Abstracts for the

International Workshop on Cold Gases in Quantum Information,

UPV/EHU Leioa, Spain, 30 June – 1 July, 2015

Invited talks

János Asbóth (MTA Wigner RCP, Budapest)
Title: Impossible spectra and quantum walks
Abstract: States at the d-1 dimensional edge of a d-dimensional topological insulator or superconductor - such as the unidirectionally propagating edge states of a Chern insulator, or the unpaired Majorana fermions at the ends of a topological superconducting wire - can obey dynamics that is impossible to obtain using a d-1 dimensional Hamiltonian. This limitiation can be phrased by giving topological invariants of d-1 dimensional Hamiltonians, which cannot take on nontrivial values. By continuity, these impossibility proofs can be carried over from time-independent Hamiltonians to effective Hamiltonians of periodically driven systems. In the talk I will show that considering the broader class of short-range translation invariant unitary operations on d-1 dimensional lattice systems the limitations above can be overcome: such operations can be used to realize "impossible spectra", with the number of edge states given by bulk topological invariants.

John Calsamiglia (GIQ-Universitat Autònoma de Barcelona)
Title: When occasional answers become ultra-precise
Abstract: Quantum metrology studies the fundamental limits in precision in a estimation of an unknown parameter given a certain amount of resources (e.g. the number of probe systems) and restrictions (e.g. limited interaction time, or coping with unavoidable presence of noise). Here we show that, even in the presence of noise, probabilistic measurement strategies (which have a certain probability of failure or abstention) can provide, upon a heralded successful outcome, estimates with a precision that improves the deterministic bounds. We develop analytical tools to obtain the asymptotic behavior of the precision and required rate of abstention. If time permits, we will show the equivalence between probabilistic metrology to probabilistic cloning of clock states. Remarkably, the cloning fidelity depends critically on the number of rationally independent eigenvalues of the clock Hamiltonian.

Tobias Grass (ICFO, Barcelona)
Title: Atomic quantum Hall solver
Abstract: Our understanding of fractional quantum Hall physics is to a large extent based on the numerical diagonalization of small-sized systems. Cold atoms in the era of artificial gauge fields could enable a new approach to the problem - the quantum simulation. This could not only provide exact results for large systems with well controlled Hamiltonians, but also realize quantum Hall phases which are not encountered in solid-state systems, such as the interacting integer quantum Hall phase of two-component bosons. Moreover, the cold atomic setup might allow for observing the intriguing quantum-statistical properties of anyonic excitations. In this talk, I will discuss some of the questions which one could address in such quantum simulation.

Péter Sinkovicz (Wigner, Budapest)
Title: Four-flavor Heisenberg model on a fcc lattice
Abstract: We investigate Néel-ordered phases of the SU(4) Heisenberg antiferromagnet on a face centered cubic lattice. We find that the Néel state is highly degenerate due to the many possible ways of arranging the SU(4) spins on the lattice. To describe symmetry breaking, we adopt linear flavor- wave theory, where fluctuations around the classical symmetry-breaking state are considered

as bosonic flavor waves. The flavor waves select the simplest of the possible symmetry-breaking states, namely a four-sublattice-ordered state. Due to geometrical constraints, flavor waves interact along specific planes only, thus rendering the system effectively two-dimensional and forbidding ordering at finite temperatures. When we introduce next-nearest-neighbor interaction, new couplings appear and we find Néel-like order also at finite temperatures.

Szilárd Szalay (MTA Wigner RCP, Budapest)
Title: Partial separability and multipartite entanglement measures
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Abstract: The main concern of this talk is how to define proper measures of multipartite entanglement for mixed quantum states. Since the structure of partial separability or multipartite entanglement is getting complicated if the number of subsystems exceeds two, one can not expect the existence of an ultimate scalar entanglement measure which grasps even a small part of the rich hierarchical structure of multipartite entanglement, and some higher order structure characterizing that is needed. In this talk I show some results from a recent paper [1], making some steps towards this direction.

First, I reveal the lattice-theoretic structure of the partial separability classification, introduced earlier [2] as an extension of preceding works on the classification problem [3,4]. It turns out that, by construction, mathematically, the hierarchic structure of the entanglement classes is the up-set lattice of the hierarchic structure of the different kinds of partial separability, which is the down-set lattice of the lattice of the partitions of the subsystems. It turns also out that, physically, this structure is related to the LOCC convertibility: if a class can completely be mapped into another one by the use of LOCC, then it can be found higher in the hierarchy.

