COMPLEX QUANTUM SYSTEMS WORKSHOP

IFISC, Palma de Mallorca, October 14 -15, 2010

UIB Universitat de les Illes Balears

CSIC Consejo Superior de Investigaciones Científicas

IFISC
Instituto de Física Interdisciplinar y Sistemas Complejos

PROGRAM

Thursday, October 14

09:30	Introduction
10:00	Sandro Wimberger *Correlation measures for many-body bosonic systems*
10:40	Giovanna Morigi *Quantum linear-zigzag transition in ultracold ion chains*
11:20	Coffee Break
11:50	Milena Grifoni *Dynamics of an ultrastrong coupled qubit-oscillator system under extreme driving*
12:30	Roberta Zambrini, Fernando Galve, Gianluca Giorgi *Complex Quantum Systems at IFISC (I)*
13:10	Lunch
14:40	Fabio Benatti *Quantum Algorithmic Complexities and Entropies*
15:20	Antonio Acín *Entanglement and Quantum Networks*
16:00	Coffee Break
16:20	Discussion: Wimberger, Morigi, Grifoni, Zambrini, Benatti, Acín
19:15	Guided tour and dinner (Palma)

Friday, October 15

09:30	John Lapeyre *Entanglement Percolation: beyond pure bi-partite states*
10:10	David Zueco *Circuit QED, from cavity QED to photonic crystals on a chip*
10:50	Coffee Break
11:20	Thomas Wellens *Quantum transport in disordered systems*
12:00	Juan Diego Urbina *Probability Distributions in Hilbert Space: from Quantum State Diffusion to Mesoscopic Superconductivity*
12:40	David Sánchez, Josep Batle *Complex Quantum Systems at IFISC (II)*
13:20	Lunch
14:40	Thomas Pohl *Light-Matter Interactions in Ultracold Rydberg Gases: From correlated states to nonlocal media*
15:20	Susana Huelga *Quantum dynamics of bio-molecular systems in noisy environments*
16:00	Coffee Break
16:30	Filippo Caruso *Noise-assisted transport in biological complex quantum networks*
17:00	Discussion: Lapeyre, Zueco, Wellens, Urbina, Sánchez, Pohl, Huelga, Caruso.

SUMMARY OF ABSTRACTS

Antonio Acín
Quantum Information Theory group, Institute of Photonic Sciences (ICFO), Barcelona

Entanglement and Quantum Networks

We analyze the problem of entanglement distribution through quantum networks. We consider networks of regular and random geometry and show that new possibilities with no classical analogue appear in this scenario due to quantum effects.

Fabio Benatti
Theoretical Physics Department, Trieste University

Quantum Algorithmic Complexities and Entropies

The algorithmic complexity of long bit-strings is closely related to Shannon entropy and to compressibility. The talk will review such relations and then focus upon some proposed algorithmic complexity quantifiers for qubit strings and upon their relations to quantum entropies.

Filippo Caruso
Institute of Theoretical Physics, Ulm University

Noise-assisted transport in biological complex quantum networks:
Experiments, quantum simulations and applications

The uncontrollable interaction of a transmission network with a noisy environment is usually assumed to deteriorate its transport capacity, especially for quantum networks. Here, following recent experimental results, we investigate the intricate interplay of noise and quantum coherence and identify the key mechanisms to explain the remarkable efficiency (99%) and robustness of energy transfer in the early steps of bacterial photosynthesis. Interestingly enough, we find that the dephasing noise may enhance, in a very remarkable way, the capability of transmitting not only energy but also classical and, more counterintuitively, quantum information over biologically inspired quantum communication networks. Finally, we propose some quantum optical experimental setups for the demonstration of the basic mechanisms underlying noise-assisted transport. Understanding the workings of such a process has the potential to be immensely valuable from a technological point of view, suggesting the possibility for achieving robust and efficient transfer of energy and classical/quantum information, assisted by noise, by designing optimized artificial nano-structures for transport, for instance, in solar cells, in quantum information processing, and in complex communication networks.

Milena Grifoni
Theoretical Physics, Regensburg University

Dynamics of an ultrastrong coupled qubit-oscillator system under extreme driving

We introduce a novel approach to study the time-dependent qubit-oscillator Hamiltonian beyond the driven Jaynes-Cummings model. We include counter-rotating terms for both the coupling of the two-level system to the quantized oscillator mode and to the external classical driving. Thus, the dynamics of the qubit can be examined analytically in the ultrastrong coupling regime, where the ratio g/Ω between coupling strength and oscillator frequency approaches unity or goes beyond, and simultaneously for driving strengths much bigger than the qubit energy splitting (extreme driving). Both qubit-oscillator coupling and external driving leads to a dressing of the qubit tunneling matrix element of different nature: the former can be used to suppress specifically certain oscillator modes in the spectrum, while the latter can yield coherent destruction of tunneling (CDT). We show that CDT is robust even in the case of ultrastrong coupling. Our findings are within the reach of present experimental superconducting set-ups for quantum information processing.

