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Gyrokinetic simulation of the ITG turbulence with toroidal geometry including the magnetic axis by using field aligned coordinates

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Simulation domain in field aligned coordinates of the electrostatic gyrokinetic nonlinear turbulence global code, NLT, is extended to include the magnetic axis. NLT is a continuum code based on the numerical Lie transform method [1, 2]. It is mainly composed of 4 parts: integration along the unperturbed orbit, pull-back transform, Poisson equation solver and numerical filter.

In the first part of NLT for computing the unperturbed guiding center orbit, Hamiltonian equations in cylindrical coordinates are solved if the guiding center is close to the magnetic axis, thus the singularity of Poisson matrix in field aligned coordinates are avoided. Note that the unperturbed orbit is unchanged in the NLT simulation, which can be computed only once at the initial by using the high-precision numerical format.

In the second part, the pull-back transform at the magnetic axis is computed by using formulations in cylindrical coordinates for avoiding the singularity of Poisson matrix in field aligned coordinates. Numerically, partial derivatives in R and Z directions of cylindrical coordinates are computed by using fixed grid points $(\Delta\psi,-\pi)$, $(\Delta\psi,0)$ and $(\Delta\psi,-\pi/2)$, $(\Delta\psi,\pi/2)$ in $\psi-\theta$ plane of field aligned coordinates and combining the toroidal Fourier transform. Thus, the high dimensional coordinates transform is not needed in the NLT simulation.

In the third part, a new gyrokinetic quasi-neutrality equation solver in the long-wavelength approximation with adiabatic electron is developed. The boundary condition at the magnetic axis is the natural boundary condition. The zonal field is solved directly from the gyrokinetic quasi-neutrality equation without using the magnetic surface averaged equation.

In the fourth part, numerical filter, a poloidal wavelength truncated condition, $\frac{m}{r}<[k_\theta\rho]_{max}$, is considered. In the region near the magnetic axis, the retained toroidal mode number is reduced with the radius by considering the new condition.

The conservation of the total gyrocenter number in the nonlinear relaxation test is much improved by including the magnetic axis in simulation domain. The relaxation process obtained in simulation with the magnetic-axis is step-like, which is not observed in previous simulations.

References

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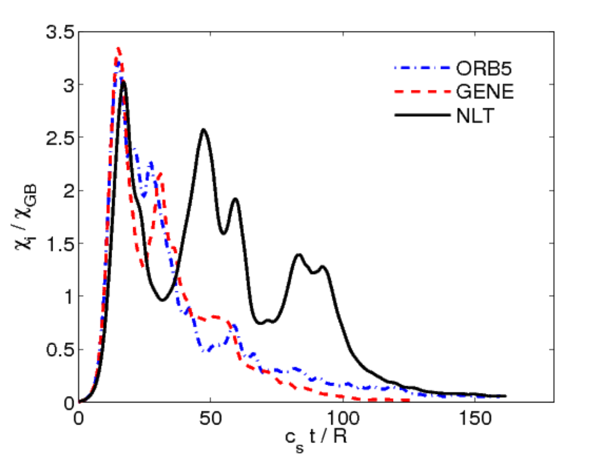

Figure 1. Time evolution of the ion heat diffusivity. The blue dash-dotted line and the red dash line are the simulation results of ORB5 [3] and GENE [4].

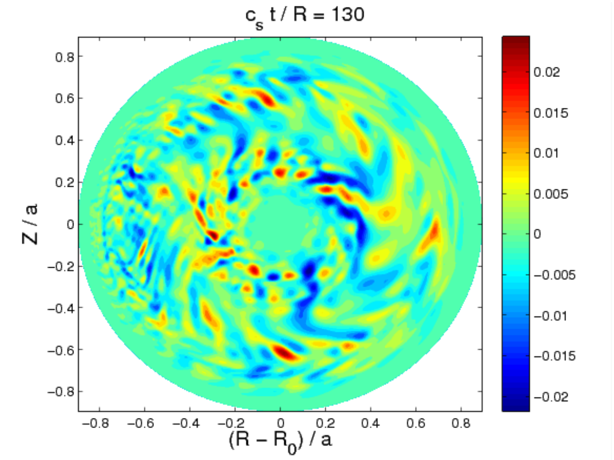

Figure 2. Contours of the non-Zonal electrostatic potential in the nonlinear stage.