A Microscopic Examination of the Josephson Junction

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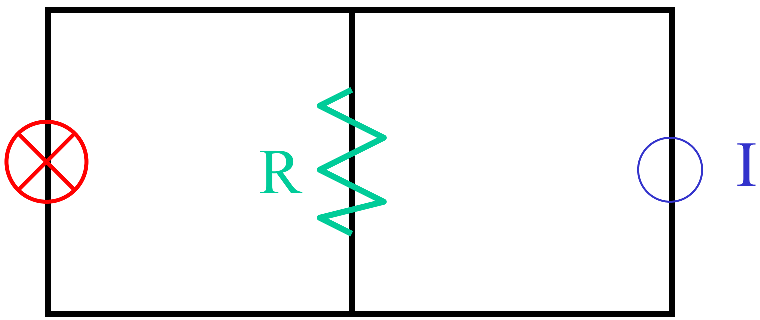
Introduction

- The Josephson-Junction Computer
- Maximize $I_c R_n$
- Resistively Shunted Junction Model

$I_c \sin\phi$



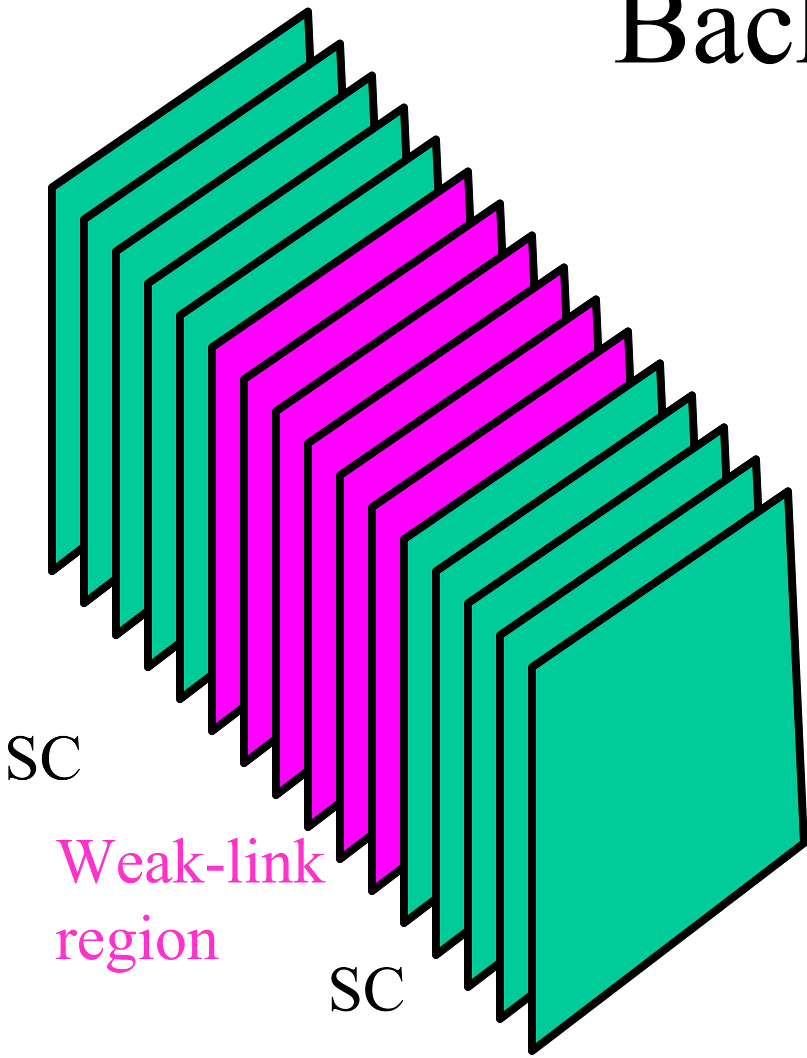
Time constant:

$$\tau = \hbar / (e I_c R_n)$$

Navy Interest

- High precision, high speed, analog-digital converters for advanced radar design (up to 20 bits of resolution and speeds in excess of 200GHZ)
- Employ High-Temperature Superconductor Technology

Background



- Insulator $\rightarrow$ high R_n low I_c
- Metal $\rightarrow$ low R_n high I_c
- Are properties optimized near the metal-insulator transition?
- What type of material produces the best JJ weak-link region?

