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ITG and TE mode turbulence and transport in advanced fluid descriptions

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We present an investigation of transport in tokamaks due to turbulence driven by ion temperature gradient (ITG) modes and collisionless trapped-electron (TE) modes. The study is based on the Weiland fluid model[1] for ions and deeply trapped electrons, which is complemented and compared with a trapped electron fluid treatment[2] retaining the contributions from the weakly trapped particles to the bounce averaged magnetic drifts. The study considers plasmas with $T_i=T_e$ as well as TE mode dominated regimes with $T_e>>T_i$, relevant to tokamak experiments with dominant central electron heating. The dependence of the transport coefficients on magnetic shear and other plasma parameters is discussed and compared with recent results obtained from nonlinear gyrokinetic simulations.

The models have been described in detail in refs 1 and 2, a brief summary is given here. Each species is described by the continuity, parallel momentum, and energy equations for the perturbations in density, parallel velocity and pressure. The ion and trapped electron fluid models are symmetric, except that the parallel velocity perturbation is zero for the bounce averaged trapped electron fluid, and electron finite-Larmor-radius (FLR) effects can be neglected. In the TE fluid treatment the electron magnetic drift is, after the bounce averaging, replaced by the precession frequency of trapped electrons as $<\omega_{De}> = \omega_{De} \cdot \lambda_t$ where $\omega_{De} = 2k_\theta\rho_s c_s/R$ and the parameter $\lambda_t=1/4+s\cdot 2/3$ characterizes the dependence of the precession frequency on the magnetic shear s. The original formulation of the Weiland model for deeply trapped particles is recovered for $\lambda_t=1$. We note that the two TE fluid models are identical for a magnetic shear of s=9/8 ($\lambda_t=1$), but may differ substantially with regard to the magnetic shear scaling. The electrostatic limit is considered and the free electrons are assumed to be Boltzmann distributed. The ion and electron perturbations are coupled through the quasineutrality condition $\delta n_i/n_i = f_t\ \delta n_{et}/n_{et} + (1-f_t)\ \delta n_{ef}/n_{ef}$, where f_t is the fraction of trapped electrons. The resulting eigenvalue equation is then reduced to a set of 5 coupled algebraic equations by assuming a strongly ballooning eigenfunction. The coupled system of 5 algebraic equations describes ITG modes, driven by R/L_{Ti} and suppressed by R/L_n, and collisionless TE modes driven by both R/L_{Te} and R/L_n.

The corresponding transport coefficients are calculated using quasilinear theory and a modified mixing length estimate, supported by nonlinear fluid simulations[3] of ITG-TE mode turbulence. In the quasilinear expressions, the space scale of the turbulence is fixed by choosing $(k_x \rho_s)^2 = (k_\theta \rho_s)^2 = 0.1$, corresponding to the scale of the fastest growing mode.

a) ITG/TE mode system

The standard set of parameters used here are taken from a recent nonlinear gyrokinetic investigation[4] with $T_e/T_i=1$, $R/L_{Ti}=R/L_{Te}=9$, $R/L_n=3$, $f_t=0.52$ ($\varepsilon=0.16$), q=2, and s=1. For these parameters, the dominant instabilities are of ITG type, propagating in the ion drift direction.

In Fig.1 the particle diffusivity D as a function of magnetic shear s is displayed with R/L_n as a parameter. The results are shown for the original Weiland model for deeply trapped particles ($\lambda_t=1$) and for the TE model including bounce averaged magnetic drift effects ($\lambda_t=1/4+s\cdot 2/3$). As observed, the magnetic shear scaling is dominated by the magnetic drift effects whereas the shear dependence in the original Weiland model, originating mainly from effects of FLR and parallel ion dynamics, is rather weak. The particle pinch, predicted by both TE models for $s\geq 1$, is reduced for weak and negative magnetic shear by the magnetic drift effects ($\lambda_t=1/4+s\cdot 2/3$). The resulting shear scaling shows a particle transport that can change sign as s is varied, in qualitative agreement with the nonlinear gyrokinetic study[4]. In Fig.2 the corresponding ITG/TE mode growth rates are displayed. For the TE mode, the $\lambda_t=1/4+s\cdot 2/3$ model predicts complete TEM stabilization as the electron precession frequency changes sign, whereas for the original Weiland model a very weak shear scaling of the TEM growth is obtained. For the ITG mode growth rate, a rather weak dependence on magnetic shear is obtained for these parameters.

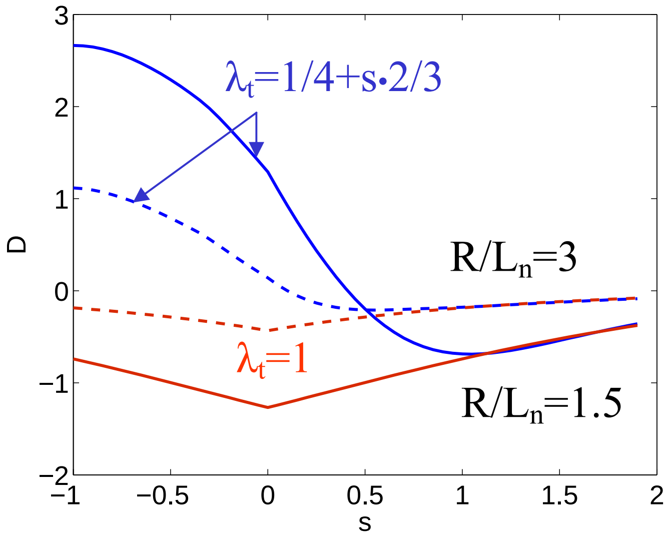

Fig. 1. Particle diffusivity (in units of $2\rho_s^2c_s/R$) as a function of magnetic shear s for λ_t=1/4+s·2/3 and λ_t=1 with R/L_n as a parameter.

