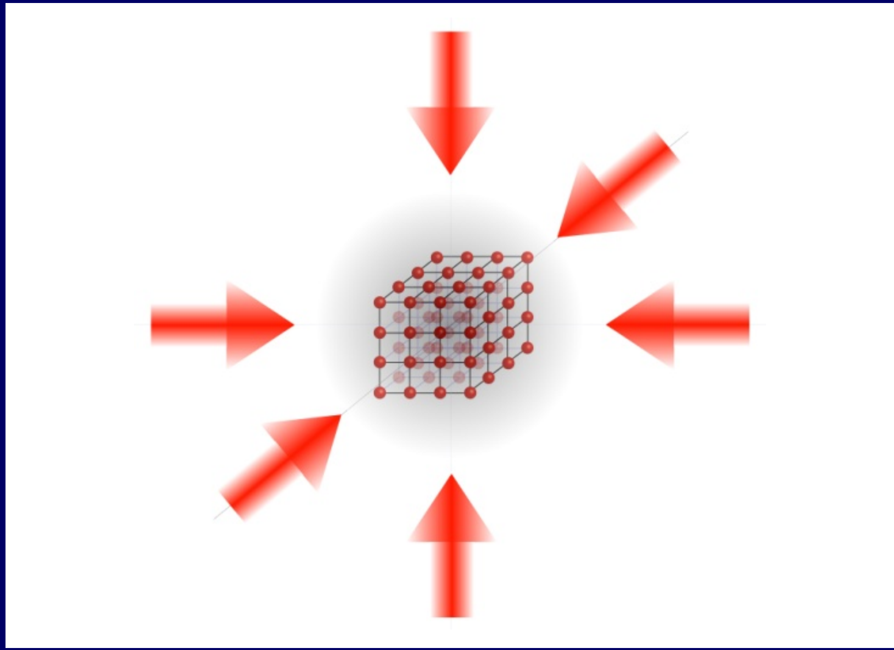
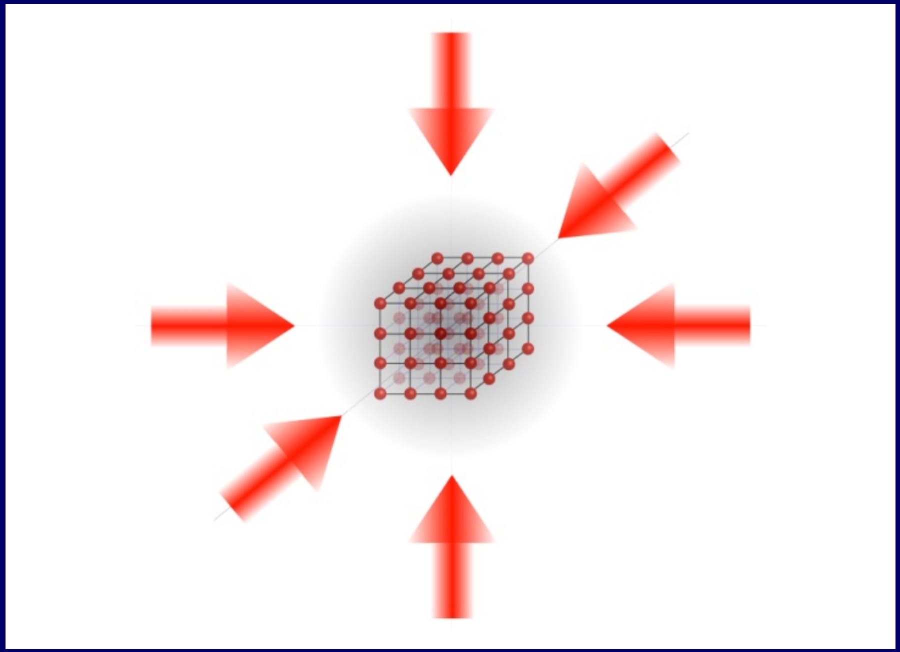
Quantum Gases in Optical Lattices



Where is the physics?



$$H = T + U + V_{trap}$$

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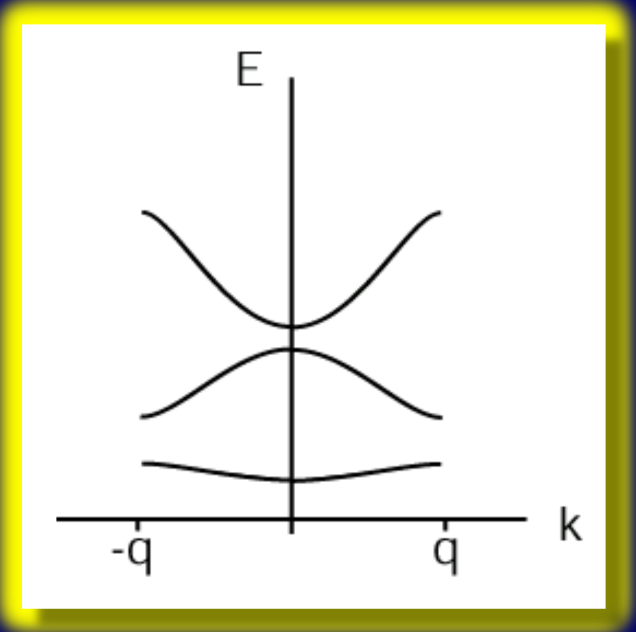

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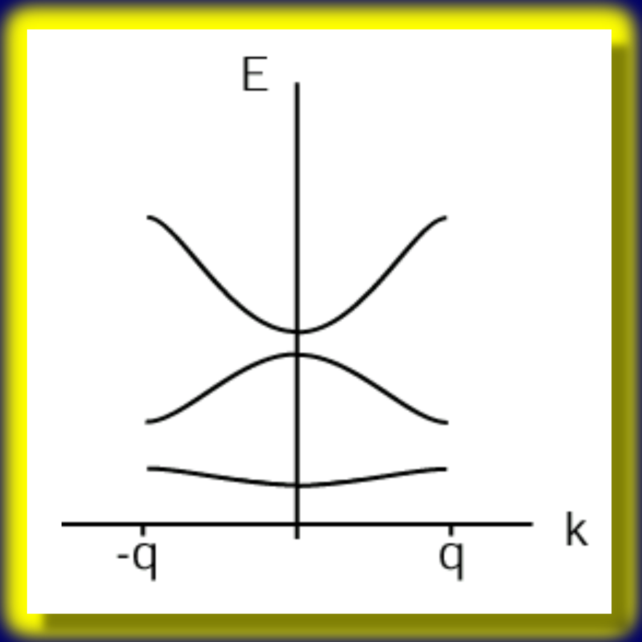
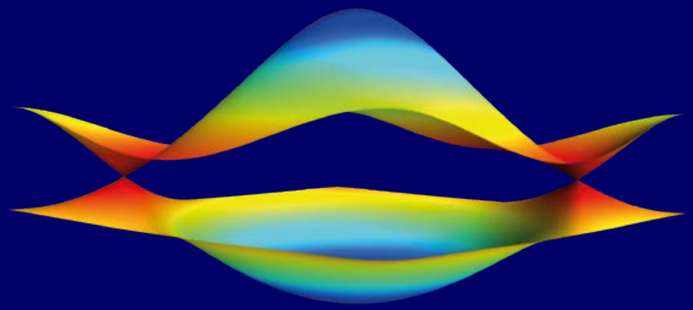
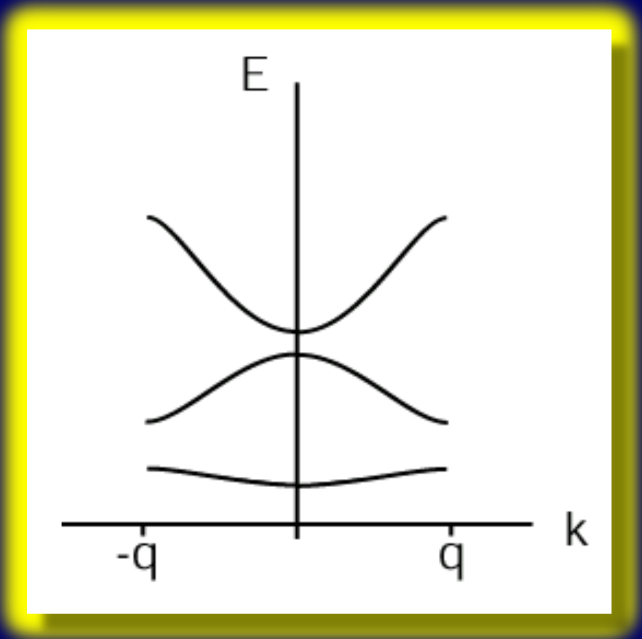
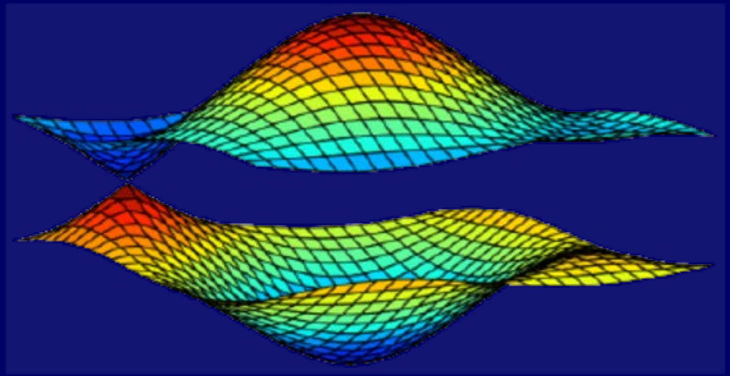




$$H = T + U + V_{trap}$$





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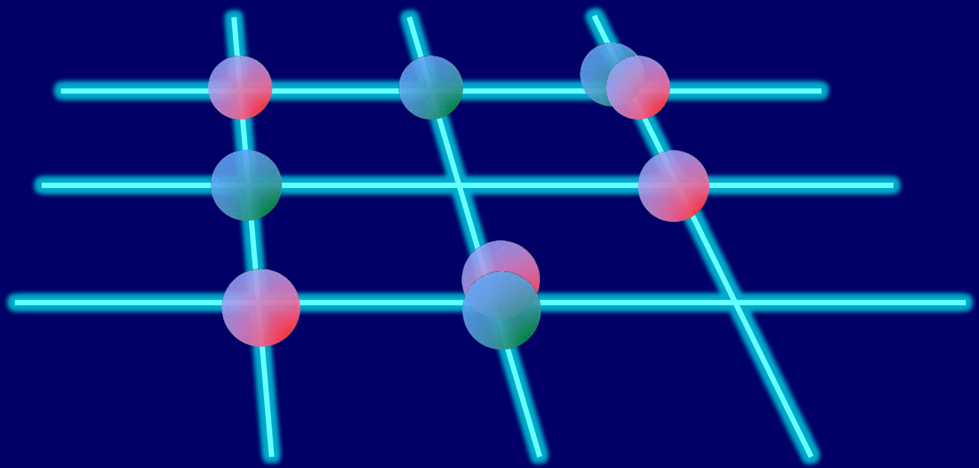
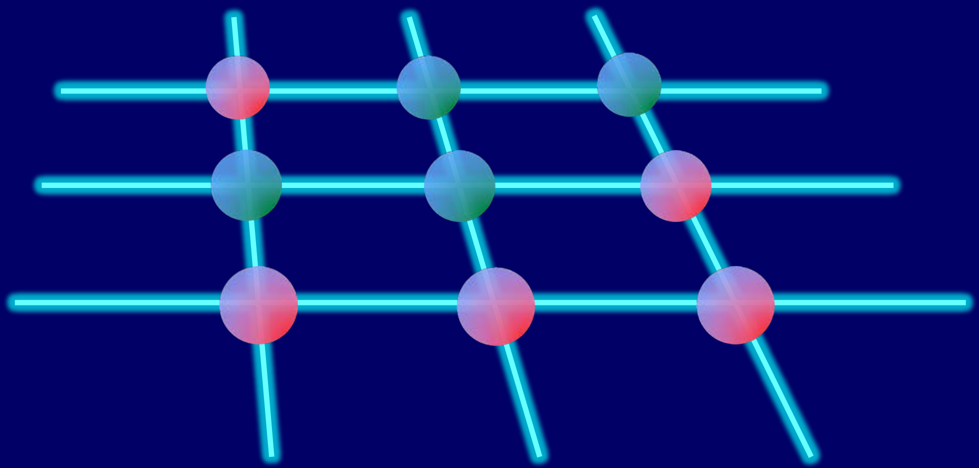
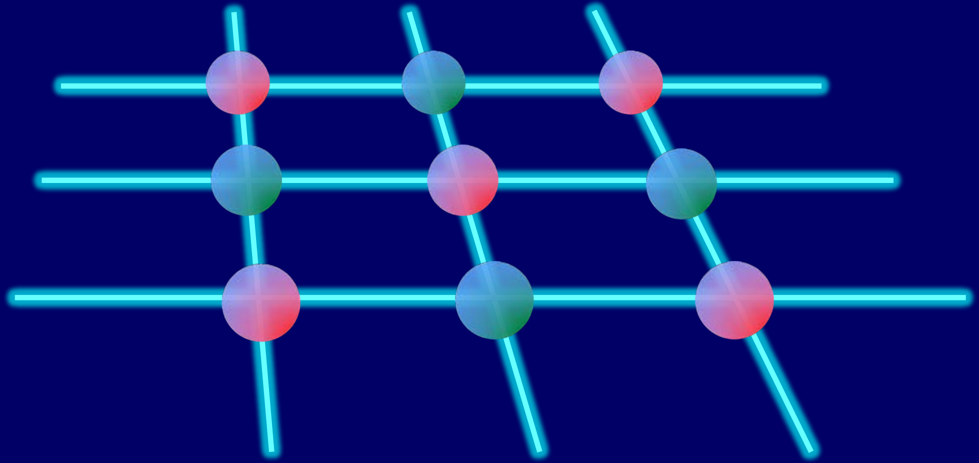


$$H = T + U + V_{trap}$$



$$H = T + U + V_{trap}$$



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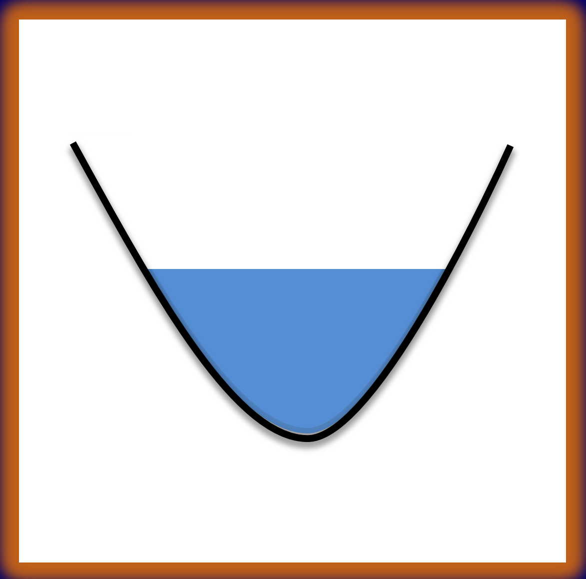
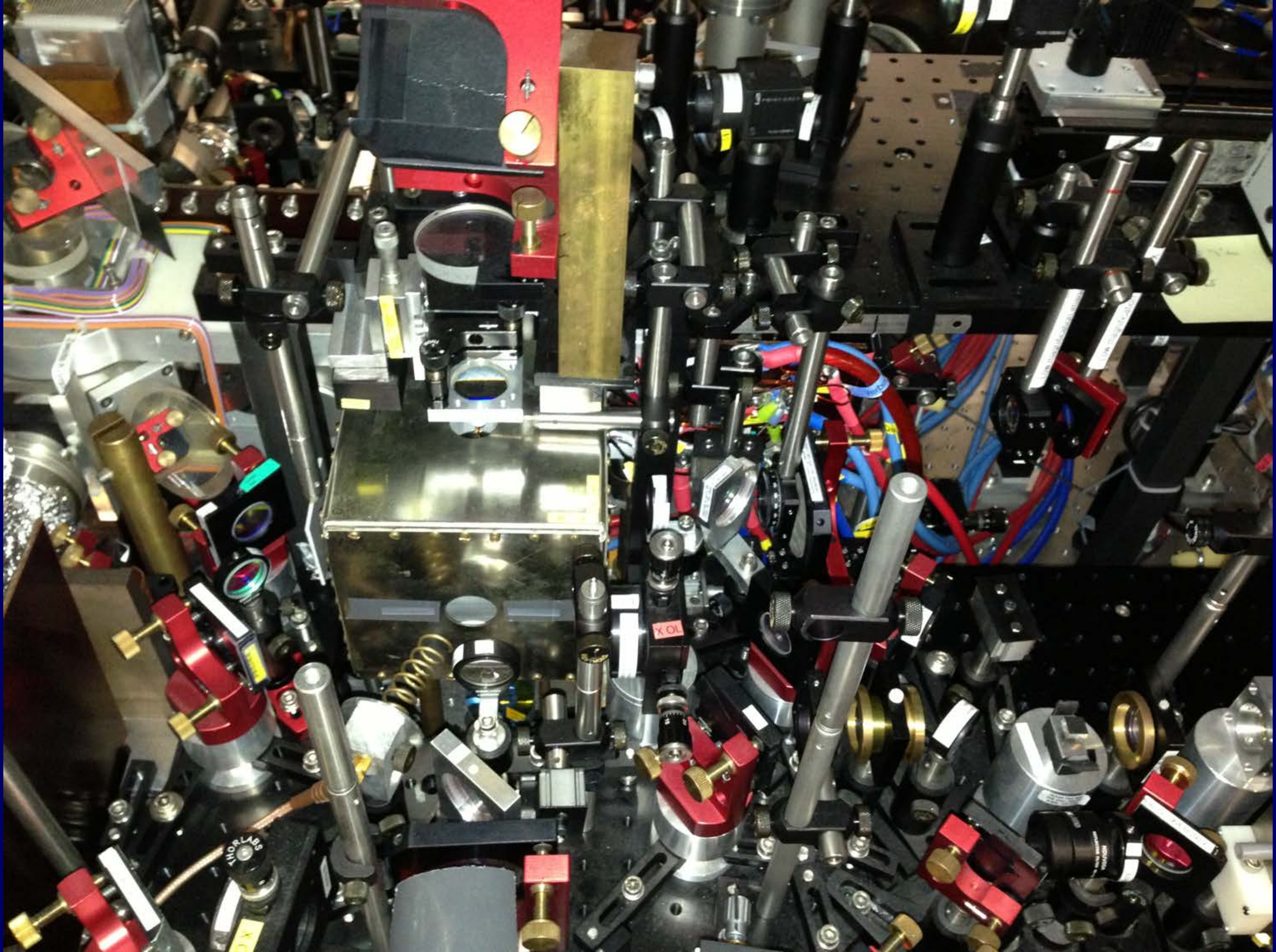
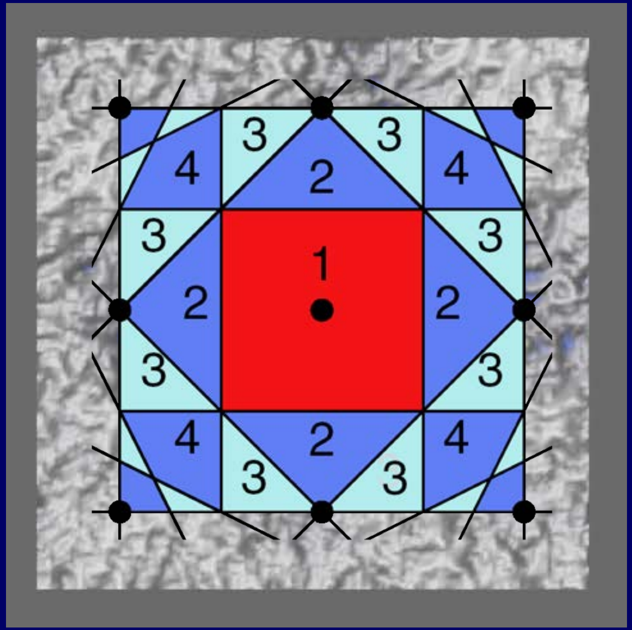
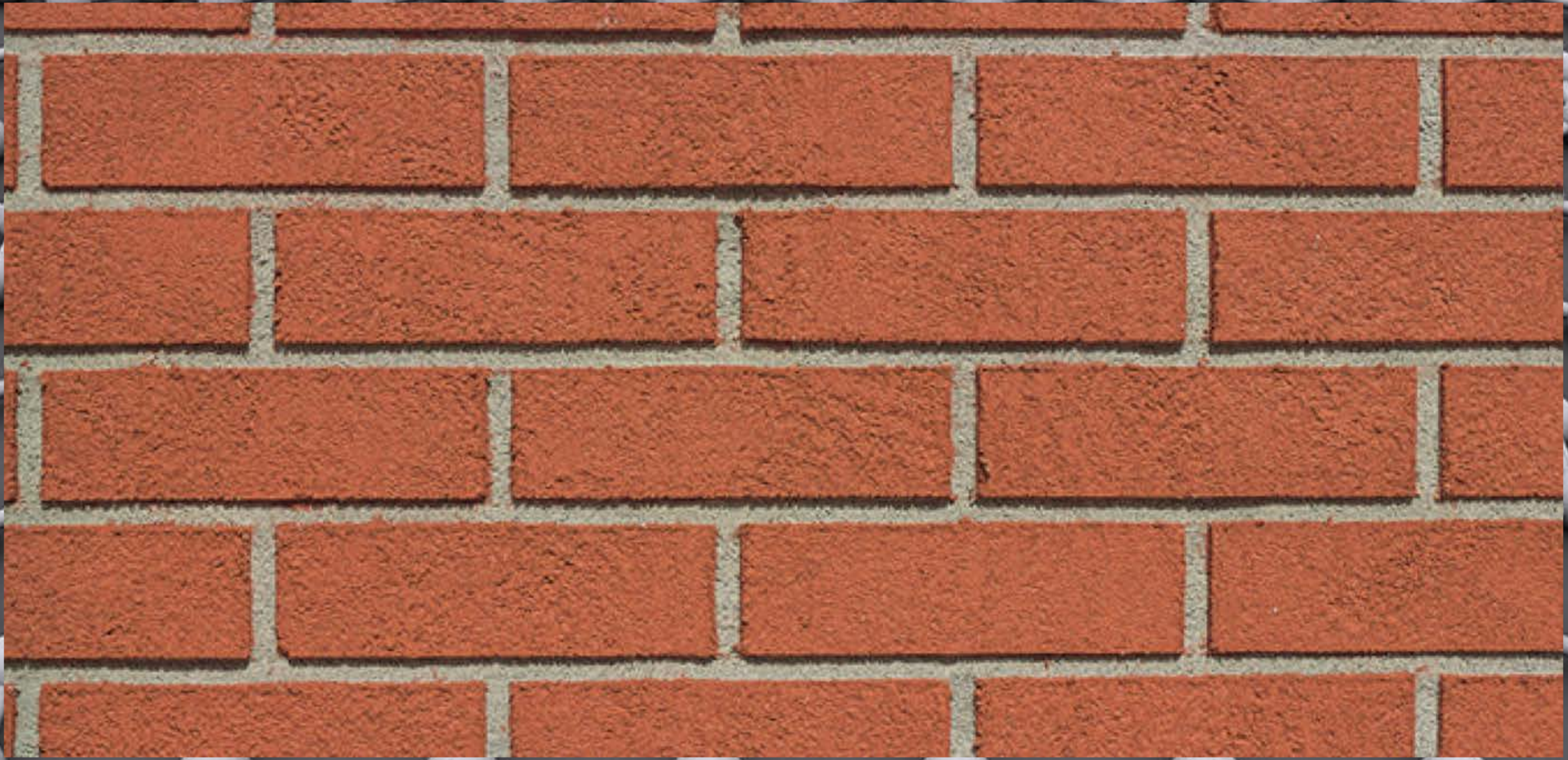



X OL
THORLABS

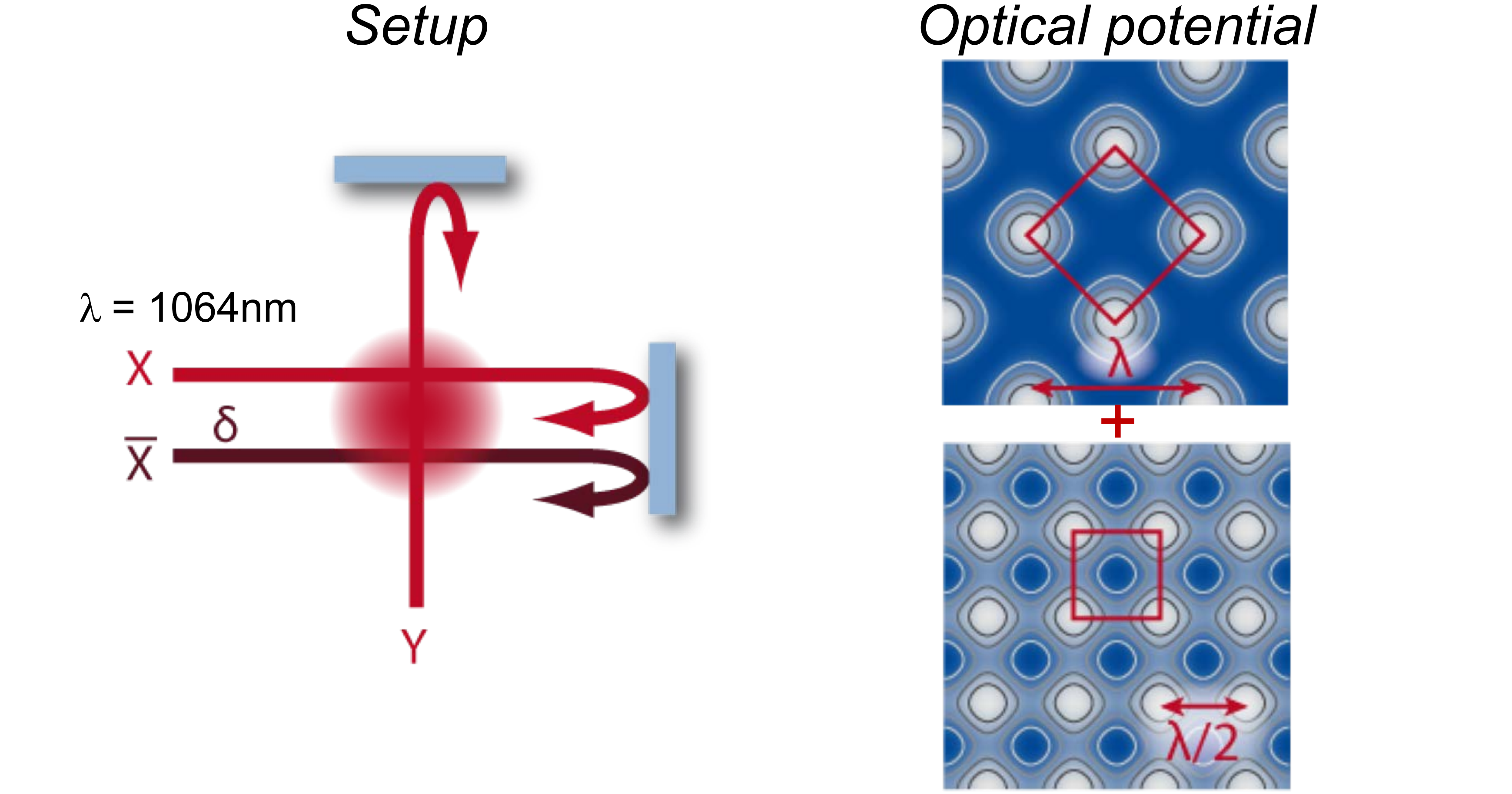
Simple Measurement...



