Phase mixing vs. nonlinear advection in drift-kinetic plasma turbulence

A. A. Schekochihin,[1,2] J. T. Parker,[3,4] E. G. Highcock,[1,4] P. J. Dellar,[3,5] A. Kanekar,[6] W. Dorland,[6,1] G. W. Hammett,[7] N. F. Loureiro,[8] C. Staines,[2] L. Stipani,[9,1]

[1]Rudolf Peierls Centre for Theoretical Physics, University of Oxford, Oxford OX1 3NP, UK
[2]Merton College, Oxford OX1 4JD, UK
[3]OCIAM, Mathematical Institute, University of Oxford, Oxford OX1 3LB, UK
[4]Brasenose College, Oxford OX1 4AJ, UK
[5]Corpus Christi College, Oxford OX1 4JF, UK
[6]Department of Physics, University of Maryland, College Park, Maryland 20742, USA
[7]Plasma Physics Laboratory, Princeton University, New Jersey 08543, USA
[8]IPFN, Instituto Superior Tecnico, Universidade de Lisboa, 1049-001 Lisboa, Portugal
[9]Dipartimento di Fisica, Universita di Pisa, Pisa, 56127, Italy

A scaling theory of long-wavelength electrostatic turbulence in a magnetised, weakly collisional plasma (e.g., drift-wave turbulence driven by ion temperature gradients) is proposed, with account taken both of the nonlinear advection of the perturbed particle distribution by the fluctuating $\mathbf{E} \times \mathbf{B}$ flows and of its phase mixing, which is caused by the streaming of the particles along the mean magnetuc field and in a linear problem would lead to Landau damping. It is found that it is possible to construct a consistent theory in which very little free energy leaks into high velocity moments of the distribution function, rendering the turbulent cascade in the energetically relevant part of the wave-number space essentially fluid-like. The velocity-space spectra expressed in terms of Hermite-moment orders are steep power laws and so the free-energy content of the phase space does not diverge at inifinitesimal collisionality (like it does for a linear problem). The partitioning of the phase space between the (energetically dominant) region where this is the case and the region where linear phase mixing wins its competition with nonlinear advection is governed by the "critical balance" between linear and nonlinear timescales. The ability of the free energy to stay in the low velocity moments of the distribution function is facilitated by the "un-phase-mixing" effect, whose presence in the nonlinear system is due to the stochastic version of the plasma echo (the advecting velocity couples the phase-mixing and un-phase-mixing perturbations). It is argued that at low collisionality, Landau-fluid closures that retain a sufficient but finite (collisionality-independent) number of moments may be sufficient for a full characterisation of kinetic turbulence, with phase mixing terms serving only to regularise the problem in the energetically subdominant part of the wave-number space.