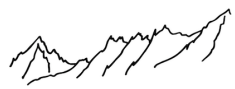
Optical lattices

Hélène Perrin

Laboratoire de physique des lasers, CNRS-Université Paris 13
Sorbonne Paris Cité

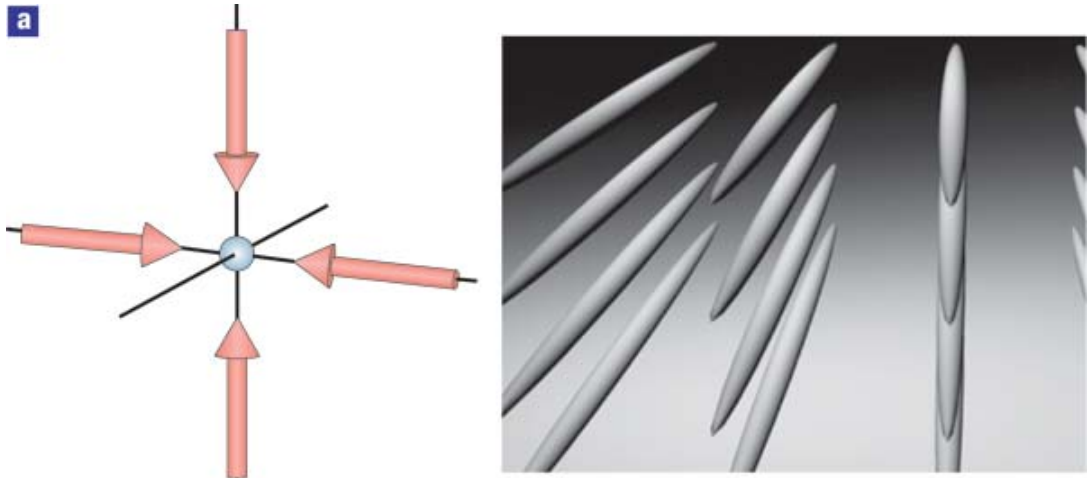
Exploring new quantum gases
Les Houches, September 14–25, 2015



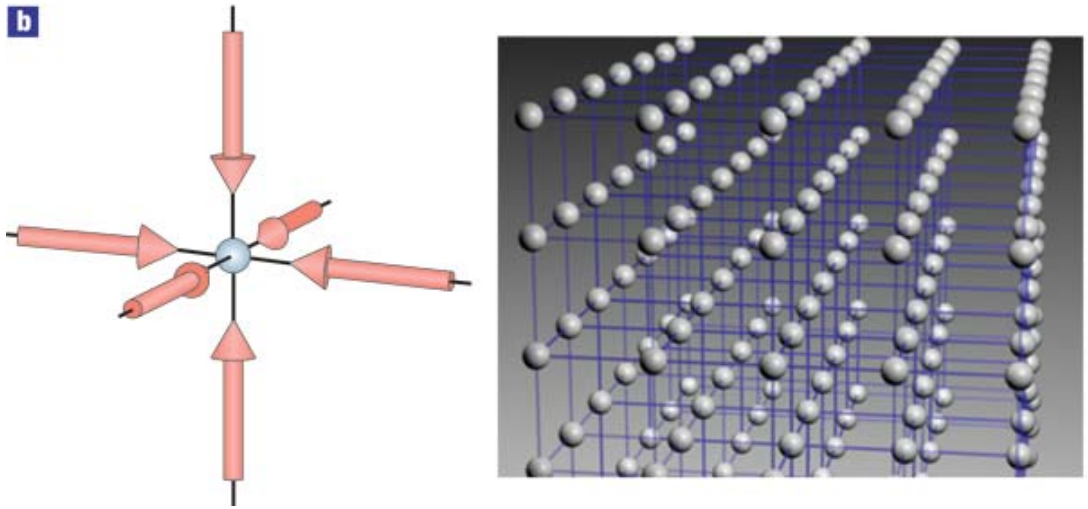
Principle of optical lattices

Standing waves along 1, 2 or 3 axes, with different frequencies.

