Discrete Breathers and Josephson Ladders

J.J. Mazo (1), E. Trías (2), T.P. Orlando (2) and L.M. Floría (1)

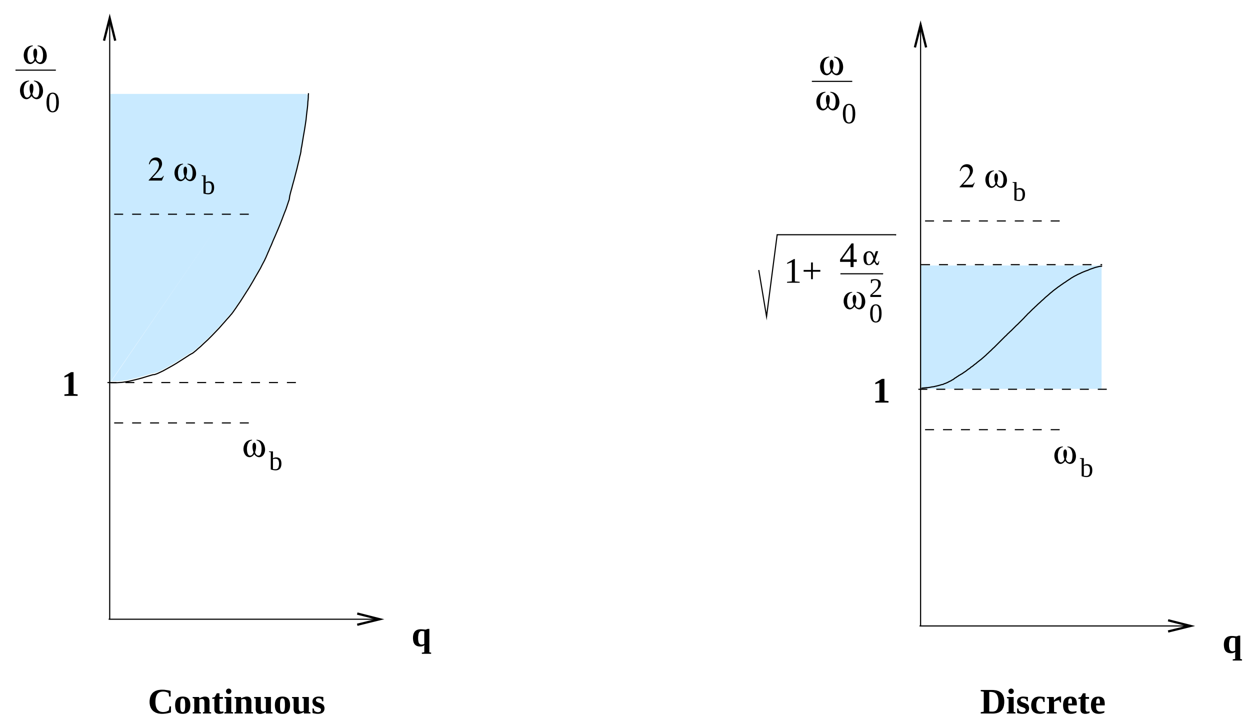
(1) Dpto. Física de la Materia Condensada and ICMA. Universidad de Zaragoza-CSIC. Zaragoza (Spain)
(2) Dpt. Electrical Engineering and Computer Science. Massachusetts Institute of Technology. Cambridge, MA (USA)

With the name of Discrete Breathers (DB) we know a type of localized excitations generic in perfect nonlinear discrete systems. In this poster we present this phenomenon and its recent experimental observation in Josephson ladders.

