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**Final report for the Marie Curie project FP7-PEOPLE-2010-IEF ("Plaquettes")**

The Marie Curie project FP7-PEOPLE-2010-IEF has been conducted from the 01/03/2011 to the 31/08/2011. I have decided to terminate it early in order to accept a permanent position at Ecole Normale Supérieure in Paris. During these six months important objectives of the project have been achieved.

The first main objective of this project was the realization and study of spin systems of small size with ultracold atoms. An atomic gas prepared in a mixture of two spin states is held in a periodic potential whose elementary cell is made of a few wells (two or four). In the regime of strong interactions the dynamics is governed by effective superexchange interactions. These systems are promising for investigating the physics of spin models and – upon doping – important questions related to high-Tc superconductivity.

In a first study we designed a new method for implementing spin model with arbitrary coupling anisotropies. By applying a periodic modulation of the optical lattice structure, one can control the tunneling of atoms from one site to the next one, which eventually leads to a new control on superexchange interactions, leading to the possibility to simulate new classes of spin models. This work has been submitted to a peer-reviewed journal and can be accessed at arXiv:1104.1833.

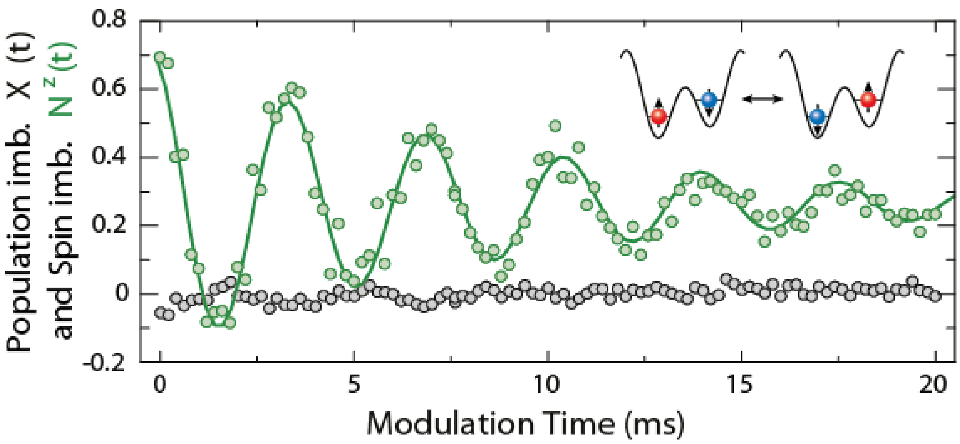
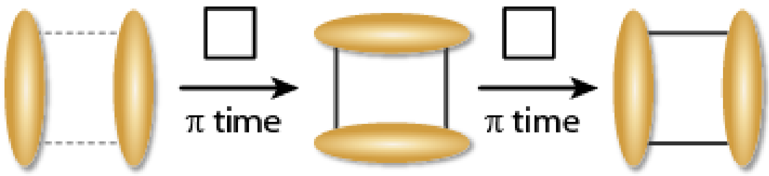



**Fig.1:** *Time-resolved measurement of AC-driven superexchange process in a modulated optical superlattice*

The second study we performed lead to the realization of one of the main goals of this project, the creation of resonating valence bond states with ultracold atoms. The resonating valence bond state is a complex state of matter that was studied in the last decades in the context of high-Tc superconductivity, but it was never observed up to now. This state exhibits a topological order, i.e. an order that is immune to local perturbations. This makes it an important candidate for realizing topologically protected qbits, the basic ingredient of topological quantum computing. In order to realize this state we created a new type of optical lattice whose elementary cell is a four-site plaquette. This constitutes the smallest structure on which the resonating valence bond state can be created. We filled the plaquettes with four atoms, two per spin state, that interact via superexchange processes. These atoms tend to form spin-singlet bonds whose directions spontaneously resonate. We measured for the first time a valence bond resonance, which is the basic mechanism behind the resonating valence bond state. We also created minimal forms of  resonating valence bond states and exhibited their main properties.



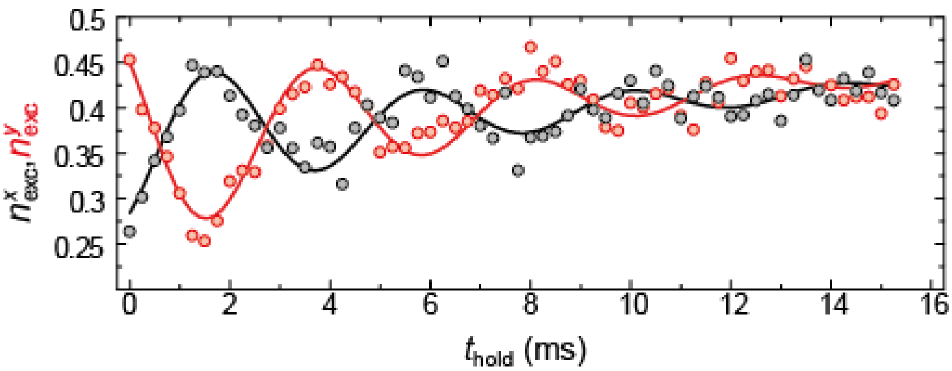




**Fig.1:** *Direct observation of a valence bond resonance in a lattice of plaquettes at half filling*

One objective of the project was the creation of minimal forms of Laughlin states inside these plaquettes. These quantum states are fundamental for the understanding of strongly-correlated fractional quantum Hall states. We rather chose a different direction towards the study of fractional quantum Hall states with ultracold atoms, based on the direct implementation of optical lattices exhibiting strong effective magnetic field. In these lattices Raman lasers are used to induce atom tunneling from one site to the next, and the local phase of the Raman beam imprinted on the atomic wavefunction can be equivalent to an applied magnetic field. We recently demonstrated the first realization of this new kind of lattice. We were able to measure the Berry phase acquired by the atoms moving though a closed loop, revealing the breaking of time-reversal symmetry. This result paves the way for the study of quantum hall physics with ultracold atoms, in particular allows the realization of strongly-correlated states of matter with topological order such as the Laughlin state.

These last two studies will soon be submitted to peer-reviewed journals. Unfortunately the reduced duration of the project did not allow us to obtain results already published.