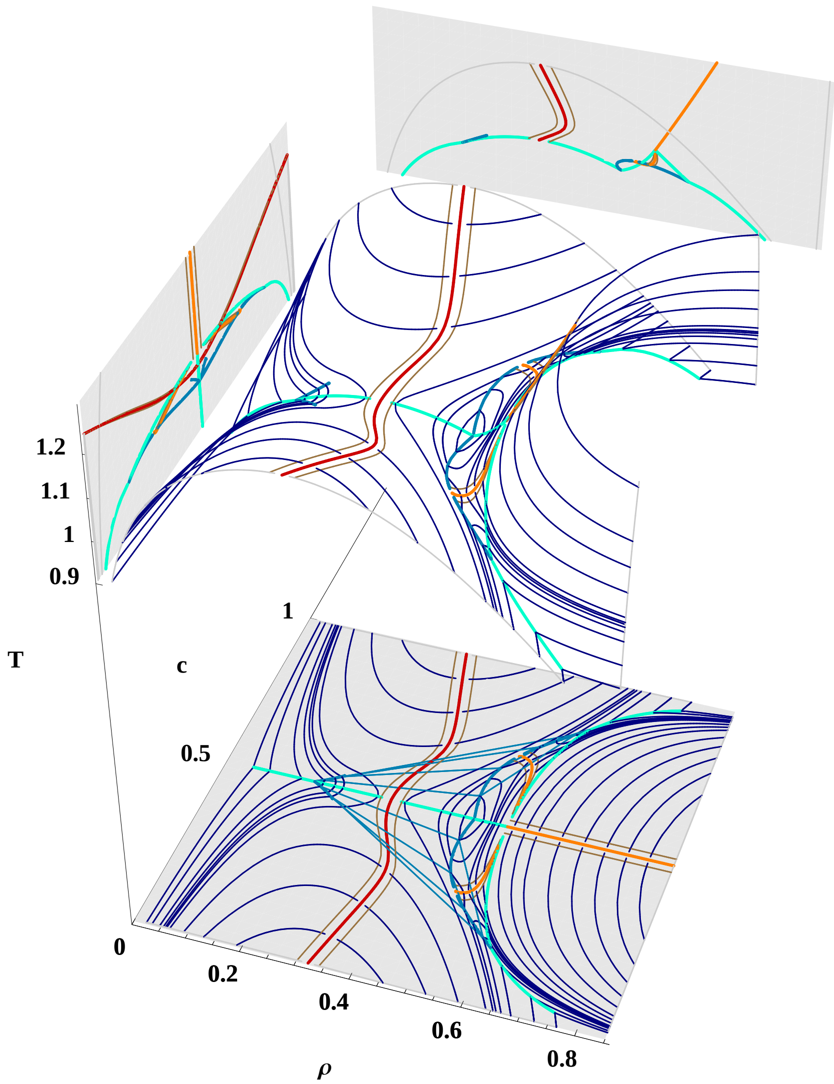

Fig. 1: Three dimensional representation of the phase diagram of a binary symmetric mixture for $\alpha = 0,69$; for details cf. text.

We present in Figure 1 results for $\alpha = 0.69$. We depict the phase diagram in the three-dimensional {temperature (T) - density (ρ) - concentration (c)}-space, along with the three respective, two-dimensional projections. Dark blue lines mark isothermal coexistence curves, the red and the orange lines are lines of critical points (i.e., of second-order transitions), bold light blue lines are triple lines, and turquoise lines mark the phase diagram, if no external field is applied, i.e., the so-called equimolar case, when the difference in the chemical potentials of the two species vanishes.

Despite the simplicity of the model, the phase behaviour of the system is rather complex and represents therefore a nice, instructive example of critical phenomena: among others we observe critical end points (where a critical line is truncated on a coexistence surface), triple lines, or tricritical points (where simultaneously three phases become critical). These results are based on an analytic solution of the MSA for a system with hard-core Yukawa interactions and have been confirmed by computer simulations, specifically designed to study critical phenomena [5].

Advanced liquid state concepts for simple fluids and their mixtures

In recent time we have successfully extended the scheme of SCOZA to a large variety of systems: for liquids with repulsive core (as they are, e.g., encountered in atomic systems) we are now able to consider potentials with arbitrary attractive tails. Comparison with computer simulations has shown that SCOZA does indeed remain accurate close to phase boundaries and in the critical region. Particular attention has recently been dedicated to soft systems, i.e., liquids where the potential of the particles remains finite at the origin or diverges only weakly for short distances; such interactions are typical for soft matter particles (see section 2.3.2). Also here we could show that computer simulation data for the structural and thermodynamic properties could be reproduced with high accuracy.

Special emphasis has furthermore been put on closer investigations of the HRT scheme. It is in particular the implementation of HRT which represents a challenge (both from the conceptual as well as from the numerical point of view). In an effort to localize the phase boundaries and the critical point with high accuracy, states of diverging compressibility have to be identified which turned out to be a very delicate problem [6].

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2.3.3 Interaction of slow highly charged ions with solid surfaces

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The study of multiply-charged ion-solid interactions is of considerable technological importance for the understanding of material damage, surface modification, and plasma-wall interactions. The recent availability of sources for slow highly charged ions (HCI), namely electron cyclotron resonance (ECR) and electron beam ion sources (EBIS) has led to a flurry of research activities, both experimental and theoretical, in the field of HCI-solid interactions [1-3]. On the most fundamental level, its importance is derived from the complex many-body response of surface electrons to the strong Coulomb perturbation.

From numerous experimental as well as theoretical studies the following scenario of the HCI-surface interaction has emerged: When an HCI approaches a solid surface, one or more electrons are resonantly captured at large distances into high Rydberg states of the projectile. As a result, so-called hollow atoms (ions) are formed where the atomic charge cloud transiently resides in shells with large diameters while the core is virtually empty. Direct observation of this short-lived state is complicated by the fact that the ion is always attracted towards the surface by its self-image potential. Consequently it will suffer close collisions upon impact on the surface and the memory of the hollow atom is all but erased. This problem has motivated the study of interactions of HCI with internal

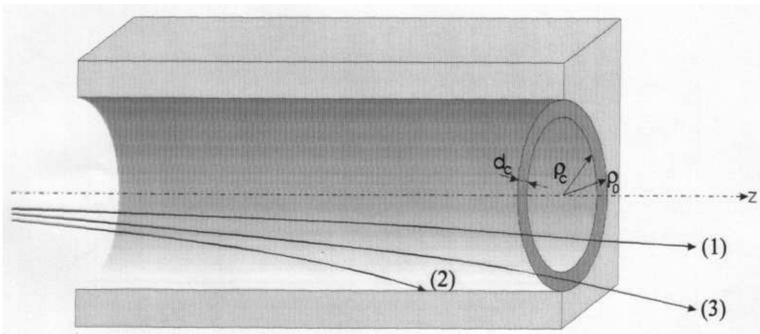

Fig. 1: Schematic picture of a capillary and three types of trajectories.

surfaces of microcapillaries and nanocapillaries as an alternative technique to study above surface processes (e.g. [4]). Metal and insulating capillaries have become available at the Tokyo Metropolitan University, Japan, and at the Hahn-Meitner-Institut Berlin, Germany [5]. The use of capillary targets allows the extraction of hollow atoms in vacuum. Observation of photons or Auger electrons emitted from them in flight becomes possible. Also the energy loss an HCI suffers when passing through a capillary at distances too large for charge transfer to take place can be measured and calculated.

During the recent year we have performed a broad range of simulations to study the interaction of HCI with capillary surfaces in detail. In particular, we have concentrated on the simulation on projectiles which did not change their initial charge state during the interaction (trajectories of type (1) in Fig. 1).

Energy loss of HCI transmitted through metal capillaries

We calculate the dissipative component of the force acting on the projectile with charge Z moving with a velocity approximately parallel to a solid surface. Within the linear-response theory all calculations for the stopping power S at fixed distance b for different ionic charges Z can be performed for unit charge $Z = 1$ using the scaling

$$S(Z, b, v) = Z^2 S(Z = 1, b, v) = Z^2 S(b, v). \tag{2.3}$$

The energy loss ($\Delta E = E_f - E_i$, where E_i and E_f are the ion energies at the position of the ion source and detector, respectively) of the charged particle can be obtained from an integration of the friction force (stopping power, S) along the trajectory of the particle. The stopping power is negligibly small for distances larger than about 100 a.u. from the metallic surface. Most of the ions passing the capillary wall without undergoing charge exchange will hardly suffer any perceptible energy loss.

