A 3: Ultracold Atoms: Manipulation and Detection (with Q)

Time: Monday 10:30–13:00 Location: SCH 251

A 3.1 Mon 10:30 SCH 251

Single-spin addressing in an atomic Mott insulator — •C. Weitenberg, M. Endres, J. F. Sherson, M. Cheneau, P. Schauss, T. Fukuhara, I. Bloch, and S. Kuhr — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, D-85748 Garching

The quest to address single sites of an optical lattice has a longstanding history in the field of ultracold atoms. Here we report on the achievement of full two-dimensional single-site spin control in an optical lattice with sub-diffraction limited spatial resolution. We use the differential light shift of a tightly focused laser beam to shift selected atoms into resonance with a microwave field. Starting from a Mott insulator with unity filling we are able to create arbitrary spin patterns. To demonstrate that our scheme leaves most of the atoms in the motional ground state, we observe the one-dimensional tunneling dynamics of the addressed atoms and discriminate the dynamics of the ground state and the first excited band. Our scheme opens the path to a wide range of novel applications from quantum dynamics of spin impurities, entropy transport, implementation of novel cooling schemes, and engineering of quantum many-body phases to quantum information processing.

A 3.2 Mon 10:45 SCH 251

Feedback control of the hyperfine ground states of neutral atoms in an optical cavity — •Stefan Brakhane[1], Wolfgang Alt[1], Miguel Martinez-Dorantes[1], Tobias Kampschulte[1], René Reimann[1], Artur Widera[1,2], and Dieter Meschede[1] — [1]Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, 53115 Bonn — [2]Fachbereich Physik der TU Kaiserslautern, Erwin-Schrödinger-Str., 67663 Kaiserslautern

Detection and manipulation of atomic spin states is essential for many experimental realizations of quantum gates. Feedback schemes to stabilize the states and their superpositions can counteract perturbations caused by the environment.

In our experiment we deduce the atomic spin state of one or two Caesium atoms by measuring the transmission of a probe laser through a high-finesse cavity. Depending on the number of atoms in the hyperfine state that strongly couples to the cavity, the resonance of the cavity is shifted and the probe laser transmission is decreased. We employ a Bayesian update formalism to obtain time-dependent probabilities for the atomic states of one and two atoms [1].

I will present an experimental implementation using a digital signal processor which allows us to determine the atomic spin state in real-time. First experimental results of an extension to a feedback loop for the preparation and stabilization of atomic states will be shown.

[1] S. Reick, K. Mølmer *et al.*, J. Opt. Soc. Am. B **27**, A152 (2010)

A 3.3 Mon 11:00 SCH 251

Measurement of the atom number distribution in an optical tweezer using single photon counting — •Andreas Fuhrmanek, Ronan Bourgain, Yvan Sortais, Philippe Grangier, and Antoine Browaeys — Institut d'Optique, RD 128 Campus Polytechnique, 91127 Palaiseau Cedex, France

In this talk I will present our experimental realisation of an atom counting method that allows us to reconstruct the atom number distribution inside a dipole trap and to measure the average atom number precisely. This method relies on counting single photon events on an intensified CCD camera when resonant light is sent on the atoms. We deduce the atom number distribution by analyzing the photon number distribution obtained over a series of images. This technique is a useful alternative to fluorescence or absorption methods, that may underestimate the atom number in dense samples due to photon reabsorption processes.

A 3.4 Mon 11:15 SCH 251

Imaging of microwave fields using ultracold atoms — •Pascal Böhi[1], Max Riedel[1], Theodor Hänsch[2], and Philipp Treutlein[1] — [1]Departement Physik, Universität Basel, Klingelbergstrasse 82, 4056 Basel, Switzerland — [2]Max-Planck-Institut für Quantenoptik and Ludwig-Maximilians-Universität, München, Germany

Clouds of ultracold atoms are used as highly sensitive, tunable and non-invasive probes for microwave field imaging with micrometer spatial resolution. The microwave magnetic field drives Rabi oscillations on atomic hyperfine transitions which are read out using state-selective absorption imaging. It is possible to fully reconstruct the microwave magnetic field, including the microwave phase distribution. We use this method to determine the microwave near-field distribution around a coplanar waveguide which is integrated on an atom chip. We compare the extracted microwave field to simulations to deduce the microwave current distribution on the waveguide.

