The Robustness of Attosecond Streaking Measurements

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Synopsis We investigate the robustness of one of the key tools of attosecond metrology: the attosecond streak camera. We consider the case of single and double attosecond pulses. For several key parameters of the electron wave packet, we systematically investigate how each one's uncertainty affects the spectrogram and the accuracy of the attosecond FROG retrieval.

Current models used to describe attosecond streaking measurements [1, 2], and the analysis techniques that are thence derived [3, 4], ignore the experimental fact that the recorded spectrogram actually results from a statistical ensemble of electron wave packets. This statistical ensemble might result from changes in the waveform of the laser field which is used both for generating and streaking, and can occur either from shot to shot or over the spatial profile. Certain streaking measurements may contain uncertainties that cannot be decoupled from the experiment. For example, when streaking is performed on electrons ejected from a conduction band, an inherent uncertainty in the electrons' central energy is present in the recorded spectra.

In this work, we address the issue of uncertainties in streaking measurements by identifying several key properties of an electron wave packet, and looking at how an uncertainty in each of them affects the streaking spectrogram and the resulting attosecond FROG reconstruction. We consider spectrograms for two types of electron wave packets: a single isolated pulse, and a sequence of two pulses separated by a laser half-cycle. The former is an ideal case of attosecond metrology, where a perfect gating mechanism has denied the contribution of all but one laser half-cycle. The latter is a more realistic case: due to the periodicity of the generating laser field, attosecond pulses are typically produced from two or more laser half-cycle. Even cutting edge gating techniques such as DOG [5], dynamic phase-matching [6] or the use of very short generating fields of $\approx 3.3\,\mathrm{fs}$ [7] still allow at least two half-cycles to contribute to the harmonic generation.

For an isolated pulse, we study uncertainties in the central energy, group-delay dispersion (GDD) and bandwidth of the electron wave packet. We find that the central energy uncertainty plays the largest role in smearing the spectrogram, resulting in an underestimated pulse duration, whereas uncertainties in the GDD and bandwidth have a minor effect.

For a sequence of two pulses, the spectrogram displays a fringe pattern resulting from the interference between the two pulses. For this case, we consider uncertainties in the relative phase, relative timing and relative intensity between the two pulses. These quantities each have their own foot print on the fringe pattern in the spectrogram. We show that the main effect of these uncertainties is a smearing of the fringe pattern, which curtails the accurate characterization of the satellite pulse (the smaller of the two pulses). However, we find that the main pulse is nevertheless correctly retrieved.

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