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Kinetic Simulation of Fast Electron Transport with Ionization Effects and Ion Acceleration

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Introduction

The generation of relativistic electrons and multi-MeV ions is central to ultraintense ($>$ 10^{18}Wcm^{-2}) laser-solid interactions. The production of energetic particles by lasers has a number of potential applications ranging from Fast Ignition ICF to medicine. In terms of the relativistic (fast) electrons the areas of interest can be divided into three areas. Firstly there is the absorption of laser energy into fast electrons and MeV ions. Secondly there is the transport of fast electrons through the solid target. Finally there is a transduction stage, where the fast electron energy is imparted. This may range from being the electrostatic acceleration of ions at a plasma-vacuum interface, to the heating of a compressed core (as in Fast Ignitor ICF). We have used kinetic simulation codes to study the transport stage and electrostatic ion acceleration.

Fast Electron Transport with Ionization Effects

We have developed a new version the Vlasov-Fokker-Planck code KALOS (orginally discussed in [1]) which includes ionization physics. In the KALOS code the electron distribution function is described by a spherical harmonic decomposition. The new version is currently only 1D in space, so this becomes a Legendre polynomial decomposition. There is only one component of the electric field, and there are no magnetic fields. The ions and atoms are stationary, with the density of each species being tracked separately. Both collisional (CI) and field (FI)ionization processes are included with the target being treated as an ensemble of atoms. The FI rate is calculated from the Landau formula [2], and the CI cross-sections are taken from the Lotz formula [3]. There is no recombination or excitation in the model. Laser physics is not included in the code, and the generation of fast electrons is treated purely as an energy deposition. Specifically, a region extending from the left hand boundary to $x = x_h$ is designated as a heating region. Fast electrons are generated here between $t = 0$ and $t = \tau_h$, with a relativistic Maxwellian. The heating region starts out as a fully ionized solid density carbon, with an initial temperature of 50eV, the rest of the computational domain being unionized solid density carbon. The heating power was chosen to give a power flux approximately equal to 10^{17}Wcm^{-2}, and the fast electron temperature was taken as 300keV. This is comparable to a 10^{18}Wcm^{-2} laser with a 10% conversion into fast electrons. In the simulations the total length of the domain was 60μm, with $x_h = 2.5\mu$m. The spatial grid was uniform with $\Delta x = 0.05\mu$m. Twenty legendre polynomials were used, and the momentum grid was set to resolve the ionization energies. Simulations were carried out for 200fs.

As the fast electrons propagate into the target, there is a strong electric field ($> 10^{10}$Vm^{-1}) which drives the breakdown of the target. This ‘front-field’ exists just behind the fast electron front, and forms a sharp electric field structure that travels into the target with a velocity comparable to the fast electron velocity. The electric field at 50fs, 100fs, and 150fs is shown in fig.1. Both CI and FI are important in the initial breakdown. After the breakdown, CI continues to ionize the target. The continual ionization of the target results in the cold electron distribution being non-Maxwellian. In fig. 3 we show the isotropic component of the distribution function at low energy at a set of positions at 150fs. This is because the CI process adds more electrons at low energy, and it removes electrons with energy greater than ionization energy, thus distorting the distribution function. The net result is a variation in ionization state (shown at 150fs in fig.2), and the details of the cold electron distribution across the target. This manifests in the electric field structure, and it can be seen in fig. 1 as the undulations behind the front-field.

