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Radiation generation in clusters

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Abstract. The generation of radiation through the interaction of ultraintense ultrashort laser pulses with clusters is explored in PIC simulations. Configurations with periodic arrangements of clusters are used to obtain a better radiation-to-noise ratio. Analysis of the dispersion relation of the generated radiation suggests the possibility of enhancing the low frequency radiation components in the interaction of an ultraintense ultrashort laser pulse with an array of clusters.

1. INTRODUCTION

Recent studies in laser-cluster interaction have focused on harmonic generation in different schemes [1]. These works have mainly been concerned with the nonrelativistic regime of the laser-cluster interaction. Here, the possibility of generation of radiation in the interaction of ultrashort ultraintense lasers with clusters is explored using PIC simulations. The analysis of the radiation spectra present in the simulations reveals that low-frequency radiation is emitted. Scenarios with periodic arrays of clusters are also analyzed.

2. INTERACTION WITH A SINGLE CLUSTER

For sufficiently high intensities the laser field sweeps off all the electrons from the cluster. At these high intensities there is also a significant ponderomotive displacement [2] of the electrons in addition to their oscillations in the laser field. Both these features can be seen in the 2D PIC simulations performed with OSIRIS 2.0 [3]. Here, some results are presented from the simulation of the interaction of a Gaussian 800 nm wavelength laser pulse (polarized in the x2 direction) with pulse duration at FWHM of 8 fs (3 laser cycles) and a normalized peak vector potential $a_0 = 5$, with a 20 nm radius Deuterium cluster (modeled as a neutral pre-formed plasma). The simulation box is a square 1024x1024 cells box with a side length of 7 μm and 16^2 particles/species/cell. Periodic boundary conditions are used in the x2 direction and Lindmann open boundary conditions in the x1 direction. A moving window is used in the x1 direction.

The radiation emitted can be seen from the comparison of a frequency-wavenumber plot (Fig.1) with the numerical dispersion relation of electromagnetic waves in PIC codes [4]. This diagnostic is calculated based on power spectrum techniques [5] and gives information on all the wavenumbers present in the simulation box during the interval studied (in this case 29 fs, corresponding to a distance of propagation over the simulation-box length). It is found that radiation in the negative direction of the x2 axis (polarization direction) is emitted continuously within a bandwidth with a cutoff at approximately $2\omega_p$. In the laser propagation direction, there is no clear evidence of radiation emitted in this frequency band (Fig.2). This does not mean that there is no radiation generation in the x1 direction since the use of a moving window (in x1 direction) makes electromagnetic waves propagating in the longitudinal direction appear slower, or static, in the case of light waves in vacuum. The latter waves

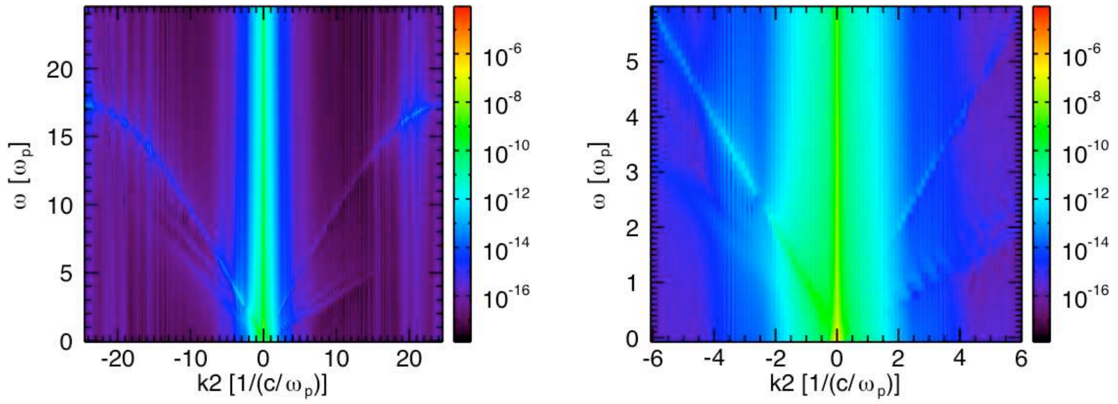

Figure 1: Frequency-wavenumber distribution in x2 direction of waves present in the simulation box (color represents the square of the field amplitude). Several points can be seen along the electromagnetic waves dispersion relation. On the right, a detail of the plot shows stronger signal at low frequencies.

