Novel plasma heating processes by relativistic-intensity electromagnetic waves under a strong magnetic field

Takayoshi Sano

Institute of Laser Engineering, Osaka University, Suita, Osaka 565-0871, Japan

Laser-plasma interaction in a strong magnetic field has attractive properties regarding particle acceleration and plasma heating. We are focusing on the role of a standing wave created by counter-propagating circularly polarized whistler waves.

It has been shown that electrons in standing whistler waves are efficiently accelerated to relativistic speeds [1]. In the standing wave, the electrons are rapidly pulled up from non-relativistic velocities to the relativistic regime by cyclotron resonance with two waves [2,3]. As a result, it is possible to accelerate all electrons in a solid to MeV or much faster electrons. This process requires a background magnetic field such that the electron cyclotron frequency is greater than the wave frequency. Furthermore, it is analytically derived that the magnetic field amplitude of the standing wave must be larger than the background magnetic field to achieve this acceleration. The stronger the external magnetic field, the higher the maximum energy of the accelerated electrons [3].

On the other hand, cyclotron resonance of electrons does not occur if the background magnetic field is too strong. Instead, it has been shown that ions are selectively heated in standing whistler waves [4,5]. Since whistler waves have no cut-off density, they can penetrate high-density plasmas. Therefore, the ability to heat bulk ions, but not electrons, to 10 keV or higher is exciting from the perspective of laser fusion [5].

Experimental verification of these acceleration mechanisms in a strong magnetic field would be valuable. The laser conditions we assumed in this study are already available with present TW-class femtosecond lasers. The most challenging part would be preparing the critical magnetic field over 10 kT for the laser wavelength of 1 micron. However, the strong magnetic field makes a dramatic difference in the wave-particle interaction; thus, we believe it is worth considering in the future.

[1] T. Sano, et al., Phys. Rev. E 96, 043209 (2017).
[2] S. Matsukiyo and T. Hada, Astrophys. J. 692, 1004 (2009).
[3] S. Isayama, K. Takahashi, S. Matsukiyo, and T. Sano, Astrophys. J. 946, 68 (2023).
[4] T. Sano et al., Phys. Rev. E 100, 053205 (2019).
[5] T. Sano et al., Phys. Rev. E 101, 013206 (2020).