Quantum to classical crossover of Floquet engineering in correlated quantum systems

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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
Floquet engineering of quantum materials

Rudner & Lindner, Nat. Rev. Phys. 2020

Floquet engineering of spin exchange
Mentink, Balzer, and Eckstein, Nat. Commun. 6, 6708 (2015)

(a) Equilibrium
(b) Band engineering
   Topological invariants
   Excitons
   Magnetism
   Fractional quantum Hall
   Superconductivity

Optically dressed


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

But: need for strong lasers, problems with heating, short-lived effect
QED quantum materials: strong light-matter coupling

Polaritonic chemistry
J. Feist et al., ACS Photonics 5, 205 (2017)
R. F. Ribeiro et al., Chem. Sci. 9, 6325 (2018)
J. Flick et al., Nanophotonics 7, 1479 (2018)

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

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

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

Energy
U
U - Ω
U + Ω
U + 2Ω

Cavity control of Hubbard model
M. A. Sentef, J. Li, F. Künzel, M. Eckstein, PRResearch 2, 033033 (2020)
**QED quantum materials: quantum to classical crossover**

**Hubbard model in cavity**

(a) Quantum system -> Floquet system for large photon number, weak light-matter coupling strength $g$

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

**Cavity Schrieffer-Wolff transformation** (confirmed by numerics)

- $\hat{A} = g(\hat{a} + \hat{a}^\dagger)$
- $A$: effective vector potential
- $g$: light-matter coupling strength

**Question:** can we control spin exchange with cavities?

**Answer:** yes, if we replace strong fields by strong light-matter coupling

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M. A. Sentef, J. Li, F. Künzel, M. Eckstein, PRResearch 2, 033033 (2020)
QED quantum materials: how to reach strong coupling?

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

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

Light-matter coupling and quantum geometry in moiré materials

TABLE I. Linear and quadratic intra- and inter-band light-matter couplings. The dependence on the quasi-momentum is not marked explicitly, it should be kept in mind that all the couplings are wavevector dependent.

<table>
<thead>
<tr>
<th>Linear ( (A_\mu) )</th>
<th>Quadratic ( (A_\mu A_\nu) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intra-band ( (n) )</td>
<td>( \partial_\mu \epsilon_n )</td>
</tr>
<tr>
<td>Inter-band ( (n, m) )</td>
<td>( (\epsilon_n - \epsilon_m) \langle m</td>
</tr>
<tr>
<td>&amp;</td>
<td>+ \frac{1}{2} \epsilon_n \langle m</td>
</tr>
</tbody>
</table>

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

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