Phase space perspective on the coherent buildup of high harmonic radiation

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When an intense low-frequency laser pulse propagates through an atomic gas, the microscopic nonlinear interaction between the atoms and the laser field produces radiation at high harmonic frequencies of the incident light, possibly reaching thousands of times the incident frequency [1]. Under the right conditions, this microscopic radiation emitted throughout the gas can coalesce into coherent, macroscopic pulses of high-frequency light which co-propagate with the incident pulse. This process is known as high harmonic generation (HHG). On a single-atom level, the sources of the high harmonic radiation are repeated collisions between tunnel-ionized electrons and their parent ions driven by the oscillating electric field of the laser, a process known as recollision [2]. On a macroscopic level, the coherent buildup of the high-frequency radiation generated by individual atoms depends sensitively on the details of the propagation of the laser pulse, which can be substantially reshaped by the radiation emitted by the ionizing atoms [3]. Indeed, accurate modeling of HHG requires a description of the self-consistent interaction between the atoms and the laser during propagation through the gas.

Here, we consider a one-dimensional classical model of the self-consistent atom-laser interaction for HHG [4]. In our model, a linearly polarized laser pulse propagating in the z direction is represented by the time-dependent electric field $\mathcal{E}(\tau, z)$, where τ is the time relative to the arrival of the pulse to a given point along the gas z. Its evolution equation is given by

$$\frac{\partial \mathcal{E}}{\partial z} = \frac{2\pi\rho}{c}\langle v(\tau, z)\rangle, \tag{1}$$

where ρ is the gas density and c is the speed of light. The source term for the field is the ensemble-averaged velocity of an atom's ionized electron, $\langle v(\tau, z)\rangle = \int v f(x, v, \tau; z)\mathrm{d}x\mathrm{d}v$. The phase space probability distribution function f satisfies at every z the Liouville equation given by

$$\frac{\partial f}{\partial \tau} = -v\frac{\partial f}{\partial x} + \left(\frac{\partial V}{\partial x} + \mathcal{E}(\tau, z)\right)\frac{\partial f}{\partial v}, \tag{2}$$

where $V(x)$ is an effective potential describing the electron-ion interaction. Numerical simulations of the classical model capture the coupled evolution of the electron dynamics and the laser field during propagation. By visualizing f in phase space at different points along the propagation, we are able to identify the creation of both a family of trapped trajectories and a family of recolliding trajectories that explain the coherent buildup of specific high harmonic frequencies of the field observed in the corresponding quantum calculation.

Références

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