Dynamics of Quantum Many-Body Systems far from Equilibrium:

latest theoretical and experimental advances

Book of abstracts

Ambrož, Krvavec, December 14^{th}-17^{th} 2014

Jožef Stefan Institute
Ljubljana, Slovenija

University *of Ljubljana*
Faculty *of Mathematics and Physics*

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Conference schedule

9^{00} - 9^{40}		Marcin Mierzejewski	Xenophon Zotos	Gabriel Lantz
9^{40} - 10^{20}		Tomaž Prosen	Andrey Mishchenko	Ivan Madan
10^{20} - 11^{10}		Coffee break	Coffee break	Coffee break
11^{10} - 11^{50}		Stuart A. Trugman	Tomaž Mertelj	Anna Pogrebna
11^{50} - 12^{30}		Anton Ramšak	Daniele Fausti	Miloš Borovšak
				Closing
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17^{10} - 17^{40}	Coffee break	Coffee break	Coffee break	
17^{40} - 18^{20}	Adrian E. Feiguin	Igor Vaskivskyi	Viktor Kabanov	
18^{20} - 19^{00}	Fabian Heidrich Meisner	Luca Perfetti	Jure Demšar	
20^{30} - 21^{10}	Lev Vidmar	Denis Golež	Zala Lenarčič	
21^{10} - 21^{30}	Marko Medenjak	Ambrož Kregar	Janez Bonča	

Dynamics of Quantum Many-Body Systems far from Equilibrium: latest theoretical and experimental advances

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Organized by

Jožef Stefan Institute, Ljubljana Slovenia

Jožef Stefan Institute
Ljubljana, Slovenija

University of Ljubljana
Faculty of Mathematics and Physics

Faculty for Mathematics and Physics, University of Ljubljana, Slovenia

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Sunday, 14 December

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Photo-induced states in materials with strong electron-phonon coupling

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Observations like photo-induced metal-insulator transitions or photo-induced superconductivity suggest ways to control complex phases and phase transitions within femtoseconds. In this talk I briefly discuss the recent development of theoretical approaches to quantum many-body systems out of equilibrium based on dynamical mean-field theory (DMFT) and its generalizations [1]. I will focus on results concerning the dynamics of electron-phonon coupled systems, and in particular discuss photo-induced states in materials with strong electron-phonon coupling. Using an exact solution of the single-electron Holstein model in nonequilibrium DMFT [2] we analyze characteristic features of excited polaron states and long-lived metastable delocalized states in a transient photo-induced metal.

[1] Aoki et al, Rev. Mod. Phys. 86, 779 (2014).
[2] S.Sayyad and M.Eckstein, arXiv:1410.4298.

Anomalous pump-driven spectral transfer in 1D spin-full Mott Insulators

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In strongly correlated systems the rigid-band picture –used to understand the phenomenology of semiconductors– fails dramatically: excitations depend drastically on the electronic density, and the spectrum changes dynamically as the system is excited out of equilibrium. In this work, we study the response of a Mott insulating Hubbard chain to pulse of radiation, and its spectral properties as it is driven out of equilibrium. We observe the emergence of excitations in the Mott gap which, for the case of weak interactions, "melt" the gap completely. We identify intra and inter-band transitions, and we analyze the role of spin and charge separation comparing to zero-temperature, and finite-temperature results in equilibrium.

Non-equilibrium dynamics of bosons in optical lattices: Mass transport and interaction quenches

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Our work is motivated by the experiment [1], where the sudden expansion of initially trapped bosons into an optical lattice was realized. The key results of [1] are the observation of (i) ballistic transport of a strongly interacting many-body system namely hard-core bosons in 1d, (ii) signatures of the interaction quantum quench that was performed simultaneously with the trap opening and (iii) indications for diffusive dynamics of interacting bosons that are either sufficiently hot or far away from integrable limits. I will first demonstrate that breaking the integrability of hard-core bosons by tunnel-coupling 1d systems indeed results in diffusive transport [2,3,4]. Then I will discuss the relaxation and thermalization dynamics [5] due to the interaction quench realized in [1]. Finally, I will turn to the transient and asymptotic regimes of expanding interacting bosons in 1d, where the phenomena of dynamical quasi-condensation at finite momenta and dynamical fermionization emerge [3].

