Dynamical Cooper pairing in non-equilibrium electron-phonon systems

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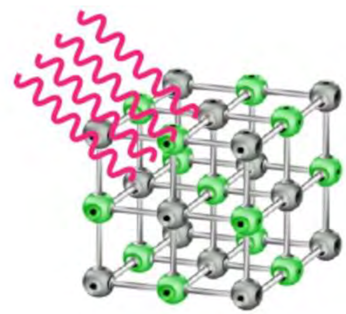

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$$ NSF DMR, Simons Foundation,
MURI QUANTUM MATTER, ITS ETH

Outline

Physical picture: enhanced electron-phonon interaction in systems with driven phonons

Floquet-Migdal-Eliashberg analysis

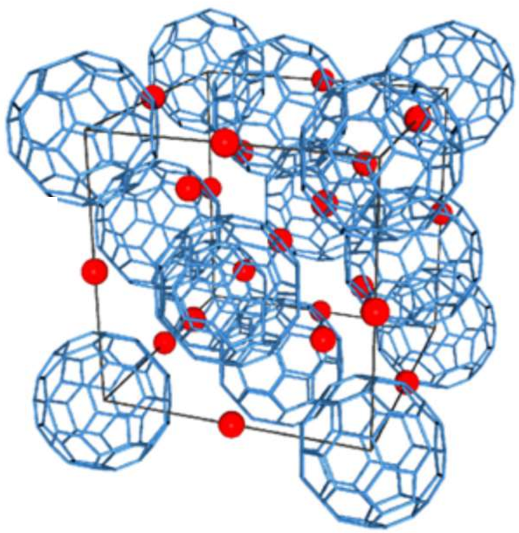
Optical response of photo-excited superconductor: Nonequilibrium dynamics with variational states

Conclusions

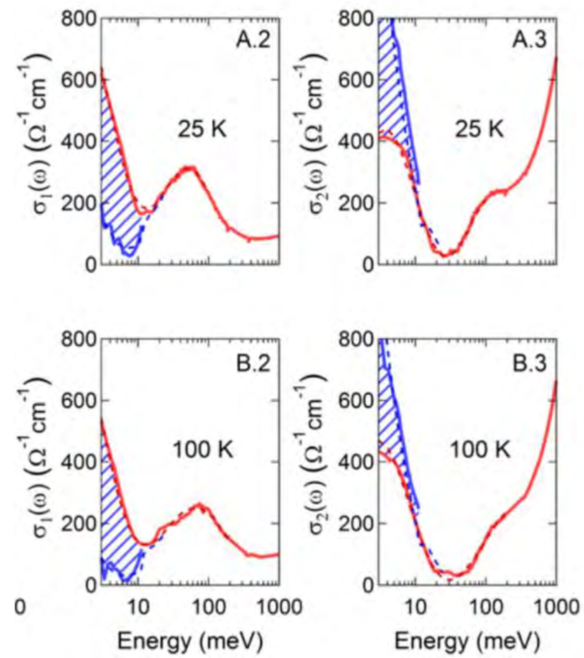
Motivation: photoinduced superconducitivty in K3C60

M. Mitrano et al.,
Nature 530, 461 (2016)

Tc=20K



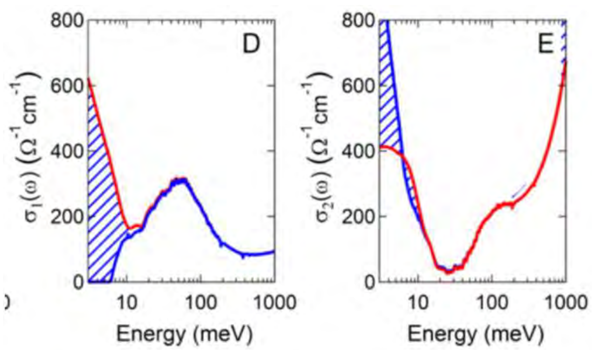
Response of photoexcited system



T=25 K

T=100 K

Equilibrium: T=25K (red) and T= 10 K (blue)



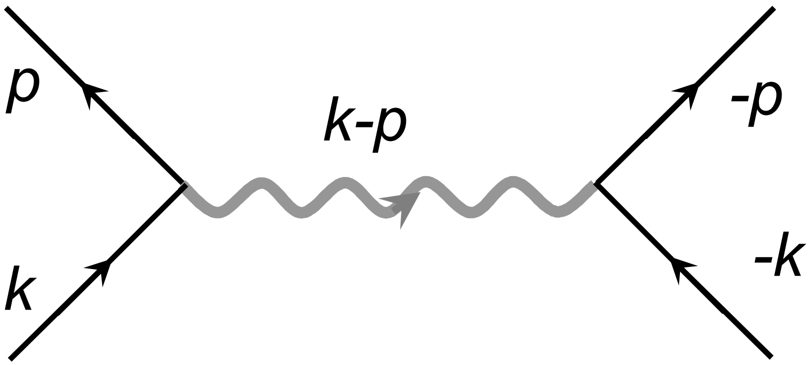
How to increase electron-phonon interaction and enhance superconductivity, CDW, …
by creating a non-equilibrium state of phonons

This talk: focus on superconductivity

Other experiments: optical control of Mott insulators,
charge and spin density wave states,
superconductivity in high Tc cuprates

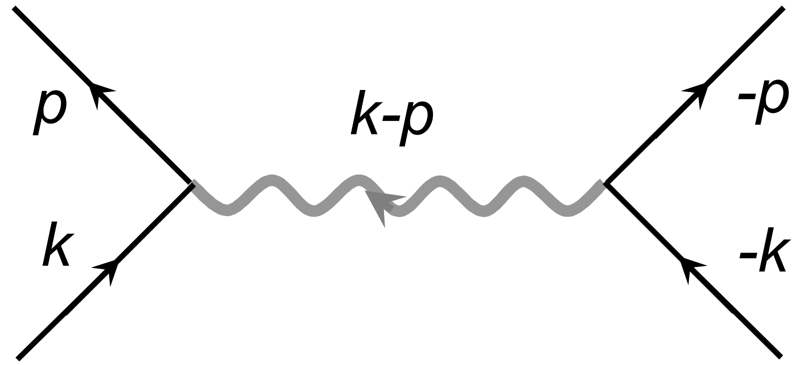
Other proposals for photoinduced superconductivity:
Jaksch, Galitski, Komnik, Thorwart, Georges,
Kollath, Mathey, Millis, Chamon, Sentef, …

