A 35: Ultracold Atoms I (joint session Q/A)

Time: Thursday 10:30–12:15 Location: K 1.022

A 35.1 Thu 10:30 K 1.022

Multi-mode double-bright EIT cooling (theory) — Nils Scharnhorst[1,2], •Javier Cerrillo[3], Johannes Kramer[1], Ian D. Leroux[1], Jannes B. Wübbena[1], Alex Retzker[4], and Piet O. Schmidt[1,2] — [1]QUEST Institute for Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany — [3]Institut für Theoretische Physik, Technische Universität Berlin, 10623 Berlin, Germany — [4]Racah Institute of Physics, Hebrew University of Jerusalem, 91904 Jerusalem, Israel

We developed a multi-mode ground state cooling technique based on electromagnetically-induced transparency (EIT) [1]. By involving an additional ground and excited state, two individually adjustable bright states together with a dark state are created. While the dark state suppresses carrier scattering, the two bright states are brought into resonance with spectrally separated motional red sidebands. The approach is scalable to more than two bright states and several dark states by introducing additional laser couplings. For large laser intensities, the Lamb-Dicke theory becomes unsuitable and a description based in a generalized fluctuation-dissipation theorem for non-linear response [2] is presented.

[1] Scharnhorst et al., arXiv:1711.00738, arXiv:1711.00732, (2017).
[2] Cerrillo et al., PRB 94, 214308 (2016).

A 35.2 Thu 10:45 K 1.022

Multi-mode double-bright EIT cooling (Experiment) — •Nils Scharnhost[1,2], Javier Cerrillo[3], Johannes Kramer[1], Ian D. Leroux[1], Jannes B. Wübbena[1], Alex Retzker[4], and Piet O. Schmidt[1,2] — [1]QUEST Institute for Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany — [3]Institut für Theoretische Physik, Technische Universität Berlin, 10623 Berlin, Germany — [4]Racah Institute of Physics, Hebrew University of Jerusalem, 91904 Jerusalem, Israel

Ground-state cooling (GSC) of ions and atoms is an essential prerequisite for many experiments in quantum optics, e.g. atomic clocks. Sideband cooling and cooling via electromagnetically induced transparency (EIT) are common techniques to achieve GSC. Due to their narrow cooling resonance, both techniques restrict cooling to a narrow frequency range. The desire to scale up the number of ions in quantum systems and to control all relevant (motional) degrees of freedom in such large atomic ensembles demands for novel cooling approaches, such as the capability to simultaneously cool several motional modes.

We developed double-bright EIT (D-EIT) cooling [1] as a novel scalable approach to standard EIT cooling by extending its level scheme by one additional ground and one excited state. D-EIT allows simultaneous GSC of modes around two separated frequencies and we experimentally demonstrate for the first time GSC of all three motional degrees of freedom of a trapped ion within a single, short cooling pulse.

[1] Scharnhorst et al., arXiv: 1711.00732v2 (2017)

A 35.3 Thu 11:00 K 1.022

Ground state cooling of atoms 300 nm away from a hot surface — •Yijian Meng, Alexandre Dareau, Philipp Schneeweiss, and Arno Rauschenbeutel — VCQ, TU Wien – Atominstitut, Stadionallee 2, 1020 Wien, Austria

Cold atoms coupled to light guided in nanophotonic structures constitute a powerful research platform, e.g., for probing surface forces, the study of light-induced self-organization, as well as quantum networking. The strong spatial confinement of the optical trapping fields in nanophotonic systems gives rise to significant fictitious magnetic field gradients. These can be used to perform degenerate Raman cooling (DRC), which has been pioneered in optical lattices [1].

Here, we implement DRC of atoms in a nanofiber-based optical trap [2]. Remarkably, this scheme only requires a single fiber-guided light field, which provides three-dimensional cooling. We show that continuously applying such cooling extends the lifetime of atoms in the trap by one order of magnitude. Using fluorescence spectroscopy [3], we precisely measure the temperature of the atoms. We find that they can be cooled close to the motional ground state despite the atoms being less than 300 nm away from the hot fiber surface. This achievement sets an excellent starting point for further experiments, for example, the investigation of heat transfer at the nanoscale using quantum probes.

[1] S. E. Hamann et al., Phys. Rev. Lett. 80, 4149 (1998).
[2] E. Vetsch *et al.*, Phys. Rev. Lett. **104**, 203603 (2010).
[3] P. S. Jessen et al., Phys. Rev. Lett. 39, 49 (1992).