2 standing waves: 2D lattice of tubes

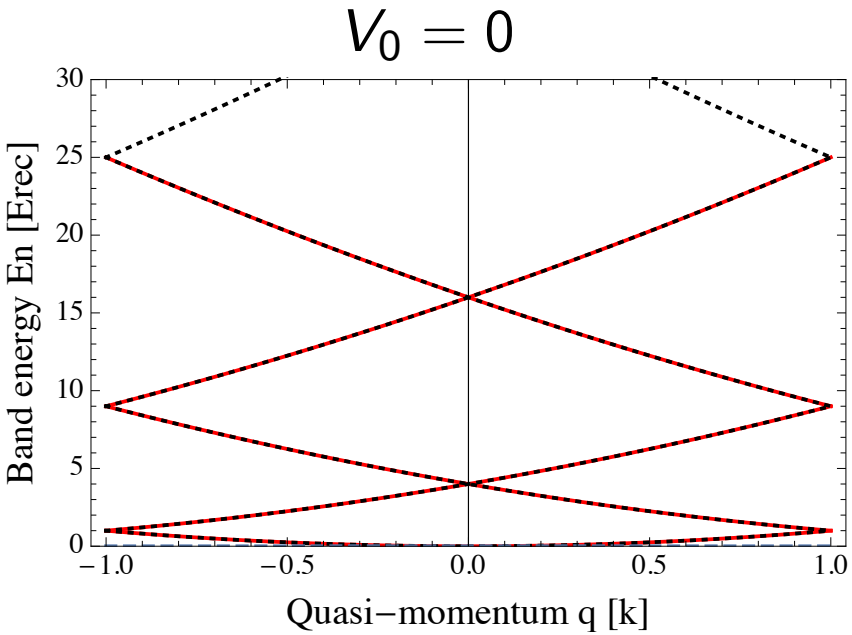


3 standing waves: 3D lattice



I. Bloch, Nat. Phys. (2005)

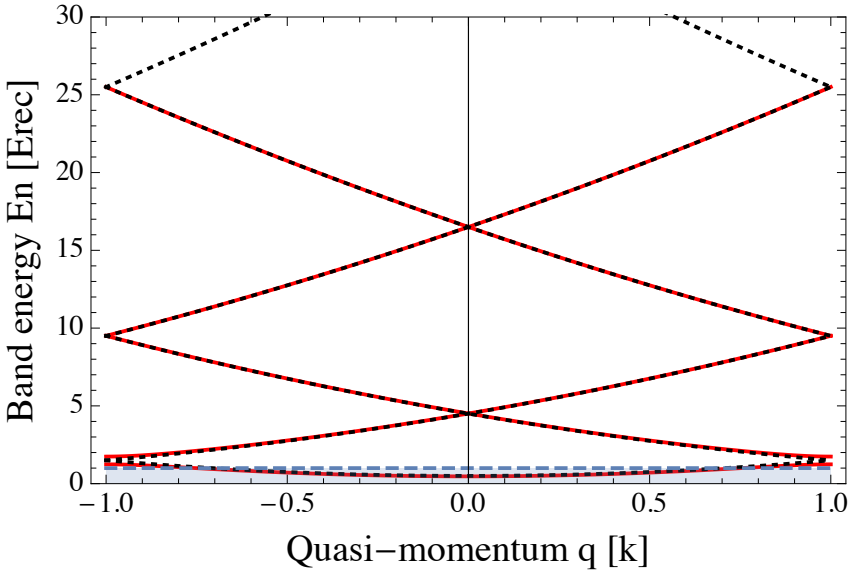
Band structure



Comparison with free particle (left) of harmonic approximation (right)

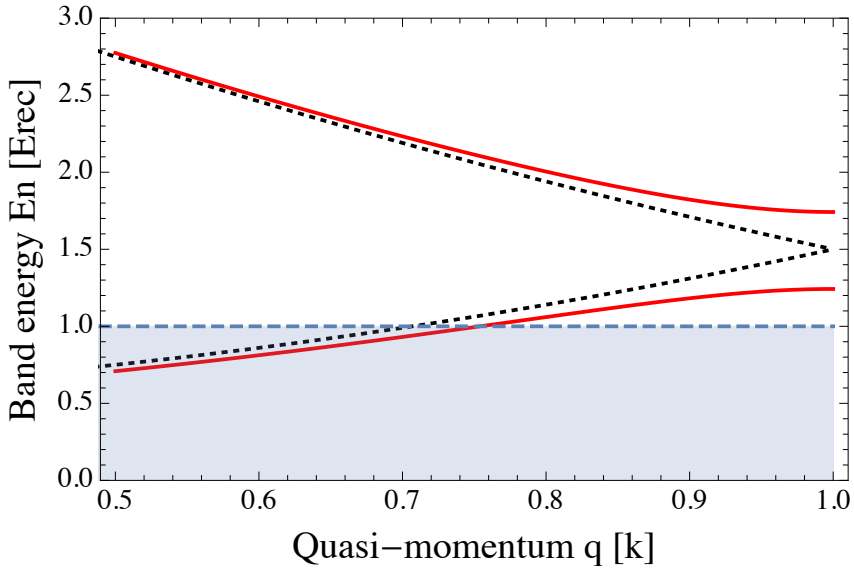
Band structure

$V_0 = E_{\mathrm{rec}}$

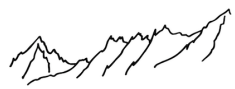


gray zone: potential depth V_0

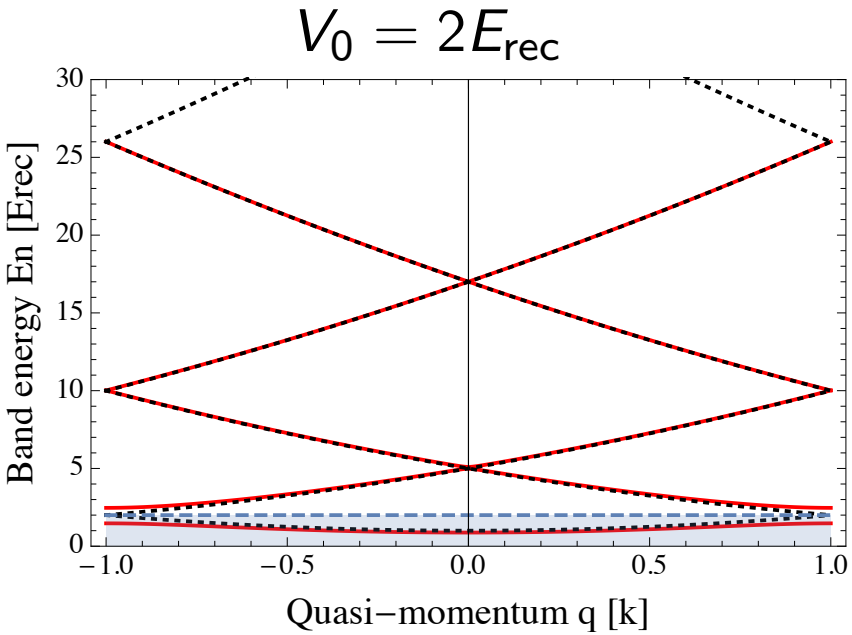
$V_0 = E_{\mathrm{rec}}$



zoom around $q = 1$: gap opening



Band structure



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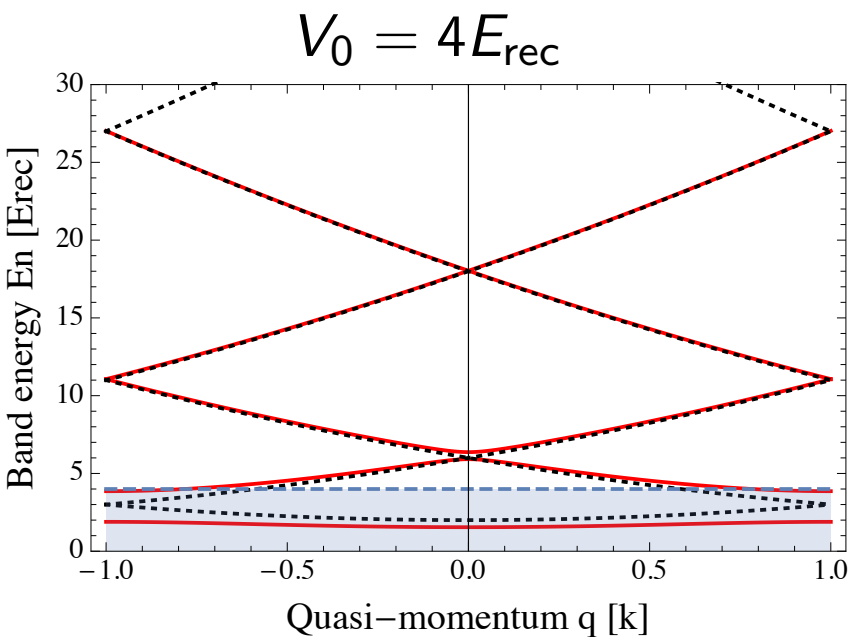

