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Relativistic electron production by stochastic laser-plasma interaction in sub-relativistic intensity regime

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In laser–plasma interactions with laser intensities in the range of $10^{15\text{-}16}$ W/cm^2 and interaction durations of tens of picoseconds (ps), electrons with energies over 100 keV are observed in particle-in-cell (PIC) simulations. Within this parameter regime, parametric instabilities (PIs), particularly stimulated Raman scattering (SRS), play a crucial role in the energy transfer from the laser to the plasma, thereby affecting the performance of inertial confinement fusion.

In SRS process, the incident laser excites electron plasma waves and induces density perturbations in underdense plasma regions. These excited electron plasma waves can trap and accelerate ambient electrons around their phase velocities. This wave-trapping process by SRS typically generates hot electrons (HEs) with energies of tens of keV. The generated HEs subsequently transport energy into overdense plasma regions, modifying plasma hydrodynamics, such as shock wave formation and propagation.

In this study, we conducted PIC simulations up to 100 ps, varying laser intensity from 10^{14} to 10^{16} W/cm^2 and plasma density scale length from 50 to 800 μm, to investigate the characteristics of HEs. Figure 1 shows the energy spectrum of the HEs measured in the simulation. The HEs consist of two components: thermal electrons with temperatures of tens of keV and superthermal (fast) ones with mean energies of 100s of keV.

To clarify the acceleration mechanism of fast electrons, we analyzed how electron plasma waves are excited and the trajectories of fast electrons as shown Fig. 2.

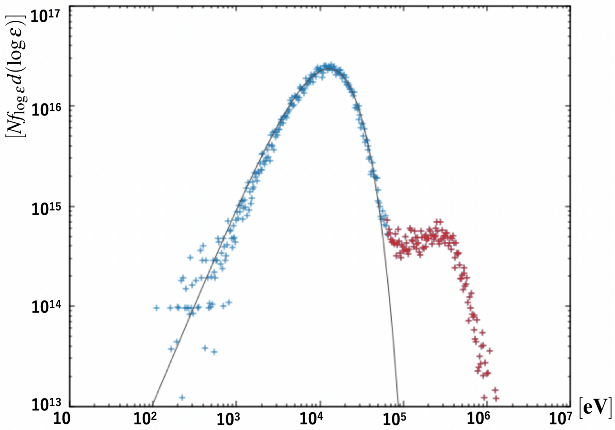

Figure 1: The energy spectrum of hot electrons (cross dots). It consists of two components: a thermal electrons (blue) that has the Maxwell distribution (solid gray line) and a non-thermal ones (red) that departs from the Maxwellian.

Our analyses reveal that, after tens of ps of laser-plasma interactions, the electron trapping and acceleration by the SRS-excited electron plasma waves no longer occur. Instead, the density perturbations induced by SRS form chaotic fluctuating fields. We found that the fast electrons gain their energy diffusively in these SRS-induced fluctuating electric field. We present the details of this stochastic acceleration process and propose a corresponding model for the mean energy.

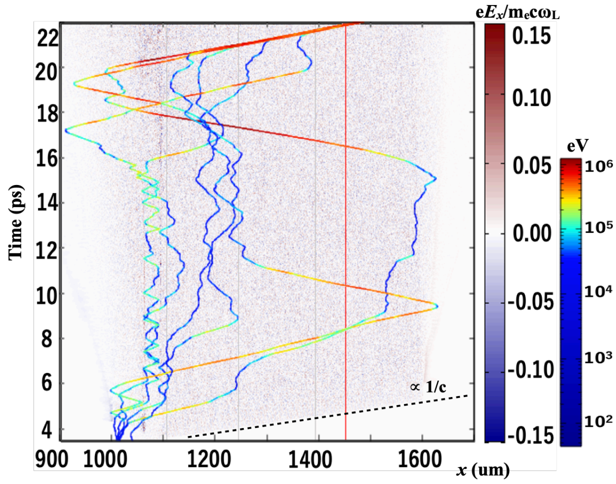

Figure 2: The trajectories of fast electrons (solid lines). The color of the lines shows the energies of the fast electrons and the background contour show the amplitude of electron plasma waves.