YAO

YOUNG ATOM OPTICIANS CONFERENCE

Book of Abstracts

JAGIELLONIAN UNIVERSITY
IN KRAKOW

Young Atom Opticians Conference 2012 program

	Sunday 25.03.12	Monday 26.03.12	Tuesday 27.03.12	Wednesday 28.03.12	Thursday 29.03.12	Friday 30.03.12
09:00 – 10:15		Sebastian Diehl	Jakub Zakrzewski	Rudolf Grimm	Talks (3)	Talks (3)
10:15 – 10:45		Coffee break				
10:45 – 12:50		Talks (5)	Talks (5)	Talks (5)	Talks (5)	Time to say goodbye :)
12:50 – 14:20		Lunch				
14:20 – 16:00		Talks (4)	Talks (4)	Lab tours (IF UJ)	Talks (4)	
16:00 – 16:30		Coffee break			Coffee break	
16:30 – 17:45		Talks (3)	City tour	Poster session	Talks (3)	
17:45 – 18:00						
18:00 – 19:00	Registration and Meeting Party					
					Conference Dinner	

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I. TALKS

A. Invited speakers

Quantum States and Phases in Open Quantum Systems with Cold Atoms

Sebastian Diehl[1]

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In this lecture, we will discuss open many-body quantum systems, in which dissipation is the dominant resource of dynamics, and unlike usually creates quantum mechanical correlation instead of destroying them. We will explain the basic mechanism, where an ensemble of bosons is dissipatively driven into a Bose-Einstein condensed state with quantum mechanical long range order, and point out how such dynamics can be engineered using cold atomic gases. We then discuss several implications: First, a dynamical phase transition which results from the competition of Hamiltonian and dissipative Liouvillian dynamics, which shares features of both classical and quantum phase transitions. Second, we present a new purely dissipative pairing mechanism for fermions, which works in the absence of attractive forces. This may provide valuable initial states for the quantum simulation of the fermionic Hubbard model, or even allow to reach topological phases of matter dissipatively.

prof. Rudolf Grimm
BEC >2000: The hunt for new species

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Institut für Quantenoptik und Quanteninformation
Österreichische Akademie der Wissenschaften
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prof. Jakub Zakrzewski
Nonadiabatic dynamics in strongly correlated systems

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Marian Smoluchowski Institute of Physics,
Faculty of Physics, Astronomy and Applied Computer Science
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B. Participants

in alphabetical order

Enhancement of optically pumped spin polarization by spin exchange collisions

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Atomic *spin exchange collisions* are known to affect many precision measurements ranging from the frequency standards to the BEC experiments. In most experiments these collisions are regarded as an undesired relaxation process, though on the other hand several techniques taking advantage of the spin transfer occurring in these collisions exist [1, 2].

We present a detailed study on the role of the spin exchange collisions in the process of optical pumping. We performed the measurements of population distribution among the ground state Zeeman sublevels for the Cs vapours kept in an anti-relaxation coated cell (temp. $\sim 20°$C, atomic density $\sim 10^{11}\,\mathrm{cm}^{-3}$) and pumped with a circularly polarized light. We determined that the spin exchange collisions influence the measurement outcomes in a non-intuitively way by narrowing the observed signals and enhancing the overall atomic spin polarization. These counterintuitive effects were studied theoretically and a comprehensive model was created to reproduce the experimental outcomes.

We believe that the spin exchange collisions need to be considered for understanding and modelling any other experiment where atom-atom collision rate is not negligible.

[1] W. Happer, *Rev. Mod. Phys.* **44**, 169 (1972)
[2] W. Happer, Y.-Y. Jau, and T. Walker, *Optically pumped atoms*, Vch Pub (2010)

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Narrow-line magneto-optical trap for erbium: A simple approach for a complex atom

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We report on the experimental realization of a robust and efficient magneto-optical trap (MOT) for erbium atoms, based on a weak cooling transition at 583 nm. The atomic beam is captured into the narrow-line MOT from a Zeeman slower operating on the strong optical transition at 401 nm. We observe up to $N = 3 \times 10^8$ atoms at a temperature of $T = 15\ \mu$K. This simple scheme provides better starting conditions for loading the dipole trap compared to approaches based on the strong cooling transition or on the combination of a strong and an ultra-narrow transition.

We demonstrate direct loading of the dipole trap from the narrow-line MOT without any additonal cooling stages. Finally we investigate collisional properties of ultracold dipolar erbium atoms.

Our cooling and trapping scheme simplifies the route towards quantum degneracy and thus we speculate it can be successfully applied to other atoms in the lanthanide series.

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MAIUS - a rocket-borne atom interferometer with a chip-based atom laser

Dennis Becker,[1,*] Stephan T. Seidel,[1] Ernst M. Rasel,[1] and the QUANTUS team[2]

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The test of the Einstein's equivalence principle with degenerate quantum matter is one of the strategies to explore the frontier between quantum mechanics and gravity. A precise test for this equivalence is the comparison of the free fall of ultra-cold clouds of different atomic species and its readout using atom interferometry. In order to increase the precision of such an interferometer the space-time-area enclosed in it has to be enlarged. This can be achieved by performing the experiments in a weightless environment that allows longer interrogation times.

In 2004 the QUANTUS project was launched with funding by the German Space Agency DLR. QUANTUS started as a feasibility study of a compact, robust and mobile experiment for the creation of a BEC in a weightless environment. Due to the success of the first QUANTUS [1] experiment, additional projects have been initiated to further investigate the potency of ultra-cold atoms in microgravity.

As a next step towards the transfer of such a system to space, either on board the international space station or as a dedicated satellite mission, a rocket-based atom interferometer is currently being build. With the launch of the rocket mission in November 2013 we plan to demonstrate and test such an apparatus in space for the first time. Its success would mark a major advancement towards a precise measurement of the equivalence principle with a space-borne atom interferometer.

The QUANTUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR 50WM1131.

[1] van Zoest et al, Science 18 June 2010 Vol. 328 no. 5985, pp. 1540 - 1543

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Photon localization and cooperative effects in cold atomic clouds.

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We investigate the influence of cooperative effects, such as Dicke Subradiance and Superradiance, on Anderson Localization in 3-Dimensional cold atomic clouds. First we consider photon escape rates from the cloud by studying the imaginary part of an effective Hamiltonian, describing light mediated atomic dipolar interaction in the scalar [1] and the vectorial cases. In both cases we observe a scaling behavior but no signature of a phase transition by increasing the density, as it has been predicted for Anderson Localization in a 3-D systems, which allows us to think that photon localization is mainly due to cooperative effects and not by disorder. We then investigate the spectrum of the effective Hamiltonian considering the distribution of its real part (Eigenfrequencies) and its imaginary part (Mode decay rate) observing that there is no signature of a phase transition.

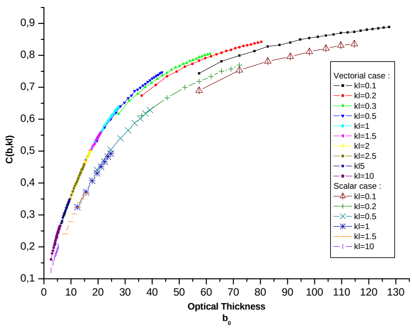

FIG. 1. Evolution of the function counting the number of modes having a vanishing escape rate as a function of the optical thickness of the cloud.

[1] E. Akkermans, A. Gero, R. Kaiser, *Physical Review Letters* **101** 103602 (2008).

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Optomechanics with Optically Levitated Microspheres

Peter Burns,[1,*] James Millen,[1] and Peter Barker[1]
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Optomechanics, the interaction of light with a mechanical degree of freedom of an oscillator, offers the possibility of cooling a macroscopic system to the quantum- mechanical ground state. The obvious application is to explore the boundary between classical and quantum mechanics. Recent experiments in the field have managed to cool oscillators down to average phonon occupancies of less than one.

The interaction of the oscillator with the environment in this context the bulk material to which it is attached, limits the level of cooling that is possible. It also places boundaries on the cooling rate and is predicted to lead to the decoherence of entangled states.

By using optically levitiated micro- (and eventually nano-) spheres, we avoid contact with a thermal bath and dissipation. Feedback can be used to cool the motion of the microsphere to the mK level. The sphere may be cooled further through interaction with light fields in an optical cavity. There is also the potential to Doppler cool spheres that are too large to be cooled in a cavity, by exploiting their internal whispering gallery mode resonances.

We are currently implementing such feedback, which we believe will allow us to overcome radiometric heating and reach a low enough vacuum to implement the cavity-cooling schemes envisaged.

[1] P.F. Barker, M.N. Shneider*Phys. Rev. A* **81** 023826 (2010)
[2] P.F. Barker *Phys. Rev. Lett* **105** 073002 (2010)

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The quantum limits of magnetometry in a cold atomic ensemble

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The investigation of atom-light quantum interaction is proposed as a tool for studying strategies to overcome standard quantum limits in atomic magnetometers [1]. In an optical magnetometer an off-resonant light interacts with an atomic ensemble and the rotation of its polarization due to paramagnetic Faraday effect is measured. From this information one can determine the external magnetic field. Quantum-non-demolition measurement [2] and squeezing can improve the measurement sensitivity once all the other sources of noise are suppressed.

The interesting variables of both light and atoms can be treated as angular momentum components, whose noise can be manipulated. A similar thing of what happens with the two quadrature of a light field, when a quadrature can be squeezed at the expense of increasing noise in the other, anti-squeezing. Using the three-dimensionality of the angular momentum variable, in particular for the case of atomic ensembles, one can hope to squeeze simultaneously two components, providing a powerful tool to reduce even more the quantum noise [3]. In previous spin squeezing experiments, feedback has been proposed to exploit squeezing along one direction, but in practical systems feedback usually is not used.

In this talk I will present theoretical features of macroscopic spin systems with two squeezed components. The study suggests that atomic systems could contribute to increase the current sensitivity in magnetometry. We propose an experiment to get a polarized state in ^{87}Rb atomic system and explore the possibility of squeezing simultaneously two components without using feedback. This will allow quantum enhancements in a magnetometer much closer to practical schemes and can increase the sensitivity of optical magnetometers.

[1] Budker D., Romalis M. *Nature* **3** 227 (2007).
[2] Braginsky, V. B. and Khalili, F. Ya. *Rev. Mod. Phys.* **68** 1 (1996).
[3] G. Tóth, M. W. Mitchell *New J. Phys.* **12** 053007 (2010).

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A numerical study of 3D solitons in optical lattices

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Our system consists of three-dimensional (3D) solitons with two different combinations of linear and nonlinear optical lattices (OLs). We have a linear OL in the $x-$direction and a nonlinear one in the $y-$direction, with the $z-$direction either unconstrained or with another linear OL. When we have an unconstrained $z-$direction there is no stable solutions, but when added the second linear OL it is possible to acquire stability for both attractive and repulsive mean interactions. We performed a full numerical study, by means of relaxation methods and direct numerical time integrations of the Gross-Pitaevskii equation, also confirmed by an variational approach based on a Gaussian ansatz for the soliton wavefunction. The results suggests the possible use of spatial modulations of the nonlinearity as a tool for the management of stable 3D solitons.

[1] M. Brtka, A. Gammal, and L. Tomio, *Phys. Lett. A* **359**, 339 (2006).
[2] H.L.F. da Luz, F.Kh. Abdullaev, A. Gammal, M. Salerno, and L. Tomio, *Phys. Rev. A* **82**, 043618 (2010).
[3] B.B. Baizakov and M. Salerno, Phys. Rev. A **69**, 013602 (2004).
[4] N.G. Vakhitov and A.A. Kolokolov, Radiophysics and Quantum Electronics **16**, 783 (1973).

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Finite-momentum Bose-Einstein condensates in shaken two-dimensional square optical lattices

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We consider ultracold bosons in a two-dimensional square optical lattice described by the Bose-Hubbard model. In addition, an external time-dependent sinusoidal force is applied to the system, which shakes the lattice along one of the diagonals. The effect of the shaking is to renormalize the nearest-neighbor-hopping coefficients, which can be arbitrarily reduced, can vanish, or can even change sign, depending on the shaking parameter. Therefore, it is necessary to account for higher-order-hopping terms, which are renormalized differently by the shaking, and to introduce anisotropy into the problem. We show that the competition between these different hopping terms leads to finite-momentum condensates with a momentum that may be tuned via the strength of the shaking. We calculate the boundaries between the Mott insulator and the different superfluid phases and present the time-of-flight images expected to be observed experimentally. Our results open up possibilities for the realization of bosonic analogs of the LOFF phase describing inhomogeneous superconductivity.

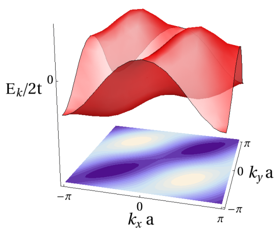

FIG. 1. Single-particle spectrum.

