L-I8 AAPPS-DPP2019

3rd Asia-Pacific Conference on Plasma Physics, 4-8,11.2019, Hefei, China

Ion acceleration by high-intensity laser-driven electrostatic collisionless shock

Y. Sakawa[1], R. Kumar[1], M. Ota[1], S. Egashira[1], M. Kanasaki[2], Y. Fukuda[3], L. Döhl[4], N. Woolsey[4], and A. Morace[1]

[1] Institute of Laser Engineering, Osaka University, Japan,

[2] Graduate School of Maritime Sciences, Kobe University, Japan,

[3] Kansai Photon Science Institute, National Institutes for Quantum and Radiological Science and Technology, Japan

[4] Department of Physics, University of York, UK

e-mail (speaker): sakawa-y@ile.osaka-u.ac.jp

Collisionless shock is a shock wave generated in a collisionless plasma, in which Coulomb collisions are negligible. Whereas the shock-front thickness of collisional shock is of the order of Coulomb mean-free-path (mfp), that of collionless shock is much smaller than the mfp, and wave-particle interactions and collective effects of electric and magnetic fields play essential roles in the shock formation [1]. Collisionless shock is ubiquitous in space and astrophysical plasmas, such as Earth's bow shock and supernova remnant shocks, and is believed to be a source of cosmic rays [1]. Thanks to the recent development of high-power laser systems, a new method of studying high-energy astrophysics, such as the formation and evolution of collisionless shocks in the laboratory, Laser Astrophysics, is emerging [2-6]. Recently, ion reflection or acceleration from laser-driven electrostatic collisionless shock (ECS) has been demonstrated [7].

By using the 2D EPOCH particle-in-cell simulation code, we study proton acceleration in ECS, and how the acceleration is influenced by different averaged charge-to-mass ratio (<Z/A> = 0.48-1) of the target plasma such as C_2H_3Cl, CH, H, etc [8]. The maximum electron density $N_e = a_0 N_{cr} = 3.3\text{x}10^{21}$ cm^{-3} (a_0 is the normalized laser vector potential, N_{cr} is critical-plasma desnity) with exponentially decreasing 30 μm scale-length in the rear-side region. The irradiated laser beam is 1.5 ps (FWHM), p-polarized pulse, with a peak intensity of $1.4\text{x}10^{19}$ W/cm^2 (a_0 = 3.35). In multi-ion plasmas the ions with different <Z/A> acquire different velocities under an ambipolar electric field in the upstream region. This relative drift between the protons (<Z/A> = 1) and the lower <Z/A> ions such as C^{6+} (<Z/A> = 0.5) leads to the excitation of electrostatic ion two-stream instability (EITI) [9]. This in turn generates a low-velocity component in the upstream expanding protons. The velocity distribution of the upstream expanding protons is further broadened toward the higher velocity by the EITI between reflected protons, which results in a large number of protons being accelerated by the shock [8].

We also conduct collisionless shock ion acceleration experiment with a beam of LFEX laser (1053 nm, 1.5 ps, ~$3\text{x}10^{18}$ W/cm^2, a_0 ~ 1.6) at the Institute of Laser Engineering, Osaka University [10]. In this experiment, a beam of Gekko XII laser (1053 nm, 1.3 ns, ~10^{12} W/cm^2) is focused on the rear-surface of the CH target with 0.7 μm in thickness to generate a pre-formed near-critical density plasma [10]. After a few ns delay, we irradiate the LFEX laser pulse on the front-side of the plasma and observe accelerated protons using Radio Chromic Film and CR-39. We also measure the electron energies using an electron spectrometer.

References

[1] Y. Sakawa, T. Morita, Y. Kuramitsu, and H. Takabe, Advances on Physics: X **1**, 425 (2016).

[2] T. Morita, Y. Sakawa, Y. Kuramitsu, S. Dono, H. Aoki, H. Tanji, J. N. Waugh, C. D. Gregory, M. Koenig, N. C. Woolsey, and H. Takabe, , Physics of Plasmas **24**, 072701-1-7 (2017).

[3] J. S. Ross, et al, Physical Review Letters **118**, 185003-1-6 (2017).

[4] Y. Sakawa, et al, High Energy Density Physics **23**, 207-211 (2017).

[8] Y. Kuramitsu, T. Moritaka, Y. Sakawa, et al, Nature Communications **9**, 5109-1-6 (2018).

[6] Takayuki Umeda, et al, Physics of Plasmas **26**, 032303-1-8 (2019).

[7] D. Haberberger, et al, Nature Phys. **8**, 95 (2012).

[8] R. Kumar, Y. Sakawa, L. N. K. Döhl, N. Woolsey, and A. Morace, Phys. Rev. Accel. Beams **22**, 043401 (2019).

[9] Y. Ohira, F. Takahara, The Astrophysical Journal **688**, 320 (2008).

[10] M Ota, A Morace, R Kumar, S Kambayashi, S Egashira, M Kanasaki, Y Fukuda, Y Sakawa, High Energy Density Physics **33**, 100697 (2019).