Quantum to classical crossover

of Floquet engineering in correlated quantum systems

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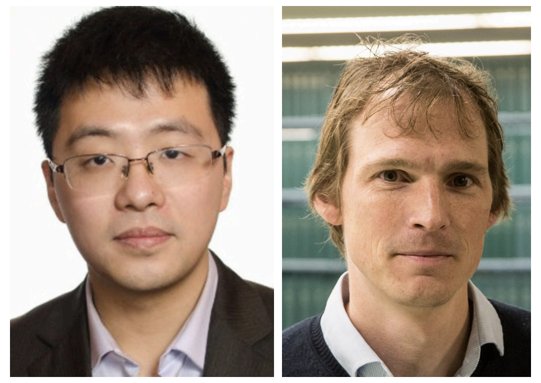
APS March meeting 2021
March 17, 2021

Cavity control of Hubbard model
M. A. Sentef, J. Li, F. Künzel, M. Eckstein,
PRResearch 2, 033033 (2020)



Light-matter coupling and quantum geometry in moiré materials
G. E. Topp, C. Eckhardt, D. M. Kennes, M. A. Sentef, P. Törmä,
arXiv:2103.04967

Gabriel Topp, X46.00002, Friday 8:12

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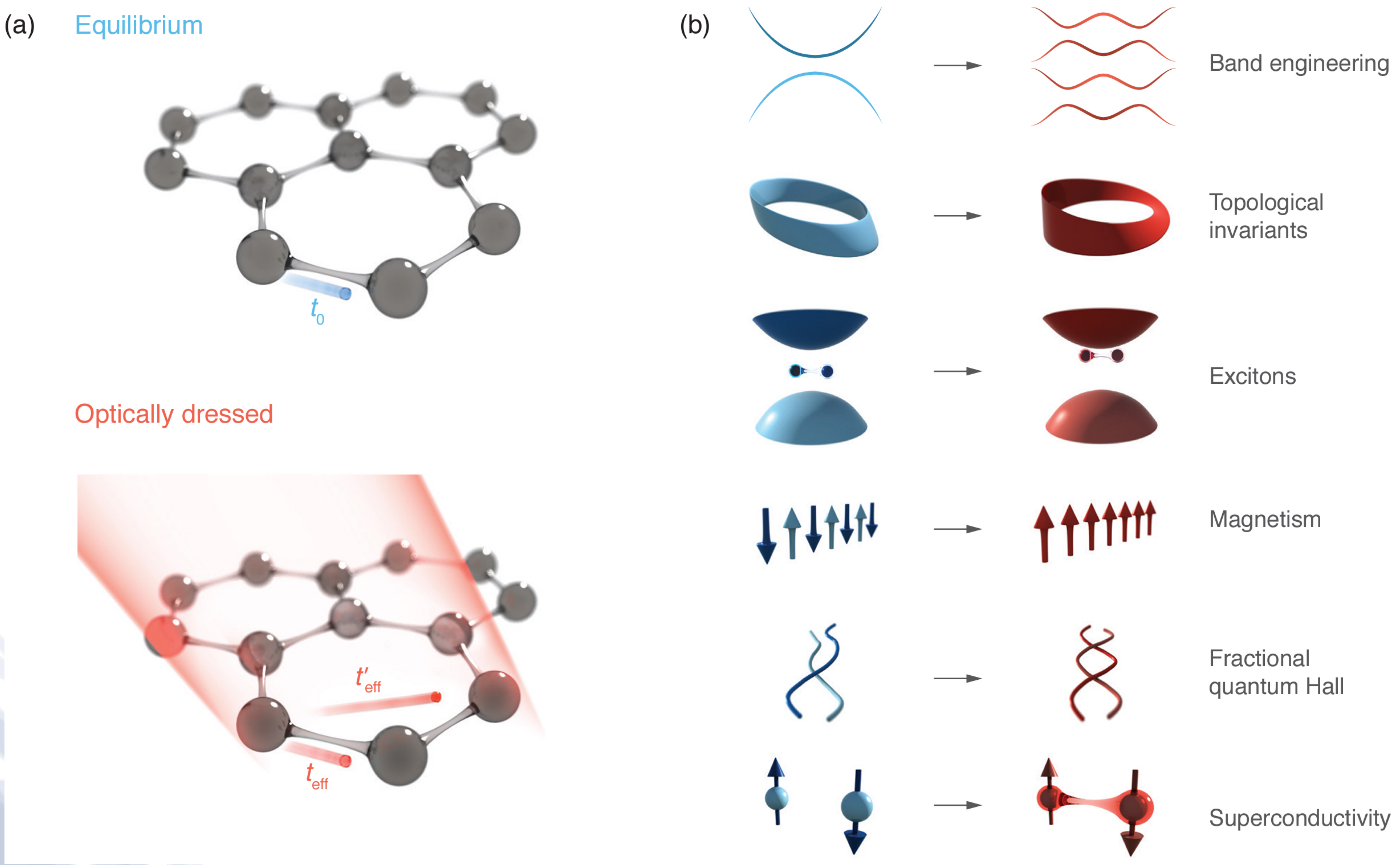
Floquet engineering of quantum materials