Can one gain from non-equilibrium state of phonons?



interaction via phonon emission

$$-\frac{g^2(1+n)}{\epsilon_p+\omega_{k-p}-\epsilon_k} \approx -\frac{g^2(1+n)}{\omega_{\text{ph}}}$$



interaction via phonon absorption

$$-\frac{g^2\,n}{\epsilon_p-\omega_{p-k}-\epsilon_k} \approx +\frac{g^2\,n}{\omega_{\text{ph}}}$$

Effective interaction

$$V_{\text{eff}} = -\frac{g^2}{\omega_{\text{ph}}}$$

This is the usual argument that real photons
do not help to increase effective pairing strength

Electron-phonon interactions in systems with driven phonons

$$\mathcal{H} = \sum_q \left(\frac{P_q^2}{2M} + \frac{M\omega_q^2}{2} Q_q^2 \right) + \mathcal{H}_{\mathrm{drive}}(t)$$

Example: parametric drive of phonons

$$\mathcal{H} = \sum_q \left(\frac{P_q^2}{2M} + \frac{M\Omega_q^2(t)}{2} Q_q^2 \right)$$

$$\Omega_q^2(t) = \omega_q^2 \left(1 + 2\,\alpha \cos(2\,\Omega_{\mathrm{drv}} t) \right)$$

Effective electron-electron interaction assuming slow electron dynamics

$$\mathcal{H}_{\mathrm{eff}} = U(t)\,\hat{\rho}_{\mathrm{el}}(t)\,\hat{\rho}_{\mathrm{el}}(t)$$

$$U(t) = \frac{|\tilde{g}_{\mathbf{q}}|^2}{\hbar} \int_{-\infty}^{t} \mathrm{d}t' \; \mathcal{D}_{QQ}^{R}(t,t')$$

$$\mathcal{D}_{QQ}^{R}(t,t') = -i\theta(t-t')\langle \hat{Q}(t)\,\hat{Q}(t') - \hat{Q}(t')\,\hat{Q}(t) \rangle$$

Electron-phonon interactions in systems with driven phonons

Compare to

$$\mathcal{H}' = \mathcal{H} - \phi \hat{Q}$$

$$\langle \hat{Q} \rangle = \chi \phi$$ Fluctuation-dissipation theorem $$\chi = \langle \hat{Q} \hat{Q} \rangle$$

$$\Delta E = -\frac{\chi \phi^2}{2}$$

From electron-phonon coupling to effective electron-electron interaction

$$\mathcal{H}_{\mathrm{el-phon}} = \sum_{k\, q\, \sigma} g_q Q_q \, c^\dagger_{k-q\sigma} \, c_{k\sigma}$$

$$\mathcal{H}_{\mathrm{eff}} = U(t) \, \hat{\rho}_{\mathrm{el}}(t) \, \hat{\rho}_{\mathrm{el}}(t)$$

$$U(t) = \frac{|\tilde{g}_{\mathbf{q}}|^2}{\hbar} \int_{-\infty}^{t} \mathrm{d}t' \; \mathcal{D}^R_{QQ}(t, t')$$

$$\mathcal{D}^R_{QQ}(t, t') = -i\theta(t - t') \langle \hat{Q}(t) \, \hat{Q}(t') - \hat{Q}(t') \, \hat{Q}(t) \rangle$$

Phonon response function

Parametric drive
$$\mathcal{H} = \sum_q \left(\frac{P_q^2}{2M} + \frac{M\Omega_q^2(t)}{2} Q_q^2 \right)$$

Harmonic oscillator equations of motion
$$\frac{\mathrm{d}\hat{Q}(t)}{\mathrm{d}t} = \frac{\hat{P}(t)}{M}$$
$$\frac{\mathrm{d}\hat{P}(t)}{\mathrm{d}t} = -M\omega_{\mathbf{q}}^2 \left[1 + 2\alpha\cos(2\Omega_{\mathrm{drv}} t)\right] \hat{Q}(t)$$

From linearity of equations
$$\hat{Q}(t) = \mathfrak{M}_{QQ}(t,t')\,\hat{Q}(t') - \mathfrak{M}_{QP}(t,t')\,\frac{\hat{P}(t')}{M\Omega_{\mathrm{drv}}}$$

Response function
$$\mathcal{D}_{QQ}^{R}(t,t') = -i\,\theta(t-t')\langle[\hat{Q}(t'),\hat{P}(t')]\rangle \times \frac{-\mathfrak{M}_{QP}(t,t')}{M\Omega_{\mathrm{drv}}}$$
$$= -\frac{\hbar}{M\Omega_{\mathrm{drv}}}\,\theta(t-t')\,\mathfrak{M}_{QP}(t,t')$$

Response function does not depend on the initial state of phonons.
It is determined by the Hamiltonian only. It is enhanced near parametric resonance.

Electron-phonon interactions in systems with driven phonons

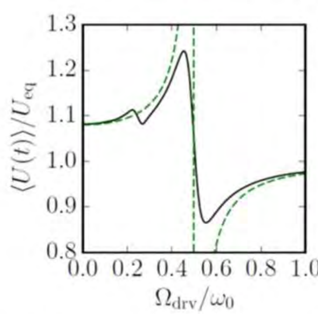
Parametrically driven phonons $\Omega_q^2(t) = \omega_q^2 \left(1 + 2\,\alpha \cos(2\,\Omega_{\rm drv} t) \right)$

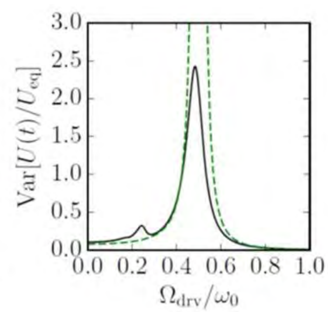
$$\frac{U(t)}{U_{\rm eq}} = 1 - \frac{2\alpha\, \omega_{\mathbf{q}}^2 \cos(2\Omega_{\rm drv} t)}{\omega_{\mathbf{q}}^2 - 4\Omega_{\rm drv}^2} + \frac{2\alpha^2\, \omega_{\mathbf{q}}^2 \left[\omega_{\mathbf{q}}^2 - 16\Omega_{\rm drv}^2 + \omega_{\mathbf{q}}^2 \cos(4\Omega_{\rm drv} t)\right]}{(\omega_{\mathbf{q}}^2 - 16\Omega_{\rm drv}^2)(\omega_{\mathbf{q}}^2 - 4\Omega_{\rm drv}^2)} + \mathcal{O}(\alpha^4)$$