[1] M. Di Liberto, O. Tieleman, V. Branchina, C. Morais Smith, *Phys. Rev. A* **84** 013607 (2011).

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Experimental realization of a distributed Bragg reflector for propagating matter waves

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I will report on the experimental study of a Bragg reflector for guided propagating Bose-Einstein condensates. A one-dimensional attractive optical lattice of finite length created by red-detuned laser beams selectively reflects some velocity components of the incident matter wave packet. I'll show that we find quantitative agreement between the experimental data and one-dimensional numerical simulations and that the Gaussian enveloppe of the optical lattice has a major influence on the properties of the reflector. In particular, it gives rise to multiple reflections of the wave packet between two symmetric locations where Bragg reflection occurs. Our results are a further step towards integrated atom-optics setups for quasi-cw matter waves.

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[1] C. M. Fabre, P. Cheiney,G. L. Gattobigio, F. Vermersch, S. Faure, R. Mathevet, T. Lahaye, D. Guéry-Odelin, *Phys. Rev. Lett.* **107** 230401 (2011).

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Dynamics of multi-component fermions in optical lattices

Nick Fläschner,[1,*] Jannes Heinze,[1] Jasper S. Krauser,[1]
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Understanding magnetic quantum phases and their underlying microscopic structure is of high interest since magnetism plays an important role in today's technology. Quantum gases in optical lattices are ideally suited to realize and investigate systems showing magnetic properties, due to the full control over lattice and interaction parameters as well as the internal atomic degrees of freedom. Here, we investigate interacting spin mixtures of fermionic potassium atoms in an optical lattice. We quench the system from a polarized to a non-polarized regime and study the resulting dynamics. We compare our data to a theoretical two-particle model and find very good agreement. In contrast to real materials with spin-1/2 electrons, we can realize large spins, increasing the complexity of the system. Our results open new perspectives to study magnetism of fermionic lattice systems beyond conventional spin-1/2 systems.

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Statistics of population difference for cold bosons and fermions in a double well potential

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Fluctuations in the atom number difference between two halves of harmonically trapped Bose gas were studied recently. Analytical expression for variance of number difference was found for noninteracting atoms in the grand canonical ensamble. However no splitting potential was taken into account. We present solution for both bosonic and fermionic atoms, when splitting potential idealized as a delta function is considered.

[1] H. D. Politzer, Phys. Rev. A, 54, 5048, (1996).
[2] M. Gajda and K. Rzążewski, Phys. Rev. Lett., 78, 2686, (1997).
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[6] S. Grossmann and M. Holthaus, Opt. Express, 1, 262 (1997).
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[12] C. Gross, J. Esteve, M. K. Oberthaler, A. D. Martin and J. Ruostekoski, Phys. Rev. A, 84, 011609(R), (2011).
[13] A. Sinatra, Y. Castin and Y. Li, Phys. Rev. A 81, 053623 (2010).

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Production and manipulation of wave packets in an ultracold lattice gas

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The coherent manipulation of wave packets is an important tool in many areas of physics. We show the experimental realization of quasi-free wave packets of ultra-cold atoms bound by an external harmonic trap. The wave packets are produced by modulating the intensity of an optical lattice containing a Bose-Einstein condensate. The evolution of these wave packets is monitored in-situ and their reflection on a band gap is observed. In direct analogy with pump-probe spectroscopy, a probe pulse allows for the resonant de-excitation of a major fraction of the wave packet into localized states at a long, controllable distance of more than 100 lattice sites from the main cloud [1].

By monitoring the resonant frequency of de-excitation during the motion of the wave packet one can gain precise knowledge on the shape of the external trap. A polynomial expansion of the trapping potential up to the fourth order allows for a precise determination of the anharmonicity.

In a further extension of the excitation technique, wave packets with high momentum can be produced and monitored. This tool extends the spatial and momentum regime for further experiments and enables complete probing of the wave packet momentum distribution.

These precise control mechanisms for ultra-cold atoms thus enable controlled quantum state preparation, opening exciting perspectives for quantum metrology and simulation.

[1] J.F. Sherson, S.J. Park, P.L. Pedersen, N.F. Winter, M. Gajdacz, S. Mai and J. Arlt, *Pump-probe coupling of matter wave packets to remote lattice states* arXiv:1107.1643v1 [cond-mat.quant-gas].

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A self-optimizing experimental apparatus

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Even though most parameters in a typical cold atom experimental setup are controlled by a computer program, optimization is still usually done by hand. However, systematically scanning the whole parameter space becomes practically impossible as the number of dimensions increases. A possible solution is to employ an automated optimization procedure. The demands on such an optimization algorithm include the detection of the global optimum, and robustness against experimental noise while reaching the solution within a small number of experimental cycles. We present a genetic algorithm based on Differential Evolution, which quickly finds the optimum even with experimental noise. It requires little computing power and is easy to implement. We demonstrate the performance of the algorithm by applying it to our atom chip experiment. We present the successful optimization of various steps of the experimental sequence with up to 12 correlated parameters. Finally, we compare the results with a numerical simulation and deduce an optimal strategy for a wide range of experimental tasks.

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Sisyphus Cooling of Polyatomic Molecules

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Due to the long-range dipole-dipole interaction and rich internal structure, polar molecules have become of great interest over the past decade. Developing methods to prepare the required cold and ultracold molecular ensembles would enable fundamental studies, ranging from many-body physics and quantum information to quantum controlled collisions and chemistry. However, a cooling mechanism for polyatomic molecules with the capability to cool to the ultracold regime has up to now seemed infeasible.

Here we present the first experimental realisation of opto-electrical cooling [1] using trapped CH_3F [2]. In this general Sisyphus-type cooling scheme the strong interaction of polar molecules with electric fields is exploited to remove a large fraction of the kinetic energy in each step of the cooling cycle. We demonstrate the functionality of the scheme by reducing the temperature from 358mK to 77mK, thereby increasing the phase-space density by a factor of 7. With no fundamental temperature limit down to the nK regime, we expect improvements to allow cooling down to the μK range opening a route to quantum-gas physics with polyatomic molecules.

[1] M. Zeppenfeld *et al.*, Phys. Rev. A **80**, 041401(R) (2009).
[2] B.G.U. Englert *et al.*, Phys. Rev. Lett **107**, 263003, (2011).

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Thermalization in a one-dimensional integrable system

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We present numerical results demonstrating the possibility of thermalization of single-particle observables in a one-dimensional system, which is integrable in both the quantum and classical (mean-field) descriptions (a quasicondensate of ultracold, weakly interacting bosonic atoms are studied as a definite example).We find that certain initial conditions admit the relaxation of single-particle observables to the equilibrium state reasonably close to that corresponding to the Bose-Einstein thermal distribution of Bogoliubov quasiparticles [1].

[1] P. Grisins and I. E. Mazets, *Phys. Rev. A* **84** 053635 (2011).

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Advanced laser systems for matter-wave interferometry in microgravity

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We present a robust and compact laser system for dual-species atom interferometry with rubidium and potassium in microgravity in the context of the QUANTUS and LASUS project. The system is built around a set of hybrid-integrated master oscillator power amplifiers (MOPA), which allow for outputpower in the Watt range, while preserving the spectral characteristics of the DFB laser diode. Results from several catapult launches at the ZARM droptower in Bremen showing the stability of the frequency locks and fiber coupling efficiencies as well as the ruggedness of the complete system will be presented. Finally, an outlook on even more sophisticated lasersystems for missions in a sounding rocket within the MAIUS project as well as perspectives for fundamental physics in space will be given.

The QUANTUS and LASUS project are supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number (DLR 50WM 1131-1137, 0937-0940).

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Sub-Hertz laser systems for a strontium optical lattice clock

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Optical clocks nowadays provide higher stability and lower systematic uncertainty than ^{133}Cs microwave clocks. Highly stable and precise clocks can now measure relativistic gravitational redshifts on earth ($\Delta\nu/\nu \approx 1 \cdot 10^{-18}$/cm) and eventually at high precision in space. Moreover, comparison of different optical clocks may be used to investigate temporal variations of fundamental constants.

Our optical atomic clock uses an ultra narrow transition at 698 nm in strontium trapped in an optical lattice. It shows a stability of $\Delta\nu/\nu = 5 \cdot 10^{-15}$, which is limited by the short-term linewidth of the clock laser. Here, we will focus on the crucial element of the clock laser system, namely the reference cavity whose mechanical stability is transferred to frequency stability through a Pound-Drever-Hall lock. The length stability of cavities is limited by the Brownian motion of the materials and physical deformation through acceleration forces.

Longer cavities may help to reduce the thermal effects at the cost of the mechanical stability. We have designed a cylindrical cavity of 47.5 cm length that is significantly longer than other optical clock laser cavities. This way relative length (and frequency) changes due to thermal noise can be reduced considerably. Our mounting design ensures that the residual accelerations on a vibration isolation table do not perturb the laser performance. The cylindrical spacer of the cavity is made from Ultra-Low-Expansion glass (ULE), with optically contacted, highly reflective fused silica mirrors. With our vacuum system and heat shields that are currently being assembled, we expect a frequency stability of $\Delta\nu/\nu = 8 \cdot 10^{-17}$ from 1 s to 100 s averaging time.

In a second approach, we have designed a smaller setup with a more rigid mounting on our way to a transportable optical clock. The cavity is shorter (12 cm long) and our alternative mounting scheme is designed to withstand transportation shocks of up to 50 g. Despite this, it has a small measured insensitivity to accelerations of $\Delta l/l = 10.7 \cdot 10^{-10}$/ g. It shows a finesse of 460 000 and a theoretical thermal noise floor of $\Delta\nu/\nu = 2.3 \cdot 10^{-16}$. With this system we achieved so far a frequency stability of $\Delta\nu/\nu = 6 \cdot 10^{-16}$ at 10 s.

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Collective interactions in Rydberg-dressed Bose-Einstein condensates

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We investigate a Bose-Einstein condensate where atoms are dressed to high Rydberg states with strong van der Waals interactions. We show that this leads to effective ground state interactions with genuine many-body character. In the limit of large laser detunings, two-body interactions dominate [1, 2] while many-body interactions become relevant in the strong-driving limit, i.e. in the limit of large laser intensities or weak detunings. We study the effects of these higher order interactions and show that nonlocal phenomena found for binary interactions are modified but are still observable in the presence of strong collective, i.e. genuine many-body, interactions.

[1] N. Henkel, R. Nath and T. Pohl, Phys. Rev. Lett. **104** 195302
[2] F. Maucher et al., Phys. Rev. Lett. **106** 170401

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A quantum degenerate mixture of Rb and Cs: Towards ground state heteronuclear molecules

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The preparation of a mixture of two or more atomic species in a quantum degenerate state opens up many new research avenues, including the formation of ultracold heteronuclear molecules. Such molecules possess permanent electric dipole moments which give rise to anisotropic, long range dipole-dipole interactions. These interactions differ greatly from the isotropic, short-range contact interaction commonly encountered in quantum degenerate atomic gases and consequently offer novel applications in quantum information processing and simulation [1]. Recently, great successes have been achieved in the creation of high phase space density molecular gases by combining magneto-association on a Feshbach resonance with stimulated Raman adiabatic passage (STIRAP) to transfer the molecules to the ro-vibrational ground state [2, 3]. We demonstrate the first stage of this scheme by creating Cs_2 Feshbach molecules via a magnetic field sweep across a narrow resonance at 19.8 G [4] and report the observation of several interspecies Feshbach resonances. STIRAP transfer for the creation of ground state RbCs requires the simultaneous frequency stabilisation of two diode lasers operating at 980 nm and 1570 nm [5]. Therefore we present a scheme using a transfer cavity for the stabilisation of the lasers.

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[2] K.-K. Ni et al., *Science*, **322** 5899 (2008).
[3] J.G. Danzl et al., *Nature Phys.*, **6** 265 (2010).
[4] H.W. Cho et al., *Phys. J. D*, **65** 125 (2011).
[5] M. Debatin et al., *Phys. Chem. Chem. Phys.*, **13** 18926 (2011).

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Coherence on Förster resonances between Rydberg atoms

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Förster resonances are non-radiative dipole-dipole interactions between oscillating dipoles. Especially in biochemistry these resonances play a crucial role and describe the energy transfer process between two chromophores, parts of molecules which are responsible for their colors. In our work these resonances occur between a pair of Rydberg atoms, creating strong interactions between the atoms.

We report on studies of Förster resonances between Rydberg atoms in an ultra-cold atomic cloud of ^{87}Rb. By applying a small electric field we tune dipole coupled pair states into resonance, giving rise to Förster resonances. Via a Ramsey-type atom interferometer we can resolve several resonances at distinct electric field strengths. We study the coherence of the system at and close to the resonances and we observe a change in phase and visibility of the Ramsey fringes on resonance. The individual resonances are expected to exhibit different angular dependencies, opening the possibility to tune not only the interaction strength but also the angular dependence of the pair state potentials by an external electric field. In summary, we now have a tool to coherently tune interactions between Rydberg atoms. In further studies Rydberg atoms could be used as a model system to simulate energy transfer processes in bio-molecules.

