§21. What is Cross-ferroic Plasma Turbulence?

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In the non-equilibrium system, structures are continuously generated and dissipated. Cross-correlation between various kinds of thermodynamical force in transport process (such as gradients of temperature and velocity) is one of the essential mechanisms that realize varieties in structures of matters. Cross-correlations being associated with phase transition have led the concept of multi-ferroic materials, which have impacts on pure and applied physics today. In the extremely non-equilibrium system, a variety of scalar and vector fields is formed. The magnetically confined plasma is one of the examples of the extremely non-equilibrium system. How do multiple structure-formation mechanisms take place in extremely non-equilibrium plasmas? Self-organization of large-scale orders can also be caused by turbulence. The interplay between gradients through relaxation and structure formation via turbulence is the central issue in modern plasma physics. Drift-wave fluctuations play important roles in turbulent structure formation in magnetized plasmas, causing cross-field flux to generate, e.g. zonal flows and zonal magnetic fields, which circumnavigate the main magnetic field. The sheared flow in the direction of magnetic fields is predicted to cause Kelvin-Helmholtz type instability (D'Angelo mode). Both drift wave and D'Angelo mode fluctuations induce cross-field fluxes of particle and momentum, and the interferences and competition between gradients of different fields (density, azimuthal and axial velocities) interfere and compete. Concerning the flow-shear driven mode, although it was identified experimentally, direct interference between density and velocity inhomogeneities associated with this mode has not been measured.

Experiment was performed in a linear device, PANTA [1]. A helicon plasma source is located at one side of a vessel. Argon gas at 0.1 Pa is fed in the quartz tube and is ionized by 2.7 kW of 7 MHz rf waves from an antenna on the tube. On the other side of the vessel, the plasma is terminated by an endplate (stainless steel). This boundary condition (source at one end and metal plate at the other end) induces a plasma flow and weak gradient of electron pressure in the direction of the magnetic field, and determines the axial mode structure of the drift wave. Typical plasma parameters are as follows: plasma radius a = 5 cm, plasma length L = 4 m, electron density $n_e \sim 1\text{x}10^{19}$ m^{-3}, electron temperature T_e = 3 eV, and ion temperature T_i = 0.3 eV. A 4-tips probe is used to measure scalar-fields (n_e, T_e) and flow vector-field. In the region of $z < 2.5$ m, the cross-field transport by turbulence is dominant loss channel of plasma, and the plasma weakly varies along the field line. Two tips are aligned in the axial direction, to measure the long time-averaged axial velocity and axial velocity fluctuation, with Mach probe technique. Another two are coordinated in the azimuthal direction for radial velocity measurement (and its fluctuation), through the difference of floating potentials. The axial flow velocity is evaluated from asymmetry of ion saturation currents in the upstream and downstream. An alternative Mach probe model to evaluate the flow velocity yields identical results. The upstream tip and downstream tip are exchanged in a shot-by-shot manner to balance the small individual variability of tips. Double-probe method is also applied by using a pair of tips and long time-averaged n_e, T_e are evaluated. The long time-averaged potential is estimated from the floating potential, while considering the impact of T_e. Relative density fluctuations are provided by relative ion saturation current fluctuations. The temperature fluctuation amplitude of the drift-wave is evaluated as 10 % of and by using a triple-probe method in PANTA [2].

We discovered a new order in cross-ferroic turbulence, in which chained structure formation is realized by cross-interaction between different fields (in scalar as well as vector quantities) [3]. Drift-wave fluctuations are found to enhance the velocity gradient. The enhanced gradient excites Kelvin-Helmholtz type instability [4], which causes an up-hill flux of particles in the strong-velocity-shear region. This result shows the cross interferences of multi-ferroic property of turbulent plasmas. The origin is identified by measuring the relaxation rate and dissipation power in the complex turbulence-driven flux. The relations between global gradients, multiple kinds of fluctuations and turbulence-driven fluxes, as summarized in Fig.1

The cross-ferroic plasma turbulence is a new feature in the extremely non-equilibrium system. Experimental results reported here are largely compelling, and are of significant interest to broader fields of modern science that involves turbulence (in particular, fluid dynamics, plasma physics, astrophysicists, meteorology, oceanography, engineering, etc.). This study pioneers a breakthrough in research of the non-equilibrium non-linear systems.

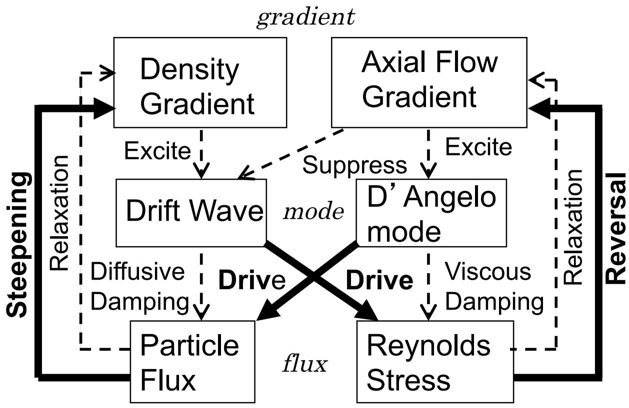

Fig. 1 Cross-ferroic plasma turbulence

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