Gyrokinetic Simulations of Magnetic Reconnection & Turbulence Spectrum with Zonal flows

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Journée Turbulence
February 27, 2015
Topics

- Magnetic reconnection in the presence of pressure gradients
- Interactions between turbulence and zonal flows
Diamagnetic flows: \[ \vec{v}_\alpha = c\vec{B} \times \nabla p_\alpha / (nq_\alpha B^2) \]

When diamagnetic flows are strong enough, No reconnections

\[ \Delta V_*/V_{out} = (\rho_s P'/ (n_e B))(B/B_{rec})\sqrt{\beta/2} \gtrsim 1 \]
Finite gradients at core region of Tokamak

- Reconnection important in Tokamak as well -

Electron Heat escapes from core region
- Critical issue in ITER -

Sawtooth Crash

[Nagayama et al, 1996]

Mechanisms not well-understood
Question:

How does the pressure gradients affect magnetic reconnection?
How about we check this with kinetic simulations?

- "Gyrokinetic simulations"
- 5-dimensional (3-spatial and 2-velocity)
- Include Kinetic physics (FLR effects, Landau damping, etc)
- Can simulate "collisionless" plasma
  (both space and lab plasmas are collisionless)

ok, so let's do simulations!
“Gyrokinetic simulations”

[Kobayashi, Rogers, and Numata, 2014]
“PoP Editor’s pick 2014”

\( \nabla P_0 = 0 \)

\( \nabla N_0 \neq 0 \)

\( \nabla T_0 \neq 0 \)

Reconnection occurs as expected

Kinetic physics trigger turbulence

Kinetic physics trigger turbulent reconnection!
Heat transport consistent with tokamak
**$T_{\text{ele}}$ profile flattening**

ions          electrons

(a)            (b)

Electron Heat transport relevance with tokamak observations?
Summary
(for Reconnection part)

Even if fluid model predicts no reconnection,

- Kinetic Instabilities may appear

- Cause Turbulent Reconnection

- Diamagnetic stabilization might not be true anymore!
Topics

- Magnetic reconnection in the presence of pressure gradients
- Interactions between turbulence and zonal flows
Turbulence can create self-organized flows such as zonal flows... Jupiter, Saturn, Earth’s jet streams, etc.

“Zonal flows” suppress Turbulence... Critical for Magnetic Fusion

[ Lin et al, Science, 1998]
Question:

Is there any characteristic spectrum in the presence of zonal flows?
Zonal flows create characteristic spectra

Gyrokinetic Spectra in Zpinch system

- Agree with theoretical prediction
- “Disparate” scale interactions dominate “Local” interactions
- Dynamical spectra (instead of Kolmogorov-type static spectra)
Question:

What kind of relation does “turbulence” have with “zonal flows”? 
Predator-Prey dynamics between turbulence and zonal flows

Can be fitted with simple Predator-Prey model

\[
N = \sum_k |\phi_k|^2 (1 + k^2)
\]

\[
E_v = |\phi_q|^2 q^2
\]

\[
\frac{\partial N}{\partial t} = \gamma_{\text{lin}} N - c_1 N E_v
\]

\[
\frac{\partial E_v}{\partial t} = c_2 E_v N - \gamma_{zf} E
\]
Predator-Prey dynamics between turbulence and zonal flows

\[ \frac{\partial N}{\partial t} = \gamma_{lin} N - c_1 N E_v \]
\[ \frac{\partial E_v}{\partial t} = c_2 E_v N - \gamma_{zf} E \]

- “Zonal flow damping” agrees with collisionality
- Constant “effective linear growth”
- Predator-Prey disappear as couplings become weak
Predator-Prey dynamics actually observed in experiments

- Appear during L-H transition
- Mechanism not well understood (thought to be linked to turbulence/mean flow interactions)
- Similar fitting technique can be used on data?

[ Estrada et al, EPL, 2010]
Summary
(for zonal flow part)

In the presence of zonal flows,

- Turbulence creates characteristic spectra
- Dominated by “disparate scale” interactions
  (weak “local interactions”)
- “Predator–prey” can be modeled with dynamical fitting technique
- Able to extract “effective” zonal flow damping, linear growth rates, etc