Effective interaction: time average and variance. $\alpha = 0.2$

$$\left\langle \frac{U(t)}{U_{\rm eq}} \right\rangle = 1 + \frac{2\alpha^2\, \omega_{\mathbf{q}}^2}{\omega_{\mathbf{q}}^2 - 4\Omega_{\rm drv}^2} + \mathcal{O}(\alpha^4)$$

$$\mathrm{Var}\left[\frac{U(t)}{U_{\rm eq}} \right] = \frac{2\,\alpha^2\, \omega_{\mathbf{q}}^4}{(\omega_{\mathbf{q}}^2 - 4\Omega_{\rm drv}^2)^2} + \mathcal{O}(\alpha^4)$$





Strong enhancement near resonance. Large response function near "instability"

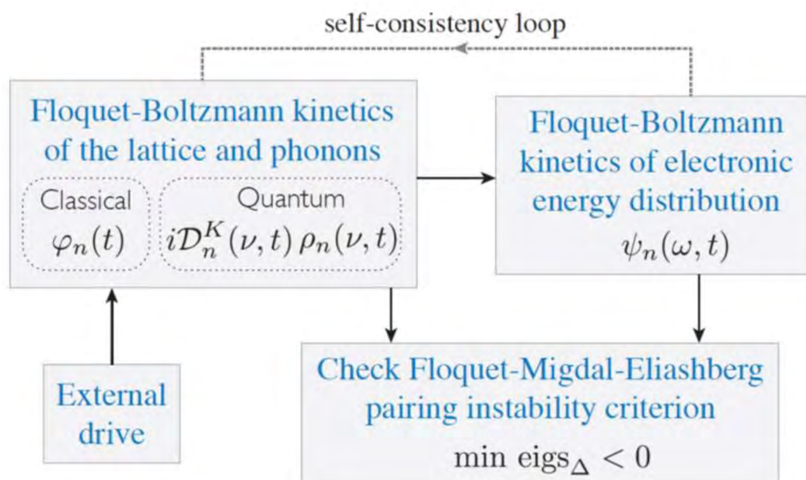
"Naïve" averaging

$$\left\langle \frac{T_c^{\rm BCS}(t)}{T_{c,\rm eq}^{\rm BCS}} \right\rangle = \left\langle e^{-\frac{1}{\nu(0) U_{\rm eq}} + \frac{1}{\nu(0) U(t)}} \right\rangle$$

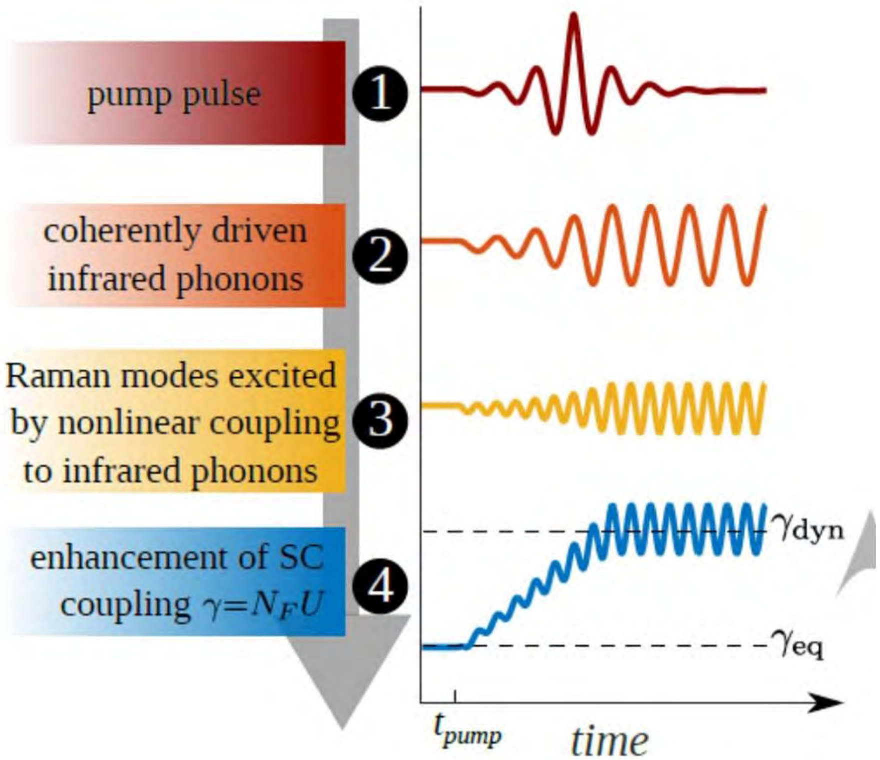
Exponential dependence of Tc: gain on increase in U is larger than suppression due to decrease

Photo-induced superconductivity
Floquet-Keldysh-Migdal-Eliashberg approach

M. Babadi, M. Knap, G. Refael, I. Martin, E. Demler



Driven electron-phonon system



$$\tau_{\text{decoherence}} \gg \tau_{\text{pairing}}, \tau_{\text{therm}}$$

This talk: focus on dynamical effects

Microscopic model

$$\mathcal{L}[\varphi,\Psi](t) = \sum_{\mathbf{k}} \Psi^\dagger_{\mathbf{k}} \left(i\partial_t \mathbb{I} - \xi_{\mathbf{k}}\hat{\sigma}_3\right)\Psi_{\mathbf{k}} - \frac{1}{2}\sum_{\mathbf{q}} \frac{1}{2\omega_{\mathbf{q}}}\varphi_{\mathbf{q}}\left(\partial_t^2 + \omega_{\mathbf{q}}^2\right)\varphi_{-\mathbf{q}}$$
$$- \sum_{j\in \text{lattice}} \mathcal{V}^{\text{ph}}(\varphi_j) - \frac{1}{\sqrt{N}}\sum_{\mathbf{k},\mathbf{k}'} g_{\mathbf{k},\mathbf{k}'}\varphi_{\mathbf{k}-\mathbf{k}'}\Psi^\dagger_{\mathbf{k}'}\hat{\sigma}_3\Psi_{\mathbf{k}} + \frac{\Lambda}{2}|F(t)|^2 \sum_{j\in\text{lattice}} \varphi_j$$

Phonons are driven only at q=0: e.g. $\Lambda\varphi^2_{\text{IR},q=0}(t)\varphi_{q=0}$.

