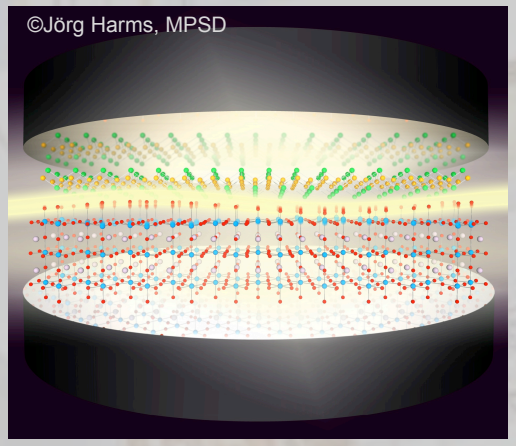
Cavity-enhanced electron-phonon coupling in monolayer FeSe/STO



M. A. Sentef, M. Ruggenthaler, A. Rubio, arXiv:1802.09437
Science Advances 4, eaau6969 (2018)

APS March Meeting, Boston, March 6, 2019

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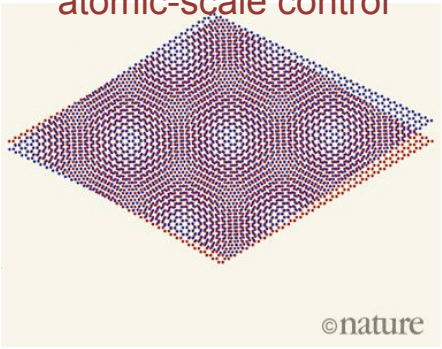
Max Planck Institute for the Structure and Dynamics of Matter

Engineering materials with light

condensed matter

quantum materials

atomic-scale control



Y. Cao et al., Nature 556, 43 (2018)

ultrafast spectroscopy

revealing elementary couplings

light-induced new states of matter

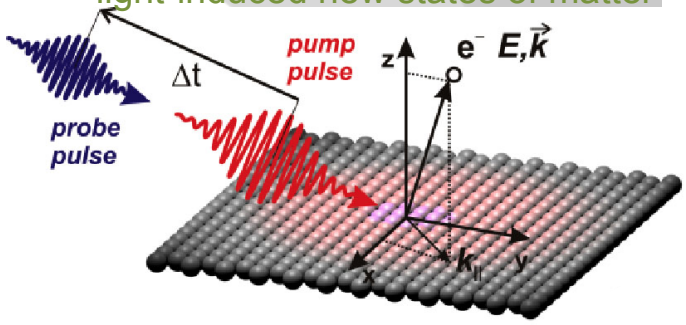
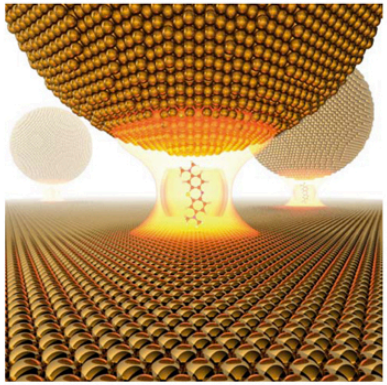


Image courtesy: J. Sobota

pump-probe: strong classical fields



R. Chikkaraddy et al., Nature 535, 127 (2016)

quantum optics

nanoplasmonics

polaritonic chemistry

QED: vacuum fluctuations

Cavity materials

BCS superconductors: phonon-mediated superconductivity
Ginzburg, Phys. Lett. 13, 101 (1964): exciton-mediated superconductivity?
Ruvalds, Phys. Rev. B 35, 8869(R) (1987): plasmon-mediated superconductivity?

PRL 104, 106402 (2010) PHYSICAL REVIEW LETTERS week ending 12 MARCH 2010

Exciton-Polariton Mediated Superconductivity

Fabrice P. Laussy,[1] Alexey V. Kavokin,[1,2] and Ivan A. Shelykh[3,4]

Cavity-assisted mesoscopic transport of fermions: Coherent and dissipative dynamics.

