

# ITG & TEM Gyrofluid Model

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## INTRODUCTION

Typical tokamak plasmas are low  $\beta$  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 ( $P, v_{\parallel}, \phi, n_{te}$ ) model for ITG driven instability and TEM:

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

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

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

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

where  $d_t = \partial_t + \mathbf{b} \times \nabla \phi$ .  $\kappa_n = \rho_i L_n^{-1}$ ,  $\eta_T = L_T^{-1}/L_n^{-1}$  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  $\eta_B$  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  $\gamma$ .

### Growth rate, $\gamma$

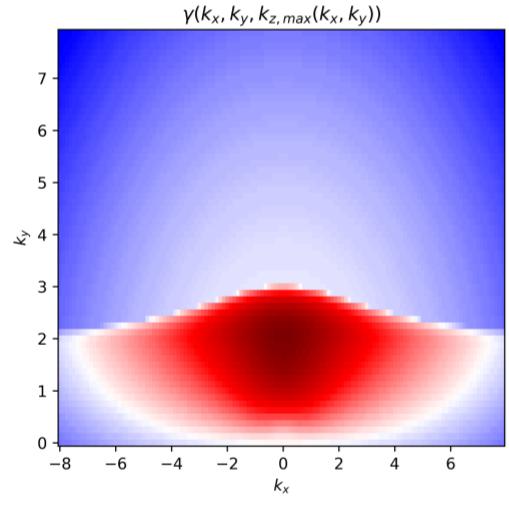


Figure 1:  $\gamma(k_x, k_y)$

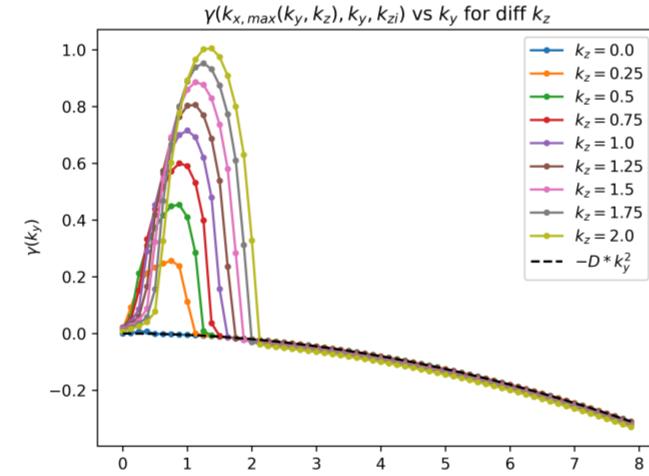


Figure 2:  $\gamma(k_y, k_{z,i})$

### $\gamma(k_y)$ for different $\eta_T/\sqrt{\epsilon}$

- The  $k_y$  values that maximise  $\gamma$  are confined to  $< 3.8$  (for  $\eta_T$  scan) and  $< 2.7$  (for  $\sqrt{\epsilon}$  scan). 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.
- $\gamma_{max}$  decreases shortly but increases after a critical value in the case of  $\eta_T$ . The value of  $k_y$  that maximises  $\gamma$  steadily decreases except for the jump at the critical  $\eta_T$ .
- $\gamma_{max}$  steadily increases for  $\sqrt{\epsilon}$  with a steady decrease in the value of  $k_y$  that maximises  $\gamma$ .

