LENS European Laboratory for Nonlinear Spectroscopy,
Dipartimento di Fisica
Università di Firenze
INFM-CNR

Disorder and low dimensonality physics with ultracold atoms

Massimo Inguscio

…the naif view of an experimentalist

GGI 7-8 october 2008

The coldest side of Florence

http://quantumgases.lens.unifi.it

Ultracold atoms in disordered potentials

✓ *Why disorder?*

- Disorder is a key ingredient of the microscopic (and macroscopic) world
- Fundamental element for the physics of **conduction**
- **Superfluid-insulator transition** in condensed-matter systems

✓ *Why cold atoms?*

- Ultracold atoms are a versatile tool to study disorder-related phenomena
- **Precise control** on the kind and amount of disorder in the system
- Quantum simulation

✓ *Localization effects*

- **Bose glasses**, spin glasses (strongly interacting systems)

- **Anderson localization** (weakly interacting systems)

Optical trapping

Far off resonance light induces an electric dipole

$$p = \alpha E$$

The atomic induced electric dipole then interacts with the e.m. wave

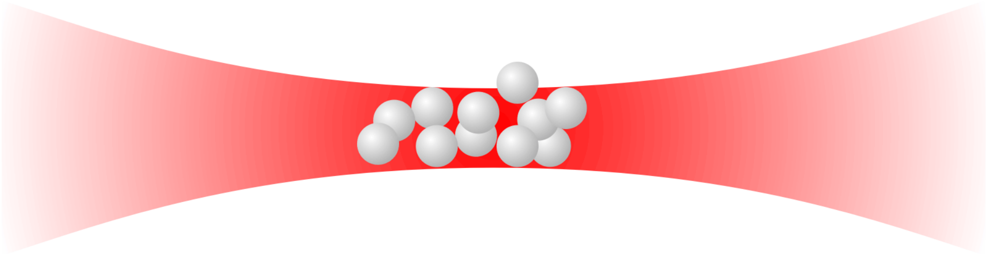
$$U(r) = -p \cdot E(r)$$

$$\downarrow$$

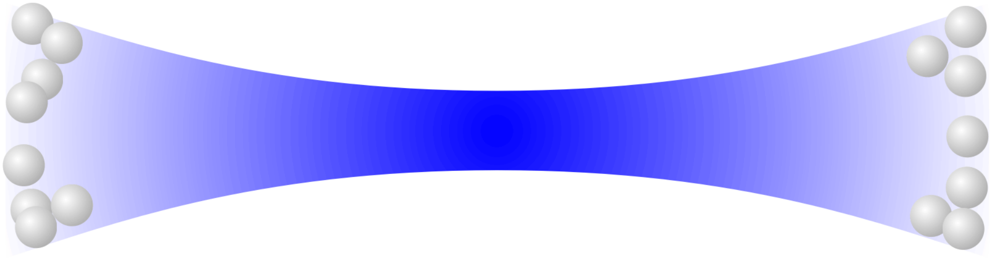
Optical trapping

Optical traps

Red detuning

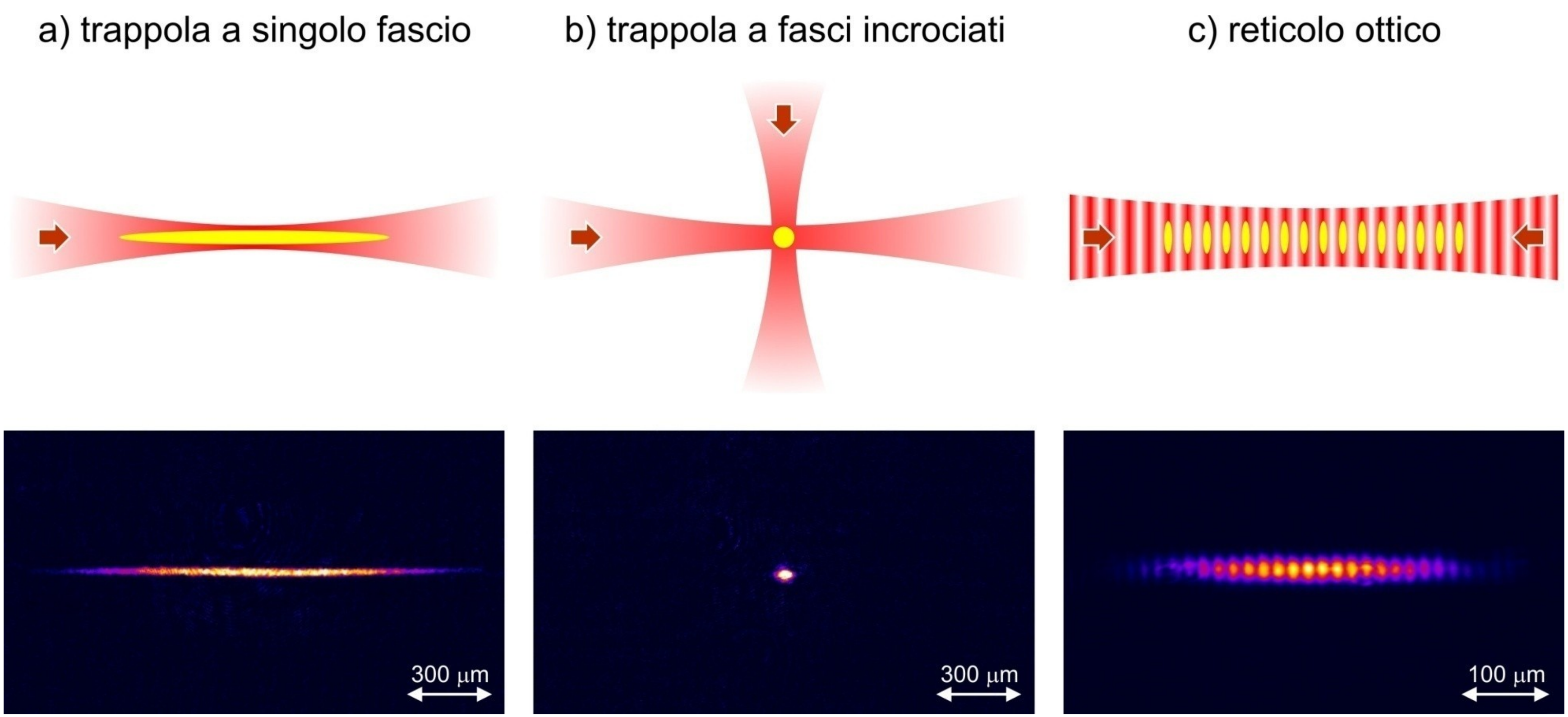


Blue detuning



Optical trapping

L.Fallani, C.Fort, M.Inguscio
Bose Einstein Condensates in Optical Potentials
Riv.Nuovo Cimento 28, serie 4 n.2 (2005)

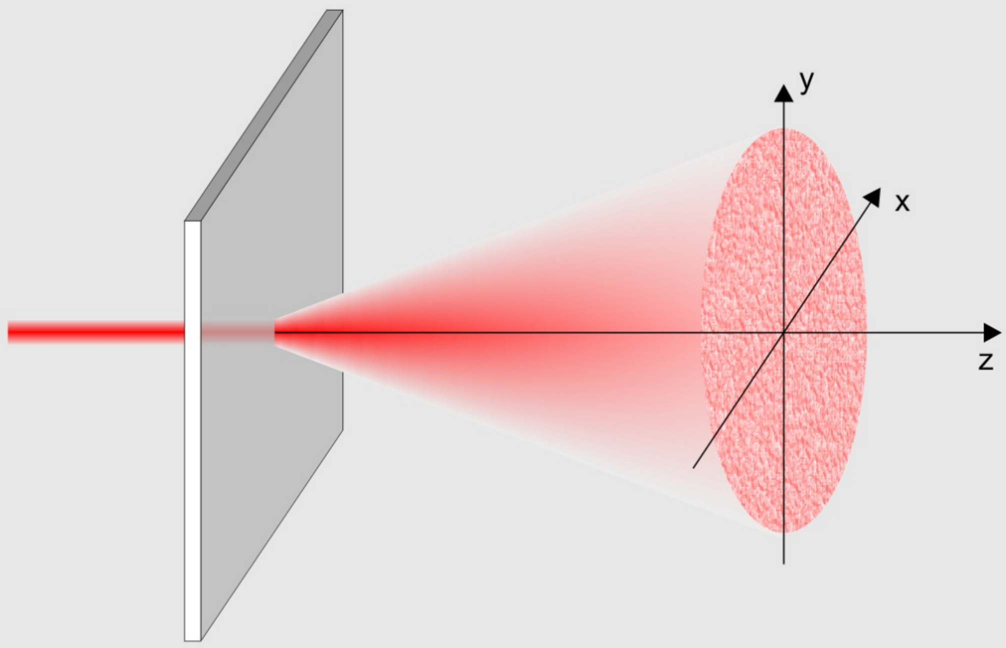


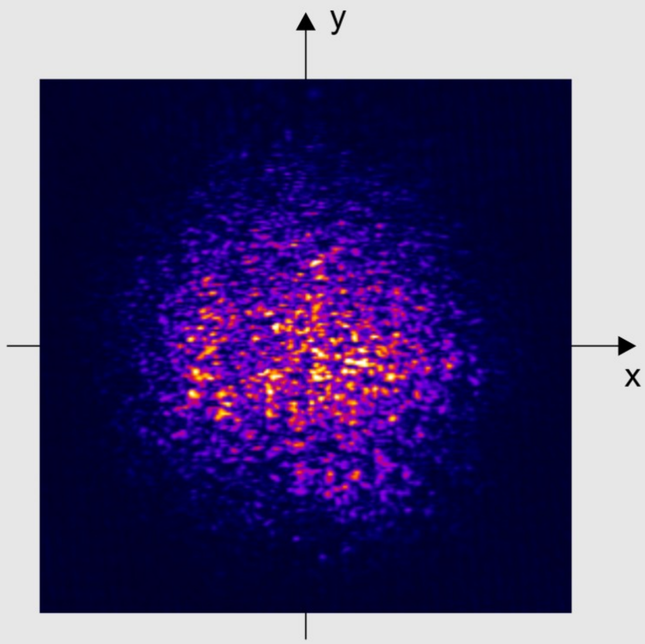
Speckle potential

*J. Lye et al., PRL **95**, 070401 (2005)*

The random potential is produced by shining an off-resonant laser beam onto a diffusive plate and imaging the resulting speckle pattern on the BEC.

LENS, Orsay, Hannover, Rice, Illinois...





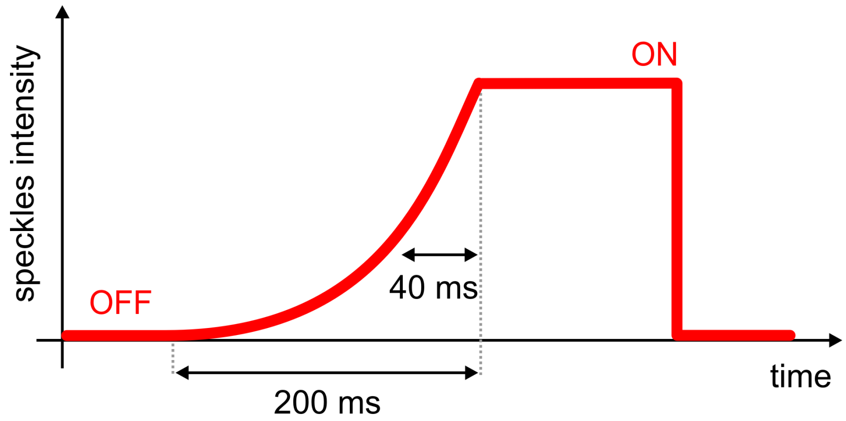
$$V(x,y) = \frac{3\pi c^2}{2\omega_0^3}\frac{\Gamma}{\Delta} I(x,y)$$ optical dipole potential

stationary in time
randomly varying in space

Expansion from the speckle potential

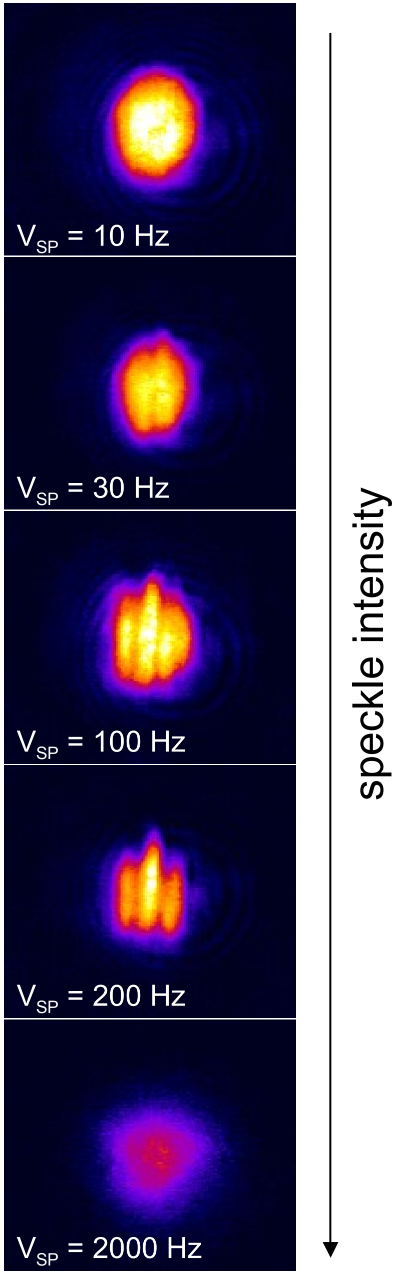
Lye et al. PRL ***95****, 070401 (2005)*

We adiabatically ramp the intensity of the speckle pattern on the trapped BEC, then we suddenly switch off both the magnetic trap and the speckle field and image the atomic cloud after expansion:

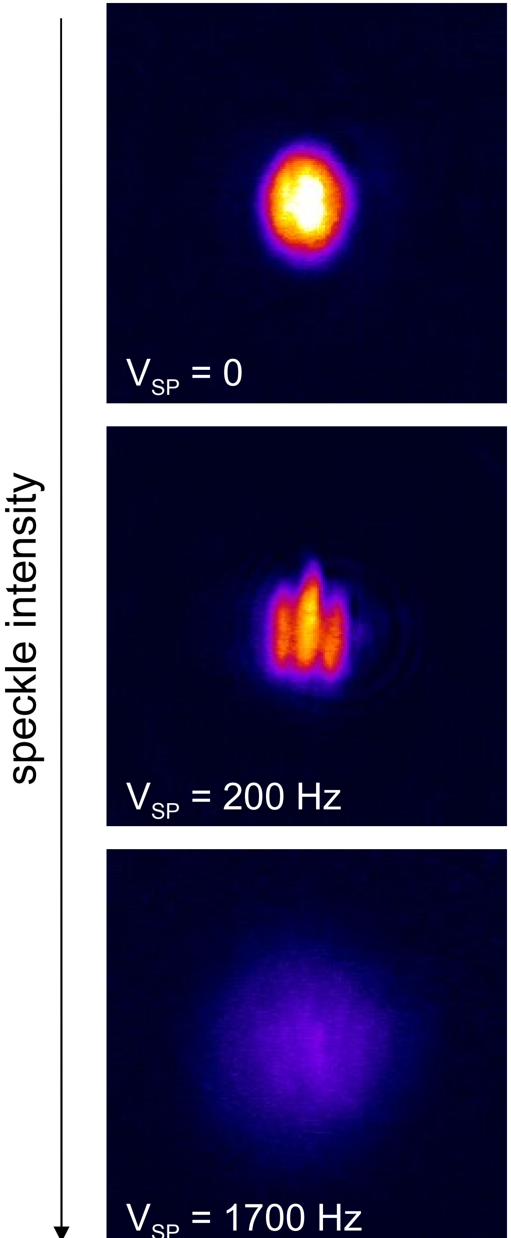


Releasing the BEC from the **weak speckle** potential we observe some irregular stripes in the expanded cloud.

Releasing the BEC from the **strong speckle** potential we observe the disappearance of the fringes and the appareance of a broader gaussian unstructured distribution.