Second, I introduce the notion of multipartite monotonicity, expressing that a given set of entanglement monotones, while measuring the different kinds of entanglement, shows also the same hierarchical structure as the multipartite entanglement. Then I construct such hierarchies of entanglement measures, and propose a physically well-motivated one, being the direct multipartite generalization of the entanglement of formation based on the entanglement entropy, motivated by the notion of statistical distinguishability. The multipartite monotonicity shown by this set of measures motivates me to consider the measures to be the different manifestations of some "unified" notion of entanglement.
[1] Sz. Szalay, preprint, arXiv:1503.06071 [quant-ph] (2015).
[2] Sz. Szalay, Z. Kökényesi, Phys. Rev. A 86, 032341 (2012).
[3] M. Seevinck, J. Uffink, Phys. Rev. A 78, 032101 (2008).
[4] W. Dür, J. I. Cirac, Phys. Rev. A 61, 042314 (2000).

Edina Szirmai (BME-MTA Exotic Quantum Phases Momentum Research Group, Budapest)
Title: Exotic superfluid states in one-dimensional high spin ultracold atomic systems
Abstract: In high spin systems a series of novel, exotic superfluid states can be stabilized, in which Cooper-like pairs or composite multiparticle bound states characterize the system. Recent experiments with Yb-173 isotopes provides new possibilities to study these high-spin fermionic systems. On one hand, in these experiments two-orbital systems can be simulated in which case part of the atoms are excited to a higher energy metastable electronic state providing an additional internal (orbital) degree of freedom [1,2]. As a consequence, the interaction between the atoms is characterized by four independent couplings. When the system is confined into a one-dimensional chain the scatting lengths can be tuned by changing the transverse confinement, and the system can be driven through four resonances. Using the new available experimental data of the scattering lengths we analyze the ground state phase diagram of the one-dimensional system as the couplings are tuned via transverse confinement, and the population of the two orbital states is changed. [3] On the other hand, these experiments open a new possibility to simulate 4-component systems with Yb-173 isotopes, too. We show that in such a 4-component one-dimensional system in presence of spin-imbalance an unusual phase separation emerges where spin-carrier Cooper pairs and fourparticle

SU(4) singlet quartets coexist forming a domain structure [5].

[1] A. V. Gorshkov, et al., Nat. Phys. 6, 289 (2010).
[2] F. Scazza, et al., Nat. Phys. 10, 779 (2014);
G. Cappellini, et al., Phys. Rev. Lett. 113, 120402 (2014).
[3] E. Szirmai, Phys. Rev. B 88, 195432 (2013); in preparation (2015).
[4] G. Pagano, et al., Nat. Phys. 10, 198 (2014).
[5] G. Barcza, E. Szirmai, J. Sólyom, Ö. Legeza, Phys. Rev. A 86, 061602(R) (2012); EPJ ST 224: (3), 533 (2015);

Gergő Szirmai (MTA Wigner RCP, Budapest)
Title: Tunneling dynamics of bosonic Josephson junctions assisted by a cavity field
Abstract: We study the interplay between the dynamics of a Bose-Einstein condensate in a double-well potential and that of an optical cavity mode. The cavity field is superimposed to the double-well potential and affects the atomic tunneling processes. The cavity field is driven by a laser red detuned from the bare cavity resonance; the dynamically changing spatial distribution of the atoms can shift the cavity in and out of resonance. At resonance the photon number is hugely enhanced and the atomic tunneling becomes amplified. The Josephson junction equations are revisited and the phase diagram is calculated. We find new solutions with finite imbalance and at the same time a lack of self-trapping solutions due to the emergence of a new separatrix resulting from enhanced tunneling.
[1] G. Szirmai, G. Mazzarella, and L. Salasnich, arXiv:1412.1014

Dominique Spehner (Institut Fourier and LPMMC, Grenoble, France)
Title: Effect of atom loss processes on superpositions of phase states in Bose-Josephson junctions
Abstract: In a two-mode Bose-Josephson junction formed by a binary mixture of ultracold atoms, macroscopic superpositions of phase states are produced during the time evolution after a sudden quench to zero of the coupling amplitude. Using quantum trajectories and an exact diagonalization of the master equation, we study the effect of one-, two-, and three-body atom losses on the superpositions by analyzing separately the amount of quantum correlations in each subspace with fixed atom number. The quantum correlations useful for atom interferometry are estimated using the quantum Fisher information. We identify the choice of parameters leading to the largest Fisher information, thereby showing that, for all kinds of loss processes, quantum correlations can be partially protected from decoherence when the losses are strongly asymmetric in the two modes.

