Q 2: Quantum Optics I

Time: Monday 10:30–12:30 Location: K 0.016

Group Report Q 2.1 Mon 10:30 K 0.016

Ultrafast quantum optics with temporal modes — •Vahid Ansari, Markus Allgaier, John M Donohue, Matteo Santandrea, Laura Padberg, Christof Eigner, Mahnaz Doostdar, Gesche Vigh, Linda Sansoni, Georg Harder, Benjamin Brecht, and Christine Silberhorn — Integrierte Quantenoptik, Universität Paderborn, Warburger Str. 100, D-33098 Paderborn

Temporal modes of photonic quantum states provide a rich framework for quantum information science. They constitute a high-dimensional Hilbert space and are compatible with the existing single-mode fibre communication networks.

In this report, we show how to create ultrashort single photons in arbitrary temporal shapes, based on ultrafast waveguided parametric down-conversion (PDC) at telecom wavelengths. By tailoring the PDC process, we can control the spectral-temporal structure of the generated states to create separable or entangled photon pairs with a well-defined number of temporal modes.

Then we use a quantum pulse gate (QPG), based on a dispersion-engineered frequency conversion device, to manipulate and detect the underlying temporal structure of multimode PDC states within a high-dimensional space. Using the QPG, we present our recent experiments on temporal-mode tomography, purification of multimode PDC states, efficient bandwidth compression of single photons, and remote state preparation of arbitrary temporal modes.

Q 2.2 Mon 11:00 K 0.016

A Source of correlated photons for femtosecond quantum spectroscopy — •Fabiano Lever, Axel Heuer, Jan Metje, and Markus Guehr — Institut für Physik und Astronomie 0.033, Haus 28, Karl-Liebknecht-Straße 24/25 14476 Potsdam-Golm

In this work, we present a source of down converted photons for future use in nonlinear quantum spectroscopy, in our case on a halogen gas sample. The broadband signal and idler photons which are generated from a narrowband pump pulse are chosen to be resonant with electronic transitions in the sample. The idler pulse creates a nuclear wavepacket whose state is then read by the signal pulse. Although the duration of the two pulses is long, as determined by the narrowband pump, time resolution is obtained due to quantum correlations.

The pump light for the down conversion is obtained in a two step process, a femtosecond Yb:KGW laser is first shifted via transient stimulated Raman scattering and subsequently doubled in an non critically phase matched LBO. A chirped PPLN crystal is then used to obtain a broadband downconversion of the pump into correlated signal and idler beams.

Q 2.3 Mon 11:15 K 0.016

Generation of Multimode Photonic States for Quantum Metrology — •Vanessa Paulisch, Martí Perarnau Llobet, Alejandro González-Tudela, and J. Ignacio Cirac — Max-Planck-Institute of Quantum Optics, Garching, Germany

The high fidelity generation of photonic states is crucial for quantum communication and quantum metrology with photons. We study the conditions under which a chain of emitters coupled to a one dimensional waveguide emits a photonic state. We have shown that arbitrary photonic states of a single mode (Fock states or superpositions thereof) can be generated when the number of emitters is much larger than the number of excitations in the emitters, i.e., the number of photons to be generated. On the other hand, when the emitters are fully excited, they emit a intricate multimode photonic state. It was unclear whether these states are as useful as the more standard single mode states. We show that, indeed, also these multimode photonic states are useful for quantum metrology on the example of a phase measurement. And quite remarkably, they still easily beat the standard quantum limit of phase estimation.

Q 2.4 Mon 11:30 K 0.016

All-optically generation of tensor network states in one and higher dimensions — •Melanie Engelkemeier[1], Ish Dhand[2], Linda Sansoni[1], Sonja Barkhofen[1], Christine Silberhorn[1], and Martin Plenio[2] — [1]Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn — [2]Universität Ulm, Institut für Theoretische Physik, Helmholtzstraße 16, 89081 Ulm

In order to realize one- and higher-dimensional tensor network states of light, we propose to generate entangled multi-mode photonic states encoded in temporal modes of light with an all-optical scheme. Within this scheme, we are able to generate two different classes of entangled tensor-network states (W and GHZ states), which are suitable for quantum communication and quantum computation applications. Furthermore, we present a variational algorithm to simulate the ground-state physics of many-body systems and show that the existing optical devices are capable of implementing the spin-1/2 Heisenberg model. Finally, we demonstrate that the scheme is robust against experimental imperfections, such as realistic losses and modemismatch.[1]

[1] arXiv:1710.06103 [quant-ph]

Q 2.5 Mon 11:45 K 0.016

Broadening of spatial Schmidt modes for high-gain parametric down-conversion — •Gaetano Frascella[1], Polina Sharapova[2], Angela M. Pérez[1], and Maria V. Chekhova[1,3] — [1]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany — [2]University of Padeborn, 33098 Padeborn, Germany — [3]Physics Department, Moscow State University, 119991 Moscow, Russia

High-gain parametric down-conversion (PDC) is a well-known process for the production of bright squeezed vacuum (BSV) state of light, whose nonclassical features, like macroscopic photon-number entanglement, can be employed in quantum information and imaging.