Simple structure...



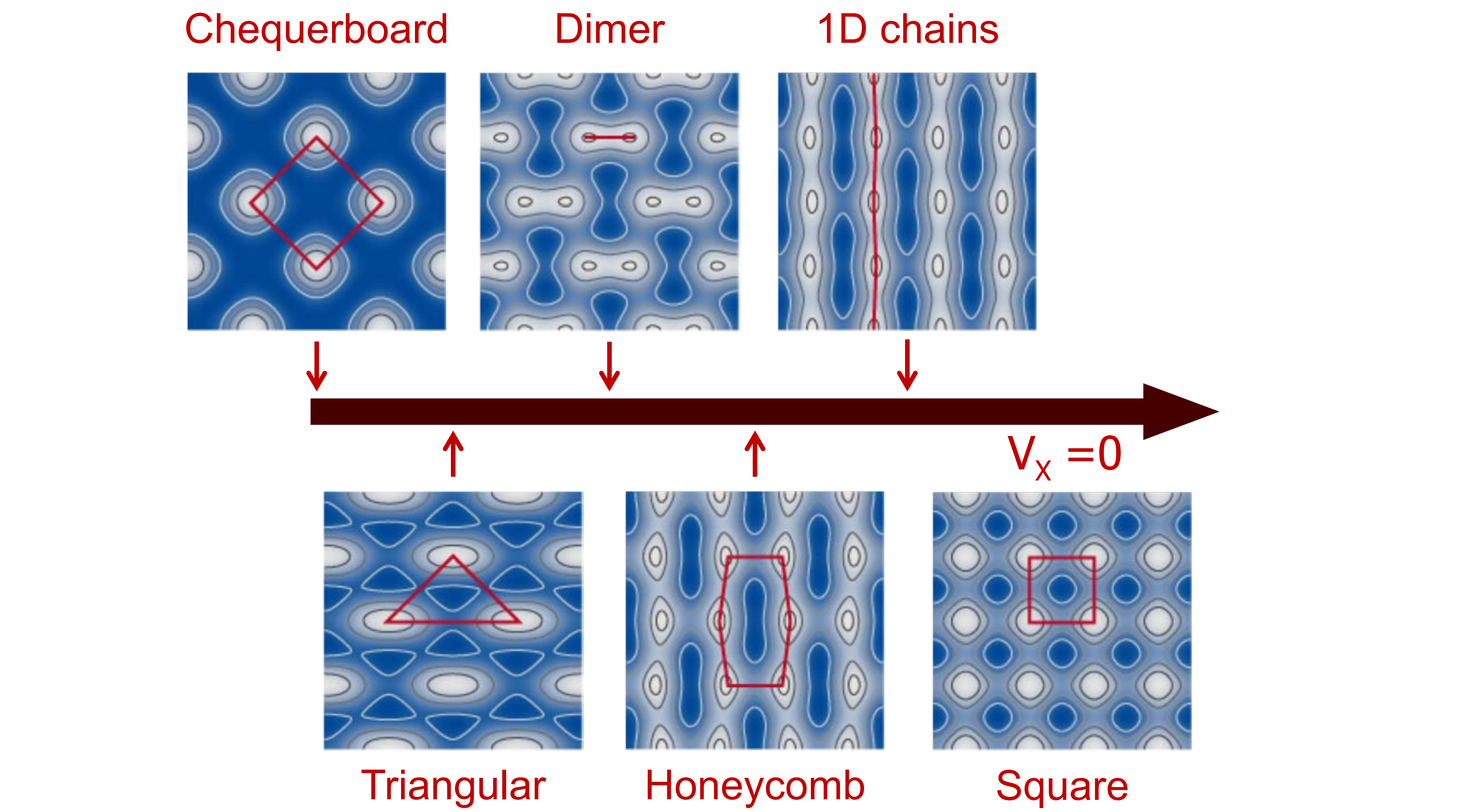
Tunable Geometry Optical Lattice



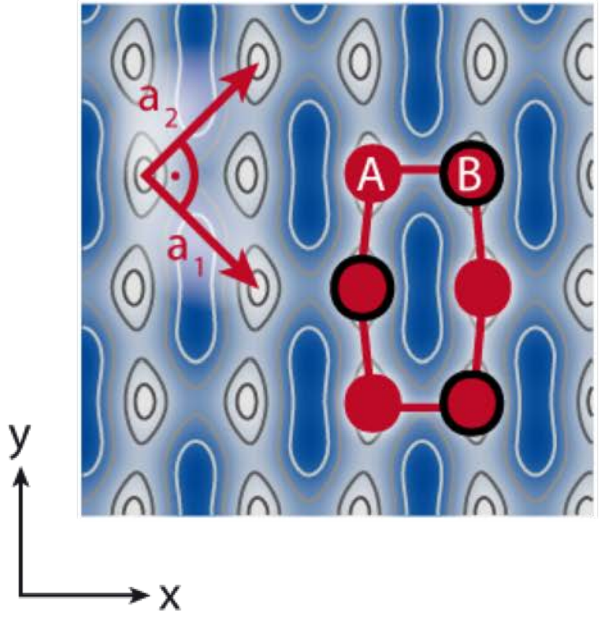
$$V(x,y) = V_{\bar{X}}\cos^2(kx+\theta/2) + V_X\cos^2(kx) + V_Y\cos^2(ky) + 2\alpha\sqrt{V_X V_Y}\cos(kx)\cos(ky)$$

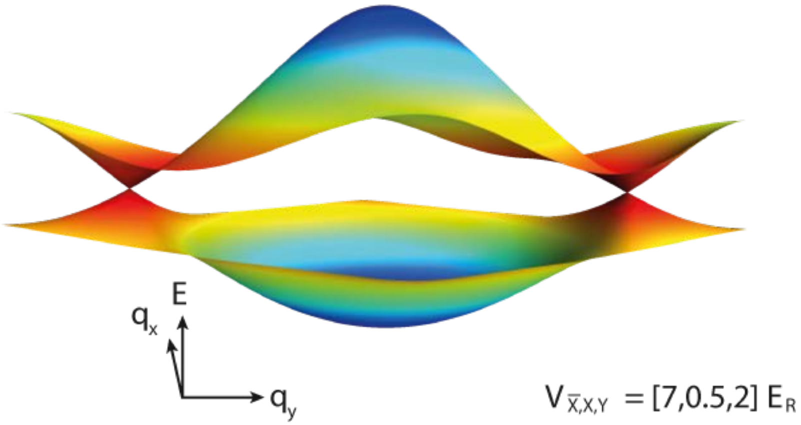
Other engineered lattices: NIST, Munich, Hamburg, Berkeley, …

Tunable Geometry Optical Lattice



Honeycomb Lattice





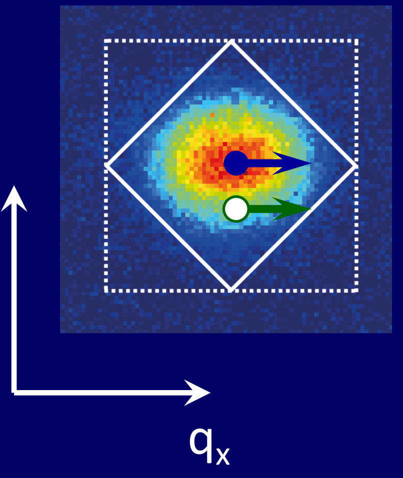
Thanks to Dario Poletti, Corinna Kollath

Probing the Dirac points

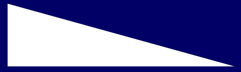
vanishing density of states

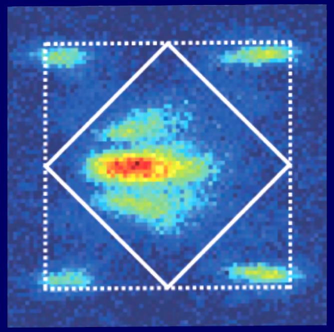
small energy scales

Bloch oscillation and interband transitions

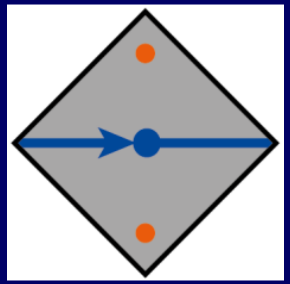


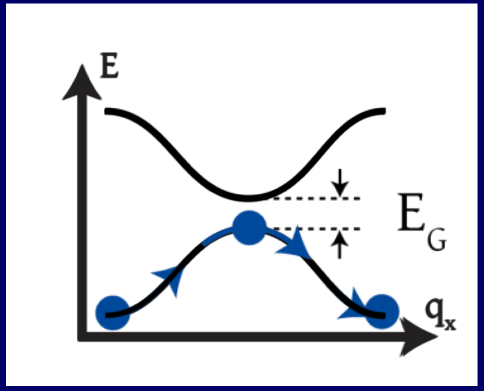
+ magnetic gradient

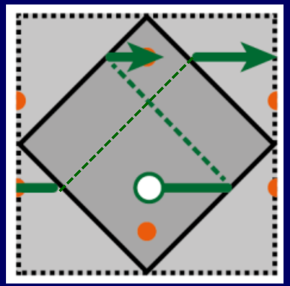


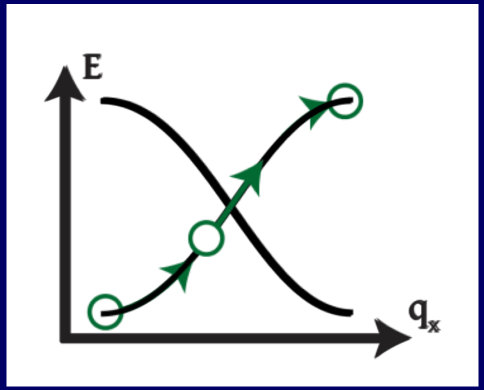


Transfer to 2nd band



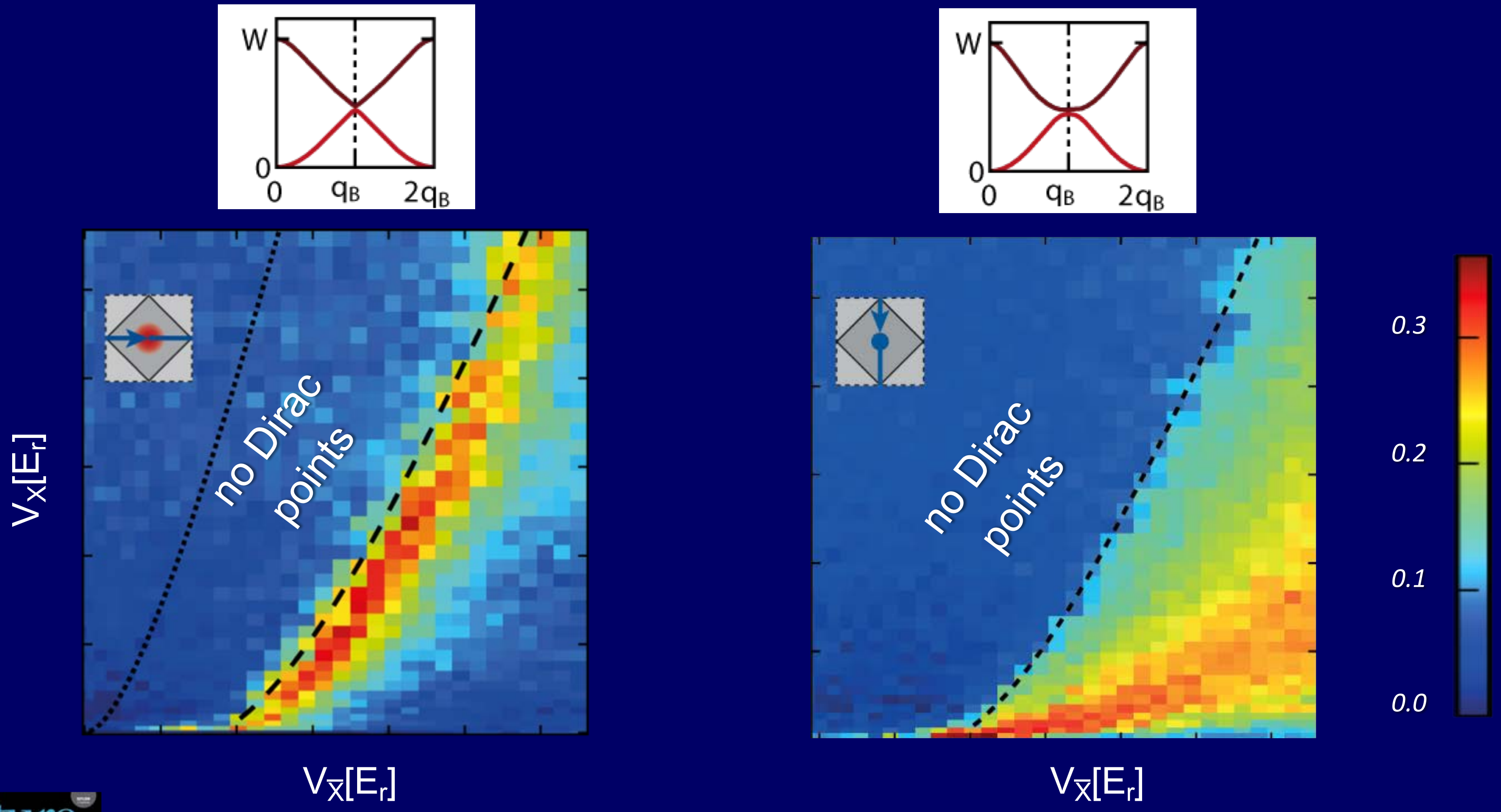






Method in 1D: T. Salger et. al, Phys. Rev. Lett. 99, 190405 (2007)

Touching Dirac points

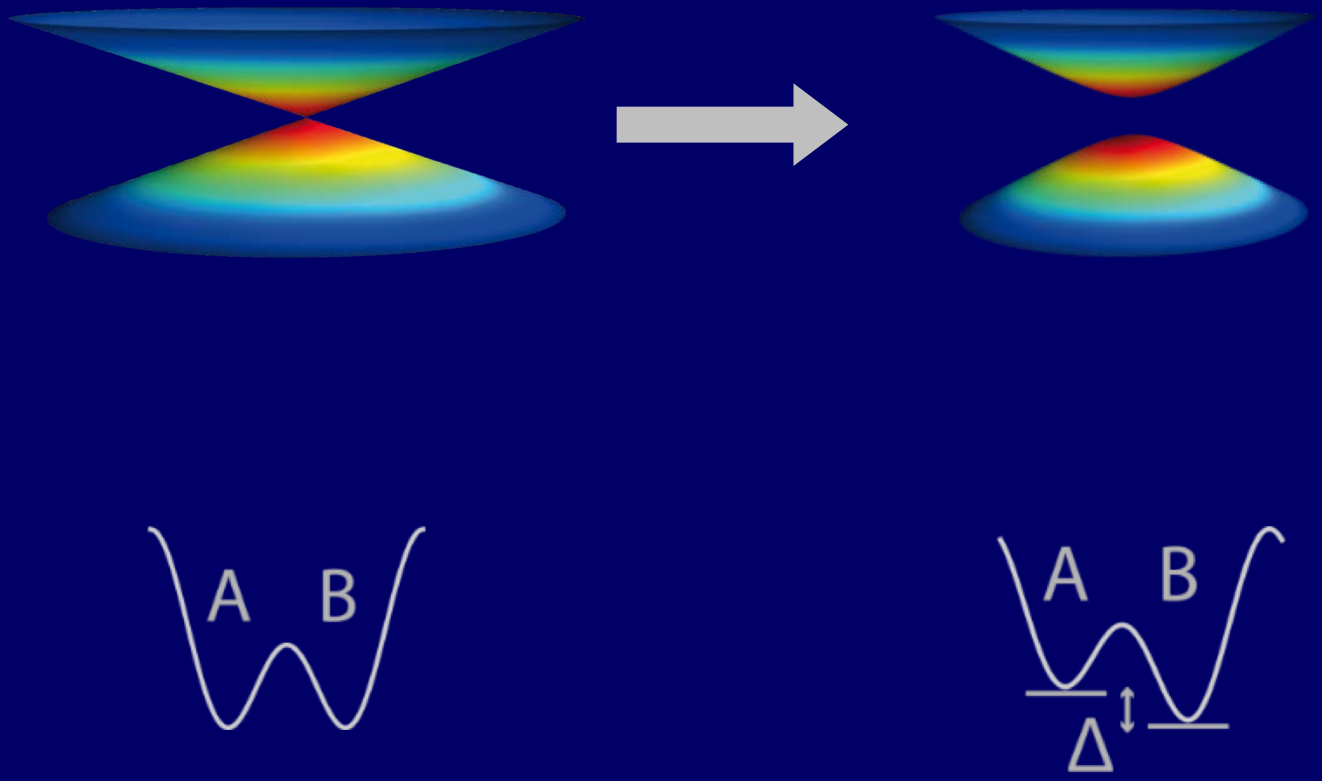


L. Tarruell, D. Greif, T. Uehlinger, G. Jotzu, and T. Esslinger, Nature 483, 302–305 (2012).

Theory, see also: L.-K. Lim, J.-N. Fuchs, G. Montambaux, PRL 108, 175303 (2012)

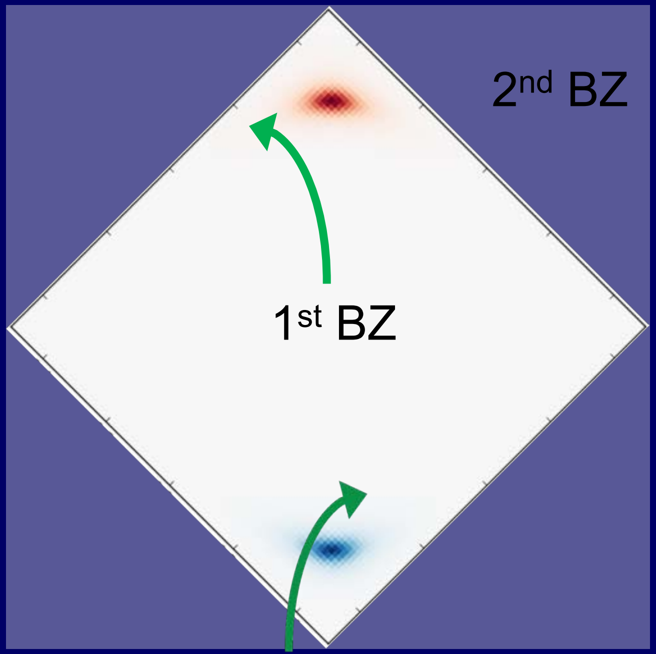
Breaking Inversion Symmetry

Berry curvature



See also: L. Duca, Science 347, 288 (2015)
Review: N. Goldman, G. Juzeliunas, P. Ohberg, I. Spielman, Rep. Prog. Phys. 77, 126401, (2014)

Berry Curvature and Transverse Drift

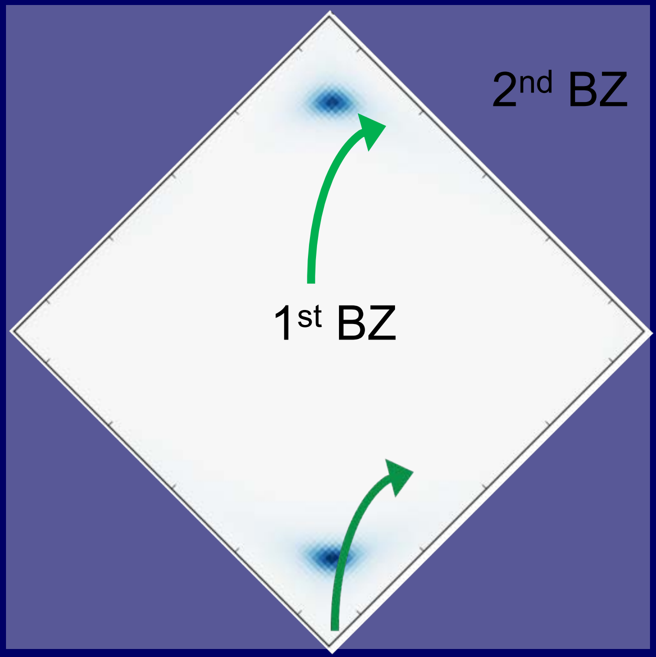


$$\dot{\boldsymbol{r}} = \frac{1}{\hbar}\partial_{\boldsymbol{k}}\epsilon(\boldsymbol{k}) - \dot{\boldsymbol{k}} \times \boldsymbol{\Omega}(\boldsymbol{k})$$

$$\hbar\dot{\boldsymbol{k}} = \boldsymbol{F}(\boldsymbol{r})$$

Chang and Niu, PRL 75, 1348 (1995)
Price and Cooper, PRA 85, 033620 (2012)

Berry Curvature and Transverse Drift



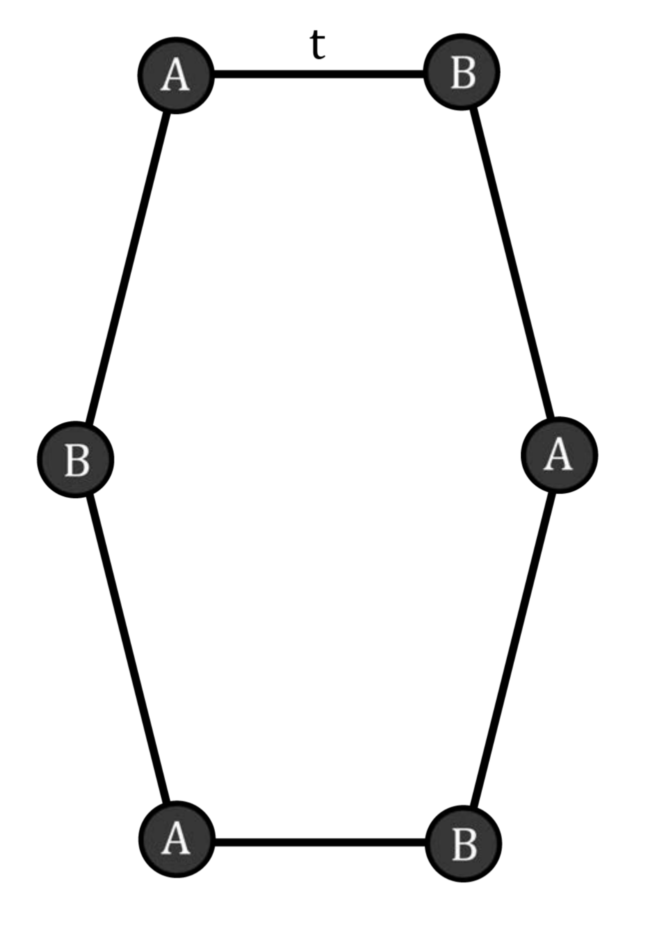
Like a Hall current

Topological Haldane model

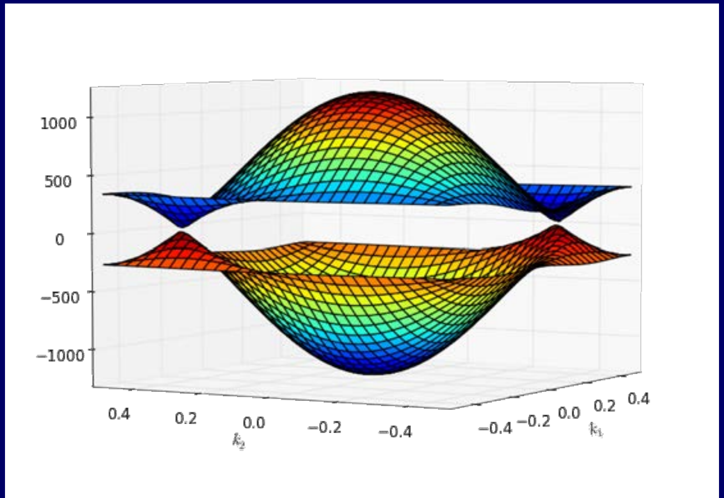
Proposal for Quantum Hall Effect *without* magnetic field!