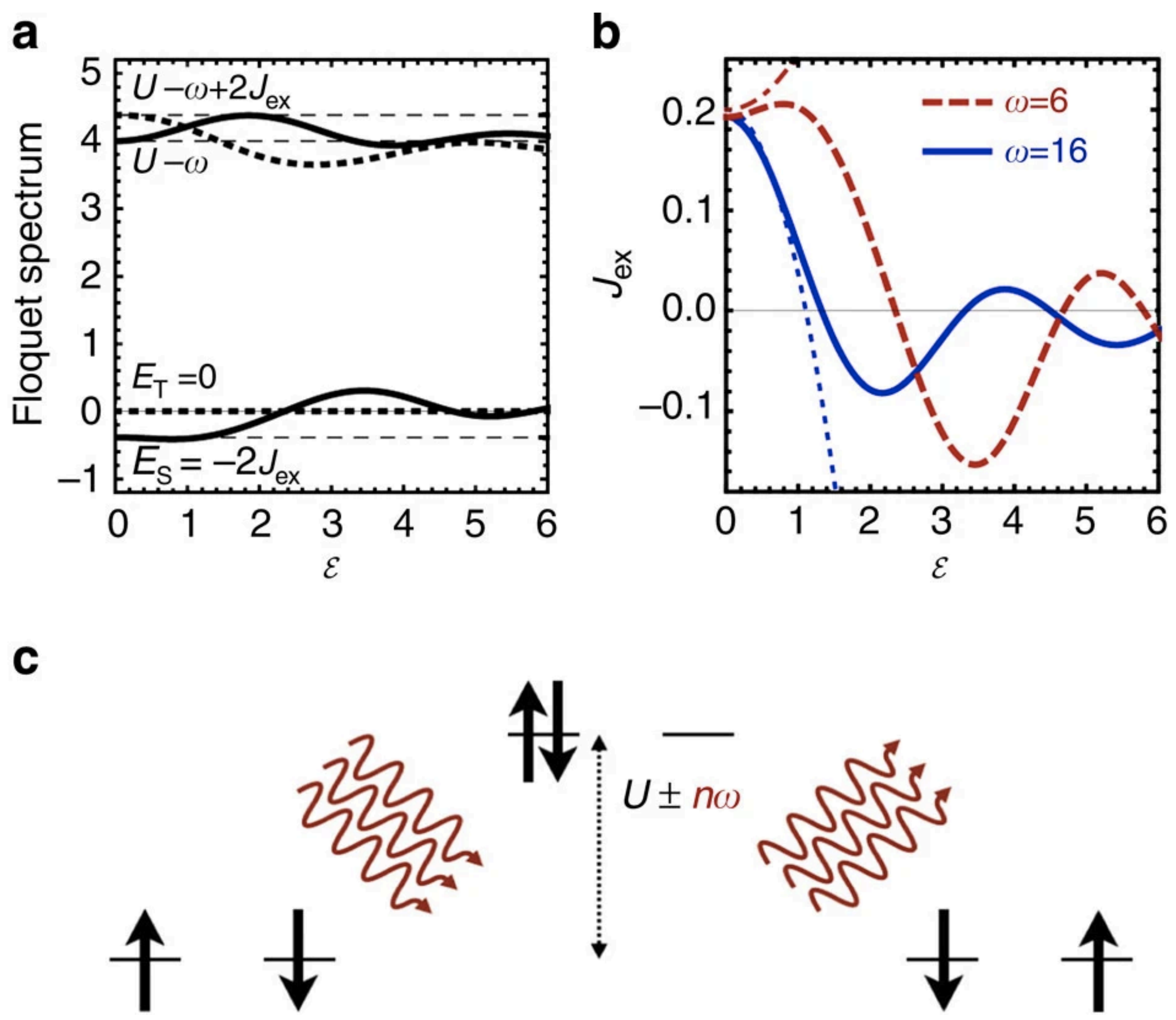
Oka & Kitamura, Ann. Rev. Condens. Matter Phys. 2019
Rudner & Lindner, Nat. Rev. Phys. 2020



A. de la Torre, D. Kennes, M. Claassen, S. Gerber, J. McIver, MAS, review in prep.

Floquet engineering of spin exchange

Mentink, Balzer, and Eckstein, Nat. Commun. 6, 6708 (2015)



