New Trends in Complex Quantum System Dynamics

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Control of Quantum Correlations in a Tailored Matter
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1. Invited Speakers

- Antonio Acín (ICFO)
- Adan Cabello (Universidad de Sevilla)
- Tommaso Calarco (Ulm University)
- Marcello Dalmonte (Universität Innsbruck)
- Rosario Fazio (Scuola Normale Superiore)
- Rienk van Grondelle (University Amsterdam)
- Sebastian Hofferberth (University of Stuttgart)
- Susana Huelga (Ulm University)
- Niek F. van Hulst (ICFO)
- Fabrizio Illuminati (Università di Salerno)
- Anne Nielsen (Max Planck Institut für quantenoptik)
- Maciej Lewenstein (ICFO)
- Miguel Ortuño (Universidad de Murcia)
- Martin B. Plenio (Ulm University)
- Ferdinand Schmidt-Kaler (Universität Mainz)
- Enrique Solano (Universidad del País Vasco)
- Carlos Tejedor (Universidad Autónoma de Madrid)
- Ian Walmsley (University of Oxford)

2. Contributed Talks

On the reversal of quantum many body dynamics and its complexity

Tommaso Caneva
ICFO

We demonstrate that via optimal control arbitrary time evolutions of many-body quantum systems can be reversed. The optimal reversed dynamics –contrary to standard time-reversal procedures– is extremely robust with respect to external source of noise. We propose a conjecture establishing a relation between control complexity and the dimension of the manifold supporting the dynamics of a quantum system, verifying its validity in three different models and elucidating the role of the integrability of the model.

Quantum diffusion with disorder, noise and interaction

Filippo Caruso
Physics Department, Florence University

Disorder, noise and interaction play a crucial role in the transport properties of real systems, but they are typically hard to control and study both theoretically and experimentally, especially in the quantum case. Here we explore a paradigmatic problem, the diffusion of a wavepacket, by employing ultra-cold atoms in a disordered lattice with controlled noise and tunable interaction. The presence of disorder leads to Anderson localization, while both interaction and noise tend to suppress localization and restore transport, although with completely different mechanisms. When only noise or interaction are present we observe a diffusion dynamics that can be explained by existing microscopic models. When noise and interaction are combined, we observe instead a complex anomalous diffusion. By combining experimental measurements with numerical simulations, we show that such anomalous behavior can be modeled with a generalized diffusion equation,

in which the noise- and interaction-induced diffusions enter in an additive manner. Our study reveals also a more complex interplay between the two diffusion mechanisms in regimes of strong interaction or narrowband noise.

Electronic coherence, recoherence and efficient energy transfer in pigment protein complexes

Alex Chin
University of Cambridge

The roles of non-equilibrium vibrational structure and frequency excitonic spectramatched Abstract: Recent observations of oscillatory features in the optical response of photosynthetic complexes have revealed evidence for surprisingly long-lasting electronic coherences which can coexist with energy transport. These observations have ignited multidisciplinary interest in the possible role of quantum effects in biological systems, including the fundamental - though still unresolved - question of how electronic coherence can survive in biological surroundings. Here we show that in photosynthetic complexes, non-trivial spectral structures in environmental fluctuations can allow for non-equilibrium processes that lead to the spontaneous generation and sustenance of electronic coherence even at physiological temperatures. Developing new simulation tools to treat these effects, this new insight provides a firm microscopic basis to successfully reproduce the experimentally observed coherence times in the Fenna-Matthews-Olson complex, and thus sets the ground for the future assessment of the role of quantum effects in photosynthetic light harvesting efficiency.

Multipartite entanglement in critical systems

Gabriele De Chiara
Queenś University of Belfast

Nowadays it is well accepted that there exists a connection between the entanglement content of a many-body quantum state and its critical properties close to a quantum phase transition. In this contribution I will show that there is a more intimate relationship between the entanglement spectrum of the ground state of a one-dimensional spin chain and the order parameter characterizing its phase. Using the density matrix remormalization group, I will prove that the so called Schmidt gap, the difference of the two largest eigenvalues of the reduced density matrix of half the chain, scales with universal critical exponents [1].

Furthermore I will discuss a technique, based on witness operators, to detect genuine tripartite entanglement of a system composed of three qubits. As an application I consider three qubits embedded in a one dimensional XXZ spin chains and I will show the emergence of tripartite entanglement close to the model phase transition. Surprisingly, this multipartite entanglement survives beyond nearest neighbours [2].

References:

[1] G. De Chiara, L. Lepori, M. Lewenstein, A. Sanpera, Phys. Rev. Lett. 109, 237208 (2012) [2] J. Stasinska, B. Rogers, G. De Chiara, M. Paternostro, and A. Sanpera, in preparation Presentation preferred: Talk Co-authors: L. Lepori, M. Lewenstein, A. Sanpera, J. Stasinska, B. Rogers, M. Paternostro

Quantum simulation and detection of topological order

Juan José García-Ripoll
Spanish Research Council (CSIC)

In this talk I will present recent advances in the field of quantum simulation of topological models using ultracold atoms, with a strong emphasis on detection methods based on time-of-flight images.

Efficient characterization of quasi-unitary quantum operations

Giulia Gualdi
universität Kassel

We describe a simple method for assessing how well a quantum device implements a desired quantum operation. Our approach is based on characterizing only the unitary part of an open system evolution. This requires preparation of a minimal set of states and measurement of state fidelities. Our method is applicable to arbitrary N qubit unitaries and is exponentially faster than full quantum process tomography and Monte Carlo quantum process certification.

Robustness of quantum memories based on Majorana zero modes

Leonardo Mazza
Scuola Normale Superiore, Pisa

Quantum memories for the reliable storage of quantum states over long times constitute one of the the basic ingredients for most applications in quantum information science. The so-called self-protected quantum memories (SPQM) constitute appealing candidates for realization of quantum memories.

