Engineering artificial gauge fields with ultracold atoms - part I

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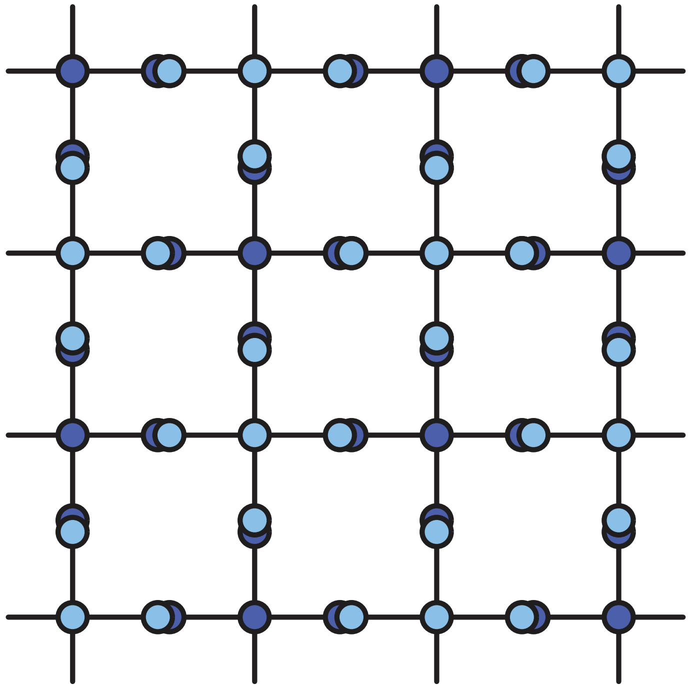