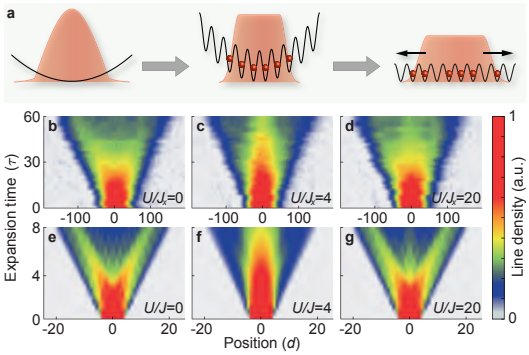

Figure 1: Density profiles of bosons described by the Bose-Hubbard model expanding in 1d [1]. Top row: Experimental data, bottom row: DMRG results.

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[5] S. Sorg *et al.*, *Phys. Rev. A* **90**, 033606 (2014).

Real-time decay of a highly excited charge carrier in the one-dimensional Holstein model

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We study the real-time dynamics of a highly excited charge carrier coupled to quantum phonons via a Holstein-type electron-phonon coupling [1]. This is a prototypical example for the non-equilibrium dynamics in an interacting many-body system where excess energy is transferred from electronic to phononic degrees of freedom. We are interested in the dynamics emerging from an initial state with all excess energy contained in the electronic sector, see also Fig. [1].

The investigation of real-time energy transfer within the Holstein model is one of the few quantum many-body problems with bosonic degrees of freedom far away from equilibrium, where numerically exact solutions can be obtained by using different methods. We compare three wave-function based methods: exact diagonalization, diagonalization in a limited functional space and the time-evolving block-decimation method, which show perfect agreement. We find that the most powerful method to treat this class of problem is diagonalization in a limited functional space, introduced more than a decade ago to describe the Holstein polaron ground state [2]. We apply the method on a finite lattice and show that it allows for the efficient simulation of dynamics in *both* the relaxation regime as well as in the long-time stationary regime. This complements the initial work using the same method [3,4], where the real-time dynamics on an infinite lattice was studied.

To understand the role of phonons in non-equilibrium systems in more detail, the main theoretical questions that motivate our investigation are: *(i)* How efficient is the energy transfer to phonons, depending on the characteristic energy scales of the electrons and phonons and the electron-phonon coupling strength? *(ii)* What is the relevant time scale for the energy transfer to phonons? *(iii)* To which extent is the knowledge of the unitary time evolution required to describe the dynamics of a quantum many-body system, or in which cases are semi-classical approaches sufficient?

For weak electron-phonon coupling, we calculated the relaxation dynamics from

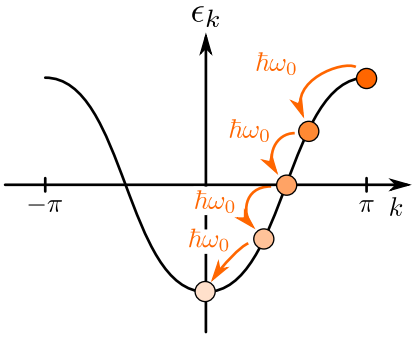

Figure 1: Sketch of the initial condition and the time evolution: We start from the state with one electron at momentum $k = \pi$ and no phonon. Due to the coupling to phonons, the electron loses energy by exciting phonons of energy $\hbar\omega_0$ while moving through the lattice, which also results in the redistribution of its momentum occupations.

the Boltzmann equation and obtained good agreement with the numerical data. Assuming a constant electronic density of states, an analytical expression for the complete quasi-particle relaxation time τ follows from the Boltzmann equation, $\tau\omega_0 = (16/\pi)(t_0^2/\gamma^2)$. Our numerical results for relaxation, obtained by using the actual density of states of a 1D tight-binding system, are interestingly consistent with this prediction.

When the electron-phonon coupling γ or the phonon frequency ω_0 are increased, coherent temporal oscillations are enhanced and it becomes more difficult to disentangle the relaxation regime from the stationary regime. In general, there are two well-defined regimes of model parameters where persistent coherent oscillations govern the dynamics: when ω_0 is much larger than the electronic bandwidth and when the electron-phonon coupling γ gets much larger than the hopping amplitude t_0. The simplest model which captures the essence of both scenarios is the single-site Holstein model.

