YAO 2015

The 21st international
Young Atom Opticians conference
at ETH Zürich, Switzerland
April 19-24, 2015

OFFICIAL PROGRAM

Zürich, April 2015

Dear YAO participants,

we warmly welcome you to the 21st YAO conference in Zurich! The Young Atom Opticians (YAO) conference is a yearly international meeting for young researchers in the fields of quantum optics, quantum computation and quantum gases.

The YAO conference follows a long tradition and has been hosted in many cities all over Europe. This year's 21st edition will take place in Switzerland for the first time and is hosted by the quantum optics group at ETH Zurich. We are looking forward to a week full of interesting discussions, talks and poster presentations. In addition, there will be time to get in touch outside the conference, to socialize with the other participants and build new friendships. We will do our best to make this week as enjoyable as possible for all of us.

We wish you an exciting conference and a memorable time in Zurich!

Your YAO 2015 organization committee

Lorenz Hruby, Dominik Husmann, Martin Lebrat, Julian Leonard, Michael Messer and Andrea Morales

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Luca Bayha University of Heidelberg
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Moritz Hambach Imperial College London
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3:30 pm **Coffee break** HIT foyer

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Simone Donadello University of Trento
Solitonic vortices in Bose-Einstein condensates

Camille Frapolli Collège de France
Spin-nematic order and phase locking in antiferromagnetic spinor condensates

Simona Scaffidi Abbate University of Florence
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Simon Balthasar Jäger Saarland University
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Nishant Dogra ETH Zürich
Extended Bose-Hubbard model with cavity-mediated long-range interactions

Julia Benedikter Max-Planck Institute for Quantum Optics
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Gordon McDonald Australian National University
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Logan Richardson University of Hanover
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Pierre Dussarrat Institut d'Optique Palaiseau
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Pau Farrera Institut de Ciencies Fotoniques
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Valentina Caprara Vivoli University of Geneva
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Sebastian Scherg Max-Planck Institute for Quantum Optics
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Squeezed Baryons in synthetic dimensions

Neven Santic University of Zagreb
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Vito Giovanni Lucivero Institut de Ciencies Fotoniques
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Talks: Monday, April 20

Tilman Esslinger, ETH Zürich

Tilman Esslinger received his PhD in physics from the University of Munich and the Max-Planck Institute for Quantum Optics in 1995. In his doctoral research he worked under the supervision of Theodor Hänsch on subrecoil laser cooling and optical lattices. Further research included pioneering work on atom lasers, long-range phase coherence in Bose-Einstein condensates and the realization of the superfluid to Mott-insulator transition with a Bose gas in an optical lattice. In October 2001, he was appointed full professor at ETH Zürich, where he conducted research on one-dimensional quantum gases, Fermi-Hubbard models with atoms and of quantum gas experiments with cavity quantum electrodynamics.

The work of Esslinger and his group has stimulated an interdisciplinary exchange between the condensed-matter and quantum-gas communities. Recent notable results include the development of a quantum simulator for graphene, the observation of the Dicke quantum phase transition with ultracold atoms in an optical cavity, as well as the creation of a cold-atom analogue of mesoscopic conductors. In 2015, his group is hosting the YAO conference.

A cold grip on topology and transport with atoms

The remarkable advances in cooling and manipulating atomic gases have opened up new avenues to explore fundamental concepts in quantum many-body physics. Control over parameters at a microscopic level makes it possible to tailor the properties of the experimental systems almost at will. In my talk I will review some ideas that influenced quantum gas experiments. To illustrate the recent progress in creating topologically non-trivial systems, I will show how time-reversal symmetry can be broken in an optical lattice of honeycomb geometry. This enabled us to realize the topological Haldane model [1, 2]. I will also report on a new generation of experiments in which the conduction of neutral atoms through single and multimode tubes is studied in both normal and superfluid regimes [3–6].

[1] F.D.M. Haldane, *Phys. Rev. Lett.* **61**, 2015-2018 (1988)
[2] G. Jotzu, M. Messer, R. Desbuquois, M. Lebrat, T. Uehlinger, D. Greif, and T. Esslinger, *Nature* **515**, 237 (2014)
[3] J. - P. Brantut, J. Meineke, D. Stadler, S. Krinner, and T. Esslinger, *Science* **337**, 1069 (2012)
[4] D. Stadler, S. Krinner, J. Meineke, J. - P. Brantut, and T. Esslinger, Nature 491, *Nature* **491** 7736 (2012)
[5] J. - P. Brantut, C. Grenier, J. Meineke, D. Stadler, S. Krinner, C. Kollath, T. Esslinger, and A. Georges, *Science* **342** 713 (2013)
[6] S. Krinner, D. Stadler, D. Husmann, J. - P. Brantut, and T. Esslinger, *Nature* **517** 64 (2015)

Ultracold fermions trapped in nanostructured optical lattices

Caroline Busquet,[1,*] Hugo Savalador Vásquez Bullón,[1]
Jin-Yi Zhang,[1] Simon Bernon,[1] and Philippe Bouyer[1]

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Ultra-cold atoms systems used as quantum simulators offer an alternative way to simulate many-body systems behaviour in condensed matter. Indeed, we can create artificial matter with optical lattices: the stationnary wave reproduces the potential wells in the crystalline structure. Moreover, the big advantage of using cold atoms is that the parameters of the simulated crystal can be well controlled so that we can understand the electrical and magnetism properties of the condensed matter such as conductivity, ferromagnetism [1, 2], ... The common approach for generating optical lattices is interfering two laser beams in one dimension. And in the new ongoing project, we are going to produce lattices by irradiating a nanostructure gold layer, which can realize sub-wavelength optical lattices due to the surface resonance plasmon effect.

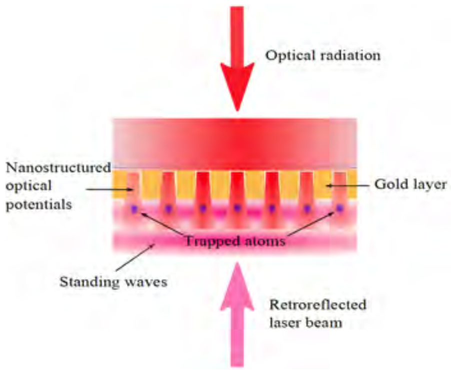

FIG. 1: Nanostructured optical lattice

[1] Bloch I., *Nature Physics*, Volume 1, p. 23, 2005.
[2] Esslinger T., *Annual Review of Condensed Matter Physics*, volume 1, p. 129-152, 2010.

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Thermometry of fermions in optical lattices by modulation spectroscopy

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Monday

The possibilities to probe and accurately characterize an ultracold Fermi gas trapped in an optical lattice are still very limited. In particular, experimentalists lack reliable methods to adequately measure the temperature. We propose a scheme to directly measure the temperature of non-interacting fermionic atoms confined to a three-dimensional optical lattice by superlattice modulation spectroscopy (see FIG.1). The superlattice modulation is applied along one direction and injects momentum into the system which strongly affects the nature of excitations. This leads to a strong temperature dependence of the spectral response such that the temperature may be easily extracted from a fit with a minimum of fitting parameters. Moreover, the experimental realization is temptingly simple since the spectral response can be determined from adiabatic band mapping when exciting to higher bands owing to the fact that the superlattice perturbation only excites distinct quasimomenta. This scheme extends down to very low temperatures of about 10% of the hopping strength that have not been observed in experiment so far and that lie below the Néel temperature where antiferromagnetic ordering is expected to occur.

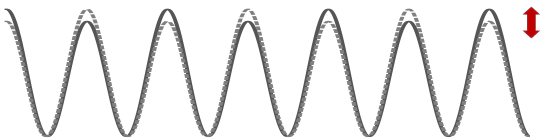

FIG. 1: Sketch of the basic setup: The optical superlattice is periodically modulated between the two configurations indicated by dashed and solid lines.

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Unconventional superfluid in quasi-one dimension

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[2]*Collège de France, 11 place Marcelin Berthelot, 75005 Paris, France*

We show that novel unconventional superfluids triggered by state-dependent hoppings are realized in repulsively interacting fermionic ladder systems. When a phase of a hopping matrix has a state dependence (Fig.1 (a)), which corresponds to a system with a spin-orbit coupling, a competition between spin singlet and triplet pairings occurs due to the breaking of inversion symmetry [1]. We show that both superfluid orders decay algebraically with the same exponent except for special coupling constants for which a dominant superfluid is determined solely by the spin-orbit coupling. On the other hand, when a hopping amplitude has a state dependence (Fig.1 (b)), we show that *d*-wave superfluid, spin-density wave, and spin-triplet superfluid are allowed [2]. We also propose an experiment to observe such phases with cold atoms.

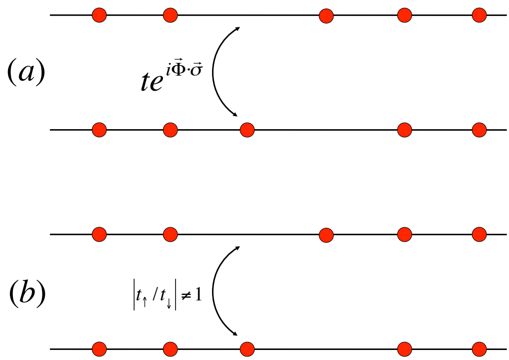

FIG. 1: Fermionic ladder system in the presence of state-dependent hoppings.

[1] S. Uchino, A. Tokuno, and T. Giamarchi, Phys. Rev. A **89**, 023623 (2014).
[2] S. Uchino and T. Giamarchi, arXiv:1411.3905.

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Direct observation of Landau Levels in artificial strained graphene

Grazia Salerno,[1,*] Tomoki Ozawa,[1] Hannah Price,[1] and Iacopo Carusotto[1]
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We study the steady state of out-of-equilibrium artificial graphene in the presence of unidirectional strain. We demonstrate that the equilibrium energy spectra of such a system exhibits Landau levels [1, 2], and we calculate the analytical eigenspectrum around the Dirac cones. We find deviations from the usual flat Landau levels due to a space-dependent Fermi velocity. We also describe how to probe the Landau level spectra in the steady state of a lossy, coherently-pumped system like, for instance, a photonic lattice made of coupled micropillars arranged in a honeycomb geometry [3]. We show that each eigenstate corresponds to a peak in the frequency spectra so that, on resonance with that peak, the spatial field amplitude distribution follows the wavefunction of that mode. These features could be measured directly in experiments and would be a clear validation of the Landau level description.

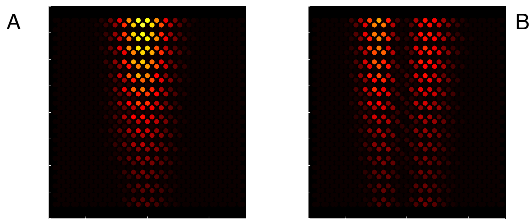

FIG. 1: Field amplitude distribution in the steady-state for the $n = 1$ Landau level, separated for the two inequivalent sites A and B of the honeycomb lattice.

[1] F. Guinea et al., *Nat.Phys.* **6** 30 (2010).
[2] M. C. Rechtsman et al., *Nat. Phot.* **7** 153 (2013).
[3] T. Jacqmin et al., *Phys.Rev.Lett.* **112** 116402 (2014).

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Demonstration of nonlinear π-phase shift for single fiber-guided photons

Michael Scheucher,[1,*] Elisa Will,[1] Christian Junge,[1] Jürgen Volz,[1] and Arno Rauschenbeutel[1]

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Realizing a strong interaction between individual photons is the key ingredient for scalable photon-based quantum processing. Since photons in free space do not interact, a medium which introduces a photon number dependent phase shift is required for this purpose. However, standard optical media cause a nonlinear response which is orders of magnitude too week for implementing high-fidelity quantum logic operations.

I will report on the realization of a fiber-integrated optical Kerr-nonlinearity on the single photon level that imprints the maximal nonlinear phase shift. In our experiment, we couple single ^{85}Rb atoms to a bottle microresonator [1] a novel type of whispering-gallery-mode microresonator. By making use of the particular polarization properties of our resonator we can obtain the ideal situation, where the atom exclusively interacts with one of the two counterpropagating resonator modes [2]. The presence of the single atom in the evanescent field of the resonator results in a strong nonlinear response of the coupled atom-resonator system to the photon number in the incident light field. This causes a nonlinear phase shift on the light passing the resonator. Analyzing the transmitted light, we observe a nonlinear phase shift close to the maximum value of between the cases where one or two photons pass the resonator [3]. This results in entanglement between the two previously independent fiber guided photons, which we verify by performing a full quantum state tomography of the transmitted two-photon polarization state.

[1] M. Pöllinger et al., *PRL* **103** 053901 (2009).
[2] C. Junge et al., *PRL* **110** 213604 (2013).
[3] J. Volz et al., *Nature Photonics* **8** 965-970 (2014).

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Atomic selfordering in a ring cavity with counterpropagating pump fields

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The collective dynamics of mobile scatterers and light in optical resonators generates complex behaviour. For strong transverse illumination a phase transition from homogeneous to crystalline particle order appears. In contrast, cold particles inside a single-side pumped ring cavity exhibit an instability towards bunching and collective acceleration called collective atomic recoil lasing (CARL). We demonstrate that by driving two orthogonally polarized counter propagating modes of a ring resonator one realises both cases within one system. As a function of the two pump intensities the corresponding phase diagram exhibits regions in which either a generalized form of self-ordering towards a travelling density wave with constant centre of mass velocity or a CARL instability is formed. Time dependent control of the cavity driving then allows to accelerate or slow down and trap a sufficiently dense beam of linearly polarizable particles.

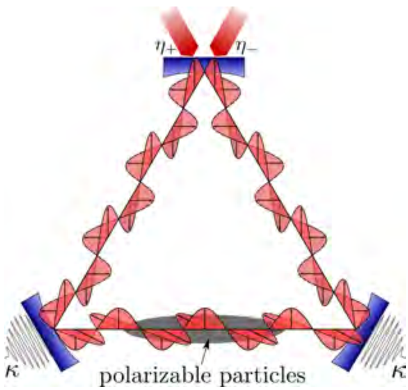

FIG. 1: Schematic picture of the considered setup.

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A novel experiment for coupling a Bose-Einstein condensate with two crossed cavity modes

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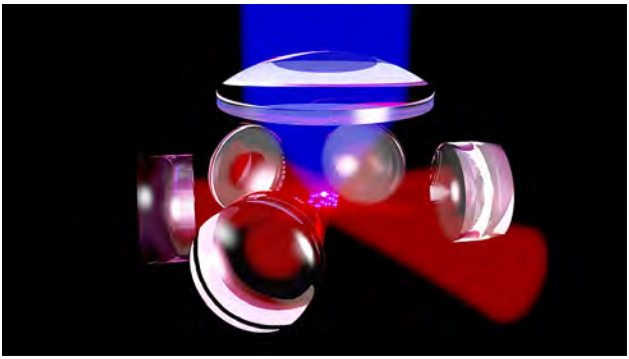
The realization of cavity-mediated long-range interactions in ultracold quantum gases leads to intriguing new many-body phenomena such as quantum phase transitions to self-ordered superradiant states. While such a state has been observed in a one-dimensional setup [1], extensions to higher dimensions that aim to exploit multimode configurations have only been suggested theoretically. Such systems are expected to exhibit rich phase diagrams with higher broken symmetries, frustration and glassy behavior [2].
We report on our latest results on coupling a Bose-Einstein condensate with two crossed cavity modes intersecting under an angle of 60°, which allows us the study of self-ordered phases in different lattice shapes, such as hexagonal and triangular geometries. The cavities are mounted on an interchangeable science platform that will facilitate a shift to even more diverse geometries later on. In addition, a high-resolution imaging system will enable us to manipulate and probe the system locally.



[1] K. Baumann, C. Guerlin, F. Brennecke and T. Esslinger, *Nature* **464** 7293 (2010).
[2] S. Gopalakrishnan, B.L. Lev, P.M. Goldbart, *Nature Physics* **5** 11 (2009).

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Demagnetization cooling of ultracold Dysprosium atoms

Clarissa Wink,[1,*] Thomas Maier,[1] Holger Kadau,[1] Matthias Schmitt,[1] Matthias Wenzel,[1] Jahn Rührig,[1] Igor Ferrier-Barbut,[1] and Tilman Pfau[1]

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In demagnetization cooling [1] inelastic dipolar relaxation collisions [2] transfer energy from the external (angular momentum) to the internal (spin) degree of freedom. Optical pumping into a dark state constantly recycles the atoms that were thermally excited to higher spin states. This cooling technique is favourable since it is theoretically lossless in contrast to evaporative cooling which relies on atom loss. The figure of merit of any cooling technique is the efficiency $\chi = \frac{d \ln PSD}{d \ln N}$, that relates the gain in phase space density (PSD) to the loss of atoms. Demagnetization cooling has been demonstrated in chromium [2–4] and efficiencies of $\chi \geq 17$ could be reached [3], which significantly outperform evaporative cooling with typical $\chi \approx 4$. However, with rising atomic density, limiting mechanisms such as light-assisted collisions [5] arise due to the presence of photons [4] and prevented Bose-Einstein condensation by demagnetization cooling up to now [3].
The recoil temperature T_R for ^{164}Dy is lower than for ^{52}Cr due to its higher mass and the larger wavelength of the pumping transition. Assuming the minimum temperature that can be reached by demagnetization cooling is $T_{min} \approx T_R$, this results in a reduction of the critical densit y n_C by a factor of four [4]. Finally, this motivates to investigate whether dysprosium atoms can reach quantum degeneracy by demagnetization cooling.

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[1] A. Kastler, *Le Journal de Physique et le Radium* **11** 255 (1950).
[2] S. Hensler, J. Werner, A. Griesmaier, P.O. Schmidt, A. Görlitz, T. Pfau, S. Giovanazzi, and K. Rkzażewski, *Appl. Phys. B* **77** 765 (2003).
[3] J. Rührig et al., in preparation (2015).
[4] V. Volchkov, J. Rührig, T. Pfau, and A. Griesmaier, *Phys. Rev.* **A 89** 043417 (2014).
[5] A. Gallagher and D.E. Pritchard, *Phys. Rev. Lett.* **63** 957 (1989).

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Non-destructive imaging and feedback stabilized production of cold atomic clouds

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Andrew J. Hilliard,[1] Jacob F. Sherson,[1] and Jan Arlt[1]

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Reliable production of cold atomic clouds with well-defined properties is a notoriously difficult task. Variations in the final atom number and temperature arise mainly due to unpredictable fluctuations in the experimental sequence. Non-destructive measurements of the ensemble properties within the sequence allow for an adjustment of the cooling procedure to obtain the desired outcome. Our scheme utilizes an imaging technique based on Faraday rotation[1] combined with on-line digital image evaluation and feedback to the evaporation sequence. We demonstrate run to run stability at the permille level of the final atom number obtained by a single point feedback.

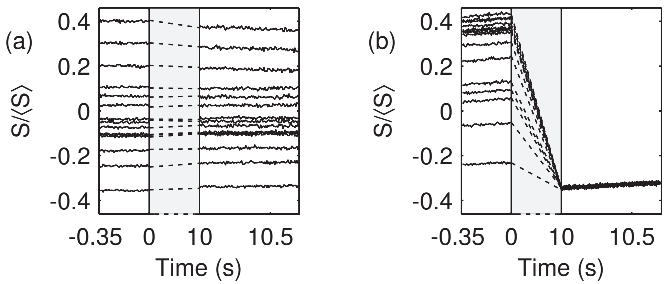

FIG. 1: Normalized Faraday signal $S/\langle S\rangle$ (proportional to atom number) during the experimental sequence. Time zero indicates the point where feedback is applied. *(a)* Without feedback. *(b)* With feedback.

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[1] M. Gajdacz, P.L. Pedersen, T. Mørch, A.J. Hilliard, J. Arlt and J.F. Sherson, *Rev. Sci. Instrum.* **84** 083105 (2013).

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Imaging the collective excitations of an ultracold gas using statistical correlations

C. De Rossi[1,*] and R. Dubessy, L. Longchambon,
T. Badr, R. Romain, H. Perrin[1]

[1] *Laboratoire de Physique des Lasers, CNRS,
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Collective modes provide a unique insight into the system properties. For example they can reveal the collective superfluid behavior of Bose gases or probe system dimensionality [1]. The usual approach in their analysis consists in following an a priori observable, such as the Thomas Fermi radius, as a function of time. However a statistical approach would allow to extract data without a priori knowledge of the shape of the collective modes.
In the past advanced data analysis techniques have already proved to be crucial for extracting information from noisy images. In this talk I will show that principal component analysis [2] can be successfully applied to ultracold gases to unveil their collective excitations. By analyzing the correlations in a series of images we are able to identify the collective modes which are excited, determine their population, image their eigenfunction, and measure their frequency [3].

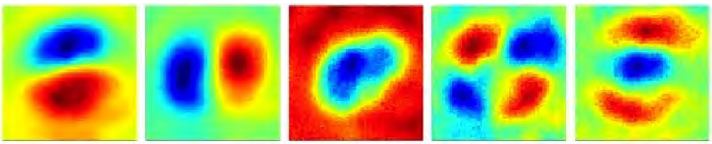

FIG. 1: First five principal components of an excited two-dimensional Bose gas. We can identify, from left to right, the two dipole modes, the fluctuations of atom number, the scissors mode and a monopole-like mode.

[1] K. Merloti, R. Dubessy, L. Longchambon, M. Olshanii, and H. Perrin, *Phys. Rev. A* **88** 061603 (2013).
[2] I. T. Jolliffe, *Principal Component Analysis*, New York: Springer, (2002).
[3] R. Dubessy, C. De Rossi, T. Badr, L. Longchambon and H. Perrin, *New J. Phys.* **16** 122001 (2014).

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Talks: Tuesday, April 21

Selim Jochim, University of Heidelberg

Selim Jochim studied physics at the University of Heidelberg, the University of California, Berkeley and the San Francisco State university. He received his PhD on the Bose-Einstein condensation of molecules at the Max-Planck Institute for Nuclear Physics at Heidelberg and at the University of Innsbruck. In 2004, he organized the YAO conference, when it was hosted by the University of Innsbruck for the second time. After research periods at the IBM laboratory in Zurich and the James-Franck Institute at Chicago, he returned to Heidelberg for a joint junior professor position at the Max-Planck Institute for Nuclear Physics and the University of Heidelberg, where he is leading his group on ultracold quantum gases since then. In 2005, he was awarded the research prize of the Principality of Liechtenstein for his work at the University of Innsbruck.

In 2009, Selim Jochim was appointed full professor at the University of Heidelberg. His research includes the study of scattering properties of Fermi gases, Feshbach resonances and Efimov states. Recently, the ability to prepare and probe a very well-controlled few-Femion system has allowed to observe the transition between single and many-body physics of interacting Fermi gases.

