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Charge Conservative Geometric Structure Preserving Particle-in-Cell Scheme for the Relativistic Vlasov-Maxwell System

Jianyuan Xiao[1], Hong Qin[1,2]
[1] Department of Engineering and Applied Physics, USTC,
[2] Plasma Physics Laboratory, Princeton University
e-mail: xiaojy@ustc.edu.cn

The particle-in-cell (PIC) method [1, 2] has been widely applied in simulations of plasma physics. In this method the electromagnetic fields (or the electric potential in electrostatic models) are discretized over a finite mesh and discretized charged particles are moving between these fields. The evolution of particles obeys the discrete Lorentz force equation. When moving they also generate discrete currents, and these currents will again be used in the discrete Maxwell equation (or Poisson equation in electrostatic models) to calculate fields in the next time step. So this method can be viewed as a direct discretization of the particle-field system. In the real world, plasmas often contain particles with very different charge mass ratios, which means they naturally contain multiple time-scales. For example in a typical magnetized electron-proton plasma, the cyclotron frequency of electrons are more than a thousand times larger than ions. So the simulation time step is bounded by the highest frequency in the model, and a lot of time steps are needed when simulating the low frequency physics such as ion motions. This will become a serious draw back for conventional PIC methods because of the accumulation of truncation error, and due to this limit we cannot obtain effective long-term simulation results even using super computers.

To overcome this difficulty, recently a series of geometric structure preserving algorithms for plasma simulations are developed. They have all shown excellent long-term stability and conservation property compared with corresponding conventional methods. The main idea of structure preserving methods is construct discrete iteration maps that preserve the geometric structure associated with the original Hamiltonian system. As long as these geometric structures are preserved, under certain circumstances all invariants (such as total energy and momentum) in the system are also bounded, which is much stronger than introducing artificial constrains on a few conservations.

In this talk, we will give a short introduction on existing structure preserving PIC schemes [3-6]. Then introduce our recent developments on the charge conservative geometric structure preserving PIC scheme for the relativistic Vlasov-Maxwell system [7]. It utilizes modern advanced tools such as discrete exterior calculus (DEC), high-order Whitney interpolating forms and variational symplectic integrators. The resulting scheme has all conservative properties that are desired in long-term PIC simulations, and it can be used to simulating the relativistic Vlasov-Maxwell system, which is also crucial in high energy beam, astrophysical and laser plasmas.

References

[1] R. W. Hockney and J. W. Eastwood, Computer Simulation Using Particles (CRC Press,1988).
[2] C. K. Birdsall and A. B. Langdon, Plasma Physics via Computer Simulation (IOP Publishing, 1991).
[3] J. Squire, H. Qin, and W. M. Tang, Physics of Plasmas 19, 084501 (2012).
[4] J. Xiao, J. Liu, H. Qin, and Z. Yu, Physics of Plasmas 20, 102517 (2013).
[5] J. Xiao, H. Qin, J. Liu, Y. He, R. Zhang, and Y. Sun, Physics of Plasmas 22, 112504 (2015).
[6] M. Kraus, K. Kormann, P. J. Morrison, and E. Sonnendrücker, Journal of Plasma Physics 83 (2017).
[7] J. Xiao, H. Qin, J. Liu, arXiv:1804.08823.