A 17: Precision Measurements and Metrology IV (with Q)

Time: Tuesday 14:30–16:30 Location: P/H1

A 17.1 Tue 14:30 P/H1

Recent results of the Space Optical Clock 2 EU project (SOC2). A compact, transportable optical lattice clock. — •Lyndsie Smith[1], Stefano Origlia[2], Joshua Hughes[1], Wei He[1], Ole Kock[1], Dariusz Świerad[1], Yeshpal Singh[1], Kai Bongs[1], Soroosh Alighanbari[2], Stephan Schiller[2], Stefan Vogt[3], Uwe Sterr[3], Christian Lisdat[3], Rudolphe Le Targat[4], Jèrôme Lodewyck[4], David Holleville[4], Bertrand Venon[4], Sébastien Bize[4], Geoffrey P Barwood[5], Patrick Gill[5], Ian R Hill[5], Yuri B Ovchinnikov[5], Nicola Poli[6], Guglielmo M Tino[6], Jürgen Stuhler[7], Wilhelm Kaenders[7], and and the SOC2 team[7] — [1]University of Birmingham (UoB), Edgbaston, Birmingham B15 2TT, UK — [2]Institut für Experimentalphysik,Heinrich-Heine-Universität Düsseldorf (HHUD),40225 Düsseldorf, Germany — [3]Physikalisch-Technische Bundesanstalt (PTB), 38116 Braunschweig, Germany — [4]SYRTE, Observatoire de Paris, 75014 Paris, France — [5]National Physical Laboratory (NPL), Teddington TW11 0LW, UK — [6]Università di Firenze (UNIFI) and LENS, Firenze, Italy — [7]TOPTICA Photonics AG, 82166 Gräfelfing, Germany

With timekeeping being of paramount importance for modern life, much research and major scientific advances have been undertaken in the field of frequency metrology, particularly over the last few years. New Nobel-prize winning technologies have enabled a new era of atomic clocks; namely the optical clock. These have been shown to perform significantly better than the best microwave clocks reaching an inaccuracy of $1.6{\cdot}10^{-18}$ (doi:10.1038/nature12941). With such results being found in large lab based apparatus, the focus now has shifted to portability - to enable the accuracy of various ground based clocks to be measured, and compact autonomous performance - to enable such technologies to be tested in space. This could lead to a master clock in space, improving not only the accuracy of technologies on which modern life has come to require such as GPS and communication networks. But also more fundamentally, this could lead to the redefinition of the second and tests of fundamental physics. Within the European collaboration, Space Optical Clocks 2 (SOC2) consisting of various institutes and industry partners across Europe we have tried to tackle this problem of miniaturisation whilst maintaining stability, accuracy ($5{\cdot}10^{-17}$) and robustness whilst keeping power consumption to a minimum - ideal for space applications. I will present the most recent results of the Sr optical clock in SOC2 and also the novel compact design features for reducing BBR, new methods employed and outlook.

A 17.2 Tue 14:45 P/H1

Absolute frequency measurement of the ^{87}Sr lattice clock at PTB — Ali Al-Masoudi, •Sören Dörscher, Vladislav Gerginov, Stefan Weyers, Christian Grebing, Burghard Lipphardt, Sebastian Häfner, Uwe Sterr, and Christian Lisdat — Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig

Comparisons of optical clocks to microwave or other optical clocks are of great importance e.g. for the search for drifts of fundamental constants, and they also serve to ascertain the correctness and completeness of their error budgets. We report on a recent measurement of the absolute frequency of the $^1S_0$–$^3P_0$ transition in ^{87}Sr against a Cs fountain clock. The result is in excellent agreement with recent measurements in other laboratories as well as our own previous measurements. The preliminary fractional uncertainty of this measurement is 4×10^{-16}, to which the statistical uncertainty due to the measurement time of 267000 s still contributes considerably. However, this uncertainty can be reduced to below the systematic uncertainty of the Cs clock by an extension of the effective total measurement time through interpolation, which is currently under investigation. Finally, we present recent improvements of the lattice clocks at PTB for this measurement and towards a direct comparison of two separate ^{87}Sr clocks. This work is supported by QUEST, the DFG within CRC 1128 (geo-Q) and RTG 1729, and the EMRP within IND14, ITOC, and QESOCAS. The EMRP is jointly funded by the EMRP-participating countries within EURAMET and the European Union.

