Q 18: Precision Spectroscopy of atoms and ions III (joint session A/Q)

Time: Monday 16:15–18:00 Location: S HS 2 Physik

Invited Talk Q 18.1 Mon 16:15 S HS 2 Physik

Non-equilibrium Dynamics of Ion Coulomb Systems — •Tanja E. Mehlstäubler — Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany

Single trapped and laser-cooled ions in Paul traps allow for a high degree of control of atomic quantum systems. They are the basis for modern atomic clocks, quantum computers and quantum simulators. Our research aims to use ion Coulomb crystals, i.e. many-body systems with complex dynamics, for precision spectroscopy. This paves the way to novel optical frequency standards for applications such as relativistic geodesy and quantum simulators in which complex dynamics become accessible with atomic resolution. The high-level of control of self-organized Coulomb crystals open up a fascinating insight into the non-equilibrium dynamics of coupled many-body systems, displaying atomic friction and symmetry-breaking phase transitions. We discuss the creation of topological defects and Kibble-Zurek tests in 2D crystals and present recent results on the study of tribology and transport mediated by the topological defect.

Q 18.2 Mon 16:45 S HS 2 Physik

High intensity laser cooling with electromagnetically induced transparency beyond the Lamb-Dicke limit — •Javier Cerrillo — Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstr 36 10623 Berlin

Laser techniques for ground state cooling of trapped ions, cold atoms or nanomechanical oscillators are well understood in the limit of slow cooling but lack a comprehensive description for very large laser intensities or, equivalently, beyond the well-studied Lamb-Dicke limit. The exploration of this regime has so far been uncommon due to the laser intensity limitations imposed by heating effects of carrier and blue sideband transitions. We present a scheme where coherent combination of scattering paths based on electromagnetically induced transparency (EIT) can cancel both carrier and blue-sideband excitations, so that all heating contributions vanish within the Lamb-Dicke limit. The use of multiple EIT features also facilitates simultaneous cooling of several modes and has been experimentally demonstrated. For all these schemes, a new theoretical tool based on a generalized master equation formalism is proposed for the analysis and optimization of cooling rate and final temperature which automatically incorporates polaronic and squeezing effects.

Q 18.3 Mon 17:00 S HS 2 Physik

Towards Sympathetic Cooling of Protons and Antiprotons — •Matthew Bohman[1,2], Pascal Blessing[2,3], Jack Devlin[2], James Harrington[1], Andreas Mooser[1,2], Gerog Schneider[2,5], Christian Smorra[2], Markus Wiesinger[1,2], Elise Wursten[2,6], Klaus Blaum[1], Yasuyuki Matsuda[4], Wolfgang Quint[3,7], Jochen Walz[5,8], and Stefan Ulmer[2] — [1]Max-Planck-Institut für Kernpysik, Germany — [2]Fundamental Symmetries Laboratory, RIKEN, Japan — [3]GSI, Germany — [4]University of Tokyo, Japan — [5]Mainz University, Germany — [6]CERN, Switzerland — [7]Heidelberg University, Germany — [8]Helmholtz-Institut Mainz, Germany

High precision measurements on trapped protons and antiprotons provide some of the most stringent tests of CPT symmetry in the baryon sector. In particular, these experiments confirm CPT symmetry and provide further evidence of Lorentz invariance at the level of 10e-24 GeV on an absolute energy scale. Further precision, however, is limited by high particle energies and requires moving beyond the traditional techniques available in high precision cryogenic Penning trap experiments. We present a novel technique to sympathetically cool protons and antiprotons stored in separate traps, by coupling single particles to laser cooled ions via image currents induced in a common endcap electrode. We place our work in the context of an improved g-factor measurement of the proton and show early results including the application of methods to measure sub-thermal single particle energy distributions in the laser cooled limit.

