Towards Quantum Magnetism with Ultracold Quantum Gases in Optical Lattices

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Quantum mechanical superexchange interactions form the basis of quantum magnetism in strongly correlated electronic media and are believed to play a major role in high-Tc superconducting materials. We report on the first direct measurement of such superexchange interactions with ultracold atoms in optical lattices. After preparing a spin-mixture of ultracold atoms with the help of optical superlattices in an antiferromagnetically ordered state, we are able to observe a coherent superexchange mediated spin dynamics down to coupling energies as low as 5 Hz. Furthermore, it is shown how these superexchange interactions can be fully controlled in magnitude and sign. The prospects of using such superexchange interactions for the investigation of dynamical behaviour in quantum spin systems and for quantum information processing will be outlined in the talk. In addition results on strongly interacting Fermi-Fermi mixtures in optical lattices are presented. We probe the degenerate fermionic quantum gases with initial temperatures as low as $T/T_F = 0.13$ by both measuring local and global observables of the system and by comparing these measurements to 3D numerical Dynamical Mean Field Theory (DMFT) calculations for the case of repulsive interactions. We furthermore discuss the case of strong attractive interactions, where the fermionic quantum gas has converted into a gas of strongly bound pairs, whose behaviour can be mapped onto a quantum spin model.