ITG & TEM Gyrofluid Model

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Introduction

Typical tokamak plasmas are low β and operate in the low collisionality limit. In this regime the toroidal ion temperature gradient driven instability or the trapped electron mode is the dominant instability. These instabilities explain turbulent transport in most of the device except near the edge.

Model

We combine the results of [waltz, 1984] and [brizard, 1991] to obtain the four field (P, $v_\parallel$, ϕ, n_{te}) model for ITG driven instability and TEM:

$$d_t P + (1+\eta_T)\kappa_n \partial_y \phi = -\gamma \nabla_\parallel v_\parallel \tag{1}$$

$$d_t v_\parallel = -\nabla_\parallel (P + \phi) \tag{2}$$

$$\begin{aligned} d_t\big((1-\sqrt{\epsilon})\tau\tilde{\phi} - \nabla_\perp^2 \phi\big) + \boldsymbol{\nabla}_\perp \cdot \{\boldsymbol{\nabla}_\perp \phi, p\} + (1-\sqrt{\epsilon})\kappa_n \partial_y \phi \\ +(1+\eta_T)\kappa_n \partial_y \nabla_\perp^2 \phi - 2\eta_B \kappa_n \partial_y (P + n_{te}/\tau) \\ = -\nu_{eff}\big(\sqrt{\epsilon}\tau\phi - n_{te}\big) - \nabla_\parallel v_\parallel \end{aligned} \tag{3}$$

$$d_t n_{te} + \sqrt{\epsilon}\kappa_n \partial_y \phi = \nu_{eff}\big(\sqrt{\epsilon}\tau\phi - n_{te}\big) \tag{4}$$

where $d_t = \partial_t + \boldsymbol{b} \times \boldsymbol{\nabla}\phi$. $\kappa_n = \rho_i L_n^{-1}$, $\eta_T = L_T^{-1}/L_n^{-1}$ and $\eta_B = L_B^{-1}/L_n^{-1}$ characterize the equilibrium density gradient, equilibrium temperature gradient and the magnetic field gradient respectively. The model presented above makes the small η_B assumption which is physically reasonable considering a/R is small in tokamaks.

Linear Analysis

Linearising the model allows us to determine an optimal k_z that can be used for simulations and also understand the values of k_x and k_y that maximise γ.

Growth rate (γ)