Q 18.4 Mon 17:15 S HS 2 Physik

Experimental setup for sympathetic laser cooling of single atomic ions and protons in a Penning trap — •Juan M. Cornejo[1], Johannes Mielke[1], Teresa Meiners[1], Malte Niemann[1], Nicolás Pulido[1], Jonathan Morgner[1], Matthias Borchert[1,3], Amado Bautista-Salvador[2,1], Stefan Ulmer[3], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Physikalisch-Technische Bundesanstalt, Braunschweig — [3]Ulmer Fundamental Symmetries Laboratory, RIKEN

High-precision measurements of the (anti-)proton g-factor provide a stringent test of CPT invariance in the baryonic sector [1]. However, current cooling and state detection schemes are highly sensitive on the motional energy of the particles. For faster cooling to mK temperatures and efficient detection, we pursue an approach where a single, well-controlled atomic ion serves as a link to manipulate and detect the motional and spin state of a single (anti-)proton [2, 3].

An overview of the experimental setup including a cryogenic Penning trap stack for first demonstrations of the motional coupling between two $^9Be^+$ ions in a double well potential is given. We report on the latest progress regarding trapping, manipulation and detection of the atomic ion. Prospects for proton loading and a micro-coupling trap are discussed.

[1] C. Smorra *et al.*, Nature **550**, 371-374 (2017)
[2] D. J. Heinzen and D. J. Wineland, Phys. Rev. A **4**2, 2977 (1990)
[3] D. J. Wineland *et al.*, J. Res. NIST, **103**, 259-328 (1998)

Q 18.5 Mon 17:30 S HS 2 Physik

Resistive cooling of highly charged ions in a Penning trap to a fluidlike state — Mohammad Sadegh Ebrahimi[1], •Zhexi Guo[1,2,3], Manuel Vogel[1], Marco Wiesel[1,4], Wolfgang Quint[1,3], and Gerhard Birkl[4] — [1]GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany — [2]Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany — [3]Physikalisches Institut, Universität Heidelberg, 69120 Heidelberg, Germany — [4]Institut für Angewandte Physik, Technische Universität Darmstadt, 64289 Darmstadt, Germany

Resistive cooling of large ensembles of highly charged ions such as Ar13+ was studied in detail in a cryogenic Penning trap. In contrast to earlier measurements by Vogel et al. [Phys. Rev. A 90, 043412 (2014)], purely exponential cooling behaviour was observed when conditions were chosen to allow collisional thermalisation of the ions. The results obtained under such conditions indicate that resistive cooling time constants and final temperatures are independent of the initial ion energy and that the cooling time constant of a thermalised ion ensemble is identical to the single-ion cooling time constant. For sufficiently high ion number densities, measurements showed discontinuities in the spectra of motional resonances which indicate a transition of the ion ensemble to a fluidlike state when cooled to temperatures below approximately 14 K. With the final ion temperature at 7.5 K, ions of the highest charge states are expected to form ion crystals solely through resistive cooling without the need for laser cooling.

Q 18.6 Mon 17:45 S HS 2 Physik

Staggered-immersion cooling of a quantum gas in optical lattices — •Bing Yang[1,2,3], Hui Sun[1,2,3], Chun-jiong Huang[2,3], Han-yi Wang[1,2,3], You-jin Deng[2,3], Han-ning Dai[1,2,3], Zhensheng Yuan[1,2,3], and Jian-wei Pan[1,2,3] — [1]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Hefei National Laboratory for Physical Sciences at Microscale and Department of Modern Physics, University of Science and Technology of China, Hefei, Anhui 230026, China — [3]CAS Centre for Excellence and Synergetic Innovation Centre in Quantum Information and Quantum Physics, University of Science and Technology of China, Hefei, Anhui 230026, China

Here we realize efficient cooling of ten thousand ultracold bosons in staggered optical lattices. By immersing Mott-insulator samples into removable superfluid reservoirs, thermal entropy is extracted from the system. Losing less than half of the atoms, we lower the entropy of a Mott insulator by 65-fold, achieving a record-low entropy per particle of 0.0019 k_B (k_B is the Boltzmann constant). We further engineer the sample to a defect-free array of isolated single atoms and successfully transfer it into a coherent many-body state. The present staggered-immersion cooling opens up an avenue for exploring novel quantum matters and promises practical applications in quantum information science.