Hagenmüller et al., 1801.09876

Cavity-mediated electron-photon superconductivity

Frank Schlawin[1], Andrea Cavalleri[1,2] and Dieter Jaksch[1]

1804.07142

PHYSICAL REVIEW B 93, 054510 (2016)

Superconductivity and other collective phenomena in a hybrid Bose-Fermi mixture formed by a polariton condensate and an electron system in two dimensions

Ovidiu Cotleţ,[1,*] Sina Zeytinoğlu,[1,2] Manfred Sigrist,[2] Eugene Demler,[3] and Ataç Imamoğlu[1]

Cavity quantum-electrodynamical polaritonically enhanced electron-phonon coupling and its influence on superconductivity

M. A. Sentef,[1,*] M. Ruggenthaler,[1] and A. Rubio[1,2,3]

1802.09437

Superradiant Quantum Materials

Giacomo Mazza[1,2,*] and Antoine Georges[2,3,1,4]

1804.08534

Cavity Quantum Eliashberg Enhancement of Superconductivity

Jonathan B. Curtis,[1,2,*] Zachary M. Raines,[1,2] Andrew A. Allocca,[1,2] Mohammad Hafezi,[1] and Victor M. Galitski[1,2]

1805.01482

Manipulating quantum materials with quantum light

Martin Kiffner[1,2], Jonathan Coulthard[2], Frank Schlawin[2], Arzhang Ardavan[2], and Dieter Jaksch[2,1]

1806.06752

Cavity superconductor-polaritons

Andrew A. Allocca,* Zachary M. Raines, Jonathan B. Curtis, and Victor M. Galitski

1807.06601

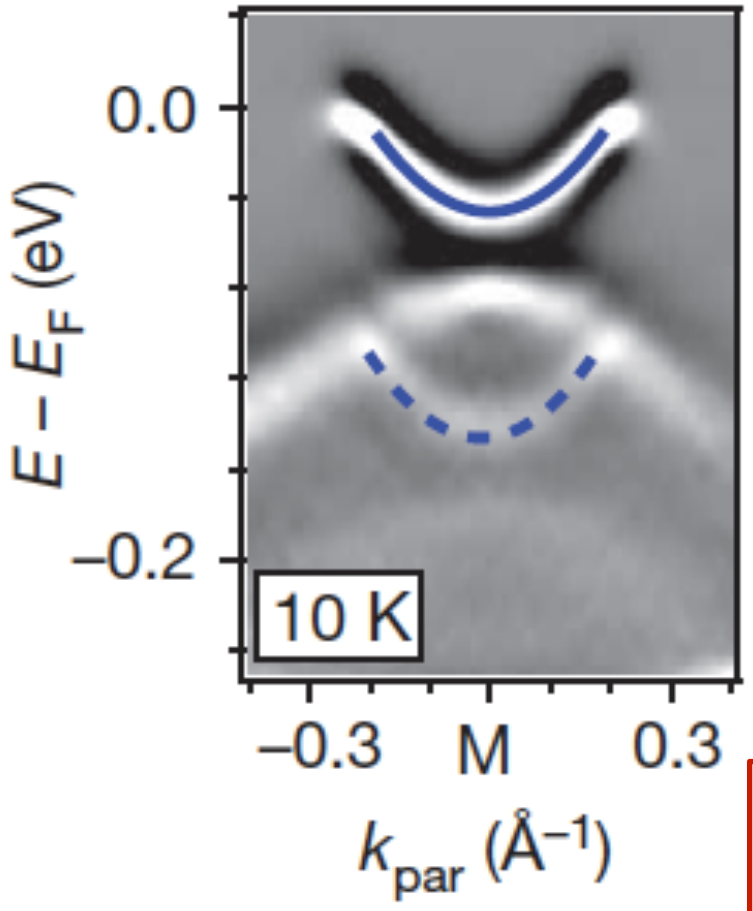
Ab-initio Exciton-polaritons: Cavity control of Dark Excitons in two dimensional Materials

Simone Latini,[1,*] Enrico Ronca,[1,†] Umberto De Giovannini,[1,2,‡] Hannes Hübener,[1,§] and Angel Rubio[1,3,¶]