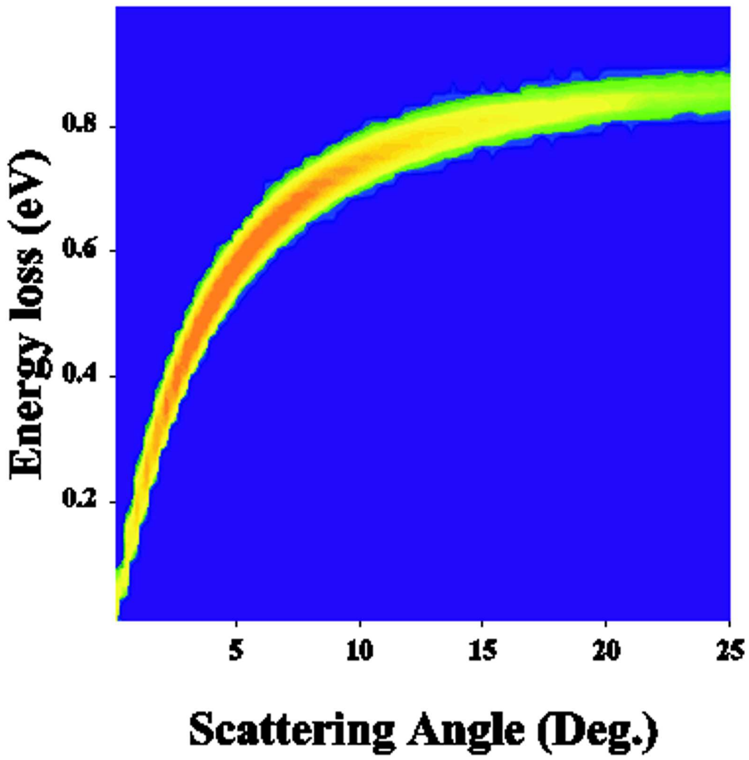

Fig. 2: 2D correlation pattern between the energy loss and the scattering angle of Kr^{30+} ions passing through a Ni microcapillary at 2.5 eV/amu energy.

However, the strength of the stopping power strongly increases as the particle approaches the surface. Fig. 2 shows the two-dimensional correlation pattern between the scattering angle and the energy loss for Kr^{30+} transmitted through a Ni capillary. We find a maximum energy loss of about 0.9 eV that should be detectable.

Transmission of HCI through insulating capillaries

Very recently, capillaries through insulating foils (PET ("Mylar") [5] and SiO_2 [6]) have become available. Unexpectedly, considerable transmission rates for projectiles in their initial charge state were measured for incidence angles as large as 25°. Ions were guided along the capillary axis with a spread (FWHM) of $\Delta\theta_{out} \approx 5°$ for Mylar but close to geometric opening θ_0 for SiO_2. Interpretation of these results run along the following lines: First, projectiles hitting the capillary surface close to its entrance area deposit their charge at the surface which - due to the small conductivity of the material - remains localized in a self-organized charge patch. Projectiles entering the capillary in a later stage of the experiment are deflected by the Coulomb field of the charge patch passing the surface in a distance larger than the critical distance for charge transfer $R_c \approx \sqrt{2Q}/W$ as predicted by the classical over barrier model [2] with Q and W being the projectile charge state and workfunction of the capillary material, respectively.

Our simulation consists of several ingredients bridging processes occurring at vastly different time scales: microscopic charge-up ($\sim 10^{-15}$ s), transport of a single ion ($\sim 10^{-10}$ s), time interval between subsequent ions ($\sim 10^{-1}$ s), and approach of dynamical equilibrium ($\sim 10^2$ s). Initially, Q charges are deposited on the surface where Q is the initial charge state of the projectile. Due to the finite conductivity of the target material these charges move along the capillary wall or, with a small probability, diffuse into the bulk. Subsequent projectile trajectories are calculated taking into account the electric field of charges deposited previously on the capillary wall.

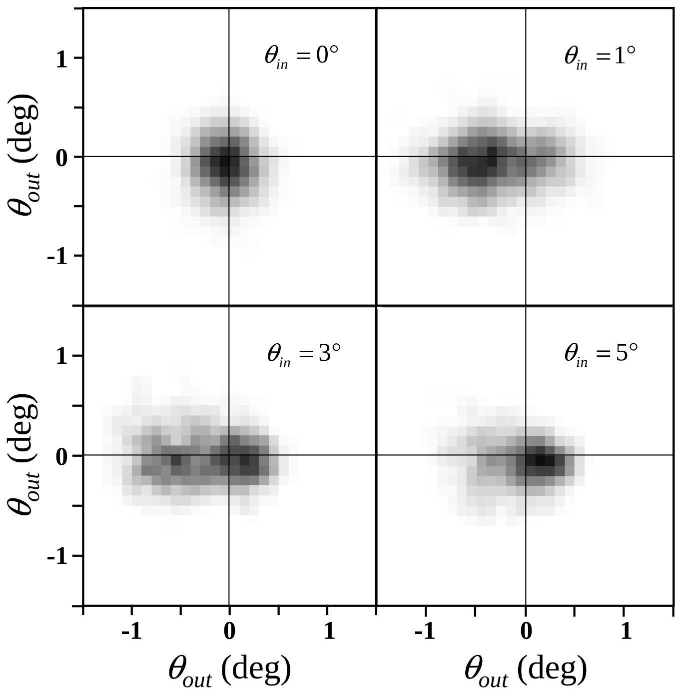

Fig. 3: Two dimensional angular distribution of transmitted Ne^{7+} ions for $\theta_{in} = 0°$, 1°, 3°, and 5°.

We were able to reproduce the transmission rates for HCI transmitted through Mylar and SiO_2 capillaries at energies ranging from 3 keV to 7 keV.

Another result that is consistent with experimental findings are increasing differences in the angular distributions of transmitted ions parallel and perpendicular to the plane of incidence with increasing θ_{in}. In Fig. 3 we show the two-dimensional distribution of exit angles for $\theta_{in} = 0°, 1°, 3°$, and $5°$. The distribution normal to the plane of incidence (y-direction) remains almost constant for all angles. Parallel to the plane of incidence (x-direction) a slight widening and displacement of the peak from the center of the distribution is found. This is in agreement with experiments showing a small deviation of the centroid of the scattering distribution towards larger deflection angles. For incidence angles larger than 10° even the formation of double peak structures could be observed as in experiment[7].

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Appendix A

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A.1 Permanent staff

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LANDSTEINER Karl	Lecturer [e]

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Vienna University

STRICKLAND Mike
University of Helsinki, Finland

THEIS Ulrich
Friedrich Schiller-University, Jena

WEINGARTNER Bernhard
University of Natural Resources and Applied Life Sciences, Vienna

A.3 Visitors

- Matthias Ballauf
  Physikalische Chemie I der Universität Bayreuth
  Bayreuth, Germany
  15.05.2004 - 19.05.2004

- Kurt Binder
  Institut für Physik, Universität Mainz
  Mainz, Germany
  29.11.2004 - 12.11.2004

- Jean-Paul Blaizot
  ECT*
  Trento, Italy
  12.10.2004 - 15.10.2004

- Douglas Bridget
  University of Canterbury, Dept. of Physics
  Christchurch, New Zealand
  23.1.2004 - 26.1.2004

- Gerhard Findenegg
  Stranski-Laboratorium für Physikalische und Theoretische Chemie
  TU Berlin, Germany
  20.03.2004 - 24.03.2004

- Kazuo Fujikawa
  Department of Physics, Tokyo University
  Tokyo, Japan
  19.2.2004 - 27.2.2004

- Francois Gelis
  CE Saclay
  Gif-sur-Yvette, France
  11.10.2004 - 15.10.2004

- Christos N. Likos
  Institut für Theoretische Physik,
  Heinrich Heine-Universität
  Düsseldorf, Germany
  16.02.2004 - 25.02.2004
  09.10.2004 - 16.10.2004

- Carlos Reinhold
  Oak Ridge National Laboratory, Physics Division
  Oak Ridge, USA
  23.6.2004 - 2.7.22004

- Michaela Oswald
  Niels-Bohr Institut, Univ. Kopenhagen
  Kopenhagen, Denmark
  13.7.2004 - 14.7.2004

- D.V. Vassilevich
  Institut für Theoretische Physik, Universität Leipzig
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  15.12.2003 - 3.1.2004

- Jean-Jaques Weis
  Laboratoire de Physique Theorique,
  Université Paris-Sud
  Orsay, France
  20.06.2004 - 28.06.2004
  14.12.2004 - 20.12.2004

Appendix B

Invited Lectures by External Speakers

- Matthias Ballauf
  Physikalische Chemie I der Universität Bayreuth
  Bayreuth, Germany
  Dendrimere: Von der Spielwiese der organischen Chemie zum Modellsystem der Physik der weichen Materie, 18.05.2004

- Imre Ferenc Barna
  Max-Planck-Institute for the Physics of Complex Systems
  Dresden, Germany.
  Photoionisation of helium and coherent control, 30.3.2004