This analysis can be applied to the IR modes themselves, if they couple to electrons

We assume phonon-nonlinearities given by κ_3 and κ_4.

$$\mathcal{V}^{\text{ph}}(\varphi) = -\frac{\kappa_3}{3!}\varphi^3 - \frac{\kappa_4}{4!}\varphi^4$$

We assume finite small dissipation γ_0 for phonons at q=0 due to other modes.
Additional dissipation is generated by electrons

Phonon dynamics

Equations of motion for phonons: coherent part and fluctuations

$$\frac{1}{2\omega_0}\left(\partial_t^2+\omega_0^2+\gamma_0\partial_t\right)\varphi(t)-\frac{\kappa_4}{6}\varphi^3(t)-\frac{\kappa_3}{2}\varphi^2(t)\;-\frac{\kappa_4}{2}\chi(t)\,\varphi(t)=\frac{\Lambda}{2}|F(t)|^2+\frac{\kappa_3}{2}\chi(t)$$

$$\chi(t)\equiv\frac{1}{N}\sum_{\mathbf{q}} i\mathcal{D}_{\mathbf{q}}(t,t)$$

Force from
finite q phonons

$$-\frac{1}{2\omega_{\mathbf{q}}}\left[\partial_{t_1}^2+\omega_{\mathbf{q}}^2\right]\mathcal{D}_{\mathbf{q}}(t_1,t_2)=\delta_{\mathcal{C}}(t_1,t_2)\;+V(t_1)\,\mathcal{D}_{\mathbf{q}}(t_1,t_2)+\int_{\mathcal{C}}\mathrm{d}\tau\,\Pi_{\mathbf{q}}(t_1,\tau)\,\mathcal{D}_{\mathbf{q}}(\tau,t_2)$$

$$V(t)\equiv-\frac{\kappa_4}{2}\chi(t)-\frac{\kappa_4}{2}\varphi^2(t)-\kappa_3\,\varphi(t)$$

Drive from
q=0 phonon

$$\Pi_{\mathbf{q}}(t_1,t_2)=\frac{1}{N}\sum_{\mathbf{k}}|g_{\mathbf{k},\mathbf{k}+\mathbf{q}}|^2\;\mathrm{tr}\left[\hat{\mathcal{G}}_{\mathbf{k}+\mathbf{q}}(t_1,t_2)\,\hat{\sigma}_3\,\hat{\mathcal{G}}_{\mathbf{k}}(t_2,t_1)\,\hat{\sigma}_3\right]$$

Force from electrons
including damping
and frequency renormalization

Floquet-Wigner representation

Wigner transform—

$$\mathcal{D}(t_1,t_2) \to \mathcal{D}(\omega,T) \equiv \int \mathrm{d}t\, e^{-i\omega t}\, \mathcal{D}(T+t/2, T-t/2)$$

center-of-mass (COM) time

$$T = (t_1+t_2)/2$$

Usually:
Slow COM time evolution
Fast relative time.
Not applicable here b/c of the fast drive

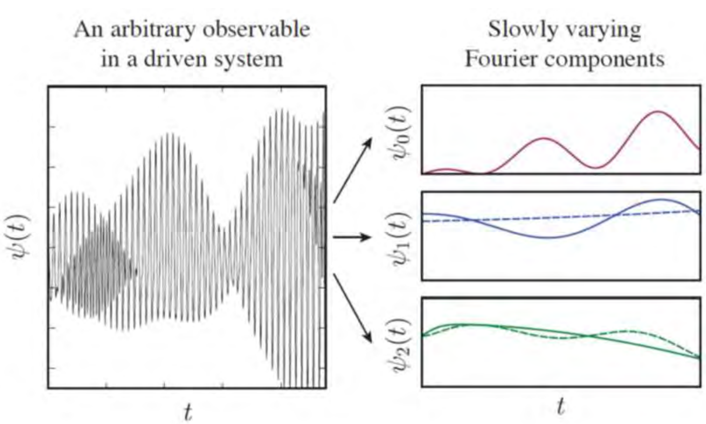
$$\varphi_{\mathrm{IR}}^2(t) = \mathcal{A}(t)\cos^2(\Omega t)$$

$$\partial_t \mathcal{A}(t)/\mathcal{A}(t) \ll \Omega^{-1}, \bar{\Omega}_0^{-1}$$

"Floquet-Wigner" representation

$$\mathcal{D}^{R/A/K}(\omega,T) = \sum_n \mathcal{D}_n^{R/A/K}(\omega;T)\, e^{-in\Omega T}$$

slowly-varying Floquet components



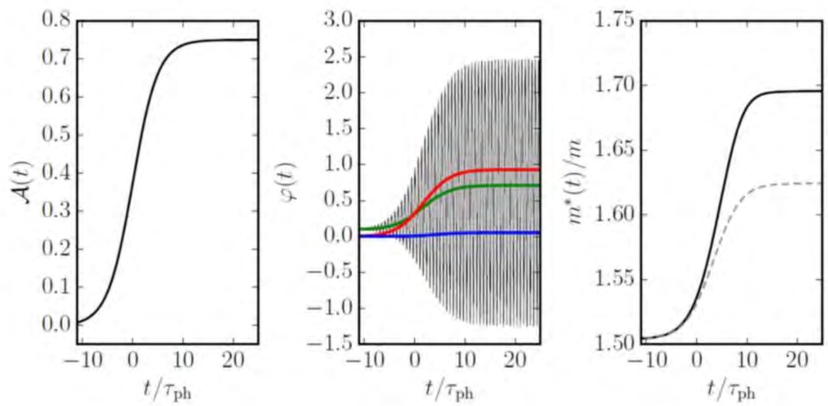
Earlier work on Floquet-Wigner:
Tsuji et al., PRB (2008),
Genske, Rosch, PRA (2015).