Expansion from the speckle potential



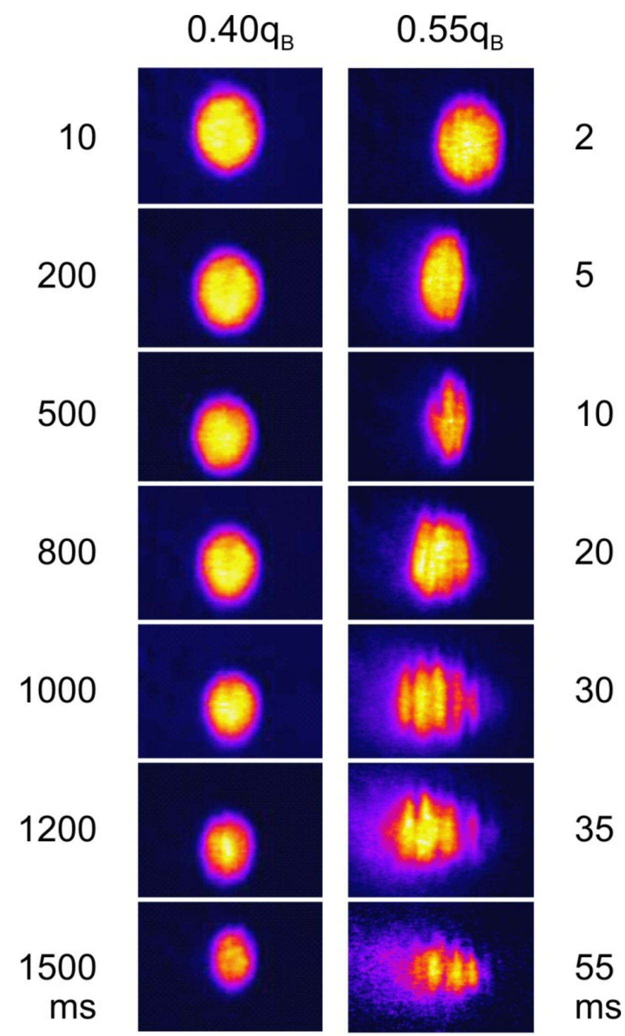
No disorder

Moderate dis

- long wavele
- breaking ph

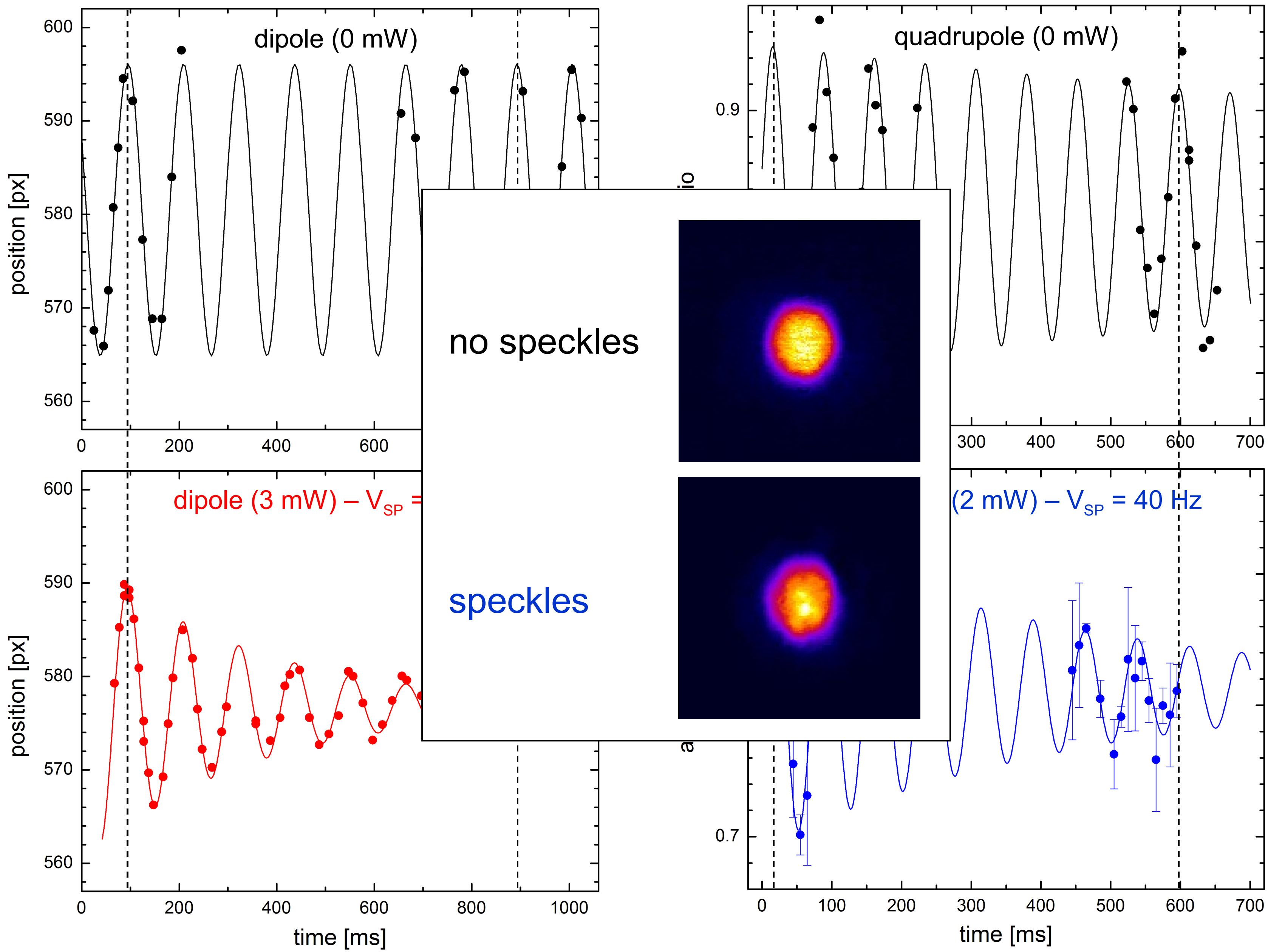
Strong disord

- broad unstr
- localization
- vanishing ir



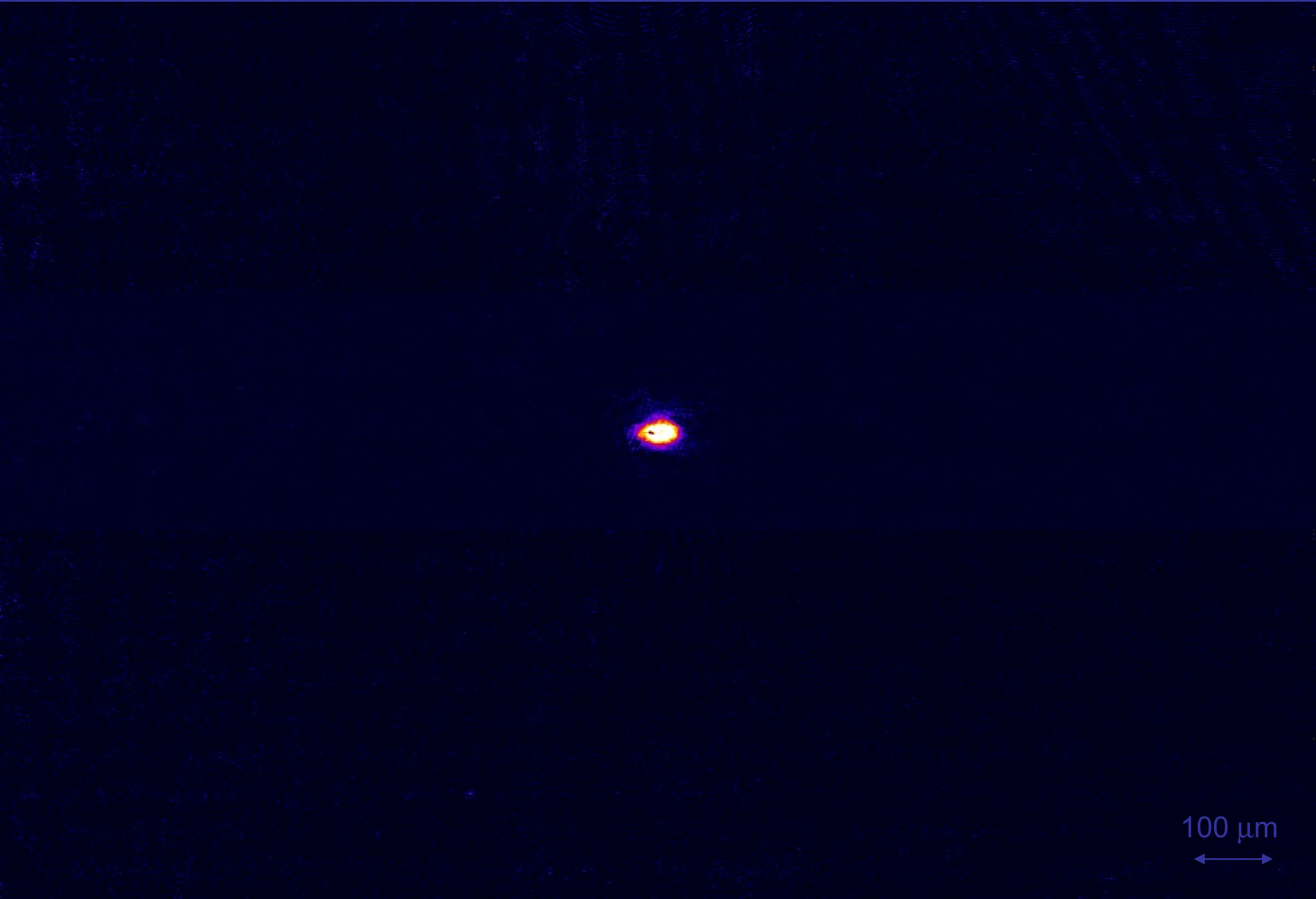
Dynamical instability of a BEC in a moving lattice
L. Fallani *et al.*, Phys. Rev. Lett. **93**, 140406 (2004)

Collective excitations in the weak speckle potential



BEC expansion in a disordered waveguide

*Fort et al. P R L **95**, 170410 (2005)*



Speckles are cool!

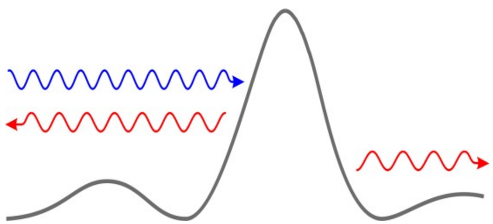
PRL 95, 070401 (2005) PHYSICAL REVIEW LETTERS week ending 12 AUGUST 2005

Bose-Einstein Condensate in a Random Potential

Problems for observing Anderson localization:

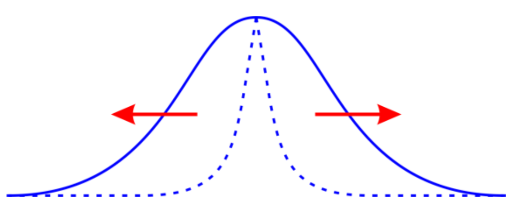
☹ *too large speckles!*

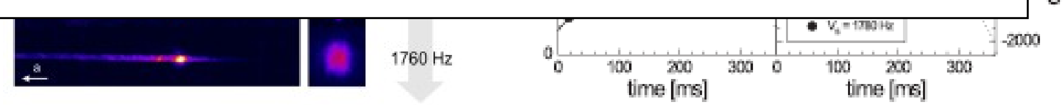
in order to observe multiple scattering in 1D it is necessary to have quantum scattering from the speckle potential barriers



☹ *too strong interactions!*

repulsive interactions plays against localization pushing to delocalize the state

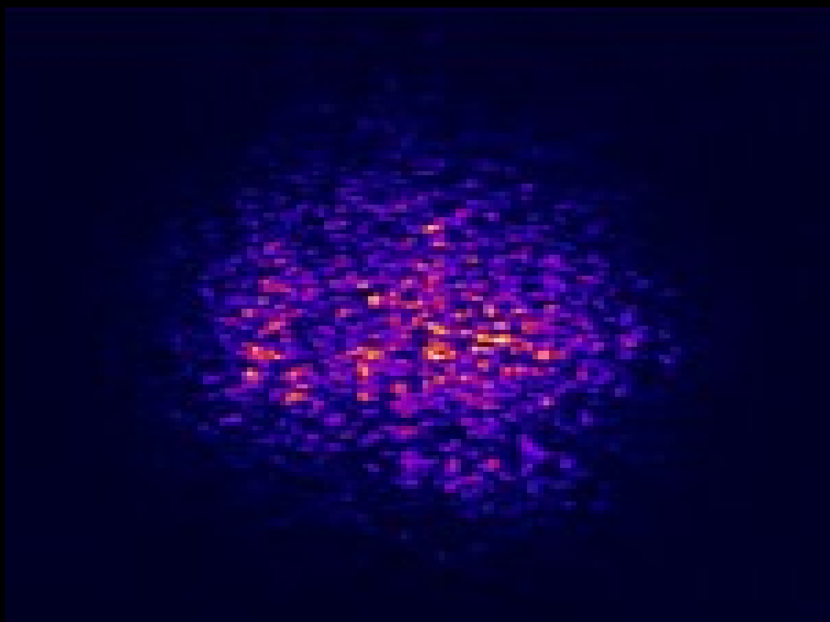




Adding disorder

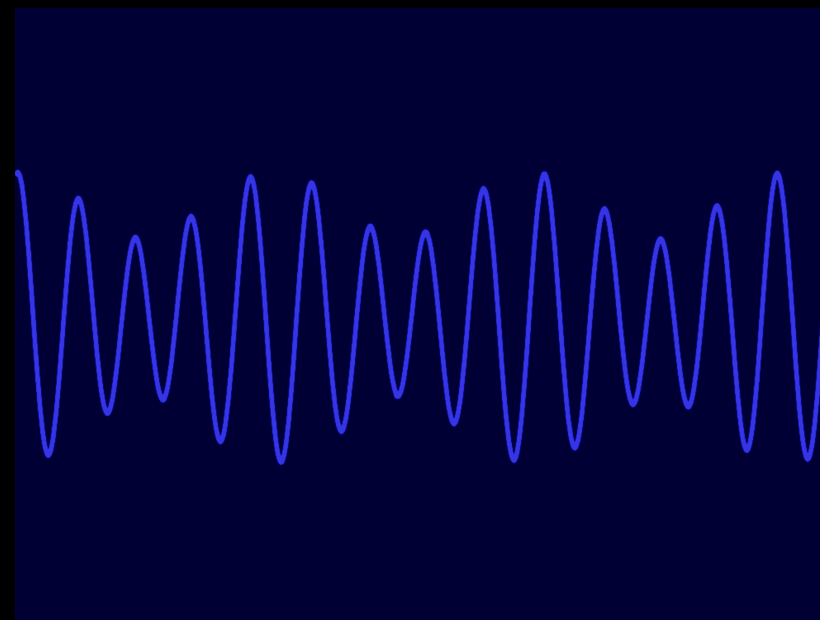
For ultracold atoms in optical lattices one can add optical disorder in two ways:

speckle patterns



random potential
(with small-wavelength cut-off)

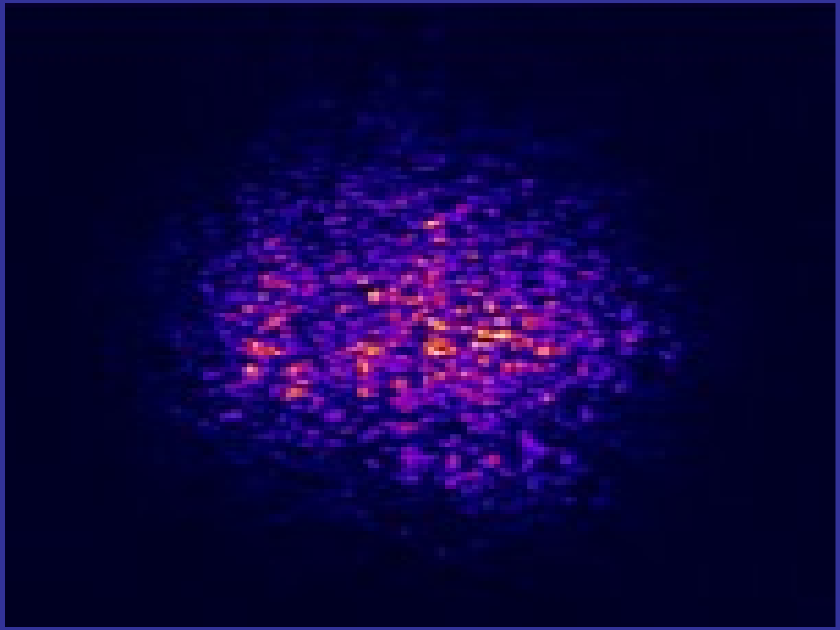
multichromatic lattices



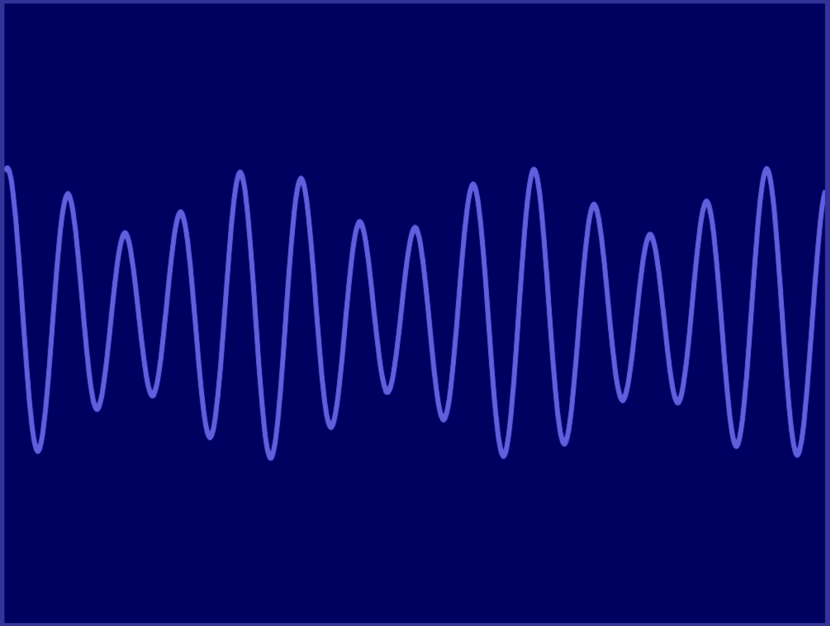
quasiperiodic potential
(discrete frequencies)

producing "dense" disorder

speckle pattern



bichromatic lattice

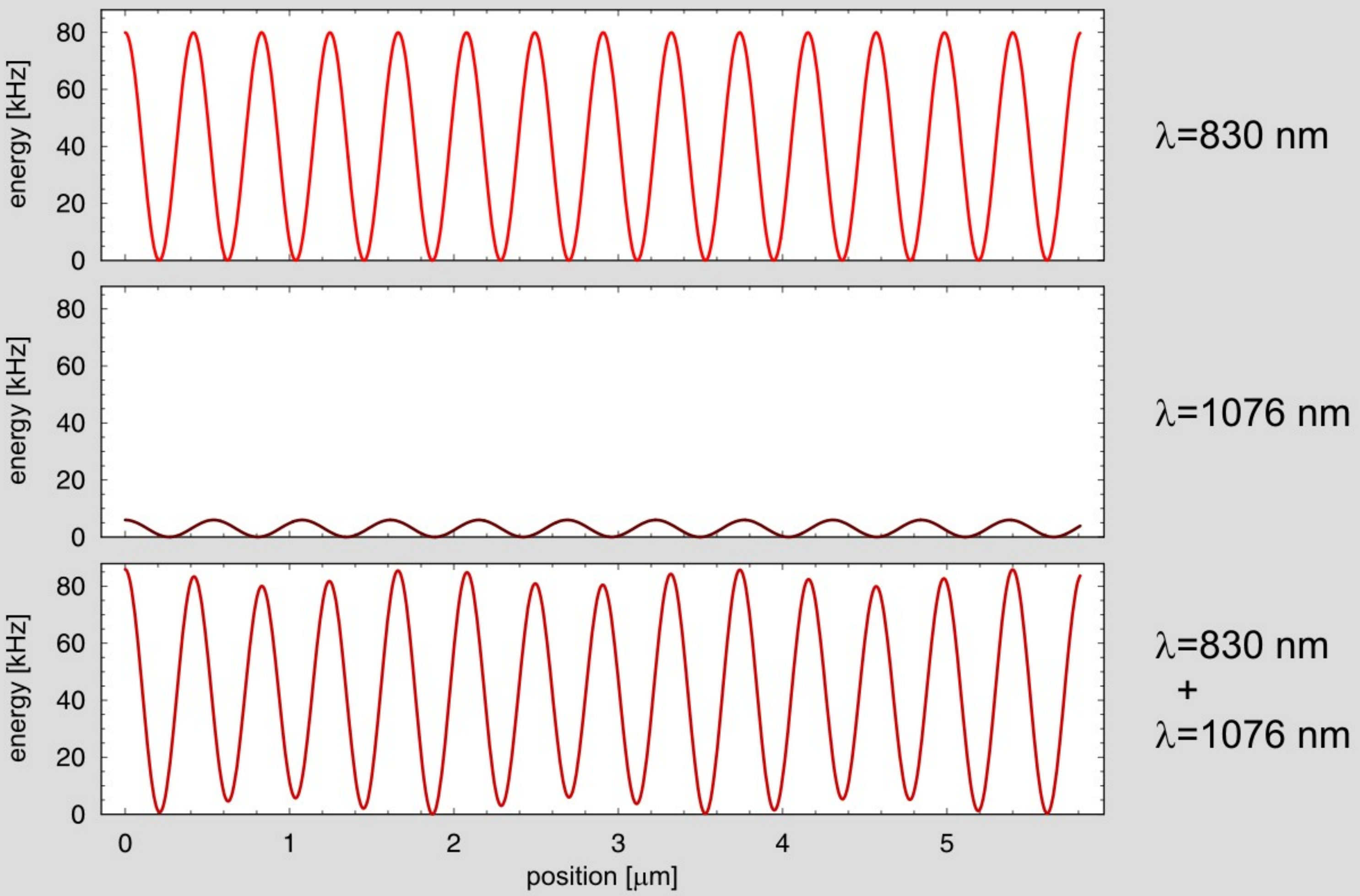


L.Fallani, C.Fort, M.Inguscio "Bose-Einstein condensates in disordered potentials"
arXiv 2888v2 *Advances Atomic, Molecular and Optical Physics (2008)*

