# §5. Energy Transfer from Micro-turbulence to Macro-MHD

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Micro-turbulence and macro-magneto-hydro-dynamic (macro-MHD) instabilities can appear at the same time and interact with each other in a plasma confinement. The multi-scale-nonlinear interaction among micro-turbulence, double tearing instability, and zonal flow is investigated by numerically solving a reduced set of two-fluid equations. It is found that the double tearing instability, which is a macro-MHD instability, appears in an equilibrium including micro-turbulence and zonal flow when the double tearing mode is unstable. The roles of the nonlinear and linear terms of the equations in driving the zonal flow and coherent convective cell flow of the double tearing mode are examined. The Reynolds stress drives zonal flow and coherent convective cell flow, while ion diamagnetic term and Maxwell stress oppose the Reynolds stress drive. When the double tearing mode grows, linear terms in the equations are dominant and they effectively release the free energy of the equilibrium current gradient.

We have developed a new simulation code solving a reduced set of two-fluid equations that extends the standard reduced two-fluid equations, by including temperature gradient effects (Ref.1). We carry out three-dimensional simulations with this simulation code. In this report, we investigate multi-scale- nonlinear interactions among kinetic ballooning modes, double tearing instability, and zonal flows. We consider a reversed-shear plasma that has its q-minimum lower than 2 and has two resonant surfaces of q=2 with beta=1%. The kinetic ballooning modes, i.e. micro-instabilities, are unstable and grow at first. The instabilities produce zonal flow which regulates the instabilities. Then a quasi-steady state including the micro-instabilities and zonal flow is established and continues. The (m,n)=(2,1) mode finally breaks out of the quasi-steady state and becomes the linear unstable double tearing mode.

We examine the contribution of each term in the vorticity equation to zonal flow drive and coherent convective cell flow drive. The Reynolds stress tends to drive zonal flow as shown in Fig. 1. On the other hand, the ion diamagnetic term and Maxwell stress oppose the Reynolds stress drive. The (m,n)=(2,1) convective cell flow is driven by micro-instabilities through nonlinear mode coupling at first, and then it becomes a part of turbulence during the quasi-steady state. The Reynolds stress drive the convective cell flow, while ion diamagnetic term and Maxwell stress counteract with the Reynolds stress drive during this state as shown in Fig.2. Thus, energy transfer from micro-turbulence to coherent convective cell flow of macro-MHD is similar to the energy transfer to zonal flow (Ref. 2). In spite of the fact that the energy transfer from micro-turbulence drives n=1 convective cell flow, the convective cell flow is different from the eigenfunction of macro-MHD instability and is a part of turbulence. Figure 3 shows this difference. The potential profile at t=136 shows convective cell flow driven by the micro-turbulence before the appearance of macro-MHD. The potential profile at t=176 shows convective cell flow after the appearance of macro-MHD. It is similar to the eigenfunction of macro-MHD instability. Hence, the micro-turbulence does not cause the macro-MHD instability, but the turbulence just produces a seed of macro-MHD instability.

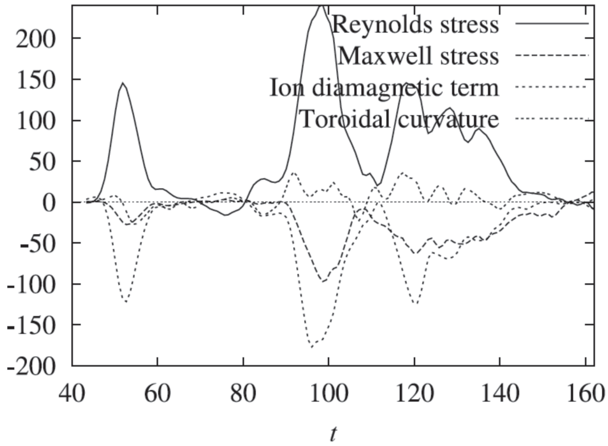


Fig.1. Energy transfer to zonal flow by the Reynolds stress, the Maxwell stress, the nonlinear ion diamagnetic term, and the toroidal curvature in the vorticity equation.

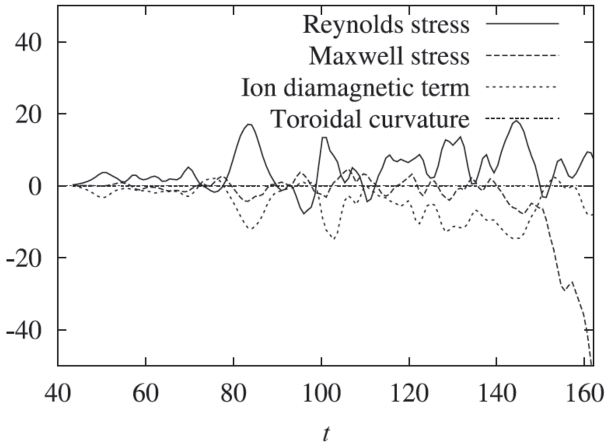


Fig.2. Energy transfer to (m,n)=(2,1) convective cell by the Reynolds stress, the Maxwell stress, the ion diamagnetic term, the toroidal curvature in the vorticity equation.

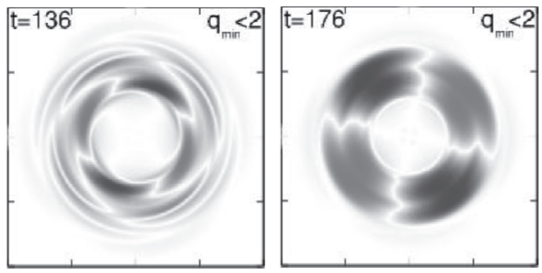


Fig.3. Electrostatic potential profile of n=1 mode.


1) A. Ishizawa and N. Nakajima, Phys. Plasmas **14**, 040702 (2007).
2) A. Ishizawa and N. Nakajima, Nuclear Fusion **47**, 1540 (2007).