A new principle for the turbulent relaxation of fluids and plasmas: looking beyond the principle of selective decay

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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 fields $\boldsymbol{b}$ and the current fields $\boldsymbol{j}$ are aligned. However, 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 keeping the slowly varying inviscid invariants as approximately constants [2]. Similar conclusion can be drawn for the alignment between the velocity and the vorticity fields in neutral fluids. However, the relaxed state of an MHD plasma is numerically found to be $\boldsymbol{j} \times \boldsymbol{b} = \boldsymbol{\nabla} P$ thus supporting a finite pressure gradient. 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 Fig. 1). This fact can also be justified by the maximization of an entropy function in spectral space. PVNLT successfully captures the relaxed states supporting a finite pressure gradient. The Beltrami aligned states are naturally obtained automatically in the limit of insignificant pressure gradient or low plasma beta. PVNLT also successfully determines whether a plasma relaxes towards a force-free state ($\boldsymbol{j} - \boldsymbol{b}$ alignment) or to a state of dynamic alignment ($\boldsymbol{v} - \boldsymbol{b}$ alignment) according to the chosen initial conditions on the helicities. Recently, our research group has successfully used PVNLT to find the relaxed states of binary fluids [4].

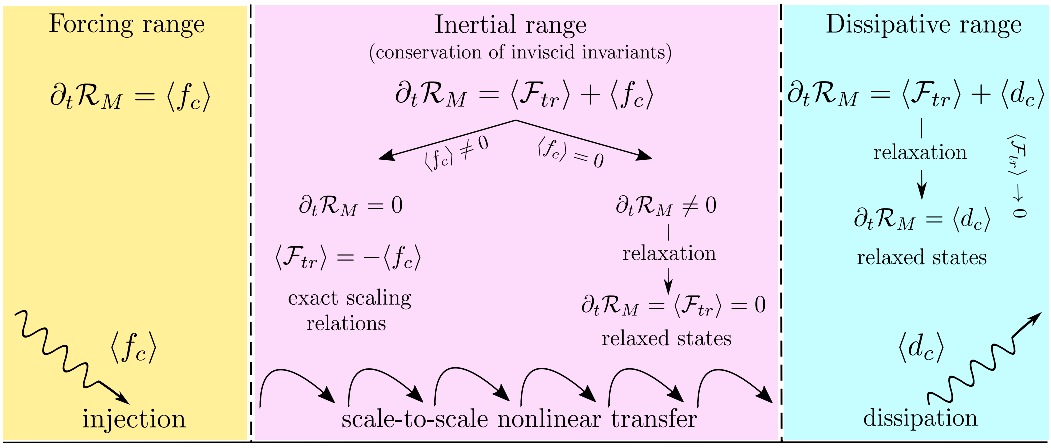

Figure 1: A schematic diagram describing turbulent relaxation.

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