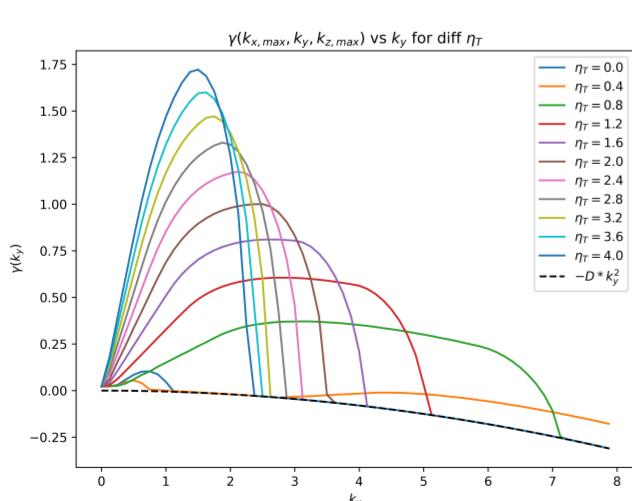


Figure 3: for different  $\eta_T$

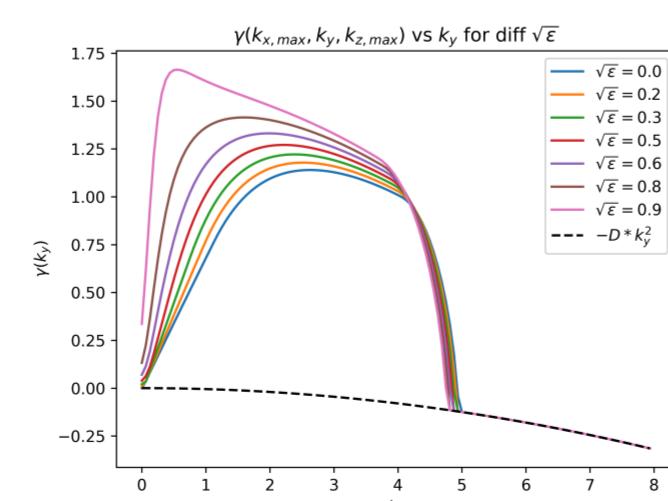


Figure 4: for different  $\sqrt{\epsilon}$

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

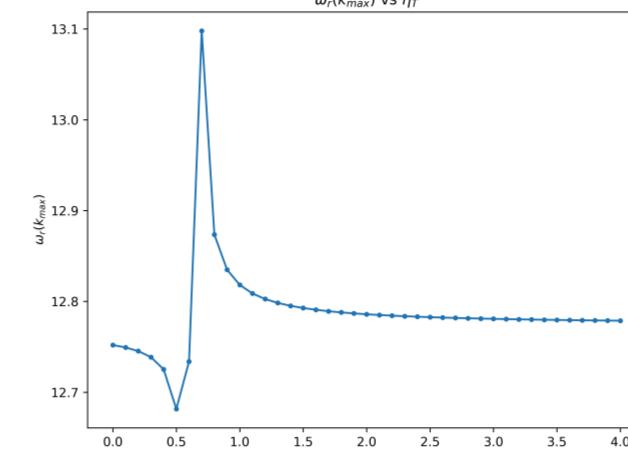


Figure 5: for different  $\eta_T$

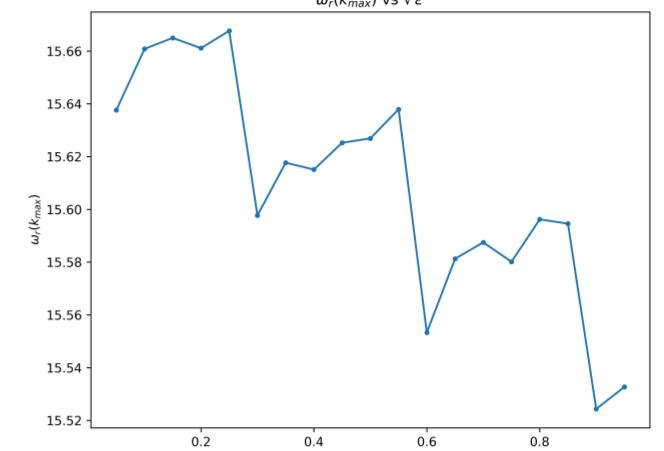


Figure 6: for different  $\sqrt{\epsilon}$

## NON-LINEAR ITG SIMULATION

We ignore trapped electrons and set  $\kappa_n = 0$  to obtain a model as in [ivanov, 2020; ivanov, 2022] and simulate the system using a pseudospectral code.

- We observe large scale ( $k_y = 0$ ) structures (zonal flows) that irregularly oscillate along  $x$ .