We extract the single-site reduced density matrix from the time-dependent total wavefunction. We calculate the von Neumann entropy and the eigensystem of the single-site density matrix. In the electron-phonon coupled systems, the corresponding eigenstates with the largest eigenvalues represent the optimal phonon modes [5]. We show that the structure of the optimal phonon modes carries valuable information about physical processes, and may complement the analysis based on observables only.

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Breaking of integrability in quantum spin chains

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The theory of integrable quantum many-particle systems yielded many insightful results regarding transport properties of such systems. Due to the existence of non-trivial conserved quantities such systems exhibit variety of interesting phenomena such as ballistic transport. The central question is what happens to transport properties and consequently the conserved charges when we break the integrability. I will present some DMRG results regarding transport properties of the Heisenberg XXZ chain in which integrability was broken with isotropic next-nearest-neighbour coupling.

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Breakdown of the generalized Gibbs ensemble for current–generating quenches

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We establish a relation between two hallmarks of integrable systems: the relaxation towards the generalized Gibbs ensemble (GGE) and the dissipationless charge transport. We show that the former one is possible only if the so called Mazur bound on the charge stiffness is saturated by local conserved quantities. As an example we show how a non–GGE steady state with a current can be generated in the one-dimensional model of interacting spinless fermions with a flux quench. Moreover an extended GGE involving the quasi-local conserved quantities can be formulated for this case.

On counting the number of quasi-local conserved operators in integrable systems

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Understanding the structure of the set of local and quasi-local operators for integrable quantum systems is an important problem with essential links to quantum transport and relaxation of quench dynamics [1]. Notably, the set of relevant quasi-local conserved operators is much richer than the set of local conserved operators derived from algebraic Bethe ansatz [2,3].
In the new work [4] which I will describe in my talk, we outline a straightforward computational procedure for counting the number $\mathcal{N}(M)$ of *all* linearly-independent quasi-local conserved operators of an integrable system, say XXZ spin 1/2 chain, composed of terms with effective supports up to M consecutive sites. We demonstrate that $\mathcal{N}(M)$ grows linearly with M, and is systematically larger than the number of exactly local conserved operators. This study gives a clear prediction on existence of novel quasi-local conserved operators in XXZ chain in other symmetry sectors as those found in [2, 3]. We predict, for example, existence of independent new quasi-local conserved operators in the isotropic Heisenberg spin 1/2 chain.

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High temperature transport in the Holstein model

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It is often assumed that at high temperatures, charge transport in models of electron-phonon coupled systems, such as the Holstein model, results in diffusive transport in which electrons hop at random between neighboring sites. We present analytic and numerical results suggesting that in semiclassical and fully quantum treatments, charge transport may be quite different from this.

Exact nonadiabatic non-Abelian geometric phases

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First we will present a short introduction to the concept of geometric phases in classical and quantum mechanics. The motivation is the manipulation of electron spin by locally applying an external electric field – in the absence of magnetic fields which in practice can not selectively be applied in spatially compact regions. We will show an exact solution for the wavefunction of an electron in a semiconductor quantum wire with spin-orbit interaction and driven by external time-dependent harmonic confining potential. This solution will further be extended to a more general system, where also the spin-orbit interaction can be time dependent. This additional time dependent degree of freedom enables a holonomic non-Abelian qubit manipulations. By the virtue of the exact solution one can also in the non-adiabatic regime construct analytically the corresponding dynamical and geometric Anandan phases, or in the adiabatic limit, the Wilczek-Zee phase. By breaking the time reversal symmetry the results reduce to the corresponding Aharonov-Anandan phase which in the adiabatic limit simplifies to the usual Berry phase.

Metastable states in macroscopic quantum systems: ultrafast switching experiments in 1T-TaS2

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Recent progress in experimental studies of nonequilibrium phase transitions have opened up a field rich with new metastable phenomena. Interest in the field is partly fundamental, simply because it presents a large challenge to our understanding of nonequilibrium quantum systems. Additional interest is driven by the urgent need for new ultrafast memory devices necessary for Big Data processing. Presently, I will discuss an experimental system (a layered charge-ordered chalcogenide) which shows ultrafast externally induced switching between different macroscopic quantum states controlled either by ultrashort laser pulses or by electric current injection. I propose a switching mechanism by which externally injected charges rapidly localise to form a textured charge-ordered state, thus modifying the potential energy, and allowing macroscopic quantum tunnelling into the new state. The relevant timescales of all the relevant processes in 1T-TaS2 are known from experiments, and appear to allow this to happen. Topological protection (associated with the domain walls in the textured state) prevents the system from returning back, making the state metastable.