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Correlated atom pair creation in a moving 1D optical lattice

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Spontaneous four wave mixing (SFWM) of matter waves is a promising source of non-classical atomic pairs states. The obtained states are similar to the twin photons states generated through parametric down-conversion, widely used in quantum optics. This source could be interesting for atomic interferometry under standard quantum limit as for demonstration of entanglement of the pairs in an EPR way.

In the present experiment, using a metastable helium BEC, the SFWM process takes place in a 1D optical lattice, whose dispersion relation enables to choose the output modes of this process: for an initial momentum k_0, atomic pairs are spontaneously generated with momentum k_1 and k_2 that fulfill phase-matching conditions as predicted by [1]. As shown on figure 1.a) this distribution exhibits 3 clouds, formed by the BEC and the pairs of scattered atoms (k_1 and k_2). The measured values of k_1 and k_2 are in remarkable agreement with the expected momenta as shown on figure 1.b).

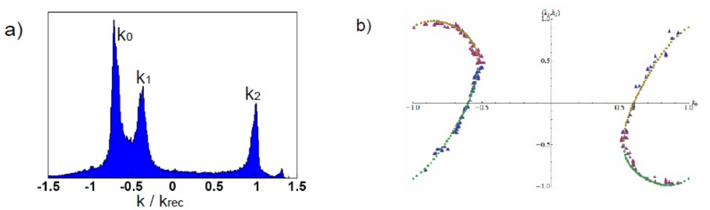

FIG. 1. a) The projection along the lattice axis shows 3 peaks, corresponding to the initial BEC (at k_0 = -0.7 k_{rec}) ansd to the atoms scattered at k_1 (-0.39 k_{rec}) and k_2 (0.99 k_{rec}).
b) Momentum k_1(red dots) and k_2 (blue dots) in function of k_0. The green line represent the expected momentum according to the theory presented by [2].

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Localization of ultracold Atoms in a 3D Speckle Disorder

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In his seminal publication in 1958 [1], P. W. Anderson postulated the "Absence of Diffusion" of electrons in random lattices. He claimed that intricate interference effects of (matter-)waves in a disordered potential alone could bring their propagation to a complete halt. Here we report the first evidence of localization of ultracold atoms in a 3D disorder [2], obtained at the same time as the group of B. DeMarco at Urbana Champaign [3]. We load a cloud of non-interacting 87Rb atoms into a disordered potential of variable strength, created by interfering two coherent, orthogonal laser speckles. A magnetic levitation cancels the influence of gravity and allows us to observe the propagation of the atoms for up to 6 s. In strong disorder we see a cloud composed of a slowly diffusive, and a localized part (up to 20%). Having a genuine 3D configuration, our experiment paves the road towards a comprehensive study of the transition from the diffusive to the localized regime, a topic that is very popular and widely debated in the field of condensed matter physics.

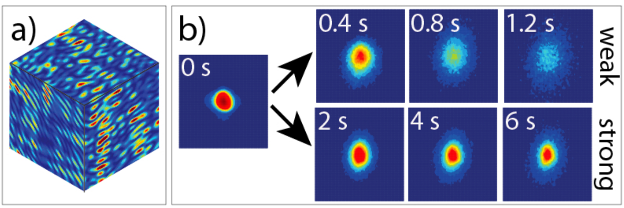

FIG. 1. a) Cross-sections of the disordered potential (simulation). b) Different evolutions of the atomic cloud: For weak disorder the behavior is purely diffusive (upper row), whereas for strong disorder the cloud consists of a slowly diffusive, and a remaining, localized part (lower row). Note the different time scales.

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[3] S.S. Kondov et al., *Science* **333**, 66-68 (2011).

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Trapping and guiding atoms on a mesoscopic chip structure

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We investigate guiding and trapping of ultracold rubidium atoms on a mesoscopic chip structure with millimeter scale wires. This structure is used to create a quadrupole field for a magneto-optical trap, a magnetic guide and flexible magnetic trapping potentials on both sides of the guide. In our experiments, the guide allows us to transport cold atoms into a region that provides better vacuum conditions and perfect stray light protection. It is therefore particularly well suited for evaporative cooling and the production of a Bose-Einstein condensate. We investigate sequential loading mechanisms with regard to a continuous loading of a magnetic trap [1].

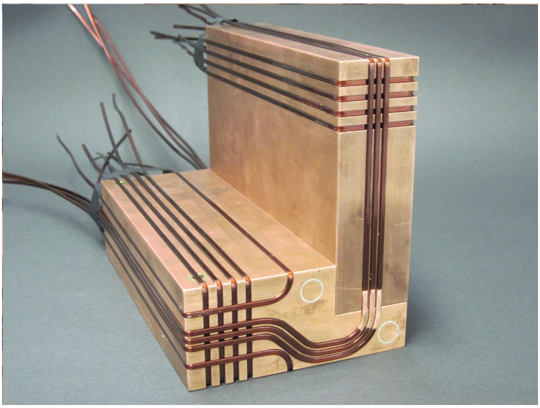

FIG. 1. The copper block holding the wire structure.

[1] C.F. Roos, P. Cren, D. Guery-Odelin and J. Dalibard, *Continuous loading of a non-dissipative atom trap*, *Europhys. Lett.* **61** 187 (2003)

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Hardcore bosons on a triangular lattice with long range interactions at a finite temperature

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We look at hardcore bosons on a triangular lattice with long range dipolar interactions as well as long range hopping. In particular the focus is on a 6 by 6 triangular lattice with up to 5 nearest neighbor interactions with a special focus on the 1/3 (or 2/3) filling lobe. By comparing this ultra-frustarted system to a system with only nearest neighbor interactions one is able to identify the differences in the phase diagrams. Examining the density, stiffness, and structure factor of each system will provide information on the type of states that appear. The superfluid, crystal, and supersolid phases that show up change depending on the ratio of hopping to dipolar interactions as well as whether the interactions are short ranged or long ranged. Finally, as the temperature is increased one can observe the melting of the crystal lobe and the disappearance of the supersolid region.

[1] P. Hauke, F.M. Cucchietti, A. Müller-Hermes, M. Bañuls, J.I. Cirac and M. Lewenstein, *New Journal of Physics* **12** (2010) 113037.
[2] M. Boninsegni and N. Prokof'ev, *Phys. Rev. Lett.* **95** 237204 (2005).
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Continuous Coupling of Ultracold Atoms to Ionic Plasma via Rydberg Excitation

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We characterize the two-photon excitation of an ultracold gas of Rubidium atoms to Rydberg states analysing the induced atomic losses from an optical dipole trap. Extending the duration of the Rydberg excitation to several ms, the ground state atoms are continuously coupled to the formed positively charged plasma. In this regime we measure the n-dependence of the blockade effect and we characterise the interaction of the exited states and the ground state with the plasma.

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BEC in a dressed quadrupole trap

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We describe an experiment to produce a ^{87}Rb Bose-Einstein condensate (BEC) in a radio-frequency (RF) dressed quadrupole trap, which is an important step in order to reach a ring-shape trap where we will investigate the connection between superfluidity and Bose-Einstein condensation in 2D and 3D. The condensate is first produced in an optically plugged magnetic quadrupole trap [1], carefully optimized to overcome Majorana losses. This trap is characterized by the measure of the oscillation frequencies and the bottom frequency.

Once condensed, the atoms are transferred to the dressed trap by a RF sweep and a slow decrease of the plug beam power. In the dressed trap, the RF coupling is precisely determined by spectroscopy and the lifetime of the dressed atoms reaches several minutes.

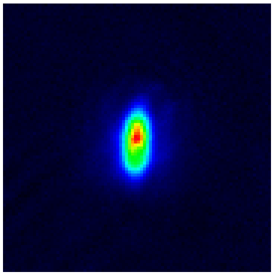

FIG. 1. BEC in the dressed quadrupole trap.

[1] R. Dubessy, K. Merloti, L. Longchambon, P.-E. Pottie, T. Liennard, A. Perrin, V. Lorent and H. Perrin, *arxiv:*1112.0660v1, 2011 (accepted in PRA).

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Towards an ultracold mixture of metastable helium and rubidium

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We present our plans to set up an experiment to produce an ultracold atomic mixture of metastable He (^{3}He* or ^{4}He*) and ^{87}Rb. Our cooling strategy is based on a two-species MOT loaded from a Zeeman slower for He* and a 2D-MOT for Rb, forced evaporative cooling of Rb and sympathetic cooling of He* in a magnetic trap, and forced evaporative cooling in a 1557-nm crossed optical dipole trap. We will search for interspecies Feshbach resonances, which will be used to control the interaction between the He* and the Rb atoms or associate ultracold He*Rb molecules. The main motivation is the detection of He*Rb_2 Efimov trimers. The large mass ratio between the two atomic species results in a dramatic reduction of the spacing between successive Efimov states, allowing a first experimental test of the periodicity of the Efimov spectrum [1].

[1] F. Ferlaino and R. Grimm, *Physics* **3** 9 (2010).

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Quantum dynamics at an unstable classical fixed point

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We experimentally investigate quantum dynamics in a two component BEC of 87-Rubidium. The system is initially prepared in a coherent spin state centered on an unstable fixed point in the classical phase space of the Bosonic Josephson Junction.

For short evolution times, the interplay of linear coupling and nonlinear interaction between the particles generates squeezing of the Gaussian quantum state. For longer evolution times, the measured distributions of the population imbalance indicate a non-Gaussian character of the many particle state. The ability to perform simultaneous measurements on up to 40 BECs in an optical lattice yields sufficient statistics for tomographic reconstruction of the final state's Wigner distribution.

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Rydberg four wave mixing in a thermal gas of Rb

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The Rydberg blockade effect is a promising candidate for use in quantum devices. In combination with a four wave mixing scheme a single photon source has been proposed. While ultracold gases seem to be the obvious choice, our vision is to use thermal atomic vapor in small glass cells which offers multiple advantages in terms of scalability and ease of use. Here we present four wave mixing measurements including a Rydberg state in a thermal vapor cell and compare our results to a single atom model. Furthermore we demonstrate the tunability of the four wave mixing scheme by means of an electric field via the Stark effect on the Rydberg state.

Secondly, we report on the status of our new setup designed for studying single collective Rydberg-excitations in tight optical traps smaller than the Rydberg-blockade sphere. Such ensembles, where all trapped atoms coherently share a single Rydberg-excitation, form a two-level "superatom" whose Rabi-oscillation is collectively enhanced by the square root of involved atoms. Our new apparatus combines single ion-detection capability, micron optical resolution, and high flexibility in creating optical trapping potentials to enable studies of coherent dynamics within a single superatom.

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A scanning electron microscope for the detection of ultracold atoms

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To be able to see the interesting properties of ultracold atoms a way of probing these samples is needed. As a technique for the detection and manipulation of ultracold atoms a scanning electron microscope is used in our group. The time resolved signal of the ions created by the electron beam hitting the atomic sample is used to create a spatial image of the atomic cloud. Among others one benefit of this method is the high spatial resolution, on the order of 100 nm, which also allows for single site detection of atoms in an optical lattice. Furthermore controlled manipulations of the sample are possible. This enables us to deplete single lattice sites or study dissipative processes in ultracold samples and especially in a BEC. This talk will give an overview of the electron microscopy on ultracold samples and present some recent measurements of the temporal correlation functions.

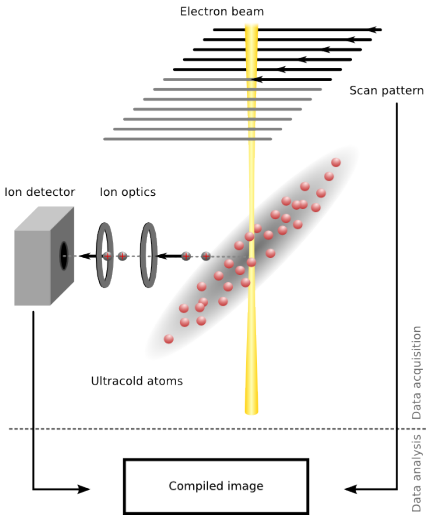

FIG. 1. The working principle of an electron microscope as imaging technique for ultracold atoms. Using a certain scanning pattern the electron beam ionizes the sample at defined positions at defined times. This can be used to extract a spatial image of the sample from the time resolved ion signal.

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3D simulation of tunneling dynamics in a two-component Bose-Einstein condensate

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During last years the study of tunneling dynamics of BEC in a double-well trap is of a keen interest. The main tunneling regimes, Josephson oscillations (JO) and Macroscopic Quantum Self-Trapping (MQST), were widely investigated, both in theory and experiment.