This work: full quantum kinetic equation beyond quasiparticle Boltzmann approximation

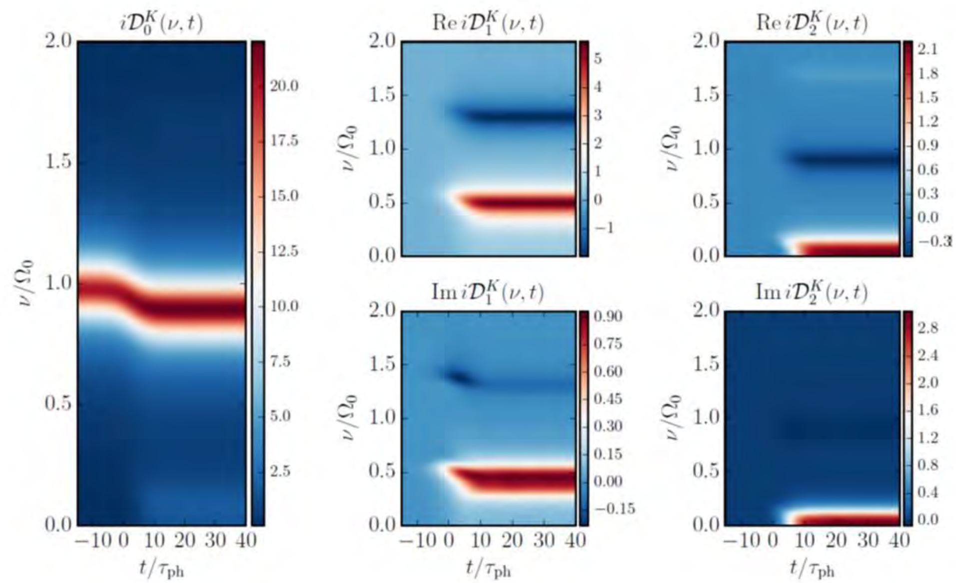
Evolution of phonons

Ramped-up external drive from with Amax=0.75

Coherent amplitude at q=0



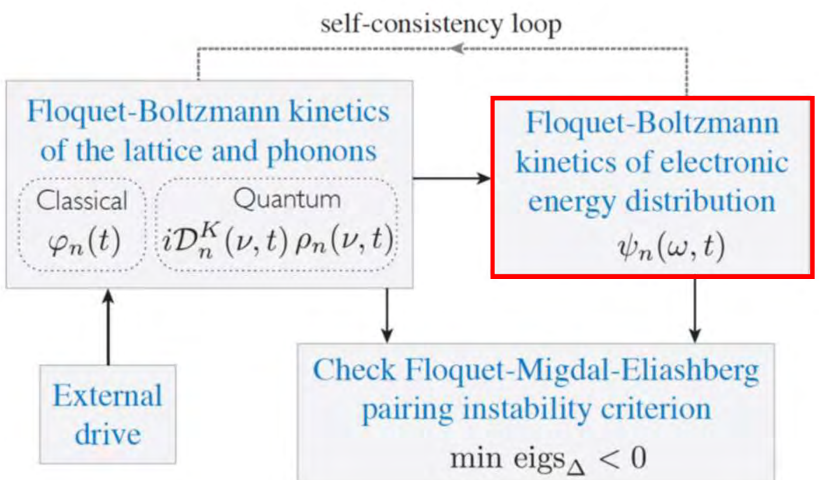
Propagators for finite q



Note the red shift in the spectrum of phonons: contributes to SC enhancement

The real time Migdal-Eliashberg theory

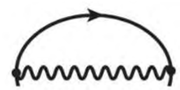
We want to compare enhancement of electron-phonon interaction with shortening of electron lifetime



The real time Migdal-Eliashberg theory

No superconductivity yet

$$\hat{\Sigma}_{\mathbf{k}}(t,t') = \frac{i}{N}\sum_{\mathbf{k}'} \hat{\sigma}_3\, \hat{\mathcal{G}}_{\mathbf{k}'}(t,t')\, \hat{\sigma}_3\, |g_{\mathbf{k}\mathbf{k}'}|^2\, D_{\mathbf{k}-\mathbf{k}'}(t,t')$$



Renormalization of electron energy, quasiparticle weight, lifetime

spectral/Keldysh decomposition

$$i\hat{\mathcal{G}}^{>}_{\mathbf{k}}(\omega,T) = \frac{1}{2}\left[i\hat{\mathcal{G}}^{K}(\omega,T) + \hat{\mathsf{A}}(\omega,T)\right]$$

$$i\hat{\mathcal{G}}^{<}_{\mathbf{k}}(\omega,T) = \frac{1}{2}\left[i\hat{\mathcal{G}}^{K}(\omega,T) - \hat{\mathsf{A}}(\omega,T)\right]$$

$$\hat{\Sigma}^{R}(\omega,T) = \frac{1}{2}\int_{-\infty}^{+\infty}\frac{d\omega'}{2\pi}\int_{-\infty}^{+\infty}\frac{d\nu}{\omega-\omega'-\nu+i0^{+}}\left\{iF^{K}(\nu,T)\,\check{\mathsf{A}}(\omega',T) + F^{\rho}(\nu,T)\, i\check{\mathcal{G}}^{K}(\omega',T)\right\},$$

Renormalization of effective mass

$$i\hat{\Sigma}^{K}(\omega,T) = \frac{1}{2}\int_{-\infty}^{+\infty}\frac{d\omega'}{2\pi}\int_{-\infty}^{+\infty} d\nu\,(2\pi)\delta(\omega-\omega'-\nu)\left\{iF^{K}(\nu,T)\, i\check{\mathcal{G}}^{K}(\omega',T) + F^{\rho}(\nu,T)\,\check{\mathsf{A}}(\omega',T)\right\}$$

