Formation of power law electron energy distribution by relativistic picosecond laser irradiation

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High power lasers with relativistic intensities above 10^{18} W/cm^2 and pulse lengths exceeding picosecond (ps) have been developed in recent years. In over-ps laser-plasma interactions, energy slope of high-energy electrons tends to be higher than the scaling laws used in the sub-ps regime, e.g., the ponderomotive scaling [1]. One of the key mechanisms of such a superthermal electron generation is stochastic acceleration in a laser-heated thin foil plasma, where fast electrons recirculate around and suffer multiple kicks from the laser field [2]. During over-ps laser heating, hot plasma at the laser-irradiated surface can blowout towards the laser [3], which also enhances the multiple interactions of fast electrons with laser light. The stochastic acceleration in such a situation is similar to the acceleration of cosmic rays which yield to power law spectra in high energy tail. For a non-relativistic laser interaction with underdense plasma, the electron energy spectrum is found to be a kappa distribution which has a power law tail [4]. Understanding characteristics of the electron energy distribution in high-intensity laser interactions is also essential for various applications using multi-ps kilo-Joule lasers such as ion acceleration, positron generation and fast ignition-based laser fusion.

Here, we model the electron acceleration in the relativistic laser-thin foil interaction and study the resulting electron energy distribution based on the Fokker-Plank equation in momentum p-space. We introduce new diffusion and friction coefficients that represent the stochastic scattering by the laser field and the energy dissipation in the sheath potential at the rear side of the foil, respectively. We find that the steady solution of the relativistic Fokker-Plank equation becomes a power law distribution when the difference of momentum dependence between diffusion and friction coefficients is p^2. This analysis can specify the origin of power law formation mathematically and provide an insight for further understanding of complex laser interactions in over-ps time scale.

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