§3. Development of a Toroidal ITG Simulation Code for a Flux Tube Geometry

Watanabe, T.-H., Sugama, H. (NIFS)

We have developed the gyrokinetic-Vlasov simulation code for the toroidal ITG mode in a flux tube geometry for a tokamak configuration [1]. In the followings, some of the linear benchmark results are briefly described, while nonlinear simulation results will be shown elsewhere.

The coordinate system and the boundary condition are based on the work by Beer [2], where concentric circular magnetic surfaces with a large aspect ratio are assumed. We consider the gyrokinetic equation for ions, the adiabatic electron response, and the quasi-neutrality. As the first trial, we deal with passing ions only, while neglecting the mirror force term. Spatial coordinates in radial (x) and field-line-label (y) directions are discretized by the Fourier expansion, while the parallel (z) derivatives are approximated by the fifth-order upwind finite difference. The parallel velocity (v₀) and the magnetic moment (μ) are chosen for the velocity space coordinates which are discretized by grid points. The Runge-Kutta-Gill method is used for the time-integration. The simulation code is well optimized in order to achieve high efficiency for vector and parallel operations.

The linear growth rate of the toroidal ITG modes for the Cyclone DIII-D base case parameters [3] are shown in Fig.1, where the solid and dashed lines represent the real and imaginary parts (denoted by ω and γ) of the eigenfrequency obtained by the linear gyrokinetic code [4], respectively. Here, we have employed (84, ±20, ±32, ±64, 32) modes/grid points in the five-dimensional (kₓ, kᵧ, z, v₀, μ)-space, where kₓ and kᵧ denote the wave numbers in the x- and y-directions, respectively. Solid squares and open circles indicate ω and γ obtained by the gyrokinetic-Vlasov simulation results which agree well with the linear code prediction.

In the absence of the electric field, the initial density perturbation n with the ballooning type mode structure is damped due to the phase mixing associated with the toroidal particle drift. Its asymptotic behavior is proportional to t⁻² [4], since not only the parallel advection term but also the toroidal magnetic drift terms contribute to generation of fine-scale structures of the distribution function in the phase space. The collisionless damping process can be successfully reproduced by our simulation as shown in Fig.2, where a finer numerical grid for the (v₀, μ)-space is employed, such as (±192, 64) grid points, in order to continue the run up to t = 100Lₙ/υₙ. In lack of the resolution, otherwise, n unphysically grows at earlier time. The result demonstrates that, also in a tokamak configuration, treatment of the fine-scale structures of the distribution function is one of the key issues for simulating the collisionless damping.

![Figure 1: Real frequency (ω) and linear growth rate (γ) of the toroidal ITG modes for the Cyclone DIII-D base case obtained by the gyrokinetic-Vlasov simulation code. Solid and dashes lines indicate ω and γ obtained by the linear gyrokinetic code [4].](image1)

![Figure 2: Collisionless damping of the density perturbation in a tokamak configuration in absence of the electric field (solid). Dashed line represents the asymptotic behavior (∝ t⁻²) predicted in Ref.[4].](image2)

References