18PB-032

Electrostatic particle simulation of drift wave instability driven thermal gradient in $2-\frac{1}{2}$ dimensions space

$2-\frac{1}{2}$ 空間における温度勾配駆動ドリフト波不安定性の静電粒子シミュレーション

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We carry out the analysis of the plasma with a temperature gradient by using the electrostatic code so that we study the drift wave instability driven temperature gradient. The code has $2-\frac{1}{2}$ dimensions system, uses Particle-in-Cell algorism, and follows the time development of the particle by solving equation of motion for all particles. We confirm the excitation of drift wave instability driven temperature gradient as the result of the simulation.

1.Introduction

The fluctuation oscillation of drift wave is observed in University of Tsukuba tandem mirror type experimental device GAMMA10. It is learned by a past experimental report that this fluctuation can be stabilized by applying $\boldsymbol{E}\times\boldsymbol{B}$ shear. We perform the study of the stabilization effect on the drift wave instability by the $\boldsymbol{E}\times\boldsymbol{B}$ shear using computer simulation to confirm the report theoretically.

As the first stage of this study, this paper reports the result that the computer simulation of drift wave instability.

2.Electrostatic particle code

The electrostatic particle code with a $2-\frac{1}{2}$ dimensions system(2D-space, 3D-velocity) uses Particle-in-Cell algorism.

The system that converted the column plasma in the open-ended system into the two dimensional slab shape in this study. It is set that diameter direction is x-axis direction and azimuthal direction is y-axis direction.

The temperature profile is given by a tanh function, and the external magnetic field $\boldsymbol{B}_{\rm ext}$ is only inclined at the amount of $\theta(\approx 1^\circ)$ in y-axis direction from z-axis direction like Fig.1.

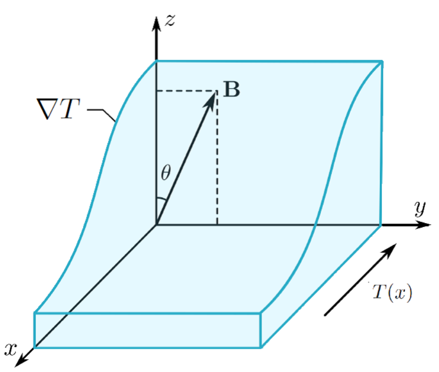

Figure 1 : Temperature Gradient

The boundary conditions are perfect conductor boundary condition in x direction, and periodic boundary condition in y direction like Fig.2.

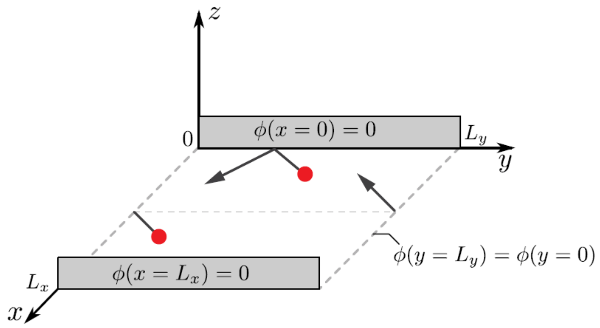

Figure 2 : Boundary Condition

3.Linear theory of Drift wave

We use Eq.(1) as the equilibrium distribution function under the assumption. Here the initial plasma in the system has a uniform density and a temperature gradient in the x-axis direction.

$$f_0 = n_0\left(\frac{1}{2\pi T_\perp(X)}\right)\left(\frac{1}{2\pi T_\parallel(X)}\right)^{\frac{1}{2}} \times \exp\left(-\frac{mv_\perp^2}{2T_\perp(X)}-\frac{mv_\parallel^2}{2T_\parallel(X)}\right) \quad (1)$$

where $X = x + v_y/\omega_c$ is invariant for time to be used as a coordinate to express the temperature gradient.

The kinetic dispersion relation is provided by substituting Eq.(1) for Vlasov equation and integrating along the particles trajectory. We calculate the integral along the particles trajectory with an approximation saying that X is an independent variable, and is not a function of $v_\perp$.

Equation (2) is the dispersion relation of drift wave instability driven by temperature gradient. It is assumed that the effect of cyclotron resonance is able to neglected because the frequency of the drift wave ω is smaller enough than the ion cyclotron frequency ω_c and $\partial\ln T_\parallel/\partial x = \partial\ln T_\perp/\partial x$ in Eq.(2).

$$k_\perp^2 + k_\parallel^2 - \sum_s \frac{1}{2\lambda_{Ds}^2}\Big[(I_0(b_s)e^{-b_s}\xi_{0s}Z(\xi_{0s}) + \frac{\omega'_{*,s}(k_y)}{\omega}\Big\{(f_0(b_s)-1)Z(\xi_{0s}) + \xi_{0s} - \left(\frac{1}{2}-\xi_{0s}^2\right)Z(\xi_{0s})\Big\} I_0(b_s)e^{-b_s}\xi_{0s}\Big] = 0 \quad (2)$$

Here $I_0(b_s), I_1(b_s)$ are the modified Bessel function of the first kind, and $Z(\xi_{s0})$ is plasma dispersion function.