Relaxation of the photoinduced hidden state in $1\,T$-TaS_2

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Controlling transitions between quantum states may be possible at high temperatures either if the system is strongly decoupled from the environment, or we are dealing with many-body macroscopic quantum states such as superconductivity, or long-range ordered charge-density wave states. Here we investigate the relaxation properties of the photoexcited hidden state in $1\,T$-TaS_2 which is reached by exposing the samples to a single ultrashort optical laser pulse while it is in low-temperature commensurate charge density wave (CCDW) state.[1]
We find the state relaxes through a sequence of metastable states from an incommensurate to commensurate state, with discrete jumps over a Devils staircase, and a glassy relaxation process in between these jumps. The origin of the glassines is in reciprocal-space commensurability frustration rather than real space disorder and structural frustration appearing in common chalcogenide glasses.
The experiments enable us to elucidate the mechanism for metastabiliy of the remarkable hidden state, and the quantum state transition between two many-body quantum states.

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Dynamics of fluctuations in high temperature superconductors far from equilibrium conditions

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Despite the extensive literature on high temperature superconductors, the critical dynamics of an incipient condensate has so far been studied just in equilibrium conditions. Here, I show that resolved THz measurements of $Bi_2Sr_2CaCu_2O_{8+\delta}$ discriminate the temperature regimes where superconductivity is coherent, fluctuating or vanishingly small. Above the transition temperature Tc the recovery to equilibrium conditions displays power law behaviour and scaling properties. The experimental evidence that some of the exponents weakly depend on doping level provide hints of universality in systems far from equilibrium. We find partial agreement between the scaling law of the optimal doped sample and the Time Dependent Ginzburg-Landau (TDGL) model. Inherent limits of TDGL call for non-equilibrium field theories treating fast degrees of freedom and fluctuations on equal footing. These results open a timely connection between superconducting condensates and Bose-Einstein condensates of ultra-cold atoms.

Nonequilibrium dynamics of screening in the extended Hubbard model

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We will present a study of the nonequilibrium dynamics in the extended Hubbard model on the square lattice using time-dependent extended dynamical mean-field theory. The short-time effect of the dynamical screening due to the photo-doping is the reduction of the effective static interaction. On the same time scale the fully screened interaction is transformed from the single to double mode structure due to photo-doped charge carriers. At longer times the the dynamical screening enhance the relaxation dynamics.

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Coherent evolution of two-electron states in a quantum dot in the presence of Rashba coupling

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Quantum dots in semiconductor heterojunctions are one of the most suitable candidates for realization of quantum computer [1,2]. Their advantages are long spin coherence times of electrons in semiconductor, well developed technology of their production and simple scalability, to only name a few [2]. Traditionally, magnetic filed is used to manipulate spin, but since it is difficult to use it to address single quantum dot, we seek different ways to address it.

In our work we theoretically study the possibility of using only electric field to manipulate spin-charge states in quantum dot. The effects of Rashba coupling, which can effectively replace magnetic field for spin manipulation, is studied in a model of two-electron square quantum dot. The strength of Rashba coupling can be externally driven by electric field perpendicular to the surface of semiconductor [3,4].

We discovered that fast (~ 1 ns) coherent evolution enables arbitrary transformation of selected singlet and triplet states, which can be viewed as qubit states. Axis of rotation on Bloch sphere and angle of rotation around it are determined by Rashba coupling and external electrostatic potential in the corners of the dot. Electrostatic interaction between two quantum dots also allows two-qubit transformations, which is essential step towards the scaling of the system and its use in quantum information processing.

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Light induced magnetization in a S=1 chain.

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We present a study of circularly polarized light induced magnetization in the spin $S = 1$ easy plane antiferromagnetic chain DTN. The thermodynamic and dynamic properties of this compound are well understood as they have been extensively studied experimentally as well as theoretically [1,2]. We will present extensive numerical simulation results on the model describing DTN. Furthermore, we will use an effective 2-level system, to understand the main features of the time evolution of the system and propose the most appropriate protocol to optimally induce a magnetization.

