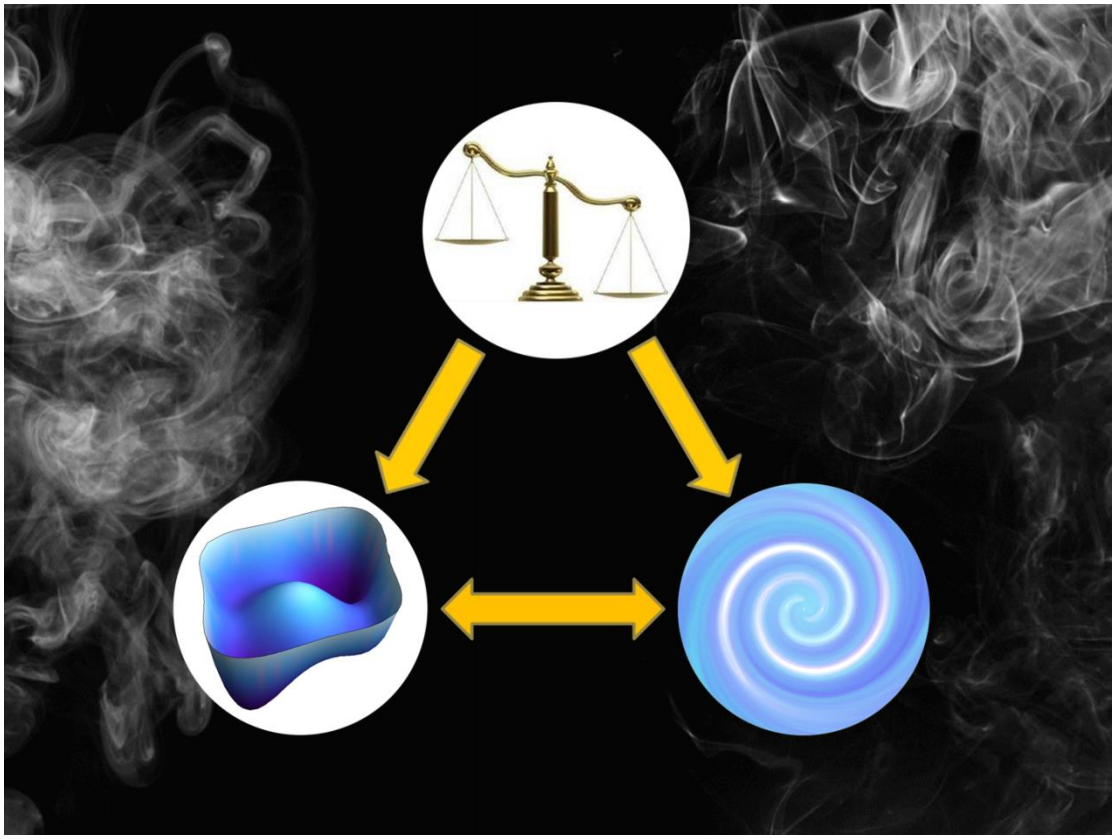
Capturing the nonequilibrium irreversible essence of turbulence



A pictorial representation of the concept of nonequilibrium trinity, consisting of detailed balance breaking (top), non-Gaussian potential landscape (bottom left) and irreversible probability flux (bottom right), which powers turbulence and nonequilibrium fluid dynamics (background).

The true nature of turbulence remains elusive despite more than a hundred years of devotion of countless geniuses. It is widely accepted that turbulence is a paradigm for far-from-equilibrium systems without time reversal symmetry. The nonequilibrium irreversible character of turbulence plays an essential role. Notably, in arguably the most important physical picture of turbulence, large vortices break up into increasingly smaller ones. This process facilitates a unidirectional flow of energy across scales termed energy cascade. However, a global, physical and quantitative characterization of the nonequilibrium irreversible dynamics of turbulent fluids was still challenging until recently.

Dr. Wei Wu, a physics Ph.D. from Stony Brook University, and Dr. Feng Zhang, now both at Changchun Institute of Applied Chemistry Chinese Academy of Sciences, and Chemistry and Physics professor Jin Wang at Stony Brook University have recently developed a theoretical framework to capture the nonequilibrium irreversible nature of turbulence and nonequilibrium fluid dynamics. The approach they adopted has a

distinctive global characteristic that goes beyond two-point and three-point correlation functions usually used in the study of turbulence statistics. Their research entitled "Potential landscape and flux field theory for turbulence and nonequilibrium fluid systems" is published in *Annals of Physics*.

In this study, the notion of nonequilibrium trinity is introduced, which consists of three interlinked components, namely detailed balance breaking, non-Gaussian potential landscape and irreversible probability flux. The latter two components are a pair of closely related consequences of the first one, thus the three forming a 'trinity'. It is proposed that the nonequilibrium trinity captures the nonequilibrium irreversible essence of turbulence and nonequilibrium fluids, and is manifested in various aspects of these systems. A force originating from detailed balance breaking has been identified that drives the nonequilibrium stochastic fluid dynamics including turbulence. The corresponding dynamics is shown to be driven by both the non-Gaussian potential landscape gradient and the irreversible probability flux. An underlying connection has been discovered between the energy flux essential for turbulence energy cascade and the irreversible probability flux as well as the non-Gaussian potential landscape generated by detailed balance breaking. The famous four-fifths law for fully developed turbulence has been demonstrated to be a reflection of the nonequilibrium trinity.

These findings not only shed new light on the nature of turbulence dynamics at the fundamental level, but also have potential applications in more general nonequilibrium stochastic dynamical systems beyond fluid dynamics context.

Read the original paper here.