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MCQST
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DFG Deutsche Forschungsgemeinschaft
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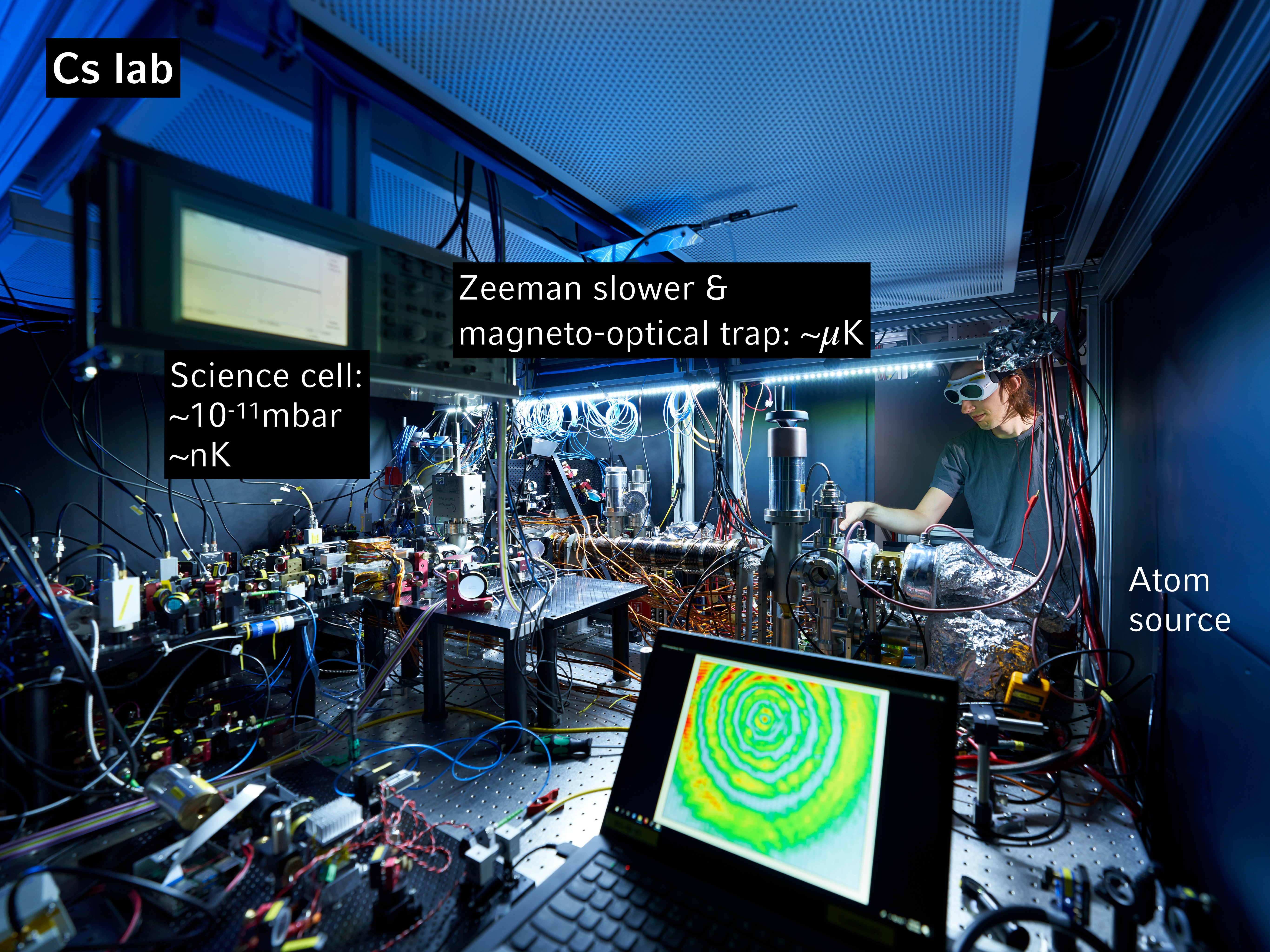
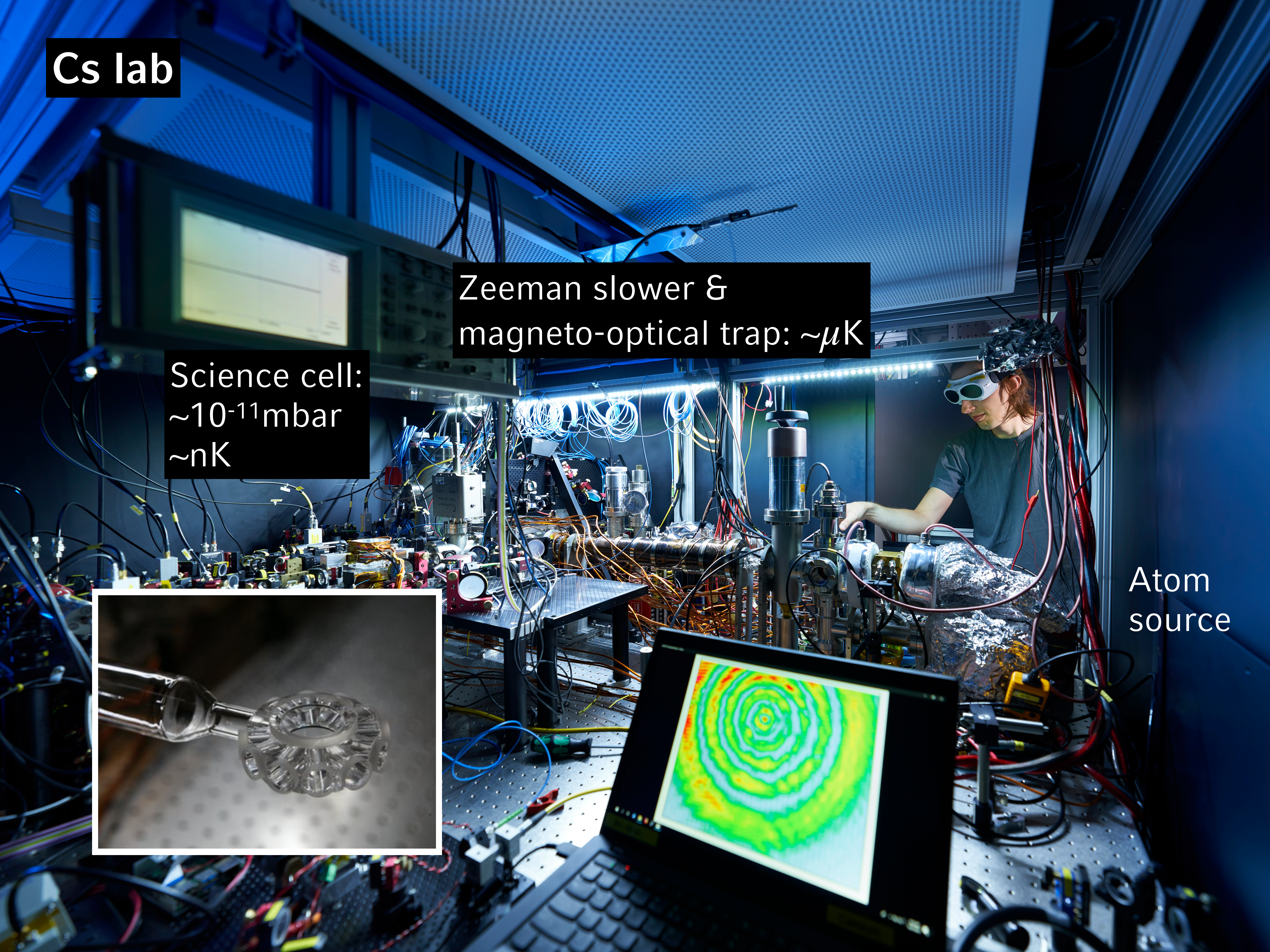