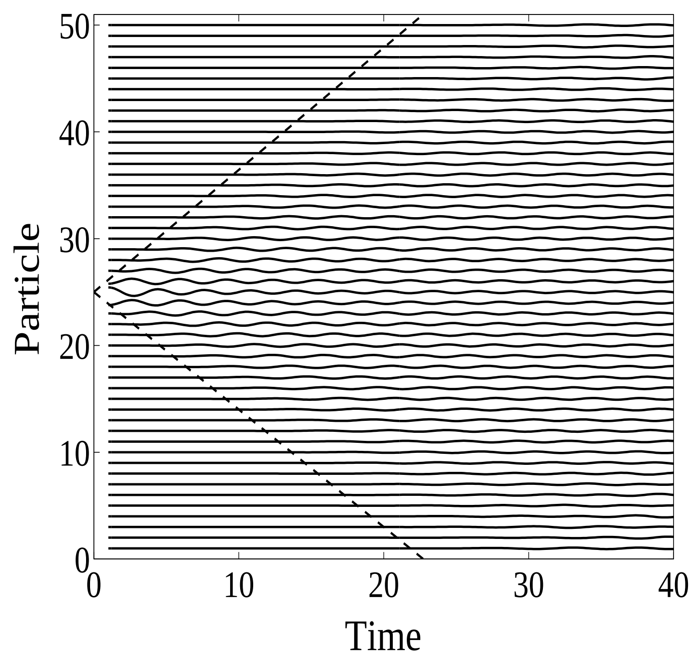
We start with a physical picture of DB and give intuitive arguments for their existence. Then we will sketch the mathematical theorem which proves it. These localised excitations have been only recently observed, measured and excited in a controlled way in Josephson-junction (JJ) ladder arrays [1,2]. We report here on one of these experiments [1]

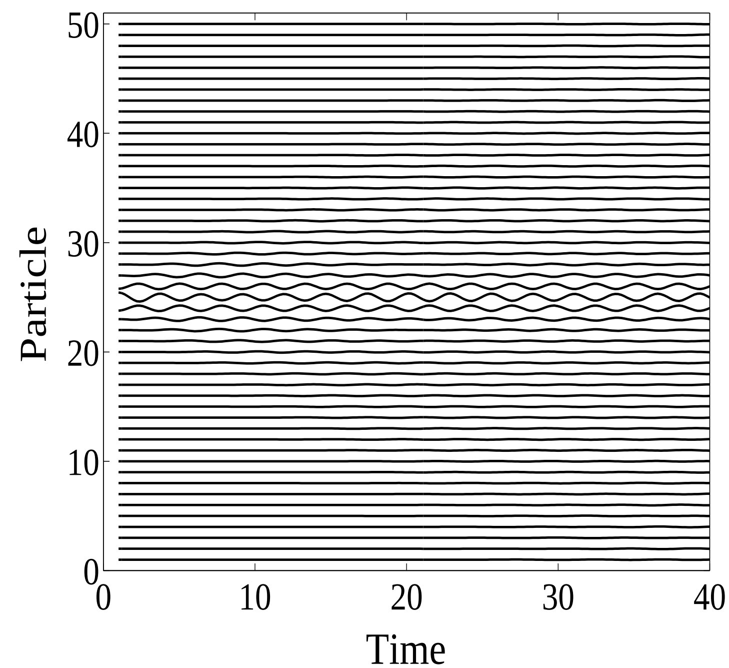
[1] E.Trías, J.J. Mazo and T.P. Orlando. Discrete breathers in nonlinear lattices: Experimental detection in a Josephson array. Phys. Rev. Lett. 84, 741-744 (2000).
[2] P. Binder, D. Abraimov, A.V. Ustinov, S. Flach and Y. Zolotaryuk. Observation of breathers in Josephson ladders. Phys.Rev. Lett. 84, 745-748 (2000).

DB are time periodic spatially localized solutions of the dynamics of discrete nonlinear systems. Discreteness and nonlinearity are the essential ingredients to have persistent localized vibrations in the lattice. The physical condition for the existence of these solutions is that the breather frequency ω_b and its harmonics are out of the band of linear excitations of the lattice (the phonon band). Nonlinearity implies amplitude dependent frequencies and allows for the possibility of a frequency out of the phonon band. Discreteness implies that the band has an upper bound (there is a maximun frequency for the propagation of linear waves). The figure sketches this situation: the breather frequency is below the phonon band and its harmonics are above it.



The figure shows simulations of the dynamics of a lattice of 50 particles with linear (left) and nonlinear (right) inter-particle force. The initial amplitudes are 0 for all the particles except the central ones. In the case of the linear array this localization rapidly disperses meanwhile in the case of the nonlinear array a DB is formed and localization persists.





DB have been proven to be generic solutions of the dynamics of hamiltonian and dissipative systems. The mathematical proof is based in the possibility of continuation of localized solutions from the anti-continuous limit (that for which all the units are uncoupled). In this limit localized solutions are trivial.

