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by

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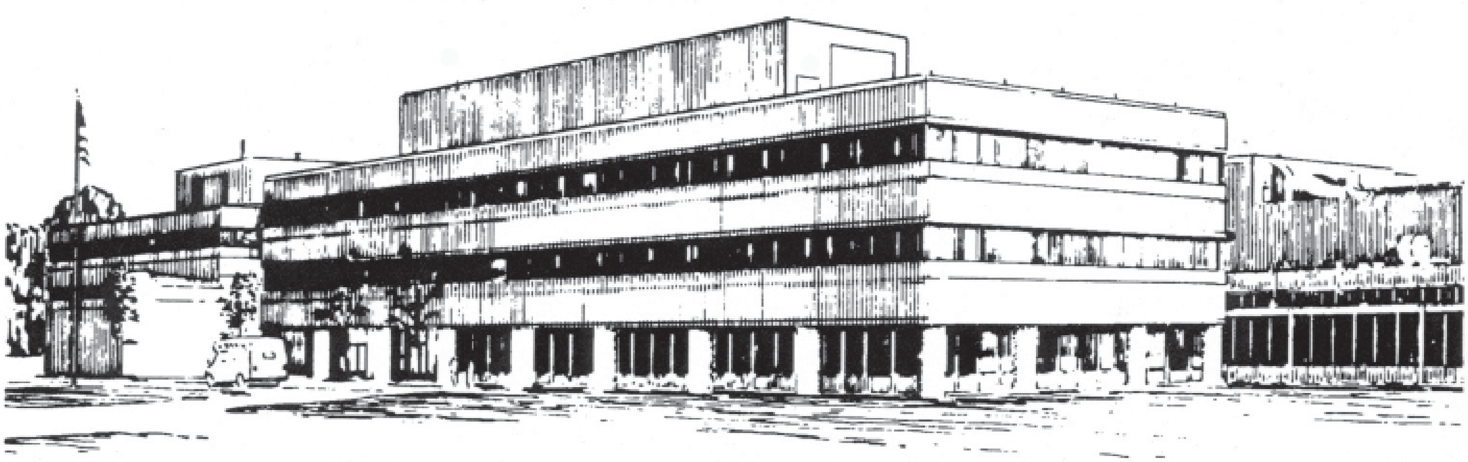

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# Trapped Electron Precession Shear Induced Fluctuation Decorrelation

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We consider the effects of trapped electron precession shear on the microturbulence. In a similar way the strong $\mathbf{E}\times\mathbf{B}$ shear reduces the radial correlation length of ambient fluctuations, the radial variation of the trapped electron precession frequency can reduce the radial correlation length of fluctuations associated with trapped electrons. In reversed shear plasmas, with the explicit dependence of the trapped electron precession shearing rate on $B_\theta$, the sharp radial gradient of $T_e$ due to local electron heating inside $q_{min}$ can make the precession shearing machanism more effective, and *reduce* the electron thermal transport constructing a positive feedback loop for the $T_e$ barrier formation.

## I. Introduction

There is accumulating evidence[1] that the $\mathbf{E}\times\mathbf{B}$ shear induced decorrelation of turbulence[2, 3] is responsible for the formation of internal transport barriers (ITB) in ion thermal transport channel. However understanding different behavior of electron thermal transport still remains one of the most challenging problems in tokamak confinement physics. While there has been revived interest in small scale electron temperature gradient (ETG) turbulence recently, qualitative difference in nonlinear simulation results[4] and the implications of the high-k fluctuation data[5] from experiments cast lingering doubts on the dominance of ETG turbulence driven transport in tokamaks.

The particular channels exhibiting ITB formation often respond to the $\mathbf{E}\times\mathbf{B}$ shear and $q$ profiles differently[6]. In some cases, with reversed magnetic shear, the barriers in $T_i, n_e$ and $T_e$ form simultaneously at the same location where the $\mathbf{E}\times\mathbf{B}$ shearing rate is high [7]. In many cases, the strong barriers in $T_i$ and $n_e$ can form with only a weak or no barrier in $T_e$[8]. In ion-heated plasmas, $T_e$ is typically most resistant to forming ITBs.

Strong $T_e$ ITBs are in general associated with strong electron local heating and reversed magnetic shear[9] sometimes with high triangularity[10]. Therefore it is natural to seek a mechanism other than the $\mathbf{E} \times \mathbf{B}$ shear, which is effective in reducing $\chi_e$ significantly when the following experimental conditions are realized.
i) $T_e > T_i$ and low collisionality such that the collisionless trapped electron mode could be important; typical of low density electron heated plasmas,
ii) reversed magnetic shear in the core typical of LHCD, and ECCD discharges.
Often relatively long wavelength density fluctuations which are measured by reflectometry tend to decrease (rather than completely quenched) either in radial correlation length[11] or in amplitude[12] when $T_e$ ITB is formed. These observations motivate us to seek a robust nonlinear mechanism which is relatively insensitive to the details of linear stability of specific modes, and which is applicable to plasmas ranging from near circular low-$\beta$ plasmas such as Tore Supra to strongly shaped high-$\beta$ plasmas. We consider the effects of trapped electron precession shear on the electrostatic fluctuations in the range of $k_\perp \rho_i \sim 1$.

