Q 52: Structured Light

Time: Thursday 14:30–16:30 Location: HS 1221

Invited Talk Q 52.1 Thu 14:30 HS 1221

Structured light and its interaction with matter — •Robert Fickler, Rafael Barros, Lea Kopf, and Marco Ornigotti — Tampere University, Tampere, Finland

Shaping light fields in all degrees of freedom, i.e., space, time, and polarization, has become a versatile tool to explore fundamental optics effects and fruitful applications in various fields of photonics and quantum optics. In this talk, I will present some of our recent studies in this thriving branch of optics.

At first, I will discuss the behavior of light having optical phase vortices getting reflected off a planar surface. It was predicted that higher-order vortices split into a constellation of unit-charged vortices, a phenomenon which is related to fundamental optical beam shifts. We were able to observe this effect for the first time experimentally and proof that that the physical quantity of interest is the mathematical abstraction of elementary symmetric polynomials of the coordinates of a vortex constellation. Our results pave the path to novel material characterization techniques and might also find applications in other system exhibiting vortices, e.g., superfluids or Bose-Einstein condensates.

I will then present a simple experimental scheme to generate more complex states of light in which space, wavelength, and polarization are non-separable. We demonstrate that these so-called spatio-spectral vector beams can exhibit simultaneously all possible polarization states across their frequency spectrum and transverse spatial extent and point out interesting analogies to entangled tri-partite quantum systems.

Q 52.2 Thu 15:00 HS 1221

Orbital angular momentum modes generated in the parametric down-conversion process with a non-Gaussian pump — •Lucas Gehse, Dennis Scharwald, and Polina Sharapova — University Paderborn, Paderborn, Germany

Electric fields can carry two types of angular momentum. The first is the spin angular momentum, which arises from the polarization of the light, and the second is the orbital angular momentum (OAM) which arises from the light phase distribution. OAM modes have an unlimited basis, which makes them very promising for fast and efficient quantum information and communication protocols [1]. In this work, we investigate an SU(1,1) interferometer consisting of two PDC sources, which are two nonlinear crystals pumped by a Laguerre−Gaussian pump with different orbital and radial numbers. We consider various crystal lengths, pump widths and distances between the crystals, in order to find configurations with high-order OAM modes populated. We have found configurations in which the orbital Schmidt number can achieve $K_n = 101.31$. The orbital Schmidt number is defined as $K_n = \frac{1}{\sum_n \Lambda_n^2}$, where $\Lambda_n = \sum_m \lambda_{mn}$ is the weights of the orbital modes, with n being the orbital number and m - the radial number of Schmidt modes. Mode shapes and intensity profiles for various configurations of the SU(1,1) interferometer were investigated.

[1] Erhard *et al.*, Light Sci Appl **7**, 17146 (2018)

Q 52.3 Thu 15:15 HS 1221

Vortex-light Raman interaction with $^{40}Ca^+$ ion crystals — •Maurizio Verde[1], Benjamin Zenz[1], Ulrich Poschinger[1], Nicolas Nuñez[3], Christian Schmiegelow[3], and Ferdinand Schmidt-Kaler[1,2] — [1]QUANTUM, Institut für Physik, Universität Mainz, Mainz, Germany — [2]Helmholtz-Institut Mainz, Mainz, Germany — [3]FCEyN, Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina

Light beams carrying Orbital Angular Momentum (OAM) differently excite electronic and motional transitions of trapped atoms, and may thus be interesting for quantum optics, -sensing and -information processing. We experimentally demonstrated the transfer of transverse optical momentum to the quantized motion of a single $^{40}Ca^+$ ion [1] and provided a general theoretical framework to describe the light-matter interaction for spatially structured light [2]. Here, we investigate vortex light in the Raman scheme, where two beams excite trapped $^{40}Ca^+$ ions near 397nm and one of them is formed as a vortex beam with topological charge $l = +1$. We report on the Raman spectra for a single ion to determine the impact on its electronic and motional excitation. We extend this study for the orbital angular momentum transfer to two-ions crystals.

[1]Stopp et al., Phys. Rev. Lett. 129, 263603 (2022)
[2]Verde et al., arXiv:2306.17571 (2023), accepted on Sci. Rep.

