Comment on “Universality of Returning Electron Wave Packet in High-Order Harmonic Generation with Midinfrared Laser Pulses”

M. V. Frolov, N. L. Manakov, Wei-Hao Xiong, Liang-You Peng, J. Burgdörfer, and Anthony F. Starace

Phys. Rev. Lett. **114**, 069301 — Published 9 February 2015

DOI: 10.1103/PhysRevLett.114.069301

Comment on "Universality of Returning Electron Wave Packet in High-Order Harmonic Generation with Midinfrared Laser Pulses"

In Ref. [1], Le *et al.* establish in the long wavelength limit a universal shape for the returning electron wave packet in high-order harmonic generation (HHG) as a function of the returning electron's energy. Based on this approach, Le *et al.* suggest a universal wavelength scaling law, $\propto \lambda^{-4.2}$, for the HHG yield for laser wavelengths in the range $3\,\mu\text{m} \leq \lambda \leq 6\,\mu\text{m}$. This scaling law differs from the faster decrease of the HHG yield with increasing λ, $\propto \lambda^{-(5-6)}$, predicted earlier [2–5]. Le *et al.* attribute this difference to the limited interval of wavelengths ($\lambda \leqslant 2\,\mu$m) used to solve the time-dependent Schrödinger equation (TDSE) in Refs. [2, 3, 5]. Since the HHG yield is a fundamental quantity for practical applications, any new scaling law for $\lambda \gtrsim 3\,\mu$m must be clearly justified owing to its importance for planning experiments involving the generation of XUV radiation by means of HHG using long-wavelength lasers.

The apparent disagreement stems from the use in Ref. [1] of a different definition of the harmonic yield $\Delta\mathcal{Y}$ from that used in Refs. [2–5]. As noted in Ref. [5], the λ-scaling law depends on the precise definition of $\Delta\mathcal{Y}$. In Ref. [2], the authors study "the scaling of an average harmonic yield, obtained by integrating the power spectrum over a fixed bandwidth." (They integrate the HHG power spectrum over harmonic energy intervals of 40–80 eV for He and 20–50 eV for Ar.) In Ref. [4] the definition of harmonic yield from Ref. [2] was adopted for a monochromatic field, defining the yield $\Delta\mathcal{Y}$ in terms of the HHG power. For a short pulse laser field, in Refs. [3, 5] a definition of the HHG yield compatible with that in Ref. [2] is used, i.e., $\Delta\mathcal{Y}$ is defined as the energy radiated per unit time by the target atom (subjected to a laser pulse of duration $\mathcal{T}$) into a fixed harmonic energy range $[\Omega_1, \Omega_2]$,

$$\Delta\mathcal{Y} = \frac{1}{\mathcal{T}} \int_{\Omega_1}^{\Omega_2} \rho(\Omega) d\Omega, \tag{1}$$

where $\rho(\Omega)$ is the spectral density of harmonics with energy Ω. [Although Ref. [3] properly defines the HHG yield in words, the factor $1/\mathcal{T}$ was inadvertently omitted in Eq. (2) of Ref. [3]; this omission was corrected in Eq. (3) of Ref. [5].] Since the laser pulse has a fixed number N of optical cycles, $\mathcal{T}$ scales linearly with λ. Inserting the recolliding wave packet results of Ref. [1] into Eq. (1), the scaling $\Delta\mathcal{Y} \propto \lambda^{-5.2}$ found in Refs. [2–5] is confirmed.

In conclusion, we have shown that when the same definition for the HHG yield is used [cf. Eq. (1)], the results of Ref. [1] give the same scaling law found earlier in Refs. [2–5] for wavelengths $\lambda \leq 2\,\mu$m. We note that this latter scaling law can be obtained analytically using results of the model developed in Ref. [6] for the description of short-pulse HHG spectra. These analytic results as well as new numerical TDSE results for longer wavelengths, $\lambda \leq 4\,\mu$m, will be published elsewhere.

This work was supported in part by NSF Grant PHY-1125915, RFBR Grant 13-02-00420, RF Ministry of Education & Science Project 1019, NSF Grant PHY-1208059, NNSFC Grant Nos. 11322437 and 11121091, Program 973 No. 2013CB922402, SFB-NEXTLITE (FWF, Austria), and the Dynasty Foundation (M.V.F.).

M. V. Frolov,[1,2] N. L. Manakov,[1] Wei-Hao Xiong,[3] Liang-You Peng,[3,4,2] J. Burgdörfer[5,2] and Anthony F. Starace[6,2]

[1]Department of Physics, Voronezh State University, Voronezh 394006, Russia

[2]Kavli Institute for Theoretical Physics, University of California Santa Barbara, California 93106-4030, USA

[3]State Key Laboratory for Mesoscopic Physics and Department of Physics, Peking University, Beijing 100871, China

[4]Collaborative Innovation Center of Quantum Matter, Beijing, China

[5]Institute for Theoretical Physics, Vienna University of Technology Wiedner Hauptstraße 8-10, A-1040 Vienna, Austria, EU

[6]Department of Physics and Astronomy, The University of Nebraska Lincoln, Nebraska 68588-0299, USA

PACS numbers: 33.80. Eh, 42.65. Ky

[1] Anh-Thu Le, Hui Wei, Cheng Jin, Vu Ngoc Tuoc, Toru Morishita, and C. D. Lin, Phys. Rev. Lett. **113**, 033001 (2014).

[2] J. Tate, T. Auguste, H. G. Muller, P. Salières, P. Agostini, and L. F. DiMauro, Phys. Rev. Lett. **98**, 013901 (2007).

[3] K. Schiessl, K. L. Ishikawa, E. Persson, and J. Burgdörfer, Phys. Rev. Lett. **99**, 253903 (2007).

[4] M. V. Frolov, N. L. Manakov, and A. F. Starace, Phys. Rev. Lett. **100**, 173001 (2008).

[5] K. L. Ishikawa, K. Schiessl, E. Persson, and J. Burgdörfer Phys. Rev. A **79**, 033411 (2009).

[6] M. V. Frolov, N. L. Manakov, A. M. Popov, O. V. Tikhonova, E. A. Volkova, A. A. Silaev, N. V. Vvedenskii, and A. F. Starace, Phys. Rev. A **85**, 033416 (2012).