The Schmidt modal decomposition is a powerful tool for the characterization of PDC's multimode structure because it offers a set of paired eigenmodes that show no correlations with other modes.

The measurement of single-shot two-dimensional far-field intensity distributions and the calculation of the covariance distribution enables the determination of the shapes and the weights of the spatial/angular Schmidt modes.

In this work, we experimentally reconstruct the spatial/angular Schmidt modes for BSV generated through high-gain PDC from a single nonlinear crystal and we show that both the angular spectrum and the Schmidt modes broaden slightly as the parametric gain increases.

This result suggests that a correction should be made to the model of gain-independent Schmidt modes.

Q 2.6 Mon 12:00 K 0.016

Photonenkorrelationsfunktion $g^{(2)}$ gemessen im Licht eines Ionenpaars - bunching oder anti-bunching? — •Sebastian Wolf[1], Stefan Richter[2], Joachim von Zanthier[2] und Ferdinand Schmidt-Kaler[1] — [1]QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz — [2]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, Staudtstraße 1, 91058 Erlangen

Die Messung der Photonenstatistik einer klassischen thermischen Lichtquelle zeigt bunching, also $g^{(2)}(0) > 1$, während eine Laserlichtquelle $g^{(2)}(0) = 1$ zeigt. Wieder andere Photonenstatistik – antibunching mit $g^{(2)}(0) < 1$ – beobachtet man für ein einzelnes Atom oder Ion. Wir berichten über den Nachweis ortsabhängiger Photonenstatistik im gestreuten Licht eines Zwei-Ionen-Kristalls in einer Paulfalle. Dieser wird mit einem Laser kontinuierlich angeregt und das emittierte Fluoreszenzlicht mit einem Objektiv gesammelt. Ein Aperturschlitz lässt dabei nur Licht aus einem schmalen Raumwinkelbereich in den Messaufbau für $g^{(2)}(t)$. Wir beobachten Werte von $g^{(2)}(0)$, die je nach Position des Schlitzes zwischen einem Maximum von 1.53(11) und einem Minimum von 0.58(6) variieren. Alternativ können wir durch Änderung des Ionenabstandes von bunching zu anti-bunching wechseln. Diese einzigartigen Eigenschaften der Photonenstatistik resultieren aus der Projektion des zwei-Ionen-Systems in einen Bell-Zustand, dessen Phase von der Richtung des einfallenden Lasers und der Beobachtungsrichtung abhängt [1].

[1] C. Skornia et al., Phys. Rev. A **64**, 063801 (2001).

Q 2.7 Mon 12:15 K 0.016

Attosecond Electron Pulse Trains and Quantum State Reconstruction in Ultrafast Transmission Electron Microscopy — Katharina E. Priebe[1], Christopher Rathje[1,2], •Thomas Rittmann[1], Sergey V. Yalunin[1], Thorsten Hohage[3], Armin Feist[1], Sascha Schäfer[1,2], and Claus Ropers[1] — [1]4th Physical

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In an ultrafast transmission electron microscope (UTEM), inelastic scattering between the free-electron beam and strong optical near-fields [1] allows for coherent manipulations of the electron quantum state [2]. Specifically, a light field imprints a phase modulation on the electron wave function, which is translated into an attosecond-structured electron density modulation by subsequent dispersive propagation [3].

Here, we employ multiple phase-locked field interactions to reconstruct the temporal structure of the electron density with our newly developed quantum state tomography technique 'SQUIRRELS' [4]. We experimentally demonstrate the compression of electron pulses into a train of attosecond bursts, which will promote new forms of ultrafast electron microscopy with attosecond resolution.

[1] B. Barwick *et al.*, Nature **462**, 902-906 (2009)
[2] K. Echternkamp *et al.*, Nature Physics **12**, 1000-1004 (2016)
[3] A. Feist *et al.*, Nature **521**, 200-203 (2015)
[4] K. Priebe *et al.*, Nature Photonics **11**, 793-797 (2017)