We analyze the robustness of a quantum memory based on Majorana modes in a Kitaev chain. We identify the optimal recovery operation acting on the memory in the presence of perturbations and evaluate its fidelity in different scenarios. We show that for time-dependent Hamiltonian perturbations that preserve the topological features, the memory is robust even if the perturbation contains frequencies that lie well above the gap. We identify the condition that is responsible for this feature. At the same time we find that the memory is unstable with respect to particle losses.

Photosynthesis Exploits Quantum Coherence for Efficient Solar Energy Conversion

Elisabet Romero
VU University Amsterdam

Photosynthesis has found an ultrafast and highly efficient way of converting the energy of the sun into electrochemical energy. The solar energy is collected by the Light-Harvesting complexes and then transferred to the Reaction Center where the excitation energy is converted into a charge separated state with almost 100% efficiency. That separation of charges creates an electrochemical gradient across the photosynthetic membrane which ultimately powers the photosynthetic organism. The understanding of the molecular mechanisms of charge separation will provide a template for the design of efficient artificial solar energy conversion systems. Upon excitation of the reaction center, the energy is delocalized over several cofactors creating collective excited states (excitons) with charge transfer (CT) character (exciton-CT states) which provide ultrafast channels for exciton relaxation and charge transfer. However, the Reaction Center has to cope with a counter effect: disorder. The slow protein motions (static disorder) produce slightly different conformations which, in turn, modulate the energy of the exciton-CT states. In this scenario, in some of the Reaction Center complexes within the sample ensemble the energy could be trapped in some unproductive states leading to unacceptable energy losses. However, the high efficiency of the charge separation process shows that the Reaction Center has developed several strategies to overcome the consequences of a highly disordered energy landscape. In this work, we present these strategies which have been unravelled by the combination of spectroscopic techniques (1, 2) as well as theoretical modelling (3, 4). In particular, this work focuses on the utilization of quantum coherence, specially on the role of specific vibrations in maintaining electronic coherences between exciton-CT states (5, 6). The central question regarding the role of quantum coherence in determining the speed and efficiency of the energy conversion process in photosynthesis will be addressed.

1. Romero, E., Diner, B. A., Nixon, P. J., Coleman, W. J., Dekker, J. P., and van Grondelle, R. (2012) Mixed exciton-charge-transfer states in photosystem II: Stark spectroscopy on site-directed mutants, Biophys. J. 103, 185-194. 2. Romero, E., van Stokkum, I. H. M., Novoderezhkin, V. I., Dekker, J. P., and van Grondelle, R. (2010) Two different charge separation pathways in photosystem II, Biochemistry 49, 4300-4307. 3. Novoderezhkin, V. I., Dekker, J. P., and van Grondelle, R. (2007) Mixing of exciton and charge-transfer states in Photosystem II reaction centers: Modeling of Stark spectra with modified redfield theory, Biophys. J. 93, 1293-1311. 4. Novoderezhkin, V. I., Romero, E., Dekker, J. P., and van Grondelle, R. (2011) Multiple charge separation pathways in photosystem II: modeling of transient absorption kinetics, ChemPhysChem 12, 681-688. 5. Kolli, A., O'Reilly, E. J., Scholes, G. D., and Olaya-Castro, A. (2012) The fundamental role of quantized vibrations in coherent light harvesting by cryptophyte algae, J. Chem. Phys. 137, 174109. 6. Chin, A. W., Prior, J., Rosenbach, R., Caycedo-Soler, F., Huelga, S. F., and Plenio, M. B. (2013) The role of non-equilibrium vibrational structures in electronic coherence and recoherence in pigment-protein complexes, Nat. Phys. 9, 113-118.

Topological pumping in the one-dimensional Bose-Hubbard model

Davide Rossini
Scuola Normale Superiore

By means of time-dependent density matrix renormalization group calculations we study topological quantum pumping in a strongly interacting system. The system under consideration is described by the Hamiltonian of a one-dimensional extended Bose-Hubbard model in presence of a correlated hopping which breaks lattice inversion symmetry. This model has been predicted to support quantized topological pumping. We provide a detailed analysis of the finite-size-scaling behavior of the pumped charge and its deviations from the quantized value. Furthermore we also analyze the non-adiabatic corrections due to the finite frequency of the modulation.

Carbon Nanotube-Based Motor Driven by a Thermal Gradient

Miguel Rubi
University of Barcelona,Faculy ofPhysics

We present a model describing the dynamics of a nanoelectromechanical device activated thermally. The nanosystem consists of two coaxial carbon nanotubes of disparate lengths. The presence of strong thermal inhomogeneities induces motion of the shorter nanotube along the track of the longer nanotube. A model which combines the action of frictional, van der Waals and thermal forces and the effects of noise is proposed and used to reproduce the motions observed in experiments and simulations. The dynamics of the nanomotor reveals the existence of a rich variety of dynamical behaviors and a high sensitivity to noise and initial conditions.

The Power of Combining Coherent Control with Noise Control

Thomas Schulte-Herbrüggen
TU Munich

Adding bang-bang switchable noise on a single qubit (out of a total of n) on top of unitary control seems magic: this simple add-on suffices for transforming any initial quantum state into any desired target state. We have extended our open-loop optimal control algorithm (DYNAMO) by such degrees of incoherent control so that these unprecedented reachable sets can systematically be exploited in experiments [1]. As illustrated for an ion trap experimental setting, open-loop control with noise switching can accomplish all state transfers one can get by the more complicated measurement-based closed-loop feedback schemes [2,3] requiring a resettable ancilla qubit.

[1] V. Bergholm and T. Schulte-Herbrüggen, arXiv/1206.4945 (2012) [2] S. Lloyd and L. Viola, Phys. Rev. A 65, 010101 (2001) [3] J. Barreiro et al., Nature 470, 486 (2011)

Dynamical control of purity and entanglement through dissipation

Jürgen Stockburger
Universität Ulm

Quantum coherence and entanglement are usually degraded by a dissipative coupling to a thermal environment. Here we present model computations showing that *cooperative* effects of single-body external control fields and dissipation can *improve* purity and entanglement in quantum systems.