From few to many: Constructing many-body systems atom by atom

During the past years we established a technique to prepare finite samples of ultracold fermions in a tightly focused optical trap with very low entropy in a quest to realize complex many-body systems atom by atom. We are currently expanding our technique to load periodic potentials with similarly low entropies. As a starting point we have realized a double well containing two fermionic atoms in a spin-singulett configuration. We can tune on-site interaction, tunneling rate and tilt of this basic building block of the Hubbard model.

In a separate effort we have realized a strongly interacting two-dimensional Fermi gas in the superfluid regime. We are now aiming to apply our low-entropy few-particle approach to this two-dimensional system to realize finite Fermi systems in tunable periodic potentials. Progress on this effort will be reported.

Continuous in situ fluorescence imaging of an ultracold Fermi gas in an optical lattice

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We demonstrate continuous in situ fluorescence imaging of ultracold fermionic ^{40}K atoms held in a three-dimensional optical lattice with 527nm periodicity. Using a 4S-4P$_{1/2}$ grey molasses cooling scheme with a coherent dark state, we obtain a photon scattering rate exceeding 1kHz while the atoms remain trapped in the deep optical lattice. When the grey molasses is applied, the steady-state population of the vibrational ground state is determined to be 80%. Collecting the scattered photons with a microscope objective through a 200μm thin sapphire vacuum window, we image the in situ density distribution of the lattice gas. Spatially selective state manipulation is used to reduce the number of occupied lattice planes along the imaging direction, as well as to create density patterns along the transverse direction. We characterize the performance of the imaging protocol over a wide range of parameters, and find that this method is suitable for high-resolution imaging of a many-body system in the Fermi-Hubbard regime.

FIG. 1: Experimental schematic, showing laser cooling beams impingent on a cloud of atoms trapped 800μm away from a thin vacuum window and a microscope objective.

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Unity filling by state-dependent transport

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Tuesday

We report on the deterministic generation of unity filling in selected regions of a one-dimensional optical lattice. Atom by atom is placed in nearest-neighbor separation, employing a novel experimental realization of state-dependent transport in combination with position-selective microwave control in a magnetic field gradient. We demonstrate that with the same technique atom pairs are prepared in a single lattice site with high efficiency. We characterize the efficiency of this novel positioning technique and discuss its scalability. Our results pave the way for the study of the quantum dynamics of small atom ensembles prepared in low-entropy states.

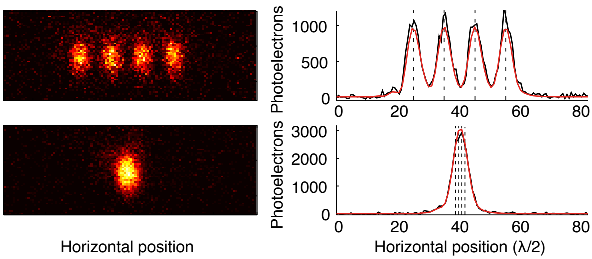

FIG. 1: Four atoms deterministically placed at equidistant interatomic separations of 10 lattice sites and unity filling (decreasing from top to bottom). The left panels shows the observed single-shot fluorescence image. The panels to the right show the vertically binned distributions and a fit based on 4 line spread functions. Dashed lines represent the reconstructed positions.

[1] C. Robens, W. Alt, D. Meschede, C. Emary, A. Alberti, *Phys. Rev. X.* **5** 011003 (2015).

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Exploring a strongly interacting Fermi gas in a 2D lattice

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Martin Ries,[1] Andre Wenz,[1] Gerhard Zürn,[1] and Selim Jochim[1]

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In this talk, we present our current progress investigating a strongly interacting Fermi gas of ultracold ^{6}Li atoms in a single–layer 2D lattice potential.
Our starting point is a quasi–2D superfluid of deeply bound bosonic dimers trapped in a single anti-node of a red–detuned standing wave trap [1]. This sample is loaded into an optical square lattice orthogonal to the tightly confined axis, which is produced by two laser beams which are retro–reflected under a small angle.
One of the main experimental challenges are the very strong interactions as we investigate a regime where the scattering length is comparable to the lattice spacing.
We are able to directly access the in–situ momentum distribution of the system [2] and hence investigate the coherence as a function of the system parameters.

[1] M.G. Ries, A.N. Wenz, G. Zürn, L. Bayha, I. Boettcher, D. Kedar, P.A. Murthy, M. Neidig, T. Lompe and S. Jochim *arXiv:1409.5373* (2014).
[2] P.A. Murthy, D. Kedar, T. Lompe, M. Neidig, M.G. Ries, A.N. Wenz, G. Zürn, and S. Jochim, *Physical Review A* **90** 043611 (2014).

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Local probing of interacting Fermions in optical lattices

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Tuesday

Quantum gases of interacting fermionic atoms in optical lattices promise to shed new light on the low-temperature phases of Hubbard-type models, such as spin-ordered phases or, in particular, on possible d-wave superconductivity. As a first step towards this goal, we employ high-resolution imaging together with radio-frequency spectroscopy in order to spatially resolve the intrap distributions of singly and doubly-occupied lattice sites after having loaded a quantum degenerate two-component Fermi gas of ^{40}K atoms into a three-dimensional optical lattice geometry. Here, I will report on our recent progress towards the observation and characterization of a fermionic Mott insulator.

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Creation of ultracold RbCs molecules in the rovibrational ground state

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C. R. Le-Sueur[2],[1] J. M. Hutson[2],[1] and S. L. Cornish[1][1]

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Tuesday

Ultracold and quantum degenerate mixtures of two or more atomic species open up many new research avenues, including the formation of ultracold heteronuclear ground-state molecules possessing a permanent electric dipole moment [1]. The anisotropic, long range dipole-dipole interactions between such molecules offer many potential applications, including novel schemes for quantum computation [2] and simulation [3]. Here we demonstrate the creation of ultracold ^{87}Rb^{133}Cs molecules in the rovibrational ground state. The molecules are created from a high phase space density mixture of ^{87}Rb and ^{133}Cs [4] in a two-step process. First weakly-bound ^{87}Rb^{133}Cs molecules are created using magnetoassociation on an interspecies Feshbach resonance [5]. The molecules are then optically transferred into the rovibrational ground state by stimulated Raman adiabatic passage (STIRAP). We present two-photon spectroscopy of the ground state using a novel well-calibrated narrow-linewidth laser system [7] to measure the splitting between the $|v'' = 0, J'' = 0\rangle$ and $|v'' = 0, J'' = 2\rangle$ states as 2940.09(6) MHz. The binding energy of the ground state is measured as 3811.576(1) cm^{-1} at zero field, in good agreement with other studies [6]. We report STIRAP transfer to the rovibrational ground state with a one way efficiency of ~ 50 %. Stark shift of the ground state in electric fields as high as 765 V cm^{-1} lead to a precise measurement of the permanent electric dipole moment as 1.225(3)(8) D [8].

[1] L. D. Carr *et al.*, New J. Phys. **11**, 055049 (2009).
[2] D. DeMille *et al.*, Phys. Rev. Lett. **88**, 067901 (2002).
[3] A. Micheli *et al.*, Nat. Phys. **2**, 341 (2006).
[4] D. J. McCarron *et al.*, Phys. Rev. A **84**, 011603 (2011).
[5] M. P. Köppinger *et al.*, Phys. Rev. A **89**, 033604 (2014).
[6] M. Debatin *et al.*, PCCP **13**, 18926 (2011).
[7] P. D. Gregory *et al.*, arXiv:1411.7951 (2014).
[8] P. K. Molony *et al.*, arXiv:1409.1485v3 (2014).

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Reactive collisions in reduced dimensions: a theoretical and experimental study

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We consider low energy reactive collisions of particles interacting with van der Waals potential at long range in the presence of external confinement. The reaction process is described in terms of the short-range reaction probability. Quantum defect theory is used to express elastic and inelastic or reaction collision rates analytically. We discuss the modifications to Wigner threshold laws for quasi-one-dimensional and quasi-two-dimensional geometries. Confinement-induced resonances are suppressed due to reactions and are completely absent in the universal limit where the short-range loss probability approaches unity. Our model can be used to describe the experiment studying inelastic collisions of triplet Rb_2 molecules confined in quasi-one-dimensional optical lattice. Due to nonadiabatic initial state preparation the decay of the molecule number exhibits interesting dynamics. Nevertheless, we are able to extract the 1D collision rates and analyze the impact of the rovibrational state on the reaction rate constants.

FIG. 1: An artist's view of the experiment.

[1] Z. Idziaszek, K. Jachymski and P. S. Julienne, arXiv:1412.2501 (2014)

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Laser cooling and slowing of CaF molecules - towards a molecular MOT

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J. J. Hudson,[1] B. Sauer,[1] M. Tarbutt,[1] and E. Hinds[1]

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Producing ultra-cold and dense samples of polar molecules is a technical challenge that has been investigated with several techniques over the last decade, including direct laser cooling [1–4]. Some of the future applications are related to quantum information, ultra-high resolution spectroscopy, tests of fundamental symmetries and ultra-cold chemistry. In my talk I will present our progress towards a magneto-optical trap (MOT) of CaF molecules. Following our successful demonstration of longitudinal laser cooling and slowing in a pulsed, seeded supersonic beam [2], we recently implemented a cryogenic buffer gas source with beam velocities below 200 m/s. To slow the molecules further down to the capture velocity of a MOT, we will apply a new type of Sisyphus decelerator, which uses permanent magnets in combination with optical pumping.

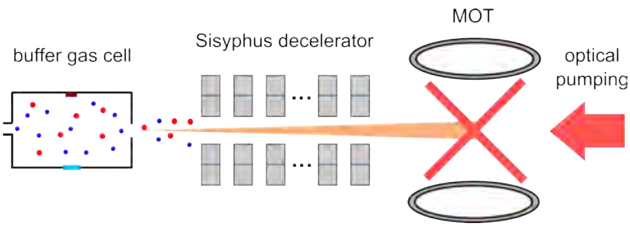

FIG. 1: Setup for magneto-optical trapping of CaF molecules.

[1] E. S. Shuman, J. F. Barry and D. DeMille, *Nature* **467**, 820-823 (2010).
[2] V. Zhelyazkova, A. Cournol, T. E. Wall, A. Matsushima, J. J. Hudson, E. A. Hinds, M.R. Tarbutt, and B. E. Sauer, *Phys. Rev. A* **89**, 053416 (2014).
[3] M. T. Hummon, M. Yeo, B. K. Stuhl, A.L. Collopy, Y. Xia and J. Ye, *Phys. Rev. Lett.* **110**, 143001 (2013).
[4] J. F. Barry, D. J. McCarron, E. B. Norrgard, M. H. Steinecker, and D. DeMille, *Nature* **512**, 286289 (2014).

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Polarons in ultracold Bose gas

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Tuesday

A system of an impurity immersed in a Bose-Einstein condensate (BEC) exhibits the polaronic effect, which is known to be an ubiquitous phenomenon in a wide range of physical systems including semiconductors, doped Mott insulators, and high-T_c superconductors. Recent analysis of the BEC-polaron problem showed that existing analytical approaches [1, 2] do not provide reliable results in the experimentally relevant range of parameters when tested against Monte Carlo simulations [3].
In this contribution we demonstrate that the description of Fröhlich polarons at finite momentum can be done by employing an analytical class of wavefunctions based on the correlated Gaussian ansatz (CGWs) [4]. We show that CGWs show excellent agreement with known diagrammatic Monte Carlo results [3] for the polaron binding energy for the wide range of interactions. We discuss the properties of the polarons and atomic mixtures in systems of ultracold atoms in which polaronic effects can be observed with current experimental technology. A novel prediction based on our variational wavefunctions is a special pattern of correlations between host atoms that can be measured in time-of-flight experiments.

[1] J. Tempere, W. Casteels, M. Oberthaler, S. Knoop, E. Timmermans, and J. Devreese, *Phys. Rev. B* **80**, 184504 (2009).
[2] A. Shashi, F. Grusdt, D. A. Abanin, E. Demler, *Phys. Rev. A* **89**, 053617 (2014).
[3] J. Vlietinck, W. Casteels, K. Van Houcke, J. Tempere, J. Ryckebusch, J. T. Devreese, arXiv:1406.6506 (2014).
[4] Y.E. Shchadilova, F. Grusdt, A.N. Rubtsov, E. Demler, arXiv:1410.5691 (2014).
[5] F. Grusdt, Y.E. Shchadilova, A.N. Rubtsov, E. Demler, arXiv:1410.2203 (2014).

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A species-specific optical lattice for single Cesium atoms

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For quantum simulations with ultracold quantum gases, typically maximum control of all relevant degrees of freedom in the system is desired. In our experiment, we aim at doping a Rubidium 87 (Rb) Bose-Einstein condensate (BEC) with single neutral Cesium 133 (Cs) atoms. The species-specific optical lattice allows for the transport of Cs impurity atoms relative to the Rb BEC cloud to enable controlled immersion and extraction operations as well as dynamical control within the BEC. For the Cs atoms the one-dimensional lattice creates a confinement in axial direction and can be used to move the atoms along this axis in a controlled manner by applying a detuning between the counterpropagating lattice beams [1]. The transportation process can be observed in the experiment with a single atom sensitive fluorescence imaging system (FIG. 1). For the Rb atoms however no dipole potential is induced by having the lattice laser tuned to the magic tune-out wavelength, which lies between the two alkali-D-lines of Rubidium [2]. The exact value of this wavelength was determined experimentally by diffraction of the BEC at the optical lattice [3].

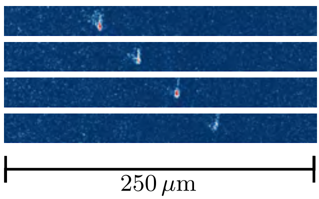

FIG. 1: Fluorescence imaging of single Cs atoms in the optical lattice (false color). The transportation process can be verified by taking subsequent images before and after each transport step.

[1] Schrader, Kuhr, Alt, Müller, Gomer, Meschede *Appl. Phys. B* **73** 819-824 (2001).
[2] LeBlanc, Thywissen, *Phys. Rev. A* **75** 053612 (2007).
[3] Gupta, Leanhardt, Cronin, Pritchard, *Comptes Rendus de l'Acadmie des Sciences-Series IV-Physics* **2** 479-495 (2001).

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Measurement of the mobility edge for 3D Anderson localization

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A. Trenkwalder,[1] M. Fattori,[1] M. Inguscio,[1,3] and G. Modugno[1]

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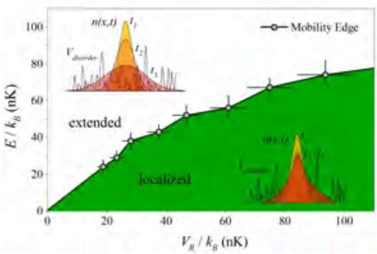
Tuesday

When traveling through a disordered environment, quantum particles may exhibit a localization phenomenon arising from interference effects between multiple scattered waves. This is the well-known Anderson localization, discovered more than 50 years ago [1] and still at the heart of intense research. An outstanding problem is the determination of the mobility edge, i.e. the energy threshold that separates localized and extended states. In our experiment we use a non-interacting Bose-Einstein condensate of ^{39}K atoms and we study its transport properties in a disordered optical potential. When releasing the atoms from a dipole trap into the disordered potential we observe two different transport regimes. In one case the atoms diffuse away from the initial position, while in a second case, after an initial evolution, they become localized and stop expanding (as shown in the time evolution of the density profiles in the figure). Thanks to novel techniques in the control of the energy of the atoms we can identify the critical energy that discriminates between extended and localized systems and then provide the first experimental determination of the mobility edge and of its dependence on the disorder strength V_R [2].



[1] P. W. Anderson *Phys. Rev.* **109** 1492-1505 (1958).
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Talks: Wednesday, April 22

Wednesday

Eugene Demler, Harvard University

Eugene Demler graduated in theoretical physics at the Moscow Institute of Physics and Technology in 1993. He then moved to Stanford University and obtained his PhD degree in 1998. In his doctoral research, he worked under the supervision of S.C. Zhang on high-temperature superconductors and Hubbard models. After his PhD work, he continued research with a short postdoctoral stay at the University of Santa Barbara, before he was recruited to Harvard University as a Junior Fellow in 1999. After two years, he became assistant professor there, and, following three further years, was appointed to full professor at Harvard University at the age of only 33 years, where he is leading his group on condensed matter theory since then.

The main focus of Eugene Demler's work has been developing general theoretical tools for understanding the effects of interactions, and establishing a common framework for understanding the physics of strongly correlated systems. His research has addressed various properties of high temperature superconductors, heavy fermion and organic superconductors, quantum Hall systems, and quantum antiferromagnets. Demler's research has a large influence on our understanding of the role that ultracold atoms play as a tool for quantum simulations of condensed matter systems.

Nature of the transition between Ergodic and Many-Body Localized phases

I will discuss quantum dynamics of isolated interacting many-body systems with strong disorder. I will show that transitions between the ergodic and many-body localized phases involve Griffiths regimes on both sides of the transition. I will review implications of Griffiths phenomena for transport and relaxation and discuss connection to experiments.

Solitonic vortices in Bose-Einstein condensates

Simone Donadello[1,*] and Marek Tylutki, Simone Serafini, Lev P. Pitaevskii, Franco Dalfovo, Giacomo Lamporesi, Gabriele Ferrari[1]

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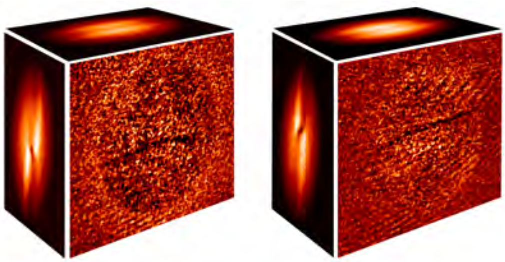
Wednesday

We observe solitonic vortices in an atomic Bose-Einstein condensate after free expansion [1]. Clear signatures of the nature of such defects are the twisted planar density depletion around the vortex line observed in absorption images, and the double dislocation in the interference pattern obtained through homodyne techniques. Both methods allow us to determine the sign of the quantized circulation. Experimental observations agree with numerical simulations [2]. These solitonic vortices are the decay product of phase defects of the BEC order parameter spontaneously created via the Kibble-Zurek mechanism after a rapid quench across the BEC transition in a cigar-shaped harmonic trap [3] and are shown to have a very long lifetime.



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[2] M. Tylutki, S. Donadello, S. Serafini, L.P. Pitaevskii, F. Dalfovo, G. Lamporesi and G. Ferrari, arXiv:1410.5475 (2014), submitted to EPJ.
[3] G. Lamporesi, S. Donadello, S. Serafini, F. Dalfovo, and G. Ferrari, Nat. Phys. **9**, 656 (2013).

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Spin-nematic order and phase locking in antiferromagnetic spinor condensates

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Andrea Invernizzi,[1] Jean Dalibard,[1] and Fabrice Gerbier[1]

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We study the equilibrium state of a spin-1 Bose-Einstein condensate of sodium with antiferromagnetic interactions. The equilibrium populations in the mean field ground state are determined by the competition between the antiferromagnetic interactions that tend to minimize the total spin of the system, and the quadratic Zeeman effect which favors atoms in the $m_F = 0$ state.
In order to minimize the magnitude of the transverse spin, antiferromagnetic interactions lock the relative phase $\theta = \Phi_{+1} + \Phi_{-1} - 2\Phi_0$ to π. By applying a spin rotation along the transverse direction, we map the transverse spin magnitude to the variance of S_z and measure it directly. We verify the phase locking due to antiferromagnetic interactions at several points on the phase diagram of the system.

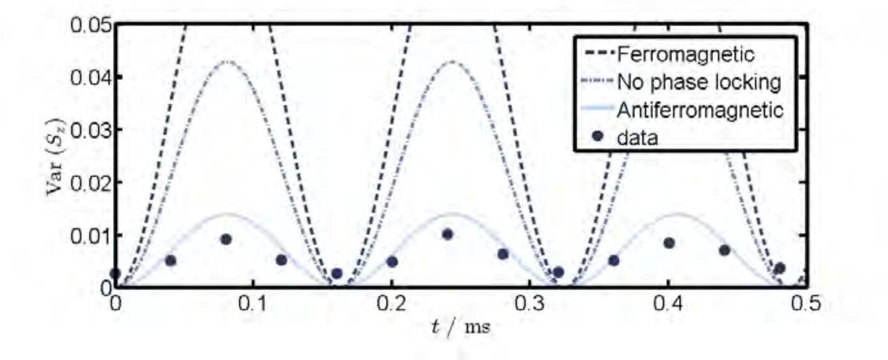

FIG. 1: Variance of S_z for $< S_z > = 0.7$ and $B = 350$ mG as a function of the spin rotation duration t. Experimental data are shown as circles and theoritical predictions as three lines that correspond to $\theta = 0$ (ferromagnetic order), $\theta = \pi$ (antiferromagnetic order) and for θ random (No phase locking).

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Evidence of quantum phase slips in 1D atomic superfluids

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Phase slips are recognized as primary excitations in one-dimensional superfluids and superconductors and they can be originated from quantum tunnelling events even at zero temperature (quantum phase slips), creating dissipation.
Quantum phase slips have been observed in quasi-1D superconducting nanowires and in Josephson junctions chains. We now get evidence of quantum phase slips in one-dimensional ultracold Bose gases.
In particular, we examine the dynamics of the superfluid in a periodic potential, studying the dependence of the dissipation on temperature, velocity and interaction strength. For the first time, we study the regime of low velocities and low interactions, far from the dynamical instability the superfluid-insulator transition.
We observe a regime of weak dissipation at small velocity and interaction, and a second regime of stronger, velocity-dependent dissipation rate for large velocity and interaction. The first regime shows a temperature dependence, differently from the second one. This behavior is consistent with the predicted crossover from thermally-assisted to purely quantum phase-slips [1].

[1] I. Danshita, *Phys. Rev. Lett.* **111** 025303 (2013).

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Unification of BKT and BEC Phase Transitions in a Trapped Two-Dimensional Bose Gas

Konrad Viebahn,[1,*] Richard J. Fletcher,[1] Martin Robert-de-Saint-Vincent,[1] Jay Man,[1] Nir Navon,[1] Robert P. Smith,[1] and Zoran Hadzibabic[1]

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We study the critical point for the emergence of coherence in a harmonically trapped two-dimensional (2d) Bose gas with tuneable interactions [1]. Over a wide range of interaction strengths we find excellent agreement with the predictions based on the Berezinskii-Kosterlitz-Thouless (BKT) theory of 2d superfluidity. This allows us to quantitatively show that the interaction-driven BKT transition smoothly converges onto the purely-statistical Bose-Einstein condensation (BEC) transition in the limit of vanishing interactions.

