MON 16: Quantum Spectroscopy

Time: Monday 16:30–18:15 Location: ZHG004

MON 16.1 Mon 16:30 ZHG004

Two-photon excitation spectroscopy of high pressure xenon-noble gas mixtures — •Eric Boltersdorf, Thilo vom Hövel, Frank Vewinger, and Martin Weitz — Institut für Angewandte Physik, Bonn, Deutschland

When confined to a dye-filled optical microcavity, photons can exhibit Bose-Einstein condensation upon thermalization after repeated absorption and (re-)emission processes on the dye molecules. This has been experimentally demonstrated first in 2010.
In this work, an experimental approach is investigated to realize a Bose-Einstein condensate of vacuum-ultraviolet photons (100nm - 200nm) by absorption and (re-)emission cycles between xenon's $5p^6$ and $5p^5 6s$ (J = 1) state in dense xenon-noble gaseous ensembles. Here, we show the results of two-photon excitation spectroscopy to higher lying electronic states. We report on excitation spectra with excitation wavelengths ranging from 220nm to 260nm. The collected emission around 147nm is attributed to the decay of the $5p^5 6s$ (J = 1) state which is proposedly populated via collisional deactivation from the higher lying excited states. We show data for xenon-krypton as well as for xenon-helium mixtures.

MON 16.2 Mon 16:45 ZHG004

Sensitivity and Bandwidth Trade-Off in Rydberg Atom Sensors: A Superheterodyne-Homodyne Approach — •Dixith Manchaiah[1,2], Nikunjkumar Prajapati[1], and Christopher L Holloway[1] — [1]National Institute of Standards and Technology, Boulder, US — [2]University of Colorado, Boulder, US

Rydberg atom-based electric field sensors are emerging as powerful alternative to conventional antennas, offering high sensitivity and a broad frequency response. In this work, we explore the bandwidth and sensitivity of such sensors using Rydberg electromagnetically induced transparency (EIT) in rubidium vapor cell. The bandwidth of Rydberg sensors is typically limited by atomic transit time and the Rabi frequency of the coupling laser. While reducing beam size can increase bandwidth, it often leads to reduced signal strength and lower sensitivity.

To address this trade-off, we employ a radio frequency(RF) superheterodyne technique combined with optical homodyne detection. This approach allows us to optimize the relationship between bandwidth and sensitivity of the sensor. We further explore the effects of probe and coupling Rabi frequencies, and modulation schemes with different symbol rates and beatnote frequencies to understand the sensor performance. These findings demonstrate a practical path toward developing high bandwidth, high sensitivity Rydberg sensors suitable for applications in communication, radar, and metrology.

MON 16.3 Mon 17:00 ZHG004

Retrieving lost atomic information of an optical quantum system — •Laura Orphal-Kobin[1], Gregor Pieplow[1], Alok Gokhale[1], Kilian Unterguggenberger[1], and Tim Schröder[1,2] — [1]Department of Physics, Humboldt-Universität zu Berlin, Berlin, Germany — [2]Ferdinand-Braun-Institut, Berlin, Germany

The precise characterization of quantum systems is critical for exploring fundamental questions and for assessing their potential in quantum technologies. Many characterization methods and prospective quantum applications rely on the detection of single photons and are therefore often time-consuming and resource-intensive. In this work, we leverage statistical Monte Carlo simulations to retrieve information from undersampled experimental data [1].

We perform a photoluminescence excitation spectroscopy measurement to estimate the optical linewidth of a quantum emitter, here a single nitrogen-vacancy center in diamond. We emulate regimes of high and low photonic signals by adding a neutral density filter in the detection path of the setup. In a regime of weak signals, standard data analysis methods result in unphysically narrow linewidths. Using a Monte Carlo method, synthetic data is generated with different input parameters, here linewidth and detected photon number. The comparison of the simulations with experimental data sets allows to determine the system parameters with high accuracy even when the experimental data are undersampled. Therefore, the Monte Carlo method unlocks new experimental regimes in quantum optics.

[1] L. Orphal-Kobin et al., arXiv:2501.07951 (2025).

MON 16.4 Mon 17:15 ZHG004

Quantum interference effects in cathodoluminescence — •Hebrew Benhur Crispin and Nahid Talebi — Christian-Albrechts-Universität, Kiel, Germany

Free electrons have emerged as a versatile tool for investigating the quantum properties of light at a nanoscale level. Recent advances in electron microscopy have made it possible to observe quantum optical phenomena, such as photon antibunching and superbunching, through the excitation of quantum emitters by an electron beam. This has sparked significant interest in understanding photon statistics and electron-emitter interactions in cathodoluminescence. Previous studies have largely relied on classical models, focusing on electron excitations of two-level quantum systems only.