Haldane, PRL **61**,2015-2018 (1988)

Topological Haldane model



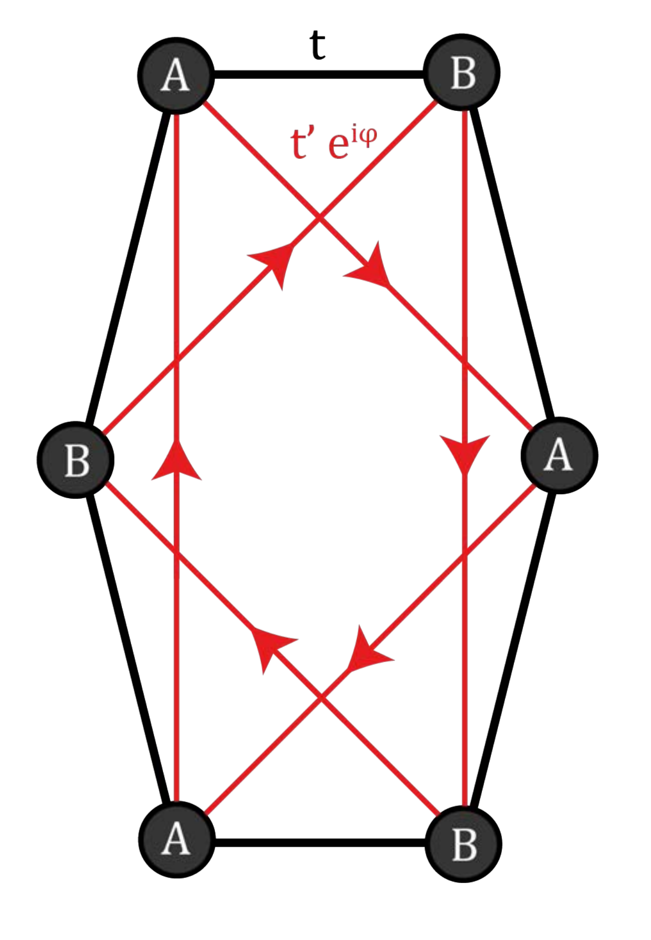
Start from a honeycomb lattice



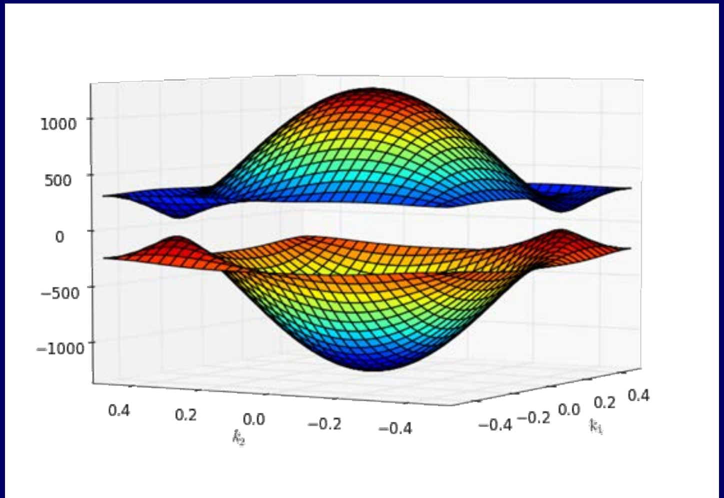
inversion and time-reversal symmertry


Topological Haldane model
break time-reversal symmetry

Topological Haldane model

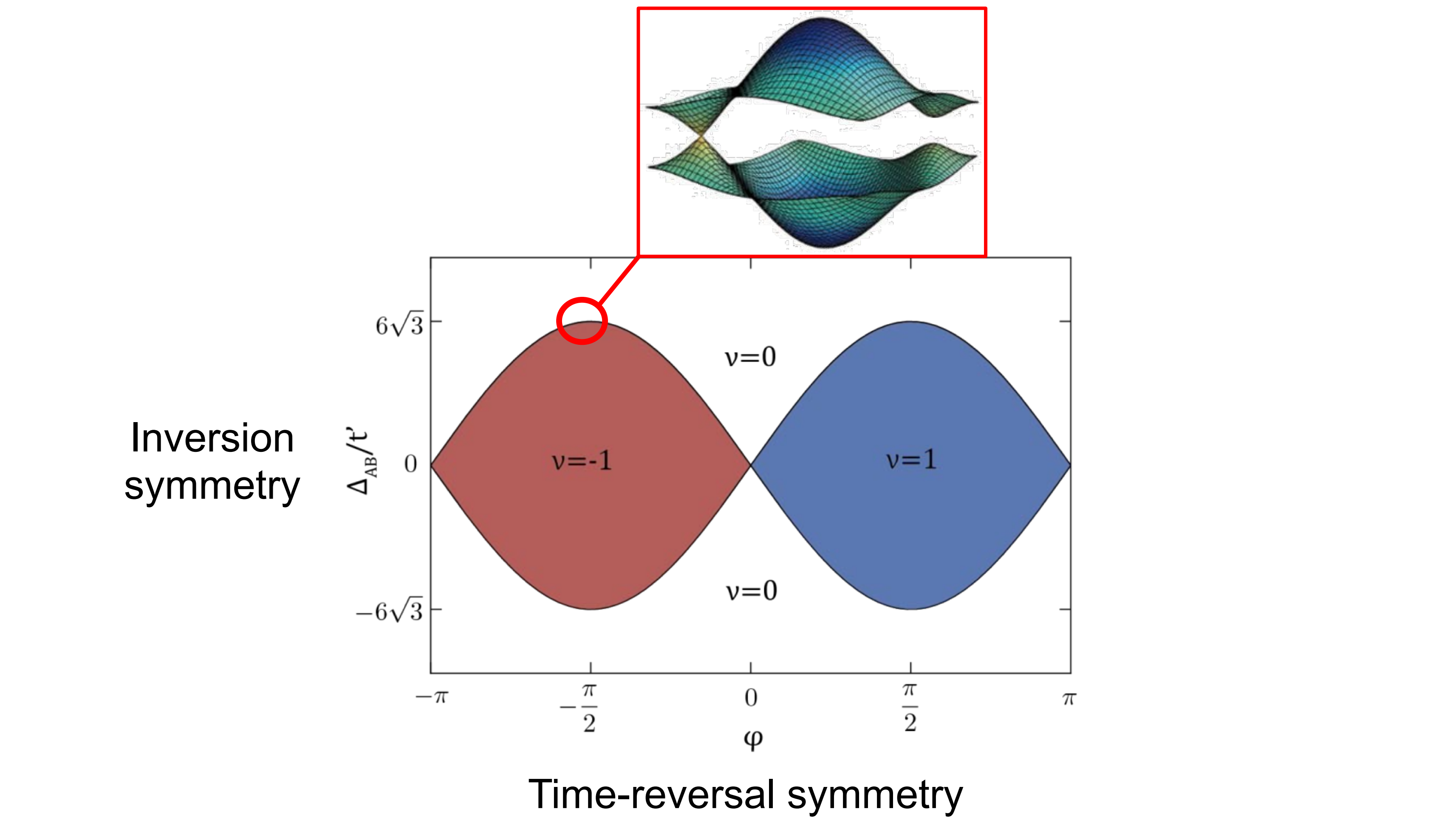


break time-reversal symmetry with complex next-nearest neighbour tunnellings



➔ Topological Chern insulator, with non-zero Hall conductance

Topological Haldane model



Haldane, PRL **61**,2015-2018 (1988)

How?

geometrical constant of order unity, and g is the Landé g factor for the electrons.

While the particular model presented here is unlikely to be directly physically realizable, it indicates that, at least in principle, the QHE can be placed in the wider context of phenomena associated with broken time-reversal invariance, and does not necessarily require external magnetic fields, but could occur as a consequence of magnetic ordering in a quasi-two-dimensional system.

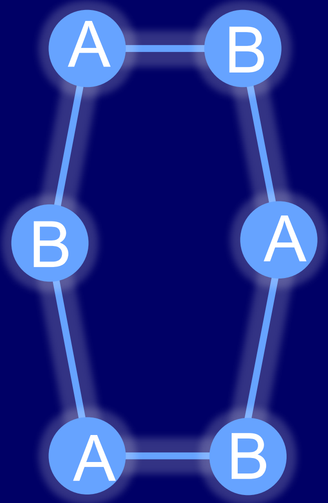
Haldane, PRL **61**,2015-2018 (1988)

Breaking time-reversal symmetry

Proposal for Photovoltaic Hall effect in graphene

T. Oka und H. Aoki, PRL **79**, 081406 (2009)

Breaking time-reversal symmetry

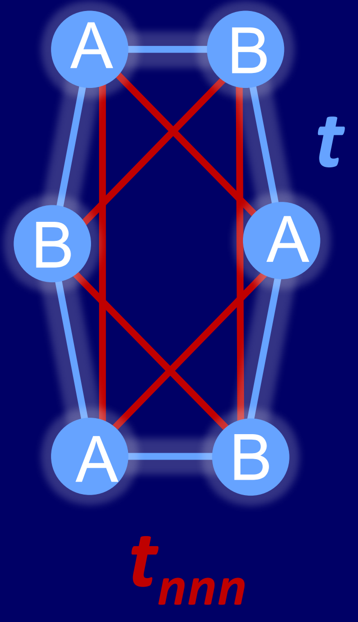


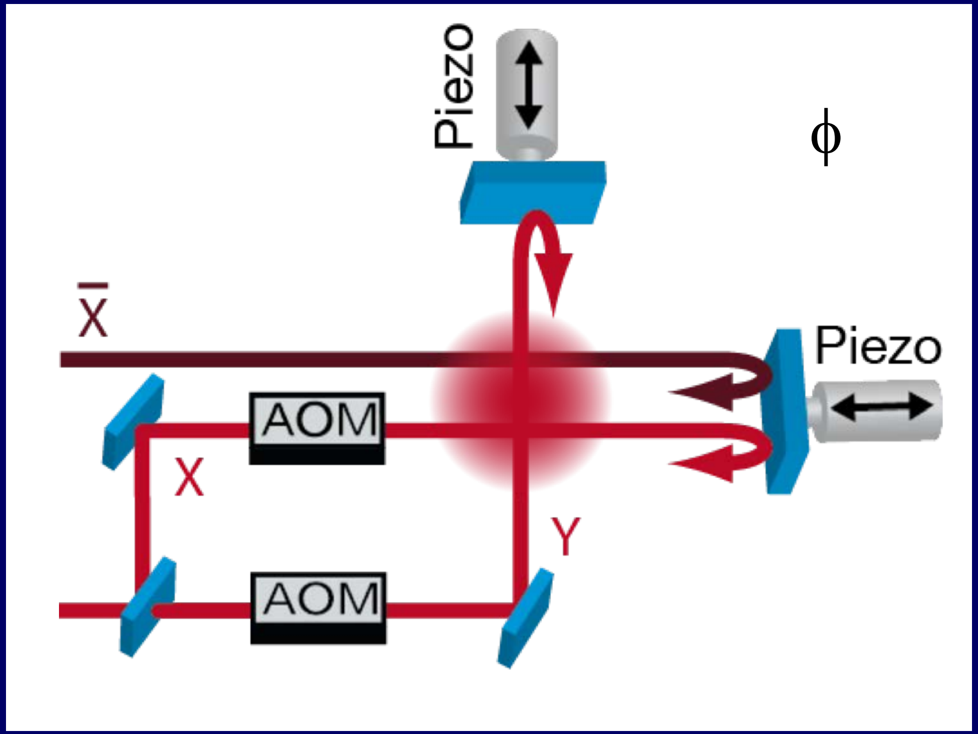
Other proposals to realize topological Hamiltonains:
T. Kitagawa et al., Phys. Rev. B 82, 235114 (2010)
P. Hauke et al., Phys. Rev. Lett 109, 145301 (2012)

Realisation in photonic system: Rechtsman et. al   Nature 496, 196–200 (2013)

Breaking time-reversal symmetry

Lattice Shaking

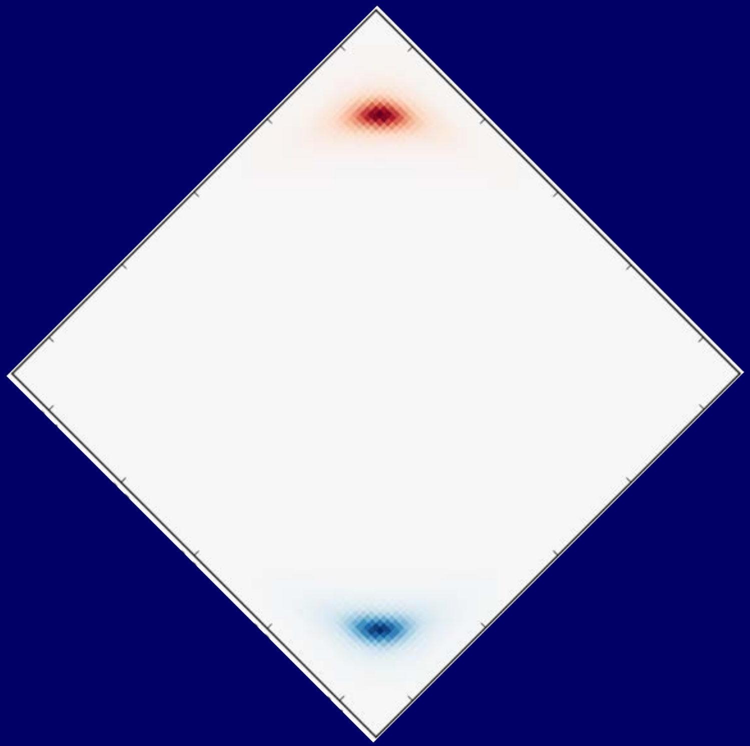




Lattice shaking: Pisa — Lignier, PRL **99**, 220403 (2007)
Hamburg/Barcelona — Struck, Science **333**, 996-9 (2011), PRL 108, 225304 (2012)
Chicago — Parker, Nat. Phys. **9**, 769-774 (2013)

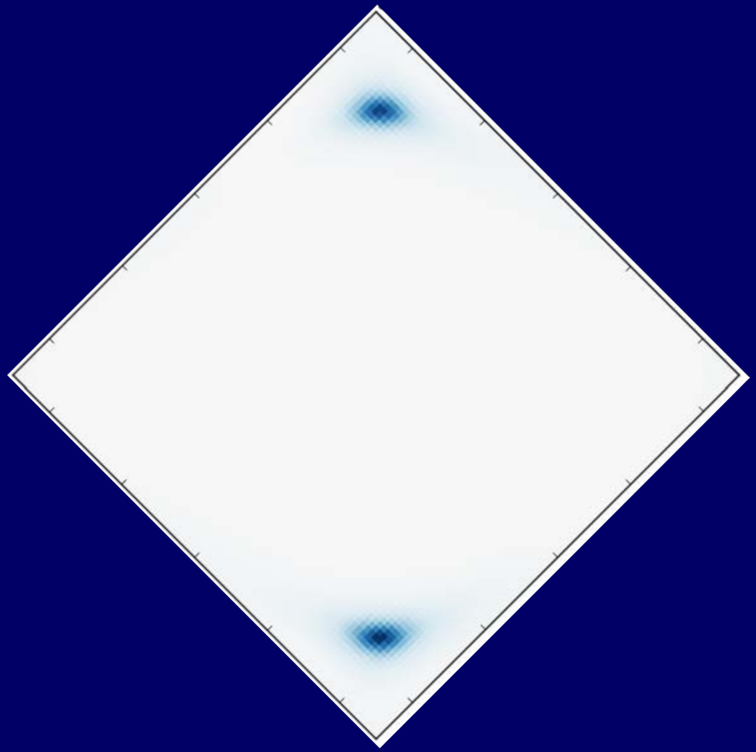
Berry Curvature

Trivial band insulator



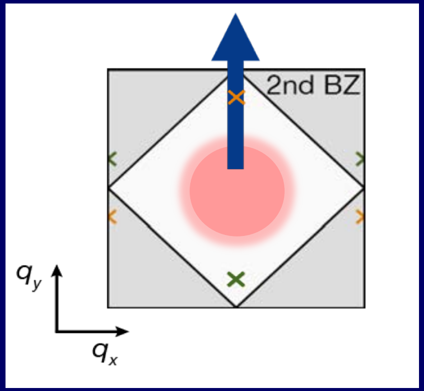
Chern number 0

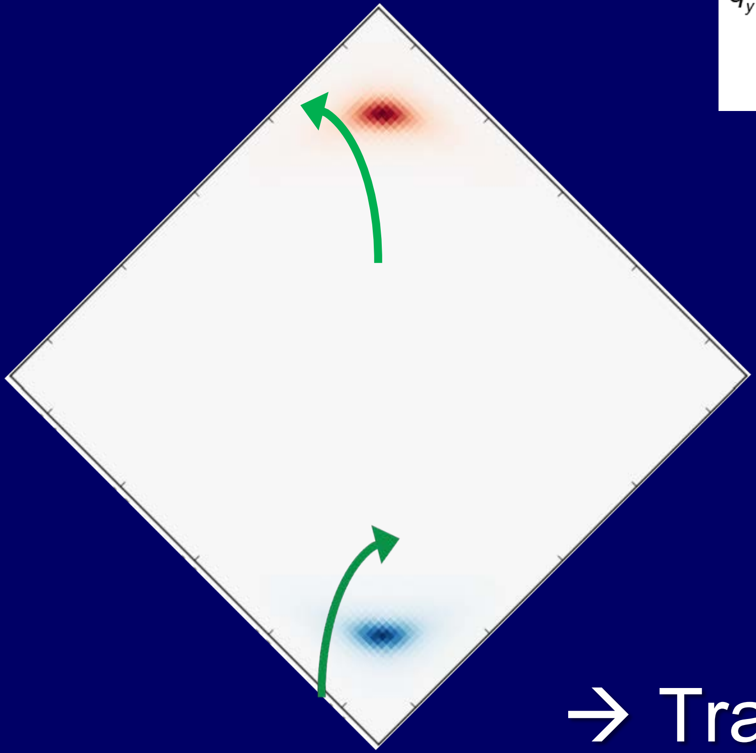
Chern insulator

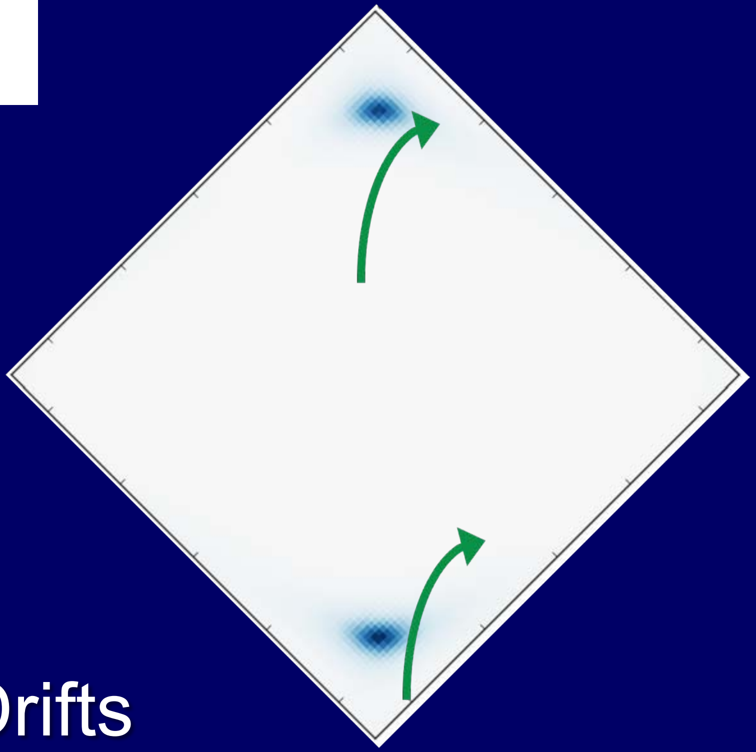


Chern number -1

Berry Curvature - Measurement



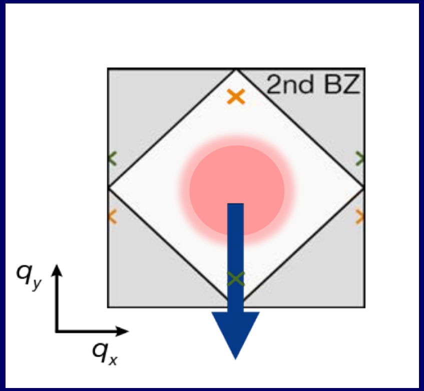


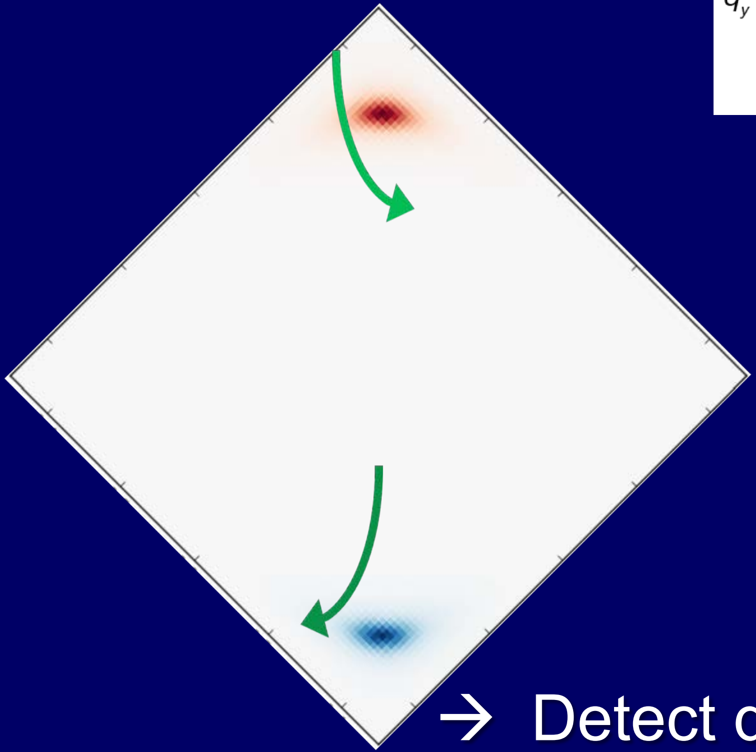


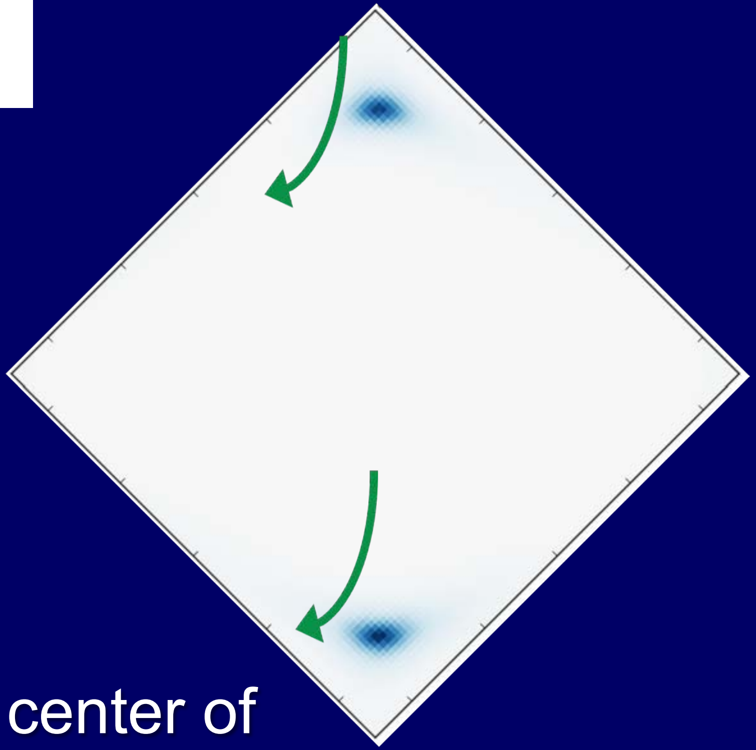
→ Transverse Drifts

See also: M. Aidelsburger et al., Nature Physics 11, 162 (2015)

Berry Curvature - Measurement





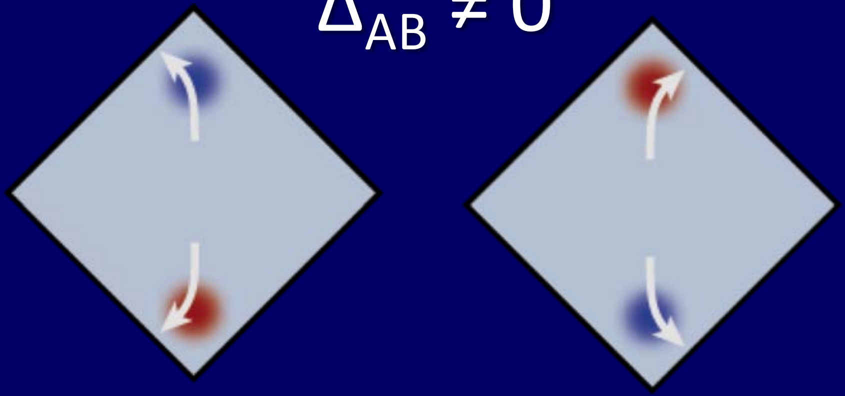


→ Detect difference in center of mass position after full Bloch cycle

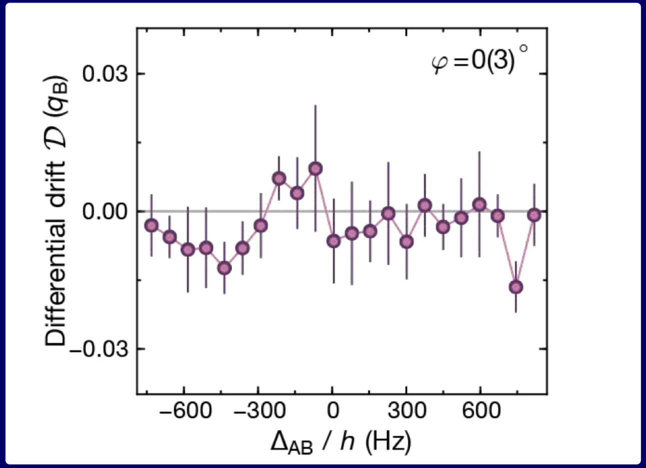
See also: M. Aidelsburger, Nature Physics 11, 162 (2015)

