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Gyro-kinetic Simulation of Ion Temperature Gradient driven Drift Wave Instability in the presence of a Magnetic Island

Paul P. Hilscher, Kenji Imadera, Jiquan Li, Kota Takaki and Yasuaki Kishimoto

Graduate School of Energy Science
Department of Fundamental Energy Science
Kyoto University, Gokasho, Uji, Kyoto 611-0011 Japan

Abstract

The ion temperature gradient (ITG) driven instability in the presence of a meso-scale magnetic island using a gyro-kinetic simulation code is investigated. We find that a magnetic island causes radial and poloidal modes to couple with each other, thus playing a stabilizing role by allowing energy transfer to stable modes. For larger island sizes, new rational surfaces appear, which again may excite destabilization. Furthermore, we study the effect of kinetic electrons and their influence on the ETG-ITG micro-instability growth in presence of a magnetic island.

1 Introduction

During a Tokamak discharge, MHD instabilities take place, which result in a magnetic island. The saturated magnetic island can span several ion gyro-radii as discovered by Isayama[3]. In the same time, a temperature gradient develops and the plasma becomes unstable to drift-wave instabilities, like the ITG mode. The ITG mode happens on a much faster time scale and thus the magnetic island can be assumed to be stationary during the time the ITG instability develops.
ITG turbulence on a magnetic island was first studied by Wang[4], who discovered using a gyro-fluid simulation code, that for a smaller island size, the island has a stabilizing role due to mode-mode coupling effects, above some threshold, the destabilizing effect due to the appearance of additional rational surfaces dominates. Here, we will study the inclusion of a magnetic island within the gyro-kinetic framework.

2 Calculation Model

For the numerical investigation of micro-turbulence, we employ a self-developed gyro-kinetic code, see Hilscher[1] and [2]. We perform local, sheared slab geometry assuming a single rational surface. The normalized, linearized gyro-kinetic equations are a coupled integro-differential equation system of the Vlasov equation and Poisson equation. The Vlasov equation has the form

$$\begin{aligned}\frac{\partial F_{1\sigma}}{\partial t} &= k_y \left(1+\eta_\sigma\left[\frac{v_\parallel^2}{2}-\frac{k_\perp^2}{2}-\frac{1}{2}\right]\right)\langle\phi\rangle F_0\\ &+ v_{\parallel\sigma}\hat{s}xk_y\left(F_{1\sigma}+\langle\phi\rangle F_{0\sigma}\right)\\ &+ v_{\parallel\sigma}\left[\langle A_{1\parallel}\rangle, F_{1\sigma}\right] - v_{\parallel\sigma}\left[\langle A_{1\parallel}\rangle,\langle\phi\rangle\right]F_{0\sigma}\ ,\end{aligned}$$

where $v_{\parallel\sigma} = v_\parallel\sqrt{2m_{i\sigma}}$ is the parallel velocity term, $m_{i\sigma}$ ion-species mass ratio, ϕ the electric potential and the Maxwellian $F_{0\sigma} = \frac{1}{\sqrt{2\pi}}e^{-v_\parallel^2/v_{\parallel\sigma}}$, while $F_{1\sigma}(x,k_y,v_\parallel)$ is its deviation, $\sigma = i,e$, is the ion and electron species and the brackets $\langle A\rangle$ denotes the gyro-averaging procedure. The last two terms in the Vlasov equation appear due to the magnetic island for whom we assume an analytic approximation,

$$A_{1\parallel} = -\frac{w^2\hat{s}}{32}\cos(\zeta x)\cosh\left(\frac{2\pi}{L_y}i\,y\right) \quad ,$$

where $\zeta = 0.1$, $\hat{s} = 0.4$ and w is the assumed magnetic island width. The Poisson equation reads

$$\Sigma_\sigma\int_{v=-\infty}^{\infty} q_\sigma\langle F_{1\sigma}\rangle\, dv_\parallel = \left[1-\Gamma_0(k_\perp^2)+\text{Ad.}\right]\phi \quad ,$$

with $k_\perp^2 = k_x^2 + k_y^2$. The last term Ad. $= 1$ is the adiabatic response term of the electrons if included; Ad. $= 0$ otherwise. A static island ($\partial_t A_{1\parallel} = 0$) is assumed, this is valid, as the evolution of the magnetic island is in general much slower than the micro-turbulence timescale.

