Edge state dynamics of a bosonic fractional Chern insulator

Adolfo G. Grushin, Néel Institute, CNRS

Benasque, 26/2/19



X. Y. Dong, AGG, J. Motruk, F. Pollmann, Phys Rev. Lett. (2018)

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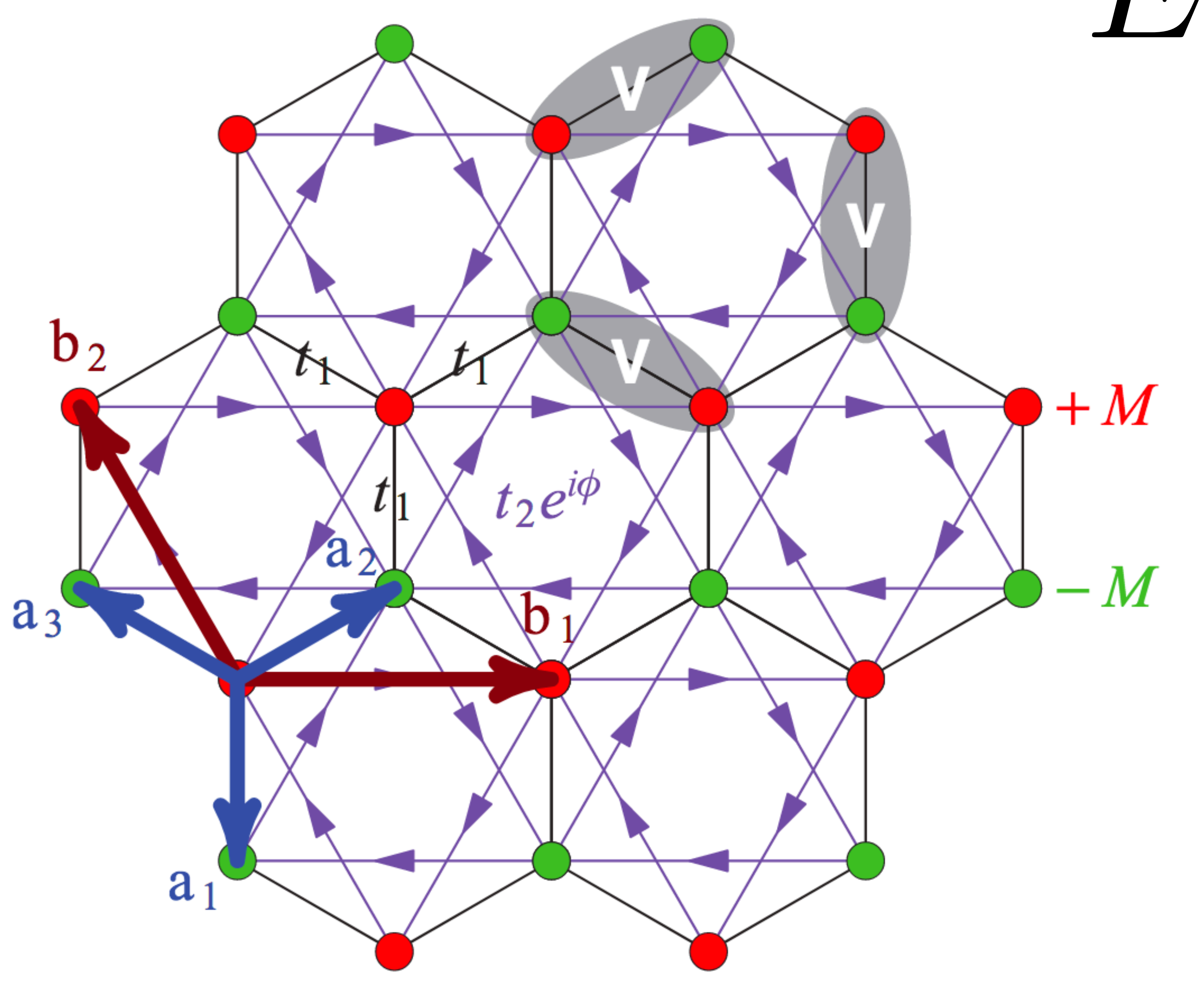
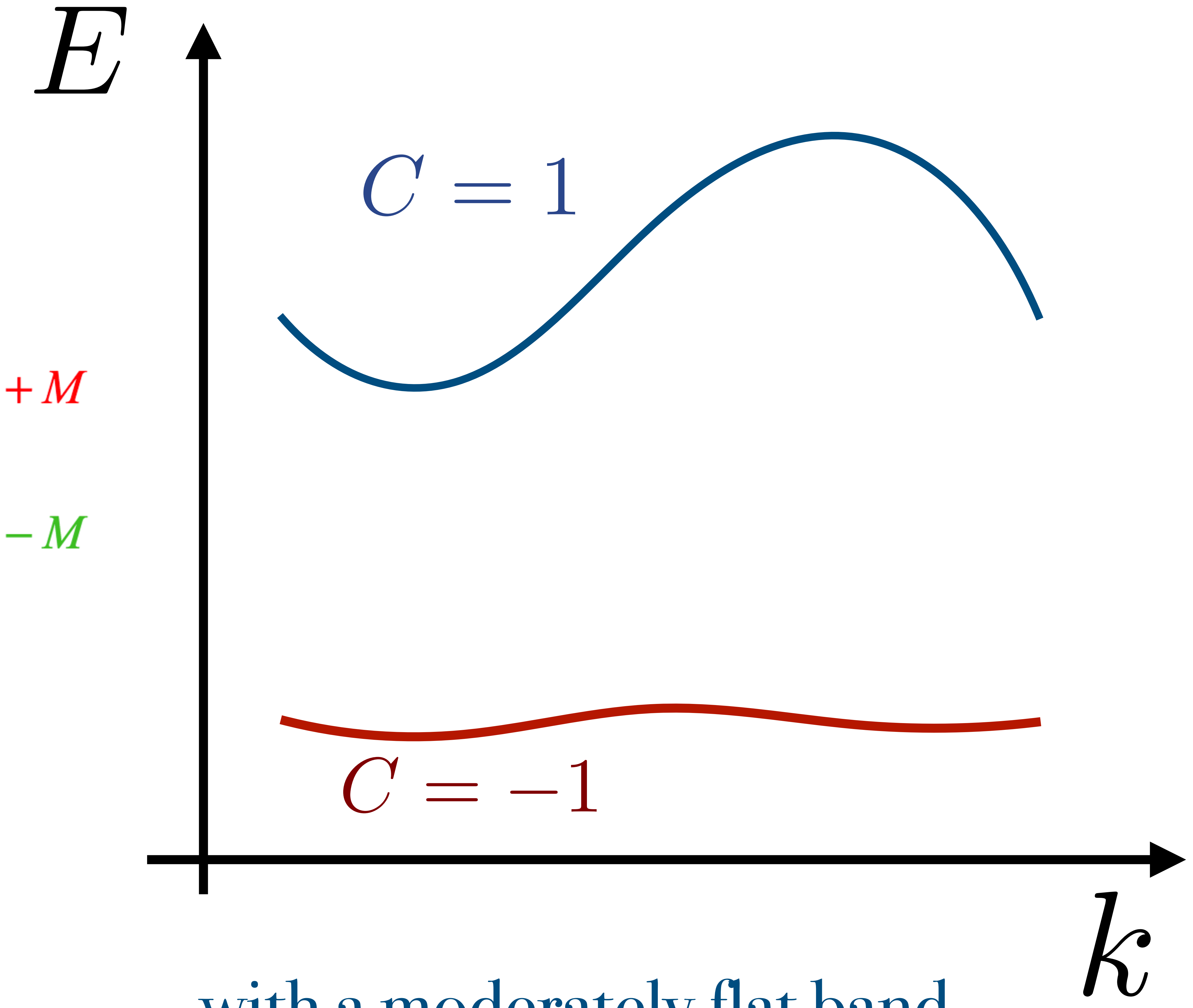
The promise of a fractional quantum Hall effect without Landau levels



A Chern Insulator



with a moderately flat band

Neupert et al. Phys. Scr. T164, 014005, (2015)

Y. L. Wu et al. Phys. Rev. B 85, 075116 (2012)

Emil J. Bergholtz, Zhao Liu Int. J. Mod. Phys. B 27, 1330017 (2013)

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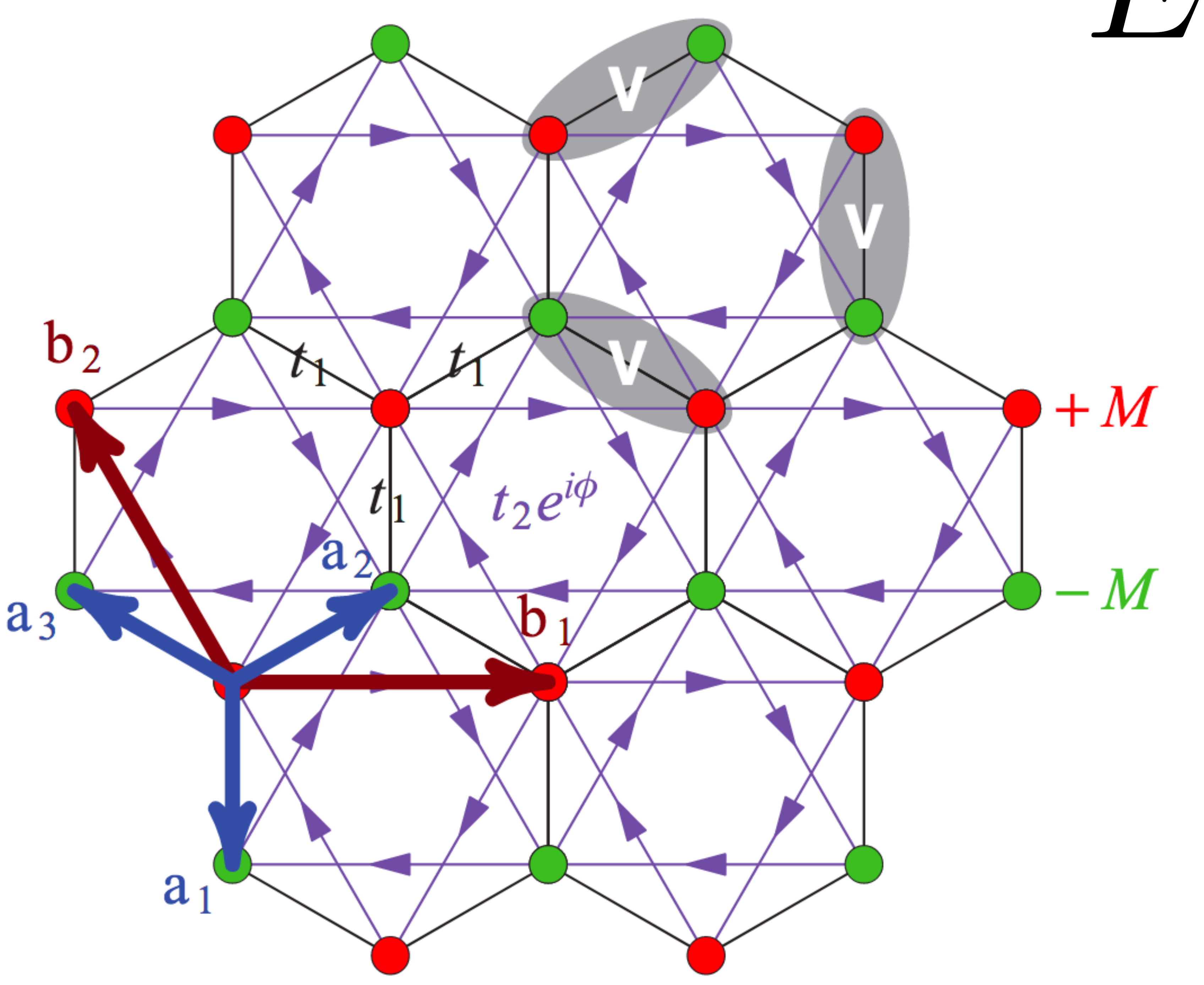

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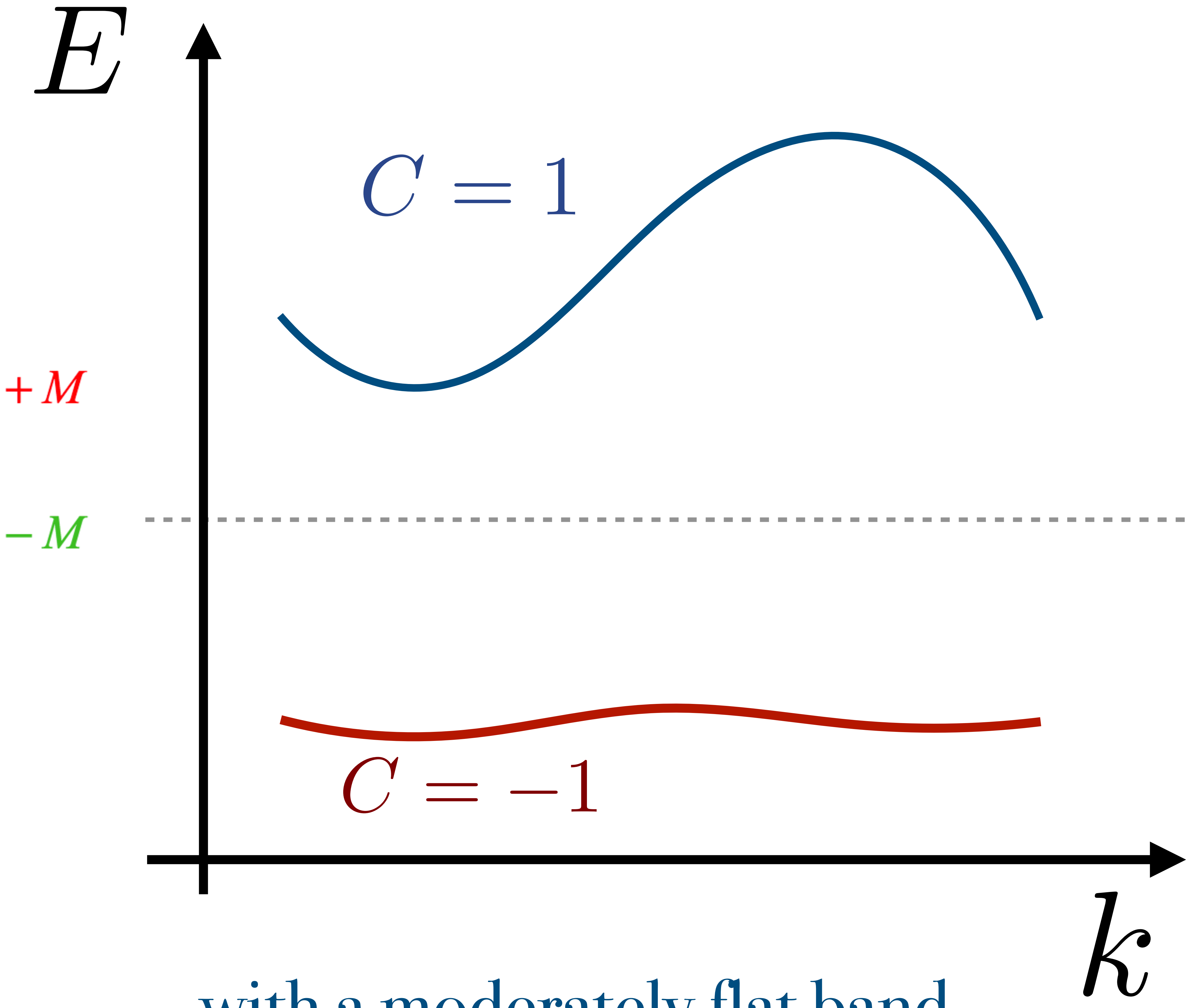

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$$\sigma_{xy} = C\frac{e^2}{h}$$

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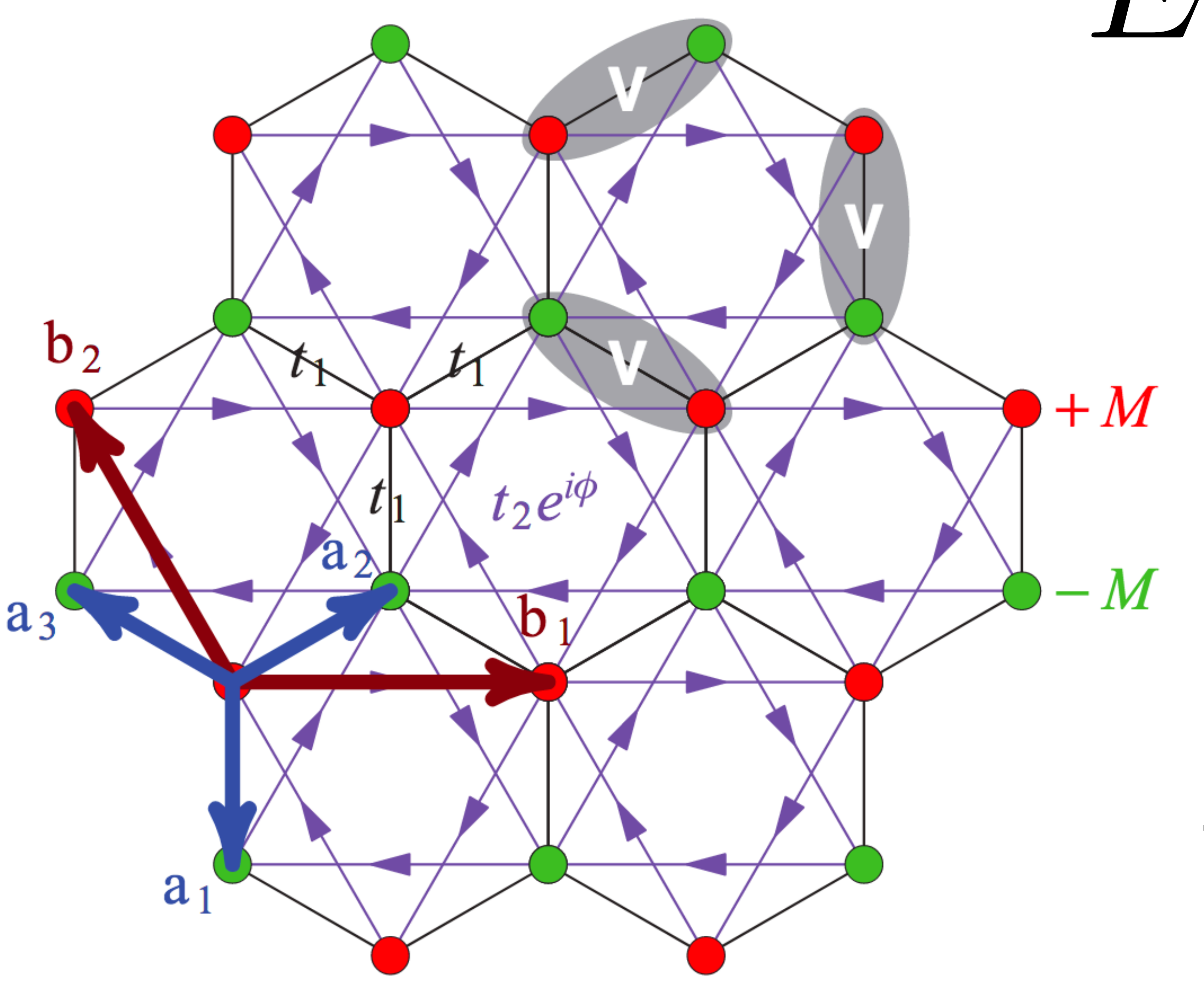
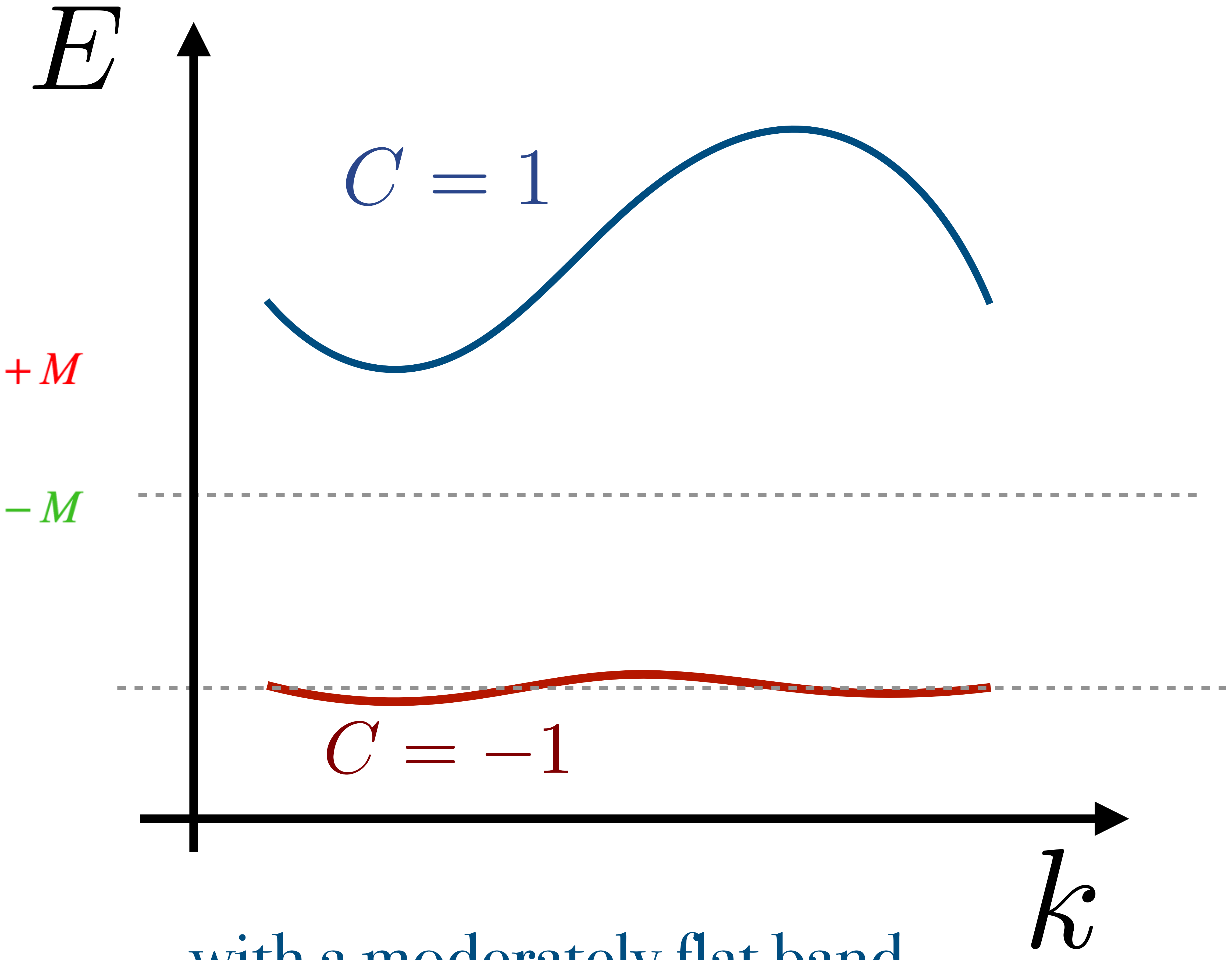


A Chern Insulator



with a moderately flat band

$$\sigma_{xy} = C\frac{e^2}{h}$$

$$\sigma_{xy} = \frac{1}{m}\frac{e^2}{h}$$

at 1/m filling

Neupert et al. Phys. Scr. T164, 014005, (2015)

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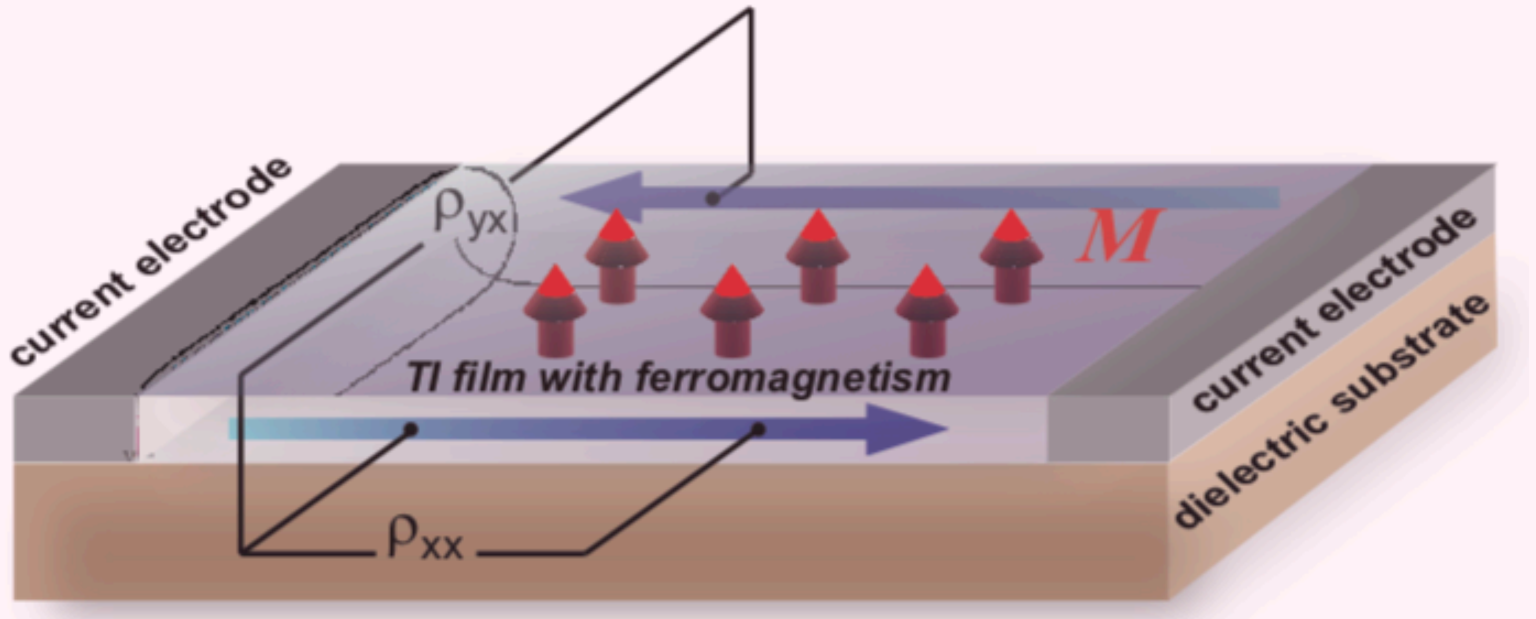
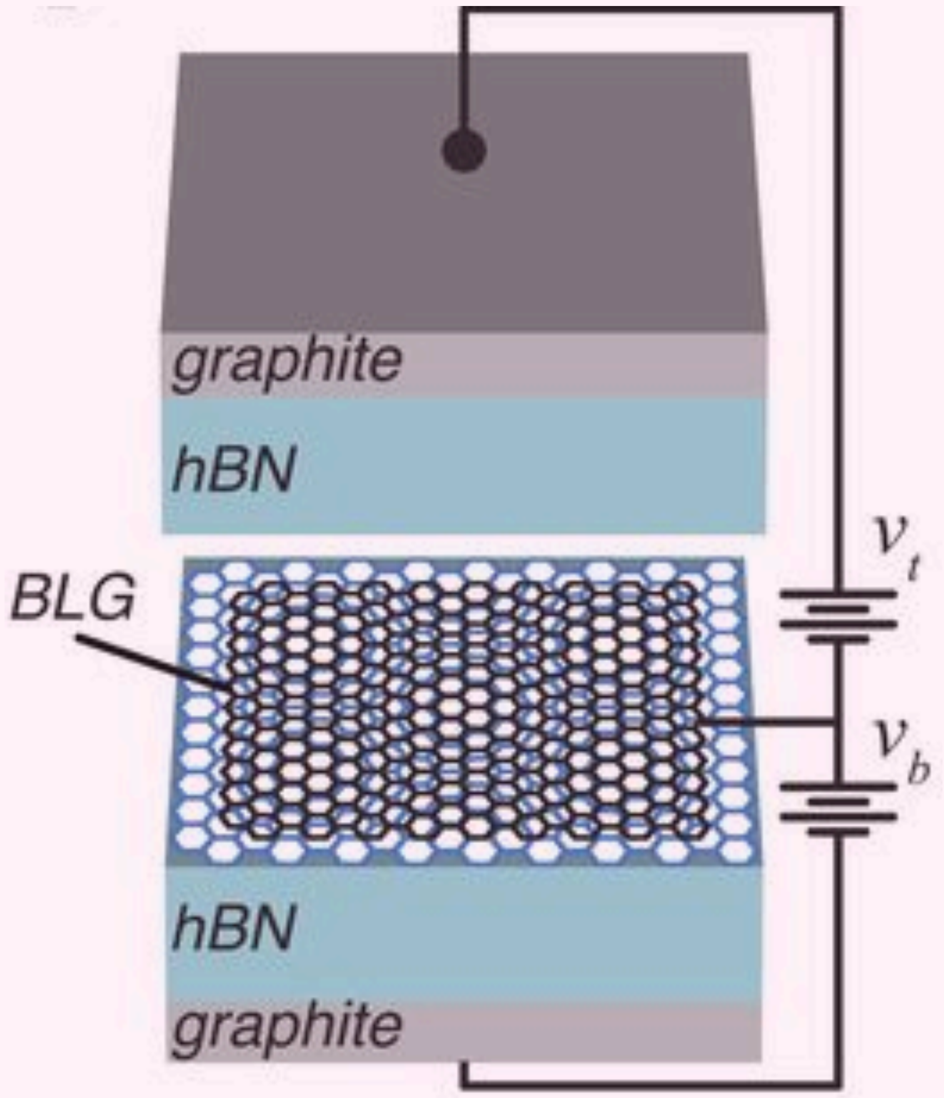
Chern insulators in the solid state