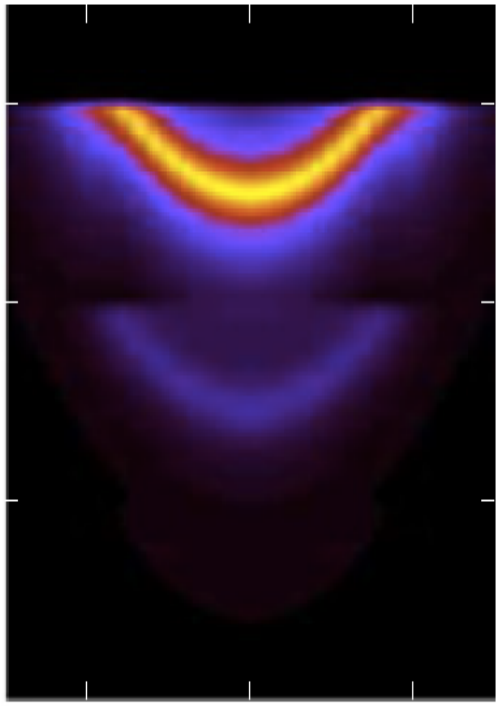
1810.02672

monolayer FeSe/STO: ARPES

experiment



theory



replica bands: forward (small-q) electron-phonon scattering

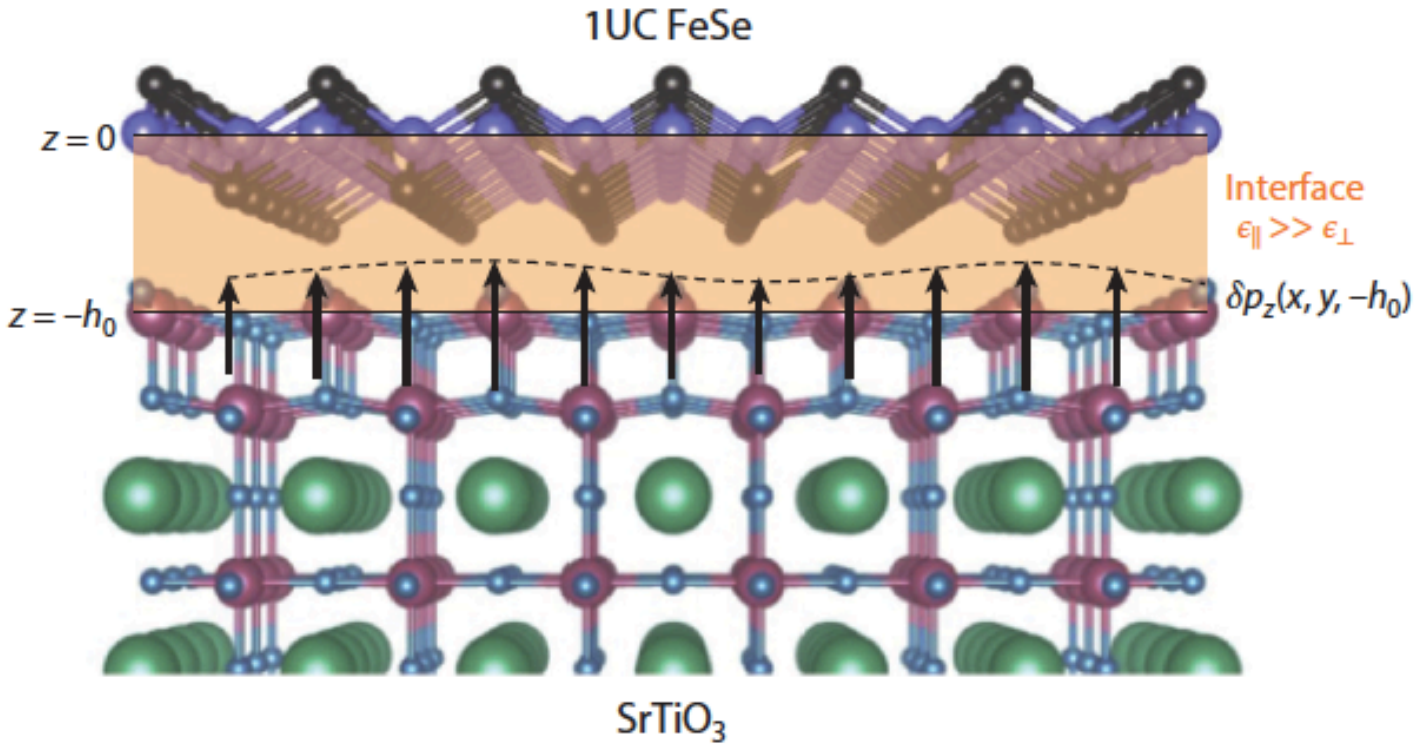
Lee et al., Nature 515, 245 (2014)