Photon dressing of intermediate states modifies kinetic exchange

But: need for strong lasers, problems with heating, short-lived effect

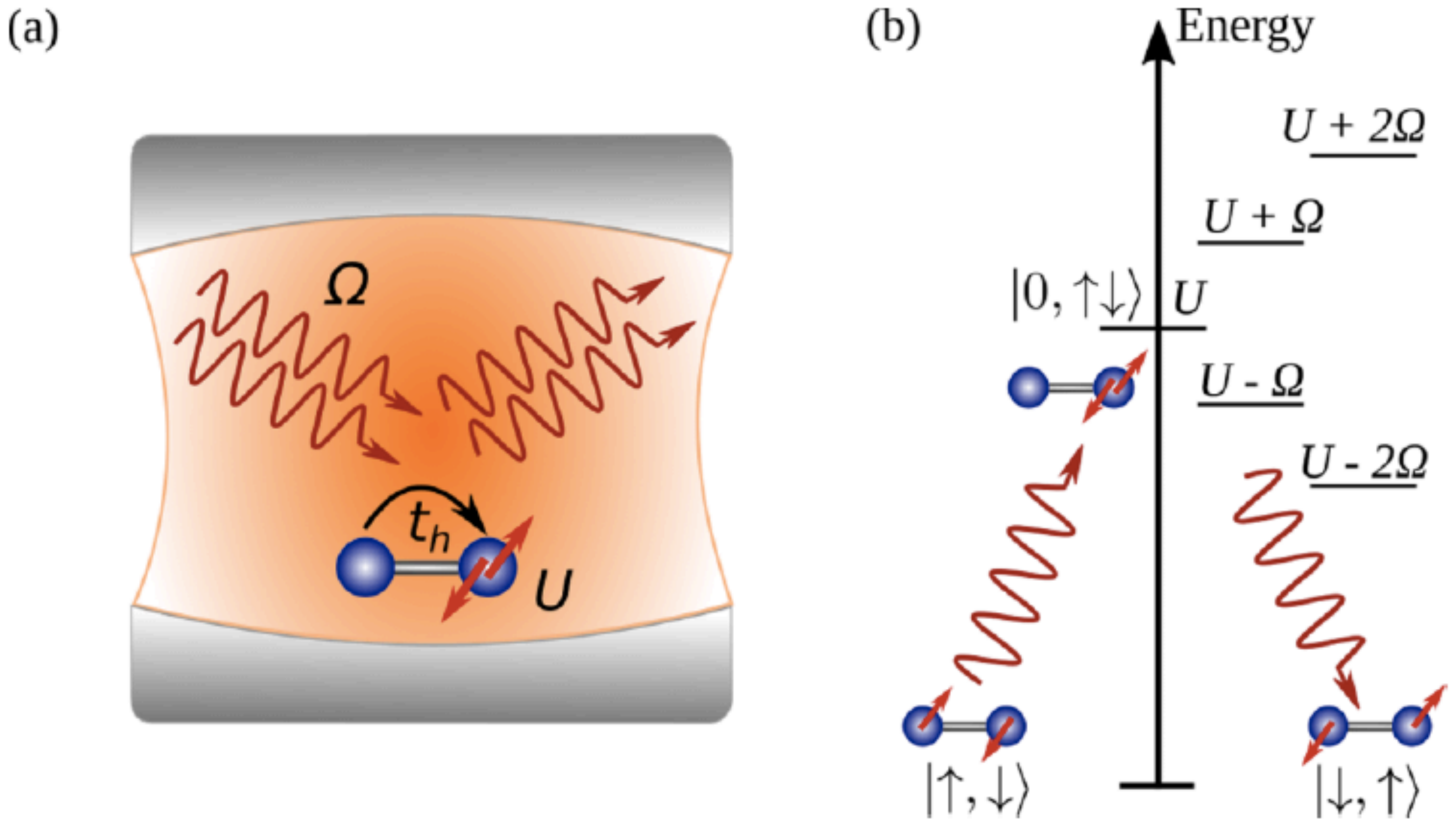
Question: can we control spin exchange with cavities?
Answer: yes, if we replace strong fields by strong light-matter coupling

QED quantum materials: strong light-matter coupling

Polaritonic chemistry

T. Ebbesen, Acc. Chem. Res. 49, 2403 (2016)
J. Feist et al., ACS Photonics 5, 205 (2017)
M. Ruggenthaler et al., Nat. Rev. Chem. 2, 0118 (2018)
R. F. Ribeiro et al., Chem. Sci. 9, 6325 (2018)
J. Flick et al., Nanophotonics 7, 1479 (2018)
A. F. Kockum et al., Nat. Rev. Phys. 1, 19 (2019)

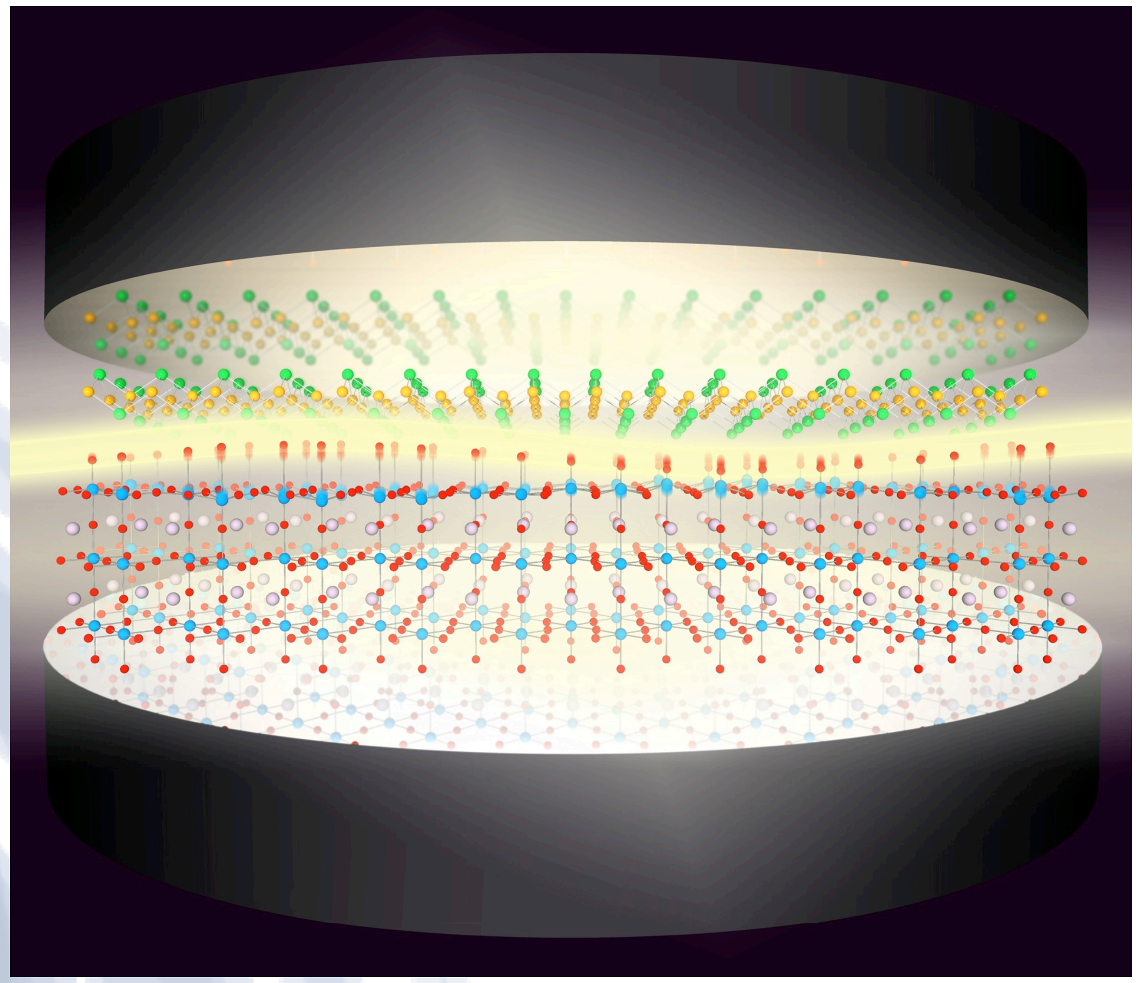
Our work: cavity control of spin exchange
Crossover from quantum to classical Floquet engineering