We propose exploration of BEC tunneling dynamics within 3D time-dependent Gross-Pitaevskii equation. The method allows to avoid numerous common approximations (two-mode treatment, time-space factorization of wave function, etc) and thus provide a realistic description. As a result, not only sub-barrier but also above-barrier dynamics can be analyzed [1]. The latter is obtained by increasing the total number of BEC atoms and thus rising the chemical potential. This results in persisting JO and transfer of MQST into a new regime combining the JO and MQST properties. The method well describes the recent experimental dates [2].

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[2] M. Albiez, R. Gati, J. Folling, S. Hunsmann, M. Cristiani and M. Oberthaler, Phys. Rev. Lett. **95**, 010402 (2005)

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Entanglement-Enhanced Atom Interferometer Probing On-Chip Microwave Fields

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We experimentally realize a Ramsey interferometer operating beyond the standard quantum limit (SQL), using two internal spin states of a two-component Bose-Einstein condensate. We first produce spin-squeezed states by controlled collisional interactions between the atoms using a state-dependent microwave near-field potential [1]. We observe spin noise reduction by up to 4.5 dB below the SQL with a spin coherence of 98%, corresponding to a depth of entanglement of at least 40 particles.

Using such spin-squeezed states as interferometer input states, we demonstrate performance beyond the SQL. Our interferometer outperforms an ideal classical interferometer with the same number of particles (≈ 1300) for interrogation times up to 10 ms.

These experiments are performed on a micro-fabricated atom chip providing small and well-localized trapped atomic ensembles. This makes our technique promising for high-precision measurements with micrometer spatial resolution. We demonstrate this by probing a microwave near-field generated on-chip with beyond-SQL performance. We measure the position dependent field strength by scanning the squeezed condensate over several micrometers, highlighting the flexibility of the atom chip based implementation.

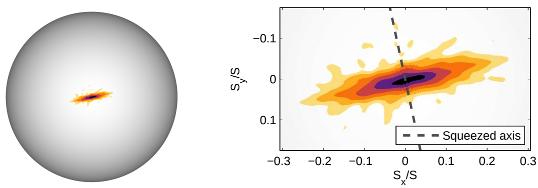

FIG. 1. Tomographic Wigner function reconstruction of the input state on the Bloch sphere [2]. The state is squeezed along the dashed line (12° rotated w.r.t the y-axis).

[1] M.F. Riedel et al, *Nature* **464** 1170 (2010).
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Matter-wave analog of an optical random laser

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The accumulation of atoms in the lowest energy level of a trap and the subsequent out-coupling of these atoms is a realization of a matter-wave analog of a conventional optical laser. Optical random lasers require materials that provide optical gain but, contrary to conventional lasers, the modes are determined by multiple scattering and not a cavity. We show that a Bose-Einstein condensate can be loaded in a spatially correlated disorder potential prepared in such a way that the Anderson localization phenomenon operates as a band-pass filter. A multiple scattering process selects atoms with certain momenta and determines laser modes which represents a matter-wave analog of an optical random laser [1].

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[1] M. Płodzień, K. Sacha Phys. Rev. A **84** 023624 (2011)

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Finite temperature correlations in 1D Bose gas

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It is a well-known fact, that the Bose gas in one dimension is solvable in the sense of the Algebraic Bethe Ansatz. Therefore all the eigenstates of the system and the action of local operators on them are known a priori. Despite this, the calculation of correlation functions (especially analytically) remains an open question. We develop a general algorithm that in principle can be used to obtain any correlation at finite temperature, for concreteness focusing on the density-density correlations. This allows us to study effects of strong correlations intertwined with thermal fluctuations. This work is also relevant in view of recent developments of the experimental methods with 1D Bose gas.

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Single Photon Control using Rydberg Superatoms

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Building on the success of early proposals to realise quantum computation [1], Rydberg atoms have emerged as a viable implementation [2] because of the extremely long range interaction between atoms [3]. For example, the dipole blockade mechanism in the 60S level of rubidium limits the number of excitations within a volume of $100\,\mu\mathrm{m}^3$ to one and only one, such that the ensemble behaves as a single "superatom" [4]. In Durham we exploit superatoms to control propagation of light through a dipole-trapped cloud of rubidium atoms [5]. Dipole blockade allows us to have only one photon at a time propagating through the ensemble. This effect can be used to implement a deterministic single photon source [6] or a photonic phase gate. Second order correlation measurements will be used to check the quantum nature of the output [7].

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A compact chip based cold atom source for atom interferometry in microgravity

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Atom chips enable compact and robust apparatus for matter-wave interferometry and condensed matter physics. Usually these setups are limited in the total number and the flux of atoms. In this talk we present the QUANTUS-II apparatus, which uses a combination of a chip-based atom trap with a 2D+ pre-cooling stage. This apparatus allows to collect $> 3 \cdot 10^9$ atoms within 3 seconds in a mesoscopic chip MOT. This is an excellent starting point towards the realisation of a high precision matter-wave interferometer.

To continue the legacy of the QUANTUS I experiment[1] with over 300 drops in the drop tower bremen, QUANTUS II will employ a dual species raman interferometer to provide a high precision test of the weak equivalence principle in the quantum regime. Therefore the experiment has to fulfill vast demands of rigidness and compactification that are required to operate in microgravity at the drop tower.

We will present the experimental setup and report on the performance of the Rb pre-cooling stage and the chip trap. Furthermore we will give a short wrapup of the concepts of atom interferometry in free fall.

The QUANTUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR 50WM1131.

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[2] J. Rudolph et al, *Degenerate Quantum Gases in Microgravity - Microgravity Sci. Technol.* **23** 287 - 292, (2011).

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Temperature dependence of three-body losses in unitary Bose gases

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Recently, new thermodynamic methods applied to cold atoms have permitted the precise measurement of the equation of state of strongly interacting Fermi gases. In contrast to fermions, experiments on strongly interacting Bose gases are limited due to three-body losses. In the low temperature regime, interactions between ultra-cold atoms are described by a single parameter: the s-wave scattering length a. In 1996, an a^4 dependence on the atomic three-body recombination loss rate L_3 was predicted[1]. However, due to finite temperature effects, a limit on the recombination rate is imposed at unitarity, where $(k|a|)^{-1} \to 0$, such that L_3 does not diverge[2]. We will introduce existing theoretical predictions of temperature-dependence of the unitarity-limited, three-body loss rate. Furthermore, we will present measurements of the variation of the three-body loss rate with temperature, that clarifies the temperature range over which the unitary Bose gas is metastable and can be studied in the framework of thermodynamics[3].

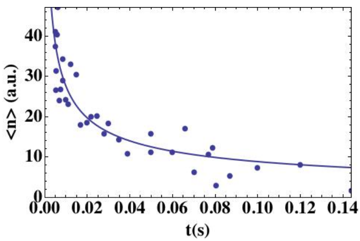

FIG. 1. A typical curve showing the number decay of a strongly interacting thermal Bose gas.

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A Compact System for Ultracold Atoms

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We propose a compact system to produce a ^{87}Rb Bose-Einstein condensate, based on a single-glass cell without the need for atom chips. Fast evaporation is achieved in a hybrid trap [1] comprising a magnetic quadrupole trap and a flexible optical dipole trap created by a Spatial Light Modulator. To enhance this efficient and rapid evaporation, we use Light-Induced Atomic Desorption [3][4] to modulate the background pressure during the cooling and trapping stage.
The Spatial Light Modulator creates a dynamic, power-law optical trap, which can be adiabatically transformed to reversibly modify the phase-space density of the cloud [2]. Additionally, this increases the number of atoms present in the BEC compared to standard evaporative methods. Furthermore, the Spatial Light Modulator can be used for creating novel non-trivial patters of dipole traps for ultracold atoms, beyond those presently achieved by standard techniques.

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Mott insulator to superfluid transition in one, two and three dimensional optical lattice

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Study of quantum phase transitions is a vital research area in the contemporary physics. An important example is found in systems of cold atomic gases in optical lattices. Such systems are decribed by the Hubbard hamiltonian or, in case of bosons, the Bose -Hubbard hamiltonian. We investigate the Mott insulator to superfluid quantum phase transition that occurs in the latter model. The Kibble - Zurek mechanism description can be applied to this transition and we test this scenario for one, two and three dimensional case. We obtain the scalings of certain observables such as kinetic or potenital energy and winding number (in 1 dimensional case). For the winding number we explain why it freezes for very slow quench rates [1]. In case of energy scaling in three dimensions we see an agreement with the experimental tests [2].

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Coherent control of a 1D Bose-Einstein quasi-condensate

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Controlling matter at the level individual atoms or ions is a subject of continued interest. Using electric and magnetic fields, it is now possible to trap particles, cool them to quantum degeneracy and detect them with high efficiency and resolution. However, controlling the quantum states of complex many-particle systems still represents a challenge for which new and efficient techniques have to be found.

In this talk, I will present a scheme of coherent control over the motional states of a one-dimensional Bose-Einstein quasi-condensate. To do so, we work on an atom chip with RF-dressed anharmonic potentials, which make it possible to excite different transverse motional states of atoms, using the results of optimal control theory. In a first series of experiments, we implement a Ramsey interferometer based on these collective vibrational states in the trap. In a second investigation, we create a full population inversion to an excited state which relaxes, producing correlated pairs of atoms in analogy to optical down conversion.

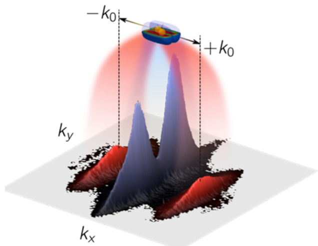

FIG. 1. Twin-beams generation.

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Numerical studies on matter waves engineering

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We will describe the outcoupling of a matter wave into a guide by a time-dependent spilling of the atoms from an initially trapped Bose-Einstein condensate. Our analysis of the time-dependent engineering and manipulation of condensates in momentum space in this context enables us to work out the limits due to interactions in the mode quality of a guided-atom laser or in the longitudinal velocity dispersion. This study is consistent with recent experimental observations. In addition, this study suggests a strategy for engineering the atomic flux of the atom laser. Then, we will describe different numerical studies on scattering of guided matter waves by different extra optical potentials (optical lattice, Bragg cavity) superimposed to the guiding potential.

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[2] C.M. Fabre, P. Cheiney, G.L. Gattobigio, F. Vermersch, S. Faure, R. Mathevet, T. Lahaye and D. Gury-Odelin, *Phys. Rev. Lett.* **107** 230401 (2011).

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Setup of a Zeeman Slower and MOT system for the creation of a degenerate Fermi gas

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We are constructing a new laboratory for the creation of a degenerate Fermi gas of Lithium 6. The first step in this direction will be taken by creating a Magneto Optical Trap (MOT) for our Lithium atoms. To achieve this we are building a Zeeman slower system designed to slow the high velocity Lithium from our hot oven source down to velocities that can be captured by our MOT. We use a compact design which consists of nine coils with decreasing winding numbers and the MOT field itself. I will present our design of the vacuum system and describe our progress towards the MOT.

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Frequency Translation of OAM in Rb^{85}vapour

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We present the efficient frequency up-conversion of light carrying Orbital Angular Momentum (OAM) through a highly efficient four wave mixing process in Rubidium vapour. (Fig. 1a) In a previous paper we reported the conversion of Gaussian pump fields at 780nm and 776nm to up to 1.1mW of 420nm light and an unobserved infrared transition. [1] Here instead we investigate pump beams in a specific Laguerre Gaussian (LG) mode or superpositions thereof. We observe complete conversion of all input OAM in a 'pure' LG mode from the two pump beams at to the 420nm output of the four wave mixing process. Absolute determination of the 420nm OAM component, $l\hbar$, of the blue is done by interference with its mirror image, producing the well known lobe structure of LG superpositions. (Fig. 1b)

We also explore the quantum nature of the process and show the conservation of OAM from superpositions of LG beams as input pump fields. The output 420nm is found to be a combination of the possible absorption pathways of the input modes. A secondary output channel at 5.3μm is unobserved but assumed to contain no OAM.

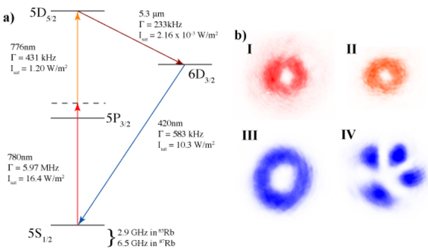

FIG. 1. a) The Blue Light pumping scheme b) Example data: I and II; The Input 780nm and 776nm beams shaped into an LG_0^1 state. III; The resulting blue output. IV; Interferogram of the blue beam with its mirror image.

[1] A. Vernier, S. Franke-Arnold, E. Riis and A.S. Arnold, *Opt. Express* 18(16): 17020-17026, Aug 2010.