Consider for instance a Klein-Gordon chain:

$$d^2x_n/dt^2 + V'(x_n) = \alpha\,(x_{n+1}-2x_n+x_{n-1})$$

where $V'(0)=0$ and $V''(0)=\omega_0^2>0$

If $\alpha=0$ then we can build a solution $(...,0,0,\omega,0,0,...)$

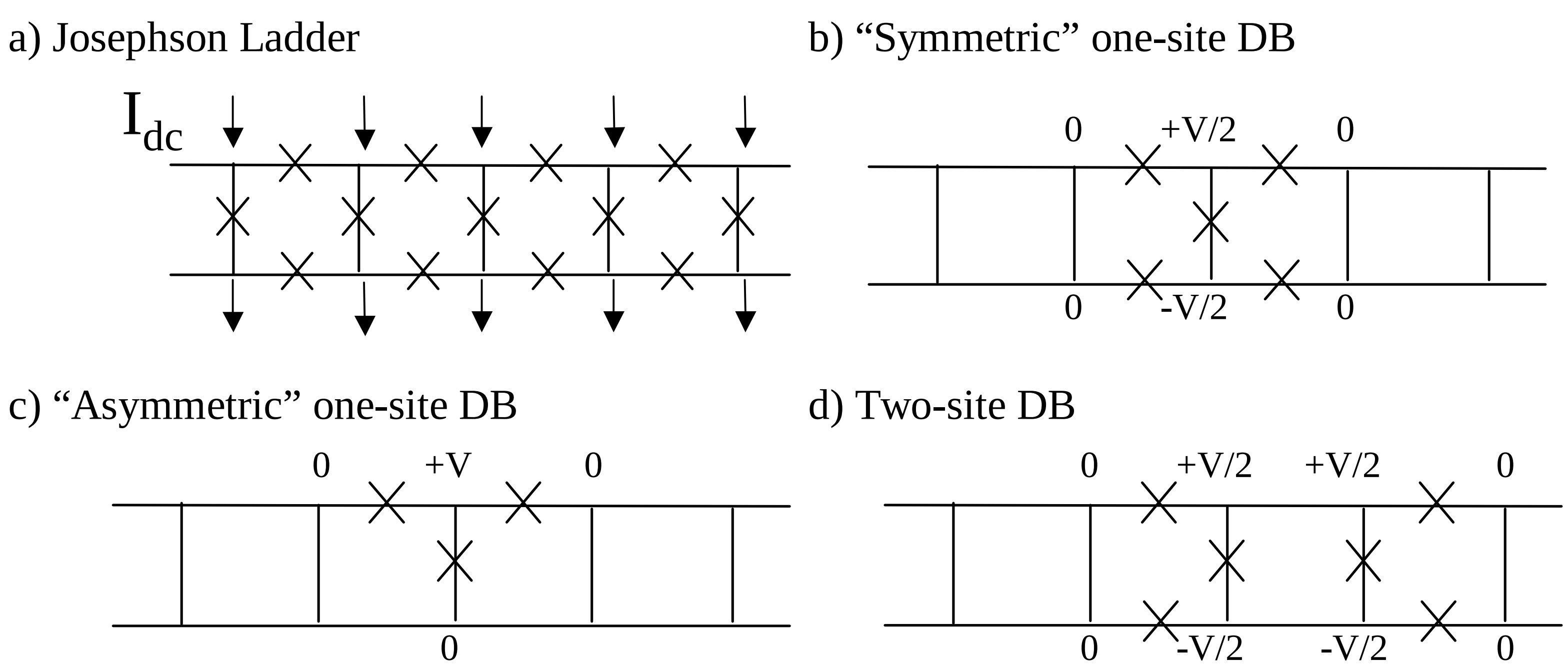
The theorem establishes that this solution has a locally unique continuation as orbit with period $T=2\pi/\omega$ and exponentially localized for $\alpha>0$ whenever:

a) ω is different from ω_0/n (non resonance condtion)