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Strong electron-boson coupling in cuprates: pump-probe response of undoped system to a short pulse with frequency below the Mott gap.

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Angle resolved photoemission spectra [1,2] and optical conductivity [3,4] of the two dimensional Hubbard model with strong coupling to bosonic excitations are in good agreement with experiments on underdoped cuprates. Comparison with experiments shows that the effective strength of the electron-boson interaction is suppressed with doping. Analysis of the doping dependence of manifestations of the electron-boson interaction with novel many-polaron diagrammatic Monte Carlo method [5] shows that it is occurs because of suppression of the vertex corrections according to Migdals theorem. General analysis shows that the energy scales of electron-electron and electron-boson interactions are very similar and it is difficult to prove or disprove its relevance in the spectroscopic experiments with the systems in equilibrium. Hence, a pump-probe technique is an exclusive route to disentangle different interactions and evaluate its importance.

Time dynamics of the physical properties and optical conductivity of the two dimensional Hubbard-Holstein model is studied theoretically and experimentally when undoped system is put out of equilibrium by an ultrashort powerful light pulse [6,7]. It is shown that the ultra-fast dynamics of the underdoped cuprates can be explained only in case when strong electron-boson coupling is assumed.

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Nonthermal destruction and recovery of SDW order in iron based pnictides

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Ultrafast phase transitions from and into ordered states, which occur during the quench following a strong femtosecond laser pulse excitation, have become a rather hot experimental and theoretical topic during the last decade. Experimentally various electronic orders were investigated with emphasis on ferromagnetism, charge and orbital ordering as well as superconductivity. Despite a signifficant occurrence frequency of antiferromagnets the collinear antiferromagnetism and the related spin density wave (SDW) order were among the less studied orders in this context, perhaps due to the absence of the linear coupling of the order parameter to photons. In undoped iron based pnictides (IBP) the SDW-like collinear antiferromagnetism of Fe ions is strongly coupled to structural/orbital degrees of freedom resulting in a coupling that enables all-optical time-resolved linear-optical-response spectroscopy of the ordered state. In this context some recent experimental results on all-optical time-resolved spectroscopy of the orthorhombic SDW state in the 122 IBP family will be presented. The emphasis will be on the strong optical drive that quenches the SDW order on 100-femtosecond timescale and the subseqent recovery, which is monitored by means of the 3-pulse quench-pump-probe experiments. The recovery dynamics of the orthorhombic SDW state will be briefly discussed in terms of time-dependent Ginzburg-Landau theory.

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Quantum Optics for studying ultra-fast non-equilibrium processes in Condensed Matter

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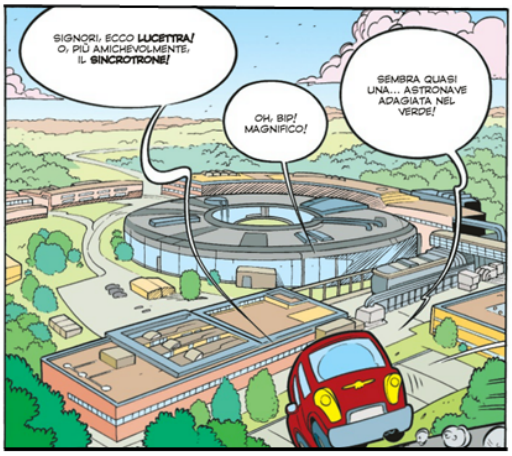

In this presentation I will focus on our proposal to employ quantum optics techniques for time domain studies of correlated electron systems. I will give an introductory talk on pulsed homodyne tomography for quantum state reconstruction of ultrashort light pulses and show how this can be applied to time domain studies.
I will introduce the case study of coherent vibrational states (“coherent phonons”) in quartz and show new measurements of the time evolution of the probe quantum state after the interaction with the material. A full reconstruction of the Wigner function revealed that the probe pulses are squeezed by the interactions with a photo-excited sample. I will discuss the perspectives of the new technique and outline possible experiments in complex materials.