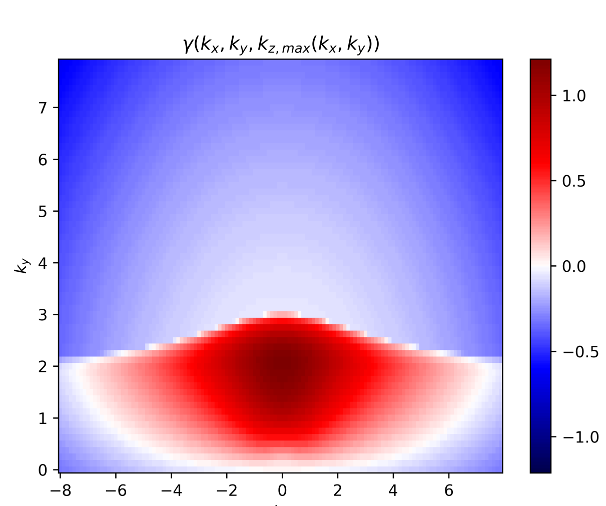

Figure 1: $\gamma(k_x, k_y)$

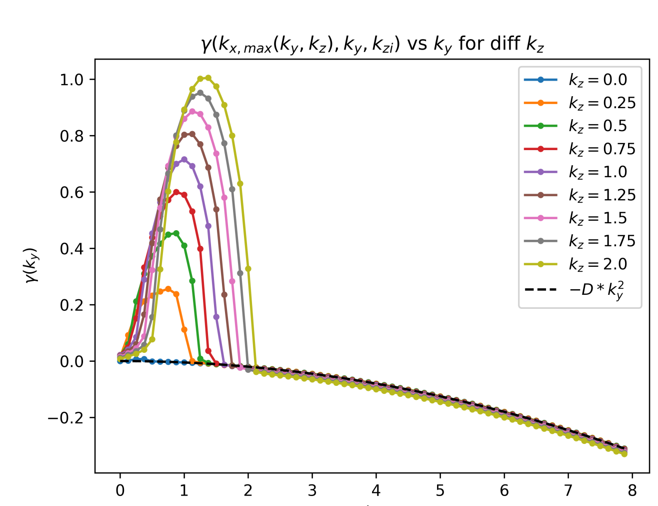

Figure 2: $\gamma(k_y, k_{z,i})$

- == $\gamma(k_y)$ for different $\eta_B/\sqrt{\epsilon}$

-The k_y values that maximise γ are confined to < 3.8 and < 2.7. This gives us an idea of the minimum box size ($L_{min} = 2\pi/k_{max}$) to be used for non linear simulations of the system.

-γ_{max} decreases shortly but increases after a threshold in the case of η_T while it steadily increases for $\sqrt{\epsilon}$.