Cs lab
Zeeman slower &
magneto-optical trap: ~μK
Science cell:
~10^-11 mbar
~nK
Atom
source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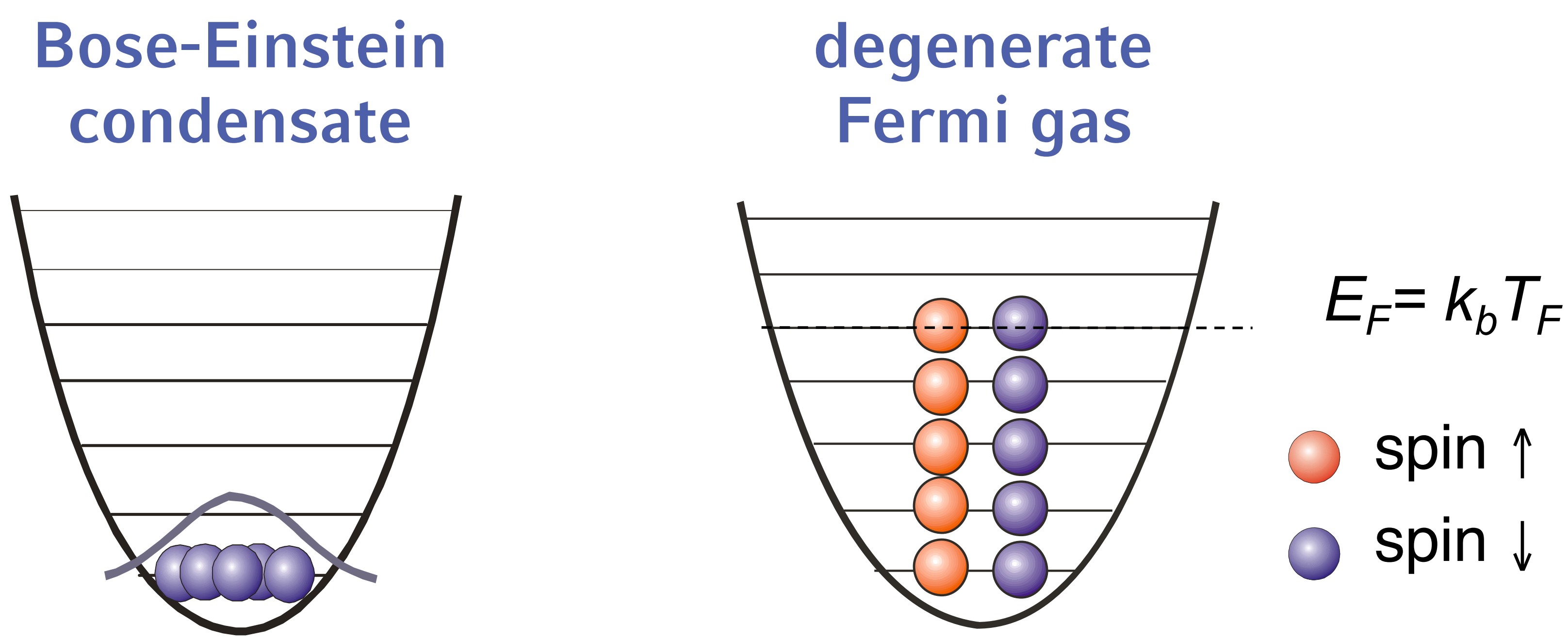
Laser cooling

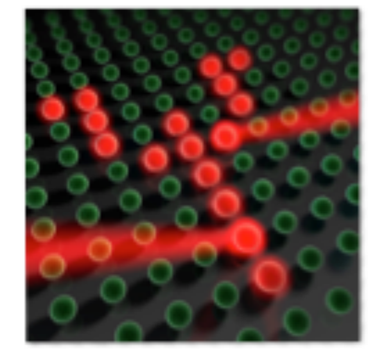
Cooling to quantum **degeneracy**
(laser and evaporative cooling)