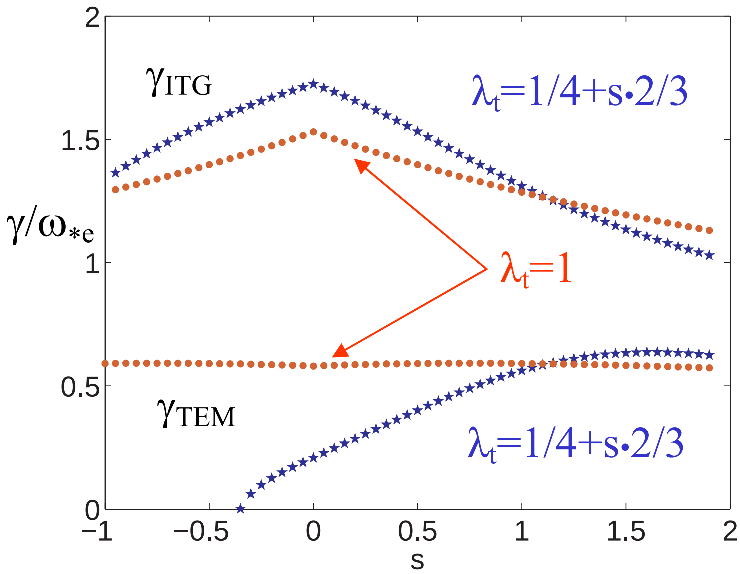

Fig. 2. ITG/TE mode growth rates as a function of magnetic shear s for R/L_n=3 and the other parameters as in Fig. 1.

b) Pure TE mode case

Here we focus on pure TEM turbulence by considering the limit R/L_{Ti}=0 and T_e>T_i where the ITG physics is suppressed. The TEM dominated regime, which is particularly suitable for a comparison of TEM models, is relevant to tokamak discharges with dominant central electron heating where the ions are rather cold. The set of parameters used are T_e/T_i=3, R/L_{Ti}=0, R/L_{Te}=6, R/L_n=3, f_t=0.52 (ε=0.16), q=1.4, and s=0.8.

In Fig.3 the scaling of TEM driven particle diffusivity as a function of magnetic shear s is displayed. The results are shown for the original Weiland model for deeply trapped particles (λ_t=1) and for the model including bounce averaged magnetic drift effects (λ_t=1/4+s·2/3). As in the ITG dominated case, the magnetic shear scaling is dominated by the magnetic drift effects. The results are in qualitative agreement with the nonlinear gyrokinetic results of ref.5.

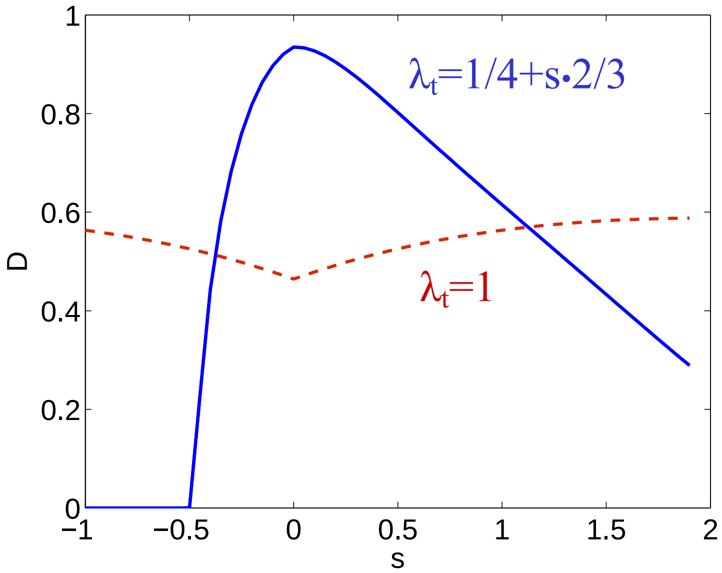

Fig. 3. TEM driven particle diffusivity (in units of $2\rho_s^2 c_s/R$) as a function of magnetic shear s for λ_t=1/4+s·2/3 and λ_t=1.

We have verified that particle pinches (inward flows) driven by pure TEM turbulence are obtained for sufficiently flat density profiles combined with steep electron temperature profiles. Electron heat pinches are obtained in the opposite limit.

References

1. J. Weiland, Collective Modes in Inhomogeneous Plasmas, IoP 2000.
2. X. Garbet, L. Garzotti, P. Mantica, et al, Phys. Rev. Lett. 91, 035001-1 (2003).
3. H. Nordman, J. Weiland, and A. Jarmen, Nucl. Fusion 30, 983 (1990).
4. J. E. Kinsey, R. E. Waltz and J. Candy, Phys. Plasmas 13, 022305 (2006).
5. T. Dannert and F. Jenko, Phys. Plasmas 12, 072309 (2005).