Topological features of the system

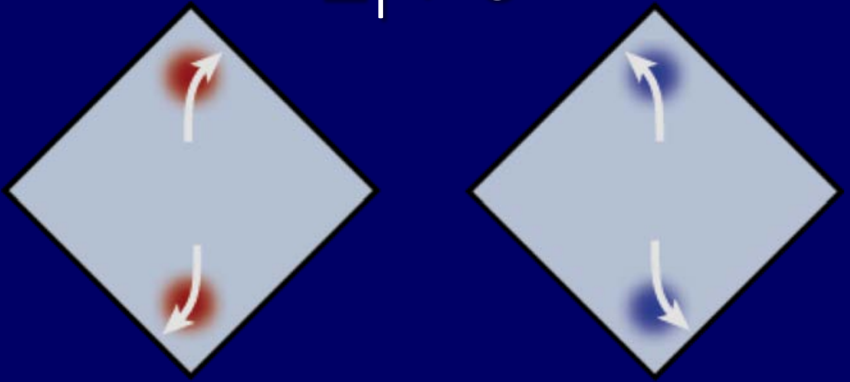
$\Delta_{AB} \neq 0$



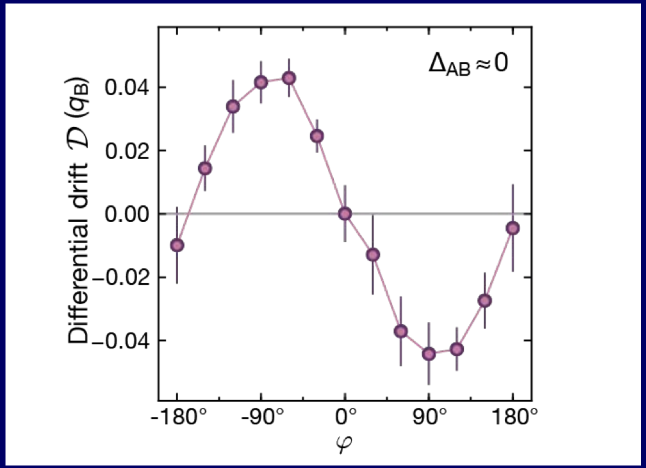
topologically trivial



$\Delta_T \neq 0$

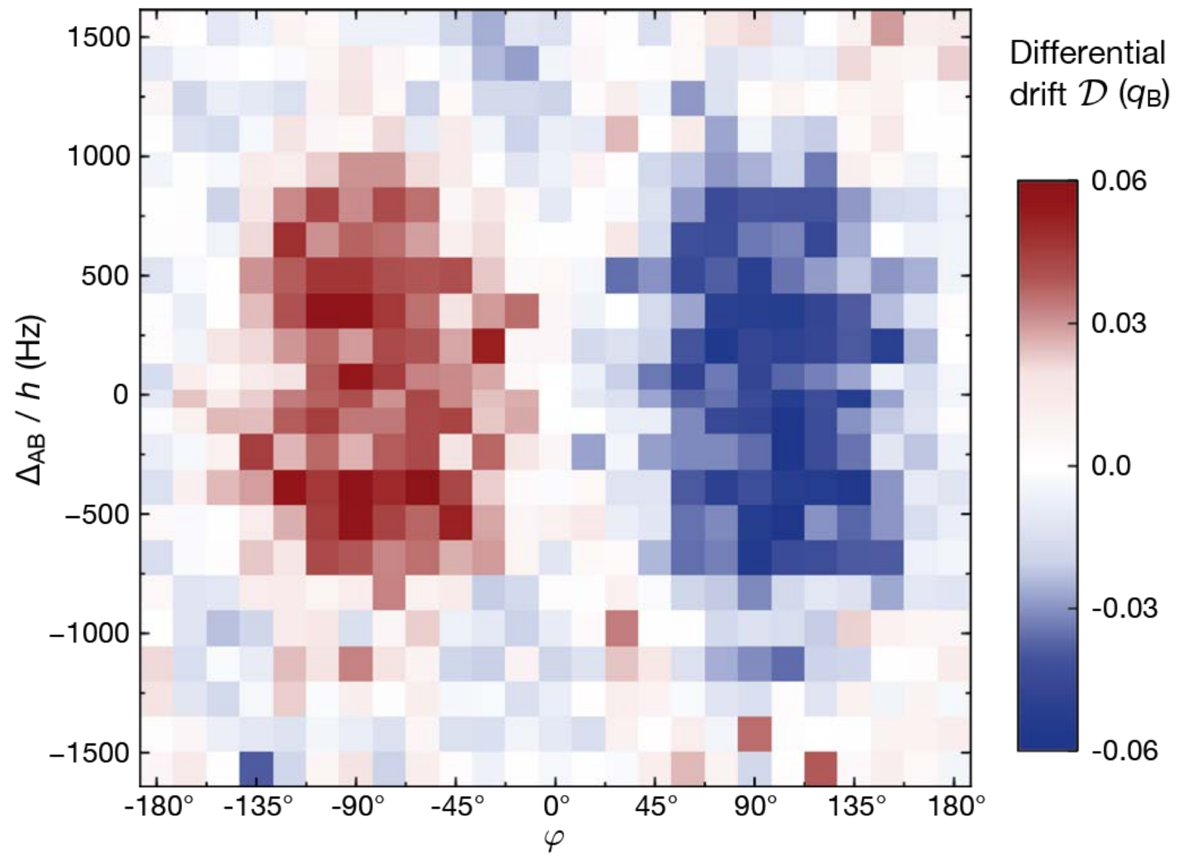


nonzero Chern number



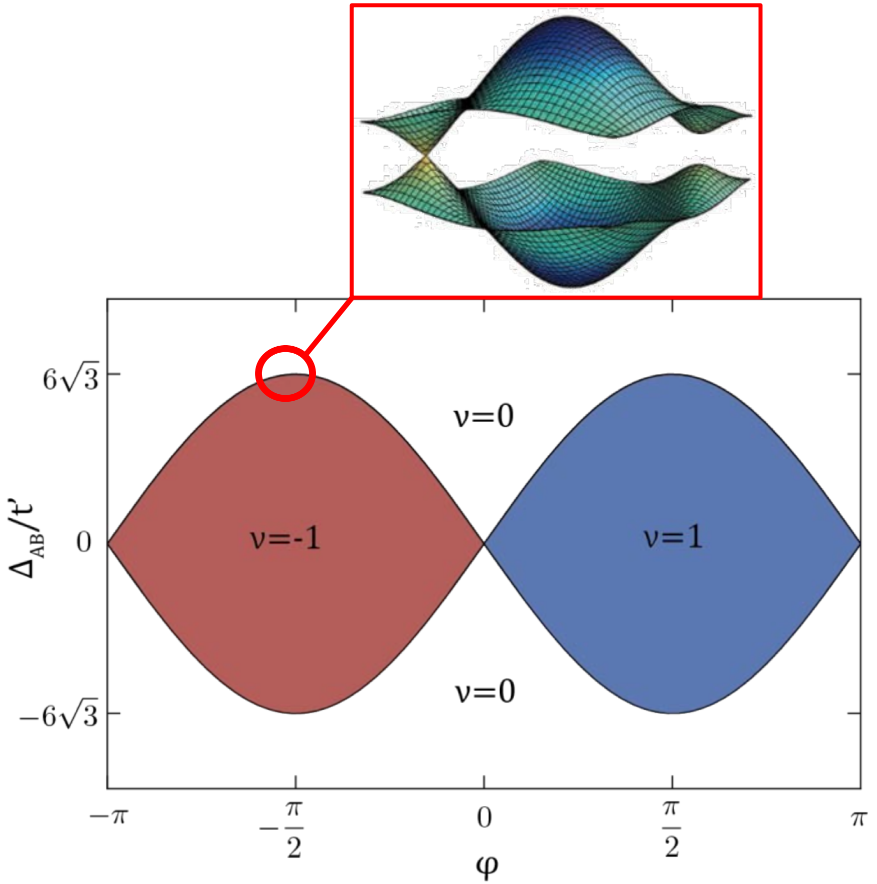
G. Jotzu, M. Messer, R. Desbuquois, M. Lebrat, T. Uehlinger, D. Greif, T. E., Nature 515, 237 (2014)

Observing Transverse Drifts

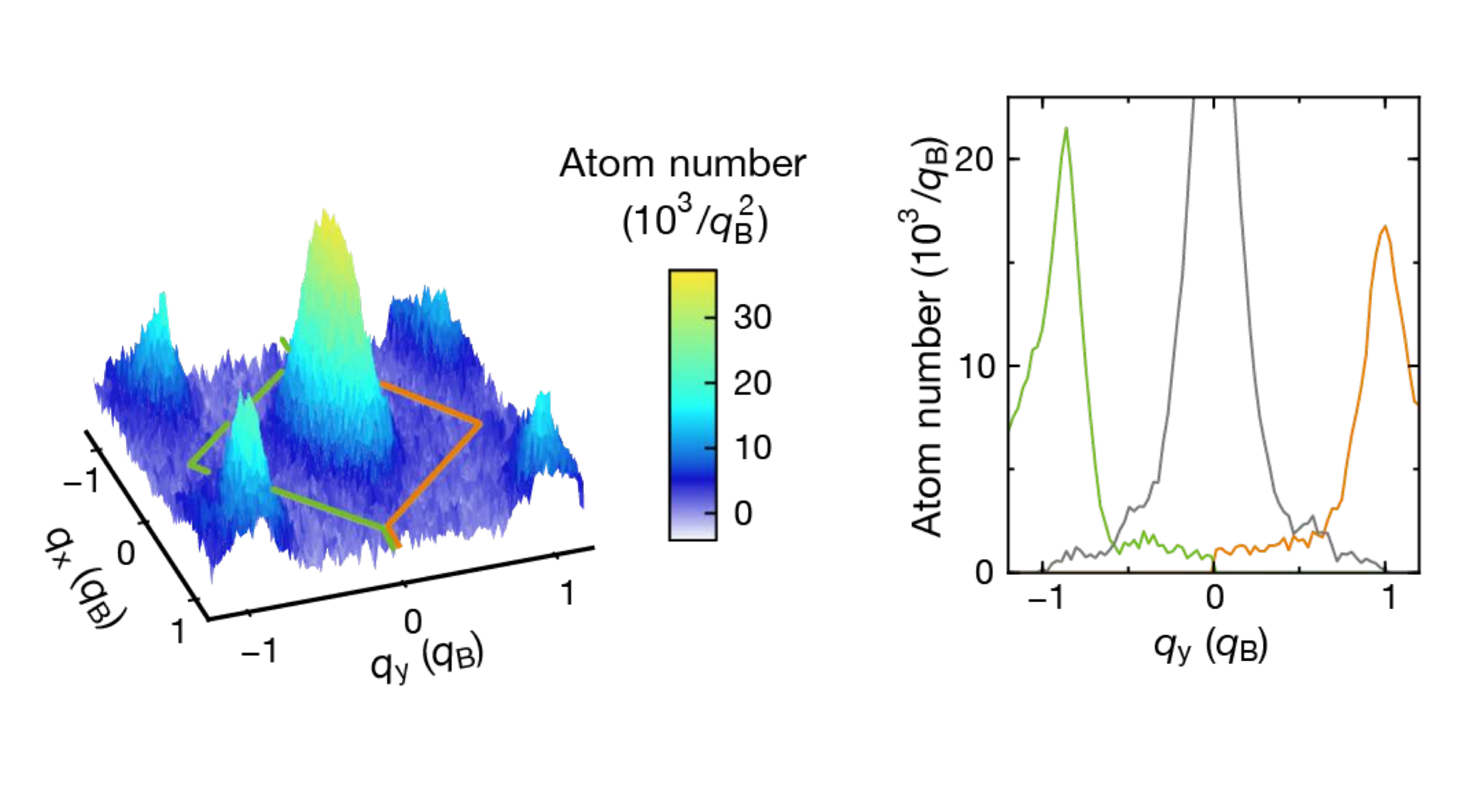


G. Jotzu, M. Messer, R. Desbuquois, M. Lebrat, T. Uehlinger, D. Greif, T. E., Nature 515, 237 (2014)

Mapping out the transition line



Mapping out the transition line



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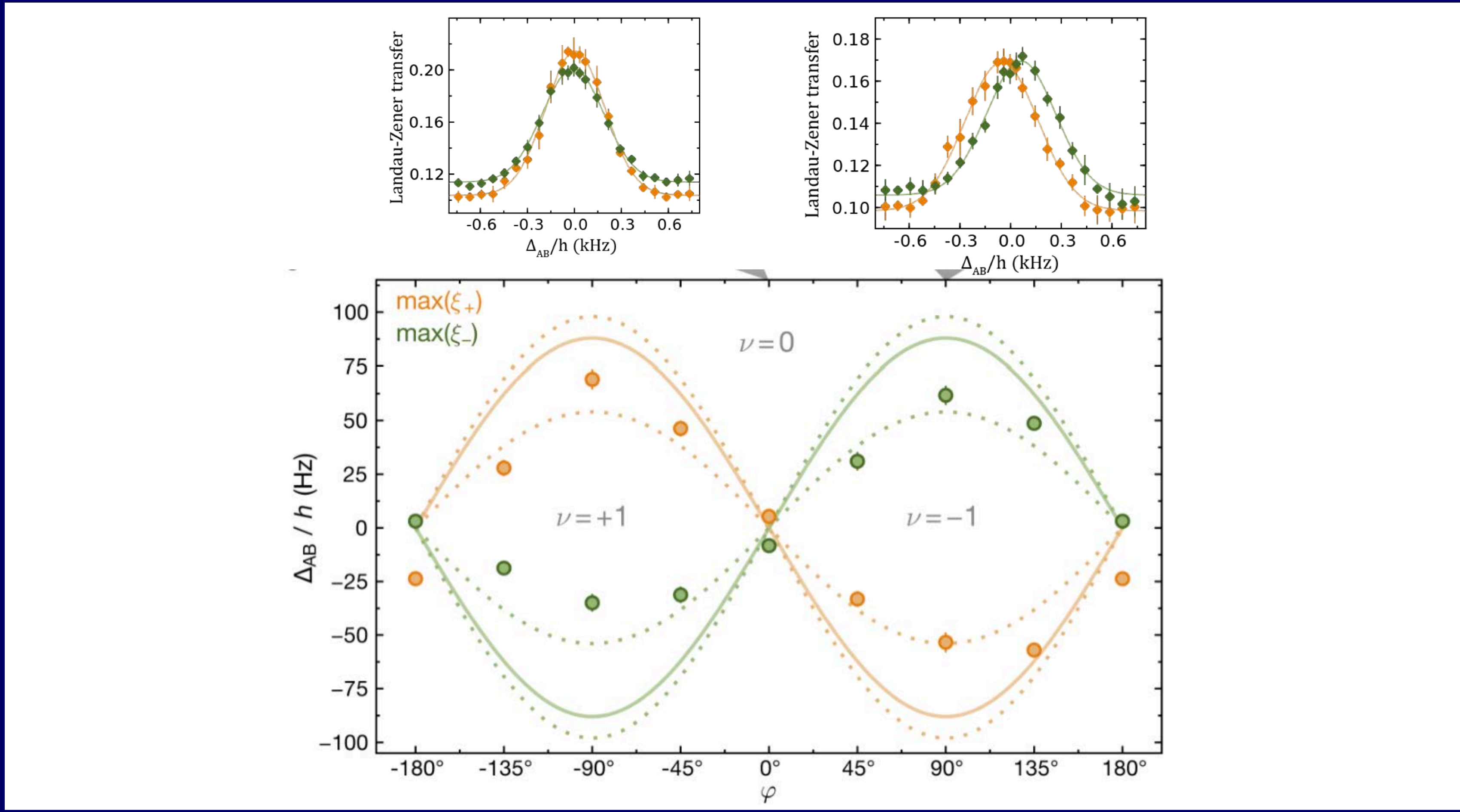
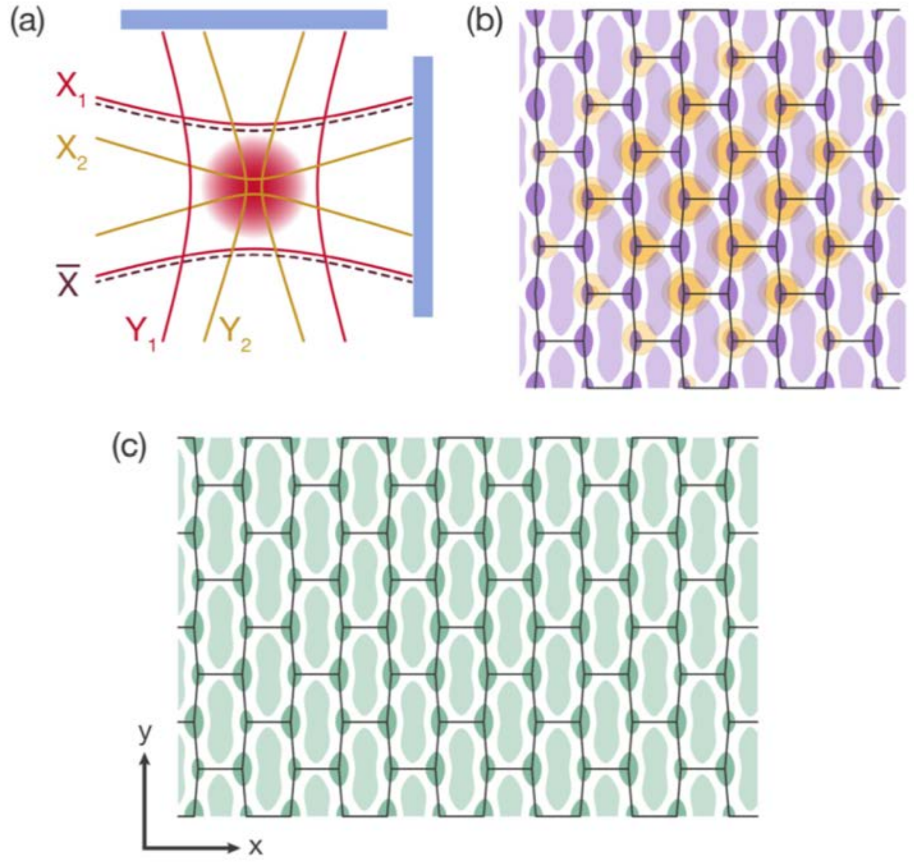


G. Jotzu, M. Messer, R. Desbuquois, M. Lebrat, T. Uehlinger, D. Greif, T. E., Nature 515, 237 (2014)

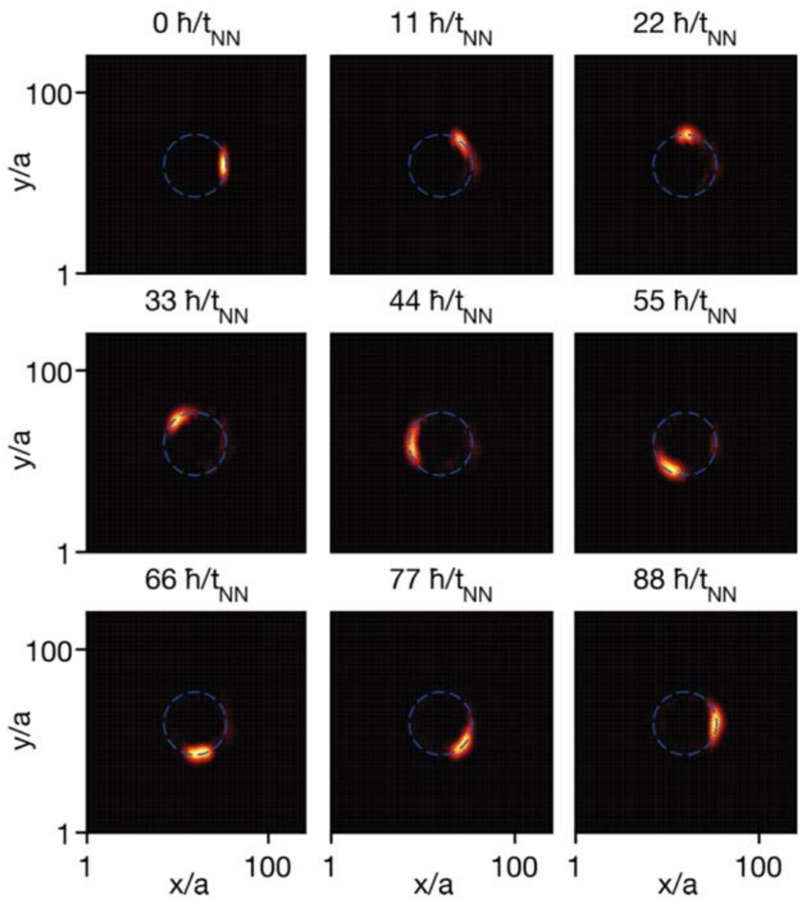
Edge states

Edge states



N. Goldman, G. Jotzu, M. Messer, R. Desbuquois, T. E., PRA 94, 043611 (2016)

Edge states



N. Goldman, G. Jotzu, M. Messer, R. Desbuquois, T. E., PRA 94, 043611 (2016)

Thanks!

Funding: ETH, SNF, NCCR QSIT, EU SIQS, TherMiQ, QUIC, ERCadv TransQ




Quantum Gases in Optical Lattices
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Administration: Stefanie Ackermann

Impact experiment
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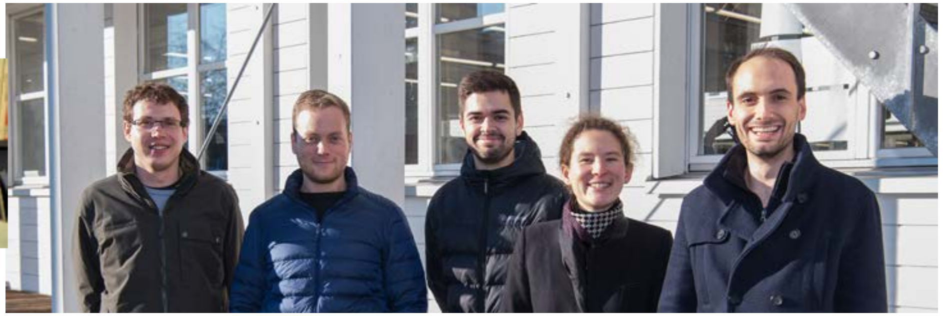
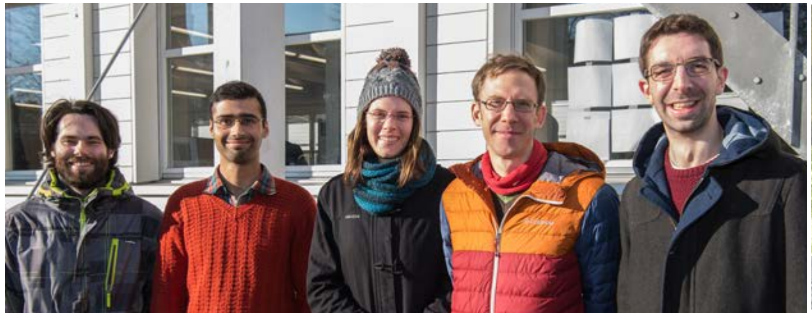
Xiangliang Li
Davide Dreon
Alexander Baumgärtner
Simon Hertlein
(Andrea Morales)
(Philip Zupancic)
(Julian Leonard, now Harvard)



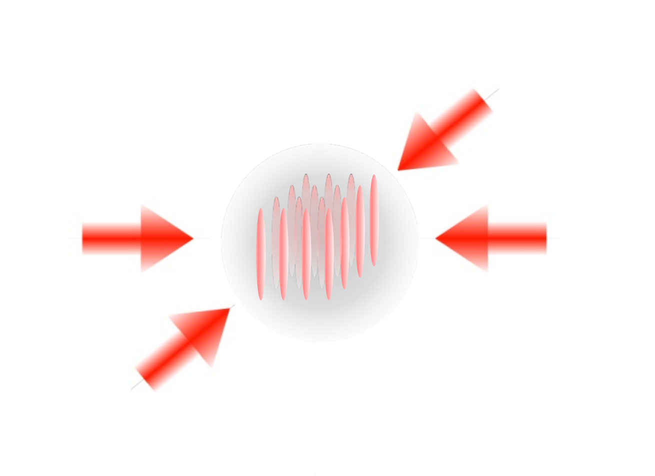



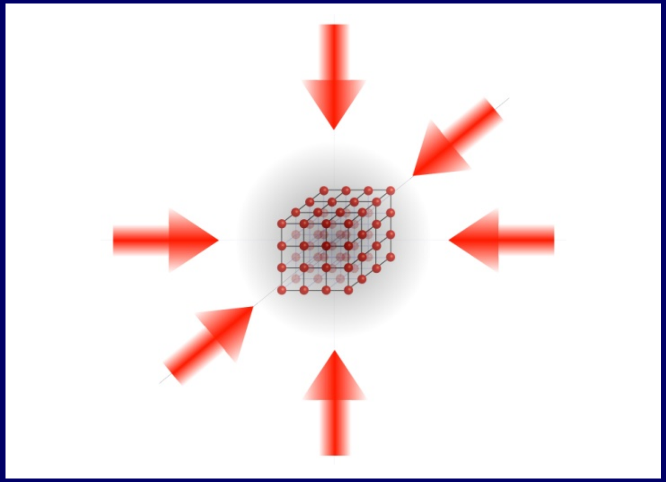

Lithium Transport
Samuel Häusler
Philipp Fabritius
Jeffry Mohan
Mohsen Talebi
Simon Wili
(Laura Corman)
(Martin Lebrat)
(Dominik Husmann)

+ Jean-Philippe Brantut
Thierry Giamarchi
Pjotrs Grisins

BEC and Cavity
Tobias Donner
Francesco Ferri
Rodrigo Rosa-Medina
Fabian Finger
(Nishant Dogra, now Cambridge)
(Katrin Kröger)
(Manuele Landini, now Innsbruck)
(Lorenz Hruby)