Adiabatic preparation of many-body ground state in optical lattice

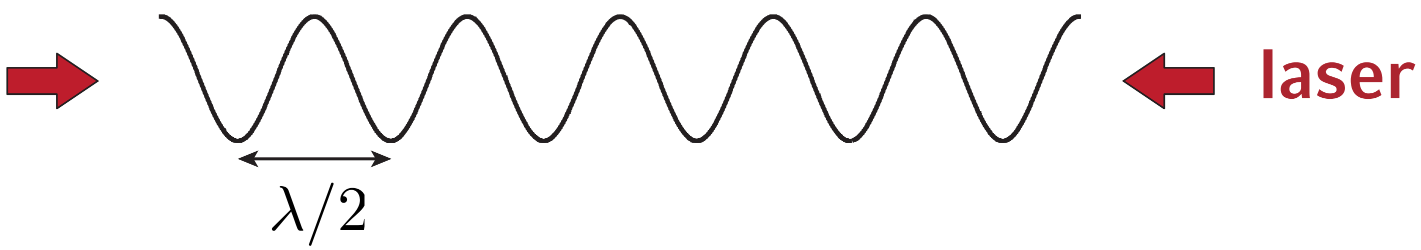
Quantum simulation with ultracold atoms

Ultracold atoms in optical lattices:



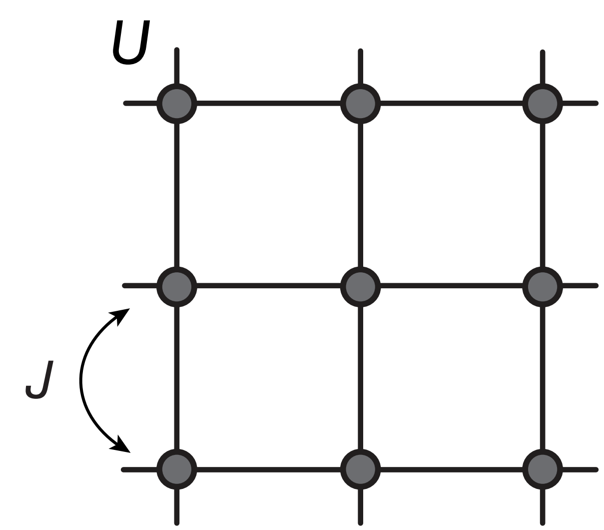
Bloch (MPQ)

- Confined in artificial crystals of light (AC Stark effect)



- **Bose-/Fermi-Hubbard** model

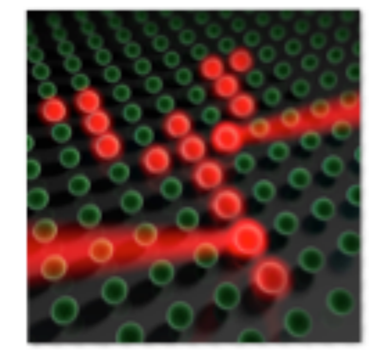
$$\boxed{\hat{H} = -J \sum_{\langle i,j \rangle} \hat{a}_i^\dagger \hat{a}_j + \frac{U}{2} \sum_i \hat{n}_i (\hat{n}_i - 1)}$$



D. Jaksch and P. Zoller, Ann. Phys. 315, 52 (2005); I. Bloch et al. Rev. Mod. Phys. 80, 885 (2008)

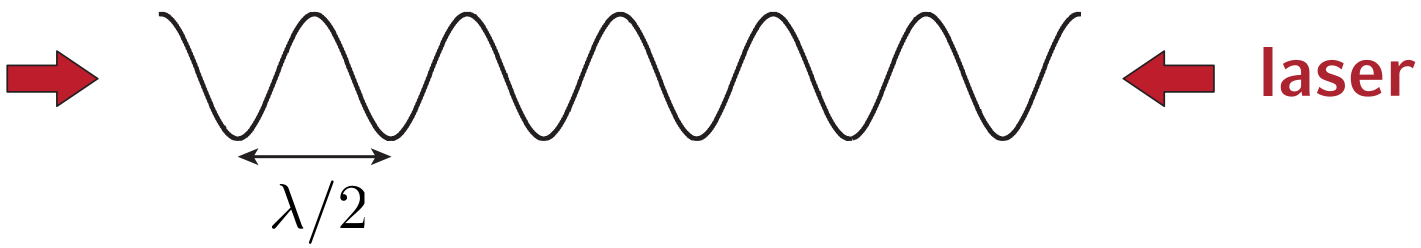
Quantum simulation with ultracold atoms

Ultracold atoms in optical lattices:

