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Multi-scale drift wave turbulence and zonal flows in magnetized plasmas

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Introduction

Multi-scale phenomena and cross-scale interactions often found in fusion, space, and astrophysical plasmas represent complexity of plasma behaviors. Magnetic reconnection and collisionless shock waves are typical examples commonly found in laboratories and space. A variety of multi-scale processes also arise in plasma turbulence.

Generation of drift wave turbulence itself is regarded as a multi-scale process where the macro-scale inhomogeneity of density and temperature profiles drive micro-scale instabilities. The micro turbulence is also influenced by equilibrium magnetic field and flows of which scales are introduced *externally*. In addition, the drift wave turbulence involves multiple space and time scales *internally*. Interaction of zonal flows and turbulence, which has been intensively investigated in the magnetic fusion research in the last two decades, is one of the well-known examples, where zonal flows have much longer temporal and spatial (poloidal and toroidal) scales than those of the micro-scale turbulence. In this talk, we discuss a more general class of multi-scale interactions in the drift wave turbulence and zonal flows.

Cross-scale interactions of the ITG/ETG turbulence

The magnetized plasma turbulence inherently involves multiple scales because of the large difference of ion and electron mass, $m_i >> m_e$, as well as the wide variety of drift waves and instabilities. The ion and electron temperature gradient (ITG/ETG) turbulence are isomorphic and their spatio-temporal scales are characterized by their gyro-radii and transit times, respectively. The large difference of their scales, which is characterized by a factor of $(m_i/m_e)^{1/2}$ for $T_i \sim T_e$, implies the scale separation, as found in gyrokinetic simulations of ITG/ETG turbulence in early days [1,2], where the ETG turbulence with smaller spatio-temporal scales is often swept out by the ITG turbulence with larger scales and amplitudes.

Recently, our peta-scale gyrokinetic simulations of ITG/ETG turbulence by means of GKV code have shown a β-value dependence of the cross-scale interaction between ITG and ETG turbulence [3]. The strongly unstable ITG mode in a low β regime suppresses the ETG turbulence. However, we have also found presence of an *inverse* process from the electron scale to the ion scale, where the ITG modes are weakly unstable with a higher β-value. In the latter case, the ITG turbulence and transport are enhanced as the zonal flow generation in a sub-ion scale is weakened by the ETG turbulence [3]. Detailed analysis of the entropy transfer among ITG/ETG turbulence and zonal flows confirms the damping effect of the ETG turbulence on the short wavelength zonal flows [4]. Existence of the cross-scale interactions between the ITG and ETG turbulence stimulates a careful validation study of transport simulation and modeling [5,6].

Multi-scale phenomena in drift wave turbulence

The cross-scale interactions of turbulence mediated by zonal flows was also found in simulations of the ETG turbulence and the trapped electron modes (TEM) [7]. The sub-ion scale zonal flows driven by the TEM regulate not only the TEM but also the finer-scale ETG turbulence, and leads to reduction of the electron heat transport.

A direct interaction of the micro-tearing mode (MTM) and ETG turbulence is recently identified by the GKV simulations. The MTM naturally involves a multi-scale structure, where a radially localized current sheet is embedded in the linear eigenmode with the ion-scale poloidal wavenumber. The thin current sheet consists of the parallel electron flow, and is destroyed by the ETG turbulence. It leads to reduction of the MTM amplitude and transport flux change [8].

The final example of the multi-scale phenomena in drift wave turbulence is related to the parallel scale-length. Fast parallel motions of electrons lead to elongation of the ballooning mode structure of turbulence, and may influence turbulence correlations and resultant fluctuation levels. Our new flux tube simulation model highlights importance of the parallel correlation for quantitative evaluation of the turbulent transport in toroidal plasmas.

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