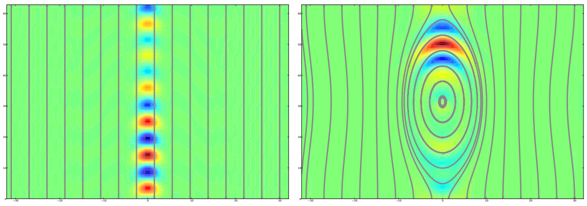

Figure 1: Contour plot of ϕ potential for an island width $w = 0$ and $w = 14$ and $\eta_i = 4.2$. The island has a significant influence on the ITG mode structure due to induced mode-mode coupling.

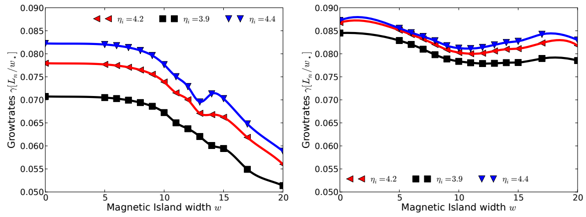

Figure 2: Growthrates of the systems total field energy, for first order gyro-kinetics (left) and (full order) gyro-kinetics (right) simulation.

3 Results and Summary

A contour plot of the ϕ-potential with the corresponding magnetic island is shown in Fig.1. The mode-mode coupling due to the magnetic island results in equal growth of the poloidal modes as shown in Fig.3. The coupling transfers energy to stable modes and thus total instability growth is reduced. On the other hand, this transfer also excites low-k modes, which may increase the total heat flux. Fig.2 shows the system total growth in respect of the magnetic island size. The island has a stabilizing effect; destabilization due to the appearance of new rational surfaces can be observed for an island width of $w = 14$, but overall stabilization effects are dominating with larger island sizes - an effect due to stronger coupling of the modes, which leads to more efficient dissipation through FLR (finite Larmor radius) effects. We also compared two gyro-kinetic models, full gyro-kinetic effects $\langle A \rangle = J_0(\sqrt{2\mu\rho_{t\sigma}k_\perp^2})A$; and only modeled to first order (a common approach for gyro-fluid models) $\langle A \rangle = \exp\left(-\frac{1}{2}\rho_{t\sigma}^2 k_\perp^2\right)A$. We note that for the first-order model instability is reduced due to the overestimation of the FLR damping.

As a next step we will present recent simulation results, where we investigate the linear instability growth, in respect to the island's size, including a kinetic electron species, as well as the influence of the island on heat transport.

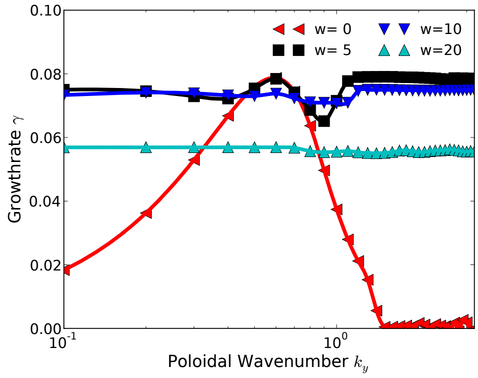

Figure 3: Growthrates for poloidal modes for magnetic island widths of $w = 0,\ 5,\ 10,\ 20$. Mode-Mode coupling results in equal growth of all poloidal modes and dissipates energy by stable modes.

Acknowledgments

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