Floquet-engineering in Hubbard models



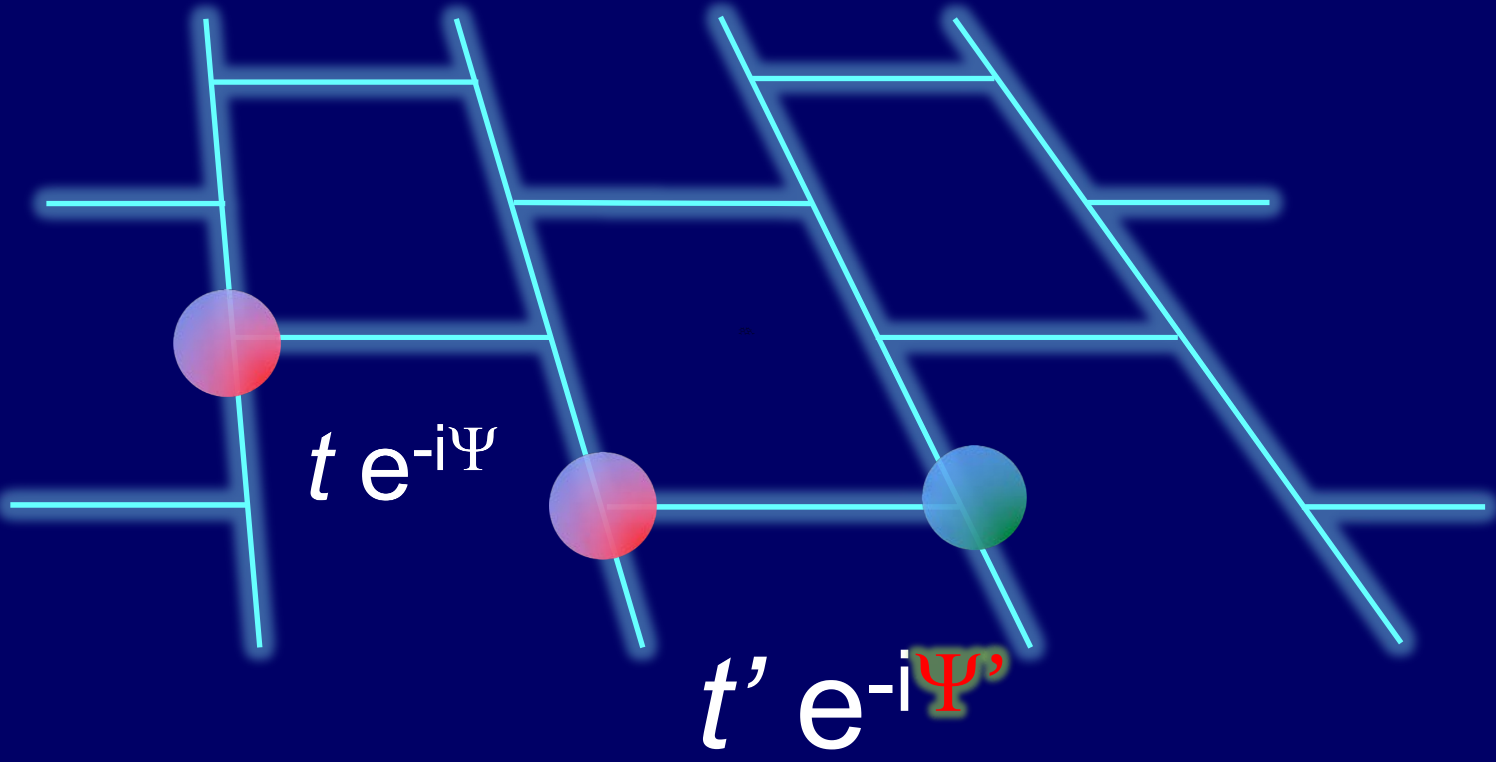


driven

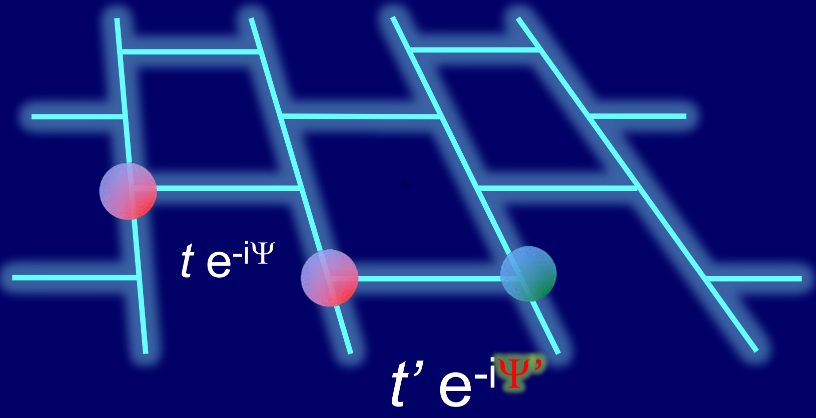
…
Harper-Hofstadter
Haldane model
…

…
Mott-Insulator
Quantum magnetism
…

Density-dependent tunneling with non-trivial Peierls phases



Density-dependent tunneling with non-trivial Peierls phases

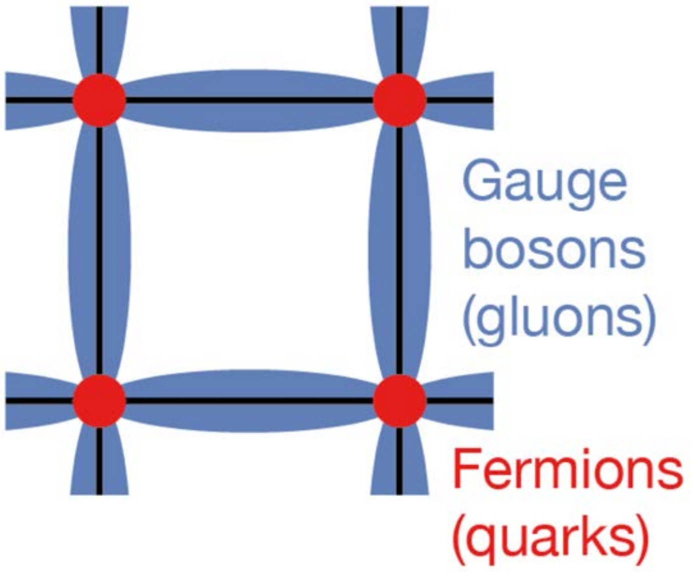


$$\hat{H}_{\text{eff}}^{(l)} = -\sum_{\langle \mathbf{i},\mathbf{j}\rangle,\sigma} \left(\hat{t}^{(l)}_{\langle \mathbf{i},\mathbf{j}\rangle,\bar{\sigma}} \, e^{i\hat{\mathcal{A}}^{(l)}_{\langle \mathbf{i},\mathbf{j}\rangle,\bar{\sigma}}} \, \hat{c}^{\dagger}_{\mathbf{j}\sigma} \hat{c}_{\mathbf{i}\sigma} + \text{h.c.} \right)$$

Operators

Coupling between gauge fields and matter

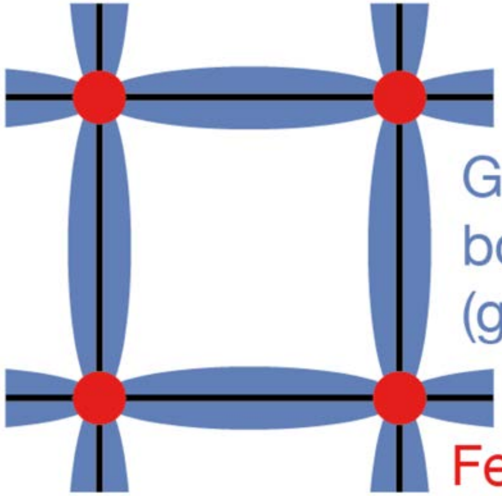
Lattice gauge theories



Kogut, RMP **51**, 659 (1979)

Coupling between gauge fields and matter

Lattice gauge theories

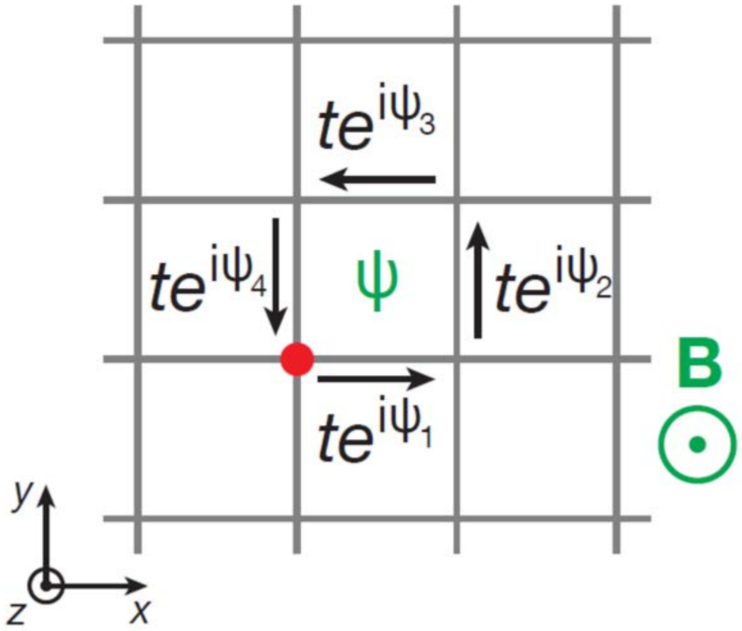


Quantum simulation:

U. J. Wiese, Annalen der Physik 525, 777 (2013).
E. Zohar, J. I. Cirac, and B. Reznik, Reports on Progress in Physics 79, 014401 (2015).
M. Dalmonte and S. Montangero, Contemporary Physics 57, 388 (2016).
E. A. Martinez, C. A. Muschik, P. Schindler, D. Nigg, A. Erhard, M. Heyl, P. Hauke, M. Dalmonte, T. Monz, P. Zoller, and R. Blatt, Nature 534, 516 (2016).
L. Barbiero, C. Schweizer, M. Aidelsburger, E. Demler, N. Goldman, and F. Grusdt, arXiv:1810.02777, Science advances 5 (10), eaav7444

Classical (static) gauge field $\mathbf{A}$

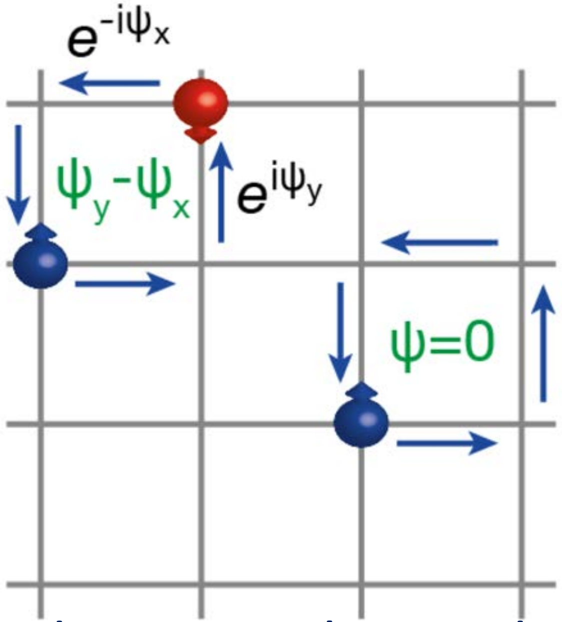
$$\psi = \psi_{\text{ext}}$$



Goldman et. al., Rep. on Prog. in Phys. **77**, 126401 (2014), N. R. Cooper, J. Dalibard, and I. B. Spielman, Rev. Mod. Phys. 91, 015005 (2018)

Quantized (dynamical) gauge field $\hat{\mathbf{A}}$

$$\psi = \psi(\hat{n}_i)$$



Density-dependent tunneling and Peierls phases

F. Görg, K. Sandholzer, J. Minguzzi, R. Desbuquois, M. Michael, T. Esslinger, Nature Physics 15, 1161 (2019).
C. Schweizer, F. Grusdt, M. Berngruber, L. Barbiero, E. Demler, N. Goldman, I. Bloch, M. Aidelsburger, Nature Phys. **15**, 1168 (2019).
B. Yang, Hui Sun, R. Ott, H.-Y. Wang, T. V. Zache, J. C. Halimeh, Zhen-Sheng Yuan, P. Hauke, J.-W. Pan, Nature 587, 392 (2020).
Dynamical gauge field (mean field BEC): L.W. Clark, B.M. Anderson, L. Feng, A. Gaj, K. Levin, and C. Chin PRL **121**, 030402 (2018).

Tunnel Engineering

Thanks to scientific calculations costly delays were avoided.
(Photo: ETH Zurich)

Tunnel Engineering

Proposals: Keilmann et. al., Nat. Comm. **2**, 361 (2011), Greschner et. al., PRL **113**, 215303 (2014), Bermudez et. al., NJP **17**, 103021 (2015), Sträter et. al., PRL **117**, 205303 (2016),

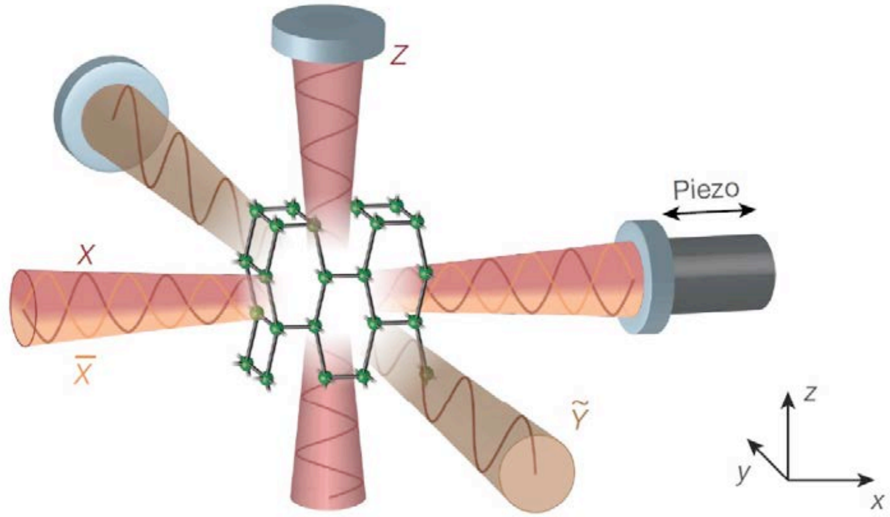
L. Barbiero, C. Schweizer, M. Aidelsburger, E. Demler, N. Goldman, and F. Grusdt, arXiv:1810.02777

Experiment broken TR drive: J. Struck, C. Ölschläger, M. Weinberg, P. Hauke, J. Simonet, A. Eckardt, M. Lewenstein, K. Sengstock, and P. Windpassinger, Phys. Rev. Lett. 108, 225304 (2012).

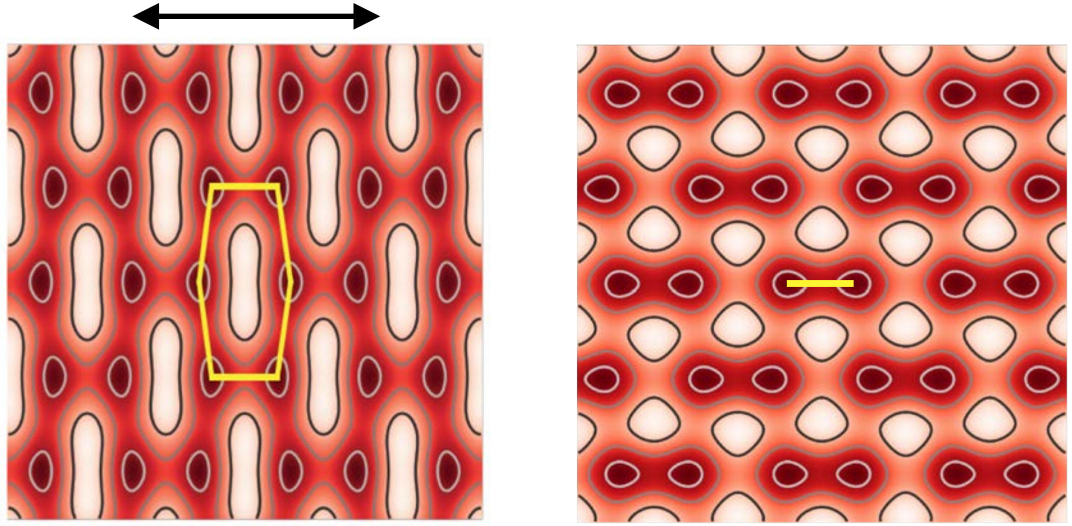
Experiment Munich: Christian Schweizer, Fabian Grusdt, Moritz Berngruber, Luca Barbiero, Eugene Demler, Nathan Goldman, Immanuel Bloch, Monika Aidelsburger, Nature Physics **15**, 1168 (2019).

+ more

Driven Fermi-Hubbard model



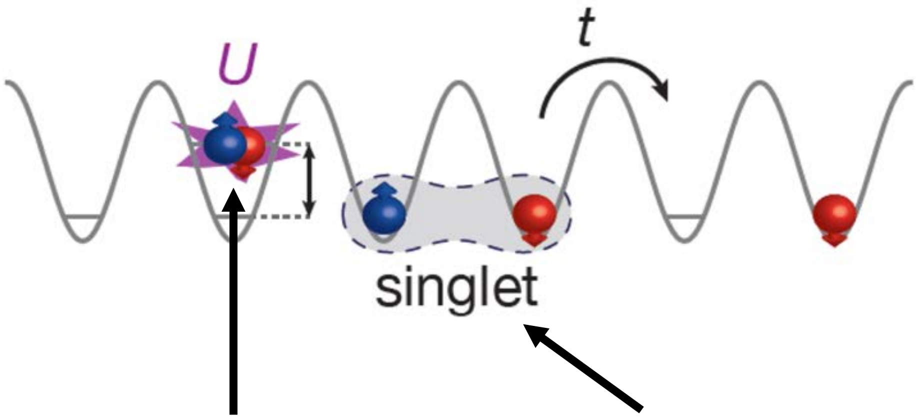
$$x(\tau) = A\cos(\omega\tau + \phi)$$



$$H = -\sum_{\langle \mathbf{i},\mathbf{j}\rangle,\sigma} t_{\mathbf{ij}} c^{\dagger}_{\mathbf{i}\sigma} c_{\mathbf{j}\sigma} + U \sum_{\mathbf{i}} \hat{n}_{\mathbf{i}\uparrow}\hat{n}_{\mathbf{i}\downarrow} + F(\tau) \sum_{\mathbf{i},\sigma} i_x \hat{n}_{\mathbf{i}}$$

$$F(\tau) = \hbar\omega K_0 \cos(\omega\tau + \phi)$$

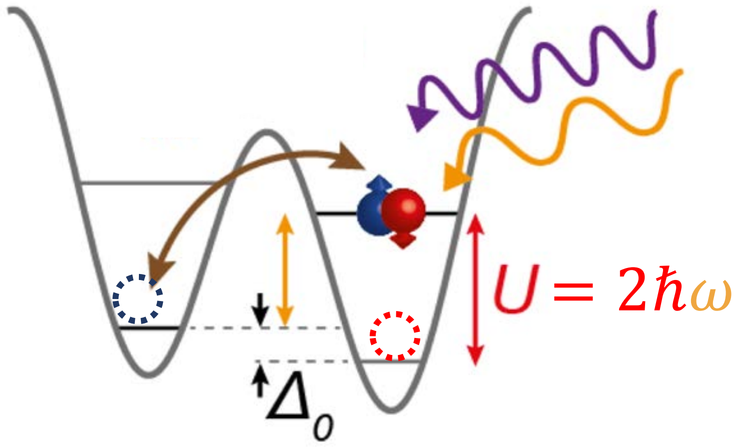
Observables

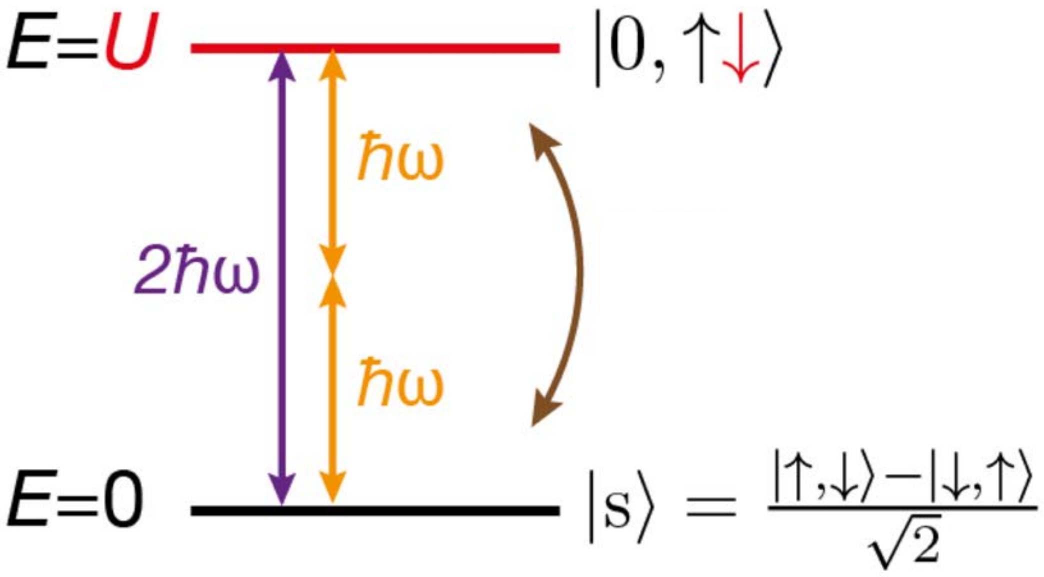


Double occupancy

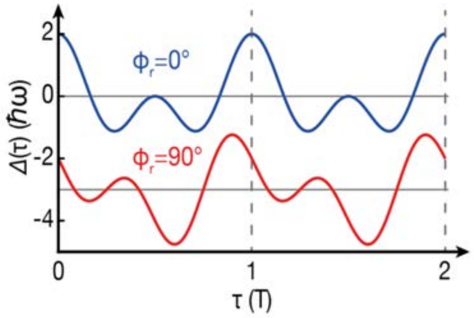
Magnetic correlations

Two-frequency driving: non-trivial Peierls phases

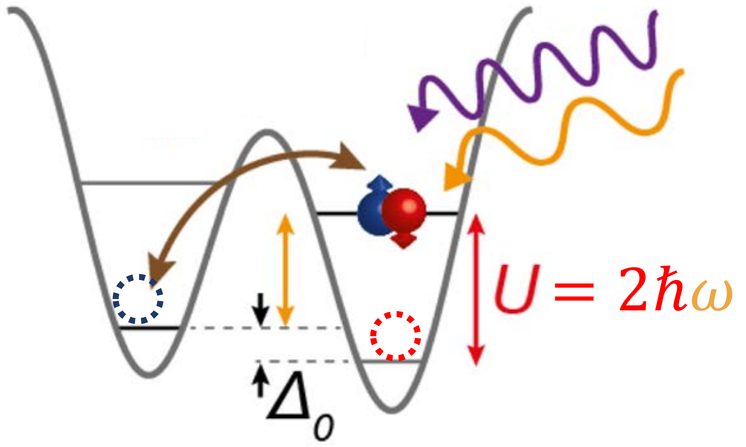


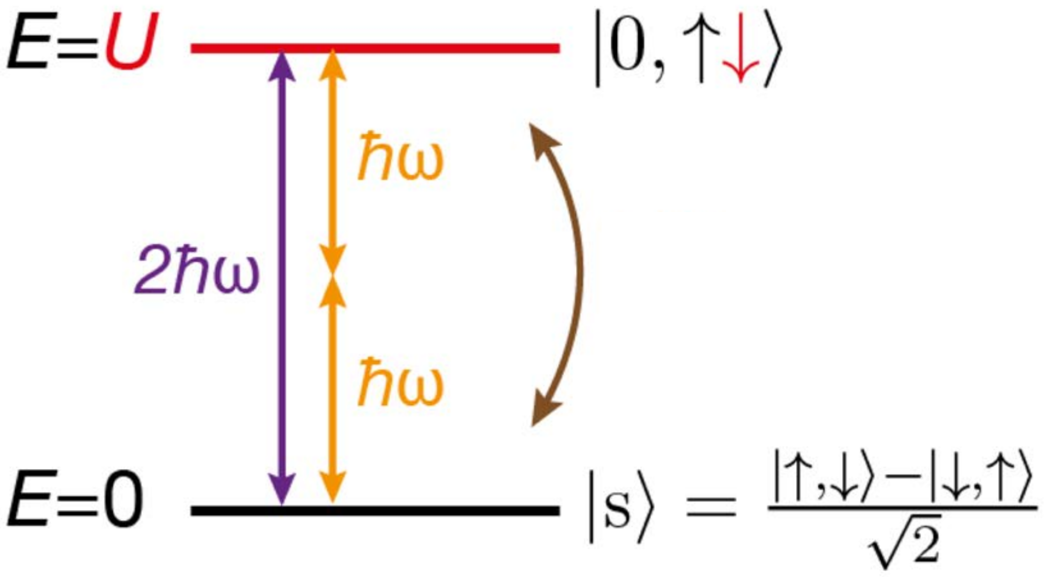


$$\Delta(\tau) = \hbar\omega K_1 \cos(\omega\tau) + 2\hbar\omega K_2 \cos(2\omega\tau + \phi_r)$$



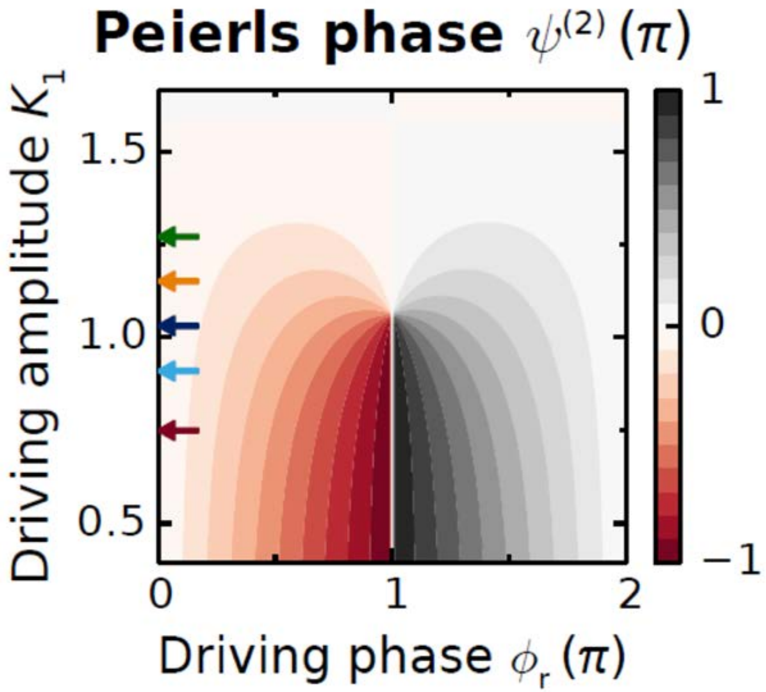
Two-frequency driving: non-trivial Peierls phases

