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Semi-implicit electron advection in GYRO*

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Abstract

In this presentation we discuss continuing progress on GYRO – a physically comprehensive global Eulerian gyrokinetic code for simulating turbulent transport in tokamaks. Beyond the now standard ion-temperature-gradient (ITG) mode turbulence, the code includes trapped and passing electrons with pitch angle collisions, finite-β fluctuations, real flux-surface shape, linear and nonlinear $\mathbf{E}\times\mathbf{B}$ rotation, and parallel flow shear. It operates at finite $\rho_* = \rho_i/a$ using a WKB-like formulation to treat the small $1/n$ corrections due to radial variation of ω_*, η_i, s, etc, not present in the flux-tube approximation. A special technique[1] to remedy the troublesome Ampère cancellation problem[2] is critical to the finite-β mode of operation. A variant of this technique has recently been adopted for use in flux-tube gyrokinetic PIC codes,[3] apparently solving a longstanding problem for finite-β particle simulations. An important previous result is that we have shown systematically how to recover gyroBohm-scaled transport in the small-ρ_* limit with both quasi-periodic and non-periodic boundary conditions.[4] In this limit, we also reproduce the nonlinear, flux-tube Cyclone benchmarks[5] over the full range of R/L_T. First attempts to simulate actual DIII-D plasmas (shown at Sherwood 2002) gave transport levels within a factor of two of experimental levels. However, new and challenging obstacles (beyond the Ampère cancellation problem) arise with kinetic electrons at long wavelength; to wit, we found that these simulations were limited to radial box sizes of $80\rho_i$ or smaller (one-third the minor radius) and $\mu = \sqrt{m_i/m_e} = 20$ due to weak a $n = 0$ *box instability*. For this reason, we have implemented and are testing various implicit-explicit Runge-Kutta methods.[6] These treat the linear parallel electron advection implicitly, coupling the Poisson and Ampère equations, and subsequently regularizing them at long wavelength. The new schemes allow simulations with unrestricted radial domain sizes. Now, $240\rho_i$ DIII-D runs with $\mu = 60$ (deuterium) now execute in about the same real time as our original $80\rho_i$, $\mu = 20$ simulations. Very exciting but still preliminary results show electron *and* ion transport move closer to the DIII-D L-mode experimental levels in real-mass-ratio, large-domain simulations. We report on these new results, on new algorithms connected with the semi-implicit solver, and also discuss the reimplementation of GYRO as tool to rapidly scan *local* linear eigenfrequencies over global experimental profiles (for use with external transport modeling). We also discuss implementation and documentation issues of interest to the growing GYRO user base.

*Work supported by the U.S. Department of Energy under Grant Nos. DE-FG03-95ER54309 and the SciDAC Plasma Microturbulence Project.

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