Vlasov simulations of intense (10^{19} Wcm^{-2}) laser interactions with overdense plasma of varying scale-length

M. Sherlock
Central Laser Facility, STFC, Rutherford Appleton Laboratory, HSIC, Didcot, Oxon OX11 0QX, UK

W. Rozmus
University of Alberta, Canada

Contact | **mark.sherlock@stfc.ac.uk**

Introduction

The theoretical view of the mechanisms of absorption of intense laser pulses with overdense plasma is varied and complicated by the non-linearity of the interaction between plasma and electromagnetic waves. Thus simulation is a necessary tool for verifying the current understanding and is particularly useful for obtaining scaling laws, for example the scaling of absorption efficiency with incidence angle [1] or the characteristic fast electron energy dependence on intensity [2]. An as yet explicitly unexplored scaling is that of absorption efficiency with the scale-length of the plasma at the target's front surface. Such scaling was implicit in the work of [3] at an intensity (I) of 10^{16} Wcm^{-2} and other simulations have shown that absorption increases in deformed targets [4]. Here the question is addressed explicitly at relativistic intensity (10^{16} Wcm^{-2}) and normal incidence. Here we explore the nature of the energy distribution of laser-accelerated electrons in phase-space at both short (much less than a laser wavelength) and long (greater than) scale-length cases.

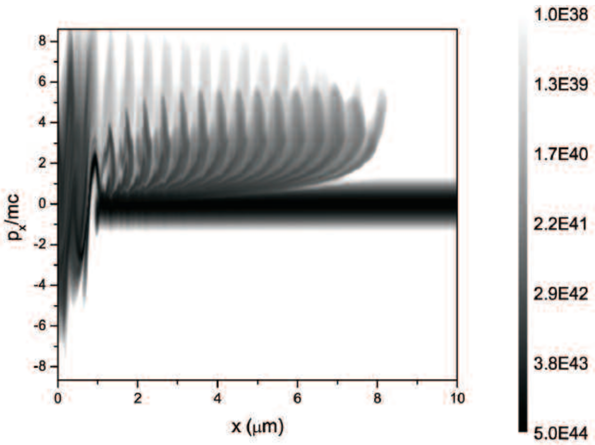

Figure 1. The electron distribution function $f(x,p_x)/n_e(x)$ in longitudinal phase-space (i.e. averaged over the transverse momentum p_y). The scale-length is 0.05 µm and the time is 30 fs.

Results

The phase-space plots at 30 fs (figures 1 and 2) indicate the change in the nature of the absorption as the scale-length increases and indicates why absorption increases. In the short scale-length case (figure 1), fast electron bunches are produced regularly at frequency $2\omega_0$ and while the bunches produced are by no means simple in shape, each bunch is similar to every other. In contrast to this the phase-space in long scale-length plasma (figure 2) shows a merged hot electron structure and there is no clear sign of regularity. This occurs because the electric field is able to penetrate through a longer length of plasma in the long scale-length case and in doing so can resonate with the plasma at more points than just the front surface, which is the case for sharp gradient plasma. This picture of absorption is verified by plotting the total energy transferred to the plasma from the longitudinal electric field.

In the short scale-length case absorption is highly peaked just behind the critical surface and is soon damped beyond it because the density rises so sharply, so that resonance occurs at only one point in space but the number of electrons accessible to the fields is relatively large due to the high density. In the long scale-length case absorption peaks at a number of places because the field decays over a longer distance and can access plasma at or near the critical density at more than one position. Thus multiple resonances are set up at frequencies dependent on the local density (which may fluctuate significantly during a laser cycle) and the fast electron bunches emerging from each resonance are merged and propagate into the dense target.

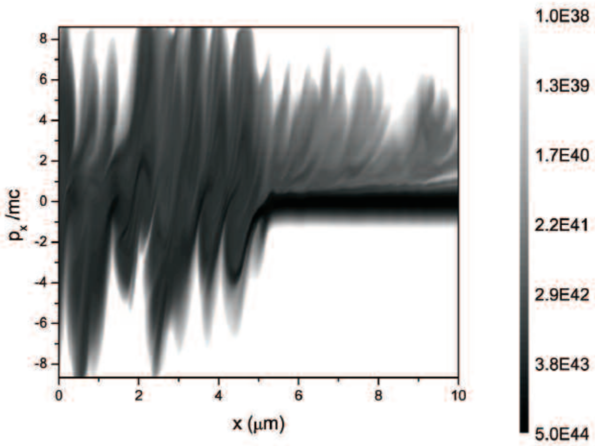

Figure 2. The electron distribution function $f(x,p_x)/n_e(x)$ in longitudinal phase-space (i.e. averaged over the transverse momentum p_y). The scale-length is 4.0 µm and the time 50 fs.

The distribution function in momentum-space, averaged over the spatial domain 5-5.5 µm, is plotted in figure 3. The fast electron distribution produced is not beam-like in the sense that there is a large kinetic energy spectrum in the longitudinal direction. This suggests that the fast electrons will not be electrostatically unstable since the gradient of distribution function along a momentum direction does not undergo a change in sign. Changes in sign do occur as the plasma evolves in between bunches, but those regions are very short lived and contain relatively little energy. The spectrum is shown in figure 4. A Maxwellian energy distribution at 300 keV is also plotted showing a reasonable fit to the hot component. Beg's scaling [6] for hot electron temperature with laser intensity gives a value of around 450 keV at $I=10^{19}$ Wcm^{-2}.

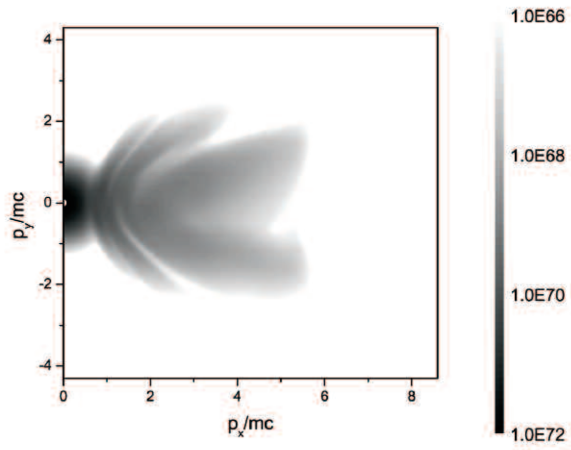

Figure 3. The electron distribution function in momentum space, averaged over the spatial region *x* = 5-5.5 µm. The scale-length is 0.05 µm and the time is 30 fs.

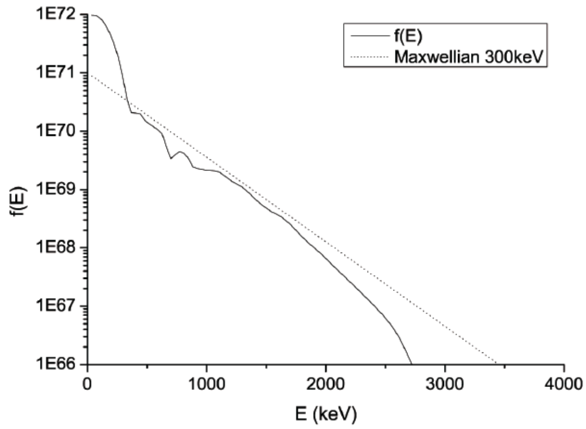

Figure 4. A line-out at p_y = 0 of the electron distribution function in momentum space after averaging over the spatial region *x* = 5-5.5 µm. Also plotted for comparison is a Maxwellian distribution at 300 keV. The scale-length is 0.05 µm.

References

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