High Harmonic Generation: The Route Towards Bright Sources in the Soft X-Ray Spectral Range

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With the process of High Harmonic Generation (HHG) in gases, the wavelength of a femtosecond (1 fs = 10^{-15} s) driving laser (from the UV to the mid-IR) can be up-converted to generate fully coherent, ultrashort pulses with spectra spanning through the extreme ultraviolet (XUV) and even into the soft X-rays. Not only can the emitted XUV pulses have durations in the order of attoseconds (1 as = 10^{-18} s), but they are also synchronized with the electric field of the driving laser within a very small fraction of the period of its carrier wavelength. Over the past 20 years, this has allowed researchers to perform experiments with temporal resolution on the order of a few attoseconds, *i.e.*, a very small fraction of the typical optical period of the driver (*e.g.*, 2.7 fs). The Nobel Prize in Physics 2023 was awarded for the experimental methods for the generation and characterization of attosecond pulses of light.

However, the main limitation of HHG is the extremely low efficiency of conversion, leading to low photon flux, especially at higher photon energies – in the hundreds of electronvolts, or few nanometer wavelengths. Significant effort is being put into the generation of soft X-ray pulses with both extended spectral range and increased photon flux. Several solutions, based on driving pulses with either longer (mid-IR) or shorter (VIS, UV) wavelengths, or even by finely shaping the electric field of the driver, have been thoroughly investigated both theoretically and experimentally.

In the perspective of power-scaling HHG sources with extended spectral range, it is important to consider not only how the parameters of the driving pulse affect the HHG conversion process, but also how, and how efficiently, the driving pulses can be obtained – usually by frequency-shifting and nonlinear post-compression techniques applied to different laser sources.