- Kurt Binder
  Institut für Physik, Universität Mainz
  Mainz, Germany
  Glas: Für die Wissenschaft "undurchsichtig", 30.11.2004

- József Cserti
  Eötvös University
  Budapest, Hungary
  Ring-shaped Andreev billards in quantized magnetic fields, 6.4.2004

- Gerhard Findenegg
  Stranski-Laboratorium für Physikalische und Theoretische Chemie
  TU Berlin, Germany
  Periodisch meosoporöse Silikate: Reagenzgläser zum Studium der räumlichen Begrenzung auf das Zustandsverhalten von Stoffen, 23.03.2004

- Kazuo Fujikawa
  Department of Physics, Tokyo University
  Tokyo, Japan
  Anomalies, local counter terms and path integral bosonization, 24.2.2004

- Francois Gelis
  CE Saclay
  Gif-sur-Yvette, France
  High-energy hadronic collisions and saturation, 12.10.2004

- Kensuke Kobayashi
  ETH Zürich
  Zürich, Switzerland
  Fano resonances in transport through nanostructures, 13.7.2004

- Eckehard Krotscheck
  Institut für Theoretische Physik, Johannes Kepler Universität Linz
  Linz, Austria
  Flüssiges ^{4}*He in eingeschränkten Geometrien*, 16.11.2004

- Colin Lambert
  Lancaster University
  Lancaster, UK
  An introduction to Andreev scattering in hybrid F/S structures, 6.4.2004

- Christos N. Likos
  Institut für Theoretische Physik,
  Heinrich Heine-Universität
  When physics meets chemistry: playing with soft matter, 12.10.2004

- Michaela Oswald
  Niels-Bohr Institut, Univ. Kopenhagen
  Kopenhagen, Denmark
  Effective theory for the Polyakov line at high temperatures, 13.7.2004

- Eugene Sukhorukov
  University of Geneva
  Geneva, Switzerland
  Shot noise in mesoscopic conductors: From Schottky to Bell, 16.12.2004

- Peter van Nieuwenhuizen
  C.N. Yang Institute for Theoretical Physics, Stony Brook
  New York, USA
  Anomalies in D=10 N=1 and N=2B supergravity from quantum mechanical path integrals, Lecture Series 8.1.2004 - 27.01.2004

Appendix C

Publications

C.1 Articles in refereed journals

- P.C. Aichelburg, H. Balasin, M. Kerber
  Head-on collision of ultrarelativistic charges
  Class. Quant. Grav.**21** (2004) 1 - 10.

- F. Aigner, M. Hillbrand, J. Knapp, G. Milovanovic, R. Schöfbeck, M. Schweda
  Technical remarks and comments on the UV/IR-mixing problem of a non-commutative scalar quantum field theory
  Czech. J. of Physics **54** (2004) 7, 711 - 719.

- J. O. Andersen, E. Petitgirard, M. Strickland
  Two-loop hard-thermal-loop thermodynamics with quarks
  Physical Review D **70** (2004) 045001-1 - 045001-43.

- A. Apolonski, P. Dombi, G. Paulus, M. Kakehata, R. Holzwarth, T. Udem
  C. Lemell, K. Torizuka, J. Burgdörfer, T. Hänsch, F. Krausz
  Observation of light-phase-sensitive photoemission from a metal
  Physical Review Letters **92** (2004) 073902-1 - 073902-4.

- D.G. Arbo, C. O. Reinhold, J. Burgdörfer
  Classical and quantum scaling for localization of HCP-driven Rydberg wavepackets
  Physical Review A **69** (2004) 023409-1 - 023409-6.

- H. Balasin, D. Grumiller
  The ultrarelativistic limit of 2D dilaton gravity and its energy-momentum tensor
  Class. Quant. Grav. **21** (2004) 2859 - 2872.

- L. Bergamin, D. Grumiller, W. Kummer
  Quantization of 2D dilaton supergravity with matter
  J. High Energy Phys. **05** (2004) 060, 1 - 35.

- L. Bergamin, D. Grumiller, W. Kummer
  Supersymmetric black holes in 2D dilaton supergravity: baldness and extremality
  Journal of Physics A: Mathematical and General **37** (2004) 3881 - 3901.

- J.-P. Blaizot, E. Iancu, U. Reinosa
  Renormalization of Phi-derivable approximations in scalar field theories
  Nuclear Physics A **736** (2004) 149 - 200.

- C.G. Böhmer
  Eleven spherically symmetric constant density solutions with cosmological constant
  General Relativity and Gravitation **36** (2004) 1039 - 1053.

- C.G. Böhmer
  The Einstein static universe with torsion and the sign problem of the cosmological constant
  Class. Quant. Grav. **21** (2004) 1119 - 1124.

- J. Burgdörfer, L. Wirtz, M. Dallos, H. Lischka
  Ab initio calculations of charge exchange in ion-surface collision: an embedded-cluster approach
  in: "Correlation Spectroscopy of Surfaces, Thin Films and Nanostructures", J. Berakdar, J. Kirschner (eds.);
  WILEY-VCH Verlag, 2004, ISBN: 3-527-40477-5, p. 130 - 143.

- J. Burgdörfer, L. Wirtz, C. O. Reinhold, C. Lemell
  Multi-electron dynamics for neutralization of highly charged ions near surfaces
  Vacuum **73** (2004) 3 - 7.

- M. Davidse, M. de Vroome, U. Theis, S. Vandoren
  Instanton solutions for the universal hypermultiplet
  Fortschr. Phys. **52** (2004) 6-7, 696 - 701.

- M. Davidse, U. Theis, S. Vandoren
  Fivebrane instanton corrections to the universal hypermultiplet
  Nuclear Physics B **697** (2004) 48 - 88.

- S. Denk, V. Putz, M. Schweda, M. Wohlgenannt
  Towards UV finite quantum field threories from non-local field operators
  Eur. Phys. J. C **35** (2004) 283 - 292.

- K. Dimitriou, D.G. Arbo, S. Yoshida, E. Persson, J. Burgdörfer
  Origin of the double-peak structure in the momentum distribution of ionization of hydrogen atoms driven by strong laser fields
  Physical Review A **70** (2004) 061401-1 - 061401-4.

- F.B. Dunning, C. O. Reinhold, J. Burgdörfer
  The kicked Rydberg atom: a new laboratory for study of non-linear dynamics
  Physica Scripta **68** (2003) C44 - C47.

- Z. Ficek, J. Seke, A. Soldatov, G. Adam, N.N. Bogolubov
  Multilevel coherence effects in a two-level atom driven by a trichromatic field
  Optics Communications **217** (2003) 299 - 309.

- S. Filipp, K. Svozil
  Generalizing Tsirelson's bound on Bell inequalities using a min-max principle
  Physical Review Letters **93** (2004) 13, 130407-1 - 130407-4.

- S. Filipp, K. Svozil
  Testing the bounds on quantum probabilities
  Physical Review A, 69 (2004), S. 032101-1 - 032101-6.

- A. Gerhold, A. Ipp, A. Rebhan
  Non-Fermi-liquid specific heat of normal degenerate quark matter
  Physical Review D **70** (2004) 105015-1 - 105015-17.

- A.S. Goldhaber, A. Rebhan, P. van Nieuwenhuizen, R. Wimmer
  Quantum corrections to mass and central charge of supersymmetric solitons
  Physics Reports, **398** (2004) 179 - 219.

- D. Gottwald, C.N. Likos, G. Kahl, H. Löwen
  Phase behavior of ionic microgels
  Physical Review Letters **92** (2004) 6, 068301-1 - 068301-4.

- E. Gratz, H. Nowotny, J. Enser, E. Bauer, K. Hense
  Magnetoresistance in RCo2 spin-fluctuation systems
  Journal of Magnetism and Magnetic Materials **272-276** (2004) e441 - e442.

- K. Grill, C. Tutschka
  One-dimensional falling bodies
  Journal of Statistical Physics **117** (2004) 1015 - 1022.

- D. Grumiller, D. Mayerhofer
  On static solutions in 2D dilaton gravity with scalar matter
  Class. Quant. Grav.**21** (2004) 5893 - 5914.

- S. Guttenberg, J. Knapp, M. Kreuzer:
  On the covariant quantization of type-II superstrings
  J. High Energy Phys. **06** (2004) 1 - 30.

- K. Hense, E. Gratz, H. Nowotny, A. Hoser
  Lattice dynamics and the interaction with the crystal electric field in NdCu2
  J. Phys.: Condens. Matter **16** (2004) 5751 - 5768.

- K. Hense, E. Gratz, H. Nowotny, M. Loewenhaupt, A. Hoser
  Crystal electric field-phonon interaction in NdCu2
  Journal of Magnetism and Magnetic Materials **272-276** (2004) 368 - 369.

