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Multi-scale modelling of HHG and its applications

J. Vábek,^{1,2,3,*} O. Finke,^{1,2} K. Veyrinas,³ C. Valentin,³ T. Němec,^{1,2,3} D. Descamps,³ M. Nevřkła,¹ C. Péjot,³ N. Bobrova,² F. Burgy,³ M. Jurkovič,^{1,2} M. Albrecht,^{1,2} A. Jančárek,^{1,2} E. Constant,⁴ O. Hort,¹ E. Mével,³ J. Limpouch,² S. Skupin,⁴ J. Nejdł,^{1,2} F. Catoire,³

¹ELI Beamlines Centre, FZU- Institute of Physics of the Czech Academy of Sciences, Na Slovance 2, 182 21 Prague, Czechia

²Czech Technical University in Prague, FNSPE, Břehová 7, 115 19 Prague 1, Czechia

³Centre des Lasers Intenses et Applications, Université de Bordeaux-CNRS-CEA, 33405 Talence Cedex, France

⁴Institut Lumière Matière, UMR 5306 Université Lyon 1 - CNRS, Université de Lyon, 69622 Villeurbanne, France

*Jan.Vabek@eli-beams.eu

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Abstract: High-harmonic generation (HHG) in gaseous media is a workhorse tool in attosecond science. Its description originates from the microscopic scale of a single atom or molecule interacting with a driving IR-laser pulse. However, its practical realization usually employs a macroscopic volume of the gas. The macroscopic aspect aggregates all the microscopic emitters and brings novel physical mechanisms that drive the generation. One of the key mechanisms within the macroscopic scale is the shaping of the driving pulse due to the non-linear response of the medium.

We present a comprehensive numerical model describing and coupling the physics on both scales. The model consists of different modules that provide different levels of approximation to choose an optimal trade-off between accuracy and computational cost. We then use it to address two generation schemes, where we provide a detailed picture together with experimental realizations. The first scheme uses a long medium homogeneously pre-ionized by an electrical discharge to optimize the phase-matching of the harmonic signal. This scheme allows, in particular, for optimizing HHG in long media where the control is difficult because the driving pulse undergoes strong re-shaping and defocusing due to the non-linear response after the entrance to the medium. The second scheme introduces a mechanism to control the divergence of the harmonic beam in thin targets. The divergence is driven by shaping the wavefront of the driving pulse. This allows for spectrally selective focusing of the harmonic beams without the use of optics, which leads to inevitable losses in the XUV region.

Summary: We present a numerical model to describe HHG. The microscopic scale is described by computationally cheap strong field approximation and/or a numerical solution of 1D time-dependent Schrödinger equation. The macroscopic propagation of the driving pulse is based on the numerical solution of the non-linear Schrödinger equation including nonlinearities such as ionization and the Kerr effect. The multi-scale model links the two scales and compares the possible different microscopic models. The model is then a part of joint work with experimentalists, where we together present two generation schemes to i) optimize the phase-matching in pre-ionized long media; ii) focus the harmonic beams generated in thin targets.