Localized Vibrational and Spin Wave Modes in Nonlinear Periodic Lattices

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Abstract

It had been known for some time that nonlinearity and discreteness can play important roles in many branches of condensed matter physics as evidenced by the appearance of domain walls, kinks and solitons. An advance of the theory of nonlinear excitations in discrete lattices in late 80 and early 90's was the discovery that some localized vibrations in perfectly periodic but non-integrable lattices can be stabilized by lattice discreteness[1]. These localized excitations are either called "intrinsic localized modes" with the emphasis on the fact that their formation involves no disorder and that they extend over a nano-length scale or "discrete breathers" to distinguish their properties from those of breathers in soliton physics. This realization has led to extensive theoretical studies of the features associated with intrinsic localization in various nonlinear lattices, and it has proven to be a conceptual breakthrough. Many physically exciting contexts are currently emerging - in nonlinear crystal dynamics, magnetic systems, electron-phonon systems, reaction dynamics, and biological matter.Thus the potential for these self-localized oscillatory excitations in nonequilibrium discrete lattices is evident. An experimental program would make u of the intense coherent far-infrared radiation produced by a perturbed 100-micron long charged particle bunch to determine the universal properties of localized dynamical structures in strongly driven periodic lattices.

1. http://www.lassp.cornell.edu/~sievers/ilm/index.html

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- For $\lambda >$ than bunch length the synchrotron, transition or Cherenkov radiated intensity is proportional to the square of number of charged particles.

- For 300 fs long bunches this high intensity wavelength region would span important collective excitation modes of solids and make possible nonlinear studies.

Outline

Concept of intrinsic localized modes

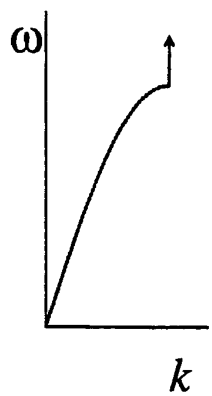
Lattice and spin wave examples

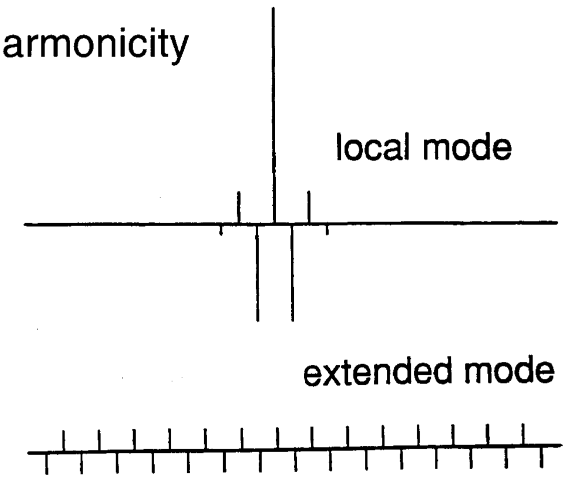
Proposed excitation method

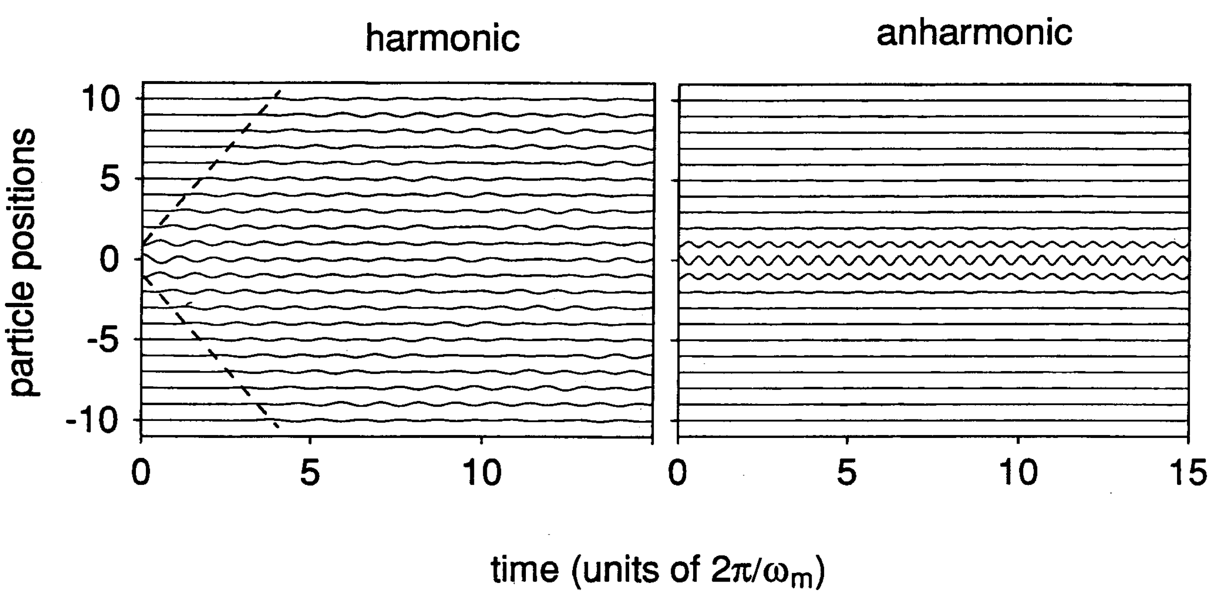
Intrinsic localized mode in a simple nonlinear lattice

