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Experimental verification of entropy cascade in two-dimensional electrostatic turbulence of magnetized plasma

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The wavenumber spectrum (k-spectrum) of turbulence reflects the universal nature hidden behind this seemingly complex phenomenon, as illustrated by a Kolmogorov's theory (K41) [1]. In the K41 theory, the well-known $k^{-5/3}$ scaling of energy flux is deduced by dimensional analysis based on a profound insight into three-dimensional (3D) isotropic turbulence. K41 considers an energy cascade through an inertial subrange of turbulence, where no energy source and dissipation exist, into a dissipative energy sink at smaller scales. Numerous following experimental studies supported the $k^{-5/3}$ spectrum in 3D isotropic turbulence and verified the existence of the inertial range and energy cascade.

The wavenumber spectrum of electrostatic potential fluctuation $|\phi_k|^2$ at sub-Larmor scales was measured in two-dimensional (2D) electrostatic turbulence in laboratory magnetized plasma. The spectrum at scales $k_\perp\rho_i > 1$, where $k_\perp$ and ρ_i are the fluctuation wavenumber perpendicular to the magnetic field and ion Larmor radius, respectively, supports the existence of the $k^{-10/3}$ inertial range of the entropy cascade induced by nonlinear phase-mixing. This indicates agreement with a theoretical prediction [2] and the result of a 2D gyrokinetic simulation [3].

The experiment was conducted in the Magnetized Plasma eXperiment (MPX) device [4]. The MPX device is a linear plasma device that can generate a plasma with a hot cathode or by electron cyclotron resonance at magnetic field strength of ~ 0.1 Tesla. We adopted the two-point technique [5] to obtain frequency and local wavenumber spectrum $S_l(\omega, k_\perp)$ with ion scale using separated two Langmuir probes.

We prepared the following three plasma states for the k-spectrum measurement: state (i) plasma in which coherent interchange modes were excited, state (ii) plasma in which resistive drift waves propagated and state (iii) turbulent state associated with the drift waves. The frequency-integrated wavenumber spectrum $|\phi_k|^2$ for the turbulent state (iii) decayed more sharply than the other states did at scales $k_\perp\rho_i > 1$ and followed the $k_\perp^{-10/3}$ law predicted in Ref. 2 (Fig. 1). The cutoff wavenumbers of the spectrum, above which the entropy cascade is smeared by collisions, in this experiment were consistent with those in the theory [3].

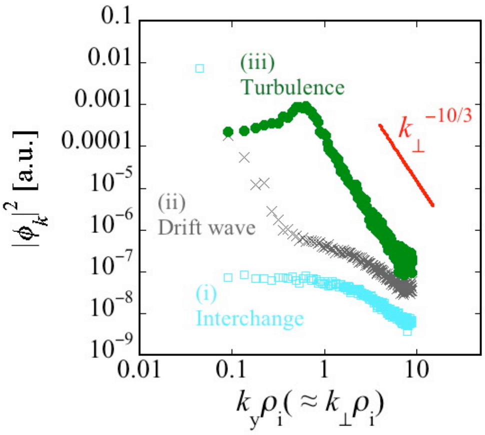

Fig. 1 Power spectra $|\phi_k|^2$ as a function of wavenumber k_y for the following states: (i) interchange mode was excited, (ii) coherent drift waves were excited, and (iii) developed turbulence.

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