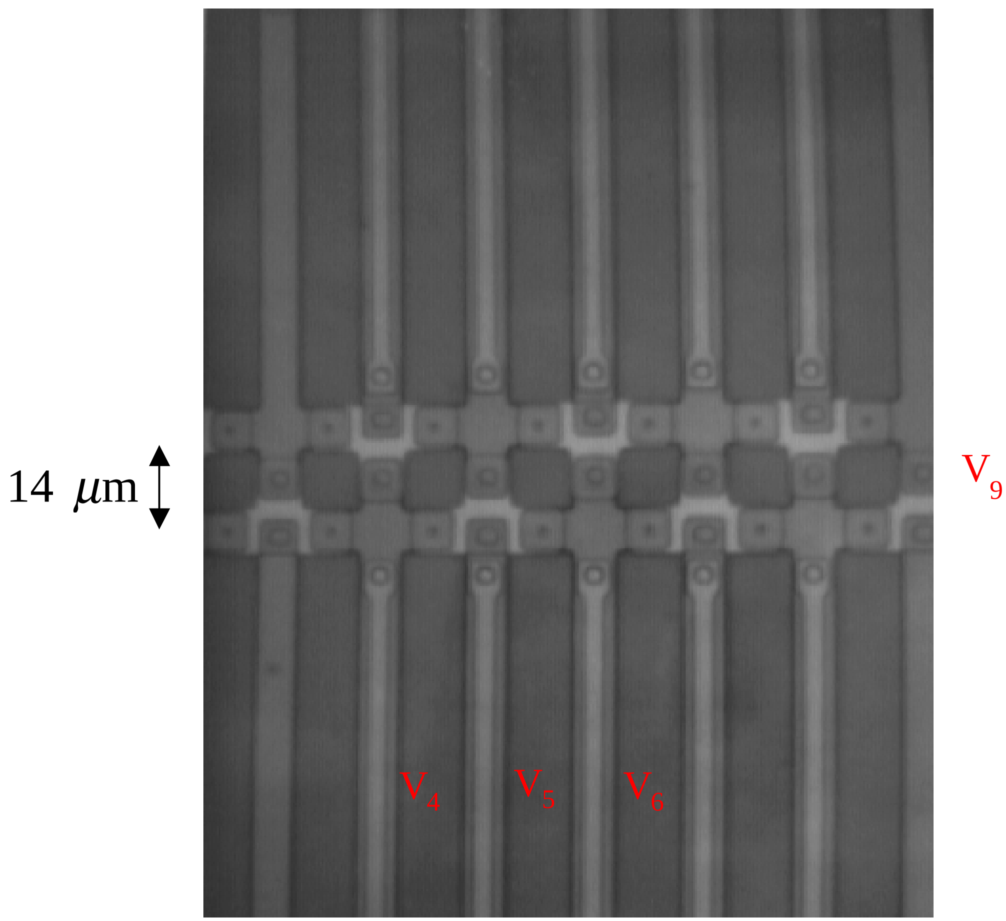
b) the system is non-isocronous, that is, amplitude dependent frequency

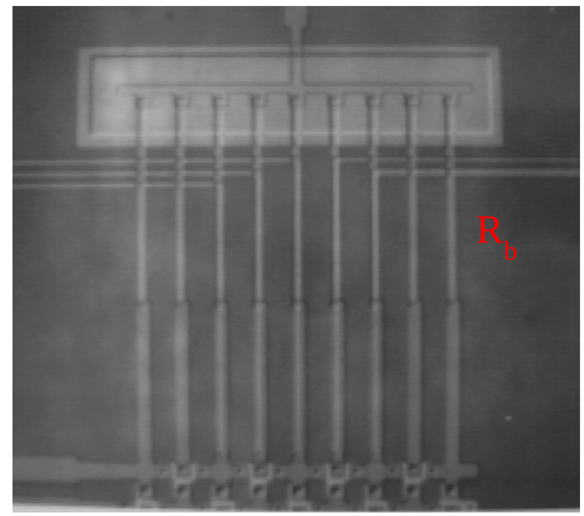
(The proof is based in a judicious choice of the functional space of solutions, define an appropriate norm and apply the implicit function theorem)

JJ arrays are excellent experimental systems for studying nonlinear dynamics and DB should be detected in these systems. The existence of DB in a JJ array was first proposed in the study of the dynamics of an ac-biased anisotropic ladder array. There, oscillating and rotating localized modes (known as oscillobreathers and rotobreathers respectively) were studied. In the case of an oscillating mode one unit describe a large amplitude oscillation and the rest a small amplitude one. In the case of a rotating mode one unit is rotating and the other librate. If the unit is a JJ then the rotating unit shows a voltage difference between the superconducting electrodes and the localized mode should be easily detected. Rotobreathers were also numerically found in the dynamics of inductively coupled JJ biased by a dc external current. The figure shows an schematic of the Josephson ladder (a) and different DB solutions (b-d). In these cases (b-d) we use ‘X’ to mark the rotating junctions in the ladder and shorts for the others.