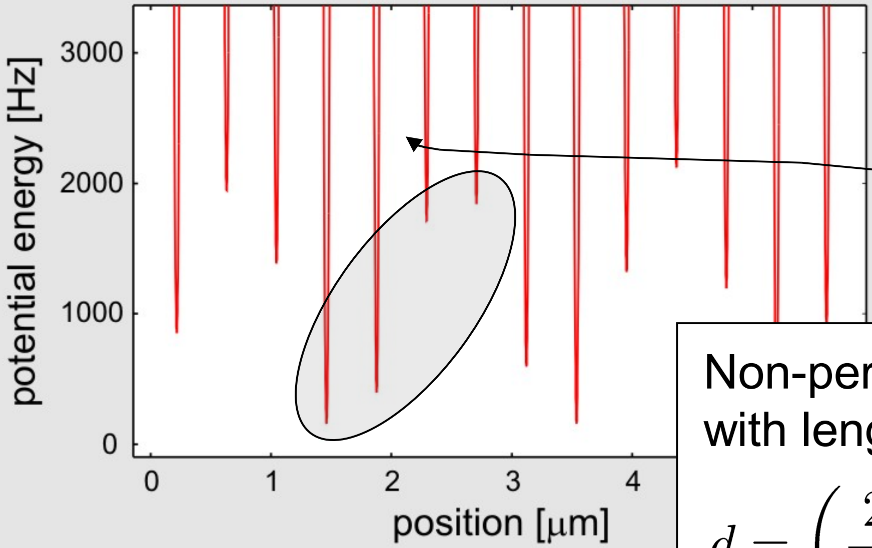
The bichromatic lattice

$$V(x) = s_1 E_{R1}\cos^2(k_1 x) + s_2 E_{R2}\cos^2(k_2 x)$$

bichromatic lattice



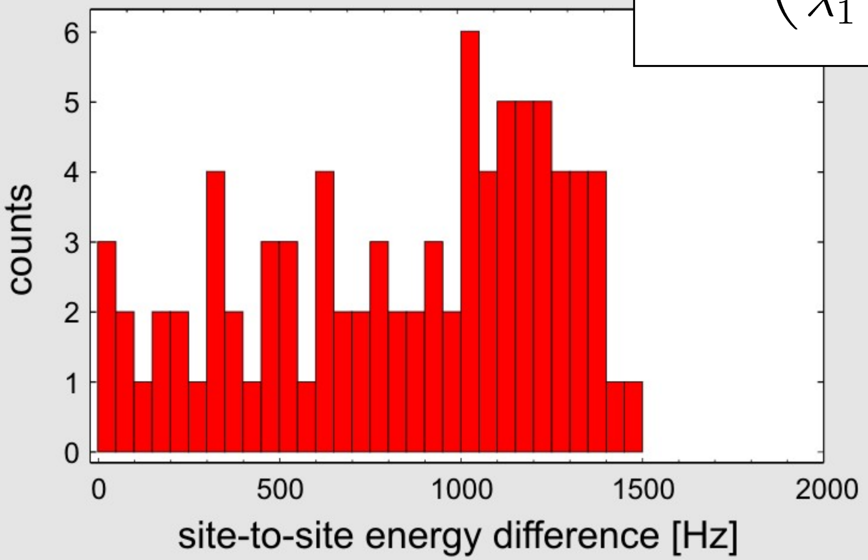
The bichromatic lattice



Energy minima of the lattice potential along *y* direction

Non-periodic modulation of the energy minima with length scale

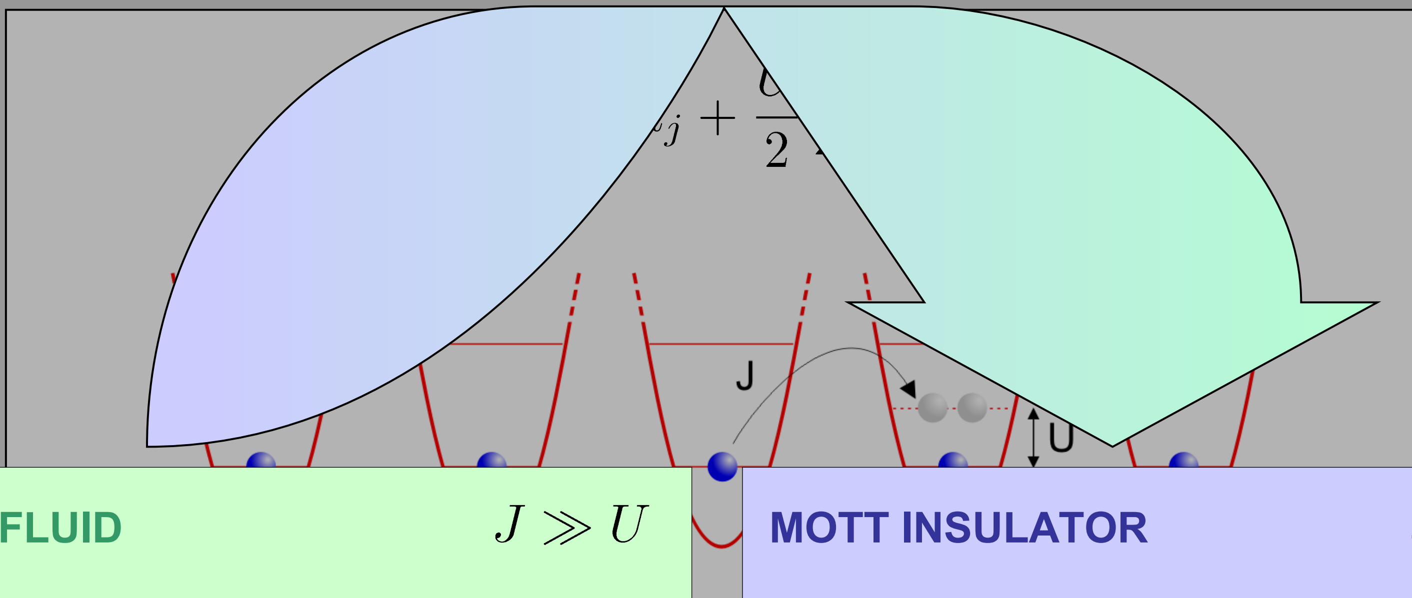
$$d = \left(\frac{2}{\lambda_1} - \frac{2}{\lambda_2}\right)^{-1} = 1.8\ \mu\mathrm{m} = 4.3 \text{ sites}$$



Strongly interacting bosons

Interacting bosons in a lattice

Bose-Hubbard model for interacting bosons in a lattice:



SUPERFLUID $J \gg U$

- ✓ Long-range phase coherence
- ✓ High number fluctuation
- ✓ Gapless excitation spectrum
- ✓ Compressible

MOTT INSULATOR $J \ll U$

- ✓ No phase coherence
- ✓ Zero number fluctuation (Fock states)
- ✓ Gap in the excitation spectrum
- ✓ Not compressible

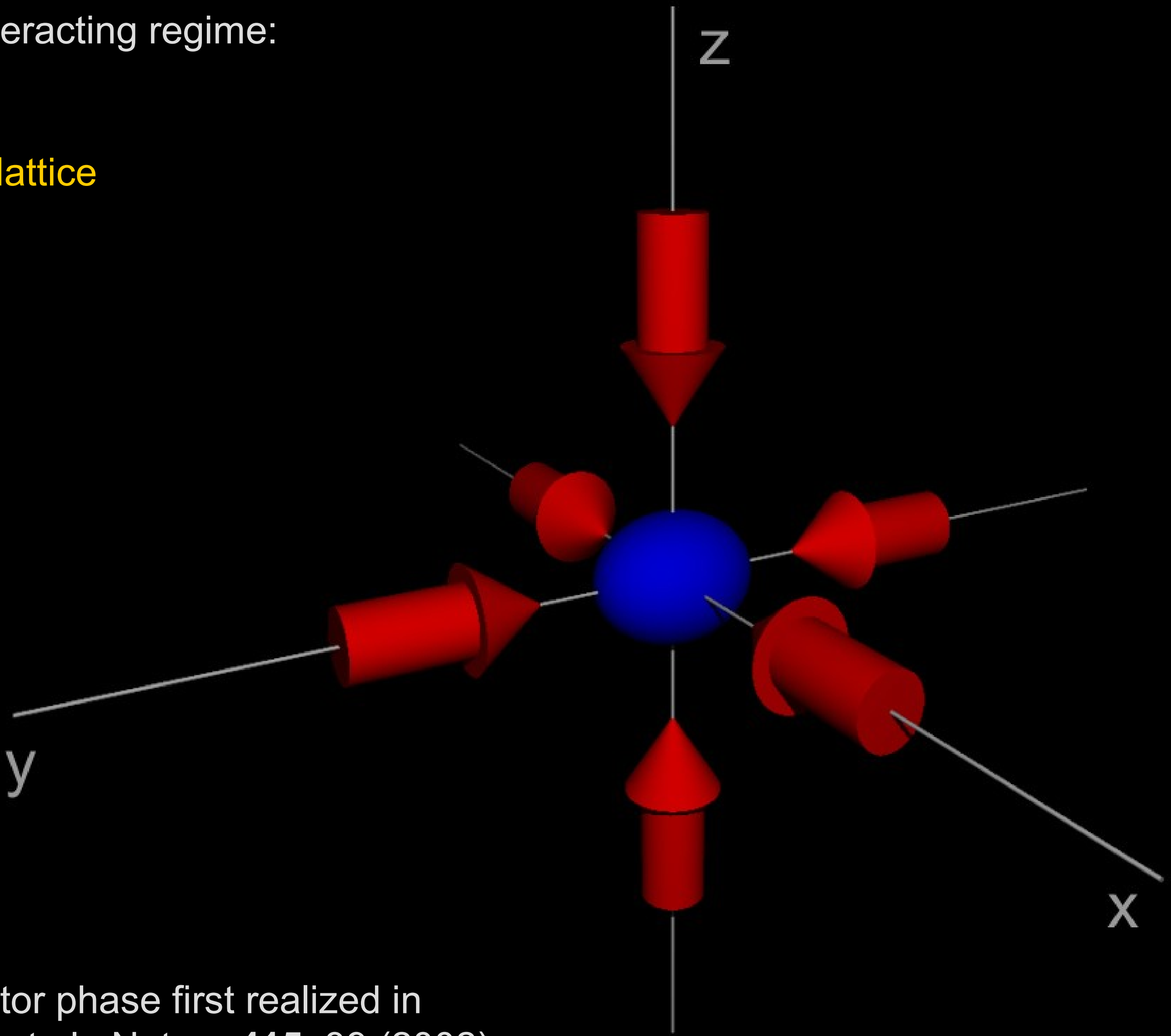
hopping energy	interaction energy
J	**U**

Experimental scheme

strongly interacting regime:

↓

3D optical lattice



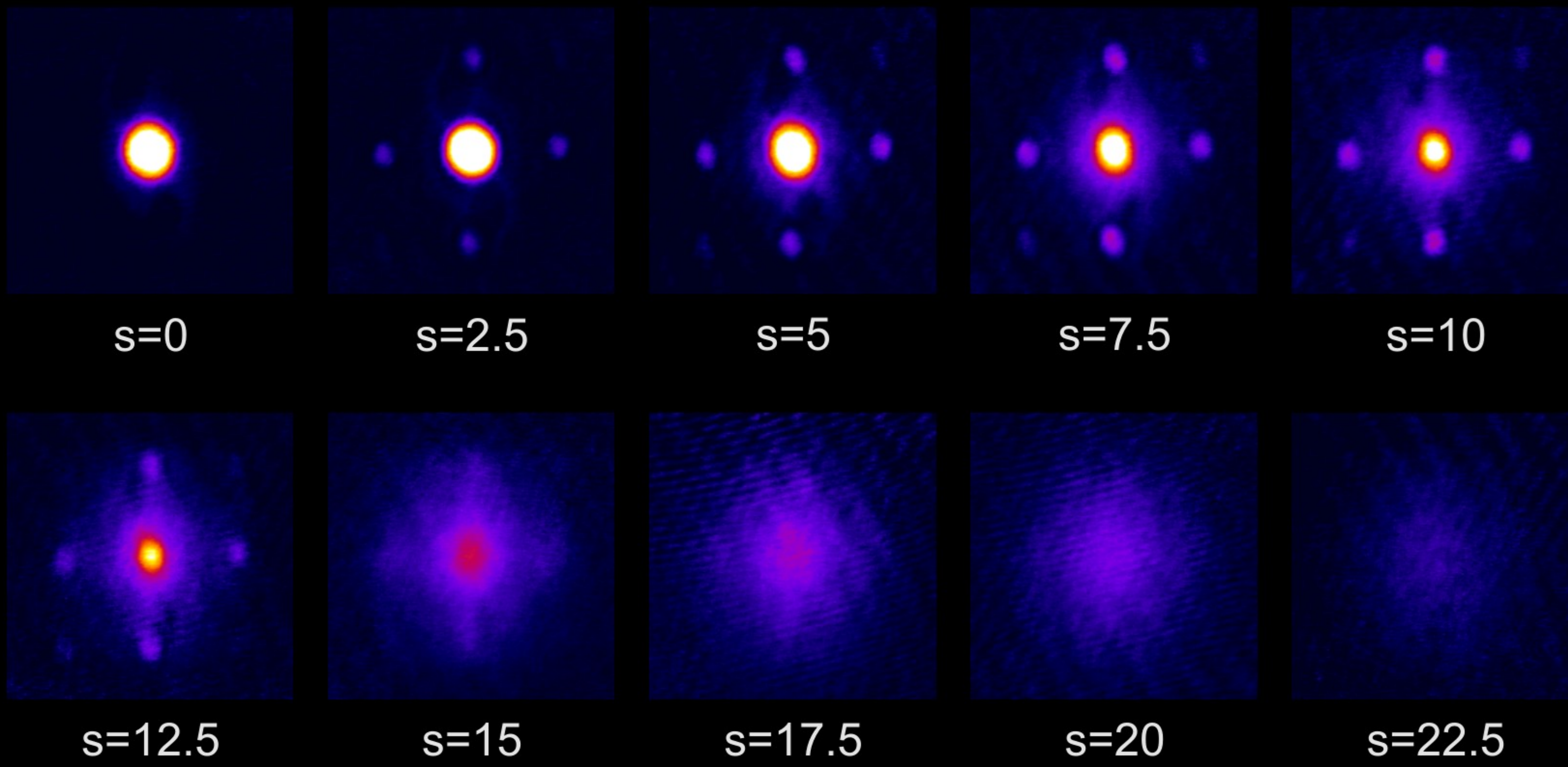
Mott insulator phase first realized in
M. Greiner et al., Nature **415**, 39 (2002).

Superfluid to Mott Insulator transition at LENS

Fallani, Fort, Guarrera, Lye, M.I. (2005)

momentum distribution of the atomic sample after expansion

test of phase coherence



increasing the lattice height ⟶ *U/J* increases

Richard P. Feynman Int.J.Theor. Phys 21, 467 (1982)

… Can physics be simulated by a universal computer?

R.P.F. realized that certain phenomena in Quantum Field Theory are well imitated

By certain Condensed Matter systems … he thought that there should be a certain

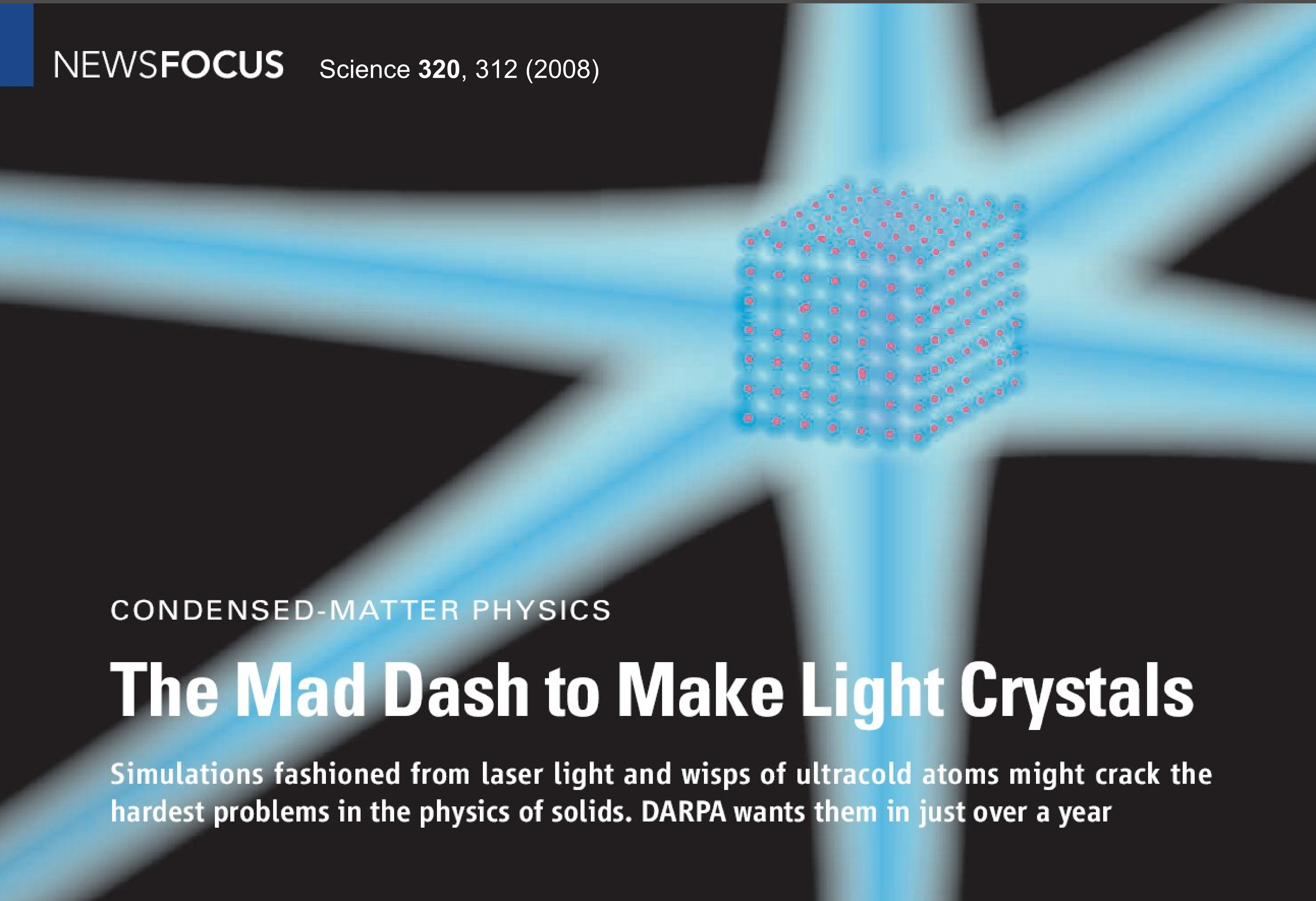
Class of quantum mechanical systems which would symulate any other system, a

UNIVERSAL QUANTUM SIMULATOR:

Could serve as a quantum laboratory where the validity of several theoretical models may be tested.

