Transport of 2D solitons in disordered media: the shape does matter

Soliton is a nonlinear localized entity that presents wave-particle duality. It originates from the observation of water waves by Russell in 1834, and has become a popular research spotlight since Zabusky and Kruskal studied the famous FPU problem in 1965. In modern physics, the soliton shape and motion, even their mutual interaction, can be manipulated by using advanced experimental techniques, for example, in the areas of nonlinear optics and ultracold atoms[1].

An interesting problem is the transport of solitons in disordered media. The investigations on one-dimensional media have provided solid evidences: on the one hand, the soliton can act as a particle that is trapped by the randomness; on the other hand, the soliton can modify its shape and attenuates during its unidirectional propagation in the disordered environment, just like waves. Hence, if we consider the soliton as a particle moving in an effective potential, the property of this potential is not only determined by the randomness, but also influenced by the soliton shape and its size[2].

Fig 1. Variance of the soliton displacements $\sigma^2(x_0) + \sigma^2(y_0)$ as functions of the time t. The curves from upper to lower correspond to the cases (I) to (III) as shown in the embedded panel, where a soliton compression (I) and a soliton expansion (III) are respectively realized.
Focusing on this important point, Dr. Zhiyuan Sun and Dr. Xin Yu from Beihang University, studied the transport of the TWO-DIMENSIONAL solitons in disordered media with an inhomogeneous nonlocality[3]. They theoretically realized a time-dependent soliton compression (Type I) and soliton expansion (Type III) in weak random potentials, and found that the variance of soliton displacements can be affected and specified by variation of the soliton shape, as seen in Fig 1. Such a remarkable phenomenon is related to the fact that the effective force drives the soliton with its strength inversely proportional to the fourth power of the soliton width. Therefore, the wider soliton usually presents a better mobility as to the influence of disorder. On the other hand, the researchers demonstrated an elliptic-shaped soliton with unequal widths along the x and y directions, which can be used to generate an anisotropic transport of soliton due to its shape configuration, as seen in Fig 2.

Fig 2. Variance of the soliton displacements as functions of the time t: blue solid line for $\sigma^2(x_0) + \sigma^2(y_0)$, red dotted line for $\sigma^2(x_0)$, and green dashed line for $\sigma^2(y_0)$. The embedded panel shows contour plots of the elliptic-shaped soliton at t = 0, 30, and 60.

These interesting results provide a further understanding of the interaction between nonlinearity and disorder, which are expected to shed light on manipulating localized nonlinear excitations for specifying their transport in disordered media. Potential applications may include controlling the diffusive transport of optical solitons in liquid crystals and thermal media, when the random fluctuations are inevitably concerned.
References

Links to the paper and figures