Coherence of quasiparticles

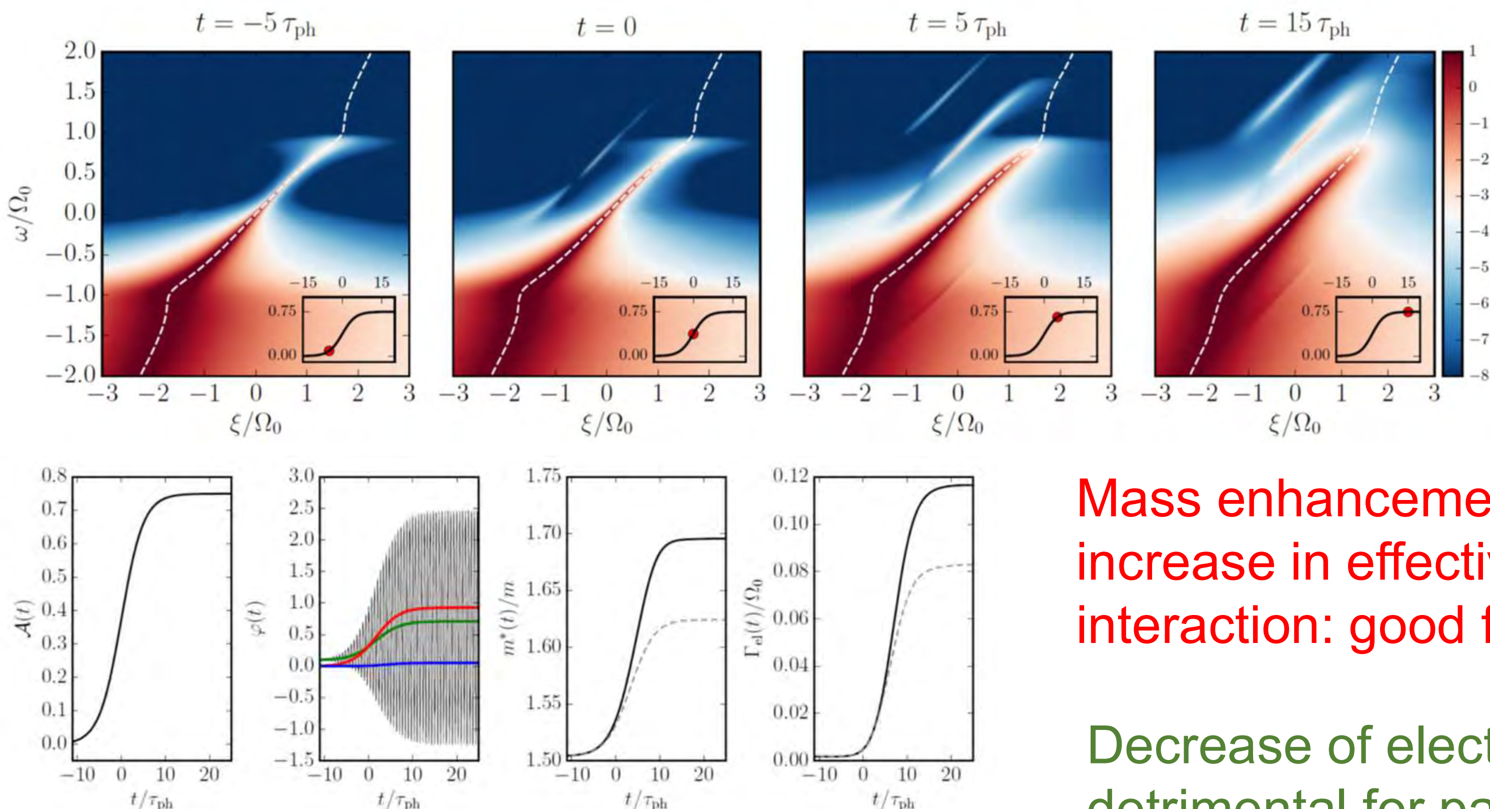
spectral Eliashberg $$F^{\rho}_{\xi,\xi'}(\nu,T) \equiv \frac{\nu(0)}{\nu(\xi)\,\nu(\xi')}\frac{1}{N^2}\sum_{\mathbf{k},\mathbf{k}'}|g_{\mathbf{k}\mathbf{k}'}|^2\,\frac{1}{2\pi}\,\rho_{\mathbf{k}-\mathbf{k}'}(\nu,T)\,\delta(\xi_{\mathbf{k}}-\xi)\,\delta(\xi_{\mathbf{k}'}-\xi'),$$

Keldysh Eliashberg $$iF^{K}_{\xi,\xi'}(\nu,T) \equiv \frac{\nu(0)}{\nu(\xi)\,\nu(\xi')}\frac{1}{N^2}\sum_{\mathbf{k},\mathbf{k}'}|g_{\mathbf{k}\mathbf{k}'}|^2\,\frac{1}{2\pi}\, iD^{K}_{\mathbf{k}-\mathbf{k}'}(\nu,T)\,\delta(\xi_{\mathbf{k}}-\xi)\,\delta(\xi_{\mathbf{k}'}-\xi')$$

Out of equilibrium phonons

The real time Migdal-Eliashberg theory

Predictions for ARPES

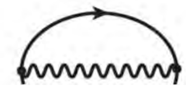


Mass enhancement indicates increase in effective electron-phonon interaction: good for pairing

Decrease of electron coherence: detrimental for pairing

Onset of pairing in non-equilibrium Floquet system

Introduce off-diagonal component of self-energy. Require self-consistency.



1. Calculate the Q-matrix—

Floquet cutoff (approx.)

$$(2\omega - m\Omega)\,\delta\mathcal{F}^R_{n,m} = -2\pi i\,\phi_{n,m} + \sum_{n'=-N_D}^{N_D} \left(\Sigma^R_{n',m-n+n'}\,\delta\mathcal{F}^R_{n-n',m+n'} + \Sigma^R_{n',m+n-n'}\,\delta\mathcal{F}^R_{n-n',m-n'}\right)$$

$$\delta\mathcal{F}^R_{n,m}(\omega) = \sum_{n',m'} \mathsf{Q}^{n,m}_{n',m'}(\omega)\,\phi_{n',m'}(\omega)$$

2. Solve the functional eigenvalue equation—

retarded interaction

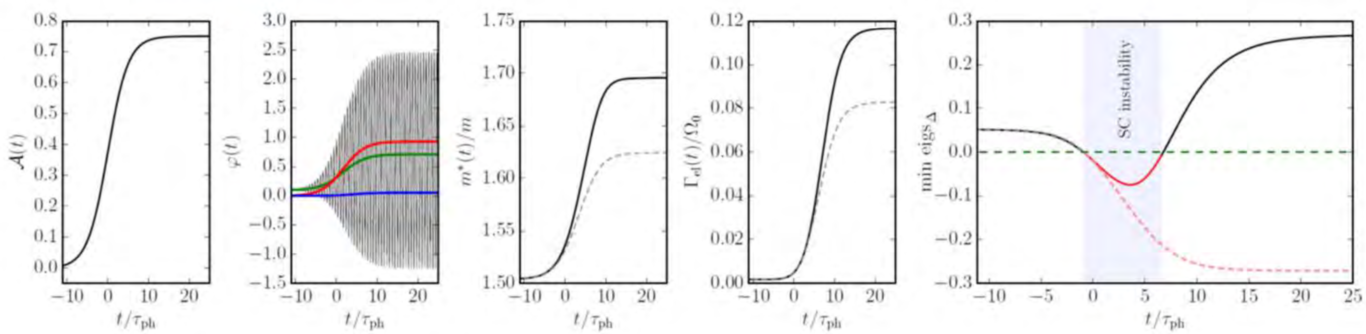
$$\Delta_n(\omega) = \frac{i\omega}{2\pi} \sum_{n'=-N_\phi}^{N_\phi} \sum_{n''=-N_D}^{N_D} \sum_{m'} \Bigg\{ \mathsf{Q}^{n,0}_{n',m'}(\omega) \int_0^{+\infty} \frac{d\omega'}{\omega'} K_{n''}(\omega - m'\Omega/2, \omega')\,\Delta_{n'-n''}(\omega') - \left[\mathsf{Q}^{-n,0}_{n',m'}(\omega)\right]^* \int_0^{+\infty} \frac{d\omega'}{\omega'} K^*_{n''}(\omega - m'\Omega/2, \omega')\,\Delta^*_{n'-n''}(\omega') \Bigg\}$$

dynamical self-energy effects (scattering, qp renormalization)

