# A 3: Precision Spectroscopy of atoms and ions I (joint session A/Q)

Time: Monday 10:30–12:30 Location: S HS 2 Physik

A 3.1 Mon 10:30 S HS 2 Physik

**An Atomic Lab on a Chip** — •Artur Skljarow[1], Ralf Ritter[1], Wolfram H.P. Pernice[2], Harald Kübler[1], Tilman Pfau[1], Robert Löw[1], and Hadiseh Alaeian[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology (IQST), Universität Stuttgart, Pfaffenwaldring 57, D-70569 Stuttgart, Germany — [2]Institute of Physics, University of Münster, Heisenbergstr. 11, D-48149 Münster, Germany

The integration of photonic structures with thermal atomic vapors on a chip provides efficient atom-light coupling on a miniaturized scale well beyond the diffraction limit hence, opening a new regime in the field of cavity quantum electrodynamics. In this talk, we present the results of our study on interactions of thermal Rb atoms with integrated $Si_3N_4$ and Si Nano-devices. In the former case, the atoms are probed with a laser at the $D_2$ transition, whereas in latter the atoms are further excited to the 4D states with an additional excitation at telecom wavelength. Our studies on Si structures benefit from a stronger mode confinement due to the large reflective index as well as a larger dipole moment. Moreover, we demonstrate novel measurements on the effects of Si surface potentials on Rb 4D states. Promising results on ring resonators pave the way towards further investigations of high-Q photonic crystal cavities in order to reach the strong coupling regime.

[1] R. Ritter et al., *New Journal of Physics* **18**, 103031 (2016)
[2] R. Ritter et at., *Phys. Rev. X* **8**, 021032 (2018)

A 3.2 Mon 10:45 S HS 2 Physik

**Spectroscopy of the $^1S_0 - {}^3P_1$ intercombination line of calcium** — •Markus Kirkines and Simon Stellmer — Physikalisches Institut der Universität Bonn, Nussallee 12, 53115 Bonn

Over the past decades, microwave frequency references have been outperformed by optical frequency standards, and there is a worldwide quest to build optical clocks that can be operated outside the laboratory. We aim to build an atomic beam clock of calcium that is not only compact in size and firm against external influences, but also has a fractional frequency stability in the order of $10^{-16}$. As a preparatory experiment, we will perform Doppler-free spectroscopy on the $^1S_0 - {}^3P_1$ intercombination line of calcium which is the designated clock transition ($\lambda = 657\,\mathrm{nm}$ and $\Gamma = 2\pi \times 370\,\mathrm{Hz}$). The spectroscopy cell is designed such that the linewidth broadening (e.g. collisional and transient broadening) of the atomic transition linewidth are kept below a few kHz. The cell should not only minimize the line broadening of the atomic transition, but should also provide high durability so that it can run without maintenance for years. We investigate different spectroscopy cell setups which will be presented in the talk.

A 3.3 Mon 11:00 S HS 2 Physik

**Relative and absolute limitations of wavelength meters for accurate laser stabilization** — •Kristian König, Phillip Imgram, Jörg Krämer, Tim Ratajczyk, and Wilfried Nörtershäuser — Institut für Kernphysik, TU Darmstadt

High-precision laser spectroscopy experiments at TU Darmstadt indicated a non-linear behavior of the employed wavelength meters. In a dedicated analysis of these interferometers with a frequency comb, surprising results were obtained. Especially the limited relative accuracy observed even for small frequency changes that are in the range of typical laser scans, was unexpected. We will present the results and discuss its consequences for experiments that base on the relative precision of wavelength meters. Furthermore, we will present a frequency-comb based stabilization scheme of a Ti:Sa laser which offers high short- and long-term stability.

A 3.4 Mon 11:15 S HS 2 Physik

**A cold lithium target for quantum interference studies** — •Marcel Willig, Stefan Schmidt, Jan Haack, Andreas Wieltsch, and Randolf Pohl — Johannes Gutenberg-Universität Mainz, QUANTUM, Institut für Physik & Exzellenzcluster PRISMA$^+$, Mainz, Germany

Precision laser spectroscopy of light atoms provides unique information about the atomic and nuclear structure of these systems and thus represents a way to access fundamental interactions, properties and constants. A particular interesting candidate for these kind of studies is atomic lithium with its unique level structure. We will use a cold sample of lithium atoms to perform high-precision laser spectroscopy and to access fundamental nuclear properties. This includes studies of (higher-order) quantum interference effects [1]. In addition, we plan to investigate cold neutral-neutral collision between hydrogen and lithium as a first step towards a cold sample of tritium atoms confined inside a magnetic trap [2].

In this contribution, we will present the current status of our apparatus and present first results. This includes detailed tests of our Zeeman-slower as well as our laser setup which will be used to generate the magneto-optical trap. Furthermore, we want to give an outlook on our future project: trapping and sympathetically cooling hydrogen in a second-generation Li-MOT.

[1] M. Horbatsch, and E. A. Hessels, PRA 82, 052519 (2010)
[2] S. Schmidt et al., J. Phys. Conf. Ser. accepted (2018), arXiv 1808.07240

A 3.5 Mon 11:30 S HS 2 Physik

**Spectroscopy of the 1001 nm transition in atomic dysprosium** — •Niels Petersen[1,2], Marcel Trümper[1], Florian Mühlbauer[1], Gunther Türk[1], and Patrick Windpassinger[1,2] — [1]QUANTUM, Institut für Physik, Johannes Gutenberg-Universität, 55099 Mainz, Germany — [2]Graduate School Materials Science in Mainz, Staudingerweg 9, 55128 Mainz, Germany

Dysprosium is a rare-earth element with one of the largest ground-state magnetic moments (10 Bohr magnetons) in the periodic table. Therefore, the dipole-dipole interaction is not a small perturbation but becomes comparable in strength to the s-wave scattering in ultracold dysprosium gases. The physical properties of the trapped atomic sample, such as its shape and stability are significantly influenced by the long-range and anisotropic dipole-dipole interaction.

