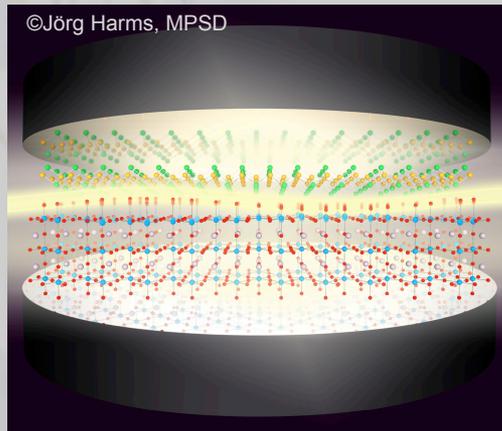


Cavity-enhanced electron-phonon coupling in monolayer FeSe/STO



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

DPG Frühjahrstagung, Regensburg, April 1, 2019

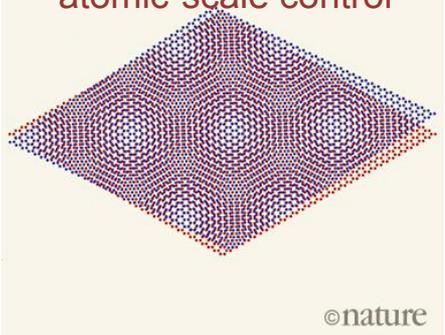


Funded through Deutsche Forschungsgemeinschaft
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Max Planck Institute for the Structure and Dynamics of Matter



Engineering materials with light

condensed matter
quantum materials
atomic-scale control



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

ultrafast spectroscopy
revealing elementary couplings
light-induced new states of matter

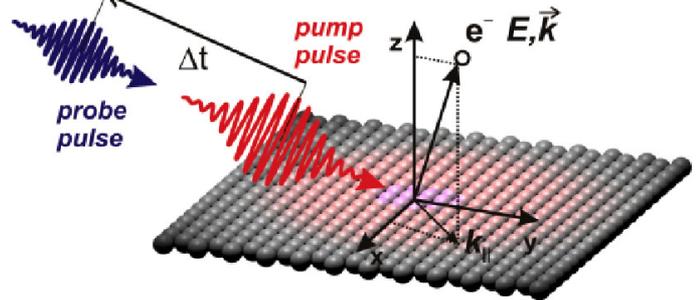
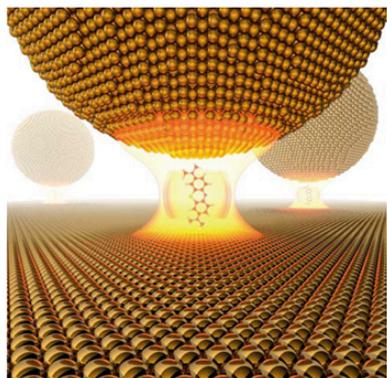


Image courtesy: J. Sobota

pump-probe: strong classical fields



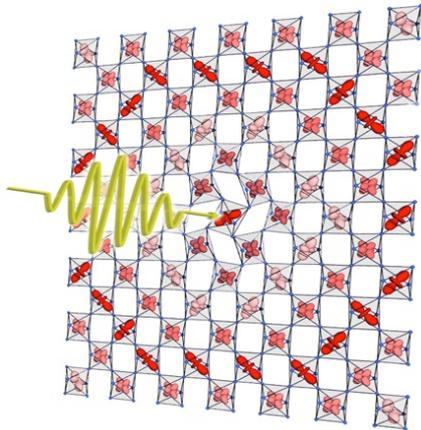
R. Chikkaraddy et al., Nature 535, 127 (2016)