Rademaker et al., New J. Phys. 18, 022001 (2016)

monolayer FeSe/STO: interfacial phonon

bare el-phonon vertex $g(\vec{q}) = g_0 \exp(-|\vec{q}|/q_0)$ *Lee et al., Nature 515, 245 (2014)*

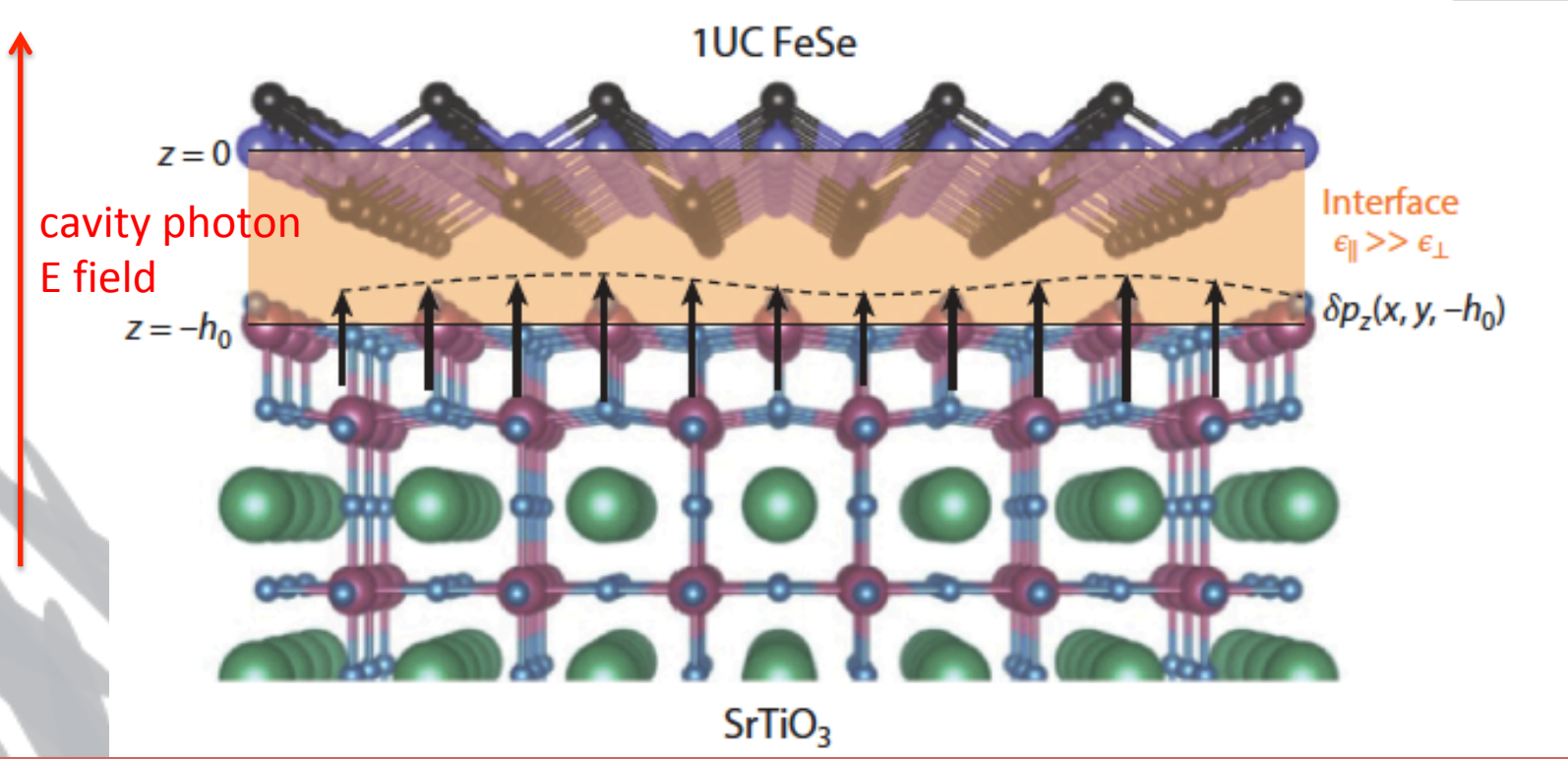
$$q_0^{-1} = h_0\sqrt{\epsilon_\parallel/\epsilon_\perp} \quad \epsilon_\parallel/\epsilon_\perp \approx 100$$