Narrow-linewidth transitions constitute highly sensitive probes for external fields, internal properties and interactions between atoms in quantum gases. Due to the long lifetimes of the upper states these transitions can be utilized to generate and precisely control mixtures of long-living excited state atoms and ground state atoms. The lifetime of the excited state of the 1001 nm ground state transition in atomic dysprosium is predicted to be on the order of a few milliseconds. We report on spectroscopy of cold dysprosium atoms in an optical dipole trap on the 1001 nm transition and present measurements of the excited state lifetime.

A 3.6 Mon 11:45 S HS 2 Physik

**Towards a $^{171}Yb^+$ single-ion frequency standard in the $10^{-19}$ uncertainty range** — •Richard Lange[1], Nils Huntemann[1], Christian Sanner[1,2], Jiehang Zhang[1], Moustafa Abdel Hafiz[1], Hu Shao[1], Christian Tamm[1], and Ekkehard Peik[1] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]present address: JILA, Boulder, CO 80309, USA

Two $^{171}Yb^+$ single-ion traps are employed in our laboratory and realize optical clocks based on the $^2S_{1/2} \to {}^2D_{3/2}$ electric quadrupole (E2) [PRA **89**, 023820] and the $^2S_{1/2} \to {}^2F_{7/2}$ electric octupole (E3) [PRL **108**, 090801] reference transitions. For the E3 transition, which is less prone to external perturbations, a frequency uncertainty of $3 \times 10^{-18}$ has recently been evaluated and demonstrated in a long-term comparison between two independent clock setups [arXiv:1809.10742]. The achieved uncertainty was essentially limited by trap imperfections, which will be further reduced with an improved ion trap design.

We will discuss the dominant contributions to the present uncertainty and show the advantages of the new trap design, e.g. low loss insulators causing smaller blackbody radiation (BBR) shift, polished gold-coated electrodes for low heating rates and large optical access for rigorous minimization of excess micromotion. In combination with a more precise measurement of the scalar differential polarizability for a precise correction of the BBR shift, the new clock setup is expected to reach an uncertainty below $10^{-18}$.

A 3.7 Mon 12:00 S HS 2 Physik

**Quantum Logic Laser Spectroscopy of $Ar^{13+}$** — •Peter Micke[1,2], Steven A. King[1], Tobias Leopold[1], Steffen Kühn[2], Janko Nauta[2], Lisa Schmöger[1,2], Julian Stark[2], José R. Crespo López-Urrutia[2], and Piet O. Schmidt[1,3] — [1]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig — [2]Max-Planck-Institut für Kernphysik (MPIK), Heidelberg — [3]Institut für Quantenoptik, Leibniz Universität Hannover

Highly charged ions (HCI) are extremely sensitive testbeds of fundamental physics. In next-generation atomic clocks, their forbidden optical transitions can be used to test a possible time variation of fundamental constants. Until now, optical spectroscopy was limited by the large Doppler broadening of hot HCIs. However, in a Paul trap advanced cooling techniques can be applied. In collaboration with MPIK, we have commissioned a cryogenic Paul trap experiment at PTB. After production in an electron beam ion trap, $Ar^{13+}$ is extracted, decelerated, and retrapped in a Coulomb crystal of laser-cooled $Be^{+}$ ions. Next, an $Ar^{13+}$-$Be^{+}$ two-ion crystal is prepared in the motional ground-state by sideband cooling. Using quantum logic, we demonstrate coherent laser spectroscopy on HCIs for the first time. We resolve the 441 nm $^2P_{1/2}$-$^2P_{3/2}$ M1 transition on a sub-kHz level, already improving previous work by seven orders of magnitude. Soon, after further stabilizing our clock laser, we will resolve the natural linewidth of 17 Hz and evaluate minuscule systematic shifts of the unperturbed transition frequency with sub-Hz accuracy, measuring relative to the SI second.

A 3.8 Mon 12:15 S HS 2 Physik

**Towards laser spectroscopy of the ground-state hyperfine splitting in muonic hydrogen** — •A. Ouf and R. Pohl on behalf of the CREMA collaboration — Johannes Gutenberg-Universität Mainz, Institut für Physik, QUANTUM & Exzellenzcluster PRISMA +, Mainz, Germany

Simple muonic atoms have proven to be of particular interest for studies of nuclear properties, such as the charge [1] and (magnetic) Zemach radii [2], and the nuclear polarizabilities. The Zemach radius encodes the magnetic properties of the proton and it is the main nuclear structure contribution to the hyperfine splitting (HFS) in hydrogen. The 1S-HFS in ordinary hydrogen (the famous 21 cm line) has been measured with 12 digits accuracy almost 50 years ago [3], but its comparison with QED calculations is limited to 6 digits by the uncertainty of the Zemach radius determined from elastic electron-proton scattering. We will present the ongoing measurement of the CREMA Collaboration at PSI which aims at a first measurement of the 1S-HFS in muonic hydrogen with the potential for a hundredfold improved determination of the proton structure effects (Zemach radius and polarizability), which will eventually improve the QED test using the 21 cm line by a factor of 100.

[1] R. Pohl *et al.*, Nature **466**, 213 (2010)
[2] A. Antognini *et al.*, Science **339**, 417 (2013)
[3] L. Essen *et al*, Nature **229**, 110 (1971)