

---

# Interaction Between Discrete Breathers and Other Non-linear Modes in Josephson Arrays

---

## Personnel

K. Segall, J.J. Mazo, and T. P. Orlando

## Sponsorship

NSF and Fulbright/MEC Fellowship

Linear models of crystals have played a fundamental role in developing a physical understanding of the solid state. However, many phenomena are unexplained until one considers non-linear interactions. One particularly interesting phenomenon is that of discrete breathers, which are time periodic, spatially localized modes. In a crystal a *discrete breather* is localized in that a few atoms are vibrating while the neighboring atoms stay still. Josephson junctions are a solid state realization of non-linear oscillators and they can experimentally be coupled in various ways using standard lithographic fabrication techniques. In Figures 19A and 20B we show a regular array of Josephson junctions, denoted by x's, which are driven by a uniform current (driving current not shown). Each junction is governed by equations isomorphic to a damped pendulum; the phase of the pendula is equivalent to the superconducting phase difference across the junction. A discrete breather is shown in Figure 19B, where a few of the junctions have their phases rotating in time while the others do not. Experimentally a rotating phase corresponds to a net DC voltage, which can be easily measured. Breathers in Josephson arrays have been studied in previous work in our group here at MIT.

In Figure 19A we demonstrate another kind of non-linear mode, a moving vortex. This is mathematically equivalent to a kink or solitonic mode. Vortices in Josephson arrays carry a quantum of magnetic flux and have been studied extensively in superconducting systems. A vortex corresponds to a  $2\pi$  phase shift in the phases of the vertical junctions in the ladder; when a uniform current is applied the vortex moves down the ladder. As the vortex passes a given junction it causes its phase to undergo a rotation and thus create a voltage. This is indicated by the time sequence shown in Figure 19A.

Our work is aimed at studying the interaction of discrete breathers with other kinds of non-linear modes, like a moving vortex. Such questions are of fundamental importance for the Non-linear Dynamics communi-

ty. In Figure 20 we show a mathematical simulation of a collision between a vortex and a breather. The vertical axis is the junction number in the array; the array in the simulation has 60 junctions. The horizontal axis is time. The color indicates the junction voltage or rotation speed, with blue indicating low voltage and red indicating high voltage. Initially there is a breather located about junction 10 and a vortex located in junction 45. As time proceeds the vortex moves toward the breather and eventually collides with it. The result of the collision is that the breather acts as a pinning center for the vortex. As time proceeds further (not shown) the vortex will eventually depin and cause the breather to decay into a different mode. We have also seen other collision scenarios in our simulations, such as ones where the breather is destroyed or where the breather pins a train of moving vortices. We are also looking for such behavior experimentally, with fabricated junction arrays and DC electronics.

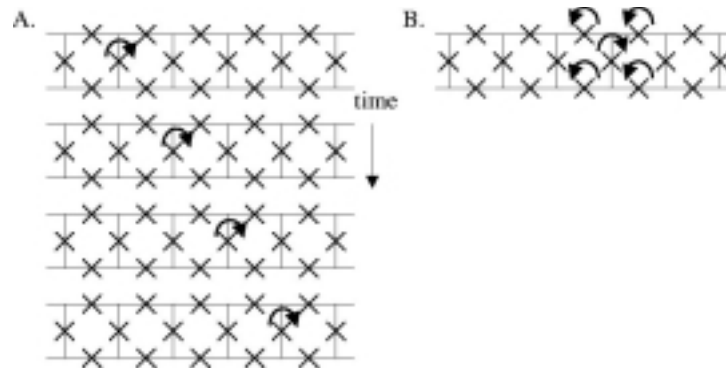


Fig. 19: Representation of two different non-linear modes in a Josephson Ladder: (a) Moving vortex: The vortex causes the phase of a junction to rotate as it passes by. (b) Discrete breather: A few junctions have their phases continually rotating while the neighboring ones do not.

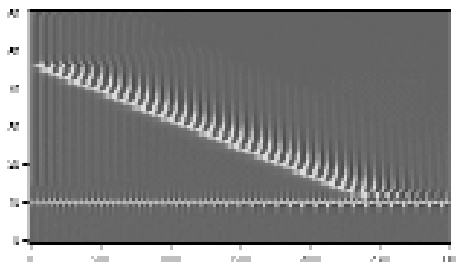


Fig. 20: Interaction of a breather with a moving vortex. Time (in arbitrary units) is on the horizontal axis, the junction number is on the vertical axis, and the color indicates the junction voltage (red=high, blue=low). The vortex starts in junction 45 and moves toward the breather, which is in junction 10. The vortex collides with the breather and is pinned by it, with the breather surviving at later times.

---