Transport in the topological insulator HgTe with superconducting contacts: In search for Majorana fermions

Grigory Tkachov
Wuerzburg University

HgTe-based topological insulators (TIs) exhibit Dirac-like charge carriers [1-3]. They are characterized by spin helicity (i.e. spin-momentum locking) and have been predicted to form unconventional Majorana fermion states at interfaces with superconductors. In this contribution, we present theoretical and experimental studies of electron transport in a three-dimensional TI HgTe with superconducting Nb contacts [2,3]. We observe and theoretically explain a zero-bias anomaly (pronounced resistance drop), a manifestation of Andreev reflection and the induced superconductivity on the HgTe TI surface. These findings show that HgTe is a promising material to search for the signatures of the Majorana states in transport. Furthermore, we identify theoretically the requirements for the existence of the Majorana states in such hybrid systems and discuss their properties [3].

1. B. Buettner, C.X. Liu, G. Tkachov, E.G. Novik, C. Bruene, H. Buhmann,E.M. Hankiewicz, P. Recher, B. Trauzettel, S.C. Zhang, and L.W. Molenkamp,Single valley Dirac fermions in zero-gap HgTe quantum wells, Nature Phys. 7, 418 (2011). 2. L. Maier, J.B. Oostinga, D. Knott, C. Bruene, P. Virtanen, G.Tkachov, E.M. Hankiewicz, C. Gould, H. Buhmann, and L. W. Molenkamp, Induced superconductivity in the three-dimensional topological insulator HgTe, Phys. Rev. Lett. 109, 186806 (2012). 3. G. Tkachov and E. M. Hankiewicz, Spin-helical transport in normal and superconducting topological insulators (Review Article), Phys. Status Solidi B, DOI: 10.1002/pssb.201248385 (2013); Sponsors:

arXiv:1208.1466.

Permutationally Invariant Quantum Tomography and State Reconstruction

Geza Toth
Theoretical Physics, UPV/EHU and Ikerbasque

We present a scalable method for the tomography of large multiqubit quantum registers. It acquires information about the permutationally invariant part of the density operator, which is a good approximation to the true state in many, relevant cases. Our method gives the best measurement strategy to minimize the experimental effort as well as the uncertainties of the reconstructed density matrix. We apply our method to the experimental tomography of a photonic four-qubit symmetric Dicke state. We also discuss how to obtain a physical density matrix in a scalable way based on maximum likelihood and least mean square fitting.

G. Tóth, W. Wieczorek, D. Gross, R. Krischek, C. Schwemmer, and H. Weinfurter, Permutationally invariant quantum tomography, Phys. Rev. Lett. 105, 250403 (2010). T. Moroder, P. Hyllus, G. Tóth, C.

Schwemmer, A. Niggebaum, S. Gaile, O. Gühne, and H. Weinfurter, Permutationally invariant state reconstruction, New J. Phys. 14, 105001 (2012).

2. Posters

Master equation in stochastic phase space

Benrabia
USTHB

We review briefly the stochastic quantum theory and project the Born-Markov master equation on this representation. This is a very simple derivation of a Master equation for a positive phase space density rather than the Wigner function.

Observable entanglement in composite two-fermion bosons

Alex Bouvrie
Departamento de Física Atómica, Molecular y Nuclear, Instituto Carlos I

Bosonic composites can be treated as fundamental particles when their internal structure is negligible and composite-particle operators obey the canonical commutation relations. We derive [1] strong bounds for the deviations from ideal bosonic behavior of composites of two-fermions strongly bounded in terms of the purity of the single-fermion states. Such deviations are observable in Hong-Ou-Mandel-like interference experiments with many composites [2], which allows to access experimentally the entanglement of the fermionic composite constituents. Bound fermionic atoms may be used to implement exotic composites in the experiment. [1] M.C. Tichy, P.A. Bouvrie and K. Mølmer Phys. Rev. A 86, 042317 (2012). [2] M.C. Tichy, P.A. Bouvrie and K. Mølmer Phys. Rev. Lett. 109, 260403 (2012).

Entanglement, fractional magnetization and long-range interactions

Andrea Cadarso
CSIC-IFF

Entanglement plays a central role in many-body quantum systems as it can be used to understand the structure of the quantum states that appear in nature. In systems governed by short-range interactions, low energy states possess very little entanglement. In contrast, states evolved after quenches display large amounts of entanglement. Apart from the cases mentioned above, there exist practically no other physical situation where the existence of large or small amounts of entanglement can be rigorously established. In this talk, we identify two other scenarios in one spatial dimension that can be connected to the presence of entanglement: namely the presence of fractionalization in the magnetization per particle of a spin chain or the existence of long-range interactions. (see arXiv:1209.3898)

Entanglement in Quantum Phase Transitions: Dicke and Vibron Models

Manuel Calixto
Universidad de Granada

Large correlations and collective behavior are an intrinsic part of quantum critical systems in many body theory and, therefore, entanglement measures capture the essence of Quantum Phase Transitions. We study two paradigmatic models: the Dicke model for matter-field (spin-boson) interactions and the vibron model for rotovibrational (boson-boson) interactions in polyatomic molecules.

References:

-Lambert N, Emary C and Brandes T 2004 Phys. Rev. Lett. 92 073602 -M Calixto , E Romera and R del Real, J. Phys. A: Math. Theor. 45 (2012) 365301 -M. Calixto and F. Pérez-Bernal, in preparation.

Performance bound for quantum absorption refrigerators

Luis A. Correa
Universidad de La Laguna

An implementation of quantum absorption chillers with three qubits has been recently proposed, that is ideally able to reach the Carnot performance regime. Here we study the working efficiency of such self-contained refrigerators, adopting a consistent treatment of dissipation effects. We demonstrate that the coefficient of performance at maximum cooling power is upper bounded by 3/4 of the Carnot performance. The result is independent of the details of the system, its interaction with the external baths or its equilibrium temperatures. We provide design prescriptions that saturate the bound in the limit of a large difference between the operating temperatures. Our study suggests that ?nonlocal dissipation?, which must be taken into account for a proper modelling of the machine-baths interaction, is a fundamental source of irreversibility which prevents the refrigerator from approaching the Carnot performance arbitrarily closely in practice. The potential role of quantum correlations in the operation of these machines is also investigated.