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Atomic magnetometry

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The atomic magnetometry is the most sensitive way of measuring magnetic field. This technique is based on the nonlinear effects in the atomic vapours (these effects are extremely sensitive to the magnetic field). Magnetic field can be measured by the observation of the time evolution of the medium magnetization (such magnetization is generated in the optical pumping process). Principles of this technique as well as experimental results will be presented.

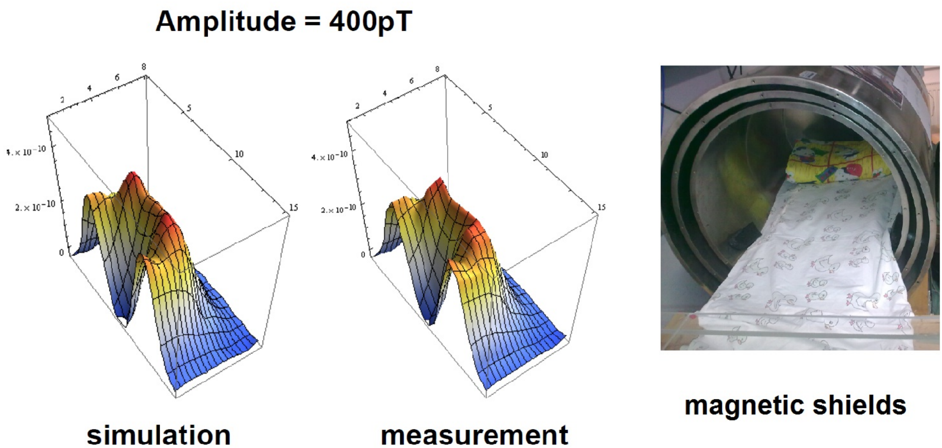

FIG. 1. The first picture (on the left side) presents comparison between simulation and measurement of exemplary magnetic field distribution, while the second illustrates the magnetic field shields adapted for tests with measurements of the magnetic field generated by human heart.

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II. POSTER SESSION

Towards temporally-multiplexed quantum memories with cold atomic gases

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The frame of our project is the study of light-matter interactions between single photons and cold atomic ensembles. We want to create a quantum memory with cold rubidium atoms in order to store and retrieve quantum information in a reversible way. This memory will be used for quantum repeater applications, using the Duan Luckin Cirac Zoller (DLCZ) architecture[1]. Our goal is to demonstrate a new generation of atomic quantum memories, with enhanced storage capabilities with respect to the current state of the art [2]. In particular, the main objective is to demonstrate a cold atoms quantum memory capable of storing multiple collective spin excitations in one ensemble using temporal multiplexing. Recent theoretical proposals have shown that such a capability would open new possibilities towards more efficient quantum repeater architectures [3]. This will require the experimental quantum control of inhomogeneous spin dephasing at the single excitation level in cold atomic ensembles using spin echo techniques, as well as placing the cold atomic ensemble inside a low finesse cavity.

In this contribution we will describe our progress towards the demonstration of controlled rephasing of single spin excitations in cold atomic ensembles.

[1] L.-M. Duan *et al.*, "Long-distance quantum communication with atomic ensembles and linear optics", Nature **414**, 413-418 (2001).
[2] N. Sangouard *et al.*, "Quantum repeaters based on atomic ensembles and linear optics", Rev. Mod. Phys. **83**, 33 (2011).
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Cold atoms and microstructures

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Employing a structured metallic surface into cold atom physics allows one to obtain sophisticated magnetic or optical potentials which ensure precise manipulation of atoms movement what in turn is the key issue for studying fundamental quantum phenomena. Neutral atoms may be controlled in atomic dipole mirrors (optical potentials) or by using atom chips (magnetic potentials).

In Laboratory of Cold Atoms Near Surfaces we plan to use a microstructured matallic surface to assure a high intensity gradient necessary for dipole mirror operation. Surface plasmon polaritons, electromegnetic charge-density waves propagating along a metallic surface, are created on a gold grating with a period comparable to the wavelength of incident light in close-to-normal incidence (see picture). Calculations and preliminary results are presented.

We also briefly present a progress in our attempt to create a Bose-Einstein condensation in an atom chip based setup (RuBECi from Cold Quanta).

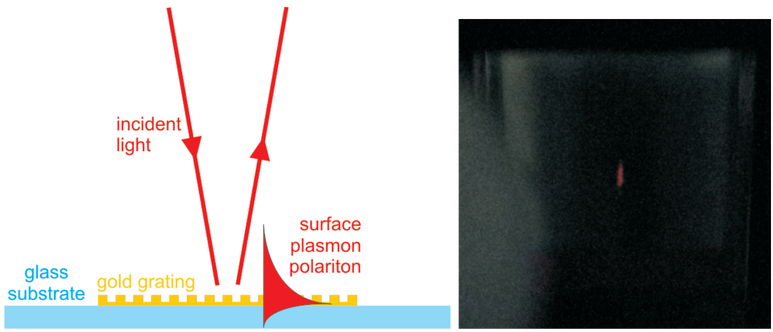

FIG. 1. Left: surface plasmon polaritons excitation on a gold grating, right: Rb atoms trapped in Magneto Optical Trap (MOT) in the upper cell of RuBECi, photo taken with an ordinary DSLR camera.

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Towards coherent interaction between single neutral atoms and a BEC

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Combining a single neutral atom with a quantum many body system, such as a Bose-Einstein condensate (BEC) poses a challenge, not only due to the different temperatures of both systems realized in experiments so far, but also because of the different measurement statistics and typical sequence durations. Studying the interaction of a single atom with a BEC requires many repetitions of the experimental cycle to obtain sufficient statistics. Thus it is essential to achieve short measuring times and therefore a high production rate of the BEC. Here we present a concept for a new setup capable of breeding an all optical BEC in less than 10 seconds and immersing single atoms into the ultracold quantum system.

Our setup will feature mechanisms for independently manipulating and detecting both single atoms and the BEC, thereby providing an unrivaled level of control over impurities in a quantum gas. Possible research directions include the investigation of coherent impurity physics and the creation and characterization of polarons in a BEC.

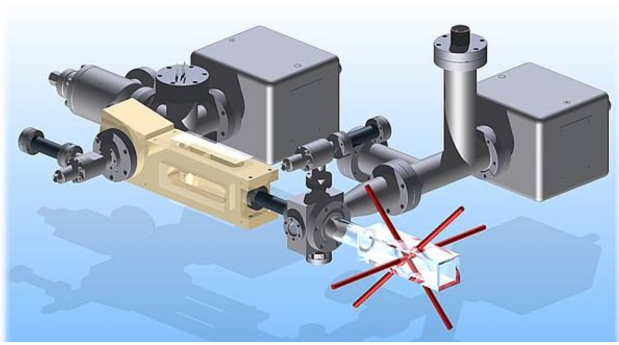

FIG. 1. Scheme of the setup.

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Towards a quantum gas of polar YbCs molecules

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The formation and study of ultracold polar molecules leads to many fascinating areas of study, including quantum computation and the behaviour of degenerate quantum gases of molecules.

This experiment aims to produce ground state YbCs molecules, using techniques such as magneto-association across Feshbach resonances [1] and Stimulated Raman Adiabatic Passage (STIRAP) [2]. The extra valence electron in ytterbium means that YbCs will have both electric and magnetic dipole moments in it's ground state, unlike bi-alkali molecules which have just an electric dipole moment. This additional degree of freedom in experiments makes it possible to explore interesting phenomena such as spin dependent interactions in lattices [3, 4].

This experiment is just beginning, therefore this poster presents current work towards developing the necessary lasers and vacuum system, as well as some theoretical background to the work.

[1] P.S. Żuchowski, J. Aldegunde and J.M. Hutson, *Phys. Rev. Lett.* **105** 153201 (2010)

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[3] A. Micheli, G. Pupillo, H.P. Büchler and P. Zoller, *Phys. Rev. A* **76** 043604 (2007)

[4] A. Micheli, G.K. Brennen and P. Zoller, *Nature Physics* **2**(5) 341 (2006)

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Mode Structure of Spontaneous Four-Wave Mixing

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I describe an experimental set-up that creates mode structure similar to that of a cavity, using backward four-wave mixing. Four-wave mixing has been widely investigated and used for creating photon pairs and correlated beams.

Our experiment is conducted using amplified spontaneous four-wave mixing in a hot rubidium vapour cell, where photons generated from two counter-propagating pump beams scatter in opposite directions. Further amplification of photons scattered near the pump axis leads to a bi-directional avalanche and even self-oscillation of the system, with the vapour cell acting like a mirrorless cavity. Slow-light propagation of the scattered photon pair can make the virtual cavity much longer than the length of the vapour cell.

I will include a summary of the theory behind the process and initial results which include the observation of the mode structure of the four-wave mixing effect, and comparison between this mode structure and that of a cavity.

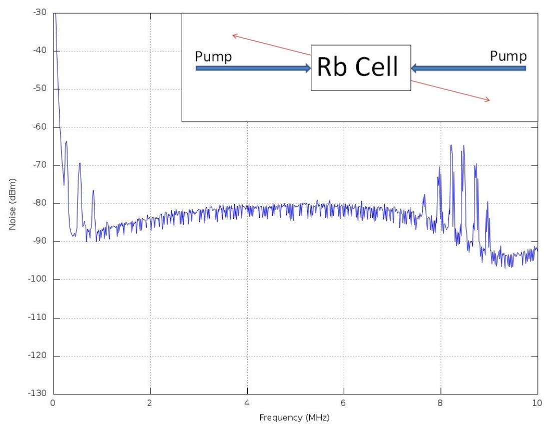

FIG. 1. The longitudinal mode structure of the system. The insert shows the experimental setup, with the blue lines being the pump photons and the red lines being the photons produced in the four-wave mixing process.

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Phase and visibility as a function of magnetic field in an atom interferometer

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We are using a lithium atom interferometer based on Bragg laser diffraction. The presence of magnetic field gradients affect the visibility and the phase of atomic fringes. We have set a compensator coil to correct the gradient of a main coil in order to be able to observe fringes (Fig.1) with a high field. We are presently investigating the effect of a change of laser frequency on the interference fringes. If the laser frequency changes, the diffraction process depending on the hyperfine states (F=1,2) is modified and the atomic fringes are affected [1]. We have developed a system based on frequency beats that allows us to know and stabilize the frequency of the stationary waves with accuracy. Thus we can force the laser frequency to jump to a precise frequency in order to quantify the observed effects on phase and visibility.

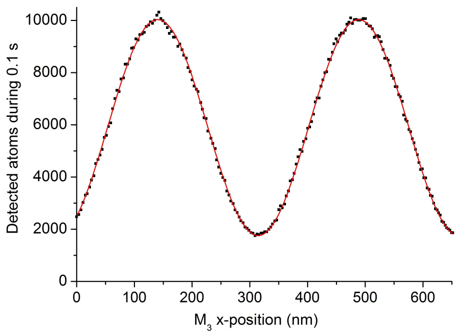

FIG. 1. Atomic fringes observed on the output of interferometer.

[1] M. Jacquey, A. Miffre, M. Buchner, G. Trenec and J. Vigue, *EPL* **77** 2 (2007).

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A compact and transportable cold atom inertial sensor for space applications

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We present the development and latest results of an airbone 0-gravity atom accelerometer. Atom interferometers achieve very high precision acceleration and rotation measurements both for tests of fundamental physics and onboard applications. We have developped a compact, robust and transportable cold atom inertial sensor to test the Univarsility of Free-Fall (UFF) during parabolic flights, where microgravity allows for longer interrogation times and better sensitivities.

Our system uses laser pulses to measure the acceleration of a cloud of cold ^{87}Rb atoms. The laser source is based on fiber optics and telecom technologies and can be operated in difficult environments [1]. The principal limitation in the plane is the vibrations, which we reject by correlating the atom sensor with an external mechanical accelerometer attached to the reference mirror. With this hybrid sensor, we have demonstrated a sensitivity of the order of 10^{-4} g [2], mainly limited by the mechanical accelerometer.

The next step, by adding another atomic species (^{39}K) to our system, is to perform a test of UFF. We have constructed a dual-wavelength laser system and performed simultaneous cooling of Rb and K in two species magneto-optic trap. We will then use the atom interferometer to measure the differential acceleration between the two atoms clouds in free-fall. This will be an important step towards a space-based test at the level 10^{-15}, such as the one planed in the frame of ESA's STE-QUEST mission [3].

[1] V. Ménoret et al, Dual-wavelength laser source for onboard atom interferometry, *Optics Lett.*, **36** 21 (2011)

[2] R. Geiger et al, Detecting inertial effects with airborne matter-wave interferometry, *Nature Communications*, **2** 474 (2011).

