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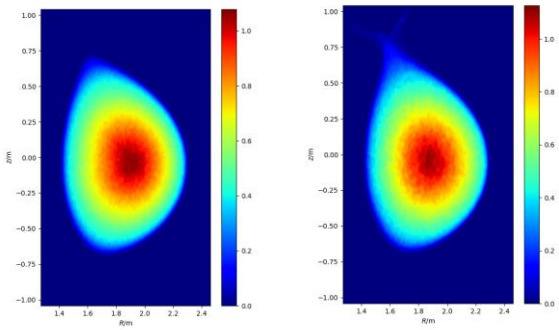
Stucture preserving Particle-in-Cell scheme and its applications on toroidal plasma simulations

Jianyuan Xiao[1]

[1] School of Nuclear Science and Technology, University of Science and Technology of China

Email: xiaojy@ustc.edu.cn

Recently with the deepening of plasma research, the Particle-in-Cell (PIC) simulation becomes more and more favorable since it directly discretize the classical charged particle-electromagnetic field system. However, there are two main difficulties when applying PIC (especially 6D PIC) method to multi-scale physical problems such as magnetic confinement fusion plasmas. Firstly the required amount of computational time is huge, and the computing hardware that is capable to hold such simulation did not exist until very recently. Secondly, conventional PIC schemes have pool long-term conservative property. For example they are usually suffering from the finite-grid instabilities which requires the gird size being smaller than the Debye length [1,2], and in problems where Debye length is significantly smaller than what we are interested, this shortage will significantly increase the computing resource. To overcome these problems, we developed the explicit symplectic structure preserving PIC algorithm in curvilinear orthogonal coordinate systems and implemented it in the SymPIC [3] framework to support all modern advanced heterogeneous large-scale supercomputers. Results show that the code can well extend to system with over 40 million computing cores which is capable to simulate over 100 trillion particles and 250 billion grids [4]. We also developed a routine for simulating toroidal magnetic confinement plasmas based on general 2D Magnetohydrodynamics (MHD) equilibrium. Several plasma edge instability and turbulence simulation cases are presented, which show the method has good agreement with experiments and other numerical simulations.



(a) (b)

Figure 1. The equilibrium 2D density distribution reconstructed from gfile (a), the evolved density distribution by the SymPIC code (b). Units are normalized by the density at the magnetic axis.

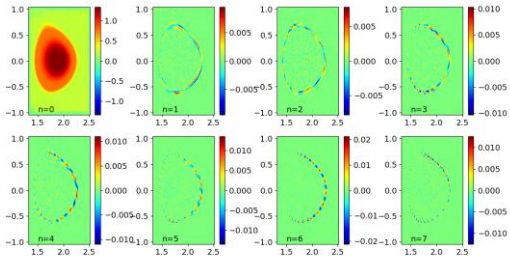


Figure 2. The mode structures for unstable modes with toroidal mode number n based on the equilibrium reconstructed from an EAST H-mode plasma.

References

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