*33rd EPS Conference on Plasma Phys. Rome, 19 - 23 June 2006 ECA Vol.**30I**, P-4.151 (2006)*

Turbulence Spreading through a Transport Barrier

T.S. Hahm, W.X. Wang, G. Rewoldt, J. Manickam, and W.M. Tang

Princeton Plasma Physics Laboratory, PO Box 451, Princeton, NJ 08543, USA

Turbulence spreading through a transport barrier is studied using newly developed gyrokinetic simulation capabilities including the mean $\mathbf{E}\times\mathbf{B}$ shear and non-circular cross section. We perform a series of numerical experiments by placing an E_r well, with varying strength, next to the region where the ITG instability is linearly unstable. It is found that an $\mathbf{E}\times\mathbf{B}$ shear layer with an experimentally relevant level of the shearing rate can significantly reduce the spreading extent and speed of the propagation. From the spatio-temporal evolution of the turbulence propagation front, we find that the spreading slows down significantly in the region of higher shearing rate, rather than at the bottom of the E_r well. Therefore, the $\mathbf{E}\times\mathbf{B}$ shearing rate, ω_E, is the key local quantity in slowing down the turbulence spreading.

I. Introduction

Tokamak experiments often show evidence that nonlocal dependence exists in plasma transport. In this work, the nonlocal physics associated with turbulent transport is investigated using newly developed simulation capabilities. Our global gyrokinetic particle simulations incorporate the comprehensive influence of non-circular cross section, realistic plasma profiles, plasma rotation, neoclassical (equilibrium) electric fields, and Coulomb collisions[1], and therefore can effectively address experimentally relevant issues.

Our previous studies have shown that turbulence spreading from a strongly unstable region to a less unstable or stable region can play an important role in both transport scaling with machine size[3] and effects of edge turbulence on core confinement[4]. Simulations of ion temperature gradient (ITG) turbulence reported in this paper are carried out for shaped toroidal plasmas based on DIII-D geometry. From numerical experiments with nonlinear mode coupling and/or zonal flows artificially suppressed[2], we find that: i) the linear toroidal coupling can induce convective propagation of fluctuations into the region of local linear stability[5]; ii) in the presence of nonlinear mode coupling, without zonal flows, the turbulence spreading is faster with temporal asymptotic behavior ranging from "convective" in the linearly unstable zone[4, 6], to more "diffusive" in the linearly weakly stable zone; iii) the principal effect of self-generated zonal flows is to reduce the intensity of fluctuations, and to slow down the turbulence spreading consequently. Spreading stops when the linear damping is strong enough[3].

II. Gyrokinetic Simulations with Mean $\mathbf{E} \times \mathbf{B}$ Shear

Some experiments report the existence of density fluctuations and anomalous heat transport in the region of almost flat density and temperature profiles, inside the location of the internal transport barrier[7]. Since microinstabilities are expected to be stable in this region[8], we look for the possibility of the turbulence spreading through a transport barrier characterized by an $\mathbf{E} \times \mathbf{B}$ shear layer. It has been found from recent gyrofluid simulations that turbulence spreading can occur through a q_{min} surface in reversed shear plasmas as well[9]. These studies can provide interesting new insight into transport barrier physics[10, 11] which were often characterized by the radially local $\mathbf{E} \times \mathbf{B}$ shearing rate, ω_E[12].

We perform a series of numerical experiments by placing a radial electric field well, with varying strength, next to the region where the ITG instability is linearly unstable. It is found that the radial extent of turbulence spreading (of steady state fluctuation intensity) is reduced, as the $\mathbf{E} \times \mathbf{B}$ shear layer, located next to the unstable ITG source region, becomes deeper as shown in Fig. 1. An $\mathbf{E} \times \mathbf{B}$ shear layer with an experimentally relevant level of the shearing rate can significantly reduce turbulence spreading, both in the spreading extent and speed. The peak $\mathbf{E} \times \mathbf{B}$ shearing rate for case 2 in Fig. 1 roughly corresponds to the value observed in a strong internal transport barrier in tokamaks. From the spatio-temporal evolution of the turbulence propagation front plotted in Fig. 2, we find that the spreading slows down significantly in the region of higher ω_E, rather than at the bottom of the E_r well where the magnitude of E_r is a maximum. Therefore, we conclude that the $\mathbf{E} \times \mathbf{B}$ shearing rate is the key local quantity in slowing down turbulence spreading. Studies of more realistic E_r profiles are in progress alongside development of an analytic model.

