Development of a global version of the gyrokinetic microturbulence code GENE

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Introduction

- The gyrokinetic code GENE [1], has been extended from its original flux-tube version to a global geometry.
- Includes radial variation of temperature and density profiles, as well as of magnetic geometry.
- Non-periodic boundary conditions allow for profile relaxation.
- Heat sources & sinks enable quasi-stationary microturbulence simulations.
- Interface with the MHD equilibrium code CHEASE [2,3].
- Various benchmarks, including comparisons with other global codes are presented.

Global GENE Model

- Field aligned coordinate system \( x = (x, \text{ radial}; y, \text{ poloidal}; z, \text{ parallel}) \) \( \rightarrow \mathcal{B}_0 = c(x) \mathbf{V} \times \mathbf{y} \).
- Gyrokinetic equation with radial \( \psi \) variations of equilibrium quantities.
- Particle distribution function \( f(Y, X, v_y) \) \( \rightarrow \psi_0 \), with \( \psi_0 \) a local Maxwellian.
- Gyrokinetic equation is solved for the perturbed distribution function \( \psi_1 \).
- Perturbed electrostatic and vector potentials \( (A_n, A_{\phi}) \) are self-consistently computed through the quasi-neutrality (Q.N.) equation and parallel component of Ampère’s law.
- Gyrokinetic ordering \( |\psi_1| < |\psi_0| \) \( \rightarrow \) Neglect \( \partial \psi_0/\partial x \) and \( \partial \psi_0/\partial y \).

The Gyrokinetic Equation

\[
\begin{align*}
\psi_1 &= \frac{1}{2} \mathbf{B}_0 \cdot \nabla \times \mathbf{Y} \times \mathbf{B}_0 + \mathbf{B}_0 \cdot \nabla \times \mathbf{Y} \times \mathbf{B}_0 + \frac{1}{\Omega_B} \nabla \times \mathbf{Y} \times \mathbf{B}_0 \\
\epsilon_{\psi_1} &= \frac{1}{2} \mathbf{B}_0 \cdot \nabla \times \mathbf{Y} \times \mathbf{B}_0 + \mathbf{B}_0 \cdot \nabla \times \mathbf{Y} \times \mathbf{B}_0 + \frac{1}{\Omega_B} \nabla \times \mathbf{Y} \times \mathbf{B}_0 \\
\psi_1 &= \frac{1}{2} \mathbf{B}_0 \cdot \nabla \times \mathbf{Y} \times \mathbf{B}_0 + \mathbf{B}_0 \cdot \nabla \times \mathbf{Y} \times \mathbf{B}_0 + \frac{1}{\Omega_B} \nabla \times \mathbf{Y} \times \mathbf{B}_0 \\
\end{align*}
\]

where \( \psi_1 - \psi_0 = q \mathbf{v}_a \mathbf{A}_0 / \mathbf{T}_p \).
- \( \mathbf{A}_0 \) - the Larmor radius, and \( \mathbf{T}_p \) the minor radius.
- Local flux tube result in black.

Benchmarking and Code Comparisons

Codes Used for Comparisons
- Global GENE :
  - Solving in direct space except \( y \)-direction for which Fourier representation is used.
  - Derivatives in real space computed with finite differences.
  - Dirichlet radial boundary conditions.
  - Direct space anti-aliasing scheme in radial direction.
  - Direct space integral gyroaveraging operator in radial direction.

Linear ITG Spectra for CYCLONE Base Case with Adiabatic Electrons

CYCLONE parameters with adiabatic electrons : \( \mathcal{A} / R = 0.36 \), \( \psi^* = \psi_0 = 1.18 \), \( q = 0.85 / 2.4 \mathbf{A} / \mathbf{T}_p, \mathbf{T}_c / \mathbf{T}_p, \) peak \( \mathcal{A} \) and \( n \) profiles with \( \mathcal{A} / \mathcal{A}_0 = 0.6 \), \( \mathcal{A}_0 / \mathcal{A}_0 = 2.2 \), and \( \psi_0 = 0.5 \).

- Good agreement on growth rates and real frequencies.
- Remaining discrepancies at high \( \psi_\phi \) can be assigned to differences in the field solvers (2nd order expansion in \( k_{\phi}/\mathcal{A} \) in GYGiLES, all orders kept in GENE).

Linear ITG-TEM Spectra for CYCLONE Base Case with Kinetic Electrons

CYCLONE parameters with kinetic electrons and mass ratio \( m_i / m_e = 400 \).

- Good agreement obtained for GAM frequency and damping rate, as well as for residual.
- Remaining discrepancies related to \( \psi \)-approximations in GENE, in particular in the gyroaveraging appearing in Q.N. equation.
- After correcting these \( \psi \)-approximations on gyroaveraging:
  - Very good agreement is reached on the Q.N. solution.
  - However, certain modes become unstable ( under investigation ).
- Current simulation results are thus still obtained using the uncorrected gyroaveraging operator.

Reference: