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Wave packet retrieval by multi-photon quantum beat spectroscopy in helium

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Synopsis We show that we can probe the components of an attosecond bound electron wave packet by mapping the quantum beat signal produced by a synchronized delayed few-cycle infrared pulse into the continuum. In addition, spectrally overlapping peaks that result from one-, two- or three-photon processes from more or less deeply bound states can in principle be interferometrically resolved with high resolution.

Attosecond pulses interacting with atoms or molecules create a broad band electron wave packet (EWP). In order to capture and ultimately control the localized electron motion, it is necessary to be able to reconstruct the excited bound states and their initial coherence. A delayed synchronized few-cycle infrared (IR) probe pulse that ionizes the excited bound states can be used as either a which-way interferometer or a quantum beat spectrometer. Such an interferometric pump-probe technique has been shown to be able to determine the bound wave packet components excited by an attosecond pulse around threshold for helium [1].

In this contribution, we propose a similar setup for measuring quantum beats separately from which-way interferences by initially exciting only a purely bound wave packet of $1snp$-states in helium by using a shaped attosecond pulse. In Fig. 1 we show a simulated spectrogram as a function of delay between attosecond and IR pulses (left) and the spectrally resolved beating thereof (right). The spectral analysis shows with high resolution the energy differences between different bound states as long as the temporal beating signal can be resolved by the delay steps. The vertical width is determined by the spectral overlap of different contributions, while the horizontal width results from the length of the time series. The high frequency beatings result from the interference between $1s2p + 3\gamma_{\mathrm{IR}}$ and $1snp + \gamma_{\mathrm{IR}}$ $(n > 3)$. Processes involving a different number of photons can be parity selected by either looking along a certain direction or at angle-integrated spectra.

While the beat frequencies in the Fourier analyzed signal are unambiguously given by the energy difference of the involved bound states no matter how many photons were involved in the ionization process, phase information of the initial wave packet is encoded in the absolute phase of the Fourier signal [2]. Analyzing the phase of the beat signals allows us in principle to distinguish the phase difference between one, two, and three photon ionization processes. In addition to the initial phases of the bound states also a possible phase difference of the ionization step is included. The latter is small for contributions from a one-photon process, however, two- or three-photon processes acquire a more complicated phase depending on the length and intensity of the IR pulse.

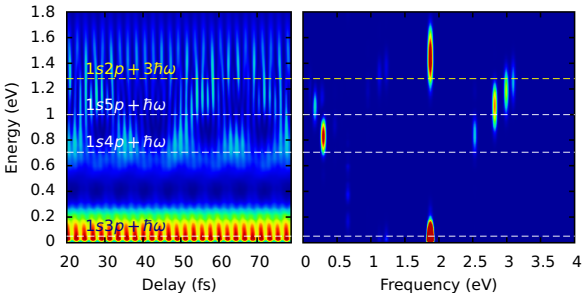

Figure 1. Simulated spectrogram as a function of XUV and IR delay along the polarization axis for collinear pulses (left) and Fourier transform of the time signal at each energy (right).

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