Josephson Ladder





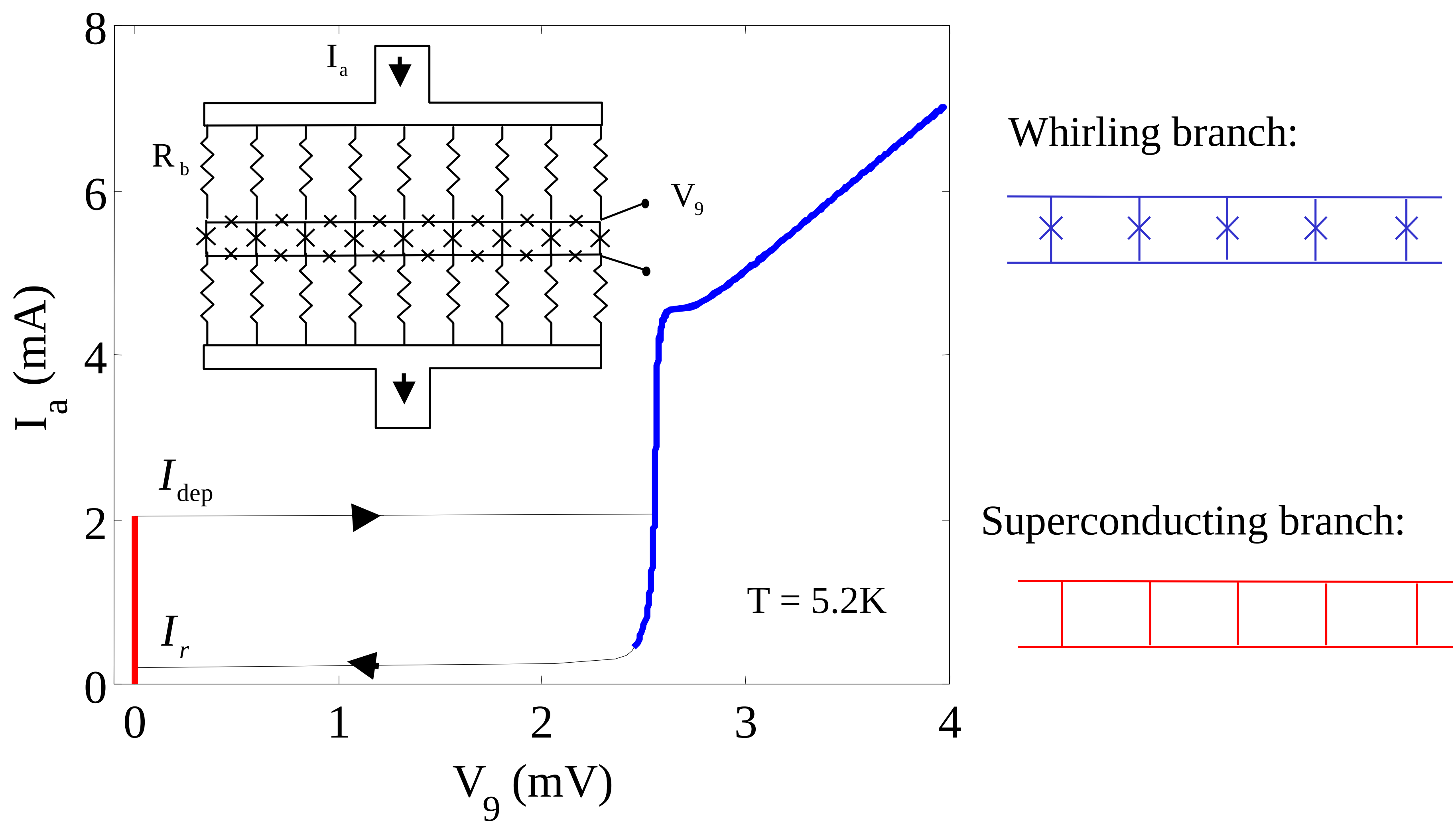
Bias R = 25 Ω $\quad \beta(0) = 39$

