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A simple model for the dynamics of the electrons in a spherical plasma irradiated by a laser pulse

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ABSTRACT

The paper deals with the dynamics of the electrons in the first phase of the expansion of a spherical plasma irradiated by an ultraintense laser pulse, in which the ions can be considered as immobile. A simple model of "competitive escape" is proposed, in which the electrons leaving the ion sphere increase a potential barrier that prevents other electrons from escaping.

1. Introduction

In a study published in 1964 [1], it was predicted that the irradiation of a solid target with an intense electromagnetic beam could induce the formation of a plasma, with a further rapid expansion into the vacuum. However, only the recent progress in the technology of ultraintense laser has permitted experimental evidence of the phenomenon to be found [2,3]. In this paper, the expansion of spherical plasmas (having a typical size of 10^{-9}–10^{-6} m) generated upon the interaction of ultraintense lasers with atomic or molecular clusters [4,5] is considered. Until a few years ago, accurate theoretical analysis for the expansion of spherical plasmas existed only for ideal cases, such as the Coulomb explosion of an ion plasma [6], which occurs when the electrons are all swept away by a laser pulse, and for the opposite condition, when the electrons are heated by the pulse but not stripped from the sphere, and hydrodynamic models [7–12] or numerical models [13,14] can be employed. However, in intermediate situations, when a significant violation of electric neutrality is present, the process of expansion depends strongly on the self-consistent dynamics of the ions and of the trapped electrons, which can be described accurately only by means of kinetic models, based on the Vlasov equation. In this framework, several researchers collaborated in a kinetic analysis of the collisionless expansion of spherical plasmas based upon a peculiar ergodic model [15]. The model has been derived in detail in [16], and its validity has been tested against reference numerical solutions obtained using particle-in-cell techniques.

In general, the expansion can be split into two successive processes: a first stage, consisting in a rapid expansion of the electrons, which leads to a Vlasov–Poisson equilibrium before the ions move appreciably, and a second stage, which is driven by the positive charge buildup accumulated in the first stage, where the plasma bulk expands slowly (with respect to the characteristic time scale of the previous electron expansion).

The present paper deals with the first phase of the expansion of a spherical plasma. Due to the large mass disparity between ions and electrons, the ions can be assumed as immobile, and only the dynamics of the electrons, which have been heated by the laser pulse, is considered. The purpose of the paper is to provide a simple model taking into account the escape of the electrons from the sphere, and it can be regarded as a refinement of the model presented in [17].

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