Compare to simple BCS

$$\Delta = -V\nu(0)\int d\xi \frac{\Delta}{|\xi|}$$

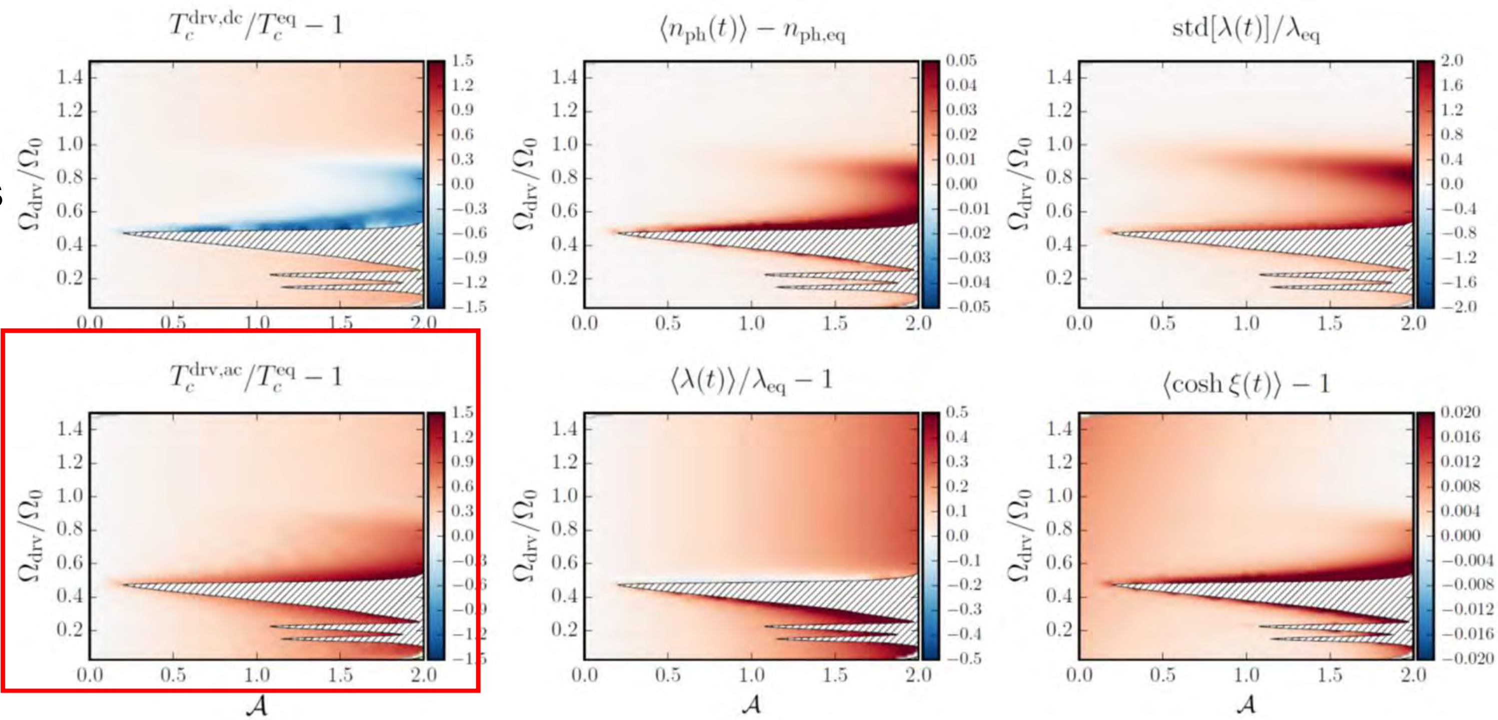
$$V = -\frac{g^2}{\omega_{\rm ph}}$$



Pairing instability in a driven electron-phonon system

Neglecting Floquet components. Use time averaged values

Include all Floquet components



Optical response of photo-excited superconductor

Mean-field as Gaussian states

Bogoliubov theory of the superfluid state of bosons

$$| \Psi_{\mathrm{Bogoliubov}} \rangle = e^{i\alpha_0 b^\dagger_{k=0} + \sum_k f_k b^\dagger_k b^\dagger_{-k}} |0\rangle$$

BCS theory of superconductivity

$$| \Psi_{\mathrm{BCS}} \rangle = \prod_k (u_k + v_k c^\dagger_{k\uparrow} c^\dagger_{-k\downarrow})|0\rangle \ = \ e^{\sum_k \frac{v_k}{u_k} c^\dagger_{k\uparrow} c^\dagger_{-k\downarrow}} |0\rangle$$

Mean-field as Gaussian states

General Gaussian state of bosons

$$R = \begin{pmatrix} b_b^\dagger + b_1 \\ i(b_1^\dagger - b_1) \\ \dots \\ b_N^\dagger + b_N \\ i(b_N^\dagger - b_N) \end{pmatrix}$$

$$|\,\Psi_{\text{Boson Gauss}}\,\rangle = e^{iR^T v - \frac{i}{4} R^T \xi_b R}$$

$$\langle R_i \rangle = v_i$$

$$\delta R_i = R_i - \langle R_i \rangle$$

$$\langle\, \{\delta R_i, \delta R_j\}_+ \,\rangle = e^{i\xi_b}$$

General Gaussian state of fermions

$$A = \begin{pmatrix} c_1^\dagger + c_1 \\ i(c_1^\dagger - c_1) \\ \dots \\ c_N^\dagger + c_N \\ i(c_N^\dagger - c_N) \end{pmatrix}$$

$$|\,\Psi_{\text{Fermion Gauss}}\,\rangle = e^{\frac{i}{4} R A^T \xi_m A}$$

$$\langle\, [A_i, A_j]_- \,\rangle = e^{i\xi_m}$$

General Gaussian state

$$|\,\Psi_{\text{Gauss}}\,\rangle = |\,\Psi_{\text{Boson Gauss}}\,\rangle \times |\,\Psi_{\text{Fermion Gauss}}\,\rangle$$

