§2. Seesaw Mechanism in Turbulence-Suppression by Zonal Flows

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Research of non-local and transit transport is an urgent issue in modern plasma physics. Experiments have reported the non-diffusive mechanisms in rapid response of transport between distant radii (see, e.g., recent report 1, 2)). Theory of non-local transport has been developed, based upon the statistical theory of plasma turbulence [3]. A change of microscopic turbulence at one radius propagates across the plasma column much faster than the diffusive response. Example is the zonal flow (ZF) [4]. Because the radial correlation length of ZF is longer than those for microscopic fluctuations, ZF induces new non-local interactions in turbulent transport. That is, strong fluctuations at particular radius can suppress fluctuations at different radius, via induction of ZFs. This is called the seesaw mechanism via ZFs. The transient response is much faster than the process governed by diffusive processes.

We employ a predator-prey model of DW-ZF system. Here, we consider a zonal flow eigenmode with radial correlation length L) which is much longer that that of drift waves. In this case, the predator-prey model takes a form

$$\frac{\partial}{\partial t} I(x) = \gamma(x) I - \omega_2 I^2 - \alpha E I \qquad (1)$$

$$\frac{\partial}{\partial t} E = \alpha E \frac{1}{2L} \int_{-L}^{L} dx\, I - \nu E \qquad (2)$$

where $I(x)$ is the intensity of DW, $\gamma(x)$ is the local growth rate, $\omega_2 I$ is the nonlinear damping rate of DW, E is the intensity of ZF, α is a coupling coefficient between DW and ZF and ν is the linear damping rate of ZF. (Intensities and are normalized to the kinetic energy density at the diamagnetic drift velocity.) Coefficients ω_2 and α can also vary in radius. However, we take them constant in radius, for the transparency of argument, without loosing the essence of the problem. The intensity of zonal flow E is constant within the correlation length L.

For explicit illustration, we take a parabolic model for the local growth rate, and take the origin at the minimum position:

$$\gamma(x) = \gamma_0 + (\gamma_1 - \gamma_0)\frac{x^2}{L^2}. \qquad (3)$$

We take the case of $\gamma_1 > \gamma_0$, and the opposite case is straightforward. We consider the case of weak collisional damping and ZF is excited. When the inhomogeneity of local growth exceeds the threshold,

$$\frac{1}{\omega_2}(\gamma_1 - \gamma_0) > 3\frac{\nu}{\alpha} \qquad (4)$$

fluctuations are suppressed ($I = 0$) in the region of weak instability $|x| < x_c$, where the boundary x_c satisfies the condition

$$\left(1 - \frac{x_c}{L}\right)^2\left(1 + \frac{2x_c}{L}\right) = 3\frac{\nu}{\alpha}\frac{\omega_2}{(\gamma_1 - \gamma_0)}. \qquad (5)$$

In this case, fluctuations are suppressed completely in the domain $|x| < x_c$ although the region is linearly unstable against linear drift mode.

Novel non-local interactions of microscopic turbulence via zonal flow are investigated. Strong fluctuations at particular radius can suppress fluctuations at different radius, via induction of ZFs. This is called the seesaw mechanism via ZFs. The threshold of turbulence suppression is formulated as a global condition. The transient response is much faster than the process governed by diffusive processes.

This work was partially supported by the collaboration programme of NIFS (NIFS06KDAD005).

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