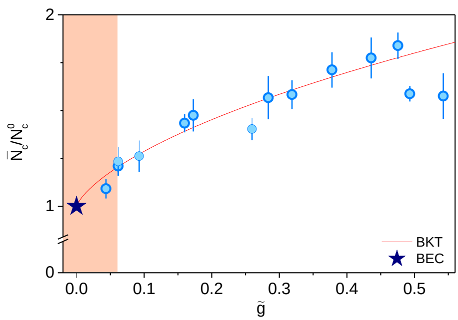

FIG. 1: Critical atom number as a function of the dimensionless interaction strength $\tilde{g}$. All numbers are scaled to the ideal-gas BEC critical number N_c^0. Solid line is the classical-field BKT prediction, without any free parameters. The star ($\star$) denotes the critical point for BEC, which only occurs in the ideal-gas limit. The shaded region indicates the regime in which our measurements stop being reliable.

[1] R.J. Fletcher et al., arXiv:1501.02262 (2015)

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Mean-field analysis of selforganization of atoms in cavities

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Wednesday

Atoms can spontaneously form spatially ordered structures in optical resonators when they are transversally driven by lasers. This occurs by means of photon-mediated long-range forces, which establish correlations when the intracavity photon number exceeds a threshold value. The selforganization transition is an out-of-equilibrium phenomenon, where losses are an essential element determining the threshold behaviour [1]. In this contribution, we analyse the nature of the transition by means of a mean-field Fokker-Planck equation (FPE), which has been systematically derived from the master equation of atoms and cavity field and describes the dynamics of the one-particle density matrix. This FPE has the form of a Vlaslov equation when retardation effects, giving rise to noise, are neglected [2]. We analyse the dynamics of the order parameter, which quantifies the localization of the atoms in ordered patterns, and show that close to the selforganization threshold its dynamics is determined by a potential of Landau form in an appropriately defined thermodynamic limit. We then perform a stability analysis which permits us to identify the spectral properties of the intracavity field.

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[2] A. Campa, T. Dauxois, and S. Ruffo, Phys. Rep. **480**, 57 (2009)

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Extended Bose-Hubbard model with cavity-mediated long-range interactions

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The transversal illumination of a strongly coupled BEC-cavity system by a laser field leads to a structural phase transition from a superfluid to a supersolid phase due to the competition between the kinetic energy and the cavity-mediated long-range interactions [1,2]. We study the effect of a 3D classical optical lattice on this system, enhancing the strength of the short-range interactions and hence introducing another competing energy scale. This system can be mapped to an extended Bose-Hubbard model. Besides the Mott insulator and the superfluid phases exhibited by the Bose-Hubbard model [3,4], the cavity-mediated long-range interactions give rise to a charge density wave insulator and a supersolid phase in the limit where the classical lattices are commensurate with the cavity generated dynamical lattice. We show the recent experimental progress in observing the charge density wave insulator phase and mapping the phase diagram of a strongly interacting Bosonic system as a function of short-range and cavity-mediated long-range interactions.

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[2] Kristian Baumann, Christine Guerlin, Ferdinand Brennecke and Tilman Esslinger, *Nature* **464** 1301-6 (2010).

[3] D. Jaksch, C. Bruder, J.I. Cirac, C.W. Gardiner and P. Zoller *PRL* **81** 3108-3111 (1998).

[4] Markus Greiner, Olaf Mandel, Tilman Esslinger, Theoder W.Haensch and Immanuel Bloch, *Nature* **415** 39-44 (2002).

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Transverse mode coupling and diffraction loss in fibre-based optical microcavities

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Wednesday

Fibre-based Fabry-Pérot resonators provide very small mode volumes and high finesse in a tuneable and accessible geometry [1, 2]. This makes them attractive for various applications ranging from cold atom and ion experiments to cavity optomechanics and cavity-enhanced single photon sources using for example colour centres in diamond. In contrast to macroscopic cavities, the mirrors are not spherical, but rather have a nearly Gaussian profile originating from the laser machining process used to shape the fibre surface. We find that non-spherical mirror shape and finite mirror size lead to loss, mode deformation, and frequency shifting at particular mirror separations. For long cavities, diffraction loss limits the useful mirror separation to values below the expected stability range. Using scanning cavity microscopy of a commercial planar high-reflectivity mirror, we observe spatially localized coupling resonances, owing to a variation of the mirror properties. We attribute these findings to resonant coupling between different transverse modes of the cavity and show that a model based on resonant state expansion [3] taking into account the measured mirror profile can reproduce the measurements, predict the cavity performance, and identify geometric regimes that avoid mode mixing.

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[1] D. Hunger, T. Steinmetz, Y. Colombe, C. Deutsch, T.W. Hänsch and J. Reichel, *NJP* **12** 065038 (2010).

[2] D. Hunger, C. Deutsch, R.J. Barbour, R.J. Warburton and J. Reichel, *AIP Advances* **2** 012119 (2012).

[3] D. Kleckner, W.T.M. Irvine, S.S.R. Oemrawsingh and D. Bouwmeester, *Phys. Rev. A* **81** 043814 (2010).

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Dispersionless atom interferometry

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Shayne Bennetts,[1] Patrick J. Everitt,[1] Paul A. Altin,[1]
John E. Debs,[1] John D. Close,[1] and Nicholas P. Robins[1]

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By varying the s-wave scattering length a in a Bose-Einstein condensate we can modify the spatial dispersion of our condensate, going from repulsive interactions and large dispersion, though non-interacting atoms and Heisenberg-limited dispersion, to attractive interactions and a collapsing condensate. A soliton is formed at just the right value of attractive interactions which cancel out the dispersion of the condensate. Changing a during an atom interferometer, we find that a soliton maximises the interference fringe visibility $\mathcal{V}$ [1].

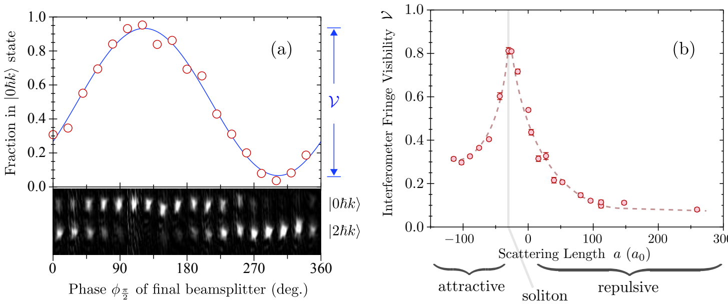

FIG. 1: (a) The interference fringe using a soliton. Below: The raw images used to count atoms in each output port of the interferometer. (b) The interference fringe visibility $\mathcal{V}$ sharply peaks at the s-wave scattering length of the soliton.

[1] *A Bright solitonic matter-wave interferometer*, G. D. McDonald, C. C. N. Kuhn, K. S. Hardman, S. Bennetts, P. J. Everitt, P. A. Altin, J. E. Debs, J. D. Close, and N. P. Robins., *Phys. Rev. Lett.* **113** 013002 (2014).

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Quantum test of the universality of free fall

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Possible violations of the universality of free fall would have deep implications on the current state of modern physics. Although the universality of free fall has been well tested classically, atom intereferometers allow access to tests of the principle from a uniquely quantum perspective. Utilizing stimulated Raman transitions we are able to create a set of Mach-Zehnder interferometers capable of simultaneously measuring the local gravitational acceleration of two different atomic species to test for violations of the universality of free fall. We present the results and developments of our experiment which employs ^{39}K and ^{87}Rb as test masses. With our current setup we were able to measure an Eötvös Ratio of $(0.3 \pm 5.4) \times 10^{-7}$. We here present our reasons for test mass choice, and the current limitations for our experiment. We further will discuss future developments, which will allow us to further con- strain systematic uncertainty in comparison with previous published results, as well the role of this experiment in the development of future large scale experiments aiming for a ppb level measurement.

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An atomic Hong-Ou-Mandel experiment

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The Hong, Ou and Mandel (HOM) experiment [1], in which, originally, two photons arriving simultaneously in the input channels of a beam-splitter always emerge together in one of the output channels, is a milestone of quantum optics. We report here the realization of an atomic analog, with Helium, closely following the original protocol, demonstrating successfully the 2-particle quantum interference of identical massive particles. The experimental methods and the results will be presented [2].

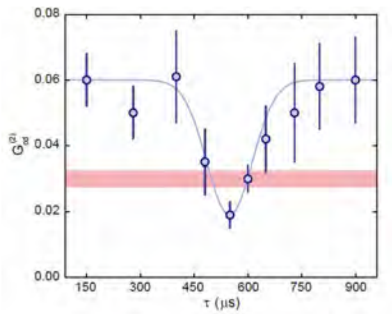

FIG. 1: HOM dip in the cross-correlation function. The measurement of the cross-correlation between the output ports as a function of the application time of the atomic beam splitter exhibits the same dip observed 27 years ago by Hong, Ou and Mandel.

[1] C. K. Hong, Z. Y. Ou & L. Mandel. Measurement of Subpicosecond Time Intervals between Two Photons by Interference. *Physical Review Letters* **59** 2044-2046 (1987).
[2] R. Lopes, A. Imanaliev, A. Aspect, M. Cheneau, D. Boiron & C. I. Westbrook An atomic Hong-Ou-Mandel experiment arXiv:150.03065 [quant-ph].

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Talks: Thursday, April 23

Rainer Blatt, University of Innsbruck and IQOQI

Rainer Blatt received his doctorate in 1981 from the University of Mainz, where he continued to work in the team of Günther Werth as a research assistant for another two years. After research periods in the group of John L. Hall at the Joint Institute for Laboratory Astrophysics at Boulder, Colorado, and the Freie Universität Berlin, he joined the group of Peter Toschek at the University of Hamburg in 1983. Following further stays in the United States, he was appointed professor of physics at the University of Göttingen in 1994 and was offered the chair of experimental physics at the University of Innsbruck in the following year. Since 2003 Blatt also holds the position of Scientific Director at the Institute for Quantum Optics and Quantum Information (IQOQI) at Innsbruck.

Rainer Blatt has carried out trail-blazing experiments in the fields of precision spectroscopy, quantum metrology and quantum information processing. He conducted pioneering experiments on quantum teleportation, quantum simulation, quantum computing and entanglement with trapped ions. In 2006, his research group managed to create the first "quantum byte" (qubyte) by entangling up to eight atoms in a controlled manner, a record the group pushed further to 14 entangled atoms in a later experiment.

Quantum information science with trapped Ca^+ ions

In this talk, the basic toolbox of the Innsbruck quantum computer based on strings of trapped Ca^+ ions will be reviewed [1] and an overview will be given on our current experiments in the field of quantum information science. For quantum information processing, the toolbox operations are used to encode one logical qubit in entangled states distributed over seven trapped-ion qubits. We demonstrate the capability of the code to detect one bit flip, phase flip or a combined error of both, regardless on which of the qubits they occur. Furthermore, we apply combinations of the entire set of logical single-qubit Clifford gates on the encoded qubit to explore its computational capabilities [2]. With the quantum toolbox both analog and digital quantum simulations are carried out [3]. The basic simulation procedure will be presented and its application will be discussed for a variety of spin Hamiltonians. Including a carefully controlled dissipation mechanism, the toolbox even allows for the quantum simulation of open systems [4]. With long ion strings, the quantum toolbox is applied to investigate the propagation of entanglement in a quantum many-body system represented by the trapped-ion qubits [5].

[1] P. Schindler et al., *New. J. Phys.* **15**, 123012 (2013)
[2] D. Nigg, M. Mller et al., *Science* **345**, 302 (2014)
[3] R. Blatt and C. F. Roos, *Nature Phys.* **8**, 277 (2012)
[4] J. T. Barreiro et al., *Nature* **470** 486 (2011)
[5] P. Jurcevic, et al., *Nature* **511** 202 (2014)

Van-der-Waals interactions in a cold Rydberg gas probed by microwave spectroscopy

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Thursday

Dipole-dipole interactions between Rydberg atoms are a flourishing tool for quantum information processing and for quantum simulation of complex many-body problems. We show that microwave spectroscopy of a dense Rydberg gas trapped close to a superconducting atom chip in the strong dipole blockade regime reveals directly the many-body atomic interaction spectrum.
We present here a direct measurement of the interaction energy distribution in the strong dipole blockade regime, based on microwave spectroscopy. We apply this method to the observation of the atomic cloud explosion driven by the repulsive Van der Waals interaction. This measurement reveals the limit of the frozen gas approximation. The observed microwave spectra are in good agreement with Monte Carlo simulations of the excitation process and of the cloud dynamics.

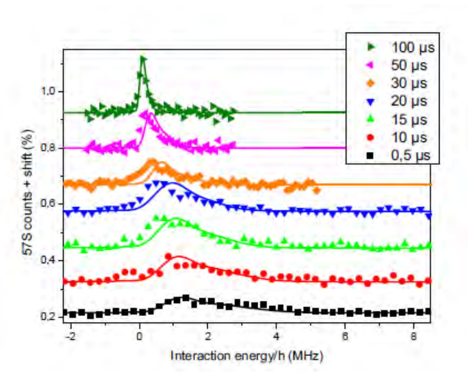

FIG. 1: Microwave spectra probing the interaction energy distribution in a dense cloud of Rydberg atoms after different expansion times, and Monte Carlo simulations (plain lines) of the excitation process and atomic motion.

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Magnetic lattice on a chip for quantum simulation with Rydberg superatoms

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Using an FePt magnetic-film atom chip we demonstrated the loading of ultracold ^{87}Rb atoms in a lattice of microtraps [1]. We aim to develop this system of magnetically trapped atomic ensembles as a scalable platform for quantum simulation and quantum information science by using long-range dipole-dipole interactions between Rydberg atoms [2]. We present experiments driving the 2-photon qubit transitions in the rubidium ground state and investigate the coherence properties for our system. Also we will discuss our progress with introducing Rydberg excitations in our system.

Thursday

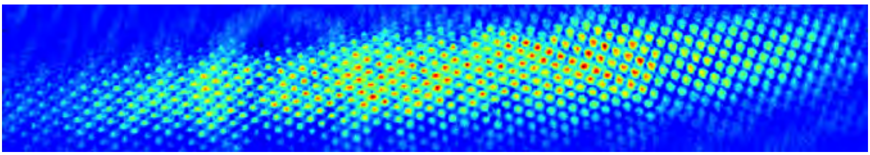

FIG. 1: Absorption image of ultracold atomic clouds in a lattice of microtraps which is based on our magnetic film atom chip. In the middle and on the left side the traps are arranged in a hexagonal lattice geometry, while on the right side the lattice geometry is square.

[1] V.Y.F. Leung, D.R.M. Pijn, H. Schlatter, L. Torralbo-Campo, A. La Rooij, G.B. Mulder, J.B. Naber, M.L. Soudijn, A. Tauschinsky, C. Abarbanel, B. Hadad, E. Golan, R. Folman, R.J.C. Spreeuw, *Rev. Sci. Instrum.* **85** 053102 (2014)

[2] V.Y.F. Leung, A. Tauschinsky, N.J. van Druten, R.J.C. Spreeuw, *Quantum Inf Process* **10** 955-974 (2011)

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Single-photon transistor using a Förster resonance

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Katharina Schneider,[1] Stephan Dürr,[1] and Gerhard Rempe[1]
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An all-optical transistor is a device in which a gate light pulse switches the transmission of a target light pulse with a gain above unity. The gain quantifies the change of the transmitted target photon number per incoming gate photon. In ref. [1], we study the quantum limit of one incoming gate photon and observe a gain of 20. The gate pulse is stored as a Rydberg excitation in an ultracold gas. The transmission of the subsequent target pulse is suppressed by Rydberg blockade which is enhanced by a Förster resonance. The detected target photons reveal in a single shot with a fidelity above 0.86 whether a Rydberg excitation was created during the gate pulse. The gain offers the possibility to distribute the transistor output to the inputs of many transistors, thus making complex computational tasks possible.

[1] D. Tiarks, S. Baur, K. Schneider, S. Dürr, G. Rempe, *Phys. Rev. Lett.* **113** 053602 (2014).

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Rydberg quantum optics in ultracold gases

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Christoph Tresp,[1] and Sebastian Hofferberth[1]

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Engineering sufficiently strong optical nonlinearities to facilitate photon - photon interaction is one of the key goals of modern optics, because such systems are required as basic building blocks for both classical and quantum optical information processing. As well, ensembles of interacting photons can be used to simulate a correlated quantum many-body systems. In our group strong interaction between two propagating photons in an ultracold atomic cloud is obtained by coupling them to Rydberg states, where coupling is achieved via a technique known as electromagnetically-induced transparency (EIT). To inflict Rydberg - Rydberg interaction onto the photons, propagation of each photon is described by polariton, and interaction of such polaritons at the distances shorter than the so-called blockade radius leads to an absorption and has a huge collective optical nonlinearity in the medium as a result. This approach offers fantastic opportunities both for fundamental and applied studies because Rydberg polaritons are highly controllable by the system parameters. Accordingly, recently, it became possible to realize a free-space single-photon transistor, where a single gate photon controls the transmission of more than 60 source photons [1]. It was shown that this transistor can also be operated as a quantum device, where the gate input state is retrieved from the medium after the transistor operation. In addition, such a transistor can be used for nondestructive detection of a single Rydberg atom.

[1] H. Gorniaczyk, C. Tresp, J. Schmidt, H. Fedder and S. Hofferberth, *Phys. Rev. Lett.* **113** 053601 (2014).

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Thursday

An ion trap built with photonic crystal fibre technology

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P. Uebel,[2] P. St.J. Russell,[2] and J. P. Home[1]

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We demonstrate a surface-electrode ion trap fabricated using techniques transferred from the manufacture of photonic crystal fibres (PCFs). A pre-step to a drawn out PCF is a cane that has the same regular hole pattern at a larger (100 micron) size. Filling the holes with gold wires and using them as electrodes provides a relatively straightforward route for realizing traps with electrode structure on the 100 micron scale. Figure 1 shows a gold filled PCF-cane and a voltage pattern for trapping ions. The described trap has a high optical access which makes it useful for interaction with strongly focused laser beams and cavity integration. The fabrication method should allow building traps of similar geometry at sizes on the 10 - 100 microns range that might allow trapping at the tip of an optically guiding PCF, and provide a route towards small two dimensional arrays of ion traps [1].

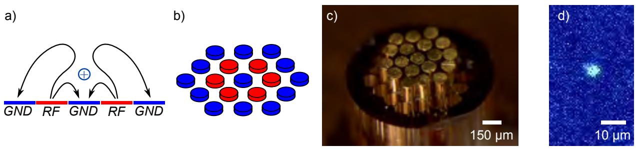

FIG. 1: a) Sketch of a quadrupole potential generated by alternating grounded (GND) and radio frequency (RF) electrodes with the potential minimum indicated by a plus sign. b) planar structure of electrodes that forms a quadrupole potential as sketched in a). c) Photograph of a gold filled PCF-cane structure. d) A trapped, fluorescing calcium ion above such a structure.

[1] F. Lindenfelser, B. Keitch, D. Kienzler, D. Bykov, P. Uebel, M. A. Schmidt, P. St.J. Russell and J. P. Home *arXiv:*1501.03727.

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Controlled rephasing of single spin-waves in cold atoms

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Matteo Cristiani,[1] and Hugues de Riedmatten[1,2]
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Mediterranean Technology Park, 08860 Castelldefels (Barcelona), Spain
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Quantum memories for light allow a reversible transfer of quantum information between photons and long lived matter quantum bits [1]. In atomic ensebles, this information is commonly stored in the form of single collective spin excitations (spin-waves). In this work we demonstrate that we can actively control the dephasing and rephasing of the spin-waves created in a quantum memory based on a cold ^{87}Rb atomic ensemble [2]. The control is provided by an external magnetic field gradient, which induces an inhomogeneous broadening of the atomic hyperfine levels. The spin-waves are then mapped into single photons, and we demonstrate experimentally that the active rephasing preserves the sub-Poissonian statistics of the retrieved photons. Finally we show that this dephasing control enables the creation and storage of multiple spin-waves in different temporal modes, which can be selectively readout. This is an important step towards the implementation of a functional temporally multiplexed quantum memory for quantum repeaters [3].

Thursday

[1] A. Lvovsky, B. Sanders and W. Tittel; Nature Photonics 3.12, 706-714. (2009)
[2] B. Albrecht, P. Farrera, G. Heinze, M. Cristiani and H. de Riedmatten; arXiv:1501.07559 (2015)
[3] C. Simon, H. de Riedmatten and M. Afzelius; Phys. Rev. A, 82, 010304 (2010)

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Revealing genuine optical-path entanglement

V. Caprara Vivoli,[1,*] F. Monteiro,[1] T. Guerreiro,[1] A. Martin,[1]
J.-D. Bancal,[2] H. Zbinden,[1] R. T. Thew,[1] and N. Sangouard[3]

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[2]*Centre for Quantum Technologies,*
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Optical path entanglement, i.e. entanglement between several optical paths sharing a single photon, is a promising resource for large scale quantum networks, like quantum repeaters, as well as for more complex, 2-D, network structures [1]. However, the challenge is to detect and verify the entanglement in a distributed scenario, i.e. using only local measurements [2, 3]. We propose an entanglement witness specifically developed as a trustworthy means of detecting path entanglement [4]. It requires no post-selection, uses only local measurements and can be scaled for genuine N-partite entangled states. A measurement scheme that combines weak optical displacement operations and single photon counting techniques is also developed [5, 6]. We finally experimentally demonstrate the entanglement witness for bipartite and tripartite entangled states, highlighting the scalability and robustness of the witness.

[1] N. Sangouard, C. Simon, H. de Riedmatten, and N. Gisin, *Rev. Mod. Phys.* **83**, 33 (2011)
[2] O. Morin, J.-D. Bancal, M. Ho, P. Sekatski, V. D'Auria, N. Gisin, J. Laurat, and N. Sangouard, *Phys. Rev. Lett.* **110**, 130401 (2013).
[3] M. Ho, O. Morin, J.-D. Bancal, N. Gisin, N. Sangouard, J. Laurat, **arXiv:1406.0381** (2014).
[4] F. Monteiro, V. Caprara Vivoli *et al.*, in preparation.
[5] J. Bohr Brask, R. Chaves, and N. Brunner, *Phys. Rev. A* **88**, 012111 (2013).
[6] V. Caprara Vivoli, P. Sekatski, J.-D. Bancal, C. C. W. Lim, A. Martin, R. T. Thew, H. Zbinden, N. Gisin, and N. Sangouard, **arXiv:1405.1939** (2014).

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Talks: Friday, April 24

Jean Dalibard, Collège de France and Laboratoire Kastler-Brossel

Jean Dalibard graduated in physics in 1981 at École normale supérieure and subsequently conducted experiments in collaboration with Alain Aspect and Gérard Roger on the EPR effect, proving the violation of the Bell inequalities. In 1986, he received his PhD in the group of Claude Cohen-Tannoudji on atom-light interactions. In 1989 he became assistant professor at the École polytechnique and, after a research period at the National Institute of Standards and Technology (NIST), Gaithersburg, became a full professor in 2003. Since april 2013, he holds the chair of *Atoms and radiation* at the Collège de France.

