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Effects of plasma current on drift wave turbulence

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Introduction

The operation mode of the future thermonuclear reactors is constrained by the demand of reducing the turbulent transport, which has a major impact on the determination of the energy confinement time. The predictions on the turbulent transport level in ITER are based on scaling laws extrapolated from experimental data, rather than a proven and justified transport model. In these laws the exponent of plasma current is of order unity, hence the importance of this parameter and the necessity to bring theoretical bases to the scaling laws found in the experiments. Global nonlinear gyrokinetic simulations can provide more insight to these experimental observations as it has been shown in [1]. From those studies a relationship emerges among the turbulent transport, zonal flow and GAM oscillations through the total plasma current. The amplitude of GAM oscillations increases at lower plasma current, resulting in a less effective suppression of ITG turbulence by zonal flows. Plasma current has an effect not only on GAMs but also on important quantities such as the orbit widths and linear stability spectrum. As a consequence of the combination of these effects, the ion heat flux in the radial direction (the direction relevant for confinement) is found to scale linearly with the total plasma current. In [1], the analysis has been restricted to a decaying turbulence because of numerical and computational limitations. In the following, it will be shown how this analysis can now be extended to stationary turbulence, thanks to recent improvements in numerical techniques and to the availability of more computational power. In particular, the introduction of a new noise control method and of heat sources [2] make it possible to run simulations of a steady state turbulence with the global nonlinear gyrokinetic code ORB5 [3][4]. These simulations, compared to the previously available ones, allow us to extend the analysis of the mutual interactions of ITG turbulence and large scale flows to a stationary state and to perform a more rigorous statistic analysis of turbulent transport.

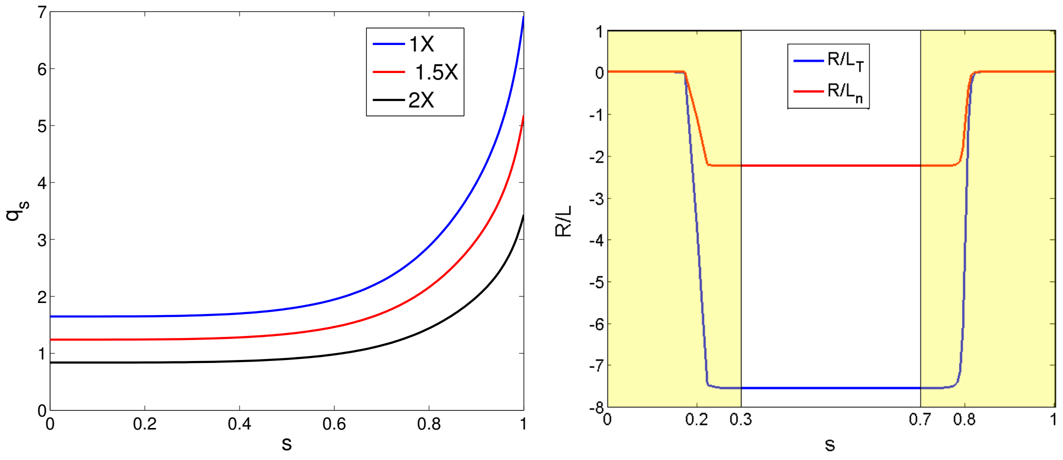

Figure 1: [left] The three safety factor q_s profiles labelled accordingly to the total plasma current case. [right] Logarithmic gradient profiles of temperature (R/L_T) and density (R/L_n). The regions where the heat source/sink is applied are marked with yellow boxes.

Model and parameters

In the code ORB5, ion motion is described by means of the nonlinear gyrokinetic Vlasov equation discretized with a Particle In Cell (PIC) scheme. An adiabatic model is used for electrons, where the flux surface averaged part of the potential has been subtracted in order to obtain the correct zonal flow amplitude [5]. The system is closed by the Poisson equation that, in the long wavelength approximation, reduces to quasi neutrality equation which is solved with a finite element scheme (FEM).

Three simulations are presented where the total plasma current has been varied in three steps: 1, 1.5, 2 (these values are used in the following to label the simulations) times a basic value of $I_{N0} = 0.31$, where I_N is the normalized current $I_N = I_P/aB$. Here, I_P is the plasma current [MA], $a = 0.48$ the minor radius on equatorial plane [m], and $B = 1.91$ the vacuum magnetic field at the center of the discharge [T]. The variation of total plasma current presented here is equivalent to a rescaling of the safety factor (q_s) profile as shown in Fig. 1-left, while all the other parameters are kept constant (in particular the magnetic shear, which is known to have important effects on the underlying micro-instabilities). The basic configuration is Deuterium plasma with circular magnetic surfaces, normalized Larmor radius $\rho_* = 1/256$ and inverse aspect ratio 0.36. The initial profiles of temperature and density gradient are shown in Fig. 1-right.

