GYRO full radius gyrokinetic simulations with transport solutions

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GYRO is a physically comprehensive continuum global 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, electromagnetic finite beta perturbations, real geometry from Miller local equilibrium, ExB and parallel flow shears. It operates at finite (but small) rho-star and treats general profile shear stabilization in a WKB-like approximation. Tremendous progress has been made since the project began in 1999: We have demonstrated comprehensive simulations of Bohm-scaled DIIID L-mode rho-star scaled discharges within a factor 2 of experimental transport levels given experimental profiles. These simulations can be done with nearly full radius radial slices (240 gyroradii) and realistic electron mass (mu = root(m_i/m_e) = 60) using 48hrs on 512ps at seaborg.nersc.gov. As we moved to larger radial slices and mu > 20, 4th order explicit Runge-Kutta (RK) methods originally used in GYRO, could not follow the extremely fast “electrostatic” Alfven modes (ESAM) and n=0 “radial box” numerical instabilities developed. New 2rd order implicit-explicit Runge-Kutta (IMEX-RK) methods which split off the stiff linear parallel electron motion for implicit treatment, damp the ESAM have proven to be essential for full radius simulations. Since the core transports in DIII is stiff, small 10% reduction in the driving gradients (well within experimental uncertainty) bring the simulated power flows into agreement with experimental flows. Gyrokinetic codes are too expensive to run longer than a few percent of the transport confinement time. Conventionally they find the power flows given the experimental plasma profiles. However given the stiff nature of core transport, it is more accurate to predict plasma profiles given experimental flows. Thus an outer transport loop has been added to GYRO. By a simple diagonal feedback which adjusts the driving gradients to force simulation flows to match experimental flows, we obtain steady state transport profile solutions. The adjusted or transported profiles are pivoted about a given radius where the temperatures and density are forced to match the experiment. The transported profiles away from the pivot are well within experimental error bars. We match both electron and ion temperature as well as the moderately density profiles. The core of DIIID operates near the null plasma flow resulting from a temperature gradient driven pinch.

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