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Phase space spectra of perturbed distribution function in three-dimensional slab ion temperature gradient turbulence

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Kinetic plasma turbulent transport is ubiquitous in fusion, space, and astrophysical plasmas with high temperature, where the low collisionality of charged particles allows the distribution function to be far from the Maxwellian. It has long been argued how fluctuations can be dissipated in the collisionless regime of drift wave turbulence. Fine structures of the perturbed distribution function continuously develop on the velocity space in the collisionless plasma turbulence, where the entropy balance relation derived from the perturbed gyrokinetic equation is confirmed by direct numerical simulations [1]. In case with finite collisionality, a steady state of the drift wave turbulence was realized and investigated in terms of the phase space spectrum of the fluctuating distribution function (δf), which clarifies the transfer and dissipation processes of the entropy variable defined by a quadratic integral of δf [2], where the Hermitian polynomial expansion is applied to the parallel velocity space. A power-law scaling derived from the theoretical analysis was verified in an “inertial” subrange of the power spectrum [2].

The previous studies on the turbulent spectrum of the entropy variable [1, 2] focused on a two-dimensional slab ion temperature gradient (ITG) turbulence with an assumption of translational symmetry in one of the coordinates so that the parallel component of the wavenumber is in proportion to one of the perpendicular ones. The present study removes the artificial restriction by considering the three-dimensional (3-D) slab ITG turbulence, while the perpendicular distribution function is assumed to be Maxwellian.

The spectrum of the entropy variable with the Hermite polynomial expansion (δS_n) obtained by the 3-D slab ITG turbulence simulation is shown in Fig. 1 for different collisionality. A clear power-law spectrum of n^{-1} is identified even in the 3-D turbulence for the case with weak collisionality, where the high parallel wavenumber components are generated through the turbulent nonlinearity.

The entropy transfer function in the Hermite spectral space also confirms a nearly flat profile where the power-law spectrum of δS_n is observed, as shown in Fig. 2, suggesting the transfer process is free from the forcing and dissipation.

It is also interesting to evaluate the effective parallel wavenumber $\langle k_\parallel \rangle_n$ weighted by the entropy variable of the order of n. Figure 3 shows that $\langle k_\parallel \rangle_n$ is roughly in proportion to $n^{1/2}$ as same as the theoretical prediction for the two-dimensional case. Universality of the $\langle k_\parallel \rangle_n$ scaling is understood in analogy to the passive scalar advection in turbulence with a large Plandtl number.

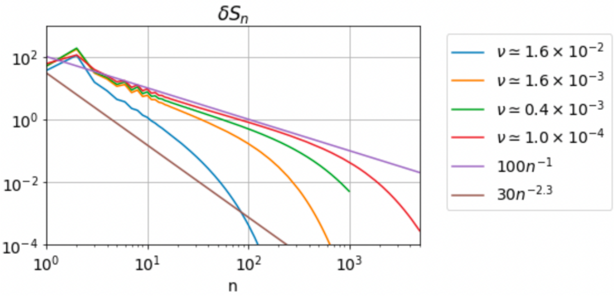

Fig. 1: Powder spectrum of the entropy variable (δS_n) obtained by the gyrokinetic simulation of the 3-D slab ITG turbulence.

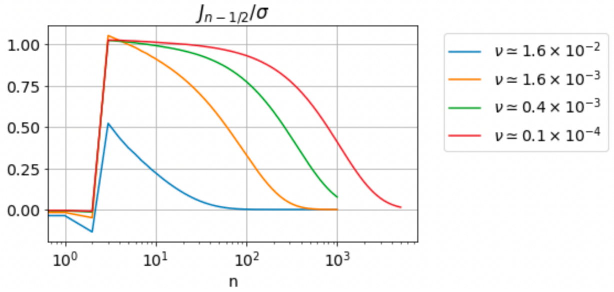

Fig. 2: Normalized entropy transfer function in the Hermite spectral space. See Ref. [2] for definition of $J_{n-1/2}$.

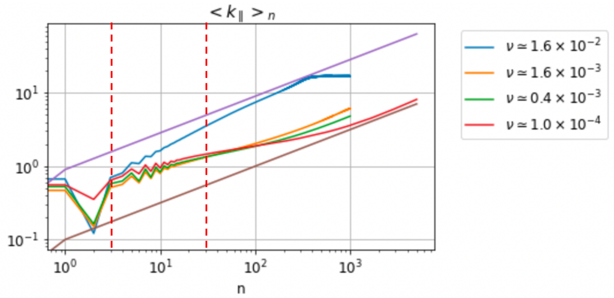

Fig. 3: Effective parallel wavenumber.

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References

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[2] T.-H. Watanabe and H. Sugama, Phys. Plasmas, **11**, 1476-1483 (2004).