# §5. Electromagnetic Structure of Large-Amplitude MHD Waves and Particle Acceleration

Ohsawa, Y., Toida, M. (Dept. Physics, Nagoya Univ.), Ishiguro, S.

We mainly studied three topics on shock waves and particle acceleration in 2010: 1) positron acceleration along the magnetic field, 2) evolution of large-amplitude magnetohydrodynamic waves arising from a strong disturbance in a plasma and ultrarelativistic electron acceleration in these waves, and 3) two and three dimensional, relativistic, electromagnetic, particle simulations on the structure of magnetosonic shock waves and particle acceleration.

1) Positron acceleration

Shock waves propagating obliquely to an external magnetic field in an electron-positron-ion (EPI) plasma can rapidly accelerate positrons along the magnetic field to ultrarelativistic energies [1,2]. When the shock speed $v_{sh}$ is close to $c \cos \theta$, where $\theta$ is the angle between the external magnetic field $\mathbf{B}_0$ and the wave normal, this acceleration is particularly strong. Since the propagation speed $v_{sh}$ depends on the strength of $\mathbf{B}_0$, the inhomogeneity of $\mathbf{B}_0$ is expected to affect the positron acceleration. We have investigated this effect with relativistic, electromagnetic particle simulations with real ion-to-electron mass ratio, $m_i/m_e$=1836 [3].

Figure 1 displays magnetic-field profiles and positron phase spaces ($x$, $\gamma$) in shock waves propagating in the $x$ direction in an external magnetic field $\mathbf{B}_0 = (B_{x0}, 0, B_{z0})$. The top panel shows the uniform-$\mathbf{B}_0$ case, in which positrons are accelerated to $\gamma \sim 10^4$, where $\gamma$ is the Lorentz factor, near the shock front by the end of the simulation run, $\omega_{pe}\, t$ =7000. Since the acceleration was not saturated, $\gamma$ would further rise if we carry out a simulation for a longer time with a larger system size. The middle and bottom panels show the cases with increasing $B_{z0}$ ($dB_{z0}/dx > 0$) and with decreasing $B_{z0}$. In both cases, rapid positron acceleration occurs when the shock front is in the region where $v_{sh} \sim c \cos \theta$. Furthermore, we find higher energy positrons in the latter than in the former, the mechanism of which is described in Ref. [3].

2) Evolution of magnetohydrodynamic waves and associated electron acceleration

If a strong disturbance is given to a plasma, magnetosonic shock waves form. In addition, large-amplitude Alfven waves are generated, which propagate with lower speeds than the shock waves. We have numerically studied their evolution in detail. Moreover, we have found three types of ultrarelativistic electron acceleration in the Alfven wave region and analyzed their motions [4].

3) Multi-dimensional effect on particle acceleration

We have developed two- and three-dimensional particle simulation models and, by using them, have studied shock waves and particle acceleration. It has been known that oblique shock waves can trap some electrons near the shock front and accelerate them to ultrarelativistic energies [5]. Although the trapping is quite stable in one-dimensional simulations [6], two-dimensional simulations show that electrons can be detrapped and that their energies further go up in this detrapping process [7,8].

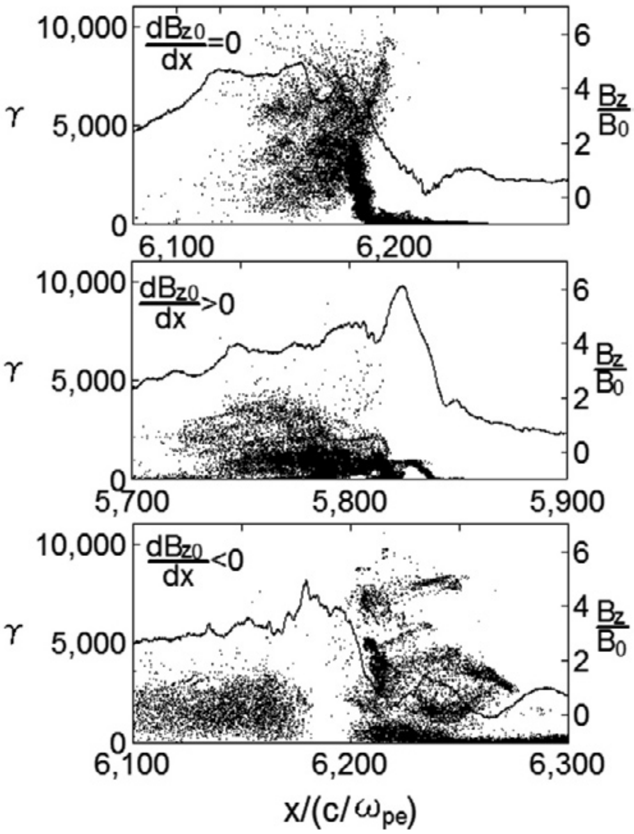


Fig. 1 Positron phase spaces ($x$, $\gamma$) and magnetic-field profiles. The top panel shows the uniform-$\mathbf{B}_0$ case, while the middle and bottom panels displays the cases with increasing $B_{z0}$ and decreasing $B_{z0}$.


[1] H. Hasegawa, K. Kato, and Y. Ohsawa, Phys. Plasmas **12**, 082306 (2005).
[2] Y. Ohsawa, Butsuri **65**, 945 (2010) (in Japanese).
[3] T. Iwata, S. Takahashi, and Y. Ohsawa, Plasma and Fusion Res. **6**, 2401025 (2011).
[4] Y. Takeyama, S. Nakayama, and Y. Ohsawa, submitted to Physics of Plasmas.
[5] N. Bessho and Y. Ohsawa, Phys. Plasmas **6**, 3076 (1999); *ibid.* **9**, 979 (2002).
[6] A. Zindo, Y. Ohsawa, N. Bessho, and R. Sydora, Phys. Plasmas **12**, 052321 (2005).
[7] M. Toida and K. Shikii, Phys. Plasmas **16**, 112305 (2009).
[8] K. Shikii and M. Toida, Phys. Plasmas **17**, 082316 (2010).