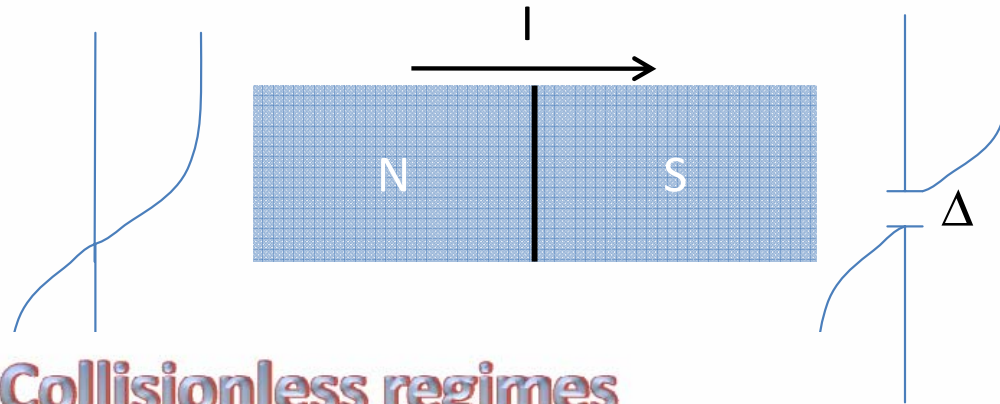


Multi-gapped states in non-equilibrium BCS superconductivity

Eldad Bettelheim

Non-equilibrium Superconductivity

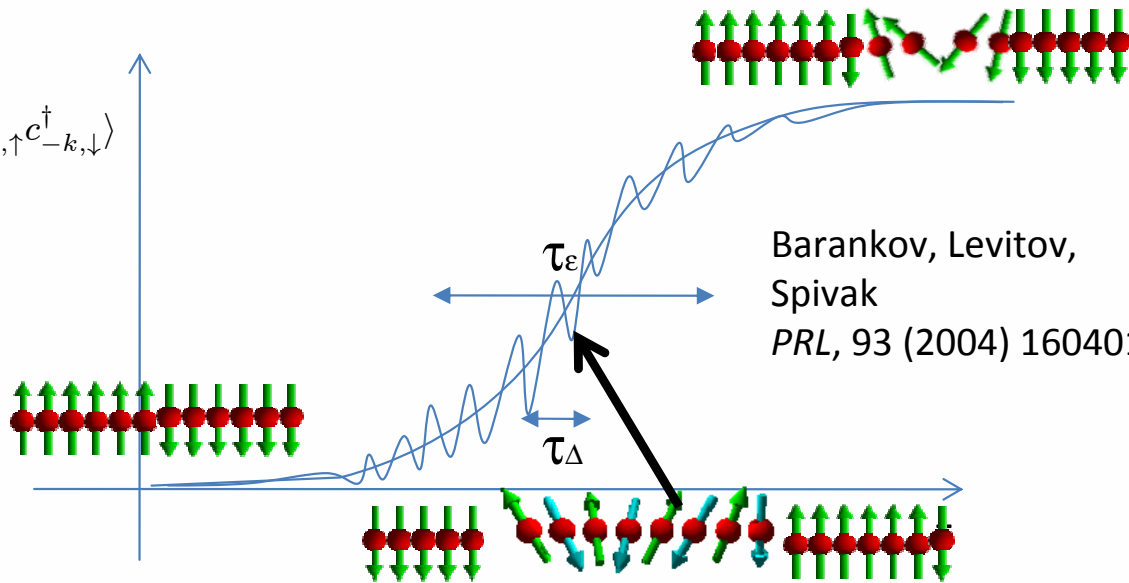


Collision and Collisionless regimes

$$H = \sum_{j \in \mathbb{Z}^M} \sum_{\mathbf{k}} \left(g_{\mathbf{k},\uparrow} c_{j,\uparrow}^\dagger + g_{\mathbf{k},\downarrow} c_{j,\downarrow}^\dagger \right) \Delta c_{-j,\downarrow}^\dagger + \text{h.c.} \quad \tau_\Delta \ll \tau_\epsilon$$

