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Dynamical behaviors of topological defects of thermal phonons in 2D dusty plasma crystals

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Topological defects (TDs), singularities of the order parameter field with unique topological characteristics, ubiquitously exist in extended systems such as crystals, layered solids, liquid crystals, ferromagnets, classical to quantum waves, and biological systems.[1] Those singular objects can be used to characterize the ordering/disordering of above systems. In the disordered dynamical system, TDs usually appear as the cores of some localized coherent entities. Their generation, annihilation and mutual interaction have been intriguing fundamental challenges. Examples include interacting multiscale vortices and saddles surrounding TD filament cores in the hydrodynamic turbulence and multiscale acoustic vortices with helical wave fronts winding around their screw dislocation defect filaments with undefined phase in three dimensional (3D) acoustic wave turbulence of gaseous dusty plasmas. [2-4]

Down to the microscopic level, multiscale (broad-band in frequency) acoustic phonons can be thermally excited or de-excited in crystals. [5] Aside from their significance in condensed matter physics, from the perspective of wave physics, thermally excited phonons in cold crystal serves as a paradigm of linear disordered waves excited by multiscale stochastic agitations, to search for coherence out of disorder. However, beyond the conventional picture of longitudinal and transverse phonons, the picture about the spatiotemporal waveforms of thermal phonons is still missing, because of the difficulty of direct visualization of the crystals in nature.

Over the past two decades, normal mode decomposition via the dynamical or Hessian matrix—constructed from particle displacements or inter-particle potential—has been used to identify the instantaneous eigen-modes of displacement fields and corresponding eigen-frequencies in both ordered crystals and amorphous solids or glasses lacking long-range order.[5-7] Snapshots of low-frequency eigenvector fields reveal swirl-like vector fields.[6,7] TDs with +1 and –1 charges corresponding to the cores of vortices and saddle, respectively, have been identified. Particularly, the locations of –1 defects are strongly correlated with "soft spots" that are more prone to structural rearrangement. However, the generic dynamical behaviors and interactions of these TDs remain elusive. Especially, in the colloidal systems commonly used for the corresponding experimental studies, the highly viscous aqueous background in which colloids are suspended, overdamps particle vibrations and disables the excitation and propagation of coherent entities surrounding TDs.

Recently, we experimentally and numerically demonstrated the discovery of the thermally excited multiscale vorticity waves (vortical phonons) and vorticity wave vortices, as multiscale coherent excitations in monolayer dusty plasma crystals at low-gaseous pressure which can sustain underdamped particle vibrations [8], by decomposing particle vibrations into different scale modes through multi-dimensional complementary ensemble empirical mode decomposition. The vorticity waves are composed of propagating swirls with alternating signs of vorticities and varying shapes. It causes the spatiotemporal fluctuation of local vorticity, such that the wave is named as vorticity wave.

In this work, we further identify the associated TDs with conjugate topological charges (+1 and –1) from the cores of above vortices and saddles, respectively, and explore their spatiotemporal behaviors for characterizing the dynamis of vortical phonons. It is found that for low-frequency modes (m = 3 - 5), vortices and saddles can be spontaneously generated, propagate and be annihilated pairwise in the *xyt* space, manifesting the finite lifetime of each TD and the conservation of topological charges. TDs with same (opposite) charges tend to repel (attract) each other. For different slow modes, defects exhibits self-similar dynamical behaviors.

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