[1] P. Böhi *et al.*, Appl. Phys. Lett. **97**, 051101 (2010).

A 3.5 Mon 11:30 SCH 251

Feedback Cooling of a Single Neutral Atom — •Christian Sames, Markus Koch, Maximilian Balbach, Haytham Chibani, Alexander Kubanek, Alexei Ourjoumtsev, Pepijn Pinkse, Karim Murr, Tatjana Wilk, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, D-85748 Garching, Germany

Feedback is a powerful tool to control the evolution of classical systems. Fast electronics enables its extension towards the quantum domain, namely the control of the motion of a single neutral atom inside a high-finesse optical resonator. The atom is trapped in an optical dipole trap and interacts strongly with a single mode of the resonator. The interaction strength determines the resonance condition of the coupled system, depending on the atomic position, and hence governs the intensity of a transmitted probe beam. We analyze the flux of the transmitted photons which carries information about the atomic position and velocity, and alter the dipole force in such a way that it counteracts the atomic motion [1]. With this feedback technique we enhance the storage time of the atom in the resonator by at least 2 orders of magnitude, reaching values of more than 17 seconds with an average of more than 1 second. Additionally, we demonstrate cooling of the single atom by this technique to a temperature of about 160 μK [2]. Feedback cooling of a single atom hence rivals state-of-the-art laser cooling with the advantage that much less optical access is required.

[1] A. Kubanek et al., Nature 462, 898 (2009).

[2] M. Koch et al., Phys. Rev. Lett. 105, 173003 (2010).

A 3.6 Mon 11:45 SCH 251

Particle counting statistics of time dependent fields — •Sibylle Braungardt[1], Mirta Rodrígues[2], Aditi Sen[3], Ujjwal Sen[3], Roy J. Glauber[4], and Maciej Lewenstein[1] — [1]ICFO - Institut de Ciències Fotòniques, Av. del Canal Olímpic s/n, 08860 Castelldefels (Barcelona), Spain — [2]Instituto de Estructura de la Materia, CSIC, C/Serrano 121, 28006 Madrid, Spain — [3]Harish-Chandra Research Institute, Chhatnag Road, Jhunsi, Allahabad 211 019, India — [4]Lyman Laboratory, Physics Department, Harvard University, 02138 Cambridge, MA, U.S.A.

Since the beginnings of quantum optics, photon counting has been used as an important tool to characterize quantum states of light. The counting distribution is typically calculated using the quantum Mandel formula [1]. Likewise, the counting statistics of atoms can give insight into the quantum properties of many-body states of ultracold atomic gases. A wide range of experimental setups with cold atoms require a time and space dependent treatment of the counting process. The quantum Mandel formula treats time in a perturbative way, and generally does not give the correct behavior for time dependent systems. We derive a non-perturbative formula for the counting distribution and apply it to different experimental situations of ultracold atoms.

[1] R.J. Glauber, in Quantum Optics and Electronics, eds. B. DeWitt, C. Blandin, and C. Cohen-Tannoudji, pp. 63-185, Gordon and Breach, New York, (1965).

A 3.7 Mon 12:00 SCH 251

Shortcut to adiabatic passage in two- and three-level atoms — •Andreas Ruschhaupt — Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany

We propose a method to speed up adiabatic passage techniques in two-level and three-level atoms extending to the short-time domain their robustness. It supplements or substitutes the standard laser beam setups with auxiliary pulses that steer the system along the adiabatic path. Compared to other strategies such as composite pulses or the original adiabatic techniques, it provides a fast and robust approach to population control.