Acknowledgments

The first author would like to thank P.H. Diamond and O. Gurcan for useful discussions. This work was supported by U.S. Department of Energy Contract No. DE–AC02–76–CHO-3073, and the US DOE SciDAC Center for Gyrokinetic Particle Simulation of Turbulent Transport in Burning Plasmas.

References

[1] W. X. Wang *et al.*, Computer Phys. Communications **164**, 178 (2004).

[2] W. X. Wang *et al.*, Submitted to Phys. Plasmas (2006).

[3] T. S. Hahm *et al.*, Plasma Phys. Control. Fusion **46**, A323 (2004).

[4] T.S. Hahm *et al.*, Phys. Plasmas **12**, 090903 (2005)

[5] X. Garbet *et al.*, Nucl. Fusion **34**, 963 (1994).

[6] O. Gurcan, P.H. Diamond, T.S. Hahm, and Z. Lin Phys. Plasmas, **12**, 032303 (2005).

[7] R. Nazikian *et al.*, Phys. Rev. Lett. **94**, 135002 (2005).

[8] G. Rewoldt *et al.*, Nuclear Fusion **42**, 403 (2002).

[9] M. Yagi *et al.*, Plasma Phys. Control. Fusion **48**, A409 (2004).

[10] P.H. Diamond *et al.,* Phys. Rev. Lett. **78**, 1472 (1997).

[11] T. S. Hahm, Plasma Phys. Control. Fusion **44**, A87 (2002).

[12] T. S. Hahm and K. H. Burrell, Phys. Plasmas **2**, 1648 (1995).

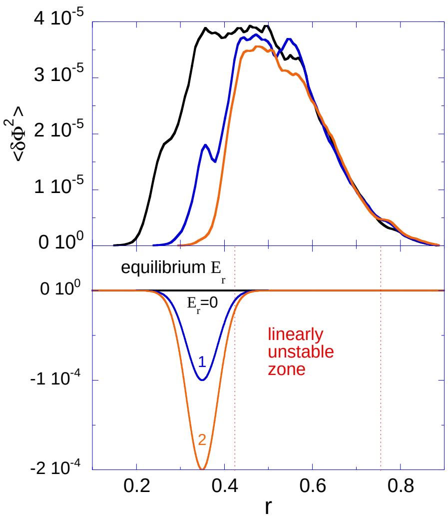

Figure 1: The radial extent of turbulence spreading (of steady state fluctuation intensity) is reduced, as the $\mathbf{E}\times\mathbf{B}$ shear layer, located next to the unstable ITG source region, becomes deeper.

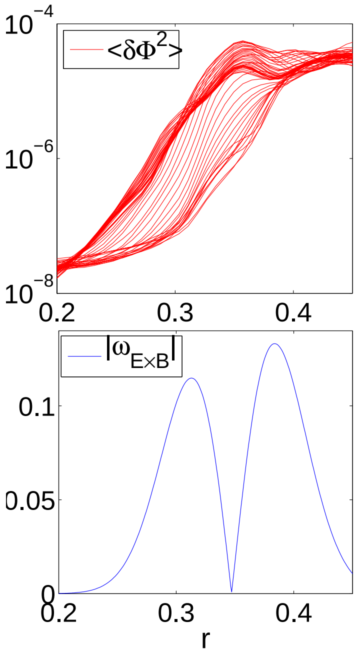

Figure 2: The spatio-temporal evolution of fluctuation front propagation shows that turbulence spreading slows down significantly in the regions where the $\mathbf{E}\times\mathbf{B}$ shearing rate peaks