Metal-Insulator Transitions

- Anderson (disorder, mobility edge)
- Mott-Hubbard (correlations)
- Periodic Anderson Model (f-electrons, Kondo effect)
- Holstein (bipolaron self-trapping)
- Falicov-Kimball (thermodynamics of localized and interacting electrons)

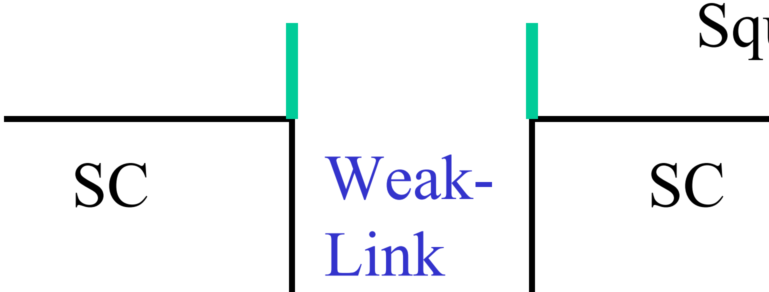
Bogoliubov-DeGennes Equations

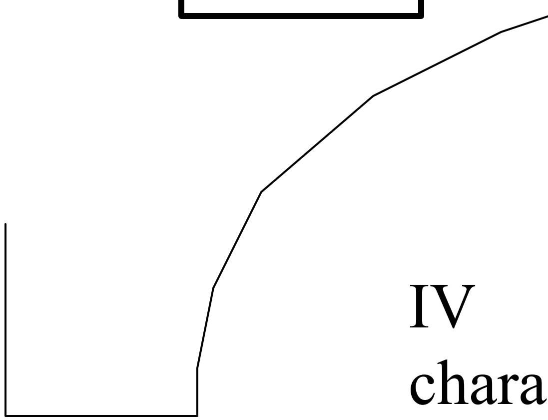
- Static Hartree-Fock approximation (self consistent solution)
- Superconducting gap varies with position, and acts like a mean-field potential in the reduced Hamiltonian
- Numerical solution is problematic for large systems (mainly due to the self-consistency)

Blonder-Tinkham-Klawijk Model

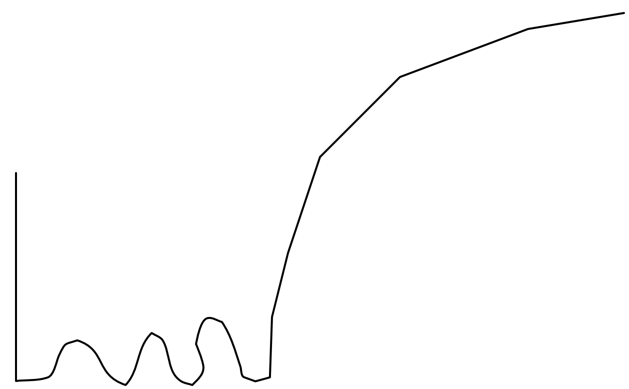
- Simplification of B-DG, not self-consistent

