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プラズマ乱流における輸送とエントロピー伝達過程
Transport and entropy transfer in plasma turbulence

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Various vortex and flow structures, i.e., turbulent vortices, axisymmetric zonal flows, and radially elongated streamers, are generated through complicated nonlinear interactions in ion temperature gradient (ITG) and electron temperature gradient (ETG) driven turbulence, which cause the anomalous transport in magnetically confined toroidal plasmas. The dynamics of turbulent vortices and zonal flows, and the related transport processes in high temperature collisionless (or weakly collisional) magnetized plasmas involve a lot of kinetic processes.

The gyrokinetic entropy balance[1], which describes directly the relation between the microscopic fluctuations of the distribution function and the turbulent transport, provides ones with fundamental understandings of the nonlinear interactions among vortices/flows and their effects on the turbulent transport. The entropy transfer function appearing in the gyrokinetic entropy balance is regarded as a kinetic extension for zonal-flow energy production due to the Reynolds stress.

In this study, the gyrokinetic entropy balance relations for zonal and non-zonal modes, and the nonlinear entropy transfer processes are carefully examined for the toroidal ITG and ETG turbulence, then, the nonlinear entropy transfer processes due to triad interactions with zonal flows are revealed. The entropy transfer from non-zonal to zonal modes is substantial in the instability-saturation phase of the ITG turbulence, while, once the strong zonal flow is generated, the entropy transfer to the zonal modes becomes quite weak in the steady state. Instead, the zonal flows play a catalytic role in the entropy transfer among non-zonal modes, i.e., the entropy of non-zonal modes with low radial-wavenumbers (much contribute to the heat flux) is successively transferred to the other non-zonal modes with higher radial-wavenumbers (but with less contribution to the heat flux) via the strong interaction with zonal flows. The transport regulation by zonal flows in the steady state is, thus, a consequence of these successive entropy transfer processes. On the other hand, in both the instability-saturation and steady phases of the ETG turbulence, the role of zonal flows in the entropy transfer to the higher radial-wavenumber modes is much weaker than that in the ITG case. Then, the entropy transfer processes are confined within the low wavenumber modes where the higher transport level is sustained.

Also we will present recent progress in entropy transfer analyses in multi-scale gyrokinetic turbulence[3] and its application to MHD turbulence.

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