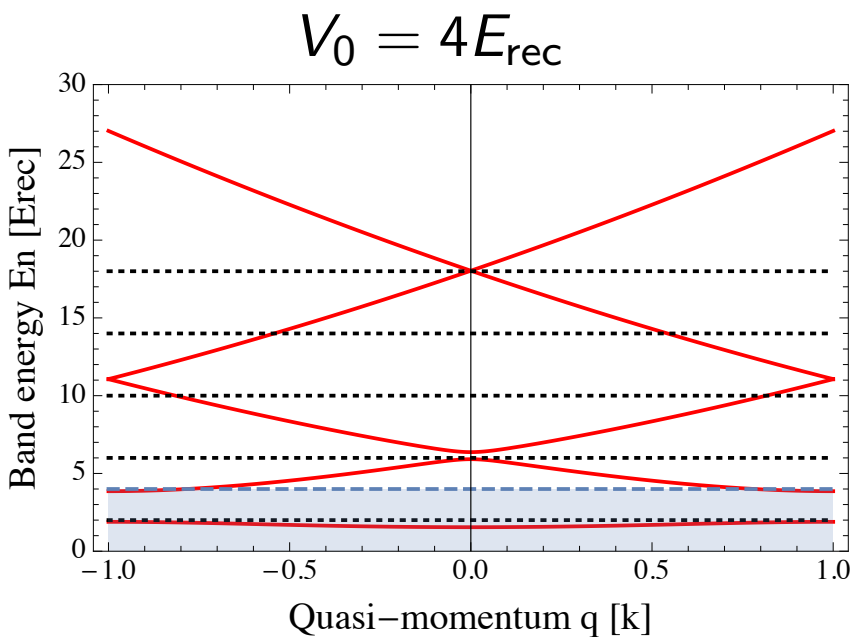

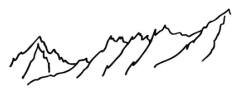

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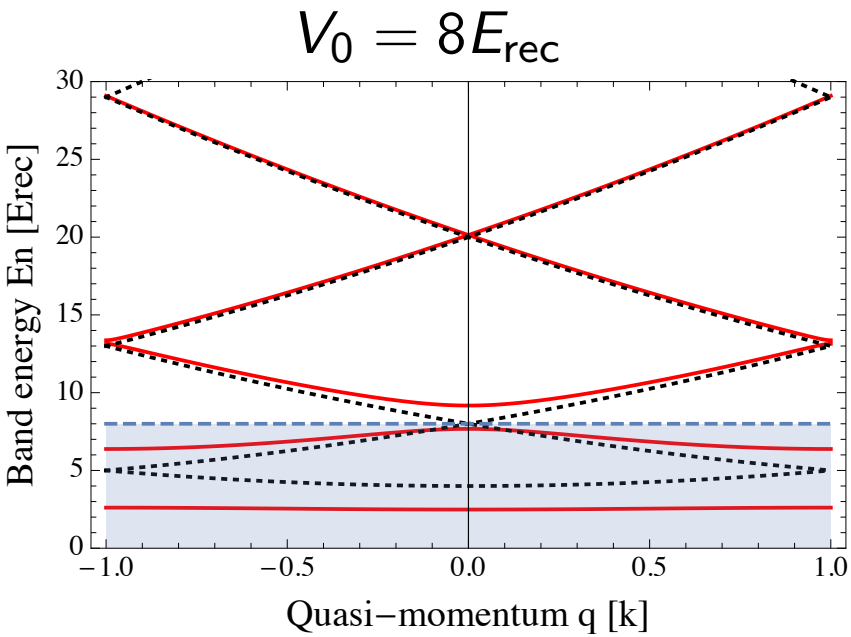

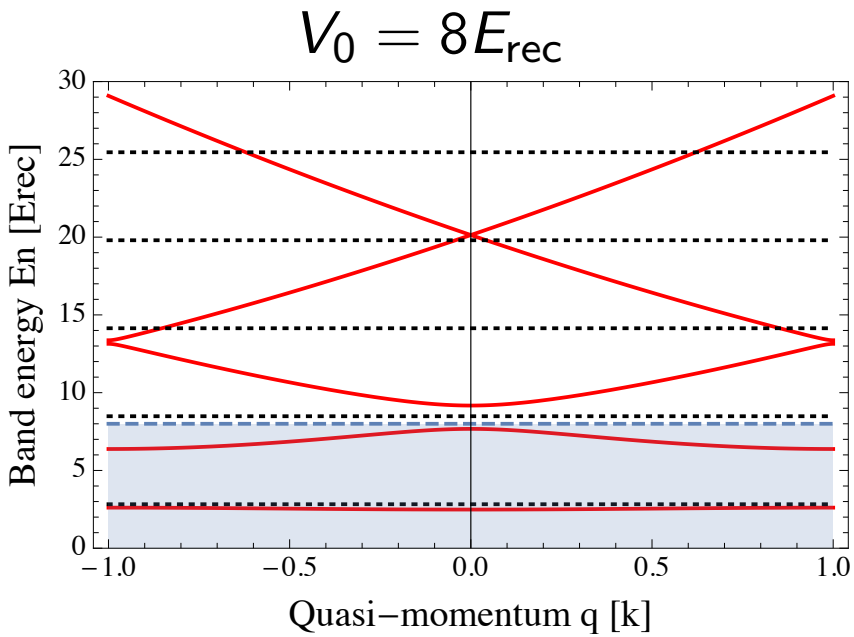

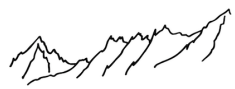

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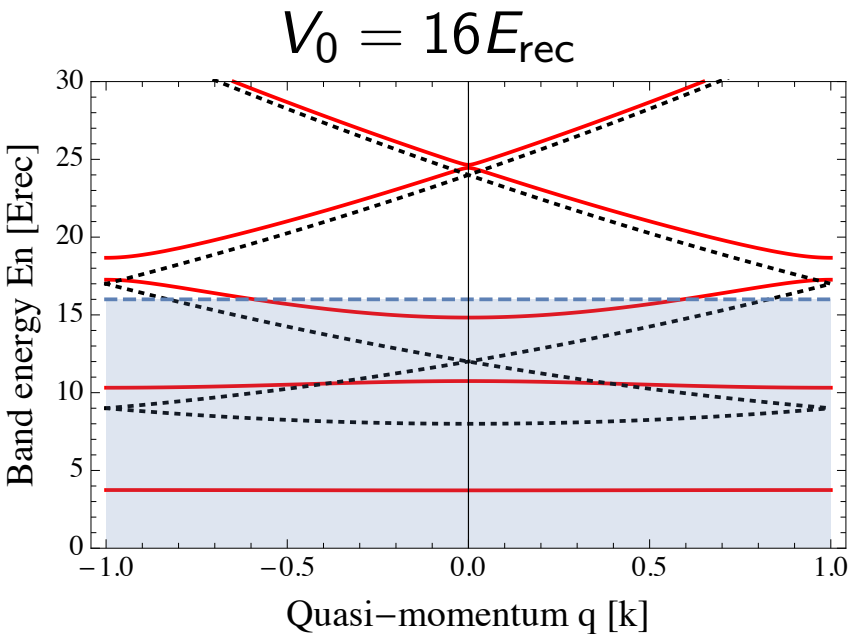