Quantum materials: towards cavity-controlled electron-boson coupling, superconductivity

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

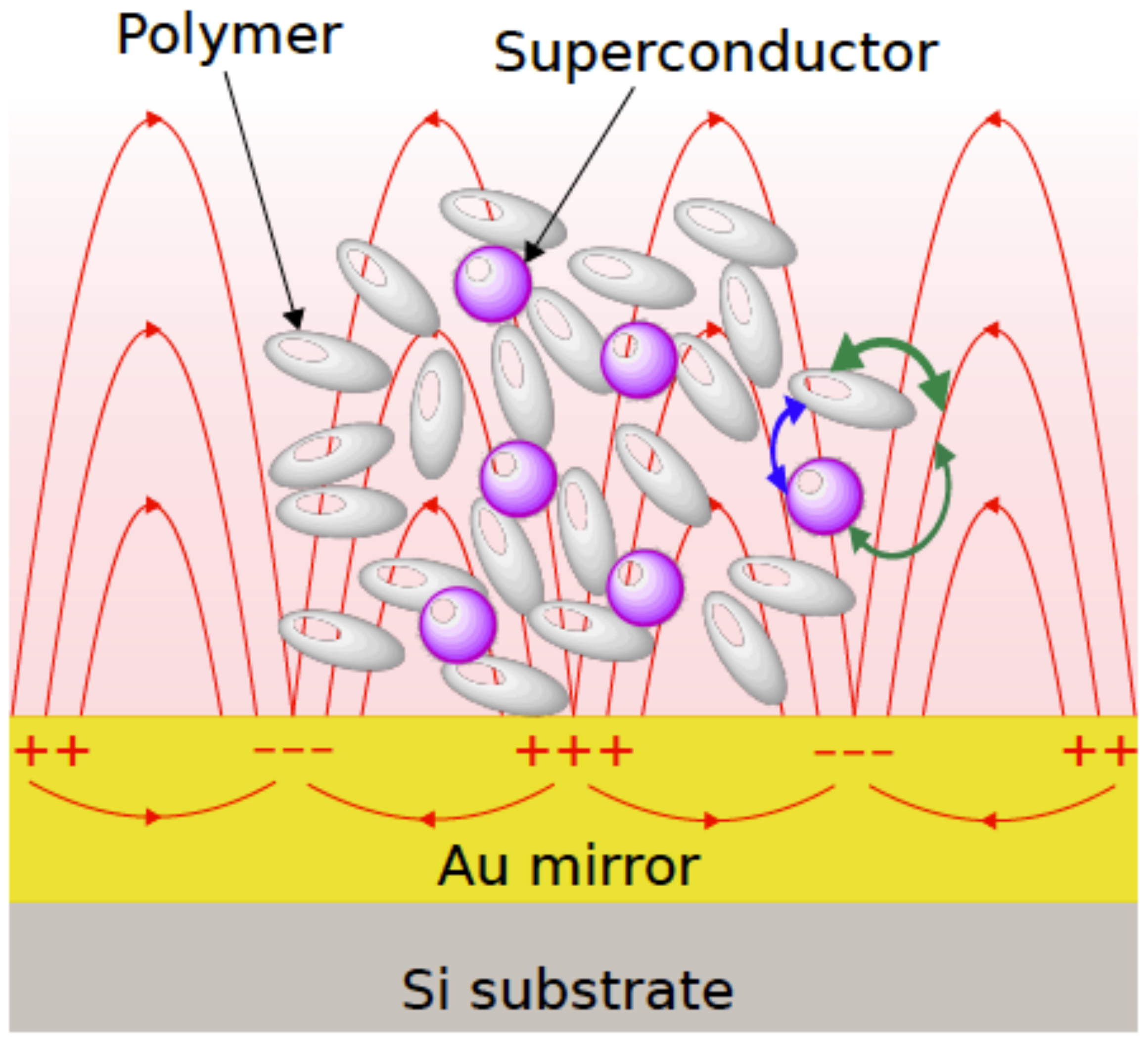
M. A. Sentef, M. Ruggenthaler, A. Rubio, Science Advances 4, eaau6969 (2018)



Exploring Superconductivity under Strong Coupling with the Vacuum Electromagnetic Field