$$U = \frac{1}{2}K_2x^2 + \frac{1}{4}K_4x^4$$

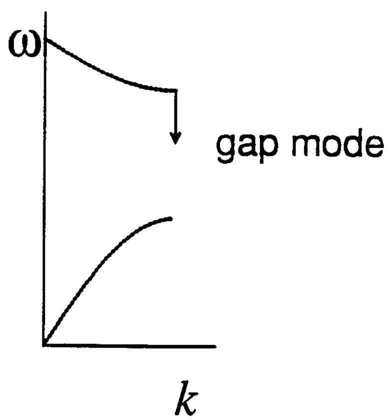
for hard anharmonicity

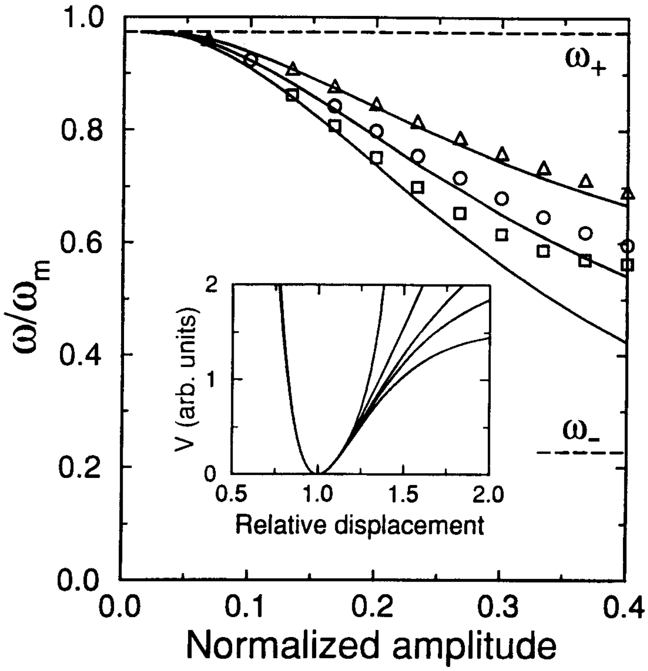


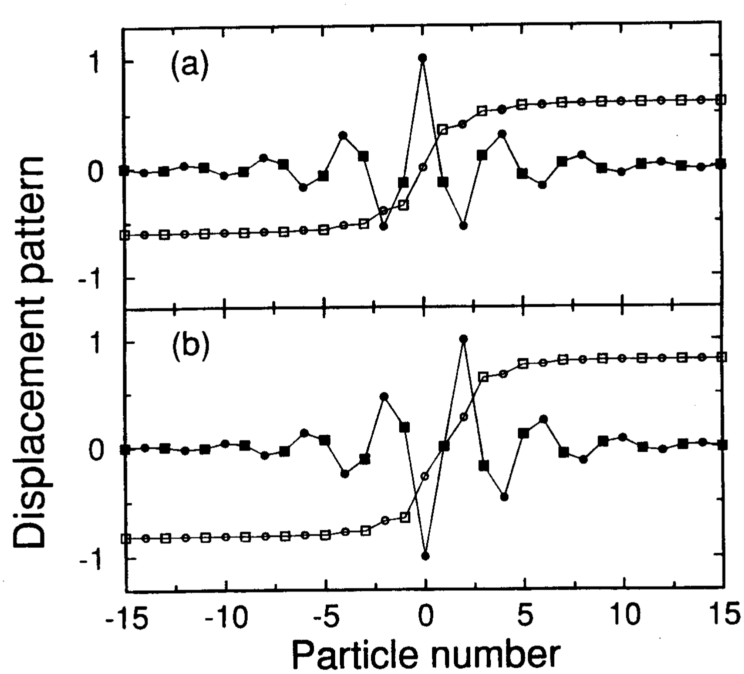