Self-Consistent Mori projector (C-MoP) approach for driven dissipative quantum many body systems

Peter Degenfeld-Schonburg
TU München

We report on a pertubative method for driven dissipative quantum many body systems on a lattice that goes beyond Meanfield. Our approach is based on the Mori projection operator technique where we treat a single lattice site as the system of interest and trace out the dynamical many body environment comprised of all remaining lattice sites. The resulting on-site master equation describes the dynamics up to second order in the hopping. To account for a dynamical environment the master equation is solved self-consistently. We apply our methods to arrays of coupled non-linear harmonic oscillators, i.e. to a Bose Hubbard model, in a driven and dissipative regime and numerically show the advantage of C-MoP over Meanfield.

A no-go result on the purification of quantum states

Carlo Di Franco
Queenś University Belfast

The information encoded in a quantum system is generally spoiled by the influences of its environment, leading to a transition from pure to mixed states. Reducing the mixedness of a state is a fundamental step in the quest for a feasible implementation of quantum technologies. Here I show that it is impossible to ẗransferp̈art of such mixedness to a ẗrashs̈ystem without losing some of the initial information. Such loss is lower-bounded by a value determined by the properties of the initial state to purify. I discuss this interesting phenomenon and its consequences for general quantum information theory, linking it to the information theoretical primitive embodied by the quantum state-merging protocol and to the behaviour of general quantum correlations.

Quantum field theory for quantum biology

Pietro Faccioli
Trento University and INFN

The propagation of quantum excitations across biomolecules is influenced by the coupling of the quantum degrees of freedom (electron holes or excitons) with the classical vibronic modes of the molecule and with the stochastic fluctuations driven by the collision with solvent. In order to investigate quantum transport dynamics in these systems, a number of coarse-grained approaches have been developed, e.g. based on the Hacken-Strobl equation. On the other hand, the development of computationally viable microscopic theories, in which the quantum effects and the dynamic disorder induced by the coupling with the solvent are rigorously and consistently taken into account remains an open challenge. In this talk, we present our recent development of a rigorous framework in which charge and exciton propagation in biomolecules is systematically and efficiently investigated, by combining the coherent state path integral formalism and the Caildlish formalism for open quantum systems. By resorting on quantum fields to describe the charge quantum dynamics and taking the classical limit on the atomic degrees of freedom, we are able to analytically compute the effect of thermal fluctuations on the charge (or exciton) propagation. As a result, the matrix elements of the density matrix can be straightforwardly computed in perturbation theory, using appropriate Feynmann rules. Application of this approach to study quantum transport and de-coherence in biopolymers will be discussed.

From classical to quantum synchronization

Fernando Galve
IFISC (CSIC-UIB)

Synchronization has been largely studied in physical, biological and chemical classical systems and the aim of this talk is to present results in the quantum regime, looking for the quantum aspects of this phenomenon. We consider a fundamental system of detuned quantum harmonic oscillators coupled between them and dissipating into the environment. We identify the conditions leading to spontaneous synchronization showing that the ability of the system to synchronize is related to the existence of disparate decay rates and depends on the coupling with the reservoir as well as its characteristics. We also show that this spontaneous phenomenon is accompanied by robust quantum discord and mutual information between the oscillators, preventing the leak of information from the system into the environment.

Tunneling, self trapping and manipulation of higher modes of a BEC in a double well

Jérémie Gillet
Okinawa Institute of Science and Technology

We study the dynamical behavior of four modes of atomic Bose-Einstein condensates (BEC) trapped in a one dimensional double well trap. A general Hamiltonian is given in terms of the creation and annihilation operators as well as in the macroscopic limit. Three regimes of interaction are studied, each showing different degree of tunneling and self trapping in the two energy levels. Influence of initial conditions in the ground modes on the excited modes is also studied

Quantum uncertainty on a single observable

Davide Girolami

Quantum mechanics predicts that measurements of incompatible observables carry an uncertainty which is independent of technical deficiencies of the measurement apparatus or incomplete knowledge of the state of the system. Nothing yet seems to prevent a single physical quantity, such as one spin component, from being measured with arbitrary precision. Here we show that an intrinsic quantum uncertainty on a single observable is ineludible in a number of physical situations. When revealed on local observables of a bipartite system, such uncertainty defines a bona fide and computable measure of general quantum correlations. We then demonstrate that these correlations, commonly referred to as quantum discord, constitute a resource for quantum enhanced metrology, as they can be exploited to improve the efficiency of parameter estimation with noisy probes

Optimal Control of Transmon Qubit Gates in the Presence of Decoherence

Michael Goerz
Universität Kassel

We consider two transmon qubits [1] coupled via a cavity bus [2]. The strong coupling of each qubit to the shared cavity modes provides an indirect interaction that can be used to implement a two-qubit gate. Describing the system numerically allows us to take into account an arbitrary number of qubit and cavity excitations. We use optimal control theory (OCT), specifically Krotovś method [3], to find microwave pulses that drive the full system in the desired way in the shortest possible amount of time. Modeling the system dynamics with a master equation in Lindblad form [4], we analyze the effect of decoherence on the feasibility of high-fidelity two-qubit gates. OCT can then specifically select pathways robust to the influence of decoherence.

[1] J. Koch et. al., Phys. Rev. A 76, 042319 (2007) [2] J. Majer et. al., Nature 449, 443 (2007) [3] D. M. Reich et. al., J. Chem. Phys. 136, 104103 (2012) [4] M. Boissonneault et. al. Phys. Rev. A 85, 022305 (2012)

Unravelling complex quantum systems dynamics with frequency and time resolved photon correlations

Alejandro Gonzalez-Tudela
Universidad Autonoma de Madrid

We apply our recently developed method to compute time and frequency resolved N-photon correlations [1] to analyse different open quantum optical systems [2]. They are an extension of the standard Nth order temporal correlation functions into the frequency domain. Heisenberg uncertainty principle requires the introduction of the detector or ?lter frequency resolution in the theory. Obtaining such cross correlations has been a common practice experimentally for years now, proving useful in many contexts such as lasers [3], cavity-QED [4] or resonance fluorescence [5-6]. However, their computation has remained a theoretical challenge due to their cumbersome integral expressions. With our formalism, we are able of studying the two-photon spectra of a variety of systems of increasing complexity: single mode emitters and the various combinations that arise from their coupling. We consider both the linear and nonlinear regimes under incoherent and coherent excitation [2]. We also apply our theory to fluctuating systems by including in the master equation both the magnitude and speed of fluctuations [7] and showing how spectral filtering can be used to recover the information otherwise blurred by the fluctuations.

