TRR 142

Tailored Nonlinear Photonics

TRR Guest Scientist Lecture / Seminar

Date/Time: 30.09.2015 / 1pm
Location: UPB, lecture hall A1

Polina Sharapova

M.V. Lomonosov Moscow State University

Quantum correlations and entanglement in non-classic states of light and atomic systems interacting with them

Abstract:

Bright squeezed vacuum (BSV) is a macroscopic non-classical state of light that can be obtained via high-gain parametric down conversion (PDC) and having sufficiently high intensity values (near or above atomic one). Due to this state is characterized by very wide distribution over photon numbers one can consider nonclassical features of this state such as high degree of entanglement [1] and noise reduction below the standard quantum limit [2]. For these reasons there are many important applications of BSV such as quantum imaging [3], metrology [4] etc. Moreover, the wide photon number distribution of BSV provides rather high probability of high order multiphoton processes in the case of interaction with an atom. In such a situation, it is expected that all the strong-field effects found in the case of classical light will be expressed more clearly. One of those phenomena is stabilization [5], which consists in the suppression of ionization of an atom with growing laser field intensity above some critical value and can not be described by traditional theoretical approaches based on the perturbation theory.

The theoretical description of BSV as well as the atom-BSV interaction reveals certain difficulties. Unlike low-gain PDC, BSV generation cannot be described in the framework of the perturbation theory. The quantum state contains not only two-photon terms but also higher-order Fock components, and its calculation in the Schrodinger picture is difficult. In a high-gain regime it is much more convenient to find the time dependence of physical operators and calculate the observables in the Heisenberg picture. In this case the Schmidt-mode formalism used in the Schrodinger picture for the description of multimode two-photon light [6] is replaced by a similar procedure, called Bloch-Messiah reduction [7]. There are several papers describing BSV correlations in terms of so-called broad-bands modes [8,9]. However, the results mainly concern correlations in the frequency domain and can be obtained only numerically from the set of integro-differential equations.

Contact: Prof. Dr. Torsten Meier
Torsten.Meier@upb.de

UNIVERSITÄT PADERBORN
Die Universität der Informationsgesellschaft

technische universität dortmund

Also an important question is how the quantum features of BSV influence the atomic dynamics and what degree of correlations arising between atomic and field subsystems during the interaction. It’s worth noting, that the single photon states are also very promising objects for considering stabilization effect and high order quantum correlations simultaneously due to high efficiency of the atom-field interaction recently reported to be achieved [10,11]. As a result, the interaction of single photons and atoms can give rise to new phenomena observed in the case of classical light in the strong field regime only.
In our work, we present fully analytical description of the angular spectrum and correlations of BSV. The theoretical approach is based on the Bloch-Messiah reduction and allows one to obtain the analytical solution for the spatial evolution of the photon-creation operators for the collective Schmidt modes. Moreover we obtain the explicit analytical expression for the spatial dependence of the photon-creation operators in each angular mode for signal and idler beams and calculate analytically all the required correlation characteristics. The obtained theoretical results are compared with the experimental data of observed spatial correlations in BSV and are found to be in a good agreement. The physics of the found entanglement is explained in terms of collective Schmidt modes of the system.
Furthermore, we consider the interaction of a model Rydberg atom with BSV and single photon light analytically beyond any limitations on the field strength. We studied a rather realistic atomic system which includes several bound levels and continuum and allows to investigate both the field-induced ionization and excitation of the atom including the resonant coupling between the highly-excited and low-lying bound atomic states. The possibility of the stabilization phenomenon in the case of non-classical field, entanglement and quantum correlations arising between atomic and field subsystems are examined. The phenomenon of interference stabilization is found to be much more pronounced in the case of non-classical initial field state. The possibility to control the ionization suppression and the population of Rydberg and low-lying states is demonstrated. Methods to generate entangled states with maximal degree of entanglement are developed and the ways to measure the arising entanglement experimentally are suggested.

References:

1. T.Sh.Iskhakov, I.N.Agafonov, M.V.Chekhova, and G. Leuchs, PRL **109**, 150502 (2012).
2. I.N. Agafonov, M.V. Chekhova, and G. Leuchs, PRA **82**, 011801 (2010).
3. G. Brida, M. Genovese, and I. Ruo Berchera, Nature Photonics **4**, 227 (2010).
4. G. Brida, I.P. Degiovanni, M. Genovese, M.L. Rastello, and I. Ruo Berchera, Optics Express **18**, 20572 (2010).
5. M.V.Fedorov "Atomic and free electrons in a strong light field" World Scientific, 1997, 452
6. M.V. Fedorov, M.A. Efremov, A.E. Kazakov, K.W. Chan, C.K. Law, and J.H. Eberly, PRA **69**, 052117 (2004).
7. S.L. Braunstein, PRA **71**, 055801 (2005).
8. A.Christ, B.Brecht, W.Mauerer and Christine Silberhorn, New Journ. of Phys. **15**, 053038 (2013)
9. E. Brambilla, A.Gatti, M.Bache and L.A. Lugiato, Phys Rev A **69**, 023802 (2004)
10. M. Sondermann, R. Maiwald, H. Konermann et. al. Appl. Phys. B **89**, 489 (2007)
11. M.K. Tey, Z. Chen, S. Aljunid et. al. Nature Phys. **4**, 924 (2008)

Contact: Prof. Dr. Torsten Meier
Torsten.Meier@upb.de

UNIVERSITÄT PADERBORN
Die Universität der Informationsgesellschaft

technische universität dortmund