Huang and Hoffman, Annu. Rev. CMP 8, 311 (2017)

Cavity engineering

- idea: use phonon polaritons to modify electron-phonon coupling



Huang and Hoffman, Annu. Rev. CMP 8, 311 (2017)

Model and Method

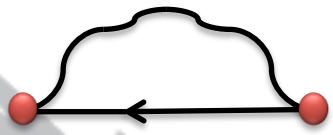
electrons el-polariton coupling polaritons

$$H = \sum_{\vec{k},\sigma} \epsilon_{\vec{k}} c^{\dagger}_{\vec{k},\sigma} c_{\vec{k},\sigma} + \frac{1}{\sqrt{N}} \sum_{\vec{k},\vec{q},\sigma,\lambda=\pm} c^{\dagger}_{\vec{k}+\vec{q},\sigma} c_{\vec{k},\sigma} (g^{*}_{\lambda}(\vec{q}) \alpha^{\dagger}_{-\vec{q},\lambda} + g_{\lambda}(\vec{q}) \alpha_{\vec{q},\lambda}) + \sum_{\vec{q},\lambda=\pm} \omega_{\lambda}(\vec{q}) \alpha^{\dagger}_{\vec{q},\lambda} \alpha_{\vec{q},\lambda}$$

bare el-phonon vertex $g(\vec{q}) = g_0 \exp(-|\vec{q}|/q_0)$ $q_0^{-1} = h_0 \sqrt{\epsilon_{\parallel}/\epsilon_{\perp}}$

G-self-consistent Migdal-Eliashberg diagram

$$\hat{\Sigma}(\vec{k}, i\omega_n) = \frac{-1}{N\beta} \sum_{\vec{q},m,\lambda=\pm} |g_{\lambda}(\vec{q})|^2 D^{(0)}_{\lambda}(\vec{q}, i\omega_n - i\omega_m) \hat{\tau}_3 \hat{G}(\vec{k}+\vec{q}, i\omega_m) \hat{\tau}_3$$