- K. Hense, U. Witte, M. Rotter, R. Schedler, E. Gratz, H. Nowotny, M. Loewenhaupt
  Comparison of the CF-induced phonon shifts in CeCu2 and NdCu2
  Journal of Magnetism and Magnetic Materials **272-276** (2004) e387 - e388.

- M. Herbst, A. Kling, M. Kreuzer
  Cyclicity of non-associative products on D-branes
  J. High Energy Phys. **03** (2004) 003, 1 - 18.

- M. Hörndl, S. Yoshida, K. Tökési, J. Burgdörfer
  Comment on "radiative recombination enhancement of bare ions in storage rings with electron cooling
  Physical Review Letters **93** (2004) 20, 209301-1.

- A. Ipp, A. Gerhold, A. Rebhan
  Anomalous specific heat in high-density QED and QCD
  Physical Review D **69** (2004) 1, 011901-1 - 011901-4.

- A. Ipp, A. Rebhan, A. Vuorinen
  Perturbative QCD at nonzero chemical potential: Comparison with the large-Nf limit and apparent convergence
  Physical Review D **69** (2004) 077901-1 - 077901-4.

- Yu.V. Kalyuzhnyi, G. Kahl, P.T. Cummings
  Phase coexistence in polydisperse charged hard-sphere fluids: Mean spherical approximation
  Journal of Chemical Physics **120** (2004) 21, 10133 - 10145.

- R. Klages, I.F. Barna, L. Mátyás
  Spiral modes in the diffusion of a single granular particle on a vibrating surface
  Physics Letters A **333** (2004) 79 - 84.

- U. Kraemmer, A. Rebhan
  Advances in perturbative thermal field theory
  Reports of Progress in Physics **67** (2004) 3, 351 - 431.

- M. Kreuzer, H. Skarke
  PALP: A package for analysing lattice polytopes with applications to toric geometry
  Computer Physics Communications **157** (2004) 87 - 106.

- S. Leroch, D. Gottwald, G. Kahl
  Thermodynamic properties of polydisperse fluid mixtures
  Condensed Matter Physics **7** (2004) 301 - 320.

- St. Mrowczynski, A. Rebhan, M. Strickland
  Hard-loop effective action for anisotropic plasmas
  Physical Review D **70** (2004) 025004-1 - 025004-7.

- V. Putz, K. Svozil
  Quantum electrodynamics in the squeezed vacuum state: Electron mass shift
  Il Nuovo Cimento **119** B (2004) 175 - 179.

- A. Rebhan, P. van Nieuwenhuizen, A. Wimmer
  A new anomalous contribution to the central charge of the N=2 monopole
  Physics Letters B **594** (2004) 234 - 240.

- A. Rebhan, P. van Nieuwenhuizen, R. Wimmer
  New developments in the quantization of supersymmetric solitons (kinks, vortices and monopoles)
  Brazilian Journal of Physics **34** (2004), 4A; S. 1273 - 1287.

- A. Rebhan, P. van Nieuwenhuizen, R. Wimmer
  Nonvanishing quantum corrections to the mass and central charge of the N=2 vortex and BPS saturation
  Nuclear Physics B **679** (2004) 382 - 394.

- C. O. Reinhold, W. Zhao, J. Lancaster, F.B. Dunning, E. Persson, D.G. Arbó, S. Yoshida, J. Burgdörfer
  Response of highly polarized Rydberg states to trains of half-cycle pulses
  Physical Review A **70** (2004) 033402-1 - 033402-7.

- P. Romatschke, M. Strickland
  Collective modes of an anisotropic quark-gluon plasma: II
  Physical Review D **70** (2004) 116006-1 - 116006-9.

- P. Romatschke, M. Strickland
  Energy loss of a heavy fermion in an anisotropic QED plasma
  Physical Review D **69** (2004) 065005-1 - 065005-13.

- S. Rotter, F. Libisch, J. Burgdörfer, U. Kuhl, H. Stöckmann
  Tunable Fano resonances in transport through microwave billiards
  Physical Review E **69** (2004) 046208-1 - 046208-4.

- E. Schöll-Paschinger
  Self-consistent Ornstein-Zernike approximation for the Sogami-Ise fluid
  Journal of Chemical Physics **120** (2004) 24, 11698 - 11711.

- E. Schöll-Paschinger, E. Gutlederer, G. Kahl
  The influence of thermodynamic self-consistency on the phase behaviour of symmetric binary mixtures
  Journal of Molecular Liquids **112** (2004) 5 - 11.

- K. Svozil
  Conventions in relativity theory and quantum mechanics
  La Nuova Critica, Nuova Serie **43-44** (2004) 59 - 70.

- K. Svozil
  Eutactic quantum codes
  Physical Review A **69** (2004) 034303-1 - 034303-3.

- K. Svozil
  Quantum information via state partitions and the context translation principle
  Journal of Modern Optics **51** (2004) 6-7, 811 - 819.

- K. Tökési, X.-M. Tong, C. Lemell, J. Burgdörfer
  Friction force for charged particles at large distances from metal surfaces
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  J.R. Sabin, E. Brändas (eds.);
  Elsevier, 2004, ISBN: 0-12-034846-2, S. 29 - 64.

- S. Yoshida, F. Großmann, E. Persson, J. Burgdörfer
  Semiclassical analysis of quantum localization of the periodically kicked Rydberg atom
  Physical Review A **69** (2004) 043410-1 - 043410-10.

- S. Yoshida, E. Persson, C. O. Reinhold, J. Burgdörfer, B.E. Tannian, C.L. Stokely, F.B. Dunning
  Tailoring and controlling wave packets in multi-photon atom collisions
  Physica Scripta **T110** (2004) 424 - 428.

- W. Zhao, J. Lancaster, F.B. Dunning, C. O. Reinhold, J. Burgdörfer
  Characterization of the quasi one-dimensional Rydberg atom using half-cycle pulses
  Physical Review A **69** (2004) 041401-1 - 041401-4.

C.2 Articles in conference proceedings

- E. Benes, M. Gröschl, S. Radel, H. Nowotny
  Splitting of dispersions by ultrasonic standing wave fields
  in: "Proc. 18th Int. Congress on Acoustics (ICA 2004)"
  Acoustical Society of Japan
  Kyoto, Japan, 2004, ISBN 4-9901915-6-0, 4 S.

- J. Burgdörfer, N. Rohringer, P.S. Krstic, C. O. Reinhold
  Nonadiabatic processes near barriers
  in: "Nonadiabatic transition in quantum systems"
  V.I. Osherov, L.I. Ponomarev (eds.);
  Institute of Problem of Chemical Physics, Russian Academy of Sciences
  Chernogolovka, Russia, 2004, ISBN: 5-901675-48-7, S. 205 - 228.

- P. Dombi, A. Apolonski, G. Paulus, M. Kakehata, K. Torizuka, R. Holzwarth, T. Udem, C. Lemell, J. Burgdörfer, T. Hänsch, F. Krausz
  Solid-state Carrier-envelope phase detector
  in: "Ultrafast Optics IV",
  F. Krausz, C. Korn, P. Corkum, I.A. Walmsley (eds.);
  Springer-Verlag, New York, 2004, ISBN: 0-387-40091-5, S. 185 - 189.

- D. Grumiller, W. Kummer, D. Vassilevich
  Three functions in dilaton gravity: The good, the bad and the muggy
  in: "Proceedings of the IVth International Hutsulian Workshop on Mathematical Theories and their Applications in Physics & Technology", S.S. Moskaliuk (ed.);
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- E. Persson, S. Puschkarski, X.-M. Tong, J. Burgdörfer
  Towards attosecond half-cycle pulses
  in: "Ultrafast Optics IV",
  F. Krausz, C. Korn, P. Corkum, I.A. Walmsley (eds.);
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- J.-P. Blaizot, E. Iancu, A. Rebhan
  Thrmodynamics of the high-temperature quark-gluon plasma
  in: "Quark-Gluon Plasma", R.C. Hwa, X.-N. Wang (eds.);
  World Scientific Publishing Co., 2004, ISBN:981-238-077-9, S. 60 - 122.

C.3 Invited talks

- J. Burgdörfer
  Concluding remarks
  8th Intern. Seminar on Fast-Ion-Atom Collisions
  Debrecen, Hungary; 01.09.2004 - 03.09.2004.

- J. Burgdörfer
  Dynamical surface interaction
  Vortrag: Austrian-Hungarian Workshop
  Vienna, Austria; 29.11.2004.

- J. Burgdörfer
  Interaction of highly charged ions with matter: from hollow atoms to nanostructure
  Int. Workshop on Atomic Collision of Slow and Trapped Highly Charged Ions, RIKEN 2004
  Tokyo, Japan; 19.02.2004 - 21.02.2004.