Jean Dalibard has made essential contributions to the field of atomic physics. In his theoretical and experimental research, he has addressed many fundamental questions of the physics of light-matter interactions and Bose-Einstein condensation. Over the last years, his group has been working on spinor condensates, two-dimensional Bose gases, superfluidity and artificial gauge fields. Recent seminal results include the realization of the Berezinski-Kosterlitz-Thouless transition, the analysis of the thermodynamic and superfluid properties of two-dimensional Bose gases and the role of phase coherence at the onset of Bose-Einstein condensation.

Gauge fields in an optical lattice: When topology meets with experimental physics

Ultracold atoms constitute a promising physical platform for the preparation and the exploration of novel states of matter. In particular, non-trivial topological fluids such as topological insulators (a material that, irrespective of its shape, always exhibits the same protected current on its edges) are certainly fascinating objects that one try to reproduce with cold atom setups.

In this talk I will discuss how the notion of topology can emerge in the context of cold quantum matter, taking as a paradigm example particles moving in a square periodic lattice penetrated by a magnetic flux. I will explain how the topology of a given energy band in this periodic potential can be characterized by an integer, the so-called Chern number. I will also present practical implementations of such topological features in the cold-atom context, using in particular time-dependent Hamiltonians and shaken lattices.

Extending Berry-flux interferometer to energy bands with non-trivial topology

Sebastian Scherg,[1,2,*] Lucia Duca,[1,2] Tracy Li,[1,2] Martin Reitter,[1,2] Monica Schleier-Smith,[3] Immanuel Bloch,[1,2] and Ulrich Schneider[1,2]

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Energy bands form the basis for describing many fundamental electronic properties of a solid. They are characterized by their dispersion relation and their geometric and topological properties, which are fundamental for a wide range of many-body phenomena, such as the integer quantum Hall effect. In our experiment, we use ultracold atoms in a graphene-like honeycomb lattice to realize a clean and highly tunable system in which to probe topological effects that are difficult to study in solid state systems. The first and the second energy band of a honeycomb lattice have a conical intersection at the corners of the Brillouin zone, known as Dirac cone, which gives rise to a localized Berry curvature in both bands. We recently implemented a Berry-flux interferometer [1] to measure the singular Berry-flux of π at a Dirac point. While these bands are topologically trivial due to a vanishing Chern number, one goal is now to extend the Berry-flux interferometer to bands with non trivial topology. We therefore analyze a periodic shaking of the honeycomb lattice, which results in a fictitious, periodic, time-reversal symmetry breaking force in the frame co-moving with the lattice. We calculate the resulting band structure within Floquet theory and make predictions on observables of the Floquet bands that can be measured with the Berry-flux interferometer.

[1] L. Duca, T. Li, M. Reitter, I. Bloch, M. Schleier-Smith and U. Schneider, *Science* **347** 288 (2014).

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Topology and flat bands out-of-equilibrium in 1D

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In this contribution, I would like to present a method for describing and simulating one-dimensional open systems. Such methods are of importance since external sources, noise, or other interactions with environments are always present. As two prominent examples we ask what happens to a 1D topological spin-chain when coupled to external baths, and consider the effects of driving a flat band in a dissipative array of photonic cavities coupled to non-linearities. As a third topic we discuss possible applications to many-body localization.

[1] E.P.L van Nieuwenburg, S.D. Huber, *PRB* **90** 075141 (2014).

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Friday

Squeezed Baryons in synthetic dimensions

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Cold atomic systems with $SU(M)$ symmetric interactions have been of recent experimental and theoretical interest. Motivated by this, we study few body physics in such systems which also realize synthetic dimensions (Celi et al., PRL 112, 043001) within the cold atom setting by coupling the atomic hyperfine states via light. Choosing the light appropriately also provides ability to control magnetic flux in the plaquettes of the synthetic lattice. Using a combination of exact diagonalization and analytical methods, we uncover the novel physics that emerges in the interplay of non-local interactions in synthetic dimensions and the magnetic flux. Attractive $SU(M)$ interactions, in absence of flux, obtains a sequence of multi-particle "baryonic" bound states. We show how the presence of flux stabilizes a different sequence of baryonic states, presenting a detailed few body phase diagram. We also discuss consequences of our findings to the many body setting, pointing out the novel phases that can be realized in these systems. These results will be of interest to both experimentalists (suggesting systems with novel physics), as well as theorists for exploring the novel phases realized.

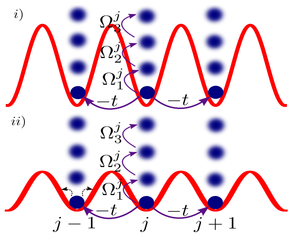

FIG. 1: Schematic plot of atoms having 4 internal hyperfine states (e. g. ^6Li in $F=\frac{3}{2}$ manifold) placed in 1d optical lattice (red). The atoms (hyperfine states) are shown in solid (faded) blue circles. Panel-(i) corresponds to a relatively deep optical lattice than that in panel-(ii). Atoms in not so deep optical lattice have finite probability of being in the vicinity of a site as well (panel-(ii) dotted black arrows). Non-local attractive $SU(M)$ symmetric interaction in the hyperfine direction gives rise to baryons and due to the phase dependent hyperfine coupling (hence flux) there are interesting sequence of transitions between different baryonic states.

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Experimental demonstration of a synthetic Lorentz force by using radiation pressure

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Synthetic magnetism plays an important role in the development of controllable quantum emulators. The first implementation of synthetic magnetism used the analogy between the Lorentz force and the Coriolis force [1]. Methods based on laser-atom interaction employ the analogy between the Berry phase in atomic systems, and the Aharonov-Bohm phase for charged particles [2]. We experimentally demonstrate a synthetic Lorentz force for cold atomic gases, based on the radiation pressure and the Doppler effect, as proposed in Ref. [3]. We measure the dependence of the transverse radiation pressure force on the velocity of a cold atomic cloud, by observing the motion of its center of mass, Fig. 1. The transverse synthetic Lorentz force is perpendicular to the velocity, and it is zero for a cloud at rest.

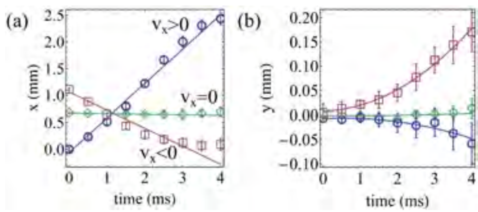

FIG. 1: The trajectories of the CM of the atomic cloud in the presence of the synthetic Lorentz force. (a) $x(t)$, and (b) $y(t)$ for three different initial velocities.

Friday

[1] K.W. Madison, F. Chevy, W. Wohlleben, and J. Dalibard, Phys. Rev. Lett. **84**, 806 (2000).

[2] Y-J. Lin, R.L. Compton, K. Jimnez-Garca, J.V. Porto, I.B. Spielman, Nature **462**, 628 (2009).

[3] T. Dubček, N. Šantić, D. Jukić, D. Aumiler, T. Ban, and H. Buljan, Phys. Rev. A **89**, 063415 (2014).

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Squeezed light spin noise spectroscopy

Vito Giovanni Lucivero,[1,*] Jia Kong,[2] Federica A. Beduini,[1] R. Jimenez-Martinez,[1] and Morgan W. Mitchell[1]

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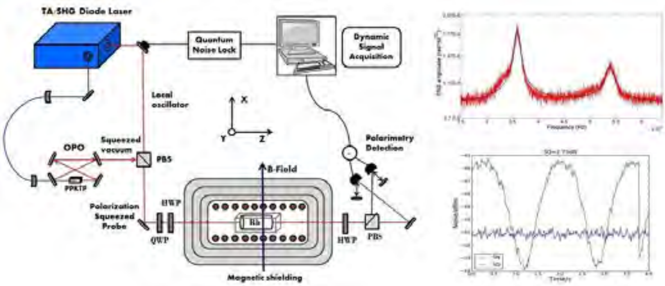
Spin noise spectroscopy (SNS) has become an efficient technique for studying spin systems under thermal equilibrium [1]. In the presence of a transverse magnetic field, we detect spontaneous spin fluctuations via Faraday rotation of a linearly polarized probe beam resulting in the excess of spectral noise at the Larmor frequency over a white photon shot-noise background. Polarization squeezing of the probe allows one to perform sub-shot-noise measurements [2] and can increase the signal-to-noise ratio of a spin noise signal.



Experimental Setup (left) – Spin noise signal amplitude (top right) and polarization squeezing oscillations around the shot-noise level (bottom right)

We describe an experiment that combines a polarization squeezed probe with a Faraday-rotation based SNS setup and we report the results of the quantum noise suppression both in frequency and time domain.

[1] S. A. Crooker et al. , *Nature* **431** 49-52 (2004).
[2] F. Wolfgramm et al. , *Phys. Rev. Lett.* **105** 053601 (2010).

* vito-giovanni.lucivero@icfo.es; http://mitchellgroup.icfo.es/mg/pmwiki.php?n=Main.HomePage

iSense - A portable ultracold-atom-based gravimeter

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Quantum sensors based on ultracold atoms regularly reach precision records for measuring gravity, gravity gradients and time. So far, these have remained confined to laboratory environments. The iSense project aims to create a modular, scalable and portable quantum technology platform for field measurements based on interferometry of ultracold atoms. The project involves miniaturisation of all components including the optics and electronic systems. In the first generation, this will be used to construct a state of the art portable gravimeter using ultracold clouds of rubidium-87 atoms. The current design and first atom interference measurements with this setup will be presented.

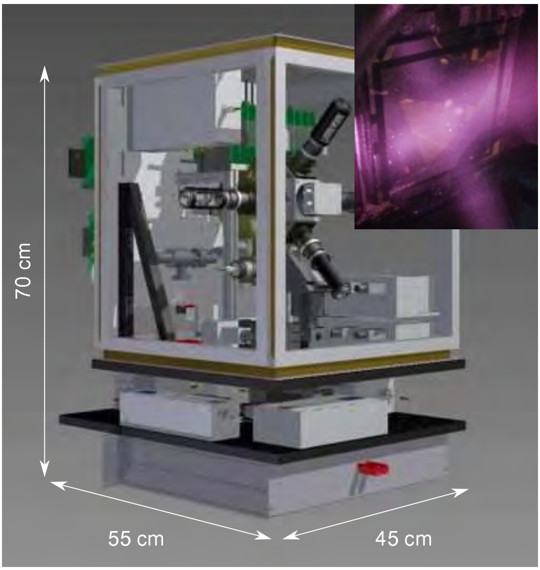

FIG. 1: CAD image of iSense gravimeter. Insert is a photograph of the mirror MOT in operation with a cloud of ^{87}Rb atoms.

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Friday

Posters: Session A

Poster presentations are divided into two poster sessions, which both take place in the *Werner-von-Siemens-Auditorium*, where also the talks for the conference take place. You can pick portrait or landscape format, but please do not exceed A0 poster size. We will provide pins to fix the posters on the walls.

The participants of the session A are:

Name	**Poster number**	**Name**	**Poster number**
Aldous, Matthew	A69	Elliott, Thomas	A82
Ball, Simon	A70	Fritsche, Isabella	A83
Behrle, Alexandra	A71	Fusco, Lorenzo	A84
Bentine, Elliot	A72	Gan, Jaren	A85
Boddeda, Rajiv	A73	Görg, Frederik	A86
Böttcher, Fabian	A74	Greveling, Sebastiaan	A87
Bouazza, Chayma	A75	Grotti, Jacopo	A88
Bowman, David	A76	Guther, Kai-Simon	A89
Bradbury, Yael	A77	Häusler, Samuel	A90
Cabrera, Cesar	A78	Hippler, Carl	A91
Dabrowski, Michal	A79	Ibrügger, Martin	A92
Denechaud, Vincent	A80	Karg, Thomas	A93
Dubcek, Tena	A81	Kedar, Dhruv	A94

Towards a fully miniaturized magneto-optical trap for portable ultracold quantum technology

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By making use of existing planar microfabrication techniques, great strides have already been made in the development of "atom chips" [2], but they remain firmly "chip-in-a-lab" devices. With a view to transitioning to a "lab-on-a-chip" paradigm, we present progress made in the miniaturisation of vacuum and optical systems for producing cold atom ensembles: the *integrated* atom chip.

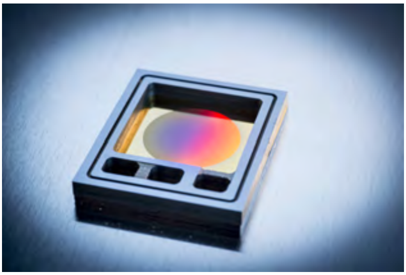

FIG. 1: The basis of the integrated atom chip is a silicon structure with a patterned gold reflector for maximum trapping region in minimal volume.

[1] Contributed Review: The feasibility of a fully miniaturized magneto-optical trap for portable ultracold quantum technology J. Rushton, M. Aldous and M. Himsworth, *Review of Scientific Instruments*, **85**, 121501 (2014), DOI:http://dx.doi.org/10.1063/1.4904066

[2] A. Sidorov, P. Hannaford (2011), From Magnetic Mirrors to Atom Chips in J. Reichel, V. Vuletic (editors), *Atom Chips*. Wiley-VCH Verlag GmbH & Co. KgaA

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Controlled interactions between two optical photons stored as Rydberg polaritons

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While optical photons are ideal carriers of quantum information due to their limited interactions with the environment, weak photon-photon interactions make it difficult to perform quantum operations on photonic qubits. We are exploiting the properties of highly excited Rydberg atoms to induce effective interactions between single photons. Using electromagnetically induced transparency [1], photons are stored as Rydberg polaritons in a cold atom cloud, thus mapping the strong dipolar interactions between Rydberg excitations onto the optical field. Since the dipole blockade effect limits the number of Rydberg excitations [2], and therefore the number of stored photons, to a single one within a few micrometers, we observe highly non-classical states of light upon retrieval [3]. The application of an external microwave field [3] allows control of the interaction strength, manifesting itself in a modification of the retrieved photon statistics [4]. Recently, we finished construction of a new experimental apparatus in which we plan to implement a universal quantum gate for photonic qubits [5].

[1] M. Fleischhauer et al., *Rev. Mod. Phys* **77** 633-673 (2005).
[2] M. D. Lukin et al., *Phys. Rev. Lett.* **87** 037901 (2013).
[3] D. Maxwell et al, *Phys. Rev. Lett.* **110** 102001 (2013)
[4] D. Maxwell et al, *Phys. Rev. A* **89** 043782 (2014)
[5] D. Paredes-Barato and C. S. Adams, *Phys. Rev. Lett.* **112** 040501 (2014)

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Towards a Na-Li Fermi gas experiment

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Since their first realization in 1999, ultracold Fermi gases have provided excellent systems in which to investigate strong interactions and correlations, which go beyond mean field theory. Fermi gas experiments provide many tunable parameters and can act as quantum simulators of solid state systems. Most notably, Feshbach resonances [1] allow experiments to probe the strongly interacting regime by tuning the inter-particle scattering length. We are currently building a new two species experiment for ultracold bosonic Sodium and fermionic Lithium atoms. The vacuum system is complete ($<10^{-11}$mbar) and we are able to trap 7×10^{9} Sodium atoms in a bright magneto-optical trap. We aim to achieve very large condensates, which will allow us to cool the fermions sympathetically to very low temperatures ($T/T_F < 0.05$). This will allow us to explore the strongly interacting regime more carefully and observe unconventional pairing of fermions in two dimensions ([2],[3]).
This pairing mechanism plays an important role in high temperature superconductors and is not yet well understood.

[1] S. Inouye, M.R. Andrews, J. Stenger, H.-J. Miesner, D.M. Stamper-Kurn and W.Ketterle, *Nature* **392** 151 (1998).
[2] W. Kohn and J.H. Luttinger, *Phys. Rev. Lett.* **15** 524 (1965).
[3] A.V. Chubukov, *Phys. Rev. B* **48** 1097 (1993).

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Multiple radiofrequency adiabatic potentials

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Adiabatic potentials (APs) are formed by dressing magnetically confined atoms with radiofrequency (RF) radiation [1]. An avoided crossing is formed where the RF resonantly drives transitions between the m_F states; for atoms in a spherical magnetic quadrupole this forms a trapping surface that is an ellipsoidal shell. APs offer the advantages of smoothness and insensitivity to alignment compared to optical trapping methods.
Recent proposals extend APs to multiple RFs [2]. These may be used for eg. multiple well potentials or interferometric measurements of rotation speed using the quasi-2d surfaces at the bottom of each shell [3]. AP shaping has been demonstrated via time-averaging [4], but with this new approach more diverse potentials are accessible via the application of arbitrary waveform RF, which can be time-dependent to facilitate loading or evaporation. We report on progress towards implementation in a Rb-87 BEC experiment.

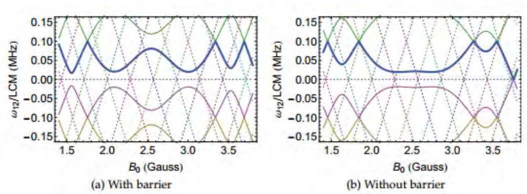

FIG. 1: Eigenenergies of atoms dressed with three radiofrequencies. The thick blue line shows a potential surface with double wells. The barrier may be raised by altering the Rabi frequencies of the dressing RF. Adapted from Fig. 12, Chap 3 [3].

Posters A

[1] O. Zobay, B. Garraway, *Phys. Rev. A* **69** 023605 (2004).
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[3] D. Trypogeorgos, *Periodically Driven Atomic Systems*, *D.Phil Thesis*, (2014).
[4] B. Sherlock, M. Gildemeister, E. Owen, E. Nugent, C. Foot, *Phys. Rev. A* **83** 043408 (2011).

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Few photon non-linearities using Rydberg polaritons

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Quantum states of light are one of the foremost and robust candidates for Quantum information transportation and processing. Cold atomic memories are one of the prime candidates for storing and manipulating photonic states. We demonstrated an on-demand retrieval of single photons by implementing the DLCZ [1] protocol in a cavity enhanced cold atomic memory. Single photon states were recovered with high efficiency (up to 82%) in a well defined spatio-temporal mode and consistently characterized by photon counting and homodyne tomography [2]. Currently, we are working on an experiment to implement non-linear effects in quantum regime by using an effect called 'Rydberg blockade'. Rydberg states are highly excited states (n>30) of atoms, which are useful in realizing photon-photon interactions because of their long distance (>10μm) dipole-dipole interactions [3]. These interactions result in a cooperative Rydberg blockade phenomenon wherein each Rydberg atom prevents the excitation of its neighbors inside a "blockade sphere". This Rydberg blockade deeply changes the "Electromagnetically Induced Transparency" (EIT) profile and leads to magnified non-linear susceptibilities [4]. We utilize a low finesse cavity to transform phase shifts into intensity correlations which would allow one to generate arbitrary non-classical states of light [5, 6].

[1] L. M. Duan, M. D. Lukin, J. I. Cirac, and P. Zoller, *Nature* **414**, 413 (2001).
[2] E. Bimbard et al. *Phys. Rev. Lett.* **112** 033601 (2014).
[3] M. Saffman et al. *Rev. Mod. Phys.* **82** 2313 (2001)
[4] M. D. Lukin et al. *Phys. Rev. Lett.* **87**, 037901 (2001)
[5] J. Stanojevic et al. *Phys. Rev. A* **86**, 021403(R) (2012).
[6] A. Grankin et al. *New J. Phys.* **16** 043020 (2014).

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A single Rydberg atom in a Bose-Einstein condensate

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A single Rydberg atom inside of a Bose-Einstein condensate (BEC) can be used to study phase transitions or ultra-cold chemistry in a quantum gas. The large electron radius of the Rydberg state and the high density in the BEC means that there are many ground state atoms that interact with the Rydberg electron leading to a shift of the Rydberg line. This effect can be used as local density probe in the BEC or complimentary, it can be used to excite a Rydberg atom in a defined density shell of the BEC. Using this density shift we present results of ultra-cold chemistry where the ionic core of a Rydberg atom bonds with neighbouring ground state atoms to form a Rydberg molecule. As future prospects we propose two approaches how a single Rydberg atom in a BEC can be used to realize a purer ion-neutral hybrid system. The first approach would be to excite the Rydberg electron to a circular state, so that the electron would orbit outside of the BEC. A second approach is to use magic wavelength light to ionize the single Rydberg atom while still trapping the ion. For both approaches the single ion in a BEC can then be used to further study collisions and chemical reactions in the ultra-cold temperature regime.

Posters A

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Topological superfluid in Dysprosium ultracold gas

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In the past decades, there has been an increasing interest in studying materials with a non-trivial topology in the field of condensed matter. Different exotic edge states arise as a result to this new topological phase, for example, topological insulators. Recent theoretical studies predicted the existence of a new type of edge states in topological superfluids that are described as Majorana fermions.

The advantage of using ultracold atoms in order to realize such systems relies on the high level of control and manipulation offered by this field. It exists few proposals on how to create a topological superfluid. The main ingredient is to introduce a strong spin-orbit coupling while keeping heating rate very low. As this combination can not be fulfilled in alkali gases, one should use another atomic specie with more suitable optical transitions. Lanthanide atoms, are a good condidate to realize spin-orbit coupling with drastically reduced heating.

The objective of our project is to create a topological superfluid in ultracold Dysprosium gas.

[1] S. Nascimbène, *J. Phys* **46** 134005 (2013).
[2] M. Lu, Y. Seo Ho and B.L. Lev, *Phys. Rev. A* **83** 012510 (2011).
[3] L. Cheuk, A.T. Sommer, Z. Hadzibabic, T. Yefsah, W.S. Bakr and M.W. Zwierlein, *Phys. Rev. Lett.* **109** 095302 (2012).

Posters A

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Holographic generation of optical traps for ultracold atoms

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A recent area of interest in the field of cold atomic physics is the development of non-trivial spatially- and temporally-varying optical trapping geometries, which may be realized with a phase-only spatial light modulator. Calculation methods for phase-only holograms which allow the calculation of smooth optical traps of arbitrary complexity have been recently developed [1, 2]. The output of these algorithms, when applied to real devices, often does not give high-quality optical traps, but a simple and robust feedback-enhanced algorithm improves the accuracy of these optical traps to the percent level, giving a wide range of potential applications of these light patterns [3–5]. We present our most recent results of holographic optical patterns, including a simple method to create arbitrary, smooth, *multi-wavelength* traps.