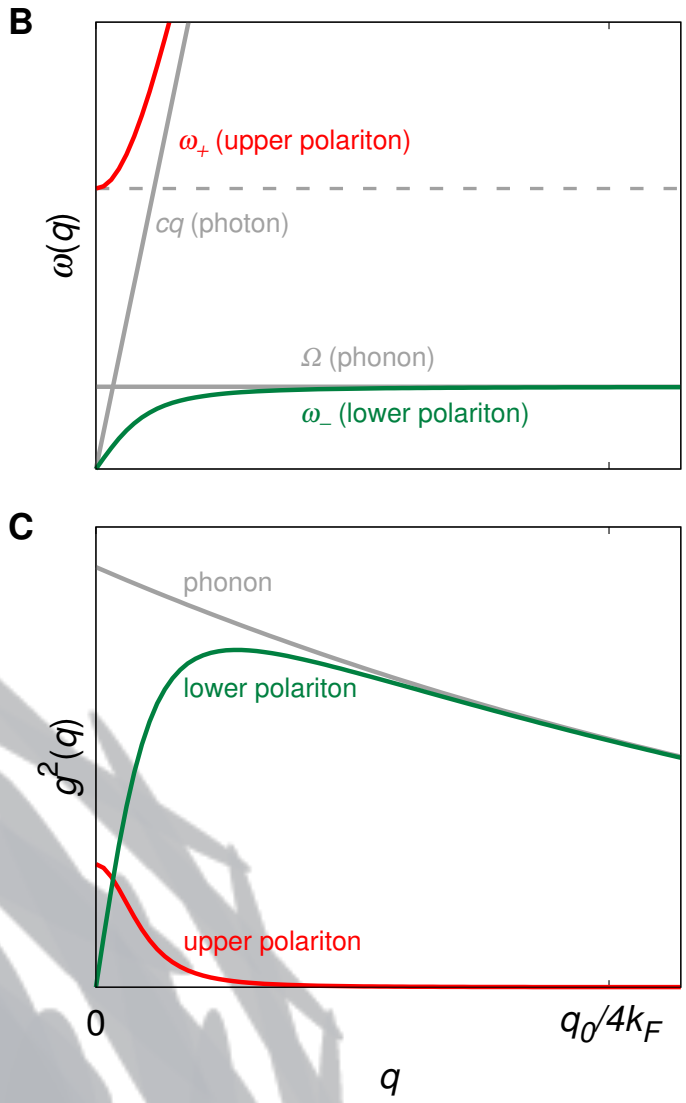


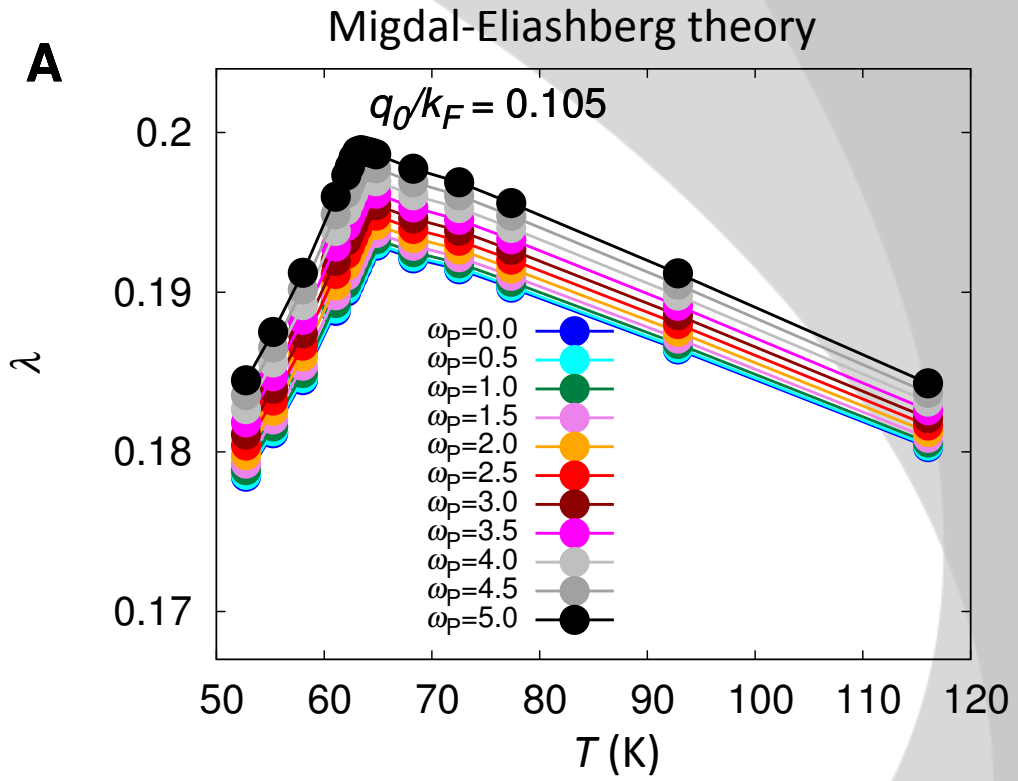
$$\hat{\Sigma}(\vec{k}, i\omega_n) = i\omega_n [1 - Z(\vec{k}, i\omega_n)] \hat{\tau}_0 + \chi(\vec{k}, i\omega_n) \hat{\tau}_3 + \phi(\vec{k}, i\omega_n) \hat{\tau}_1$$