- J. Burgdörfer
  Projectile excitation and charge transfer in solids and at surfaces, introductory lecture
  Int. Conference on Atomic Collisions in Solids
  Geneva, Italy; 04.07.2004 - 09.07.2004.

- J. Burgdörfer
  Rydberg atoms in half-cycle pulses: A laboratory for wavefunction tayloring, coherent control and chaos
  2004 APS Meeting of the Division of Atomic, Molecular and Optical Physics
  Tuscon, Arizona, USA; 27.05.2004.

- J. Burgdörfer
  Rydberg atoms in half-cycle pulses: A laboratory for wavefunction tayloring, coherent control and chaos
  Int. Workshop on Rydberg Physics, MPI
  Dresden, Germany; 04.05.2004.

- J. Burgdörfer
  Simulation of ion transport through nanocapillaries
  The Satellite Symposium of IISC-15
  Okayama University, Okayama, Japan; 14.10.2004 - 15.10.2004.

- J. Burgdörfer
  Slow highly charged ion-surface interactions
  Intern. Workshop on Inelastic Ion Surface Collisions
  Ise-Shima, Mie, Japan; 17.10.2004 - 22.10.2004.

- C. Deiss, N. Rohringer, J. Burgdörfer
  Cluster-laser interaction: fast production of hot electrons by short laser pulses
  12th Int. Conf. on the Physics of Highly Charged Ions (HCI-2004)
  Vilnius, Lithuania; 06.09.2004 - 11.09.2004.

- M.-J. Fernaud, E. Lomba
  Dipolar fluid inclusions in random ionic matrices
  NATO-Advanced Research Workshop on "Ionic Soft Matter: Novel trends in theory and applications
  Lviv, Ukraine; 14.04.2004 - 17.04.2004.

- C. Lemell
  Electron emission from magnetized surfaces
  3S04, St. Christoph/Arlberg, Austria; 05.03.2004.

- C. Lemell
  Electron emission from surfaces induced by HCI and laser
  12th Intern. Conference on the Physics of Highly Charged Ions
  Vilnius, Lithuania; 10.09.2004.

- C. Lemell
  Highly charged ions interacting with surfaces
  SPARC Collaboration Meeting
  Darmstadt, Germany; 29.10.2004.

- A. Rebhan
  Non-Fermi-liquid specific heat of normal degenerate quark matter
  ECT*-APCTP International Workshop on Novel Approaches to the Nuclear Many-Body Problem: From Nuclei to Stellar Matter
  Trento, Italy; 15.09.2004.

- A. Rebhan
  Summing bubbles in thermal field theory
  Retirement event Prof. Peter Landshoff, University of Cambridge
  Cambridge, England; 30.09.2004.

- A. Rebhan
  Weak coupling techniques for the strongly interacting quark-gluon plasma
  9‘eme Rencontre Itzykson: The New Frontiers of QCD, CEA/SPhT Saclay
  Gif-sur-Yvette, France; 10.06.2004.

- A. Rebhan
  Weak-coupling techniques for QCD thermodynamics
  4th Budapest Winter School on Heavy Ion Physics, Research Institute for Particle and Nuclear Physics of the Hungarian Academy of Sciences
  Budapest, Hungary; 03.12.2004.

- E. Scheidegger
  An introduction to the topological vertex
  Workshop "Mathematical and Physical Aspects of Branes in Calabi-Yau spaces"
  ESI Vienna, Austria; 11.05.2004.

- E. Scheidegger
  Topological string amplitudes on regular K3 fibrations
  Workshop "String-Theorie und Geometrie", MFO
  Oberwolfach, Germany; 13.08.2004.

- M. Seliger, C. O. Reinhold, T. Minami, J. Burgdörfer
  Non-unitary quantum trajectory Monte Carlo method for open quantum systems
  Intern. Workshop on Atomic Physics (ATOM 2004)
  Dresden, Germany; 30.11.2004.

- K. Svozil
  Farewell to counterfactuals
  Foundations of Probability and Physics
  Växjö, Sweden; 07.06.2004 - 12.06.2004.

- K. Svozil
  Paul Feyerabend und die Physik
  Intern. Symposium am Institut Wiener Kreis
  Vienna, Austria; 18.06.2004 - 19.06.2004.

- K. Svozil
  The diagonalization method in quantum recursion theory
  ESF International Workshop on Quantum Information, Logical Aspects
  Sassari, Sardinia; 24.09.2004.

C.4 Contributed presentations

- F. Aigner
  Recent results on shot noise in transport through open quantum dots
  Workshop on Andreev Billiards 2004
  University of Technology, Vienna, Austria; 06.04.2004

- D.G. Arbó, C. O. Reinhold, J. Burgdörfer
  Discrete scaling laws for the transiently localized Rydberg states
  35th Meeting of the Division of Atomic und Optical Physics (DAMOP)
  Tucson, Arizona, USA; 25.05.2004 - 29.05.2004.

- D.G. Arbó, C. O. Reinhold, J. Burgdörfer
  Quantum and classical scaling law for transient localization of HCP-driven Rydberg wave packets
  8th Europ. Conf. on Atomic and Molecular Physics (ECAMP VIII)
  Rennes, France; 06.07.2004 - 10.07.2004.

- D.G. Arbó, C. O. Reinhold, J. Burgdörfer
  Transient localization of HCP-driven Rydberg wave packets: Quantum and classical scaling law
  Intern. Workshop and Seminar on Rydberg Physics
  Dresden, Germany; 19.04.2004 - 14.05.2004.

- J. Burgdörfer
  Open quantum billiards: classical-quantum correspondence
  Workshop on Andreev Billiards 2004
  University of Technology, Vienna, Austria, 04.06.2004.

- J. Burgdörfer, D.G. Arbó, E. Persson, S. Puschkarski, S. Yoshida, C. O. Reinhold, F.B. Dunning, J. Lancaster, W. Zhao
  Atoms in half-cycle pulses: A laboratory for wavefunction tailoring, coherent control and quantum chaos
  2004 APS Meeting of the Division of Atomic, Molecular and Optical Physics
  Tucson, Arizona, USA; 25.05.2004 - 29.05.2004.

- C. Deiss, N. Rohringer, J. Burgdörfer
  Cluster-laser interaction: fast production of hot electrons by short laser pulses
  Workshop on Atomic Physics 2004
  Dresden, Germany; 29.11.2004 - 03.12.2004.

- K. Dimitriou, D. Arbó, S. Yoshida, E. Persson, J. Burgdörfer
  Ionization of atoms by strong laser fields: origin of the double peak structure in the longitudinal momentum distribution
  The eighth European Conference on Atomic and Molecular Physics
  Rennes, France; 06.07.2004 - 07.07.2004.

- K. Ehrenberger, K. Svozil
  Stochastic interference and auditory perception
  7th European Symposium on Paediatric Cochlear Implantation 2004
  Geneva, Switzerland; 02.05.2004 - 05.05.2004.

- A. Gerhold
  Anomalous specific heat in high density QCD
  FAKT 2004 (Österr. Physikal. Gesellschaft)
  Weyer, Austria; 27.09.2004.

- A. Gerhold
  Gauge dependence identities for color superconducting QCD
  Strong and Electroweak Matter 2004
  Helsinki, Finland; 17.06.2004.

- A. Gerhold, A. Ipp, A. Rebhan
  Anomalous specific heat in ultradegenerate QED and QCD
  Strong and Electroweak Matter 2004
  Helsinki, Finland; 17.06.2004.

- D. Gottwald, G. Kahl, C.N. Likos
  Predicting equilibrium structures in freezing processes
  Colloidal Dispersions in External Fields (CODEF)
  Bonn, Germany; 29.03.2004 - 01.04.2004.

- D. Gottwald, C.N. Likos, G. Kahl, H. Löwen
  Phase behavior of ionic microgels
  Colloidal Dispersions in External Fields (CODEF)
  Bonn, Germany; 29.03.2004 - 01.04.2004.

- Y. Hasegawa, S. Filipp, H. Rauch
  Non-cyclic Geometric Phase due to Spatial Evolution in a Neutron Interferometer
  Fachausschusstagung, ÖPG, Kern- und Teilchenphysik
  Weyer, Austria; 26.09.2004 - 28.09.2004.

- M. Hörndl, S. Yoshida, K. Tökési, J. Burgdörfer
  Enhancement of low-energy electron-ion recombination
  12th Intern. Conference on the Physics of Highly Charged Ions
  Vilnius, Lithuania; 06.09.2004 - 11.09.2004.

- A. Ipp
  Thermodynamics of deconfined QCD at small and large chemical potential
  Strong and Electroweak Matter 2004
  Helsinki, Finland; 18.06.2004.