Quantum simulators

NEWSFOCUS Science **320**, 312 (2008)



CONDENSED-MATTER PHYSICS

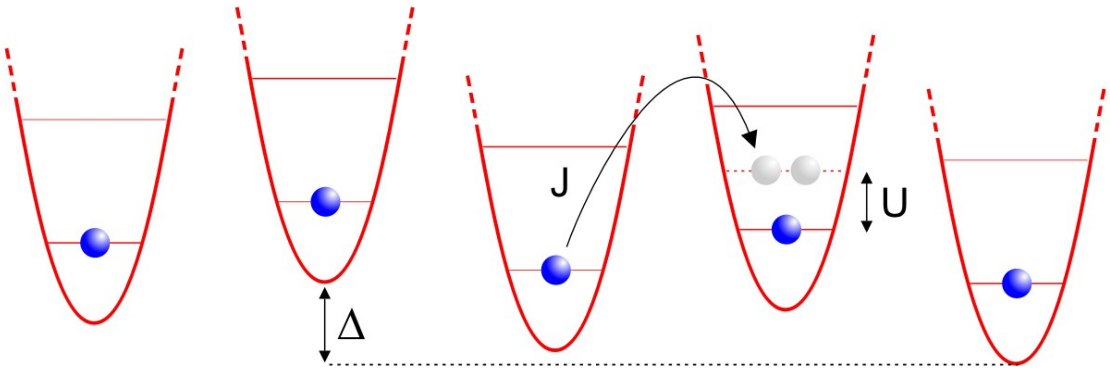
The Mad Dash to Make Light Crystals

Simulations fashioned from laser light and wisps of ultracold atoms might crack the hardest problems in the physics of solids. DARPA wants them in just over a year

Adding disorder

Bose-Hubbard model with bounded disorder in the external potential $\epsilon_j \in [-\Delta/2, \Delta/2]$

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



In the presence of disorder an additional energy scale Δ enters the description of the system. The interplay between these energy terms may induce new quantum phase transitions

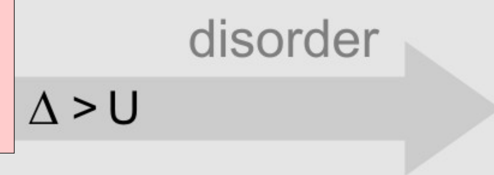
hopping energy	interaction energy	disorder
J	**U**	**Δ**

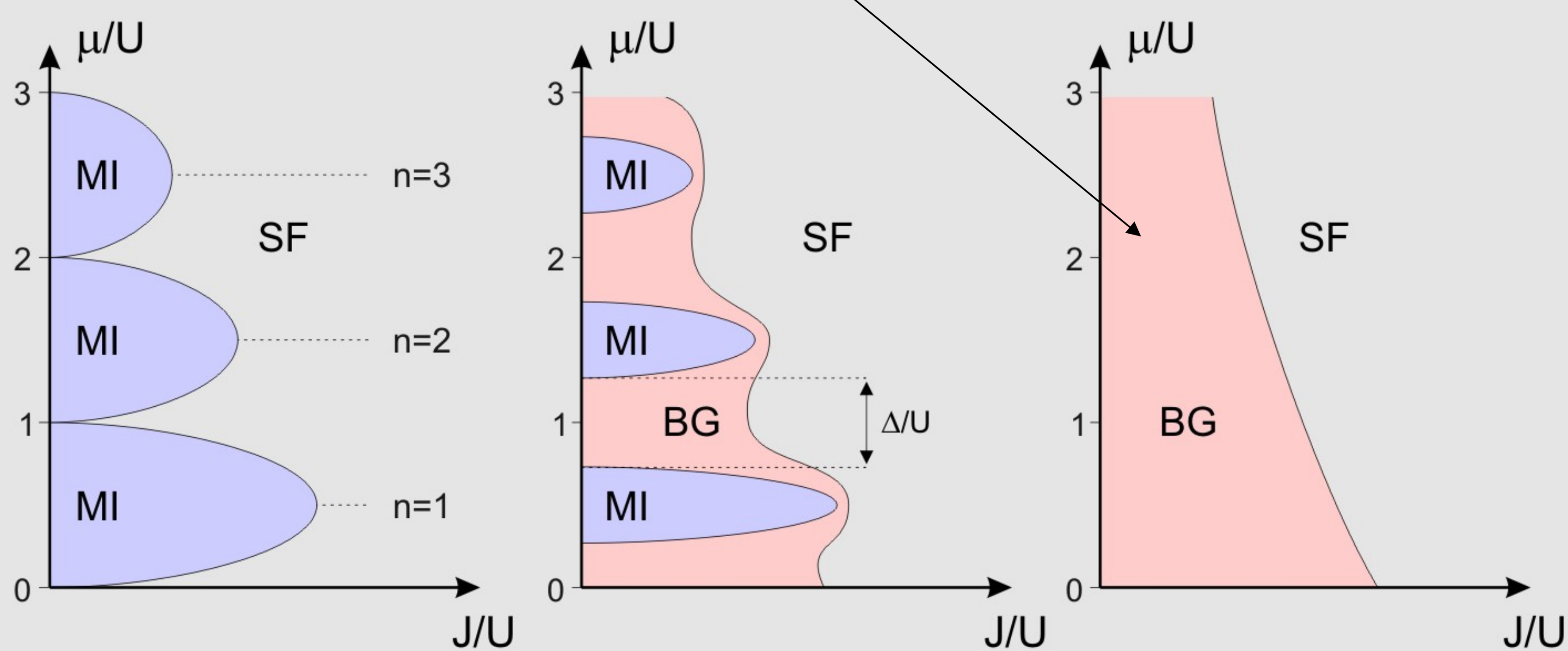
Phase diagrams

ns in a disordered lattice

BOSE-GLASS (T. Giamarchi and H. J. Schulz, PRB **37**, 325 (1988))

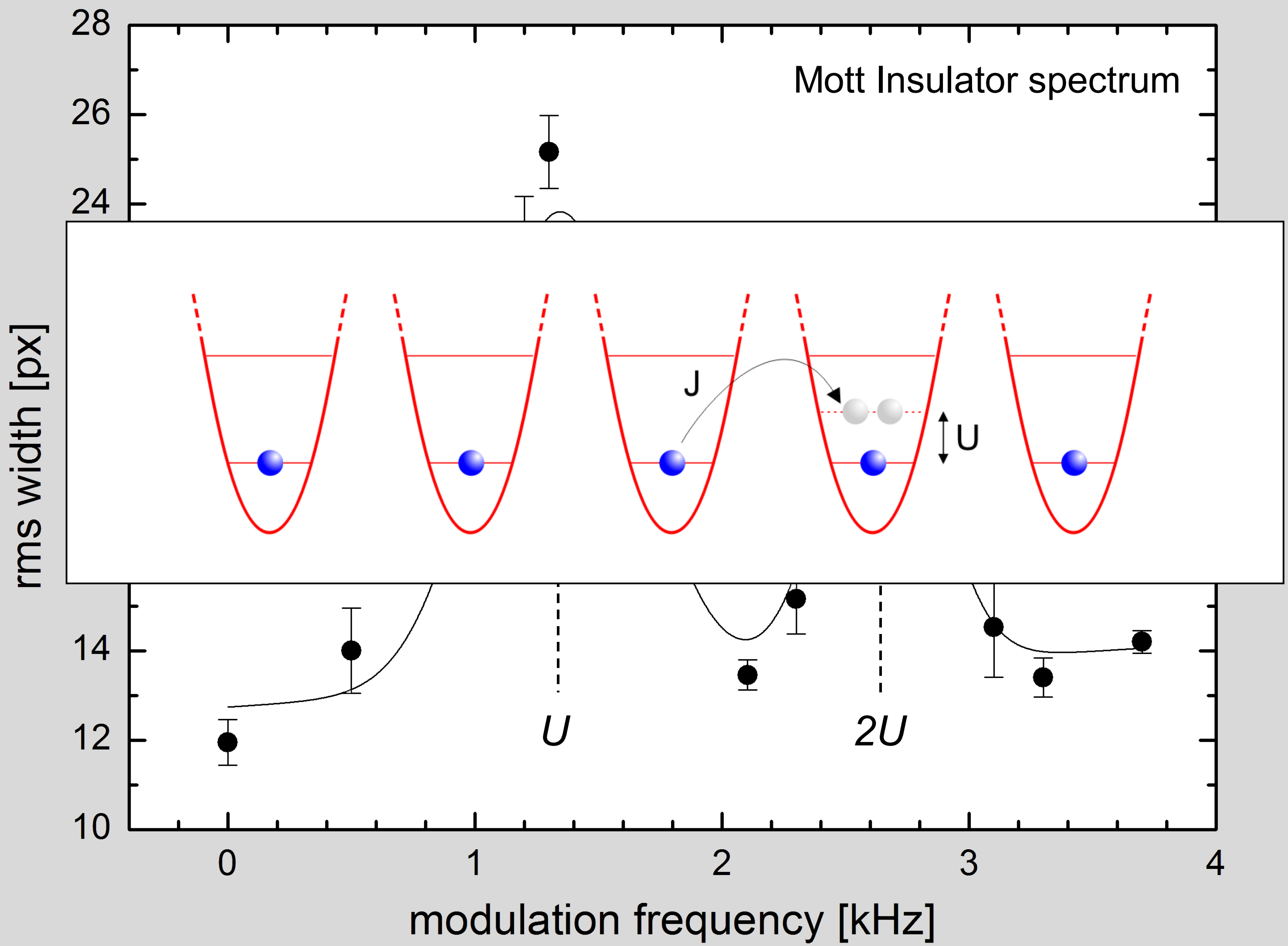
- ✓ No long-range phase coherence
- ✓ **Gapless excitation spectrum**
- ✓ **Finite compressibility**





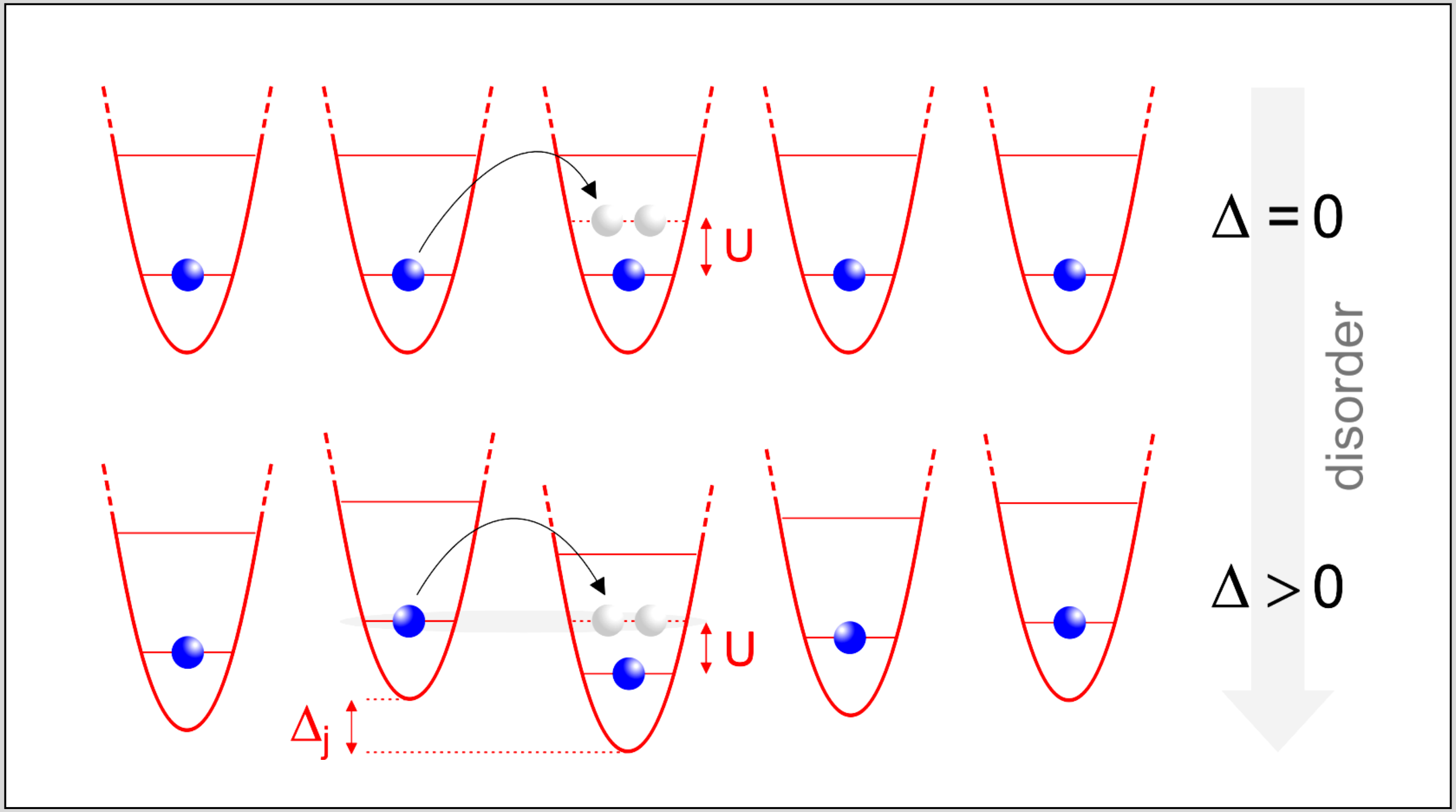
for ultracold atoms see B. Damski et al., PRL **91**, 080403 (2003); R. Roth et al., PRA **68**, 023604 (2003).

Measuring the excitation spectrum



Broadening the MI spectrum

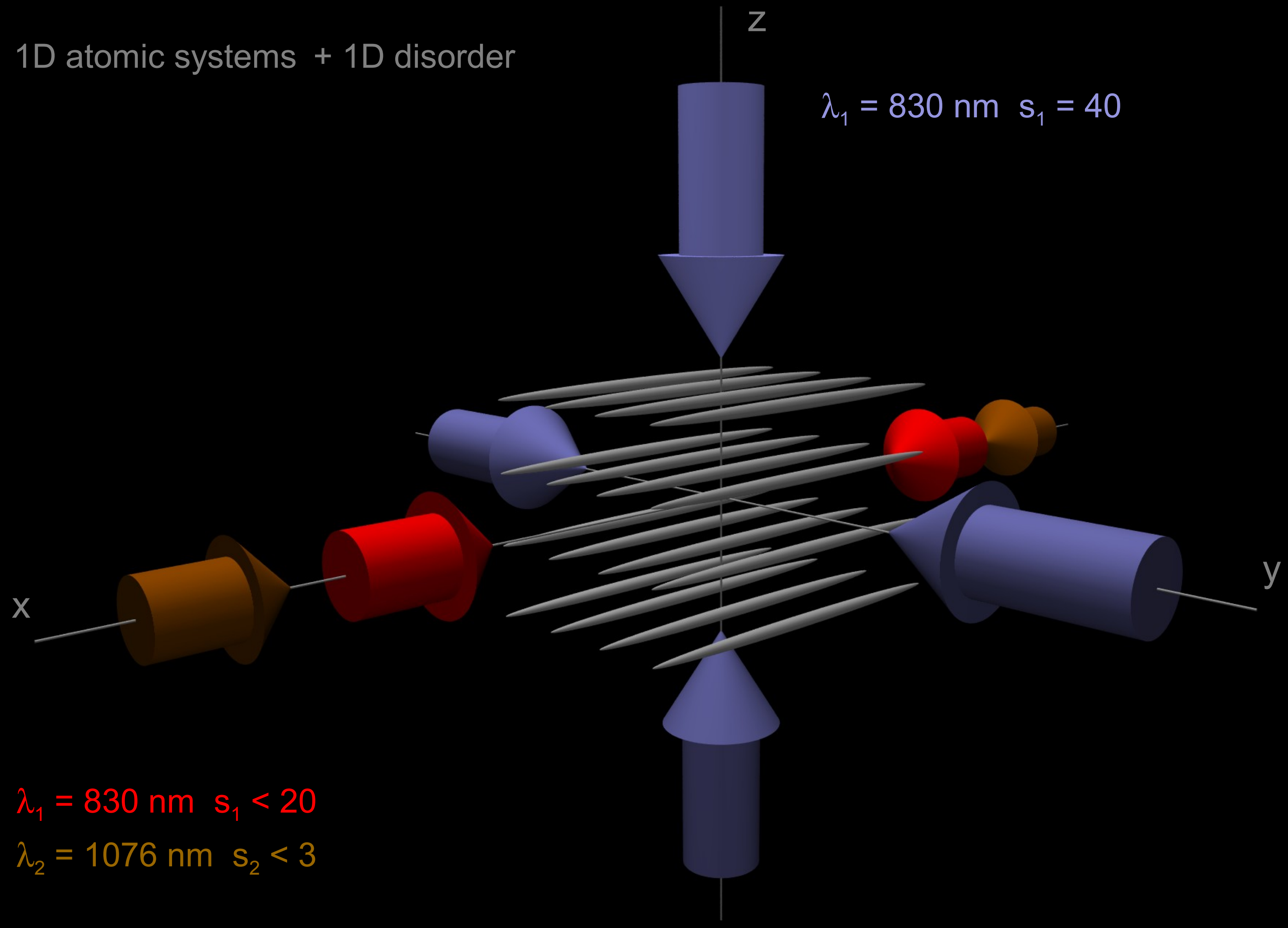
Starting from a Mott Insulator and adding disorder, the energy required for the hopping of a boson from a site to a neighboring one becomes a function of position



