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*Princeton Plasma Physics Laboratory, Princeton, New Jersey, USA.

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A New Paradigm for ExB Velocity Shear Suppression of Gyro-kinetic Turbulence and the Momentum Pinch

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G.M. Staebler[1], R.E. Waltz[1], J.E. Kinsey[1], and W.M. Solomon[2]
e-mail: staebler @fusion.gat.com

[1]General Atomics, P.O. Box 85608, San Diego, California 92186-5608, USA
[2]Princeton Plasma Physics Laboratory, Princeton, New Jersey 08543-0451, USA

The Reynolds stress produced by toroidal rotation has contributions from the parallel velocity shear as well as from the shear in the *ExB* Doppler shift γ_{ExB}. Even for pure *ExB* toroidal rotation these two terms in the gyro-kinetic equation contribute to the toroidal Reynolds stress with opposite signs. The Doppler shear part is a pinch against the parallel shear part which has the sign expected for momentum diffusion. Even without external torque (zero toroidal stress) or a seed flow, the Doppler shear pinch can generate a finite *ExB* velocity shear. If the parallel flow shear is reduced by the ion diamagnetic flow then this effect is stronger. Computing the Doppler shear pinch term with a quasilinear model is not possible using only an amplitude suppression factor like the quench rule [1]. It was conjectured [2] and later verified [3] that the momentum pinch could be caused by a shift in the radial wavenumber spectrum of the electric potential fluctuations giving a finite spectral average $\langle k_x \rangle$. A new understanding of the way in which shear in the *E*x*B* velocity Doppler shift changes gyro-kinetic transport has been achieved [4] by studying the nonlinear radial mode spectrum of simulations with the GYRO gyro-kinetic code[5]. The simulations show that the sheared Doppler shift causes the time-averaged amplitude of the electric potential fluctuations, at a fixed toroidal mode number, to be shifted off center and reduced in magnitude as illustrated in Fig. 1. The model spectra in Fig. 1 (dashed lines) use functions that depend only on the value of the radial wavenumber at the shifted peak. Hence, all of the suppression due to the Doppler shear is related to the spectral shift. This "spectral shift" model is a new paradigm for the *ExB* Doppler shear suppression mechanism. The spectral shift model yields a more accurate quasilinear calculation of the impact of toroidal rotation shear on all of the transport channels in the trapped gyro-Landau fluid (TGLF) model [6] than was obtained from the quench rule. The electron energy flux computed by TGLF using the spectral shift model and the quench rule are compared to GYRO simulation results in Fig. 2(a). The spectral shift model gives a weaker suppression at low Doppler shear than the quench rule but is stronger at large Doppler shear. It agrees better with GYRO in both ranges. These high-resolution, kinetic electron, nonlinear GYRO runs do not completely "quench" the turbulence but show an increase in the spectral shift and peak reduction at large Doppler shear. Similar improvements of the fidelity of TGLF to the GYRO

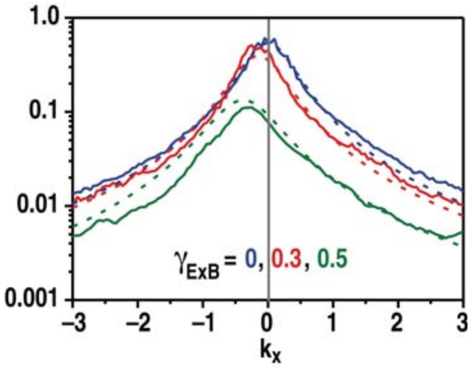

Fig. 1. Time average radial wavenumber spectrum of the electrostatic potential fluctuation amplitude in gyro-Bohm units for k_y=0.3 and three values of the *ExB* Doppler shear. GYRO (solid) and spectral shift model (dashed).

ion energy flux are obtained with the spectral shift model. It is remarkable that fitting the radial wavenumber shift and amplitude reduction of the nonlinear GYRO spectrum in Fig. 1 produces these good fits to the transport when used in the TGLF linear eigenmodes and amplitude model. The phase shift of the linear eigenmodes at finite k_x is responsible for the finite toroidal Reynolds stress computed with TGLF in Fig. 2(b). The new TGLF model was used to simulate a DIII-D discharge with nearly balanced neutral beam injection shown in Fig. 3. The integrated torque is near zero but there is a small torque density near the axis due to beam orbit effects. The effective momentum diffusivity is weak near the axis so that most of the observed rotation is due to this small torque. Kinetic impurities were included in TGLF and in the high accuracy code NEO [7] used for the neoclassical transport and poloidal flows. The agreement with the carbon rotation data is better with the diamagnetic and neoclassical flows included (green) than for a pure *ExB* rotation (red). Verification of the spectral shift model in TGLF with GYRO scans over plasma parameters will be presented. Simulation of low and high torque DIII-D discharges with the spectral shift model in TGLF will also be shown.

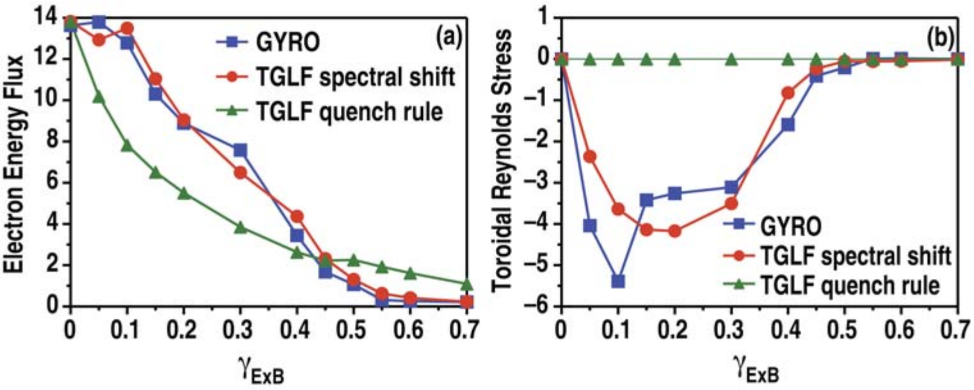

Fig. 2. (a) Doppler shear scan showing the electron energy flux (a) and toroidal stress (b) for the GA standard case comparing nonlinear GYRO and quasilinear TGLF results for the spectral shift and the quench rule models.

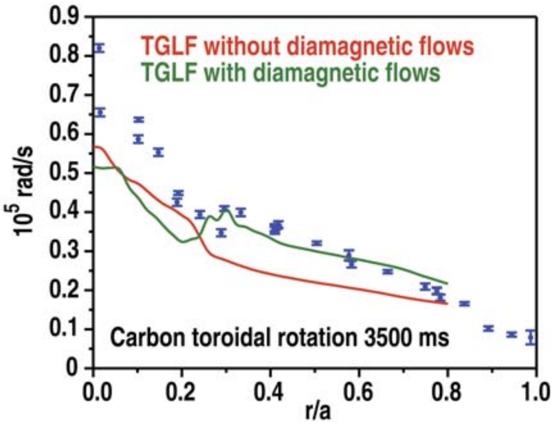

Fig. 3. TGLF simulation of the carbon toroidal rotation frequency of DIII-D discharge 125236 at 3.5 s.

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