Dynamics of Shear Layer Collapse in Modified Hasegawa–Wakatani Channel Flows

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Overview

- Topic: magnetic plasma confinement: edge transport, drift waves, zonal flow generation
- Purpose: Study density limit for the edge zonal flow layer
- Model: Modified Hasegawa-Wakatani System with variable adiabaticity parameter, $\alpha(y) = k_{\|}^2 V_{\mathrm{th}}^2 / \omega_{ci}\eta$
- Channel flow vs. periodic box: benchmarking and comparison
- Scanning ZF amplitude in α for $\alpha = const$ across the flow, zonal flow profiles, ...
- transport barriers and spillovers
- variable α across the channel: ZF localization
- density limit due to shear flow collapse

Modified Hasegawa-Wakatani Model

- two equations: for density and vorticity

$$\frac{\partial \zeta}{\partial t} + \{\phi, \zeta\} = \alpha(y)\left(\tilde{\phi} - \tilde{n}\right) - D\nabla^4 \zeta$$

$$\frac{\partial n}{\partial t} + \{\phi, n\} = \alpha(y)\left(\tilde{\phi} - \tilde{n}\right) - \kappa \frac{\partial \phi}{\partial x} - D\nabla^4 n$$

- $\{f, g\} \equiv (\partial_x f)\,\partial_y g - (\partial_x g)\,\partial_y f$ – Poisson bracket
- $\zeta \equiv \Delta\phi$ – flow vorticity
- DW instability driver $\kappa = n_0^{-1}\partial n_0/\partial y$, $n_0(y)$ – equilibrium density
- n – deviation from equilibrium normalized to n_0
- adiabaticity $\alpha = k_\parallel^2 V_{\mathrm{Te}}^2/\eta\omega_{\mathrm{ci}}$, resistivity η

$$\bar{n} \equiv \int n dx, \quad \bar{\phi} \equiv \int \phi dx, \quad \tilde{n} \equiv n - \bar{n}, \quad \tilde{\phi} \equiv \phi - \bar{\phi}$$

Why Channel Flow instead of Doubly-Periodic Box?

Neither is perfect, BUT...

Box

$f(x+L_x,y,t) = f(x,y+L_y,t)$
$= f(x,y,t)\,,$

Pros:

- simple
- some of the channel settings can still be implemented (with limited capacity)
- if rigid boundary is a bad choice, physically

Channel

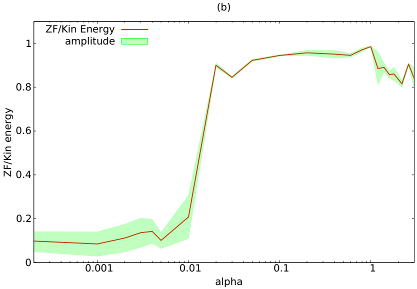
- $f(x+L_x,y,t) = f(x,y,t)$
  $f(x,0,t) \neq f(x,L_y,t) \;\; (= C)$

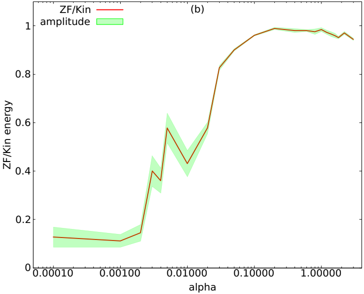
Pros:

- meaningfully apply density, temperature, etc., contrast across the channel
- **impose** $\alpha(y)$, average shear
- explore geometry (aspect ratio)
- better connect to physical boundary (edge physics)
- wall recycling, fueling, drag,...