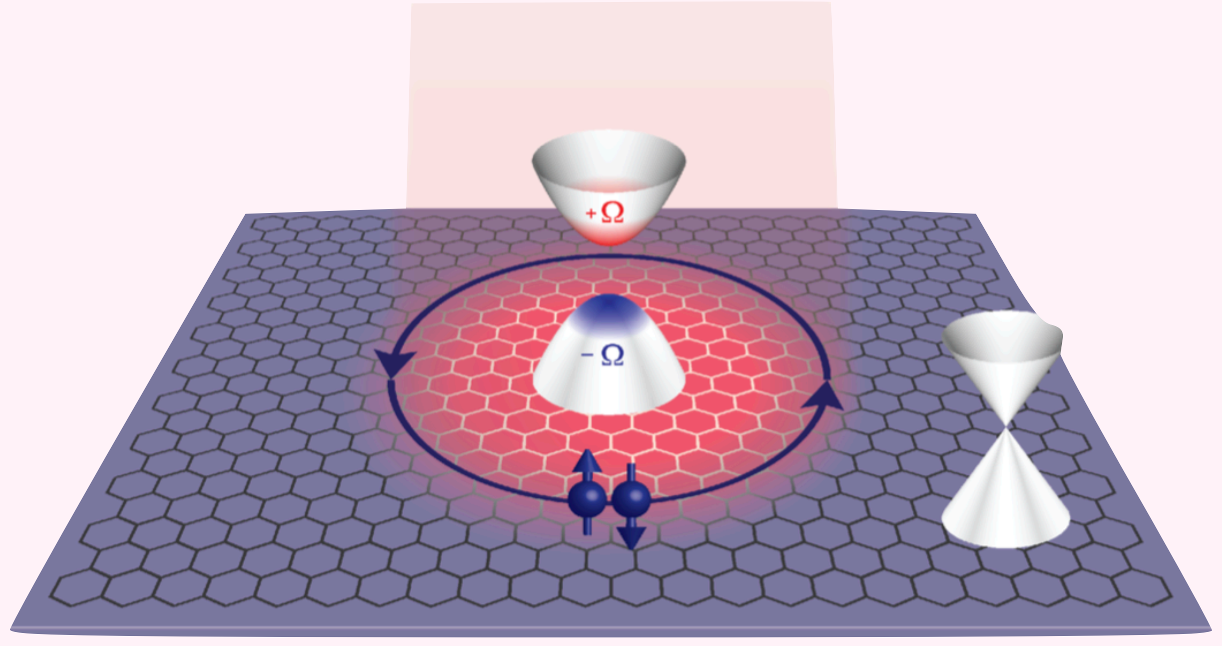
Doped topological insulators

C. Z. Chang Science (2013)



Moire Graphene

E. M. Spanton et. al Science (2018)



Irradiated Graphene

J.W. McIver et al. 1811.03522

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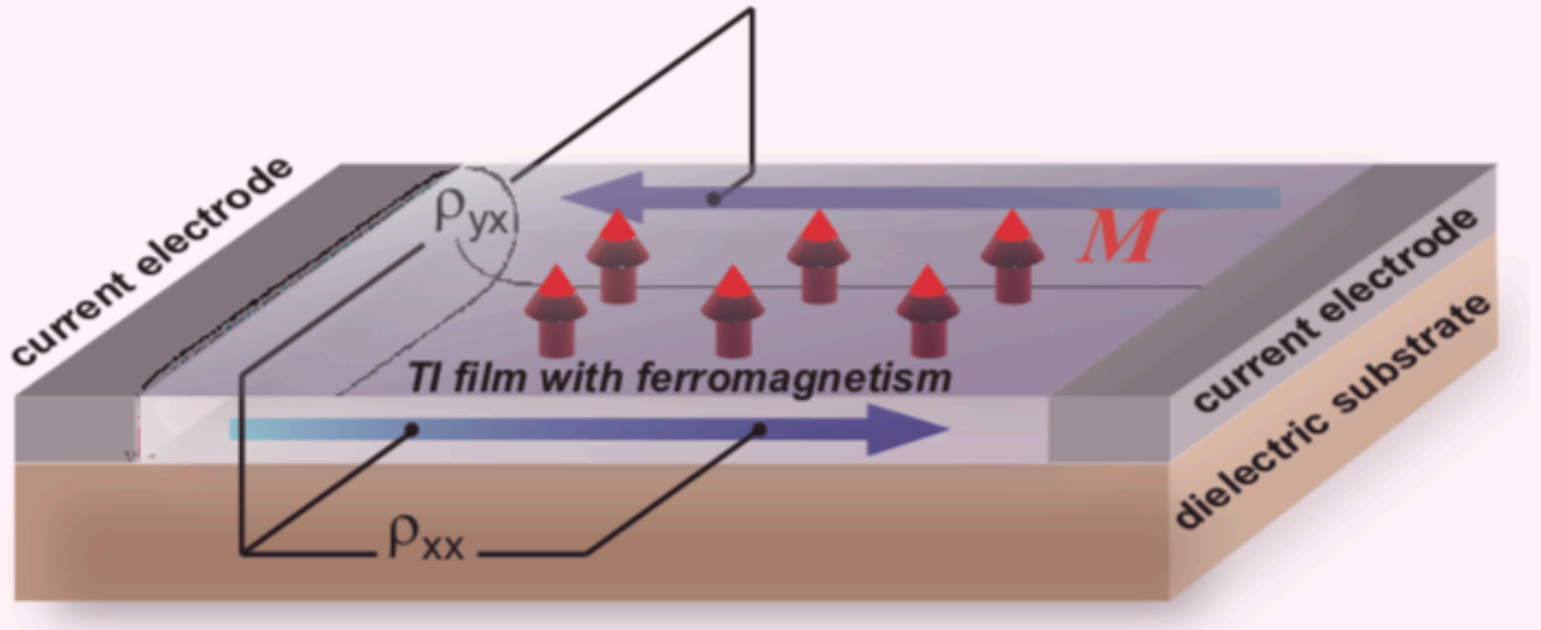

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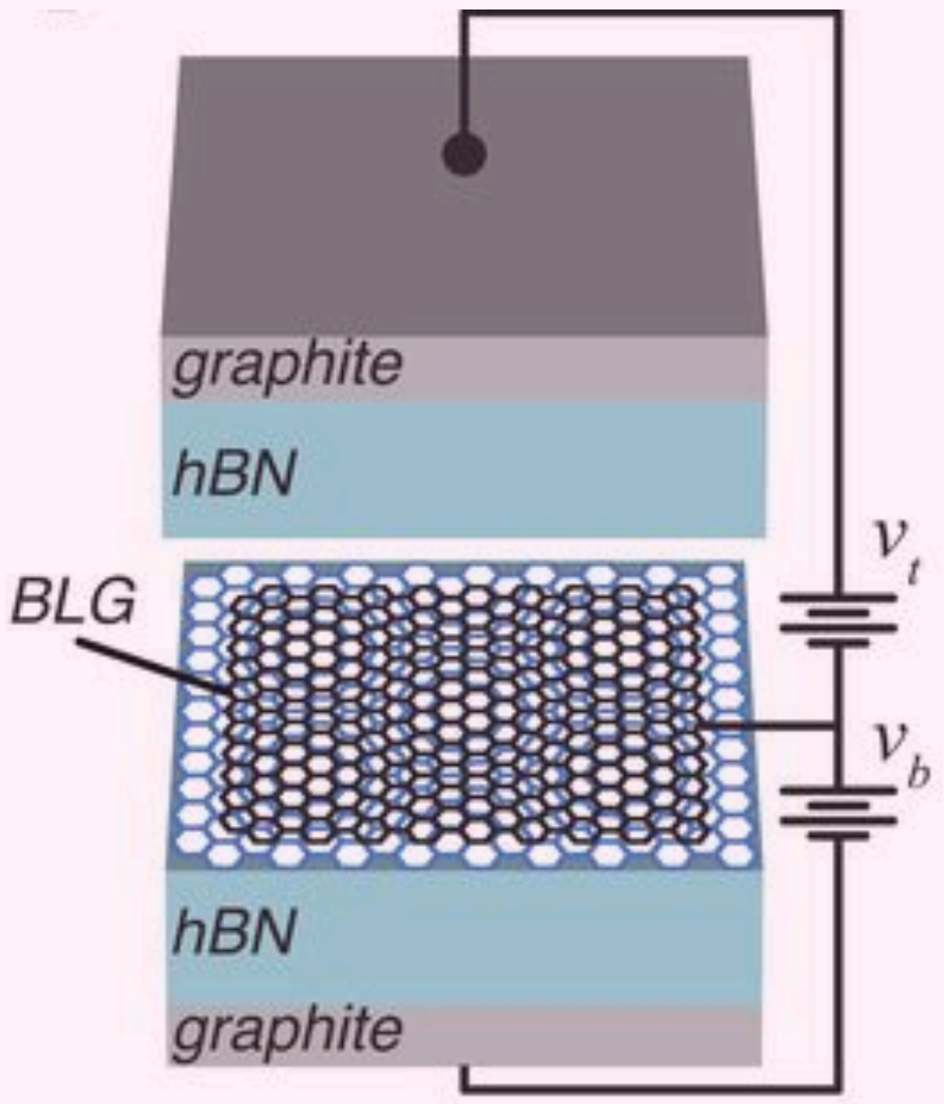
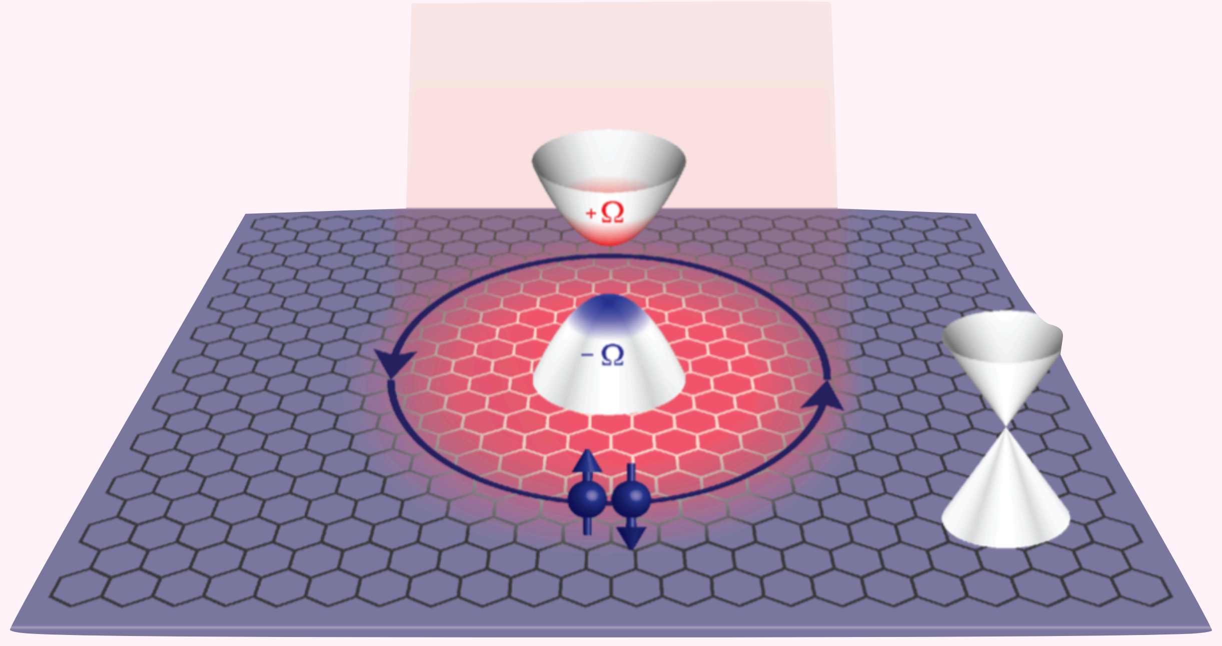


Moire Graphene

E. M. Spanton et. al Science (2018)

Floquet

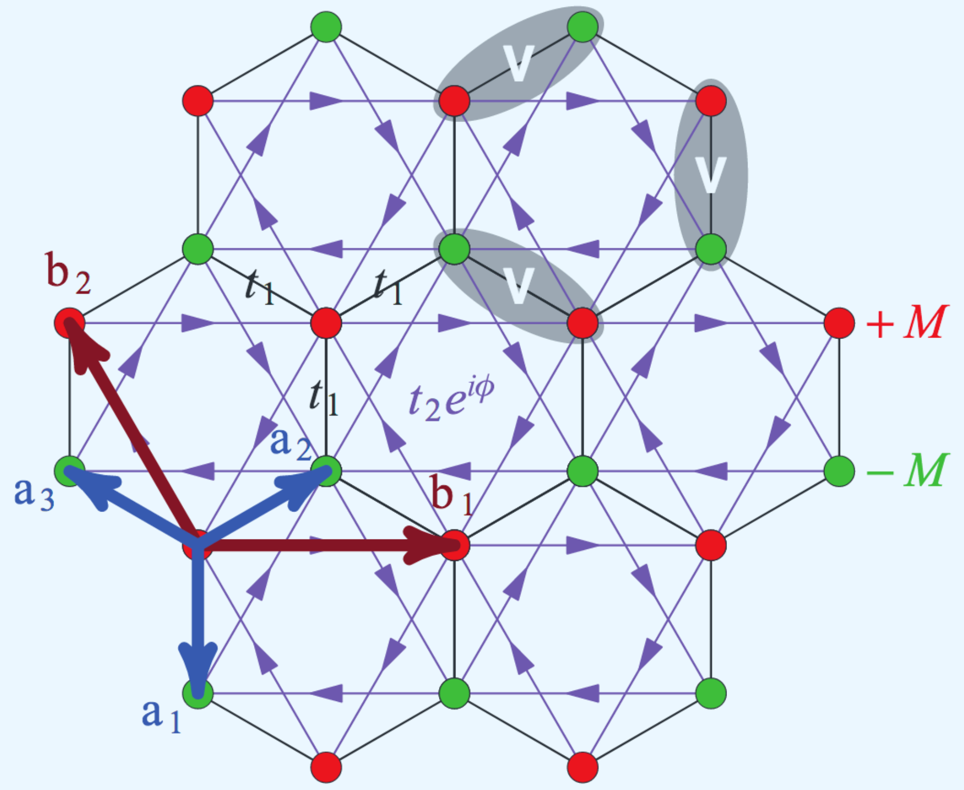


Irradiated Graphene

J.W. McIver et al. 1811.03522

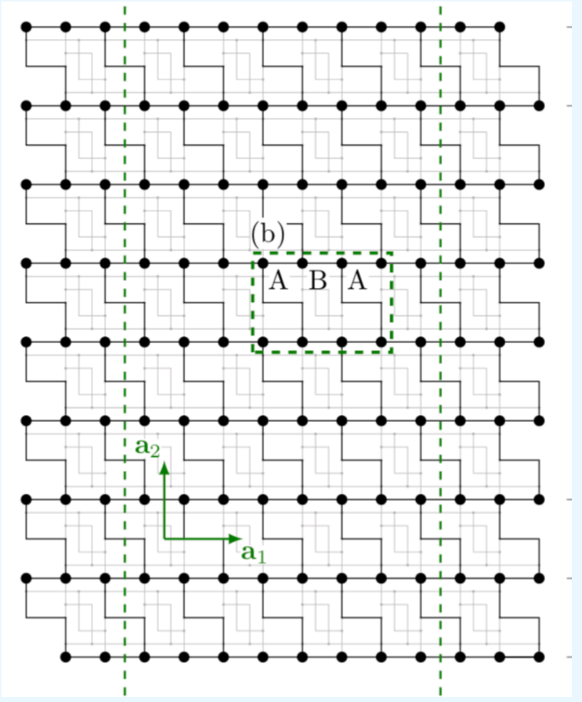
Chern insulators in synthetic matter

Ultra-cold fermions



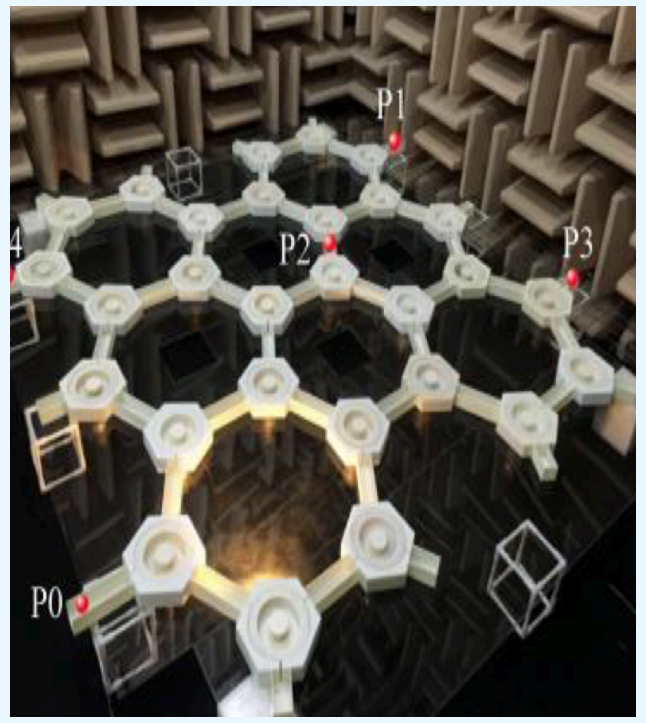
G. Jotzu et. al Nature 2014

Circuit



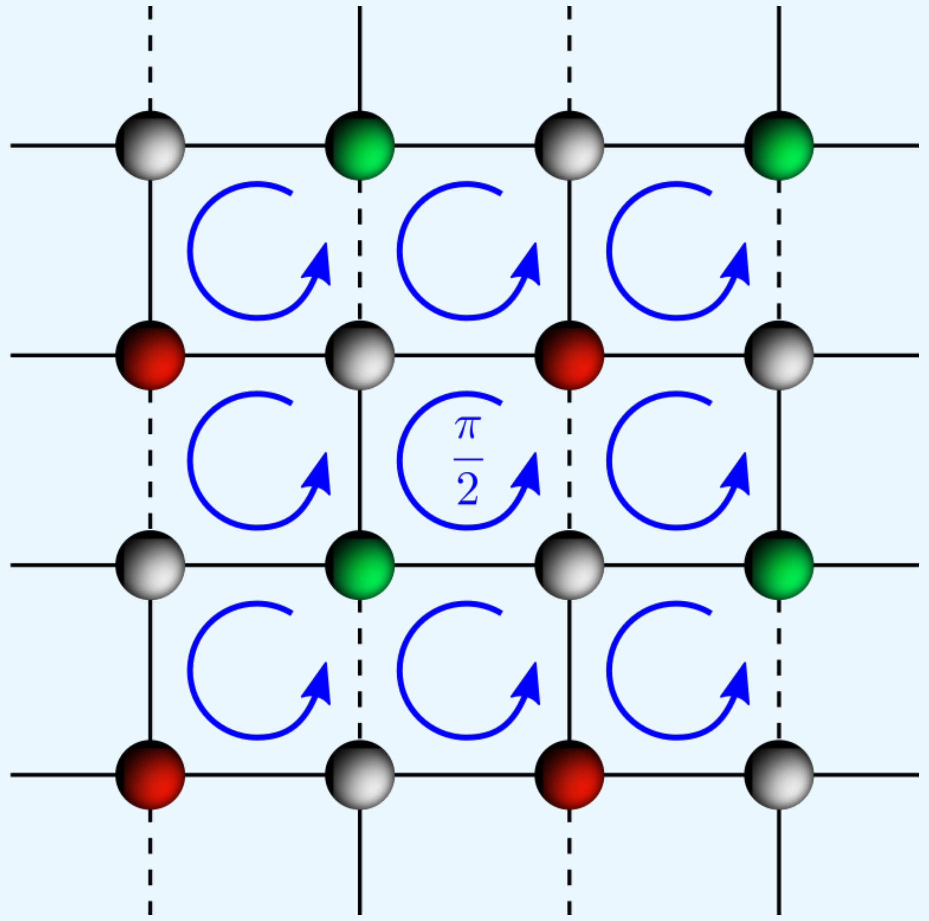
T. Hofmann et al. 1801.07942

Acoustic



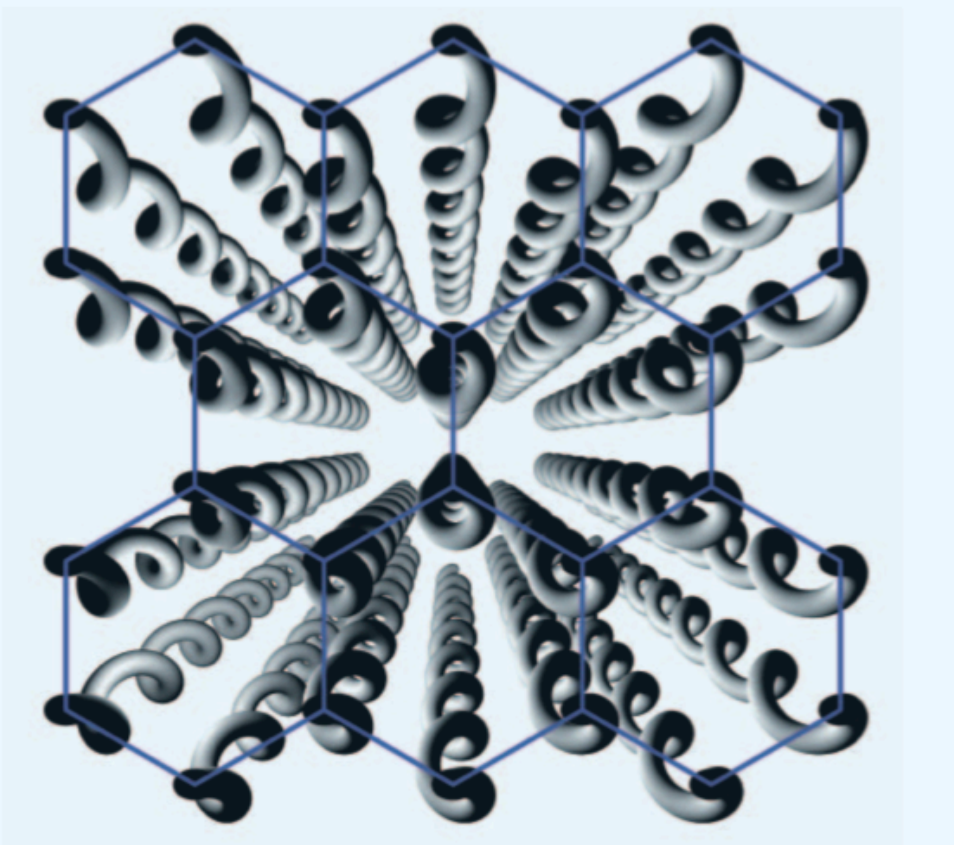
Y. Zhu et al. 1801.07942

Ultra-cold bosons



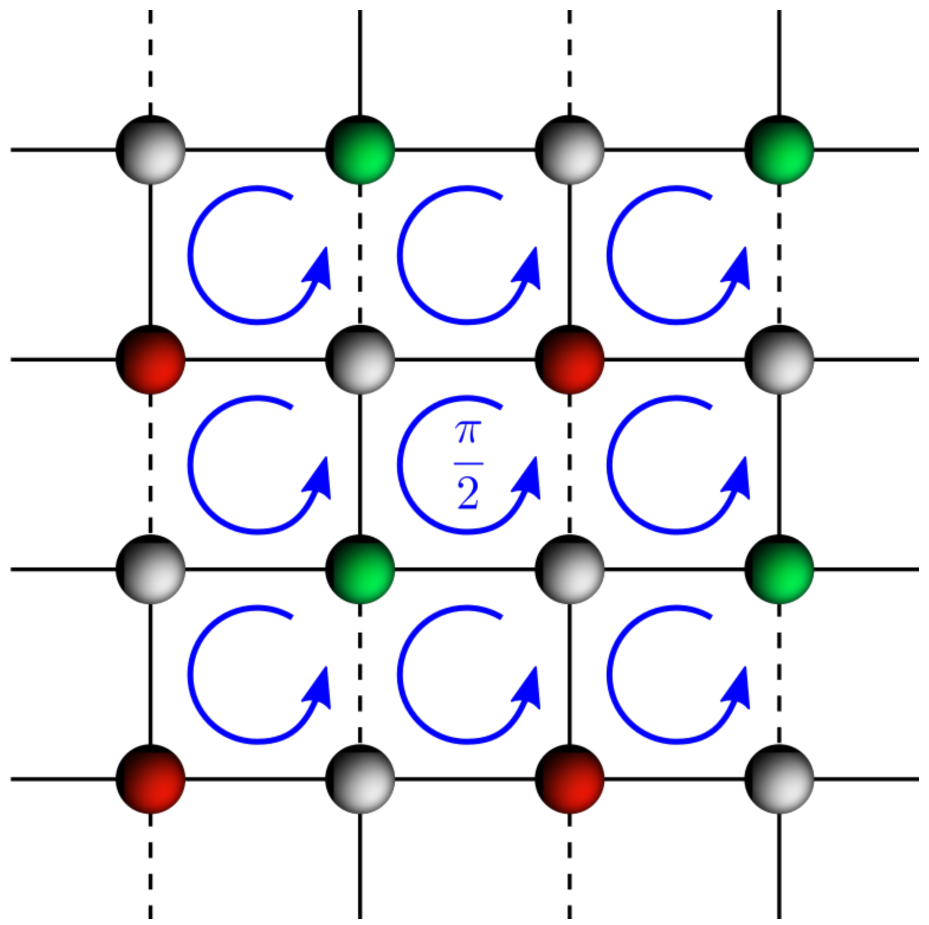
Aidelsburger et. al Nat. Phys (2013)

Photonic



M. Rechtsman, Nature (2013)

Ultra-cold bosons



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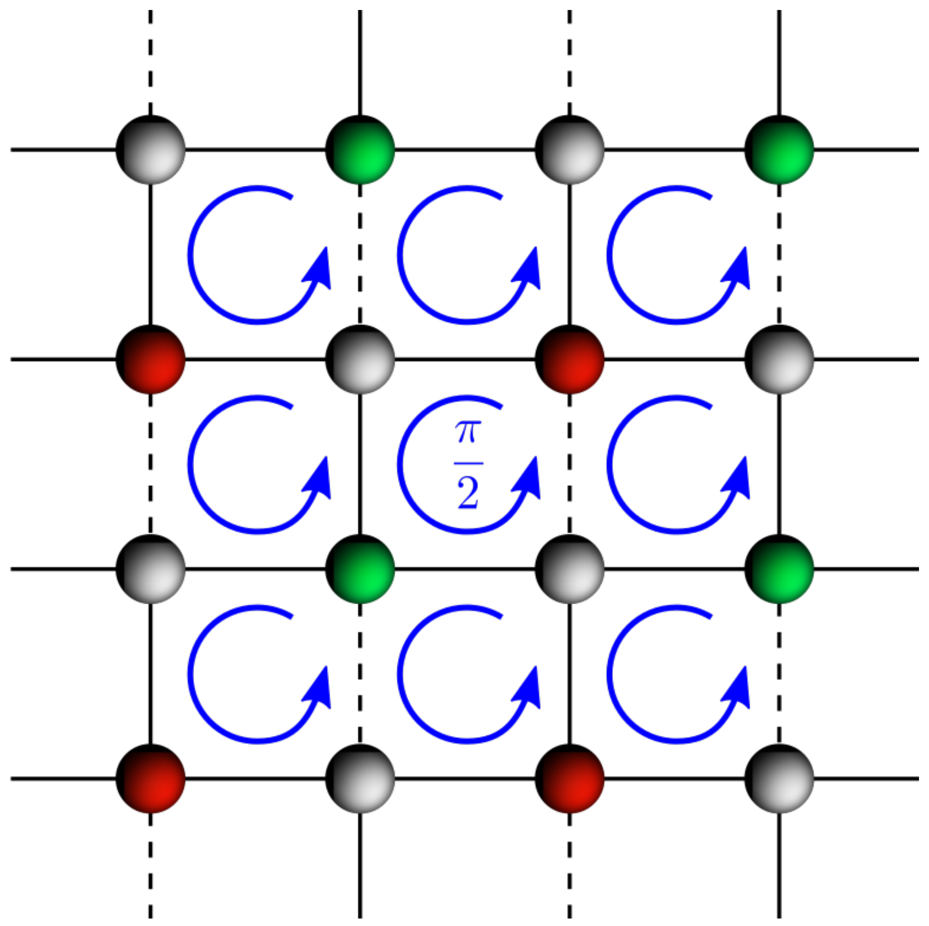
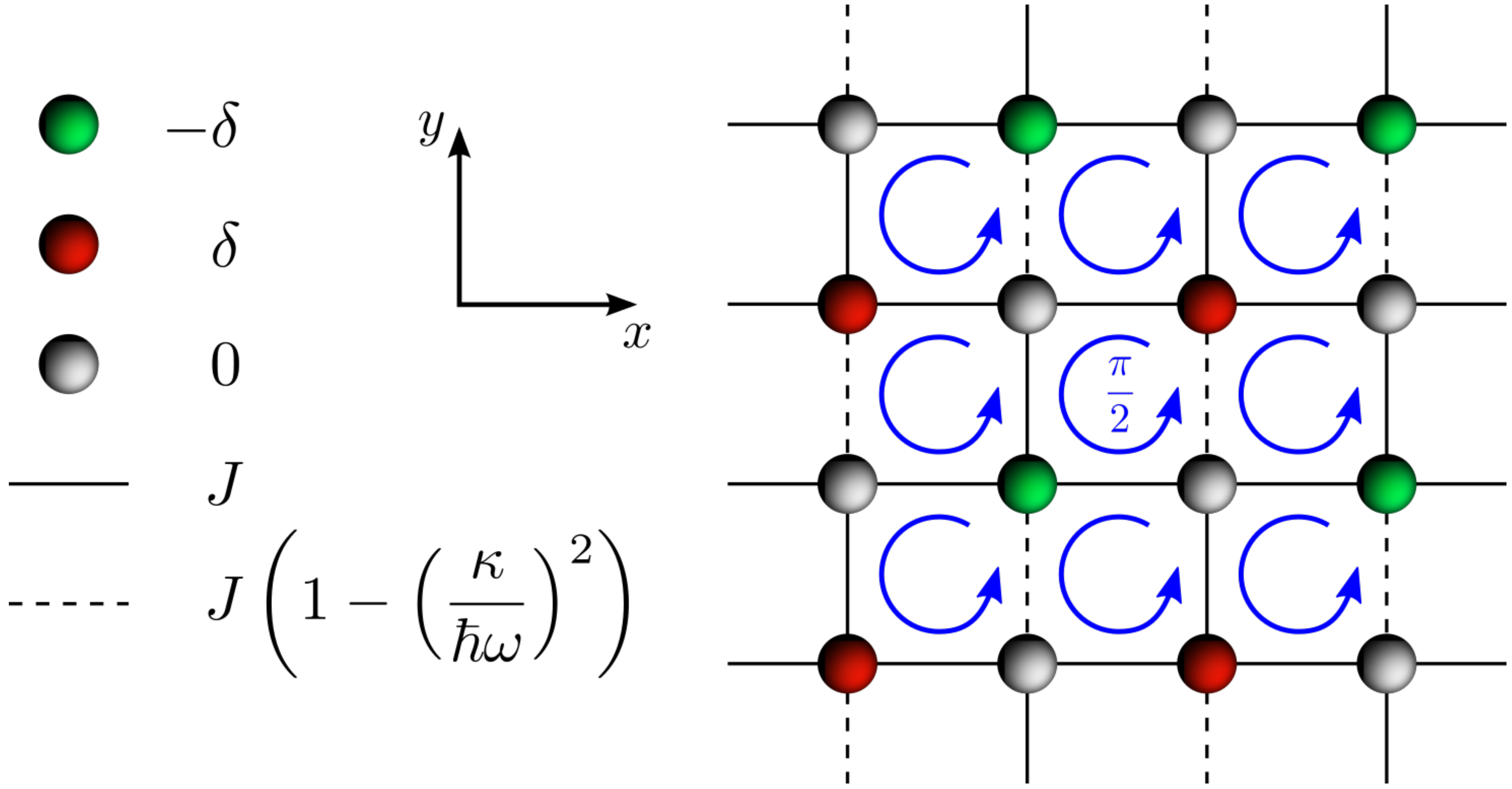


