Large Scale Flows and Nonlinear Dynamics of Flute Mode Turbulence

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Recently, several experimental investigations have revealed a strongly intermittent nature of particle and heat transport in the scrape-off-layer (SOL) of magenetized plasmas. There are strong indications that this is caused by so-called large-scale flows (streamers and zonal flows and interplay between them), spontaneously generated by nonlinear dynamics in turbulent plasma. Self-consistent description of emergence and evolution of such structures was achieved by focusing on the collective two-dimensional dynamics perpendicular to the magnetic field. To describe this dynamics we use model for interchange (flute) turbulence. We have addressed, in the context of the electrostatic flute mode turbulence, two fundamental questions regarding the physics of these sheared flows. First, what is the mechanism by which these flows are generated? Second, under what conditions are these flows stable and what will be the long term dynamics of flows in this case? The analysis performed is based on the rigorously derived nonlinear equations for flute mode where finite Larmor radius effect is taken into account.

The mechanism for the mean flow generation by flute mode turbulence is identified and elucidated. It was shown that the flow is driven by the radial divergence of the turbulent Reynolds stress and flow acceleration will occur if turbulence supports radially propagating waves. The specific role of density fluctuations and finite Larmor radius effects was clarified. Solution of the evolution equations for large-scale flows together with the WKB-type wave kinetic equation with slowly varying parameters due to the mean shear flow results in the determination of a stability criterion in terms of flute-mode turbulence spectra. Furthermore, the formation of coherent structures, which corresponds to propagating shear layer “domain walls” between regions of different velocities, is depicted. To throw light on the nonlinear evolution properties of coupled system (flute mode turbulence + large scale plasma flows) we perform the numerical investigation of the temporal evolution of flute instability with impact on excitation and suppression of large scale anisotropic modes. It was shown that formation of streamer-like structures is attributed to linear development of instability while the subsequent excitation of zonal modes is the result of nonlinear coupling between linearly growing modes. When amplitudes of zonal modes became of the same order as that of streamer modes, the flute instability get suppressed and zonal flow dominate. The ion viscosity may result in the saturation and suppression of zonal flow and this self-consistently leads, in turn, to repetitive development of the flute instability. Thus, the radially extended convective cells (streamers) build up intermittently and give rise to large scale transport events. The generation of zonal flows tends to self-regulate the turbulence. Therefore, we can conclude that transport properties in the edge of a tokamak plasma are indeed strongly intermittent in nature and governed by the interplay between streamers and zonal flows.