Square well plus an interface potential





IV
characteristics

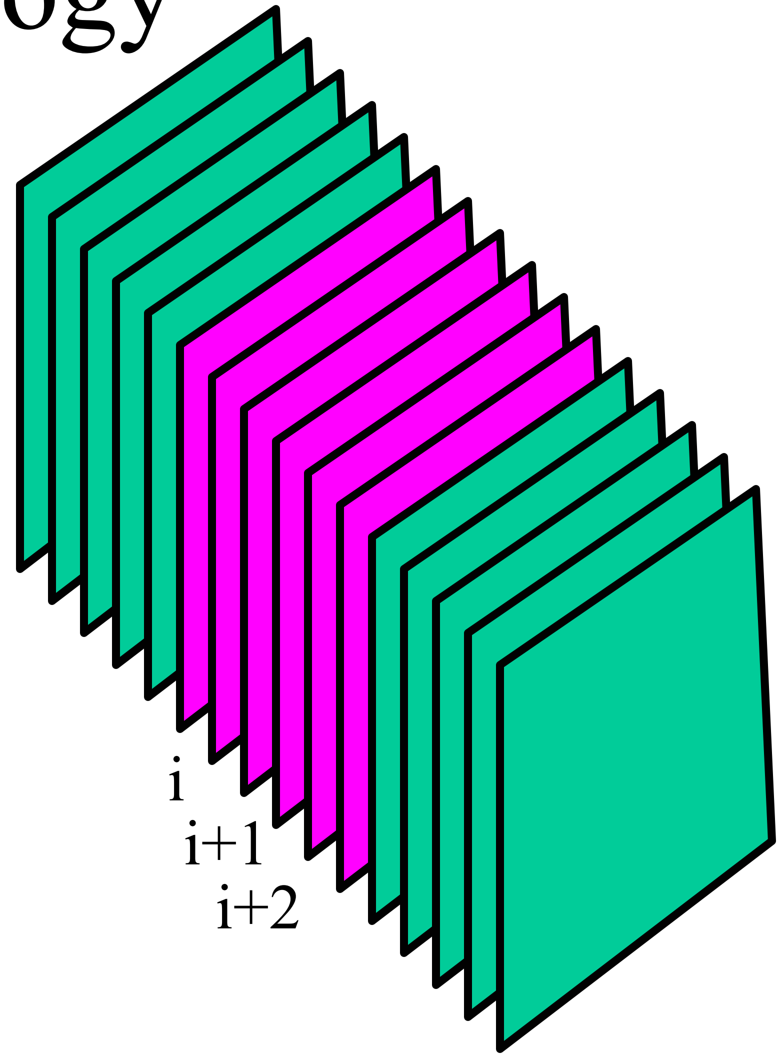


New Approach

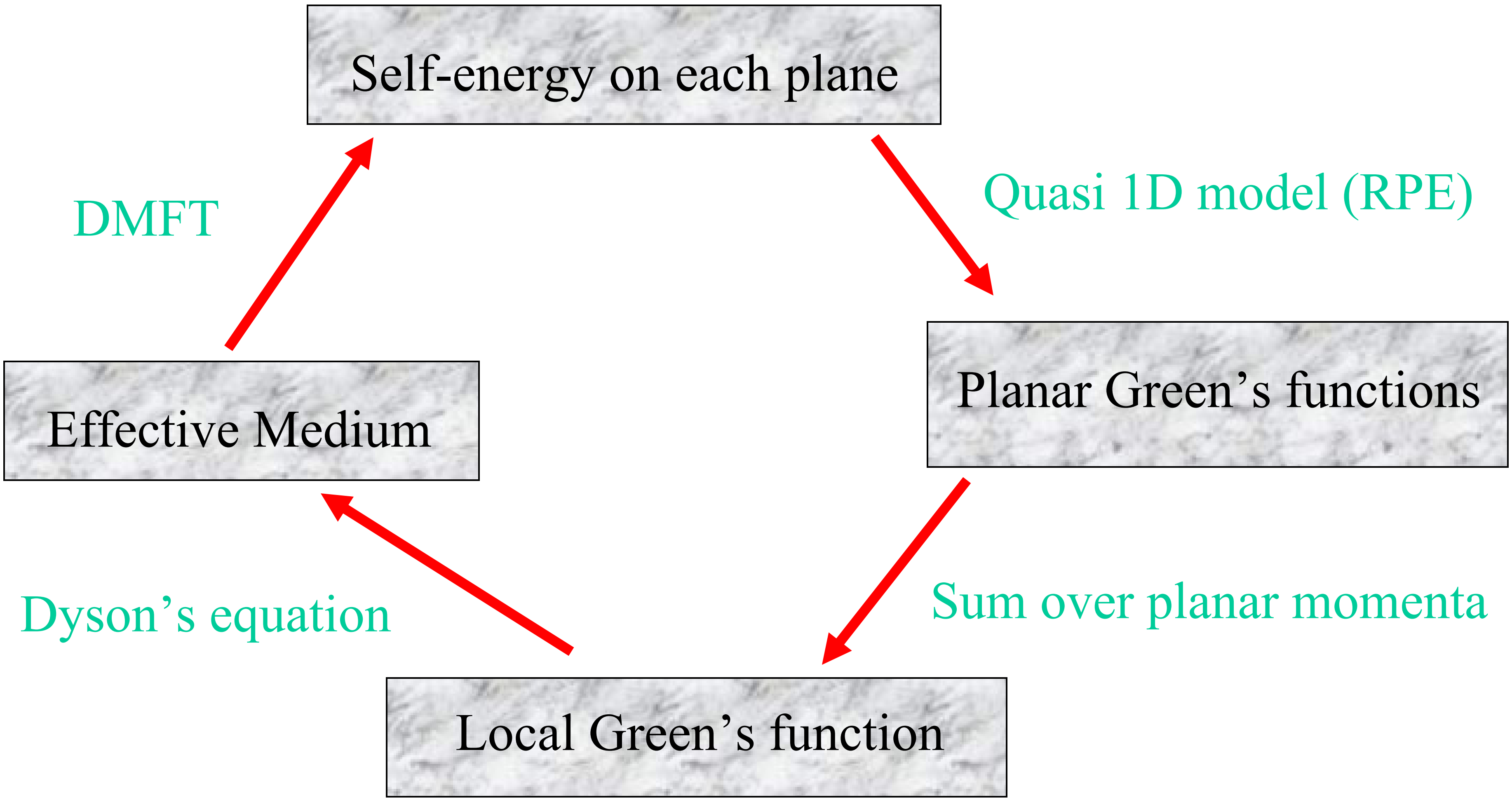
- Self-consistent solution
- Includes dynamical effects (retardation, nonconstant DOS, vertex corrections, local fluctuations, etc.)
- Exact solution through the MI transition (including all local correlation effects)
- Theoretical optimization of $I_c R_n$