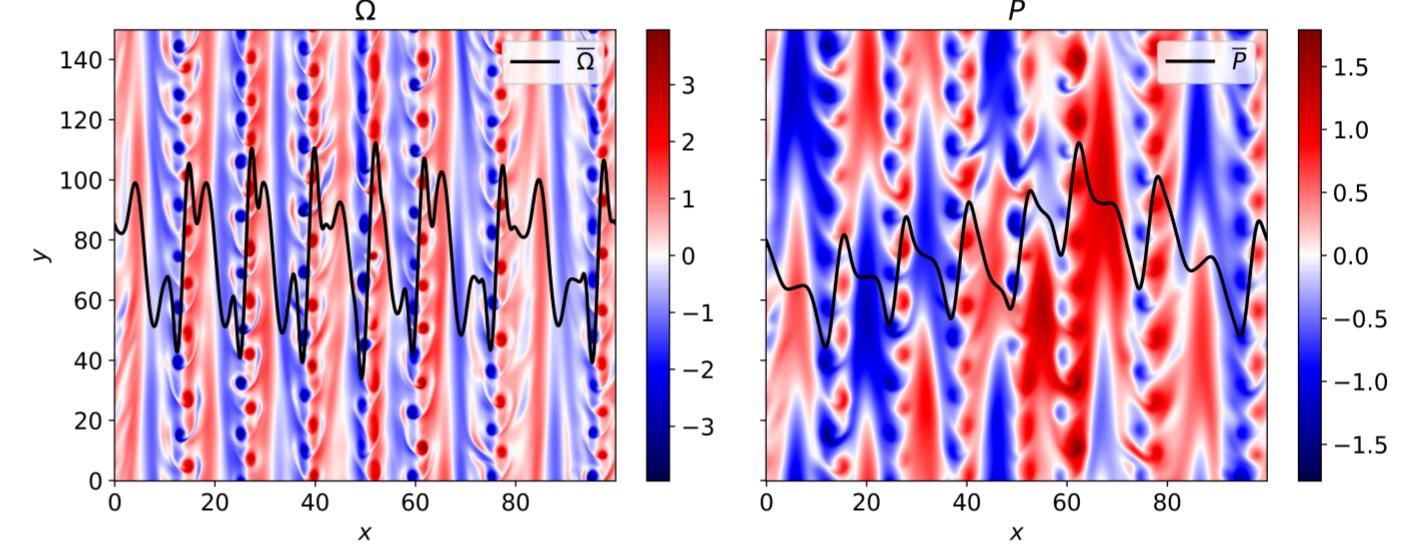


Figure 7: Heat Flux,  $Q = -\langle \partial_y \phi T \rangle$

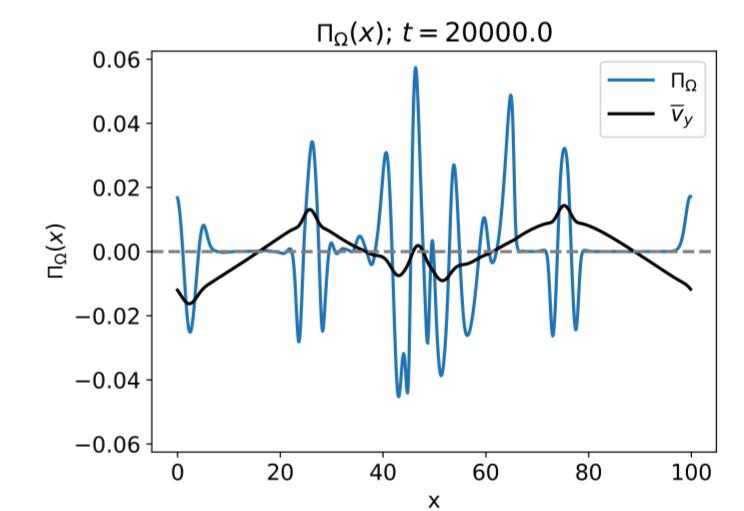


Figure 8: Vorticity flux

## FLOW EVOLUTION

- Zonal flows merge early on and also see that the extrema of zonal flows oscillate in time.
- Heat flux's time evolution, including the oscillations, resembles the evolution of the zonal flow minimas.
- Heat flux is faint in region of zonal maximas.

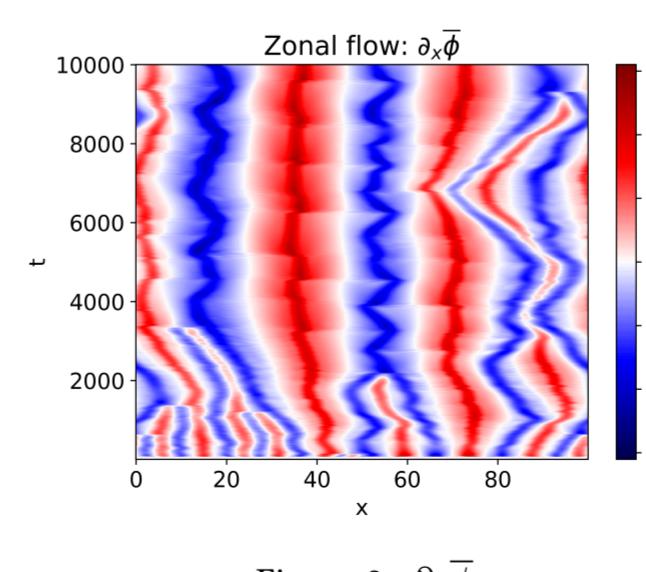


Figure 9:  $\partial_x \bar{\phi}$

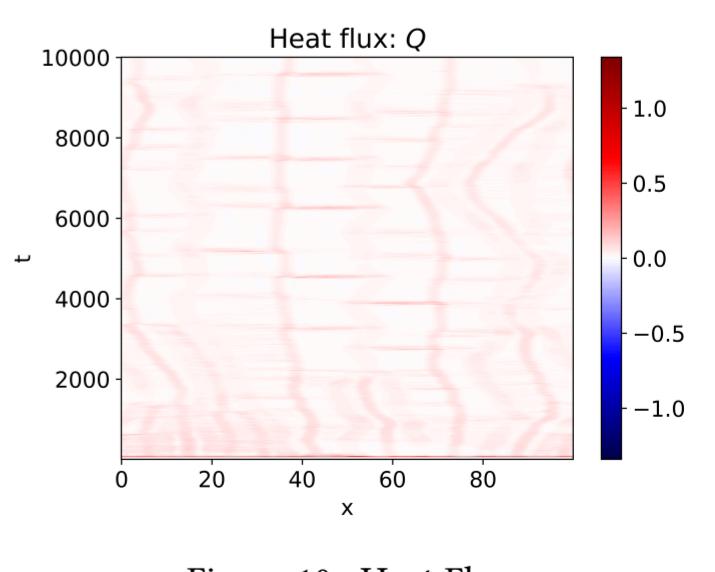


Figure 10: Heat Flux