Susana Huelga
Institute of Theoretical Physics, Ulm University

Quantum dynamics of bio-molecular systems in noisy environments

We discuss several aspects of the coherent quantum dynamics of bio-molecular systems and more generally complex networks in the presence of an environment. Three general points will be addressed. Firstly, we identify fundamental structural elements underlying the quantum dynamics of these systems. Secondly, we provide novel approaches to the description of the quantum dynamics of complex networks when the coupling to the environment is neither perturbative nor so strong as to enforce fully classical dynamics. Thirdly, we discuss possible approaches towards deciding and quantify the non-classicality of the action of the environment and the observed system-dynamics on the basis of actual experimental data.

John Lapeyre
Quantum Information Theory group, Institute of Photonic Sciences (ICFO), Barcelona

Entanglement Percolation: beyond pure bi-partite states

Technical challenges in separating entangled pairs over large distances led to the idea of the quantum repeater: a 1-d chain of nodes and links, with the nodes containing local quantum resources and the links allowing transmission of states between the nodes. The introduction of entanglement percolation generalized the repeater to multi-dimensional networks. Although entanglement percolation initially considered pure bi-partite states between nodes, clearly other possibilities exist. In this talk we present protocols improving performance via multi-partite techniques, as well protocols treating the more realistic case of full-rank mixed states.

Giovanna Morigi
Theoretical Physics, Saarlandes University, Saarbrücken

Quantum linear-zigzag transition in ultracold ion chains

A string of trapped interacting ions at zero temperature exhibits a structural phase transition to a zigzag structure, tuned by reducing the transverse trap potential or increasing the particle density. The transition is driven by transverse, short wavelength vibrational modes. We propose a quantum field--theoretical description of this transition by the one dimensional Ising model in a transverse field. Based on the mapping to this model, we estimate the quantum critical point in terms of the system parameters, and find a finite, measurable deviation from the critical point predicted by the classical theory. A measurement procedure is suggested which can probe the effects of quantum fluctuations at criticality. These results can be extended to describe the transverse instability of ultracold polar molecules in a one dimensional optical lattice.
The classical non-equilibrium dynamics is then studied when the transverse trap frequency is quenched across the value at which the chain undergoes a continuous phase transition from a linear to a zigzag structure. An equation for the order parameter, corresponding to the transverse size of the zigzag structure, is determined when the vibrational motion is damped via laser cooling. The number of structural defects produced during a linear quench of the transverse trapping frequency is predicted and verified numerically. It is shown to obey the scaling predicted by the Kibble-Zurek mechanism, when extended to take into account the spatial inhomogeneities of the ion chain in a linear Paul trap.

Thomas Pohl
Max-Planck-Institute for the Physics of Complex Systems, Dresden

Light-Matter Interactions in Ultracold Rydberg Gases: From correlated states to nonlocal media

The coherent manipulation of ultracold Rydberg atoms is currently attracting increasing interest, also exploring applications in nonlinear optics, in quantum information science and simulators for quantum magnetism. This potential largely stems from the high sensitivity of Rydberg atoms to external fields and to interactions among them.
In this talk I will review recent theoretical progress in describing the rather complex dynamics of laser driven Rydberg gases in the presence of strong interactions, thereby pointing out approaches for the controlled preparation of entangled many-body states as resources for creating non-classical light.
Building on these findings, I will further discuss their utility for nonlinear optics and for implementing nonlinear, nonlocal matter-wave dynamics, including the formation of exotic supersolid states out of Rydberg-dressed condensates.

Juan Diego Urbina
Complex Quantum Systems group, Regensburg University

Probability Distributions in Hilbert Space: from Quantum State Diffusion to Mesoscopic Superconductivity

In quantum mechanics, knowledge of the density matrix - obtained by solving the proper equation of motion like Von Neumann, Master, Boltzmann, etc- provides by definition all necessary information to fully characterize a system in the sense of giving a way to calculate the expectation value of any observable. However, there are several attempts to provide extra information into this scheme by considering the density matrix as simply the covariance matrix of a much more general object. Such approaches define a probability distribution assigning a real positive number to any state in the Hilbert space of the system, and they have different names depending on the kind of density operator they mimic: random wave models in the field of Quantum Chaos, distribution of wave-functions in the field of Quantum Statistical Physics, unravellings of the Lindblad equation in the field of Open Quantum Systems, etc. In the talk, we will present an overview of the concept of Probability Distributions in Hilbert Space, showing how it appears to be a natural approach underlining different fields and methods within what we tipically associate with complex behaviour.