Beyond Gaussian states

$$\mathcal{H} = -t \sum \langle ij \rangle \sigma c^{\dagger}_{i\sigma} c_{j\sigma} - \mu \sum_{i\sigma} c^{\dagger}_{i\sigma} c_{i\sigma} + \sum_{nm} \omega_{nm} b^{\dagger}_{n} b_{m} + g \sum_{nm} c^{\dagger}_{n\sigma} c_{n\sigma} (b_n + b^{\dagger}_{n})$$

Flow in imaginary time to find the ground state

Tao Shi, Ignacio Cirac, ED

$$|\,\Psi_{\text{Variational}}(\tau)\,\rangle = e^{iS(\tau)} \times |\,\Psi_{\text{Gauss}}(\tau)\,\rangle$$

$$S(\tau) = i \sum_{nm} \lambda_{nm}(\tau)(b_n - b^{\dagger}_{n}) c^{\dagger}_{m\sigma} c_{m\sigma}$$

Lang-Firsov transformation

Geometrical approach to variational imaginary time flow

$$|\Psi_j\rangle = \partial_{\xi_j} |\Psi(\xi)\rangle$$

$$|\mathbf{R}_{\Psi}\rangle = -(H - E)\,|\Psi(\xi)\rangle$$

$$\mathbf{G}_{ij} = \langle \Psi_i | \Psi_j \rangle$$

$$d_{\tau}\xi_i = \sum_{j=1} \mathbf{G}^{-1}_{ij} \langle \Psi_j | \mathbf{R}_{\Psi} \rangle$$

Beyond Gaussian states

Variational approach to real time dynamics

$$|\,\Psi_{\text{Variational}}(t)\,\rangle = e^{iS(t)} \times |\,\Psi_{\text{Gauss}}(t)\,\rangle$$

$$\mathcal{H} = -t\sum \langle ij\rangle\sigma c^{\dagger}_{i\sigma}c_{j\sigma} - \mu\sum_{i\sigma} c^{\dagger}_{i\sigma}c_{i\sigma} + \sum_{nm}\omega_{nm}b^{\dagger}_{n}b_{m} + g\sum_{nm} c^{\dagger}_{n\sigma}c_{n\sigma}(b_{n} + b^{\dagger}_{n}) + \mathcal{H}_{J}(t)$$

$$H_J(t) = 2J\sum_{k,\sigma,\alpha} A_\alpha(t)\sin k_\alpha c^{\dagger}_{k\sigma}c_{k\sigma},$$

Calculation of optical conductivity in parametrically driven superconductors
Work in progress …

Beyond Gaussian states

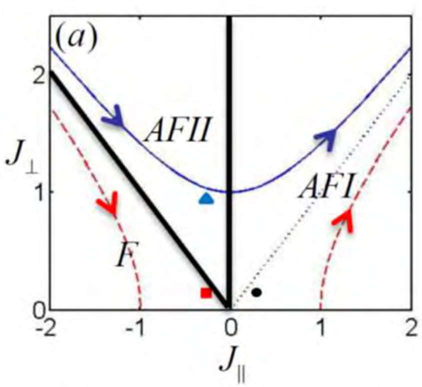
Variational approach to real time dynamics in the Kondo model

Tao Shi, Ignacio Cirac, ED

$$|\,\Psi_{\text{Variational}}(t)\,\rangle = e^{iS(t)} \times |\,\Psi_{\text{Gauss}}(t)\,\rangle$$

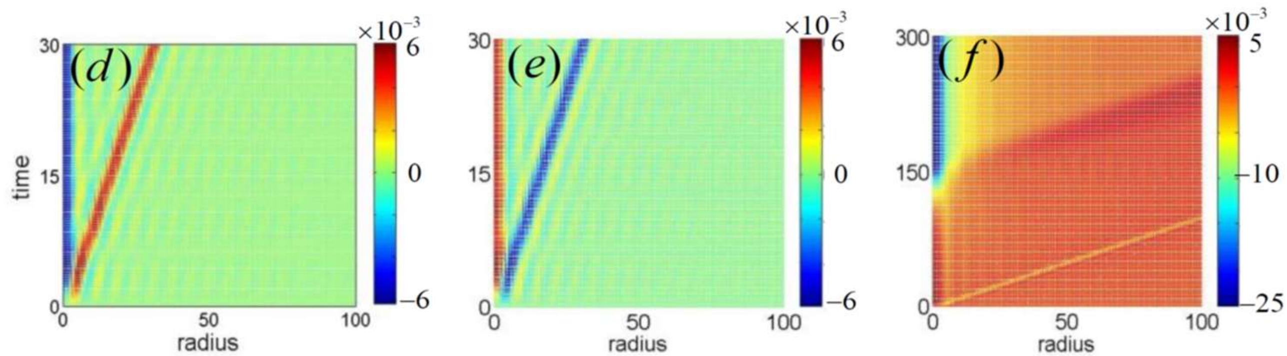
$$H_{\text{K}} = \sum_{k\sigma} k c^{\dagger}_{k\sigma} c_{k\sigma} + \frac{J_{\perp}}{2}[\sigma_{+}\psi^{\dagger}_{\downarrow}(0)\psi_{\uparrow}(0) + \text{H.c.}] + \frac{J_{\parallel}}{4}\sigma_{z}[\psi^{\dagger}_{\uparrow}(0)\psi_{\uparrow}(0) - \psi^{\dagger}_{\downarrow}(0)\psi_{\downarrow}(0)]$$

Equilibrium phase diagram



Non-equilibrium dynamics is
Challenging problem due to many crossovers

Fermion spin structure corresponding to spin up impurity state



AFI regime

F regime

AFII regime

Conclusions

External drive leads to enhancement of electron-phonon interaction. It can be understood as parametric amplification. This leads to an increase in the effective BCS coupling constant

Nonequilibrium state of phonons also results in additional scattering of electrons that leads to pair-breaking

We find that increase in BCS coupling can dominate and find possible increase of instability temperature by 150%. Floquet aspects are crucial.