Semi-analytical model for electron layer dynamics and gamma-ray emission at ultrahigh intensity laser-solid interaction

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Abstract

When a relativistically intense linearly polarized few-cycle laser pulse is incident on an overdense plasma, a dense electron layer may be formed on the plasma edge. Nonlinear motion of the layer is crucial for a number of phenomena, such as high order harmonic generation and ion acceleration. Analytical model that describes the edge motion is presented and applied to the problem of incoherent synchrotron emission by ultrarelativistic plasma electrons. The analytical results are verified with 3D PIC-MC code.

Hard X-rays and gamma-rays have become widely applied since their discovery. Nowadays gamma-ray sources are numerous, and most of them are based on radioactive decay, bremsstrahlung, and backward Compton scattering. Earlier estimations show that a large fraction of the laser pulse energy may be transformed into gamma-ray energy during laser-plasma interaction if laser intensity is high enough, e.g. persents for $I>10^{22}$ W cm^{-2} [1] and tens of persents for $I>10^{24}$ W cm^{-2} [2]. These makes such gamma-ray sources very promising in comparison with sources based on linear Compton scattering which provide lower conversion efficiency.

In order to describe electron layer dynamics and hard photon emission, we assumes, first, that under light pressure electrons of the irradiated plasma edge form a very thin layer which moves so that it always separate vacuum and unperturbed plasma. Second, considering normal incidence of linearly polarized laser pulses, we assume that the layer electrons moves in the polarization plane. Third, we suppose that the dispersion of individual electron characteristics inside the layer does not affect hard photon emission drastically, and just results in a smooth of the radiation pattern, photon spectrum, etc. In the scope of this model, ion motion is also neglected.

The total force driving electrons in the layer consists of the following parts: force caused by the incident laser field, force from self-generated electromagnetic fields (i.e. fields coherently emitted by the layer), force caused by electron-ion separation and the radiation reaction force. The equations can be formulated as follows [1]

$$\frac{dp_x}{dt}=\frac{-n_0 x_l}{2}\left(1+\frac{v_x v_y^2}{1-v_x^2}\right)-v_y E_{ly}+F_{rx}, \qquad (1)$$

$$\frac{dp_y}{dt}=\frac{-n_0 x_l v_y}{2}-(1-v_x) E_{ly}+F_{ry}, \qquad (2)$$

where $\boldsymbol{p}$, $\boldsymbol{v}$, x_l are the momentum, the velocity and the position of the electron layer, n_0 is the initial electron density, E_l is the strength of the laser field, F_r is the radiation reaction force.

The comparison of the model predictions and the results of PIC-MC simulations is shown in Fig. 1. It follows from Fig. 1 that the layer dynamics and the radiation pattern predicted by the model are in good agreement with numerical results.

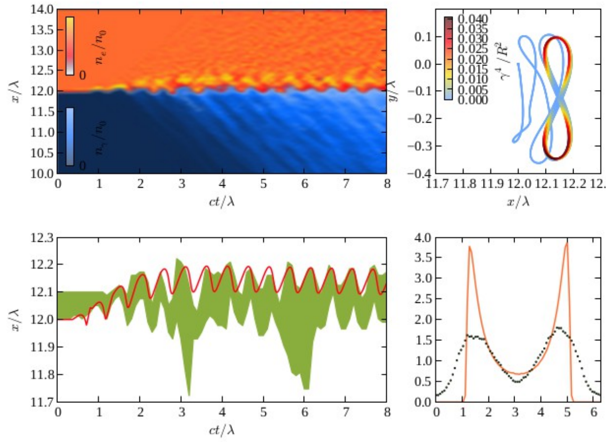

Fig. 1. (a) On-axis electron and photon densities obtained in PIC for a_0 = 220 and n_0 = 315. (b) The layer trajectory for the same parameters obtained from Eqs. (1)-(2). (c) Analytical trajectory (red) and x_l for Δ = 0.01λ (lower boundary) and Δ = 0.1λ (upper boundary). (d) Radiation pattern for theory (solid) and PIC (dotted).

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References

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