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The effect of pre-plasma formation under nonlocal transport conditions for ultra-relativistic laser-plasma interaction

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Abstract

Interaction of high-power lasers with solid targets is in general strongly affected by the limited contrast available. The laser pre-pulse ionizes the target and produces a pre-plasma which can strongly modify the interaction of the main part of the laser pulse with the target. This is of particular importance for future experiments which will use laser intensities above 10^{21} W cm^{-2} and which are subject to the limited contrast. As a consequence the main part of the laser pulse will be modified while traversing the pre-plasma, interacting with it partially. A further complication arises from the fact that the interaction of a high-power pre-pulse with solid targets very often takes place under nonlocal transport conditions, i.e. the characteristic mean-free-path of the particles and photons is larger than the characteristic scale-lengths of density and temperature. The classical diffusion treatment of radiation and heat transport in the hydrodynamic model is then insufficient for the description of the pre-pulse physics. These phenomena also strongly modify the formation of the pre-plasma which in turn affects the propagation of the main laser pulse. In this paper nonlocal radiation-hydrodynamic simulations are carried out and serve as input for subsequent kinetic simulations of ultra-high intensity laser pulses interacting with the plasma in the ultra-relativistic regime. It is shown that the results of the kinetic simulations differ considerably whether a diffusive or nonlocal transport is used for the radiation-hydrodynamic simulations.

Keywords: laser-plasma interaction, high-field, nonlocal transport

(Some figures may appear in colour only in the online journal)

1. Introduction

The interaction of high-power lasers with solid targets very often takes place under so-called nonlocal transport conditions. This means that the characteristic mean-free-path (mfp) of the transported physical quantities, e.g. electrons or photons, is of the order, or larger, than the characteristic gradient scale length of the thermodynamic variables, such as density and/or temperature. Under these conditions thermal and radiative transport can no longer be described by the usual diffusive approach on which classic hydrodynamic plasma models are based. Non-locality is in general characterized by the quantity $\mathrm{Kn} = \lambda/L$, where λ is the mfp of particles and L the plasma inhomogeneity scale length. The dimensionless quantity Kn is called the Knudsen number in standard fluid dynamics [1–5].

In the context of heat transport, it is appropriate to derive the characteristic scale length from the profile of the plasma