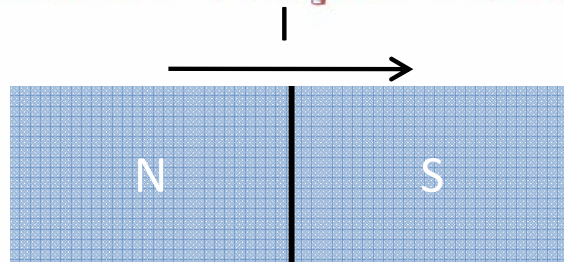
$$s_j^z = \frac{1}{2} \left(\langle \sum_\sigma c_{j,\sigma}^\dagger c_{j,\sigma} \rangle - 1 \right), \quad s_j^+ \equiv s_j^x - i s_j^y = \langle c_{j,\downarrow}^\dagger c_{j,\uparrow}^\dagger \rangle, \quad \text{Time}$$

$$\Delta = \langle c_{k,\uparrow}^\dagger c_{-k,\downarrow}^\dagger \rangle$$

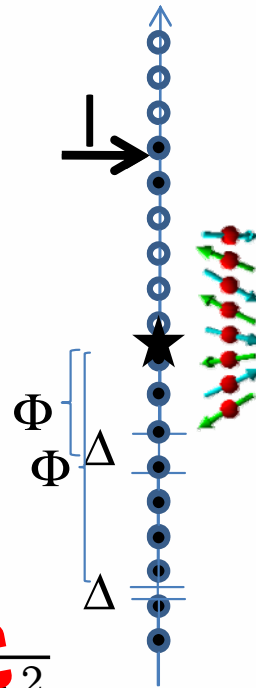
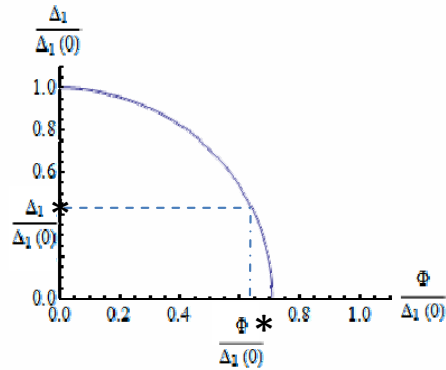


Barankov, Levitov,
Spivak
PRL, 93 (2004) 160401.

'Second' Cooper instability



$$\Delta^2 = \Delta_0^2 - 2\Phi^2$$



GalPerin Kozub Spivak
 JLTP, 50 (1983) 185

$$\epsilon(\xi) = \sqrt{(\xi - \Phi)^2 + \Delta^2}$$

Richardson's Solution

Richardson's Solution

$$H = \sum \xi_j c_j^\dagger c_j + g c_{j,\uparrow}^\dagger c_{j,\downarrow}^\dagger c_{j',\downarrow} c_{j',\uparrow}$$

$$\prod_\alpha b_\alpha^\dagger |0\rangle, \quad b_\alpha^\dagger = \sum_j \frac{1}{E_\alpha - \xi_j} c_{j,\uparrow}^\dagger c_{j,\downarrow}^\dagger$$

$$\frac{1}{g} = -\frac{1}{2} \sum_j \frac{1}{E_\alpha - \xi_j} + \sum_{\beta \neq \alpha} \frac{1}{E_\beta - E_\alpha},$$

$$E = \sum E_\alpha = \frac{\Delta_1^2}{2g} + \int \rho \sqrt{(\xi - \epsilon_1)^2 + \Delta_1^2} d\xi$$