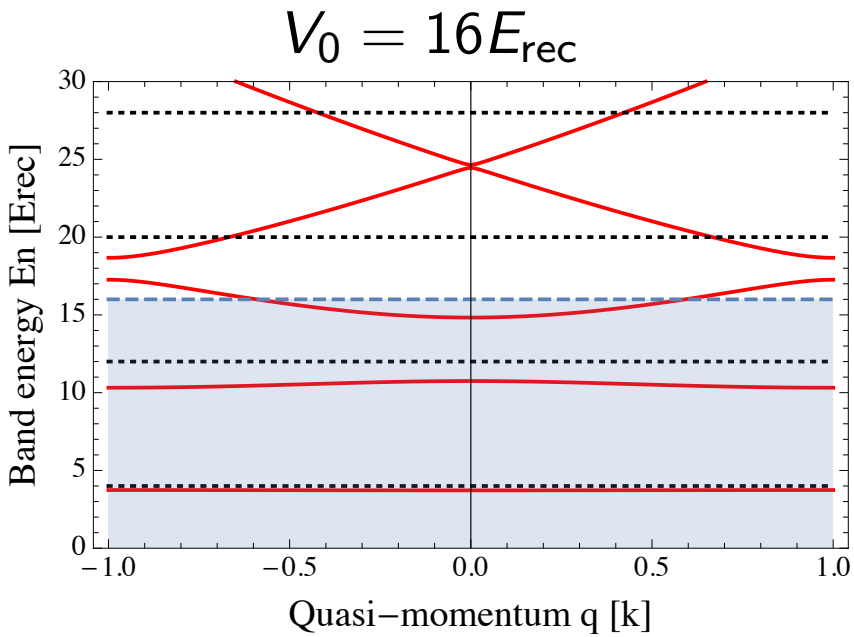

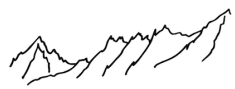

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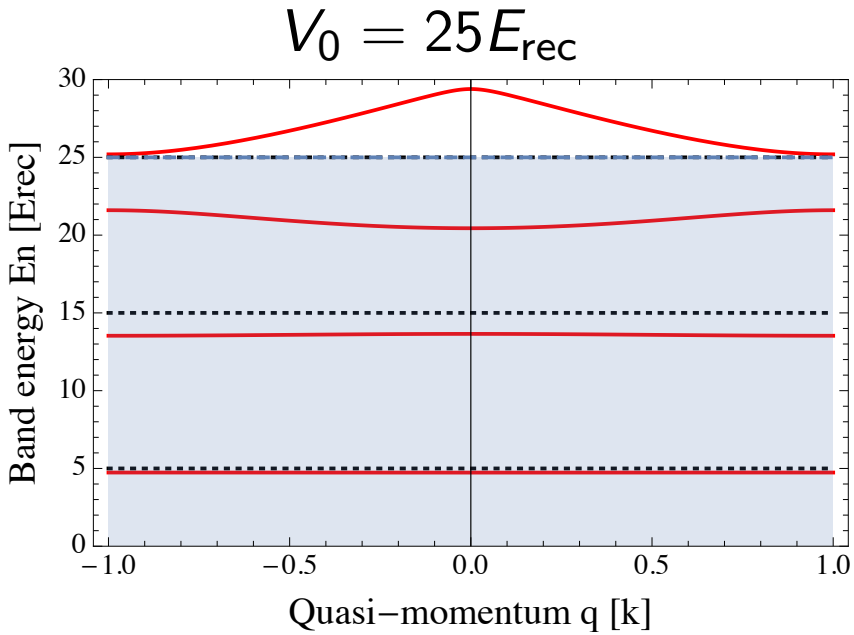
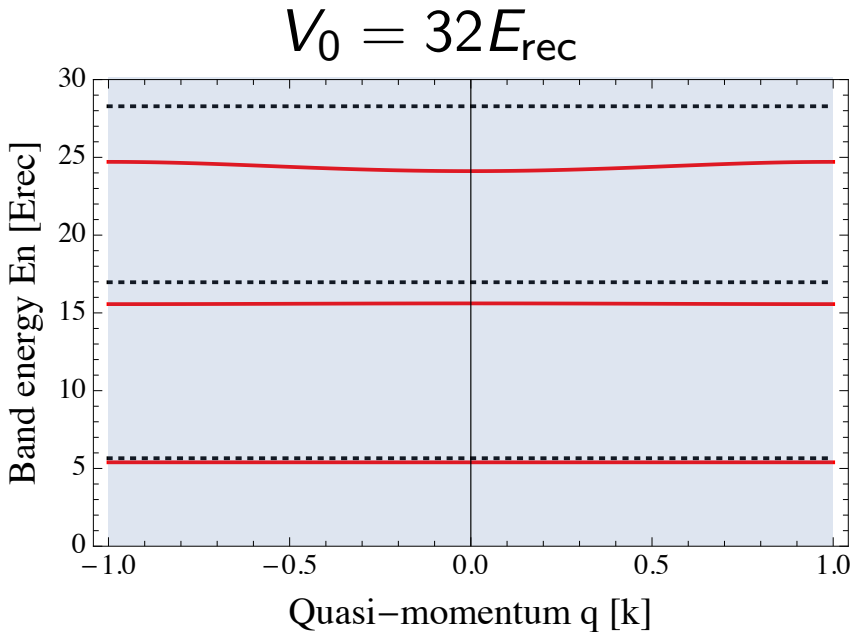


