6th Meeting of the Cold Atoms Madrid Network

Programme

09:25  WELCOME
09:30  Simon Fölling (50 min talk + 10 min discussion)
10:30  Charles Creffield (20 min talk + 10 min discussion)
11:00  coffee break
11:30  Giovanna Morigi (50 min talk + 10 min discussion)
12:30  Emilio Alba (20 min talk + 10 min discussion)
13:00  Alexandre Dauphin (20 min talk + 10 min discussion)
13:30  Lunch
15:00  Leticia Tarruell (50 min talk + 10 min discussion)
16:00  coffee break
16:30  Jordi Mur-Petit (20 min talk + 10 min discussion)
17:00  Alejandro Bermúdez (20 min talk + 10 min discussion)
17:30  closing
Abstracts

Emilio Alba (Universidad Complutense de Madrid)  
Measuring topology in complex systems: trudging through entanglement and interactions: In previous works we showed how the topology of a Chern insulator can be measured using time-of-flight imaging in an optical lattice. We dive deeper by defining this measure as a new order parameter and analyzing its role when more degrees of freedom and interactions are present. We find that entanglement plays a crucial role even in non-interacting band pictures and that interactions may suppress or reinforce this topological invariant - thus making it a resource for characterizing highly correlated systems.

Alejandro Bermúdez (QUINFOG, CSIC, Madrid)  
Hybrid quantum magnetism in circuit-QED: from spin-photon waves to many-body spectroscopy: We introduce a model of quantum magnetism induced by the non-perturbative exchange of microwave photons between distant superconducting qubits. By interconnecting qubits and cavities, we obtain a spin-boson lattice model that exhibits a quantum phase transition where both qubits and cavities spontaneously polarise. We present a many-body ansatz that captures this phenomenon all the way, from a the perturbative dispersive regime where photons can be traced out, to the non-perturbative ultra-strong coupling regime where photons must be treated on the same footing as qubits. Our ansatz also reproduces the low-energy excitations, which are described by hybridised spin-photon quasiparticles, and can be probed spectroscopically from transmission experiments in circuit-QED, as shown by simulating a possible experiment by Matrix-Product-State methods.

Charles Creffield (Universidad Complutense de Madrid)  
Synthetic gauge potentials for cold atoms: Ultracold atoms held in optical lattices provide an almost ideal arena for the study of coherent quantum phenomena. Periodically driving the lattice can produce such an effect, termed ”coherent destruction of tunneling”, in which the value of the intersite tunneling becomes renormalised. I will show how this can be used to control both the magnitude of the tunneling and its phase. This provides a powerful and flexible method to induce tunable synthetic gauge potentials in these systems.


Alexandre Dauphin ((Universidad Complutense de Madrid)  
Efficient algorithm to compute the Berry conductivity: Since the discovery of the quantum Hall effect, the study of new topological phases of matter has been a rising topic of interest. These fascinating phases, extremely robust against disorder and interactions, are characterized by a topological invariant. The question ”what happens to the transverse conductivity of a topological insulator when the Fermi energy does lie not anymore in the energy gap” is theoretically and experimentally important.
Indeed, it appears in the production of the topological insulators in solid state physics where the control of the Fermi energy is difficult. Similarly, it also arises in quantum simulation of topological insulators with cold atoms, a very versatile platform allowing the access to both insulating and metallic regimes. Finally, it plays an important role in the anomalous Hall effect where the dominant contribution to the Hall conductivity is topological. When the Fermi energy does not lie in the energy gap, the Hall conductivity is not anymore quantized. However, it is still possible to extract the topological contribution, called the Berry conductivity.

We propose a numerical algorithm to compute the Berry conductivity which is gauge invariant, efficient and with controllable error intervals. We construct the algorithm step by step. We then benchmark it on three experimentally relevant models in both solid state physics and cold atom simulation and emphasize some interesting behaviors of the topological metals.

Simon Fölling (Ludwig-Maximilians-Universität, München) Alkaline-Earth-type atoms for emulating internal and external degrees of freedom in optical lattices: For the initial quantum gas experiments the coherence properties and quantum degeneracy of the ensembles set the newly created states of matter dramatically apart from classical gases. Not so long after, however, the internal degree of freedom of the particles was made available as a free variable and led to even richer quantum many-body systems. Analog to this, initial experiments with degenerate gases in optical lattices were focusing on the external degrees of freedom - conduction vs. insulators in the lowest band, dynamics and band fillings. In the last few years, however, advances in the preparation and manipulation of such gases have made it possible to consider optical lattice systems as quantum simulators for systems with more degrees of freedom such as including more than one band, or internal states with many-body correlations in the ensemble, such as a particle’s (real or effective) spin. We will discuss current experimental advances to implement spin and multi-band physics and discuss how alkaline-earth-type atoms can allow for new possibilities for implementing additional degrees of freedom. The focus here will be on fermionic Yb and our current experimental approach in which we work on characterizing interactions in an optical lattice system involving atoms in the metastable electronic triplet state.