quantum optics
nanoplasmonics
polaritonic chemistry

QED: vacuum fluctuations

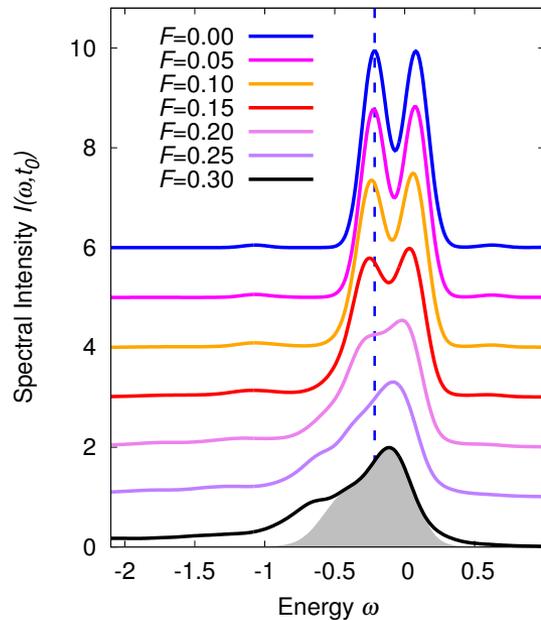
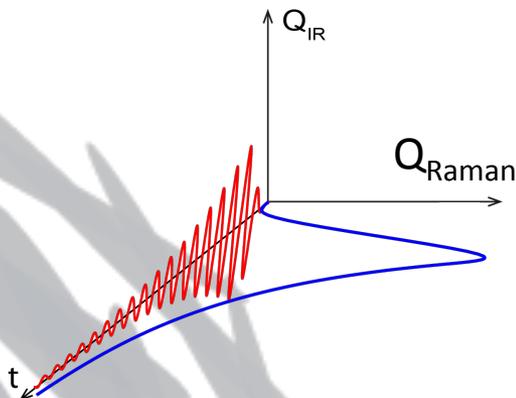
Light-enhanced electron-phonon coupling

Classical light: **nonlinear phononics**



Enhanced electron-phonon coupling in graphene with periodically distorted lattice

E. Pomarico, M. Mitrano, H. Bromberger, M. A. Sentef, A. Al-Temimy, C. Coletti, A. Stöhr, S. Link, U. Starke, C. Cacho, R. Chapman, E. Springate, A. Cavalleri, and I. Gierz
Phys. Rev. B **95**, 024304 – Published 13 January 2017

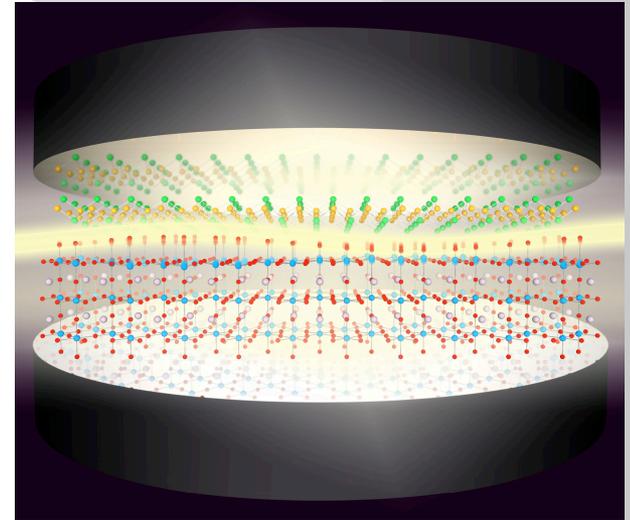


nonlinear
electron-phonon
coupling
 $n \cdot Q^2$:
enhanced coupling
for **classically** driven
phonon

M. Först et al., Nature Physics 7, 854 (2011)

D. M. Kennes et al., Nature Physics 13, 479 (2017)
M. A. Sentef, PRB 95, 205111 (2017)

quantum electrodynamics:
enhancement effects already in vacuum
and for bi-linear couplings?



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

$$H = H_{\text{el}} + H_{\text{el-phon}} + H_{\text{el-phot}} + H_{\text{phon-phot}}$$

$$\sim n_{\text{el}} * Q_{\text{phon}}$$

$$\sim A_{\text{phot}} * Q_{\text{phon}}$$

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 Schlawin¹, Andrea Cavalleri^{1,2} and Dieter Jaksch¹

1804.07142

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 Coulthard², Frank Schlawin², Arzhang Ardavan², and Dieter Jaksch^{2,1}

1806.06752

Cavity superconductor-polaritons *1807.06601*

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

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 Cotelet,^{1,*} Sina Zeytinoglu,^{1,2} Manfred Sigrist,² Eugene Demler,³ and Ataç Imamoglu¹

