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Discrete breathers: affecting the density shapes of heat transport

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Abstract—Discrete breathers (DBs), also known as intrinsic localized modes, are spatially localized nonlinear vibrational modes in anharmonic lattices, which are usually expected to affect the energy transport process. In the heat transport field of theoretical research, to predict the transport densities is currently a very fascinating topic. Inspired by these progress, we here investigate how DBs may affect the heat transport densities shapes. Through studying two peculiar one-dimensional nonlinear lattice models heat spreading processes, i.e., the Fermi-Pasta-Ulam-β chains with and without next-nearest-neighbor couplings, we will show some preliminary numerical evidences on how different types of DBs change the heat spreading densities.

1. Introduction

The studies of discrete breathers (DBs) are always hot topics of nonlinear science [1, 2, 3], among which whether DBs can contribute to heat transport in crystals is an interesting issue [4, 5, 6]. In the context of heat transport of theoretical research, recently researchers pay more attention to the densities of heat transport and its scaling behavior [7, 8, 9]. Motivated by these progress, in the present work we perform numerical simulations to investigate how DBs would affect the densities shape and their scaling law.

2. Models

We focus on the one-dimensional (1D) Fermi-Pasta-Ulam-β (FPU-β) lattices including (or not) the next-nearest-neighbor (NNN) interactions, whose Hamiltonian can be represented by

$$H = \sum_i \left[\frac{p_i^2}{2} + V(x_{i+1} - x_i) + \gamma V(x_{i+2} - x_i) \right], \quad (1)$$

where x_i is the i-th particle's displacement from its equilibrium position and p_i its momentum. The potential takes $V(x) = \frac{1}{2}x^2 + \frac{\beta}{4}x^4$ with β the nonlinear parameter. Another parameter γ (we fix γ here) specifies the comparative strength of the NNN coupling to the nearest-neighbor (NN) coupling.

We note that the focused models with $\gamma = 0$ and $\gamma \neq 0$ will support different types of DBs, i.e., in the former model there are only extra-band DBs; while in the latter case, the intra-band DBs can be excited [4, 6]. Our aim here then is to see how these two different types of DBs would affect the heat transport densities.

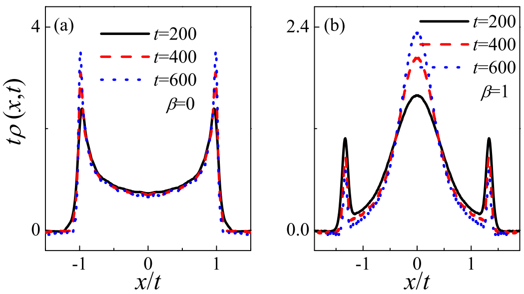

Figure 1: (Color online) Rescaled $\rho(x,t)$ for FPU-β chains without NNN couplings: (a) $\beta = 0$; (b) $\beta = 1$.

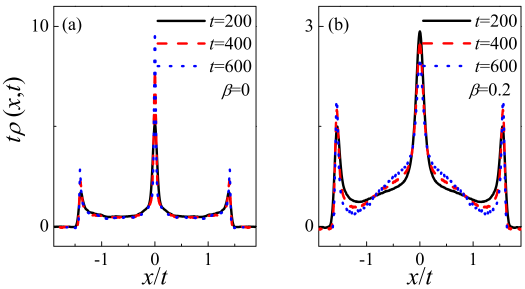

Figure 2: (Color online) Rescaled $\rho(x,t)$ for FPU-β chains with NNN couplings ($\gamma = 0.25$): (a) $\beta = 0$; (b) $\beta = 0.2$.

3. Preliminary Findings

We employ the normalized spatiotemporal correlations of heat energy fluctuations [10, 11] to represent the systems heat spreading density, which is represented by

$$\rho(x,t) = \frac{\langle \Delta Q_j(t) \Delta Q_i(0) \rangle}{\langle \Delta Q_i(0) \Delta Q_i(0) \rangle}, \quad (2)$$

where $\langle \cdot \rangle$ denotes the spatiotemporal average; $\Delta Q_i(t)$ is the fluctuations of heat energy at place i and time t.