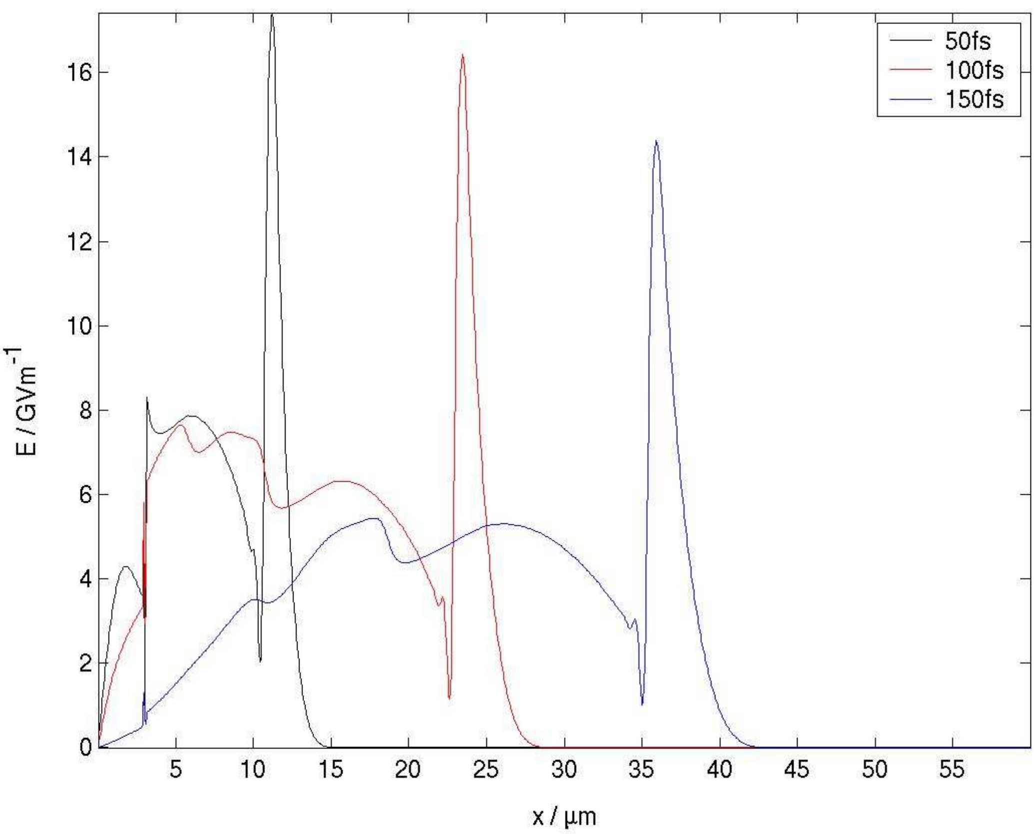

Figure 1: The Electric field profiles at 50fs, 100fs, and 150fs.

The generation of magnetic field depends on the target resistivity, which in turn depends on the target Z and cold electron temperature (or cold electron distribution). In our simulations we have observed that ionization processes affect these strongly. In 2D and 3D it may well be case that both the initial breakdown and the altered target resistivity affect how the fast electron beam filaments or collimates. In the future we intend to develop 2D and 3D versions of the code, which we believe will be powerful tools for understanding current experiments.

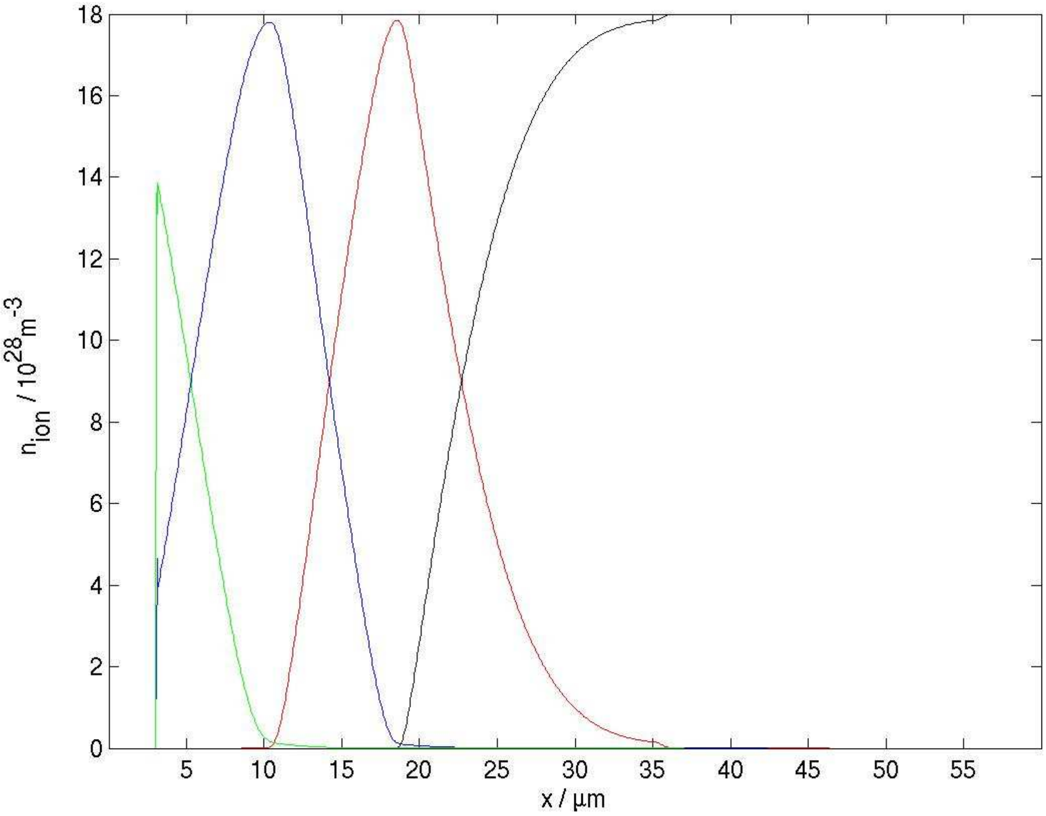

Figure 2: The ion species ($Z = 0$–4) at 150fs.

