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Multi-Scale Gyrokinetics

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Summary

Simulation codes based on mesoscale gyrokinetics for studying microturbulence in magnetic fusion plasmas using massively parallel computers have been a success for the past decade. For the present Multi-Scale Gyrokinetics (MSG) project, we have been able to develop new mathematical formulations and numerical algorithms for both high frequency gyrokinetics for simulating short wavelength ion cyclotron waves and low frequency gyrokinetics for simulating long wavelength MHD modes. The ultimate goal is to develop the numerical capability for integrated modeling of magnetically confined burning plasmas.

The gyrokinetic approach for arbitrary frequency dynamics in magnetized plasmas has been explored using the gyrocenter-gauge kinetic theory. Contrary to low-frequency mesoscale gyrokinetics, which views each particle as a rigid charged ring, arbitrary frequency response of a particle is described by a quickly changing Kruskal ring, as shown in Fig. 1. This approach allows the separation of gyrocenter and gyrophase responses and thus allows for, in many situations, larger time steps for the gyrocenter push than for the gyrophase push. The gyrophase response, which determines the shape of Kruskal rings, can be described by a Fourier series in gyrophase for some problems, thus allowing control over the cyclotron harmonics at which the plasma responds. A computational algorithm for particle-in-cell simulation based on this concept has been developed. An example of the ion Bernstein wave has been used to illustrate the numerical advantage of the new algorithm in comparisons with the direct Lorentz-force approach.

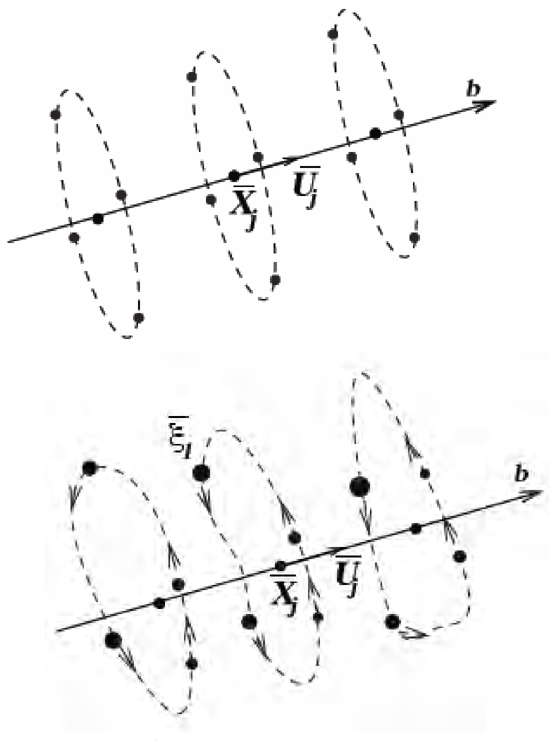

Fig. 1 Low frequency rigid charge rings vs. high frequency Kruskal rings.

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Moreover, explicit dependence on the gyrophase variable may be removed from this 6D algorithm. In the resulting 5D algorithm the gyrophase dynamics is transformed into a set of equations for a finite number of harmonics. In special situations this can result in further computing time savings. A paper, entitled “High Frequency Gyrokinetic particle Simulation,” by R. A. Kolesnikov, W. W. Lee, H. Qin and E. A. Startsev, associated with this work has just been published [Phys. Plasmas 14, 072506 (2007)]

In the low frequency gyrokinetics arena, our aim is to develop a new mathematical formulation that can eliminate the fast particle response associated with the quasi-static bending of the magnetic field lines. This separation is necessary in addition to the usual separation of the adiabatic response associated with the fast particles streaming along the magnetic field lines. With this separation, we are able to eliminate the numerical instabilities associated with finite-β simulations when shrear-Alfven waves physics become important, where β is the ratio between the plasma pressure and the magnetic pressure. A higher β in a fusion device means higher fusion power output and is, therefore, more desirable. As shown in Fig. 2, the new algorithm correctly reproduced the finite-β stabilization of ion temperature gradient drift instabilities. The algorithm is called the double split-weight scheme and the initial results will be presented in the upcoming 2007 American Physical Society/ Division of Plasma Physics Meeting – “A New Split-Weight Scheme for Finite- β Gyrokinetic Plasmas,” by W. W. Lee, E. A. Startsev and W. Wang.

Both of these algorithms will be implemented into our turbulence code, GTC-S [W. X. Wang et al., “Gyrokinetic Simulation of Global Turbulence Transport properties in Takamak Experiments,” Phys. Plasmas 13, 092505(20060], in preparation for the realistic integrated modeling of ITER experiments for burning plasmas.

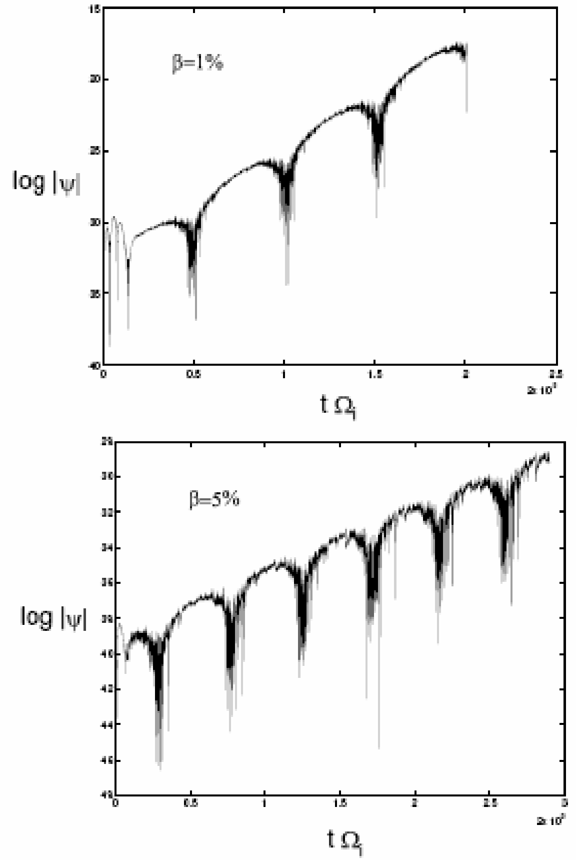

Fig. 2 Finite- β stabilization of ion temperature gradient drift instabilities for β = 1 – 5 %.

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