Unfolding the ultrafast relaxation processes in correlated materials by non-equilibrium spectroscopies

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In this talk we report on recent measurements in which we simultaneously pushed the time resolution and the frequency range of transient reflectivity measurements up to an unprecedented level that enabled us to directly observe the 16 fs build-up of the effective electron-boson interaction in hole-doped copper oxides. This extremely fast timescale is in agreement with numerical calculations based on the t-J model and the repulsive Hubbard model, in which the relaxation of the photo-excited charges is achieved via inelastic scattering with short-range antiferromagnetic excitations. Furthermore, we will address the evolution of the ultrafast electron dynamics as a function of the hole doping of the system. The relation between the ultrafast dynamics and the many elusive states (quantum critical point, charge ordering, etc.) present in the equilibrium phase diagram of cuprates will be discussed.

Hopping magnetotransport via nonzero orbital momentum states and organic magnetoresistance

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Abstract

In hopping magnetoresistance (MR) of doped insulators, an applied magnetic field shrinks the electron (hole) s-wave function of a donor or an acceptor and this reduces the overlap between hopping sites resulting in the positive magnetoresistance quadratic in a weak magnetic field, B. We have developed the theory of hopping magnetoresistance via states with nonzero orbital momenta [1]. Different from s-states, a weak magnetic field expands the electron (hole) wave functions with positive magnetic quantum numbers, m > 0, and shrinks the states with negative m in a wide region outside the point defect. This together with a magnetic-field dependence of injection/ionization rates results in a negative weak-field magnetoresistance, which is linear in B when the orbital degeneracy is lifted. The theory provides a possible explanation of a large low-field magnetoresistance in disordered pi-conjugated organic materials (OMAR), Fig.1. The linear negative orbital MR, Fig.1 is a unique signature of the broken time-reversal symmetry (TRS). We argue that some local paramagnetic centers could be responsible for the broken TRS.

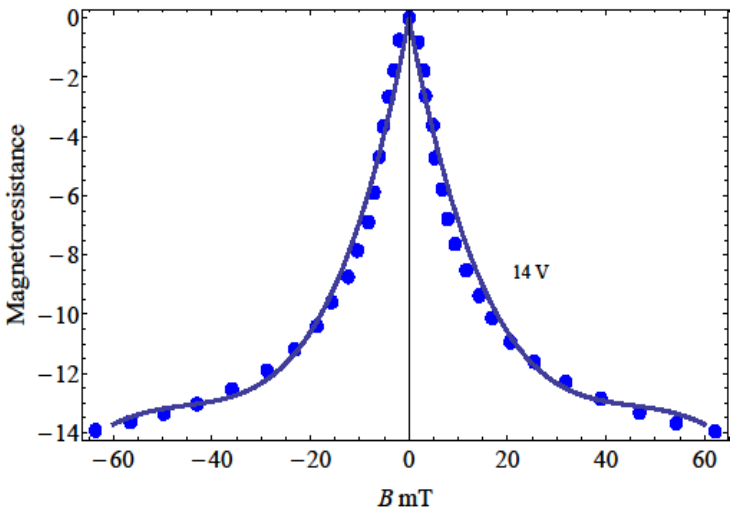

Fig.1. Negative OMAR (%) at roomtemperature in ITO/PEDOT /Alq3/Ca device at bias voltage 14 V (symbols, Ref.[2]) described by the theory (solid line, Ref.[1]).

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Cooperative atomic motion probed by femtosecond electron diffraction

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Intertwined electronic and lattice orders are common to strongly correlated materials. Femtosecond (fs) time-resolved optical [1,2] and diffraction techniques [3-6] recently contributed important insights into the origin of their ground states by tracking their dynamics following excitation with fs light pulses. Recently, several studies of structural dynamics in quasi-two-dimensional charge density wave systems were performed using fs electron diffraction in transmission [3-5]. It was demonstrated that tracking the time evolution of the lattice and super-lattice peak intensities with sub-picosecond electron pulses could provide direct access to the dynamics of the order parameter. The light-excitation and the ensuing changes in the electronic distribution result in changes in the atomic potential, driving the coherent cooperative atomic motion towards the high temperature non-modulated state [3-6]. This process, which takes place on a fraction of a period of the corresponding amplitude mode (100 fs timescale), is accompanied by a rapid sub-picosecond energy transfer to the lattice via electron-phonon and phonon-phonon scattering. Both processes, the coherent order parameter dynamics and the incoherent redistribution of energy among different subsystems, affect the diffraction pattern. For their comparable timescales they are hard to distinguish based on the analysis of dynamics alone. Here we show, that by simultaneous tracking the dynamics of intensities of super-lattice peaks, lattice peaks and that of the incoherent background for multiple diffraction orders the two processes can be effectively disentangled.