[3] STE-QUEST Mission. http://www.exphy.uni-duesseldorf.de/Publikationen/2010/STE-QUEST_final.pdf (July 2011)

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Three dimensional detection of single metastable helium atoms

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We are building a new experimental apparatus, in which we will be using a configuration of two z-stacked multi channel plates (MCP) with a delay line to detect single metastable helium atoms. Such a detection scheme will allow us to reconstruct the full three-dimensional gas after free-fall at the single atom level. At the Institut d'Optique in Palaiseau there already exists such an experiment, which delivers great results [1], however with the new experiment we aim to have detectors with a better spatial resolution than the current one. Also we are looking for ways to have a higher efficiency and to increase the flux saturation level of the detector. This implies working both on the characteristics of the MCPs as well as on the electronics used for processing the data.

To do so, we use UV light to test and calibrate the multi-channel plates in different configurations. We are investigating the influence of adding a layer of gold on the input plate and we research the effect of placing an additional voltage between the two stacked plates, which should aid in collimating the electron beam between the plates.
We find that the gold layer greatly increases the amplitude of the pulses generated on the delay line while keeping the width the same. This is beneficial for our ability to detect pulses and to separate signal from noise. Secondly we see that the implementation of the voltage between the plate decreases the pulse width and results in a lower resolution.

[1] M. Schellekens, et al. *Hanbury Brown Twiss effect for ultracold quantum gases*, Science **310**, 648651 (2005)

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Microwave Field Imaging Using Atoms

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We report on recent progress in using atoms to perform detailed imaging of microwave magnetic fields. Previous work has shown that atoms can be used to reconstruct microwave fields with high spatial resolution [1]. Microwave field imaging has important applications in industry, such as aiding in the development of monolithic microwave integrated circuits (MMICs), key components in devices ranging from mobile phones to superconducting quantum processors. Our current work focuses on improving the range of microwave frequencies over which the field is imageable. Previous work was able to measure fields at the fixed frequency of 6.8 GHz, corresponding to the hyperfine ground state splitting of ^{87}Rb. The new setup will use a tunable laboratory magnetic field to Zeeman-shift this hyperfine splitting, allowing fields over a broad range to be imaged, up to 25 GHz or more. The imaging of fields above 18 GHz is of particular interest for potential future commercial applications.

[1] P. Böhi, M. F. Riedel, T. W. Hänsch, and P. Treutlein, *Appl. Phys. Lett.* **97** : 051101 (2010).

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Strongly Repulsive Fermi-Fermi Mixture

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Research on Fermi gases in the past decade mainly focused on ground-state properties. Presently, there is a growing interest to investigate strongly interacting Fermi gases on the repulsive side of a Feshbach resonance, where new quantum states, such as magnetically ordered states, are predicted to occur [1]. The realization of such systems is challenging, since they are intrinsically unstable towards decay into the energetically lower lying molecular state [2]. However, we found that our system, consisting of a repulsively interacting fermionic mixture of ^{40}K and ^{6}Li atoms, is rather long-lived [3], which is due to the character of the Feshbach resonance that we exploit for interaction tuning. This finding motivated us to investigate the possibility of observing magnetic order in our system. Here, we present first results of the investigations of the in-situ distributions of ^{6}Li and ^{40}K, the kinetic energy of the ^{40}K component and of the lifetime of the strongly interacting clouds. Furthermore, we used RF spectroscopy to measure the interaction energy of ^{40}K atoms in the ^{6}Li Fermi sea. These results suggest that K and Li are macroscopically separated in the trap.

[1] Jo, G.-B. *et al.* Itinerant ferromagnetism in a Fermi gas of ultracold atoms. *Science* **325**, 1521-1524 (2009).
[2] Sanner, C. *et al.* Correlations and pair formation in a repulsively interacting Fermi gas. *arXiv:1108.2017.*
[3] Kohstall, C. *et al.* Metastability and coherence of repulsive polarons in a strongly interacting Fermi mixture. *arXiv:1112.0020.*

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Second-generation apparatus for Rydberg-atoms in an ultracold gas

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The giant size and large polarizibility of Rydberg-atoms, resulting in strong long-range Rydberg-Rydberg interactions, make them ideal for studying many-body cooperative effects. In particular, the investigation of dense, ultracold Rydberg-gases in a magnetic trap has opened the door to novel effects such as Rydberg-molecules. Here, we present a new experimental apparatus for the creation and dynamic study of Rydberg-atoms in dense, ultra-cold atomic ensembles. Specific design goals of this new setup are single ion-detection capability, sub-micron optical resolution, and high flexibility in creating both magnetic and optical trapping potentials. We discuss how these different aspects are combined in a single, compact experimental realization.

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Optical trapping of neutral mercury

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Laser-cooled mercury constitutes an interesting starting point for various experiment inparticular in light of the existence of bosonic and fermionic isotopes in relatively high natural abundance. On the one hand the fermionic isotopes could be used to develop a new time-standard based on a lattice optical clock employing the $^1S_0$ - $^3P_0$ transition at 265,6 nm. Another interesting venue is the formation of ultra cold Hg-dimers employing photo-association and achieving vibrational cooling by employing a special scheme.

A Yb:disc laser at 1014.8 nm is used for the trapping laser which is frequency-doubled twice to deliver up to 280 mW at 253.7 nm for the repump-free cooling process. For the photo-association process a fiber amplified and frequency quadrupled ECDL at 1016.4 nm is being setup which results in a large tuning range in the UV.

Due to the required power in the UV a power of about 5W is needed in the fundamental. Since a linewidth of less than 1,27 MHz given by the cooling transition some care must be taken. We have successfully trapped the bosonic ^{202}Hg as well as the fermionic ^{199}Hg isotopes and have performed first temperature measurement. Currently, we are focussing on improving the reliability of the cooling and also of the photo-association-spectroscopy laser system. We will report on the status of the experiments.

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Quantum Register Initialization via Deterministic Atom Sorting In Optical Lattices

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We report on recently developed techniques to perform deterministic sorting of atoms in 1D optical lattice potentials. It is of great interest to prepare predefined patterns of individual atoms, which can be eventually employed as quantum registers for computational purposes or as starting configurations for quantum simulators. For example, one can perform two-qubit operations in the form of controlled coherent collisions to produce entanglement.

We show how state-dependent transport of Cs atoms in a 1D optical lattice, which has been first used to demonstrate discrete quantum walks [1], can be conveniently employed to sort atoms into predefined positions. This procedure involves several steps: first loading the atoms into random lattice sites, imaging their positions with single-site resolution, individually addressing and spin-flipping the targeted atoms, and finally, depending on their positions as well as spin, transporting them to their desired, final positions. This requires our automation and control system to implement real-time feedback within the experimental sequence. We will consider applying error correction schemes in order to perform atom sorting over longer distances and larger ensemble of atoms.

[1] M. Karski, L. Frster, J.-M. Choi, A. Steffen, W. Alt, D. Meschede, A. Widera , *Science* **325** 174 (2009).

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Elastic and Inelastic Collisions of Single Cs Atoms in an Ultracold Rb cloud

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Ultracold gases doped with impurity atoms are promising hybrid systems that pave the way for investigation of a series of novel and interesting scenarios: They can be employed for studying polaron physics, the impurity atoms can act as coherent probes for the many-body system, and the coherent cooling of neutral atoms containing quantum information has been proposed.

Here, we immerse single and few Cs atoms into an ultracold Rb cloud. Elastic collisions lead to rapid thermalization of both sub-systems, while inelastic collisions lead to a loss of Cs from the trap. When thermalized, the impurity atom is localized inside the Rb gas. The ultracold Rb gas remains effectively unaffected by the interaction with the Cs impurity atoms. The poster will present details of the experimental setup, sequence and data analysis needed to extract the interspecies scattering length and three-body loss coefficient from the thermalization dynamics and loss rates measured.

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Few-fermion systems in multiple well potentials

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With our current experimental setup it is possible to reliably prepare systems with up to 10 fermionic ^{6}Li atoms in a single optical microtrap. The inter-particle coupling can be tuned to study interacting few-particle systems inside the potential.

We will extend the current setup in order to create a small array of such microtraps which will allow us to explore systems in periodic potentials. We present our progress creating this setup. The multiple wells will be created using a high resolution objective with a NA of 0.6 which is optimized for two wavelengths, 1064nm and 671nm. The high numerical aperture ensures a high detection efficiency of the fluorescence signal at 671nm. Starting point of our experiments will be a ground state system in one microtrap. It will be split adiabatically into a multiple well potential using a 2-D acousto-optical deflector. With this setup one can analyze the tunneling behavior of particles in a finite fermionic system. This allows us to examine magnetic ordering in ultracold Fermi gases.

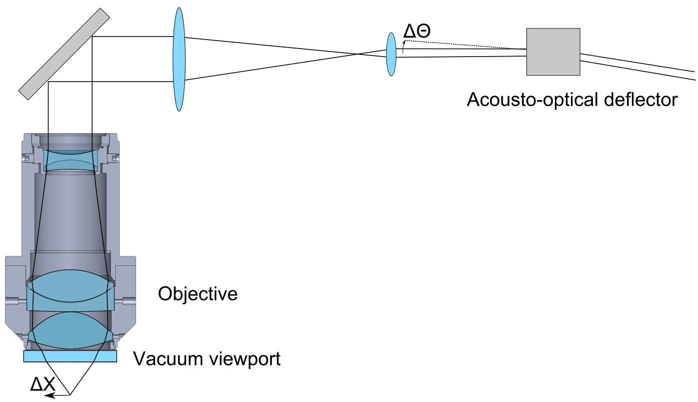

FIG. 1. Setup with AOD and high NA objective. A shift in $\Delta\Theta$ results in a shift Δx up to 8μm of the focus.

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Extracting many-body eigenstates from dynamics for 1D complex quantum systems

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Using Fourier transform directly on a time series generated by unitary evolution, we extract full, many-body eigenstates from a dynamically created wavepacked. The method is general for 1D quantum complex systems (those that can be described by DMRG/TEBD). We test the method for the Bose-Hubbard hamiltonian by analyzing excitations appearing in the trapped gas of ultracold bosons as a result of quench through MI-SF transition or time-dependent modulation of the lattice. The method provides not only information that given energy is an eigenenergy, but also accurate eigenstate as a wavevector enabling further investigation. Entanglement properties of the vectors are investigated.

[1] M. Lacki, D. Delande, J. Zakrzewski *Extracting Information from Non Adiabatic Dynamics: Excited Symmetric States of the Bose-Hubbard Model*, Acta Physica Polonica 12/2011 (2012)
[2] M. Lacki, D. Delande, J. Zakrzewski, *Characterization of excited states of ultracold atoms in optical lattices*, http://arxiv.org/abs/1106.4906, 1911).

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Mechanical stability of laser system components

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Institut für angewandte Physik TU Darmstadt,
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In this poster, we present stability tests of laser system components for high precision quantum gas experiments on different microgravity platforms. Special challenges in the construction of the laser system are posed by the vibrations and accelerations found during the launch phase of sounding rockets or in droptower experiments. Compact subcomponents and an integrated subsystem consisting of a fiber coupled master-oscillator power amplifier (MOPA) have been tested under extreme conditions to investigate their mechanical stability. These tests are especially crucial for developing a laser system for further experiments in space. The QUANTUS and LASUS project are supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR 50WM 1131-1137 and 0937-0940.

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Doppler Cooling a Microsphere

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The cooling of levitated silica microspheres via the velocity dependent scattering force from whispering gallery mode (WGM) resonances is described[1]. The technique is comparable to Doppler cooling as the center of mass motion is damped using red detuned light from the WGM resonance. This differs from conventional cavity cooling[2][3] as the microsphere acts as its own high Q ($> 10^8$) cavity. Initial experiments describe characterising the WGM resonances in a microsphere formed from, and attached to, commercial optical fibre. It is calculated that once the microspheres are trapped within an optical tweezer set-up it will be possible to cool the center of mass motion down to the micromechanical quantum ground state with a cooling time of approximately 25s using a 773nm laser.

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[1] Barker, P.F. *Doppler Cooling a Microsphere*, **Physical Review Letters 107** 7 (2010).
[2] Barker, P.F. *Cavity cooling of an optically trapped nanoparticle*, **Physical Review A: 81** 2 (2010).
[3] Pender, G. A. T., Barker, P. F., Marquardt, F., J. Millen and Monteiro, T. S. *Optomechanical cooling of levitated spheres with doubly-resonant fields* arXiv:1107.0686v1 (2011). (Accepted in **Physical Review A: Rapid Communications**).

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iSense - A portable ultracold-atom-based gravimeter

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The iSense project aims to bring the latest developments in ultracold atom science to practical applications by developing the technology that will turn laboratory-based instrumentation into portable and robust instruments and sensors.

One of the goals of the project is to build a high precision portable gravity sensor to use as a demonstration of the applications of ultracold atoms outside the laboratory. The challenges are twofold. Firstly, all the components, including the vacuum chamber, laser systems and electronics must be constructed to be compact, low power and strong. Secondly, the reduced size calls for a novel interferometry scheme that gives high precision without large fall times usual to these experiments. Investigations have already taken place into this area [1] using optical lattices.