Aidelsburger et. al Nat. Phys (2013)

(Floquet) Chern insulator with ultra cold bosons

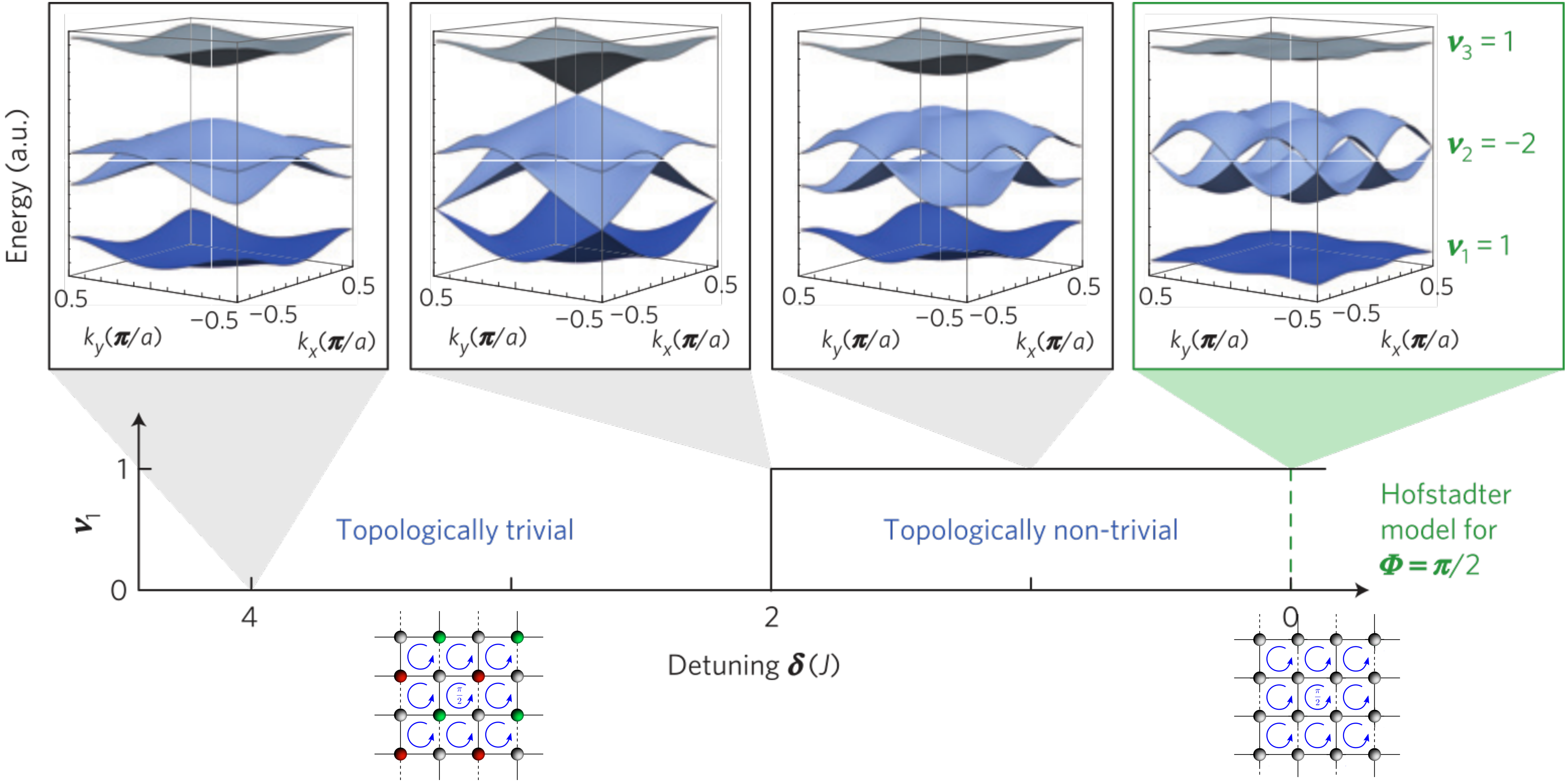


$$H_{\text{eff}} = -J\sum_{m,n}\{\hat{a}^\dagger_{m+1,n}\hat{a}_{m,n}e^{i[\pi/2(m+n)-\phi_0]} + (1+f_{m,n})\hat{a}^\dagger_{m,n+1}\hat{a}_{m,n} + \text{h.c.}\} \; + \frac{\delta}{2}\sum_{m,n}[(-1)^m + (-1)^n]\hat{n}_{m,n}$$

M. Aidelsburger et al. Nat. Phys (2015)

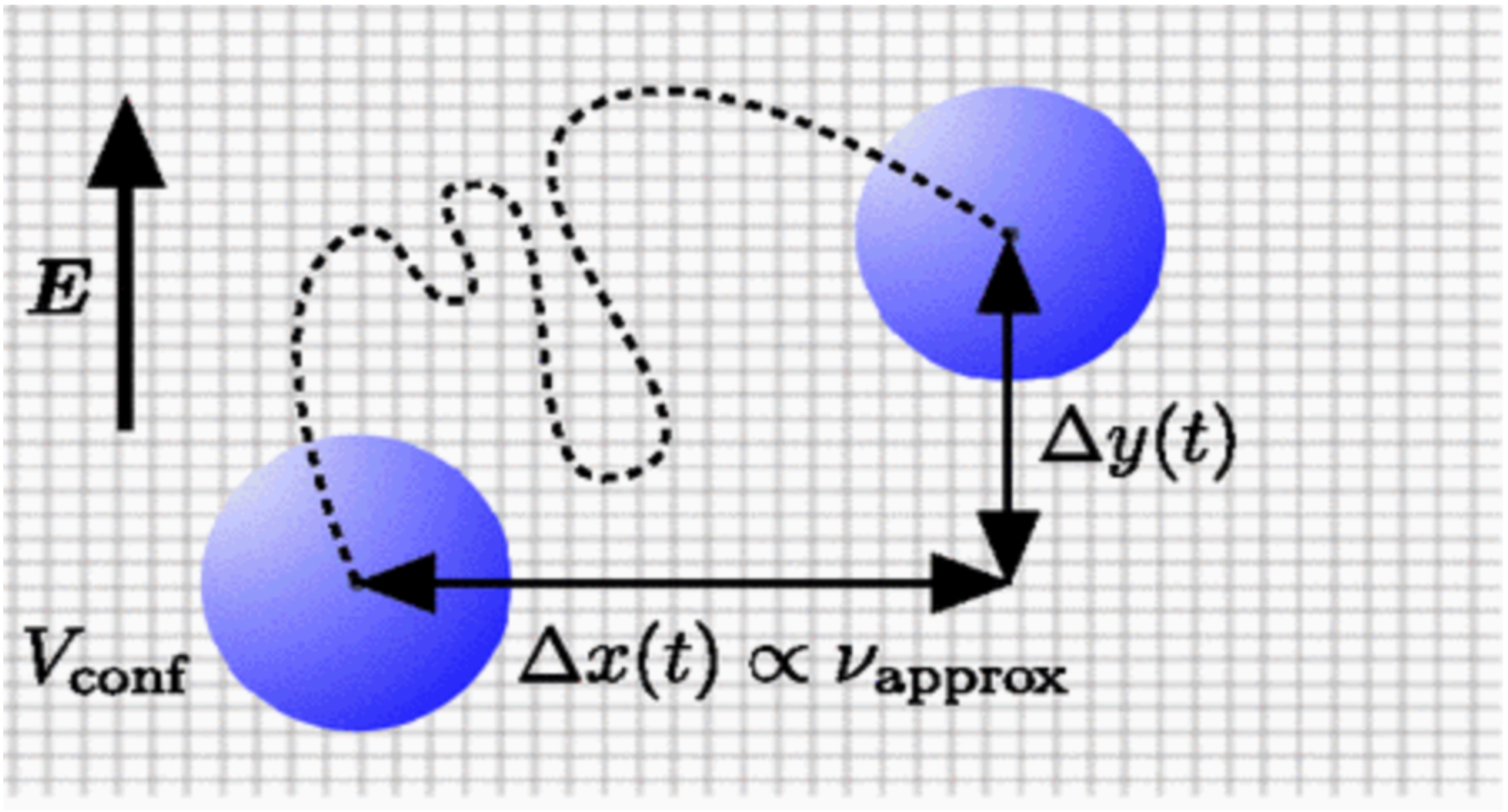
(Floquet) Chern insulator with ultra cold bosons

M. Aidelsburger et al. Nat. Phys (2015)



How does one know it is a Chern insulator?

Wave packet motion



A. Dauphin and N. Goldman PRL 2013

$$x(t) = -(a^2 t E_y / \pi\hbar)\nu_{\text{approx}},$$

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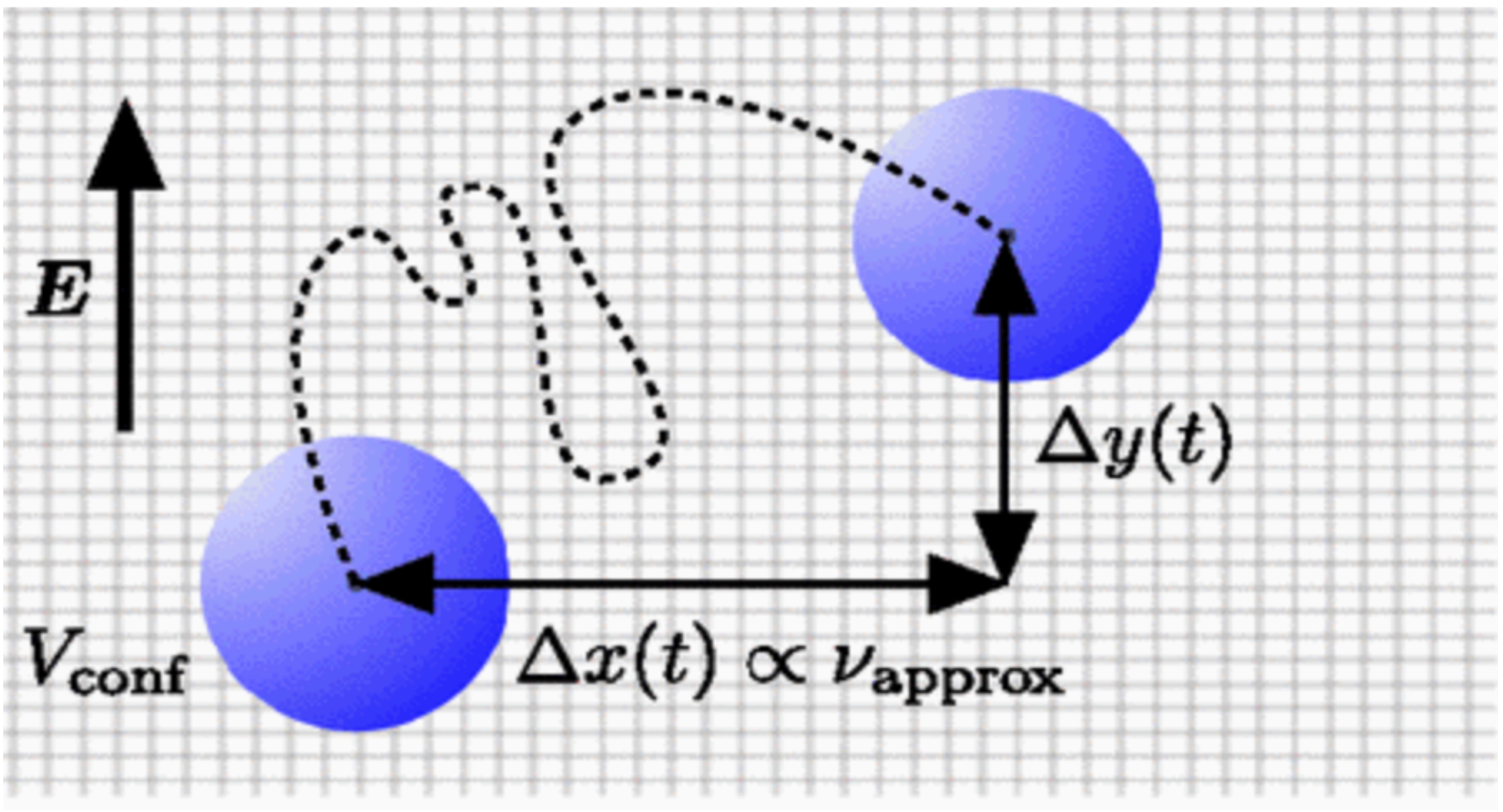

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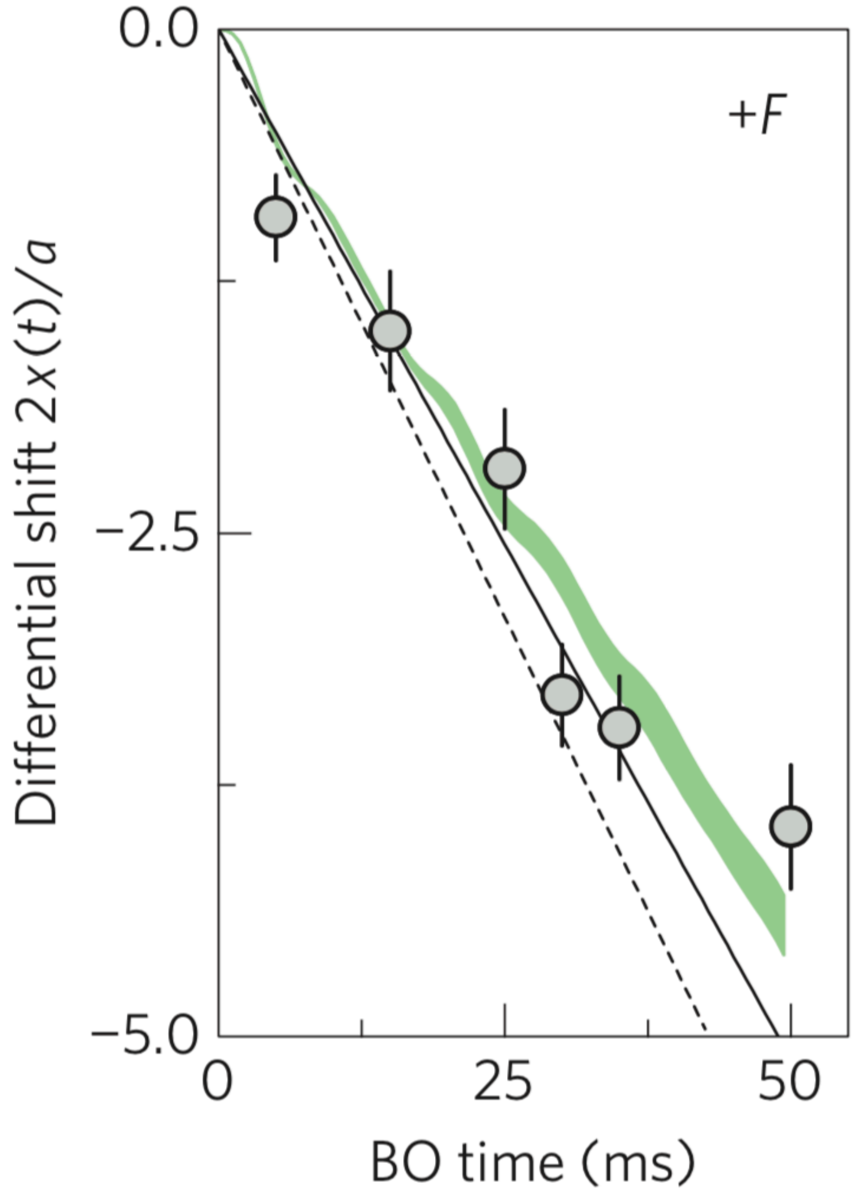

M. Aidelsburger et al. Nat. Phys (2015)

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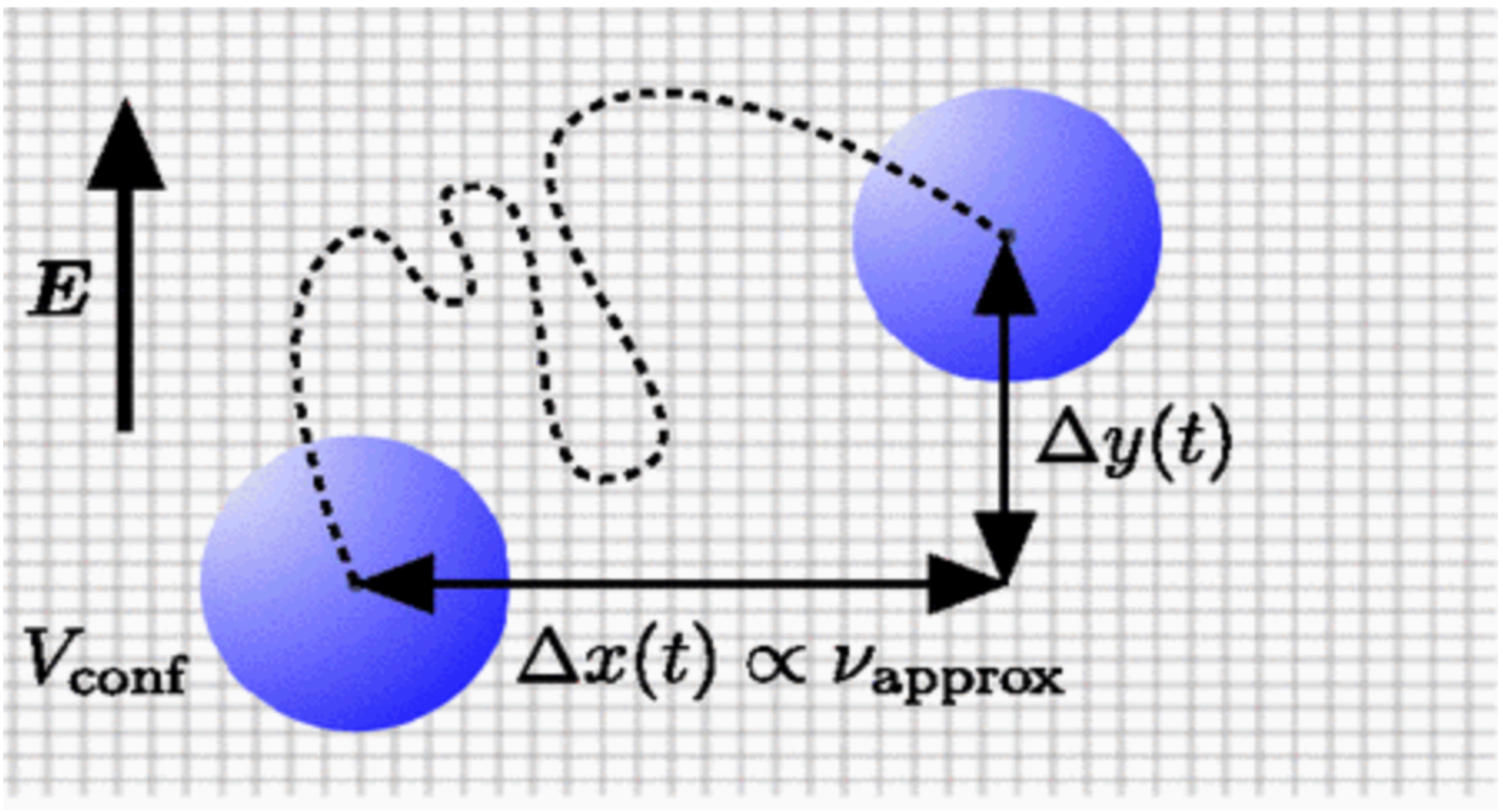

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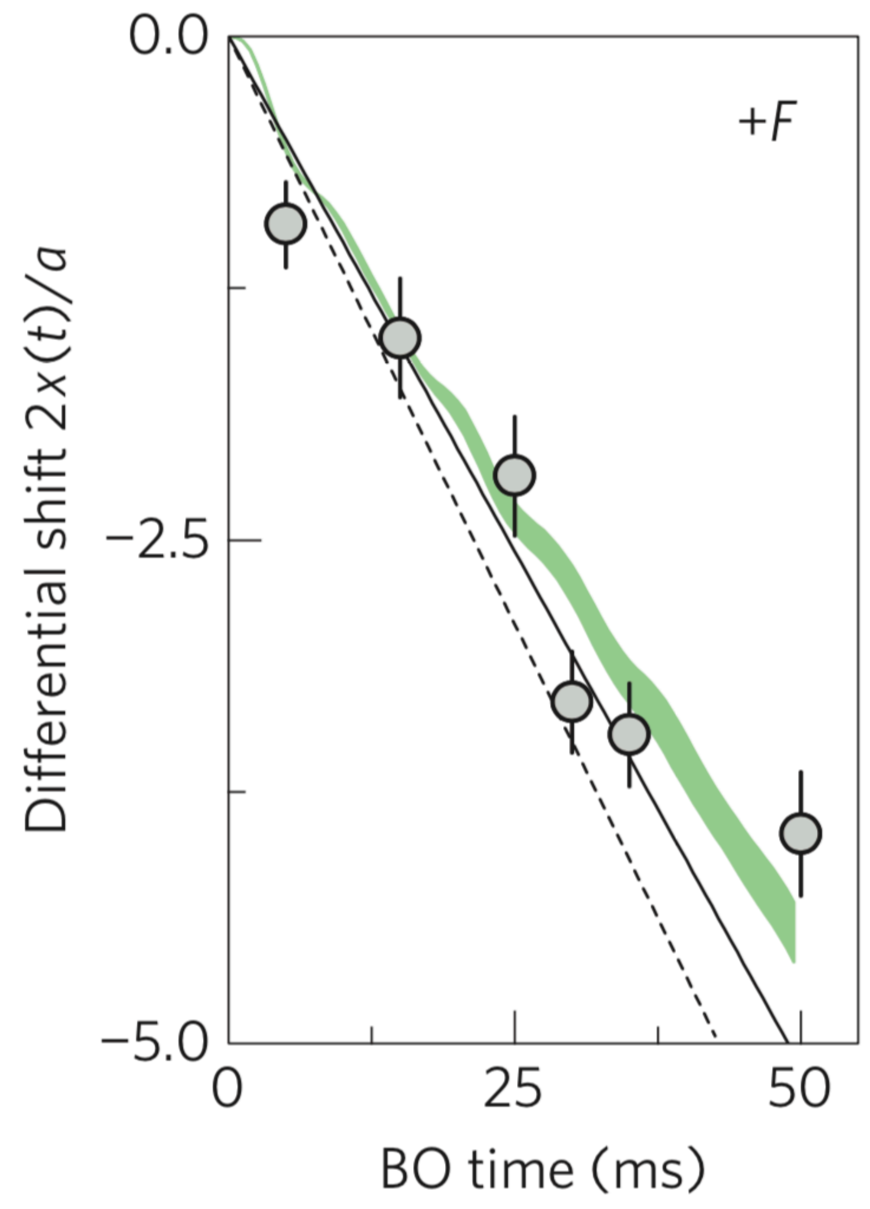

M. Aidelsburger et al. Nat. Phys (2015)

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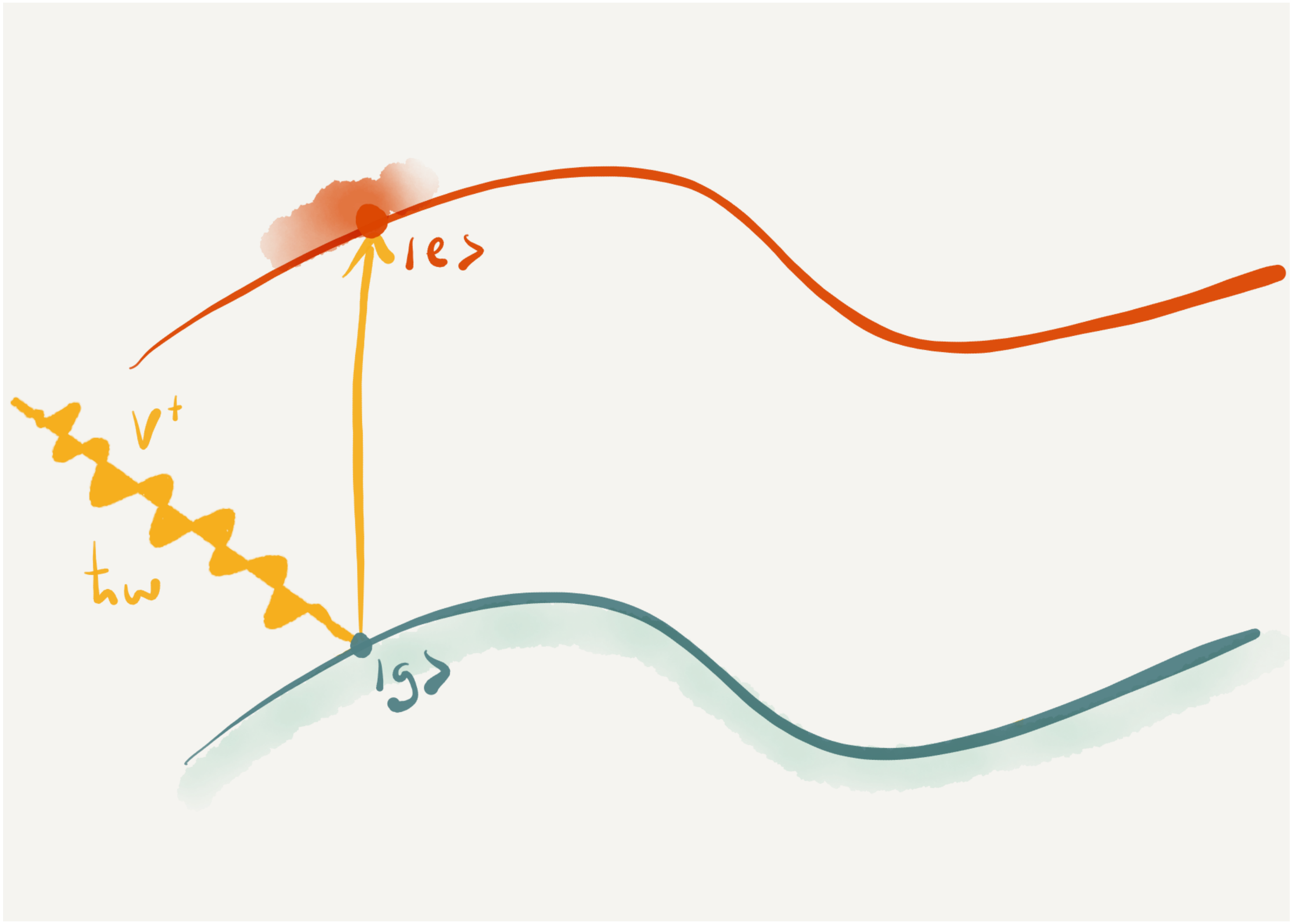
Circular dichroism

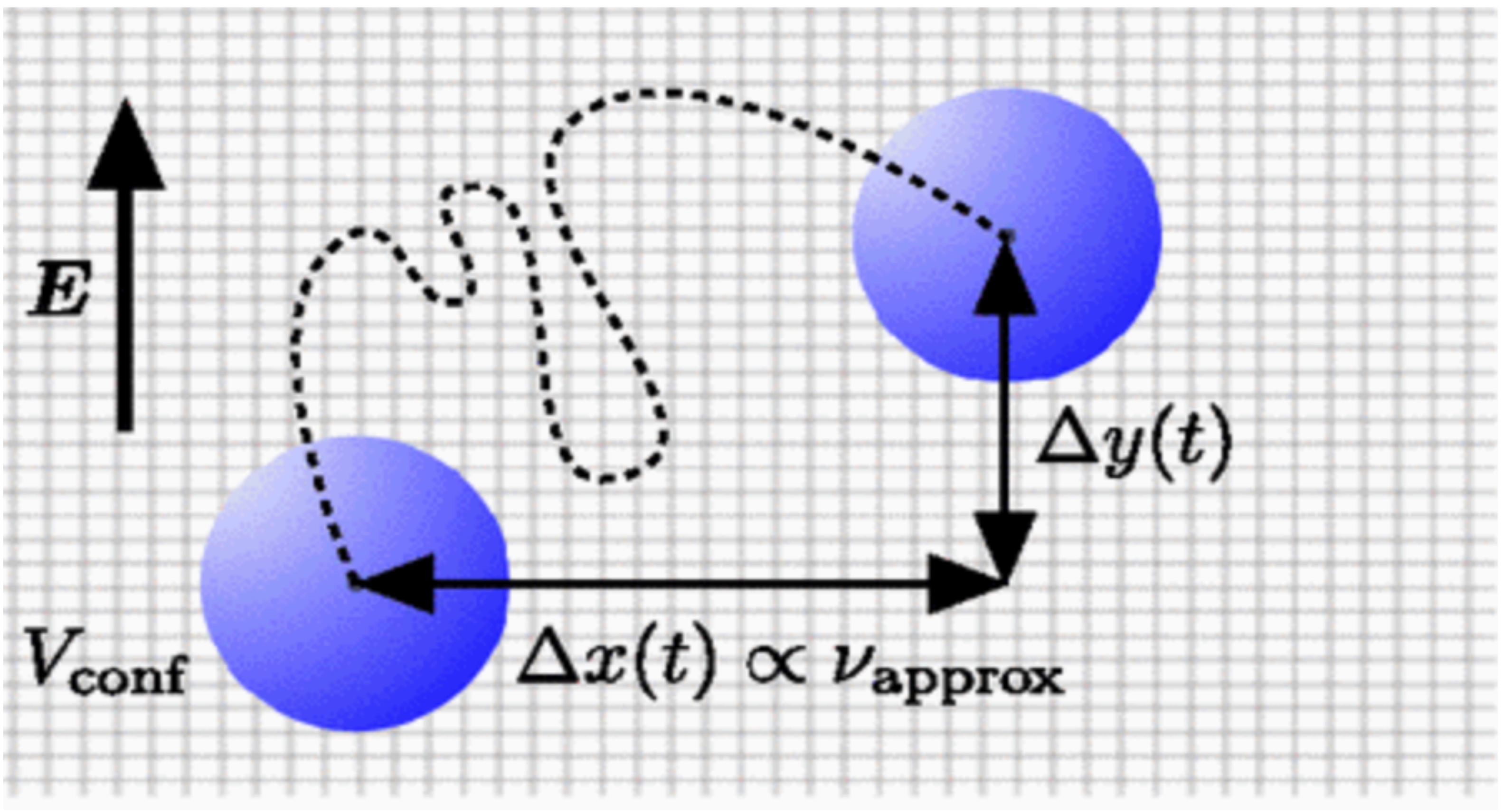


D. T. Tran, A. Dauphin, AGG, N. Goldman, P. Zoller Sci. Adv. (2018)

$$(\Gamma_+^{\text{int}} - \Gamma_-^{\text{int}})/2A_{\text{cell}} = (E_{\text{sp}}/\hbar)^2 C$$

How does one know it is a Chern insulator?

