Q 1: Quantum Technologies (joint session Q/A/QI)

Time: Monday 11:00–13:00 Location: A320

Q 1.1 Mon 11:00 A320

Holography with single photons — •Hrvoje Skenderovic and Denis Abramovic — Institute of Physics, Bijenicka cesta 46, 10000 Zagreb, Croatia

Holography relies on interference between two beams, reference and object. Although single photon can not be divided, holograms with heralded single-photon source in a classical holographic setup were recorded, due to indistinguishable paths. The amplitude and phase reconstructions show quantum enhancement for heralded over non-heralded channel. Non-classical nature of heralded photons is verified by continuous measurement of g2(0) of the light source during hologram acquisition.

Q 1.2 Mon 11:15 A320

Three-Dimensional Imaging of Single Atoms in an Optical Lattice via Helical Point-Spread-Function Engineering — •Tangi Legrand[1], Falk-Richard Winkelmann[1], Wolfgang Alt[1], Dieter Meschede[1], Andrea Alberti[1], and Carrie Weidner[2] — [1]Institut für Angewandte Physik, Universität Bonn, Germany — [2]Quantum Engineering Technology Laboratories, H. H. Wills Physics Laboratory and Department of Electrical and Electronic Engineering, University of Bristol, United Kingdom

Quantum gas microscopes can resolve atoms trapped in a 3D optical lattice down to the single site in the horizontal plane. Along the line of sight, however, a much lower resolution is achieved if the position is inferred from the defocus alone, although tomographic methods have been applied to extract this information [1]. However, phase-front engineering can be used to localize emitters in 3D with sub-micrometer resolution from a single experimental image [2]. The technique consists of shaping the imaging system's point spread function (PSF) such that it results in an axially rotating azimuthally asymmetric distribution. By means of a spatial light modulator, we create a double-helix PSF consisting of two lobes whose relative angle encodes an atom's axial position. We demonstrate 3D localization at the level of single lattice sites in a quantum gas microscope. As we show, the technique also features an increased depth of field. This method can find applications in other quantum gas experiments to extend the domain of quantum simulation from 2D to 3D. [1] O. Elíasson *et al.* Phys. Rev. A **102**, 053311 (2020), [2] S.R.P. Pavani *et al.* PNAS **106**, 2995 (2009).

Q 1.3 Mon 11:30 A320

Tomography of distant single Atoms — •Florian Fertig[1,2], Yiru Zhou[1,2], Pooja Malik[1,2], Anastasia Reinl[1,2], Tim van Leent[1,2], and Harald Weinfurter[1,2,3] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [3]Max-Planck-Institut für Quantenoptik, Garching, Germany

Entanglement of distant quantum memories forms the building block of quantum networks. Neutral atoms with long coherence times are possible candidates for such a quantum network link and can be entangled via the entanglement swapping protocol. Our experiment consists of two nodes, currently 400 m apart, employing single optically trapped Rubidium-87 atoms as quantum memories. A new collection setup allows for an increased entanglement event rate of 1/6 Hz allowing a state analysis and reconstruction of the entangled state.

Here, we use quantum state tomography for the first time on atom-atom entanglement and evaluate the influence of different kind of experimental improvements on the fidelity of the entangled state. We introduce time-filtering, a method to increase the atom-atom entanglement fidelity. At the cost of events we reach a fidelity $> 90\%$ well suited for demanding tasks like device-independent QKD.

Q 1.4 Mon 11:45 A320

Mid-Infrared Quantum Scanning Microscopy with Visible Light — •Josué R. León-Torres[1,2], Jorge Fuenzalida[1], Marta Gilaberte Basset[1], Sebastian Töpfer[1], and Markus Gräfe[1,2,3] — [1]Fraunhofer Institute of Applied Optics and Precision Engineering IOF, Albert-Einstein-Straße 7, D-07745 Jena, Germany — [2]Friedrich-Schiller-Universität Jena, Abbe Center of Photonics, Max-Wien-Platz 1, D-07745 Jena, Germany — [3]Technische Universität Darmstadt, Institute of Applied Physics, Hochschulstraße 6, D-64289 Darmstadt, Germany

Abstract: Laser scanning microscopy (LSM) is known to be the workhorse for modern life-science, it allows to get new insights into a variety of biological processes. LSM together with illumination in the mid infrared region (Mid-IR) permits to map the chemical composition of samples to a space frame. However, low-light observations in the Mid-IR spectrum are still challenging and a limiting factor for a faster development. A label-free quantum imaging system is presented here, capable of performing the detection in the visible regime, while illuminating the sample with undetected light in the Mid-IR region. Our quantum imaging with undetected light implementation aims to retrieve amplitude and phase images of biological samples containing a variety of functional groups that are present in the Mid-IR region. Due to the momentum correlations shared by the entangled photon-pair the illumination can take place in the Mid-IR spectrum and the detection can be carried out with silicon-based technology in the VIS spectrum.

