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A contour dynamics method for Vlasov-Poisson system

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In space and laboratory plasmas, collisionless kinetic interactions of charged particles and waves generate a variety of nonlinear plasma phenomena, where the distribution function is largely deformed along particle trajectories in the phase space. Because of the stretching effect near unstable particle orbits, fine-scale structures of the distribution function are spontaneously generated through the wave-particle interactions, of which the simplest example is the ballistic mode. For accurately simulating time-evolution of the fine structures, a novel simulation method is necessary avoiding the numerical dissipation and the artificial entropy production.

Contour dynamics (CD) methods have been employed for simulations of vortex dynamics in two-dimensional incompressible inviscid flows, where iso-contours of vorticity are traced following motion of fluid elements. Piece-wise constant vorticity profile assumed inside of the contours is used for determining the velocity field. It is equivalent to solve a set of the vorticity equation for a given vortex profile and the Poisson equation for the stream function. Since identity of each contour is preserved, the CD method is advantageous for tracking strong deformation of vortices.

The CD method originates from a classical simulation model for the Vlasov-Poisson system, that is, the 'water-bag' model where iso-contours of distribution function are traced in the x-v phase space. In the 'water-bag' model, however, numerical grids were also employed in real space for solving the Poisson equation. It leads to coarse-graining of fine-scale fluctuations, and, in turn, produces numerical dissipation. We have developed a CD method for the Vlasov-Poisson system without using any numerical grids, and report initial results of the CD simulation for a self-gravity system. The numerical accuracy and the conservation properties are examined for symplectic integrators. Applications to the nonlinear Landau damping and the collisionless magnetic reconnection will also be discussed.