Wave packet motion



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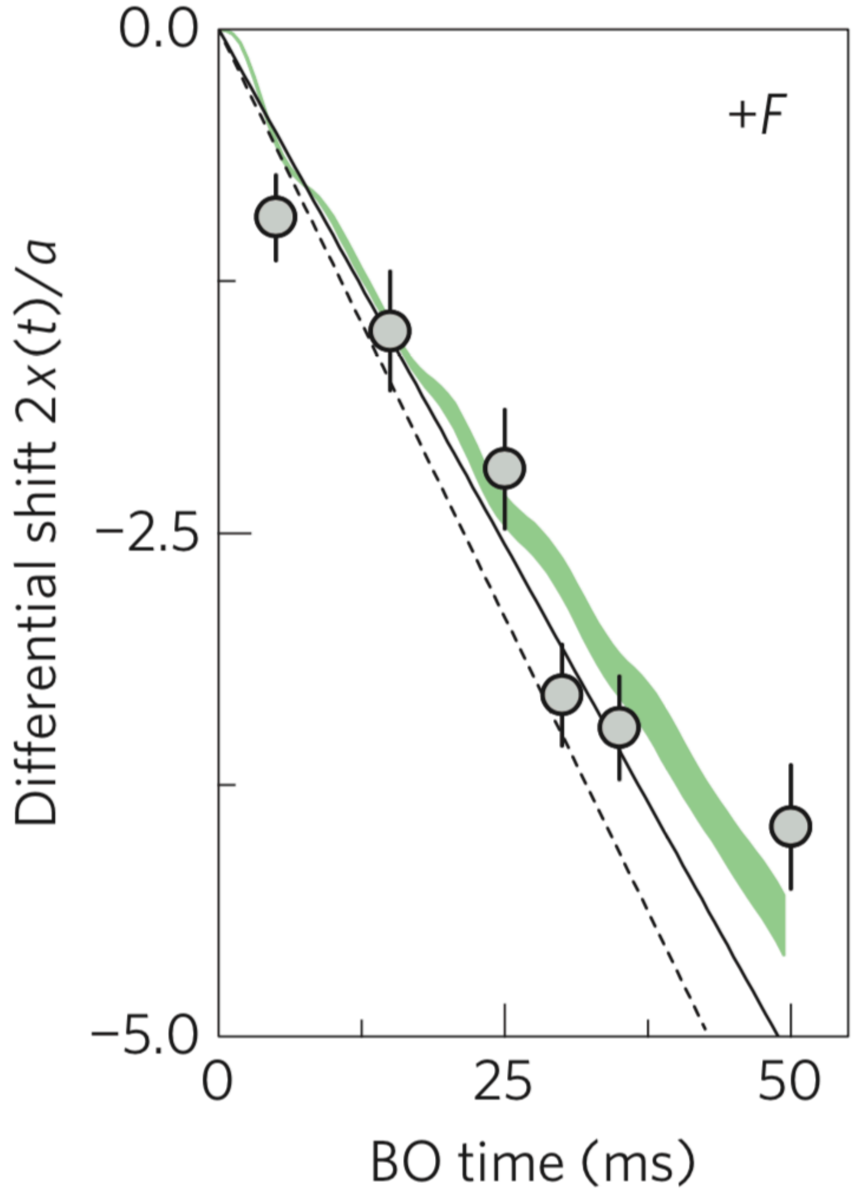

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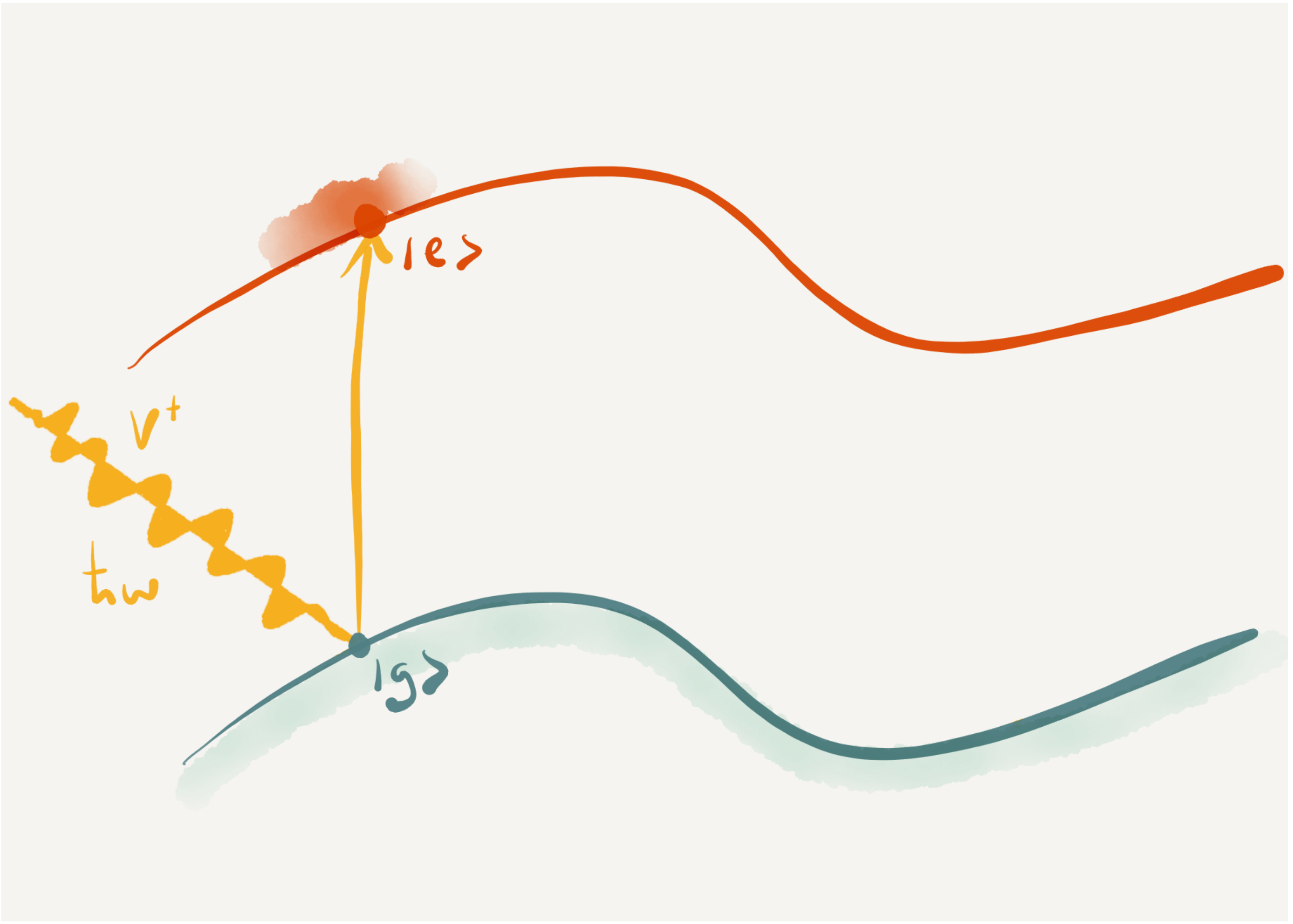

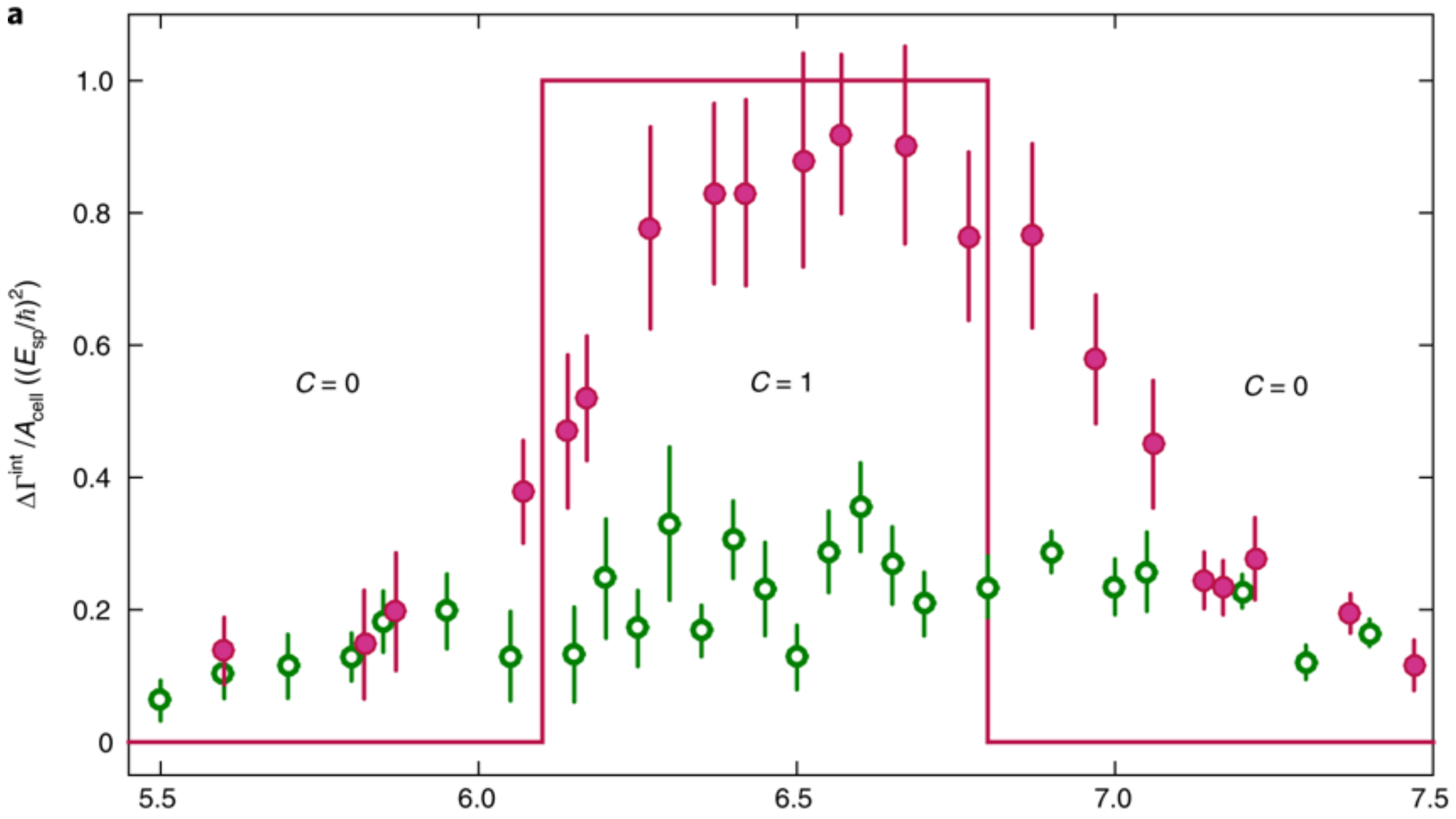

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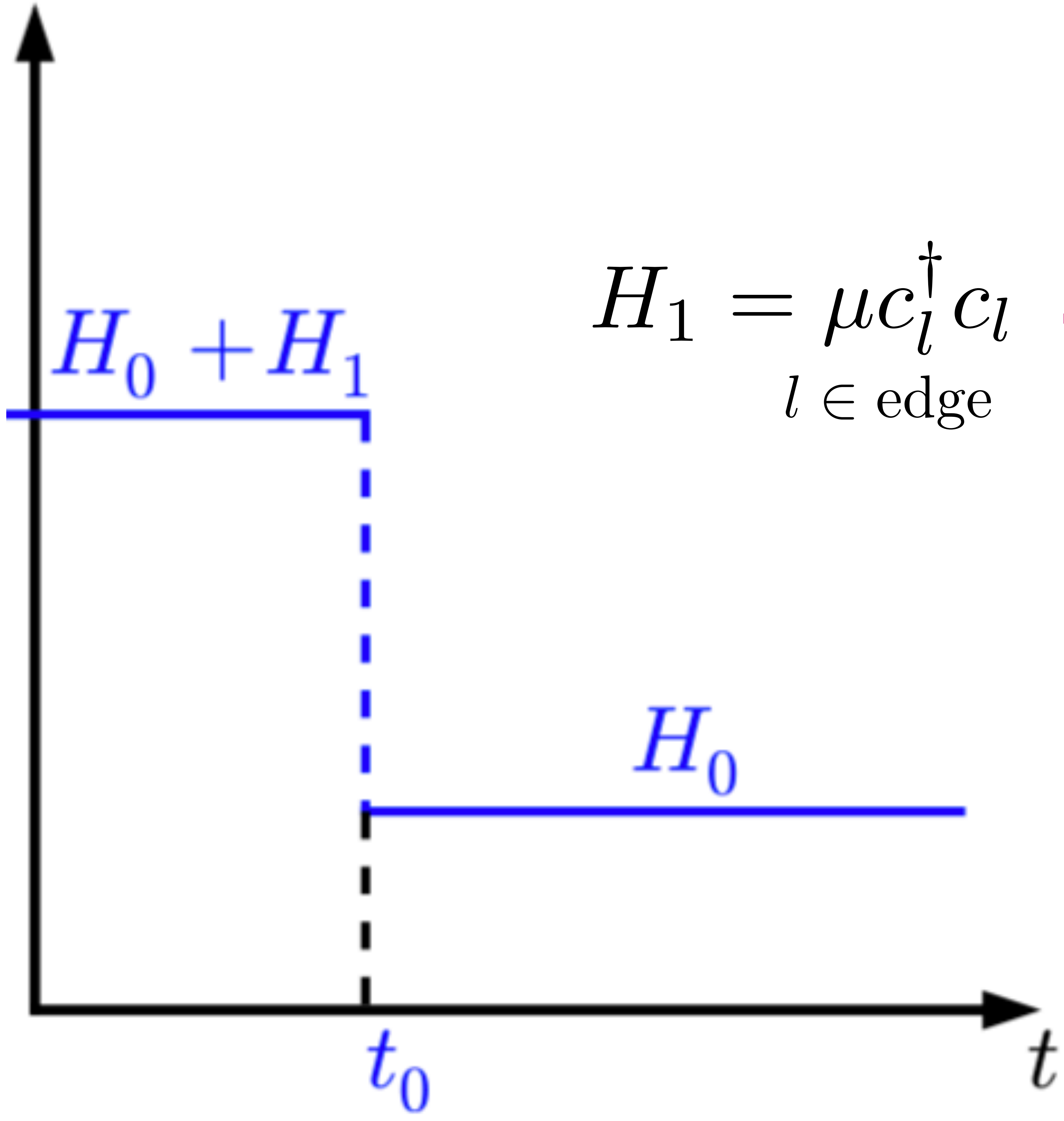
D. T. Tran, A. Dauphin, AGG, N. Goldman, P. Zoller Sci. Adv. (2018)

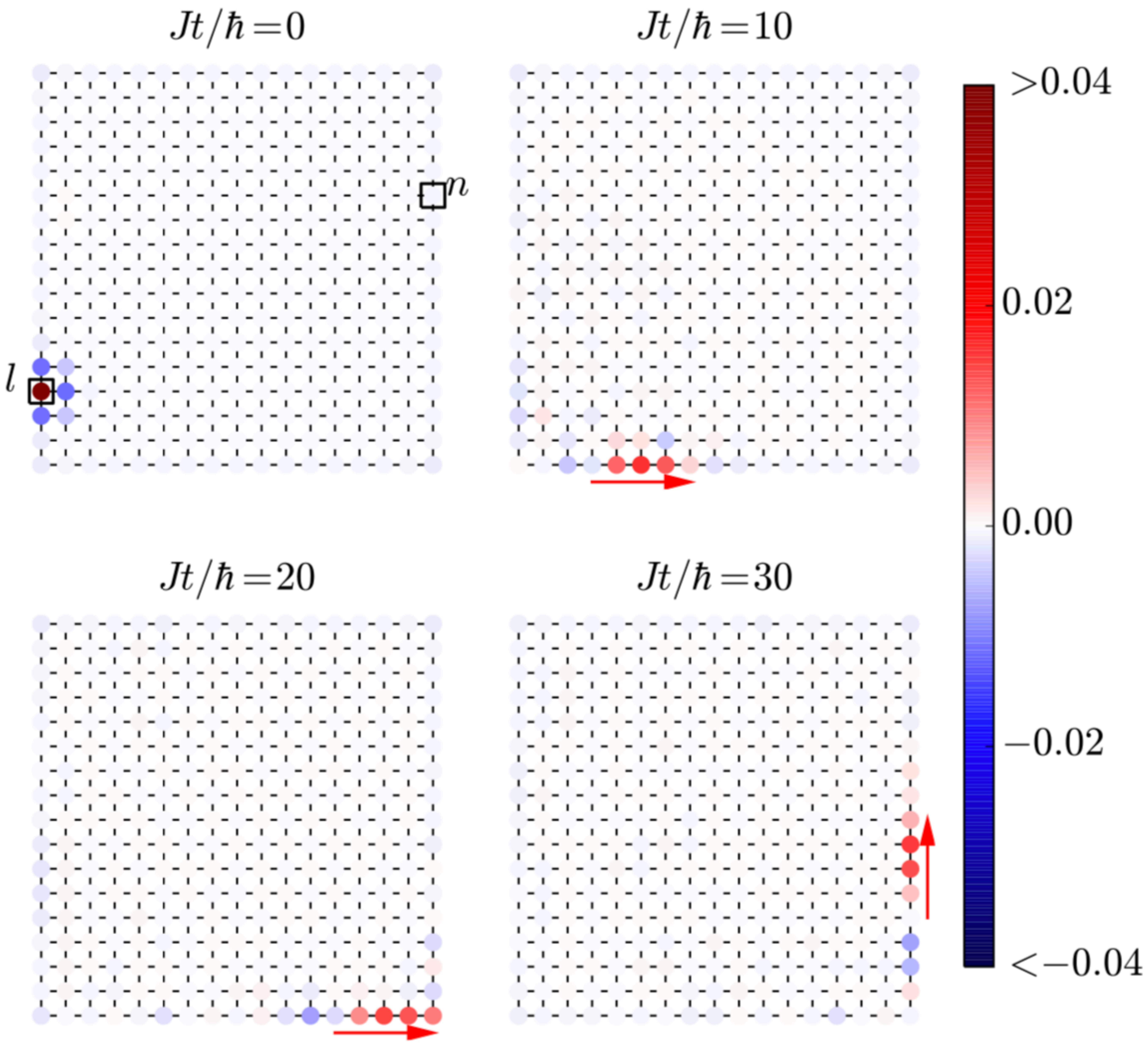
L. Asteria, et. Al Nat. Phys, 2019

Can we distinguish a fractional Chern insulator by looking at edge state dynamics?

Edge state dynamics of a Chern insulator



$$H_1 = \mu c_l^\dagger c_l$$
$$l \in \text{edge}$$



N. Goldman et. al PNAS 2013
A. Grushin et. al J. Stat. Mech. (2014)

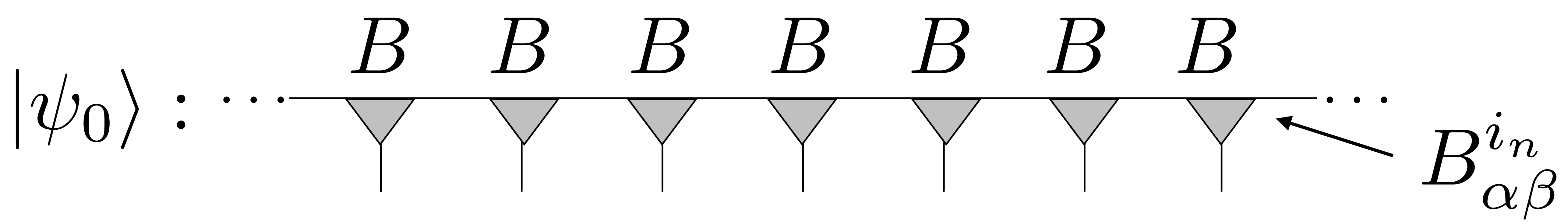
Edge state dynamics of a bosonic fractional Chern insulator

X. Y. Dong, AGG, J. Motruk, F. Pollmann, Phys Rev. Lett. (2018)

Density Matrix Renormalization Group

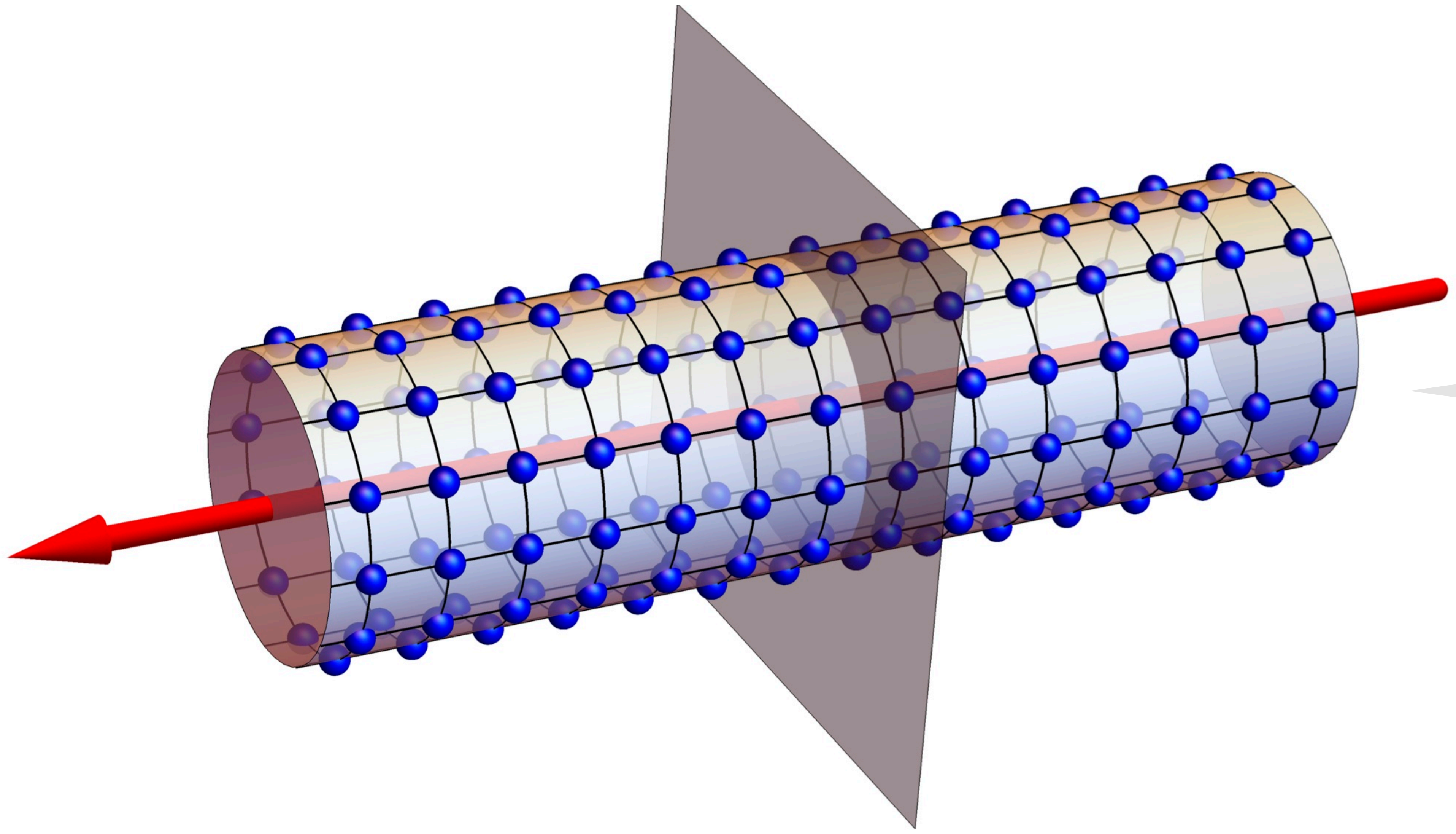
Matrix-Product State representation of the ground state

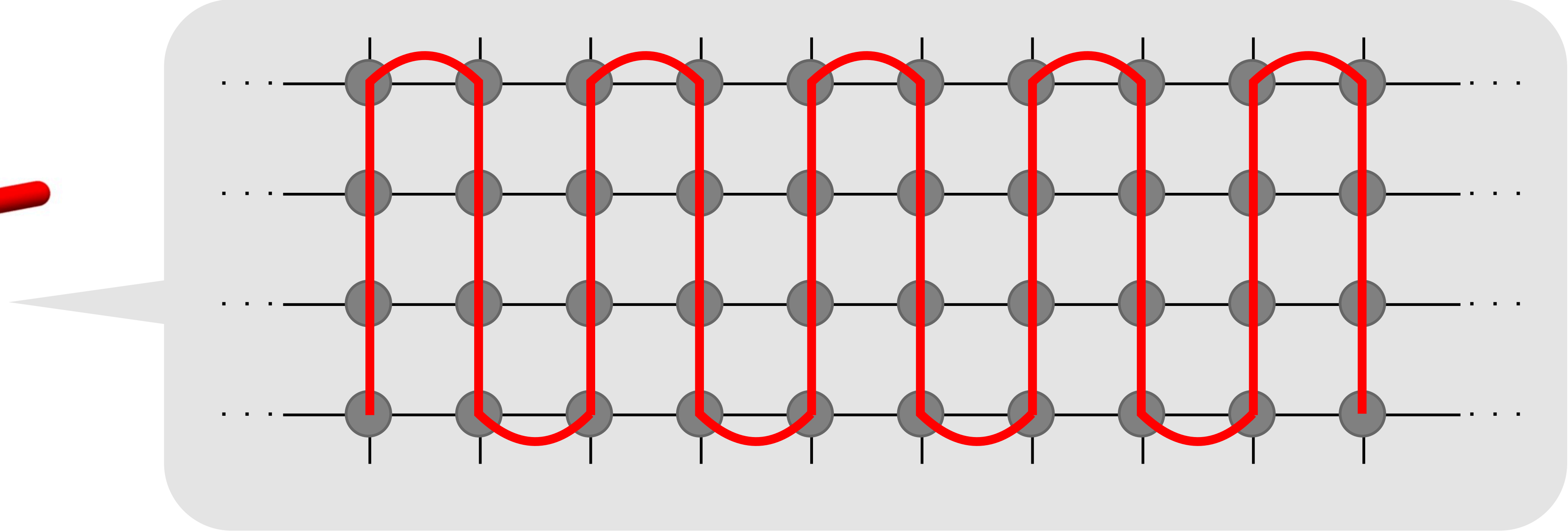
M. Fannes et al Comm Math. Phys. '92, Schollwoeck Ann. Phys.'11



