9th Asia-Pacific Conference on Plasma Physics, 21-26 Sep, 2025 at Fukuoka

Viscoelastic turbulence in strongly coupled plasmas

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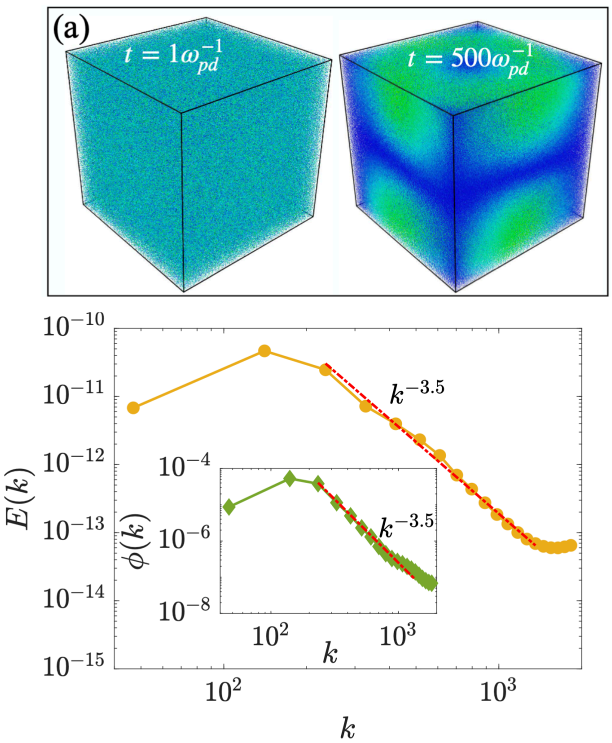
Hydrodynamic turbulence typically arises in a flows with high Reynolds numbers (Re ≳ 4000), where inertial forces far outweigh viscous resistance [1.However, turbulence can also emerge in low-Reynolds-number flows (Re ~ 1) when the Weissenberg number (Wi) which measures the ratio of elastic to viscous stresses exceeds unity. This type of turbulence, known as *elastic turbulence*, is a hallmark of viscoelastic fluids such as polymer solutions, gels, and various biological fluids, including blood. In such systems, external stresses can be partially stored as elastic energy, and upon stress relaxation, this stored energy induces anisotropic effects and modifies the transfer of energy across scales.

In strongly coupled plasmas (SCPs), viscoelastic behavior naturally emerges due to microscopic particle interactions [2]. Heavier charged particles interact through long-range pair potentials, and as the coupling strength defined by the ratio of Coulomb potential energy to thermal energy increases, the system undergoes phase transitions and displays intermediate fluid-like or solid-like characteristics. SCPs typically operate in low-Reynolds-number regimes and exhibit properties such as shear thinning and the propagation of elastic waves, akin to non-Newtonian fluids. These behaviours raise a fundamental question: Can SCPs support viscoelastic turbulence, and if so, how is energy transferred among different dynamical modes of the system.

To explore this, we utilise three-dimensional molecular dynamics simulation (MD) focussing on dusty plasma as a representative system. MD provides a robust, first-principles approach that resolves both microscopic correlations and macroscopic transport behavior without relying on empirical models. Using this framework, we present the first evidence of intermittent viscoelastic turbulence in SCPs. In a driven and dissipative dusty plasma, we identify scale-dependent flow structures shaped by the competition between potential (elastic) and viscous energy dissipation at the particle scale. In contrast to classical turbulence driven by inertia and viscosity the energy transfer in SCPs is governed by their intrinsic viscoelasticity.

Our results show that both kinetic and elastic energy spectra follow power-law scaling $E(k), \phi(k) \propto k^{-3.5}$. In physical space, velocity structure functions reveal non trivial scaling behavior, and the probability distribution functions (PDFs) of velocity increments exhibit significant deviations from Gaussian form, especially in the tails clear signatures of intermittency. These observations establish strongly coupled plasmas as a compelling platform for investigating viscoelastic turbulence, with implications extending to astrophysical environments, soft matter systems, and broader



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