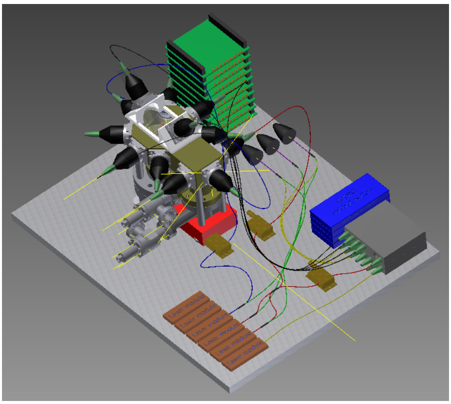

FIG. 1. Design of complete iSense system

[1] G. Tackmann, B. Pelle, A. Hilico, Q. Beaufils and F. Pereira dos Santos, *Phys. Rev. A* **84** 6 (2011).

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Diagnostics of laser induced plasma in double laser pulse configuration

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Investigations of laser induced plasma (LIP) are carried out by scientific community for several years. It is an object of great interest since it gives insight into fundamentals of laser-mater interactions, as well as due to its numerous possible applications, like for example Laser Induced Breakdown Spectroscopy (LIBS). Despite great experimental efforts and numerous works on modeling of laser induced plasmas the understanding of its generation and evolution is not yet complete. The characteristics of the laser induced plasma can be extremely variable in space and time, which makes LIP investigations a very complex task.

Recently, great interest is given to modifications of plasma plume by additional laser pulse, used in order to increase signal-to-noise ratio in LIBS technique, and therefore to improve its sensitivity. Additional energy applied to the system by interaction with another laser pulse can significantly change plasma properties. Those effects depend strongly on delay between pulses, and their parameters as well as geometry of experimental setup.

In presented experimental configuration one laser pulse creates breakdown in gas while the second pulse is used to probe created plasma by laser light scattering methods. Unlike emission spectroscopy, active laser methods are characterized by good spatial and temporal resolution and the interpretation does not require strong assumption about the thermodynamic state of the plasma. Probing pulse can be simultaneously used for plasma modifications as well as for its diagnostics. Our experimental setup consists of two ns-pulse Nd:YAG lasers operating at 532 nm, aluminum chamber filled with gas at atmospheric pressure and spectrometer with gated ICCD camera. All elements are temporally synchronized by digital delay generator, enabling good temporal resolution of performed measurements.

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Towards quantum simulations in a triangular surface trap

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Ions confined in linear Paul traps have proven to be ideally suited for quantum information processing and quantum simulations [1-4]. While many proof-of-principle experiments have been realized in these traps with up to tens of ions [4], scalability of ion based quantum processors and simulators remains a major issue.

To overcome the limitations of one-dimensional linear Paul traps, a novel type of surface traps with a triangular geometry of the electrodes has been developed [5]. While in this new approach the ions will be stored in individual minima of the potential, the mutual distances are kept small enough to provide sufficient coupling strengths between them. This should open up for quantum simulation experiments in two dimensional lattices [6]. We will report on the current status of the experimental setup and will present first proposals for quantum simulations that could be envisioned in this new system.

[1] A. Friedenauer *et al.*, Nature Phys. **4**, 757-761 (2008)
[2] H. Schmitz *et al.*, PRL **103**, 090504 (2009)
[3] F. Zähringer *et al.*, PRL **104**, 100503 (2010)
[4] R. Islam *et al.*, Nature Comm. **2**, 377 (2011)
[5] R. Schmied *et al.*, PRL **102**, 233002 (2009)
[6] A. Bermudez *et al.*, RL **107**, 150501 (2011)

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Towards optical strontium clock

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We report on the status of cold strontium apparatus for the optical atomic clock in the Polish National Laboratory of AMO Physics in Toruń (KL FAMO). The system allows to collect up to 10^9 ^{88}Sr atoms at about 1 mK in the blue MOT. We report on construction of a microcontroller based setup for laser stabilization to a clock line.

Described apparatus is part of clock system (FIG. 1) consists of: (1) a Zeeman slower and magneto-optical traps (at 461 nm and 689 nm) [1], (2) a frequency comb, and (3) a narrow-band laser coupled to an ultra-stable optical cavity [2]. So far, all parts of the experiment are working and the whole system is tested at the $^1S_0$–$^3P_1$ 689 nm optical transition in ^{88}Sr atoms with 7 kHz linewidth.

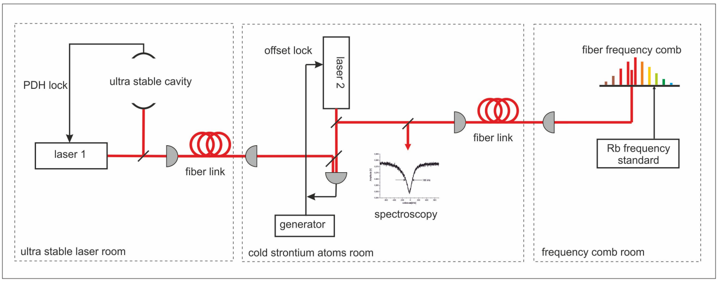

FIG. 1. Setup of the clock system.

[1] M. Bober, J. Zachorowski and W. Gawlik, *Designing Zeeman slower for strontium atoms - towards optical atomic clock*, Optica Applicata, **40**, 547 (2010).
[2] D. Lisak *et al.*, *Ultra narrow laser for optical frequency reference* submitted to Acta Physica Polonica A

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Ultracold Quantum Gases in a High-Finesse Optical Ring Cavity

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This new experiment aims to study the cooperative behaviour of quantum gases in a high finesse optical ring cavity. Initial experiments will focus on coherent scattering of light into the cavity mode, both for improving laser cooling techniques and for studies of spatial self-organisation and its relation to Dicke super- and sub-radiant scattering. Motivation for using a ring cavity lies in the fact in this geometry, separate modes exist for light travelling in the two counter-propagating directions. We can drive both directions (and modes) with photons by irradiating the ring cavity with two laser beams, one for each direction. A consequence of this is that the counter-propagating modes have separate photon budgets, implying that a scatterer located inside the mode volume can scatter photons from one mode to the other. Additionally, a standing wave inside the cavity is free to rotate, unlike for linear cavities, as the phase is not fixed by boundary conditions at the mirror surfaces. This will allow us to study the influence on the atomic dynamics of collective coupling to the cavity field, both in static harmonic potentials and accelerating optical lattices, where Bloch oscillations and dynamical localisation can occur.

As well as giving an overview of our experiment l will report on initial efforts to build an optical transfer cavity to be used for stabilising far off-resonant lasers in the experiment. This involves generating an error signal which will correct the laser frequency when it differs from that of an exact cavity resonance. We are testing generalisations of the confocal resonator which exploit the rational values of the Gouy phase shift for certain cavity lengths, leading to significant mode frequency degeneracies, and therefore effectively cutting the free spectral range by any desired integer value. This reduction in modes spacing is useful for providing laser lock points with relatively fine resolution. I will discuss practical limits to how small the spacing can be, and assess the dependence of the phase-sensitive error signal on modulation frequency.

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Towards ultra cold Potassium atoms in a high-finesse ring cavity

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I describe the design of an apparatus to study ultra cold potassium atoms in a high-finesse optical ring cavity. These experiments will initially focus on coherent scattering of light into the cavity mode for improving laser cooling techniques, in particular 'cooling without spontaneous emission'. The influence on the atomic dynamics of collective coupling to the cavity field will also be studied, both in static harmonic potentials and accelerating optical lattices, where Bloch oscillations can occur. A necessary ingredient for these experiments is to precisely stabilize lasers near the potassium cooling transitions with the help of appropriate spectroscopy techniques. Compared to rubidium and cesium, potassium spectroscopy is complicated by isotope shifts which are on the order of the Doppler temperature, and hyperfine structure on the order of the natural linewidth. I describe a variety of spectroscopic methods we have tried, and compare their usefulness for laser cooling experiments. Of particular interest is modulation transfer spectroscopy (MTS)[1], whose nonlinear origin eliminates the broad Doppler structure of conventional frequency modulation spectroscopy (FMS). Although conventional wisdom suggests MTS strongly favours cycling transitions (which are effectively absent in potassium), we observe a dominant MTS signal at the ground-state crossover resonance of 39K. We additionally investigate modulation-free methods based on polarisation spectroscopy and split beam spectroscopies, those include very simple optical set-ups, resulting in a high-amplitude, high-resolution and optimum slope signal. Advantages and limitations of the various methods are described in detail.

[1] L. Mudarikwa, K. Pahwa and J. Goldwin, *arXiv:1112.4998v1 [physics.atom-ph]* (2011).

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Setup of a Laser system for cooling of Li6 atoms in order to prepare a degenerate Fermi gas

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We are building a new setup for the preparation of a degenerate Fermi gas of lithium. The first step for this is the realization of a Magneto Optical Trap (MOT). For this we need stabilized lasers, which we lock at the wavelength of the lithium crossover peak (see Fig. 1). My task is to create a laser system for the cooling of lithium atoms and for the MOT. I will present our laser cooling scheme and our progress towards the lithium MOT.

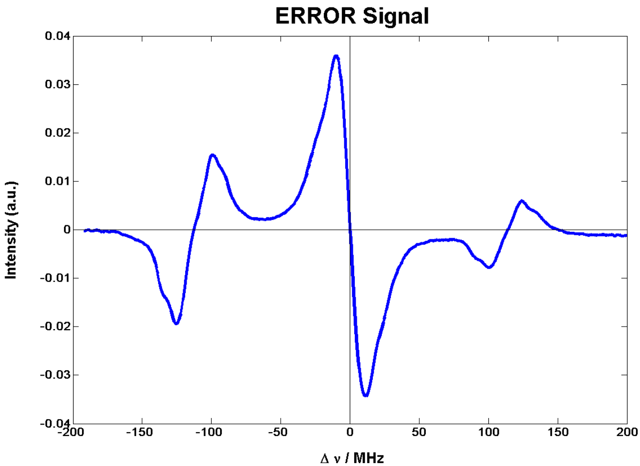

FIG. 1. Error signal for locking the Laser at the crossover peak of Lithium.

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Single Permanent Magnetic Microtraps

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[2] *Universitat Ulm, Institut fur Quantenmaterie, D-89069, Ulm, Germany.*

We introduce two permanent magnetic microstructures for creating single and double well magnetic microtraps for direct evaporative cooling of neutral atoms without using spin flips to gain Bose-Einstein condensation (BEC). A bias magnetic field is applied to vary the trap frequencies, minimum and depth. Using a non-homogeneous magnetic bias field along the z direction, we can also produce asymmetrical double well.

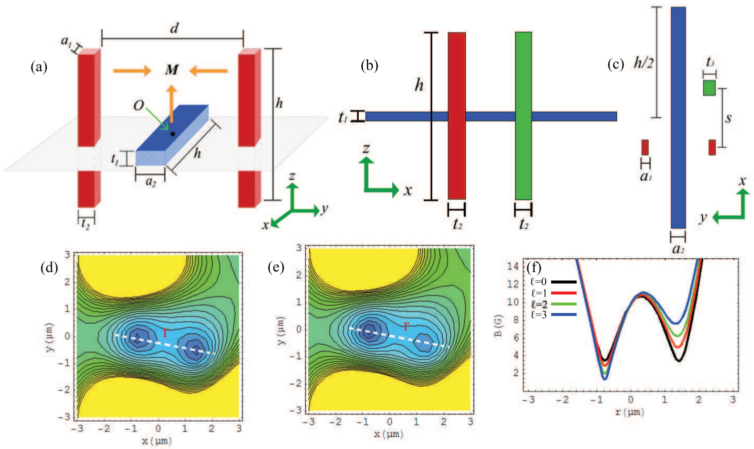

FIG. 1. (a) Schematic of a H-like-shaped permanent magnetic microtrap. The middle (blue) slab has a thickness of $t_1 = 200nm$ and thickness of the parallel (red) ones is $t_2 = 250nm$. Also, separation between the parallel slabs is $d = 9.75\mu m$. Magnetization is in the direction shown in the figure and has a magnitude of $4\pi M \sim 800$G. Slabs have length of $h = 80\mu$m and widths of $a_1 = 2\mu m$ and $a_2 = 3\mu m$. (b) and (c) Schematic of another H-like-shaped permanent magnetic microtrap. Here, we have added a slab with $t_3 = 500nm$ and $s = 5\mu m$ to the first configuration of magnetic slabs to produce double well permanent magnetic microtrap. (d) and (e) Contour plots of B in the xoy plane. (d) shows a symmetric double well. (e) By applying the bias field $\mathbf{B} = B_z\hat{z} = lx + c$ an asymmetrical double well is formed, where l and c are arbitrary constants. (f) B as a function of r, defined in (e). The asymmetry depends on the parameter l.