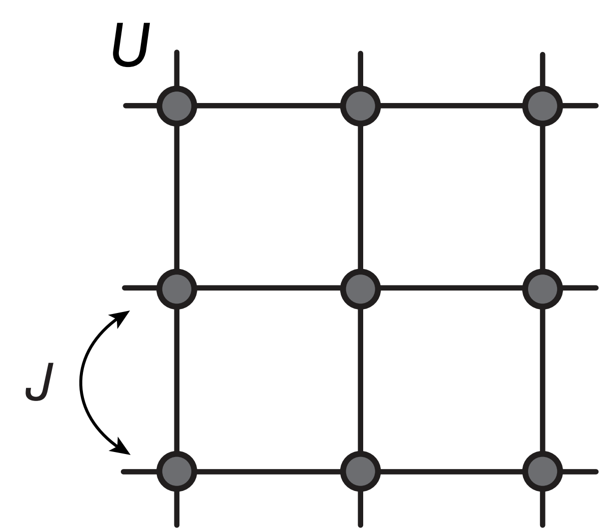


Bloch (MPQ)

- Confined in artificial crystals of light



- Well-isolated from environment
- Control over microscopic parameters



analog quantum Simulation

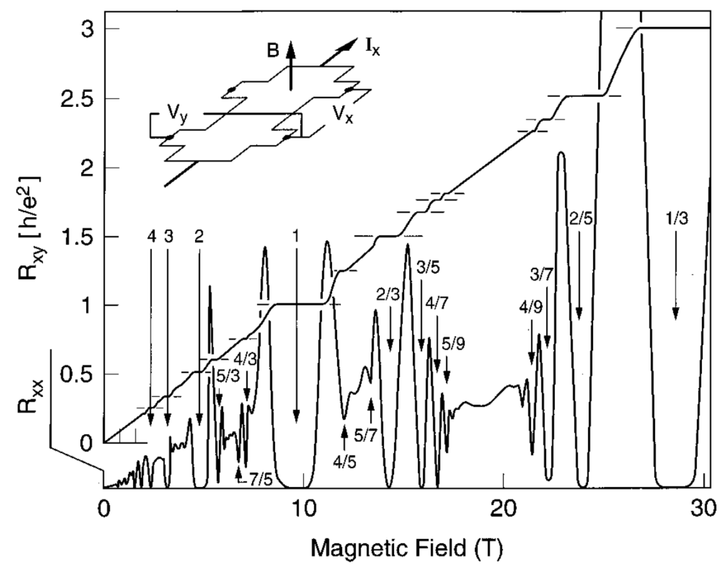
of condensed matter models

D. Jaksch and P. Zoller, Ann. Phys. 315, 52 (2005); I. Bloch et al. Rev. Mod. Phys. 80, 885 (2008)

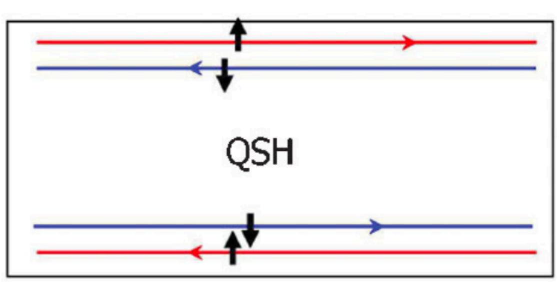
Topological phases of matter

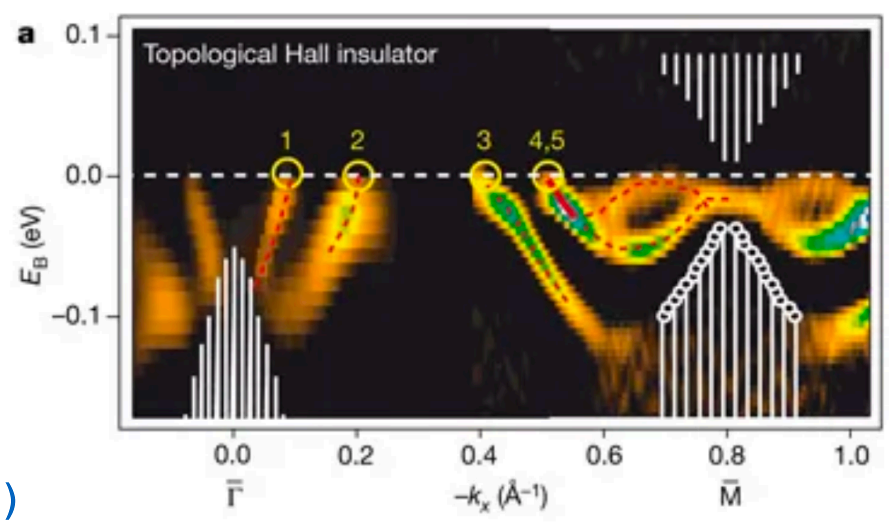
Integer & fractional
quantum Hall insulators

