Development of multi-scale simulation method via pseudo-particle method

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We develop a new multiscale simulation method, modelling both microscopic kinetic structure and macroscopic fluid motion via pseudo-particle methods. The method can track a transfer from a macroscopic fluid description to a microscopic kinetic description depending on the structure of the system automatically. In the method, we employed PIC to express the microscale, but there was no suitable pseudo-particle method to model the macroscopic fluid motion. Therefore we also develop a pseudo-particle method modelling fluid plasmas extending the Smoothd Particle Hydrodynamics method (SPH)[1] which is popular in the simulations of self-gravitating many body systems.

It is often observed that a microscale structure is driven by macroscopic flow of plasmas and kinetic effect is typically important in that created structure, such as Magnetic Reconnection or Vorticity motion in the turbulence. To treat such complicated multiscale phenomena effectively, we have to find a minimum description of the phenomena, i. e., we have to tackle a generalized 'Closure Problem'. 'PIC-MHD Interlocked Simulation'[[3] proposed by Earth Simulator is one of the efficient approach to this problem. In this presentation, we state that a pseudo-particle method can be a possible canditate of the numerical method to the problem.

This presentation consists of three parts mainly. At first, we show that SPH can be extended to model plasma fluids, i. e., coupling of matter fields with EM fields is accomplished. We call that method EMSPH here. The difference of the particle's property between EMSPH and PIC is that a particle in EMSPH interacts with neighbors, which interaction expresses pressure effect. It is shown that EMSPH also formulated by variational principle as the original SPH and the fact signifies this method reflects Hamiltonian structures of original continuous fluid systems.

Secondly, we discuss the difference between kinetic PIC simulation and fluid EMSPH simulation. To understand a multiscale property of the phenomena, it is important to clarify a limitation of each description and how the difference occurs. We concentrate our attention on kinetic instabilities, such as two-stream instability and Weibel instability[2] which are typical examples of multiscale phenomena because of allowing kinetic and mesoscopic fluid description. We compared nonlinear time development of both simulations. For Weibel instability, it is shown that a saturation level of magnetic field in EMSPH simulation is higher than PIC simulation. This difference can be understood as follows: the pressure effect violates conservation law for EMSPH pseudo-particles.

Thirdly, applying the clarification derived theoretically or numerically in the above , we develop a scale-transiting pseudo-particle method. The method is schemed to develop kinetic effect by changing particle's property and number of particles when the macroscopic description breaks down. We discuss how we transit between different scales and how extent it works. Although the fundamental limitation of this method is given by linear dispersion relation, a possibility of macroscopic description of a steady non-equilibrium state estimated by this method is exploited.

In the presentation, we discuss these subjects via specific simulation results as examples. Also, we will discuss a numerical efficiency of this 'multiscale pseudo-particle method'.

[1] J. J. Monaghan, *Rep. Prog. Phys.*, ***68*** *,1703 (2005)*
[2] E. S. Weibel, *Phys. Rev. Lett*. **2**, 83 (1959)
[3] T. Sugiyama, etc., *Journal of Computational Physics*, **227**, 1340 (2007)