- Yu.V. Kalyuzhnyi, S.P. Hlushak, G. Kahl
  Phase coexistence in polydisperse Yukawa hard-shpere fluids. Van der Waals and mean spherical approximations
  NATO-Advanced Research Workshop on "Ionic Soft Matter: Novel trends in theory and applications
  Lviv, Ukraine; 14.04.2004 - 17.04.2004.

- Yu.V. Kalyuzhnyi, G. Kahl
  Phase coexistence in polydisperse charged hard-sphere fluids: Mean spherical and associative mean spherical approximations
  NATO-Advanced Research Workshop on "Ionic Soft Matter: Novel trends in theory and applications
  Lviv, Ukraine; 14.04.2004 - 17.04.2004.

- J. Köfinger, G. Kahl, N.B. Wilding
  Phase diagrams of symmetrical binary fluids in a field
  Conference of the ESF Program SIMU "Bridging the Scales"
  Geneva, Italy; 29.08.2004 - 31.08.2004.

- J. Lancaster, W. Zhao, F.B. Dunning, C. O. Reinhold, J. Burgdörfer
  Characterization of quasi one-dimensional Rydberg atoms using oriented, half-cycle pulses
  2004 APS Meeting of the Division of Atomic, Molecular and Optical Physics
  Tucson, Arizona, USA; 25.05.2004 - 29.05.2004.

- C. Lemell
  Determination of the carrier-envelope phase of ultrashort laser pulses unsing metal surfaces
  DPG Munich, Germany; 25.03.2004.

- C. Lemell, P. Dombi, X.-M. Tong, F. Krausz, J. Burgdörfer
  Determination of the carrier-envelope phase of ultrashort laser pulses using metal surfaces
  68. Physikertagung und AMOP-Frühjahrstagung
  Munich, Germany; 22.03.2004 - 26.03.2004.

- C. Lemell, P. Dombi, X.-M. Tong, F. Krausz, J. Burgdörfer
  Determination of the carrier-envelope phase of ultrashort laser pulses using metal surfaces
  2004 APS Meeting of the Division of Atomic, Molecular and Optical Physics
  Tucson, Arizona, USA; 25.05.2004 - 29.05.2004.

- F. Libisch
  Recent results in wavefunctions in Andreev billiards
  Workshop on Andreev Billiards 2004, Technische Universität Wien
  Vienna, Austria; 06.04.2004.

- B. Mladek
Thermodynamically self-consistent liquid state theories for systems with bounded potentials
Erwin Schroedinger International Institute for Mathematical Physics
Vienna, Austria; 30.06.2004.

- B. Mladek, D. Gottwald, G. Kahl, G. Neumann
Computer simulations for the clustering transition in the generalized Gaussion core model
Conference of the ESF Program SIMU "Bridging the Scales"
Geneva, Italy; 29.08.2004 - 31.08.2004.

- B. Mladek, D. Gottwald, G. Neumann, G. Kahl
The clustering transition in the generalized Gaussion core model
Soft Matter Days
Kerkrade, The Netherlands; 16.11.2004 - 19.11.2004.

- B. Mladek, M. Neumann, G. Kahl
Integral equation theories and computer simulations for systems with bounded potentials
Colloidal Dispersions in External Fields (CODEF)
Bonn, Germany; 29.03.2004 - 01.04.2004.

- E. Persson
Towards attosecond half-cycle pulses
DPG, Munich
Germany; 21.03.2004.

- E. Persson, S. Puschkarski, X.-M. Tong, J. Burgdörfer
Towards attosecond half-cycle pulses
8th Europ. Conf. on Atomic and Molecular Physics (ECAMP VIII)
Rennes, France; 06.07.2004 - 07.07.2004.

- E. Persson, S. Yoshida, X.-M. Tong, C. O. Reinhold, J. Burgdörfer
A Floquet study of the periodically kicked Rydberg atom
Resonances - From Physics to Mathematics and Back, MPIPKS
Dresden, Germany; 23.01.2004 - 30.01.2004

- A. Rebhan
Thermodynamics of Large-Nf QCD at Nonzero Chemical Potential and Non-Fermi-Liquid Behavior
QCD and Dense Matter: From Lattices to Stars, INT, University of Washington
Washington, USA

- C. O. Reinhold, E. Persson, D. Arbó, S. Yoshida, J. Burgdörfer, W. Zhao, J. Lancaster, F.B. Dunning
The kicked Rydberg atom: effect of noise and external fields on dynamical stabilization
2004 APS Meeting of the Division of Atomic, Molecular and Optical Physics
Tucson, Arizona, USA; 25.05.2004 - 29.05.2004.

- U. Reinosa
  Renormalization and gauge symmetries for 2PI effective actions
  Strong and Electroweak Matter 2004
  Helsinki, Finland; 19.06.2004.

- N. Rohringer, S. Peter, J. Burgdörfer
  Time dependent density functional theory: A critical case study: Unltra short pulse excitation of interacting two electron systems
  Intern. Workshop and School: Time Dependent Density Functional Theory: Prospects and Applications
  Benasque, France; 28.08.2004 - 12.09.2004.

- P. Romatschke
  Mountains on spirals
  Strong and Electroweak Matter 2004
  Helsinki, Finland; 17.06.2004.

- S. Rotter
  A modular recursive Green's function method: perspectives for future applications
  Workshop on Andreev Billiards 2004, Technische Universität Wien
  Vienna; 06.04.2004.

- S. Rotter
  Decoherence and Fano resonances in transport through quantum dot
  Frontiers of Quantum and Mesoscopic Thermodynamics
  Prague, Czech Republic, 28.07.2004.

- E. Scheidegger
  Higher genus topological string amplitudes
  Beyond the Standard Model 2004
  Bad Honnef, Germany; 08.03.2004.

- E. Scheidegger
  Higher genus topological string amplitudes
  Workshop "Algebraic Geometry and Physics" WAGP 2004
  Lisbon, Portugal; 12.09.2004.

- E. Scheidegger
  Higher genus topological string amplitudes
  Workshop "Mathematical and Physical Aspects of String Theory",
  Centro Stefano Franscini
  Ascona, Schwitzerland; 20.07.2004.

- M. Seliger, T. Minami, C. O. Reinhold, J. Burgdörfer
  Non-unitary quantum Monte Carlo method for transport of atomic states through solids
  35th Meeting of the Division of Atomic und Optical Physics (DAMOP)
  Tucson, Arizona, USA; 25.05.2004 - 29.05.2004.

- M. Seliger, C. O. Reinhold, T. Minami, J. Burgdörfer
  Monte Carlo description of open quantum systems
  25. Tagung über energiereiche atomare Stöße (EAS)
  Riezlern, Austria; 10.02.2004.

- M. Seliger, C. O. Reinhold, T. Minami, J. Burgdörfer
  Non-unitary master equation for the internal state of ions traversing solids
  21st Intern. Conference on Atomic Collisions in Solids (ICACS)
  Geneva, Italy; 04.07.2004 - 09.07.2004.

- A. Soldatov, J. Seke, G. Adam
  On the momentum representation of the spinor components of relativistic eigenfunctions and the Fourier transformation of their multiple products for hydrogen-like atoms
  Jahrestagung der Österreichischen Physikalischen Gesellschaft
  Linz, Austria; 28.09.2004 - 30.09.2004.

- M. Strickland
  Collective modes of an anisotropic quark-gluon plasma
  Strong and Electroweak Matter 2004
  Helsinki, Finland; 16.06.2004.

- M. Wickenhauser, J. Burgdörfer, F. Krausz, M. Drescher
  Time resolved autoionization
  68. Physikertagung und AMOP-Frühjahrstagung
  Munich, Germany; 22.03.2004 - 26.03.2004.

- M. Wickenhauser, J. Burgdörfer, F. Krausz, M. Drescher
  Time resolved Fano resonances
  2004 APS Meeting of the Division of Atomic, Molecular and Optical Physics
  Tucson, Arizona, USA; 25.05.2004 - 29.05.2004.

- S. Yoshida, K. Dimitriou, D. Arbó, E. Persson, J. Burgdörfer
  Quasi-classical analysis of atom-laser interaction: limitation of the classical method including tunneling
  The eighth European Conference on Atomic and Molecular Physics
  Rennes, France; 08.07.2004 - 09.07.2004.

- W. Zhao, J. Lancaster, F.B. Dunning, C. O. Reinhold, J. Burgdörfer
  Engineering atomic wavefunctions using sequences of orthogonally-directed half-cycle pulses
  2004 APS Meeting of the Division of Atomic, Molecular and Optical Physics
  Tucson, Arizona, USA; 25.05.2004 - 29.05.2004.

C.5 Talks at other institutions

- D.G. Arbó
  Ionization of atoms by short-laser pulses
  University of Buenos Aires
  Buenos Aires, Argentina; 16.12.2004

- L. Bergamin
  Background independent quantization of 2D dilaton supergravity
  Universität Bern
  Bern, Switzerland; 07.05.2004.