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

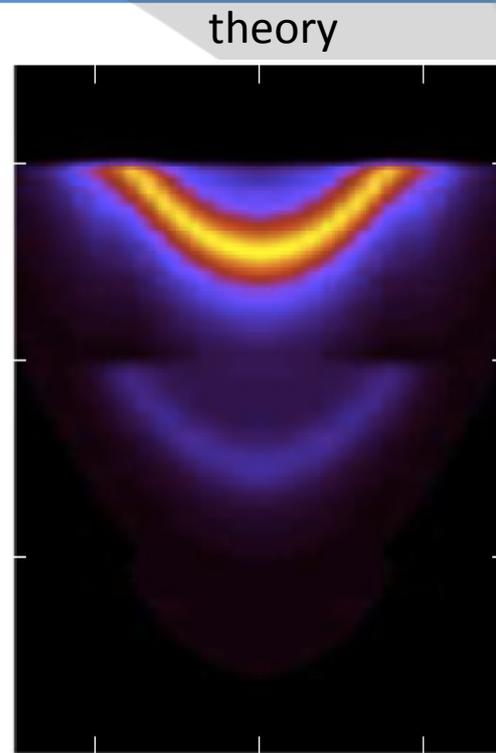
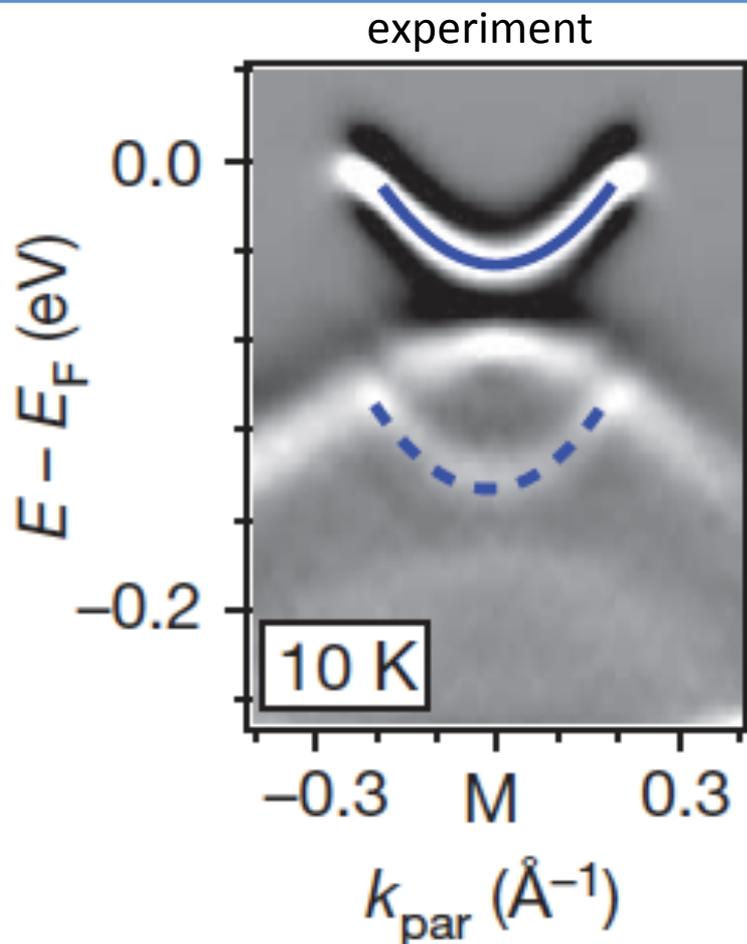
Ab-initio Exciton-polaritons:

Cavity control of Dark Excitons in two dimensional Materials

Simone Latini,^{1,*} Enrico Ronca,^{1,†} Umberto De Giovannini,^{1,2,‡} Hannes Hübenner,^{1,§} and Angel Rubio^{1,3,¶}