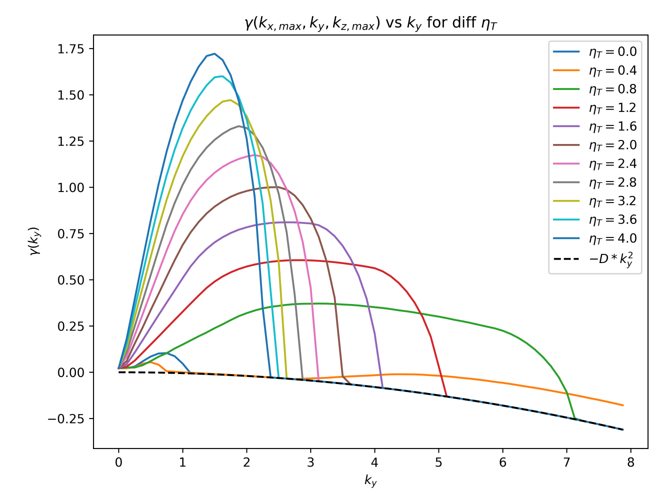

Figure 3: for different η_T

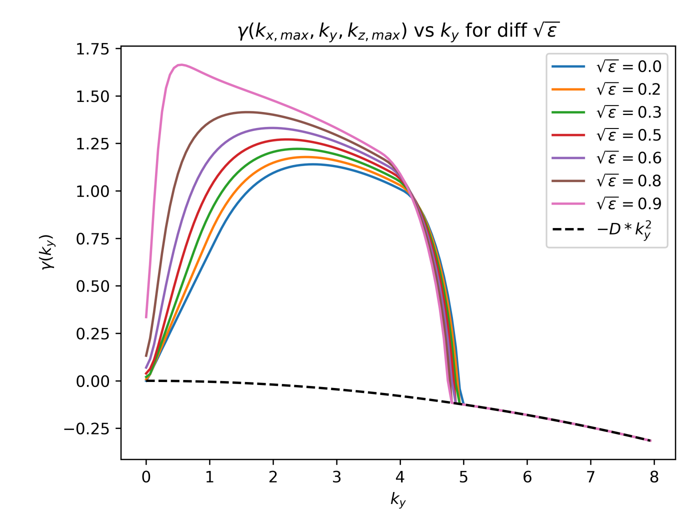

Figure 4: for different $\sqrt{\epsilon}$

$\omega(k_{y,max})$ vs $\eta_B/\sqrt{\epsilon}$

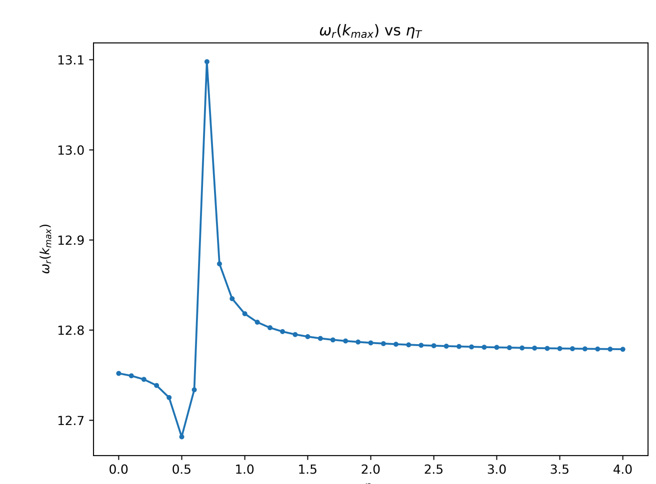

Figure 5: for different η_T

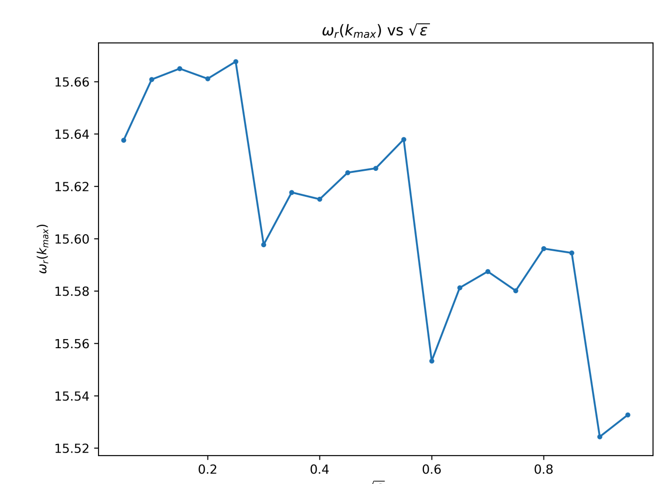

Figure 6: for different $\sqrt{\epsilon}$

ITG [ivanov]

We ignore trapped electrons and set $\kappa_n = 0$ to obtain a model as in [ivanov, 2020; ivanov, 2021] and simulate the system using a pseudospectral code.