[1] E. del Valle, A. Gonzalez-Tudela, F. P. Laussy, C. Tejedor and M. J. Hartmann, Phys. Rev. Lett. 109, 183601 (2012). [2] A. Gonzalez-Tudela, F. P. Laussy, C. Tejedor, M. J. Hartmann, E. del Valle, arXiv:1211.5592 (2012) (NJP in press) [3] R. Centeno Neelen et al., Optics Communications 100, 289 (1993) [4] K. Hennessy et al., Nature 445, 896 (2007) [5] A. Aspect et al., Phys. Rev. Lett. 45, 617 (1980) [6] A. Ulhaq et al., Nature Photonics 6, 238 (2012) [7] A. A. Budini, Phys. Rev. A 79, 043804 (2009)

Heats of formation of Zirconium binary transition metal alloys

Krarcha Hadda
University of batna

D-band model is used to predict enthalpies of formation of binary transition metal alloys. One of the input parameters of the model namely bandwidth is optimized by refinement procedures based on ab initio calculations and reliable calometric data for Zr-, Hf-,V-,Nb and Ti-compounds. Revised values of enthalpies of formation for Zr-binary transition metal compounds using new values of bandwidth are substantially improved. This improvement can be applied for other problematic cases in order to ameliorate results of calculated by d-band model.

A tunable macroscopic quantum system based on two fractional vortices

Dennis M. Heim
Universität Ulm

We propose a tunable macroscopic quantum system based on two fractional vortices. Our analysis shows that two coupled fractional vortices pinned at two artificially created
kappa discontinuities of the Josephson phase in a long Josephson junction can reach the quantum regime where coherent quantum oscillations arise. For this purpose we map the dynamics of this system to that of a single particle in a double-well potential. By tuning the
kappa discontinuities with injector currents we are able to control the parameters of the effective double-well potential as well as to prepare a desired state of the fractional vortex molecule. The values of the parameters derived from this model suggest that an experimental realisation of this tunable macroscopic quantum system is possible with todayś technology.

The structure of multidimensional entanglement in multipartite systems

Marcus Huber
University of Bristol, UAB, ICFO

We explore the structure of multipartite quantum systems which are entangled in multiple degrees of freedom. We find necessary and sufficient conditions for the characterization of tripartite systems and necessary conditions for any number number of parties. Furthermore we develop a framework of multi-level witnesses for efficient discrimination and quantification of multidimensional entanglement that is applicable for an arbitrary number of systems and dimensions.

Energy transport in strong coupling regimes

Jake Iles-Smith
Imperial College London

The role of quantum mechanics in energy transport has attracted much interest in recent years. In particular, the mechanisms responsible for the highly efficient and robust energy transport observed in photosynthetic complexes remains an open question. One possible explanation for this is the interplay between quantum coherence and dissipation, making understanding such systems of both practical and foundational importance. However, complex system-environment interactions make modelling and understanding the behaviour of these systems a daunting task. By taking a master equation approach we can acquire a set of simple and often intuitive equations describing the system dynamics. Unfortunately, however, many of these techniques struggle to accurately describe system behaviour in highly non-Markovian regimes. In this poster we present a mapping between the spin-boson model to the so-called reaction coordinate model, in which a two level system is coupled to a single harmonic mode, which is in turn coupled to a dissipative bath. By deriving a second order master equation for the mode-bath coupling and treating the system-mode coupling non-perturbatively, we can account quantitatively for non-Markovian behaviour in strong coupling and high temperature regimes.

Dynamics of quantum discord and entanglement in a spin-valley graphene system

Esther Jódar
UPCT - Cartagena

It is important to characterize whether a complex quantum system is entangled or separable and to figure out whether the system has classical or quantum cor- relations. Studying these features is of a great interest for quantum computation and quantum information fields. We investigate a two-electron double quantum dot with both spin and valley degrees of freedom in graphene. These degrees of freedom can be considered as a potential four qubit register. In particular, we focus on the dynamics of correlations (such as quantum discord[1] and entan- glement[2]) between the subsystems of the model. The two quantum dots are coupled by the spin and valley preserving hopping. The effective Hamiltonian is Heisenberg-exchange between the spin-spin, spin-valley and valley-valley[3]. A pulse-like exchange coupling is used to control the quantum dynamics, where we evaluate the evolution of quantum discord in the known SWAP and half SWAP quantum gate on spin or valley qubits.

[1] Mazhar Ali, A. R.P. Rau and G. Alber Phys. Rev. A 81 (2010) 042105.
[2] Jürgen Audretsch Entangled Systems (Eds. Wiley-VCH 2006).
[3] Niklas Rohling and Guido Burkard New Journal of Physics 14 (2012) 083008.

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Tweeting Quantum Biology

Iannis Kominis
University of Crete - Department of Physics

Radical-ion-pair reactions are spin-dependent biochemical reactions studied by the field of spin chemistry since the 60ś. They underlie the avian compass mechanism and also participate in photosynthesis. We were the first [1-7] to show that radical-ion-pair reactions exhibit a host of quantum effects familiar from atomic/quantum physics experiments with well-isolated quantum systems. We showed that the fundamental theoretical description of radical-ion-pair reactions is based on quantum measurement theory [1,2], we discovered the fundamental decoherence process in these reactions, we showed that they exhibit the quantum Zeno effect [1,6] and we mapped them to the archetypal quantum system, the double slit interferometer [2], pointing to the fundamental role played by spin coherence in understanding the reaction dynamics. Furthermore, we analyzed [4] radical-ion-pair reactions from the perspective of quantum metrology, since they are natural biochemical magnetometers, demonstrating the role of coherence and entanglement dynamics. Essentially, we pointed to the first to our knowledge biological system exhibiting the whole conceptual machinery of quantum information science, inspiring the quantum physics community to further address the

quantum coherence properties of avian. We will review this work, as well as follow up work by other groups [8,9] in order to motivate further progress in this exciting new field driving quantum biology.

