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Non-equilirbruim and extreme state – Structural formation of density profile driven by parallel velocity shear
非平衡極限 −平行速度シアが駆動する密度分布構造形成−

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A theory to describe density peaking by parallel flow shear driven instability is discussed. In the presence of parallel flow shear, D'Angelo mode appears. D'Angelo mode drives inward particle pinch. When parallel velocity is strong enough, pinch can overcome outward diffusive flux and hence net inward particle flux is expected. Application to many systems, including astrophysical jets, toroidal devices, linear machines is also discussed.

1. Introduction

Turbulent plasmas are typical example of a system in non-equilibrium and extreme state. In this non-equilibrium and extreme state, turbulent plasmas are characterized by formation of various structures and their interplay. A well-known example is drift wave-zonal flow turbulence. In this system, density gradient drives drift wave turbulence, which in turn drives zonal flow by exerting Reynolds stress. Another example is parallel flow along the magnetic flow, which is self-organized by Reynolds stress exerted by drift wave turbulence. The formation of parallel flow structure has been observed in linear plasmas[1] and toroidal plasmas.[2] Interestingly, in turn, parallel flow shear drive Kelvin-Helmhortz type turbulence. It is also observed that the parallel flow shear driven KH drives inward particle pinch.

From theoretical perspective, instability driven by parallel shear flows was described by D'Angelo. In that analysis, D'Angelo identified instability driven by parallel shear flow. D'Angelo mode is stabilized by drift waves. However, their impact on transport has not been explored before.

In this work, we report our recent progress on modeling transport caused by D'Angelo mode. First, we discuss its mode feature. We derive stability diagram (Fig.1) and mode structure is discussed.(Fig.2) Transport driven by D'Angelo mode is discussed. Interestingly, D'Angelo mode tends to drive inward particle flux, as shown in Eq.(4). We then discuss application of the result to linear machine, toroidal plasmas, and astrophysical jets.

2. Model

We use a fluid model to describe coupled drift-D'Angelo turbulence:

$$\left(\frac{d}{dt}+\nu_{in}\right)\rho_s^2\nabla_\perp^2\frac{e\phi}{T_e} = -D_\parallel\nabla_\parallel^2\left(\frac{e\phi}{T_e}-\frac{n_e}{n_0}\right) \quad (1)$$

$$\frac{d}{dt}\frac{n_e}{n_0} = -D_\parallel\nabla_\parallel^2\left(\frac{e\phi}{T_e}-\frac{n_e}{n_0}\right)-\nabla_\parallel v_i \quad (2)$$

$$\frac{d}{dt}v_i = -c_s^2\nabla_\parallel\frac{n_e}{n_0}-\nu_{in}(v_i-v_n) \quad (3)$$

Here, the total derivative is along ExB drift. ν_{in} is neutral drag, c_s is ion sound speed and ρ_s is ion sound Larmor radius. $D_\parallel$ is the parallel electron diffusivity. The first two sets of equation, without coupling to parallel flows, is Hasegawa-Wakatani mode for collisional drift waves. In addition, here we have coupling to parallel flow. The coupling allows parallel flow shear driven instability, which is described in the following.

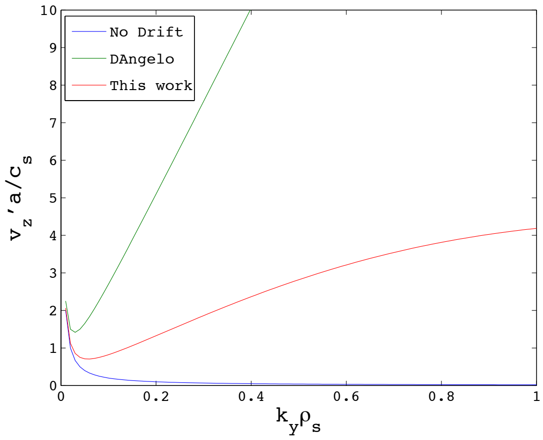

Fig.1. Stability diagram for D'Angelo mode.