Methodology

- Inhomogeneous planar system
- Local self energy on each plane
- Reduces to a quasi-1D "tight-binding" problem at each planar momentum plus a dynamical MFT



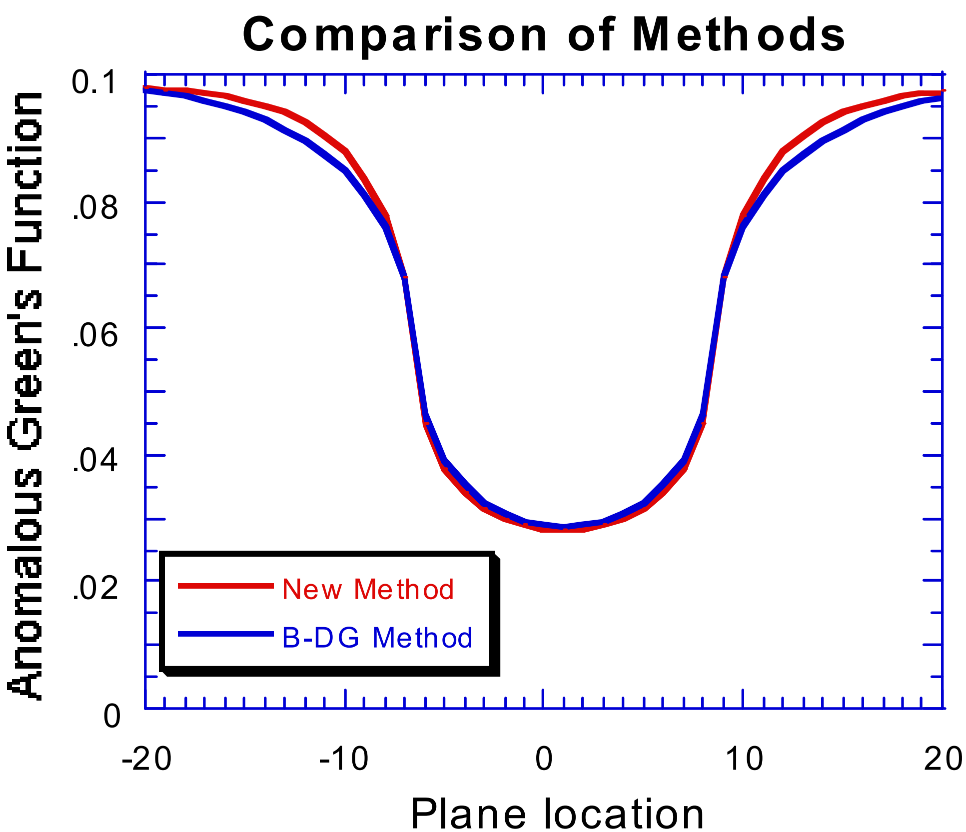
Details of Algorithm



Algorithm is iterated until a self-consistent solution is achieved

Comparison of Methods

$$F(\tau = 0) = < c^{+} c^{+} >$$



- Computational time reduced by a factor of 1000 versus a direct solution of the B-DG equations
- Compared to the DMFT at the HF level

