Numerical interpolation schemes for Vlasov simulations

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We discuss numerical interpolation schemes used in Vlasov simulation codes. Due to their low noise level, Vlasov codes are widely used for studies of nonlinear wave-particle interactions in plasmas. The numerical methods for solving Vlasov-Maxwell equations fall into two groups. One is particle-in-cell (PIC) simulation which follows motions of individual particles in a self-consistent electromagnetic field. However, limitation of number of superparticles gives rise to numerical thermal fluctuations. Another approach is Vlasov simulation which integrate distribution functions defined in the position-velocity phase-space. An advantage of Vlasov codes is that we can suppress the thermal fluctuations which are strongly enhanced in PIC simulations.

In recent Vlasov simulation codes Vlasov-Maxwell equations are solved based on the numerical interpolation method because of its simplicity of algorithm and easiness for programming. However, we need a large number of grid points in both configuration and velocity spaces to keep mass conservation and to suppress numerical diffusion. In the present study we developed new Vlasov codes with recent higher-order interpolation schemes. We compare the interpolation schemes for a long-time nonlinear problem with respect to numerical diffusion, stability, mass and energy conservations.

We solved the Vlasov equation with the time-advance algorithm called “splitting method” (Cheng & Knorr, 1976). To solve the advection equations split from the Vlasov equation, we used several different numerical interpolation schemes. We found that the mass conservation is an important feature in Vlasov simulations that has a direct influence on the energy conservation. In the present study we propose a new Non-Oscillatory (NO) numerical interpolation scheme for Vlasov simulations, which will be called Polynomial Interpolation for Conservation laws (PIC). The NO-PIC scheme has advantages in numerical stability, computing speed, shape preservation, and energy conservation in Vlasov simulations.