High order harmonic beams emitted from plasma gratings

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When focusing an ultra-intense femtosecond laser pulse ($I>10^{16}W/cm^2$) onto a solid target, it is ionized at the very beginning of the laser pulse. The resulting dense plasma specularly reflects the laser: this is a plasma mirror. The nonlinear response of the plasma to the ultra-intense laser field results in the generation of trains of attosecond pulses associated, in the frequency domain, to high-order harmonics of the laser frequency.
Two main HHG processes on plasma mirrors have been observed for different interaction conditions. At moderate laser intensities ($I<10^{18}W/cm^2$), Brunel electrons, accelerated into the target, excites plasma oscillations in the high density plasma gradient, which radiate at the local plasma frequency. It is the Coherent Wake Emission (CWE) process. At ultra-high intensity ($I>10^{18}W/cm^2$), the electron density oscillates normally to the target with a relativistic velocity. It periodically distorts the reflected field by a Doppler effect: this is the Relativistic Oscillating Mirror (ROM) process.
These two processes carry rich information on the laser-plasma interaction. For instance, the spatial curvature of each emitted attosecond pulse directly results from the interaction properties: the spatial curvature either of the plasma oscillations or of the plasma surface under radiation pressure.

However, measuring the spatial curvature of the harmonic source is very challenging as the detection occurs at macroscopic distances from target. To circumvent this issue, a coherent diffraction imaging technique, named ptychography, was adapted to this system. It consists in measuring the angular profile of a probe beam diffracted out on an object for different relative positions of one to the other. This technique was transposed to HHG on plasma mirrors by spatially microstructuring the target with an ionizing pre-pulse, typically a few picoseconds before the main pulse which drives HHG [1]. Harmonic fields in the target plane are then reconstructed spatially in amplitude and phase [2].
This new method is used to study of the harmonic spatial properties in different interaction conditions. Thanks to a parametric study, previously developed analytical models of the interaction in the non-relativistic and relativistic regimes are experimentally validated [3]. Its accuracy is also used to test different numerical schemes of Maxwell's equations solvers in PIC simulations.

[1] *Optically controlled solid-density transient plasma gratings*, Monchocé et al, Phys. Rev. Lett. 112 (2014).
[2] *Ptychographic measurements of ultrahigh-intensity laser-plasma interactions*, Leblanc et al, Nat. Phys. 12 301 (2016).
[3] *Spatial properties of high-order harmonic beams from plasma mirrors: a ptychographic study*, Leblanc et al, Phys. Rev. Lett. 119 (2017).