Here, we introduce a theoretical model for cathodoluminescence from a multi-level quantum emitter. We derive a quantum optical master equation for the system by treating the free-electron beam excitation as an incoherent, broadband pump driving the emitter. We demonstrate that the existence of numerous transition pathways can result in quantum interference effects that significantly modify both the emitter dynamics and the time-resolved cathodoluminescence spectra. We demonstrate that the excitation rate, initial coherence and energy spacing between excited states are crucial parameters determining the influence of interference. Our work sheds light on free-electron-induced quantum interference in cathodoluminescence emission, providing a general framework with which to investigate quantum optical effects in the electron-beam excitation of multi-level quantum emitters.

MON 16.5 Mon 17:30 ZHG004

Attosecond pulse generation in laser-assisted radiative recombination — •Katarzyna Krajewska[1], Deeksha Kanti[1], Jerzy Z. Kaminski[1], and Liang-You Peng[2] — [1]University of Warsaw, Warsaw, Poland — [2]Peking University, Beijing, China

Electron-ion radiative recombination in the presence of a bicircular laser pulse is analyzed beyond the dipole approximation [1]. A bicircular pulse consists of two counter-rotating circularly polarized laser pulses with commensurate carrier frequencies. It is demonstrated that the broad bandwidth radiation can be generated in the process and that its spectrum can be significantly enhanced by tailoring the laser field [2]. A special emphasis is put on analyzing temporal properties of generated radiation, which is released as either an isolated attosecond pulse or an attosecond pulse train.

References
[1] D. Kanti et al., Phys. Rev. A 110, 043112 (2024).
[2] D. Kanti et al., Photonics 12, 320 (2025).

MON 16.6 Mon 17:45 ZHG004

Nondipole effects in multiphoton ionization — •Katarzyna Krajewska and Jerzy Z. Kaminski — University of Warsaw, Warsaw, Poland

We study nondipole effects in multiphoton ionization of a two-dimensional hydrogen-like atom by a flat-top laser pulse. To this end, we solve numerically the Schrodinger equation treating a propagating laser pulse exactly in the entire interaction region [1]. We demonstrate a directional dependence of the energy-angular photoelectron distributions for propagating laser pulses of moderate and high intensities. It is analytically interpreted based on the leading order relativistic expansion of the electron Volkov state, showing a significant contribution of the electron recoil to that behavior. In contrast, the retardation correction originating from the space- and time-dependence of the laser field leads to a tiny redshift of the photoelectron energy spectra. Other features of ionization distributions are also analyzed, including the sidelobes and the double-hump structures of multiphoton peaks, or their disappearance for intense propagating laser pulses [2].

References
[1] M. C. Suster et al., Phys. Rev. A 107, 053112 (2023).
[2] K. Krajewska, J. Z. Kaminski, Phys. Rev. A (submitted) (2025).

MON 16.7 Mon 18:00 ZHG004

Control of laser-assisted radiative recombination beyond the dipole approximation — Deeksha Kanti[1], •Mateusz Majczak[1], Jerzy Kamiński[1], Liang-You Peng[2], and Katarzyna Krajewska[1] — [1]Institute of Theoretical Physics, Faculty of Physics, University of Warsaw, Warsaw, 02-093, Poland — [2]State Key Laboratory for Mesoscopic Physics and Frontiers Science Center for Nano-optoelectronics, School of Physics, Peking University, Beijing, 100871, China

We present a comprehensive theoretical description of laser-assisted radiative recombination (LARR) in the presence of short laser pulses, that accounts for nondipole corrections of the leading order in $1/c$. They are derived systematically by the relativistic reduction, enabling us to follow the origin of various nondipole contributions. As it follows from our numerical analysis, the most important of them originates from the electron recoil off the laser pulse. We recognize that it results in extension of the LARR high-energy plateau and is a cause of an asymmetry of energy distributions of generated radiation with respect to the polar angle of the recombining electron. As we show, the remaining nondipole corrections of the leading order in $1/c$ turn out to be less significant.

In addition, we analyze ways to control the LARR radiation using external laser pulses. Despite the aforementioned nondipole effects which arise entirely from the presence of the laser field, we investigate the possibility of manipulating the intensity of the cutoff portion of LARR by chirping the accompanying laser pulse.