

Negative contribution to the resistivity in intense laser-plasma interactions

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Introduction

In high-intensity laser-plasma interactions, fast electrons are produced in a thin region near the plasma surface and travel into the plasma at relativistic speeds. As they do so, they set up a space-charge electric field which in principle acts to decelerate the fast electrons. However, the electric field also acts on the cold electrons which make up the bulk of the plasma through which the fast electrons are traveling, thus the cold electrons form a current opposing the forward current of the fast electrons. Being less energetic, these cold electrons are collisional and so may be expected to respond linearly to electric fields, as in the simple relation of Spitzer's transport theory (in the absence of temperature gradients): $j_x = \sigma(Z, T_e)E_x$, where σ is the temperature-dependent Spitzer conductivity. Spitzer conductivity (see, e.g. [1]) is strictly only valid when the perturbation on the electron distribution function due to the current is small, the unperturbed distribution function is Maxwellian and the electrons are collisional. Strong fields and Joule heating, both of which are a feature of intense laser-plasma interactions, may force the plasma into a non-Spitzer response regime. In this report two important effects will be described that occur in regions of low density and are not considered in Spitzer transport: (a) the isotropic component of the background electron distribution function can become strongly non-Maxwellian and (b) large isotropic and anisotropic pressure inhomogeneities develop that drive an electric field an order of magnitude larger than that of Spitzer transport.

The computational model

The computational model is KALOS [2], a code for solving the relativistic Vlasov-Fokker-Planck equation expanded in spherical harmonics. Maxwell's equations are solved for implicitly and beam-plasma instabilities are not considered.

The initial electron density profile (see Fig. 1) is chosen to represent an advanced fast ignition scenario in which

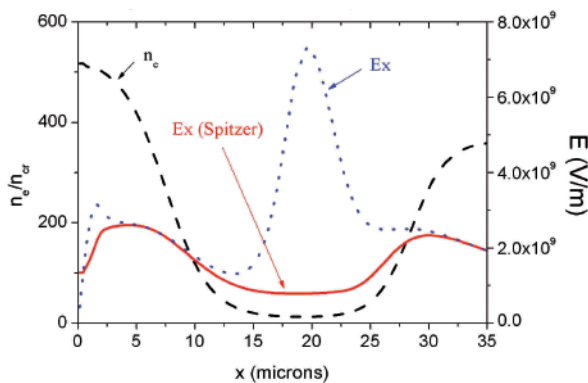


Figure 1. Electric field and electron density.

electrons travel first through ~ 10 microns of solid density gold (representing a cone tip) and then into a Beryllium fuel shell coronal plasma which rises from $\sim 10n_{cr}$ toward solid density over ~ 35 microns. The cone density drops over a scale-length of ~ 10 microns. This profile is also relevant to conventional approaches to fast ignition (which do not make use of a gold cone) and any long scale-length laser-plasma interaction. The rear (RHS) boundary is absorbing.

Highly non-Maxwellian background plasma

All results in this section refer to 300fs after the pulse is turned on (corresponding to 50fs after the peak laser intensity). Shown in Fig. 1 is the electric field calculated self-consistently in the simulation along with the electric field resulting from Spitzer's transport theory. The actual electric field deviates from the Spitzer value by up to an order of magnitude near the density minimum, clearly demonstrating that Spitzer transport is inadequate. Physically, the transport differs from Spitzer transport because the background plasma undergoes such rapid Joule-heating that large anisotropic pressure inhomogeneities are set up in it. The resulting particle flux leads to a larger space-charge electric field.

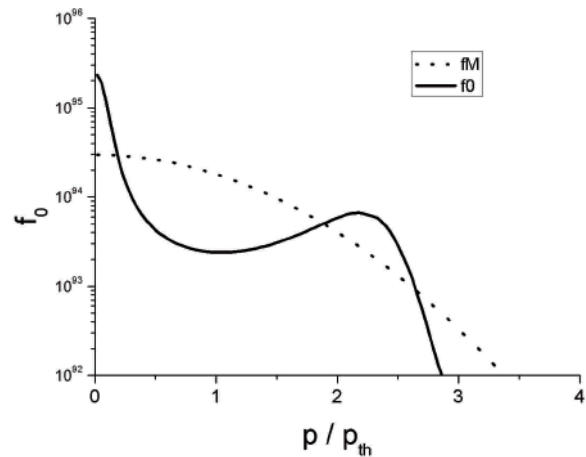


Figure 2. The isotropic component of the distribution function.

Shown in Fig. 2 is the isotropic component of the distribution function at 20 microns, along with a Maxwellian with the same root-mean-square energy. This only shows the part of the distribution that provides the return current. Such a distribution results from the colder, more collisional electrons resisting acceleration and so remaining at low momenta, while those with energy beyond the thermal energy are more easily accelerated to higher energies by the field. The appearance of a second

local maximum in f_0 leads to a negative electrical conductivity. By expanding the Fokker-Planck equation for a homogeneous plasma in spherical harmonics (up to f_1), it is possible to show that the current density is related to the field via:

$$j_x = \left\{ -const \times \int_0^\infty v^4 \frac{\partial f_0}{\partial p} p^2 dp \right\} E_x$$

after also neglecting inertial effects (see^[3]). Since the coefficient of proportionality depends on the slope of f_0 , it can become negative where f_0 has a positive slope. The integrand of the above integral gives the contribution to the current density for each p and is plotted in Fig. 3. When f_0 is Maxwellian Spitzer's theory applies (as indicated by the black curve) and the current is carried by electrons with momentum between 2 and 3 times the thermal momentum. Under the extreme conditions studied in this simulation, the conductivity is such that most electrons respond to the field in the usual positive sense (but within a much narrower energy band) while some actually contribute in a negative sense.

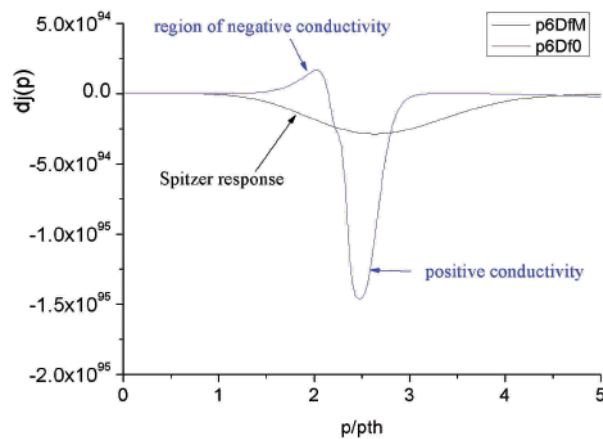


Figure 3. The contribution to the current driven by the field.

These results, although preliminary, will have direct implications for models of laser-plasma interactions in which intense electron beams penetrate relatively low density plasma.

References

1. E. M. Epperlein and M. G. Haines, *Phys. Fluids* **29**, p1029 (1986).
2. A. R. Bell *et al.*, *Plasma Phys. Control. Fusion* **48**, R37 (2006).
3. M. Sherlock *et al.*, Submitted to *Physics of Plasmas*.