Other factors in Eq.(2) express as follow.

$$b_s = \frac{k_\perp^2 v_{ths}^2}{2\omega_{cs}^2} \qquad f_0(b_s) = 1 - b_s + \frac{b_s I_1(b_s)}{I_0(b_s)}$$

$$\xi_{0s} = \frac{\omega}{k_\parallel v_{ths}} \qquad \omega'_{*,s}(k_y) = \frac{q_s}{e}\frac{k_y}{m_s\omega_{cs}}\frac{\partial T_s}{\partial x}$$

4.Result and Summary

We try the analysis of the electron temperature gradient instability in the range $v_{thi} \ll \omega/k_\parallel \approx v_{the}$. It is assumed that ion and electron temperature gradients are equal, and defined the gradients in Eq.(3). The parameters that we used in this study are shown in Tab.1.

$$T_s(x) = T_{s0}\left\{1 - \kappa_s \tanh\left(\frac{(x - L_x/2)}{A\rho_i}\right)\right\} \qquad (3)$$

Particle count N_0	147456
System size $L_{x,y}$	128Δ
Particle size $a_{x,y}$	1.0Δ
Mass ratio m_i/m_e	64.0
Temp. ratio T_e/T_i	4.0
Angle θ	1.0
Debye length λ_{De}	3.5Δ
Cyclotron freq. ω_{ce}	$3.0\omega_{pe}$
Time step Δt	$0.1/\omega_{pe}$
gradient factor κ_s	0.9
gradient factor A	1.25
Ini. perturbation	0.01

Table 1 Simulation parameters

Figures 3-6 express the equi-contours of electostatic potential at various times when the simulation carried out in the parameters of Table.1. The contour line in those figures are defined as the line which divided into 10 between the maximum and the minimum of the potential.

Figure 7 is the one which expresses the time development of wave with mode number = $(1,1)$. This expresses the growth of the drift wave clearly.

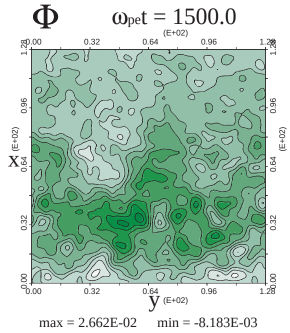

Figure 3

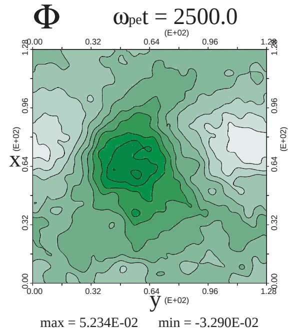

Figure 4

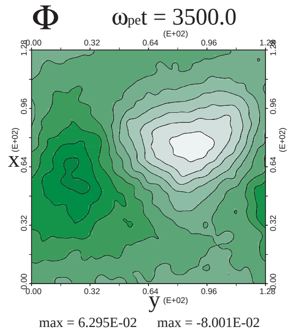

Figure 5

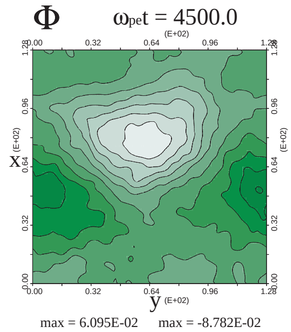

Figure 6

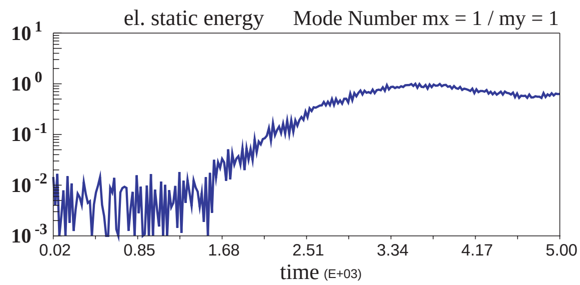

Figure 7 : Time development of (1,1) wave mode energy

1. S.Tokuda, T.Kamimura and H.Ito, JPSJ, Vol.48, No.5, May, 1980

2. Nicholas A.Krall, Alvin W.Trivelpiece, “Principles of Plasma Physics”, McGraw-Hill Inc.