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Entangled matter waves for sub-shot-noise interferometry

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Matter wave optics with ultracold samples has reached the point where nonclassical states can be prepared and their fascinating properties can be explored. In optics, parametric down conversion is routinely used to generate light with squeezed observables as well as highly entangled photon pairs. The applications of these nonclassical states range from fundamental tests of quantum mechanics to improved interferometers and quantum computation. Therefore, it is of great interest to realize such nonclassical states with matter waves. Bose-Einstein condensates with non-zero spin can provide a mechanism analogous to parametric down conversion, thus enabling the generation of nonclassical matter waves. The process acts as a two-mode parametric amplifier and generates two clouds with opposite spin orientation consisting of the same number of atoms. At a total of 10000 atoms, we observe a squeezing of the number difference of -7 dB below shot noise, including all noise sources. A microwave coupling between the two modes allows for an investigation of the interferometric sensitivity. We find that the created state is entangled and useful for sub-shot-noise interferometry.

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Path Integral Monte Carlo Simulations of condensed phases of $^4\boldsymbol{He}$

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Path-Integral Monte Carlo is a sophisticated Monte Carlo method for simulating the behavior of many-body quantum systems. It is particularly useful for systems composed of identical Bosons. In this work we apply this method, as implemented in the PIMC++ package, to condensed phases of 4He. In addition to properties as the total energy and the specific heat of the liquid phase, we compute the condensate fraction and superfluid density as a function of temperature and compare the results to experimental data. Furthermore, we also study properties of several crystalline phases , including the HCP phase. In particular, we determine the elastic constants of this structure [1] and compare the results to recent insight obtained using a variational wave function approach [2].

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All optical rubidium BEC setup

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Optical dipole traps, which store atoms with all spin components rather than just the low-magnetic-field seeking spin states of magnetic traps, allow studies of spinor Bose-Einstein condensates (BEC). Spinor BEC [1], in which atoms may occupy all Zeeman sub-levels of the hyperfine angular momentum state, give access to interesting static and dynamical properties of a magnetic superfluid, such as spinor dynamics, spin domains, metastability, quantum tunneling and vortex dynamics.

We present an experimantal setup for producing BEC, that is currently constructed. The quantum degenaracy will be reached by all-optical runaway evaporation cooling in a misaligned-crossed-beam, far off-resonance optical dipole trap [2]. We aim at production of ^{87}Rb condensates of up to 10^6 atoms within a few seconds long cycle. That will allow us to efficiently study spinor BECs.

Finally, we plan to use the apparatus also for studying electromagnetically induced transparency and nonlinear magneto-optical effects.

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Pre-thermalization in a many-body quantum system

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We employ measurements of full quantum mechanical probability distributions of matter-wave interference to characterise the relaxation dynamics of a coherently split one-dimensional Bose gas. This new tool allows us to obtain unprecedented information about the evolution of this non-equilibrium system. The understanding of such non-equilibrium dynamics in many-body quantum systems is still elusive despite its significance for many areas of physics. An interesting new phenomenon that has been suggested in the context of high-energy heavy ion collisions is pre-thermalization[1]. Its basic concept is that certain system parameters equilibriate on a much shorter timescale than the general thermalisation, leading to a quasi-stationary transient state that differs from the real thermal equilibrium. Our experimental measurements[2] show that following an initial rapid evolution, the full distributions reveal the approach towards such a pre-thermalized state that is thermal-like in form and is characterized by an effective temperature eight times lower than the initial equilibrium temperature of the system before the splitting process.

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A Two-Level Quantum System Immersed in a Bosonic Bath

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We present studies on a motional two-level quantum system immersed in a BEC of Na atoms. In our experiment fermionic Li atoms are exposed to a species-selective one dimensional lattice. By controlled shaking of the lattice the lithium atoms can be transferred coherently between first and second Bloch band, representing the ground and excited state of the two-level system. We measure the quasi-momentum of the lithium atoms to determine the population of the different Bloch bands. Therefore the lattice potential is ramped down adiabatically to conserve the band population and the quasi-momentum is detected by a subsequent time of flight measurement.

Due to the sodium background, relaxation of the second Bloch band into the first Bloch band can be observed. To gain further insight into this dissipative process we also perform Ramsey spectroscopy. Thereby we study the decay of the coherent superposition of first and second Bloch state due to the interaction with the background.

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Superactivation of Superoperator

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The superactivation of quantum channels, which are described by superoperators may be the starting-point of a large-scale revolution in quantum information theory and in the communication of future quantum networks. The term of superactivation of quantum channels implies the fact that a possible combination of quantum channels with zero capacity exists, where individually totally useless channels can activate each other, and their joint capacity will be greater than zero. Recently, G. Smith, Horodecki et al. [1] have found one of possible combinations for superactivation of the capacity of quantum channels, and they have opened the debate on the existence of other possible channel combinations. Main goal of our project presented on this poster is finding a smallest quantum channel in the sense of complexity, in which superactivation can be realized. Our work concentrates around symmetrical one-qubit quantum channels as assisted channels joined with Horodecki's channels as a main communication medium. We give an algorithmic solution to the problem. Our method is efficient algorithmic solution to discover the still unknown combinations to determine the superactivation of quantum channels, without the extremely high computational costs.

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Frustration and time reversal symmetry breaking for a Bose-Fermi mixture

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The modulation of an optical lattice potential that breaks time-reversal symmetry enables the realization of complex tunneling rates in the corresponding tight-binding model. A superfluid Fermi gas and a Bose-Fermi mixture of bosonic molecules and unbound fermions in a triangular lattice potential with complex tunnelings is considered.

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Stabilisation of a femtosecond laser frequency comb

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The production of Rb_2 ground state molecules with a STIRAP technique requires extremely stable lasers with a fixed phase relationship. Currently, the best way to achieve this stability is to lock both lasers to a frequency comb, which itself must be stabilized. We use a TOPTICA FFS laser system with an Er:fiber ring cavity, producing a comb ranging from about 1000 nm to 2100 nm. The repetition frequency is locked to a 100 MHz oscillator, which itself is phase locked to a stable Rb atomic clock. Our new optical scheme allows us to measure the carrier-envelope-offset frequency by exploiting the imperfect polarisation of the comb's emitted light. The setup is very compact, consisting of only a BBO-crystal, a polarising beam splitter, two lenses and a photodiode. The stable comb can then be used to measure a beat signal between itself and the lasers used for the molecular spectroscopy. This beat signal is used to stabilize the spectroscopy lasers to any of their accessible wavelengths. I will present our comb stabilization scheme as well as first results on the stabilization of the spectroscopy lasers to the comb.

---

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A single-atom quantum memory

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Quantum networks are the basis of distributed quantum computing architectures and quantum communication. For the implementation of universal quantum networks, efficient photonic quantum memories are required that are capable of receiving, storing and retrieving quantum information. We report on the most fundamental implementation of such a memory: A single atom embedded in a high-finesse optical cavity[1]. The quantum information to be stored is encoded in the polarization state. A Raman adiabatic passage maps this input state onto the internal Zeeman states of the single atom. After a user-selectable storage time the initial state can be faithfully recreated by the emission of a single photon.

We will discuss our progress towards the implementation of an elementary cell of a quantum network by linking two independent single atom-cavity systems. This setup will allow for the implementation of in principle deterministic networking schemes like the transfer of quantum information and remote entanglement between distant nodes by exchange of a single photon. We will discuss the prospects of establishing a scalable architecture for quantum networks with particular emphasis on the potential of fiber-based cavities.

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Tests of Bell inequalities for entangled cadmium atoms

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In recent years experiments with entangled states have become increasingly interesting. Entangled state is a correlated quantum state which has a non-classical feature: the state of the whole system is better characterized than the states of individual parts of the system. Due to their nature entangled objects have a whole spectrum of applications, from tests of fundamental laws of quantum mechanics (Bells inequalities), via quantum information processing (quantum computer), towards quantum cryptography (unbreakable quantum ciphers). Here, we present an experiment based on proposal of Fry et al. [1]. A purpose of the experiment is to create pairs of entangled ^{111}Cd atoms with regard to their nuclear spin orientations. The $^{111}Cd_2$ dimers, produced in supersonic molecular beam, are irradiated by two dye-laser pulses and undergo photodissociation in a process of stimulated Raman passage. Thanks to the $^{111}Cd_2$ characteristics (one-half nuclear spin of ^{111}Cd and zero total orbital momentum of $^{111}Cd_2$), the ^{111}Cd atoms are produced with anti-parallel nuclear spins and with zero orbital momenta. In the experiment, orientations of nuclear spins are going to be measured using spin-state-selective two-photon excitation-ionization method [2]. Consequently, it will be possible to experimentally corroborate an existence of entanglement between ^{111}Cd atoms and test of Bells inequality for atoms in the future.

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The project is financed by the National Science Centre according to the contract no. UMO-2011/01/B/ST2/00495.

Spectroscopy in photonic crystal fibres

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Photonic crystal fibres are special optical waveguides with various specific capillary structures along the fibre. That microstructure makes it possible to introduce various media (gas or liquid) into the fibre. Thanks to that, light transmitted through the fibre is coupled to the mediums atomic or molecular states and allows to perform spectroscopic measurements inside the very specific long and thin cuvettes. The length of such cuvettes may reach several meters and their typical diameters are about few micrometers. Under such conditions surface effects, like capillary forces or evanescent wave absorption, need to be taken into account. With proper understanding of all such effects, the photonic crystal fibres should allow one to develop new methodology of sensitive atomic and molecular spectroscopy.

We will present our attempts to measure fluorescence and absorption signals of organic dyes introduced into the photonic crystal fibres, especially suspended core fibres. Preliminary studies demonstrate an increased sensitivity of such absorption measurements relative to the standard cuvettes [FIG.1].

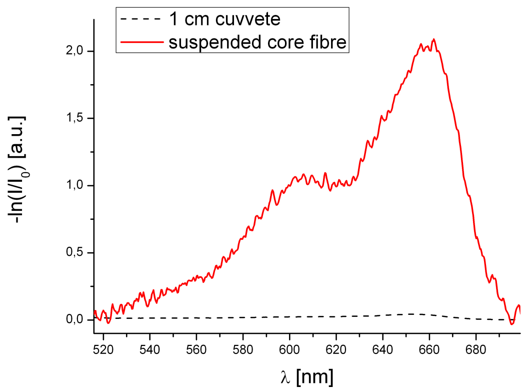

FIG. 1. The absorbance spectrum of 0,2μM solution of oxazine 725 perchlorate in water, measured in a 1 cm cuvette and in a 23 cm long piece of suspended core fibre.

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Project of two-photon photoassociation in ultracold Rb and Hg mixture

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The photoassociation is a sophisticated technique in atomic and molecular spectroscopy which can provide experimental data inaccessible for other molecular spectroscopic methods. Within this project we will use the photoassociation process to create ultracold homo and heteronuclear molecules (Rb-Rb and Rb-Hg).

Another purpose of this project is to take advantages of two-photon transition (5^2S → 7^2S) in Rb to induce optical Feshbach resonances. A small probability of this transition will allow us to reduce losses in our system efficiently.

Particular attention will be paid to the part of the experiment setup responsible for stabilizing and scanning of the laser system which will drive the photoassociation transition.

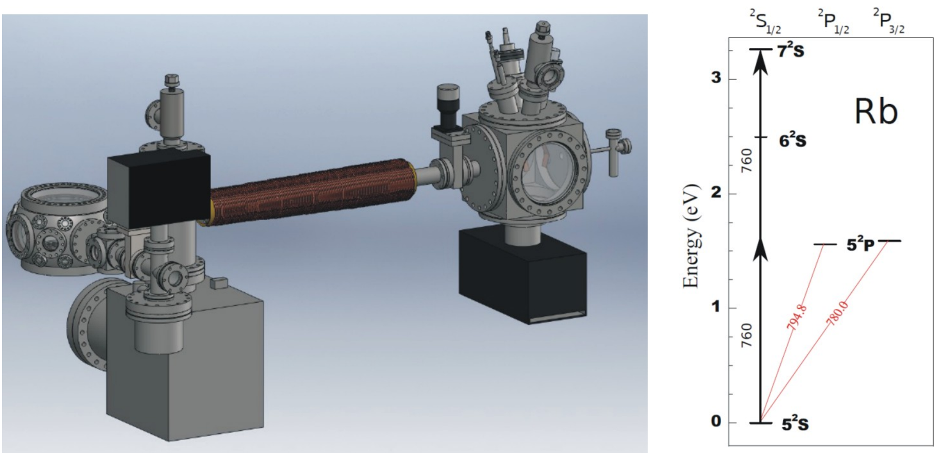

FIG. 1. The first picture (on the left side) presents vacuum system of our experiment, while the second illustrates the 5^2S → 7^2S two-photon transition in Rb.

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