Ref.: X. Chen, I. Lizuain, A. Ruschhaupt, D. Guéry-Odelin, and J. G. Muga, Phys. Rev. Lett. 105, 123003 (2010)

A 3.8 Mon 12:15 SCH 251

Coherent control of atoms using STIRAP: Two realistic systems. — •Tadhg Morgan, Brian O'Sullivan, and Thomas Busch — Physics Department, University College Cork, Co. Cork, Ireland

Developing strategies for coherent control of quantum states is one of the keys for successful engineering of quantum mechanical structures or quantum information processors in the future. Due to the fragile nature of quantum states these techniques need to be, most importantly, fault tolerant and lead to high fidelities. One class of techniques that can achieve this are so-called adiabatic techniques and their use in optical systems has been widely investigated in the past. Recently, it has been shown that similar techniques can, in principle, be used to prepare and process quantum states of single atoms and that, in particular, the counter-intuitive STIRAP process is an excellent candidate for the coherent movement of ultra-cold atoms. As atomic traps are currently not at the technologically advanced state where they can easily be moved in space we propose two realistic setups in which STIRAP can be observed, an atomchip with three current carrying wires and triple well radio frequency potential. We show that both systems provide high fidelity STIRAP and also that the radio frequency potential allows us to extend the application of the STIRAP technique a cloud of interacting atoms.

A 3.9 Mon 12:30 SCH 251

Improved detection of small atom numbers through image processing — •Caspar Ockeloen[1,2], Atreju Tauschinksy[1], Robert Spreeuw[1], and Shannon Whitlock[1,3] — [1]University of Amsterdam, The Netherlands — [2]Universität Basel, Switzerland — [3]Universität Heidelberg, Germany

We demonstrate improved detection of small trapped atomic ensembles through advanced post-processing and optimal analysis of absorption images. These techniques provide the basis to improve the readout of trapped atom interferometers to the quantum limit or to better resolve number/spin-squeezing and entanglement between small atomic ensembles. A fringe removal algorithm reduces imaging noise to the fundamental photon-shot-noise level and proves beneficial even in the absence of fringes. A maximum-likelihood estimator is then derived for optimal atom-number estimation and is applied to real experimental data to measure the population differences and intrinsic atom shot-noise between spatially separated ensembles each comprising between 10 and 2000 atoms. The combined techniques improve our signal-to-noise by a factor of 3, to a minimum resolvable population difference of 17 atoms, close to our ultimate detection limit.

A 3.10 Mon 12:45 SCH 251

Control of refractive index and motion of a single atom by quantum interference — •Tobias Kampschulte[1], Wolfgang Alt[1], Stefan Brakhane[1], Martin Eckstein[1,2], Miguel Martinez-Dorantes[1], René Reimann[1], Artur Widera[1,3], and Dieter Meschede[1] — [1]Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, 53115 Bonn — [2]Max-Born-Institut, Abteilung A2, Max-Born-Str. 2 A, 12489 Berlin — [3]Fachbereich Physik der TU Kaiserslautern, Erwin-Schrödinger-Str., 67663 Kaiserslautern

The properties of an optically probed atomic medium can be changed dramatically by coherent interaction with a near-resonant control light field. I will present our experimental results on the elementary case of electromagnetically induced transparency (EIT) with a single neutral atom inside an optical cavity probed by a weak field [1]. We have observed modification of the dispersive and absorptive properties of a single atom by changing the frequency of the control light field in the off-resonant regime.

In this regime, the creation of a transparency window close to a narrow absorption peak can give rise to a sub-Doppler cooling mechanism. I will present the observation of strong cooling and heating effects in the vicinity of the two-photon resonance. The cooling increases the storage time of our atoms twenty-fold to about 16 seconds. Recent investigations of this effect outside the cavity using microwave sideband spectroscopy have revealed that a large fraction of atoms is cooled to the axial ground state of the trap.

[1] T. Kampschulte *et al.*, Phys. Rev. Lett. **105**, 153603 (2010)