Q 1.5 Mon 12:00 A320

GHz bandwidth four-wave mixing in a thermal rubidium vapor — •Max Mäusezahl[1], Felix Moumtsilis[1], Moritz Seltenreich[1], Jan Reuter[2,3], Hadiseh Alaeian[4], Harald Kübler[1], Matthias Müller[2], Charles Stuart Adams[5], Robert Löw[1], and Tilman Pfau[1] — [1]5. Physikalisches Institut, Universität Stuttgart, Germany — [2]Forschungszentrum Jülich GmbH, PGI-8, Germany — [3]Universität zu Köln, Germany — [4]Departments of Electrical & Computer Engineering and Physics & Astronomy, Purdue University, USA — [5]Department of Physics, Joint Quantum Centre (JQC), Durham University, UK

Fast coherent control of Rydberg excitations is essential for quantum logic gates and on-demand single-photon sources based on the Rydberg blockade as demonstrated for room-temperature rubidium atoms in a micro-cell. During our ongoing development of the next generation of this single-photon source we employ state-of-the-art 1010 nm pulsed fiber amplifiers to drive a Rydberg excitation via the 6P intermediate state.

Here we report on time resolved observations of nanosecond pulsed four-wave mixing and GHz Rabi cycling involving the 32S Rydberg state. Our results show oscillating dynamics of the mixed photons on the final transition of the FWM cycle. The MHz repetition rates and significantly higher photon yields allow us to study and optimize the antibuching through elaborate pulse shaping motivated by numerical simulations. Such excitation timescales also pave the way towards fast optimal control methods for high fidelity Rydberg logic gates.

Q 1.6 Mon 12:15 A320

Absorption sensing mode in radio frequency electrometry using Rydberg atoms in hot vapors — •Matthias Schmidt[1,2], Stephanie Bohaichuk[1], Chang Liu[1], Harald Kübler[2], and James P. Shaffer[1] — [1]Quantum Valley Ideas Laboratories, 485 Wes Graham Way, Waterloo, ON N2L 6R1, Canada — [2]5. Physikalisches Institut, Universität Stuttgart, Pfaffendwaldring 57, 70569 Stuttgart

We present theoretical work on atom-based RF E-field sensing using Rydberg atoms in hot vapors. There are two distinct strategies to detect the electric field strength of the RF wave, namely the Autler-Townes limit, where the splitting of the dressed states is proportional to the incident RF electric field strength and the amplitude regime, where we determine the electric field by measuring the difference of transmission in the presence of the RF electromagnetic field. We present theoretical calculations for the amplitude regime, using a two photon excitation scheme, that show how the scattering of the probed transition changes in the presence of the RF electromagnetic field. We find an analytical expression in the thermal limit with finite wave vector mismatch that yields an accurate approximation compared to full density matrix calculation in the strong coupling limit. Our work extends the understanding of the detection of weak RF E-fields with Rydberg-atom based RF sensors.

Q 1.7 Mon 12:30 A320

Light Filtration With Hot Atomic Vapor Cells — •Denis Uhland, Yijun Wang, Helena Dillmann, and Ilja Gerhardt — Institute of Solid State Physics, Light and Matter Group, Leibniz University Hannover

The interaction of light and atoms is one of the cornerstones to study quantum effects. Atomic vapor cells offer a convenient and robust framework to such studies. Not only can fundamental quantum effects be studied, but their robustness and ease of handling is beneficial for a vast array of applications in quantum technology. Examples are magnetometers, electrometers, atomic clocks, or laser frequency stabilization. We probe hot vapor cells with lasers and external magnetic fields to enable spectral narrow filtering and show their potential to improve confocal and wide-field imaging in microscopy [1]. Not only does this method efficiently suppress the undesired laser leakage of scattered excitation light, but it also enhances the detection efficiency by 15% compared to one of the best commercially available long-pass filters. Another flavor of such filters utilizes magnetic fields and founds on the Macaluso-Corbino effect. This allows to enable GHz-wide band-pass filters in a Faraday configuration.

[1] Uhland, D., Rendler, T., Widmann, M. et al. Single molecule DNA detection with an atomic vapor notch filter. EPJ Quantum Technol. 2, 20 (2015). https://doi.org/10.1140/epjqt/s40507-015-0033-1

Q 1.8 Mon 12:45 A320

Optimization and readout-noise analysis of a hot vapor EIT memory on the Cs D1 line — •Luisa Esguerra[1,2], Leon Messner[1,3], Elizabeth Robertson[1,2], Norman Vincenz Ewald[1], Mustafa Gündoğan[1,3], and Janik Wolters[1,2] — [1]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Optische Sensorsysteme, Rutherfordstr. 2, 12489 Berlin, Germany. — [2]TU Berlin, Institut für Optik und Atomare Physik, Hardenbergstr. 36, 10623 Berlin, Germany. — [3]Institut für Physik, Humboldt-Universität zu Berlin, Newtonstr. 15, 12489 Berlin, Germany.

Efficient, noise-free quantum memories are indispensable components of quantum repeaters, which will be crucial for the realization of a global quantum communication network [1, 2]. We have realized a technologically simple, in principle satellite-suited quantum memory in Cesium vapor, based on electromagnetically induced transparency (EIT) on the ground states of the Cs D1 line [3]. We simultaneously optimize the end-to-end efficiency and the signal-to-noise level in the memory, and have achieved light storage at the single-photon level with end-to-end efficiencies up to 13(2)% at a minimal noise level corresponding to $\bar{\mu}_1 = 0.07(2)$ signal photons. From varying the control laser power at different detunings we gain profound understanding of the physical origin of the readout noise, and thus determine strategies for further minimization.

[1] M. Gündoğan et al., npj Quantum Information 7, 128 (2021)
[2] J. Wallnöfer et al., Commun Phys 5, 169 (2022)
[3] L. Esguerra, et al., arXiv:2203.06151 (2022)