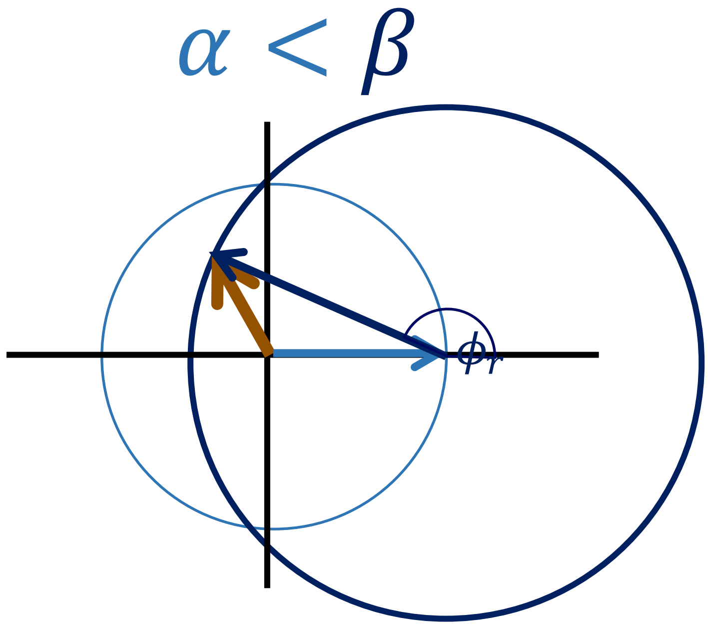




$$t_{eff}^{(2)} = t\left(\alpha^{(2)} + \beta^{(2)} e^{-i\phi_r}\right)$$

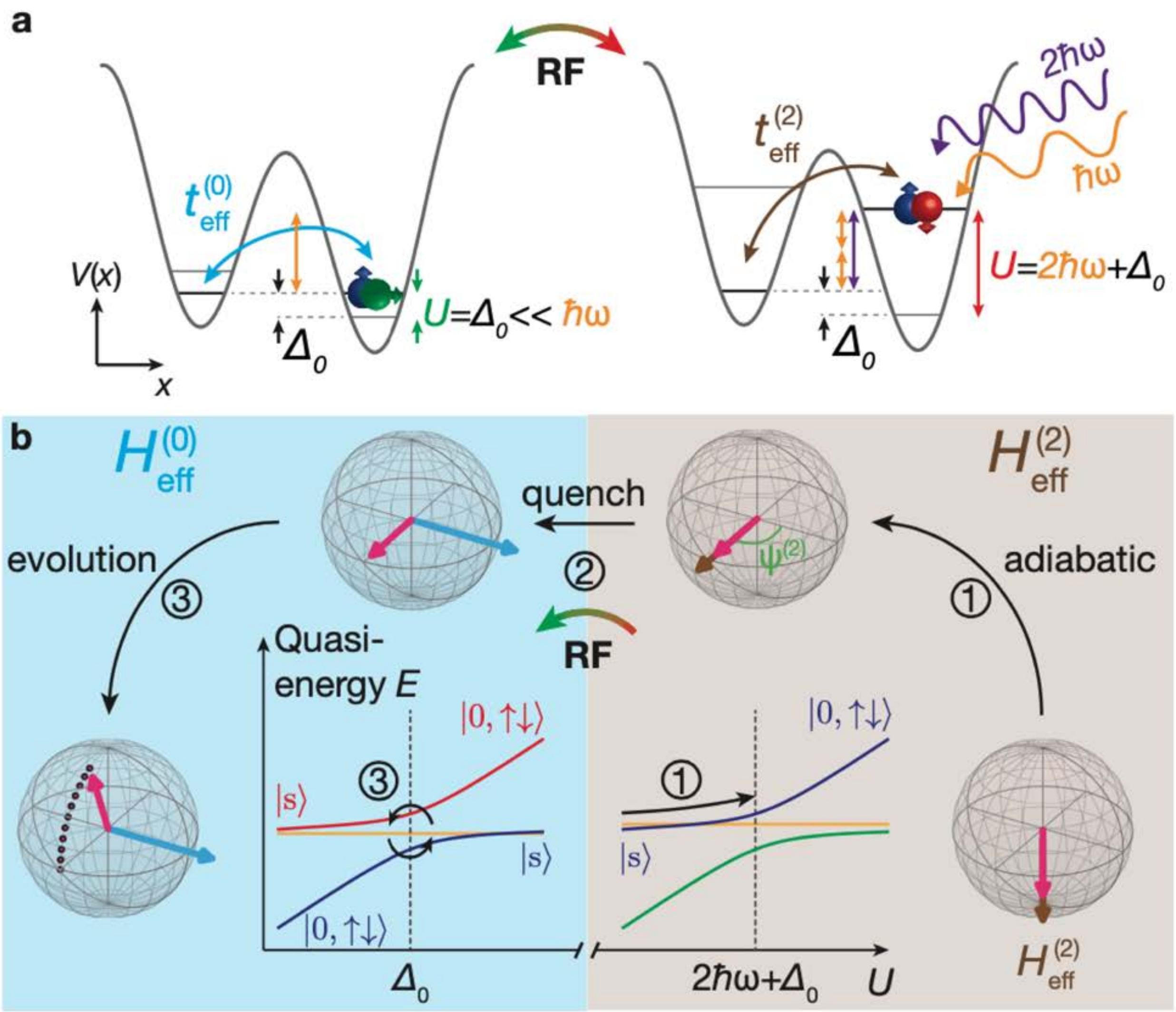
The Nature of the Peierls phase $\psi^{(2)}$



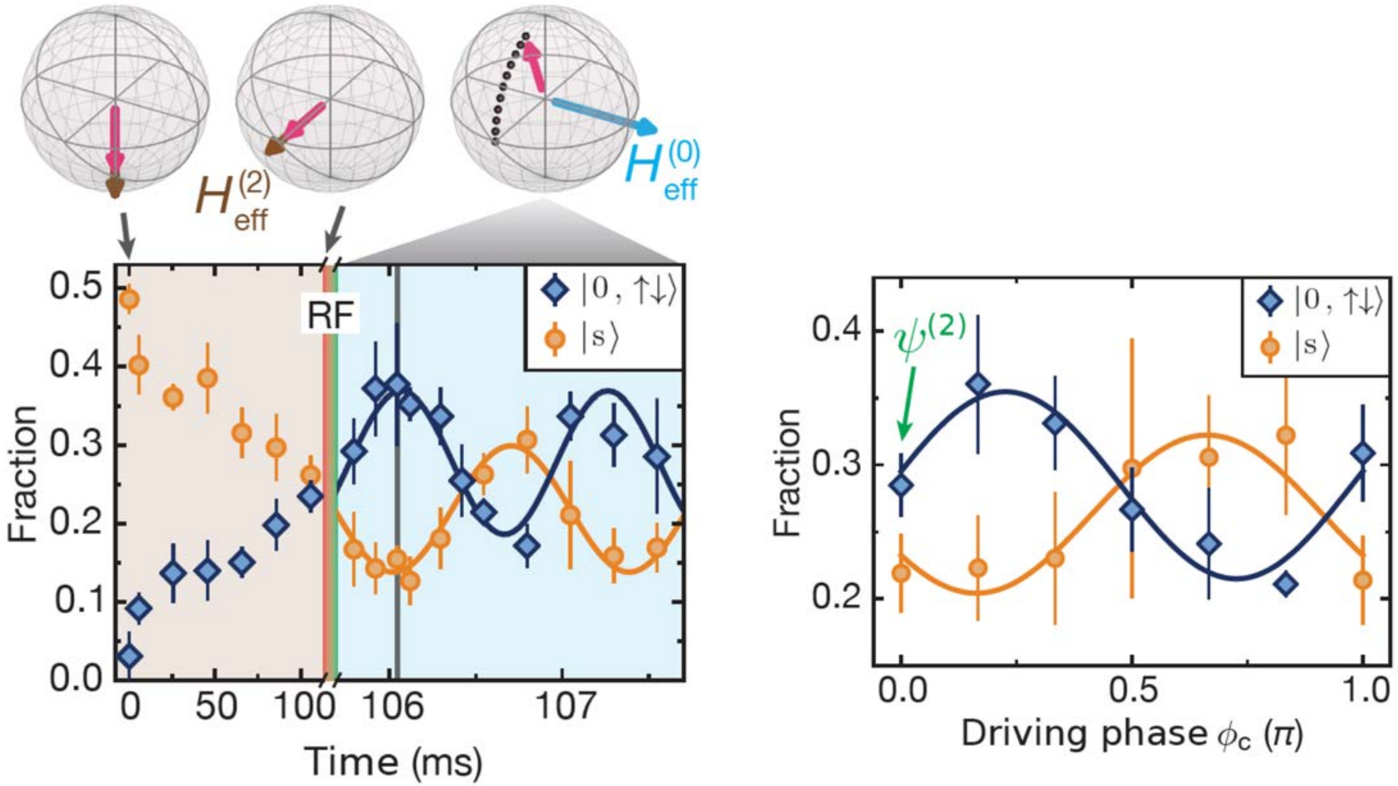


$$t_{eff}^{(2)} = t\left(\alpha^{(2)} + \beta^{(2)} e^{-i\phi_r}\right)$$

Measuring the Peierls phase $\psi^{(2)}$

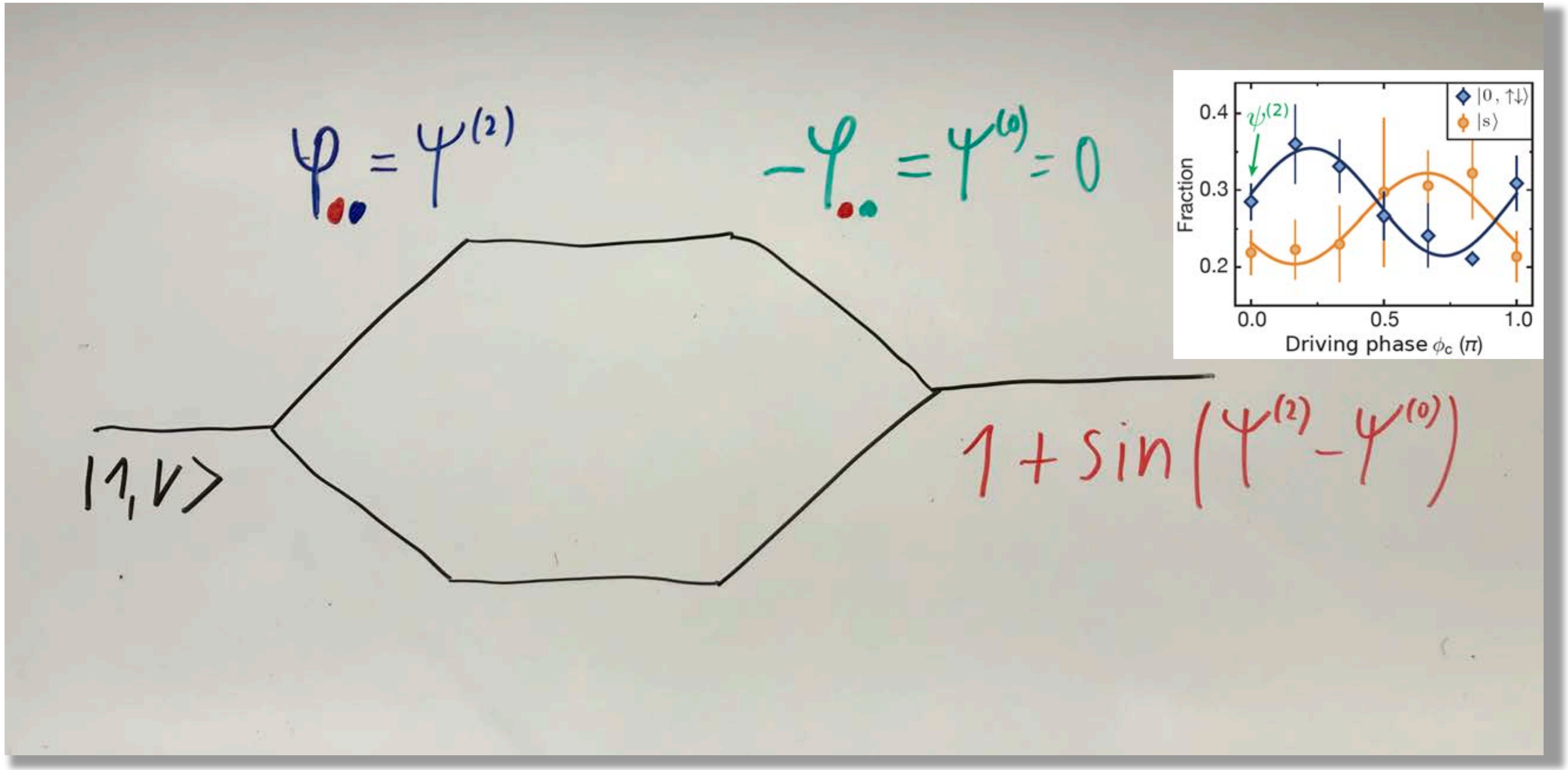


Measuring the Peierls phase $\psi^{(2)}$



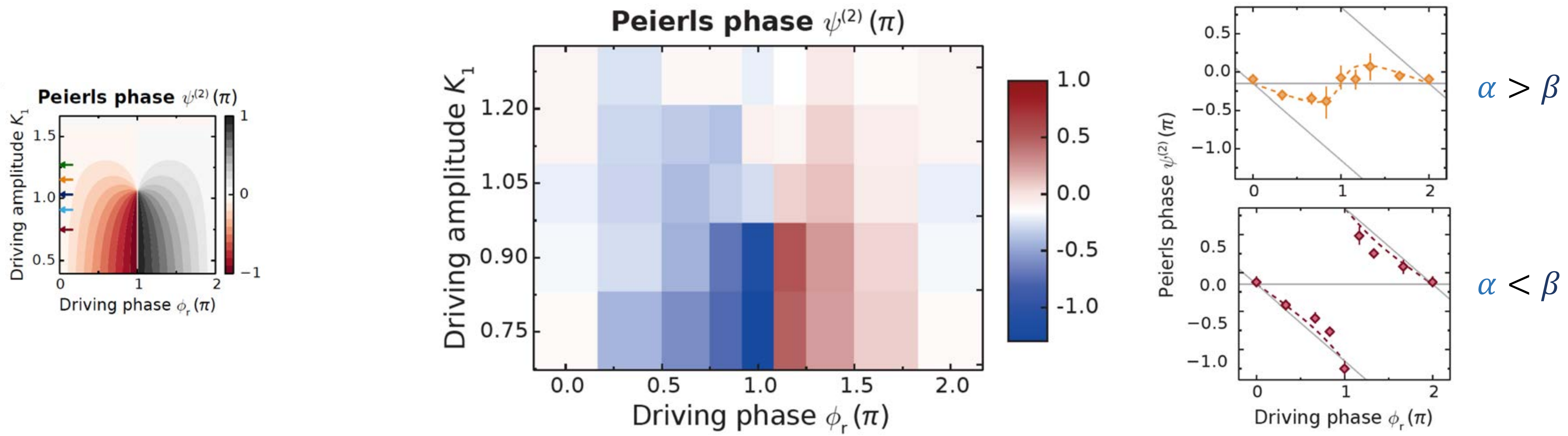
$$\mathcal{D}(\phi_c), \mathcal{S}(\phi_c) = \left[1 \pm \sin\left(-2\phi_c + \psi_r^{(2)}\right)\right]/2$$

$$\psi^{(2)} = -2\phi_c + \psi_r^{(2)}(K_1, K_2, \phi_r)$$



F. Görg, K. Sandholzer, J. Minguzzi, R. Desbuquois, M. Messer, and T. Esslinger, arXiv:1812.05895, Nature Physics **15**, 1161 (2019)

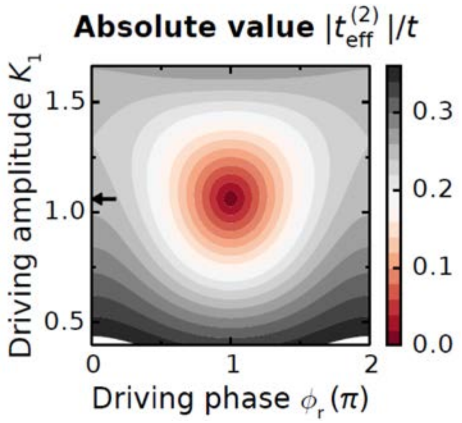
Measuring the Peierls phase $\psi^{(2)}$

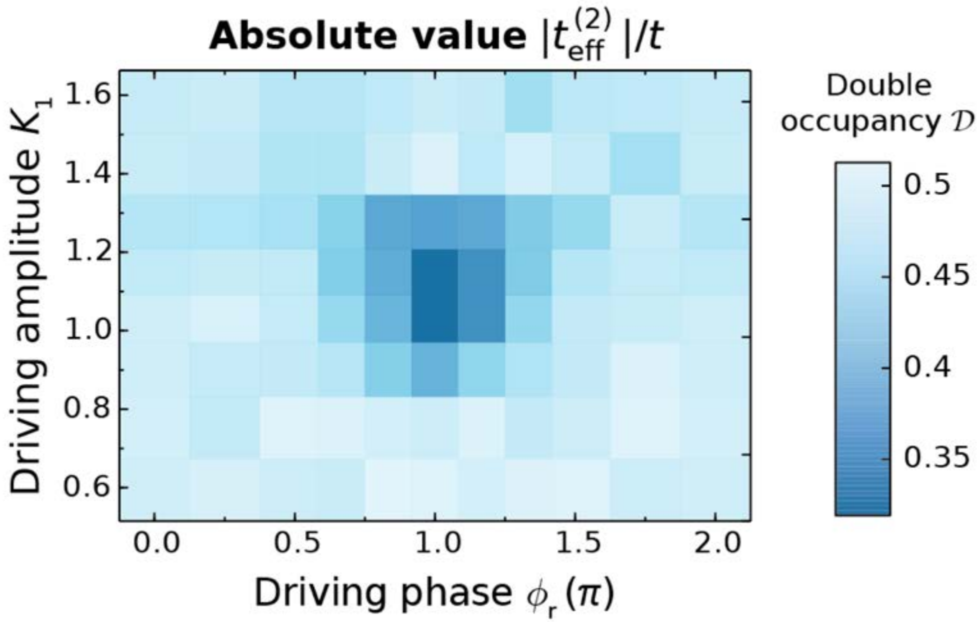


$$t_{eff}^{(2)} = t\left(\alpha^{(2)} + \beta^{(2)} e^{-i\phi_r}\right)$$

F. Görg, et al. , arXiv:1812.05895, Nature Physics 15, 1161 (2019)

Gap closing at Dirac point



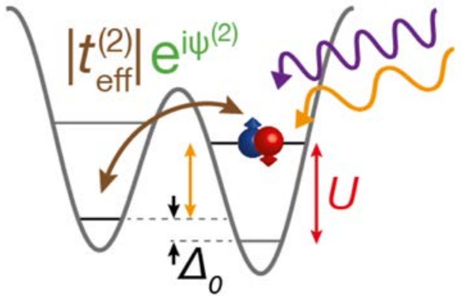


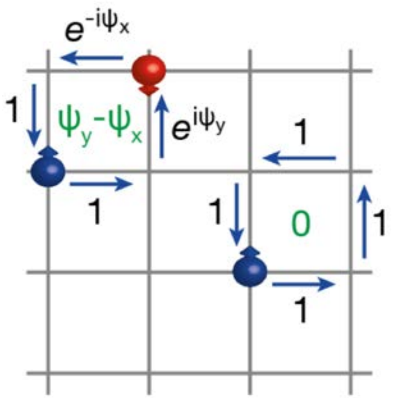
$$t_{eff}^{(2)} = t\left(\alpha^{(2)} + \beta^{(2)} e^{-i\phi_r}\right)$$

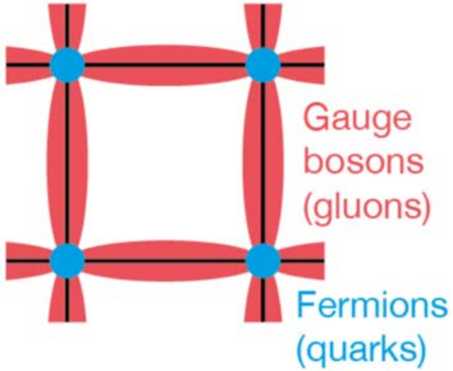
F. Görg, et al. , arXiv:1812.05895, Nature Physics 15, 1161 (2019)

Route towards quantum simulation of lattice gauge theories

Route towards quantum simulation of lattice gauge theories







Coupling mechanism

- density-dependent Peierls phases

L.W. Clerk … Chin, PRL **121**, 030402 (2018)]
Görg et al., Nat. Phys. 2019
Schweizer et al., Nat. Phys. (2019)

Theory: L. Barbiero, C. Schweizer, M. Aidelsburger, E. Demler, N. Goldman, F. Grusdt, Science advances 5 (10), eaav7444

Extended lattice

- shaking many-body sytems
- theoretical understanding
- suitable observables

Zenesini et. al., PRL **102**, 100403 (2009)
Parker et. al., Nat. Phys. **9**, 769-774 (2013)
…
e.g. Görg et al., Nature **553**, 481 (2018),
Messer et al., PRL **121**, 233603 (2018),
Sandholzer et al., arXiv:1811.12826 (2018)]

Lattice gauge theories

- Bose-Fermi mixtures
- Lorentz invariance
- Local gauge invariances

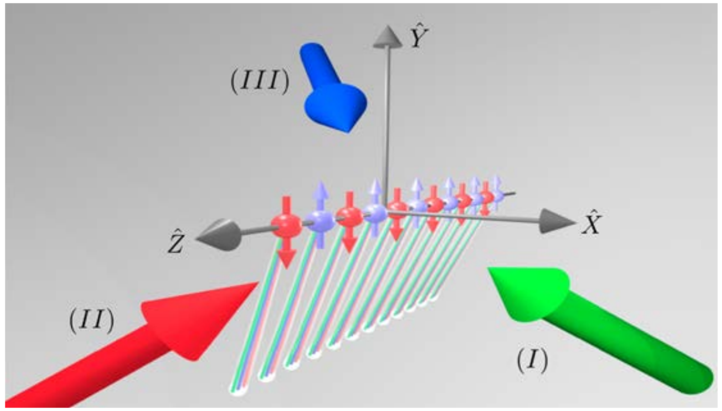
[see reviews: Zohar et al., Rep. Prog. Phys. **79**, 014401 (2016),
Wiese, Ann. Phys. **525**, 777–796 (2013)]

B. Yang, et al., Nature 587, 392 (2020)

More routes towards quantum simulation of lattice gauge theories

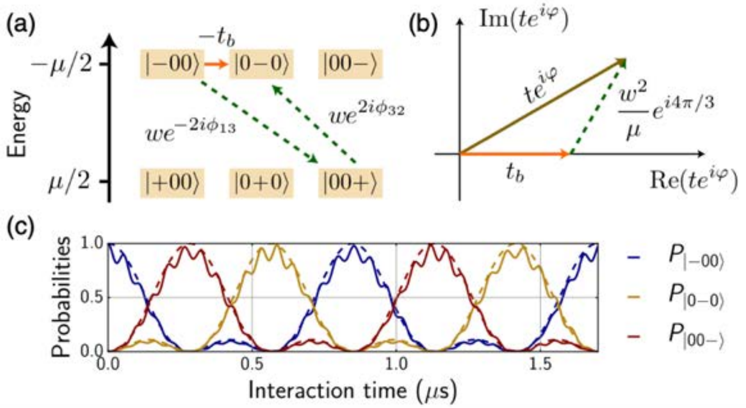
Simulating Lattice Gauge Theories within Quantum Technologies
M.C. Bañuls, R. Blatt, J. Catani, A. Celi, J.I. Cirac, M. Dalmonte, L. Fallani, K. Jansen, M. Lewenstein, S. Montangero, C.A. Muschik, B. Reznik, E. Rico, L. Tagliacozzo, K. Van Acoleyen, F. Verstraete, U.-J. Wiese, M. Wingate, J. Zakrzewski, P. Zoller
https://arxiv.org/abs/1911.00003

Ion Traps



Towards analog quantum simulations of lattice gauge theories with trapped ions
Zohreh Davoudi, Mohammad Hafezi, Christopher Monroe, Guido Pagano, Alireza Seif, and Andrew Shaw
Phys. Rev. Research **2**, 023015 – Published 8 April 2020

Rydberg atoms



Realization of a Density-Dependent Peierls Phase in a Synthetic, Spin-Orbit Coupled Rydberg System
V. Lienhard, P. Scholl, S. Weber, D. Barredo, S. de Léséleuc, R. Bai, N. Lang , M. Fleischhauer, H. P. Büchler, T. Lahaye, and A. Browaeys, PHYSICAL REVIEW X 10, 021031 (2020)

Floquet engineering

1. N. Goldman and J. Dalibard, “Periodically Driven Quantum Systems: Effective Hamiltonians and Engineered Gauge Fields, Physical Review X 4, 31027 (2014).
2. Marin Bukov, Luca D’Alessio, and Anatoli Polkovnikov, “Universal high-frequency behavior of periodically driven systems: from dynamical stabilization to Floquet engineering,” Advances in Physics 64, 139–226 (2015).
3. Martin Holthaus, “Floquet engineering with quasienergy bands of periodically driven optical lattices,” Journal of Physics B: Atomic, Molecular and Optical Physics 49, 013001 (2016).
4. André Eckardt, “Colloquium: Atomic quantum gases in periodically driven optical lattices,” Reviews of Modern Physics 89, 11004 (2017).

Floquet engineering: heating, losses

1. Martin Reitter, Jakob Näger, Karen Wintersperger, Christoph Sträter, Immanuel Bloch, André Eckardt, and Ulrich Schneider, “Interaction Dependent Heating and Atom Loss in a Periodically Driven Optical Lattice,” Physical Review Letters 119, 200402 (2017).
2. K. Singh, C. J. Fujiwara, Z. A. Geiger, E. Q. Simmons, M. Lipatov, A. Cao, P. Dotti, S. V. Rajagopal, R. Senaratne, T. Shimasaki, M. Heyl, A. Eckardt, and D. M. Weld, “Quantifying and Controlling Prethermal Nonergodicity in Interacting Floquet Matter,” Physical Review X 9, 41021 (2019).
3. T. Boulier, J. Maslek, M. Bukov, C. Bracamontes, E. Magnan, S. Lellouch, E. Demler, N. Goldman, and J. V. Porto, “Parametric Heating in a 2D Periodically Driven Bosonic System: Beyond the Weakly Interacting Regime,” Physical Review X 9, 11047 (2019).
4. K. Wintersperger, M. Bukov, J. Näger, S. Lellouch, E. Demler, U. Schneider, I. Bloch, N. Goldman, and M. Aidelsburger, “Parametric Instabilities of Interacting Bosons in Periodically Driven 1D Optical Lattices,” Physical Review X 10, 11030 (2020).
5. Antonio Rubio-Abadal, Matteo Ippoliti, Simon Hollerith, David Wei, Jun Rui, S. L. Sondhi, Vedika Khemani, Christian Gross, and Immanuel Bloch, “Floquet prethermalization in a Bose-Hubbard system,” arXiv:2001.08226 [cond-mat, physics:quant-ph] (2020), arXiv: 2001.08226.
6. Tomotaka Kuwahara, Takashi Mori, and Keiji Saito, “Floquet–Magnus theory and generic transient dynamics in periodically driven many-body quantum systems,” Annals of Physics 367, 96–124 (2016).
7. R. Moessner and S. L. Sondhi, “Equilibration and order in quantum Floquet matter,” Nature Physics 13, 424– 428 (2017).
8. Gaoyong Sun and André Eckardt,“Optimal frequency window for Floquet engineering in optical lattices,” Physical Review Research 2, 013241 (2020).

Floquet engineering: heating, losses

Who is responsible?