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Fast dynamics for atoms in optical lattices

Mateusz Lacki
Jagiellonian University

Cold atoms in optical lattices allow for accurate studies of many body dynamics. The tight-binding description leads to the Bose-Hubbard model, which allows efficient of the computational problem. When the dynamics is quick, the time-dependence of the Wannier functions has to be taken into account to achieve a faithful description. This leads to modification of the time-dependent Schrodinger equation in the lattice representation, giving rise to additional terms coupling different Bloch bands. In my talk I will review the derivation of such a result and show the effect of this modifications on the dynamics. I will discuss two specific issues: how fast is fast and what this implies on state preparation problem.

M.Lacki, J. Zakrzewski, arXive:1210.7957

Mass effects on the entanglement features of an exactly soluble quantum many-body system

Ana Majtey
Universidad de Granada

We explore the entanglement properties of the states of an exactly soluble many-body model consisting of Nn nuclei and Ne electrons interacting in a confining harmonic trap. We present exact entanglement calculations for the ground and some excited states of this model. We investigate the entanglement dependence upon the different parameters characterizing the system such as the relative interparticle interaction, the confining harmonic force, the size of the system and the particle masses. Particular attention is paid to the dependence of the entanglement on the ratio of the masses of the constituent particles. As a general trend, we find that the entanglement vanishes when the subsystems have very different masses. Since the validity of the Born-Oppenheimer approach is closely related to the mass of the particles, we study the validity region of this approach depending on the parameters of the model. We shed new light on the understanding of the vanishing bipartite entanglement with the different mass of the subsystems.

Quantum equilibration for a particle in a box

Artur Malabarba
University of Bristol

We consider in detail the equilibration of a quantum particle in a one-dimensional box. Given access to a single dichotomic measurement (e.g. whether the particle is on the left side of the box or not), the particle will appear to equilibrate to its time-averaged state. We analyse this equilibration behaviour over finite and infinite times, and its dependence on the systemś effective dimension.

A quantum optical Diode: nonlinear-linear resonator junction

Eduardo Mascarenhas
UFMG

We present a quantum optical diode for photonic transport. The diode is based on a nonlinear- linear resonator junction and it acts as a valve that induces unidirectional photonic conduction. In the same resonator valve different frequencies can be rectified, that is unidirectionally transmitted, in different directions. We also show that for a specific resonant configuration the system is a single-photon-rectifying source.

Dephasing enhanced transport in non-equilibrium strongly-correlated quantum systems

Juan Jose Mendoza Arenas
University of Oxford

Recently, the transport properties of noisy many-body systems have been intensively studied. A fundamental observation consists on the enhancement of transport efficiency in networks of non-interacting particles by dephasing processes, due to the suppression of destructive interference that leads to an insulating state. In the present work we analyze how dephasing affects the transport of strongly-interacting 1D systems. We consider a XXZ spin chain driven out of equilibrium by reservoirs at the boundaries, with dephasing in the bulk, and obtain its steady state applying the time evolving block decimation algorithm to the Lindblad master equation describing its dynamics; we then calculate spin and heat currents, and magnetization and energy density profiles. Interestingly, we find a new mechanism of dephasing assisted spin transport, which in contrast to those reported previously, emerges for strong interactions only. In addition, the transport enhancement is also manifested in heat transport, although in lesser extent. We unveil the basic requirements for this phenomenon to occur, and illustrate them using a toy model, showing its generality. We also give evidence supporting a non-equilibium phase transition at the isotropic point of the model, based not only on the different transport regimes separated by this point (of degradation and enhancement by dephasing), but also on correlations. Finally we discuss the possible experimental observation of the reported effects in ultracold atomic systems.

Transport Properties of Incoherently-Coupled Chains

Mark Mitchison
Imperial College/Oxford University

We numerically study spin transport in arrays of boundary-driven spin chains governed by the Heisenberg XXZ Hamiltonian. The chains are coupled by incoherent hopping of spin excitations between sites of neighbouring chains. This model should be relevant for conjugated polymer arrays used, for example, in organic solar cells, where intrachain transport is believed to be coherent, while interchain transport is mostly incoherent. We find an enhancement of the current in the presence of interactions or disorder for moderate hopping rates, which represents a novel noise-assisted transport mechanism.

Environment-assisted quantum transport on disordered graphs

Leonardo Novo
Physics of Information Group, Instituto de Telecomunicações

In this work, we consider the quantum walk of a particle on different disordered graphs, under the effect of pure dephasing noise. We study the efficiency of the transport of the particle and analyse how it varies with the disorder and the dephasing rate. Furthermore, we study the conditions in which environment-assisted transport exists, what is the optimal dephasing regime for enhancing transport and how it depends on the structure of the graph.

The effects of long- and short-range interacctions on localization.

Manuel Pino García
universidad de Murcia

We use exact diagonalization to study the localization properties of electrons in a Many-Body state. Specifically, we compute the localization length of the ground-state and the eigenstate in the middle of the band for long- and short-range interactions. Our results indicate that the interaction does not substantially change the localization properties of the ground-state, while it increases the localization length of the state at the middle of the band. The observed increase is greater for short range interactions than for long-range ones.

Matter waves analog of an optical random laser

Marcin Plodzien
Jagiellonian University

The accumulation of atoms in the lowest energy level of a trap and the subsequent out-coupling of these atoms is a realization of a matter-wave analogous to a conventional optical laser. Optical random lasers require materials that provide optical gain but, contrary to conventional lasers, the modes are determined by multiple scattering and not a cavity. We show that a Bose-Einstein condensate can be loaded in a spatially correlated disorder potential prepared in such a way that the Anderson localization phenomenon operates as a band-pass filter. A multiple scattering process selects atoms with certain momenta and determines laser modes which represents a matter-wave analogous to an optical random laser.