A. Thomas[1], E. Devaux[1], K. Nagarajan[1], T. Chervy[1], M. Seidel[1], D. Hagenmüller[1], S. Schütz[1], J. Schachenmayer[1], C. Genet[1], G. Pupillo[1*] & T. W. Ebbesen[1*]

arXiv:1911.01459



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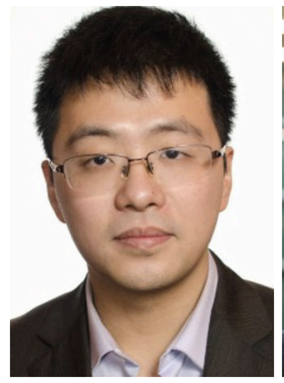
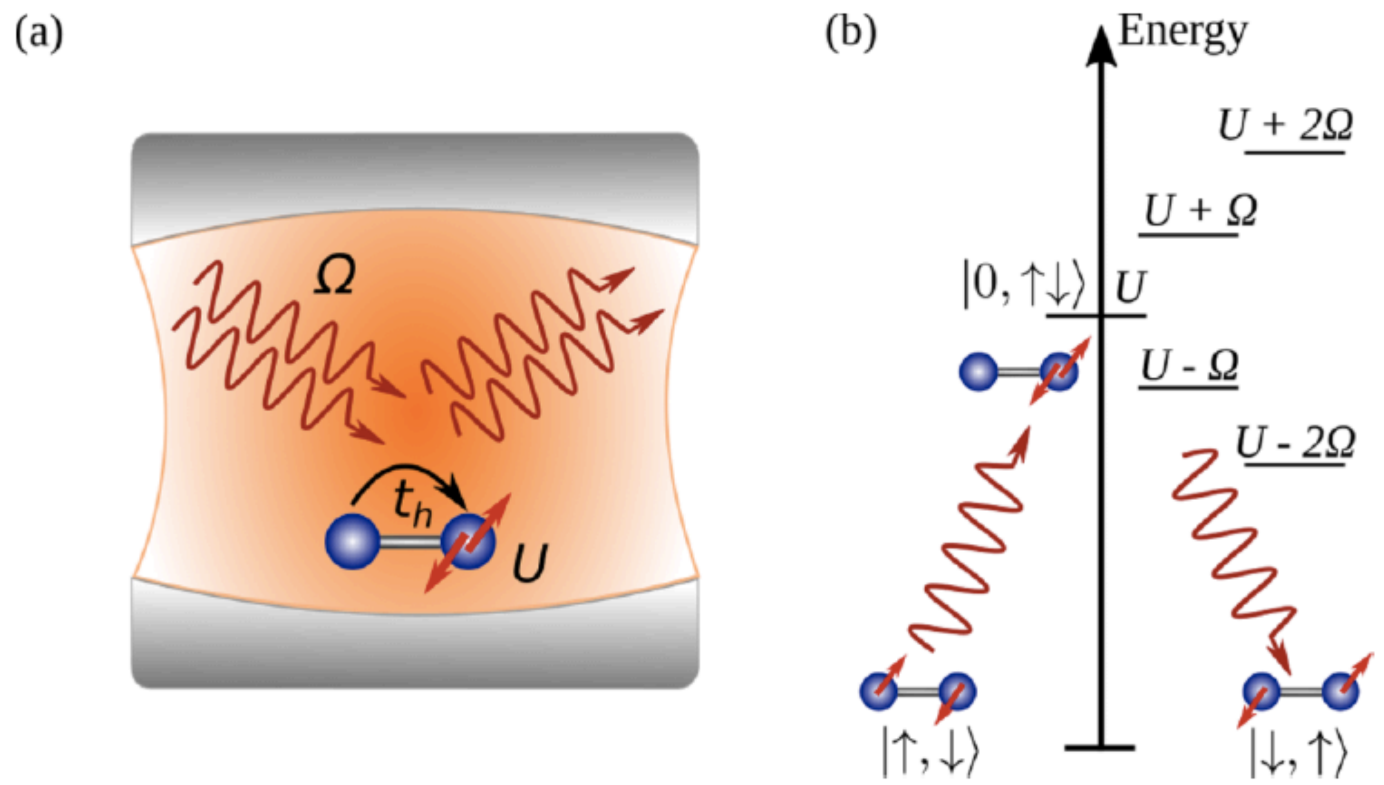



Cavity materials: Laussy, Kavokin, Shelykh 2010, Cotlet et al 2016, Kavokin & Lagoudakis 2016, Schlawin, Cavalleri, Jaksch 2019, Hagenmüller et al 2019, Curtis et al 2019, Wang, Ronca, MAS 2019, Kiffner et al 2019, Mazza & Georges 2019, Andolina et al 2019, Gao et al 2020, Chakraborty & Piazza arXiv 2020, Li & Eckstein 2020, Hübener et al 2020, Ashida et al 2020, Latini et al arXiv 2021, …