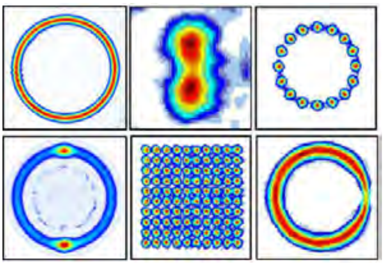

FIG. 1: Holographically-generated optical atom traps

[1] M. Pasienski and B. DeMarco, *Opt. Express* **16** 2176 (2008).
[2] T. Harte *et al.*, *Opt. Express* **22** 26548 (2014)
[3] G. D. Bruce *et al.*, *Phys. Scr.* **T143** 014008 (2011)
[4] G. D. Bruce *et al.*, arXiv:1409.3151
[5] G. D. Bruce *et al.*, *Phys. Rev. A* **84** 053410 (2011)

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A cold-atom interferometric rotation sensor

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We propose a prototype inertial rotation sensor based on Coriolis-sensitive matterwave interference. In our scheme, we trap a cloud of cold Rb 85 atoms in a magneto-optical trap (MOT), and using laser beams drive Raman transitions between the ground hyperfine states to create an atom interferometer. The Coriolis accelerations are measured by the interferometer and the rotation of the device is manifest in the produced fringe pattern. We will demonstrate the miniaturisation of the apparatus using a micro-fabricated integrated vacuum cell and develop composite-pulse sequences to enhance the fidelity of the interferometer and allow for increased sensitivity in the rotation measurements. Finally, we will explore a novel , quantum-enabled readout process based on Raman quantum memory which will allow for direct optical readout without the need for image processing.

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A new experimental setup for studying isotopic potassium mixtures in optical lattices

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In our experiment we want to perform studies of strongly correlated systems with atomic mixtures of essentially equal masses. To this end, we are currently constructing an experiment for studying strongly interacting potassium Bose and Fermi gases in complex optical lattices [1]. Our setup will allow for the investigation of the different isotopes of potassium (bosonic ^{39}K, ^{41}K and fermionic ^{40}K) in the same apparatus, without major changes needed.
The experiment takes place in a UHV chamber which is loaded with a cold atomic beam coming from a 2D^{+}-MOT. The quantum degenerated regime will be reached using a 3D MOT followed by sub-Doppler cooling on the D1 atomic transition (so-called "gray molasses") [2]. Finally the atoms will be transferred to a hybrid optical dipole trap. Employing these techniques, we expect to start evaporative cooling with an improved initial phase-space density and reach quantum degeneracy in a fast and simple way. The magnetic fields employed in the hybrid trap and in the control of Feshbach resonances will be produced by a Bitter-type coil, allowing for large optical access [3]. The Bitter configuration, traditionally used in high-field magnets, allows for parallel cooling of the different coil layers and should allow us to produce very stable and homogeneous magnetic fields, avoiding unwanted coil heating. Due to the versatility of our setup, we will be able to work arbitrarily with bosonic and fermionic gases as well as with all the possible mixtures between them. This should allow the study of situations similar to the ones occurring in ^{3}He-^{4}He mixtures, but give access to new parameter regimes.

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[3] D. Sabulsky, C. Parker, N. Gemelke and C. Chin, *Rev. Sci. Instrum.*, **84**, 104706 (2013)

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Hamiltonian design in readout from room-temperature Raman atomic memory

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We present an experimental demonstration of the Hamiltonian manipulation in light-atom interface in Raman-type warm rubidium-87 vapor atomic memory. By adjusting the detuning of the driving beam we varied the relative contributions of the Stokes and anti-Stokes scattering to the process of four-wave mixing which reads out a spatially multimode state of atomic memory. Our experimental results agree quantitatively with a simple, plane-wave theoretical model we provide [1] which allows for a simple interpretation of the coaction of the anti-Stokes and the Stokes scattering at the readout stage.

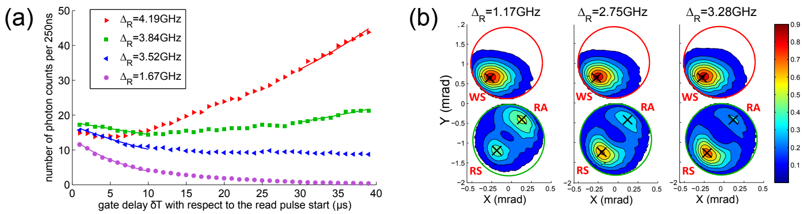

FIG. 1: Measured temporal evolution of the readout fieds (a) and the spatial intensity correlations between write-in and readout (b) as a function of detuning Δ_R.

The correlation maps enabled us to resolve between the anti-Stokes and the Stokes scattering and to quantify their contributions. The Stokes contribution yields additional, adjustable gain at the readout stage, albeit with inevitable extra noise. We provide useful framework to trace it and the results can be utilized in the existing atomic memories setups. Furthermore, the shown Hamiltonian manipulation offers a broad range of atom-light interfaces readily applicable in current and future quantum protocols with atomic ensembles.

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Suppression and revival of weak localization through manipulation of time-reversal symmetry

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Transport in a disordered media can be described as a random walk. However, due to their coherence (ability to produce interferences), waves propagating in disorder can exhibit surprising features that cannot be explained with a simple random walk model, such as Anderson (strong) localization and weak localisation [1]. Even if this topic had been deeply studied through many decades, there still some open questions [2]. Weak localization is manifested by coherent back scattering (CBS), which correspond to the enhancement of the probability for the wave to be scattered in the backward direction. Such phenomenon stems from constructive interferences of counter-propagating multiple scattering paths, relying on time reversal symmetry. In the last years, Anderson localization [3][4] and CBS [5] had been studied with ultra-cold atoms in a controlled way.
Here, we report on the observation of suppression and revival of CBS of ultracold atoms propagating in an optical speckle disorder and exposed to a short dephasing kick during the propagation, as suggested by Micklitz et al [6]. We observe the suppression of time reversal symmetry and CBS, except for a very specific propagation time, where time reversal symmetry and CBS are shortly restored.

[1] P. W. Anderson, "Absence of Diffusion in Certain Random Lattices", Phys. Rev. 109, 1492 (1958)
[2] A. Lagendijk, "Fifty years of Anderson localization", Phys. To- day, 62, 24 (2009)
[3] J. Billy et al. "Direct Observation of Anderson localization of matter-waves in a controlled disorder", Nature 453, 891 (2008)
[4] F. Jendrzejewski et al. "Three-dimensional localization of ultra- cold atoms in an optical disordered potential", Nat. Phys. 8, 392 (2012)
[5] F. Jendrzejewski et al. "Coherent Backscattering of Ultracold Atoms" , Phys. Rev. Lett. 109, 195302 (2012)
[6] T.Micklitz et al, "Echo spectroscopy of Anderson Localisation", arXiv:1406.6915

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Weyl points in three-dimensional optical lattices: synthetic magnetic monopoles in momentum space

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We show that Hamiltonians with Weyl points can be realized for ultracold atoms using laser-assisted tunneling in three-dimensional (3D) optical lattices. Weyl points are synthetic magnetic monopoles that exhibit a robust, 3D linear dispersion. They are associated with many interesting topological states of matter, such as Weyl semimetals and chiral Weyl fermions. However, Weyl points have yet to be experimentally observed in any system. We show that this elusive goal is well-within experimental reach with an extension of the techniques recently used to obtain the Harper Hamiltonian [1].

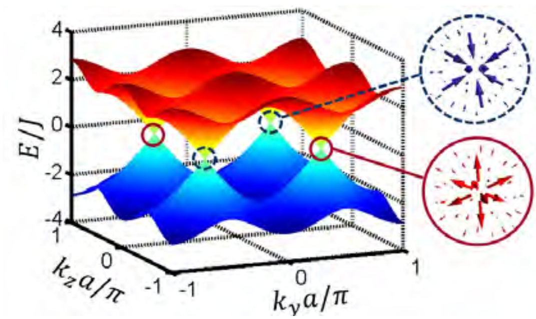

FIG. 1: Energy spectrum in the $k_x = 0$ plane of the Brillouin zone, showing linear dispersion in the proximity of the four Weyl points. The insets show the Berry curvature of two Weyl points, demonstrating that they are synthetic magnetic monopoles in momentum space.

[1] T. Dubček, C. J. Kennedy, L. Lu, W. Ketterle, M. Soljačić and H. Buljan, arXiv:1412.7615.

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Multipartite entangled spatial modes of ultracold atoms controlled by quantum measurement

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In the fully quantum regime of interactions between light and many-body atomic systems, the light and matter can become entangled, imprinting properties of the matter onto the light state. We show that when the light field is measured the measurement back-action effect results in the generation of a spatial mode structure for ultracold atoms trapped in an optical lattice. We show how the multipartite mode entanglement properties can be manipulated by tuning the optical geometry, and how this can be used to engineer quantum states and dynamics of the matter fields. We give examples of multimode generalizations of parametric down-conversion, Dicke and other states, and study their entanglement properties. We also propose how the multimode structure can be used to detect and measure entanglement in quantum gases.

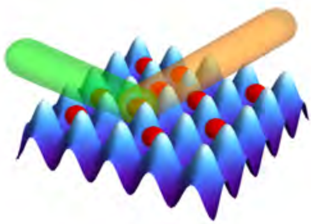

FIG. 1: Setup: light scattered from ultracold atoms trapped in an optical lattice results in light-matter entanglement that can be used to control the atomic state.

[1] T.J. Elliott, W. Kozlowski, S.F. Caballero-Benitez and I.B. Mekhov, *arXiv:1412.4680*

[2] W. Kozlowski, S.F. Caballero-Benitez and I.B. Mekhov, *arXiv:1412.4680*

[3] I.B. Mekhov and H. Ritsch, *J. Phys. B* **45** 102001 (2012).

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Sub-Doppler cooling of ^{6}Li for improved preparation of strongly interacting Li-K mixtures

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In our experimental approach to prepare strongly interacting Li-K mixtures [1], fermionic ^{6}Li acts as the cooling agent. The high temperature of ^{6}Li in the standard magneto-optical trap (MOT), operated on the D2 transition, limits the efficiency. To overcome this limitation, we implement a gray molasses cooling scheme on the D1 transition to reach sub-Doppler temperatures [2, 3]. In this technique, cooling arises from the Sisyphus effect in combination with a sharp cooling feature near the Raman transition where the two ground states (F=1/2 and F=3/2) are coupled via two lasers, blue detuned from the F'=3/2 excited state of the D1 transition. Using separate light paths for the gray molasses and the MOT, we can access a wide parameter range where we are able to investigate the influence of different polarizations and intensities on the D1 cooling feature. This enables us to cool our Li atoms from initially $\sim$250 μK after the MOT to temperatures below 50 μK. The very robust cooling technique offers us better starting conditions for our optical dipole trap, where Li sympathetically cools K.

[1] M. Jag, M. Zaccanti, M. Cetina, R.S. Lous, F. Schreck, R. Grimm, D.S. Petrov, and J. Levinsen *Phys. Rev. Lett.* **112**, 075302 (2014)
[2] A.T. Grier, I. Ferrier-Barbut, B.S. Rem, M. Delehaye, L. Khaykovich, F. Chevy, and C. Salomon *Phys. Rev. A* **87**, 063411 (2013).
[3] A. Burchianti, G. Valtolina, J.A. Seman, E. Pace, M. De Pas, M. Inguscio, M. Zaccanti, and G. Roati *Phys. Rev. A* **90**, 043408 (2014).

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Entropy production rate in the open Dicke model

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One of the most important thermodynamic property that quantifies the degree of irreversibility of a transformation is the entropy production. In this work we study the rate of production of entropy in the open Dicke model, described by linear Langevin equations. Extending the method used in Ref. [1] for classical systems, we calculate the total change of the entropy between the non-equilibrium steady state and the initial uncoupled state, the entropy production rate and the three components of the entropy production in terms only of the means and covariances of the operators which express fluctuation with respect to the mean fields. We show that the entropy production rate is measurable in the context of the setup in Ref. [2]. In particular the open system due to the cavity losses allow the experimenter to measure non-destructively and in real time the average number of photons, which we show to be linked to the entropy production rate. Thus, by combining current available technology and the quantum simulation capability of a cold atomic setup, we can be able to infer not only physical properties typically important in the context of quantum optics, but also we can characterise the real non-equilibrium, and inherently irreversible, thermodynamics of a driven dissipative quantum many-body system.

[1] G. T. Landi, T. Tome, and M. J. de Oliveira, *J. Phys. A: Math. Theor.* **46**, 395001 (2013).

[2] F. Brennecke, R. Mottl, K. Baumann, R. Landig, T. Donner, and T. Esslinger, *PNAS* **110** 11763 (2013).

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Two-stage magneto-optical trapping and narrow-line cooling of ^{6}Li atoms to high phase-space density

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As part of our approach to obtain a fermionic quantum degenerate sample with all-optical methods, the peak and phase-space density of a two-stage magneto-optical trap (MOT) with ^{6}Li atoms was studied experimentally. After cooling and compression on the D2 transition at 671 nm, the atom cloud is further cooled using the narrower $2S_{1/2} \rightarrow 3P_{3/2}$ ultra-violet (UV) transition at 323 nm. The UV MOT is then compressed to give a phase-space density of up to 3×10^{-4}, which is two orders of magnitude higher than on the D2 transition[1]. This improvement increases the efficiency of direct loading into an optical dipole trap and facilitates evaporative cooling to degeneracy.

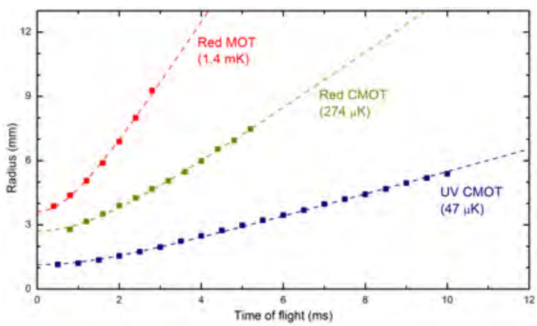

FIG. 1: Comparison of Time-of-Flight measurements between the red MOT (1.4mK), compressed red MOT (274 μK), and the compressed UV MOT (47 μK).

[1] J. Sebastian, Ch. Gross, Ke Li, H. C. J. Gan, Wenhui Li and K. Dieckmann, Phys. Rev. A **90** 033417 (2014).

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Realizing spin-dependent optical lattices for ultracold atoms by periodic driving

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Ultracold atoms in optical lattices offer the possibility to engineer specific Hamiltonians with widely tunable properties. For example, time-modulated optical lattices have been demonstrated to allow for the dynamical control of atomic tunneling and the realization of effective lattice Hamiltonians with a non-trivial topological band structure. While previous implementations relied on the physical motion of the lattice potential, this effect can also be realized by a periodic modulation of a magnetic field gradient. As the coupling of an atom to this magnetic field gradient depends on its magnetic moment and therefore its internal state, the effective Hamiltonian then becomes spin-dependent.

We realized a state-dependent lattice for fermionic potassium atoms and characterized the different band structures for each internal state by measuring the expansion rate of an atomic cloud in the lattice and by a measurement of the effective mass through dipole oscillations. This method of creating spin-dependent optical lattices can be used to create novel situations, such as systems where one state is pinned to the lattice, while the other remains itinerant.

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Designing large area photonic crystal microcavities

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Photon gases are a standard element of statistical physics textbooks, yet in the lab there was no way to create and control such a gas. This changed with the achievement of Bose-Einstein condensation of light in a dye-filled cavity [1]. We plan to create a photon gas in a periodic potential using a photonic crystal microcavity. The design of such a microcavity is however a formidable computational task. We present a semi-analytical approach to design one-, two- and three-dimensional cavities, with and without dissorder, and with and without access waveguides. We compare the modes predicted by our local density approach with the results of brute force simulations and find excellent agreement.

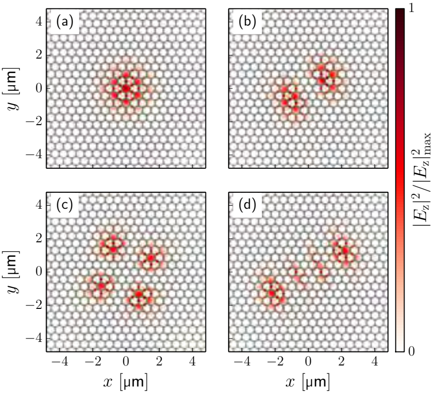

FIG. 1: FDTD results of the field patterns in two dimensions for (a) the first, (b) the second, (c) the third, and (d) the fourth eigenmode. On top of the field patterns the chirped photonic crystal is plotted, where the dielectric material is depicted in black and the air holes in white

[1] J. Klaers, J. Schmitt, F. Vewinger and M. Weitz, *Nature* **468**, 545 (2010).

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Posters A

Characterization of a transportable Sr lattice clock

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The excellent performance of optical clocks offers new prospects for applications as well as fundamental research. Applications include the operation of optical clocks for time keeping and relativistic geodesy.
We are now working on a new apparatus for an optical lattice clock with strontium atoms, which is designed to be transportable. This kind of clocks, that can be operated outside the laboratory, can be used for direct frequency comparison between distant experiments and local measurements of the geopotential (relativistic geodesy). In 2015 we scheduled proof of principle experiments like measuring a 1000 m height difference by comparison of optical clocks over a 100 km fiber link.

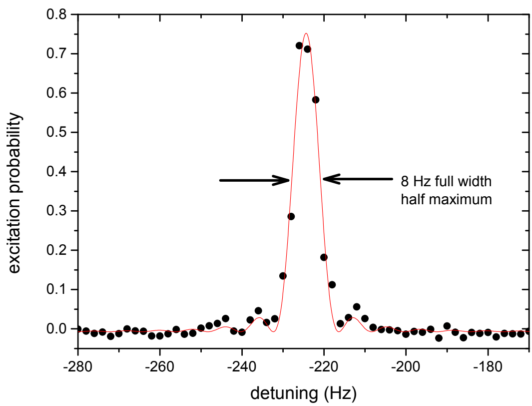

FIG. 1: Spectroscopy on the clock transition of ^{87}Sr.

This work is supported by QUEST, DFG (RTG 1729, CRC 1128), EU-FP7 (SOC2, FACT) and EMRP (ITOC, QESOCAS). The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union.

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On Majorana modes in p-wave superfluids

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The appearance of Majorana modes in topological superconductor is currently of interest in context of quantum information processing. A recent proposal by Bühler et al. uses fermions in an optical lattice with a coupling to inter-site orbital states to obtain a p-wave pairing [1]. There the setup allows for two distinct coupling terms to appear where one of them is known to have nontrivial topological properties and exhibit Majorana modes.
Here, the topological phases for the second possible coupling are derived within mean field theory and it is shown that can give rise to Majorana modes at topological defects. We demonstrate the appearance of a topological phase with chern number two for anisotropic inter-site hopping.

[1] A. Bühler, N. Lang, C.V. Kraus, G. Mller, S.D. Huber and H.P. Büchler, *Nature Communications* **5** 4504 (2014).

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Quantized conductance in neutral matter

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Fermions coherently flowing through a narrow one-dimensional constriction connected to two reservoirs exhibit quantum effects. As the constriction only supports quantized transverse modes the conductance jumps by a quantum $1/h$ when a new mode contributes to transport. This effect has solely been observed for electrons, among them in quantum point contacts realized in two-dimensional electron gases [1], although quantization is also expected for neutral particles.

Recently we implemented such structures with neutral ultracold atoms [2]. A cigar-shaped cloud of fermionic Lithium atoms is first pinched at its center forming two reservoirs connected by a quasi-two-dimensional channel. Then the one-dimensional constriction is imprinted onto the channel using a lithographically engineered beam. The beam is focused with a microscope to achieve a small constriction. The system exhibited distinct conductance plateaus when varying the width of the constriction or an attractive gate potential. The steps are separated by the conductance quantum and are well explained by Landauer's formula without free parameters. Our results provide a fundamental step towards quantum simulation of mesoscopic devices.

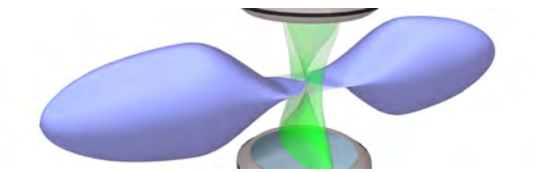

FIG. 1: Reservoirs of Lithium atoms connected by a one-dimensional constriction.

[1] B. J. van Wees, et al., *Phys. Rev. Lett* **60** 848-850 (1988).
[2] S. Krinner, et al., *Nature* **517** 64-67 (2014).

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Observation of chiral superfluid order by matter-wave interference

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The overall goal of our experiment is to explore ultracold bosonic quantum gases in excited bands of an optical lattice. We investigate ^{87}Rb atoms in a bipartite interferometric lattice allowing us to change the lattice geometry dynamically. We observe the formation of a chiral superfluid order, arising from the interplay between the contact interaction of the atoms on each lattice site and the degeneracy of the p orbitals in the second Bloch band. A periodic pattern of locally alternating orbital currents and circular currents establishes in the lattice, time-reversal symmetry being spontaneously broken [1, 2]. We report on a technique that lets us directly observe the phase properties of the superfluid order parameter. Here, two independent atomic samples are produced in the second band at well separated spatial regions of the lattice and subsequently brought to interference [3].

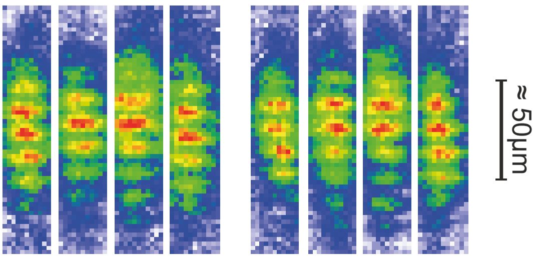

FIG. 1: Interference patterns observed in our experiment, showing the breaking of time-reversal symmetry in the second Bloch band of the bipartite optical lattice

[1] G. Wirth, M. Ölschläger and A. Hemmerich, *Nature Physics* **7** 147 (2011).
[2] M. Ölschläger, T. Kock, G. Wirth, A. Ewerbeck, C. Morais Smith and A. Hemmerich, *New J. Phys.* **15** 083041 (2013).
[3] T. Kock *et al.*, arXiv:1411.3483 (2014), accepted by *Phys. Rev. Lett.*

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Rotational cooling of electrically trapped polyatomic molecules

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Due to their long-range interaction and the large number of internal states, polar molecules cooled to low and ultralow temperatures offer a wide range of exciting applications such as quantum simulation or controlled chemistry. For these prospective experiments controlling the external and internal degrees of freedom of the molecules is mandatory.

Here, we present results recently achieved on rotational-state cooling. The molecules are trapped inside an electric trap [1] and control over the internal degrees of freedom is achieved via optical pumping of J-states to a vibrational excited state as illustrated in FIG. 1. In combination with motional cooling [2, 3] a polyatomic molecular ensemble could be created with more than 70% of the molecules occupying one single rotational state. We expect this to be a versatile scheme adaptable to many other molecule species.