DMRG on cylinders with circumference up to L= 12

S. R. White PRL '92

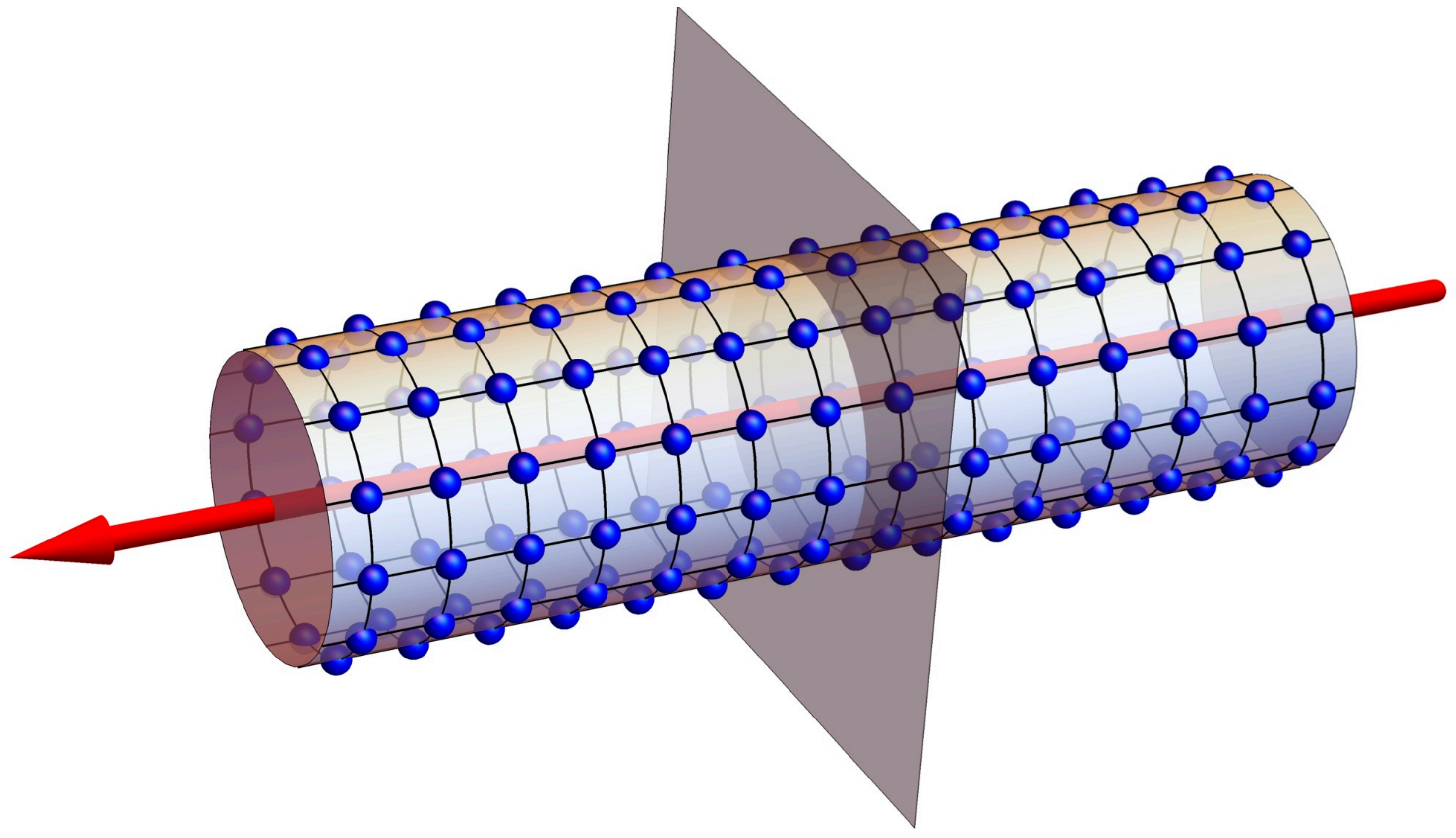


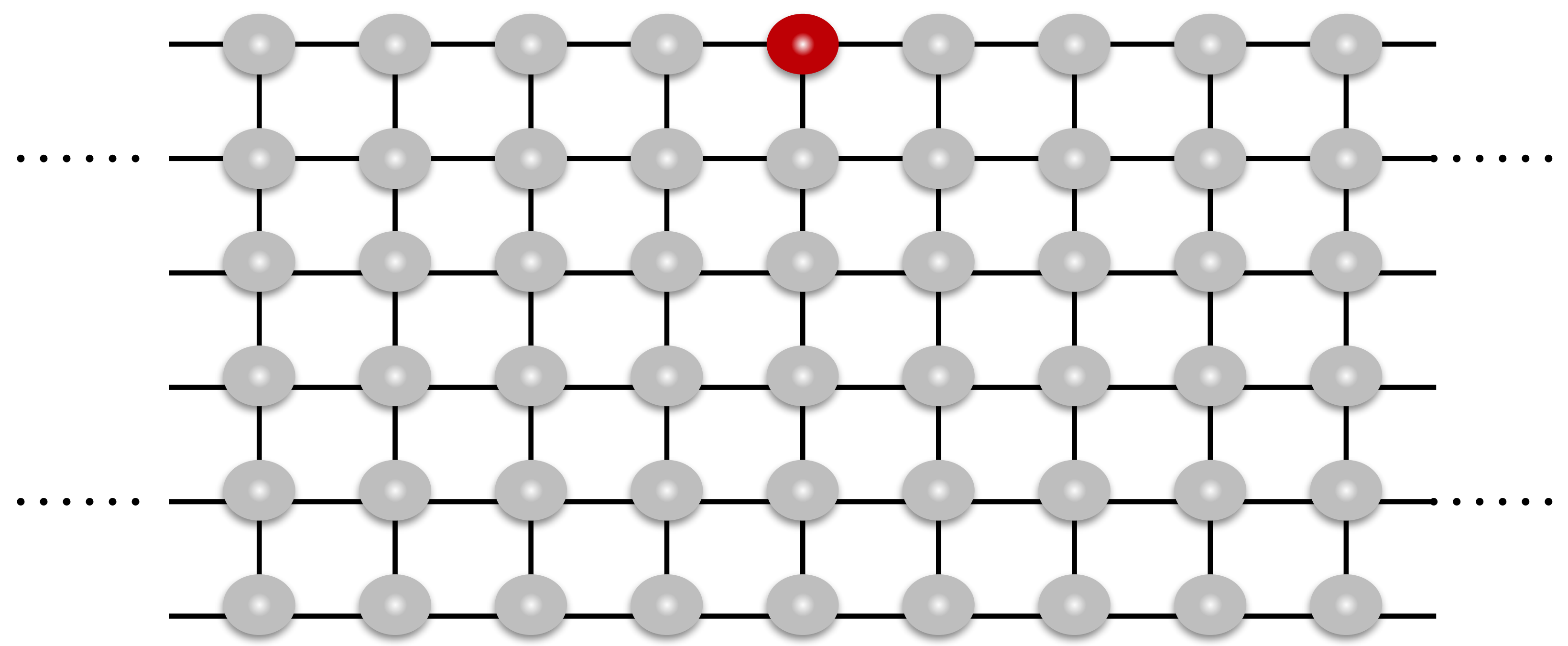


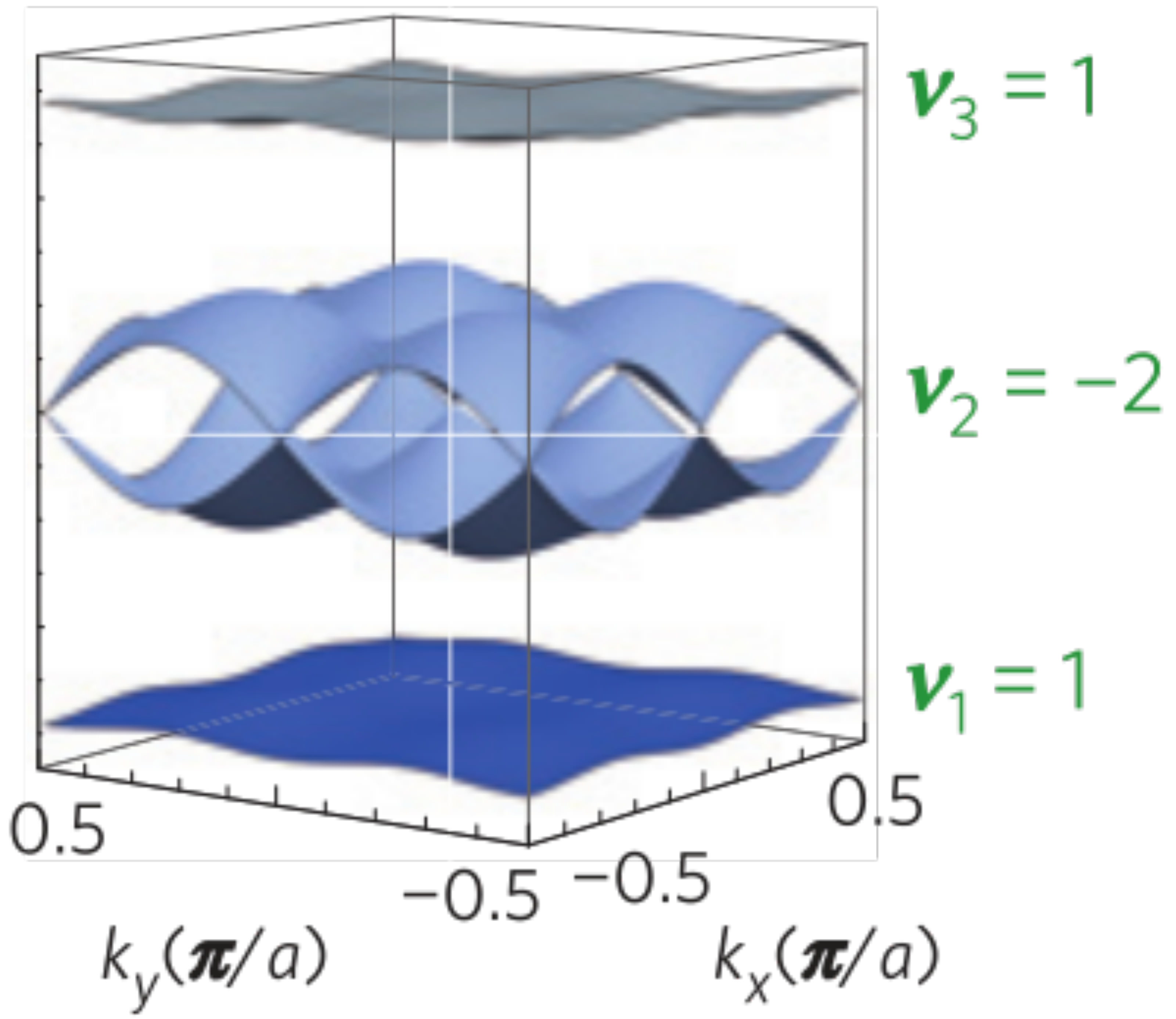
2D physics at cost of long-range interaction in 1D representation

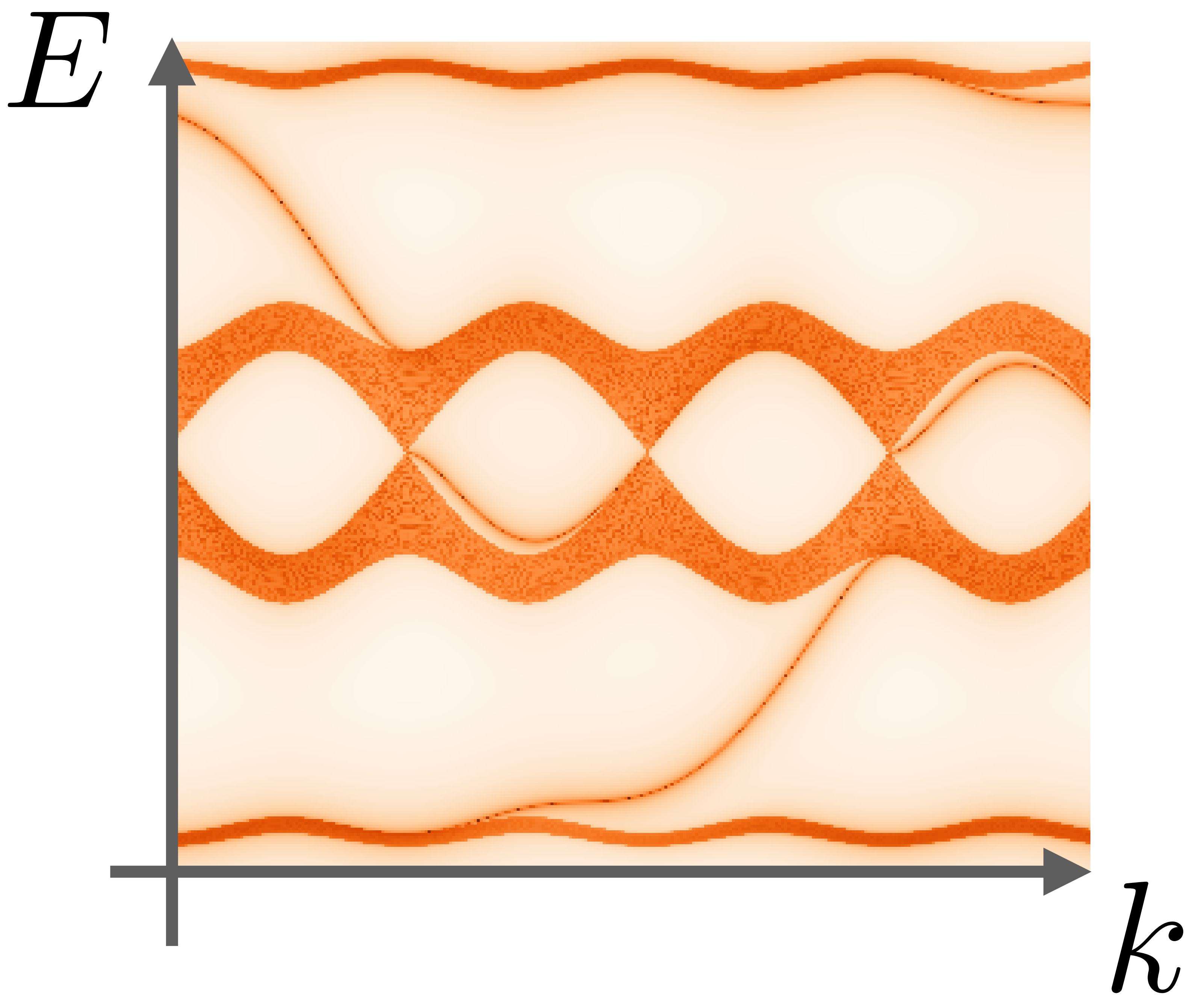
Infinite cylinder

Finite cylinder









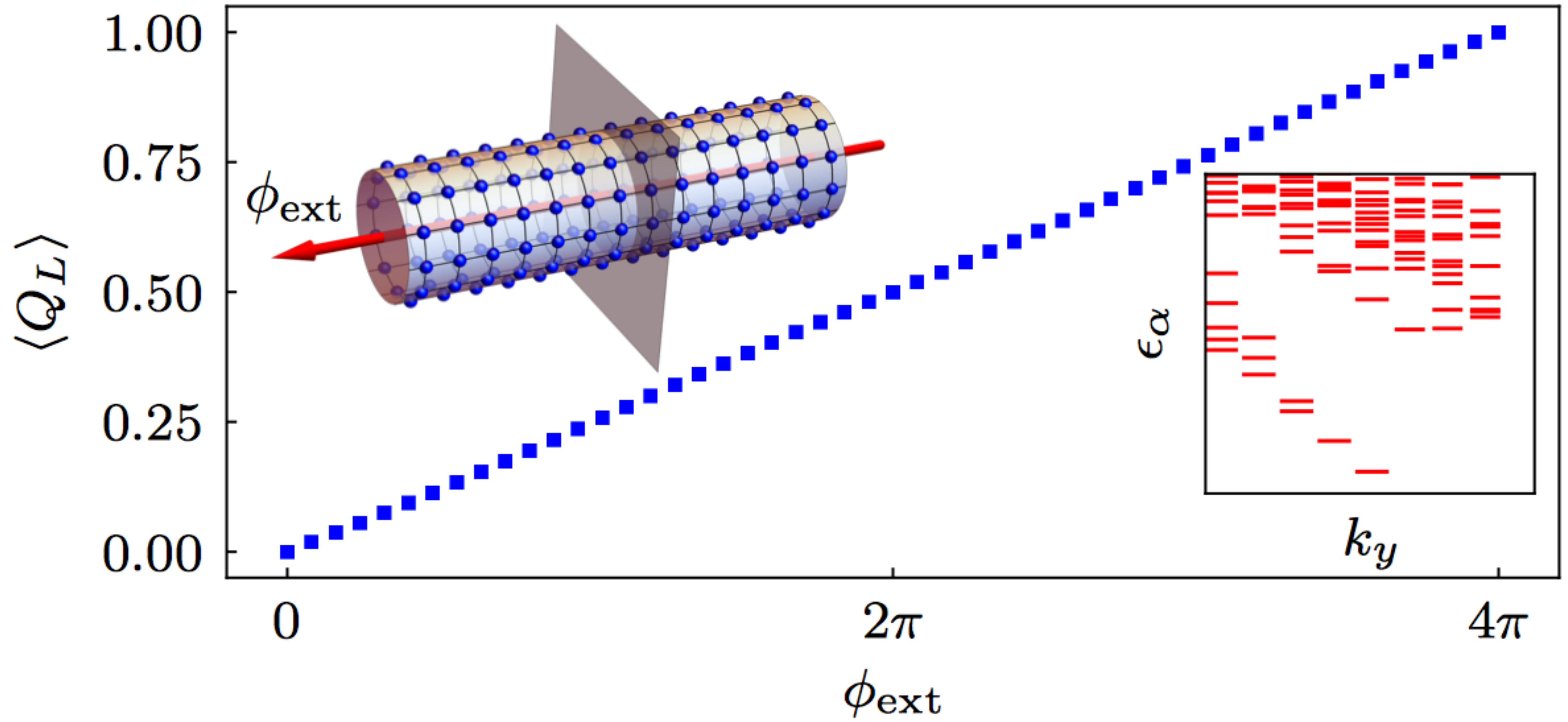
Static ground state: fractional Chern insulator at 1/8 filling

Its been a while…

[Hafezi et al. '07; Möller and Cooper '09; …]

Quantized Hall conductivity

$$\sigma_{xy} = 1/2$$



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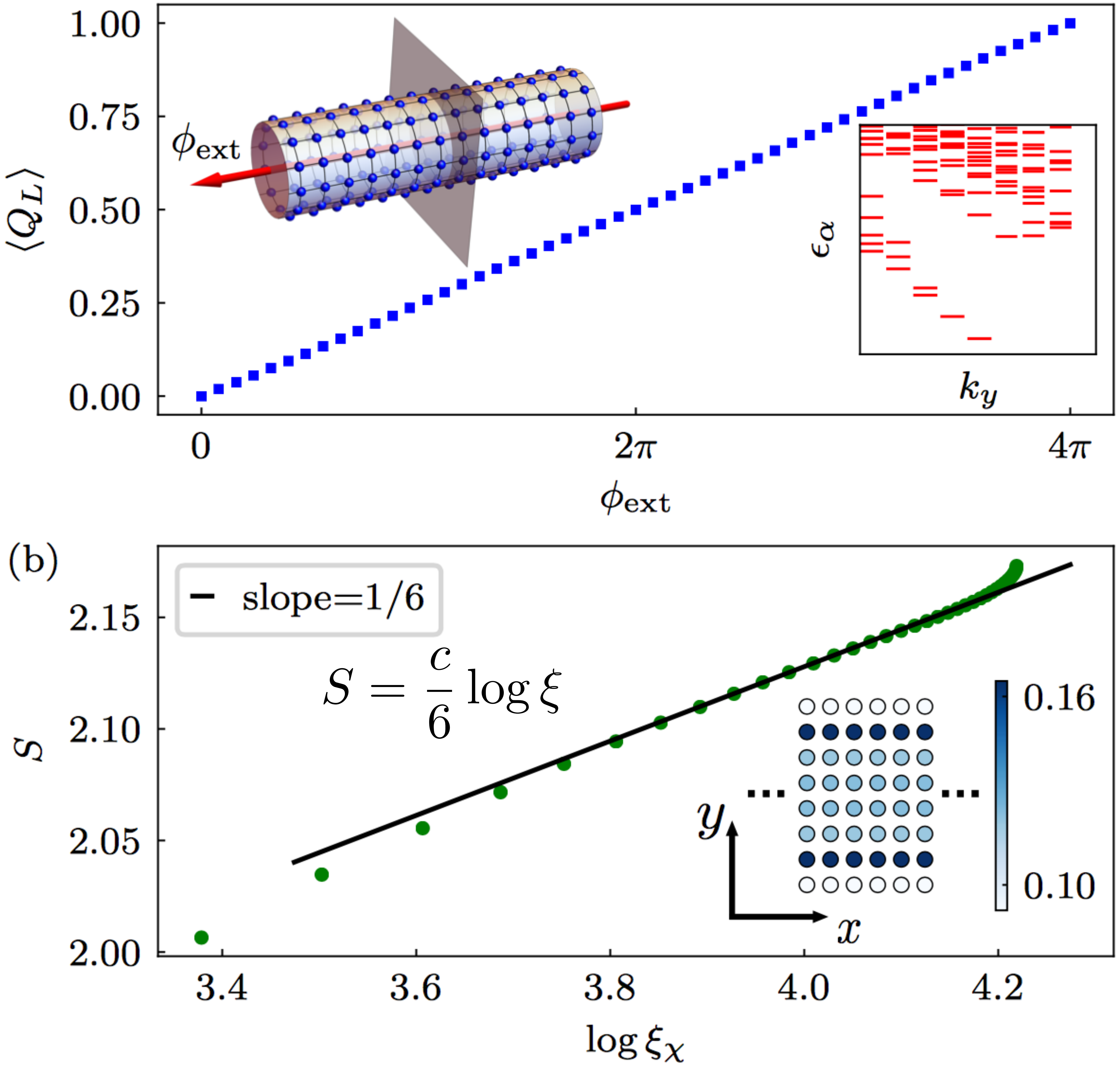
Gapless edge states

$$c = 1$$



Time evolution

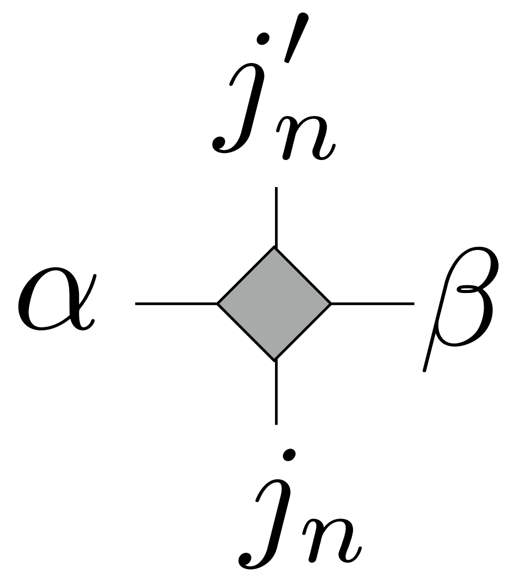
Hamiltonian expressed as a sum of local terms $H = \sum_x H_x$

Expand $U = \exp(-itH)$ for $t \ll 1$:

$$U(t) = 1 + t\sum_x H_x + \frac{1}{2}t^2 \sum_{x,y} H_x H_y + \cdots$$

Compact Matrix Product Operator (MPO)

$$W_{\alpha\beta}^{[n]j_n j'_n} =$$



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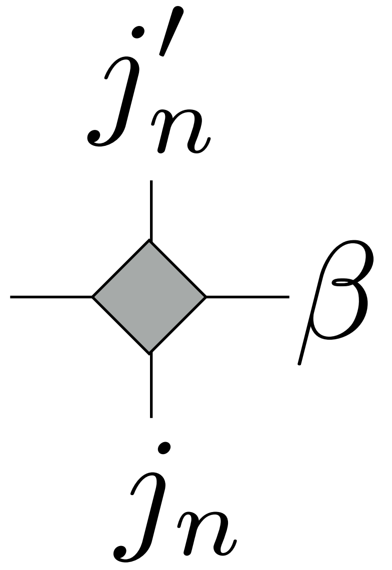
$$\approx 1 + t\sum_x H_x + t^2 \underbrace{\sum_{x<y} H_x H_y}_{\epsilon \sim \underline{L} t^2}$$

Neglect overlapping terms in expansion

Compact Matrix Product Operator (MPO)

$$W^{[n] j_n j_n'}_{\alpha\beta} = \alpha$$ 

M. P. Zaletel et al 'PRB 15

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$$\underbrace{1 + t\sum_x H_x}_{\epsilon \sim L^2 t^2} \to \underbrace{\prod_x (1 + tH_x)}_{\epsilon \sim Lt^2}$$

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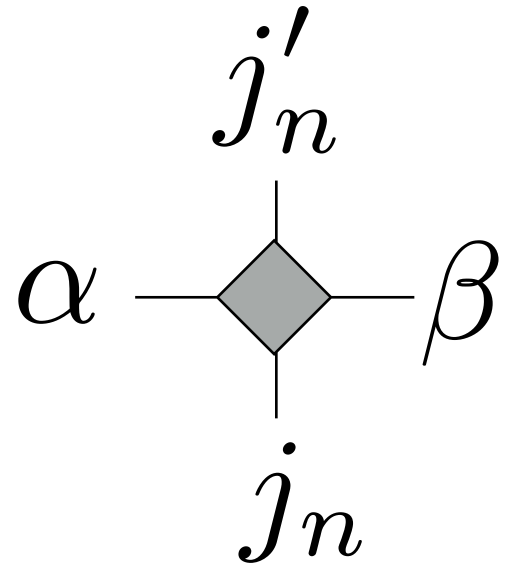
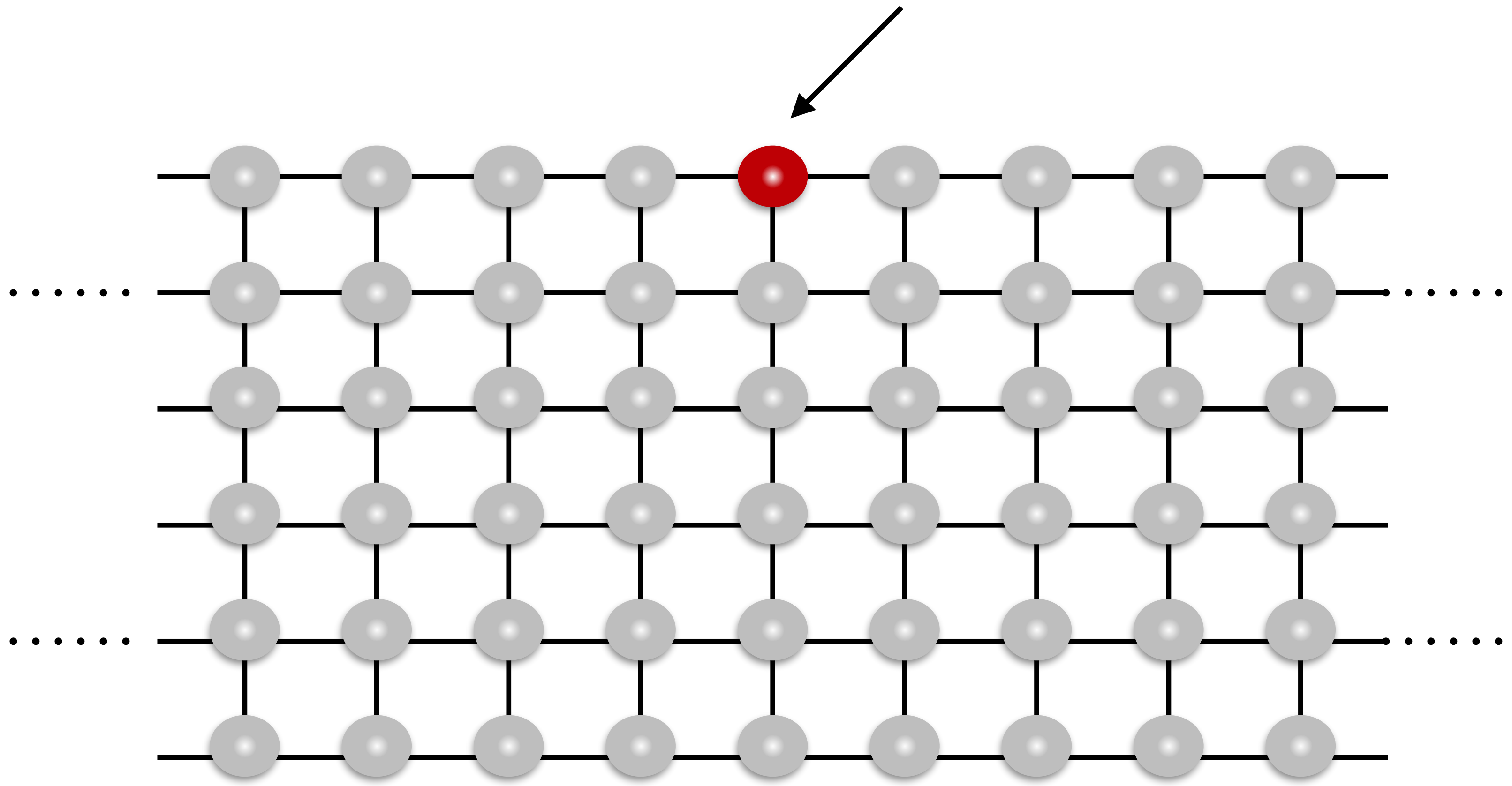


