Title: Nonadiabatically Boosting the Quantum State of a Cavity

Speakers: David Long

Series: Quantum Matter

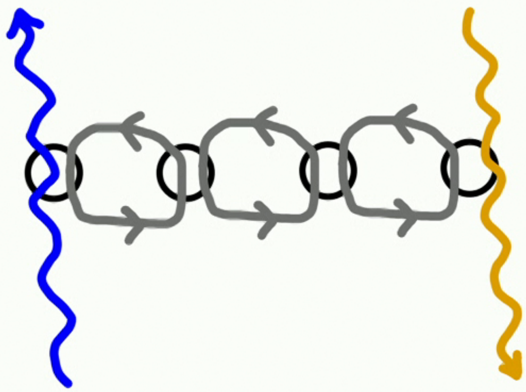
Date: December 12, 2022 - 2:00 PM

URL: https://pirsa.org/22120049

Abstract: Periodic driving is a ubiquitous tool for controlling experimental quantum systems. When the drive fields are of comparable, incommensurate frequencies, new theoretical tools are required to treat the resulting quasiperiodic time dependence. Similarly, new and surprising phenomena of topological origin may emerge in this regime, including the quantized pumping of energy from one drive field to another. I will describe how to exploit this energy pumping to coherently translate--or boost--quantum states of a cavity in the Fock basis. This protocol enables the preparation of highly excited Fock states for use in quantum metrology--one need only boost low occupation Fock states. Energy pumping, and hence boosting, may be achieved nonadiabatically as a robust edge effect associated to a topological phase. I will present a simple coupled-layer model for the phase, and briefly describe the topological classification which characterizes its robust properties.

Zoom link: https://pitp.zoom.us/j/94040881668?pwd=THh1WlIxZmZnYlp6QVRKRDhMWnk1UT09

Nonadiabatically Boosting the Quantum State of a Cavity



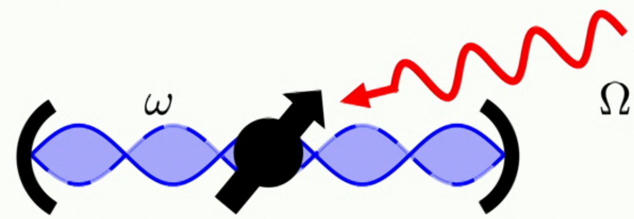
David M. Long

dmlong@bu.edu

PRL **126**, 106805 (2021)

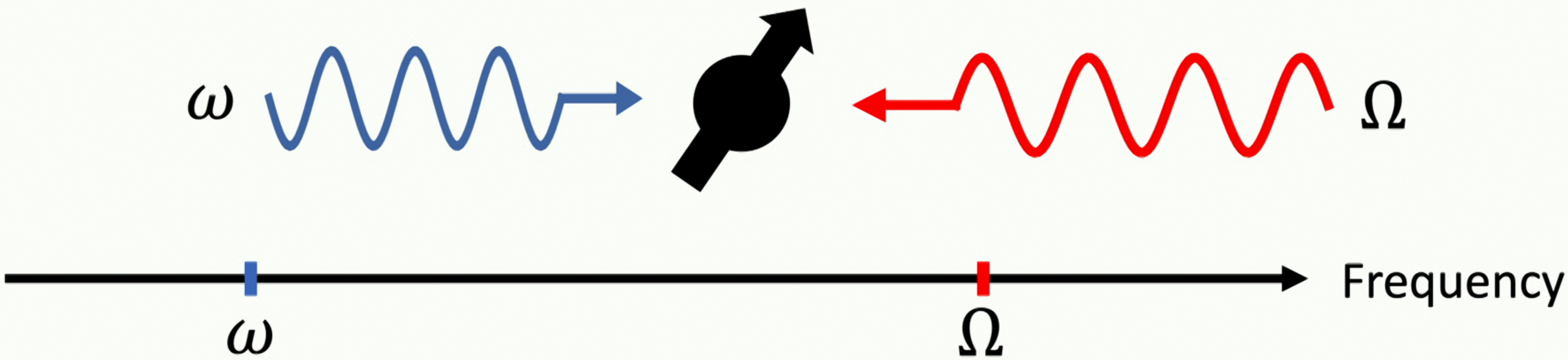
PRL **128**, 183602 (2022)

PRB **106**, 144203 (2022)

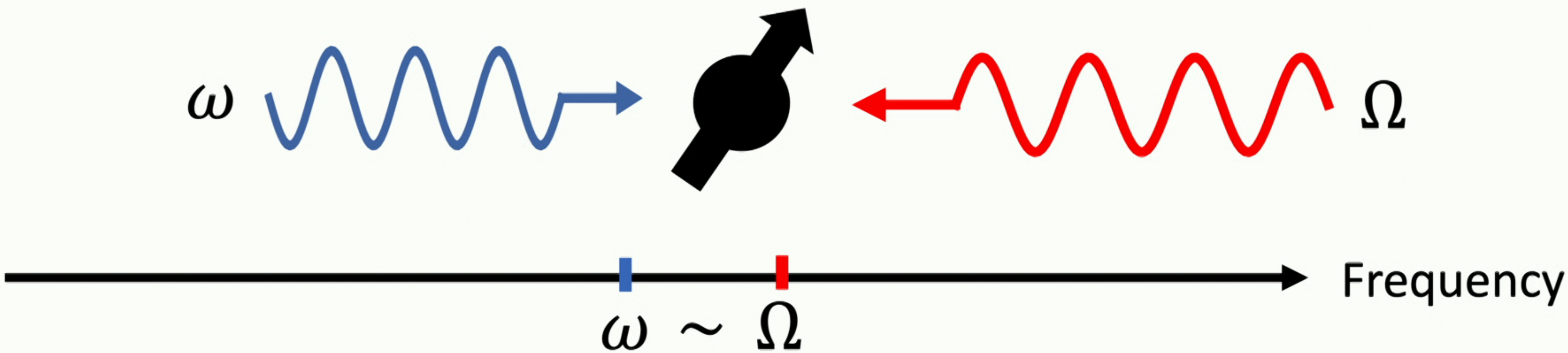


Perimeter Institute – 12 December 2022

Quasiperiodic Driving



Quasiperiodic Driving

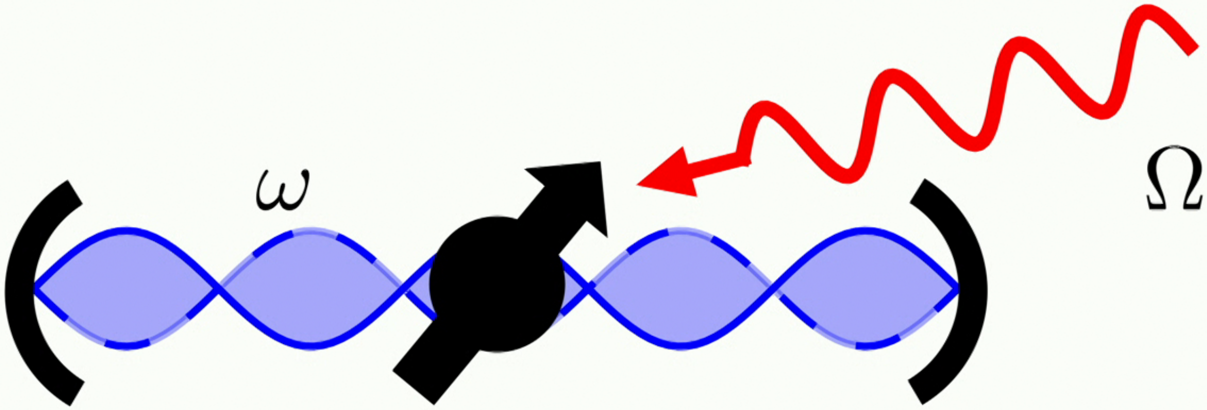


- No separation of scales
- $\omega/\Omega \notin \mathbb{Q}$ – *quasiperiodic* (can't use Floquet)
- **Does quasiperiodic get us anything?** *(Yes!)*

Outline

- Motivation – boosting cavity states
- Background – Frequency lattice
- Boosting on the frequency lattice
- Nonadiabatic boosting – topological quasiperiodically driven phases

System – Cavity, Qubit, Classical Drive



Circular polarization

Cavity frequency: ω
Drive frequency: Ω
Drive amplitude: B
Coupling: g

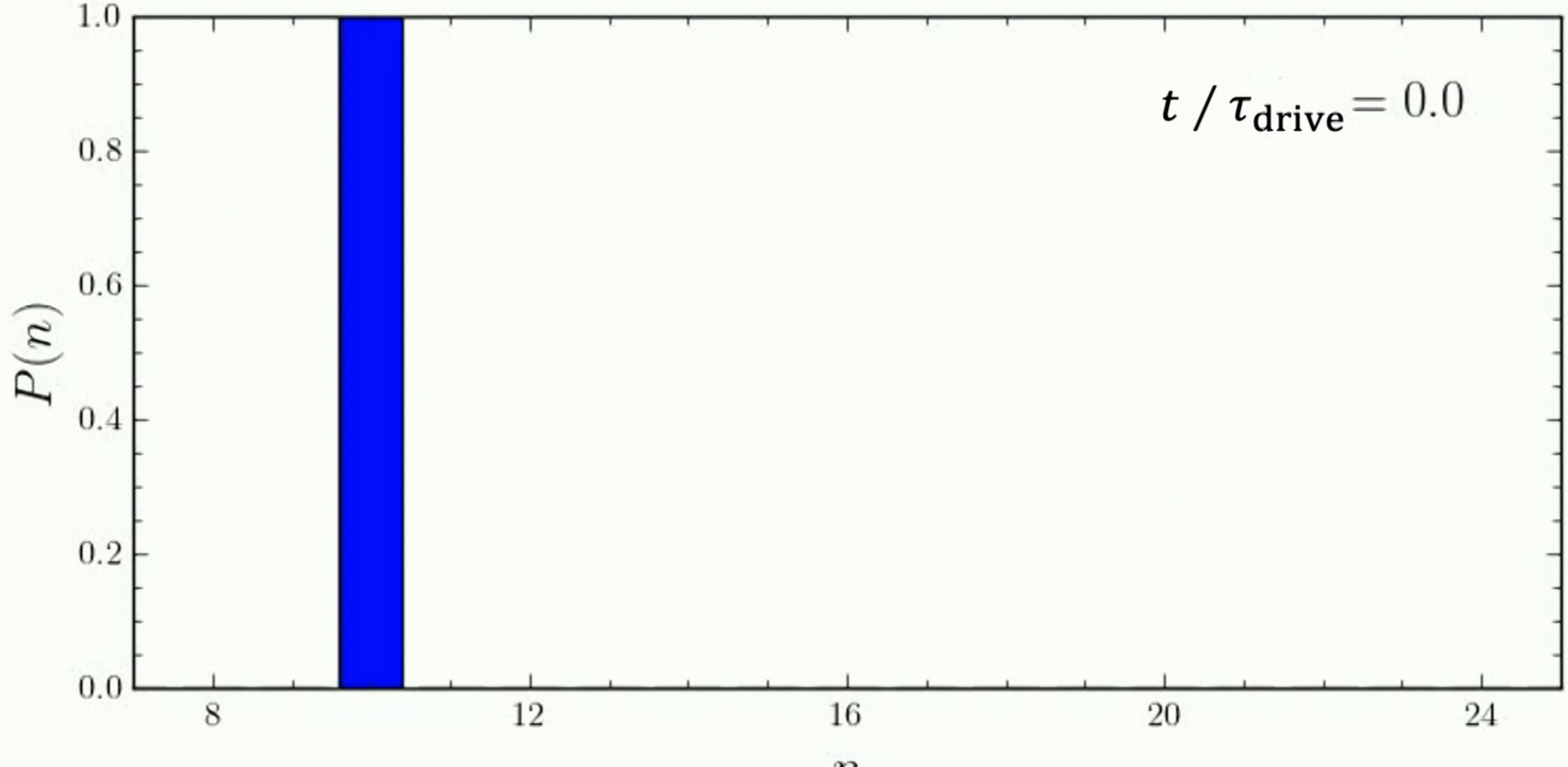
Parameter regime: $\omega, \Omega \ll g, B$ $\qquad$ $\omega/\Omega \notin \mathbb{Q}$

Quasiperiodic

[DML, Crowley, Kollár, Chandran, PRL **128**, 183602 (2022)]

Boosting

$|\psi_0\rangle = |n\rangle| \rightarrow\rangle$



[DML, Crowley, Kollár, Chandran, PRL **128**, 183602 (2022)]

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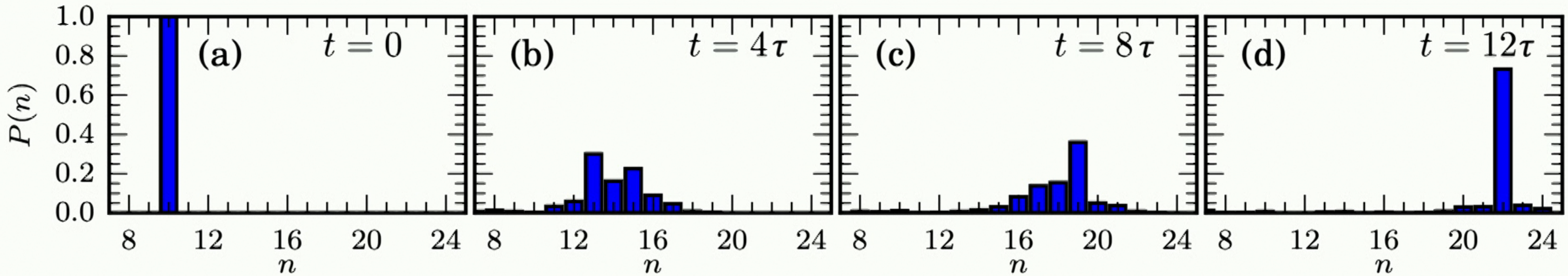