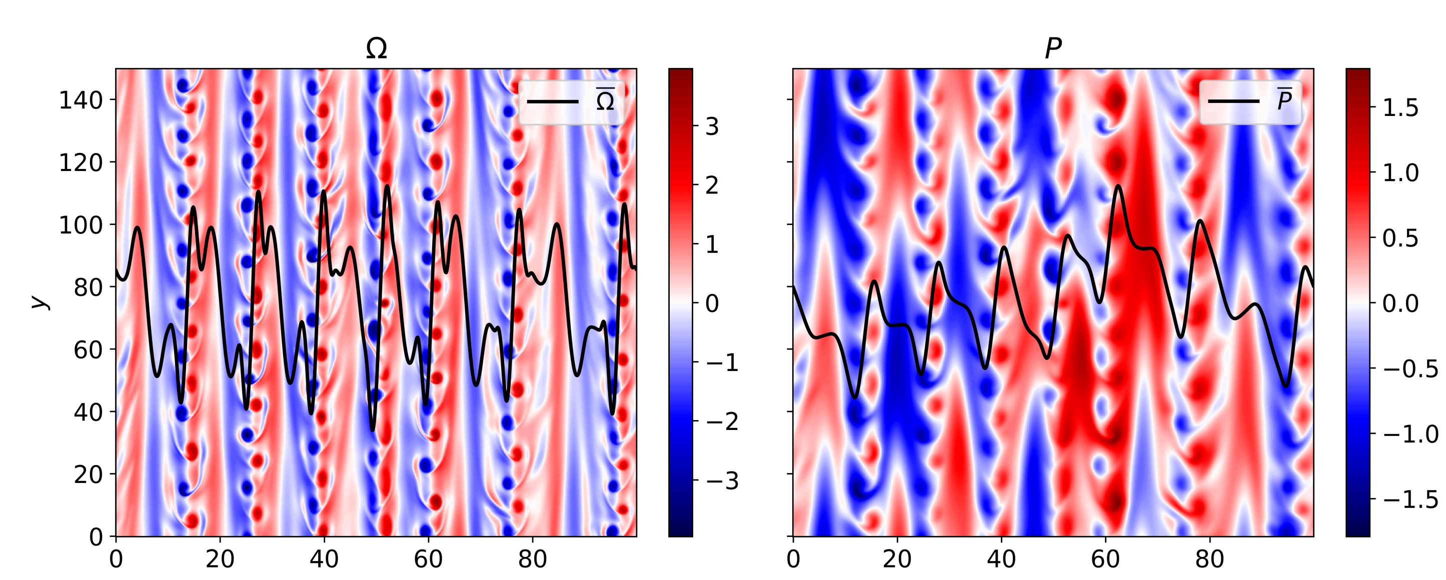

Figure 1: Fields: $\Omega = \nabla_\perp^2 \phi$, P

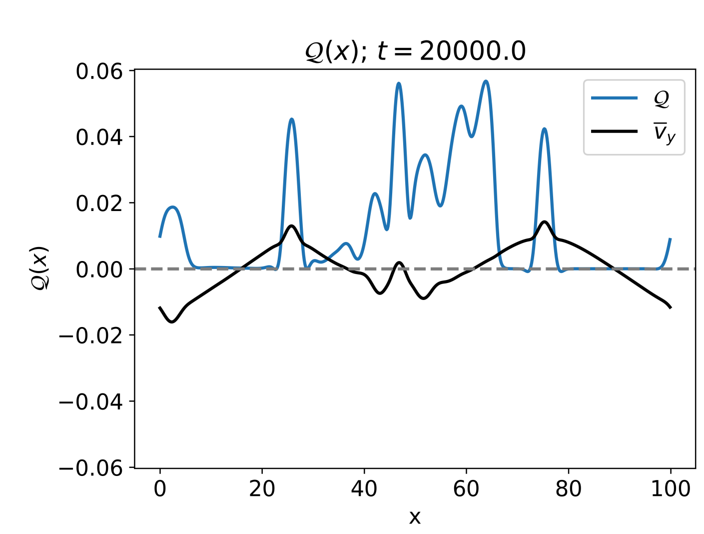

Figure 7: Heat Flux, $Q = -\langle \partial_y \phi T \rangle$

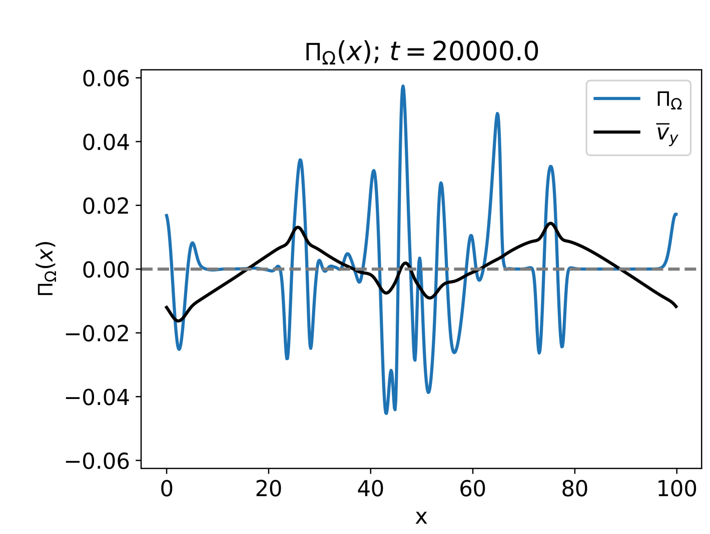

Figure 8: Vorticiy flux

ITG Zonal Flow Evolution

Zonal flows are $k_y = k_z = 0$ modes. We observe that zonal flows merge early on and also see that the extremas of zonal flows oscillate in time. Heat flux's evolution resembles the evolution of the zonal flow minimas.