Intrinsic localized gap mode in a diatomic lattice for two body potentials





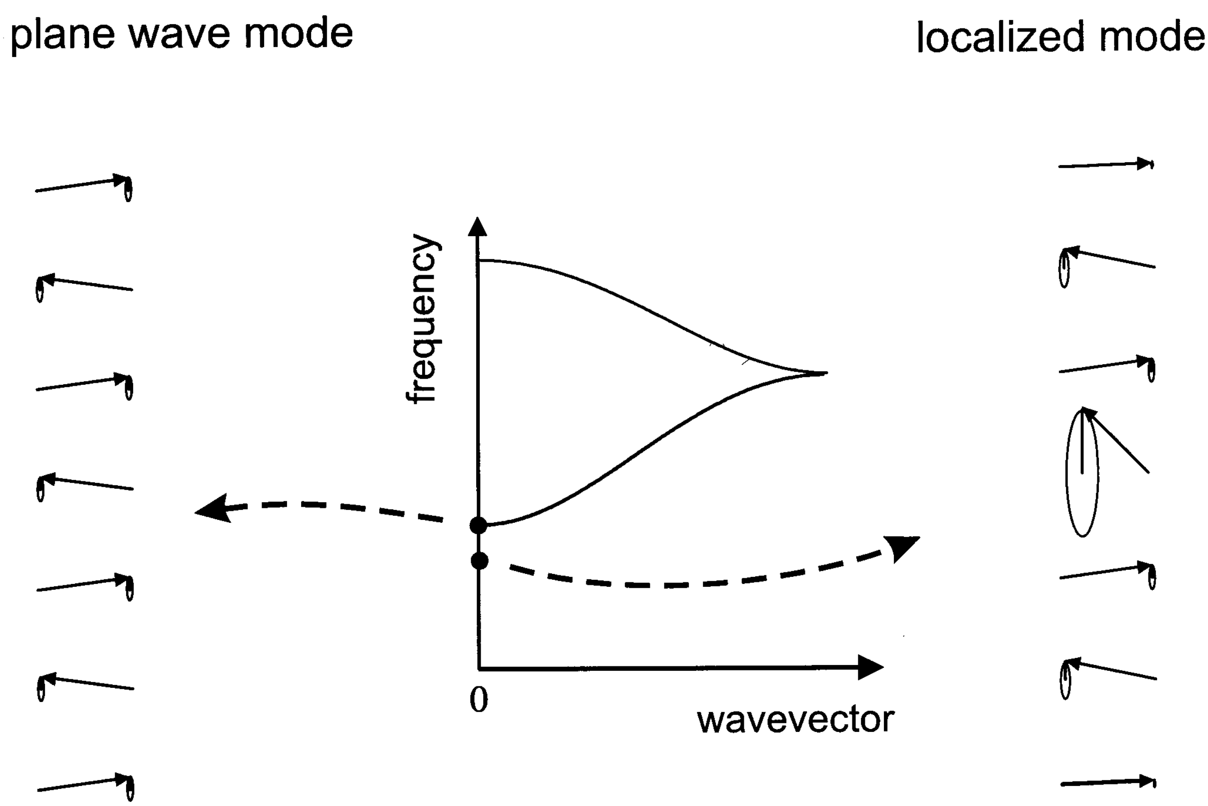


Intrinsically localized spin waves

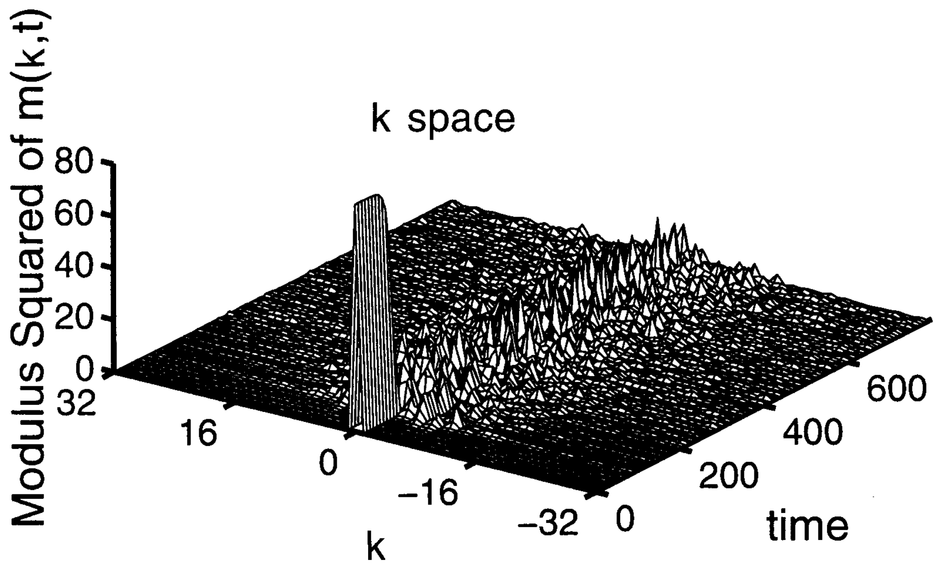
Hamiltonian of easy-plane antiferromagnet