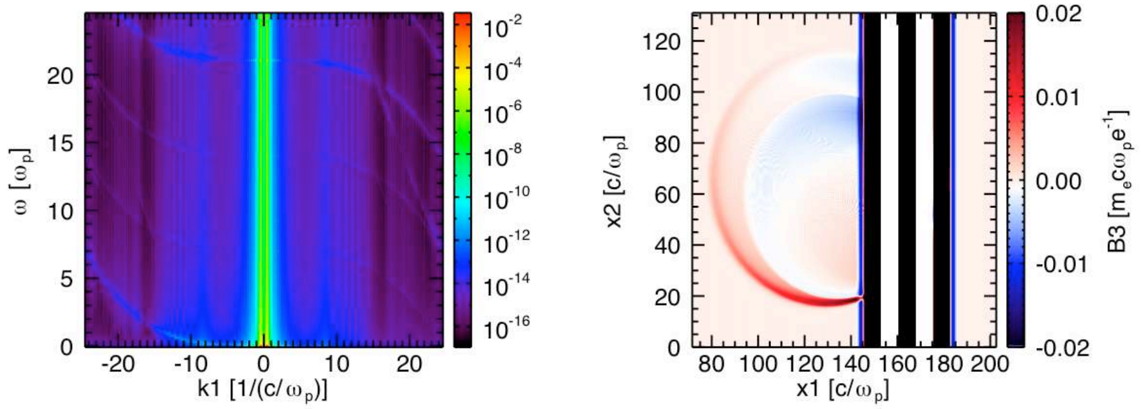

Figure 2: Frequency-wavenumber distribution in x1 direction of waves present in the simulation box (color represents the square of the field amplitude). No clear signal of electromagnetic waves propagating in this direction other than the laser pulse (two red spots on the k1 axis) is seen. However, the B3 field suggests that there might be some radiation emitted in the x1 direction. On the right, the B3 field is represented at time t=13 fs (scaling is adjusted for small amplitudes causing saturation in the regions occupied by the laser field which appear as vertical stripes).

appear as points over the k1 axis. In fact, the B3 field suggests that there is some radiation emitted in the longitudinal direction (see Fig. 2). There are also points with much lower signal at higher frequencies in the dispersion relation for the x2 direction; further exploration is required to determine the relevant features of these high frequency components.

3. INTERACTION WITH AN ARRAY OF CLUSTERS

Simulations were also performed in which a laser pulse with the same parameters as in the previous section irradiates a row of clusters aligned along the propagation direction, centered in the middle of the simulation box. The distance between clusters was fixed for each simulation.

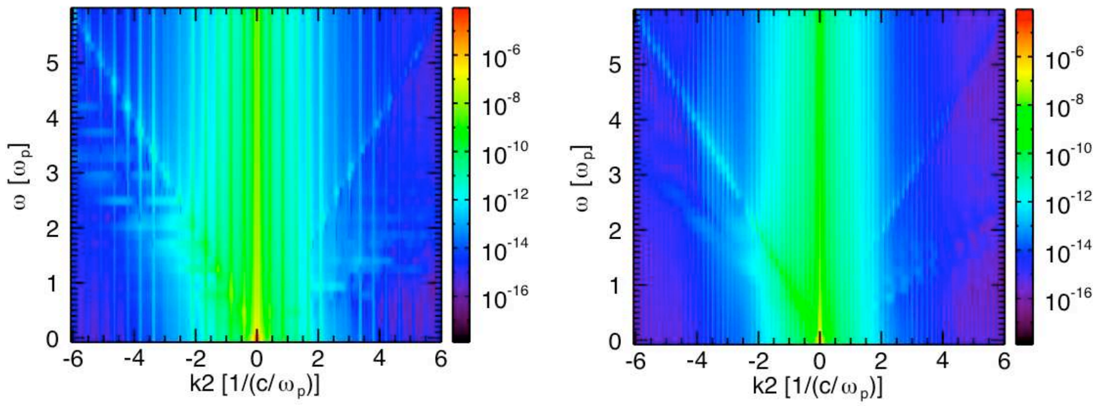

Figure 3: Detail of the frequency-wavenumber in x2 direction of waves present in the simulation box (color represents the square of the field amplitude; cluster spacing is 0.8 μm on the left and 2.1 μm on the right). A stronger signal is observed at discrete intervals on the low frequency region of the dispersion relation.

The analysis of the radiation present in the box (Fig. 3) reveals that the periodic arrangement of the clusters causes the enhancement of radiation signal at discrete wavenumbers spaced approximately by $2\pi/\Delta x_C$, where Δx_C is the intercluster spacing. In this scenario, radiation is still only observable in the dispersion relation in the transverse direction. This should be motivated by the same reasons presented in the discussion of the single cluster scenario. There are indications that radiation is due to the scattering of electrons driven by the laser in the electrostatic potential due to the ion spheres. Future work will explore the novel features of this scheme, namely the use of very high ion charge for scattering and the possibility of tunability from the control of the cluster interspacing in nanomaterials.

The scenario analyzed in this work presents similarities with the Smith-Purcell effect

[6] and studies of harmonic generation in periodic structures irradiated by lasers [7].

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