Ion Acceleration

We have developed a 1d1p three species (electrons, protons, and heavy ions) relativistic Vlasov solver for studying electrostatic ion acceleration. The distribution function is represented on a Eulerian $x - p_x$ grid, and the Vlasov equation is solved by standard upwind methods [4]. Electrostatic ion acceleration has already been studied using hybrid methods [5], and the single temperature, single ion species expansion has been studied thoroughly [6]. We are currently studying the effect of varying the composition of a homogeneous target on the proton spectrum.

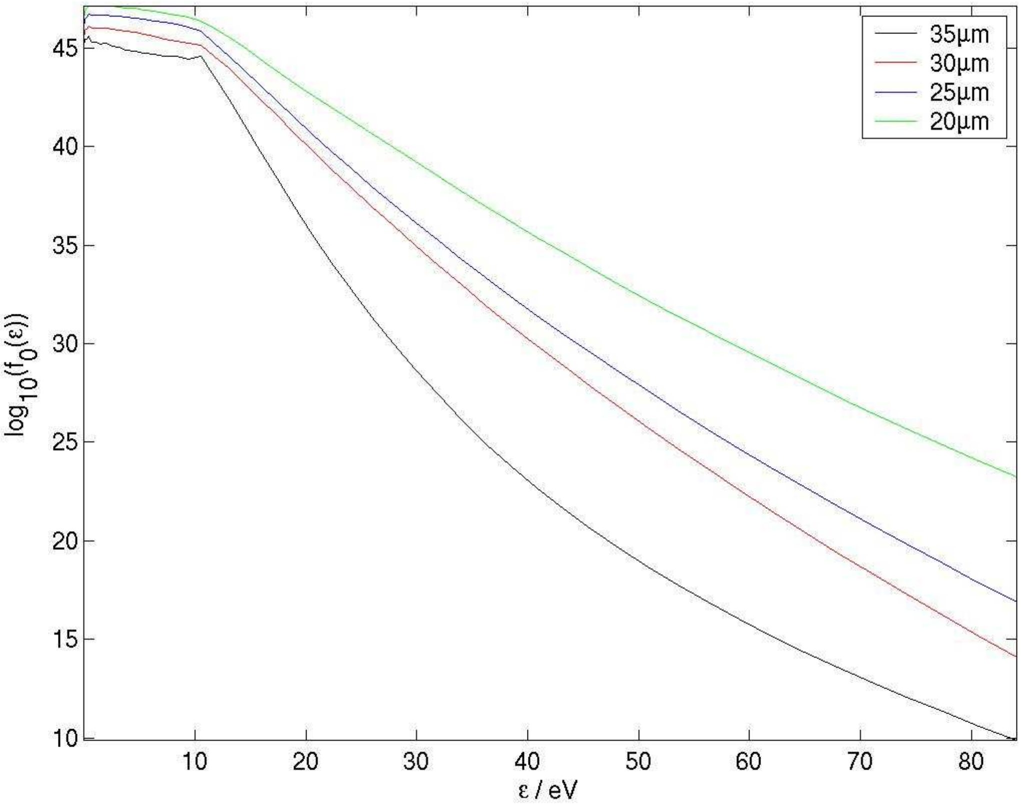

Figure 3: The electron distribution function at low energy for $x = 20, 25, 30, 35\mu$m, at 150fs.

References

[1] A.R.Bell and R.J.Kingham, Phys.Rev.Lett. **91**, No.3 (2003)

[2] Landau and Liftshitz, *Quantum Mechanics*, Pergamon (1964)

[3] Märk and Dunn, *Electron Impact Ionization*, Springer (1985)

[4] T.Arber and R.Vann, J.Comp.Phys. **180**, p.339 (2002)

[5] Bychenkov and Novikov, Phys.Plasmas **11**, p.3242 (2004)

[6] P.Mora, Phys.Rev.Lett., p.185002-1 (2003)