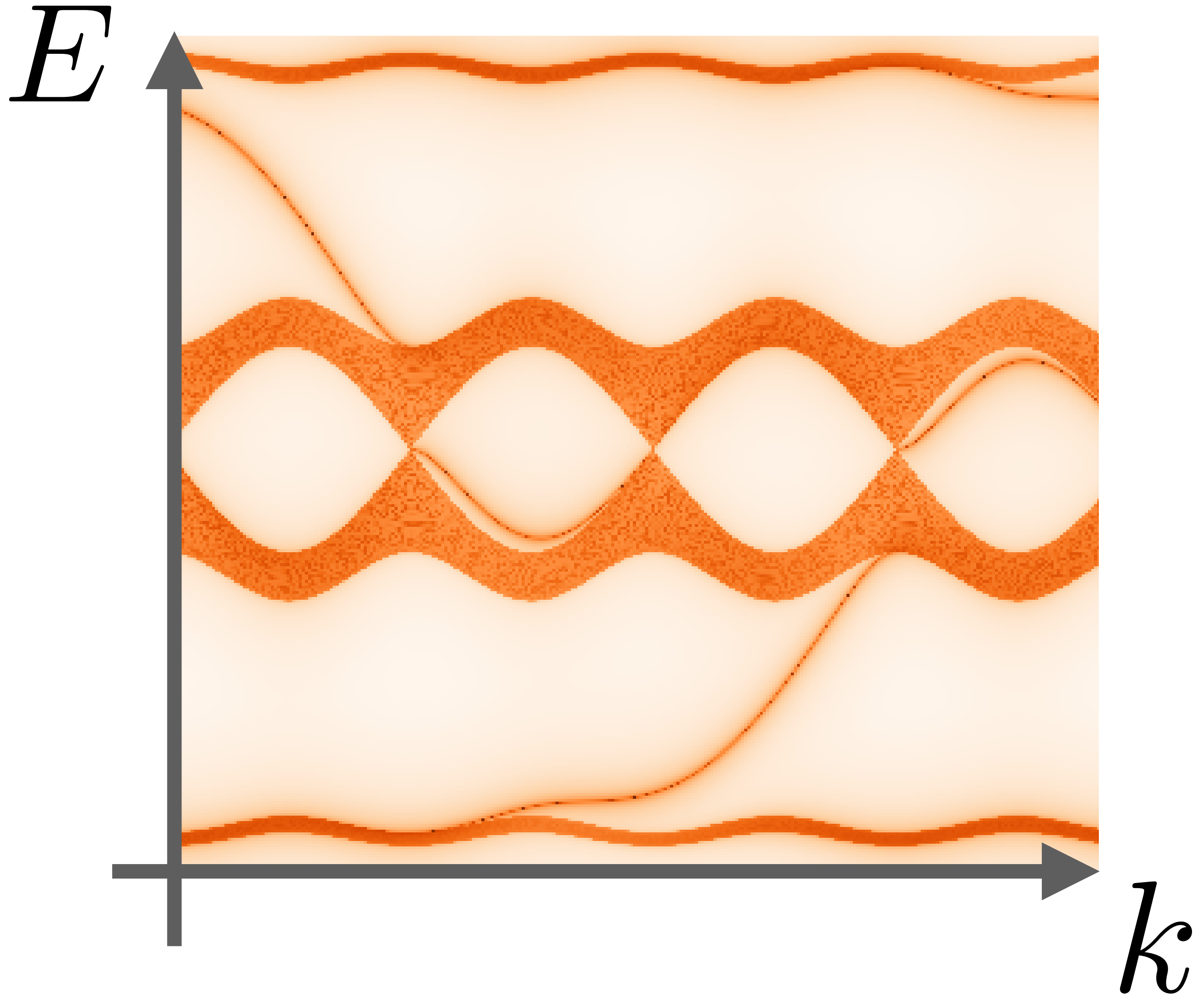
M. P. Zaletel et al 'PRB 15

Dynamical signatures of the FCI phase

Dynamical correlation function

$$G(x,t) = \langle b(x,t) b^\dagger(0,0) \rangle$$





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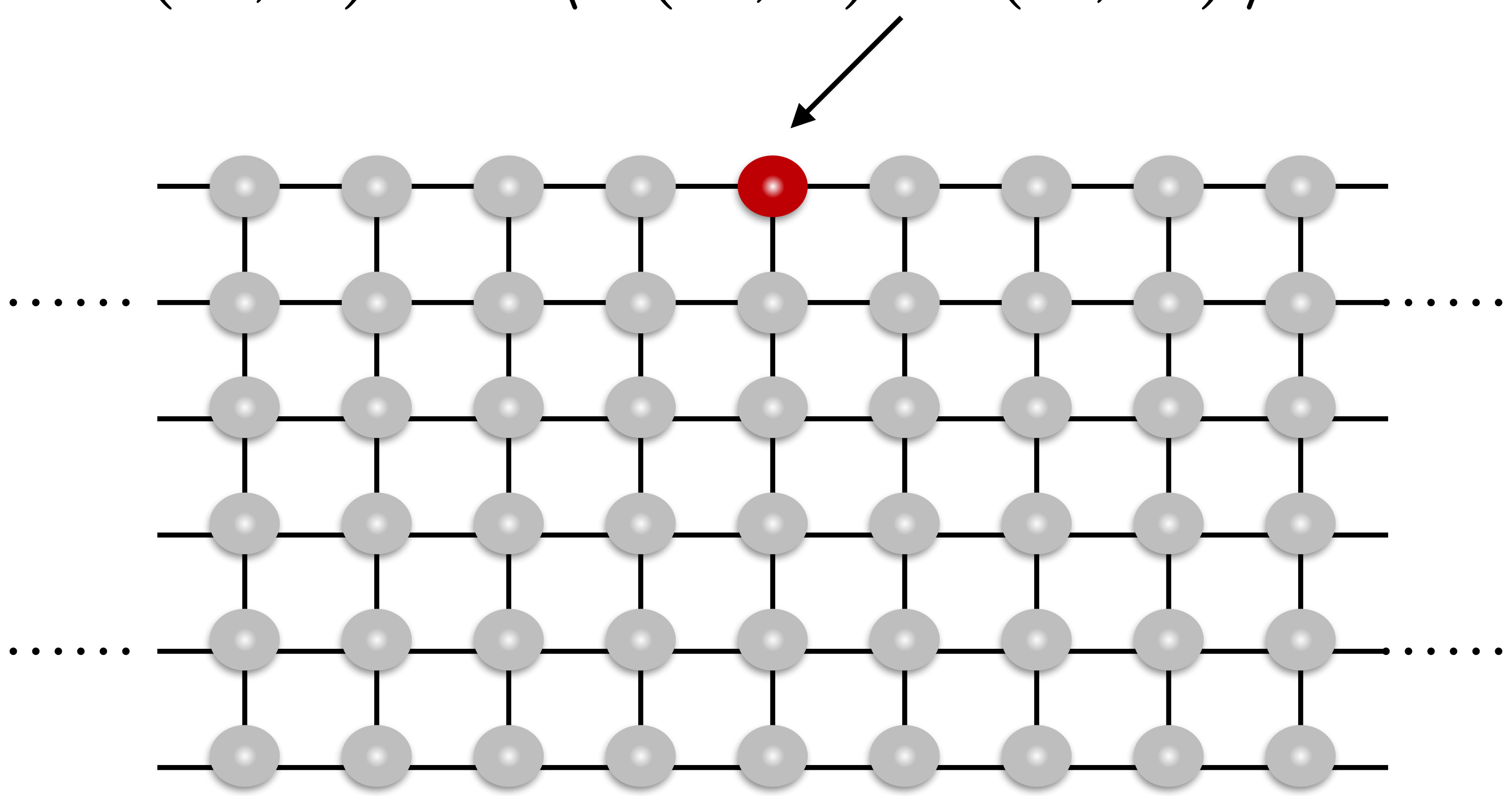

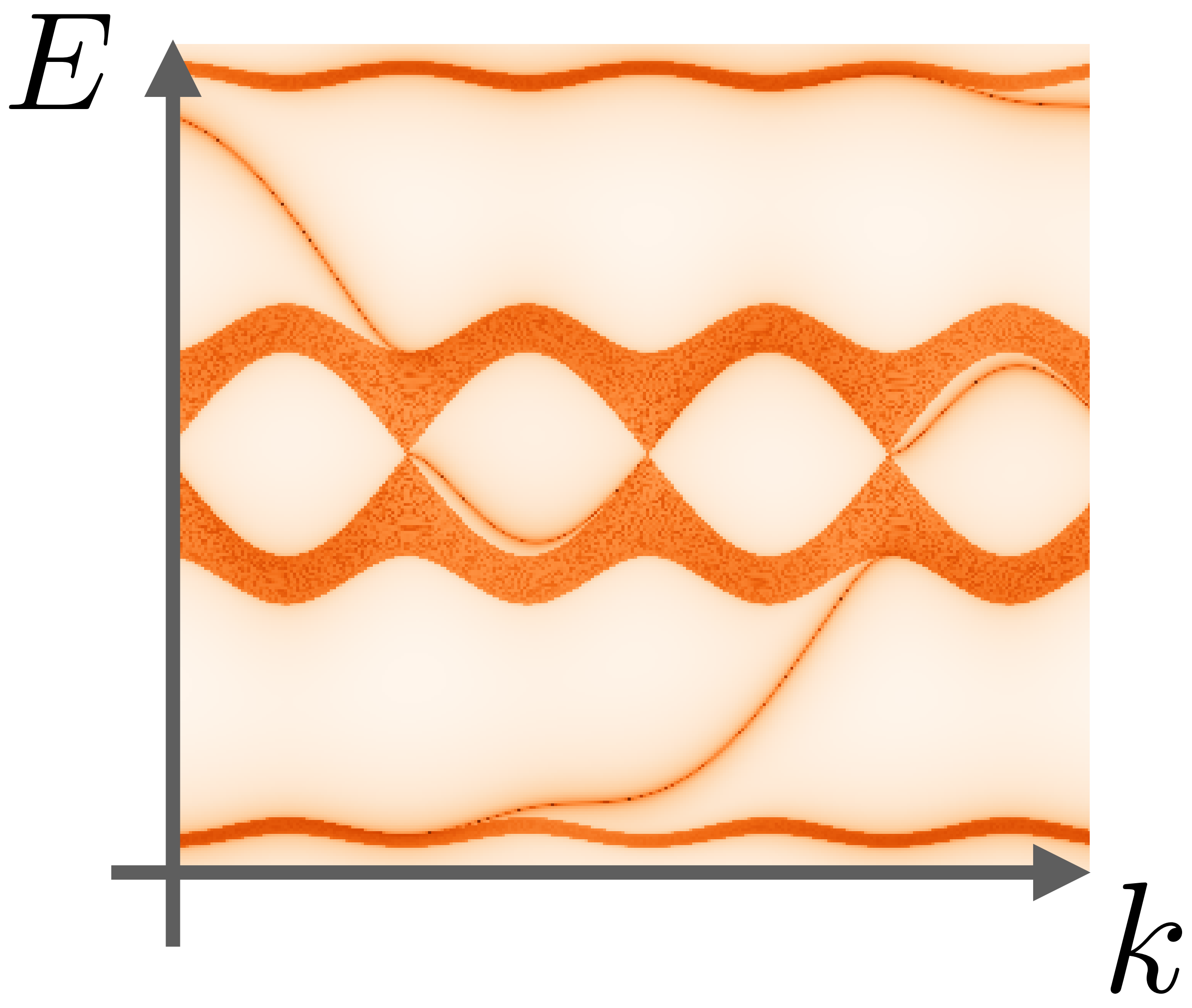

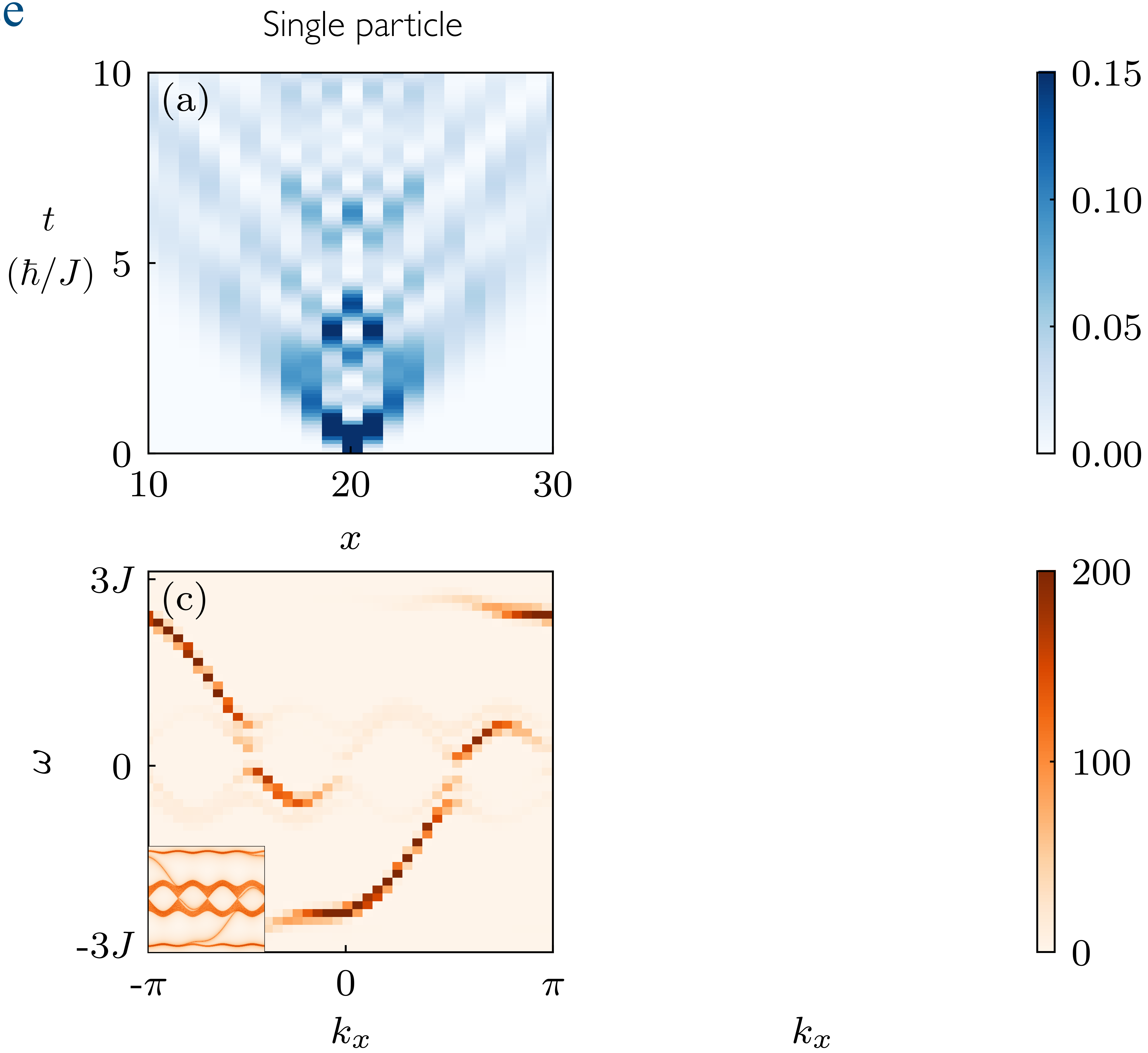

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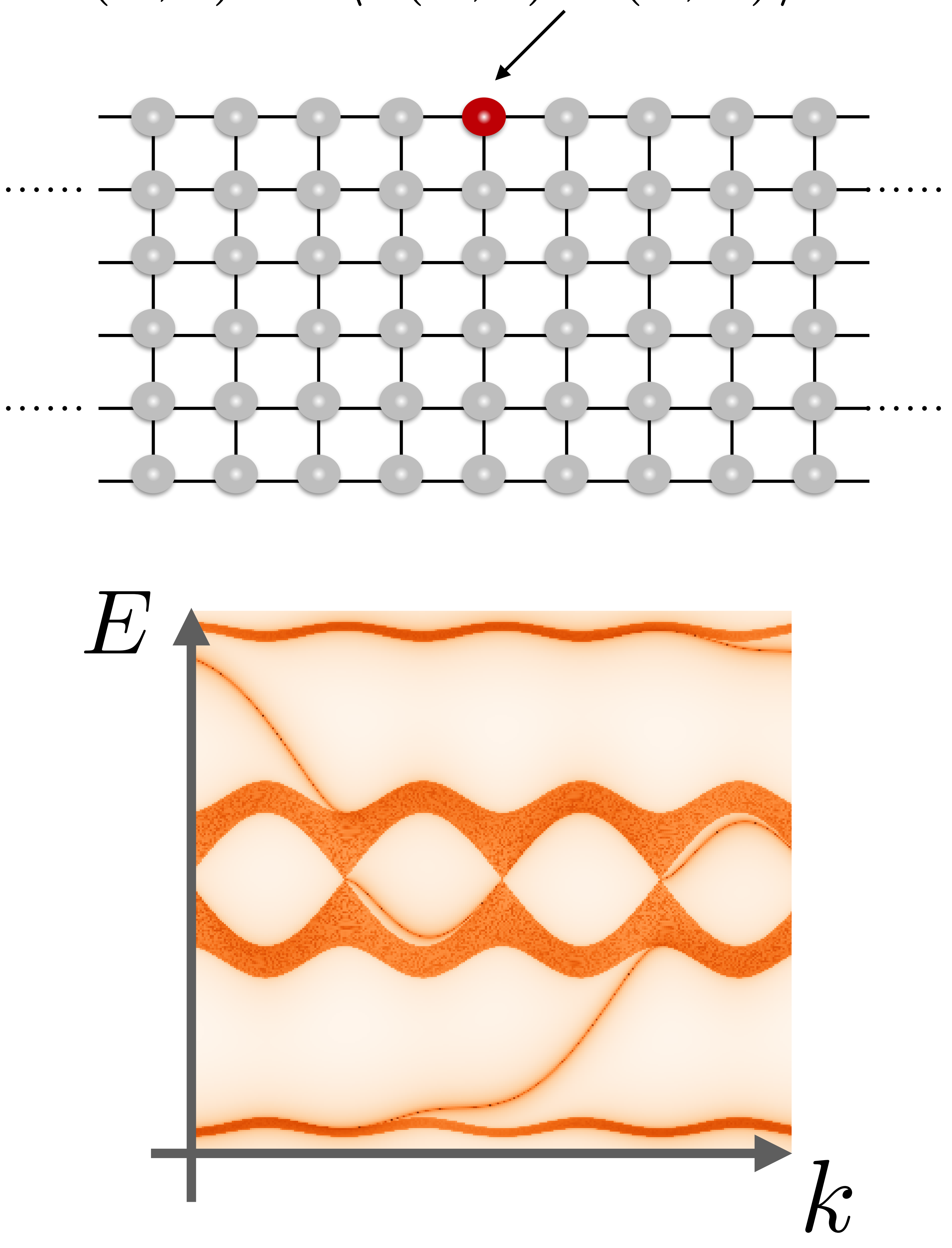
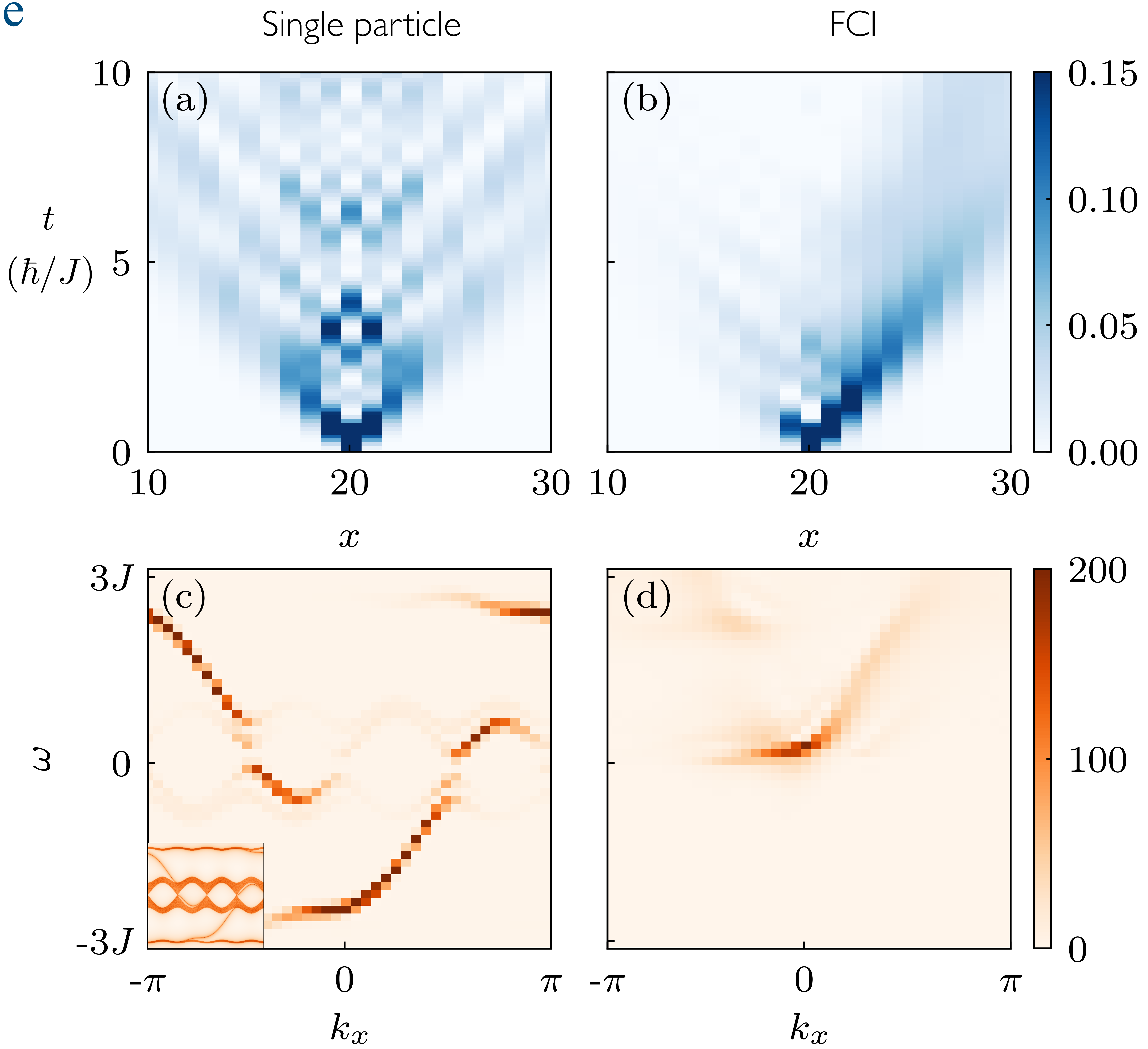
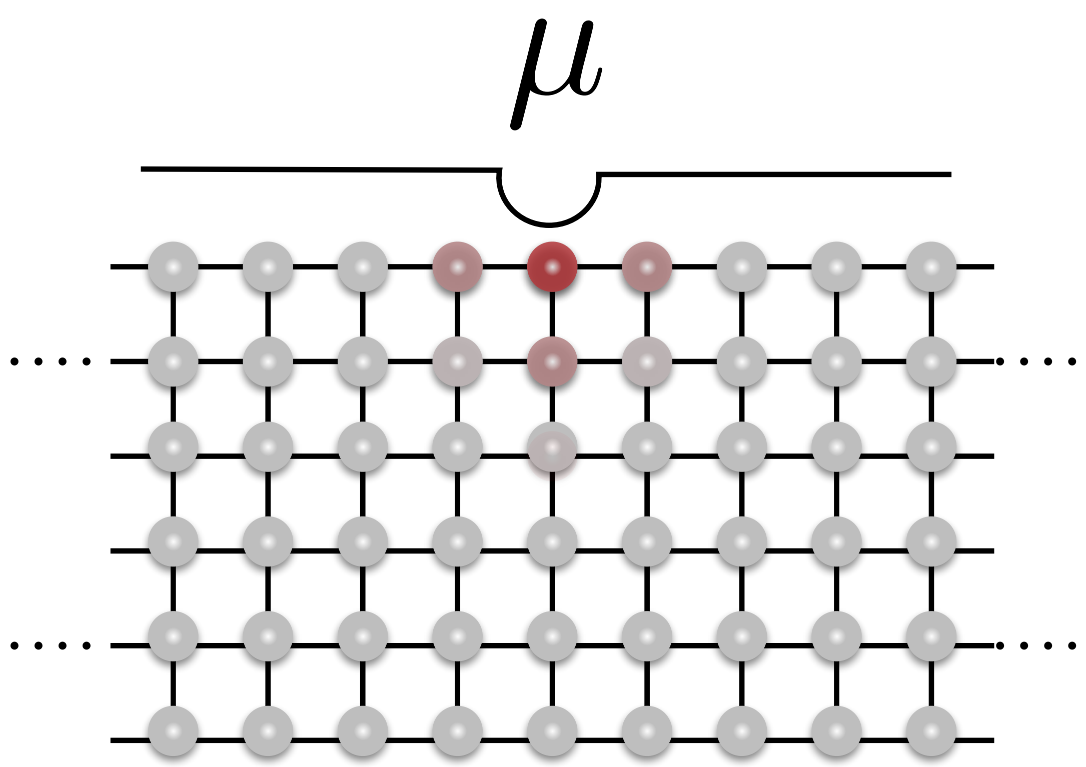




Dynamical signatures of the FCI phase

Fourier transformation of the density evolution following local quench:



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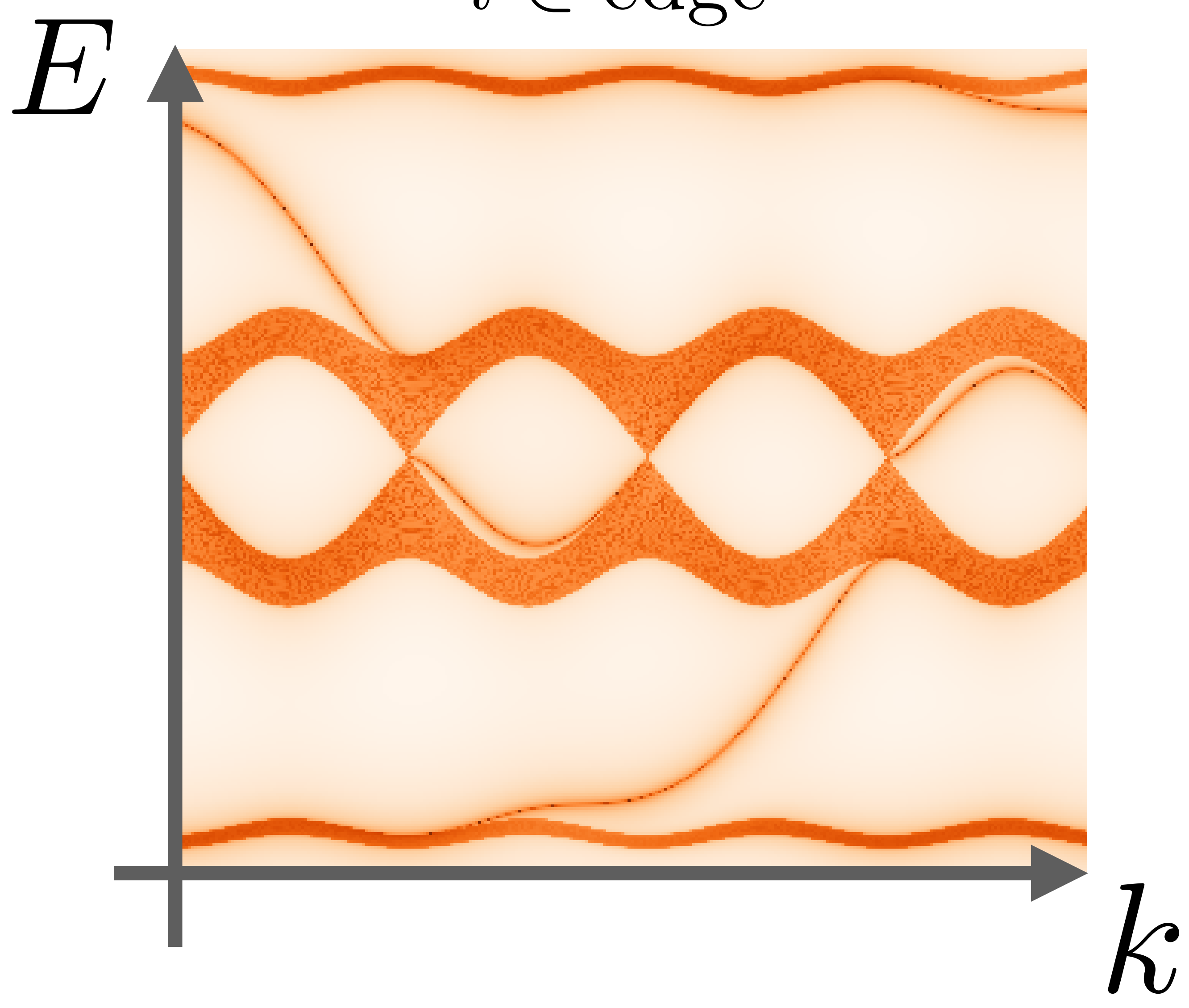

