Comment on ”Transition to the Relativistic Regime in High Order Harmonic Generation”

F. Quéré, Cédric Thaury, J-P. Geindre, Ph. Martin

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In [1], Tarasevitch *et al.* demonstrate the existence of two generation mechanisms for laser high-order harmonics from overdense plasmas. One of these mechanisms leads to harmonics with frequencies up to the maximum plasma frequency ω_p of the target and occurs even at nonrelativistic laser intensities. We show that the mechanism responsible for these harmonics is coherent wake emission (CWE) [2,3], a process that significantly differs from the qualitative model proposed by these authors, and it leads to a different interpretation of several essential features of this emission.

Figure 1 shows the result of a particle-in-cell (PIC) simulation, where a p-polarized laser field, with a normalized vector potential $a_0 = 0.2$, impinges an overdense plasma with an incidence angle of 45°. Ions are assumed to be fixed, and an exponential density gradient of scale length $L = 0.02\lambda$ is imposed at the surface. This figure reveals the main features of CWE. High-frequency plasma oscillations (PO's) are impulsively excited in the highly overdense part of the plasma, once every optical cycle, in the wake of ultrashort energetic electron bunches created by the laser field around the critical density n_c. These PO's emit extreme ultraviolet light through linear mode conversion, in the form of one chirped attosecond pulse once every optical cycle, thus resulting in a spectrum consisting of harmonics of the laser field.

The authors of [1] state that this harmonic emission occurs when electrons that "are pushed back and forth in the gradient of charge density" have an oscillation amplitude s_0 comparable to the gradient scale length L, resulting in a "motion that is strongly anharmonic". On the contrary, the CWE model, clearly supported by PIC simulations, shows that in this regime the anharmonicity of the plasma surface motion is irrelevant. PO's observed on Fig. 1 are linear, and the intensity of the emitted harmonics scales almost linearly with the laser intensity (Fig. 1 in [2]).

CWE provides a direct interpretation of the sharp cutoffs observed at ω_p both on simulated and experimental harmonic spectra [1–3], independently of the laser intensity (below the relativistic regime), since in this mechanism the maximum harmonic frequency is determined by the maximum plasma density. This is not the case of the model proposed in [1], which, according to Eq. (14) of [4], would lead to an emission that tends to 0 only when $\omega \gg \omega_p$, i.e., to a smooth roll-off beyond ω_p. This roll-off should moreover strongly depend on the parameter s_0/L, and hence on the laser intensity.

Tarasevitch *et al.* show that this harmonic emission decreases when the gradient scale length gets too long. Their interpretation is that for long gradients, the laser field

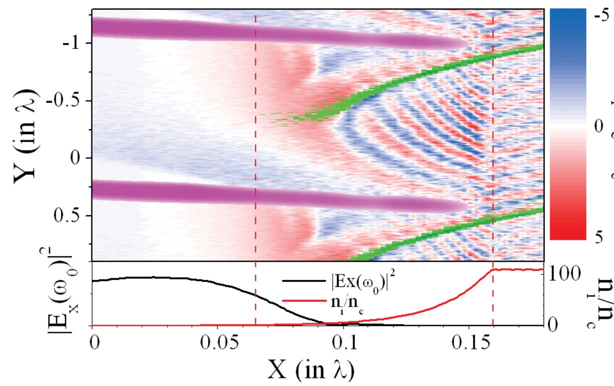

FIG. 1 (color). PIC simulation of coherent wake emission. The upper panel shows the total charge density (blue to red scale) $n_i - n_e$, the energetic ($p_x > 0.15mc$) electron density (green scale), and the electromagnetic field frequency-filtered from harmonics 4 to 10 (purple scale). The lower panel shows $|E_x(\omega_L)|^2$ (ω_L being the laser frequency) in black, and the ion density profile in red. The dashed lines indicate the positions of n_c and $110n_c$.

fails to "penetrate far enough into the plasma". Figure 1 (lower panel) shows that even when this emission does occur, the laser field does not penetrate the density gradient beyond a few n_c, and is hence absolutely negligible in the area where the harmonics are emitted, thus ruling out this interpretation. In CWE, in analogy with resonant absorption of laser light, each harmonic frequency $p\omega_L$ forms an evanescent wave between its point of generation, at $n = p^2 n_c$, and $n = p^2 n_c \cos^2\theta$ (θ being the laser angle of incidence), where it becomes a progressive wave and escapes the plasma. Since the distance between these two points increases with the gradient scale length, this accounts for the decrease in efficiency for long density gradients.

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