Avoiding Molecular Dynamics by Quantum Mechanics

Thomas Prevenslik

BACKGROUND Molecular Dynamics (MD) is used in computational heat transfer to determine the thermal response of nanostructures. With theoretical basis in statistical mechanics, MD relates the thermal energy of the atom to its momentum by the equipartition theorem. Momenta of atoms in an ensemble are determined by solving Newton?s equations with inter-atomic forces derived from Lennard-Jones potentials. Statistical mechanics always assumes the atom has heat capacity as otherwise the momenta of the atoms cannot be related to their temperature. In heat transfer simulations of bulk materials, MD simulates the continuum by imposing periodic boundary conditions (PBC) on an ensemble of atoms having heat capacity in submicron computation boxes. MD simulations of the bulk are valid because atoms in the bulk do indeed have heat capacity.

PROBLEM: MD simulations of heat transfer in discrete nanostructures differ from that in the bulk because of quantum mechanics (QM). Unlike statistical mechanics, QM precludes atoms from having heat capacity at the nanoscale. By QM, atoms in discrete nanostructures lacking heat capacity cannot conserve heat by an increase in temperature, and therefore the classical Fourier heat conduction equation that depends on temperature has no meaning. Nevertheless, MD heat transfer simulations of discrete nanostructures having heat capacity abound the literature. Even if the computationally intensive nature of MD is set aside, MD solutions of discrete nanostructures are not only invalid by QM, but give unphysical results, e.g., thermal conductivity of thin films depends on thickness, heating nanocars does not cause observed motion, and so forth.

SOLUTION: Lacking heat capacity, heat transfer in discrete nanostructures by QM proceeds by the conservation of absorbed EM energy by the creation of non-thermal QED induced EM radiation that charges the nanostructures by the photoelectric effect, or is emitted to the surroundings. EM stands for electromagnetic and QED for quantum electrodynamics. Instead of MD, nanoscale heat transfer is proposed to proceed by formulating a finite element (FE) model of one or more nanostructures interacting with each other and the surroundings. Estimates of the EM radiation and charge induced by QED of each nanostructure are then input as point sources into the FE model to determine the system response. MD of individual nanostructures may be made to determine the QED induced EM radiation, i.e., QM requires constant temperature implemented with the Nose-Hoover thermostat, the QED induced EM radiation equal to the thermostatic heat.

RESULTS: In the simulation of heat transfer of nanostructures, the advantage of QM over the classical statistical mechanics in MD is that computationally intensive and invalid solutions are avoided. Examples of how unphysical MD simulations of heat transfer in nanostructures are presented that show how invalid solutions can be avoided.

Wavelength infrared study of GaAs-AlxGa1-xAs superlattices

Djelti Radouan
Mostaganem University

Laser infrared radiation, having a wavelength between ultraviolet and visible, has a number of highly interesting applications in biological imaging, surface chemistry, and high-field condensed matter studies. Many materials have been the subject of investigation in the infrared. Interest has focused on wavelengths between (4, 20) length required by the IR photodetectors and IR cameras but in recent years, the focus is increasingly on longer wavelengths required on space applications telecommunications, rapid detection and new opto-electronic devices. The interesting aspect of this work is the systematic study of the influence of correlated structural disorder on the transmission property and wavelenght of Dimer and Trimer Height Barrier Superlattices (DHBSL/THBSL). Ours system consists of a stack ultra fine layer of semiconductor which are alternated periodically, where the small gap material (GaAs) plays the well potential role, and the large gap material (AlGaAs) plays the barrier potential role. For the dimer structure, the electron will emit on 11.02?m wavelength corresponding to jump 182meV, while the trimer structure electron will emit on three wavelengths (38.19?m, and 66.21?m 104.52?m) respectively corresponding to jump (50meV, 30meV and 20meV). We notice that this wavelength range matches to the range required by the infrared photodetectors (4 to 20?m), infrared cameras (8 to 12?m), fluid detectors and biological molecules detectors (60 to 200 ?m). We have observed from measurements of wavelength, that the introduction of correlated structural disorder by (Doublet, Triplet, Quadruplets, Quintuplets?) provides more wavelengths located above visible domain (far-infrared, microwave).

Dissipation in Topological Insulators

Ángel Rivas
Universidad Complutense

In this contribution we present recent results regarding the stability of topological order in the presence of dissipation. Particularly, in our study we focus on topological insulators coupled to thermal baths. These systems present non-vanishing topological conductivity at zero temperature, as their conduction and valence bands are connected by the so-called (topologically protected) edge states. We shall explain how, in general, these edge states are no longer protected when the system is in contact with a thermal bath. Interestingly, for some kind of environments, it is possible to obtain topologically ordered phases even in the presence of dissipation.

Phase-space analysis of quantum phase transitions by means of Husimi distribution: Dicke and U(3) Vibron models.

Elvira Romera
Universidad de Granada

The Husimi distribution is proposed for a phase-space analysis of quantum phase transitions in the Dicke and Vibron models of spin-boson and boson-boson interactions, respectively. We show that the inverse participation ratio and Wehrl entropy of the Husimi distribution give sharp signatures of the quantum phase transition. The analysis is done using two frameworks: a numerical treatment and an analytical variational approximation. Additionally, we propose a characterization of the quantum phase transition by means of the zeros of the Husimi distribution in the variational approach in both models.