Dynamical signatures of the FCI phase

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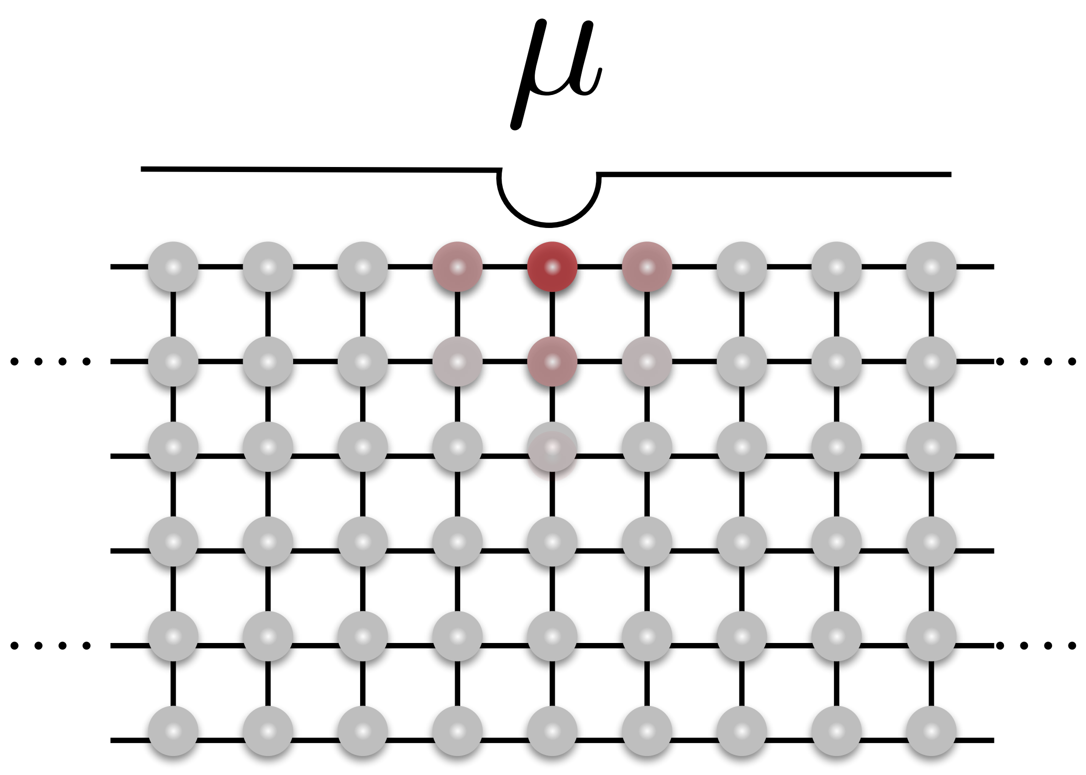
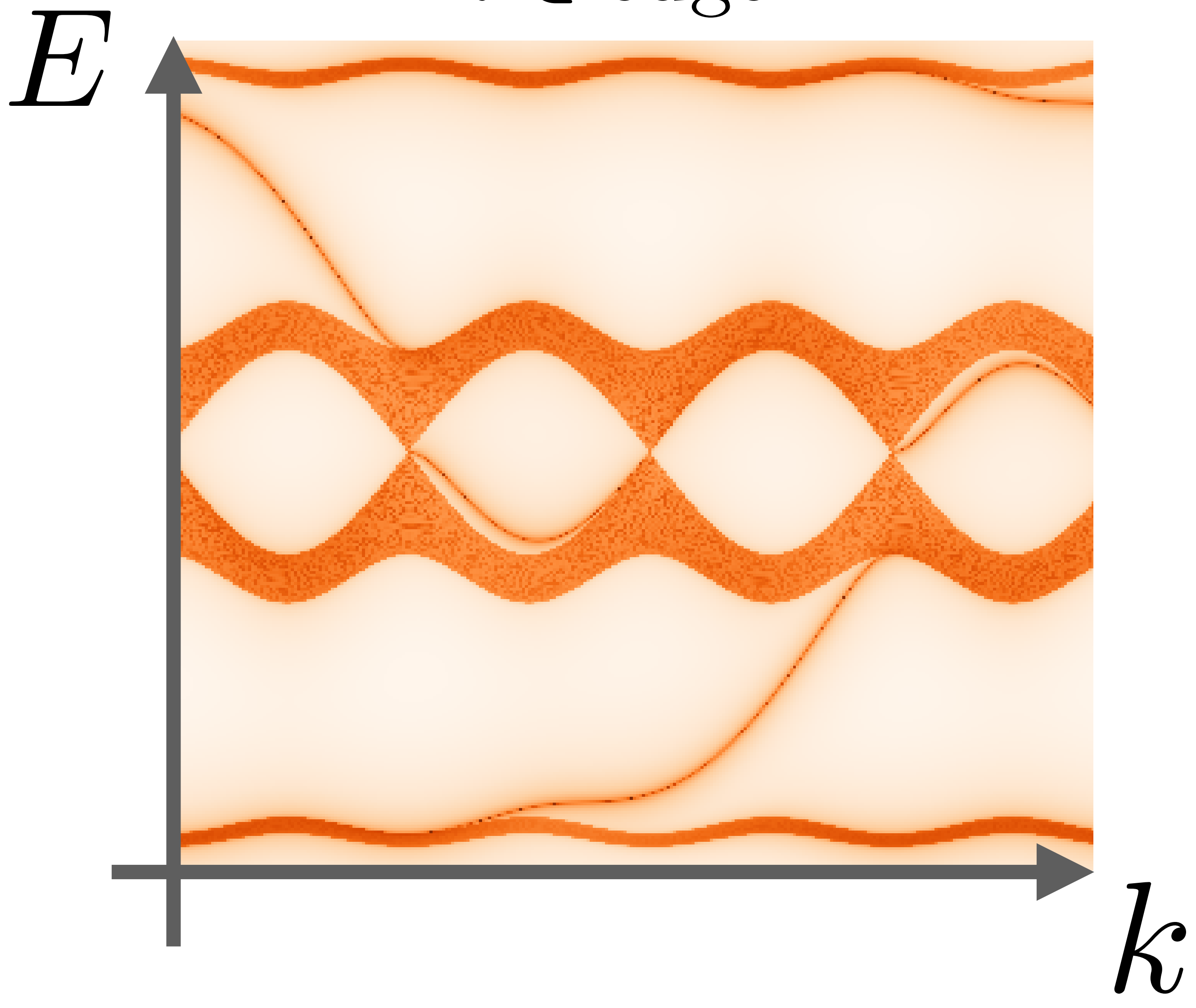
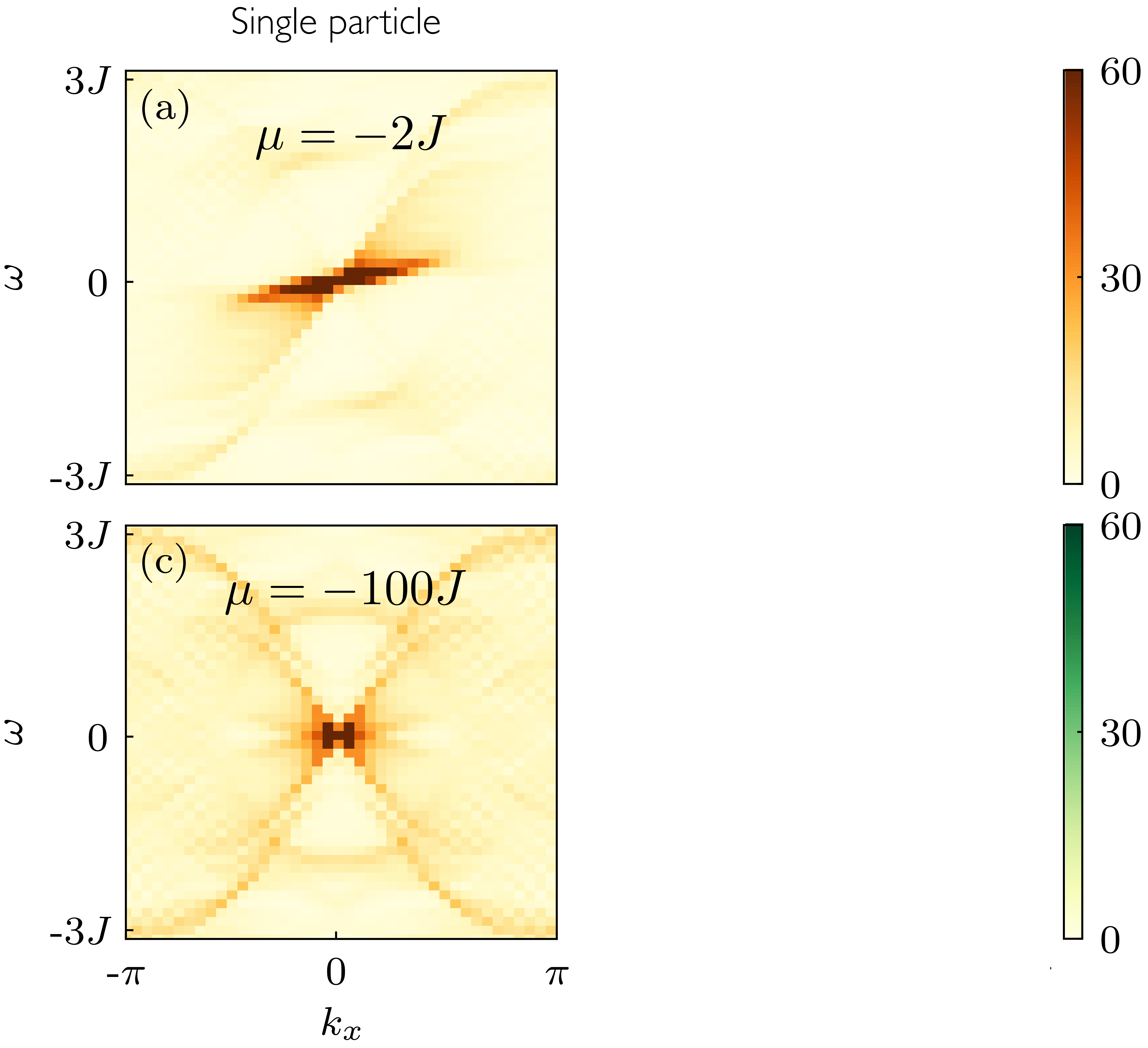


$$H_1 = \mu c_l^\dagger c_l$$
$$l \in \text{edge}$$





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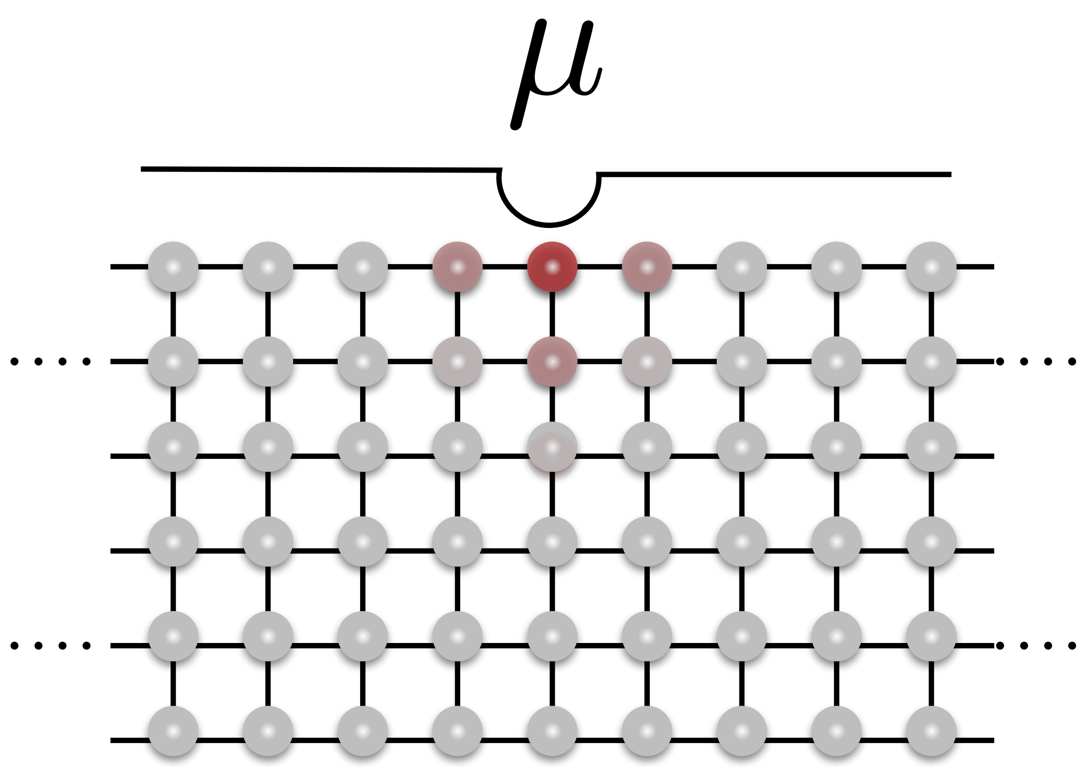

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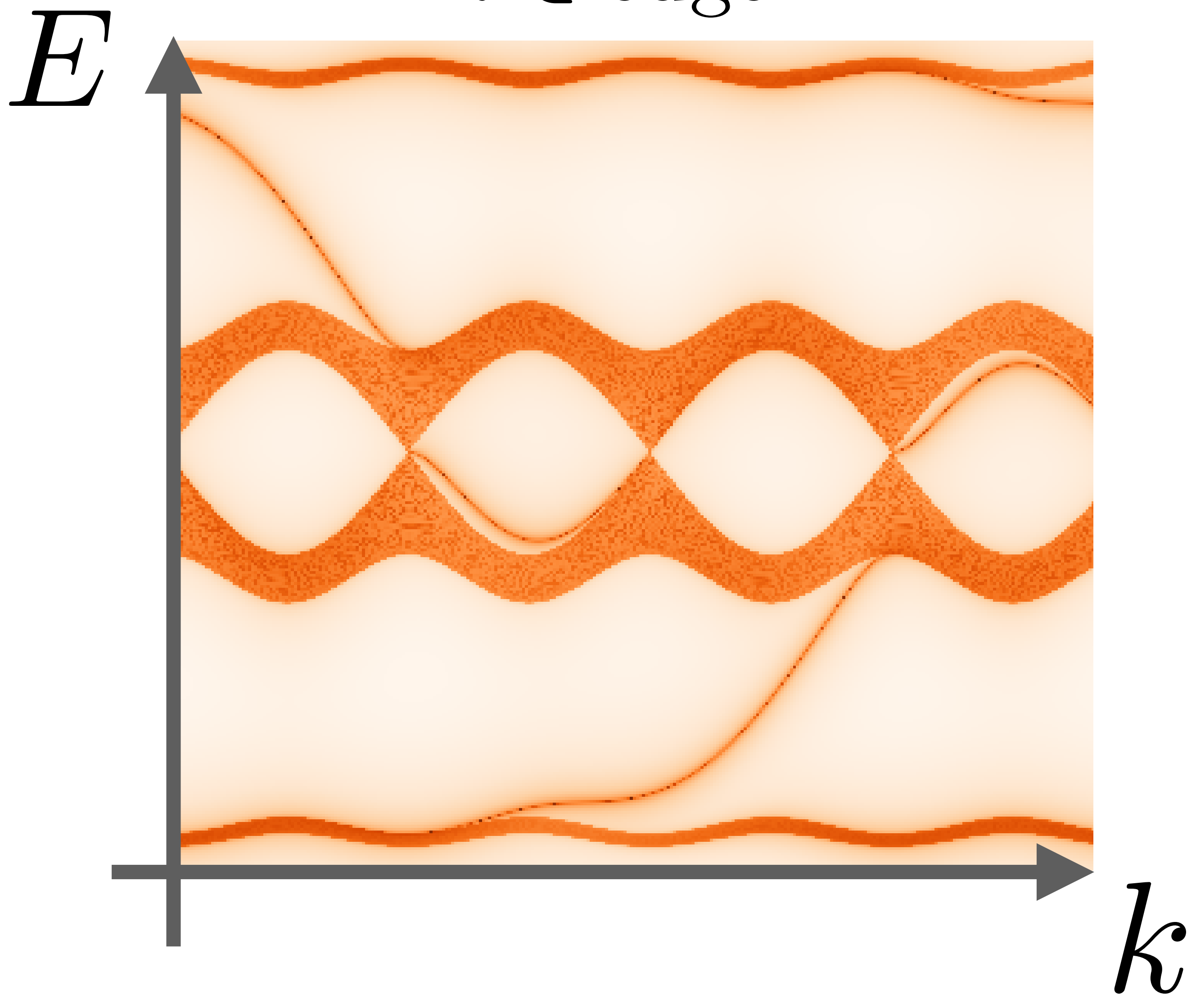
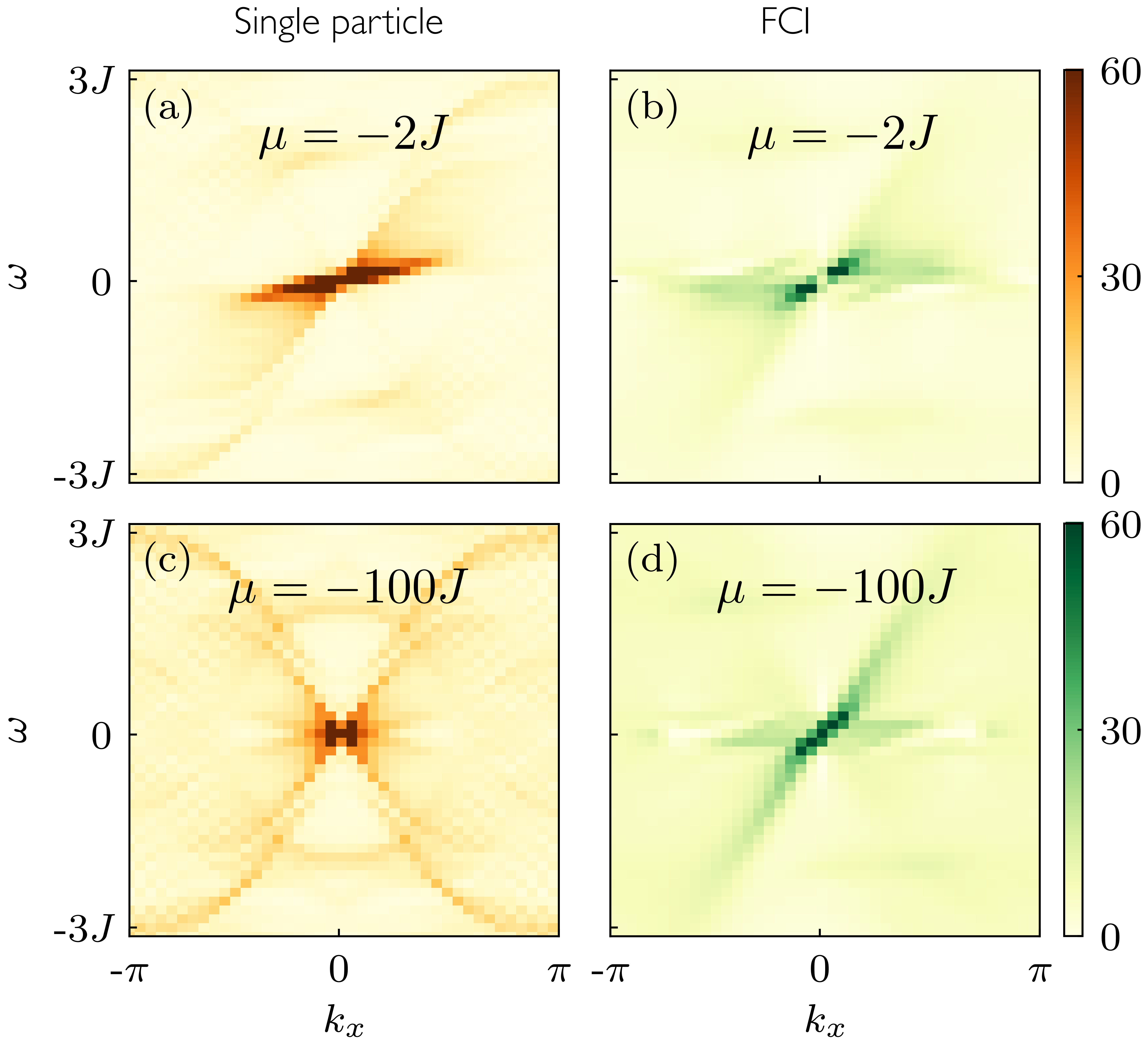
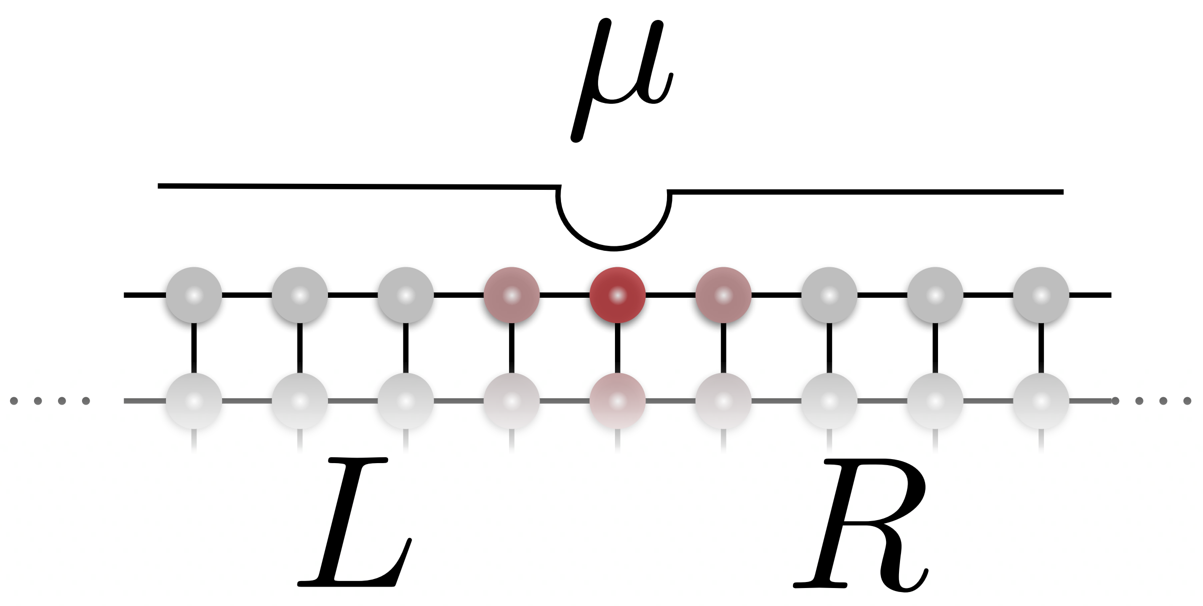


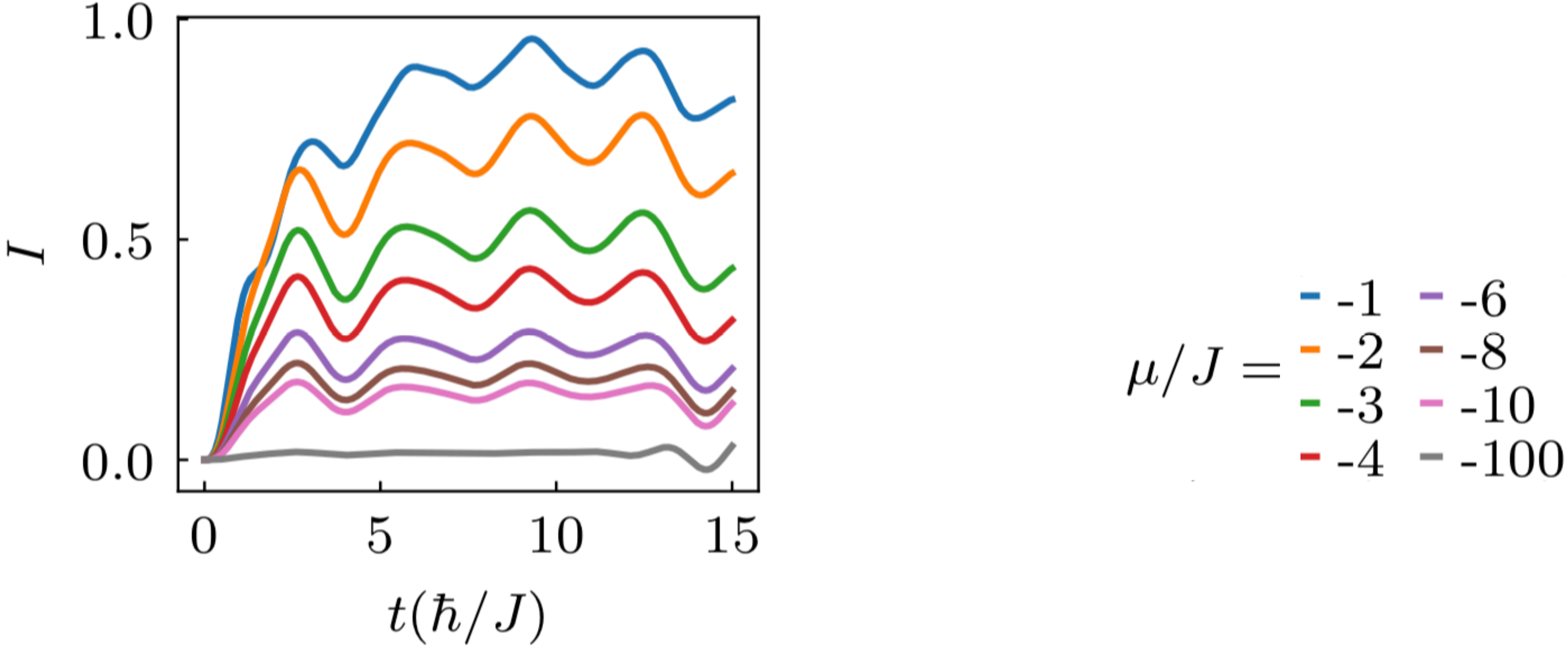


Dynamical signatures of the FCI phase

The time evolution of the imbalance : $I = N_R - N_L$



Single particle



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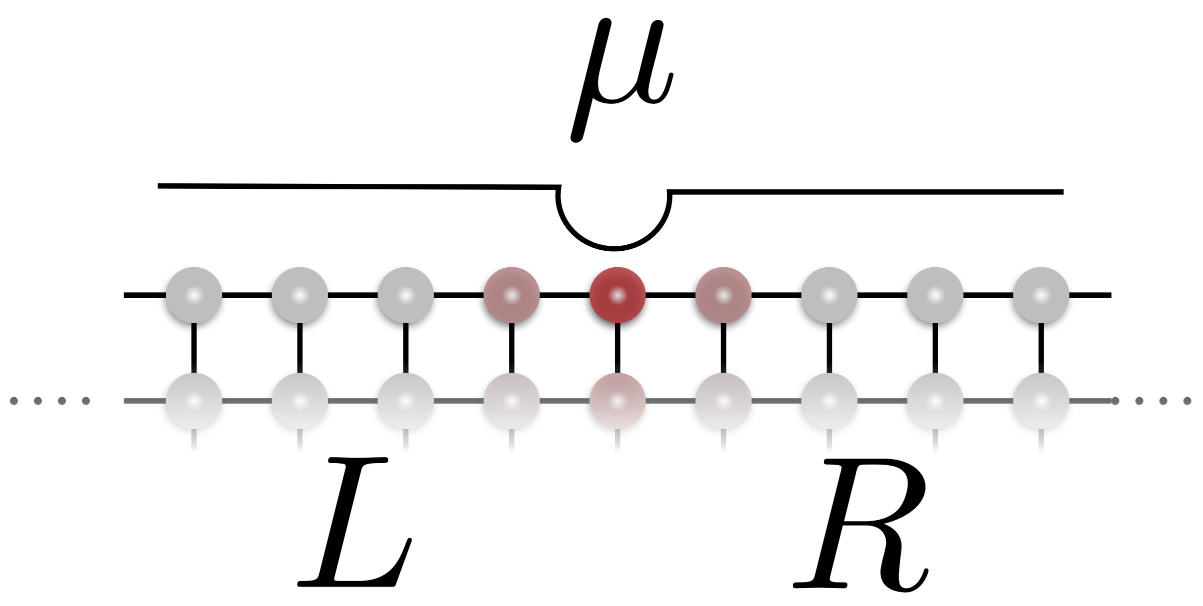
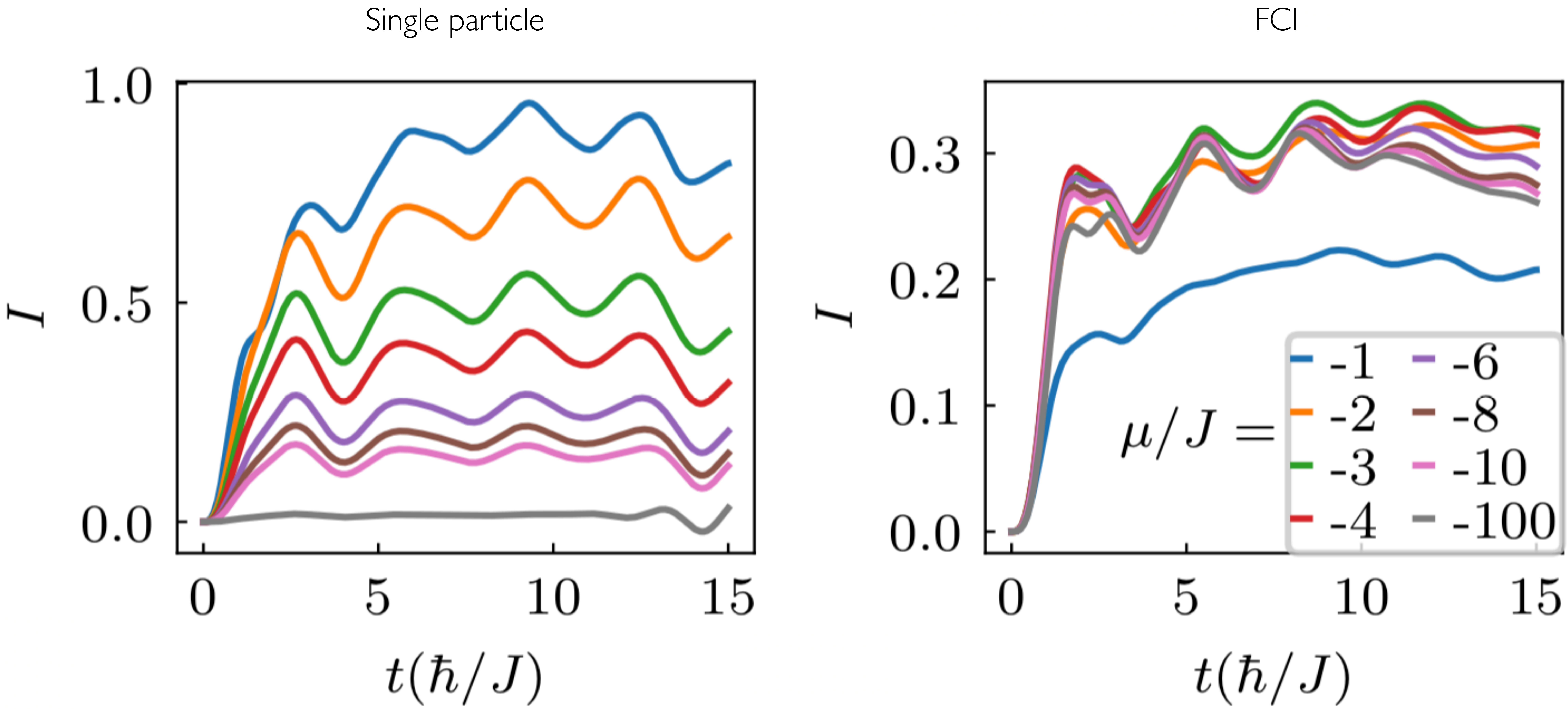




