Hybridized PIC-Vlasov simulation toward ion acceleration

*Takashi Minoshima[1], Yosuke Matsumoto[2]

1. Center for Mathematical Science and Advanced Technology, Japan Agency for Marine-Earth Science and Technology, 2. Graduate School of Science, Chiba University

Kinetic plasma simulation is an indispensable tool to study microscopic physics such as the wave-particle interaction and the particle acceleration. There are two major methods to numerically treat kinetic plasma. The popular one is the Particle-In-Cell (PIC) simulation, which approximates the velocity distribution by a finite number of superparticles, and each Lagrangian superparticle is advanced in time by solving the equation of motion. The other is the Vlasov simulation, which discretizes the velocity distribution on computational grids, and the Eulerian phase space distribution function is advanced by solving the Vlasov equation. The Vlasov simulation provides noiseless solution though it requires higher computational cost, whereas the PIC simulation is computationally more efficient but inherently suffers from considerable numerical noise.

Due to their pros and cons, the object suited for the PIC and Vlasov simulations is different with each other. The PIC simulation is advantageous to treat cold particles (the bulk velocity is much faster than the thermal velocity), e.g., ions in shock upstream. In contrast, the Vlasov simulation is, by virtue of its noiseless feature, advantageous to treat hot particles, e.g., weakly-magnetized electrons. The Vlasov simulation is known to be robust even with the spatial grid length wider than the Debye length, which may allow large scale simulations. These features evoke us to solve ions by PIC simulations and electrons by Vlasov simulations to enjoy the advantages of both methods. For example, it may allow us to perform large scale, less noisy simulation of ion acceleration. The hybridized particle-Vlasov method has been applied to a cosmological simulation including cold dark matter and hot neutrinos (Yoshikawa et al. 2020), but not to plasma simulation thus far.

We develop the first hybridized PIC-Vlasov simulation method for kinetic plasma, which treats ions as Lagrangian superparticles and electrons as Eulerian phase space distribution function. Standard numerical tests are presented to check the accuracy, stability, and computational efficiency of the method. The method succeeds in solving the ion acoustic instability, which is a stringent problem for both the PIC and Vlasov simulations, indicating that the method is a unique tool to treat the system including cold ions and hot electrons, and their interaction.

Keywords: Particle-In-Cell simulation, Vlasov simulation, Ion acceleration