Band structure

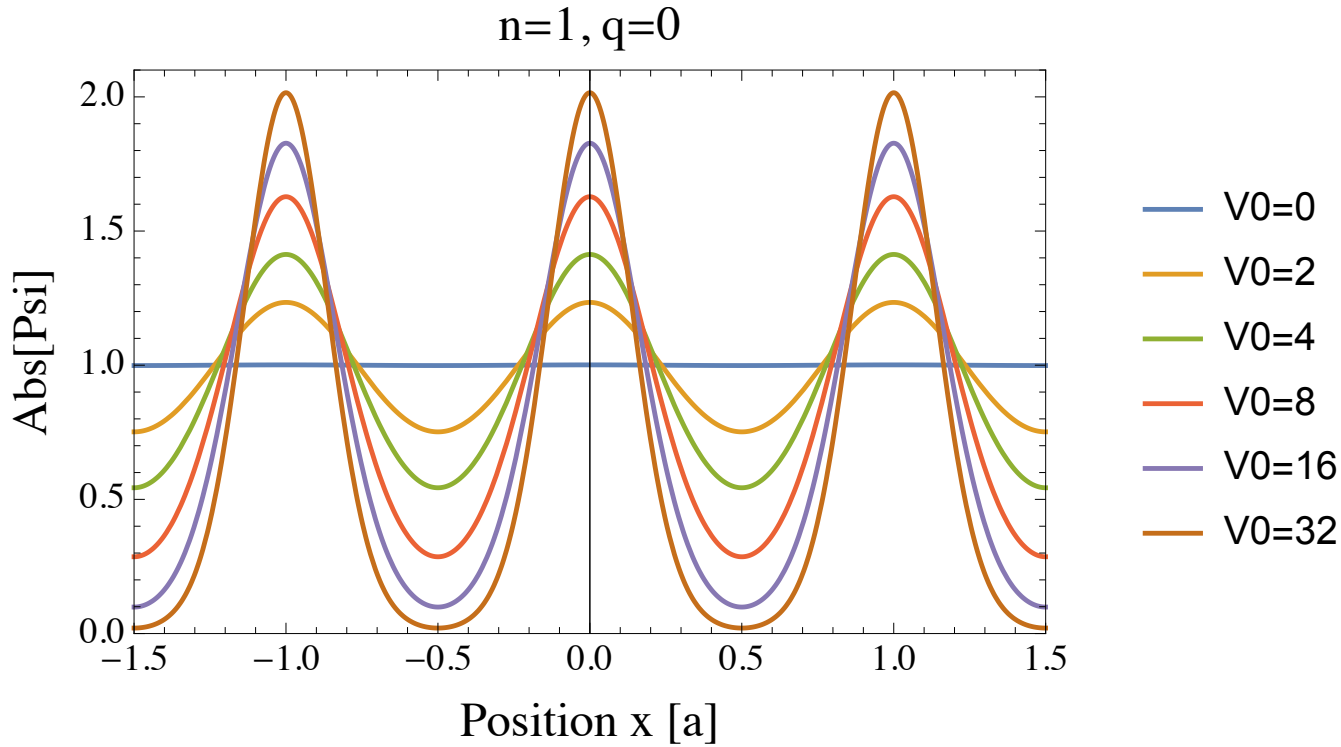


Bloch functions

Bloch functions resemble plane waves at low V_0, and series of peaks at large V_0.

lowest band

$V_0 = 0 \ldots 32 E_{\mathrm{rec}}$

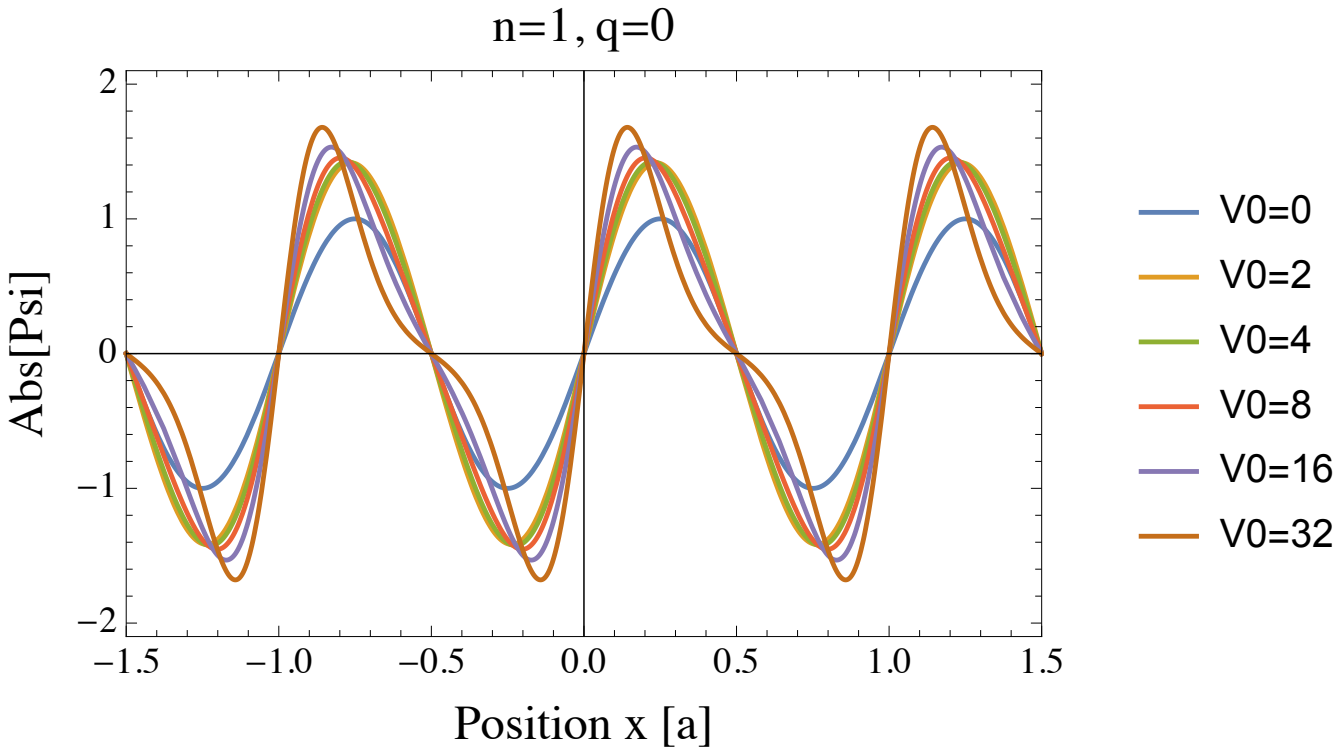


Bloch functions

Bloch functions resemble plane waves at low V_0, and series of peaks at large V_0.