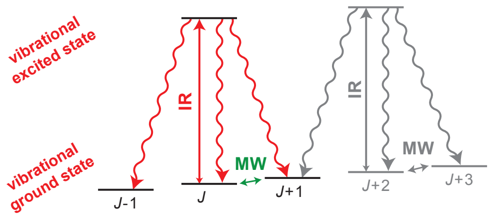

FIG. 1: Illustration of the general idea of rotational-state cooling via optical pumping to a vibrational excited state.

[1] B.G.U. Englert *et al.*, *Phys. Rev. Lett.* **107**, 263003 (2011).
[2] M. Zeppenfeld *et al.*, *Phys. Rev. A* **80** 041401 (2009).
[3] M. Zeppenfeld *et al.*, *Nature* **491**, 570-573 (2012).

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Hybrid atom-membrane optomechanics

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Hybrid systems in which a mechanical degree of freedom is coupled to a microscopic quantum system promise control and detection of mechanical motion at the quantum level. This will open up possibilities for precision sensing, quantum-limited signal transduction and fundamental tests of quantum mechanics. In our experiment, interaction between atomic motion in an ultracold ensemble and vibration of a Si_3N_4 membrane is mediated by a standing wave laser beam. Currently, we exploit this long-distance coupling to sympathetically cool the membrane's fundamental vibrational mode from room temperature to 650 ± 330 mK [1].

In future experiments we plan to couple the membrane vibrations to the internal atomic states [2]. This enables coupling to higher-order modes of the membrane at MHz frequencies, where laser noise is reduced and mechanical quality factors are higher. Another major advantage of the internal atomic states over motional states is that they can be prepared and detected with higher precision, a favorable condition for generating atom-membrane entanglement. On the technical side the experiment has been successfully adapted for a more compact and more stable membrane-cavity system compatible with cryogenic pre-cooling. With these improvements ground state cooling and quantum control of the membrane are expected to come within reach.

[1] A. Jöckel, A. Faber, T. Kampschulte, M. Korppi, M.T. Rakher, and P. Treutlein, *Sympathetic Cooling of a Membrane Oscillator in a Hybrid Mechanical-Atomic System*, Nature Nanotechnology **10**, 55-59 (2015).

[2] B. Vogell, T. Kampschulte, M.T. Rakher, A. Faber, P. Treutlein, K. Hammerer, and P. Zoller, *Long Distance Coupling of a Quantum Mechanical Oscillator to the Internal States of an Atomic Ensemble*, preprint arXiv:1412.5095 (2014).

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Posters A

Study of phase correlations in a trapped 2D interacting quantum gas

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Trapped ultracold fermions are an excellent model for studying quantum phenomena which arise from many-body physics. We study phase correlations in a 2D interacting quantum gas by measuring the first order correlation function. Unlike in 3D where condensation into a superfluid results in constant phase coherence, true long range order is forbidden in 2D by the Mermin-Wagner theorem. Nevertheless, condensation in 2D is replaced by the Berezinskii Kosterlitz Thouless (BKT) mechanism, which predicts a qualitative change to algebraically decaying quasi-long range order when the gas crosses the transition to the superfluid phase [1]. We extract a trap averaged spatial correlation function $g_1(r)$ from the pair momentum distribution for our inhomogeneous 2D system [2]. The trap contribution and its finite size lead to an obtained algebraic decay differing from the behaviour expected for a homogeneous system, but in agreement with QMC simulations for a trapped Bose gas.

[1] V.L. Berezinskii, *Soviet Physics JETP* **34** 610 (1971).
[2] M.G. Ries, A.N. Wenz, G. Zürn, L. Bayha, D. Kedar, P.A. Murthy, M. Neidig, T. Lompe and S. Jochim, *arXiv:1409.5373* (2014).

Posters A

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Posters: Session B

Poster presentations are divided into two poster sessions, which both take place in the *Werner-von-Siemens-Auditorium*, where also the talks for the conference take place. You can pick portrait or landscape format, but please do not exceed A0 poster size. We will provide pins to fix the posters on the walls.

The participants of the session B are:

Name	Poster number	Name	Poster number
Kerkmann, Andreas	B96	Reshodko, Irina	B109
Kresic, Ivor	B97	Rojan, Katharina	B110
Kunkel, Philipp	B98	Schuster, Simon	B111
Lachmann, Maike Diana	B99	Seeßelberg, Frauke	B112
Laurent, Sébastien	B100	Simonelli, Cristiano	B113
Lausch, Tobias	B101	Solaro, Cyrille	B114
Lim, Chin Chean	B102	Thirumalai, Keshav	B115
Lous, Rianne	B103	Thomas, Oliver	B116
Mahdian, Amir	B104	Torggler, Valentin	B117
Mugel, Sam	B105	Vanhala, Tuomas	B118
Ohl de Mello, Daniel	B106	Weber, Sebastian	B119
Onishchenko, Oleksiy	B107	Welte, Stephan	B120
Petralia, Lorenzo	B108	Wieburg, Phillip	B121

Construction of a Lithium quantum gas machine

Andreas Kerkmann,[1,*] Jan Mika Jacobsen,[1] Niels Rohweder,[1]
Benno Rem,[1] Christof Weitenberg,[1] and Klaus Sengstock[1]

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We are setting up a new quantum gas machine for the preparation of small degenerate samples of Lithium atoms. In this poster, we present the planned setup and its current status. The laser system has master lasers on the D2 line for the operation of a MOT and on the D1 line for the operation of a grey molasses. The lasers are locked using spectroscopy in Lithium heat pipes. The master lasers then seed TAs, which provide the light for a 2D-MOT and a 3D-MOT. The repumping transition frequency is added by modulating the light with an EOM, thus allowing the operation of lambda-enhanced grey molasses. We plan to directly load a crossed optical dipole trap at 1070 nm from the molasses. The laser system is designed to easily switch between the ^{6}Li and ^{7}Li isotopes.

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Pattern formation in cold atoms via a single-mirror feedback scheme

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Optomechanical symmetry breaking experiments in cold and ultracold atomic matter hold great potential for simulating condensed matter phase transitions in a controlled setting [1]. We report on studies of a thermal cold atomic gas placed near a retro-reflecting mirror, driven by a red detuned pump beam. Properties of the spatialy ordered signal observed on a charge coupled device (CCD) depend on the applied B-field, indicating a spin nonlinearity is present in the system. This is in contrast to the blue detuned case reported in Ref. [2], where only two-level (electronic) and optomechanical nonlinearities were observed. Experiments with optical molasses hint at a coexsistence of optomechanical and spin nonlinearity induced patterns.

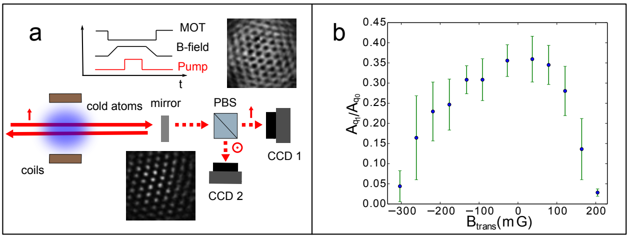

FIG. 1: **a**, Experimental setup and timing diagram (MOT - magneto-optical trap, PBS - polarizing beam splitter). **b**, Ratio of first to zeroth order signal powers in orthogonal polarization channel v. the magnetic field in the direction transverse to the pump. The ^{87}Rb cloud has N$= 10^9$ atoms, temperature of T$= 145\ \mu$K and an optical density of $b_0 = 30$.

[1] H. Ritsch, P. Domokos, and F. Brennecke, T. Esslinger, *Rev. Mod. Phys.* **85** 2 (2013).
[2] G. Labeyrie, E. Tesio, P.M. Gomes, G.-L. Oppo, W.J. Firth, G.R.M. Robb, A.S. Arnold, R. Kaiser, T. Ackemann, *Nat. Phot.* **8** 321 (2014).

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Accurate detection of atom numbers in a BEC experiment

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We implemented a detection scheme capable of single-atom resolution in our already existing BEC-experiment. There we routinely prepare entangled states in a Bose-Einstein condensate of ^{87}Rb atoms in an optical dipole trap. For our new detection we recapture the atoms in a magneto-optical trap and detect the fluorescence signal of the atoms with a low noise CCD camera.
In a test setup we could already achieve single-atom resolution for a mesoscopic ensemble of up to 1200 atoms [1].
This improves the resolution of the so far used absorption imaging system, which reaches about 4 atoms, [2] and allows for detection of quantum entanglement in the system at the single atom level.

[1] D.B. Hume, I. Stroescu, M. Joos, H. Strobel W. Müssel and M.K. Oberthaler, *Phys. Rev. Lett.* **111** 253001 (2013).
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MAIUS - atom interferometry on sounding rockets

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Increasing the space-time-area in atom interferometers is one approach towards precise measurements of the equivalence principle. This can be achieved by performing the experiments in a weightless environment. In the past the QUANTUS-experiments have demonstrated the feasibility of operation of an atom interferometer in the drop tower facilities in Bremen [1], [2].
As a next step towards the transfer of such a system in space a rocket-based atom interferometer is currently being build. With the launch of the rocket mission in 2015 we plan to demonstrate and test such an apparatus in space for the first time.
The poster shows the setup, the up to date progress and future prospects of this ambitious and technically challenging project.
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 50 WM 1131-1137.

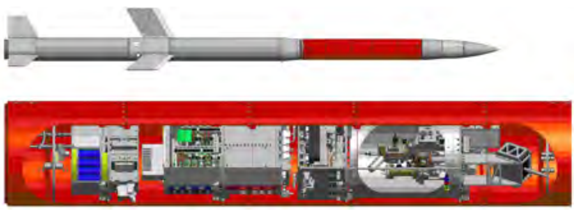

FIG. 1: Flight design of the MAIUS apparatus

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[2] H. Mntinga et al., Phys. Rev. Lett. 110, 093602 (2013)

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Three-body losses in a unitary Bose gas

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Recent advances in manipulating cold atomic vapors have enabled the study of Bose gases at the unitary limit where the scattering length a describing two-body interactions becomes infinite. Unlike fermions, the study of bosons is hampered by three-particle recombination that leads to a very short lifetime of the system. However in the dilute regime when the three body losses rate is of the order of the two body scattering rate, the system can be described as in a quasi-equilibrium state and quantitative information can be extracted. We present here an overview of two studies focusing on different consequences of the interplay between elastic two body collisions and three body recombinations in the dilute regime.

[1] S. Laurent, X. Leyronas, F. Chevy, *Physical Review Letters* **113** 220601 (2014).

Posters B

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Optimization of an ultracold quantum gas experiment by artificial evolution

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In our experiment, we aim at doping a Rubidium 87 (Rb) Bose-Einstein-Condensate (BEC) with single neutral Cesium 133 (Cs) atoms to observe their interaction processes and elucidate the quantum-dynamics within optical lattices. For the observation of the fundamental cooling and interaction dynamics of single impurities immerserd into ultracold quantum gases many repetitions and therefore short cycle times of the exeriment are required to achieve significant statistics. Especially the production time of the BEC can be improved in many ways [1]: For instance, increasing loading rates in the magneto-optical trap (MOT) or the transfer efficiency from the MOT to the optical dipole trap by adjusting laser detunings, intensities or the modification of more complex parameters such as the shape of the evaporation ramp.
In order to automate the optimization process, we implemented an evolutionary algorithm [2]. The basic working principle, the survival of the fittest, is enhanced by differential evolution. The algorithm is designed to improve any measurable feedback with a given set of parameters. By analyzing the data obtained, knowledge about constraints of the experimental setup and significance of the parameters is gained as well as a set of optimal values for the creation of a BEC which led to e.g. an increase of the MOT-loading rates by more than a factor of 3 in contrast to manually obtained parameters. Furthermore we were able to reduce the production time of the BEC by 50 % down to 4s.

[1] I. Geisel, K. Cordes, S. Jöllenbeck, J. Ostermann, J. Arlt, W. Ertmer and C. Klempt *Appl. Phys. Lett* **102** 214105 (2013)
[2] D.H.G. Beyer *The Theory of Evolution Strategies*, Springer-Verlag (2001).

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Millikelvin System for Cold Atoms and Superconductors

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Hybridisation of atomic systems with solid state systems could offer a viable mean to achieve better quantum state manipulation and to study interesting physical phenomena. In our new experimental direction, we work towards the coupling between ultracold atoms and solid state systems with the help of a superconducting resonator under applied microwave field. This will be done by trapping ultracold Rb atoms in proximity of a superconducting coplanar waveguide cooled to less than 100mK with a dilution refrigerator, and applying a microwave field to induce coupling with the atoms. We predict coherent coupling between trapped 87Rb atoms and the superconducting cavity, and would attempt to manipulate atomic states through the superconducting resonator.

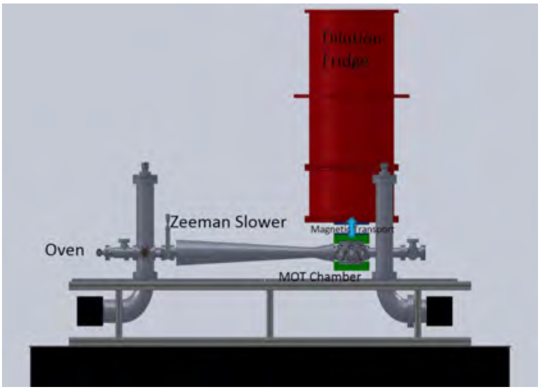

FIG. 1: Setup for hybrid system.

Posters B

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Mass-imbalanced Bose-Fermi mixture of ^{6}Li and ^{41}K

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The concept of quasiparticles is an essential building block for the understanding of strongly interacting Fermi systems, especially in the case of population-imbalance [1]. Previously we studied fermionic ^{40}K impurities in a Fermi sea of ^{6}Li [2]. They behave as Fermi polarons and we are currently investigating their quantum dynamics and coherence properties as a function of time, temperature and interaction strength. The interaction between the impurities is suppressed by Pauli blocking. When the impurity is a boson, however, the effect is no longer present. This paves the way to revealing novel physical phenomena arising due to the interactions of multiple quasiparticles. Here, we report on the implementation of a bosonic species of potassium, ^{41}K, into our existing ^{6}Li-^{40}K apparatus. The interaction between the lowest spin states can be tuned using a Feshbach resonance (FR) at 335.8 G [3], which is comparable in its properties to the ^{6}Li-^{40}K FR exploited in past experiments [2]. In addition to the interacting Bose impurities, the setup allows the study of mass-imbalanced Bose-Fermi mixtures and Fermi-Fermi mixtures of ^{6}Li and fermionic ^{6}Li-^{41}K molecules.

[1] P. Massignan, M. Zaccanti and G. Bruun, *Rep. Prog. Phys.* **77** 034401(2014)

[2] C. Kohstall, M. Zaccanti, M. Jag, A. Trenkwalder, P. Massignan, G.M. Bruun, F. Schreck and R. Grimm, *Nature* **485** 616 (2012)

[3] C. Wu, I. Santiago, J.W. Park, P. Ahmadi and M.W. Zwierlein, *Phys. Rev. A* **84** 011601 (2011)

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An ion in a sea of ultracold neutral atoms

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In our hybrid atom-ion experiment we investigate the interaction of cold ions with ultracold Rb atoms. When the ion is immersed into the atom cloud, the atom-ion collision rates depend on the atoms' density and collision energy. Having control over these parameters, the interaction of atomic Rb^+ with ultracold atoms have been investigated showing that the dominant inelastic channel is three body recombination [1]. A set of measurements are also performed in case of Ba^+ in order to extract two-body and three-body collision rate coefficients. Moreover, as we are able to create Rb_2^+ molecules in a REMPI photoionization [2], the next step is to study these molecular ions. We want to study the collision dynamics of these molecules with Rb atoms by investigating their energy and density dependence.
On the other hand, in order to have better understanding of atom-ion interaction, a resolved sideband system is being implemented into our setup. This allows measuring the phonon distribution and hence, the average kinetic energy of the Barium ion in addition to providing the possibility to cool down the ion beyond the Doppler limit. The latest results of our experiment will be presented in my poster.

[1] A. Härter, A. Krükow, A. Brunner, W. Schnitzler, S. Schmid, and J.H. Denschlag , *PRL* **109** 123201 (2012).
[2] A. Härter, A. Krükow, M. Deiss, B. Drews, E. Tiemann, and J.H. Denschlag , *Nature Physics* **9** 512 (2013).

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Topological bound states generated by cold atoms performing a quantum walk

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We suggest protocols for building a discrete-time quantum walk with ultracold atoms in a one dimensional lattice. The particles intrinsic spin is represented by the atoms Zeeman levels. The spin dependent shift operation is implemented by time evolving the system for a fixed amount of time. Short pulse Raman transitions are used to induce instantaneous spin mixing operations. By changing the system's parameters, we are able to generate well localized zero energy states, which are symmetry protected.

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Scalable architecture for quantum computation with more than 100 individually addressable qubits

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Felix Stopp,[1] Kathrin Luksch,[1] and Gerhard Birkl[1]

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Efficient quantum simulation and quantum information processing requires scalable architectures that guarantee the allocation of large-scale qubit resources. In our work, we focus on the implementation of multi-site geometries based on microfabricated optical elements. This approach allows us to develop flexible, integrable and scalable configurations of multi-site focused beam traps for the storage and manipulation of single-atom qubits and their interactions [1]. We give an overview on the investigation of ^{85}Rb atoms in two-dimensional arrays of well over 100 individually addressable dipole traps featuring trap sizes and a tunable site-separation in the single micrometer regime. Furthermore, we experimentally demonstrate single-atom quantum registers with more than 100 occupied sites, single-site resolved addressing of single-atom quantum states in a reconfigurable fashion and discuss progress in introducing Rydberg-state based interactions in our setup.

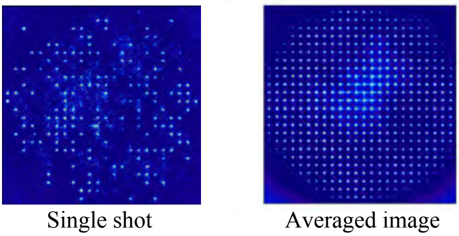

FIG. 1: Fluorescence images of a loaded trap array with a spacing of 9.8 microns. Each bright spot corresponds to a single atom at the respective trap site.

[1] M. Schlosser, S. Tichelmann, J. Kruse and G. Birkl, *Quant. Inf. Proc.* **10**, 907 (2011).

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Towards a Strontium quantum gas microscope

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We aim to build a versatile ultracold quantum gas machine for strontium that will include a quantum gas microscope. Strontium is an alkaline earth element with easily available bosonic and fermionic isotopes and two electrons in its valence shell [1]. Its electronic structure provides a megahertz-wide and a kilohertz-wide transition, which are useful for laser cooling, and a millihertz-wide transition useful for precision spectroscopy [1]. Fermionic ^{87}Sr has nuclear spin $I = 9/2$, resulting in 10 spin projection states [1], which are at the basis to study magnetic interactions with SU(N) symmetry [2]. The first SU(N) magnetism experiments have already been performed using clock transition spectroscopy of thermal Sr gases [3]. We aim to extend these studies to quantum degenerate gases of Sr. Quantum gas microscopes for rubidium have made it possible to study and manipulate strongly correlated many-body systems at the single-site and single-atom level [4, 5]. However no Sr microscope exists yet. We will build a Sr quantum gas microscope, which will open a new window on quantum simulation and computation with Sr. Working with Sr will also allow us to extend the techniques of quantum gas microscopy to 3D imaging, nuclear spin state imaging, and superresolution imaging.

[1] S. Stellmer. *Degenerate quantum gases of strontium*, PhD Thesis, University of Innsbruck, Innsbruck, January 2013.

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[4] W.S. Bakr, J.I. Gillen, A. Peng, S. Fölling, M. Greiner, *Nature* **462** 74 (2009).

[5] J.F. Sherson, C. Weitenberg, M. Endres, M. Cheneau, I. Bloch, S. Kuhr, *Nature* **467** 68 (2010).

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Cold ion-molecule reactive collisions

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Cold atoms and molecules are of great interest within both physics and chemistry. In the milliKelvin temperature regime, atoms and molecules are characterised by a greatly extended de Broglie wavelength - wave effects are likely to dominate the collisional process if the de Broglie wavelength is long compared to the range of intermolecular interactions.

Triggered by the interest to explore the quantum dynamics of ion-neutral reactions in cold conditions, we employ two sources of cold neutral molecules in combination with laser-cooled or sympathetically cooled ions trapped in a linear Paul trap. The two sources of cold neutral molecules we adopt are a Stark decelerator and a quadrupole guide velocity selector combined with a buffer gas cooling system. The ensemble of laser-cooled atomic ions within the trap undergoes a phase transition, adopting an ordered structure called a Coulomb crystal. We investigate reactions by monitoring the change in the laser-induced fluorescence pattern of the Coulomb crystal over time.

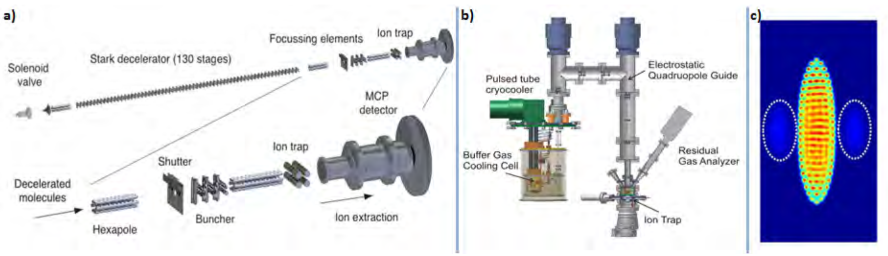

FIG. 1: a) Schematic of the Stark decelerator combined with an ion trap. b) Schematic of the buffer gas apparatus which comprises buffer gas cell, three-bend electrostatic guide and an ion trap. c) Simulated Coulomb crystal containing 500 Ca^+ and 100 Xe^+ ions

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Controlled tunneling in two-particle systems

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Developing techniques for controlling interacting quantum systems with a high degree of fidelity is one of the most important tasks in the area of quantum engineering. In general, it is impossible to calculate the precise number of particles in a given volume of a gas of ultracold atoms, but for the applications, such as quantum computing, it is crucial to know and control the number of particles, and hence their tunneling in complex geometries. The most important step towards this goal is being able to achieve high fidelity tunneling of a single particle in or out of a potential well.
Here we present simulations that describe the tunnelling process for two interacting ultra cold atoms, using an adiabatic technique. While the technique (Spatial Adiabatic Passage) is well understood for single particles [1], its extension to systems of many interacting particles is non-trivial and reveals important new processes. In particular we show that these can be used to create single atom sources, where the emitted particle is strongly entangled with the remaining gas.

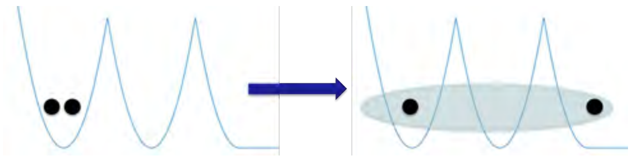

FIG. 1: Potential configuration which consists of two harmonic traps and an open space. Controlled emission of a single particle can be used as a source of entangled two-particle states.

