Theoretical Quantum Photonics and Spectroscopy Group

PhD, postdoctoral and senior research positions in theoretical quantum and nonlinear optics, photonics and spectroscopy.

Presently multiple hiring opportunities are for the following projects:

1. **Studies of complex systems with quantum light.**

Nonlinear optical signals are commonly calculated using a semiclassical approach that assumes a quantum system interacting with classical fields. This powerful approach is routinely used for the design and interpretation of multidimensional signals in molecules and semiconductor nanostructures. Quantum states of light provide an important tool for quantum information processing, secure communication, lithography. Classical light is fundamentally limited by the frequency-time uncertainty, whereas quantum light, e.g. entangled photons have independent temporal and spectral characteristics not subjected to this uncertainty. In addition low intensity requirements for multi-photon processes make them ideally suited for minimizing damage in imaging applications. Recently we developed techniques that make use of the quantum nature of the field in spectroscopic applications and allow to distinguish quantum pathways of matter. Modern quantum technologies use quantum fields but typically employ very simple models of matter (q bits). We developed a dagrammatic approach which can handle complex fields interacting with complex molecules. Unlike the semiclassical formalism that treats the signal mode macroscopically using Maxwell's equations, our approach allows for a fully microscopic calculation of the entire process.

Using above formalism we have developed a novel pulse delay scanning protocol based on loop diagrams for multidimensional spectroscopy with shaped entangled light, which provides high selectivity and background free measurement of the various resonances. We have further explored entangled photons as a tool for quantum control of exciton distributions and dynamics in complex biological molecules such as photosynthetic reaction center. We recently developed a microscopic theory for generation (via parametric down conversion (PDC)) and quantum control of entanglement for optical/information protocols that includes bath fluctuations. Finally we merged spectroscopy using entangled light with Hanbury-Brown-Twiss-inspired interferometry to significantly enhance the resolution and selectivity of Raman signals. The availability of entangled photon sources and ultrafast optical setups suggest that the spectroscopy with quantum light is an emerging field in physics, where theoretician can make a distinct contribution by predicting and simulating novel experiments.

K.E. Dorfman, F. Schlawin, and S. Mukamel, "Nonlinear optical signals and spectroscopy with quantum light", accepted to Review of Modern Physics, 88, 045008 (2016).

2. **Ultrafast studies of complex system using high harmonics generation**

The aim of the ultrafast studies is to monitor superposition of electronic and vibrational states. For electronic states few eV apart, an X-ray laser source would be required. We developed an alternative method based on the time-domain high-order harmonic spectroscopy. In our scheme, a coherent superpostion of the electronic states is first prepared by the strong optical laser pulse using a three-step mechanism introduced by Lewenstein and Corkum. Then the coherent dynamics can be probed by the higher order harmonics generated by the delayed probe pulse. The mean advantage of the method is that only optical (non X-ray) laser is needed. In addition, a semiperturbative model based on the Liouville space superoperator approach is developed to describe different orders of the nonlinear response for the high-order harmonic generation using multiple pulses. Coherence between bound electronic states can be observed in one-dimensional harmonic spectra from both the first and the second order responses.

K.E. Dorfman, P. Wei, J. Liu, and R. Li, “Quantum interference and collisional dynamics in excited bounds states revealed by time-resolved pump-High-Harmonic- Generation-probe spectroscopy”, Optics Express **27**, 7147 (2019).

3. Quantum thermodynamics of optical measurements

Quantum thermodynamics allows to investigate thermodynamics laws on a scale where quantum effects become important. System focused research provides a new insights on operation of so called quantum heat engines, such as lasers, solar cells, photosynthesis etc. which operate with quantum-enhanced efficiencies. Various models have been investigated in the context of quantum coherence and interference and other system-bath effects and their connection with efficiencies and power of the devices. We now apply this formalism to investigate various optical signals and optimize the information that can be achieved from such experiments. While nonlinear optical signals are typically measured with lasers we developed an alternative thermodynamical formalism of an effective thermal baths that can model laser-matter interaction. Effects of quantum nature of light, measurements, system-bath interactions will be investigated.

K.E. Dorfman, D. Xu, J. Cao, "Efficiency at maximum power of a laser quantum heat engine enhanced by noise-induced coherence", Phys. Rev. E, 97, 042120 (2018).
K.E. Dorfman, D.V. Voronine, S. Mukamel, and M.O. Scully “Photosynthetic reaction center as a quantum heat engine”, PNAS, 110, 2746 (2013).

4. Topological quantum metaphotonics

Flat light elements such as metasurfaces demonstrated its powerful nature in various engineering applications. The majority of optical elements such as lenses, mirrors, waveplates and polarizers can be now created using subwavelength arrays of nanopillars on a flat surfaces. While experimentally this research field is matured and various software packages allow to calculate optical responses of such systems with many applications, a simple intuitive formalism that connects experimental observables with microscopic models is missing. Our aim is to develop such formalism and turn the metadevices into a more general platform for manipulation of light-matter interaction. We predict novel effects such as quantum light generation and manipulation, topological phases, imaging and spectroscopy etc.

More details about research can be found here: http://faculty.ecnu.edu.cn/s/3628/t/36557/main.jspy

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