first excited band

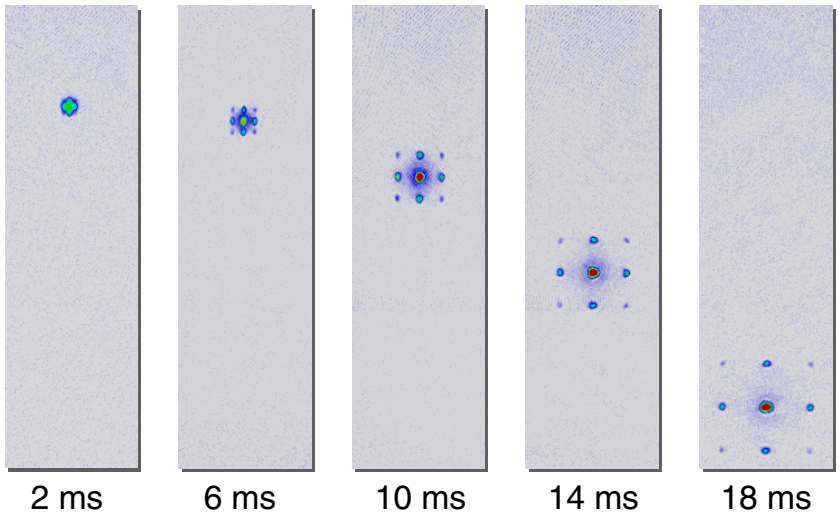
$V_0 = 0 \ldots 32 E_{\mathrm{rec}}$



Momentum comb: sudden release

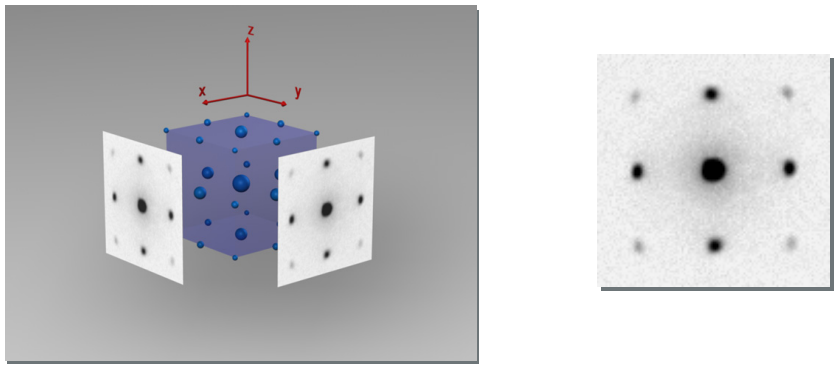
Sudden release of the optical lattice: the momentum distribution presents a periodicity $2\hbar k$.

Expansion with time



Interference between the wells

bosons in a 3D lattice



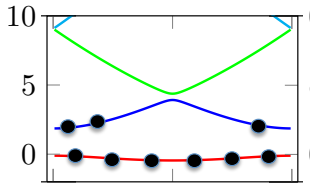
Observation along two orthogonal axes $\Rightarrow$ recover the 3D distribution

From Markus Greiner's PhD thesis.

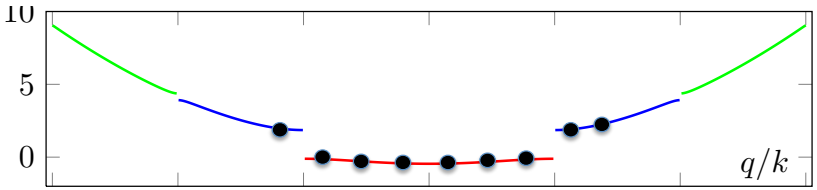
Band mapping: adiabatic release

Example: population in 2 bands

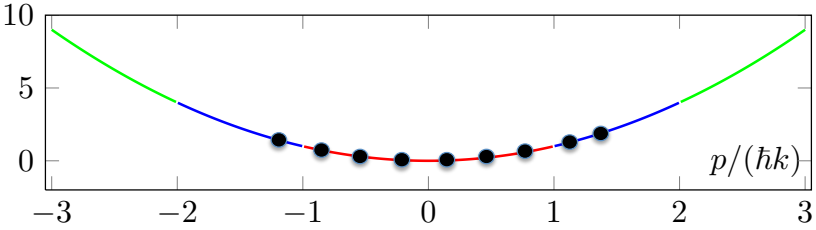
$V_0 = 4E_{\mathrm{rec}}$



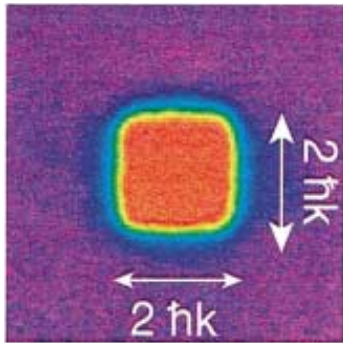
$\Leftrightarrow$



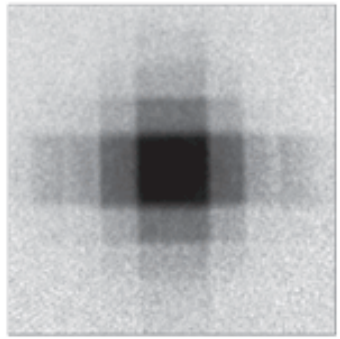
$V_0 \longrightarrow 0$



bosons in a 2D lattice
(Greiner et al. 2001)