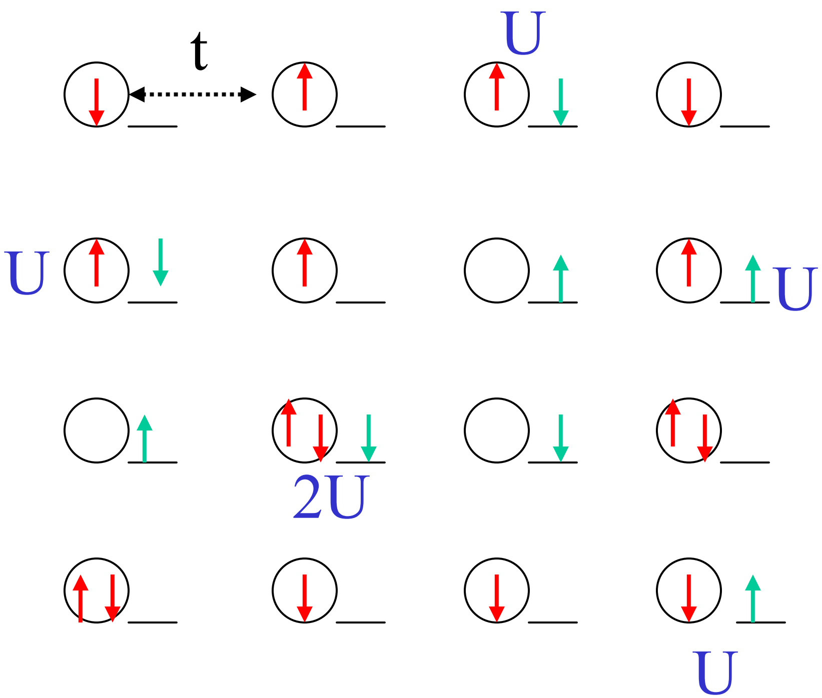
Summary of Algorithm

- Fast
- Includes dynamical effects
- More realistic model of the JJ weak-link region
- “Black Box” method to study different kinds of superconductors and interface materials

Superconductors

- Migdal-Eliashberg materials (Nb, Pb, Al, etc.)
- Vertex-corrections or nonconstant density of states (BKBO, Nb-doped Strontium titanate, doped fullerenes)
- D-wave superconductors (YBCO, BSCCO, etc.)
- Heavy-Fermions

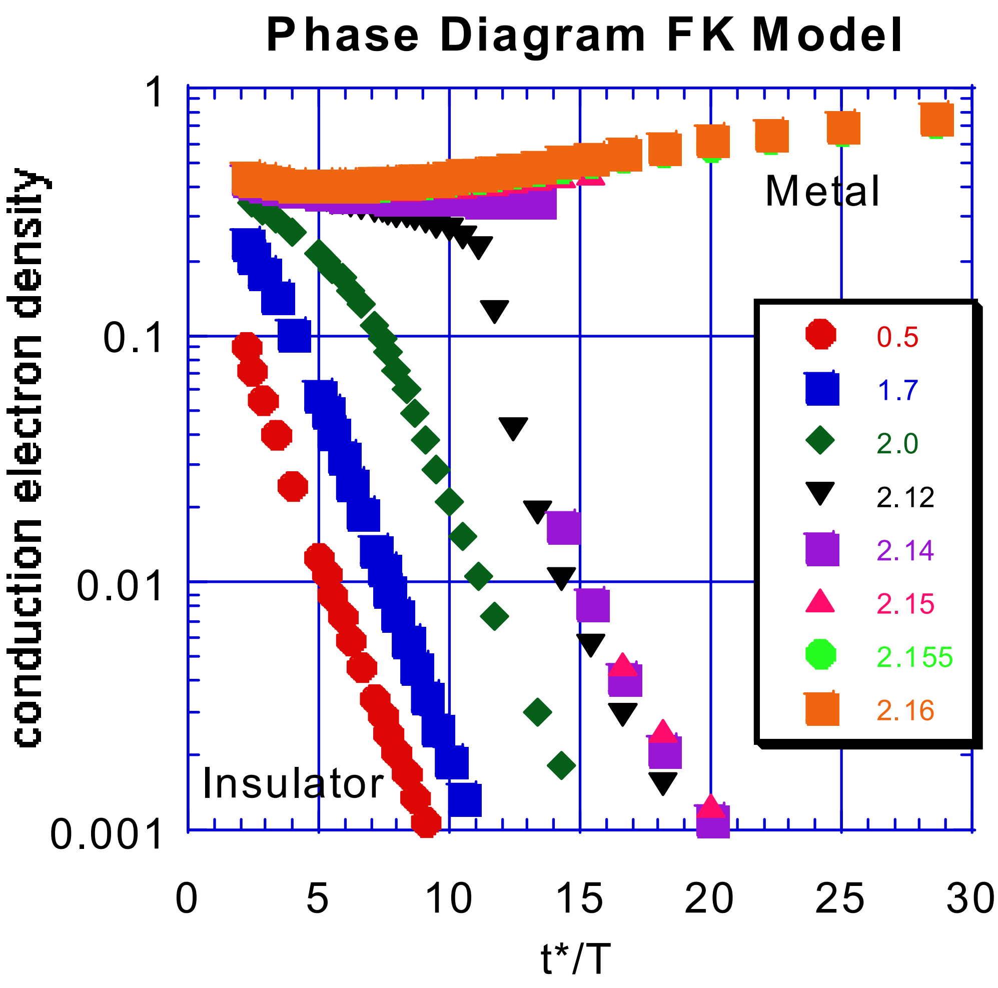
Example Weak-Link (FK model)