- L. Bergamin
  Background independent quantization of supergravity in 2D"
  Albert Einstein Institut Golm
  Golm, 27.04.2004.

- L. Bergamin
  Gravity in 2D: Why? How?
  Universität Bern
  Bern, Switzerland; 06.05.2004.

- J. Burgdörfer
  Quantum chaos and Rydberg atoms
  Lecture Series MPI
  Dresden, Germany; 19.04.2004 - 23.04.2004.

- J. Burgdörfer
  Atoms in half-cycle pulses: a laboratory for wavefunction tayloring, coherent control and quantum chaos
  Center of Excellence Colloquium, Univ. of Electro-Communication
  Chofu-Shi, Japan; 17.02.2004.

- J. Burgdörfer
  Atoms in half-cycle pulses: a laboratory for wavefunction tayloring, coherent control and quantum chaos
  Coherent Science Colloquium, RIKEN 2004
  Wako-Shi, Japan; 16.02.2004.

- J. Burgdörfer
  Atoms in half-cycle pulses: a laboratory for wavefunction tayloring, coherent control, and quantum chaos
  Colloquium, College of William and Mary
  Williamsburg, VA, USA; 17.09.2004.

- J. Burgdörfer
  Interaction of highly charged ions with matter: from hollow atoms to nanostructures
  Faculty of Mechanical Engineering, Kyoto University
  Kyoto, Japan; 27.02.2004.

- M.-J. Fernaud
  Dipolar fluid inclusions in random ionic matrices
  Max-Planck-Institut für Metallforschung
  Stuttgart, Germany; 09.11.2004.

- D. Gottwald
  Clustered crystals
  Heinrich-Heine Universität
  Düsseldorf, Germany; 12.11.2004.

- D. Gottwald
  Genetic algorithms - an attractive tool in condensed matter theory
  Evaluation Meeting of the Science College "CMS"
  Technische Universität Wien
  Vienna, Austria; 14.12.2004

- D. Gottwald, J. Köfinger, B. Mladek
  Einfache Methoden zur Visualisierung von Simulationsdaten
  Universität Wien
  Vienna, Austria; 16.06.2004.

- G. Kahl
  Genetic algorithms - possibly a new tool in condensed matter physics
  Max-Planck-Institut für Metallforschung
  Stuttgart, Germany; 25.05.2004.

- Y.V. Kalyuzhnyi
  Multidensity theory for associating and complex fluids
  University of Regensburg, Department of Chemistry
  Regensburg, Germany; 25.02.2004

- W. Kummer
  Classical and quantum gravity in 2 dimensions
  Ukrainische Akademie der Wissenschaften, Bogoliubov Institute
  Kiev, Ukraine; 19.02.2004.

- W. Kummer
  Extended supergravity from graded Poisson-sigma models
  Ukrainische Akademie der Wissenschaften, Bogoliubov Institute
  Kiev, Ukraine; 13.09.2004.

- C. Lemell
  Transport of highly charged ions through micro- and nanocapillaries
  Seminar Institut für Allgemeine Physik (IAP), TU Wien
  Vienna, Austria; 09.11.2004.

- B. Mladek
  The self consistent Ornstein-Zernike approximation
  Heinrich-Heine Universität
  Düsseldorf, Germany; 26.11.2004

- A. Rebhan
  New analytical results on the thermodynamics of deconfined quark-gluon matter
  Niels-Bohr-Institut, Univ. Kopenhagen
  Copenhagen, Denmark; 05.07.2004.

- S. Rotter
  Ballistic quantum transport at high magnetic fields
  University of Lancaster
  Lancaster, UK; 18.05.2004.

- S. Rotter
  Electron transport through quantum dots with a mixed classisal phase space
  TU Dresden
  Dresden, Germany; 11.06.2004.

- S. Rotter
  Recent results on shot noise in quantum dots
  MPI Dresden
  Dresden, Germany; 08.06.2004.

- S. Rotter
  Tunable Fano resonances in transport through quantum dots
  MPI Dresden
  Dresden, Germany; 04.06.2004.

- E. Scheidegger
  Physics and Calabi-Yau manifolds
  Alfred Renyi Institute of Mathematics
  Budapest, Hungary; 21.05.2004.

- E. Schöll-Paschinger
  Self-consistent liquid state theories
  Institut für Experimentalphysik, Universität Wien
  Vienna, Austria; 30.06.2004.

- J. Seke
  A new U-matrix formalism in QED including a new renormalization procedure
  Florida International University
  Miami, USA; 19.05.2004.

- J. Seke
  The same vacuum state without adiabatic switching for both interacting and free fields
  City College, City University of New York
  New York, USA; 19.04.2004.

- J. Seke
  The same vacuum state without adiabatic switching for both interacting and free fields
  University of Miami
  Miami, USA; 12.05.2004.

- M. Seliger
  Quantum-trajectory Monte Carlo method for non-unitary open quantum systems
  ATOMKI, Debrecen, Hungary; 16.01.2004.

- M. Strickland
  Instabilities - a faster way to thermalize
  Ohio State University
  Columbus, USA; 08.01.2004.

- M. Strickland
  QGP Instabilities - a faster way to thermalize
  University of Virginia
  Charlottesville, USA; 06.01.2004.

- C. Tutschka
  Classical statistical mechanics of rectilinear assemblies under
  Erwin Schroedinger International Institute for Mathematical Physics
  Vienna, Austria; 25.10.2004.

Appendix D

Graduates

D.1 Master degrees (Diploma)

- D. Blaschke
  Non-commutative two plus one dimensional quantum electrodynamics with Chern-Simons term
  Supervisor: M. Schweda

- M. Hillbrand
  Non-commutative gauge theories & UV/IR mixing
  Supervisor: M. Schweda

- S. Hohenegger
  UV/IR analysis of a noncommutative scalar quantum electrodynamics
  Supervisor: M. Schweda

- J. Knapp
  Covariant quantization of the superstring
  Supervisor: M. Kreuzer

- J. Köfinger
  Phase behaviour of symmetrical binary mixtures in a field
  Supervisor: G. Kahl

- P. Kristöfel
  Stochastic nets in quantum mechanics
  Supervisor: J. Burgdörfer, S. Yoshida

- F. Libisch
  Electron and hole wave functions in Andreev billiards
  Supervisor: J. Burgdörfer, S. Rotter

- D. Mayerhofer
  On static solutions of 2-dimensional dilaton gravity with scalar matter
  Supervisor: W. Kummer

- G. Pauschenwein
  Electrodynamics on the Möbius strip
  Supervisor: K. Svozil

- S. Peter
  Qualitative test of time dependent density functional theory for one-dimensional model systems
  Supervisor: J. Burgdörfer, N. Rohringer

- S. Puschkarski
  Optimization of high harmonics generation
  Supervisor: J. Burgdörfer, E. Persson

- E. Schöll-Paschinger
  Self-consistent Ornstein-Zernike approximation for simple fluids and their mixtures
  Supervisor: f. Rattay, G. Kahl

- B. Weingartner
  Electron transport through a quantum dot with mixed classical dynamics
  Supervisor: J. Burgdörfer, S. Rotter

D.2 Doctorates

- A. A. Bichl
  Ultraviolet / infrared mixing & non-commutative instanton calculus
  Supervisor: M. Schweda

- C.G. Böhmer
  Spherically symmetric systems in general relativity
  Supervisor: W. Kummer

- S. Denk
  Perturbative aspects of non-local and non-commutative quantum field theories
  Supervisor: M. Schweda

- V. Putz
  Symmetries and renormalization of noncommutative field theories
  Supervisor: M. Schweda

- S. Rotter
  Ballistic quantum transport at high energies and high magnetic fields
  Supervisor: J. Burgdörfer

Appendix E

Projects

E.1 Projects started in 2004

- **Gerhard Kahl**
  Phase transitions and critical behaviour of the primitive model
  Österreichischer Akademischer Austauschdienst (öAD)
  Projekt-Nr.: 7/2004
  Amount: EUR 6.140,–
  01.01.2004 - 31.12.2004

- **Wolfgang Kummer**
  Quantum gravity
  Österreichischer Akademischer Austauschdienst (ÖAD)
  Projekt-Nr.: 349-1/2004
  Amount: EUR 8.460,–
  01.10.2004 - 30.06.2005

- **Wolfgang Kummer**
  Dilaton supergravity
  Fonds zur Förderu.ng der wissenschaftlichen Forschung (FWF)
  Projekt-Nr.: P16030-N08
  Amount: EUR 41.772,–
  01.11.2004 - 31.07.2005

- **Joachim Burgdörfer**
  Simulation of chaotic Andreev Billards
  Fonds zur Förderu.ng der wissenschaftlichen Forschung (FWF)
  Projekt-Nr.: P17359-N08
  Amount: EUR 188.622,–
  01.11.2004 - 31.10.2007