Portrait de Charles Floquet
Wikipedia

3 avril 1888 – 14 février 1889 (10 mois et 11 jours)	
Président	Sadi Carnot
Président du Conseil	*Lui-même*
Gouvernement	Floquet
Prédécesseur	Ferdinand Sarrien
Successeur	Ernest Constans
Président de la Chambre des députés	
16 novembre 1889 – 10 janvier 1893 (3 ans, 1 mois et 25 jours)	
Législature	Ve
Prédécesseur	Jules Méline
Successeur	Jean Casimir-Perier
8 avril 1885 – 3 avril 1888 (2 ans, 11 mois et 26 jours)	
Législature	IVe
Prédécesseur	Henri Brisson
Successeur	Jules Méline
Président du Conseil de Paris	
1874 – 1875 (1 an)	
Prédécesseur	Henri Thulié
Successeur	Pierre Marmottan
Biographie	
Nom de naissance	Thomas Charles Floquet
Date de naissance	2 octobre 1828
Lieu de naissance	Saint-Jean-Pied-de-Port (Pyrénées-Atlantiques)
Date de décès	19 janvier 1896 (à 67 ans)
Lieu de décès	Paris
Nationalité	Française
Parti politique	Sans étiquette

Achille Marie Gaston Floquet	
Born	15 December 1847 Épinal, France
Died	7 October 1920 (aged 72) Nancy, France
Education	École Normale Supérieure
Known for	Floquet theory
Scientific career	
Fields	Mathematics

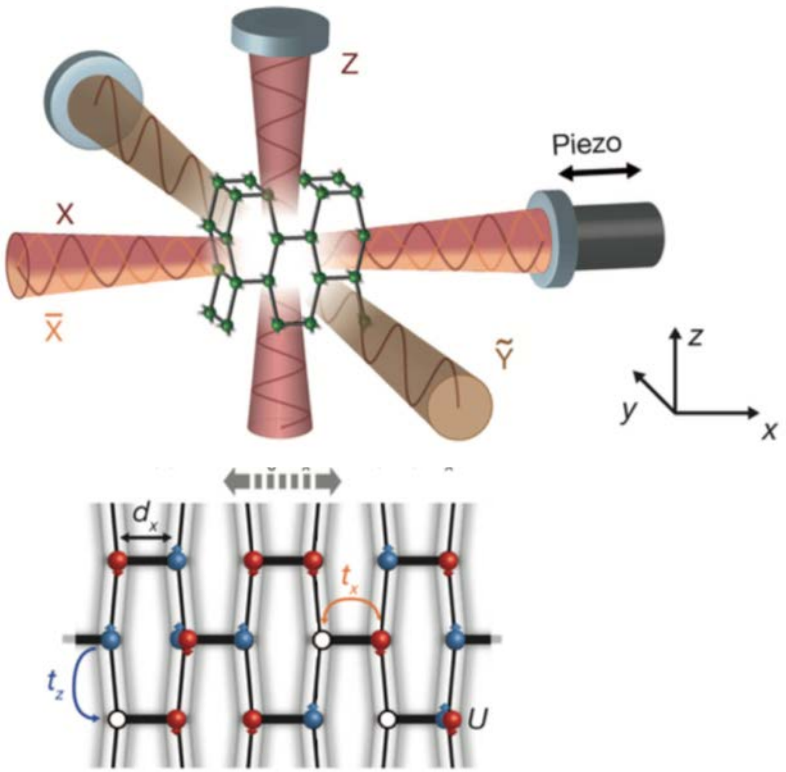
Floquet engineering

heating

losses

What is responsible?

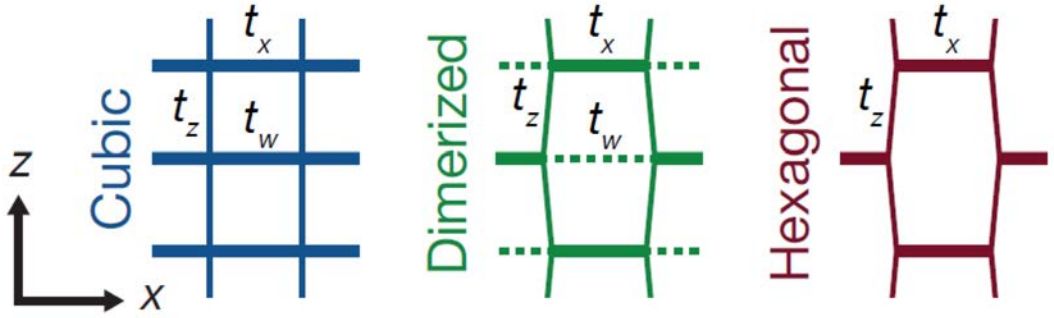
Magnetic correlations in driven lattice



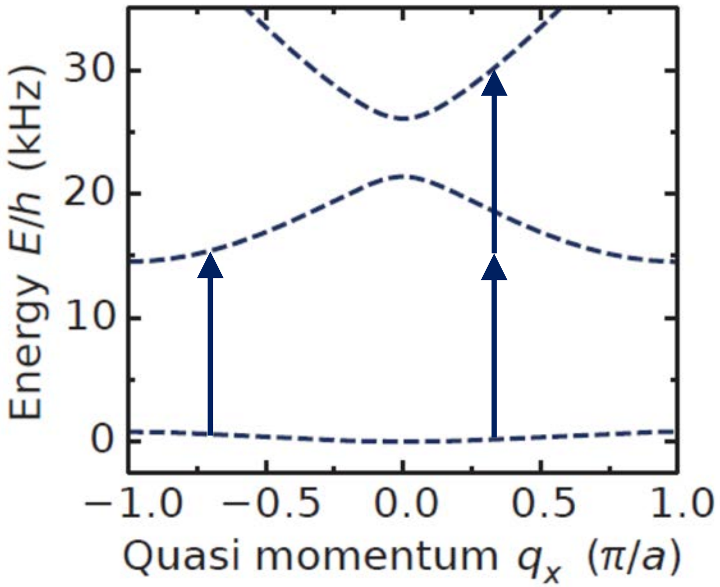
F. Görg, M. Messer, K. Sandholzer, G. Jotzu, R.Desbuquois, T.E., Nature 553, 481-485 (2018)
Also: J. Coulthard, S. R. Clark, S. Al-Assam, A. Cavalleri, D. Jaksch, Phys. Rev. B 96, 085104 (2017)
J.H. Mentink,w, K. Balzer, M. Eckstein, Nat. Commun. 10.1038/ncomms7708 (2015)

Bandstructure engineering to avoid atom loss in driven lattices

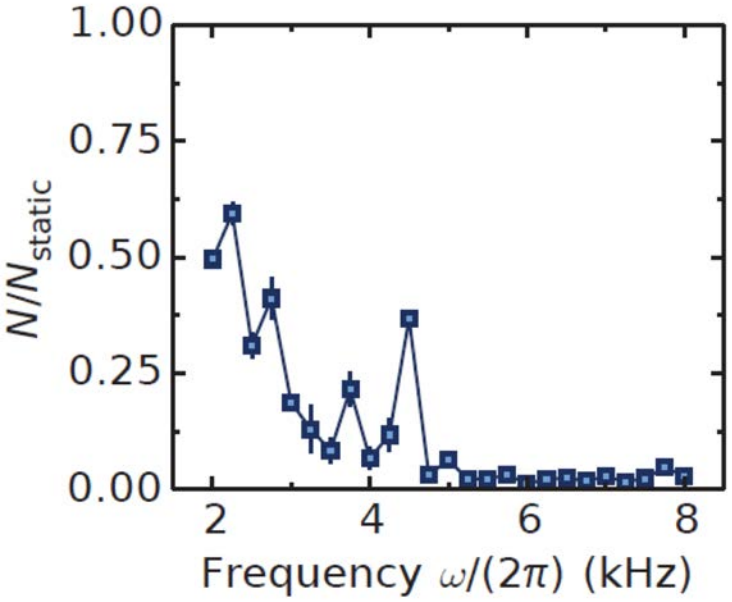
Lattice geometries



t_x=200 Hz
t_w=200 Hz
$t_{y,z}$=100 Hz



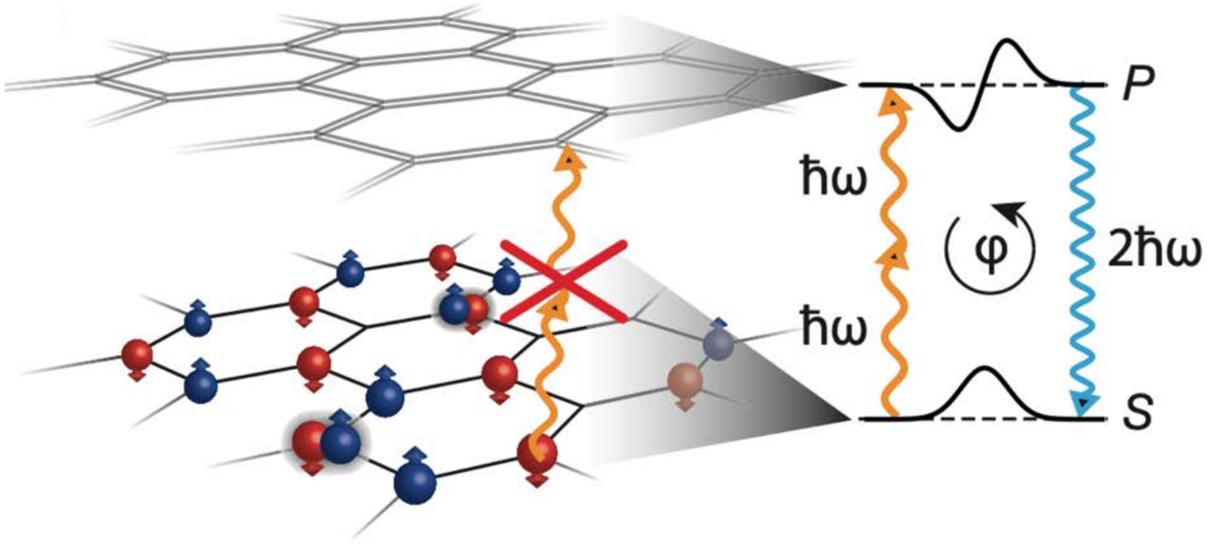
1 s modulation time at K_0=1.43



U=700 Hz

M. Messer, K. Sandholzer, F. Görg, J. Minguzzi, R. Desbuquois, T. Esslinger, PRL 121, 233603 (2018), arXiv:1808.00506

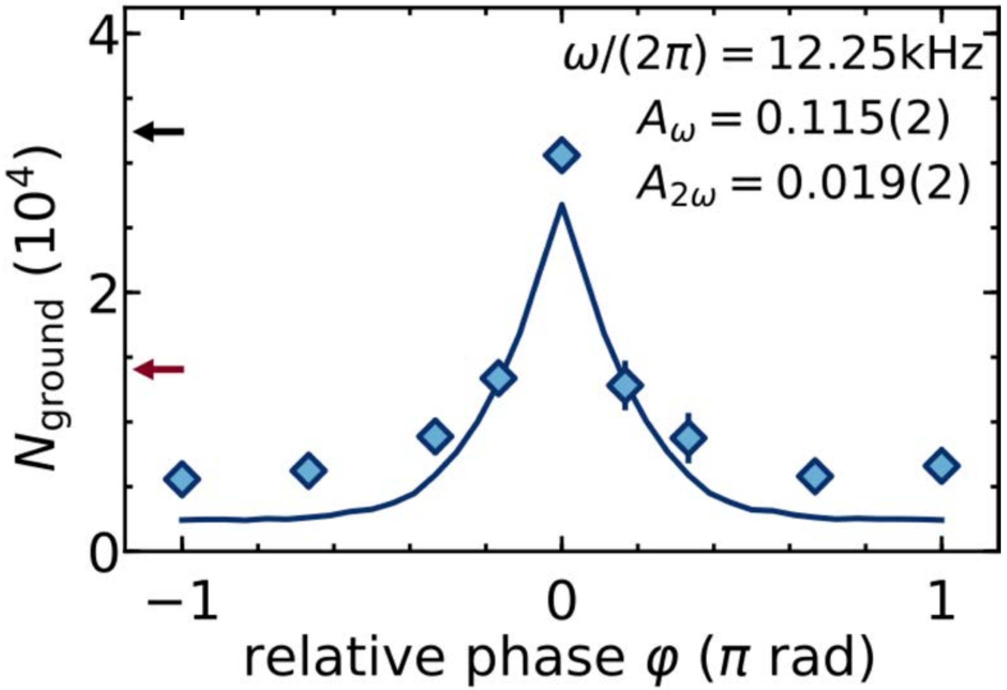
Two frequency drive: two path interference

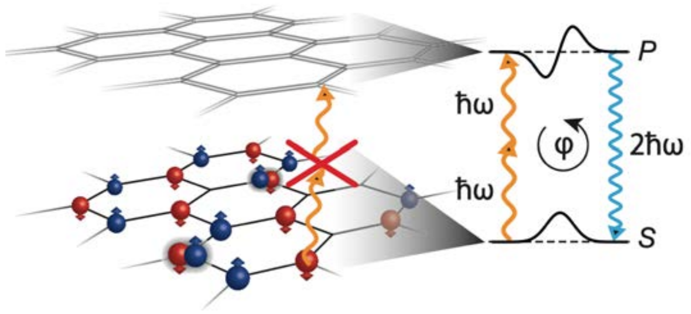


K. Viebahn, J. Minguzzi, K. Sandholzer, Anne-Sophie Walter, F. Görg, T. Esslinger, Suppressing dissipation in a Floquet-Hubbard system, arXiv:2003.05937

M. Schiavoni, L. Sanchez-Palencia, F. Renzoni, and G. Grynberg, “Phase Control of Directed Diffusion in a Symmetric Optical Lattice,” Physical Review Letters 90, 94101 (2003).
C. Zhuang, C. R. Paul, X. Liu, S. Maneshi, L. S. Cruz, and A. M. Steinberg, “Coherent Control of Population Transfer between Vibrational States in an Optical Lattice via Two-Path Quantum Interference,” Physical Review Letters 111, 233002 (2013).
L. Niu, D.Hu, S. Jin, X. Dong, X.-z. Chen, and X. Zhou, “Excitation of atoms in an optical lattice driven by polychromatic amplitude modulation,” Optics Express 23, 10064 (2015).
F. Görg, K. Sandholzer, J. Minguzzi, R. Desbuquois, M. Messer, and T. Esslinger, arXiv:1812.05895, Nature Physics 15, 1161 (2019)

Two frequency drive: two path interference

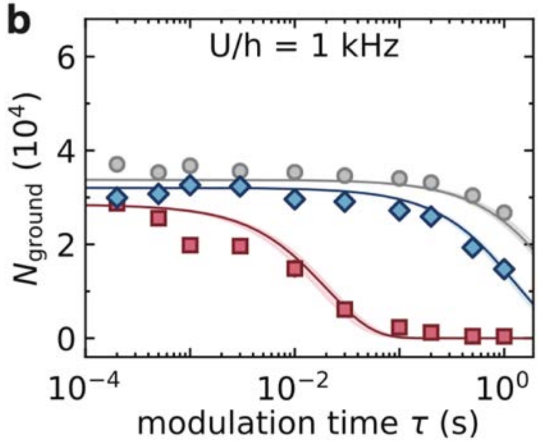




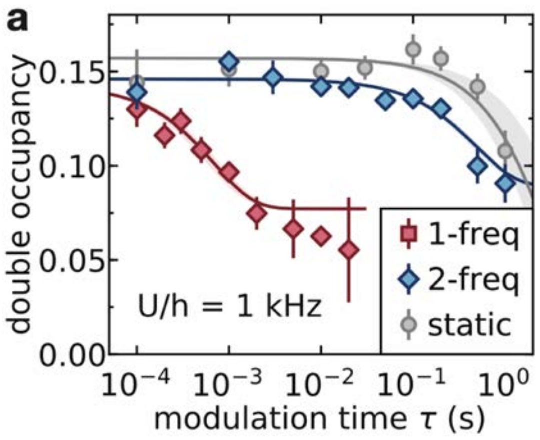
K. Viebahn, J. Minguzzi, K. Sandholzer, Anne-Sophie Walter, F. Görg, T. Esslinger, Suppressing dissipation in a Floquet-Hubbard system, arXiv:2003.05937

Two frequency drive: interactions

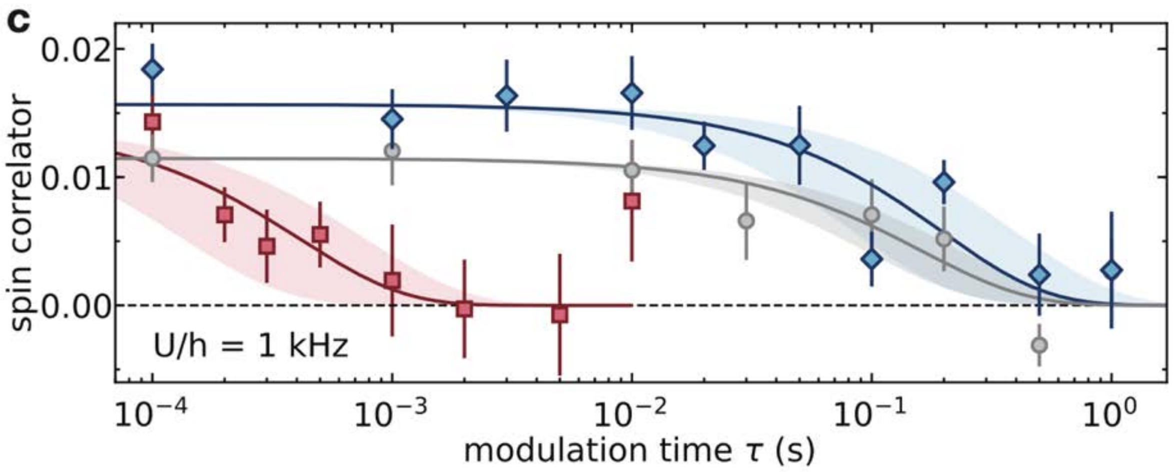
Atom number ground band



Double occupancy

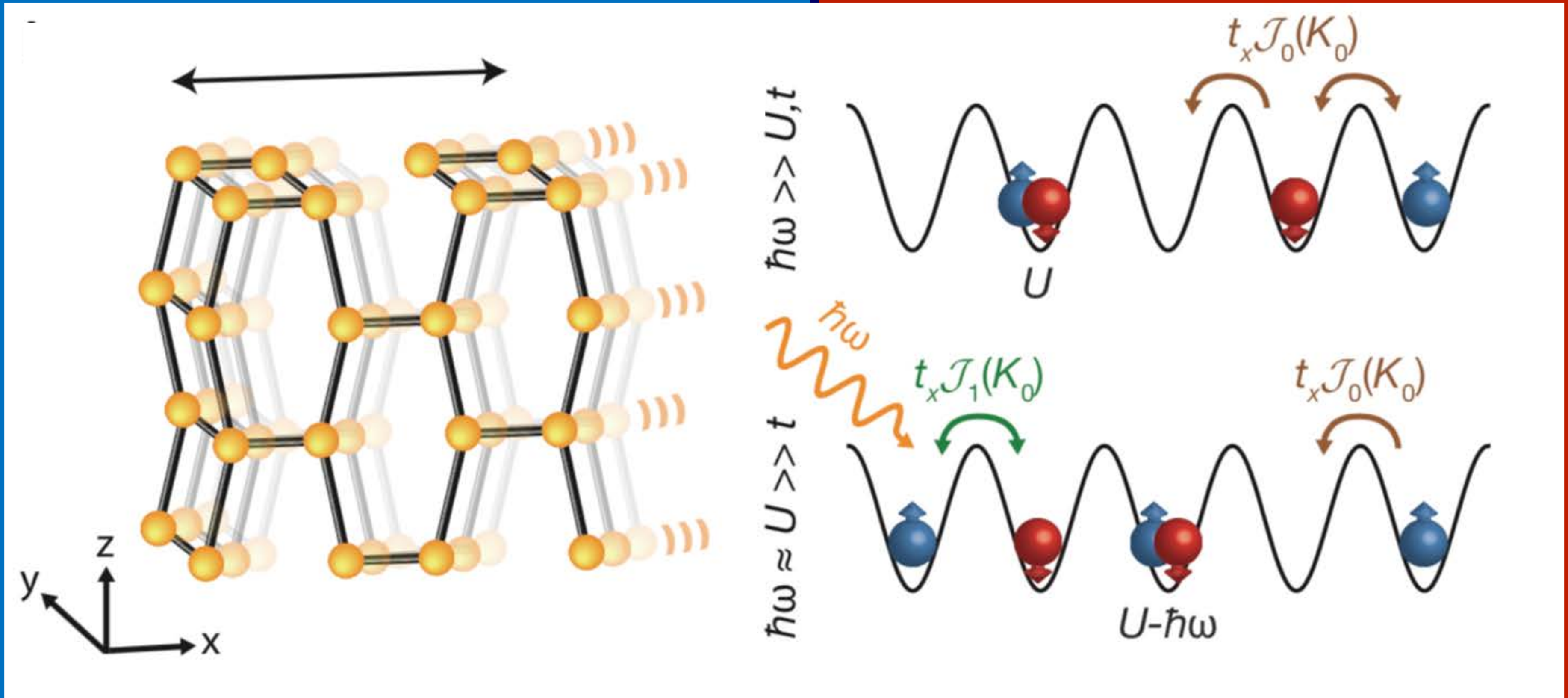


Nearest neighbor spin correlator



K. Viebahn, J. Minguzzi, K. Sandholzer, Anne-Sophie Walter, F. Görg, T. Esslinger, Suppressing dissipation in a Floquet-Hubbard system, arXiv:2003.05937