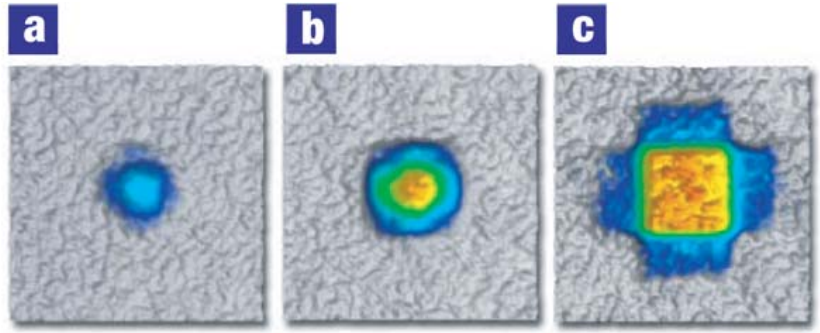


$n = 0$ only



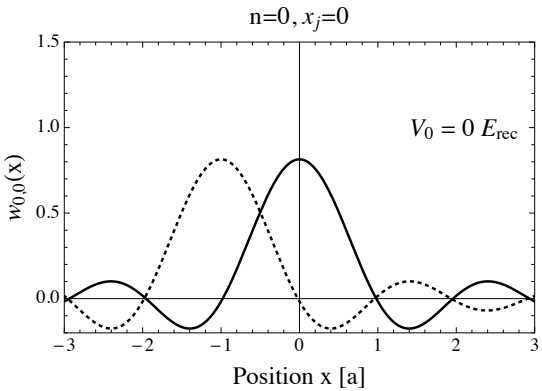
several bands

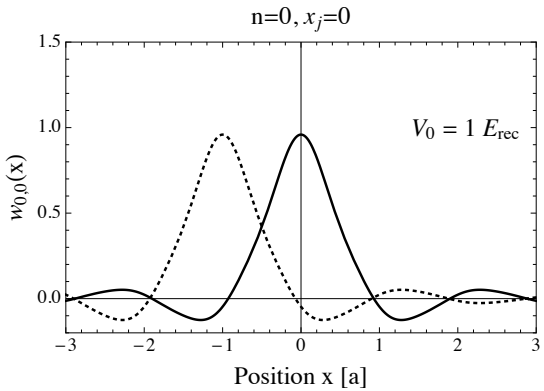
fermions in a 3D lattice
(Köhl et al. 2004)

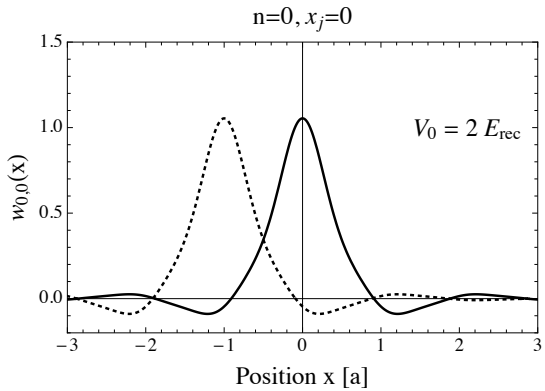


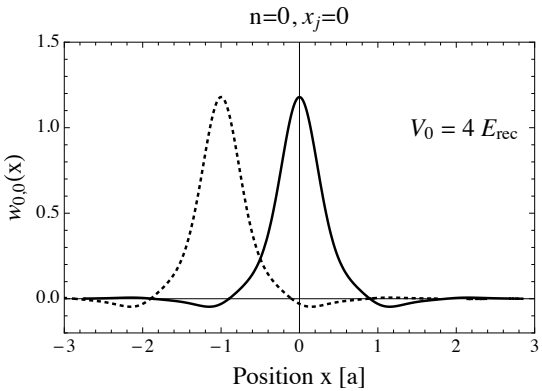
Wannier functions

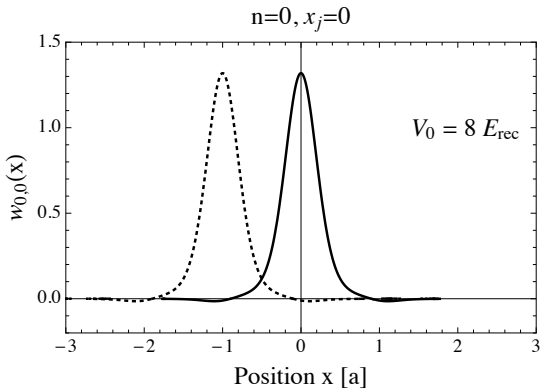
Wannier functions are located around a given lattice site.