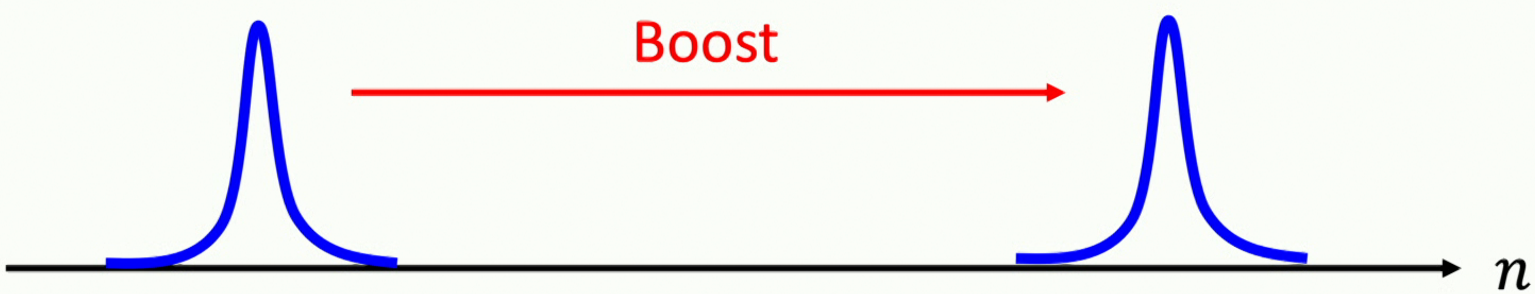

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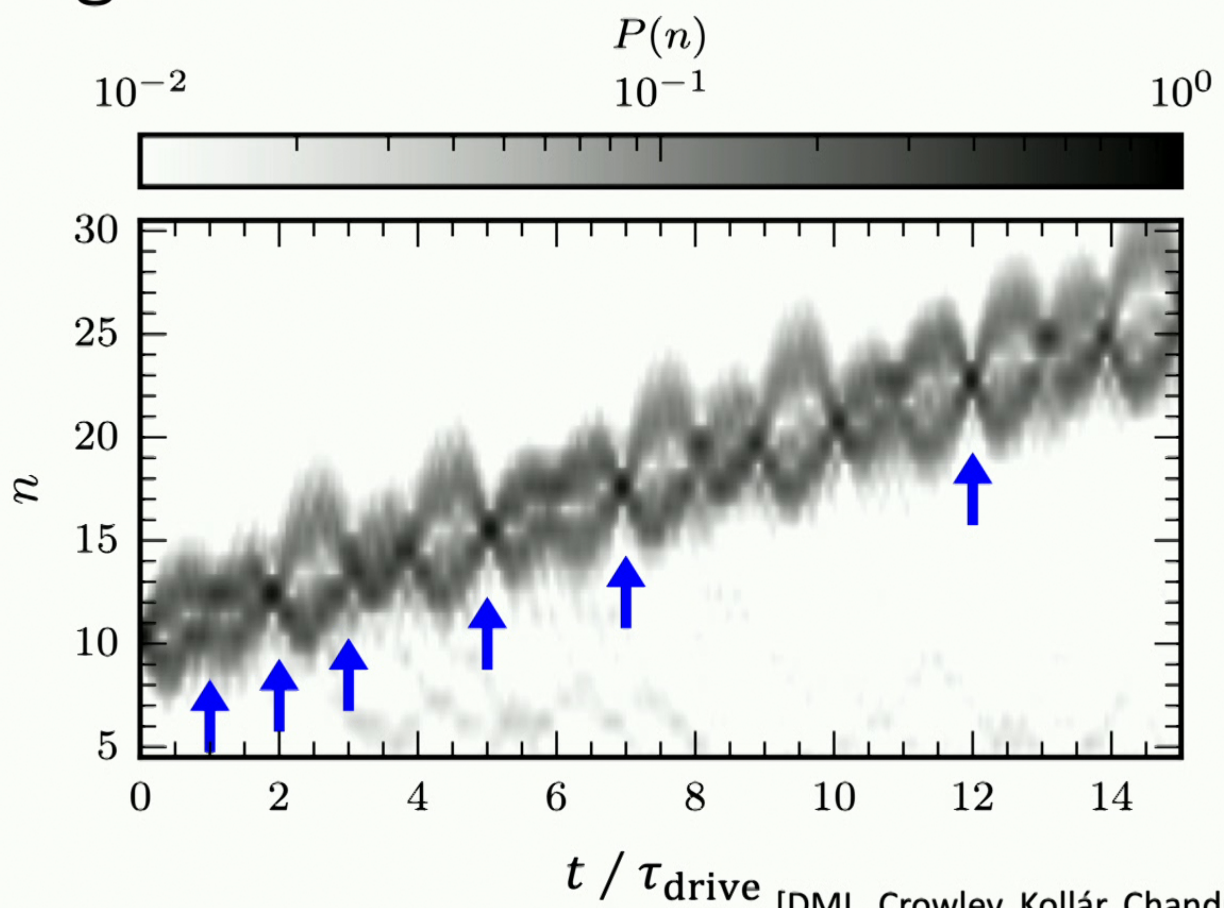

[DML, Crowley, Kollár, Chandran, PRL **128**, 183602 (2022)]

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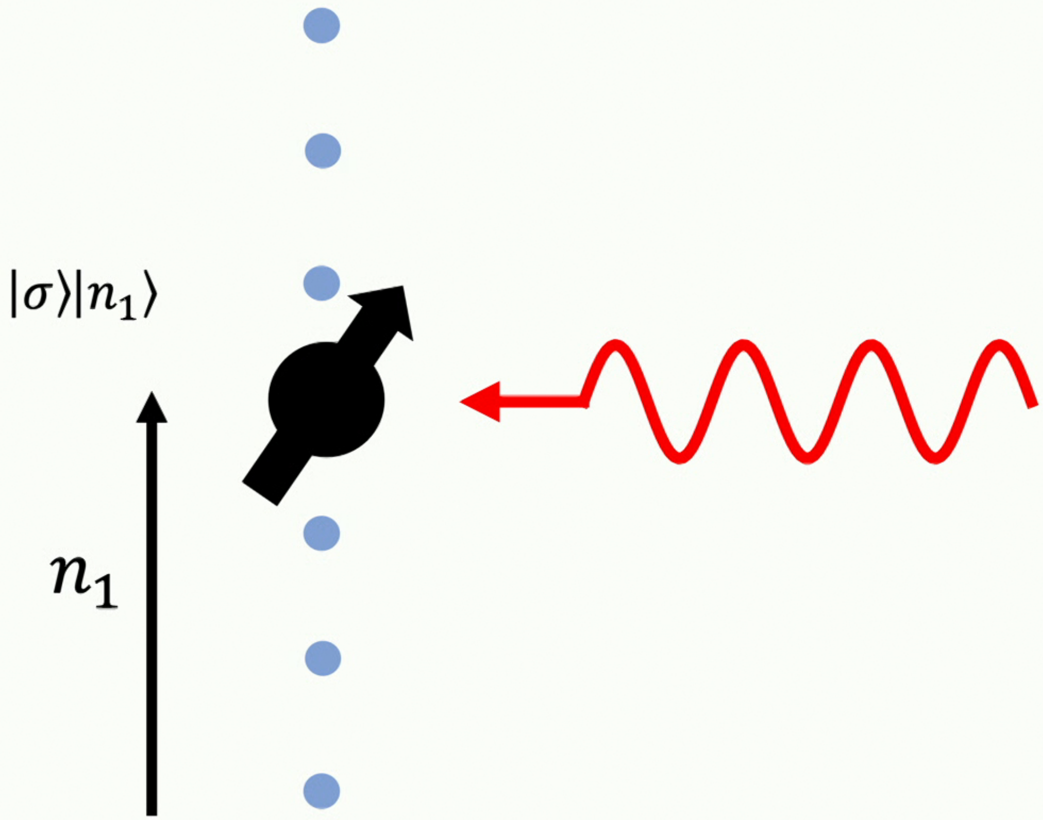
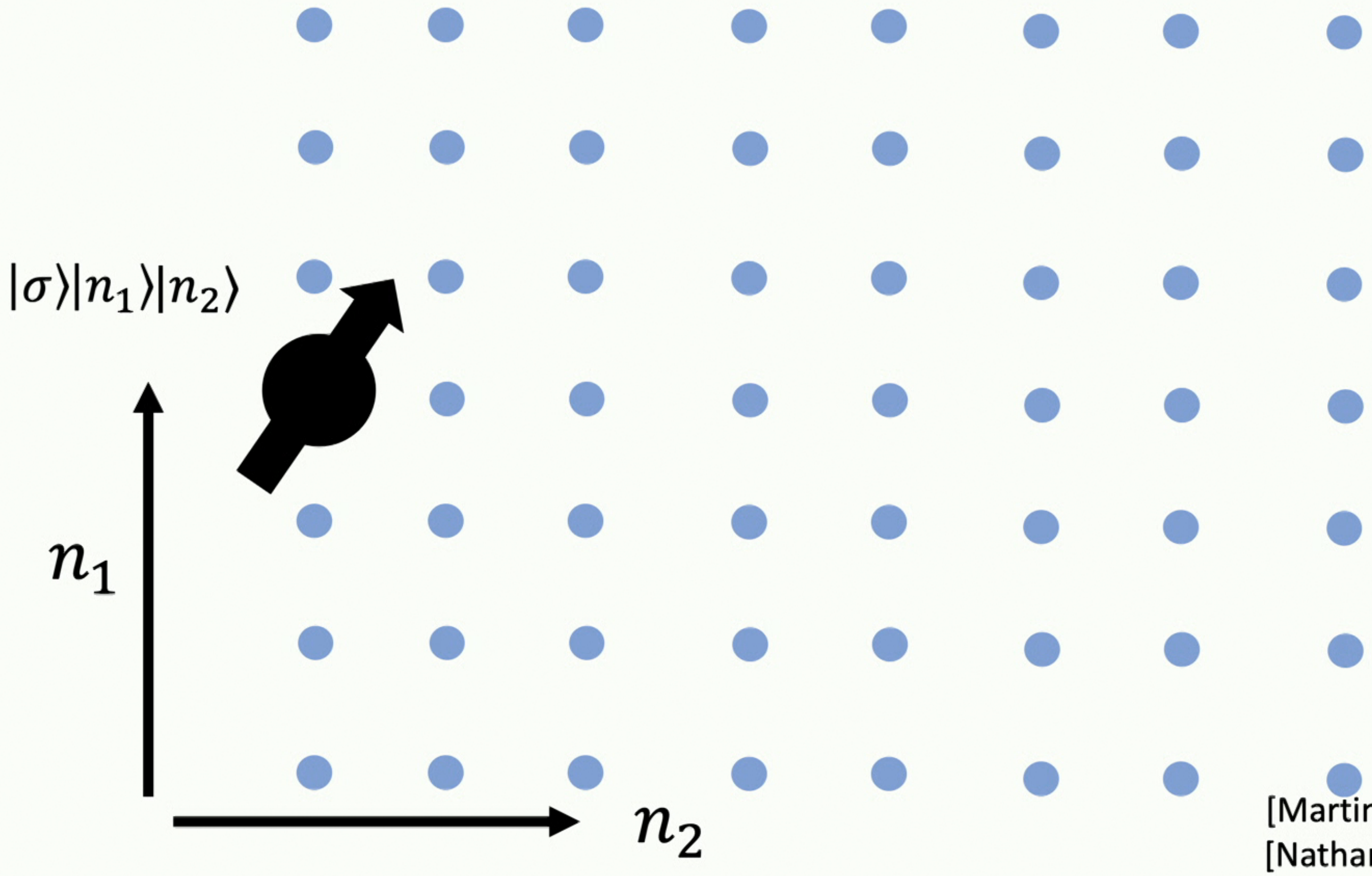
Frequency Lattice



[Martin, Refael, Halperin, PRX **7**, 041008 (2017)]
[Nathan, Martin, Refael, PRB **99**, 094311 (2019)]

