

Multi-scale interactions among macro-MHD, micro-turbulence, and zonal flows

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Appearance of macro-magnetohydrodynamic (macro-MHD) instability is found after a quasi-steady equilibrium has been formed by a balance between micro-turbulence and zonal flow by solving reduced two-fluid equations numerically. Only after obtaining the equilibrium which includes zonal flow and the turbulence caused by kinetic ballooning mode is this simulation of macro-MHD mode, double tearing mode, accomplished. In the quasi-steady equilibrium a macro-fluctuation which has the same helicity as that of double tearing mode is a part of the turbulence until it grows as a macro-MHD mode finally. When the macro-MHD grows it effectively utilize free energy of equilibrium current density gradient because of positive feedback loop between suppression of zonal flow and growth of the macro-fluctuation causing magnetic reconnection. Thus once the macro-MHD grows from the quasi-equilibrium, it does not go back. The macro-MHD violates the magnetic surfaces globally and thereby substantially changes the balance between the turbulence and zonal flow.