Radial zonal flow pattern formation by phase synchronization in ITG turbulence

Sumin Yi and Hogun Jhang

Korea Institute of Fusion Energy, Daejeon 34133, Republic of Korea

contact: yism ⊕ kfe.re.kr

Zonal flows and their roles in turbulence regulation have been the most active research subject in magnetic fusion plasma physics for the past decades. Theories of zonal flow generation often involve either a low dimensional model such as the modulational process or infinite dimensional one such as the wave kinetic equation. In experiments and global gyrokinetic simulations, a well-defined radial pattern of zonal flows is often observed. This phenomenon is one manifestation of the more general category of the nonlinear wave number selection problem. Up to now, no concrete answer has been established about physics behind the radial zonal flow pattern formation in magnetic fusion plasmas. In this talk, from global gyrokinetic simulations of long wave length toroidal ion temperature gradient-driven (ITG) turbulence, we identify two physical processes by which zonal flow generation and its radial pattern formation is governed. The potential vorticity flux is used to elucidate the zonal flow generation mechanism, limiting the validity of this analysis within ITG turbulence. When the unstable region is wider than the correlation length of the modes, the zonal flow structure changes in a turbulence time scale. We discover that the radial phases of ITG modes determine the evolution of the zonal flow structure. The nonlinear $E \times B$ advection driven by the zonal flow itself brings about the synchronization of mode phases, resulting in a fine-scale zonal flow pattern. When the unstable region is comparable to the mode correlation length, the phase synchronization effect almost vanishes. In this regime, the modulational instability takes over and amplifies a coherent zonal flow, leading to a lower turbulence saturation level. One may expect the prompt response of zonal flow will be important in the flat-q region where the correlation length is supposed to relatively wider while the unstable region is narrow.