Frequency Lattice



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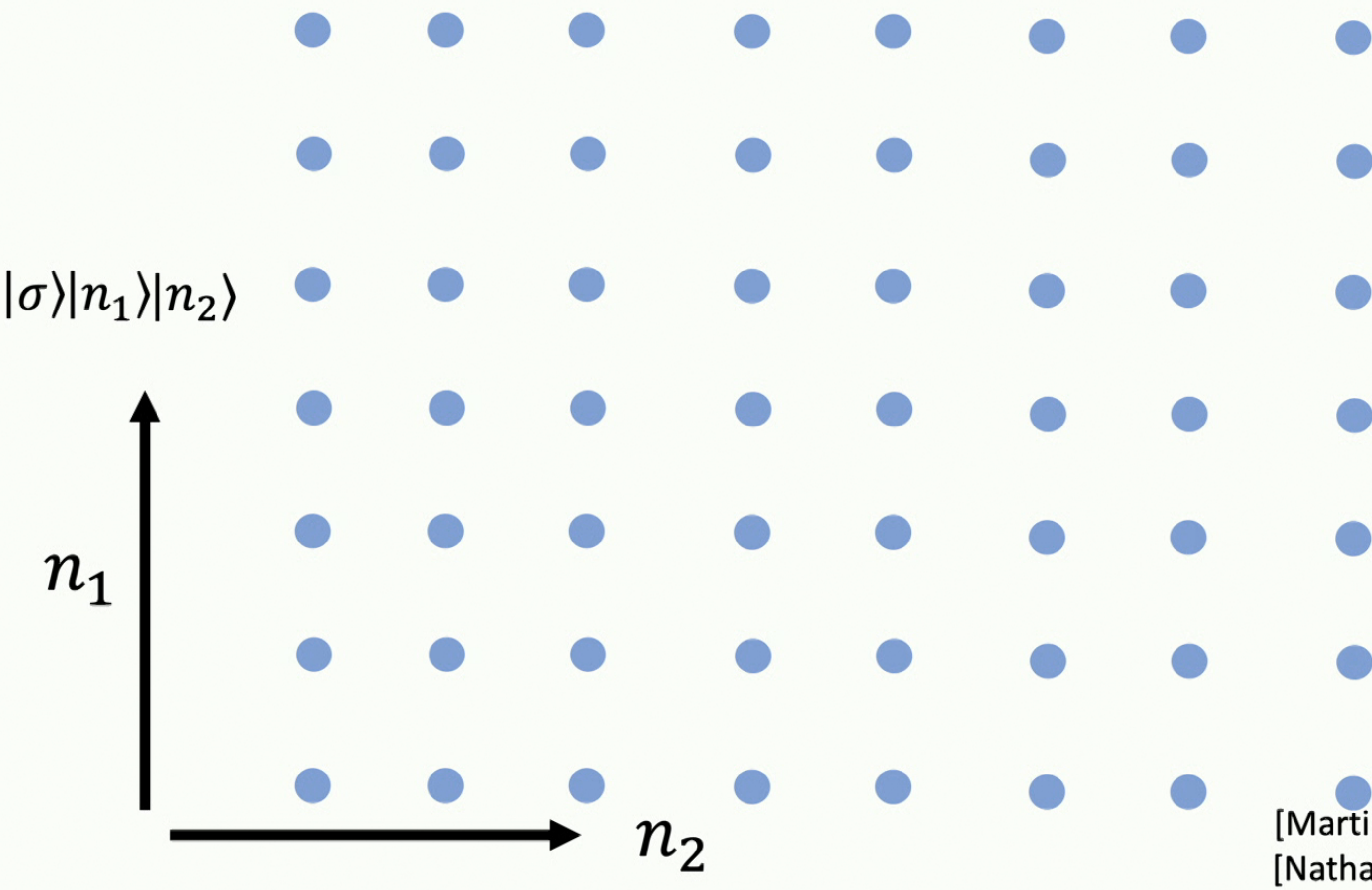
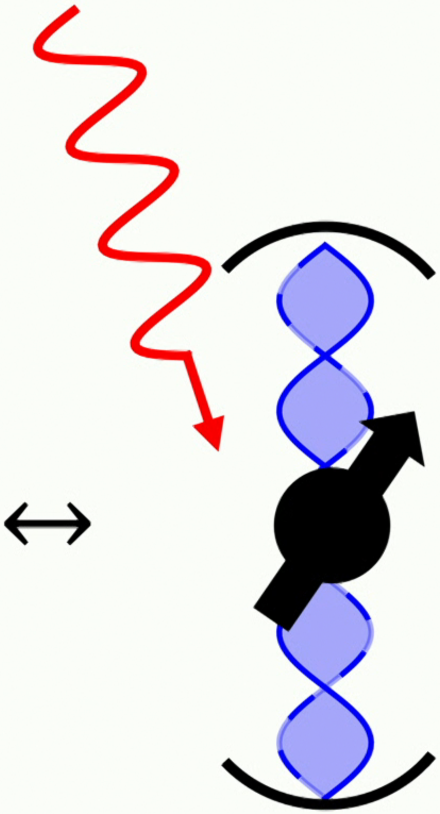
Frequency Lattice



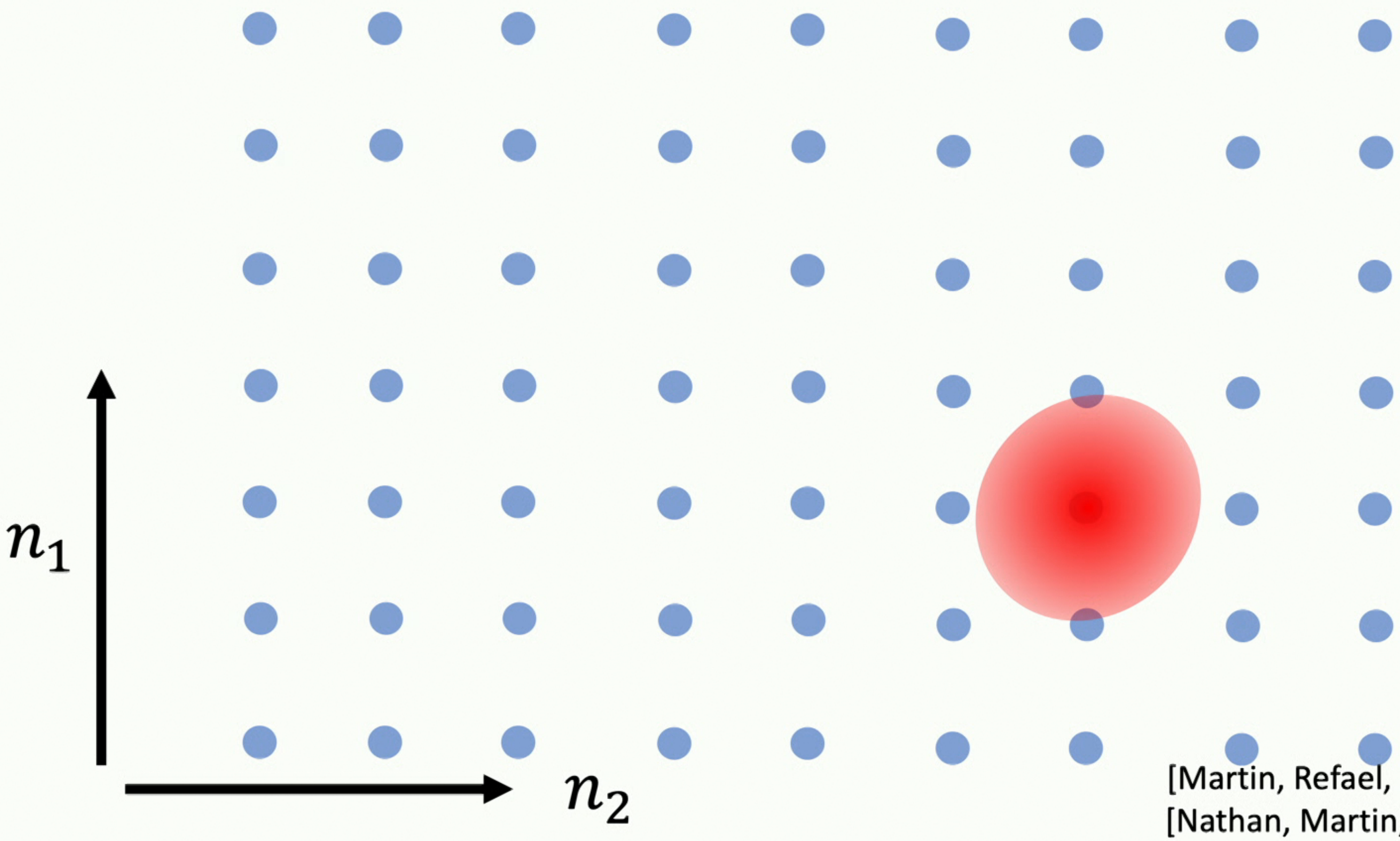
$\leftrightarrow$



"Synthetic dimensions"

[Martin, Refael, Halperin, PRX **7**, 041008 (2017)]
[Nathan, Martin, Refael, PRB **99**, 094311 (2019)]

Frequency Lattice – Energy Pumping



$$\vec{\Omega} = (\omega, \Omega)$$

[Martin, Refael, Halperin, PRX **7**, 041008 (2017)]
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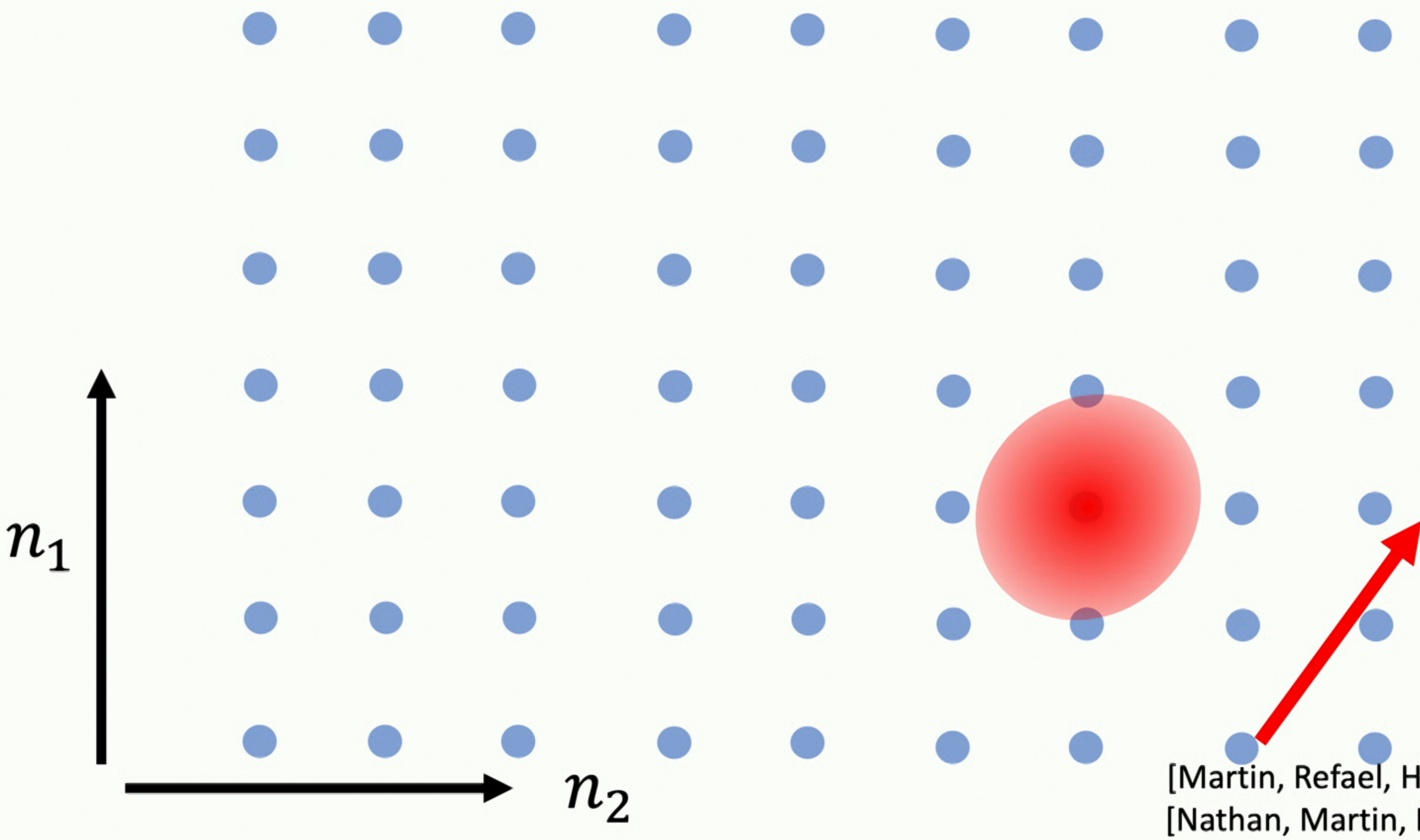
Frequency Lattice – Energy Pumping



$\vec{\Omega} = (\omega, \Omega)$

"Electric field"