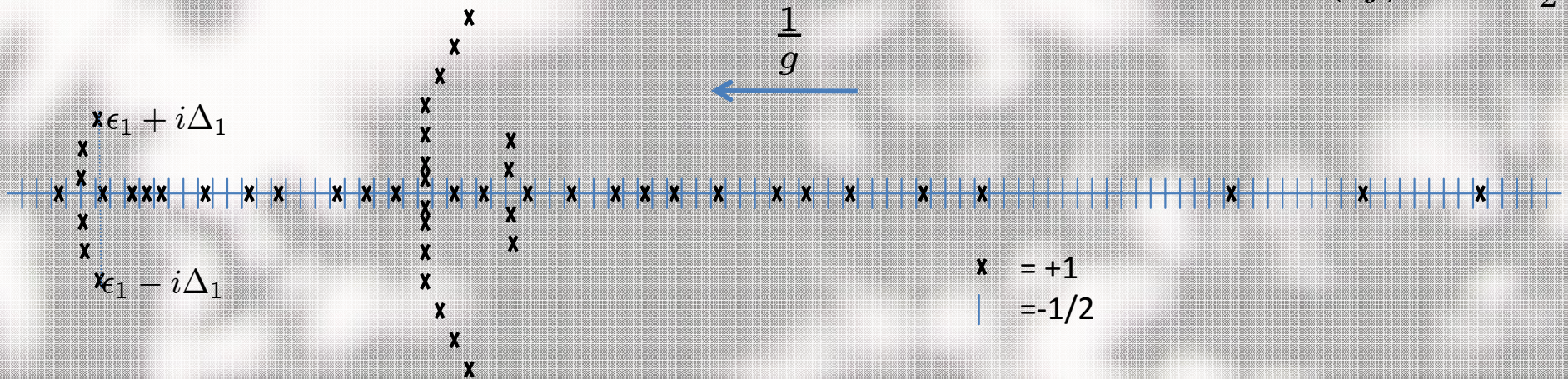
$$\frac{2}{g} \equiv \int \frac{\rho}{\sqrt{(\xi - \epsilon_1)^2 + \Delta_1^2}}$$

$$\begin{array}{|c} \hline \xi_j \\ \hline \end{array} \quad n = 0, \quad \rho = -1/2$$

$$\begin{array}{|c} \bullet \\ \hline \xi_j \end{array} \quad n = 1, \quad \rho = 0$$

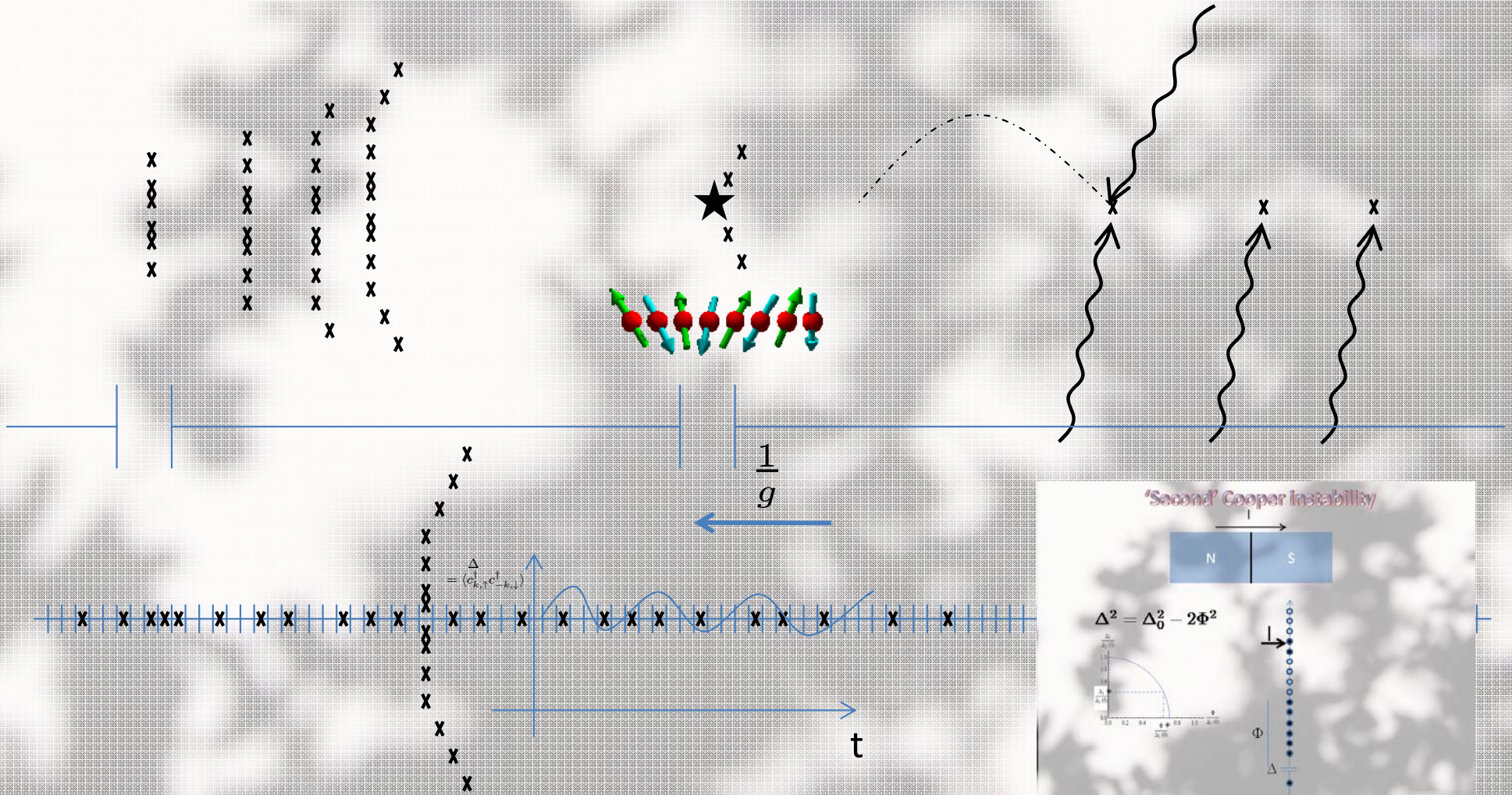
$$\begin{array}{|c} \times \\ \hline \xi_j \end{array} \quad n = 2, \quad \rho = +1/2$$

