Percolating transition from ordered plane dust acoustic wave to wave turbulence in dusty plasmas

Lin I, Po-Cheng Lin and Weng-Ji Chen
Department of Physics, National Central University, Taiwan
lini@phy.ncu.edu.tw

Increasing driving, a nonlinear extended system can change from ordered state to the disordered state. Recent studies showed that, in the hydrodynamic flow, the turbulent transition starts from intermittent emergence of localized turbulent puffs in the laminar flow background, followed by the emergence of one percolating turbulent puff leading to full turbulence [1-3]. It is akin to the order-disorder transition in many nonequilibrium systems such as forest fire and epidemic spread, governed by the percolation theory [4]. Whether the similar percolating transition is also followed in the wave turbulence transition, and the associated spatiotemporal waveform dynamics are unexplored important fundamental issues.

The dusty plasma is composed of micro-meter sized dust particles suspended in the low pressure gaseous plasma background. The higher mobility of electrons than that of ions causes strong negative charging up to 10^4 electrons per dust particle. Through the interplay of dust inertia, the screened Coulomb field, ion streaming, and unfrozen ionization, dust acoustic waves (DAWs) with longitudinal dust particle oscillation can be self-excited [5, 6]. This fundamental acoustic-type density wave exhibits many ubiquitous nonlinear cooperative phenomena from order to turbulence with increasing driving. The proper dust size and spatiotemporal scales of the DAW make it a good platform to visualize and understand those ubiquitous nonlinear wave phenomena from the micro- to the macroscopic level, through optical tracking individual particle motion and monitoring dust density evolution illuminated by a laser sheet over a large area [7-9].

Here, we present our recent experimental study on the whether percolating transition is also followed in the wave turbulence transition from the three dimensional ordered plane wave, and the associated spatiotemporal waveform dynamics, using the self-excited nonlinear dust acoustic wave in a dusty plasma system as a platform [10]. Turbulent sites (TSs) with a wide instantaneous bandwidth in the 2+1D spatiotemporal space are identified through wavelet transform. It is found that the transition from the plane wave to the weakly disordered states starts with a small fraction of intermittently emerging and decaying turbulent sites (TSs) in the ordered wave background. TSs appear in the form of clusters in the 2+1D space, with cluster size distribution follows a power law decay. Further transition to turbulence is associated with a smooth rapid increase in the fraction of TSs, and emergence of a large TS cluster percolating through the 2 +1D spatiotemporal space. The observed transition is similar to the percolating turbulent transition in hydrodynamic flows.

References

[1] K. Avila, D. Moxey, A. D. Lozar, M. Avila, D. Barkley, and B. Hof, "The onset of turbulence in pipe flow," Science 333, 192 (2011).
[2] M. Sano and K. Tamai, "A universal transition to turbulence in channel flow," Nat. Phys. 12, 249 (2016).
[3] H.-Y. Shih, T.-L. Hsieh, and N. Goldenfeld, "Ecological collapse and the emergence of travelling waves at the onset of shear turbulence," Nat. Phys. 12, 245 (2016).
[4] H. Hinrichsen, "Non-equilibrium critical phenomena and phase transitions into absorbing states," Adv. Phys. 49, 815 (2000).
[5] N. N. Rao, P. K. Shukla, and M. Y. Yu, "Dust acoustic waves in dusty plasmas", Planet. Space Sci. 38, 543 (1990).
[6] Chen-Ting Liao, Lee-Wen Teng, Chen-Yu Tsai, Chong-Wai Io, and Lin I, "Lagrangian-Eulerian micro-motion and wave heating in nonlinear self-excited dust-acoustic waves", Phys. Rev. Lett., 100, 185004 (2008).
[7] Ya-Yi Tsai and Lin I, "Observation of self-excited acoustic vortices in defect mediated dust acoustic wave turbulence", Phys. Rev. E. 90, 013106 (2014).
[8] Ya-Yi Tsai, Jun-Yi Tsai, and Lin I, "Generation of acoustic rogue waves in dusty plasmas through 3D particle focusing by distorted waveforms", Nature Physics, 12, 573 (2016)
[9] Po-Cheng Lin and Lin I, "Interacting multiscale acoustic vortices as coherent excitations in dust acoustic wave turbulence", Phys. Rev. Letts. 120, 135004 (2018).
[10] Po-Cheng Lin, Weng-Ji Chen, and Lin I, "Percolating transition to acoustic wave turbulence in dusty plasmas". Phys. Plasma, 27, 010730 (2020).