When Δ_j = U the excitation energy goes to zero and the gap disappears

Experimental geometry

1D atomic systems + 1D disorder



λ_1 = 830 nm s_1 = 40

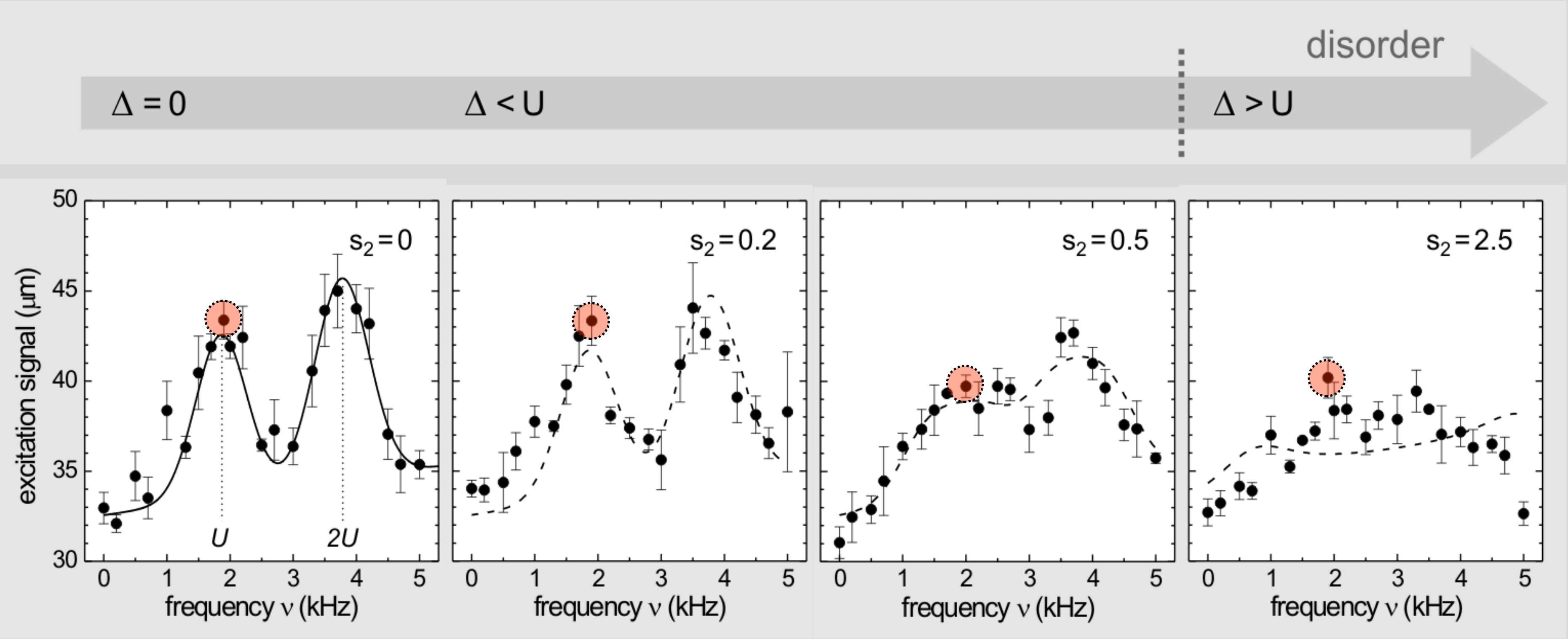
λ_1 = 830 nm s_1 < 20

λ_2 = 1076 nm s_2 < 3

Excitation spectra

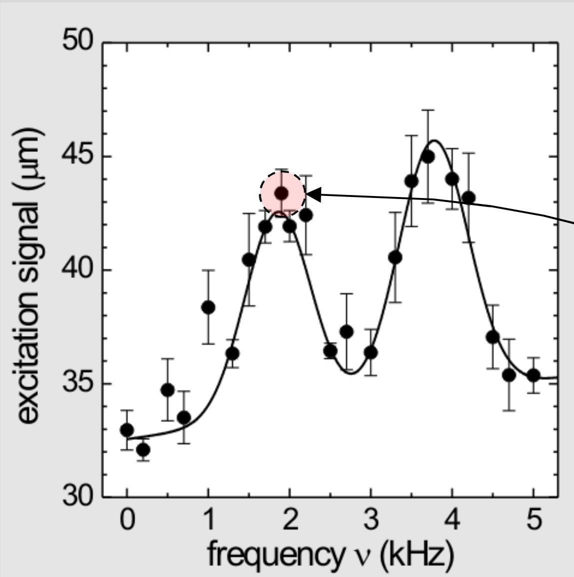
*L. Fallani et al., PRL **98**, 130404 (2007)*

Excitation spectrum for s_1=16 and increasing disorder strength from s_2=0 to s_2=2.5:

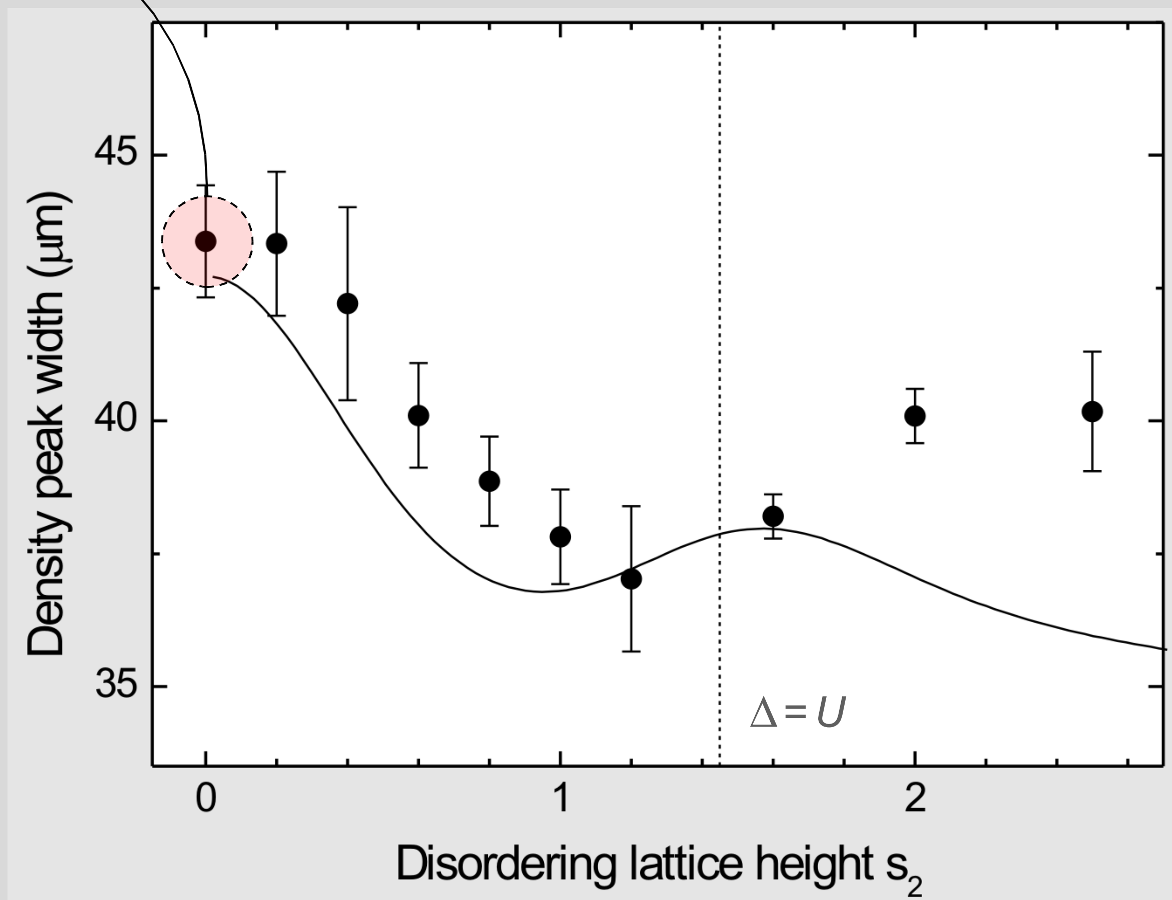


MI spectral brodening

*L. Fallani et al., PRL **98**, 130404 (2007)*



Excitation maximum at *U*
as a function of disorder strength:



Good agreement with the MI broadening for weak disorder Δ<U

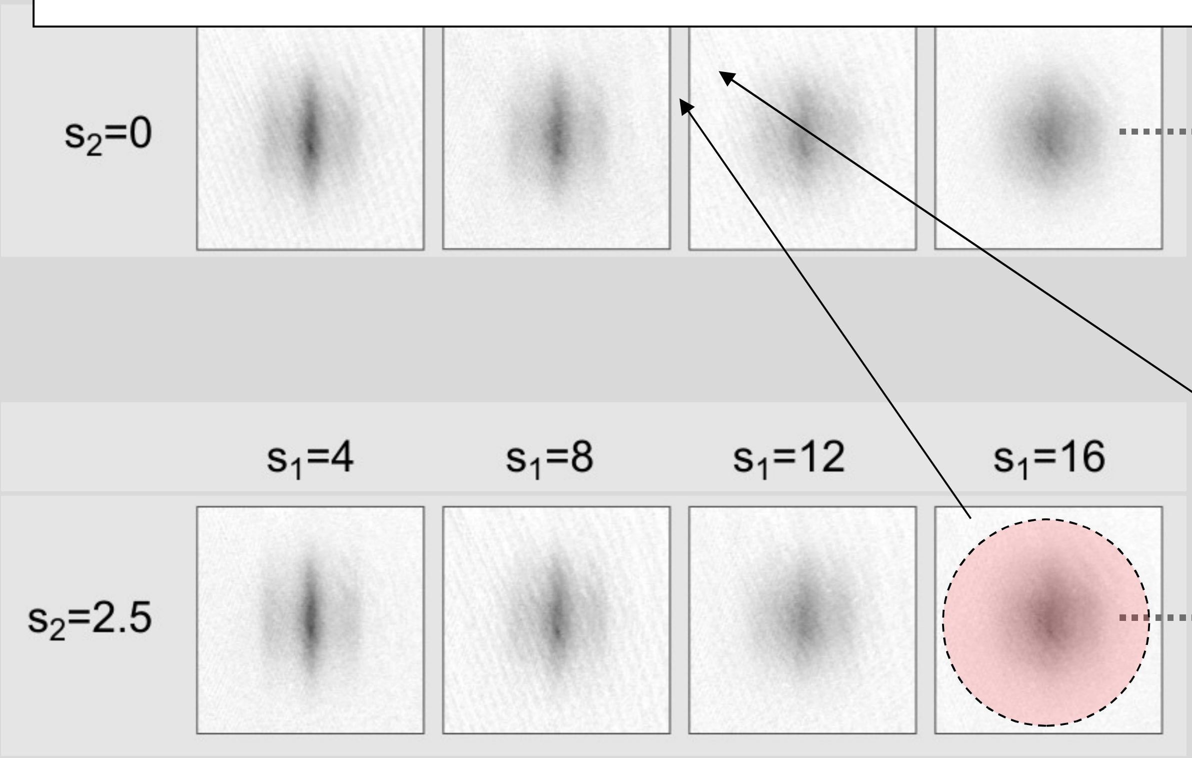
No agreement for strong disorder Δ>U when the gap goes to zero

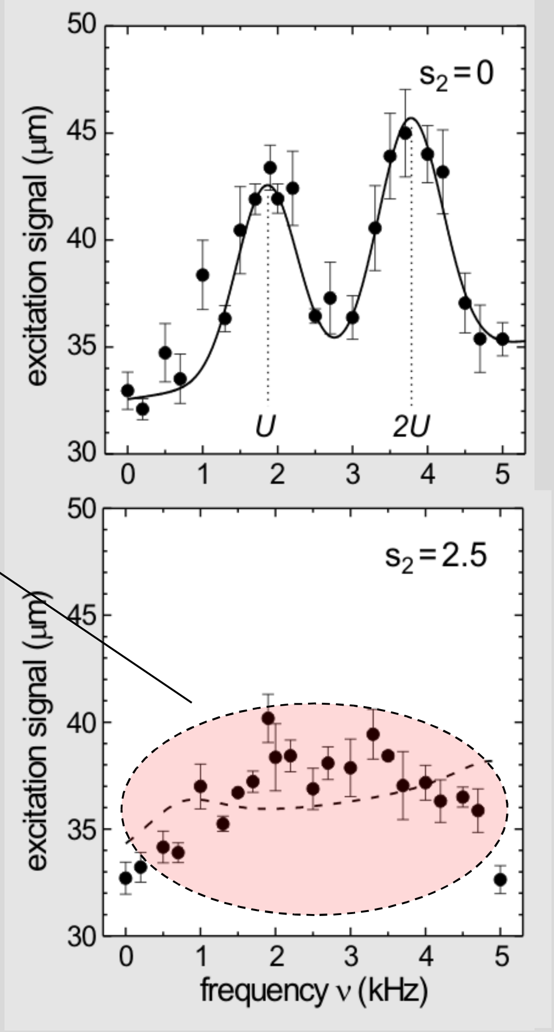
Phase coherence

L. Fallani et al., PRL **98**, 130404 (2007)

Insulating state (no long-range phase coherence) with broad excitation spectrum

Bose-Glass





Noise interferometry

Quantum interpretation of HB&T effect

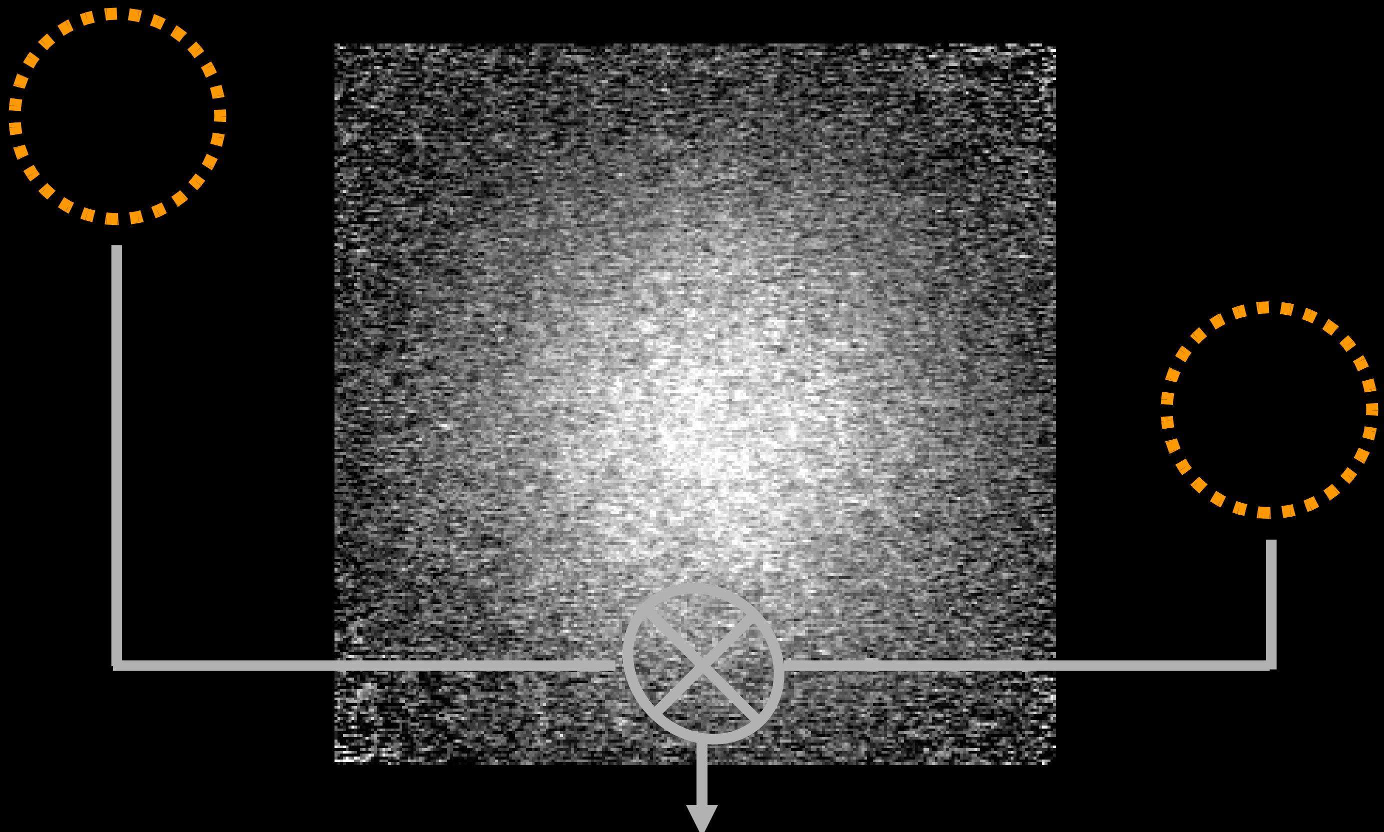
correlations between joint probability at detector positions

interference between quantum-mechanical paths of identical particles

Fano-Glauber

HB&T noise interferometry in quantum gases

absorption image of a Mott Insulator state



in a single image we have approx. 30000 detectors!

noise correlations

noise correlations

PHYSICAL REVIEW A **70**, 013603 (2004)

Probing many-body states of ultracold atoms via noise correlations

Ehud Altman, Eugene Demler, and Mikhail D. Lukin
Physics Department, Harvard University, Cambridge, Massachusetts 02138, USA
(Received 10 June 2003; published 6 July 2004)

$$\mathcal{G}_{\alpha,\beta}(\mathbf{r},\mathbf{r}') \sim \frac{1}{W^{2d}} \sum_{ii'jj'} e^{i\mathbf{R}_{ii'}\cdot\mathbf{Q}(\mathbf{r})+i\mathbf{R}_{jj'}\cdot\mathbf{Q}(\mathbf{r}')} \langle a^{\dagger}_{i\alpha} a^{\dagger}_{j\beta} a_{j'\beta} a_{i'\alpha} \rangle + \delta_{\alpha\beta}\delta(\mathbf{r}-\mathbf{r}')\langle n_{\alpha}(\mathbf{r})\rangle_t - \langle n_{\alpha}(\mathbf{r})\rangle\langle n_{\beta}(\mathbf{r}')\rangle.$$

Experiments: Mainz (Nature 2005)