Junc. R = 20 Ω $\quad \lambda(0) = 0.03$

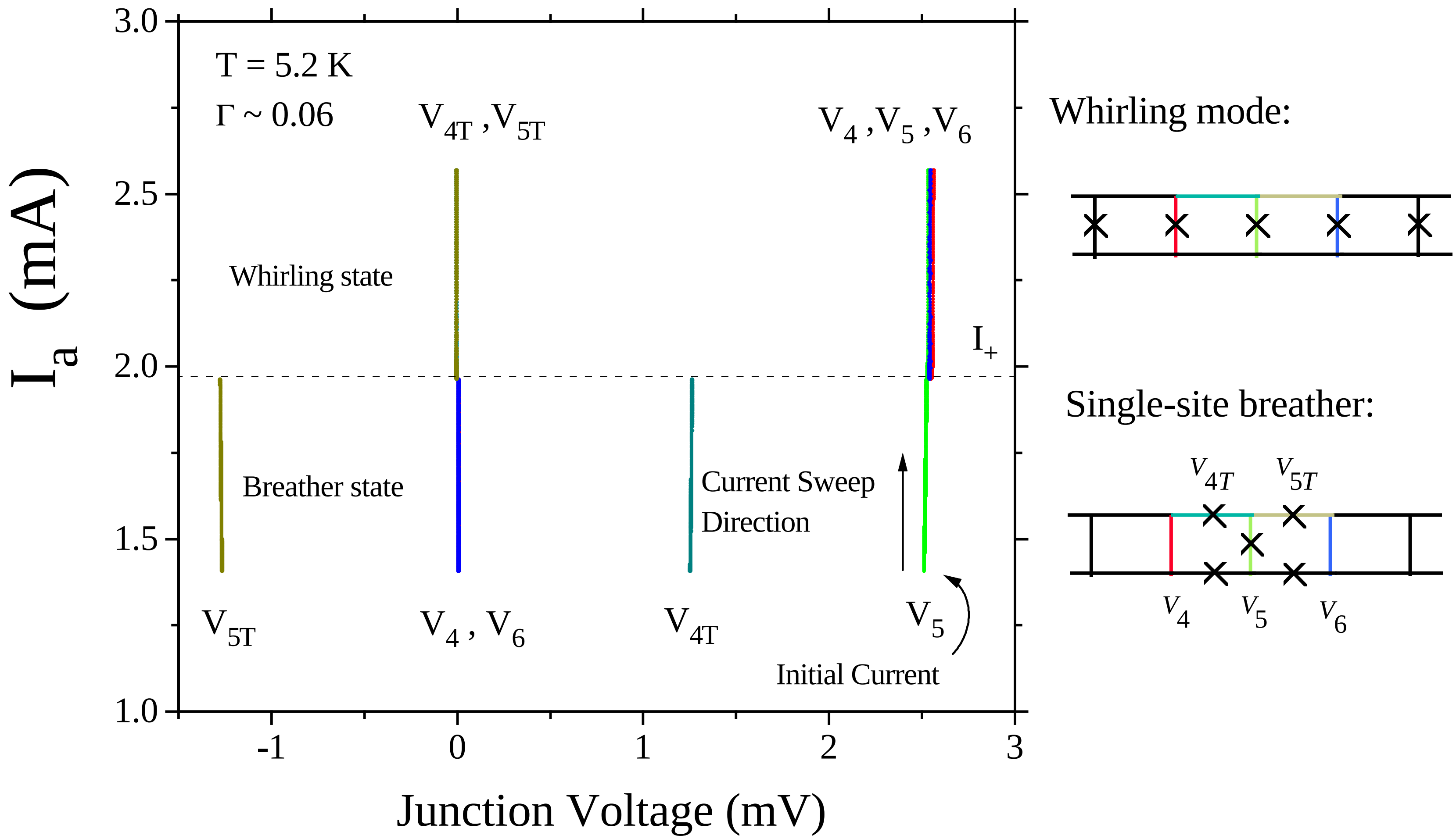
Experimental procedure:

