A new universal mechanism for the turbulent relaxation in incompressible fluids and plasmas

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Turbulent relaxation in cosmic plasmas is nearly a seventy-year-old problem. When the external forcing is quenched, a turbulent plasma is believed to relax to a Beltrami-Taylor state where the magnetic field ***b*** and the current ***j*** are aligned. Such alignments are already observed in the stellar envelopes, gaseous nebulae and interstellar plasmas. Why a turbulent system attains such an aligned state is pivotal to understand the relaxation dynamics of fluids and plasmas. Despite several theories, a clear unambiguous understanding of the same remains a mystery [1]. Of all competing theories of relaxation, the most popular one is the theory of selective decay where such a relaxed state can be attained by minimizing the quickly varying quantities (the target function) keeping the slowly varying inviscid invariants as approximately constants [2]. Similar conclusion can be theoretically drawn for the alignment between the velocity and the vorticity fields in neutral fluids. Interestingly, the relaxed state of an MHD plasma with moderate beta is numerically found to be $\boldsymbol{j} \times \boldsymbol{b} = \nabla p$, thus supporting a finite pressure gradient. Similar pressure balanced relaxed states are found for the turbulent relaxation of neutral fluids as well. Selective decay, however, cannot account for a finite pressure gradient at relaxed state.

The present work proposes a universal explanation of the turbulent relaxation of fluids and plasmas in terms of the principle of vanishing nonlinear transfer (PVNLT). According to PVNLT, the relaxed states are achieved when the average scale-to-scale nonlinear transfer vanishes identically at all scales in the inertial zone [3]. These relaxed states are therefore obtained to ensure an equilibrium steady state in the inertial range in the absence of any energy input in the large scales (see Figure 1 below). This is in consistency with the conservation of the inviscid invariants. Microscopically, such behaviour can be justified by the maximization of an entropy function in spectral space. PVNLT successfully captures the relaxed states supporting a non-zero finite pressure gradient. The Beltrami-Taylor aligned states are naturally obtained automatically in the limit of insignificant pressure gradient or low plasma beta. Furthermore, PVNLT also successfully determines whether a plasma relaxes towards a force-free state (***j-b*** alignment) or to a state of dynamic alignment (***v-b*** alignment) according to the chosen initial conditions on the helicities. The proposed theory correctly produces all the previously obtained relaxed states in both two-dimensional and three-dimensional fluids and plasmas. The fundamental universal nature of PVNLT assures its applicability to more complicated systems like binary fluids, ferrofluids, compressible fluids and plasmas.

References

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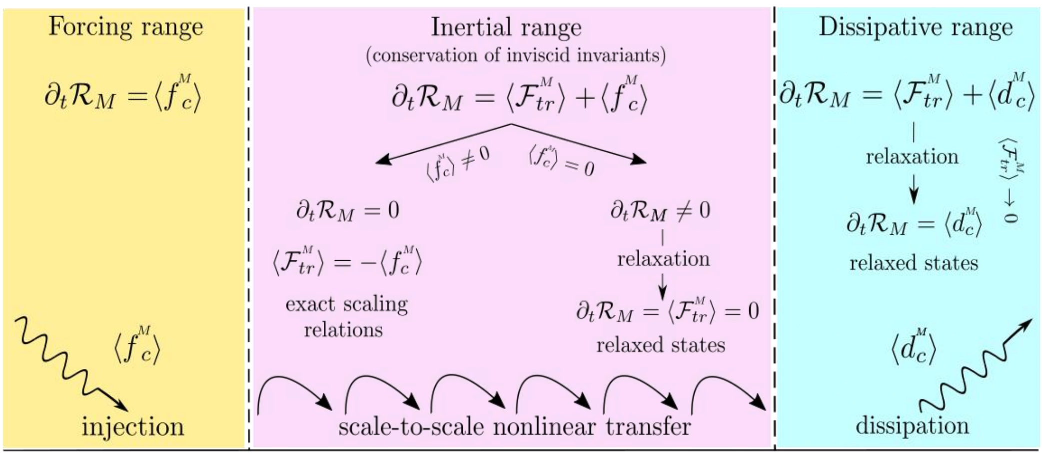

Figure 1. A schematic diagram of the Principle of Vanishing Nonlinear Transfer