1810.02672

monolayer FeSe/STO: ARPES



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

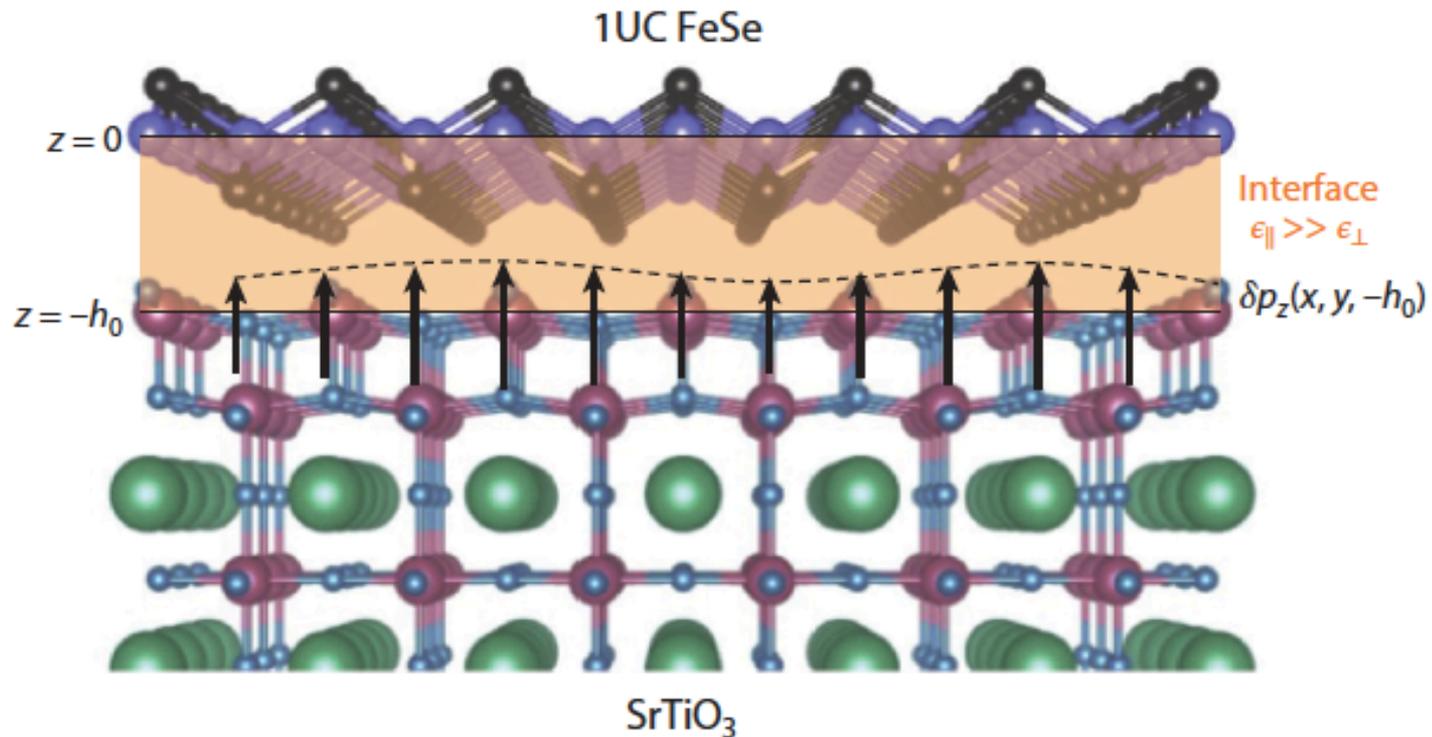
Lee et al., Nature 515, 245 (2014)

