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Phonon turbulence leading to the seismic-like structural rearrangement in dusty plasma liquids

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The traditional understanding of wave turbulence is that it only occurs in macroscopic systems such as water waves and acoustic waves. However, the concept of turbulence in phonons in microscopic media, remains a challenging and elusive topic. Understanding the complicated phonon dynamics and how the phonon affects microscopic structure change is important. Here, we demonstrated the pioneering laboratory observation of wave turbulence in a microscopic system, named phonon turbulence [1,2].

The microscopic system with tiny scales is hard to observe. Here, the model system used is a cold dusty plasma liquid (DPL), which is a good platform with spatiotemporal scales easy for direct experimental observations [2]. The experimental setup is a cylindrical rf (radio frequency) chamber with low-pressure Argon plasma, in which micrometer-sized polystyrene particles are suspended. The quasi-2D DPL is formed by many vertical chains of particles aligned by the ion flow and confined by the plasma sheath field of a hollow cylindrical trap. The chain can hop horizontally without vertical flipping, allowing quasi-2D behavior. A horizontal laser sheet lights up a cross-section of DPL. A camera on top of the chamber records the particle motion.

To understand the phonon dynamics from the recorded particle motion, a novel method, multidimensional complementary ensemble empirical mode decomposition is used for decomposing the thermally excited particle motions into various transverse phonon modes at different scales [3]. The instantaneous phases and amplitudes of these modes can be accessed, which is useful to observe the spatiotemporal waveform evolutions.

It is found that phonons at different scales exhibit intermittent excitation, propagation, scattering, and annihilation. The coherent wavefront of phonons in the xyt space form spatiotemporal clusters with self-similar power-law cluster size distributions. The local structure with poor interlocking facilitates the excitation of large amplitude slow modes. Once the phase synchronization of various-scale modes occurs, particle hopping associated with the structural rearrangement occurs.

The abrupt irreversible responses in the form of seismic-like spatiotemporal clusters are ubiquitous phenomena in heterogeneous strongly coupled systems. Many systems with small to enormous scales (e.g. microscopic systems to seismic systems) also exhibit such phenomena. It is thereby important to understand such phenomena and find certain precursors for the extreme event. Here, we used the concept from the above-mentioned work to study this issue. The goal is to find the phonon-related precursors for the extreme event [4]. It is found that the defective structure (topological defect) facilitates the cascade excitation of multiscale phonons. The earlier rise of the amplitude of the slow phonon and the poor-interlocked region with more and spread defects can be used as the precursor for the extreme event.

This series of works is important because it understands the generic multiscale coherent phonon excitation and its correlation with the local structure and particle motion, paving a new way to study the relevant issue such as extreme seismic-like events.

References

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