QED quantum materials: quantum to classical crossover

Hubbard model in cavity



$$\hat{H} = t_h \sum_{j\sigma} (\hat{c}^\dagger_{j,\sigma} \hat{c}_{j+1,\sigma}\, e^{i\hat{A}} + \text{H.c.}) + U \sum_j \hat{n}_{j,\uparrow}\hat{n}_{j,\downarrow} + \Omega \hat{a}^\dagger \hat{a}.$$

$$\hat{A} = g(\hat{a} + \hat{a}^\dagger)$$

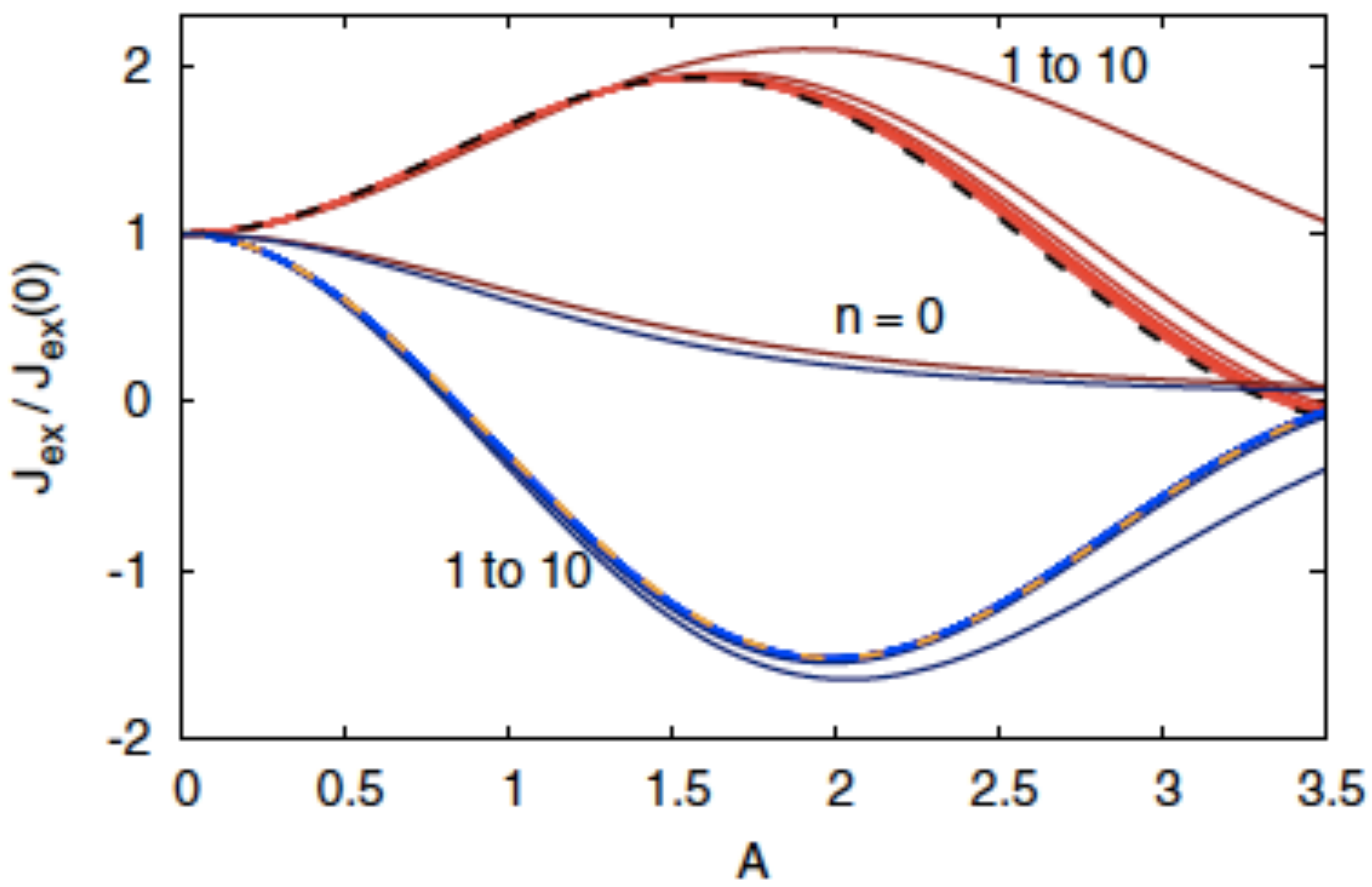
A: effective vector potential
g: light-matter coupling strength

Quantum system -> Floquet system for $n \to \infty, \quad g\sqrt{n}$ fixed.
(large photon number, weak light-matter coupling strength g)

Photon number states are good enough to see Floquet-engineering effects at sufficiently large coupling strength g – coherent states not required!

Question: can we control spin exchange with cavities?
Answer: yes, if we replace strong fields by strong light-matter coupling

Cavity Schrieffer-Wolff transformation
(confirmed by numerics)