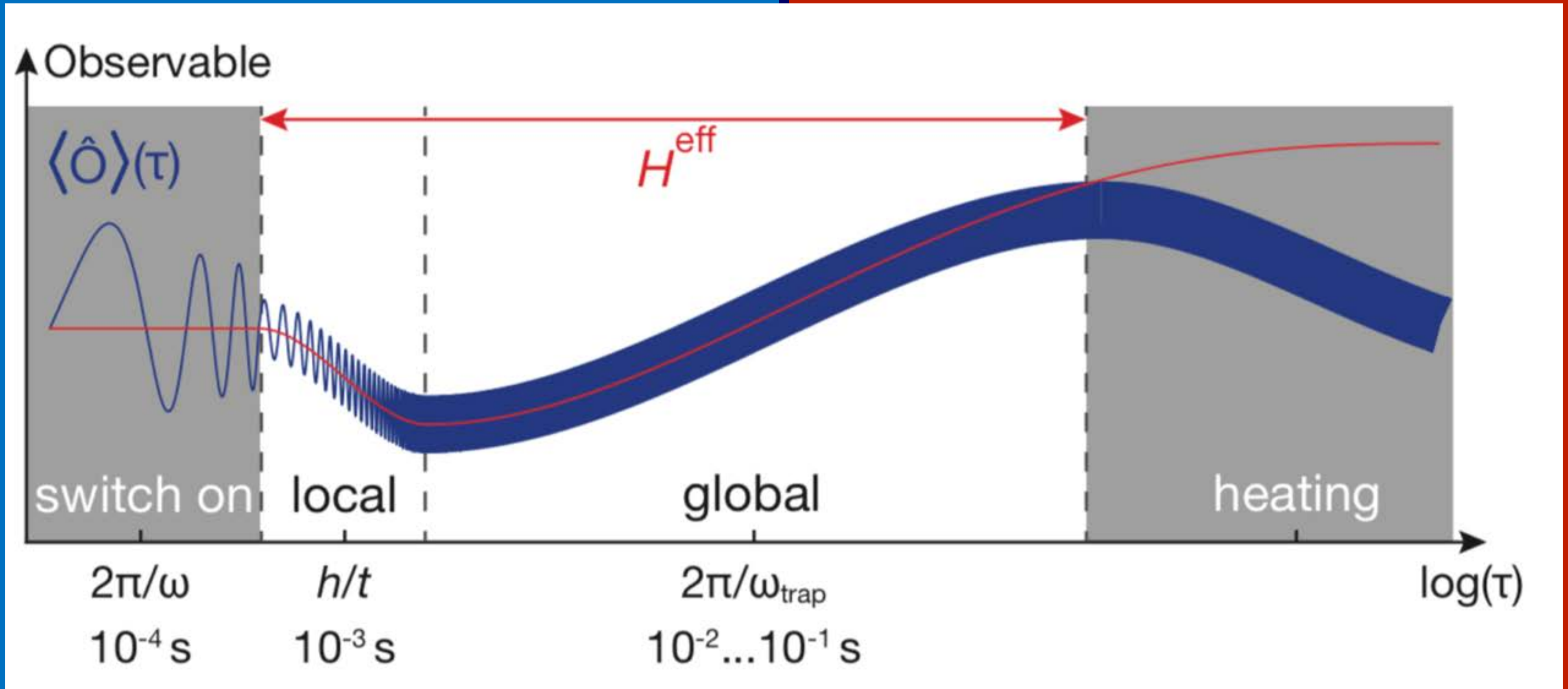
Shaking a Fermi-Hubbard model



Off-resonantly driven

Resonantly driven

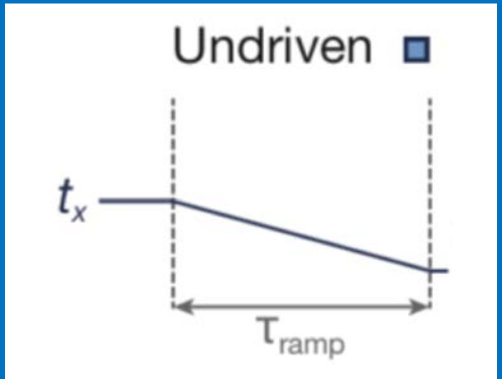
Time Scales

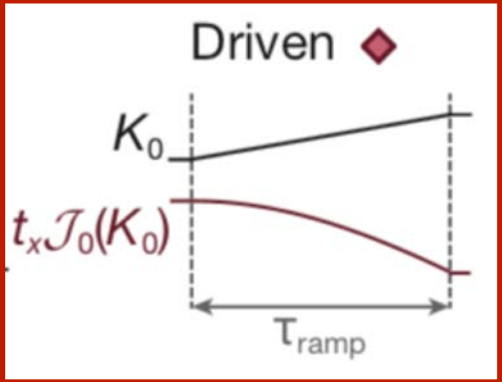


M. Messer, K. Sandholzer, F. Görg, J. Minguzzi, R. Desbuquois, T. Esslinger, PRL 121, 233603 (2018), arXiv:1808.00506

Local time scale

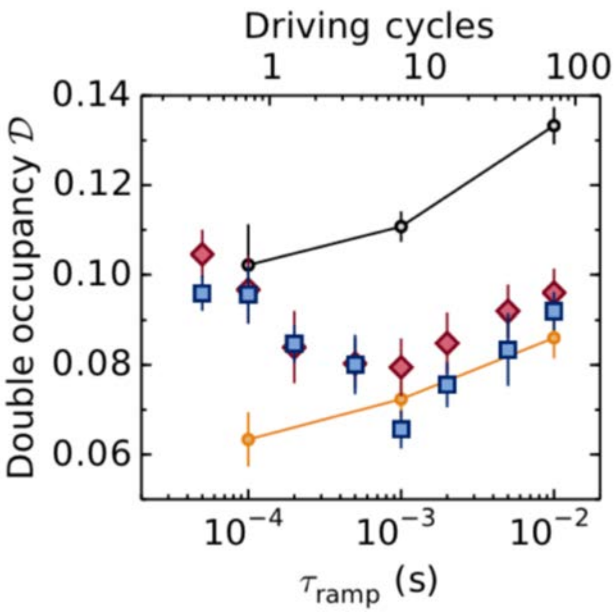
Undriven





Off-resonantly driven

Double occupancy



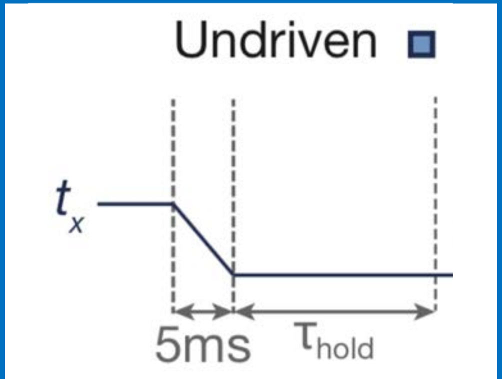
starting

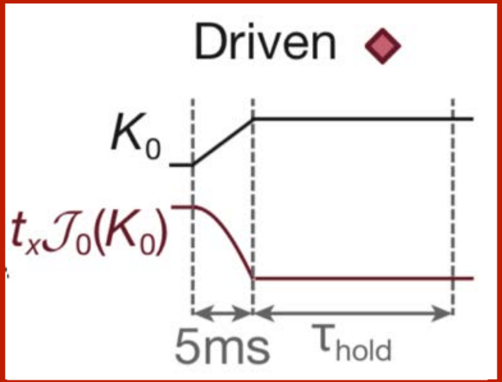
final

M. Messer, K. Sandholzer, F. Görg, J. Minguzzi, R. Desbuquois, T. Esslinger, PRL 121, 233603 (2018), arXiv:1808.00506

Global time scale

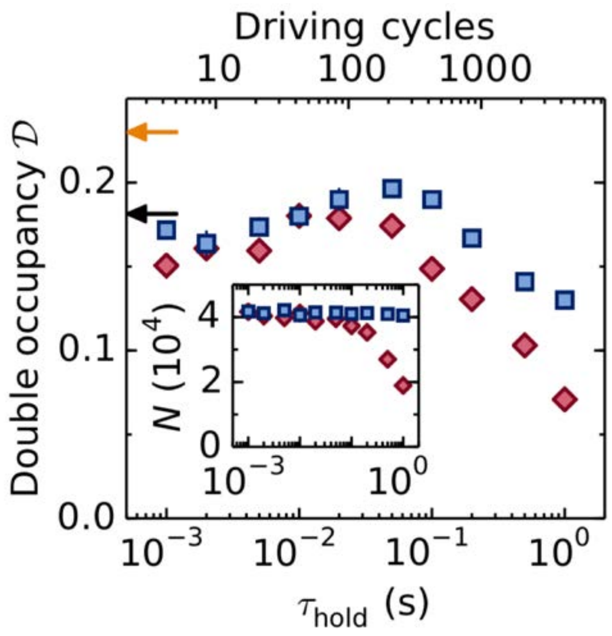
Undriven





Off-resonantly driven

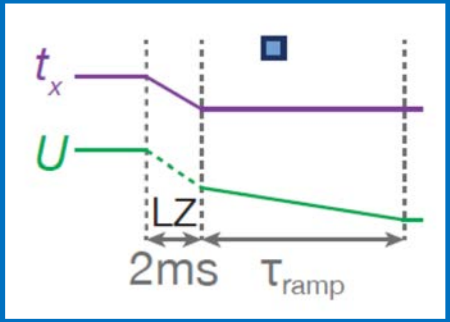
Double occupancy

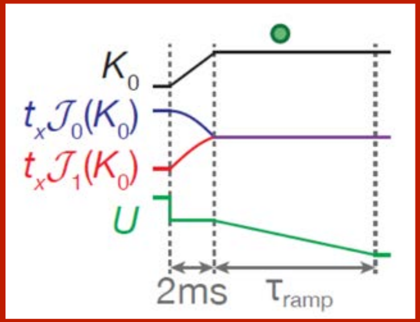


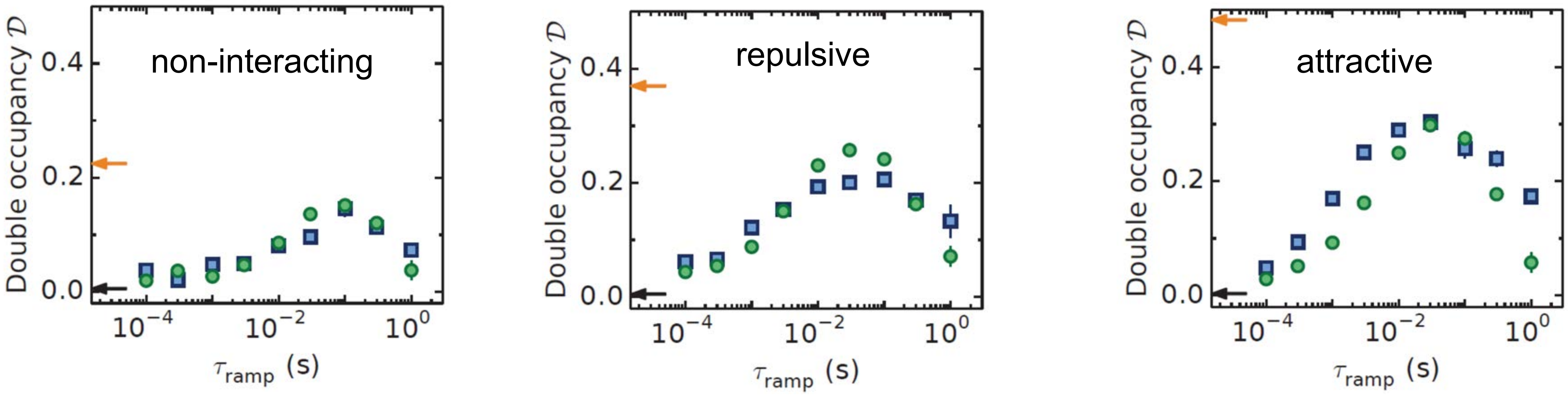
Michael Messer, Kilian Sandholzer, Frederik Görg, Joaquín Minguzzi, Rémi Desbuquois, Tilman Esslinger, arXiv:1808.00506

Resonantly driven!

Undriven



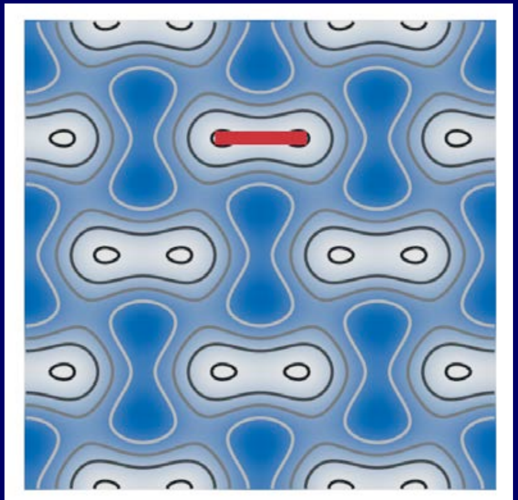




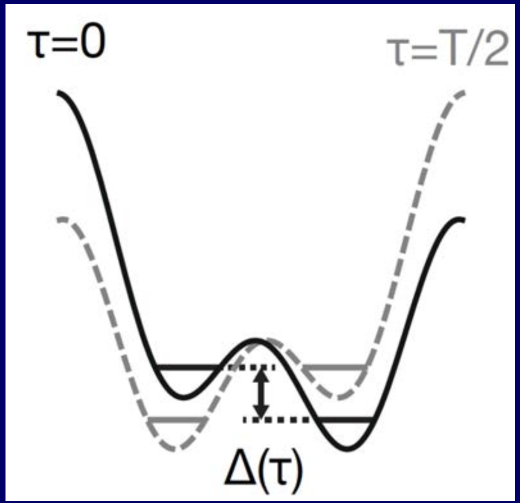
M. Messer, K. Sandholzer, F. Görg, J. Minguzzi, R. Desbuquois, T. Esslinger, PRL 121, 233603 (2018), arXiv:1808.00506

Magnetic correlations in driven lattice

Driven double well



$$t \rightarrow t J_0(K_0)$$



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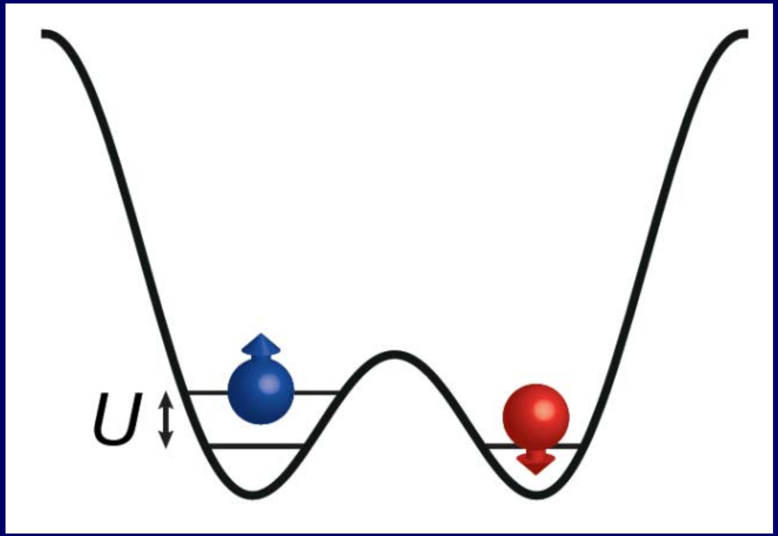
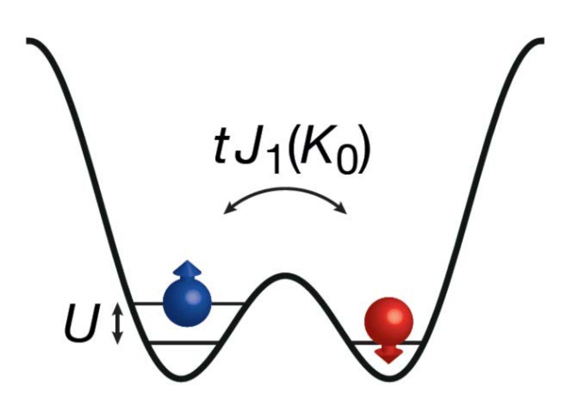
S. Fölling, S. Trotzky, P. Cheinet, M. Feld, R. Saers, A. Widera, T. Müller, and I. Bloch, Nature (London) 448, 1029 (2007).

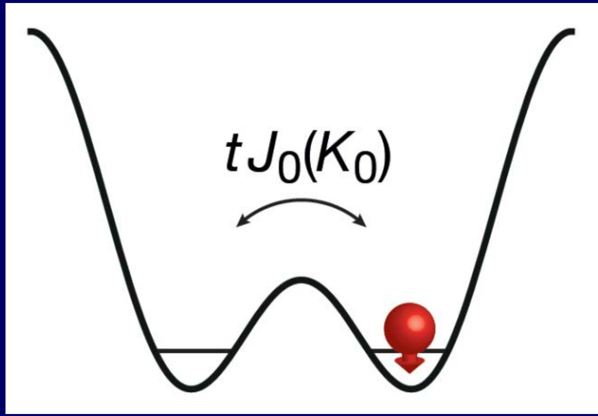
Driven double well



$U \approx \omega$

Driven double well





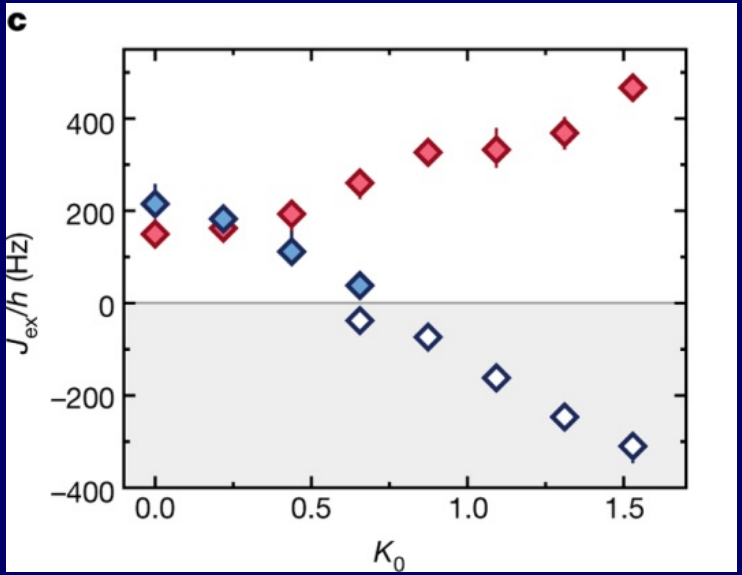
Exchange

$$\hbar\omega >> (\hbar\omega - U) > t$$

$$J_{ex} = -\frac{4t^2 J_0^2(K_0)}{U} - \frac{4t^2 J_1^2(K_0)}{U - \hbar\omega}$$

R. Desbuquois M. Messer, F. Görg, K. Sandholzer, G. Jotzu, and T. E., PRA **96**, 053602 (2017)

Driven double well

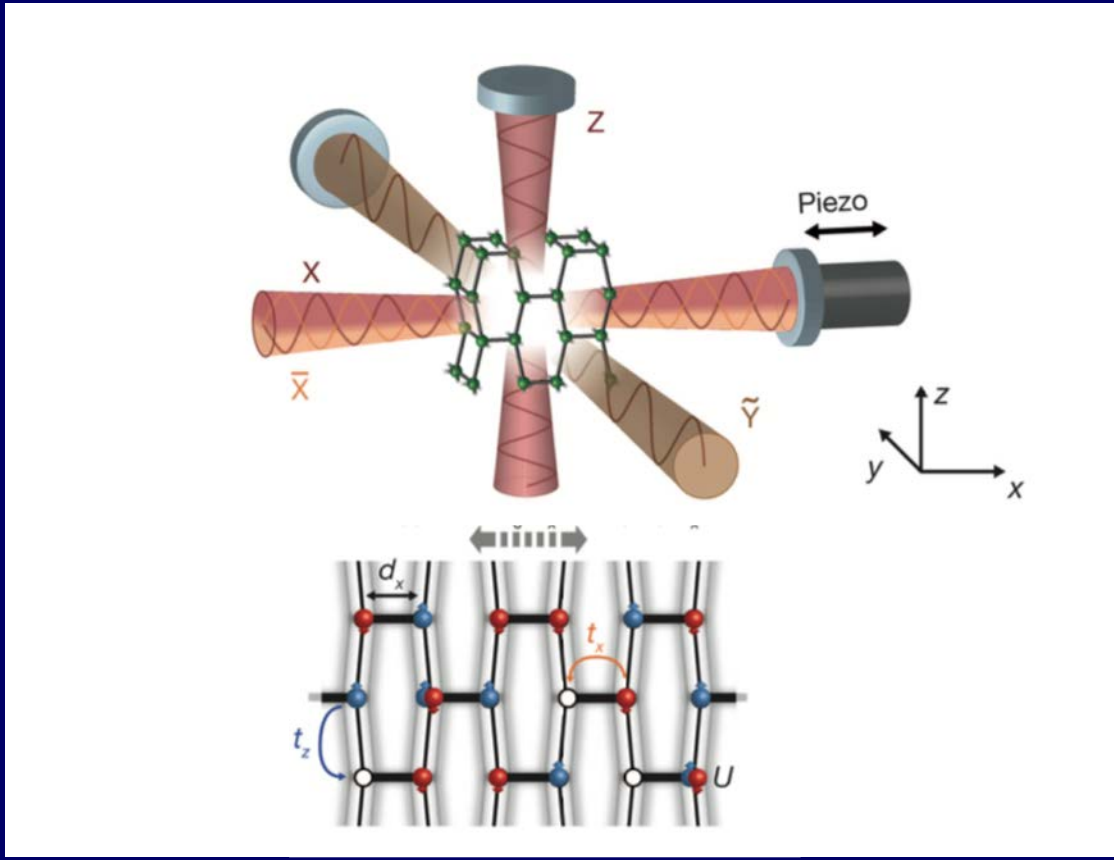


U=9.1 kHz > ω

U=6.5 kHz < ω

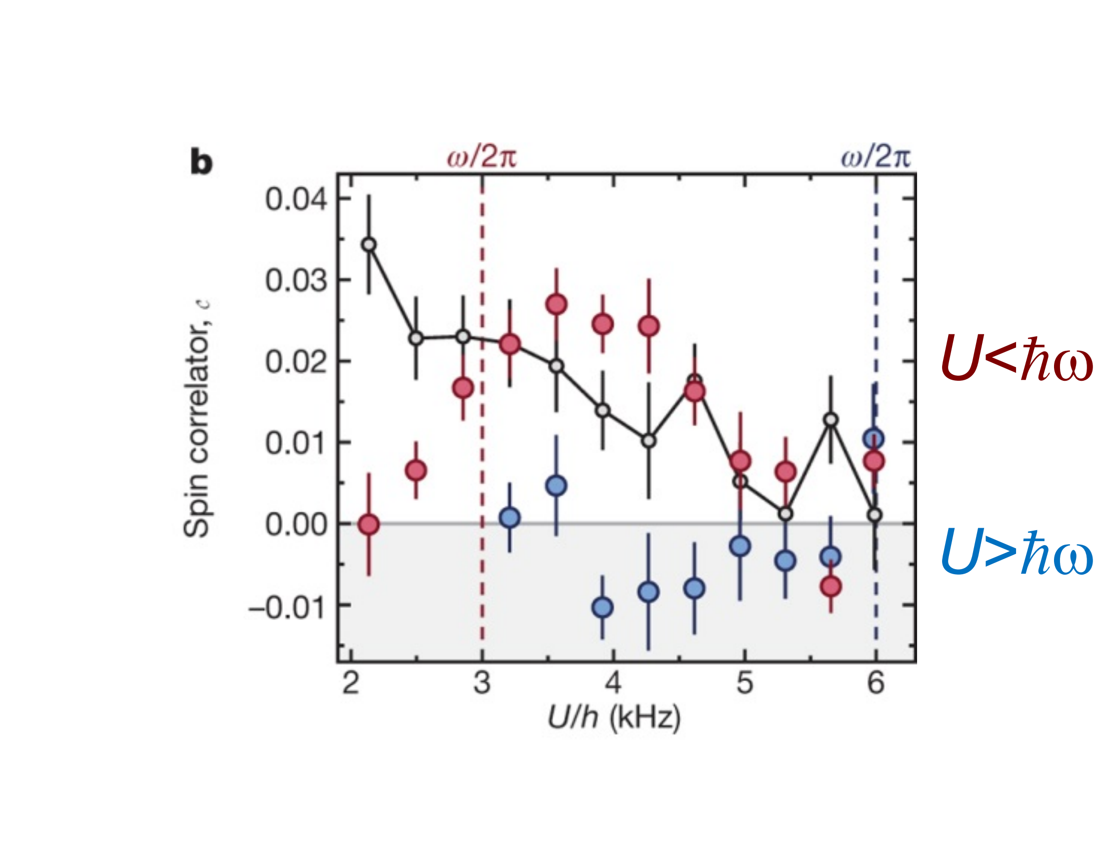
R. Desbuquois M. Messer, F. Görg, K. Sandholzer, G. Jotzu, and T. E., PRA **96**, 053602 (2017)

Magnetic correlations in driven lattice



F. Görg, M. Messer, K. Sandholzer, G. Jotzu, R.Desbuquois, T.E., Nature 553, 481-485 (2018)
Also: J. Coulthard, S. R. Clark, S. Al-Assam, A. Cavalleri, D. Jaksch, Phys. Rev. B 96, 085104 (2017)
J.H. Mentink,w, K. Balzer, M. Eckstein, Nat. Commun. 10.1038/ncomms7708 (2015)

Enhancement of magnetic corrlations in driven lattice

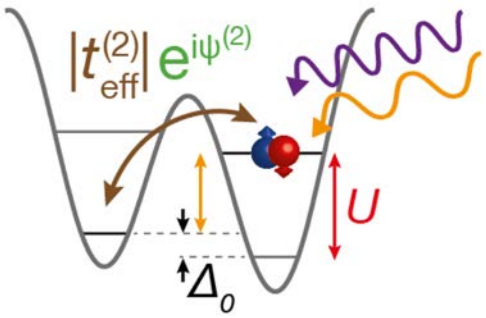


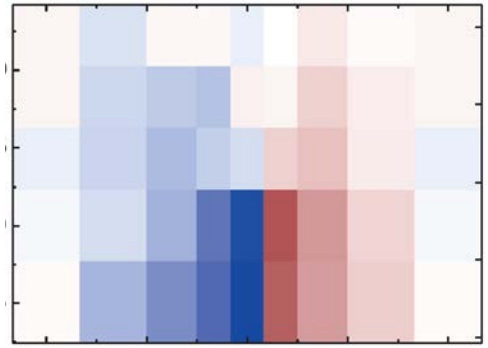
$U<\hbar\omega$

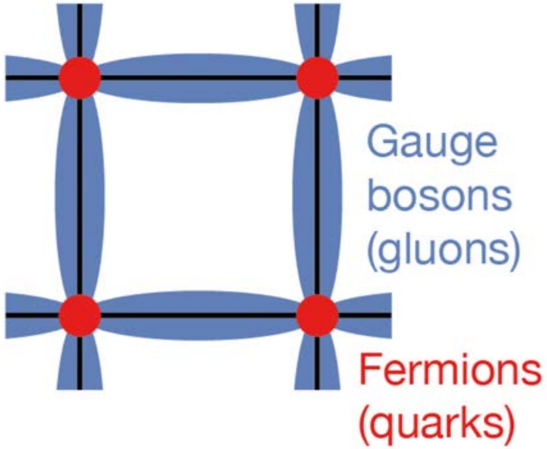
$U>\hbar\omega$

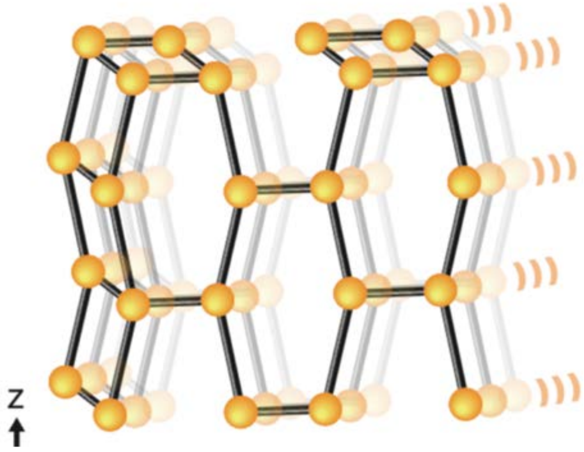
F. Görg, M. Messer, K. Sandholzer, G. Jotzu, R.Desbuquois, T.E., Nature 553, 481-485 (2018)
Also: J. Coulthard, S. R. Clark, S. Al-Assam, A. Cavalleri, D. Jaksch, Phys. Rev. B 96, 085104 (2017)

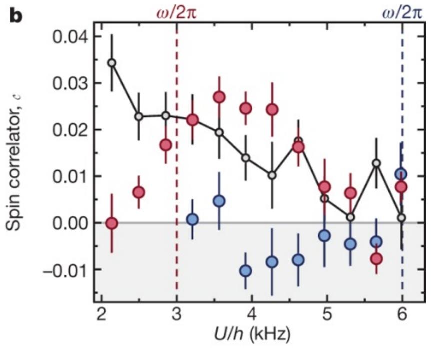
Conclusions











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Quantum Gases in Optical Lattices
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Anne-Sophie Walter
Zijie Zhu
(Frederic Görg)
(Michael Messer)


Electronics: Alexander Frank
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Impact experiment
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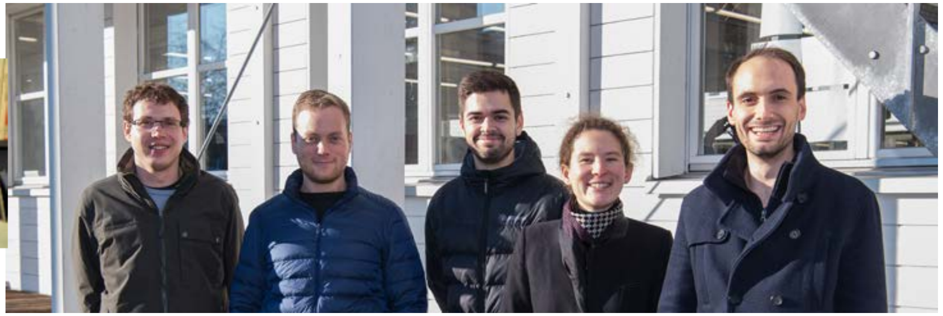
Simon Hertlein
(Andrea Morales)
(Philip Zupancic)
(Julian Leonard, now Harvard)





Lithium Transport
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(Martin Lebrat)
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+ Jean-Philippe Brantut
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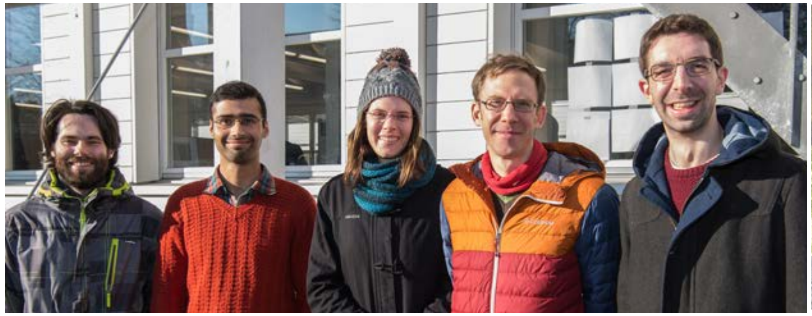

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