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Charge Recombination in Undoped Cuprates

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Recent femtosecond pump-probe experiments on Mott-Hubbard insulators [2-4] reveal charge recombination, which is in picosecond range, much faster than in clean band-gap semiconductors although the excitation gaps in Mott-Hubbard insulators are larger. I will present our proposals [1,2] for the mechanisms that explain the recombination in effectively one- and two-dimensional cuprates. Based on the two-dimensional model relevant for undoped cuprates, I will show that such fast recombination processes can be explained even quantitatively with the multi-magnon emission. As suggested by experiments we assumes that holon and doublon are bound in an exciton and I will show that in this case recombination rate can be expressed analytically, as calculated from an effective exciton-boson model.
One-dimensional systems due to the charge-spin separation call for a different explanation and we propose that the dominant mechanism involves multi-phonon emission. We show that a reasonable coupling to phonons is sufficient to explain the fast recombination observed by pump-probe experiments on ET-F_2TCNQ, whereby we can also account for the pressure dependence of the measured decay rate.

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Relaxation dynamics of many-body systems

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I will present a fundamental study of the relaxation dynamics of a single hole in the two dimensional t-J-Holstein model initially excited by a strong quench. Taking fully into account quantum effects we follow the time-evolution of the system from a highly excited state until it reaches a steady state. Relaxation occurs on the time-scale of 10 fs due to inelastic scattering of a photo-excited carrier on spin excitations [1]. I will also present relaxation dynamics of a carrier coupled to spin and lattice degrees of freedom based on the one dimensional t-J-Holstein under the influence of an external staggered field [2]. After an initial ultrafast relaxation a subsequent energy transfer from lattice to spin degrees of freedom is observed.

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Ultrafast evolution of the model Mott-Hubbard compound V_2O_3

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Abstract

Mott insulators are a perfect example of how local electronic correlations can change macroscopic properties of materials. Varying slightly the doping or the pressure can transform a metal to an insulator. These properties can be modified extremely rapidly by driving these materials far from equilibrium. We have investigated the model Mott-Hubbard material Cr-doped V_2O_3 using state of the art pump-probe techniques, namely angle resolved photoelectron spectroscopy, optical reflectivity, and X-ray diffraction. We were able to unequivocally disentangle the electronic and the lattice response of the system to a femtosecond laser excitation, which was kept in all cases at a wavelength of 800 nm. We present a comparative study of these transient responses, which demonstrates the strong electron-phonon coupling of this strongly correlated model material. We show that before thermalization, spectral weight is transferred from the lower Hubbard band towards the Mott gap. On a longer time scale a metastable state is stabilized by the lattice structure. The interplay between the electron and lattice structure is clearly identified in the model Mott-Hubbard compound V_2O_3.

Nonequilibrium phase transitions in BSCCO

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We present the study of non-equilibrium phase transition experiments in BSCCO-2212, namely normal-to-pseudogap and normal-to-superconducting transitions, measured by 3 pulse femtosecond technique with polarization sensitive detection. From particular form of fluence dependence of the pseudogap response, fluence and temperature independent dynamics of the pseudogap formation, and the absence of divergence of single particle excitations along the transition we conclude the short-range local nature of carriers forming the pseudogap state. The clear divergence of single-particle relaxation is observed in the normal-to-superconducting transition. We present systematics of the superconducting transition trajectory dynamics with fluence and temperature and discuss applicability of TDGL approach for it's description.

The 3 pulse pump-probe technique allows to discriminate between pseudogap response and superconducting fluctuations response. From comparison to THz conductivity we establish linear relation between pump-probe response and bare superfluid density in the vicinity of transition and observe clear distinction between critical behaviour of phase and amplitude relaxation times. Role of superconducting fluctuations in the formation of the superconducting condensate in the non-equilibrium phase transition is discussed.

