Theoretical modelling of picoseconds petawatt laser-plasma interactions

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With the development of kJ, petawatt (PW) class lasers, laser pulses with relativistic intensities (≥ 10^{18} W/cm^2) and over-picosecond (ps) pulse durations are becoming available. In such a ps relativistic regime, the energy transfer enters in a new regime as indicated by the recent multi-ps PW laser experiments, e.g., superthermal electron acceleration beyond the conventional ponderomotive scaling, and the consequent boosting of ion acceleration beyond the isothermal plasma expansion theory [1,2]. Laser-plasma interactions (LPI) with such a ps relativistic regime belong to the mesoscale between kinetic and fluid regimes, where energetic acceleration of kinetic electrons by the laser field takes place with the dynamic change of plasma structure in the ion fluid time scale. In this mesoscale regime, numerical simulation is challenging due to the extremely-high computational cost for the kinetic model.

Here, we present theoretical modeling of particle acceleration and plasma heating in the relativistic ps LPI. Relativistic laser lights push the overdense plasma surface by the giga-bar level light pressure, i.e., the hole boring (HB) process, which makes a steep laser-plasma interface and is essential for particle acceleration/heating. During over-ps laser irradiation, the pressure balance between plasma and laser light is established, and the HB stops eventually, owing to the formation of a steady ion flow at the HB front in the ps time scale [3]. After the HB stops, the hot plasma starts to blowout back towards the laser. This transition from the HB stage to the blowout stage enhances energetic electron acceleration and also bulk plasma heating. Moreover, in the case of thin foil plasmas, a Fermi-type stochastic acceleration of electrons takes place in the expanding plasma, which results a superthermal tail in electron energy spectrum. Such enhanced electron accelerations in the ps LPI result a boosted TNSA ion acceleration [1,4]. For high contrast lasers, the heat in the pre-plasma region can be transferred diffusively into the solid density region with the heat velocity of $\mathcal{O}$(μm/ps), which enables a volumetric over-keV heating of dense plasmas with rich radiations [5]. These understandings are of fundamental importance not only for the ps PW lasers but also for LPI for the pedestal component of femtosecond ultrahigh intensity lasers.

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