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Magnetic reconnection and electron acceleration driven by ultra-intense Fs lasers

Yongli Ping[1], Jiayong Zhong[1], Xiaogang Wang[2] and Gang Zhao[3]
[1] Department of Astronomy, Beijing Normal University, Beijing 100875, China
[2]Department of Physics, Harbin Institute of Technology, Harbin 150001, China
[3]Key Laboratory of Optical Astronomy, National Astronomical Observatories, Chinese Academy of Sciences (CAS), Beijing 100012, China
e-mail (speaker): ylping@bnu.edu.cn

Magnetic reconnection (MR) occurs widely in fast energy release processes such as in solar flares, coronal mass ejections, interaction of solar and magnetosphere, certain explosive astrophysical events, and fusion plasma instabilities. Moreover, the relativistic magnetic reconnection may play an important role for energy conversion in relativistic objects, for example, hard x-ray and higher energy spectrum bursts in solar flares, pulsars, gamma-ray bursts, and active galactic nuclei.

Three-dimensional fast magnetic reconnection driven by two ultraintense femtosecond laser pulses is investigated by relativistic particle-in-cell simulation, where the two paralleled incident laser beams are shot into a near-critical plasma layer to form a magnetic reconnection configuration in self-generated magnetic fields. Fig. 1 presents at t = $35T_0$ when the laser pulses have not yet reached most of the right half of the simulation box, two magnetic flux tubes have already clearly shaped shown in Fig. 1(a). Then, a fully developed 3D magnetic reconnection configuration is formed at t = $50T_0$ [Fig. 1(b)] with the two flux tubes reconnecting into one in the outer region. Meanwhile, the reconnection rate is found to be faster than that found in previous two-dimensional Hall magnetohydrodynamic simulations and electrostatic turbulence contribution to the reconnection electric field plays an essential role as shown in Fig.1(d)[1].

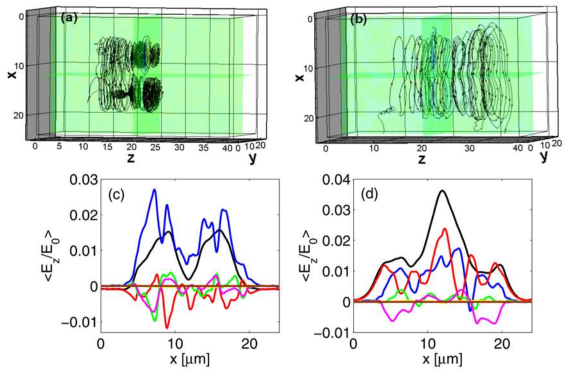

Fig.1(a,b) Snapshots of three-dimensional magnetic field lines (a) at $35T_0$ and (b) at $50T_0$. (c), (d) Contributions of terms in the generalized Ohm's law from Eq. (1) to $\langle E_z\rangle$ (black) along the x axis at (c) and (d) for $y = 12\ \mu$m, as $\frac{1}{e\langle n_e\rangle}(\langle \mathbf{j}\rangle \times \langle \mathbf{B}\rangle)_z$ (purple), $-\frac{1}{e\langle n_e\rangle}\langle \nabla \cdot \mathbf{P}_e\rangle_z$ (blue), $\frac{m_e}{e^3\langle n_e\rangle}(\langle \mathbf{j}\rangle \cdot \nabla\langle \frac{\mathbf{j_z}}{\mathbf{n_e}}\rangle)$ (brown), $\frac{m_e}{\langle n_e\rangle e^2}\frac{\partial\langle \mathbf{j_z}\rangle}{\partial t}$ (yellow), $-\frac{1}{\langle n_e\rangle}\langle \delta n_e \delta E_z\rangle$ (red), and $\frac{1}{e\langle n_e\rangle}\langle \delta \mathbf{j} \times \delta \mathbf{B}\rangle_z$ (green). $\langle A\rangle$ means that variable A is smoothed over the fast oscillation and then averaged over the z direction from 5 to 35 μm. Here, the electric fields is normalized by the initial laser field $E_0 = cB_0 = 4.34 \times 10^{13}$ V/m.

From the generalized Ohm's law[2,3] of the mean field, $\langle E_z\rangle$ can be written as

$$\langle E_z\rangle = \frac{1}{e\langle n_e\rangle}(\langle \mathbf{j}\rangle \times \langle \mathbf{B}\rangle)_z + \frac{-1}{e\langle n_e\rangle}\langle \nabla \cdot \mathbf{P}_e\rangle_z + \frac{m_e}{e^3\langle n_e\rangle}\left(\langle \mathbf{j}\rangle \cdot \nabla\left\langle \frac{\mathbf{j_z}}{\mathbf{n_e}}\right\rangle\right) + \frac{\mathbf{m_e}}{\langle \mathbf{n_e}\rangle \mathbf{e^2}}\frac{\partial\langle \mathbf{j_z}\rangle}{\partial \mathbf{t}} + \frac{-1}{\langle n_e\rangle}\langle \delta n_e \delta E_z\rangle + \frac{1}{e\langle n_e\rangle}\langle \delta \mathbf{j} \times \delta \mathbf{B}\rangle_z. \quad (1)$$

In Fig.2, pickup ring of energetic electrons found in relativistic magnetic reconnection (MR) driven by two relativistic intense femtosecond laser pulses. And In the field line diffusion region, electrons are accelerated to multi-MeV with a flatter power-law spectrum due to MR[4].

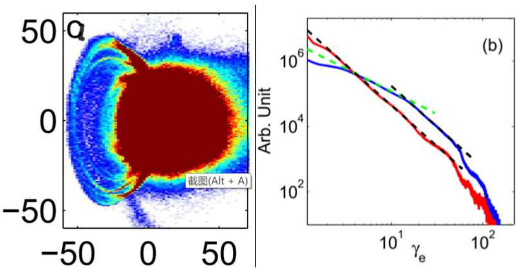

Fig. 2 (a)Electron distributions in the phase space of (p_z, p_y); (b) Energy spectra for the electrons in the reconnection region (b), where the dashed lines indicate the power law of the spectrum, γ_e^{-p}, with the black line for p = 2.5 and the green line for p = 1.4.

In recent simulations, three-dimensional asymmetric magnetic reconnection (AMR) driven by ultraintense femtosecond (fs) lasers is investigated[5]. The reconnection rate is found to be only one-third of that in the previous symmetric reconnection PIC simulations. And, magnetic X- and velocity stagnation points are not colocated, with the X-point at the lower field side and the stagnation point at the higher field side. Then, the hosing instability triggered by AMR and the merging of two parallel currents resulting in the tilt of the electron beam generated by the weak laser are also investigated.

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