A 17.3 Tue 15:00 P/H1

Lifetime of the $5s4d$ $^3D_1$ transition in neutral strontium — •Joshua Hughes[1], Marco Menchetti[1,2], Yeshpal Singh[1], Kai Bongs[1], Ian Hill[2], Richard Hobson[2,3], Anne Curtis[2], Ross Williams[2], and Patrick Gill[2,3,4] — [1]University of Birmingham, Birmingham, UK — [2]National Physical Laboratory, Teddington, UK — [3]Clarendon Laboratory, University of Oxford, Oxford, UK — [4]Imperial College London, London, UK

Atomic clocks based on neutral strontium have now reached both accuracies and stabilities at the 10^{-18} level. The accuracy is currently limited by the uncertainty of the blackbody radiation (BBR) shift in neutral strontium at room temperature. Improved measurements of the strontium $5s4d$ $^3D_1$ lifetime, which contributes to 98% of the uncertainty in the dynamic correction term to the BBR shift, will lead to a further reduction of the overall systematic uncertainty in room temperature strontium lattice clocks. I will present an update on the status of the strontium lattice clock at NPL as well as measurements we have made of the $^3D_1$ state lifetime.

A 17.4 Tue 15:15 P/H1

Miniaturised optical lattice clock — •Ole Kock, Wei He, Lyndsie Smith, Dariusz Swierad, Qasim Ubaid, Sruthi Viswam, Yeshpal Singh, and Kai Bongs — University of Birmingham (UoB), Edgbaston, Birmingham B15 2TT, UK

A major scientific development over the last decade, namely clocks based on optical rather than microwave transitions, has opened a new era in time/frequency metrology. Several Physics Nobel prizes (1997, 2001, 2005, 2012) were awarded for methods that have enabled optical clocks showing the significance of their development. Optical clocks have now achieved a performance significantly beyond that of the best microwave clocks, down to a fractional frequency inaccuracy of $1.6 \cdot 10^{-18}$. The advances in this field open up a multitude of new applications. One can envision optical clocks improving the accuracy of GNSS receivers and the resilience of high speed communication networks as well as enabling the operation of a master clock in space. For such endeavours great work has to be done to miniaturise optical clocks and increase their robustness. I will present our design of a portable miniaturised optical lattice clock which aims at a stability of one part in 10^{16} or better. As part of the miniaturisation efforts a novel method of a very compact atomic source which greatly reduces effects of the blackbody shift on the clock transition and new technologies for a miniature self-contained vacuum chamber will be introduced.

A 17.5 Tue 15:30 P/H1

Magic wavelength for the clock transition in Magnesium-24 — •Dominika Fim, André Kulosa, Steffen Rühmann, Klaus Zipfel, Nandan Jha, Steffen Sauer, Wolfgang Ertmer, and Ernst M. Rasel — Gottfried Wilhelm Leibniz Universität

For this purpose we trap 10^4 magnesium-24 atoms in a power enhanced linear optical lattice near the magic wavelength. We succeeded to directly excite the spin forbidden clock transition $^1S_0 \rightarrow {}^3P_0$ by using the magnetic field induced spectroscopy [1]. The interrogation laser has an instability of $5 \cdot 10^{-16}$ at 1 s. A spectroscopy of the blue and red sideband and the carrier give access to important parameters. First, a measurement of the shift of the carrier frequency as a function of trap depth gives insight in the differential AC stark shift. Here from we could determine the magic wavelength to 468.4(0.1) nm which is in a good agreement with theoretical calculations. By means of the difference in height of the sidebands we could evaluate the temperature of the atoms to 7 μK.
Currently, we are investigating systematic shifts of the clock transition (e.g. 2nd order Zeeman shift).

