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Multiscale interactions in compressible plasma turbulence and acceleration of particles in space physics

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Turbulence is ubiquitous in space physics and astrophysics, exciting a wide variety of temporal and spatial scales. This is the case in the solar wind and in the interstellar medium, where energy is transferred from large to small kinetic scales where it is finally dissipated. In the macroscopic description of a plasma, turbulence in magnetohydrodynamics (MHD) and in two-fluid approximations is the result of nonlinear interactions of fluctuations of the velocity and magnetic fields, leading to the excitation of waves, and to the generation of spatially intermittent structures that impact on heating, transport, and particle acceleration. Can we use this large-scale description of a plasma to understand multiscale interactions, and to understand their impact on particle acceleration and heating?

Turbulence is often represented as a random collection of waves, or as a random superposition of eddies that lead to a disordered, out-of-equilibrium state of the plasma. However, turbulence is significantly richer in its dynamics, displaying coherent structures, long lived and large-scale ordered states, and non-trivial coupling between the waves and the dynamics of the eddies. In particular, magnetohydrodynamic and two-fluid descriptions of plasmas display non-local coupling between scales. This can lead to the rapid development of small-scale structures, as well as to the rapid amplification of magnetic fields, both at large and at small scales. Recent advances [1,2] allowed quantification of the interactions between scales, through the so-called shell-to-shell transfer functions, and through exact theorems for the energy flux in plasma turbulence. Another recent development, the spatio-temporal spectrum [3,4], allowed the quantification of the strength of waves excited in a turbulent flow, and of their interaction with turbulent eddies (see Fig. 1).

These features are important for the acceleration of protons and electrons by turbulence [5,6]. In particular, they allow quantification of the role of Alfvén waves, of flow compressibility, and of current sheets in particle acceleration, even under a hydrodynamic description of a plasma by considering test particles, which are described by an equation of motion that considers electron pressure and Hall currents among other effects [5]. While turbulence is often considered as a random collection of motions, we argue that this picture lacks the presence of coherent structures that play a central role in particle acceleration and heating.

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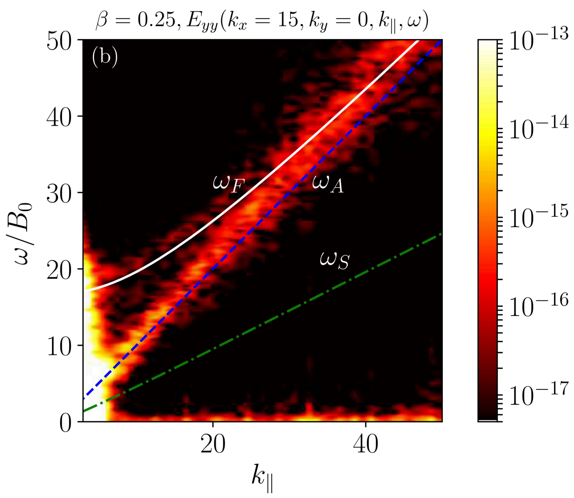

Fig. 1: Spatio-temporal spectrum of a turbulent MHD flow with the dispersion relation of Alfvén, slow and fast magnetosonic waves indicated as references.