[Martin, Refael, Halperin, PRX **7**, 041008 (2017)]
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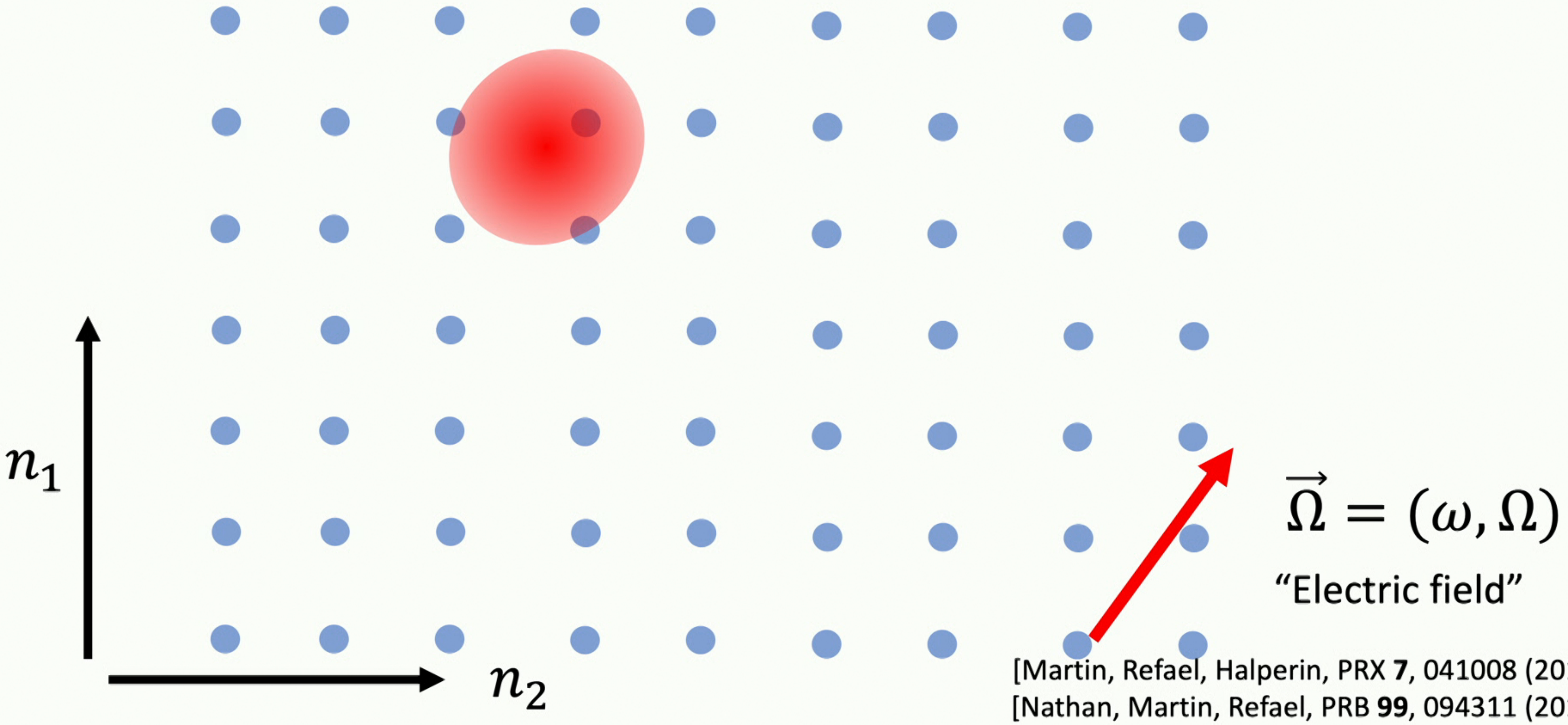
Frequency Lattice – Energy Pumping



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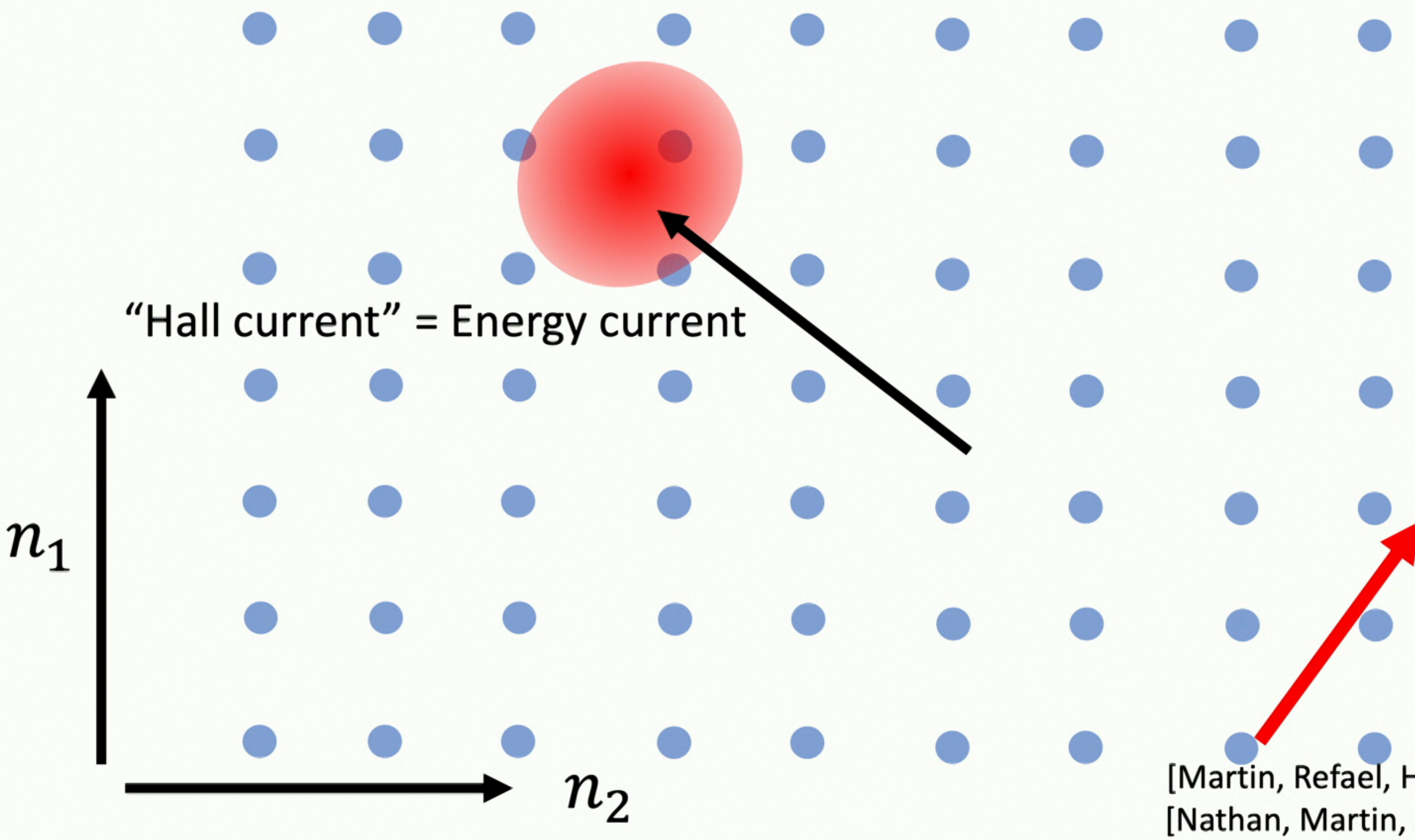
Frequency Lattice – Energy Pumping



Pumping rate:

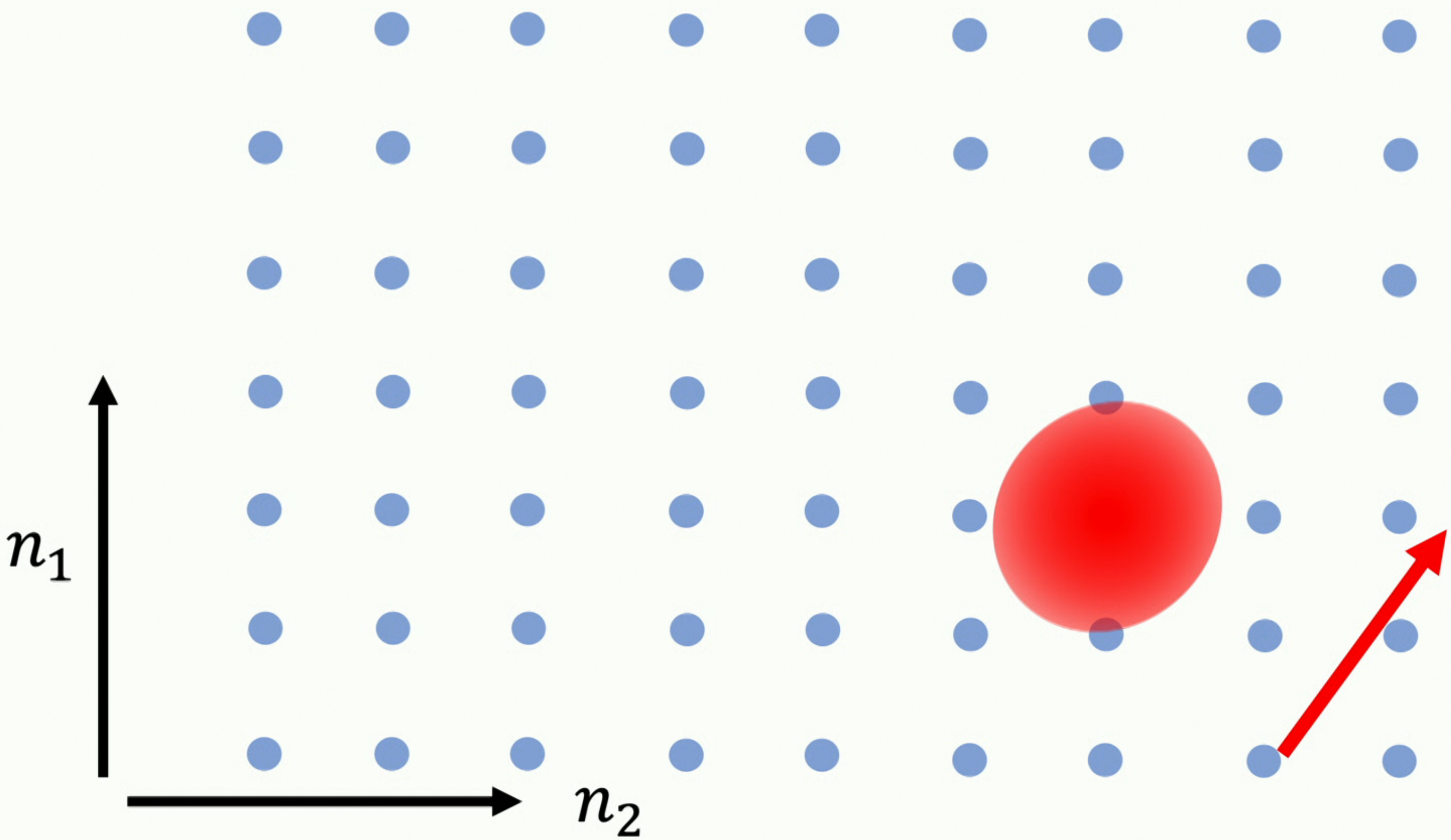
$$P_{\text{top}} = \frac{\Omega\omega}{2\pi} C$$

$$\vec{\Omega} = (\omega, \Omega)$$

"Electric field"

[Martin, Refael, Halperin, PRX **7**, 041008 (2017)]
[Nathan, Martin, Refael, PRB **99**, 094311 (2019)]

Frequency Lattice – Breathing



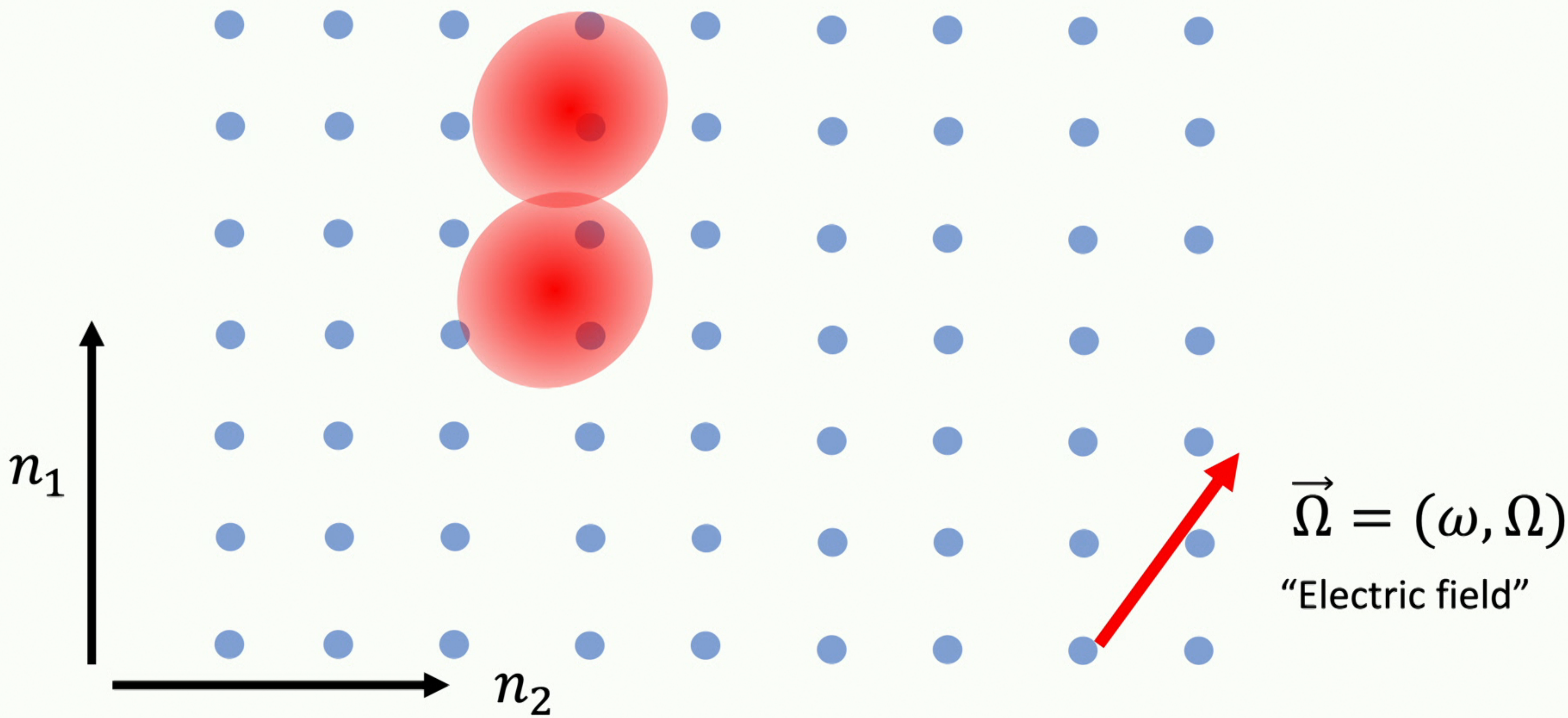
Bloch oscillations
= Breathing

Rephases quasiperiodically!