1. bias array below depinning
2. inject current in V5 so that it begins to whirl
3. Reduce this extra current to zero.
4. Measure V4, V5, V6 and V4H while sweeping the array bias

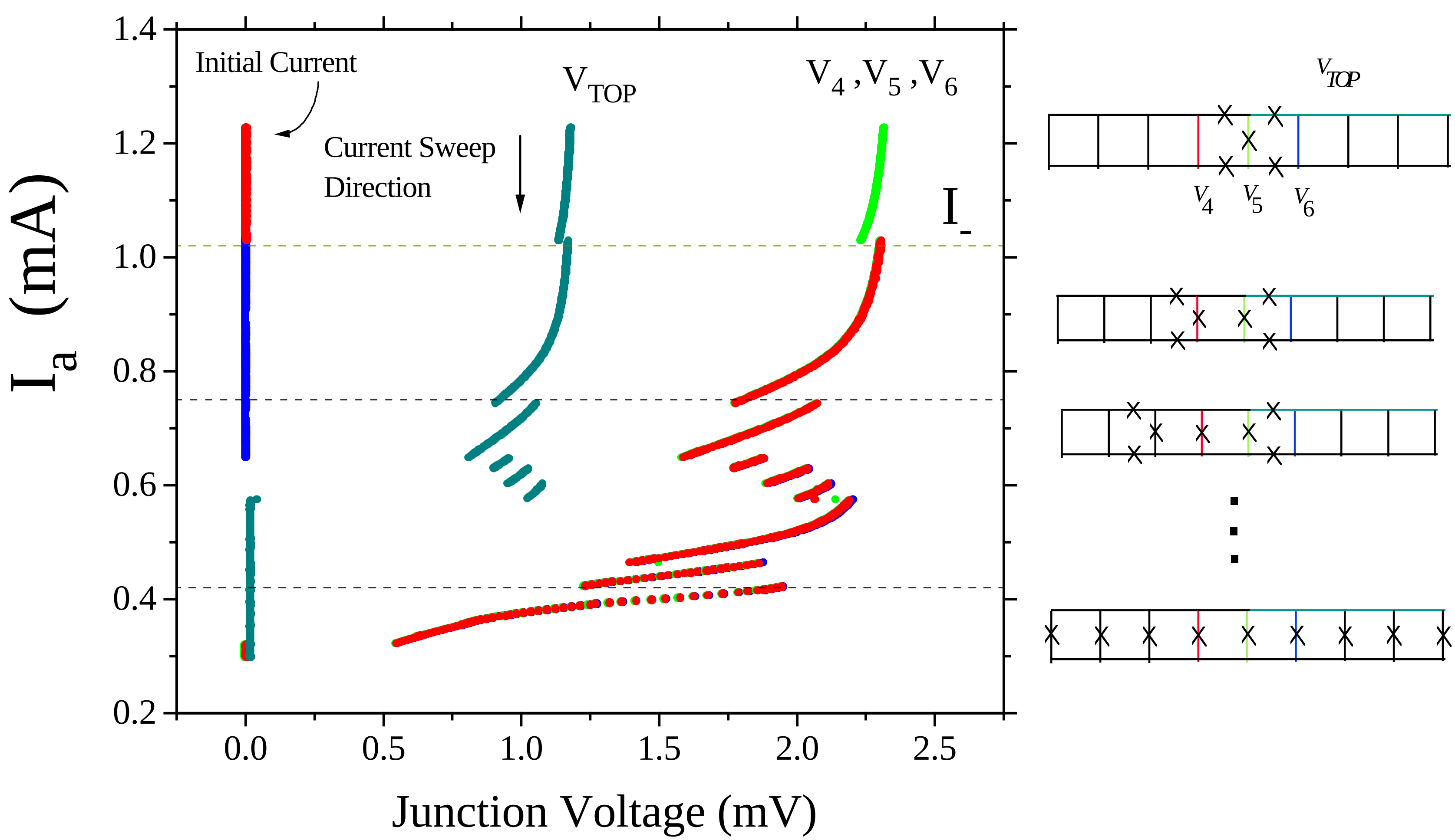
Ladder Uniform Solutions



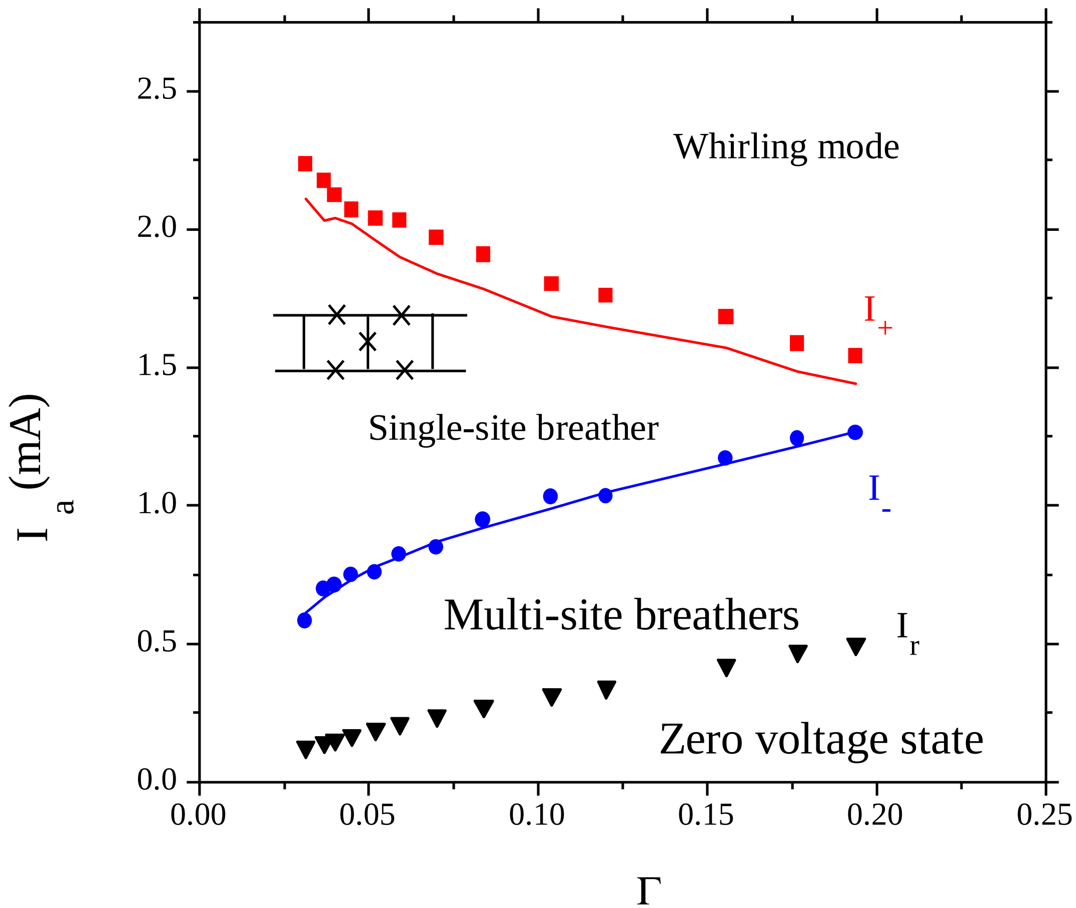
Increasing Bias Current



Decreasing Bias Current



Breather Instabilities



$I_+ \rightarrow$ Nearest quiet vertical junction switches

$$I_+ \sim \frac{2h+2}{3h+2} I_{cv}$$

$I_- \rightarrow$ Horizontal junction retraps

$$I_- \sim (2h+2) I_{ch}$$

This publication is based (partly) on the presentations made at the European Research Conference (EURESCO) on “Future Perspectives of Superconducting Josephson Devices: Euroconference on Physics and Application of Multi-Junction Superconducting Josephson Devices”, Acquafredda di Maratea, Italy, 1-6 July 2000, organised by the European Science Foundation and supported by the European Commission, Research DG, Human Potential Programme, High-Level Scientific Conferences, Contract HPCFCT-1999-00135.

This information is the sole responsibility of the author(s) and does not reflect the ESF or Community's opinion. The ESF and the Community are not responsible for any use that might be made of data appearing in this publication.