Flows with constant α and κ : box - channel ZF generation

$$\epsilon = E_{ZF}/E_k \equiv \int \left(\frac{\partial \phi}{\partial y}\right)^2 dxdy \bigg/ \int |\nabla \phi|^2 \, dxdy$$





- ϵ vs α scan for flows in a periodic box
  - $\kappa = 0.1$
- ϵ vs α scan for flows in a channel
  - $\kappa = 0.1$

Flows with constant α and κ : box - channel ZF generation

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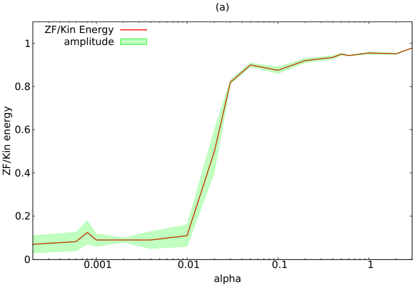
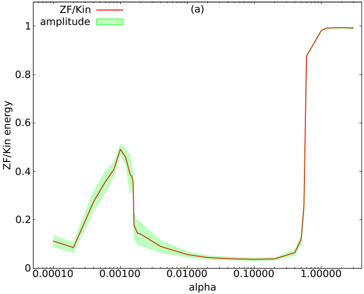
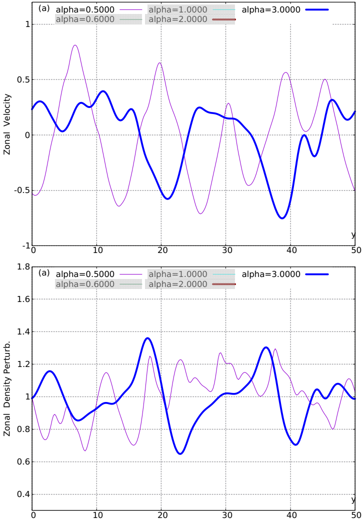




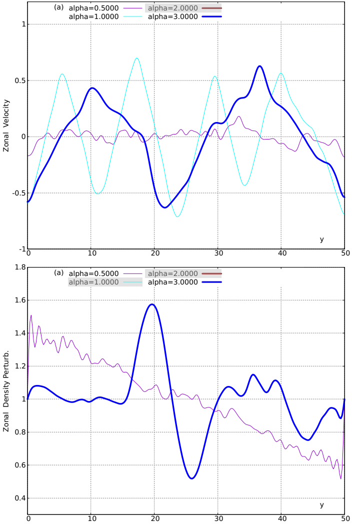
- ϵ vs α scan for flows in a periodic box
  - $\kappa = 0.3$
- ϵ vs α scan for flows in a channel
  - $\kappa = 0.3$

Constant α and κ : box - channel: Zonal Velocity-Density

Periodic Box

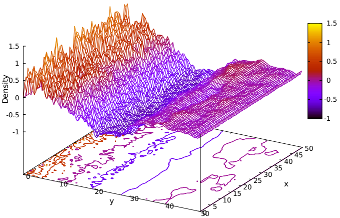


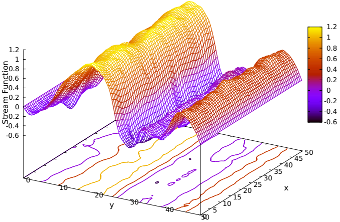
Channel



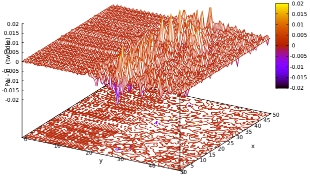
Variable α, channel: Density, Stream function

- $\alpha(y) \propto y$, transport barrier forms where $\alpha \approx \alpha_{cr} \approx 0.3$

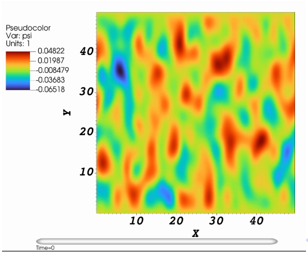




Interaction $\tilde{\psi} - \tilde{n}$



- Stream function movie



Conclusions

- Density limit phenomenology studied using modified HW system with constant and variable adiabaticity parameter $\alpha = k_{\|}^2 V_{\mathrm{th}}^2 / \omega\eta$
  - Both periodic box and channel flows simulated and compared
  - Somewhat stronger and coherent channel flows documented
- **Sharp transport barrier forms in the channel where $\alpha(y) \sim \alpha_{\mathbf{cr}}(\kappa)$**
- ZF collapses when density increases as to make α decrease below α_{cr}