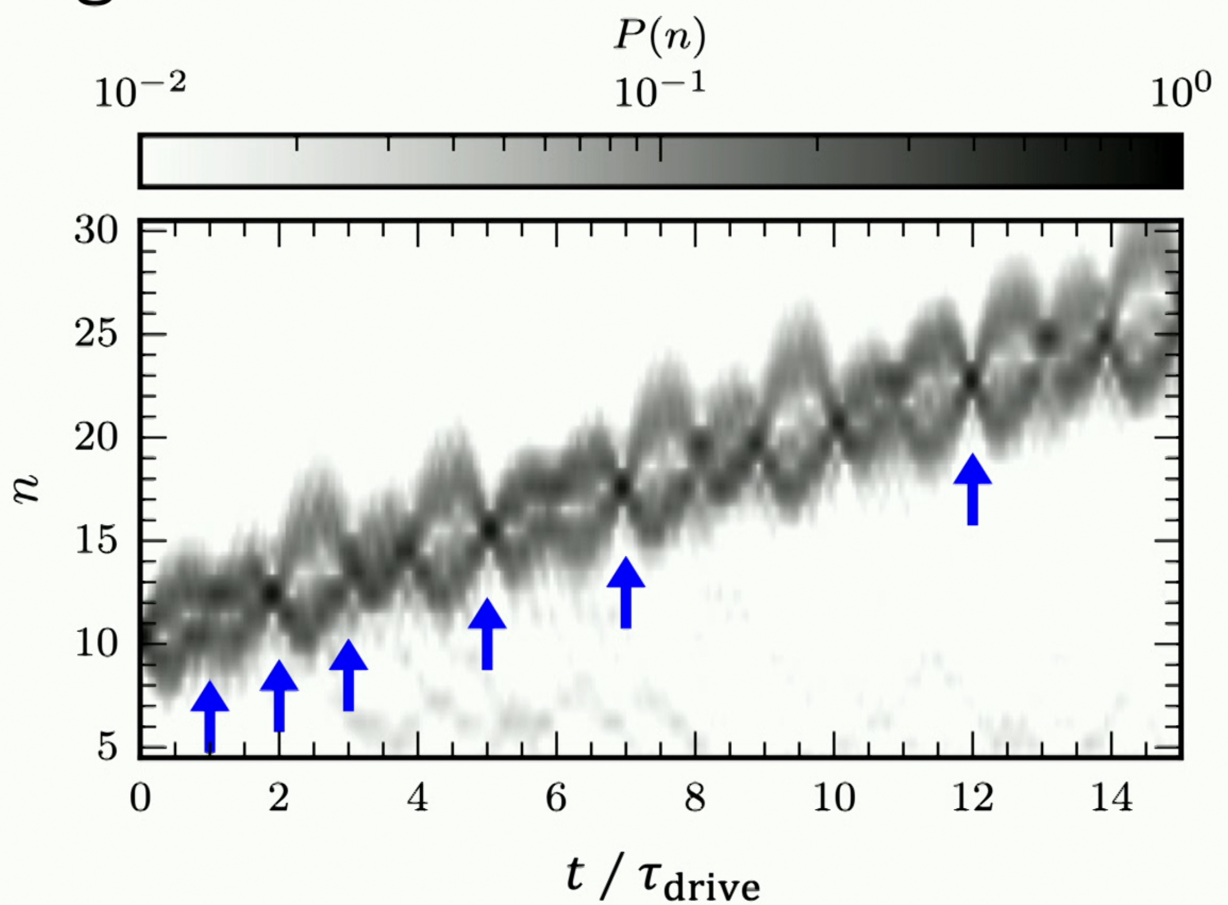
$$\vec{\Omega} = (\omega, \Omega)$$

"Electric field"

Frequency Lattice – Boosting

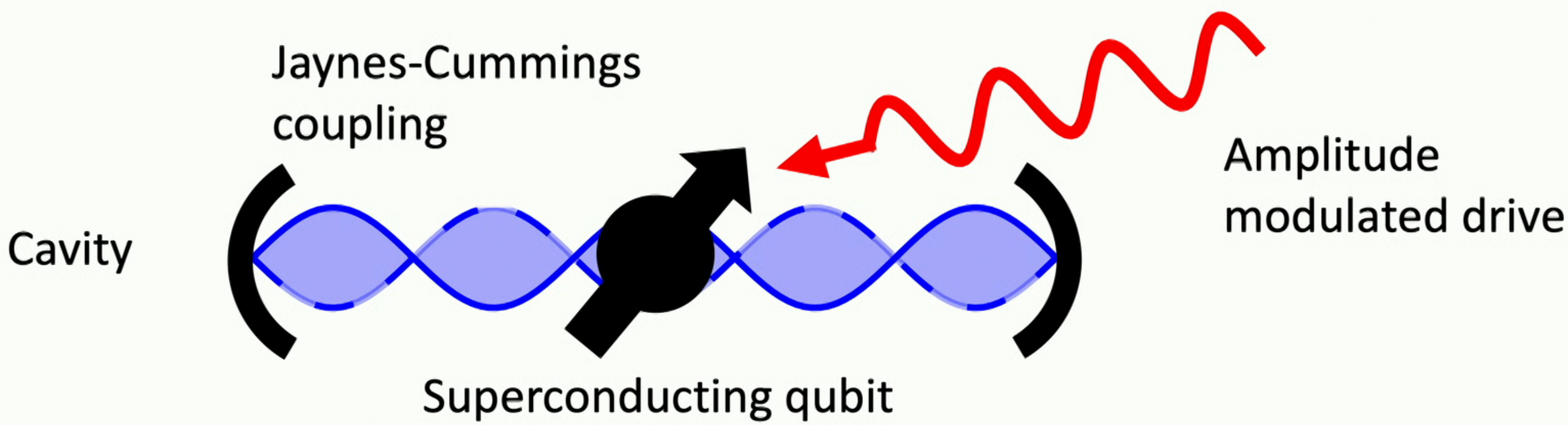


Boosting



Experiment – Hamiltonian

$$H(t) = (\omega_q + \omega)\hat{n} + (\omega_q - B\sin\Omega t)S^z$$
$$+g(\hat{a}^\dagger S^- + \hat{a}S^+) - 2B(1 - \cos\Omega t)\cos(\omega_q t)\,S^x$$



[DML, Crowley, Kollár, Chandran, PRL **128**, 183602 (2022)]

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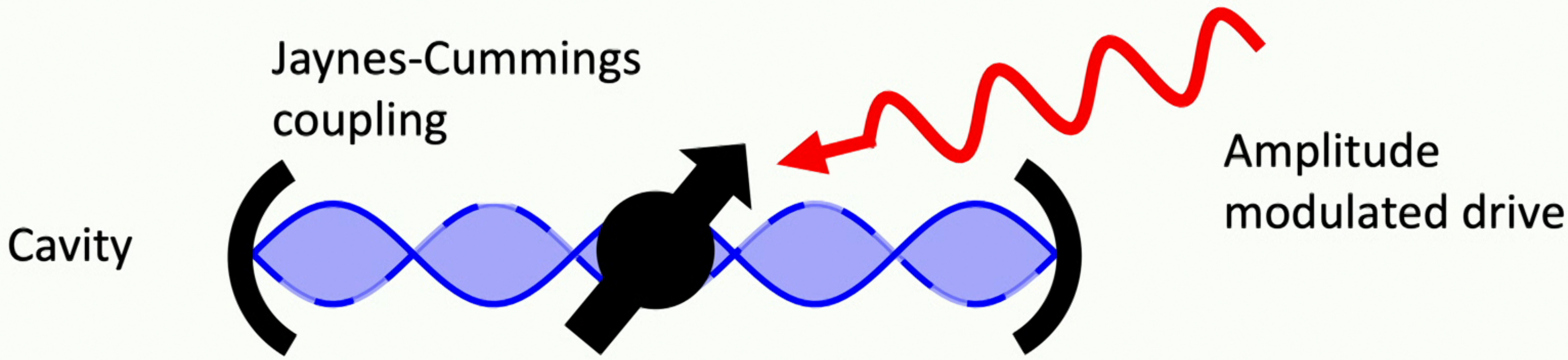


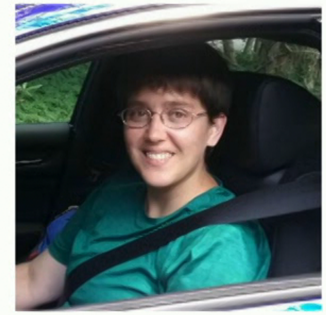
Rotating frame

Parameter regime: $\omega, \Omega \ll B, g\sqrt{n} \ll \omega_q$

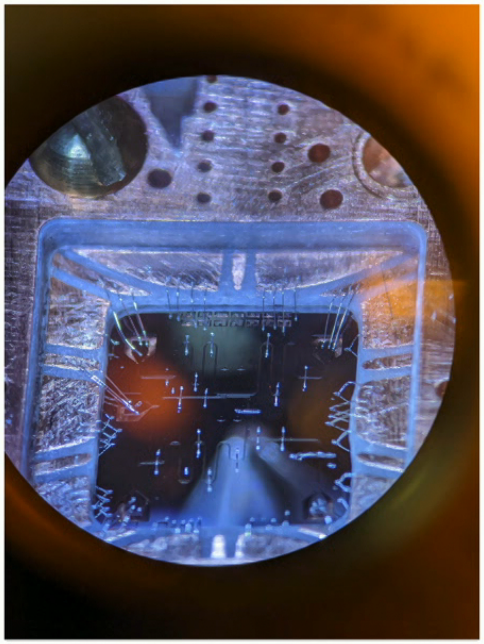
[DML, Crowley, Kollár, Chandran, PRL **128**, 183602 (2022)]