Edge state dynamics of a quantum Hall edge

X. G. Wen PRB (1990)

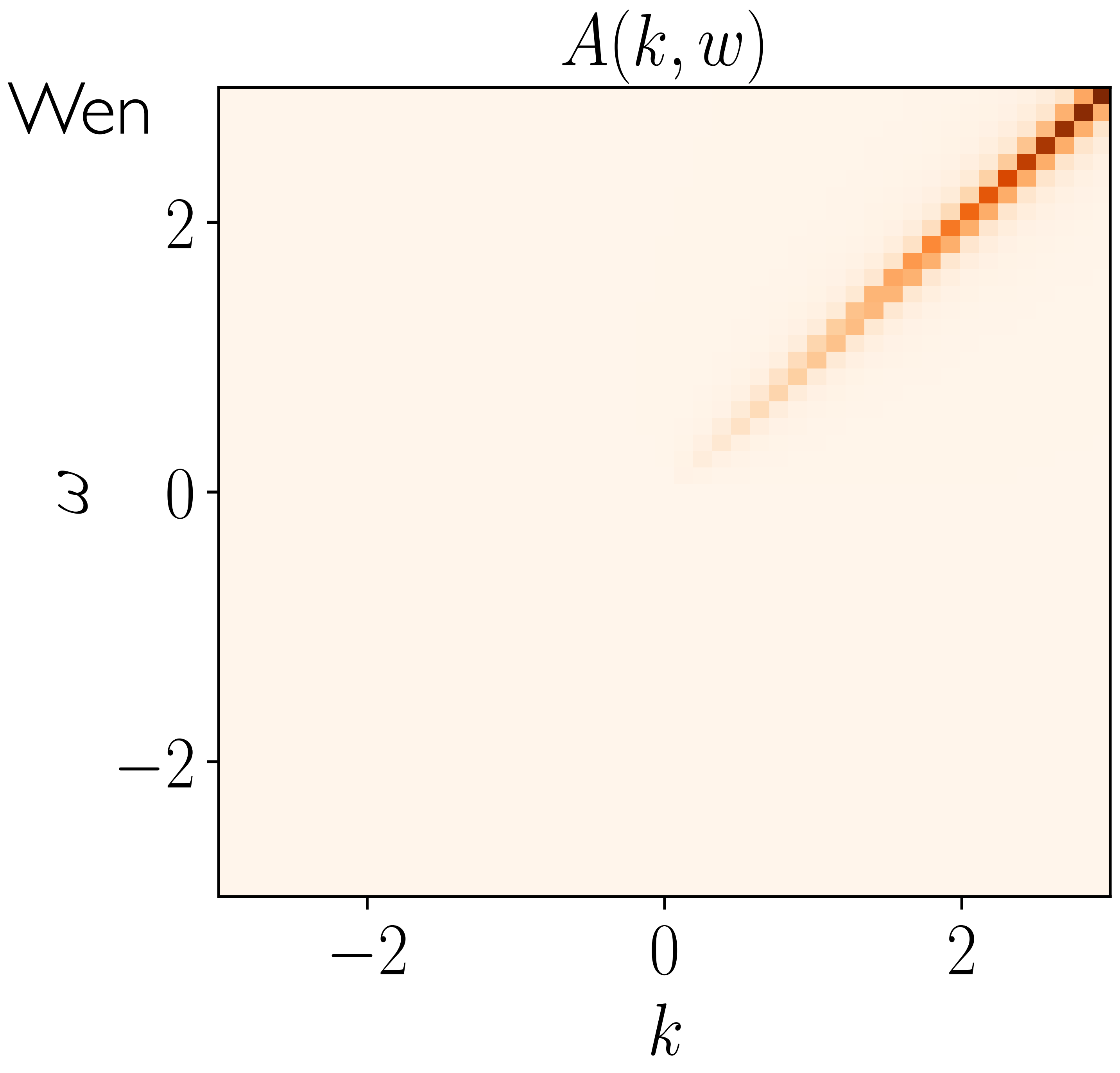
Edge state spectral function knows about fractional excitations

For a state with $\sigma_{xy} = \frac{1}{m}\frac{e^2}{h}$

The spectral function is* $A(k,\omega) \propto (\omega + vk)^{m-1}\delta(\omega - vk)$

and the DOS is $N(\omega) \propto \omega^{m-1}$

*Assumptions: thermodynamic limit of a 1D isolated edge



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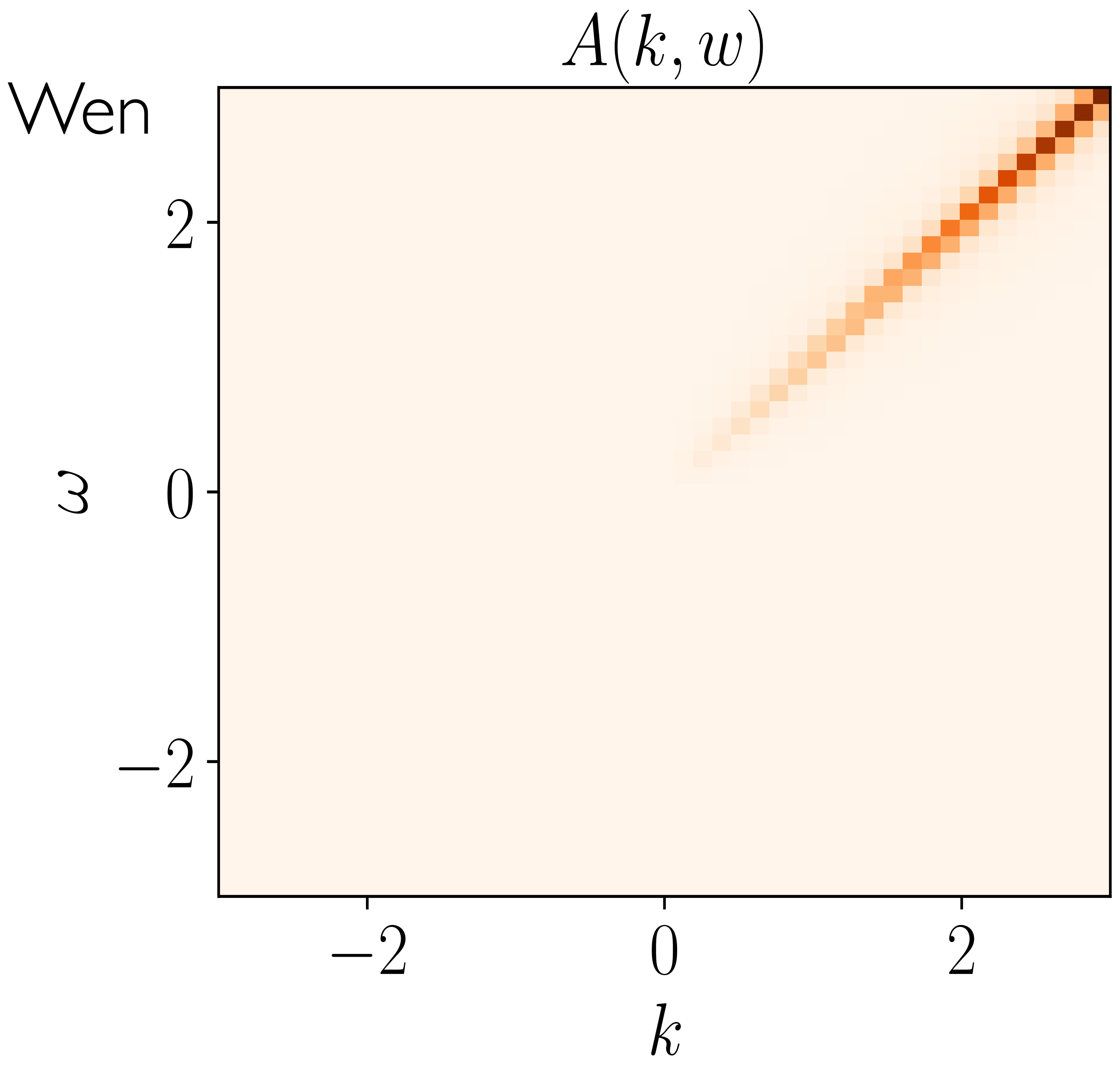

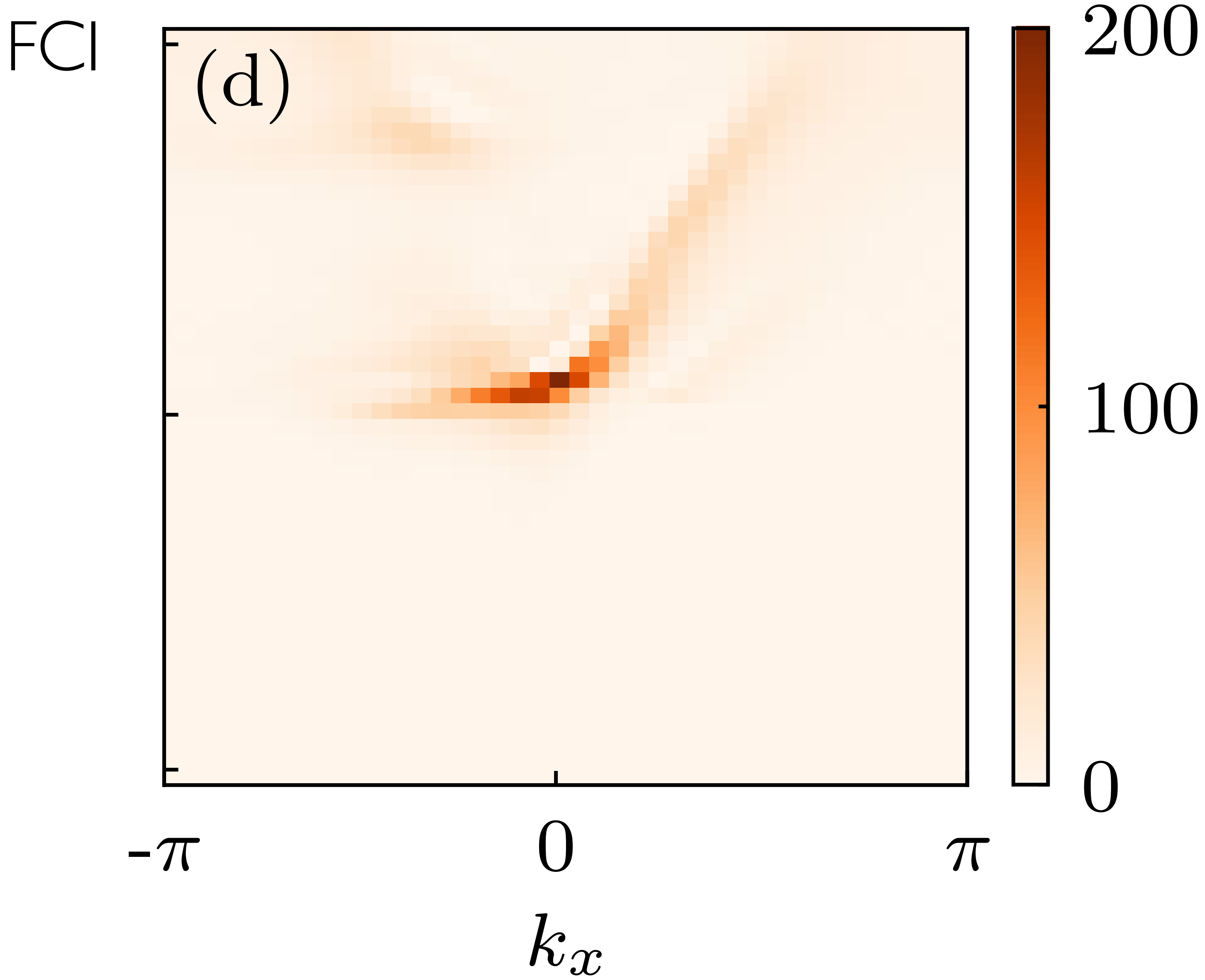

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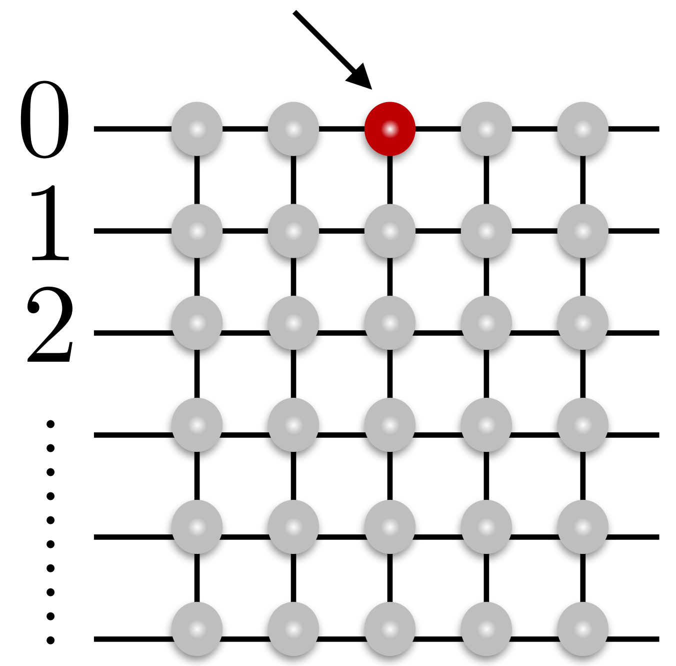
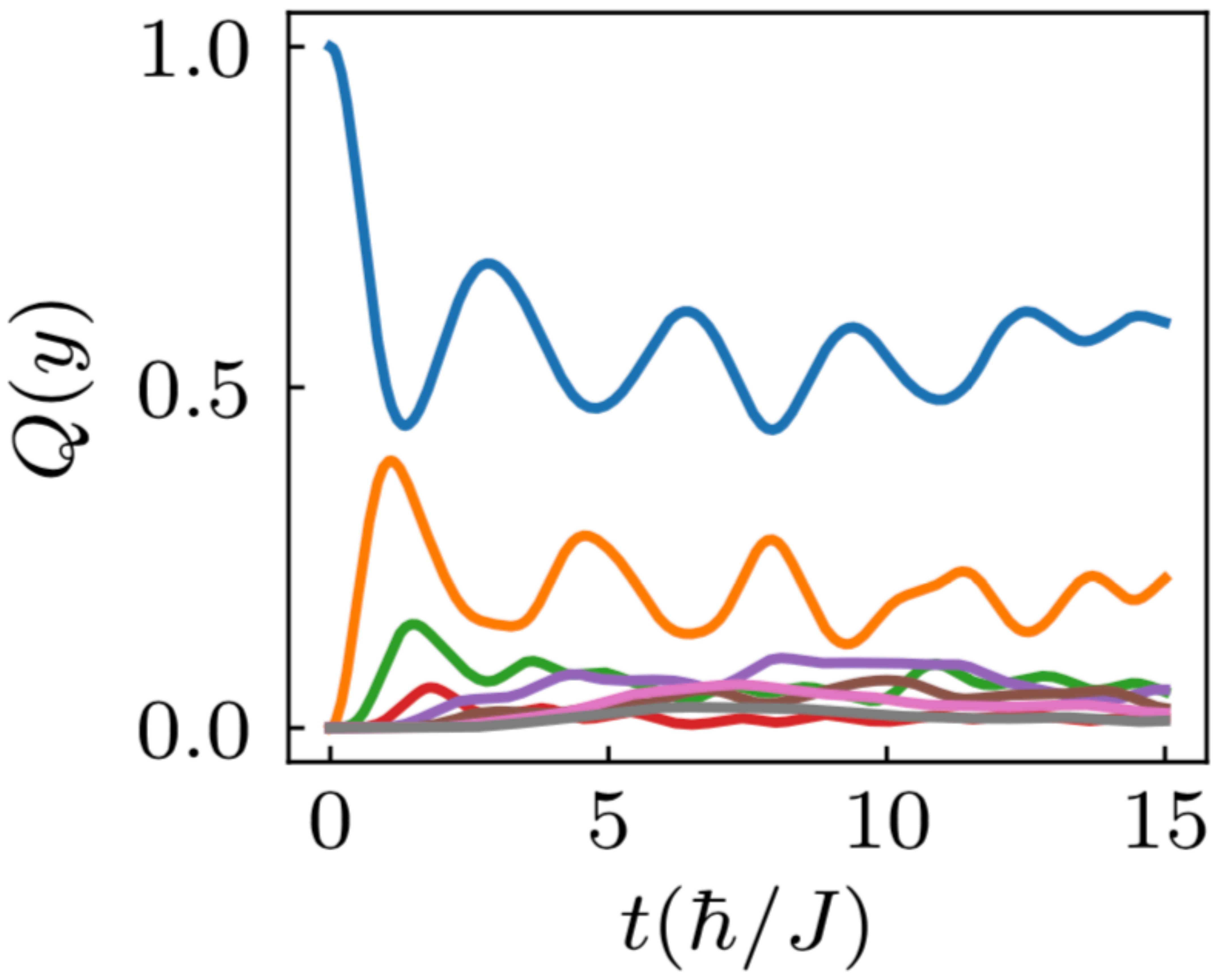


The edge does not behave as an isolated Luttinger liquid:

Single particle



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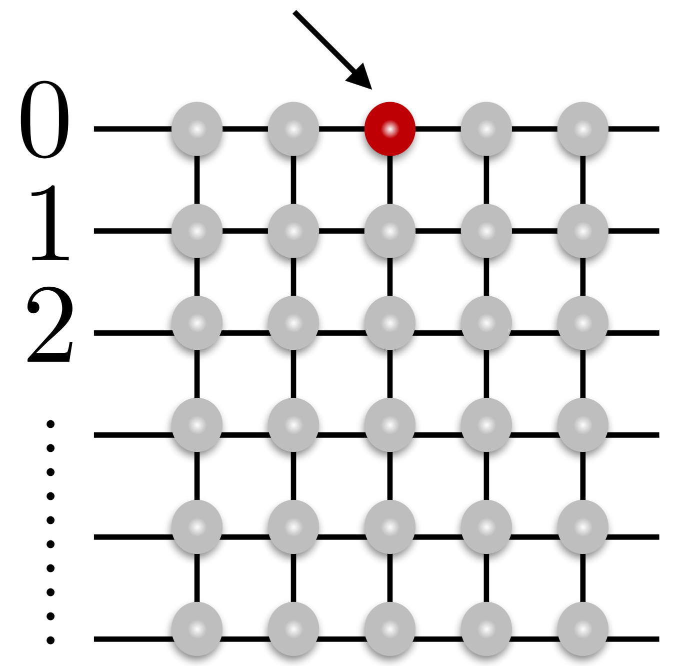

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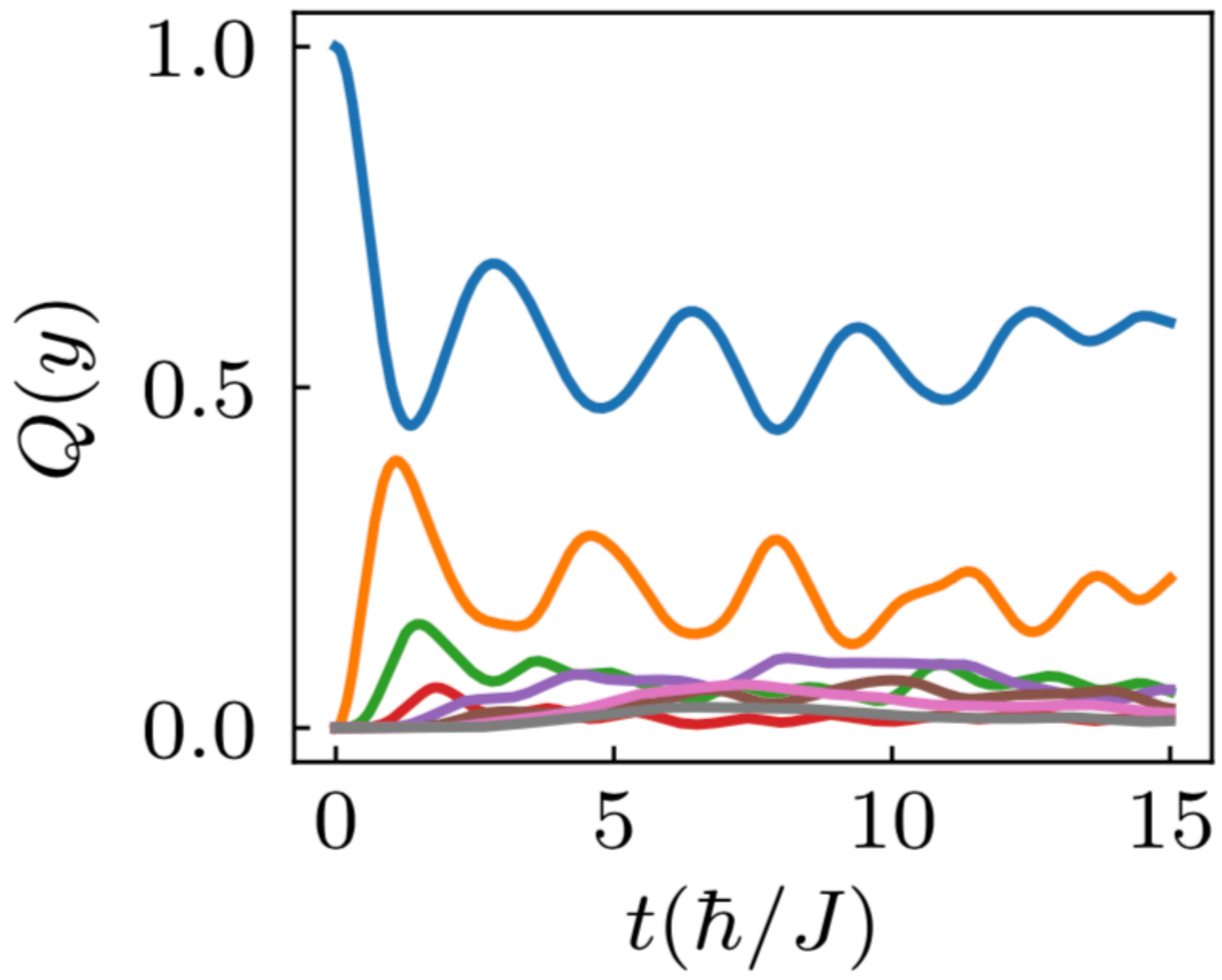
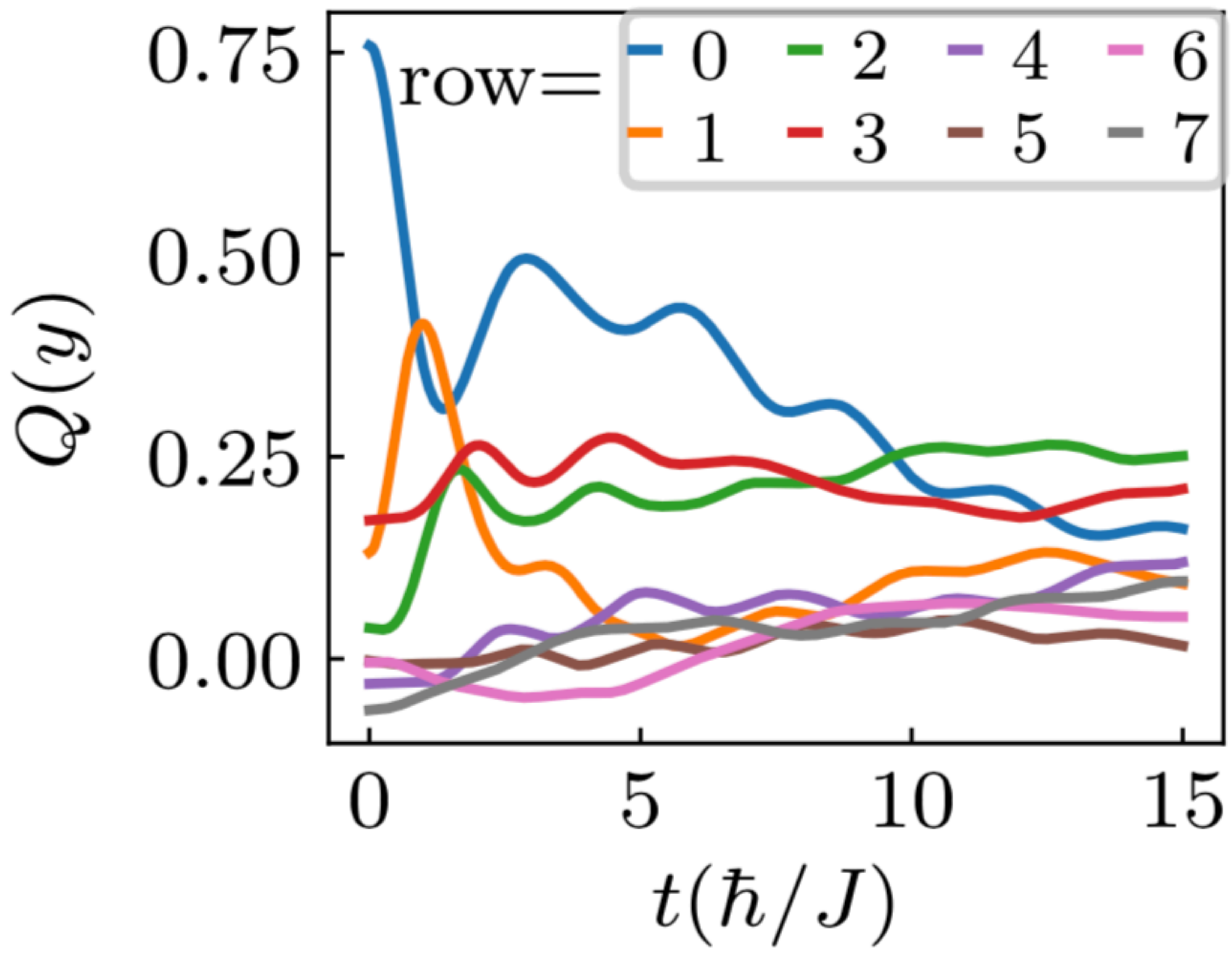


FCI



Harper-Hofstadter

Edge state dynamics of a bosonic fractional Chern insulator

is chiral but not that of an isolated Luttinger liquid.

It is insensitive to the strength of a perturbation, unlike the Chern insulator

X. Y. Dong, AGG, J. Motruk, F. Pollmann, Phys Rev. Lett. (2018)

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Dynamical signatures of the Chern insulator