Figures 1 depicts the rescaled $\rho(x,t)$ for FPU-β chains without NNN coupling. As can be seen, when no nonlinearity (β = 0) has been introduced, there are no DBs, the density shows U shape; while if $\beta \neq 0$, the extra-band DBs emerge, the density turns to be W shape with more localization, especially on the central parts. Thus the results seem to support that the extra-band DBs will localize energy, which agrees well with the previous conjecture on the role of this type of DBs [5].

On the other hand, in [4, 6] we have suggested that compared with the extra-band DBs, the intra-band ones can be scattering with phonons, thus destroying the localization. With this picture in mind, in Fig. 2 we plot the similar results as Fig. 1 while under the systems with NNN coupling. Under this setup, the main type of DBs are the intra-band ones, then if our conjecture on intra-band DBs is still right, we should see delocalization, which has indeed been verified by Fig. 2, where the densities clearly show less localization after introducing the nonlinearity into the focused system.

Another detail is that both types of DBs appear to change the scaling [12] behaviors of the densities, i.e., when β = 0, both systems (with and without NNN couplings) show ballistic scaling behaviors; while in the case of $\beta \neq 0$, the ballistic scaling has been clearly destroyed. So one may conjecture that the DBs can not only affect the densities shapes, but also change their scaling behaviors.

4. Conclusion

To summarize, we have showed some preliminary numerical evidences on how different types of DBs affect the heat spreading densities, not only their shapes but also the scaling properties. The roles of extra-band and intra-band DBs shown in this study appear to be in good agreement with our previous conjecture, though further detailed examinations/efforts are still required on this topic.

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References

[1] S. Flach, A. V. Gorbach, "Discrete breathersładvances in theory and applications," *Phys. Rep.*, vol.467, pp.1, 2008.

[2] S. Flach, C. R. Willis, "Discrete breathers," *Phys. Rep.*, vol.295, pp.181, 1998.

[3] S. V. Dmitriev, A. P. Chetverikov, M. G. Velarde, "Discrete breathers in 2D and 3D crystals," *Phys. Status solidi B*, vol.252, pp.1682, 2015.

[4] D. Xiong, J. Wang, Y. Zhang, H. Zhao, "Nonuniversal heat conduction of one-dimensional lattices," *Phys. Rev. E*, vol.85, pp.020102, 2012.

[5] D. Xiong, Y. Zhang, H. Zhao, "Heat transport enhanced by optical phonons in one-dimensional anharmonic lattices with alternating bonds," *Phys. Rev. E*, vol.88, pp.052128, 2013.

[6] D. Xiong, Y. Zhang, H. Zhao, "Temperature dependence of heat conduction in the Fermi-Pasta-Ulam-β lattice with next-nearest-neighbor coupling," *Phys. Rev. E*, vol.90, pp.022117, 2014.

[7] H. Spohn, "Nonlinear fluctuating hydrodynamics for anharmonic chains," *J. Stat. Phys*, vol.154, pp.1191, 2014.

[8] D. Xiong, "Crossover between different universality classes: Scaling for thermal transport in one dimension," *Europhys. Lett.*, vol.113, pp.140002, 2016.

[9] D. Xiong, "Underlying mechanisms for normal heat transport in one-dimensional anharmonic oscillator systems with a double-well interparticle interaction," *J. Stat. Mech.: Exp. Theor.*, vol.04, pp.043208, 2016.

[10] H. Zhao, "Identifying Diffusion Processes in One-Dimensional Lattices in Thermal Equilibrium," *Phys. Rev. Lett.*, vol.96, pp.140602, 2006.

[11] S. Chen, Y. Zhang, J. Wang, H. Zhao, "Diffusion of heat, energy, momentum, and mass in one-dimensional systems," *Phys. Rev. E*, vol.87, pp.032153, 2013.

[12] V. Zaburdaev, S. Denisov, J. Klafter, "Lévy walks," *Rev. Mod. Phys.*, vol.87, pp.483, 2015.