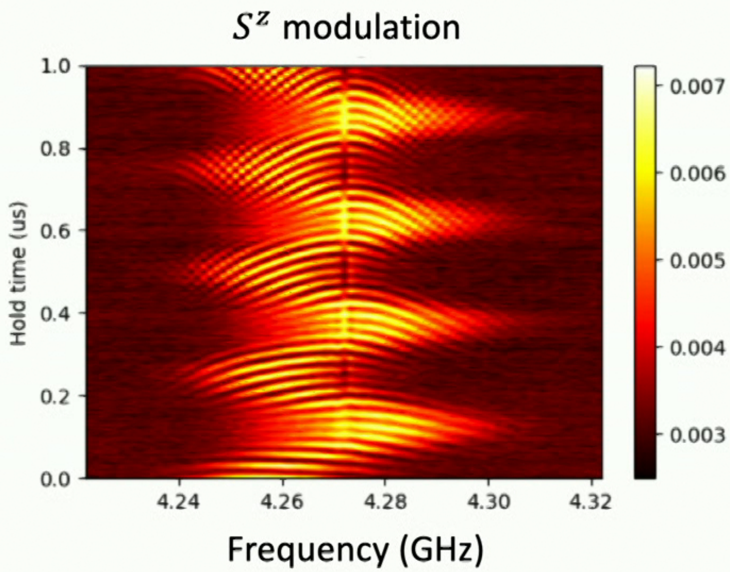
Ongoing Experiment

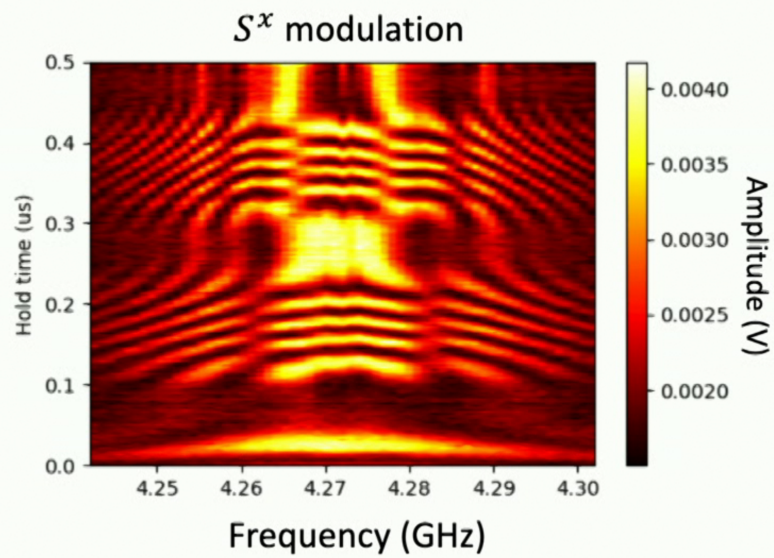
Martin Ritter



Alicia Kollár







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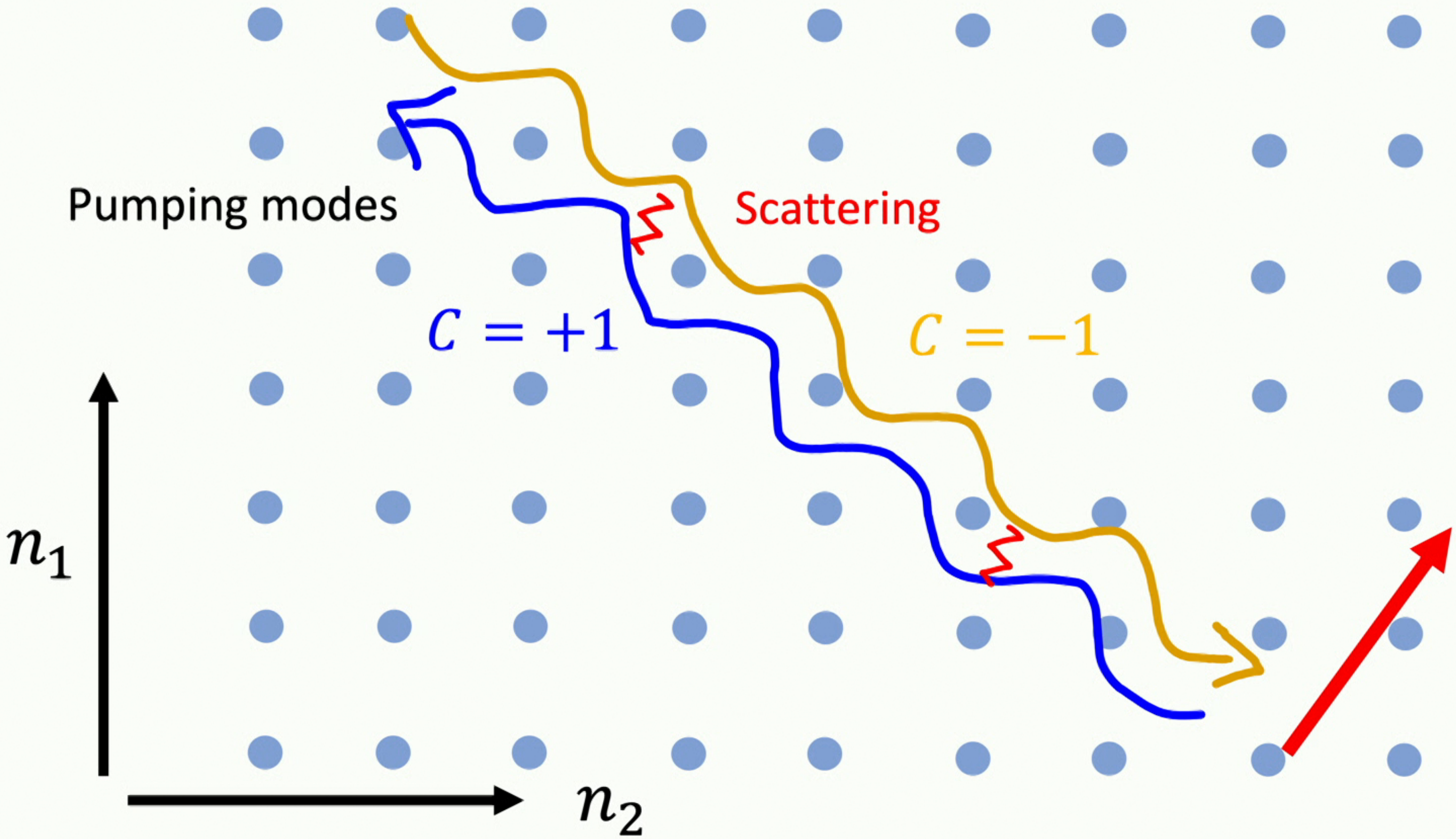
Nonadiabatic Processes

[Crowley, Martin, Chandran, PRB **99**, 064306 (2019)]
[Crowley, Martin, Chandran, PRL **125**, 100601 (2020)]
[DML, Crowley, Chandran, PRB **105**, 144204 (2022)]



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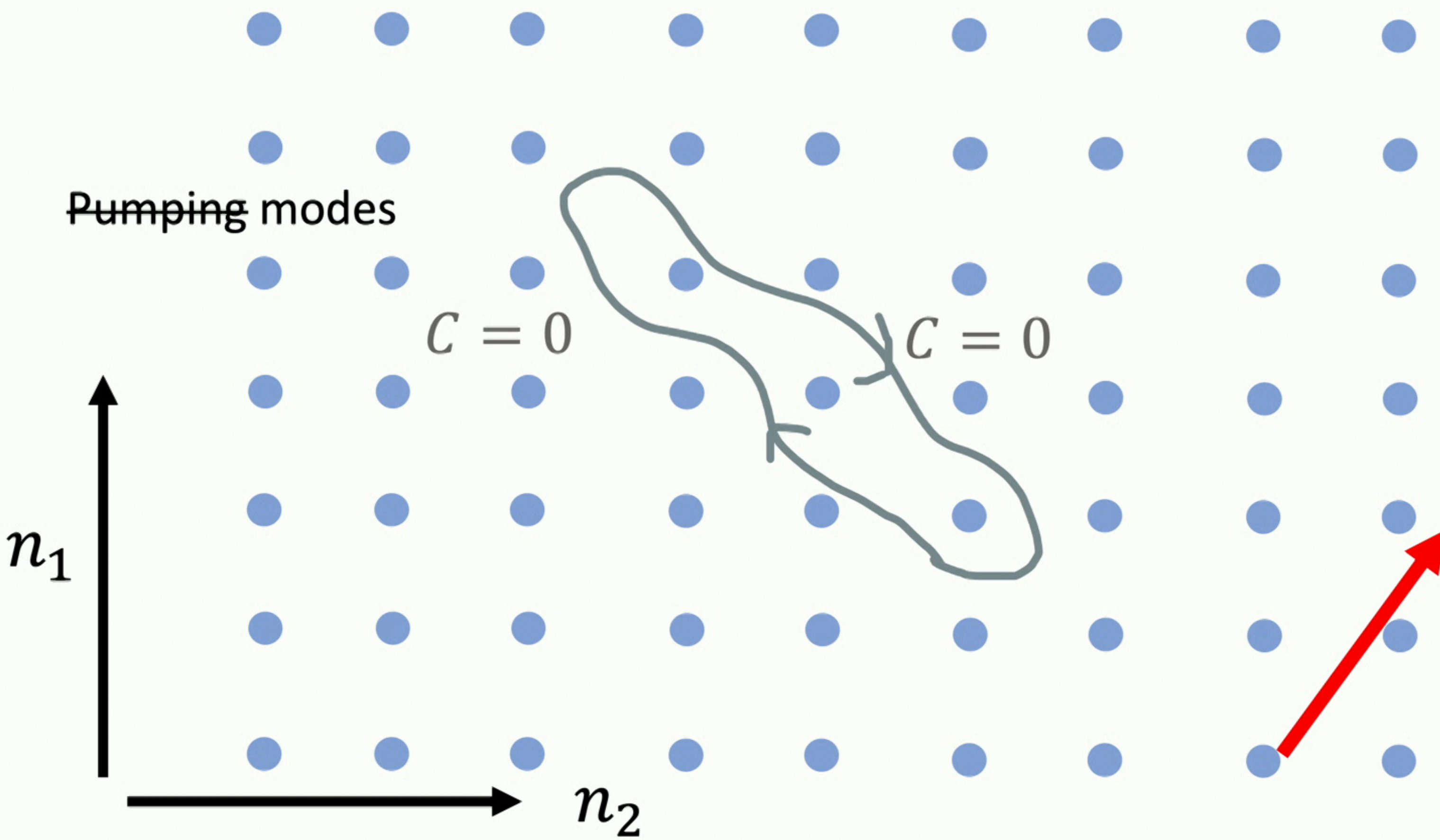
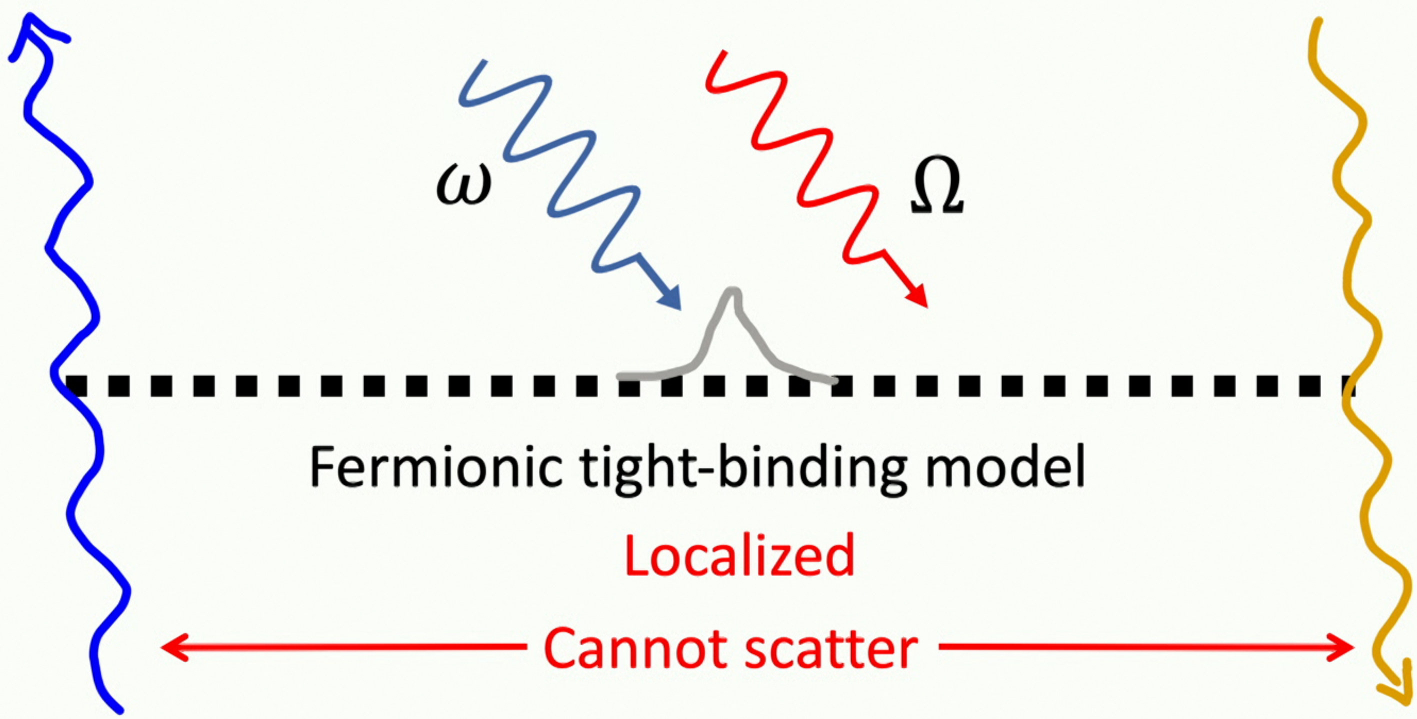


Pumping needs fine tuning

Cannot go fast

Nonadiabatic Boosting

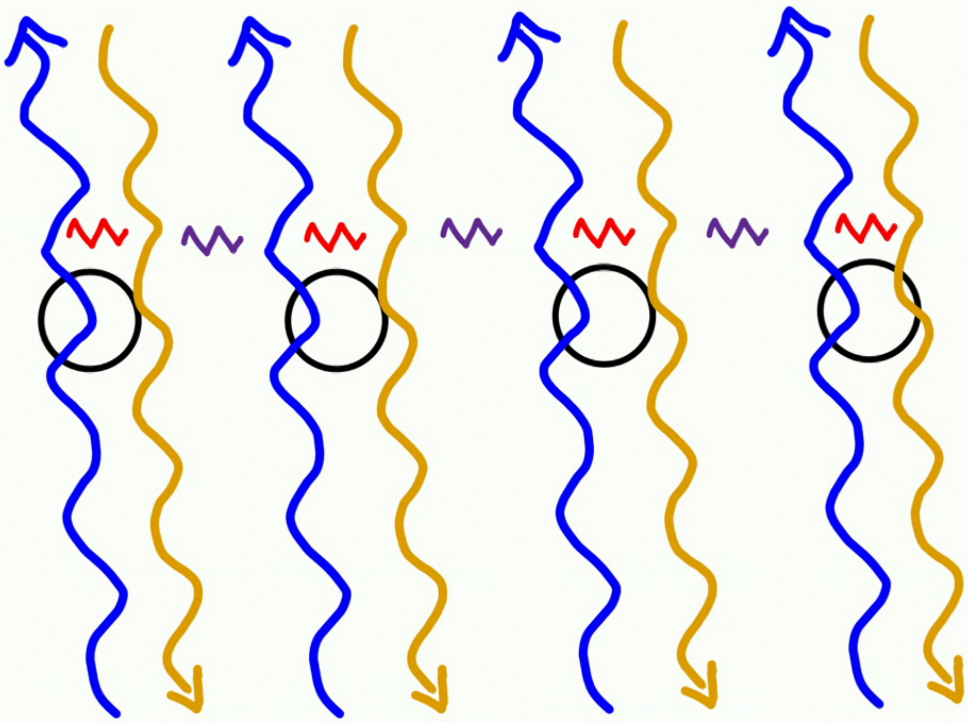
- Achieve boosting as an edge effect in topological phase



[DML, Crowley, Chandran, PRL **126**, 106805 (2021)]
[Nathan, *et al.*, PRL **127**, 166804 (2021)]
[DML, Crowley, Chandran, PRB **106**, 144203 (2022)]

Coupled Layer Model

- Analytically soluble limits



$$H_{\mathrm{hop}}(t) = J(t)[(1-\epsilon)c^{\dagger}_{j,+}(t)\ c_{j,-}(t) + \epsilon c^{\dagger}_{j,-}(t)\ c_{j+1,+}(t)]$$

$c^{\dagger}_{j,+}(t)$ – "up" pumping mode
$c^{\dagger}_{j,-}(t)$ – "down" pumping mode