[1] A. V. Taichenachev et al., Phys. Rev. Lett. 96, 083001 (2006)

A 17.6 Tue 15:45 P/H1

Optical Bloch band spectroscopy with laser cooled magnesium atoms — •André Kulosa, Steffen Rühmann, Dominika Fim, Klaus Zipfel, Nandan Jha, Steffen Sauer, Wolfgang Ertmer, and Ernst Rasel — Leibniz Universität Hannover, Institut für Quantenoptik, Hannover

Here we report on optical Bloch band spectroscopy of laser cooled magnesium atoms trapped in a magic wavelength lattice. Phenomena observed with atoms in lattices show close analogies to those known for electrons in solid state physics as the periodic light field potential can be directly related to a periodic crystal structure. Moreover, tunneling between the lattice sites leads to delocalization of atoms with a resulting band structure in the atomic energy spectrum. We employ spectroscopy of the band structure to gather information about the atomic polarizabilities of the involved electronic states.

Atoms are probed on the spin-forbidden $^1S_0 \rightarrow {}^3P_0$ clock transition at 458 nm with a spectroscopic linewidth of about 3 kHz. Lowering the trap depth to less than 10 recoil energies, we expect a bandwidth resulting from the energy dispersion of the lower and upper band to be larger than the spectroscopic linewidth and a line shape reflecting the band structure of the lower and upper electronic state. For an increasing trap depth and as a consequence a decreasing ground state bandwidth, we see the corresponding decreasing in the carrier frequency shift as it has been postulated by P. Wolf and P. Lemonde [1].

[1] P. Lemonde and P. Wolf, *Phys. Rev. A* **72**, 033409 (2005)

A 17.7 Tue 16:00 P/H1

Precision isotope shift measurements of calcium ions using photon recoil amplification schemes — •F. Gebert[1], Y. Wan[1], J. C. Heip[1], F. Wolf[1], J. Berengut[2], and P. O. Schmidt[1,3] — [1]QUEST Institut, Physikalisch-Technische Bundesanstalt, 38116 Braunschweig — [2]School of Physics, University of New South Wales, Sydney — [3]Institut für Quantenoptik, Leibniz Universität Hannover

We present isotope shift measurements of the $^2D_{3/2}$-$^2P_{1/2}$ and $^2S_{1/2}$-$^2P_{1/2}$ transitions in calcium ions using the photon recoil spectroscopy technique (PRS). In PRS, a spectroscopy ion is trapped and sympathetically cooled by a cooling ion. Photon recoil from absorption on a spectroscopy transition results in motional excitation probed by the cooling ion using quantum logic techniques. In a new approach single-photon repumping from the meta-stable $^2D_{3/2}$ state via the $^2D_{3/2}$-$^2P_{1/2}$ transition serves as the spectroscopy signal, which is efficiently translated into motion of the two ion crystal, through amplification via recoil from absorption of photons resonant with the $^2S_{1/2}$-$^2P_{1/2}$ transition. The residual motional ground state population is then probed using a stimulated Raman adiabatic passage pulse driving a motional sideband on the 25Mg+ logic ion. We present isotope shift measurements using the new technique with an accuracy improved by up to two orders of magnitude. We performed a multidimensional King plot analysis and extracted important nuclear constants from the optical data.

A 17.8 Tue 16:15 P/H1

Suppressing high-frequency noise in phase-locks to fiber frequency combs — •Nils Scharnhorst, Jannes B. Wübbena, Stephan Hannig, Ian D. Leroux, and Piet O. Schmidt — QUEST Institute of Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt and Leibniz Universität Hannover, Bundesallee 100, D-38116 Braunschweig, Germany

We demonstrate a high-bandwidth transfer-lock scheme which is capable of transferring short-term stability from a stable master laser to an otherwise free-running diode laser at 729 nm via a frequency comb.

Limited by the intrinsic noise of the comb at high Fourier-frequencies and the available feddback bandwidth, we synthesize a virtual beat signal for the 729 nm laser in which the effect of the comb noise is suppressed by microwave feed-forward electronics, a so-called transfer-oscillator lock [1], circumventing a tight comb lock.

By eliminating the need for auxiliary reference cavities for laser prestabilization at each wavelength, this capability allows a substantial simplification of experimental setups requiring multiple stable lasers, such as high-accuracy frequency standards based on quantum logic spectroscopy, experiments in Rydberg spectroscopy, or coherent photoassociation and control of molecules with Raman pulses.

[1] J.Stenger et al., Phys. Rev. Lett. **88**, 073601 (2002)