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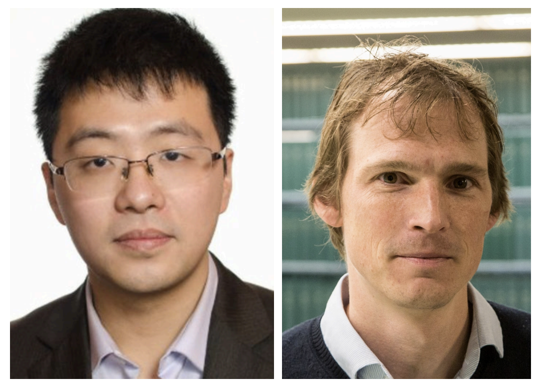
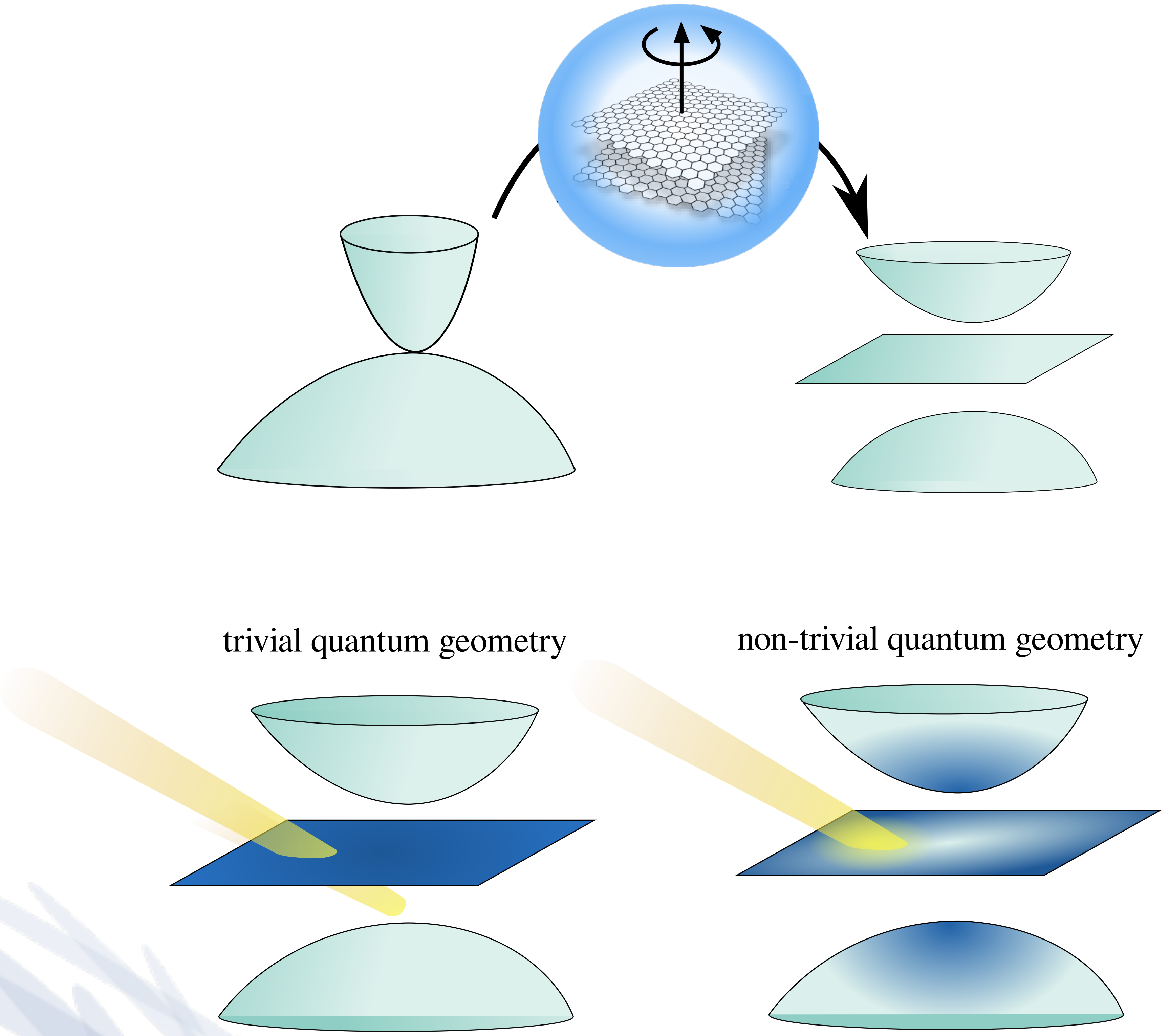


QED quantum materials: how to reach strong coupling?



	Linear (A_μ)	Quadratic $(A_\mu A_\nu)$
Intra-band (n)	$\partial_\mu \varepsilon_n$	$\partial_\mu \partial_\nu \varepsilon_n - \sum_{n \neq n'} (\varepsilon_n - \varepsilon_{n'}) \left(\langle \partial_\mu n \vert n' \rangle \langle n' \vert \partial_\nu n \rangle + \text{h.c.} \right)$ curvature without band curvature
Inter-band $(n,\, m)$	$(\varepsilon_n - \varepsilon_m) \langle m \vert \partial_\mu n \rangle$	$\left[\frac{1}{2} (\partial_\mu \varepsilon_n - \partial_\mu \varepsilon_m) \langle m \vert \partial_\nu n \rangle + \frac{1}{2} \varepsilon_m \langle \partial_\mu \partial_\nu m \vert n \rangle + \frac{1}{2} \varepsilon_n \langle m \vert \partial_\mu \partial_\nu n \rangle + \sum_{n'} \varepsilon_{n'} \left(\langle \partial_\mu m \vert n' \rangle \langle n' \vert \partial_\nu n \rangle \right) \right] + (\mu \leftrightarrow \nu)$

Non-trivial quantum geometry enables light-matter coupling in flat bands

Can we reach strong light-matter coupling by quenching electronic kinetic energy?