K. Klitzing, Rev. Mod. Phys. (1986)
H. L. Stormer et al.,
Rev. Mod. Phys. (1999)



Topological insulators
in 2D & 3D

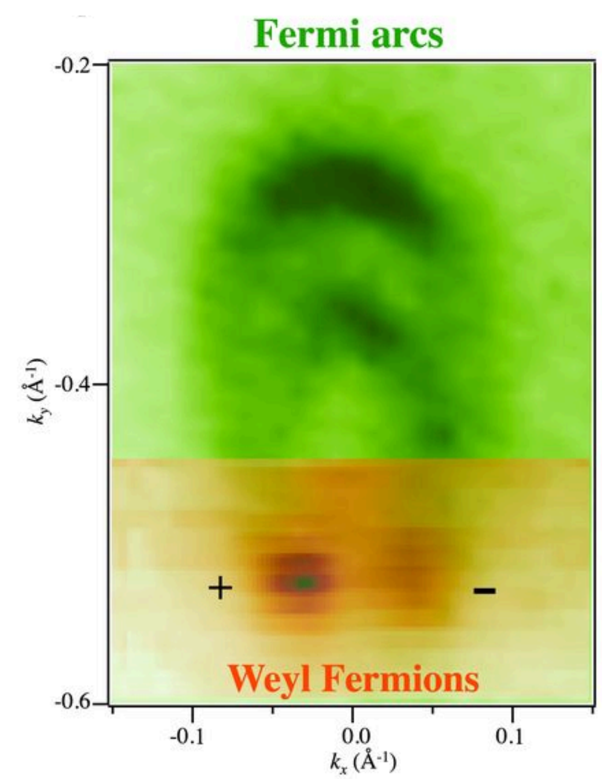




M. König *et al.*, Science (2007)
A. Roth *et al.*, Science (2009)

D. Hsieh *et al.*, Nature (2008)

Weyl semimetals



L. Lu *et al.*, Science (2015)
S.-Y. Xu *et al.*, Science (2015)

...

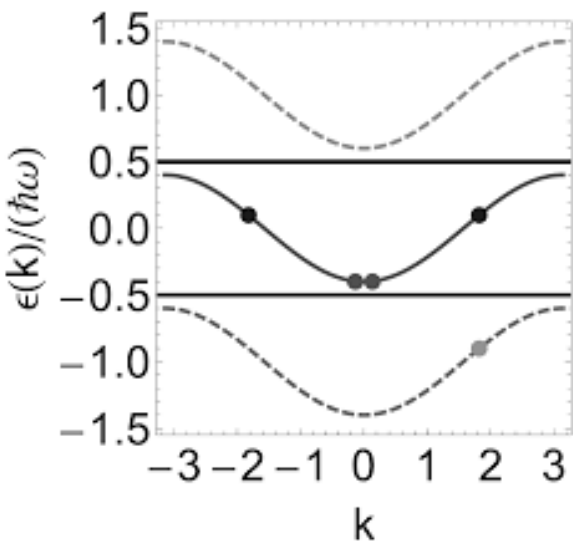
Review: X.-L. Qi & S.-C. Zhang, Rev. Mod. Phys. (2011)

Floquet engineering

Basic idea:

- Time-periodic driven Hamiltonian

$$\boxed{\hat{H}(t) = \hat{H}(t+T)}$$ *T*: driving cycle



- *Stroboscopic* time evolution governed by *time-independent Floquet Hamiltonian* $\hat{H}^F$

$$\boxed{\hat{U}(T,0) = \exp\left(-\frac{i}{\hbar} T \hat{H}^F\right)}$$

$\Rightarrow$ Engineer **Floquet Hamiltonian** with desired properties!

N. Goldman et al. PRX (2014); M. Bukov et al. Adv. in Phys. (2015); A. Eckardt, Rev. Mod. Phys. (2017)

Experimental realizations - see notes