Thomas Wellens
Institute of Physics, Albert-Ludwigs-University, Freeburg

Quantum transport in disordered systems

In general, transport of waves in disordered media cannot fully be described as a simple diffusion process, since wave interference effects lead to a reduction or even complete suppression of the diffusion constant (weak or strong localization) and the appearance of a coherent backscattering peak. This talk presents a diagrammatic theory for treating the impact of nonlinearities on these coherent transport effects. In particular, the conditions under which nonlinear effects diminish or enhance the height of the coherent backscattering peak are discussed. Whereas most of these results apply to classical or single-particle quantum waves, we will finally also address multi-photon scattering from strongly driven two-level atoms, where coherent transport is additionally affected by quantum mechanical decoherence.

Sandro Wimberger
Complex Dynamics in Quantum Systems, Institute of Theoretical Physics, Heidelberg University

Correlation measures for many-body bosonic systems

Experimentalists nowadays can control the initialization and the dynamics of ultracold atoms to an extreme precision. We will describe a series of measures for correlations in bosonic many-particle Hubbard models. Understanding the various degrees of complexity by these measures is one goal, arriving at a unifying view in the description of correlations in complex quantum matter another one.

David Zueco
Institute of Material Sciences of Aragón (ICMA), Zaragoza University

Circuit QED, from cavity QED to photonic crystals on a chip

Circuit QED is the solid state analogue of cavity QED. In the circuit the atom is placed by a superconducting qubit and the optical cavity by a transmission line operating in the microwave. In this talk I will give an overview on the light-matter coupling in these systems from weak to ultra-strong coupling. I will also discuss the tunable coupling of two transmission lines. The tunable coupling, analogue to a parametric optical amplifier, is shown to be useful to create stationary entanglement robust against decoherence. In the final part "structured transmission lines" will be introduced. These lines are interrupted by Josephson-Junctions. I will see how the junctions mimic scatterers recovering phenomena as the electromagnetic induced transparency. Finally periodic arrangements of these scatterers form a band structure in the photon transport. First applications of these structured lines will be discussed.

Complex Quantum Systems at IFISC

Josep Batle

Nonlocality and entanglement in an infinite system

Nonlocality and quantum entanglement constitute two special features of quantum systems of paramount importance in quantum information theory (QIT). Essentially regarded as identical or equivalent for many years, they constitute different concepts. Describing nonlocality by means of the maximal violation of two Bell inequalities, we study both entanglement and nonlocality for two and three spins in the XY model. Our results shed a new light into the description of nonlocality and the possible information-theoretic task limitations of entanglement in an infinite quantum system.

Fernando Galve

Quantum correlations of dissipative oscillators: driving and synchronizations effects

We will discuss how a highly nonequilibrium forcing can lead to a sustained entangled state of two identical dissipative oscillators, whereas its equilibrium counterpart is purely a thermal classical state. This highlights the idea of a rich variety of new phenomena stemming from time dependence in systems previously thought as understood and uninteresting. In addition, we will comment on recent results concerning the relation between synchronization of two nonidentical dissipative oscillators and its quantum information contents, showing that synchronization can lead, at the quantum level, to an artificially long preservation of quantum correlations.

Gianluca Giorgi

Critical properties of quantum magnetic systems

Spin chains showing a critical diagram in the quantum regime are studied under different perspectives: (i) probing the magnetic phase transition by measuring light; (ii) observing a completely uncorrelated ground state in a dimer-type chain; (iii) understanding the physics of PT-symmetric, non-Hermitian, Hamiltonians.

David Sánchez

Kondo effect in mesoscopic systems

The Kondo effect is a central paradigm in strongly correlated electron systems. It occurs due to an antiferromagnetic exchange interaction between a local magnetic moment (the quantum impurity) and a band of conduction electrons. Such interaction emerges only at very low temperature when the impurity spin becomes screened due to high-order tunneling processes. As a consequence, the resistivity of the metallic host shows an anomalous increase when the temperature reaches a characteristic energy scale (the Kondo temperature). The complexity that arises from this many-body interaction requires the use of renormalization techniques, slave-boson theories or functional integration methods. Here, we focus on the Kondo effect in quantum dots coupled to electronic reservoirs. A wide range of manifestations can be observed: nonequilibrium dephasing, Kondo effect in the presence of ferromagnetism, fractional shot noise and spin-orbital entanglement induced SU(4) states, just to mention a few. We will discuss our recent findings and highlight open issues and challenges for potential future directions.

Roberta Zambrini

Quantum aspect of spontaneous pattern formation

Spontaneous pattern formation is a widespread phenomenon largely studied in biology, chemistry and different physical systems. In particular, multi-mode nonlinear optical devices are known to give rise to a great variety of controllable patterns with fast time scales. The quantum aspects of this process will be reviewed considering spatial quantum correlations of optical fields in different instability regimes.