Giovanna Morigi (Saarland University, Saarbrücken) Ion Coulomb crystals: quantum dynamics at structural instabilities: Coulomb crystals are organized structures of charged particles, which interact through the Coulomb repulsion and organize in regular patterns at sufficiently low temperatures in presence of a confining potential. These potentials are realized by means of Paul or Penning traps, and their geometry determines the crystal’s structure. These crystals represent a kind of rarefied condensed matter, the interparticle distance being of the order of several micrometers, allowing to study the structure by means of optical radiation. Variation of the potential permits one to control the crystal shape as well as the number of ions, thus offering the unique opportunity to study the transition from few particles to mesoscopic systems.

In this talk I show that a string of trapped ions at zero temperature exhibits a structural phase transition to a zigzag structure, tuned by reducing the trans-
verse trap potential or the interparticle distance. The transition is driven by transverse, short wavelength vibrational modes. This is a quantum phase transition, which can be experimentally realized and probed. Indeed, by means of a mapping to the Ising model in a transverse field, one can 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. These results are confirmed by numerical simulations based on DMRG. A measurement procedure is suggested which can probe the effects of quantum fluctuations at criticality.

I then discuss various schemes realizing quenches of the trapping potential across the linear-zigzag instability. In particular, a procedure is presented which allows one for creating coherent superpositions of motional states of ion strings. The motional states are across the structural transition, and their coherent superposition is achieved by means of spin-dependent forces, such that a coherent superposition of the electronic states of one ion evolves into an entangled state between the chain's internal and external degrees of freedom. It is shown that the creation of such an entangled state can be revealed by performing Ramsey interferometry with one ion of the chain.

Jordi Mur-Petit (Instituto de Estructura de la Materia, CSIC, Madrid)

Measurement and control of polar molecules using trapped atomic ions: We have studied a hybrid quantum system composed of a trapped ion and a polar molecule, and determined analytically its collective mode eigenfrequencies. Based on this, we propose a quantum protocol relying on the ion-dipole interaction and state-dependent forces to realize a quantum phase gate between them. I will discuss our calculations and present numerical results that demonstrate that this procedure can be used to determine the electric dipole moments of a broad range of heteronuclear molecules –from alkaline-earth hydrides such as CaH, to bialkali dimers as KRb– trapped together with an atomic ion as Ca+. I will discuss several experimental approaches to build and operate such a hybrid setup, and their potential application to molecular cooling, entangling ions and molecules, and mapping ordered phases of dipoles.

Leticia Tarruell (ICFO The Institute of Photonic Sciences, Barcelona)

Ultracold fermions in tunable-geometry optical lattices: Ultracold atomic gases in optical lattices provide the opportunity of engineering synthetic quantum materials in a clean and highly controlled environment. On the one hand, these systems can be viewed as experimental quantum simulators for exploring challenging problems of condensed matter physics. On the other hand, they also allow for the realization of completely novel materials of interesting properties, without counterpart in solid-state systems. In my talk, I will present experiments where an ultracold Fermi gas trapped in an optical lattice of tunable geometry is used to explore both aspects. By loading non-interacting atoms into a honeycomb structure, we realize artificial graphene and observe the presence of two Dirac points in the band structure. The flexibility of our experimental approach allows us to adjust the properties of these Dirac points at will, moving them inside the Brillouin zone and changing the effective mass of the associated Dirac fermions. Furthermore, we observe how the two Dirac points annihilate each other when coming too close together, a situation which is presently out of...
reach in solid-state samples. Preparing instead a repulsively interacting gas of atoms in two different internal states, we implement the Fermi-Hubbard model and aim at simulating quantum magnetism in this system. In particular, we explore experimentally how certain crystal geometries favor the emergence of short-range magnetic order, and directly probe the nearest-neighbor spin correlations of the system. In a dimerized lattice, the correlations manifest as an excess number of singlets as compared to triplets, whereas in an anisotropic simple cubic lattice we observe the appearance of antiferromagnetic correlations along one spatial axis.