$$\lambda \equiv Z(\vec{k}_F, i\pi/\beta) - 1$$

Mass enhancement: $m^*/m = 1 + \lambda$

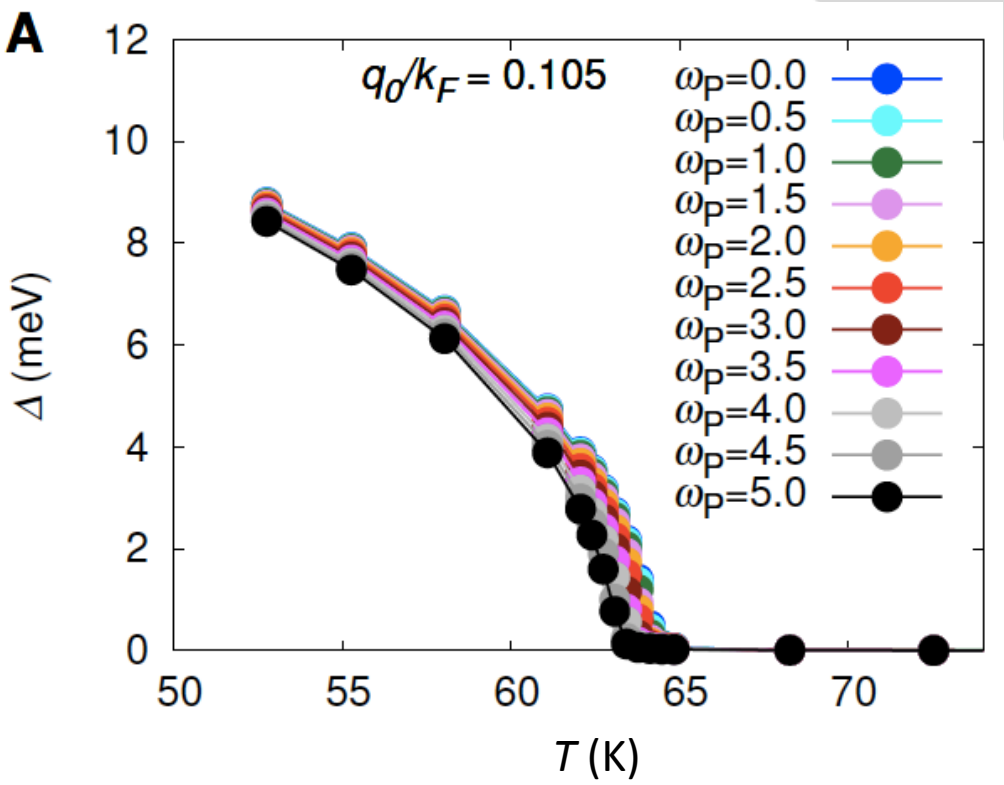
Cavity materials: Phonon polaritons





enhanced electron-phonon coupling, controlled by cavity volume

Cavity superconductivity?



suppressed superconductivity despite enhanced el-ph coupling

forward scattering

$$T_C \approx \frac{\lambda\Omega}{2+3\lambda}$$

vs. $T_{C,\mathrm{BCS}} \approx 1.13\Omega \exp(-\frac{1}{\lambda})$

q-independent scattering

Summary

- cavity leads to enhanced electron-phonon coupling
- FeSe/STO: works in conjunction with other pairing mechanisms
- can one also enhance superconductivity?

M. A. Sentef, M. Ruggenthaler, A. Rubio, arXiv:1802.09437
Science Advances 4, eaau6969 (2018)