- Conduction electrons that hop between lattice sites
- Localized electrons which are limited to one per site
- Coulomb interaction only between localized and itinerant electrons

- Metal-Insulator transition driven by thermodynamics

FK model phase diagram



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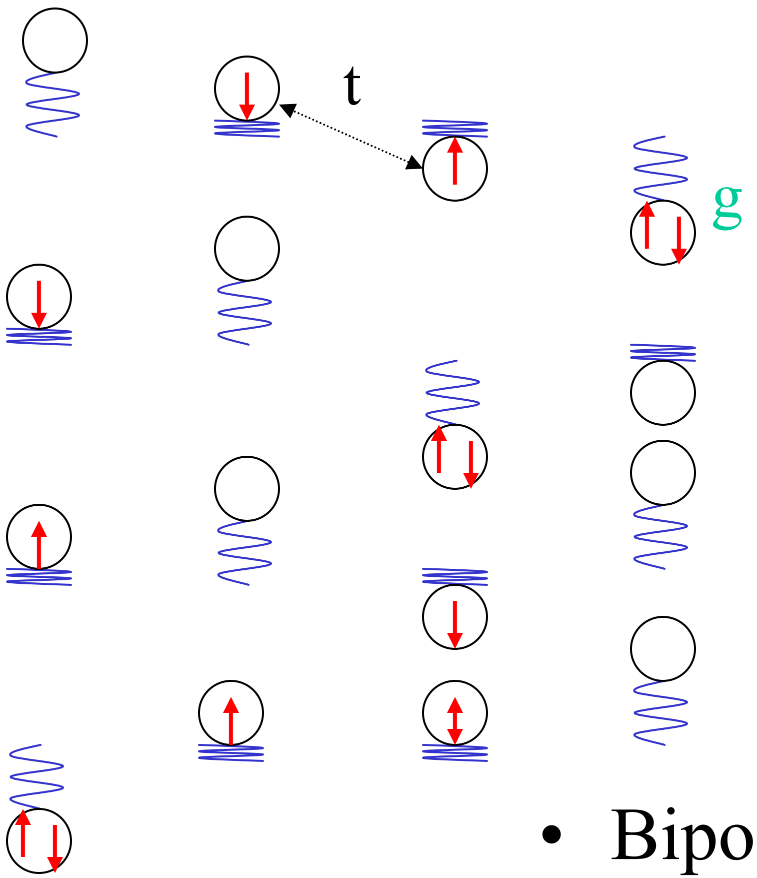
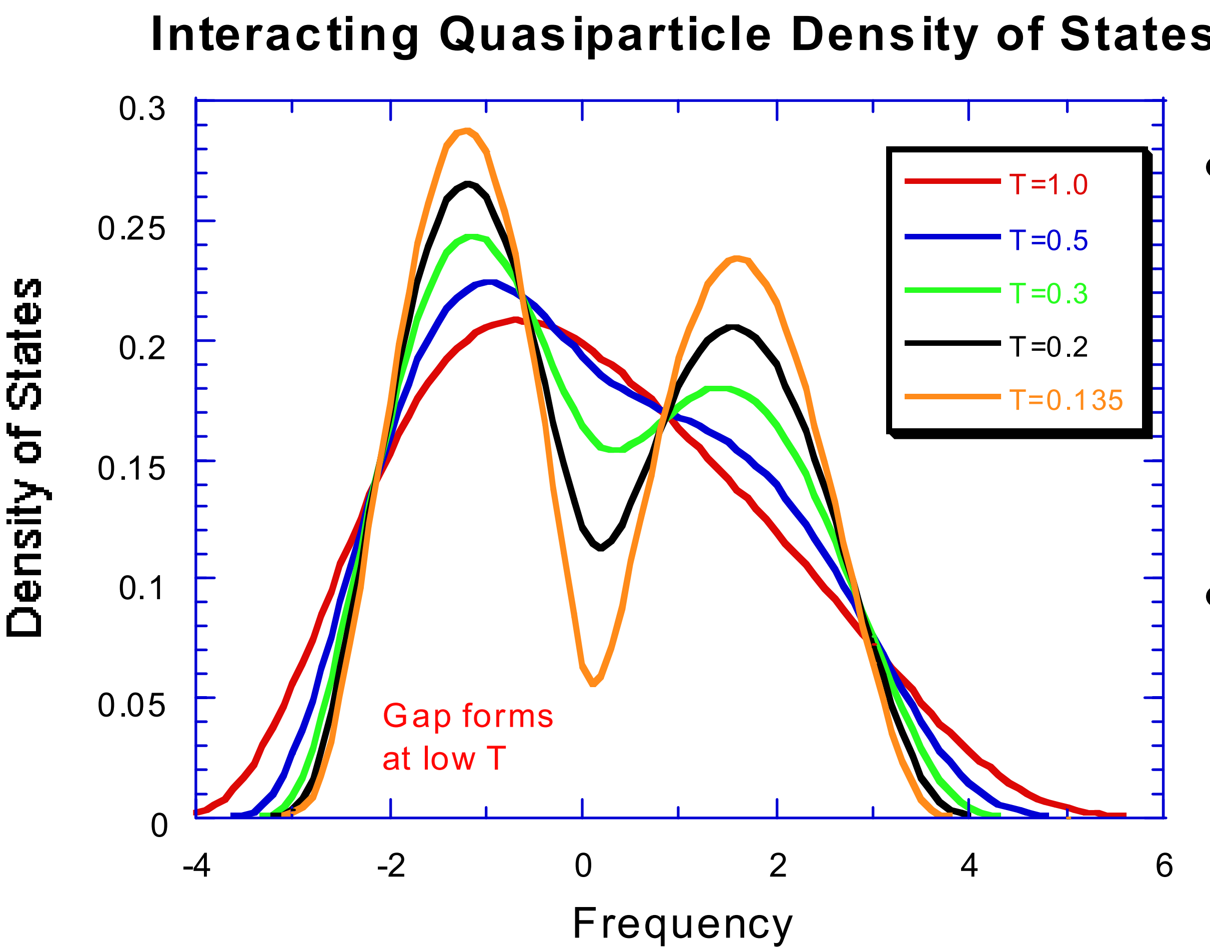
Example Weak-Link (Holstein Model)



- Conduction electrons with a hopping t
- Einstein phonons (harmonic or anharmonic)
- Linear coupling between the electron number and the phonon coordinate

- Bipolaronic Insulator

DOS, static Holstein model



- Asymmetry caused by the anharmonic interactions
- Note gap formation as Tc is approached

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ONR collaborations and open questions

- (Price and Rogers) Nb superconductor and Nb-doped STO weak-link; YBCO superconductor and Nb-doped STO weak-link
- (Greene) Nb superconductor and InAs weak-link
- Interface roughness effects (neglected here, but can be included by employing phenomonology and results from these microscopic models)
- Experimental results on JJs made from other materials

Conclusions

- Theoretical optimization of the JJ
- Model includes dynamical effects and real material properties
- “Black box” nature allows examination of a number of different SC’s and weak-links, including HTSC’s
- Does not include any interface roughness effects