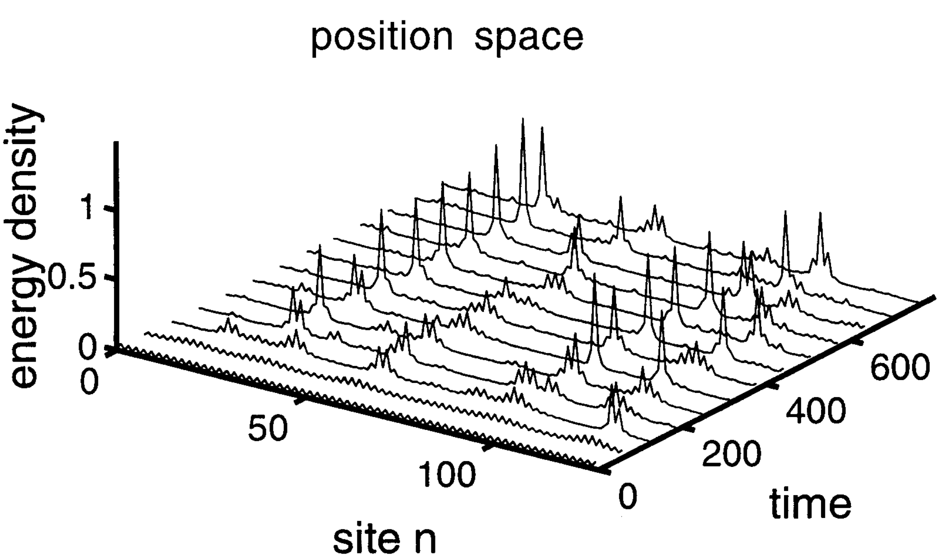
$$H = 2J_{AF}\sum_{n}\vec{S}_n\cdot\vec{S}_{n+1} + \sum_{n}\vec{S}_n\cdot\overleftrightarrow{D}\cdot\vec{S}_{n+1} + \tfrac{1}{2}\sum_{n,n'}\vec{S}_n\cdot\overleftrightarrow{F}(n-n')\cdot\vec{S}_{n'}$$

exchange — anisotropy — dipole-dipole (anisotropic)



Creation of ILM's from the uniform mode via the modulational instability



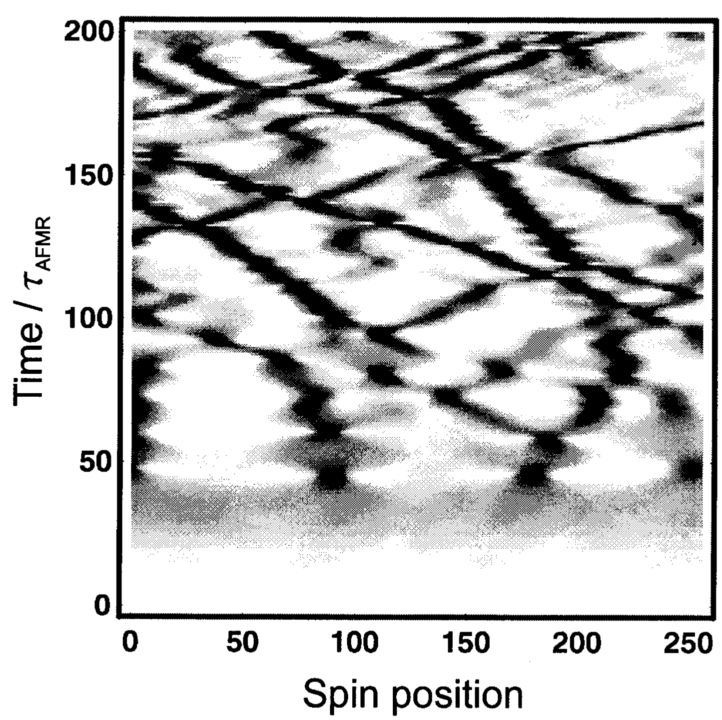


ILM excitation

Use the modulational instability of the large amplitude uniform mode against breakup into ILMs.

Drive the system below the uniform mode frequency with high power pulses.

MD simulation for 1-D antiferromagnetic spin system



Conclusions

-> In general, nonlinearity plus lattice discreteness can produce localized excitations.

-> Soft anharmonicity => only gap modes and resonances for the discrete dielectric and magnetic lattices.

-> These localized excitations can be dynamically created via a modulational instability.

-> High power, short pulse far infrared experiments can be used to investigate nanoscale nonlinear localization in atomic lattices.