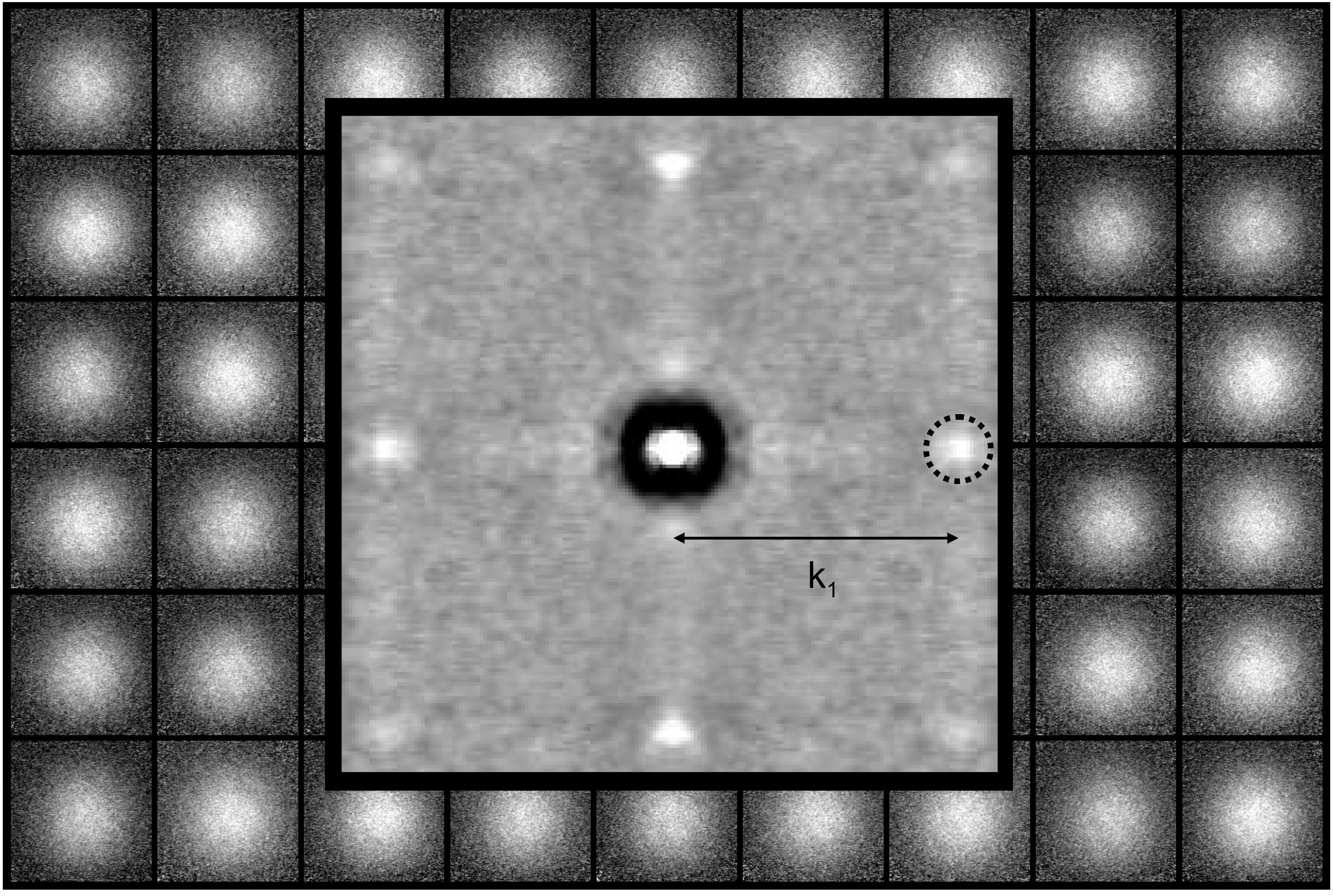
JILA (PRL 2005) – pairs from molecules

NIST- Maryland (PRL 2007)

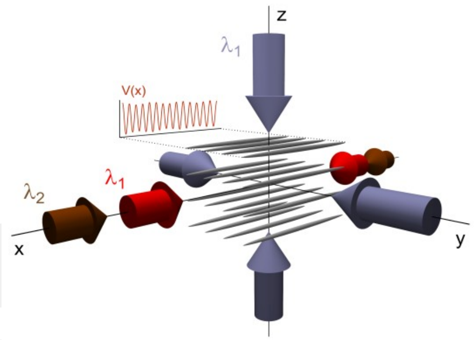
LENS (2007) – **Breaking of Mott order**

Noise correlations (Mott phase)

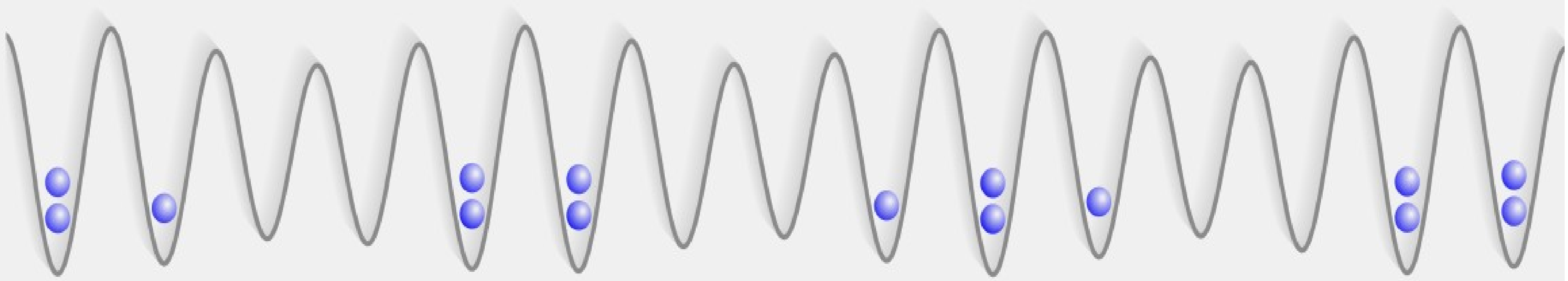
V. Guarrera, N. Fabbri, L. Fallani,
C. Fort, K.M.R. van der Stam, M. I. Phys Rev Lett(2008)



Breaking the MI order

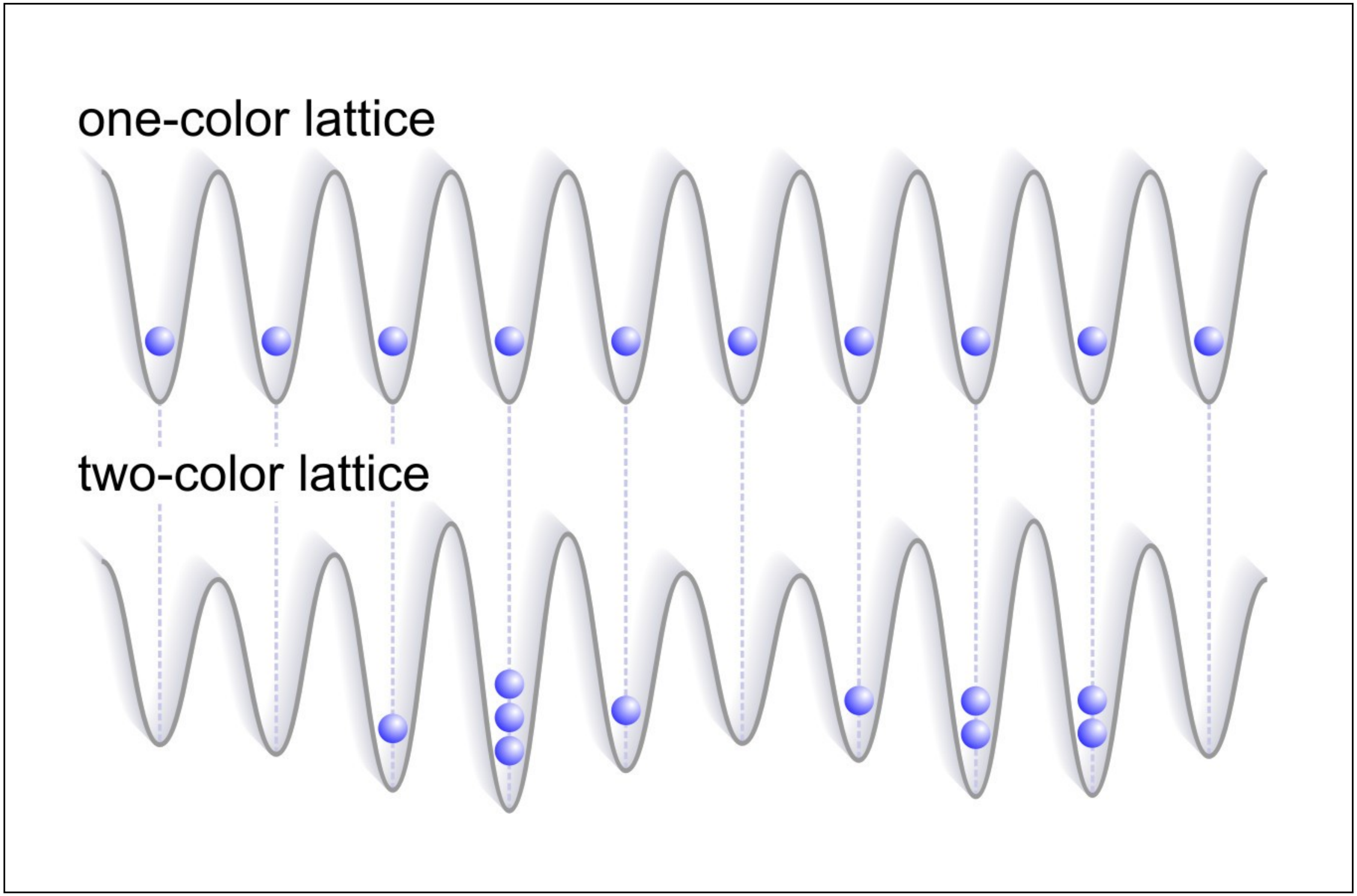


2 optical lattices

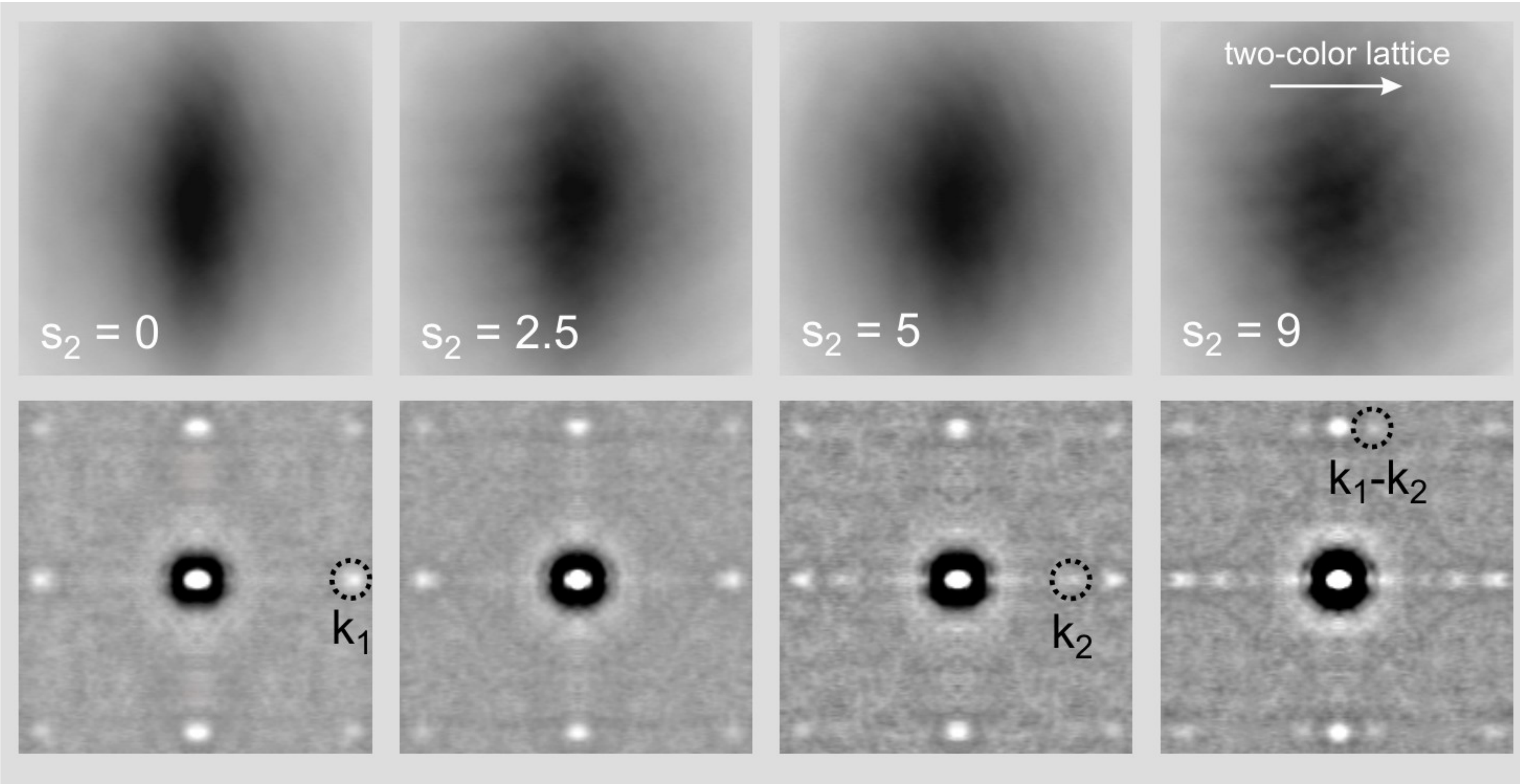


inhomogeneous filling of (almost) regularly-spaced lattice

Breaking the MI order



1st and 2nd order correlations



noise correlations reveal the inhomogeneous filling of the lattice
when first-order coherence does not provide any spatial information

Calculating noise correlations

PHYSICAL REVIEW A **70**, 013603 (2004)

Probing many-body states of ultracold atoms via noise correlations

Ehud Altman, Eugene Demler, and Mikhail D. Lukin
Physics Department, Harvard University, Cambridge, Massachusetts 02138, USA
(Received 10 June 2003; published 6 July 2004)

$$\mathcal{G}_{\alpha,\beta}(\mathbf{r},\mathbf{r}') \sim \frac{1}{W}$$

$+$

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

calculation of the ground state for J=0

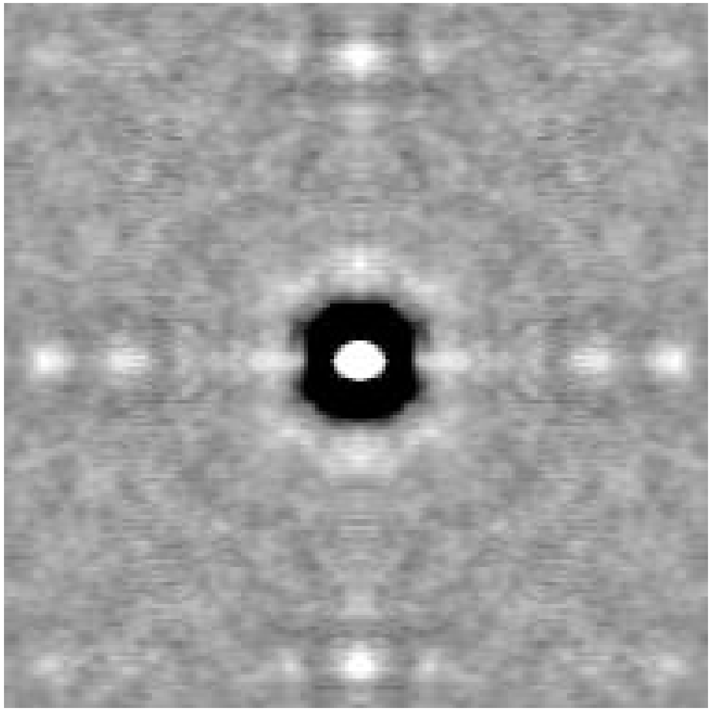
$\downarrow$

the ground state is a disordered Mott insulator with the site filling minimizing the total energy

$$|\Psi\rangle = |n_1\rangle \otimes |n_2\rangle \otimes |n_3\rangle \otimes \dots$$

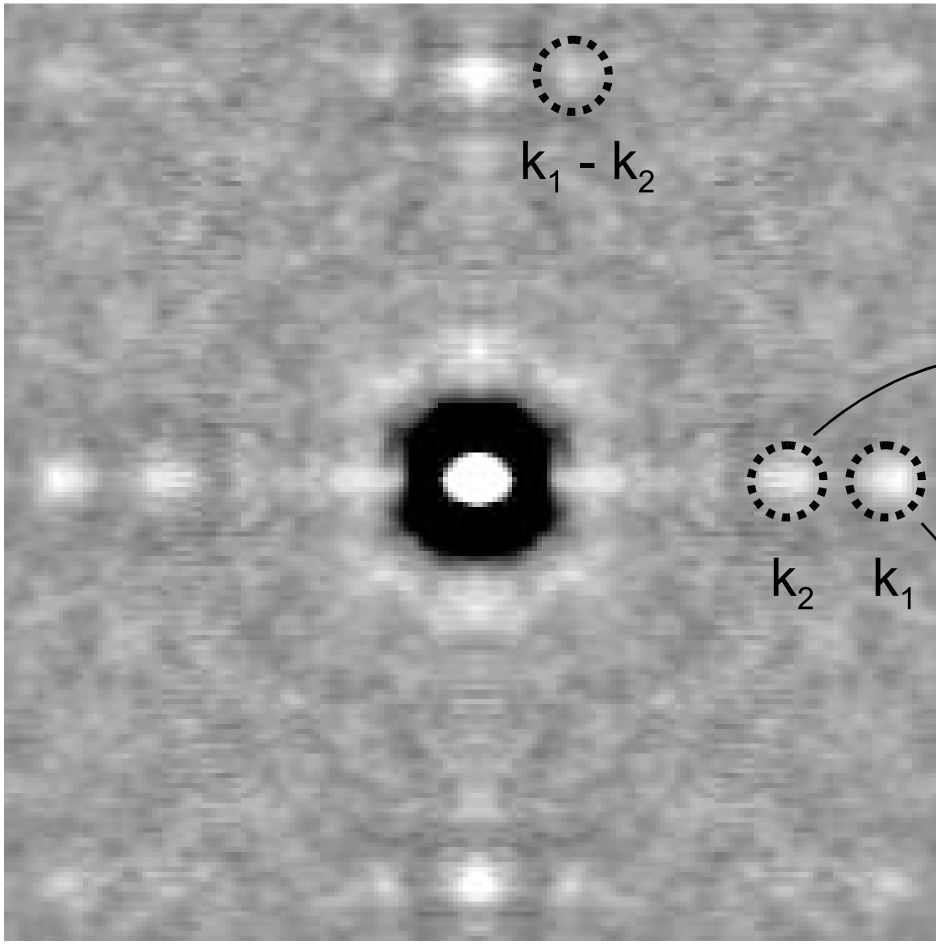
V. Guarrera, N. Fabbri, L. Fallani,
C. Fort, K.M.R. van der Stam, M. I. Phys Rev Lett (2008)

experiment



theory (disordered MI)