Prasanna Venkatesh (Institute for Quantum Optics and Quantum Information, Innsbruck, Austria)
Title: Back-action driven transport of Bloch oscillating atoms in ring cavities
Abstract: Transport under uniform bias in normal metallic systems requires dephasing of Bloch oscillations due to presence of impurities. In contrast, for atoms in optical lattices (with an external applied uniform bias force), it has been shown theoretically and experimentally that an amplitude and/or phase modulation of the lattice can lead to coherent transport and resonant tunneling. In the talk I will focus on resonant tunneling and directed transport of ultracold atoms that are strongly coupled to an optical lattice inside a ring-cavity and to which an uniform bias force is applied. The bias force induces Bloch oscillations and the atomic backaction on the cavity light field causes amplitude and phase modulation of the intra-cavity lattice. We show how different aspects of the transport such as the direction and magnitude can be simply controlled by changing the cavity-pump detuning. This can also be considered as an example of an optomechanical system with the atomic Wannier-Stark ladder playing the role of a material oscillator.

Contributed talks

Iagoba Apellaniz (UPV/EHU, Bilbao)
Title: Verifying the metrological usefulness of Dicke states with collective measurements
Abstract: We present a method that can verify the metrological usefulness of noisy Dicke states with few collective measurements. Our method proves the usefulness of the state for estimating the angle of rotation when the Dicke state is in a homogenous magnetic field. We assume that after the rotation a collective operator is measured to estimate the angle, which is the most relevant case in practice for many-particle systems. We apply our method to recent experimental results with Dicke states.
[1] I. Apellaniz, B. Lücke, J. Peise, C. Klempt, and G. Tóth, Verifying the metrological usefulness of Dicke states with collective measurements,arXiv:1412.3426.

Iñigo L. Egusquiza (UPV/EHU, Bilbao)
Title: Beyond adiabatic elimination
Abstract: In many contexts in cold atom physics it is necessary to obtain effective Hamiltonians given disparity of scales. One well known technique in quantum optics to achieve this goal is adiabatic elimination. Here we indicate how it is a first approximation within an approximation scheme, we relate it to other methods, and explain some issues that had before been identified in the literature.

Urtzi Las Heras (UPV/EHU, Bilbao)
Title: Digital Quantum Simulations with Superconducting Circuits
Abstract: Digital quantum simulators are a promising research line in superconducting circuit architectures. We present both the theoretical proposal and the experiment of a digital quantum simulation of spin models in circuit quantum electrodynamics. We show that dynamics of Ising and Heisenberg models can be implemented in superconducting architectures following the Trotter expansion, performing only exchange interactions and single-qubit rotations. This approach is universal and efficient, employing only polynomial resources in the number of spins, and indicates a path towards the controlled simulations of general spin dynamics in superconducting qubit platforms. Furthermore, in this talk we review some other digital quantum simulations proposals such as Rabi model, fermionic systems, and quantum chemistry. Finally, we discuss the possibility of using genetic algorithms for engineering quantum error resilience protocols in analog quantum simulations.

Michele Modugno (UPV/EHU, Bilbao)
Title: Simulating condensed matter with ultracold atoms: the Haldane model and the Peierls substitution
Abstract: In a recent work [1], we have pointed out that the conditions for the applicability of the so-called Peierls substitution (PS) are explicitly violated in the Haldane model and in any other model where the vector potential varies on the same scale of the underlying lattice. Nonetheless, we have shown that the general structure of the Haldane model is in fact preserved, as it is a direct consequence of the symmetries of the system, and no additional assumptions are required.