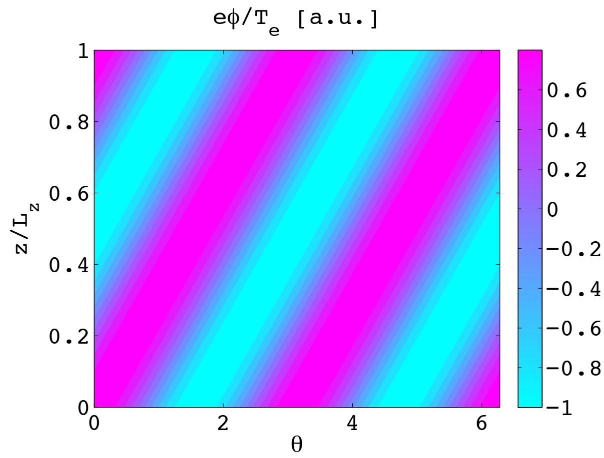

Fig.2. Potential contour of D'Angelo mode

3. Analysis

3.1 *Linear stability*

In order to elucidate the onset condition of D'Angelo mode, linear dispersion relation is calculated for adiabatic electron limit. The result is plotted in Fig. 1. The curve is determined from marginal condition. The curve is plotted for k_zL_n=1/50. Above the curve, parallel flow shear drivne instability (D'Angelo mode) develops. The three different curves are for the case without drift wave coupling, the work by D'Angelo, and the result from this work. From this, we can see that drift wave coupling is stabilizing for D'Angelo mode. In our work, polarization charge effect is retained. Thus drift wave frequency is lowered and its effect on D'Angel mode is weakened.

3.2 *Linear mode pattern*

Potential fluctuation contour is plotted in Fig.2. Since D'Angelo mode is unstable only for $k_y k_\parallel \langle v_z \rangle' > 0$, the pitch of the mode is fixed for a given shear. The feature is manifested in Fig. 2. The potential is plotted for fixed radial location.

3.3 *Transport*

D'Angelo mode drive inward particle flux. This can be shown by calculating quasilinear particle flux, as:

$$\frac{\Gamma_n}{n_0 c_s} \cong \sum_{\mathbf{k}} k_y \rho_s \frac{\omega_{*e}}{k_\parallel^2 D_\parallel} \frac{1+2k_\perp^2\rho_s^2}{2(1+k_\perp^2\rho_s^2)} \left| \frac{e\tilde{\phi}_{\mathbf{k}}}{T_e} \right|^2 - \sum_{\mathbf{k}} \frac{2(1+k_\perp^2\rho_s^2)}{k_\parallel^2 D_\parallel} (|L_n| k_\parallel \rho_s k_y \langle v_z \rangle') \left| \frac{e\tilde{\phi}_{\mathbf{k}}}{T_e} \right|^2 \quad (4)$$

For unstable D'Angelo mode, the second term is always negative. Thus D'Angelo mode can drive net inward particle flux, for strong enough shear.

4. Summary and discussion

In summary, we discussed typical feature of D'Angelo mode and its impact on particle transport. Stability diagram is given by Fig. 1 and drift wave coupling is stabilizing. Mode structure is given by Fig. 2 and has a fixed pitch pattern. Once excited, D'Angelo mode drives inward pinch. Net inward particle flux is possible for strong enough shear.

Based on our result, we discuss that the net inward particle flux observed in recent experiment on linear machine can be explained by D'Angelo mode. Quantitative comparison will be reported elsewhere. A similar situation may occur in toroidal devices. NBI drives parallel sheared flows and D'Angelo mode may be excited. This can lead to density peaking as discussed above. We also note that the theory presented here may be important for stability of astrophysical jet.

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References

[1] T. Kobayashi: *"Parallel flow structure formation by turbulent momentum transport in linear magnetized plasma"* 4th Asia Pacific Transport Working Group (Fukuoka, 2014)

[2] D'Angelo: Phys. Fluids **8** 1748 (1965)

[3] N. Mattor and P.H. Diamond: Phys. Fluids **31** 1180 (1988)