[1] K. Eckert, M. Lewenstein, R. Corbalán, G. Birkl, W. Ertmer and J. Mompart, *Phys. Rev. A* **70** 023606 (2004).

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Dynamical localization in a quantum André-Aubry potential

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We study the dynamics of a single cold atom tightly confined in an optical lattice, whose dipolar transition strongly couples with a second sinusoidal potential at a different wavelength than the confining lattice. When the second lattice is originated by the coupling with a standing-wave cavity, then its form depends nonlinearly on the atomic wave function. We determine the ground state of the atom by solving self-consistently the corresponding master equation, and identify the conditions under which phenomena occur that are analogous to localization in the André-Aubry model.

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Nanomembranes in optical resonators

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Nanomechanical oscillators coupled to optical or microwave cavities are currently discussed as attractive hybride quantum system with many fascinating aspects concerning fundamental physics as well as applications [1]. In a number of experiments the delayed detuning effect of a nanomembrane in the light field of a Fabry-Perot interferometer has been exploited to damp the motion of the membrane. Successful cooling to the vibrational ground state has been demonstrated [2, 3].

In my PhD thesis I plan to explore the combination of two nanomembrans inside an optical ring resonator. The resonators light field acts as a medium that transfers mechanical momentum between the two membranes. We plan to investigate the collective motion of the two membranes for varying parameters. The regime of synchronized phases will be mapped out by varying the light power and pump cavity detuning. Furthermore, membrane cooling should be possible in a ring resonator if pumped from both directions. Ring cavities will be compared to standing wave geometries and the possibilities of quantum effects will be investigated.

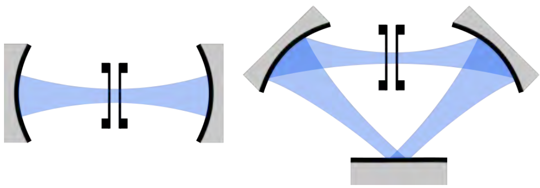

FIG. 1: Self-synchronisation and optical cooling will be exploited for a combination of two nanomembranes in optical ring and standing wave resonators.

[1] M. Aspelmeyer et al., *Cavity Optomechanics*, *Rev. Mod. Phys.* 86, 1391 (2014)
[2] Teufel et al., *Sideband cooling of micromechanical motion to the quantum ground state*, *Nature* Vol. 475 (2011)
[3] Dalziel Joseph Wilson, *Cavity Optomechanics with High-Stress Silicon Nitride Films*, *California Institute of Technology* (2012)

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Posters B

En route to many-body physics with polar molecules: Spectroscopy of an ultra cold ^{23}Na-^{40}K mixture

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Ultra cold quantum gases with long-range dipolar interaction promise exciting new possibilities for quantum simulation of strongly interacting many-body systems. One way to realize a system with this interaction is to create an ultra cold sample of ground state polar molecules.

Since direct cooling of molecules is difficult due to their complex internal structure, in our setup sodium and potassium atoms are cooled close to quantum degeneracy first. Via an interspecies Feshbach resonance they are then associated to weakly bound molecules. Those have to be transferred to the absolute molecular ground state (of electronic, rotational, vibrational and hyperfine energy), which is expected to be stable and long lived.

To ensure high transfer efficiencies a process called stimulated Raman adiabatic passage (STIRAP) shall be employed. It is a two-photon process involving a resonant intermediate state, as shown in the figure.

In my poster I will discuss the spectroscopy we did to identify a promising intermediate level as well as report on our progress towards transferring the Feshbach molecules to the absolute molecular ground state.

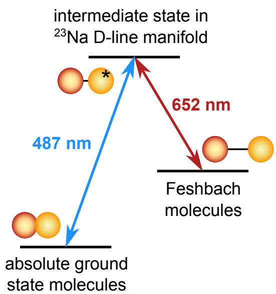

FIG. 1: STIRAP from a NaK Feshbach molecular state to the absolute groundstate

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Correlated excitation dynamics in an ultracold Rydberg gas

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[3] *Laboratoire Aimé Cotton, CNRS, Univ Paris-Sud, ENS-Cachan, Campus d'Orsay Batiment 505, 91405 Orsay, France*
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The van-der-Waals interaction between ultracold atoms excited to high-lying Rydberg states can lead to strongly correlated excitation dynamics. Here we study these correlations for resonant and off-resonant driving of cold atoms in a magneto-optical trap. In the resonant case we observe dynamical constraints similar to those found in glassy systems. By contrast, for off-resonant driving facilitated excitations mediated by Rydberg-Rydberg interactions lead to avalanche-like events in which a chain reaction of successive excitations occurs. We show that this effect can be induced by a seed excitation and that the resulting full counting statistics of excitation events can be reproduced by a simple analytical model. Finally, we measure the effect of the van-der-Waals force on the Rydberg atoms using a time-of-flight technique.

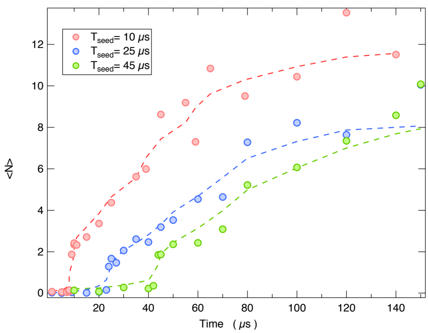

FIG. 1: Avalanche excitation process induced by a seed excitation as a function of time. Shown here is the average number of Rydberg excitations as a number of time for different times at which the seed excitation is created by resonant pulse.

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Collisional frequency shift in a Wannier-Stark trapped atom interferometer

Cyrille Solaro,[1,*] Matthias Lopez,[1] and Franck Pereira dos Santos[1]

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In our experiment, we realize a trapped atom interferometer of ^{87}Rb in a vertical optical lattice. For shallow depths of the lattice, stimulated Raman transitions can be used to induce coherent transport between adjacent Wannier-Stark states, allowing us to perform atom interferometry and to measure with very high sensitivity, shifts in the Bloch frequency [1][2].

We recently installed a crossed dipole trap in order to increase the atomic density thanks to evaporative cooling. Working with smaller atomic cloud allowed reducing coupling and phase inhomogeneities in the interferometer and increasing the contrast decay time constant by a factor 4. At densities of a few 10^{11}cm^{-3}, we observe effects related to atomic interactions, such as large frequency shifts as well as identical spin rotation effect (ISRE). In trapped atomic clocks, ISRE, originating from particle indistinguishability, can enhance the clock's coherence via the so-called spin self-rephasing mechanism, up to several tens of seconds![3] In our interferometer scheme the two partial wavepackets, spatially separated by a laser induced transport in adjacent Wannier-Stark states, are also in two different internal states - enhancing the full richness of these effects. There, by contrast with a microwave clock, the two partial wavepackets do not perfectly overlap, which limits the efficiency of the spin synchronization. In our very specific configuration, we can thus test the limitations to the ISRE as a function of the overlap between the two partial wavepackets.

[1] Q. Beaufils, et al., *Physical Review Letters* **106**, 213002 (2011)
[2] B. Pelle, et al., *Physical Review A* **87**, 023601 (2013)
[3] C. Deutsch, et al., *Physical Review Letters* **105**, 020401 (2010)

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High fidelity qubit operations with Ca^+ ions

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T. P. Harty,[1] H. A. Janacek,[1] D. P. L. Aude Craik,[1] M. A. Sepiol,[1]
J. E. Tarlton,[1] D. N. Stacey,[1] A. M. Steane,[1] and D. M. Lucas[1]

[1] *Clarendon Laboratory, Department of Physics, University of Oxford*
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We present results demonstrating state-preparation, readout, and single- and two-qubit gates in trapped Ca^+ ions with errors below the threshold required for an error correcting quantum computer. Using a macroscopic Paul trap and laser driven Raman transitions we achieve the highest ever reported two-qubit gate fidelity of 99.9(1)% using a pair of $^{43}Ca^+$ ions[1], and perform mixed species gates between $^{40}Ca^+$ and $^{43}Ca^+$ to 99.8(5)%. The next generation of our experiment will work towards a scalable modular architecture[2] by heralding entanglement between two ions in separate traps using Bell state measurements on spontaneously emitted photons.

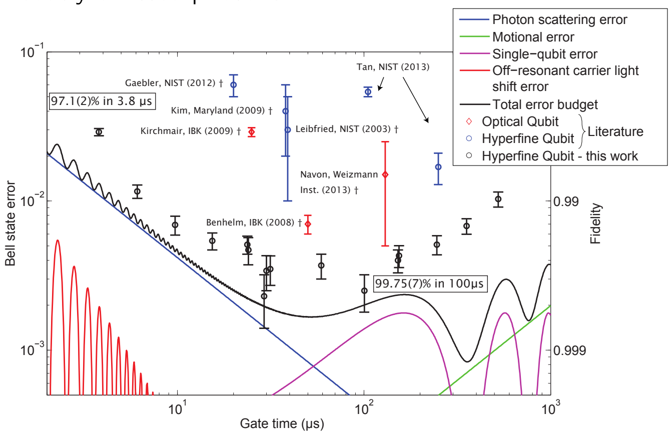

FIG. 1: Trade-off between gate speed and error when producing a Bell state in a pair of $^{43}Ca^+$ hyperfine qubits. Qubit state-preparation and readout errors (~0.1%) have been normalized.

[1] C. J. Ballance, *High-Fidelity Quantum Logic in Ca^+*, PhD thesis, University of Oxford, (2014).

[2] C. Monroe and J. Kim, Scaling the Ion Trap Quantum Processor, *Science*, **339**(6124), 11641169 (2013).

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Mesoscopic Rydberg-blockaded ensembles in the superatom regime and beyond

O. Thomas[1,*] and T.M. Weber, M. Höning, T. Niederprüm, T. Manthey, V. Guarrera, M. Fleischhauer, G. Baronitnin & H. Ott[1]

[1] *TU Kaiserslautern, Erwin-Schrödinger-Str. 46, 67663, Kaiserslautern, Germany*

In recent years great progress has been made in understanding the collective behaviour introduced by Rydberg excitations in ultra cold gases. Because of their strong van der Waals interaction it is not possible to excite two Rydberg atoms resonantly within a blockade volume defined by the interaction strength and the excitation bandwidth. In dense atomic clouds hundreds of ground state atoms can be found within this volume, forming a so-called superatom. These strongly correlated ensembles show an increased excitation probability, described by an effective two-level system.

Here we report on the controlled creation and characterization of an isolated mesoscopic superatom by means of accurate density engineering and excitation to Rydberg p-states [1]. Its variable size allows us to investigate the transition from a strongly confined effective two-level to an extended many-body system. By monitoring continuous laser-induced ionization we are able to determine the $g^2(\tau)$ correlation function and observe the expected anti bunching effect for resonant excitation, as well as bunching for off resonant coupling. The observed amplitudes and timescales can be described with an effective rate-equation model.

[1] T.M. Weber, M. Höning, T. Niederprüm, T. Manthey, O. Thomas, M. Fleischhauer, G. Barontini and H. Ott, *Nature Physics* Mesoscopic Rydberg-blockaded ensembles in the superatom regime and beyond, doi:10.1038/nphys3214.

Posters B

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Adaptive multifrequency light collection by self-ordered mobile scatterers in optical resonators

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Photons carry momentum, and thus their scattering not only modifies light propagation but at the same time induces forces on particles. Confining mobile scatterers and light in a closed volume thus generates a complex coupled nonlinear dynamics. As a striking example, one finds a phase transition from random order to a crystalline structure if particles within a resonator are illuminated by a sufficiently strong laser. This phase transition can be simply understood as a minimization of the optical potential energy of the particles in concurrence with a maximization of light scattering into the resonator. Here, we generalize the self-ordering dynamics to several illumination colors and cavity modes. In this enlarged model, particles adapt dynamically to current illumination conditions to ensure maximal simultaneous scattering of all frequencies into the resonator as a sort of self-optimizing light collection system with built-in memory. Such adaptive self-ordering dynamics in optical resonators could be implemented in a wide range of systems from cold atoms and molecules to mobile nanoparticles in solution.

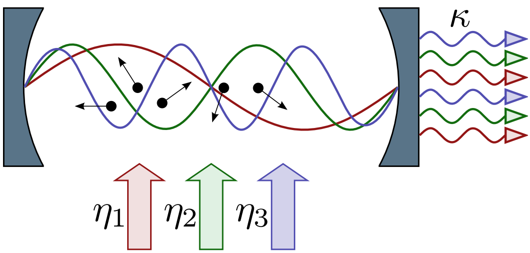

FIG. 1: Particles moving inside a lossy optical resonator are illuminated by several laser beams with various frequencies close to distinct cavity resonances.

[1] V. Torggler and H. Ritsch, *Optica* **1(5)** 336-342 (2014)

* valentin.torggler@uibk.ac.at

Superfluidity and density order in a bilayer extended Hubbard model

Tuomas I. Vanhala,[1,*] Jildou E. Baarsma,[1] Miikka O. J. Heikkinen,[1] Matthias Troyer,[2] Ari Harju,[1] and Päivi Törmä[1]

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[2] *Theoretische Physik, ETH Zurich, 8093 Zurich, Switzerland*

We use cellular dynamical mean field theory to study the phase diagram of the square lattice bilayer Hubbard model with an interlayer interaction. The layers are populated by two-component fermions, and the densities in both layers and the strength of the interactions are varied. We find that an attractive interlayer interaction can induce a checkerboard density ordered phase and superfluid phases, with either interlayer or intralayer pairing. The latter phase does not require an intralayer interaction to be present, and can be attributed to an induced attractive interaction caused by the other layer. We propose that this model could be realized in a cold atomic gas. [1]

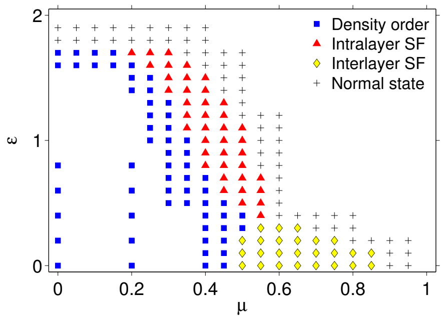

FIG. 1: The phase diagram of the system as a function of the chemical potential μ and the field ϵ driving a polarization (density difference) between the layers. We find density order near half filling and superfluid states at higher density or polarization.

[1] Tuomas I. Vanhala, Jildou E. Baarsma, Miikka O. J. Heikkinen, Matthias Troyer, Ari Harju, and Päivi Törmä, arXiv preprints: 1411.3541.

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Posters B

Topological bands in cold gases

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Recently it has been demonstrated that topological band structures can be realized by exploiting dipolar exchange interactions [1]. This idea can be implemented with trapped polar molecules or Rydberg atoms. We investigate how the molecules or atoms can be arranged to obtain systems that show signatures of topological bands like edge states. In particular we search for minimal systems that are experimentally feasible.

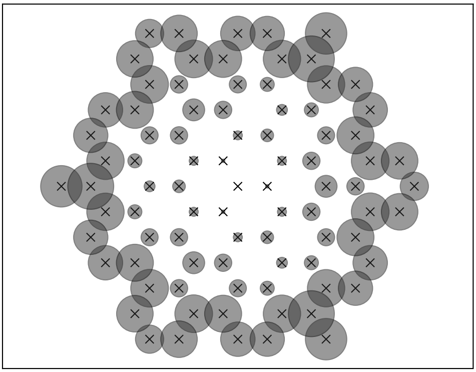

FIG. 1: Visualization of an edge state in a system of polar molecules or Rydberg atoms. The area of the circles is proportional to the probability density.

[1] D. Peter et al., *Topological flat bands with Chern number C=2 by dipolar exchange interactions*, arXiv:1410.5667, 2014.

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Posters B

Optimisation of an atom-photon quantum gate

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Norbert Kalb,[1] Stephan Ritter,[1] and Gerhard Rempe[1]

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Quantum gates between light and matter qubits are promising tools for future applications in quantum information science. To give two examples, they allow for interactions between remote quantum network nodes and promise to bridge the gap between photonic and matter-based approaches to quantum information processing. Recently, such a quantum gate between a single atom trapped in a high-finesse optical cavity and a photon was demonstrated experimentally [1]. The gate mechanism is based on the reflection of a single photon off the resonant cavity. The phase flip in the atom-photon state induced by the gate has also been used to nondestructively detect an optical photon [2]. This requires excellent control over both the internal and the external state of the trapped atom. For more complex tasks in quantum information processing, the degree of control needs to be improved even further. We will present ongoing experiments with single atoms and atom-photon gates and discuss future challenges and perspectives.

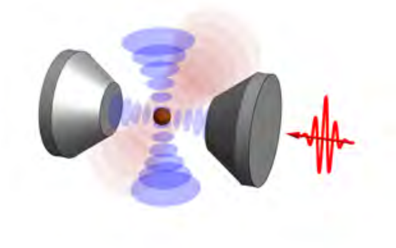

FIG. 1: A single atom (brown) is trapped by three standing waves of laser light inside a high-finesse cavity. The gate is performed by impinging a single photon (red) from the right. Upon its reflection from the cavity a conditional phase shift is induced in the combined state of atom and photon.

[1] A. Reiserer, N. Kalb, G. Rempe and S. Ritter, *Nature* **508**, 237 (2014).
[2] A. Reiserer, S. Ritter and G. Rempe, *Science* **342**, 1349 (2013).

* stephan.welte@mpq.mpg.de; http://www.mpq.mpg.de/quantumdynamics/

Trapping and studying Fermionic Potassium atom by atom

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Luruper Chaussee 149, 22761, Hamburg, Germany

Investigating the Fermi-Hubbard model is typically done by filling a large optical lattice with an ultracold Fermi gas. In our new experiment, we are planning to use a different approach: A mesoscopic fermionic system is built up site by site using optical microtraps. Each of them contains a single atom cooled to the vibrational ground state by Raman-sideband cooling. This bottom-up approach will provide us with a better understanding of the basic processes governing the Fermi-Hubbard model.

We present the general design and some technical aspects of a new ^{40}K-experiment, which is going to be able to cool a gas of ^{40}K to quantum degeneracy as well as to directly lasercool single atoms into optical microtraps. For achieving loading of single atoms with high fidelity, light-assisted collisions as described in [1] might be exploited. The cooling of the atoms will be performed using a Raman-sideband cooling technique similar to the one described in [2].

In order to achieve high loading rates for the 3D MOT, a short duration for one experimental cycle as well as a compact vacuum setup, the 3D MOT will be loaded from a 2D MOT setup which will be presented in detail.

[1] T. Grünzweig, A. Hilliard, M. McGovern and M.F. Andersen, *Nature Physics* **6** 951 (2010).

[2] A.M. Kaufman, B.J. Lester and C.A. Regal, *Physical Review X* **2** 041014 (2012).

* pwieburg@physnet.uni-hamburg.de; http://www.photon.physnet.uni-hamburg.de

Additional information

Hotel Senator

Hotel Senator entrance

Hotel map

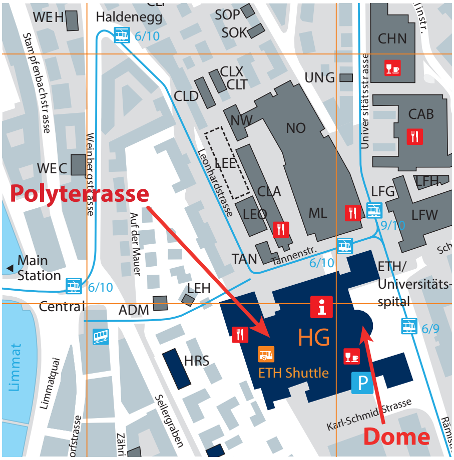
Accomodation: Your accomodation (including breakfast) during the conference has been arranged in the Hotel Senator. You can check in on Sunday starting from 2 pm, please remember to check out on Friday before the first session.

Address: Hotel Senator, Heinrichstrasse 254, 8005 Zürich

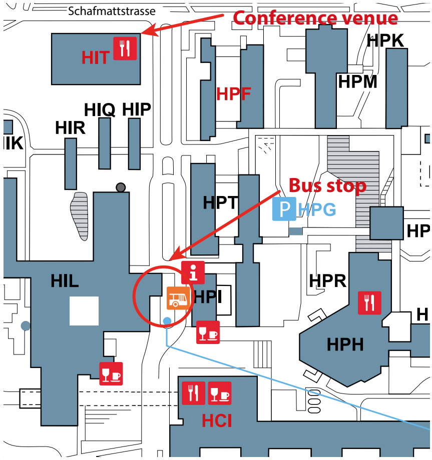
How to get to the hotel: Upon arrival in the main station, go through the main hall following the tram signs for the stop Bahnhofquai/HB. The stop is located right at the exit, along the river. Take tram 4, 13 or 17 (towards *Bahnhof Altstetten Nord*, *Frankental* or *Werdhölzli* respectively) and stop at *Escher-Wyss-Platz*. The hotel is a three-minutes walk from there.

How to get to ETH Hönggerberg: Starting from the hotel, go to the bus stop *Escher-Wyss-Platz* (on the upper street level), take bus 72 towards *Milchbuck* and change at *Bucheggplatz* to bus 69, which will bring you directly to ETH Hönggerberg. You should expect around thirty minutes go get to ETH Hönggerberg from the hotel.

ETH campuses



Campus ETH Zentrum



Campus ETH Hönggerberg

ETH Zentrum: The welcome apéro is held in the dome of the historic main building of ETH Zürich. Starting from the hotel, go to the tram stop *Escher-Wyss-Platz* and take tram 4 until the stop *Central*. Then take tram 6 or 10 and exit at *ETH/Universitätsspital*. The ETH main building (*HG* in the map) with the dome is directly next to you. Enter the building at the main entrance (below the dome) and take the elevator up to the top, following the signs for the dome *(Dozentenfoyer/Kuppel)*. If you like, come to the hotel lobby at 6.30 pm and we will go together to the welcome apéro. After 8 pm, we will have to close the door of the main building, so in case you want to join the welcome apéro afterwards you have to call us by phone and we will come down to the entrance and open you.

ETH Hönggerberg: Except for the welcome apéro, most of the conference program takes place on the campus Hönggerberg (for the bus connection from the hotel cf. p. 123). Upon arrival, you will find youself at the center of the campus. The conference takes place in the *Werner-von-Siemens-Auditorium*, which is located behind the entrance hall of the HIT building (see map). Lab tours will be given in the HPF building. Your lunch tickets are valid in the university restaurant on the first floor of the HCI building (*FUSION*).