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)*

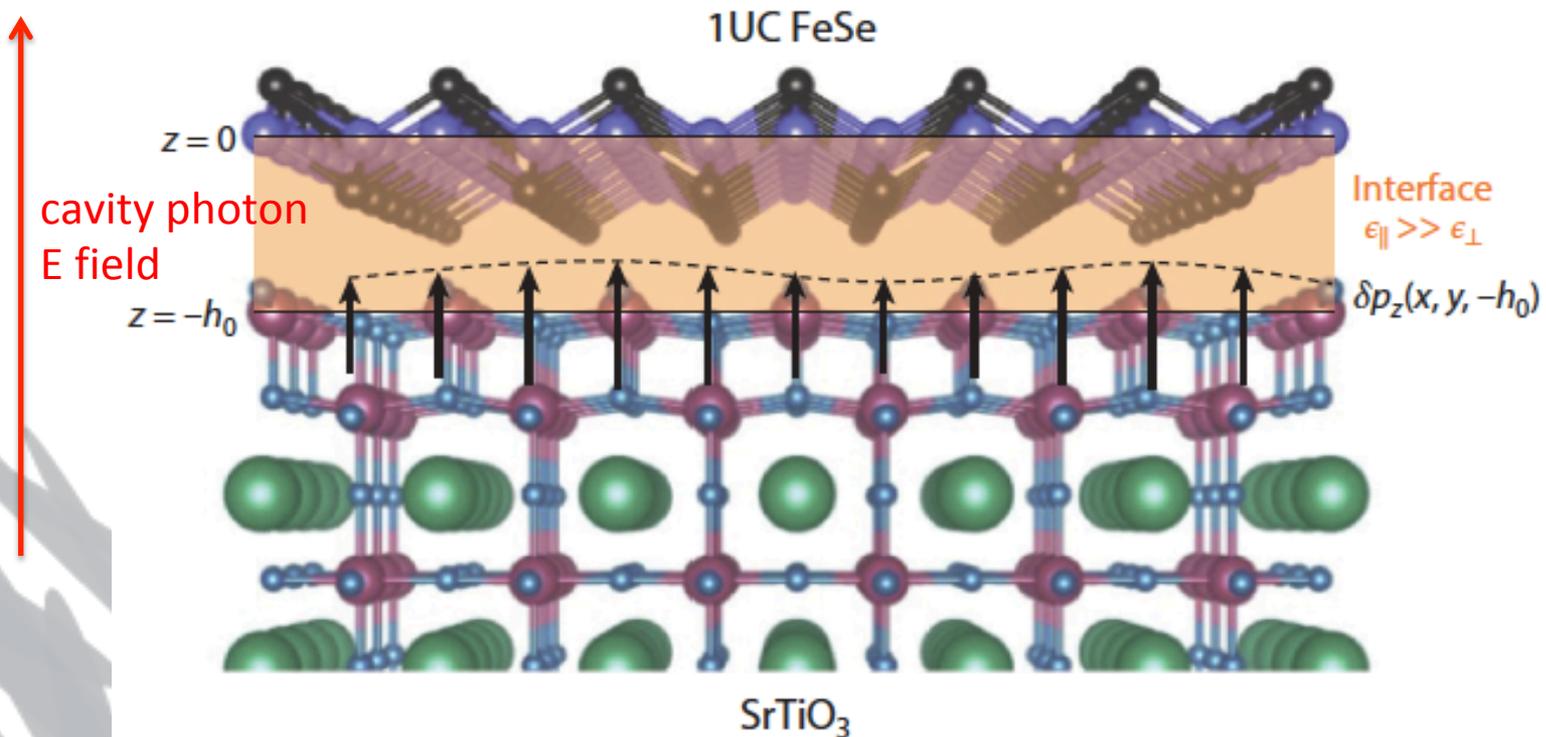
$$q_0^{-1} = h_0 \sqrt{\epsilon_{\parallel}/\epsilon_{\perp}} \quad \epsilon_{\parallel}/\epsilon_{\perp} \approx 100$$



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

Cavity engineering

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



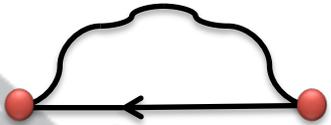
Huang and Hoffman, Annu. Rev. CMP 8, 311 (2017)