[DML, Crowley, Chandran, PRL **126**, 106805 (2021)]
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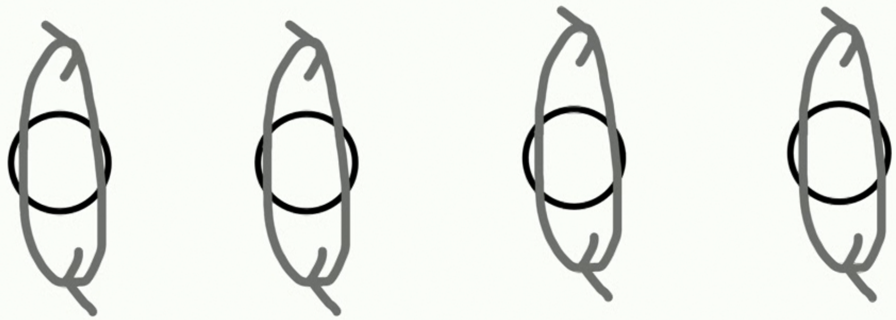

$$H_{\text{hop}}(t) = J(t)[(1-\epsilon)c^\dagger_{j,+}(t)\, c_{j,-}(t) + \epsilon c^\dagger_{j,-}(t)\, c_{j+1,+}(t)]$$

$\epsilon = 0$ Trivial

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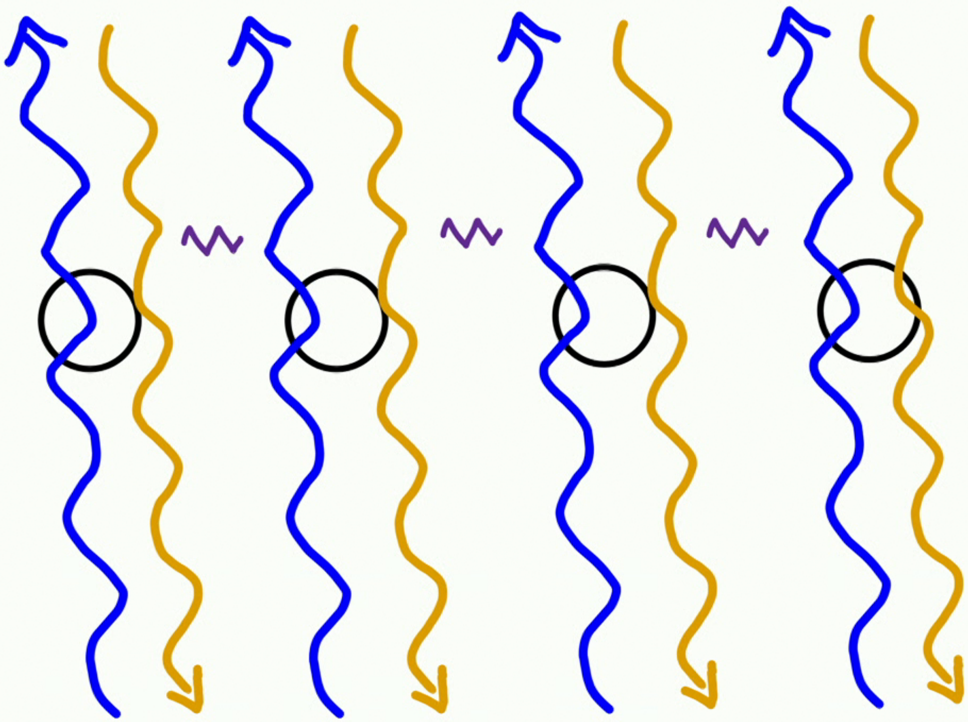

$$H_{\mathrm{hop}}(t) = J(t)[(1-\epsilon)c_{j,+}^{\dagger}(t)\ c_{j,-}(t)$$
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$$\epsilon = 1$$

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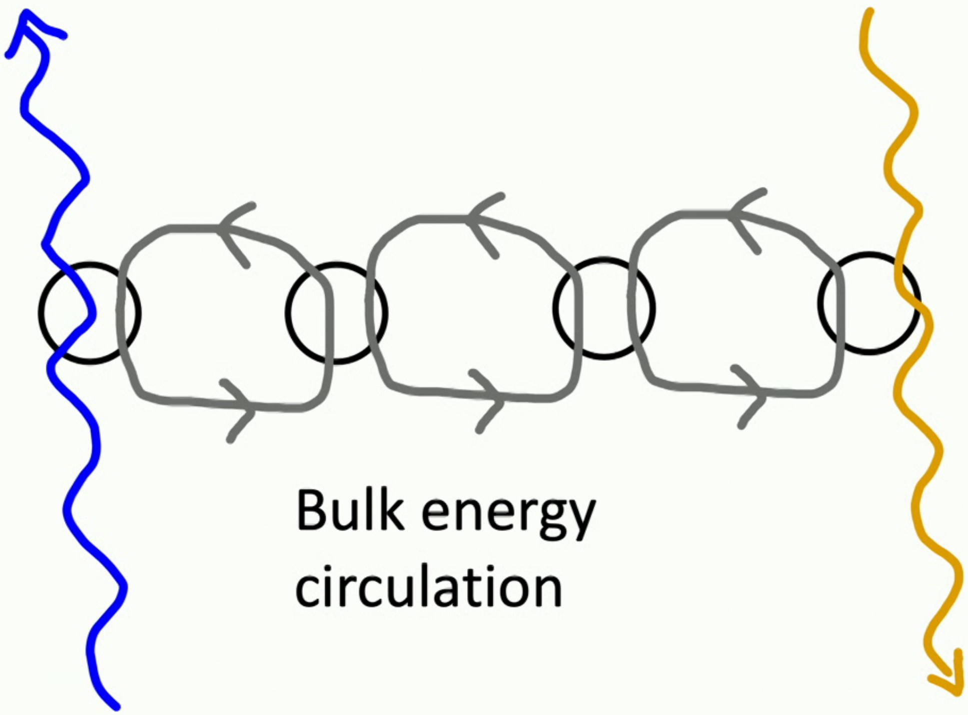

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$\epsilon = 1$ Topological

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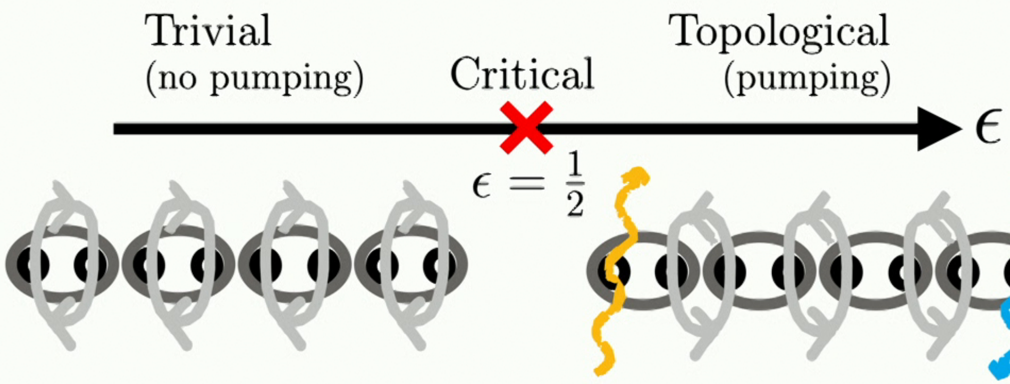
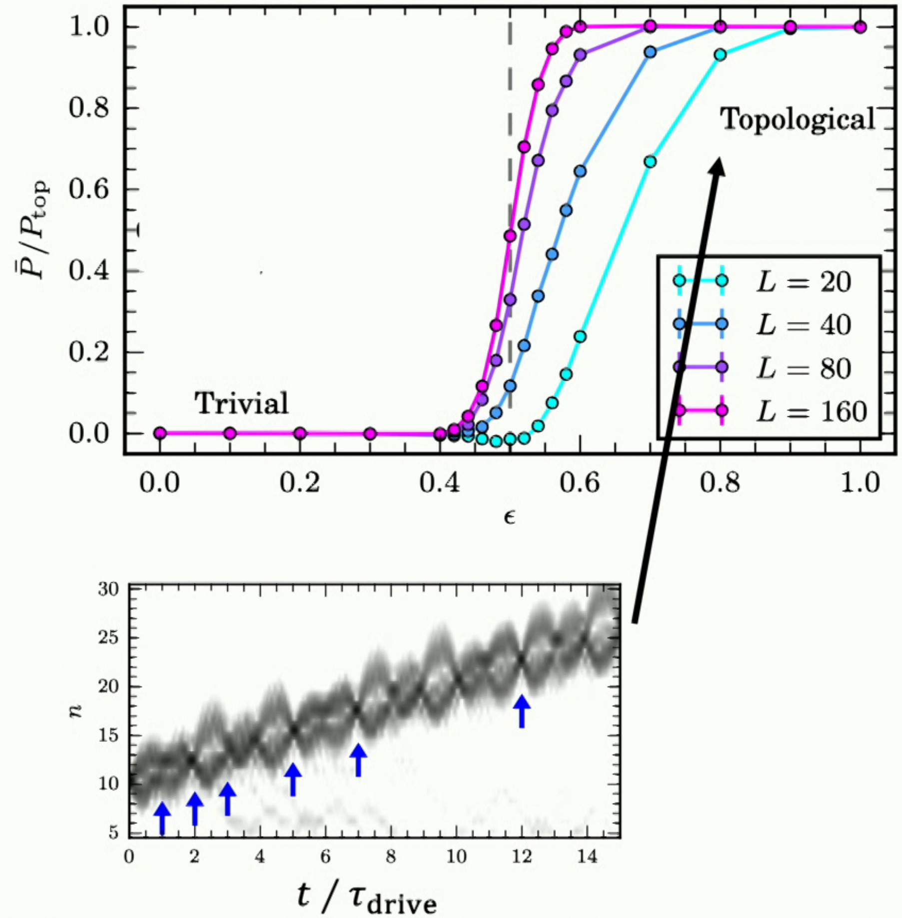
Phase Diagram

- Rest of phase diagram: numerics

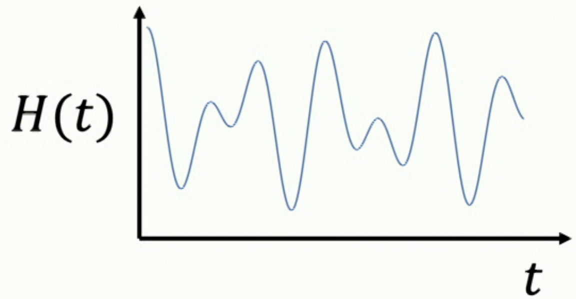




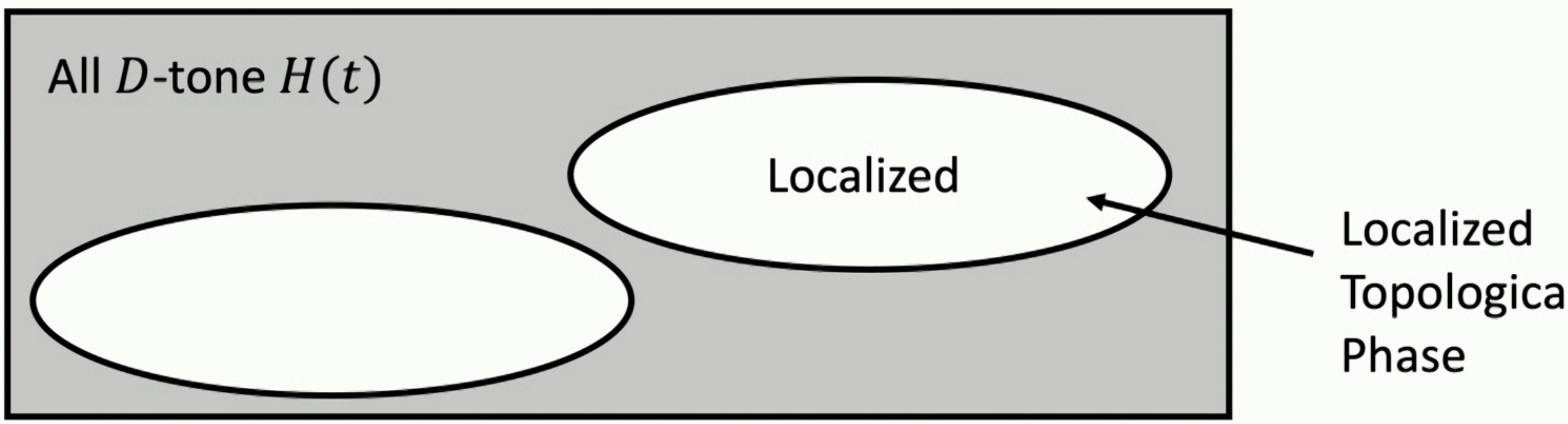
[DML, Crowley, Chandran, PRL **126**, 106805 (2021)]

Topological Classification

- No gaps!
- Criteria:
  - Single-particle
  - Fixed number of tones
  - Localized in real and synthetic dimensions



$\Rightarrow$ Dense spectrum



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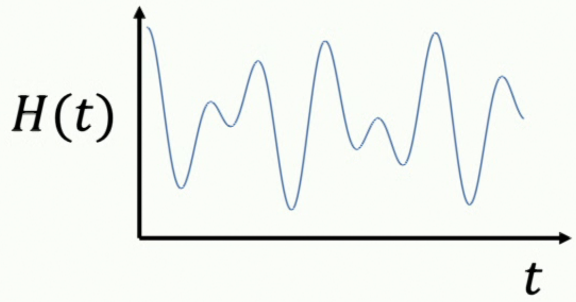