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Single ion heat engine with maximum efficiency at maximum power

Johannes Rossnagel
University of Mainz

While thermodynamic systems are generally treated by averaging over many body systems we scale such a system down to the ultimate limit of a single quantum particle. We propose an experimental scheme for a nano-heat engine using a single ion as working gas [1]. An Otto cycle may be implemented by confining the ion in a linear Paul trap with tapered geometry and coupling it to engineered reservoirs. The quantum efficiency is analytically determined and Monte-Carlo simulations with realistic parameters demonstrate its experimental feasibility and its ability to operate at maximum power with an efficiency of 30

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Quantum simulation with superconducting circuits: a PEPS analysis

Hamed Saberi
Shahid Beheshti University

Cavity lattices provide a viable platform for quantum simulation of strongly correlated systems both in and out of equilibrium. We consider here arrays of resonators in a Kagome geometry described by a Jaynes-Cummings-Hubbard Hamiltonian. A quantitative analysis of such a Jaynes-Cummings lattice has hitherto been possible only for small number of cavities with numerical diagonalization techniques. However, more sophisticated and e fficient numerical techniques that can account for many-polariton correlations are needed in order to study the dynamics of larger arrays with the possibility of the emergence of various intriguing collective phenomena such as superfluid-to-Mott-insulator transition etc. In this talk, I would demonstrate how the two-dimensional version of the powerful and recently developed tensor network techniques, i.e., the so-called projected-entangled pair states(PEPS)can be invoked to address such issues.

Loop Models and Quantum Magnets

Pablo Serna Martínez
University of Murcia

Many statistical mechanics problems can be framed in terms of random curves; we consider a class of three-dimensional loop models that are prototypes for such ensembles. We map them to CP^{n-1} sigma models. The results are relevant to $(2+1)$-dimensional quantum magnets as well as to Anderson localization and to line defects in random media.

Linear-Zigzag quantum transition in 1D arrays of interacting atoms with DMRG

Pietro Silvi
Ulm University

Quasi one-dimensional arrays of repulsively-interacting atoms, confined by external potentials, exhibit a structural transition between a linear equilibrium configuration, and a zigzag shaped one. By means of density matrix renormalization group we study the quantum version of this transition for various physical settings and scenarios.

Neural networks as a tool to study quantum chaotical system

Marek Smaczynski
Jagiellonian University

We analyze with the use of neural network a model of quantum dynamical system called generalized baker map subjected to periodic interaction with an environment, which can describe quantum measurements. Under the condition of strong classical chaos and strong decoherence due to large coupling with the measurement device, the spectra of the evolution operator exhibit an universal behavior. Studying showed that standard neural networks and self-organizing Kohonen network map can recognize certain general features in quantum chaotic system.

Broadband entangled photons for light-matter interaction and quantum information

André Stefanov
University of Bern

Photonic entanglement is one of the most common methods to generate and study entangled states. Photon pairs can be entangled in different degrees freedom including polarisation, momentum or energy. Broadband energy entangled photons offer very interesting features for both quantum information and quantum metrology. On one side their entanglement content can be very large, as shown by computing the entropy of entanglement and one the other side their wavefunction can be shaped by techniques similar to the shaping of short laser pulses. We show how the two-photon wavefunction can be measured by applying interferometric autocorrelation schemes using a pulse shaper based on a spatial light modulator and by simultaneously shaping both amplitude. Such two-photon shaping is a very promising tool to study the interaction of non-classical light with matter, either for spectroscopic or scattering measurements. Finally we generate, manipulate and characterize qudits by different discretization procedures of the two-photon photon spectrum. Frequency-entangled qudits are analysed by tomographic protocols. Violations of Bell inequalities for qudits are demonstrated for frequency- and time-entanglement as well as for qudits in the Schmidt basis.

Estimating Quasi-Long-Range Order via Renyi Entropies

Luca Taddia
Universitaḑi Bologna

We show how entanglement entropies allow for the estimation of quasi-long-range order in one dimensional systems whose low-energy physics is well captured by the Tomonaga-Luttinger liquid universality class. First, we check our procedure in the exactly solvable XXZ spin-1/2 chain in its entire critical region, finding very good agreement with Bethe-ansatz results. Then, we show how phase transitions between different dominant orders may be e fficiently estimated by considering the superfluid-charge density wave transition in a system of dipolar bosons; moreover, we discuss the application of this method to multispecies systems such as the one dimensional Hubbard model. Finally, we study the case of the critical non-integrable XXZ spin-3=2 chain.

Superradiance and spin lattice formation in a BEC-cavity system with Raman coupling

B. Tanatar
Bilkent University

In a system consisting of an atomic Bose-Einstein condensate, with two hyperfine spin components, confined inside a one dimensional optical cavity, subject to two laser fields parallel and perpendicular to the cavity axis, we study formation of a spin lattice as a result of the Raman superradiance. We consider the case where the hyperfine spin states are coupled to the transverse laser field and cavity mode via the atomic excited state in Raman scattering manner and in dispersive regime where laser fields and the cavity mode are detuned from the atomic transition. We examine the spatio-temporal evolution of the relative population of the hyperfine spin states (magnetization) by numerically solving the coupled cavity-condensate equations of motion in mean field regime and show that beyond a certain threshold, depending on the transverse and parallel laser pumps and the atom-atom interactions, Raman superradiance and a self-organization of the hyperfine spin components take place simultaneously. Robustness of the spin lattice can be achieved by turning off the laser fields when the lattice has been formed.

Entropy and complexity analysis of Rydberg atoms

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The internal disorder of Rydberg atoms as contained in their position and momentum probability densities is examined by means of the following information-theoretic spreading quantities: the radial and logarithmic expectation values, the Shannon entropy and the Fisher information. As well, the complexity measures of Cramer-Rao, Fisher-Shannon and LMC types are investigated in both reciprocal spaces. The leading term of these quantities is rigorously calculated by use of the asymptotic properties of the concomitant entropic functionals of the Laguerre and Gegenbauer orthogonal polynomials which control the wavefunctions of the Rydberg states in both position and momentum spaces. The associated generalized Heisenberg-like, logarithmic and entropic uncertainty relations are also given. Finally, application to linear, circular, and quasicircular states is explicitly done.

Mathematical snapshots of quantum computing

Sebastian Xambó-Descamps
Universitat Politècnica de Catalunya

The goal is to phrase the mathematical underpinnings of quantum computing. In particular, the geometry of the qubit registers and the stochastic model of measuring an observer. It should help mathematicians to understand the physics of quantum information and the physicists and engineers to understand the fundamental mathematical ideas involved.