Also cf. Iskin PRA 2019;
Ahn, Guo, Nagaosa, Viswanath arXiv 2021

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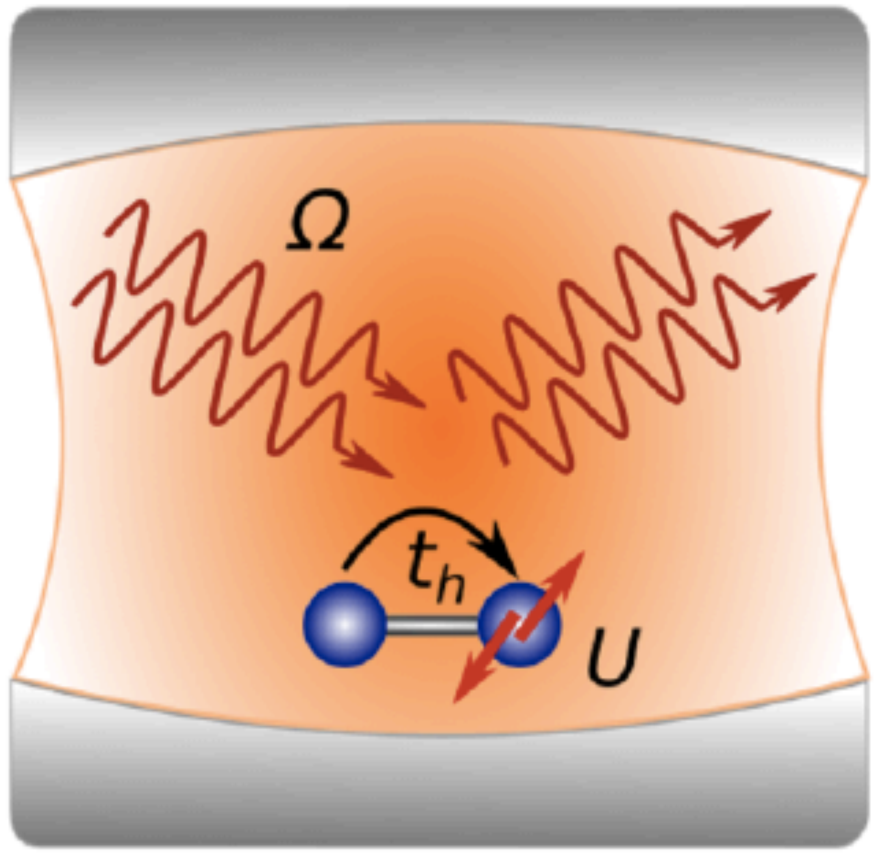
Summary



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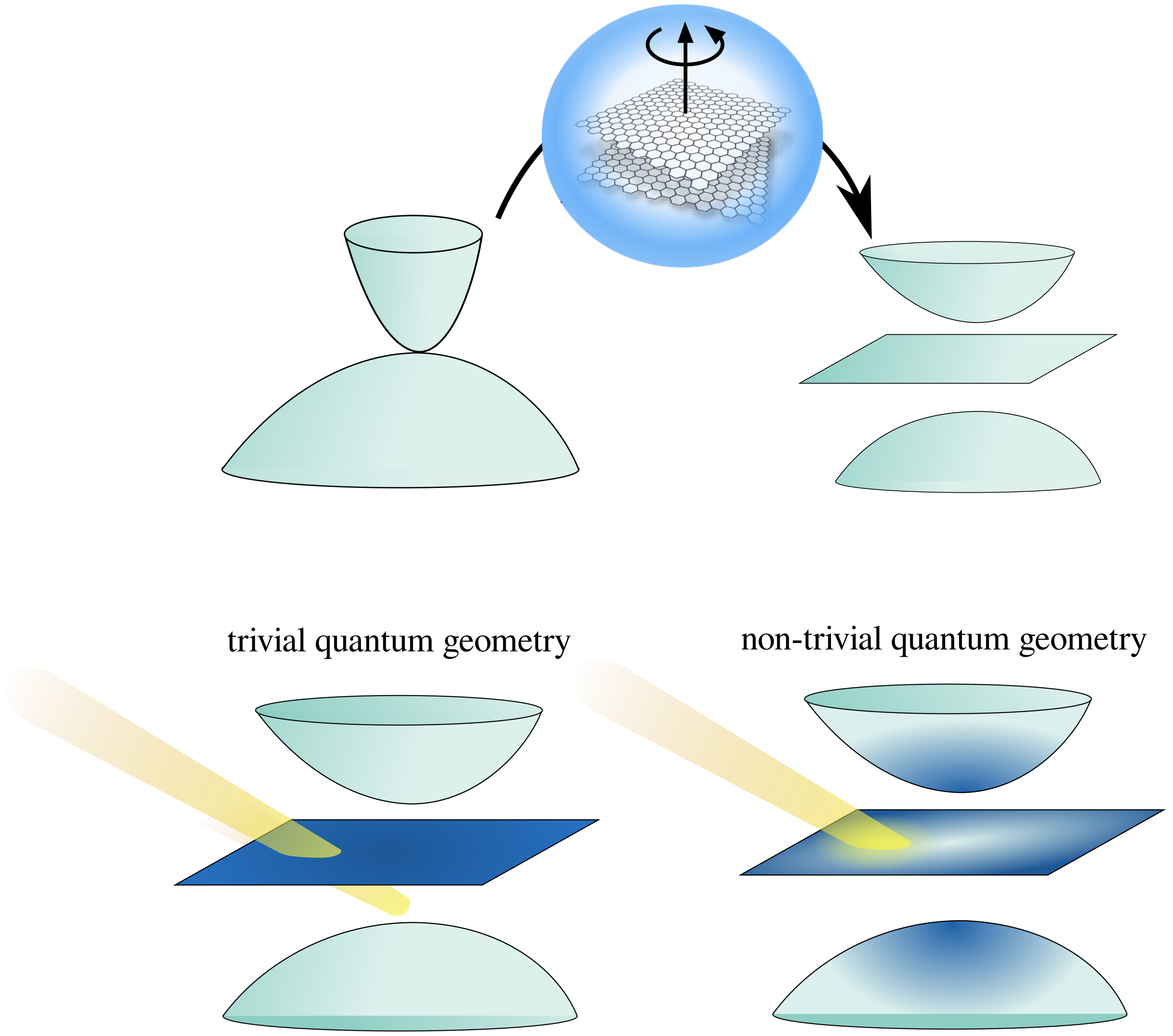

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