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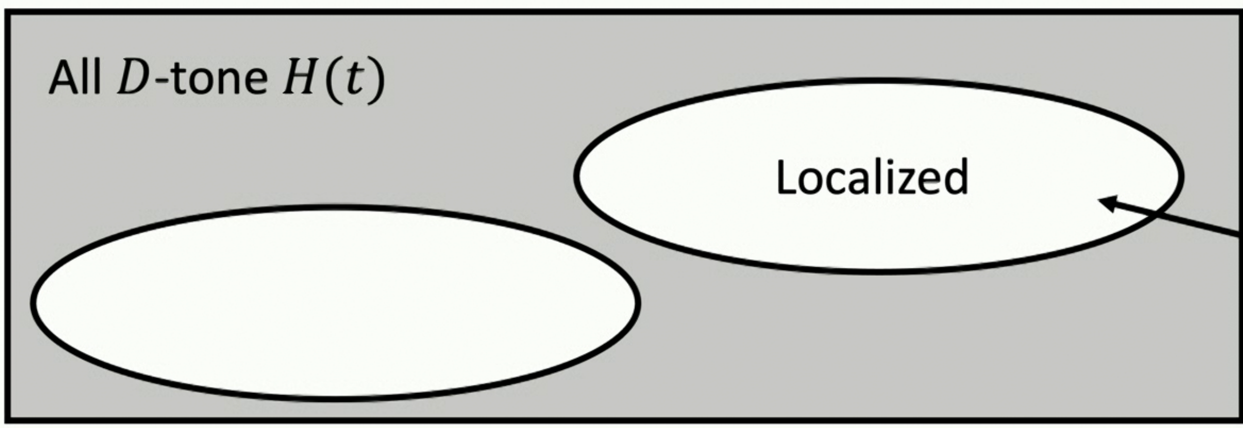
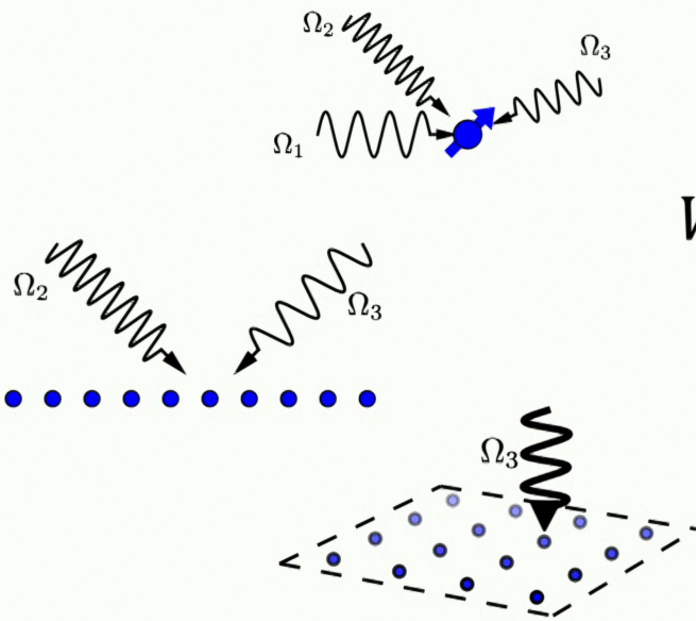


"Anomalous" Localized Topological Phase (ALTP)

[DML, Crowley, Chandran, PRL **126**, 106805 (2021)]

Topological Classification

d-dimensional driven by D tones: $(d+D)$-dimensional ALTP $\Rightarrow$ Topological classification (by winding number) depends on $d+D$ only!



$d+D$ odd $\Rightarrow$ integer
$d+D$ even $\Rightarrow$ trivial

$$W[V] = C_{d+D} \int \mathrm{d}^d\Phi \mathrm{d}^D\theta \, \epsilon^{j\ldots k} \times \mathrm{Tr}\left[\left(V^\dagger \partial_j V\right) \ldots \left(V^\dagger \partial_k V\right)\right]$$

[DML, Crowley, Chandran, PRL **126**, 106805 (2021)]

Topological Classification

d-dimensional driven by D tones: $\Rightarrow$ Topological classification (by winding
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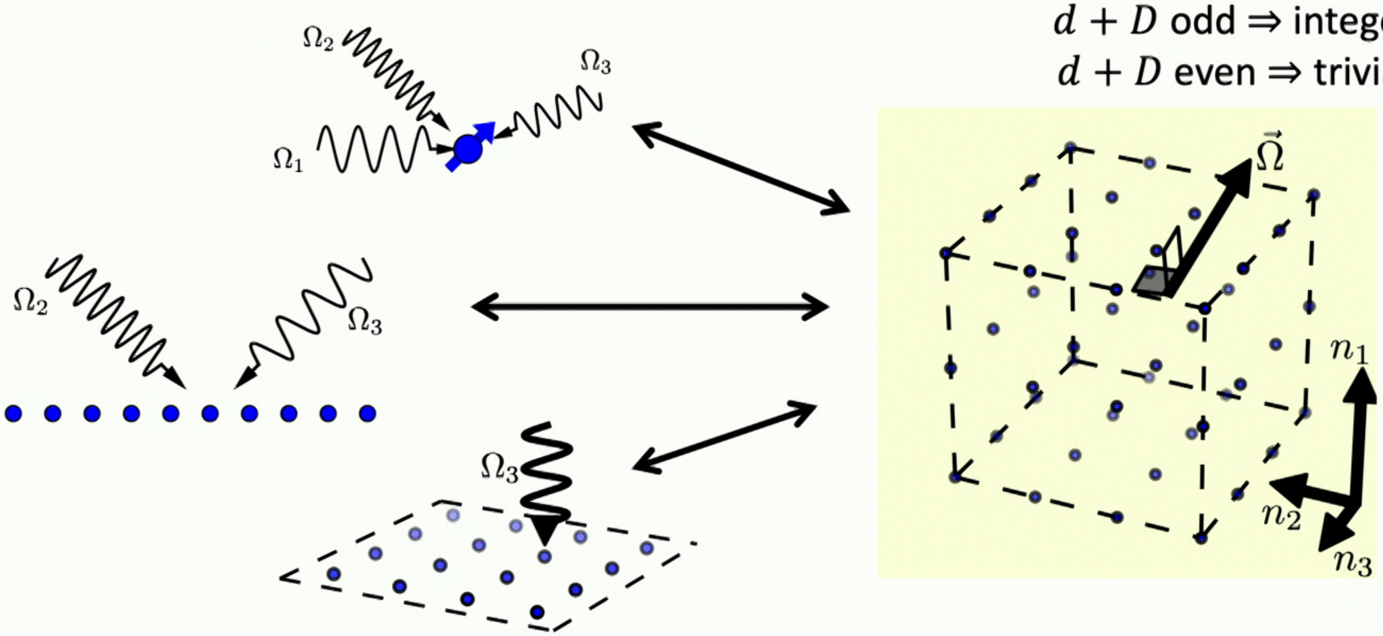
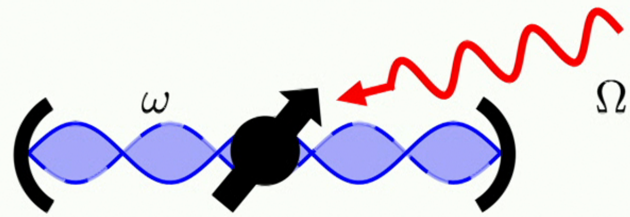
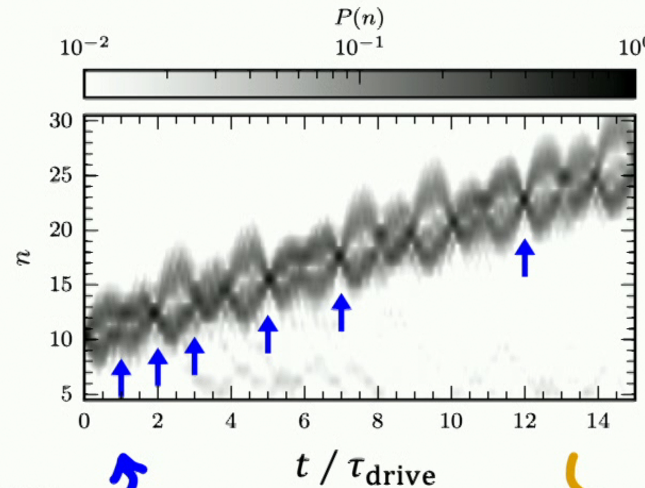
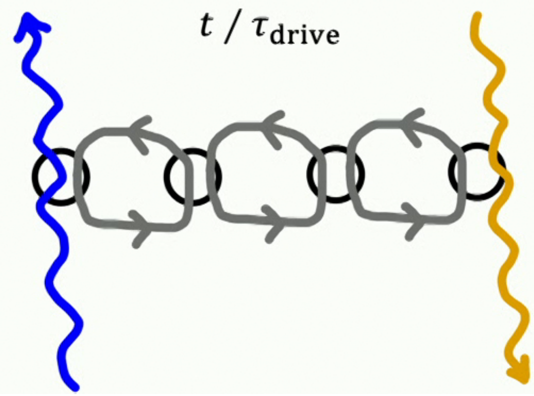


Discussion

- Summary
  - Boost cavity states
  - Nonadiabatic: use edge modes
- Immediate experiments are possible
  - [Boyers, *et al.*, PRL **125**, 160505 (2020)]
  - [Malz, Smith, PRL **126**, 163602 (2021)]
  - … and ongoing
- $(1+2)$-ALTP stable to weak interactions
  - [DML, Crowley, Chandran, PRB **105**, 144204 (2022)]
- Future work:
  - Applications of higher D ALTPs
  - Classification of ALTPs with symmetry
  - Critical point in $(1+2)$-ALTP







dmlong@bu.edu

Quasiperiodic driving

[**DML**, Crowley, Chandran, PRL (2021)]
[**DML**, Crowley, Kollár, Chandran, PRL (2022)]
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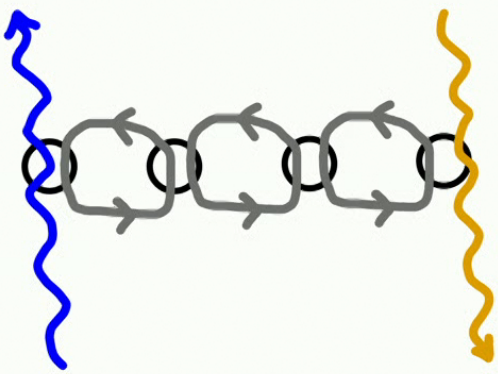

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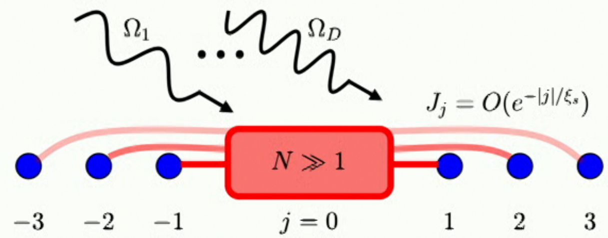
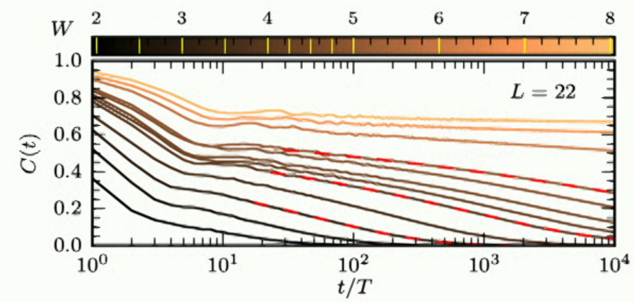


Non-equilibrium quantum dynamics

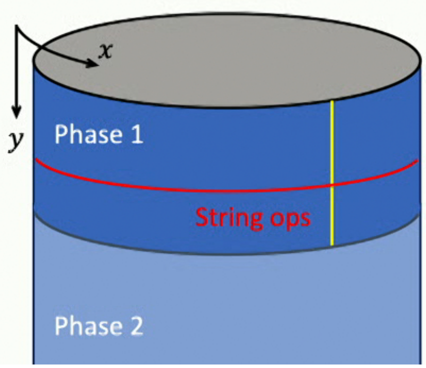
Slow thermalization/ localization

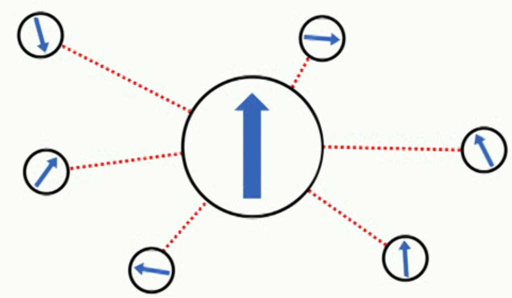
[**DML**, Crowley, Khemani, Chandran, arXiv:2207.05761]



Topology

[**DML**, U. Sydney Masters Thesis]





Integrability

[Tang, **DML**, Polkovnikov, Chandran, Claeys, arXiv:2212.04477]

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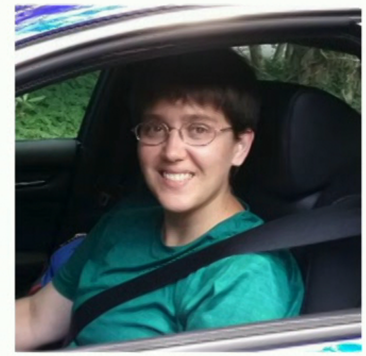

Alicia Kollár

NSF

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