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# Phononic Skyrmions: a new horizon to structure acoustic and elastic waves ?

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**Abstract:** Skyrmion, a topologically stable three-component vector field, was initially developed in elementary particles and has since been demonstrated in condensed-matter systems. In this talk, I will report theoretically and experimentally on the existence of *phononic skyrmions* as new topological structures formed by the three-dimensional hybrid spin of elastic waves.

Elastic phonons form an excellent platform for carrying and processing information due to their unique advantages, including orders of magnitude lower phononic wavelength in comparison with photonic systems<sup>1</sup>, scalability toward integrated devices<sup>2</sup>, and extremely low losses<sup>3</sup>. The development of phonon physics has advanced the technology in high signal-to-noise information processing<sup>3</sup>, high-sensitive remote sensing, and intense wave-matter interaction for future quantum networks<sup>4</sup>. Thus, in actual solid carriers with ubiquitous defects, realizing a new topological robust mode, i.e., phononic skyrmion, could lead to transformative phononic applications, especially in a generally concise configuration that can be scaled accordingly for future chip-scale technologies.

Recently, the hybrid spin induced by mixed transverse–longitudinal waves, which is responsible for abnormal phenomena beyond pure transverse waves and longitudinal waves (i.e., acoustic waves), has been uncovered in the elastic phononic system<sup>5</sup>. The hybrid spin can inspire strong spin-momentum locking of the elastic edge modes. However, the trivial topological invariant of the latter is not robust against defects<sup>6</sup>. In this talk, I will describe how to construct a new nontrivial topological structure of ultra-broadband phononic skyrmions based on the three-dimensional hybrid spin of elastic waves. It should, however, be pointed out that the formation of phononic and photonic skyrmions comes from different spin textures, with the latter being based on transverse wave spin.

In more details, I will talk about using spin angular momentum as a new degree of freedom to manipulate wave propagation. Some examples on photonic and acoustic systems generating skyrmions will be presented. I will then delineate the main part of this talk related to phononic/elastic skyrmions<sup>7</sup>, and how we can use them as a powerful degree of freedom to generate more functionalities for engineering applications.

To illustrate the formation of phononic skyrmions by intrinsic hybrid spins, and to make the structure compact, we have built the skyrmion system in a thin plate model supporting the hybrid spin of the Lamb wave arising from the hybridization between the longitudinal wave and the transverse wave in the upper and lower plate interfaces. The three-dimensional hybrid spin field of plane Lamb waves can be expressed by the axial (out-of-plane) and transverse (in-plane) field components.

To produce the phononic skyrmions, we have designed a hexagonal meta-plate with pillared resonators (figure 1), and excited three pairs of counterpropagating plane Lamb waves with hybrid spins along with the directions of  $\theta = 0^\circ$ ,  $60^\circ$ , and  $-60^\circ$ , as shown in Fig. 1A. The corresponding wave-number of these exciting plane waves can be presented by six points in the momentum space (the lower right corner of Fig. 1A). The interference of these wave fields constructs the three-dimensional skyrmion lattice configuration of the real wavefield.

The Ultra-broadband and tunable characteristic of phononic skyrmions have been also investigated. Actually, for classical waves, constructed photonic<sup>8</sup> or acoustic<sup>9</sup> Néel-type skyrmions, with the former based on transverse waves and the latter based on longitudinal waves, require an evanescent wave field to create the three-dimensional wave fields. Once their carrier structure is designed, these skyrmions have a limited bandwidth since the evanescent waves in the near field can be only visualized in

a narrow frequency band. In this talk, I will show that phononic skyrmions have an ultra-broadband topological robustness feature, due to the frequency-independent three-dimensional hybrid spin texture of the elastic wave (A0-mode wave).

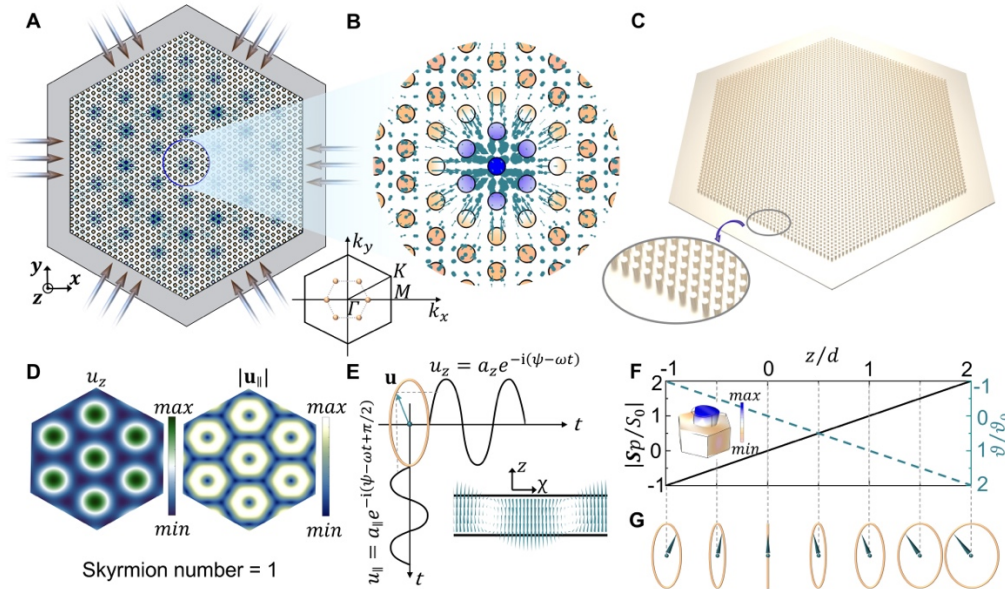


Figure 1: Formation of phononic skyrmions. (A) The interference of three pairs of counterpropagating plane Lamb waves with hybrid spins construct the phononic skyrmion lattice in a hexagonal elastic meta-plate. (B) Enlarged view of the local vector field. (C) The meta-plate with periodically pillared resonators. (D) The theoretical axial (out-of-plane)  $u_z$  and transverse  $u_{\parallel}$  (in-plane) fields of the skyrmion lattices. (E) The axial and transverse fields have a phase difference of  $\pi/2$ , creating a spiral spin geometry with an elliptical trajectory. The inset is a spin vector field at the plane formed by the  $z$ -axis and  $\chi$ -axis (same as the direction vectors  $k$ ). (F) The inset shows a unit structure with six-fold rotational symmetry, including an oscillating non-resonant pillared resonator on the hosting plate with a thickness of  $h$ . The resonator with the height of  $l$  (here  $l = h/2 = d = 0.5$  mm at the frequency of 8 kHz) can linearly amplify spin angular momentum and the polarization along the  $z$ -axis ( $-d < z < 2d$ ). The coordinate origin is on the neutral plane of the hosting plate. The  $s_0$  and  $g_0$  are the spin angular momentum magnitude and the polarization on the plate surface (i.e.,  $z = d$ ). (G) The elliptical spin trajectories of different particles along the plate thickness.

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