4th Asia-Pacific Conference on Plasma Physics, 26-31Oct, 2020, Remote e-conference

Formation of Weibel-instability mediated collisionless shock using large-scale laser systems

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Collisionless shock is a shock wave generated in a collisionless plasma. The shock-front thickness of collisionless shock is much smaller than the Coulomb collision mean-free-path, and the wave-particle interactions and collective effects of the electric and magnetic fields play essential roles in the shock formation. Collisionless shocks are ubiquitous in space and astrophysical plasmas, such as Earth's bow shock and supernova remnant shocks, and are believed to be sources of cosmic rays. [1, 2] Thanks to the recent development of high-power laser systems, in addition to the local observations of space plasmas by spacecraft and global emission measurements of astrophysical plasmas, laboratory experiments can be an alternative approach to study the formation of collisionless shocks [3].

We can distinguish collisionless shocks in three categories [3]. The first is the magnetized or magneto-hydrodynamic (MHD) shocks under an external magnetic field. This shock is ubiquitous in the space and astrophysical plasmas. The second and third are the ones in the absence of an external magnetic field; electromagnetic-turbulence sustaining shock (EM shock), and electrostatic shock (ES shock). ES shock is rare in the Universe; it may occur even with an external magnetic field under special conditions, such as in the auroral zones. Recently, in addition to the shock formation using ns-high-power lasers [3], ion reflection or acceleration from high-intensity laser-driven collisionless ES shock has been studied by many authors [4, 5]. EM shock is predicted to be mediated by self-generated turbulent electromagnetic field such as in gamma-ray bursts after glows. The Weibel instability is a leading candidate for the generation mechanism of the turbulent electromagnetic fields and shocks.

Kato and Takabe have studied the Weibel-instability mediated collisionless shock (Weibel shock) formation in two-dimensional PIC simulations [6]. The derived scaling-law revealed that high-density (electron density ~ 10^{20} cm^{-3}), high-flow velocity (~1000 km/s), large volume (plasma length > a few mm), and long lived (> a few ns) plasmas are required for the shock formation, and hence requires to use hundreds of kJ high-power laser system [7].

We have investigated Weibel shock in a self-generated turbulent magnetic field using large-scale laser systems.

On Omega (LLE, USA) laser experiments (351 nm (3ω), 1 ns, 8 kJ on each plane of CH/CH planar double-plane target, separation = 8 mm), plasma parameters such as electron and ion temperatures, electron density, and flow velocity of counter-streaming flows were measured by collective Thomson scattering [8], and temporal evolution of Weibel filaments were observed by D-3He fusion produced proton radiography [9].

On the National Ignition Facility (NIF) (LLNL, USA) experiments (351 nm (3ω), < 5 ns, < 455 kJ on each plane of double-plane target, separation = 6 - 25 mm), CD/CD, CD/CH, and CH/CH double-plane targets were used. The transition from the collisional to collisionless flows was investigated when the foil separation is increased [10]. Excess neutrons, when comparing the CD/CD and CD/CH interactions, indicated a strong thermalization [10]. We used D-3He proton radiography for the first time on the NIF and investigated temporal evolution of the Weibel-instability and shock formation. A proton source was generated by an implosion of a SiO_2 capsule filled with D-3He with 64 beams (58 kJ total, 1 ns). Finally, we showed the formation of collisionless Weibel shock by using collective Thomson scattering measurements, and results in the non-thermal electron acceleration [11].

References

[1] F. A. Aharonian, et al., Nature **432**, 78 (2004).
[2] Y. Uchiyama, et al., Nature **449**, 576 (2007).
[3] Y. Sakawa, T. Morita, Y. Kuramitsu, and H. Takabe, Advances on Physics: X **1**, 425 (2016).
[4] D. Haberberger, et al, Nature Phys. **8**, 95 (2012).
[5] R. Kumar, Y. Sakawa, L. N. K. Döhl, N. Woolsey, and A. Morace, Phys. Rev. Accel. Beams **22**, 043401 (2019).
[6] T. N. Kato and H. Takabe, The Astophys. J. Lett. **681**, L93 (2008).
[7] Y. Sakawa, et al., European Physical Journal Web of Conferences **59**, 15001 (2013).
[8] J. S. Ross et al, Phys. Plasmas **19**, 056501 (2012).
[9] C. M. Huntington et al, Nature Physics **11**, 173 (2015).
[10] J. S. Ross et al, Phys. Rev. Lett **118**, 185003 (2017).
[11] F. Fiuza et al, Nature Physics, Published online 8 June (2020). https://doi.org/10.1038/s41567-020-0919-4.