§24. Self-Sustained Turbulence and Anomalous Transport

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The anomalous transport coefficient D is usually evaluated by γ^L/k^2, where γ^L and k are the linear growth rate and wave number for the most unstable mode [1]. There are mysteries, such as the radial shape of thermal conductivity χ, the dependence of energy confinement time on current and ion mass. To resolve these problems, we proposed a new approach for the turbulence and transport, i.e., the picture of the self-sustained turbulence [2]. It is shown that the anomalous electron viscosity μ_e can cause nonlinear microscopic ballooning mode and interchange mode in toroidal plasmas. The balance between the stabilization by χ and ion viscosity μ determines the stationary turbulence and anomalous transport. Figure 1 shows schematic view.

The reduced set of equations is used for the high-aspect ratio circular tokamaks. The equation of motion, Ohm's law, and energy balance equation are employed. The ExB nonlinearlity is treated in the following manner. First, we calculate the driven mode (k_2) by the interaction between the test mode (k) and the back-ground turbulence (k_1). The back-interaction of the driven mode with back-ground fluctuations gives the nonlinear effect on the test mode. This effect is expressed in terms which are proportional to $[\phi_{-1},[\phi_1,Y_k]]$, where ϕ is the static potential, the suffix 1 denotes k_1, Y_k is the test wave component., and [,] denotes Poisson bracket. With the assumptions that the gradient scale of the envelope $|\phi_{-1}\phi_1|^2$ is much longer than 1/k and that turbulence is isotropic, the term $[\phi_{-1},[\phi_1,Y_k]]$ is approximated as $|k_{1\perp}\varphi_1|^2\Delta_\perp/2$. Finally, we use the mean field approximation (Onsagar ansatz) that the diffusion terms on the mode k are approximated by those of $k \rightarrow 0$ limit.

By these procedures we have the renormalized set of equations for the test mode components {$U=\Delta_\perp\varphi$, J and p} (suffix k is suppressed) as

$$\frac{dU}{dt}-\frac{B^2\nabla_{/\!/}J}{m_in_i}-\frac{B}{m_in_i}\nabla p\times\nabla\left(\frac{2r\cos\theta}{R}\right)\cdot\hat{\zeta} = D_{11}\Delta_\perp U + D_{12}\Delta_\perp J + D_{13}\Delta_\perp p$$

$$-E - v\times B + \frac{1}{\sigma}J = D_{21}\Delta_\perp U + D_{22}\Delta_\perp J + D_{23}\Delta_\perp p$$

$$\frac{dp}{dt} - \frac{1}{B}[\varphi, p] = D_{31}\Delta_\perp U + D_{32}\Delta_\perp J + D_{33}\Delta_\perp p$$

where σ is the classical conductivity, and transport coefficients D_{ij} are given as

$D_{ij} = \Sigma\left(|k_{1\perp}\varphi_1|^2 B^{-2}K_1^{-1}H_{ij}\right)/2$, $H_{11} = k_{1\perp}^2$,
$H_{12} = i\,g k_{1/\!/}k_{1\perp}^2\gamma_{j1}^{-1}$, $H_{13} = A_1 k_{1\perp}^2\gamma_{p1}^{-1}$,
$H_{21} = i\,\xi k_{1/\!/}\gamma_{j1}^{-1}$,
$H_{22} = \gamma_{u1}k_{1\perp}^2\gamma_{j1}^{-1} + iA_1 k_{1\theta}\nabla p_0 B^{-1}\gamma_{j1}^{-1}\gamma_{p1}^{-1}$,
$H_{23} = i\xi A_1 k_{1/\!/}\gamma_{p1}^{-1}$, $H_{31} = -ik_{1\theta}\nabla p_0 B^{-1}\gamma_{p1}^{-1}$,
$H_{32} = k_{1\theta}\nabla p_0 g k_{1/\!/}B^{-1}\gamma_{j1}^{-1}\gamma_{p1}^{-1}$,
$H_{33} = \gamma_{u1}k_{1\perp}^2\gamma_{p1}^{-1} + g\xi k_{1/\!/}^2\gamma_{j1}^{-1}\gamma_{p1}^{-1}$, where
$\gamma_{u1} = \gamma(1) + \mu k_{1\perp}^2$, $\gamma_{j1} = \gamma(1) + \mu_e k_{1\perp}^2$,
$\gamma_{p1} = \gamma(1) + \chi k_{1\perp}^2$, $\gamma(1)$ is defined as
$\partial\tilde{y}/\partial t = \gamma(1)\tilde{y}$, $g = B^2/m_in_i$, $\xi = n_e e^2/m_e$,
$A_1 p = B(m_in_iR)^{-1}\nabla p\times\nabla(2r\cos\theta)\cdot\hat{\zeta}$
$K_1 = \gamma_{u1}k_{1\perp}^2 + e^2B^2k_{1/\!/}^2(m_im_e\gamma_{j1})^{-1}$
$iA_1 k_{1\theta}\nabla p_0 B^{-1}\gamma_{p1}^{-1}$ and other notation is standard. The diagonal elements D_{11}, D_{22} and D_{33} are the ion viscosity, current diffusivity and thermal transport coefficient.

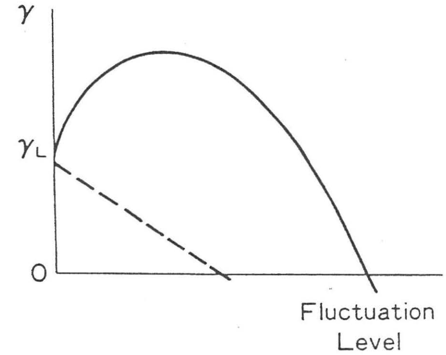

Fig.1 Mode growth rate vs turbulence level

References

1) Kadomtsev B B: in *Plasma Turbulence* (Academic press, New York, 1065),
2) Itoh K, Itoh S-I and Fukuyama A: Phys. Rev. Lett. **69** (1992) 1050.