Conference venue

Werner-von-Siemens-Auditorium

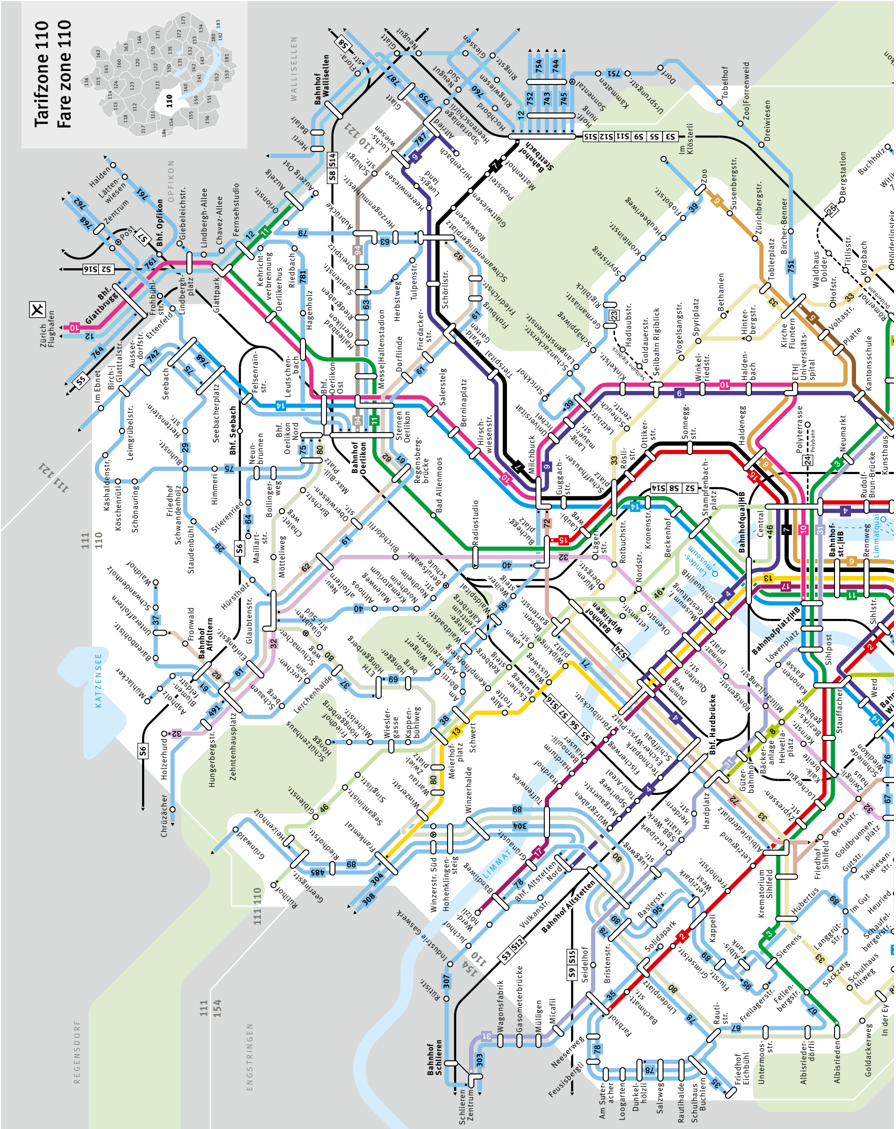
HCI university restaurant (*FUSION*)

All presentations will take place in the *Werner-von-Siemens-Auditorium* in the HIT building on ETH Hönggerberg. You will have free wifi access in the building over the whole conference week by logging into the network *public*. The username is *yao2015* and the password is *sackmesser*. Alternatively, you can use your university account to log into the *eduroam* network, which is accessible all over the campus.

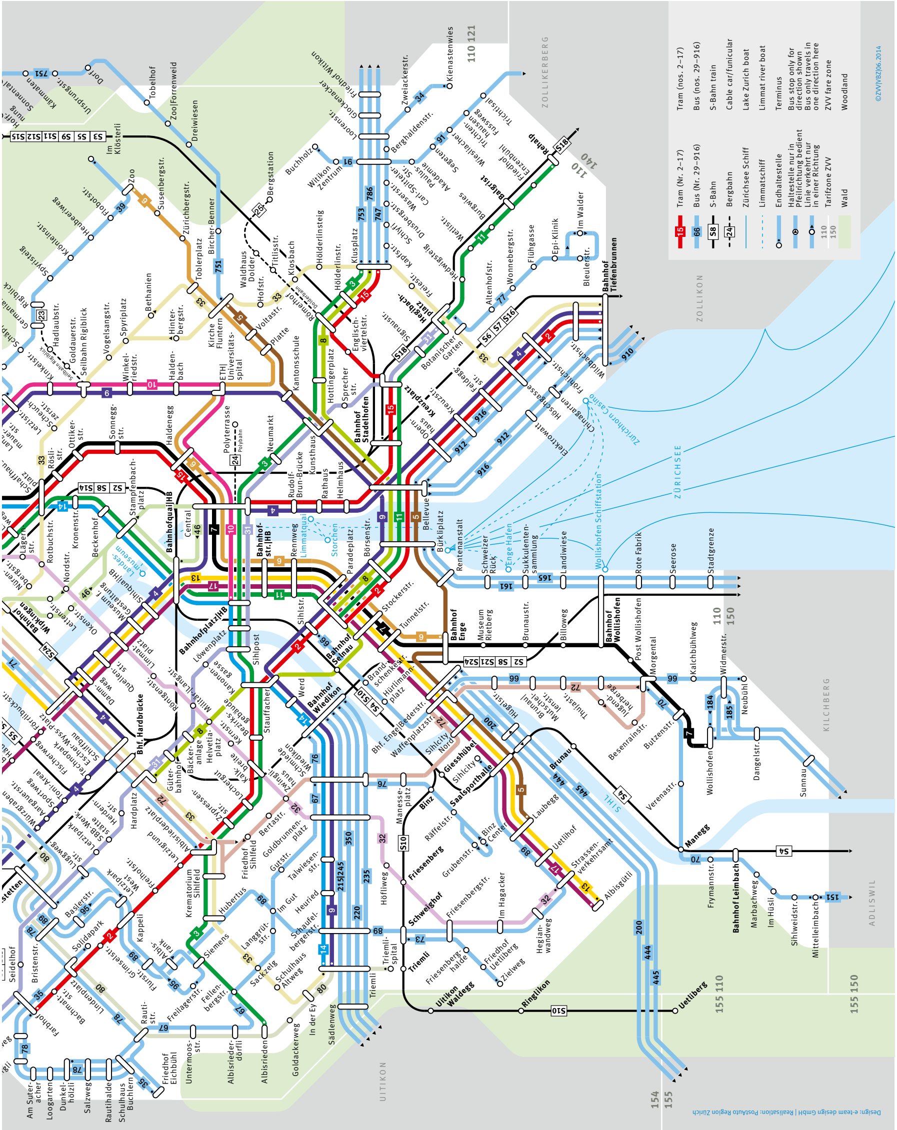
We will have lunch in the university restaurant at the HCI building. The conference name tag allows you to have free food for a price up to 7.90 CHF, anything above is at your own costs. You can choose among several dishes, which mostly cost 6.20 CHF and include one side dish, such as vegetables, salad, fruit or dessert. Further side dishes usually cost 1.30 CHF. In addition, there is a salad buffet and often a warm buffet, where you pay by weight.

There are also other options to eat on campus. The university restaurant in the HPH building provides around four different menues and a salad buffet (similar prices as HCI). The *Woka* in the HIT building offers Asian Wok food and the *AlumniLounge* has some daily varying dishes as well. In addition, there are a few food trucks visiting the campus during the day and a small supermarket, which is open from 7 am to 8 pm. On Thursdays, there is a small market on the campus with booths offering diverse food. However, your conference tag is valid as a food voucher only in the HCI university restaurant (*FUSION*).

Public transport



The ZVV pass that you got with your welcome bag is valid everywhere in Zurich (Zone 110) from Monday to Friday. A one hour ticket for this zone costs



4.30 CHF, a day pass 8.60 CHF. If you want to travel outside Zurich with the local trains (S-Bahn), you can buy an extension ticket (*Zonenerweiterung*).

City tour and conference dinner

ETH main building and Polyterrasse

Banquet hall in the Zunfthaus zur Haue

City tour: We will start at 4.15 pm on the *Polyterrasse*, a ground in front of the ETH main building (cf. map on p. 124), from where you have a great view over the city. You can reach this place via the direct bus shuttle link (Bus E/Science city link) between ETH Hönggerberg and ETH Zentrum, which leaves at 3.34 pm and 3.54 pm and takes around 15 minutes. The bus stop is directly below the Polyterrasse. Alternatively, you can take bus 69 to *Milchbuck* and change there to tram 9 or 10 towards *Triemli* or *Bahnhofsstrasse/HB*, respectively. Exit the tram at the stop *ETH/Universitätsspital* and walk straight through the main building to the Polyterrasse.

How to get to Zunfthaus zur Haue: After the city tour, you will have time to go back to the hotel or stroll around the old town. Coming from the hotel, you can reach the Zunfthaus by going to the tram stop *Escher-Wyss-Platz* and taking tram 4 in the direction *Bahnhof Tiefenbrunnen*. Exit at the stop *Rathaus*, the Zunfthaus zur Haue is located around thirty meters ahead of you on the same street. The conference dinner starts at 7.30 pm. You should expect around twenty to thirty minutes to get there from your hotel. If you like, we will catch you in the hotel lobby at 7 pm and go to the conference dinner together.

Sightseeing at Zurich

Zurich offers enough things to discover to stay several days in addition to the conference. Here are some ideas for you in case you have some spare time or want to extend your stay in the city.

Bahnhofstrasse Zurich's biggest shopping place and one of the most expensive streets in the world. It starts at the main station where big labels follow one after the other, culminating in the *Paradeplatz* with its bank buildings and the famous *Sprüngli* chocolate shop (try a *Luxemburgerli*!).

Boat trip The Zurich public transport also includes the boats on the Limmat and the Zürisee, which allows you to have a little boat trip for free with you conference public transport week pass. The ZVV map shows you all boat stops within the city zone. If you want to go further out on the lake, you have to buy an extension ticket.

Fraumünster Being a former monastery, the Fraumünster is one of Zurich's main churches and situated right opposite the river with respect to the Grossmünster. Marc Chagall created the beautiful windows in the choir.

Grossmünster One of Zurich's biggest landmarks and the place, where Huldrych Zwingli was priest and formed his theological doctrine, which then started to spread and led to the formation of the reformed church.

Lindenhof The hill in the center of the old town between Bahnhofsstrasse and Limmat is called Lindenhof and constitutes the oldest part of the city of Zurich. Here, the romans built their fort, whose ground walls still exist and form a square with a beautiful view on the river and the Niederdorf.

Old botanic garden A beautiful green place right in the city center (tram stop *Sihlstrasse*). The garden includes a historic cast-iron palm house and a herb garden. Free entry, open until 7 pm.

Üetliberg The top of Zurich's local hill can be easily reached in a small hike and rewards you with a great view over the city of Zurich, the lake and many alpine mountains such as the Pilatus, the Mythen or Eiger, Mönch and Jungfrau. The path to the top starts at tram stop *Triemli*.

Zoo Located on top of the Züriberg, the zoo Zurich shows a manifold selection of animals from all over the world. The latest attraction is the Masuala hall, representing a complete reproduction of the madagascan rain forest. Tram stop *Zoo*, open till 6 pm every day.

Zurich at night

Zurich has a very rich nightlife, which is concentrated around three areas: the *Niederdorf*, the *Langstrasse* and *Hard*. The senator hotel is located close to the latter, but it is definitely worth discovering the other areas as well. The distances are all very small, around ten minutes by tram or a twenty-minutes walk. On the following pages, you find some suggestions from our side for nice locations.

Bar Rossi Nice bar/club at Langstrasse, often live music, great atmosphere. Sihlhallenstrasse 3 (bus stop *Militär-/Langstrasse*), open till 2 am on weekdays, Friday and Saturday till 4 am.

Bellevue On every sunny evening, the Quaianlagen (starting at Bellevue and following the lake shore until Bahnhof Tiefenbrunnen) turn into a lively area with many people strolling along the lake shore, street artists, etc. Many bars invite you to stop and enjoy the view on the lake at a drink. Tram stop *Bellevue*.

BQM Students bar directly next to the ETH center, some evenings events, great to meet other students. Leonhardstrasse 34 (tram stop *ETH/Universitätsspital*), open until 11 pm on Monday to Thursday, till 10 pm on Friday.

Cabaret Voltaire Alternative bar/location, founding place of dadaism (the cultural scene of the early 1900s). Spiegelstrasse 1 (tram stop *Rathaus*), open till midnight on Monday to Thursday, till 2 am on Friday and Saturday.

Café Zähringer Fair priced café/restaurant with an alternative atmosphere, organic-style food and nice swiss cuisine. Zähringerplatz 11 (tram stop *Rudolf-Brun-Brücke*), open till midnight every day.

Clouds Enjoy a beer in the bar at the top of Switzerland's highest building, the prime tower. Trendy and snobby place with a beautiful view over the city. Maagplatz 5 (tram stop *Hardbrücke*), open till midnight on Tuesday to Thursday, till 2 am on Friday ans Saturday and till 11 pm on Sunday and Monday.

Club Zukunft Electronic music, nice concerts, international and local DJs, bands and performances. Free entry on Thursdays. Dienerstrasse 33 (bus stop *Militär-/Langstrasse*), open Thursday 11 pm to 4 am, Saturday and Sunday from midnight to 7 am.

El local Experimental-alternative atmosphere with spanish harbour style, many concerts in the evenings. On sunny evenings, you can hang out at the backyard on the shore of the Sihl river. Gessnerallee 11 (tram stop *Sihlpost*), open till 2 am on Friday and Saturday, till midnight on all other days.

Frau Gerolds Garten The trendy outdoor restaurant offers a unique urban atmosphere. Summer restaurant/café, nice terrace, in the middle of an urban garden, next to the Freitag flagship store (bags, etc.). Geroldstrasse 23 (tram stop *Hardbrücke*), open till midnight every day, except for Sundays.

Henrici Nice café/bar in the old town and famous for its Flammkuchen. Niederdorfstrasse 1 (tram stop *Rathaus*), open till midnight on Tuesday and Thursday to Saturday, till 11pm on Wednesday, till 10 pm on Sunday and Monday.

Hiltl Trendy veggie-temple with modern interior, oldest vegetarian restaurant in the world. Great atmosphere, huge buffet with delicious food. At night, it turns into a club with events several times a week. Sihlstrasse 28 (tram stop *Rennweg*), restaurant open till midnight on Monday to Thursday, till 4 pm on Friday, to Sunday, club open till 4 am on Friday and Sunday, till 5 am on Saturday.

Les Halles French style, very lively restaurant/bar, also includes a supermarket and a small bike shop. Special beers, nice wines and famous for their moules & frittes. Pfingstweidstrasse 6 (tram stop *Schiffbau*), open every day until midnight, except Sunday.

Letten Great place to spend a sunny evening on the riverside with several bars, e.g. the Panama bar or the Primitivo (both open till midnight every day). In the summer, the Letten turns into a huge swimming area. Tram stop *Beckenhof*.

Mehrspur Bar, café and nightlife club, the concert location of the Jazz and pop department of the Zurich university of the arts. Great lively place right at the new campus on Toni-Areal. Förrlibuckstrasse 109 (tram stop *Toni-Areal*), open till midnight on Monday, Tuesday, Thursday, till 2 am on Wednesday and till 4 am on Friday and Saturday.

Moods Great location for Jazz, Funk and Blues. Located in an old industrial building, which also houses the second stage of the Schauspielhaus, the most prominent theatre of Zurich. Many live concerts nearly every evening. Schiffbaustrasse 6 (tram stop *Schiffbau*), open till midnight on Monday to Thursday, all night through on Friday and Saturday and till 10 pm on Sunday.

Nachtflug Nice small bar in the old town with Jazz music, sometimes live. Great place also to sit outside in the backyard on a warm night. Stüssihofstatt 4 (tram stop *Rathaus*), open till midnight on Sunday to Thursday, till 1.30 am on Friday and till 2 am on Saturday.

Nelson Pub Pub with a little bit of club feeling, no entry fee. Music and beer, upper floor club (Lady Hamilton). Beatengasse 11 (tram stop *Bahnhofsstrasse/HB*, open till 2 am on Monday to Thursday, till 4.30 am on Friday and Saturday.

Oliver Twist Classic irish pub with many irish beers, very international people, good food, english-speaking service and sport screens. Rindermarkt 6 (tram stop *Rathaus*), open till midnight every day.

Rheinfelder Bierhalle Restaurant/bar with hearty atmosphere and swiss cuisine. Here you get the biggest cordon-bleu in Zürich (Jumbo-Jumbo). Niederdorfstrasse 76 (tram stop *Central*), open till midnight every day.

Rote Fabrik Former industrial site, which is now used as a music venue and one of the biggest and most diverse cultural centers in Europe with concerts nearly every night. The location also includes the restaurant Ziegel au lac, which offers an alternative style and many vegetarian dishes. Seestrasse 409 (tram stop *Post Wollishofen*), restaurant open till midnight on Tuesday to Sunday.

Sphères Café/bar in combination with a book shop in an old industrial building, lots of events in the evening, nice place to hang out. Hardturmstrasse 66 (tram stop *Förrlibuckstrasse*), open till midnight on weekdays, till 7.30 pm on weekends.

Stall 6 This bar/club is located in a former horse stable, which gives its interior a very special atmosphere. Many concerts in the evenings, also on weekdays. Gessnerallee 8 (tram stop *Sihlpost*), no information when they close, but usually open till long after midnight, also on weekdays.

Swiss-german for beginners

Although german is the official language, everybody in Zurich speaks a swiss-german dialect, which is quite distinct from the standard german and even for germans hard to understand in the beginning. Here we provide you with some basic vocabulary. Important exceptions from german pronounciation rules are the *ch*, which is always pronounced like in the german *Bach*, the *k*, which when being spoken becomes a *kch*, the *r* rolled like the spanish *r* and all *s* pronounced sharp. Accentuations are always (!) on the first syllable, even for loanwords like *Velo* (*bike*) or *Glacé* (*ice cream*).

Basics

Grüezi!	Guten Tag!	Hello!
Hoi/Salü!	Hallo!	Hi!
Hoi zäme/Salü mitenand!	Hallo zusammen!	Hi guys!
Guete morge!	Guten morgen!	Good morning!
(Uf) widerluege!	Auf Wiedersehen!	Good bye!
Bis spöter!	Bis später!	See you later!
Merci vilmol.	Vielen Dank.	Thank you very much.
Äxcüsi	Entschuldigung	Excuse me
Min Name n isch...	Ich heisse...	My name is...

Eat and drink

En guete!	Guten Appetit!	Enjoy./Have a nice meal!
Mit Gmües gärn.	Mit Gemüse, bitte. (in der Mensa)	With vegetables, please. (at university restaurant)
Was choschteds?	Was kostet das?	How much does that cost?
Kafi	Kaffee	coffee
Schale	Tasse Kaffee	cup of coffee
Zmorge	Frühstück	breakfast
Zmittag	Mittagessen	lunch
Znacht	Abendessen	dinner
Beiz	Bar	pub
Stange	kleines Bier (0.3 l)	small glass of beer (0.3 l)
es Grosses	grosses Bier (0.5 l)	big glass of beer (0.5 l)
No eis, gärn!	Noch eins, bitte!	One more, please!
Pröschtli!	Prost!	Cheers!
Gömmer go suufe?/ Wämer eis go zie?	Gehen wir was trinken?	Shall we go out for a drink?

Numbers and weekdays

Eis, zwei, drü, vier, foif, sächs, sibe, acht, nüün, zäh.	Eins, zwei, drei, vier, fünf, sechs, sieben, acht, neun, zehn.	One, two, three, four, five, six, seven, eight, nine, ten.
Zwänzg, driissg, vierzg, füfzg, sächzg, sibezg, achtzg, nünzg, hundert.	Zwanzig, dreissig, vierzig, fünfzig, sechzig, siebzig, achtzig, neunzig, hundert.	Twenty, thirty, fourty, fifty, sixty, seventy, eighty, ninety, hundred.
tuusig	tausend	thousand
umegavil	sehr viel	a lot
Mäntig, Zischtig, Mittwuch, Donschtig, Fritig, Samschtig, Sunntig	Montag, Dienstag, Mittwoch, Donnerstag, Freitag, Samstag, Sonntag	Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, Sunday

Tongue breakers

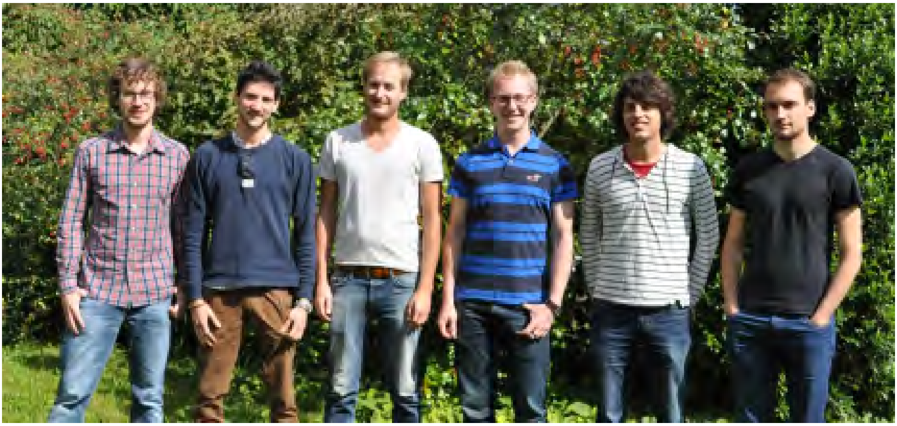
Chäs-Chüechli	Käsetörtchen	small cheese pie
Chuchichäschtli	Küchenschrank	kitchen cupboard
De Papst hät z Spiez s Späckpsteck z spaat bschtellt.	Der Papst hat in Spiez das Speck-Besteck zu spät bestellt.	The pope ordered the bacon cutlery too late at Spiez.

Miscellaneous

(u)huere	sehr	very
Isch hueregeil gsi.	Das war super.	This was awesome.
Natel	Handy	cell phone
mol	doch	well, yes
öpis	etwas	something
. . . , gäll?	. . . , oder?	. . . , right?
Äbä.	Genau.	Exactly.
es bitzeli	ein bisschen	a little
Chuntsch?	Kommst Du?	Are you coming?
weisch	weisst du	you know
Hämmer. . . ?	Haben wir. . . ?	Do we have. . . ?
Ich lüt dier a.	Ich ruf dich an.	I give you a call.
Dubel	Idiot	idiot
verräckte Hueresaucheib	verdammtes Arschloch	damned asshole
Gopferdammi!	Verdammt noch mal!	Bloody hell!

Index of participants

Organization committee



From left to right: Lorenz Hruby, Andrea Morales, Dominik Husmann, Michael Messer, Julian Léonard, Martin Lebrat.

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