Q 52.4 Thu 15:30 HS 1221

Universal crosstalk of structured light in random media — •David Bachmann[1], Asher Klug[2], Mathieu Isoard[1,3], Vyacheslav Shatokhin[1], Giacomo Sorelli[1,4], Andreas Buchleitner[1], and Andrew Forbes[2] — [1]Physikalisches Institut der Albert-Ludwigs-Universität Freiburg — [2]University of the Witwatersrand, Johannesburg, South Africa — [3]Laboratoire Kastler Brossel, Paris, France — [4]Fraunhofer Institute for Optronics, Ettlingen, Germany

Structured light offers wider bandwidths and higher security for communication and strives to answer the growing demand of nonstationary links. However, propagation through complex random media, such as the Earth's atmosphere, typically induces crosstalk between spatial modes of light. We show numerically and experimentally that coupling of photonic orbital angular momentum (OAM) modes is governed by a universal function of a single parameter – the ratio between the random medium's and the beam's transverse correlation lengths, even in the regime of pronounced intensity fluctuations.

Q 52.5 Thu 15:45 HS 1221

Optimized generation of maximally entangled photon pairs in orbital angular momentum by simultaneous pump and crystal engineering — •Richard Bernecker[1,2], Baghdasar Baghdasaryan[2,3], and Stephan Fritzsche[1,2] — [1]Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743, Jena, Germany — [2]Helmholtz-Institut Jena, Fröbelstieg 3, 07743, Jena, Germany — [3]Institut für Angewandte Physik, Friedrich-Schiller-Universität Jena, Albert-Einstein-Str. 6, 07745, Jena, Germany

Photon pairs generated from spontaneous parametric down-conversion (SPDC) are the predominant method to realize photonic entanglement. Laguerre-Gaussian modes, which carry orbital angular momentum (OAM), are commonly exploited to encode high-dimensional states experimentally. In particular, maximally entangled states (MES) in dimensions $d > 2$ show promising features like improving the capacity and security of quantum communication protocols. However, the direct generation of MES in higher-dimensional subspaces of the OAM basis remains a challenging task in the SPDC process. The manipulation of entangled OAM states by shaping the spatial profile of the pump beam and the increase of the single-photon purity by customized crystal-domain configurations have been demonstrated lately. We combine these both approaches and show theoretically that simultaneous pump and crystal engineering enables the direct preparation of full MES within OAM subspaces of varying dimensions.

Q 52.6 Thu 16:00 HS 1221

Scalable Generation of Continuous Variable Multipartite Quantum Correlated States of Light — •Daida Thomas[1,2], Saesun Kim[1,2], and Alberto Marino[1,2,3,4] — [1]Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, OK, 73019, USA — [2]Center for Quantum Research and Technology, University of Oklahoma, Norman, OK, 73019, USA — [3]Quantum Information Science Section, Computational Sciences and Engineering Division, Oak Ridge National Laboratory, Oak Ridge, TN, 37831, USA — [4]Quantum Science Center, Oak Ridge National Laboratory, Oak Ridge, TN 37381, USA

Continuous variable (CV) entangled states of light serve as the foundation for a number of applications in quantum information science, such as quantum sensing, quantum computing, and quantum networking. To build a long distance multichannel quantum network or the resource states for CV quantum computing, multi-partite entangled states are needed. Here we report on the experimental scalable generation of CV multi-partite quantum correlated states. To this end, we leverage the multi-spatial mode properties of four wave mixing to implement a modified SU(1,1) interferometer that introduces quantum correlations between the different spatial modes. The expected quantum correlations involving conjugate variables are analyzed in terms of squeezing for all possible bipartitions. These results represent a first step toward the generation of multi-partite entangled states in connected graph states and show the expected connectivity of the graph.

Q 52.7 Thu 16:15 HS 1221

Image resolution of quantum imaging with undetected light

— •René Sondenheimer[1,2] and Marta Gilaberte Basset[2,3] — [1]Institute of Condensed Matter Theory and Optics, Friedrich-Schiller-University Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Albert-Einstein-Str. 7, 07745, Jena, Germany — [3]Institute of Applied Physics, Abbe Center of Photonics, Friedrich-Schiller-University Jena, Albert-Einstein-Str. 6, 07745, Jena, Germany

Image resolution of quantum imaging with undetected photons is governed by the spatial correlations existing between the photons of a photon pair that has been generated in a nonlinear process. These correlations allow for obtaining an image of an object with light that never interacted with that object. Depending on the imaging configuration, either position or momentum correlations can be exploited. We analyze how different source parameters affect the image resolution when using spatial correlations of photons that have been generated via spontaneous parametric down conversion in a nonlinear interferometer. In particular, we discuss the intricate dependency of the resolution on the strength of the correlations within the biphoton states.