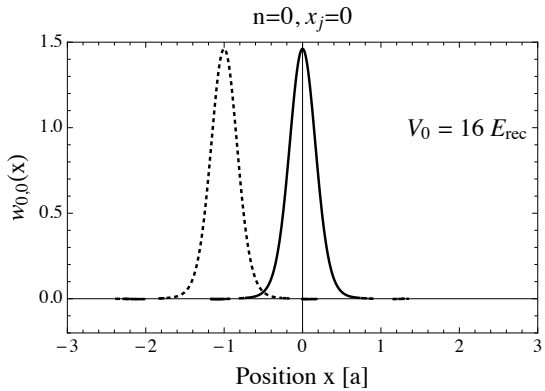


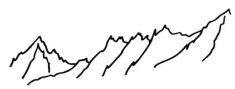












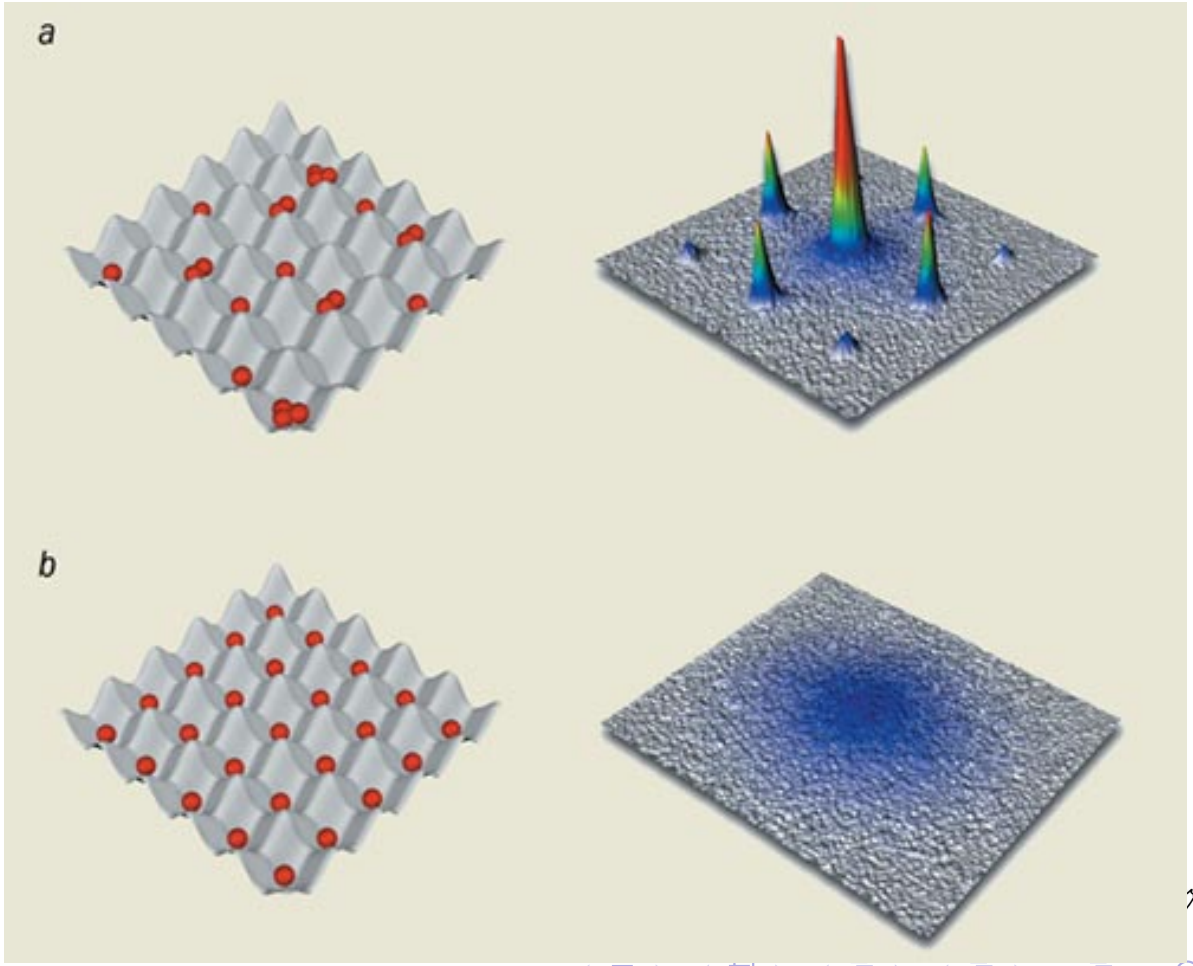
Mott transition

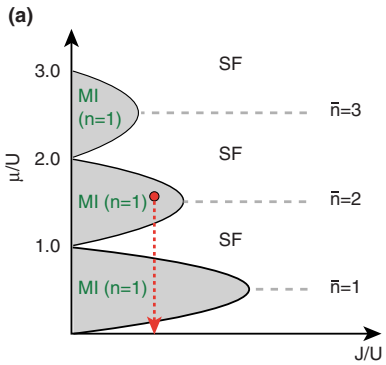
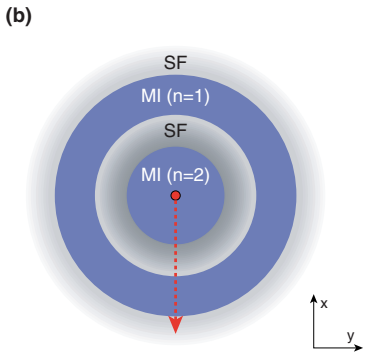
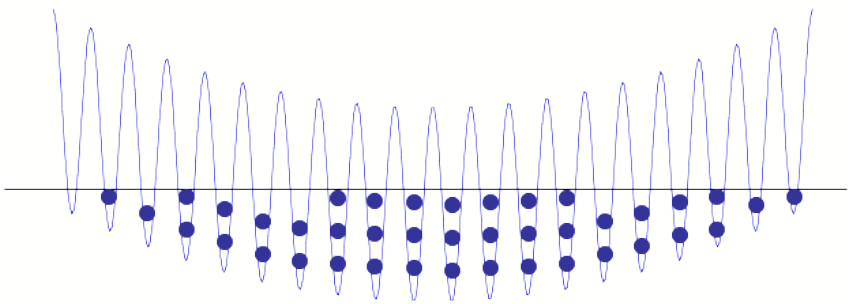
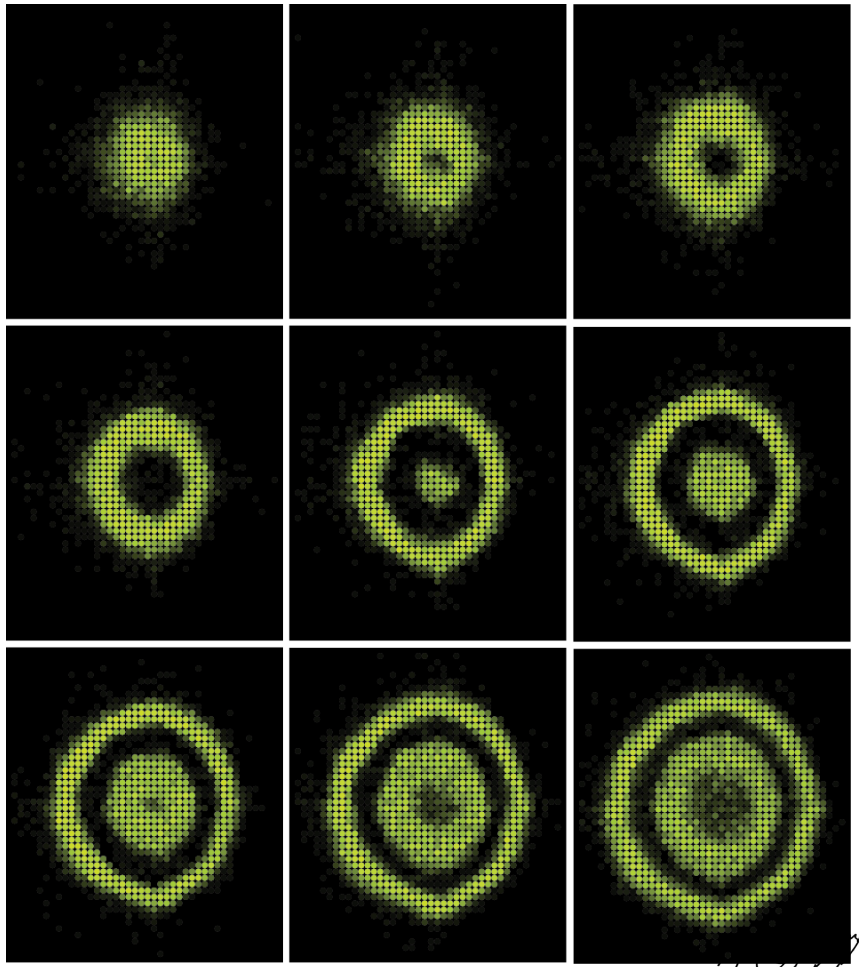
Observation of the Mott insulator to superfluid transition (2002):
A competition between kinetic energy and interactions

Small V_0/E_{rec}
(small U/J)

Greiner et al.,
Nature 2002

Large V_0/E_{rec}
(large U/J)



Mott transition

Mott shells in a lattice + harmonic trap (Greiner/Bloch 2011)