A Krook operator modified to conserve energy and preserve zonal flows [2] has been applied. Values used in this paper for the Krook noise control coefficient are $\gamma_s \sim \gamma_{ITG}/20$ (where γ_{ITG} is the linear growth rate of the ITG instability), which will be found effective

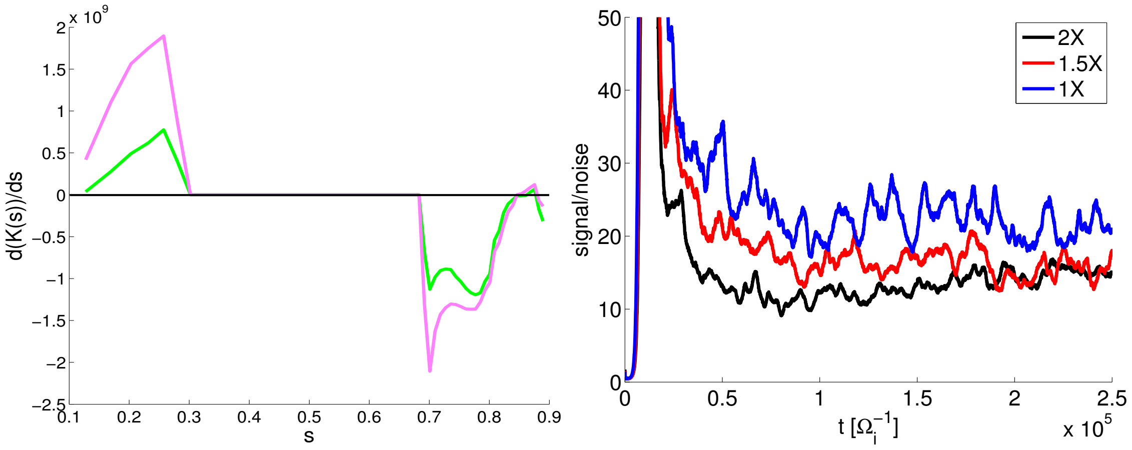

Figure 2: [left] Power per unit radius. $K(s)$ is the power deposited in the volume inside the flux surface s, with the energy in units of $m_i v_{Ti}^2$, m_i and v_{Ti} being the ion mass and thermal velocity respectively. [right] Signal to noise ratio.

to avoid sampling noise accumulation at late times. In all simulations the noise to signal level is kept below 10% as shown in Fig. 2-right (the noise definition used here is the one proposed in [6]). In addition, a heating operator has been chosen to act only in selected 'buffer' regions, one spanning the radial interval $0. < s < 0.3$ and the other spanning the radial interval $0.7 < s < 1$ (s is the radial coordinate defined as $s = \sqrt{\psi/\psi_{edge}}$). This choice, combined with the shape of the temperature gradient, effectively couples the plasma with a thermal bath, sustaining the temperature at the center and cooling down the plasma edge, but leaving a turbulent region where the temperature gradient is left free to evolve self-consistently. The effective profile of the energy deposited, integrated over the whole simulation time, is plotted in Fig. 2-left.

Results and conclusions

We compare the time evolutions of the temperature gradient (represented by the temperature gradient length R/L_T) and of the heat flux. These two quantities are averaged over the radial interval $0.3 < s < 0.7$, where the drive of the turbulence is maximum and the source is switched of. A temporal moving average is also applied with a time window of $7 \cdot 10^4\,\Omega_{ci}^{-1}$. Fig. 3 shows that decreasing the total plasma current causes a net increase in the turbulent heat flux which results in an increased difficulty in sustaining the temperature gradient with a fixed source level (here represented by the Krook heating coefficient $\gamma_H = 1 \cdot 10^{-4}$). Doubling the input power in the 1X case compared to the 2X case (Fig. 2) is still not sufficient to maintain a temperature gradient as steep as for the 2X case, see Fig. 3-left.

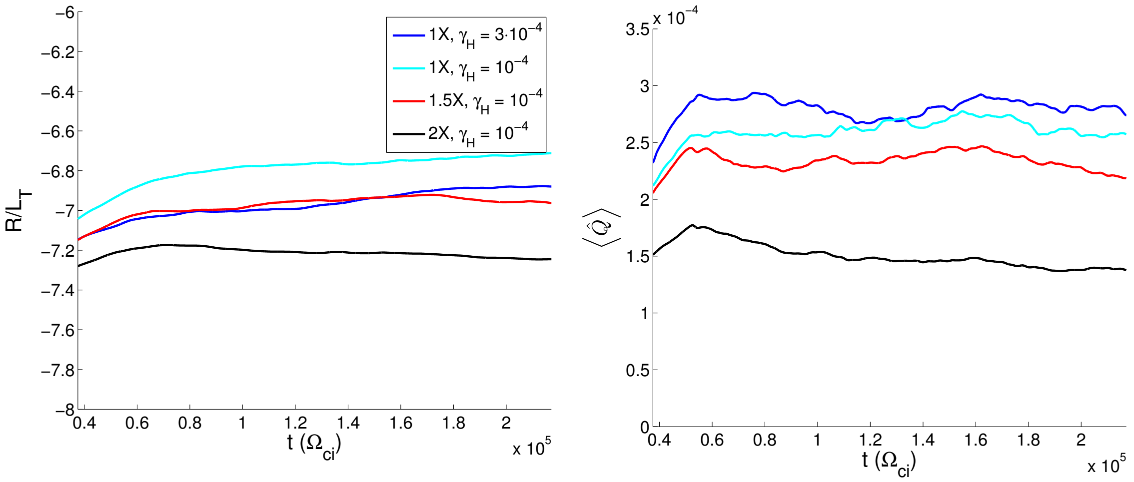

Figure 3: [left] Temporal moving average of the ion temperature gradient length R/L_T. [right] Temporal moving average of the normalized heat flux $\hat{Q} = Q/(n_i c_s T_e)$. n_i is the ion density, c_s the sound speed and T_e the electron temperature.

These results show that the dependence on the current of the turbulent transport found for decaying turbulence [1] can be extended to a stationary turbulent state, thus the presence of an extra degree of freedom, represented by the heat source, makes not trivial to recover the linear behavior of transport with the total plasma current (see Fig. 3-right). A statistical analysis of zonal flow and GAM properties will be the subject of future work.

Acknowledgments

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