Relativistic particle acceleration in two-dimensional Alfvén wave turbulence

S. Isayama[1], S. Matsukiyo[1], T. Sano[2]

[1] Interdisciplinary Graduate School of Engineering Sciences Faculty of Engineering Sciences, Kyushu University

[2] Institute of Laser Engineering, Osaka University Institute of Laser Engineering, Osaka University

e-mail(speaker): isayama@esst.kyushu-u.ac.jp

Coherent large amplitude magnetohydrodynamic (MHD) waves are ubiquitous in space and they are considered to play crucial roles in the acceleration of high energy cosmic rays. Several models of large amplitude Alfvén generation accompanying cosmic ray acceleration have been proposed so far [1-3]. In 2009, by 1D simulation, Matsukiyo and Hada [4] showed that a relativistic Alfvén wave in a pair plasma is unstable to form the coherent standing waveform which consists of counter-propagating Alfvén waves, resulting in particle acceleration much more efficient than in a non-relativistic case. Recent studies have also shown that when the amplitude of the two counter-propagating Alfvén waves exceeds critical amplitude, any particles irreversibly gain relativistic energy within a short time regardless of their initial energy [5].

In this study, we investigate the particle acceleration in 2D Alfvén wave turbulence where the long-time evolution of parametric instability could be different from that in 1D. It is clarified that the particle acceleration process strongly depends on the magnetized parameter (σ) due to the difference in the rate of decay process.

In 2D Particle-In-Cell simulation, large amplitude ($\delta B/B_0$=1) right-hand polarized parent Alfvén wave is set as an initial condition with the background of pair plasma. When σ is large (σ=1), the parent wave forms the coherent standing wave in the preceded successive decay instabilities, as in the 1D case [Fig. 1 (b)]. At that time, the electrons are efficiently accelerated to relativistic energy at the trough of the magnetic field envelope [Fig. 1 (c)]. On the other hand, when σ is small (σ =0.1), the parent wave rapidly decays into oblique propagating waves at $\omega_{pe}t$=152 [Fig. 1 (a)], the efficient particle acceleration doesn't occur.

References

[1] B. Zhang, ApJ. **836**, L32 (2017).
[2] P. Kumar and P. Bosnjak, MNRAS. **494**, 2385 (2020).
[3] X. Li, A. M. Beloborodov and L. Sironi, ApJ. **915**, 101 (2021).
[4] S. Matsukiyo and T. Hada, ApJ. **692**, 1004 (2009).
[5] S. Isayama, K. Takahashi, S. Matsukiyo and T. Sano, ApJ. **946** 68 (2023).

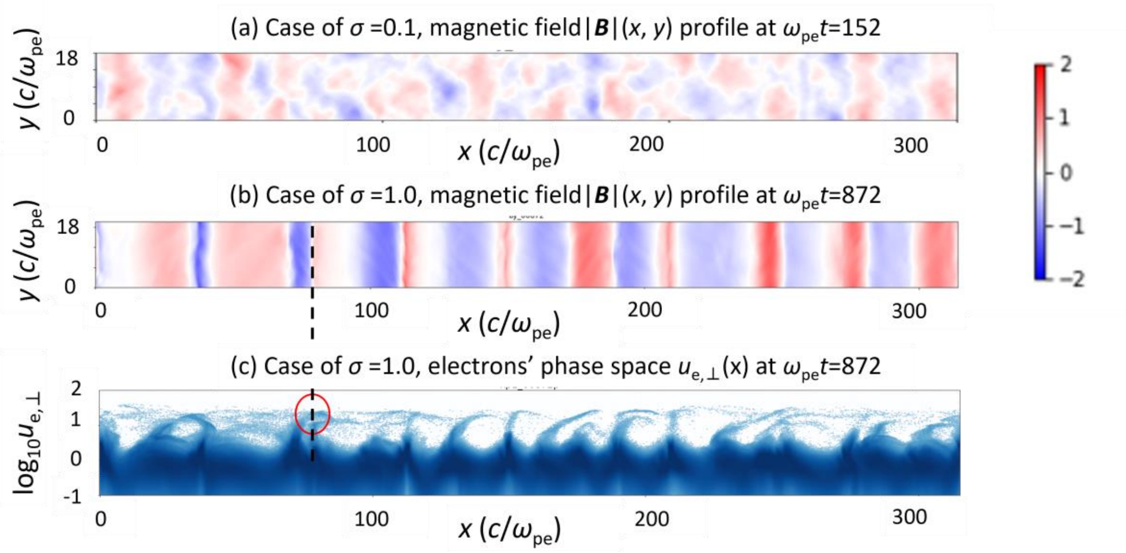

Figure 1 (a), (b) 2D (x-y) profile of the strength of the magnetic field $|\boldsymbol{B}|=\sqrt{B_y^2+B_z^2}$ in the case of σ =0.1 and σ =1.0, respectively. (c) Distribution of electrons' perpendicular (with respect to the ambient magnetic field) momentum $u_{e,\perp}$ in the case of σ=1.0. In the case of σ=1.0, electrons are accelerated at the trough of the magnetic field envelope. Example of such electrons are indicated by the red circle.