Turbulence Shearing in Fusion Plasmas

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Control of turbulent transport is a key issue in many physical systems. In fusion experiments, the plasma is confined to reach conditions very far from thermodynamical equilibrium with its environment. Despite the effectiveness of magnetic confinement, which allows one reaching temperatures comparable and even larger than that considered in the sun, one finds that plasma turbulence is a key player in the self-organisation of the system. The turbulence that prevails stems from instabilities that feed on large free energy reservoirs governed by the departure from thermodynamical equilibrium. Several mechanism are present even in the simplest models such as drift wave, interchange and Kelvin-Helmholtz instabilities. The two latter are also present in neutral fluid turbulence, the interchange instability being comparable to Rayleigh-Bénard and Rayleigh-Taylor instabilities. The former exhibits similarities to Rossby wave turbulence. In fusion plasmas, the turbulence is quasi 2D leading to a specific drive of zonal flows, both generated by turbulence and stabilising it by eddy shearing. Magnetic shearing, specific of magnetically confined plasmas also regulates plasma turbulence. Furthermore, it impedes the inverse cascade by driving linear stability of the larger modes. These shearing effects are involved in the turbulence self-organisation and consequent transport. They can drive transport barriers, namely regions with improved confinement and strongly reduced turbulence.

The effect of shearing, via both velocity and magnetic shear as well as their interplay, is first addressed analytically starting from the Dupree-like model. This indicates that magnetic shearing can inhibit the stabilising effect of velocity shearing. The latter approach, that involves non-linear evolution times, is applied to the calculation of eigen-functions and eigen-modes of more realistic turbulence models.

In this work, we also analyse simulation results of velocity shearing effects using a modulational model of the Kelvin-Helmholtz instability. Both gyrokinetic and fluid simulations are addressed. In the simulations of interchange turbulence, with conditions appropriate for comparison with linear theory, one finds that the interchange instability grows into the non-linear regime with a broad spectrum in one direction and condensates on the largest possible mode in the other direction, that of the gradients driving the instability. When the Kelvin-Helmholtz driven perturbation is large enough, the spectrum is reorganised and the turbulent energy spreads into a broad spectrum in both direction, leading to close to homogeneous 2D turbulence. These results are analysed in the modulational instability framework with good agreement. This provides a basis to analyse other simulation conditions, in particular that considered in the gyrokinetic framework.