$$\rho(\xi_j) = \frac{n(\xi_j) - 1}{2}$$

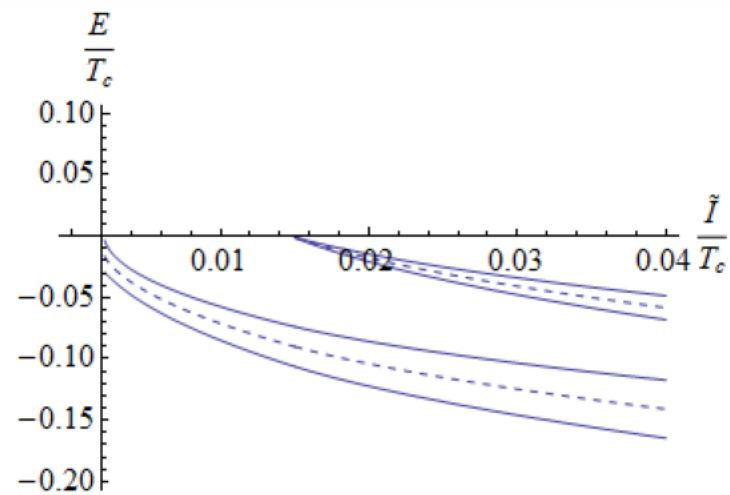
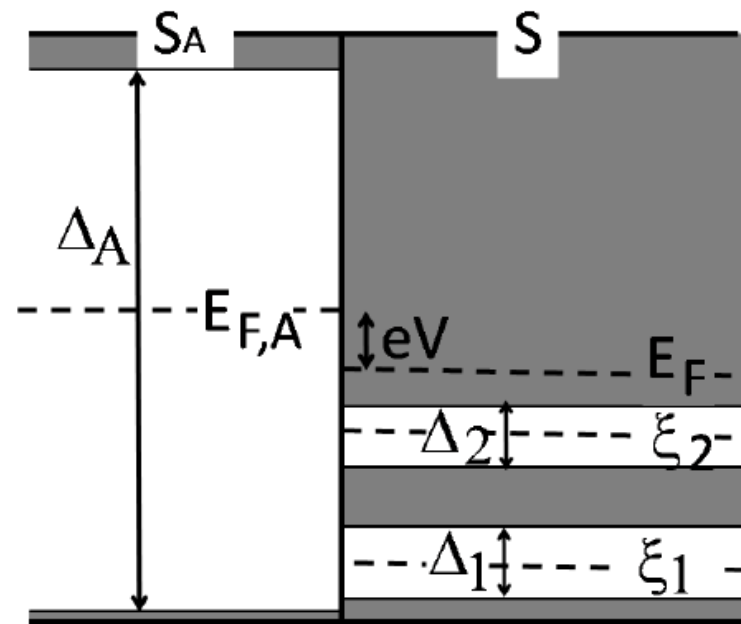


Kinetics of Richardson's state

E.B., EPL, 90, (2010) 67002



Results



Outlook

1. Full characterization of state
2. Beyond zero dimension
3. Beyond small gaps
4. Full Boltzmann equation to deal with various non-equilibrium situations