Noise correlations in the bichromatic lattice

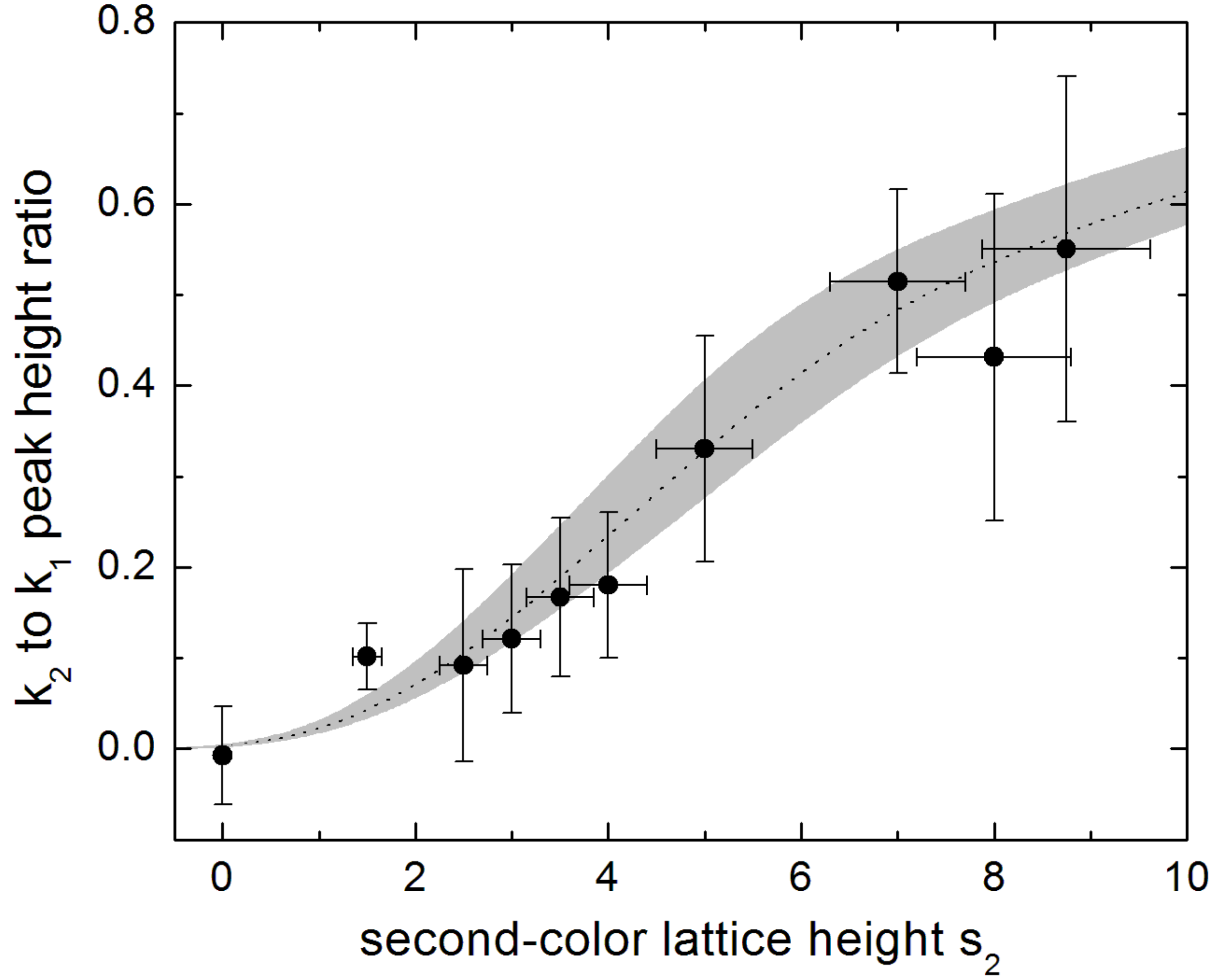


Observable:

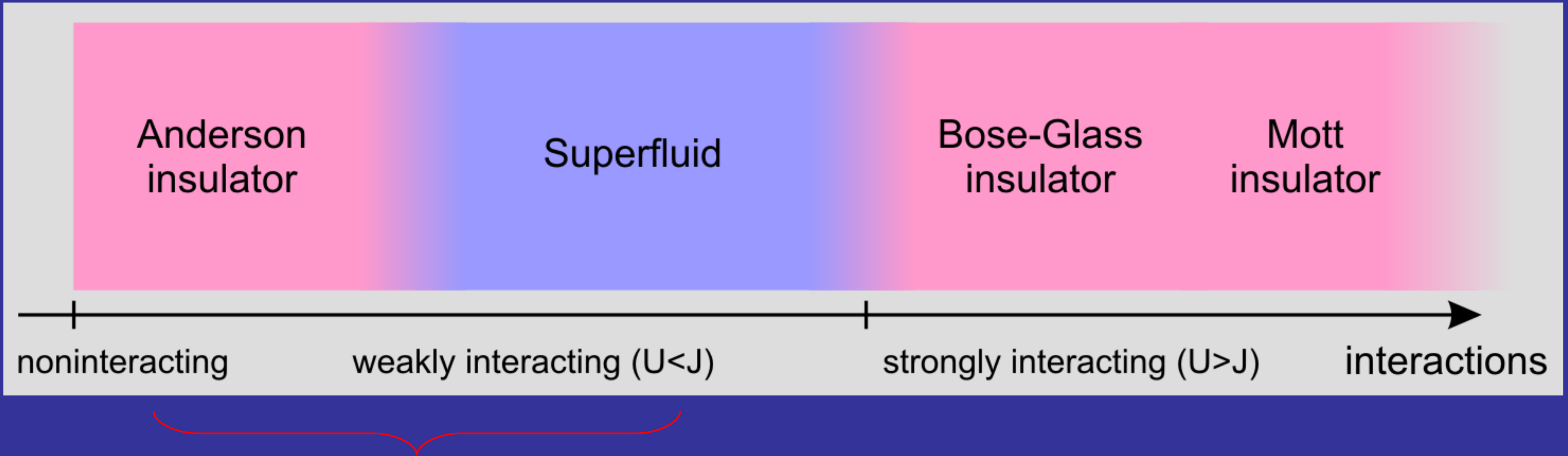
the ratio between the heights of the k_2 peak and the k_1 peak along the horizontal median line

$$\frac{P(k_2)}{P(k_1)}$$

Quantitative analysis of the k_2 peak growth



Disordered systems: Role of interactions

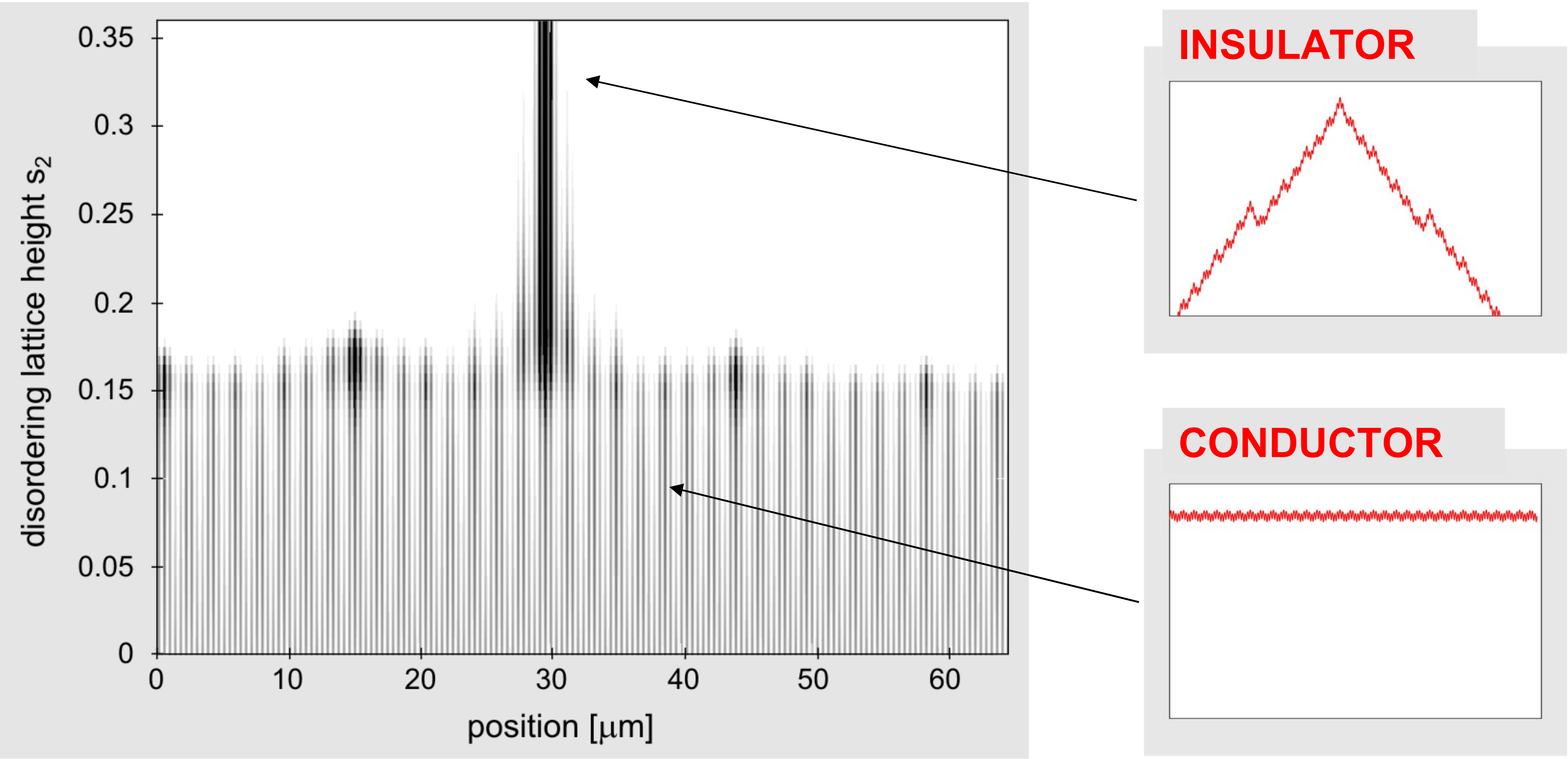


Effects of interaction in the Anderson localization

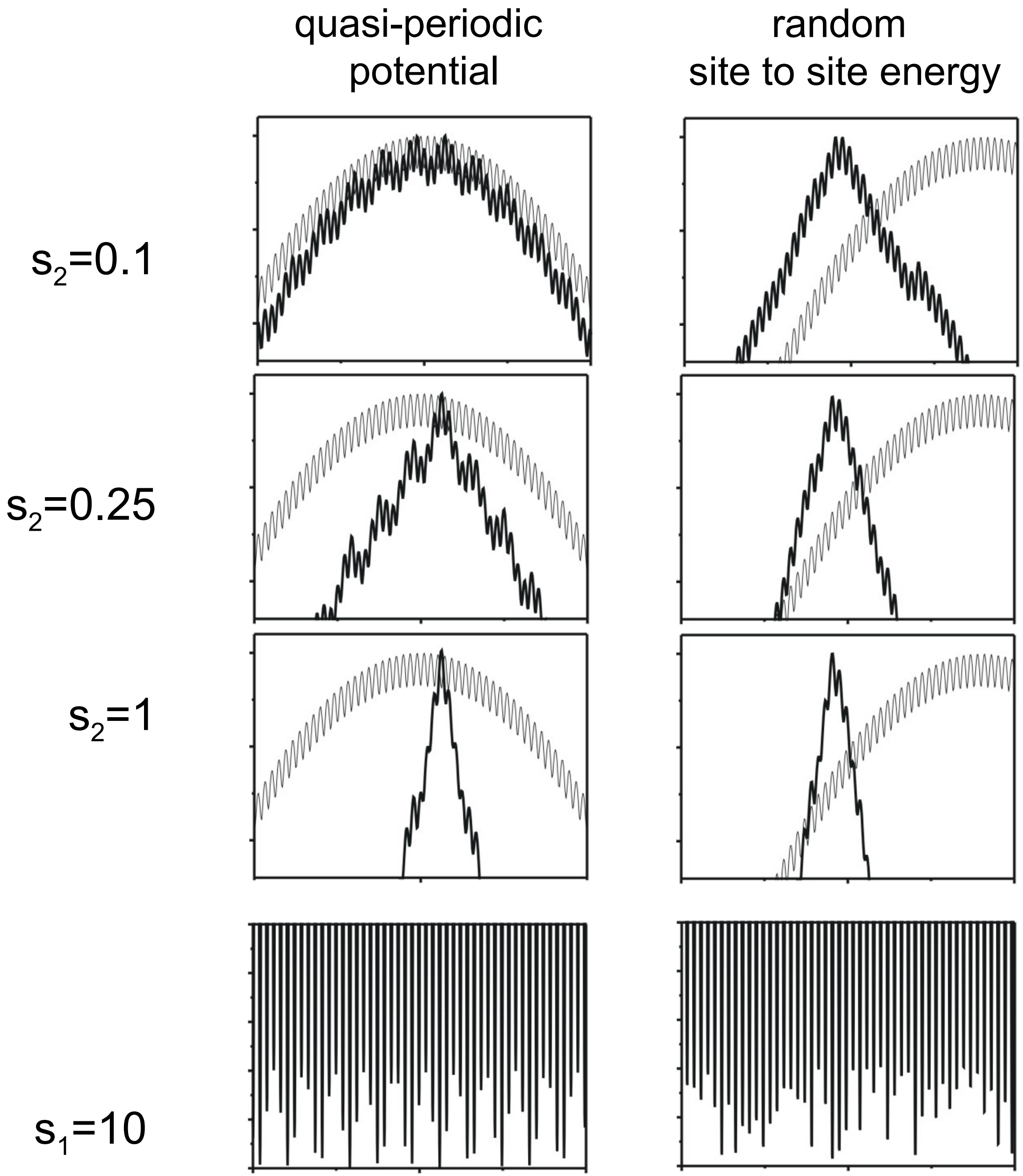
Localization transition in a 1D quasiperiodic potential

Incommensurate bichromatic lattices can be used to study quantum localization!

Localization transition in 1D: see *S. Aubry and G. André, Ann. Israel Phys. Soc.* ***3****, 133 (1980).*



Localization in a quasi-periodic lattice + harmonic trap

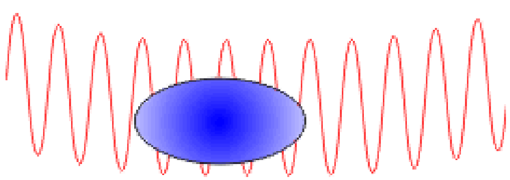


Oscillations in the bichromatic potential

J. Lye et al., PRA 75, 061603R (2007)

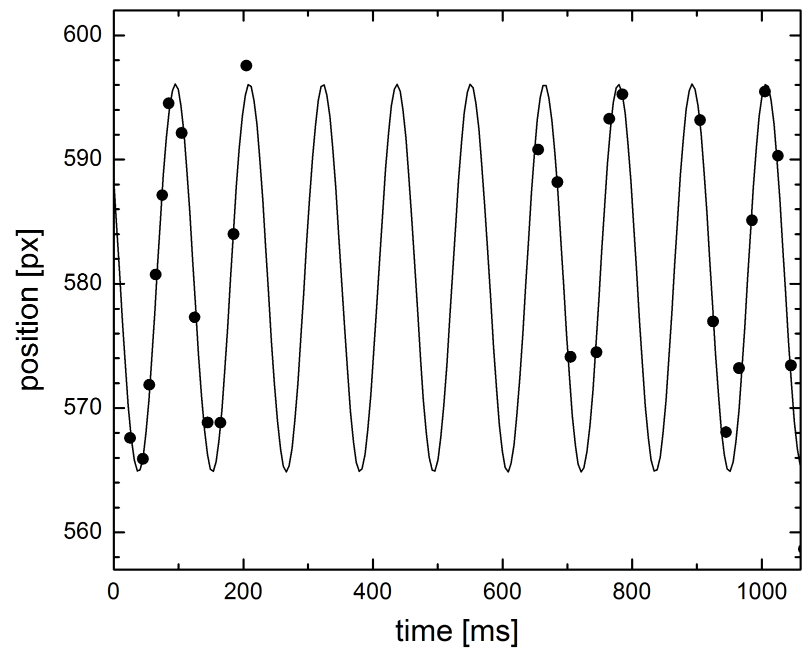
Localized states can be revealed by setting the system out of equilibrium and observing the following dynamics under the action of a harmonic driving force.