In addition, we have shown that the values of the tunneling coefficients can be obtained from simple closed expressions in terms of gauge invariant, measurable properties of the spectrum (namely, the gap at the Dirac point and the bandwidths). These formulas evidence that the phase acquired by the next-to-nearest tunneling amplitude is quantitatively different from that predicted by the PS, and it also presents a pronounced dependence on the intensity of the underlying lattice potential. Moreover, even the tunneling amplitudes turn out to be dependent on the intensity of teh vector gauge field A, violating the hypotheses behind the PS. These results have been also checked against ab-initio calculations by means of the maximally localized Wannier functions (MLWFs) [2], which are also helpful in understanding the origin of the breakdown of the PS.

I will present a pedagogical introduction to the Peierls substitution, the role of the MLWFs in the construction of tight-binding models for ultracold atoms in optical lattices, and their implications in the derivation of the Haldane model.

[1] J. Ibañez-Azpiroz, A. Eiguren, A. Bergara, G. Pettini, and M. Modugno, Phys. Rev. A 90, 033609 (2014).
[2] N. Marzari and D. Vanderbilt, Phys. Rev. B 56, 12847 (1997).

Gonzalo Muga (UPV/EHU)
Title: Shortcuts in a double well
Abstract: I will review several recent works where we speed up operations relevant to quantum information processing in a double well, such as multiplexing, motional-state population inversion by trap deformation, beam splitters, (toy model of) insulator-superfluid transition, or ion chain separations.

Enrique Rico (UPV/EHU, Bilbao)
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Title: Non-Abelian Lattice Gauge Theories in Superconducting Circuits
Abstract: We propose a digital quantum simulator of non-Abelian pure-gauge models with a superconducting circuit setup. Within the framework of quantum link models, we build a minimal instance of a pure SU(2) gauge theory, using triangular plaquettes involving geometric frustration. This realization is the least demanding, in terms of quantum simulation resources, of a non-Abelian gauge dynamics. We present two superconducting architectures that can host the quantum simulation, estimating the requirements needed to run possible experiments. The proposal establishes a path to the experimental simulation of non-Abelian physics with solid-state quantum platforms.
[1] A. Mezzacapo, E. Rico, C. Sabín, I. L. Egusquiza, L. Lamata, E. Solano, arXiv:1505.04720

Mikel Sanz (UPV/EHU, Bilbao)
Title: Entanglement Matryoshka: Entanglement Classification with Matrix Product States
Abstract: Entanglement is widely considered the cornerstone of quantum information and an essential resource for relevant quantum effects, such as quantum teleportation, quantum cryptography, or the speed-up of quantum computing, as in Shor’s algorithm. However, up to now, there is no general characterization of entanglement for many-body systems. In this sense, it is encouraging that quantum states connected by stochastic local operations assisted with classical communication (SLOCC), which perform probabilistically the same quantum tasks, can be collected into entanglement classes. Nevertheless, there is an infinite number of classes for four or more parties that may be gathered, in turn, into a finite number of entanglement families. Unfortunately, we have not been able to relate all classes and families to specific properties or quantum information tasks, although a few of them have certainly raised experimental interest. Here, we present a novel entanglement classification for quantum states according to their matrix-product-state structure, exemplified for the symmetric subspace. The proposed classification relates entanglement families to the interaction length of Hamiltonians, establishing the first connection between entanglement classification and condensed matter. Additionally, we found a natural nesting property in which the families for N parties carry over to the N + 1 case. We anticipate our proposal to be a starting point for the exploration of the connection between entanglement classification properties and condensed-matter models.

Luca Tagliacozzo (ICFO, Barcelona)
Title: Classical and quantum simulations of Lattice gauge theories
Abstract: I will review the advances in simulating systems of interest in theoretical physics using both tensor networks and quantum simulations.

Giuseppe Vitagliano (UPV/EHU, Bilbao)
Title: Generalized spin squeezing in the vicinity of Dicke states
Abstract: We study the problem of detecting entanglement and its depth in systems composed of very many particles. We derive entanglement criteria based only on few easy measurable quantities such as the mean values and variances of collective spin components. In particular we present what we call a generalized spin squeezing parameter, that can be used to detect a class of states wider than the spin squeezed states as defined in [A. Sorensen et al., Nature 409, 63 (2001)]. Moreover we present a criterion to estimate the entanglement depth that outperforms previous well-known criteria. It has been used in a recent experiment [B. Lucke et al., PRL 112, 155304 (Editor's suggestion)] to prove that the produced Dicke-like state had an entanglement depth of at least 28 particles.