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

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

G-self-consistent Migdal-Eliashberg diagram

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

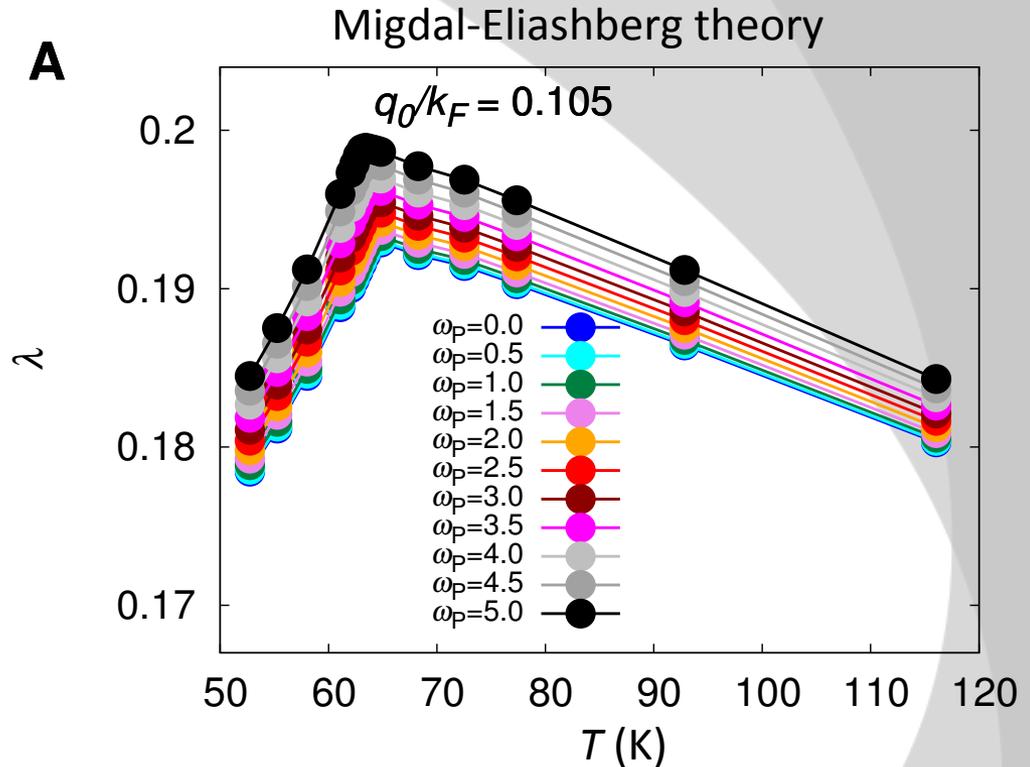
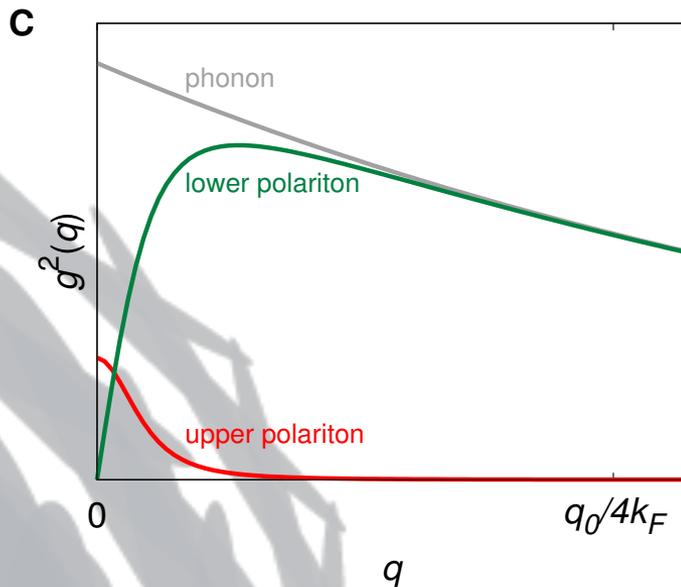
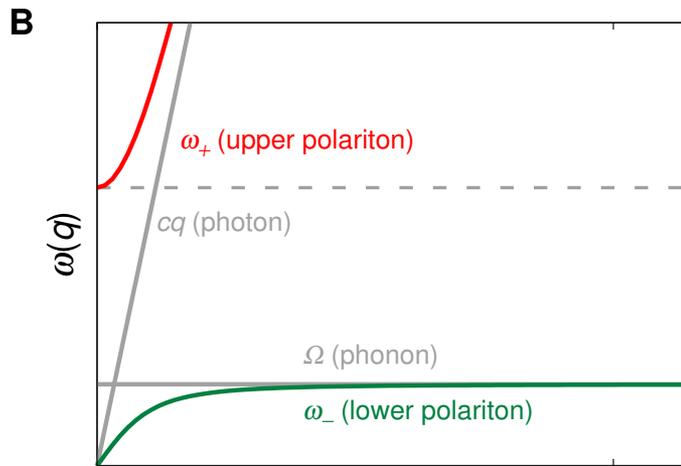


$$\hat{\Sigma}(\vec{k}, i\omega_n) = i\omega_n [1 - Z(\vec{k}, i\omega_n)] \hat{\tau}_0 + \chi(\vec{k}, i\omega_n) \hat{\tau}_3 + \phi(\vec{k}, i\omega_n) \hat{\tau}_1$$