## II. Radial Decorrelation due to Trapped Electron Precession Shear

Following the previous work[13] on the trapped electron dynamics, we start from an electrostatic bounce averaged drift kinetic equation in which the non-adiabatic part of the perturbed trapped electron distribution function $\delta H \equiv \delta f_e - \frac{e\phi}{T_e} F_0$ is convected by the precession drift $\mathbf{V_{de}}$, and the fluctuating $\mathbf{E} \times \mathbf{B}$ velocity $\tilde{\mathbf{V}}_E$,

$$(\partial/\partial t + \mathbf{V_{de}} \cdot \nabla + \tilde{\mathbf{V}}_\mathbf{E} \cdot \nabla)\delta \mathbf{H} = \mathbf{i}\{\omega_{*\mathbf{e}}(\mathbf{1} + \eta_\mathbf{e}(\epsilon/\mathbf{T_e} - \mathbf{3/2})) - \omega\}\frac{\mathbf{e}\phi}{\mathbf{T_e}}\mathbf{F_0}, \quad (1)$$

where $\tilde{\mathbf{V}}_\mathbf{E} = \mathbf{B} \times \nabla\delta\mathbf{\Phi}/\mathbf{B^2}$, other notations are standard.We note that $\mathbf{V_{de}} \cdot \nabla = \mathbf{i}\mathbf{k}_\perp \cdot \mathbf{V_{de}} \equiv \mathbf{i}\omega_\mathbf{De} \equiv \omega_{\mathbf{D}\phi}\partial_\phi$. Here, the trapped electron precession frequency $\omega_{D\phi}$ is related to more commonly used one $\omega_{De}$ by $\omega_{De} = n\omega_{D\phi}$ where $n$ is the toroidal mode number.

The two-point correlation evolution equation is then derived following the standard procedure of symmetrization with respect to $(\psi_1, \phi_1, \epsilon_1, \kappa_1)$ and $(\psi_2, \phi_2, \epsilon_2, \kappa_2)$ followed by an ensemble average.

$$\left\{\frac{\partial}{\partial t} + \psi_- \Omega_\psi \frac{\partial}{\partial \phi_-} + \epsilon_- \Omega_\epsilon \frac{\partial}{\partial \phi_-} + \kappa_- \Omega_\kappa \frac{\partial}{\partial \phi_-} - D_-^{\text{eff}} \frac{\partial^2}{\partial \phi_-^2}\right\} < \delta H(1)\delta H(2) >= S_2. \quad (2)$$

Here, the radial shear of the precession frequency in toroidal direction is given by

$$\Omega_\psi \equiv -\frac{\partial}{\partial \psi}\omega_{D\phi}(\psi_+, \epsilon_+, \kappa_+). \quad (3)$$

Additionally, the variations of precession frequency in energy and pitch angle variable are characterized by $\Omega_\epsilon$ and $\Omega_\kappa$ respectively. In Eq. (2), $S_2 =< \delta H(1)S(2) > + < \delta H(2)S(1) >$ is the source term for the two-point correlation function and the $\mathbf{E} \times \mathbf{B}$ nonlinearity is approximated as a turbulent diffusion along the perpendicular direction which vanishes at zero separation[14]. The decorrelation dynamics due to the coupling of the precession shear in phase space and turbulent diffusion can be studied by taking various moments of the left hand side (lhs) of Eq. (2). By calculating the eddy lifetime which is a function of the initial separation between two nearby points, one can derive that The radial correlation length $\Delta r_t \equiv \Delta\psi/RB_\theta$ , is reduced by the flow shear relative to its value $\Delta r_0 \equiv \Delta\psi_0/RB_\theta$, determined by ambient turbulence alone:

$$\left(\frac{\Delta\psi_0}{\Delta\psi}\right)^2 = 1 + \frac{\omega_{PS}^2}{\Delta\omega_T^2}. \tag{4}$$

Therefore, we expect that fluctuation suppression occurs when the decorrelation rate of the ambient turbulence $\Delta\omega_T$ is exceeded by the precession shearing rate, $\omega_{PS}$:

$$\omega_{PS} \equiv \frac{\Delta\psi_0}{\Delta\phi}\frac{\partial}{\partial\psi}\omega_{D\phi}(\psi,\epsilon,\kappa) = \frac{\Delta\psi_0}{\Delta\phi}\frac{\partial}{\partial\psi}(\frac{cT_eG(\kappa)}{eB_\theta R^2}) = \frac{\Delta r_0}{\Delta l_\perp}\frac{(RB_\theta)^2}{B}\frac{\partial}{\partial\psi}(\frac{cT_eG(\kappa)}{eB_\theta R^2}), \tag{5}$$

where $G(\kappa)$ is the pitch angle dependence of the precession frequency which varies from $1$ for deeply trapped particles to $-1$ for particles near trapped-passing boundary. We note that this mechanism works for both resonant and non-resonant (interchange-type) trapped electron driven turbulence, without relying on the linearly stabilizing influence of the trapped electron precession reversal[15]. In reversed shear plasmas, with the explicit dependence of $\omega_{PS}$ on $B_\theta$, the sharp radial gradient of $T_e$ due to local electron heating inside $q_{min}$ can make $\omega_{PS}$ higher, and *reduce* the electron thermal transport constructing a positive feedback loop for the $T_e$ barrier formation.

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