- **Bianca Mladek**
  Erwin Schrödinger Junior Research Fellowship
  Erwin Schrödinger International Institute for Mathematical Physics
  Projekt-Nr.: ESI-RSB 0104
  Amount: EUR 7.800,–
  01.04.2004 - 30.09.2004

- **Joachim Burgdörfer zs. mit Friedrich Aumayr (E 134)**
  How do insulator surfaces react to highly charged ions
  Fonds zur Förderung der wissenschaftlichen Forschung (FWF)
  Projekt-Nr.: P17449-N02
  Amount : EUR 123.711,–
  01.11.2004 - 31.10.2007

- **Christian Tutschka**
  Interacting particle systems under gravity
  Erwin Schrödinger International Institute for Mathematical Physics
  Projekt-Nr.: ESI-RS/16/04
  Amount: EUR 12.000,–
  01.07.2004 - 31.12.2004

- **Albert Reiner**
  Advanced liquid state theories for fluid criticality
  Erwin Schrödinger Stipendium
  Projekt-Nr.:FWF J2380-N08
  Amount: EUR 68.500,–
  15.06.2004 - 15.06.2006

E.2 Current projects and projects completed in 2004

- **Wolfgang Kummer**
  Quantum gravity
  Österreichischer Akademischer Austauschdienst (ÖAD)
  Projekt-Nr.: 798-1/2003
  Amount: EUR 8.460,–
  01.10.2003 - 30.06.2004

- **Gerhard Kahl**
  Structure, thermodynamics, and phase transitions in polydisperse liquid mixtures
  Fonds zur Förderung der wissenschaftlichen Forschung (FWF)
  Projekt-Nr.: P14371-TPH
  Amount: EUR 88.566,–
  12.5.2000 - 31.05.2004

- **Gerhard Kahl**
  Structure, thermodynamics, and phase transitions in polydisperse liquid mixture
  Bundesministerium für Bildung, Wissenschaft und Kultur (BM:BWK)
  Projekt-Nr.: GZ45.492/1-VIII/B/8a/2000 (D13600040500)
  Amount: EUR 26.889,–
  14.11.2000 - 31.12.2005

- **Shuhei Yoshida**
  Enhanced recombination in low temperature magnetized plasmas
  Fonds zur Förderung der wissenschaftlichen Forschung (FWF)
  Projekt-Nr.: P15025
  Amount: EUR 155.168,–
  01.07.2001 - 30.06.2005

- **Gerhard Kahl**
  Atomic-scale computational materials science
  European Commission (EC)
  Projekt-Nr.: IHP-MCHT-01-1
  Amount: EUR 66.000,–
  06.08.2001 - 06.08.2005

- **Joachim Burgdörfer**
  Ion TMP facilities for highly charged heavy ions
  European Commission (EC)
  Projekt-Nr.: HPRI-CT-2001-50036
  Amount: EUR 176.617,–
  1.11.2001 - 31.10.2005

- **Manfred Schweda**
  Supersymmetry in commutative and non commutative QFT
  Fonds zur Förderung der wissenschaftlichen Forschung (FWF)
  Projekt-Nr.: P15015
  Amount: EUR 121.380,– 10.10.2001 - 30.09.2006

- **Anton Rebhan**
  Quantisation of supersymmetric solitons
  Fonds zur Förderung der wissenschaftlichen Forschung (FWF)
  Projekt-Nr.: P15449
  Amount: EUR 59.661,–
  30.11.2001 - 31.12.2004

- **Joachim Burgdörfer**
  Classical and quantum transport
  Aktion Österreich-Ungarn (AÖU)
  Projekt-Nr.: 486/2003
  Amount: EUR 13.130,–
  25.06.2003 - 31.07.2004

- **Maximilian Kreuzer**
Non-commutative structures in the open string theory
Fonds zur Förderung der wissenschaftlichen Forschung (FWF)
Projekt-Nr.: P15553
Amount: EUR 144.171,–
11.03.2002 - 28.02.2005

- **Maximilian Kreuzer**
D-branes on Calabi-Yau manyfolds
Fonds zur Förderung der wissenschaftlichen Forschung (FWF)
Projekt-Nr.: P15584
Amount: EUR 126.070,–
11.3.2002 - 30.04.2005

- **Manfred Schweda**
Mitarbeiter: P. Fischer, M. Wohlgenannt
Non-commutative gauge field theories
Fonds zur Förderung der wissenschaftlichen Forschung (FWF)
Projekt-Nr.: P15463
Amount: EUR 93.468,–
11.3.2002 - 30.09.2006

- **Rainer Dirl, Gerhard Kahl, Peter Kasperkovitz**
Computational materials science
Fonds zur Förderung der wissenschaftlichen Forschung (FWF)
Projekt-Nr.: WK W004
Amount: EUR 245.921,–
19.03.2002 - 31.12.2005

- **Gerhard Adam**
Nachweis der Inkonsistenz der konventionellen Renormierungstheorie und Ausarbeitung sowie Anwendung eines neuen konsistenten Renormierungskonzepts in der Quantenelektrodynamik
Österreichische Akademie der Wissenschaften (ÖAW)
Projekt-Nr.: EST-254/2002
Amount: EUR 104.640,–
10.5.2002 - 31.12.2005

- **Gerhard Kahl**
Phase behaviour and critical behaviour in simple liquids
Fonds zur Förderung der wissenschaftlichen Forschung (FWF)
Projekt-Nr.: P15758
Amount: EUR 138.802,–
21.5.2002 - 31.12.2005

- **Wolfgang Kummer**
  Dilaton supergravity
  Fonds zur Förderung der wissenschaftlichen Forschung (FWF)
  Projekt-Nr.: P16030-N08
  Amount: EUR 101.548,–
  01.11.2002 - 31.10.2005

- **Gerhard Kahl**
  Phase transitions in colloids
  Jubiläumsfonds der Stadt Wien (JSW)
  Projekt-Nr.: H-1080/2002
  Amount: EUR 4.000,–
  Zusage: 17.10.2002

- **Anton Rebhan**
  Improved resummation techniques in quantum field theories at high temperatures and densities
  Österreichischer Akademischer Austauschdienst (ÖAD)
  Projekt-Nr.: 16/2003
  Amount: EUR 3.900,–
  03.11.2003 - 31.12.2004

- **Manfred Schweda**
  Renormalization of noncommutative gauge field models via field redefinition - Seiberg-Witten map
  Österreichische Akademie der Wissenschaften (ÖAW)
  Projekt-Nr.: DOC/21283
  Amount: EUR 42.000,–
  01.02.2003 - 31.12.2004

- **Joachim Burgdörfer**
  Advanced light sources - interaction of ultrashort pulses with matter theory
  Fonds zur Förderung der wissenschaftlichen Forschung (FWF)
  Projekt-Nr.: F 1610
  Amount: EUR 220.020,–
  01.04.2003 - 30.03.2006

- **Anton Rebhan**
  Colour superconductivity
  Fonds zur Förderung der wissenschaftlichen Forschung (FWF)
  Projekt-Nr.: P16387-N08
  Amount: EUR 154.014,–
  06.03.2003 - 31.03.2006

- **Wolfgang Kummer**
  Quantum gravity
  Österreichischer Akademischer Austauschdienst (ÖAD)
  Projekt-Nr.: 798-1/2003
  Amount: EUR 5.850,–
  01.10.2003 - 30.06.2004

- **Joachim Burgdörfer**
  Classical and quantum transport
  Aktion Österreich-Ungarn (AÖU)
  Projekt-Nr.: 55öu1
  Amount: EUR 13.130,–
  01.08.2003 - 31.07.2004

- **Anton Rebhan**
  Phenomenological and theoretical applications of finite temperature resummation techniques
  Fonds zur Förderung der wissenschaftlichen Forschung (FWF)
  Projekt-Nr.: M790-N08
  Amount: EUR 62.030,–
  01.11.2003 - 31.10.2004

- **Gerhard Kahl**
  Simple and complex fluids in disordered porous media
  Ministerio de Educacion, Cultura y Deporte (MECD)
  Projekt-Nr.: EX2003-0580
  Amount: EUR 36.542,–
  01.12.2003 - 30.11.2005

- **Joachim Burgdörfer**
  Study of normal-superconducting hybrid nanostructures
  Österreichischer Akademischer Austauschdienst (ÖAD)
  Projekt-Nr.: A-2/2003
  Amount: EUR 11.730,–
  30.11.2003 - 31.12.2005

- **Joachim Burgdörfer**
  The theory of electronic stucture and transport in hybrid nanostructures
  Britsh Council (BC)
  Projekt-Nr.: ARC03
  Amount: EUR 1.885,–
  11.12.2003 - 31.12.2004