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

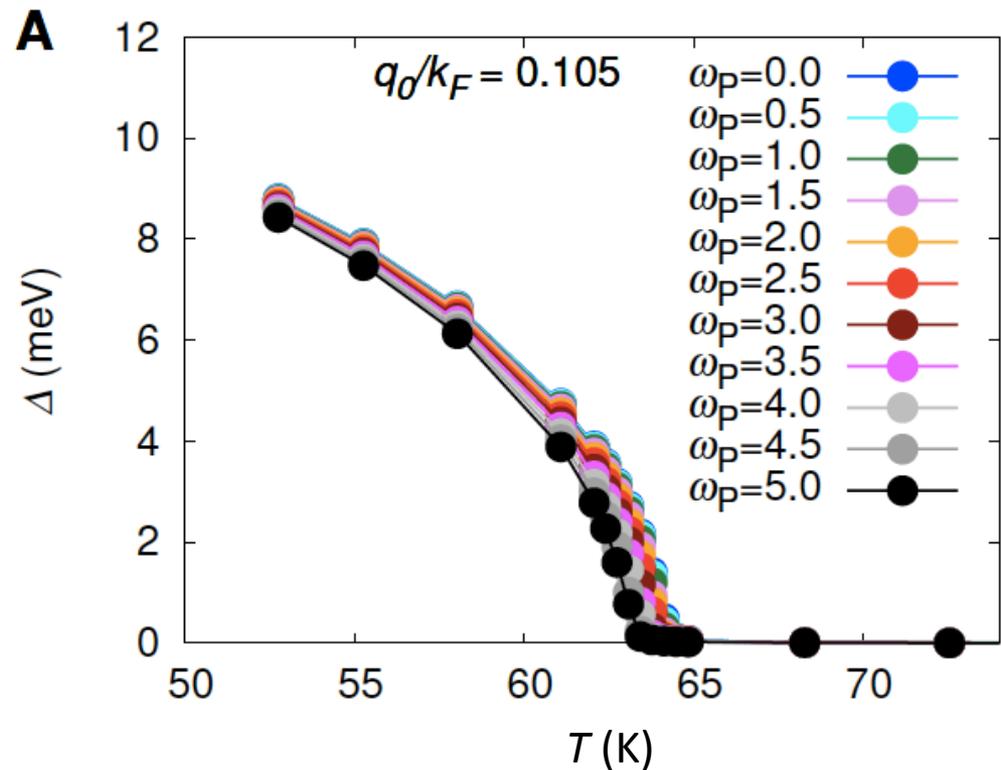
Mass enhancement: $m^*/m = 1 + \lambda$

Cavity materials: Phonon polaritons



enhanced electron-phonon coupling,
controlled by cavity volume

Cavity superconductivity?



suppressed superconductivity despite enhanced el-ph coupling

forward scattering

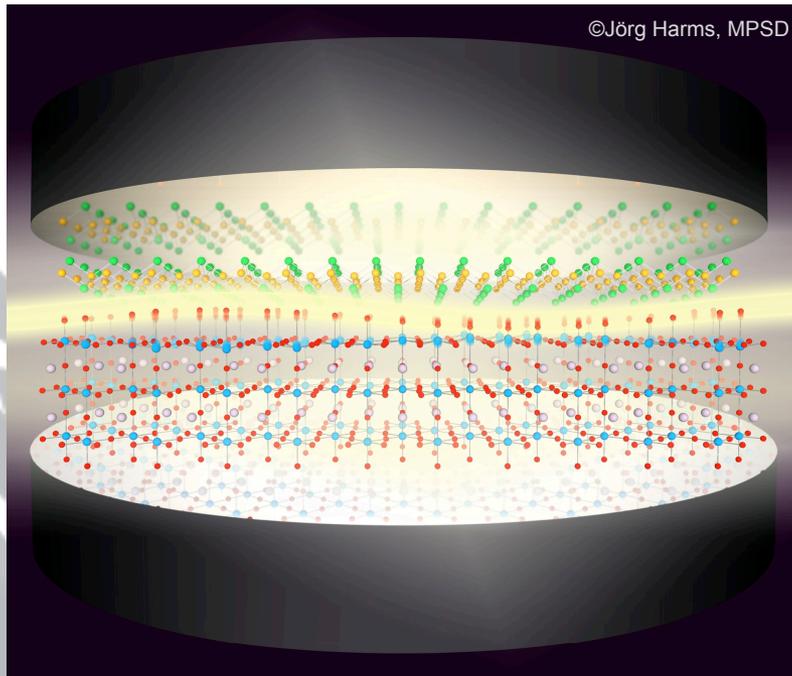
$$T_C \approx \frac{\lambda\Omega}{2 + 3\lambda}$$

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



Cavity-induced quantum-anomalous
Hall effect in graphene:

*Xiao Wang, E. Ronca, M. A. Sentef
arXiv:1903.00339*