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Coexistence of ferromagnetism and superconductivity in iron based pnictides: a time resolved magnetooptical study

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Coexistence of superconductivity and ferromagnetism (FM) implies either a modulated ferromagnetic order parameter on a lengthscale shorter than the superconducting coherence length or a weak exchange coupling between the itinerant superconducting electrons and the localized ordered spins. Recently discovered iron based compounds exhibit superconducting (SC) order next to the magnetically ordered phase. Among various iron pnictide superconductors Eu based stand out due to the coexistence of FM of the localized Eu^{2+}-*f* spins and SC of the itinerant carriers in Fe-*d* derived bands. The nature of the coexistence, however, remains elusive since no clear understanding of the spin structure in the superconducting state has been reached and the reports on the coupling strength are controversial.
Employing optical pump-probe femtosecond spectroscopy we investigate the Eu^{2+} dynamics in $EuFe_2(As_{0.7}P_{0.3})_2$ (EuP-122) and $Eu(Fe_{1-x}Co_x)_2As_2$ (EuCo-122) pnictide superconductors and the parent nonsuperconducting $EuFe_2As_2$ (Eu-122) in magnetic field. We show, by a direct optical pump-probe experiment, that the coupling is weak, since the transfer of the excess energy from the itinerant electrons to ordered localized spins is much slower than the electron-phonon relaxation implying the coexistence without the short-lengthscale ferromagnetic order parameter modulation.
In the superconducting EuP-122 a coherent magnon oscillation is observed in the transient reflectivity signal in applied magnetic field close to metamagnetic transition. The polarization analysis of the coherently excited spin wave response points towards a simple ferromagnetic ordering of spins with two distinct types of ferromagnetic domains.

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Time resolved measurments on molybdenum oxide η-Mo_4O_{11}

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Molybdenum oxides exist in many stoichiometries like MoO_2, Mo_4O_{11}, Mo_5O_{14}, MoO_3 and some others which properties strongly depends on its structure [1]. Mo_4O_{11} is a quasi 2D system with metallic behaviour and exist in two different crystal structures: orthorhombic (γ-Mo_4O_{11}) and monoclinic (η-Mo_4O_{11}). We have studied single crystals of η-Mo_4O_{11}. The material has two Peierls transitions at 105 K and 35 K [2, 3]. A strong electron-phonon interaction and particular shape of the Fermi surface gives the origin of first transition to incommensurate CDW. The system has multiple bands crossing the Fermi level, some of which open a gap due to a CDW, while other remain metallic. The charge transport exhibits extremely high mobilities $>10^4$ cm^2/(Vs), in spite of opening of a gap due to the CDW.

We present the first systematic study of transient reflectivity $\Delta R/R$ in single crystals of η-Mo_4O_{11} by means of femtosecond optical laser spectroscopy. The electron relaxation dynamics in different bands are nicely observed in the pump-probe spectra under different laser resonance conditions. Temperature and fluence dependence of dynamics was investigated with two different pump energies (3.1 eV and 1.55 eV) at temperatures above and below CDW transition temperatures T_{CDW}. Depending on the probe energy the amplitude of the transient reflectivity changes its sign in agreement with previously published data on optical properties [4]. We have observed a remarkable slowing down of the relaxation dynamics at T_{CDW}, whereas the amplitude of the signal shows no dependence on pump fluence. We also observed that the lattice and electronic degrees of freedom are remarkably decoupled from the behaviour of single particle relaxation and collective modes with temperature and time.

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9^{00} - 9^{40}		Marcin Mierzejewski	Xenophon Zotos	Gabriel Lantz
9^{40} - 10^{20}		Tomaž Prosen	Andrey Mishchenko	Ivan Madan
10^{20} - 11^{10}		Coffee break	Coffee break	Coffee break
11^{10} - 11^{50}		Stuart A. Trugman	Tomaž Mertelj	Anna Pogrebna
				Miloš Borovšak
11^{50} - 12^{30}		Anton Ramšak	Daniele Fausti	Closing
	Opening remarks			
16^{30} - 17^{10}	Martin Eckstein	Dragan Mihailović	Claudio Giannetti	
17^{10} - 17^{40}	Coffee break	Coffee break	Coffee break	
17^{40} - 18^{20}	Adrian E. Feiguin	Igor Vaskivskyi	Viktor Kabanov	
18^{20} - 19^{00}	Fabian Heidrich Meisner	Luca Perfetti	Jure Demšar	
20^{30} - 21^{10}	Lev Vidmar	Denis Golež	Zala Lenarčič	
21^{10} - 21^{30}	Marko Medenjak	Ambrož Kregar	Janez Bonča	