A 35.4 Thu 11:15 K 1.022

Radio-frequency sideband cooling and sympathetic cooling of trapped ions in a static magnetic field gradient — Theeraphot Sriarunothai[1], •Gouri Shankar Giri[1], Sabine Wölk[1,2], and Christof Wunderlich[1] — [1]Department Physik, Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Str. 3, 57068 Siegen, Germany — [2]Institute for Theoretical Physics, University of Innsbruck, Technikerstraße 21a, 6020 Innsbruck, Austria

We report a detailed investigation on near-ground state cooling of one and two trapped atomic ions [1]. We introduce a simple RF sideband cooling method for confined atoms and ions, using RF radiation applied to bare ionic states in a static magnetic field gradient, and demonstrate its application to ions confined at secular trap frequencies, $\omega_z \approx 2\pi \times 117$kHz. For a single ^{171}Yb^{+} ion, the sideband cooling cycle reduces the average phonon number, $\langle n \rangle$ from the Doppler limit to $\langle n \rangle = 0.30(12)$. This is in agreement with the theoretically estimated lowest achievable phonon number in this experiment. We extend this method of RF sideband cooling to a system of two ^{171}Yb^{+} ions, resulting in a phonon number of $\langle n \rangle = 1.1(7)$ in the center-of-mass mode. Furthermore, we demonstrate the first realisation of sympathetic RF sideband cooling of an ion crystal consisting of two individually addressable identical isotopes of the same species.

[1] Th. Sriarunothai et al., arXiv: 1710.09241 (2017)

A 35.5 Thu 11:30 K 1.022

Synchronization-assisted cooling of atomic ensembles — •Simon B. Jäger[1], Minghui Xu[2,3], Stefan Schütz[4], John Cooper[2,3], Murray Holland[2,3], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany — [2]JILA, National Institute of Standards and Technology and Department of Physics, University of Colorado, Boulder, Colorado 80309-0440, USA — [3]Center for Theory of Quantum Matter, University of Colorado, Boulder, Colorado 80309, USA — [4]icFRC, IPCMS (UMR 7504), ISIS (UMR 7006), Université de Strasbourg and CNRS, 67000 Strasbourg, France

We analyze the dynamics leading to radiative cooling of an atomic ensemble inside an optical cavity when the atomic dipolar transitions are incoherently pumped. Our study is performed in the regime where the cavity decay is the largest rate in the system. Using a semiclassical approximation we identify three stages of cooling. At first hot atoms are cooled by the cavity friction forces. After this stage, the atoms' center-of-mass motion is further cooled by the coupling to the internal degrees of freedom while the dipoles synchronize. In the latest stage dipole-dipole correlations are stationary and the center-of-mass motion is determined by the interplay between friction and dispersive forces due to the coupling with the collective dipole. For this final stage we derive a mean-field model that is valid on a timescale where particle-particle correlations build up slowly. On this timescale we observe that the system can reach momentum widths below the recoil limit. Beside this we find limit cycles and chaotic dynamics.

A 35.6 Thu 11:45 K 1.022

Dissipative cooling of quasi-condensate excitations — •Carsten Henkel[1] and Isabelle Bouchoule[2] — [1]Universität Potsdam — [2]Institut d'Optique, Palaiseau

The elementary excitations of a Bose condensate are described by the celebrated Bogoliubov dispersion. Their spectrum is discrete for a trapped system. We discuss the theory of these excitations in experiments where atoms leave the trap in a controlled way. One observes a stationary non-equilibrium situation where temperature measurements give different results, either from the density profile or from density fluctuations [1]. We develop a simple stochastic theory based on quantum projection noise and find that the limiting temperature is slightly below the chemical potential. The calculations need accurate Bogoliubov mode functions that interpolate smoothly between the dense (Thomas-Fermi) region and the low-density wings [2, 3], a region

where mean-field theories fail [4, 5].

[1] A. Johnson, S. Szigeti, M. Schemmer, and I. Bouchoule, Phys. Rev. A 96 (2017) 013623

[2] A. L. Fetter and D. L. Feder, Phys. Rev. A 58 (1998) 3185

[3] A. Diallo and C. Henkel, J. Phys. B 48 (2015) 165302

[4] L. Pitaevskii and S. Stringari, Phys. Rev. Lett. 81 (1998) 4541

[5] C. Henkel, T.-O. Sauer, and N. P. Proukakis, J. Phys. B 50 (2017) 114002

A 35.7 Thu 12:00 K 1.022

Semiclassical Laser Cooling in Standing Wave Configurations
— •Thorsten Haase and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt, Germany

Laser cooling is a widely used technique in experiments in quantum optics and quantum information science. For most purposes of cooling above the Doppler limit laser fields are used which can be modelled by plane running waves. In this regime, the interaction between the radiation field and particles, modelled by two-level systems, is well explained by the semiclassical theory of Doppler cooling. Standing waves exhibit a different behaviour with analogies to blue detuned laser cooling at higher intensities [Ci92]. We present a semiclassical model for the interaction of a two-level system with arbitrary field modes, which includes standing and strongly focused waves. Our model exactly reproduces the theory of Doppler cooling for running plane waves. Additionally, it gives rise to different cooling properties inside standing laser fields. Our results are consistent with a special case investigated in [Ci92]. We simulate the interaction of a trapped two-level ion in the particular field configuration relevant for the 4Pi-Pac experiment in Erlangen [Al17], where the ion is trapped around the focus of a parabolic mirror to achieve almost perfect atom-photon coupling.

[Ci92] Cirac et. al, Phys. Rev. A, Vol. 46, No. 5, Sep 1992, 2668-2681 [Al17] Alber et. al, J. Europ. Opt. Soc. Rap. Public. 13, 14 (2017)