Undamped oscillation of a Bose-Einstein condensate in a periodic optical lattice + harmonic potential (magnetic trap)

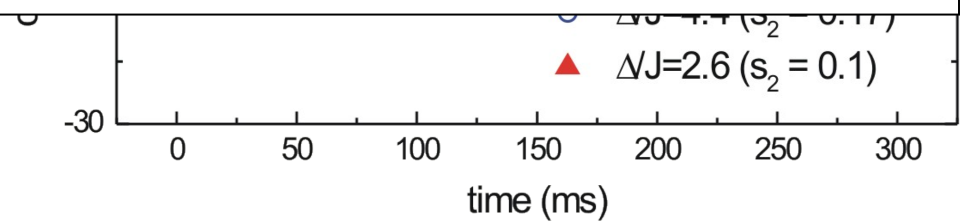


Oscillation frequency: $$\omega^* = \sqrt{\frac{m}{m^*}}\omega$$

F. S. Cataliotti et al., *Science* **293**, 843 (2001)



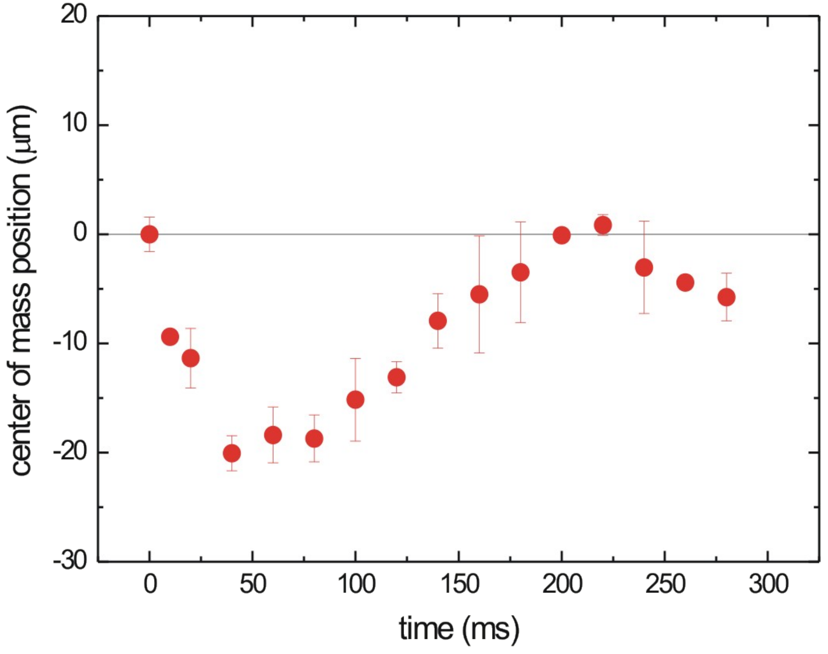
increasing disorder



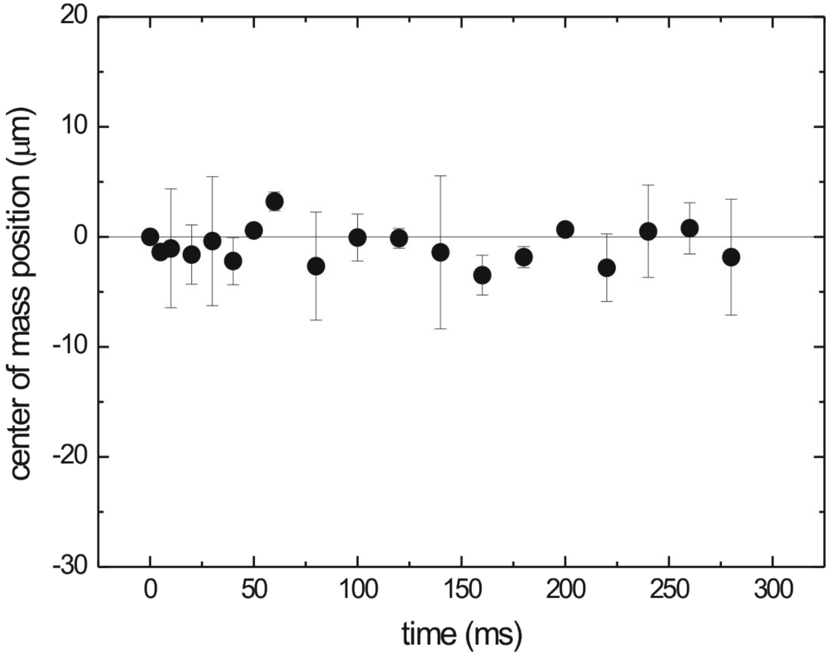
Oscillations in the bichromatic potential

Decreasing the number of atoms the “localization” effect increases

N = 300k



N = 15k



But disorder alone is not the only effect that can lead to localization...

L.Fallani, G.Modugno, C.D'Errico   C.Fort G.Roati, M.I., M.Fattori, M.Modugno M.Zaccanti

PHYSICAL REVIEW VOLUME 109, NUMBER 5 MARCH 1, 1958

Absence of Diffusion in Certain Random Lattices

P. W. Anderson
Bell Telephone Laboratories, Murray Hill, New Jersey

(Received October 10, 1957)

This paper presents a simple model for such processes as spin diffusion or conduction in the "impurity band." These processes involve transport in a lattice which is in some sense random, and in them diffusion is expected to take place via quantum jumps between localized sites. In this simple model the essential randomness is introduced by requiring the energy to vary randomly from site to site. It is shown that at low enough densities no diffusion at all can take place, and the criteria for transport to occur are given.

We assume that we have sites j distributed in some way, regularly or randomly, in three-dimensional space; the array of sites we call the "lattice." We then assume we have entities occupying these sites. They may be spins or electrons or perhaps other particles, but let us call them spins here for brevity. If a spin occupies site j it has energy E_j which (and this is vital) is a stochastic variable distributed over a band of energies completely randomly, with a probability distribution $P(E)dE$ which can be characterized by a width W. Finally, we assume that between the sites we have an interaction matrix element $V_{jk}(r_{jk})$, which transfers the spins from one site to the next.

$$\boxed{i\dot{a}_j = E_j a_j + \sum_{k\neq j} V_{jk} a_k.}$$

J

Δ

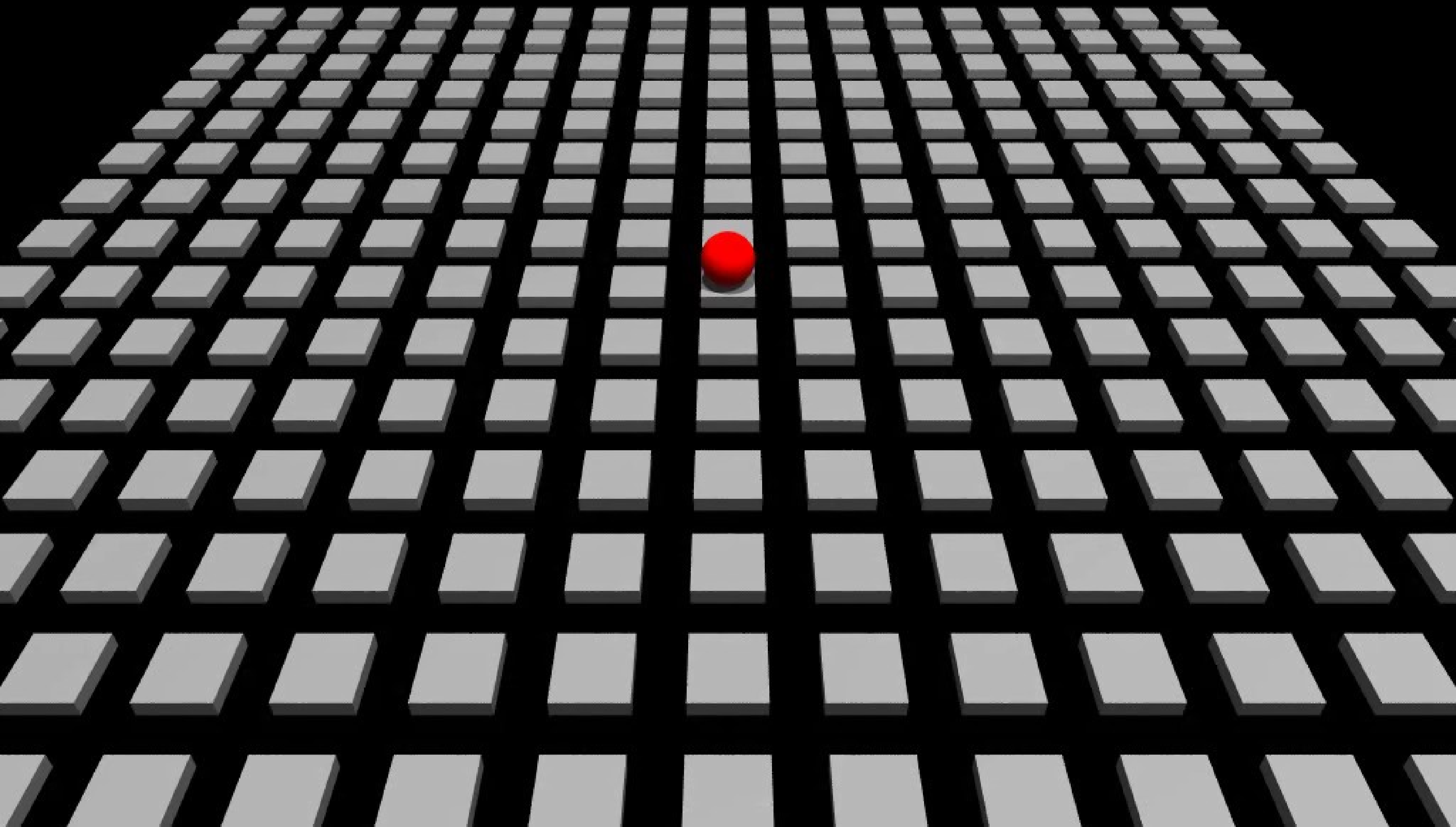
Our basic technique is to place a single "spin" on site n at an initial time $t=0$, and to study the behavior of the wave function thereafter as a function of time. Our fundamental theorem may be restated as: if $V(r_{jk})$ falls off at large distances faster than $1/r^3$, and if the average value of V is less than a certain critical V_c of the order of magnitude of W; then there is actually no transport at all, in the sense that even as $t\rightarrow\infty$ the amplitude of the wave function around site n falls off

One can understand this as being caused by the failure of the energies of neighboring sites to match sufficiently well for V_{jk} to cause real transport. Instead, it causes virtual transitions which spread the state, initially localized at site n, over a larger region of the lattice, without destroying its localized character.

Anderson localization

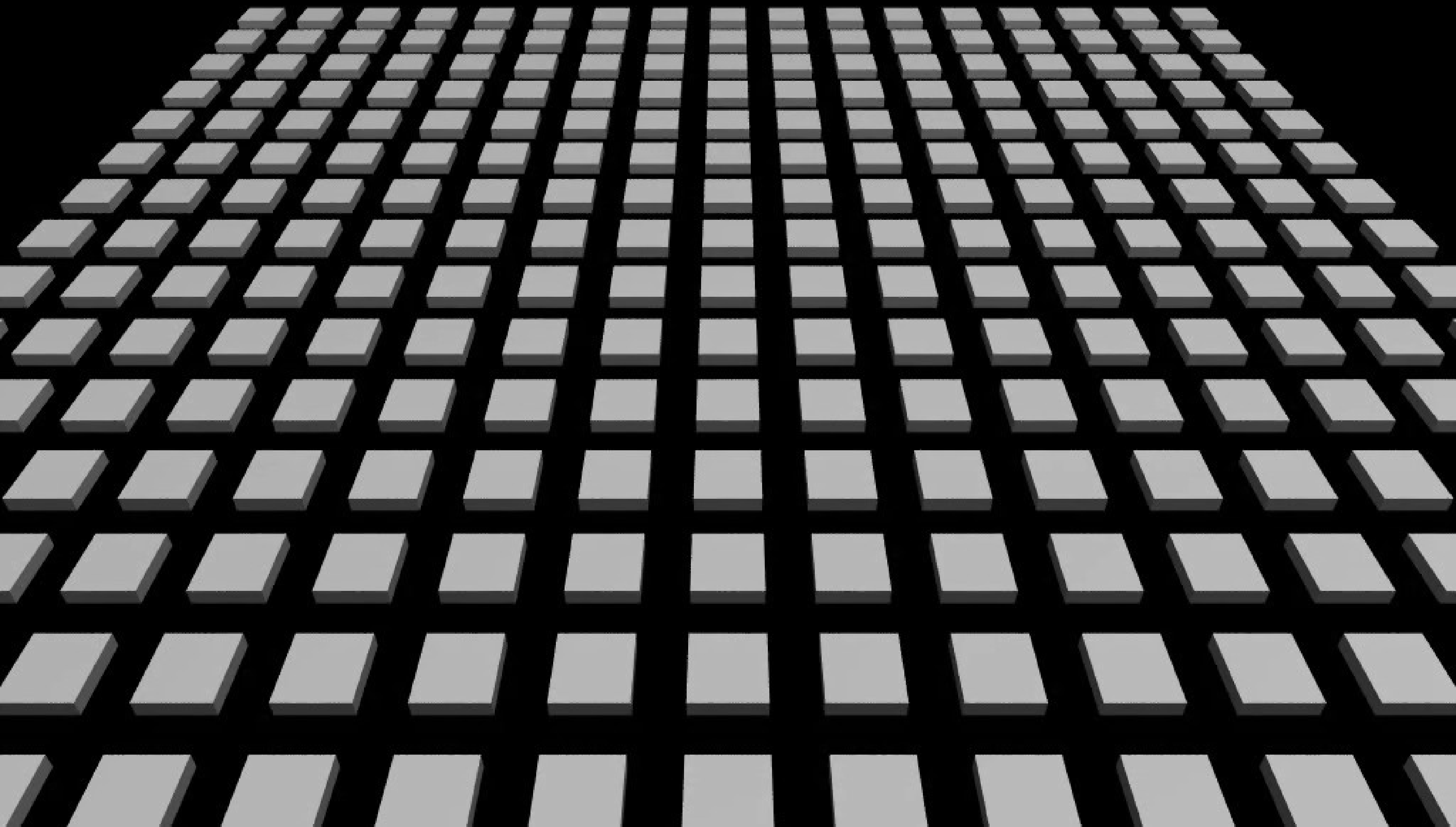
one electron in a periodic lattice

DIFFUSION



Anderson localization

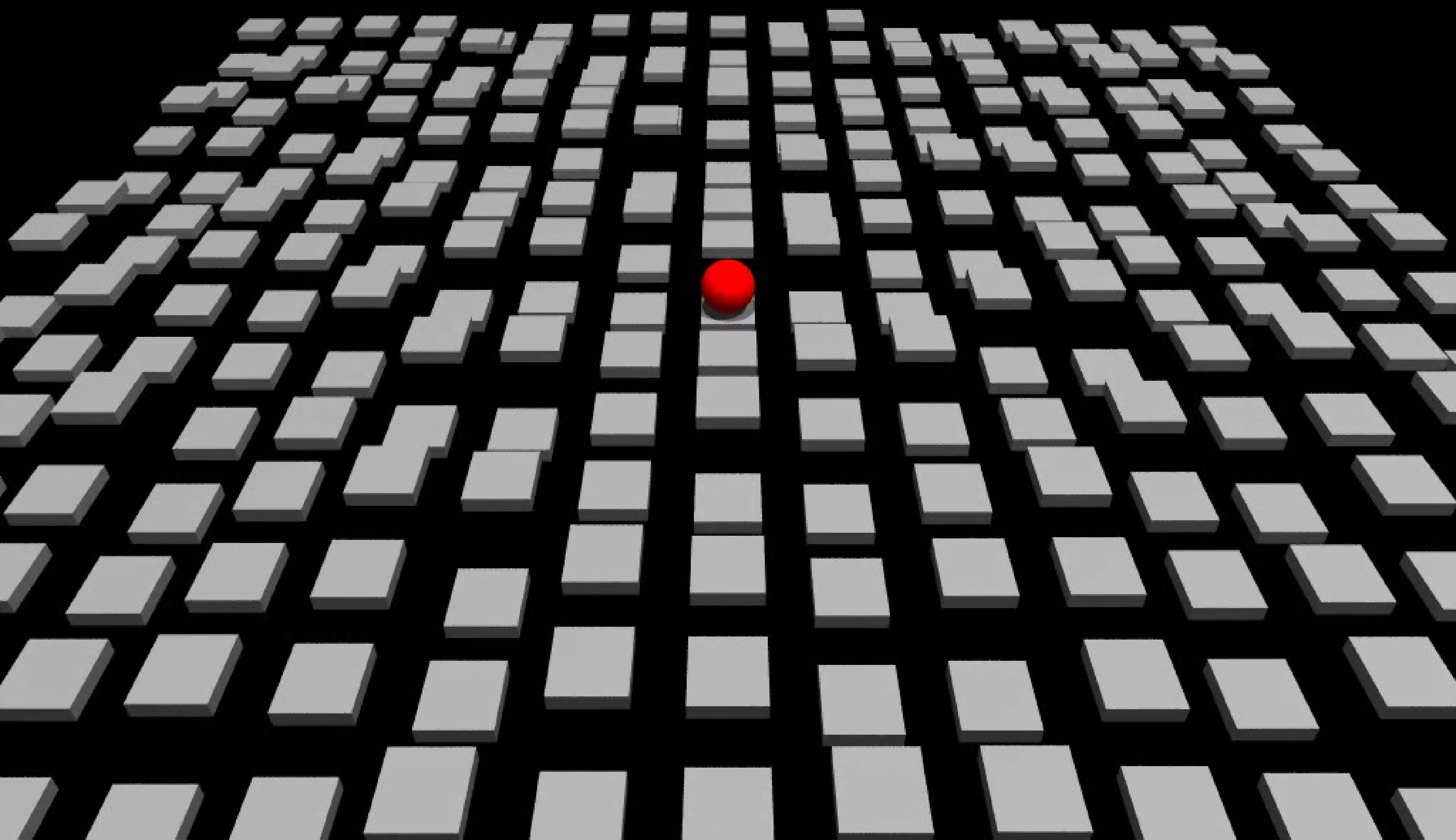
introducing disorder in the lattice



Anderson localization

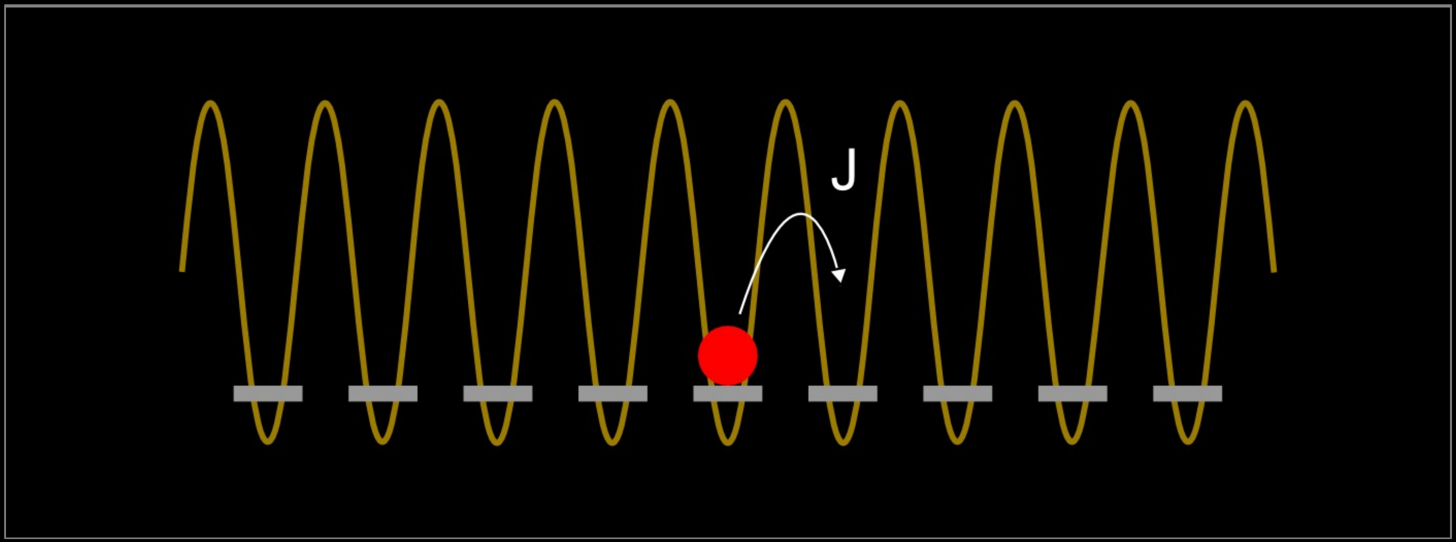
one electron in a disordered lattice

LOCALIZATION



How to realize the Anderson model with cold atoms!

A deep optical lattice realizes a tight binding lattice model...



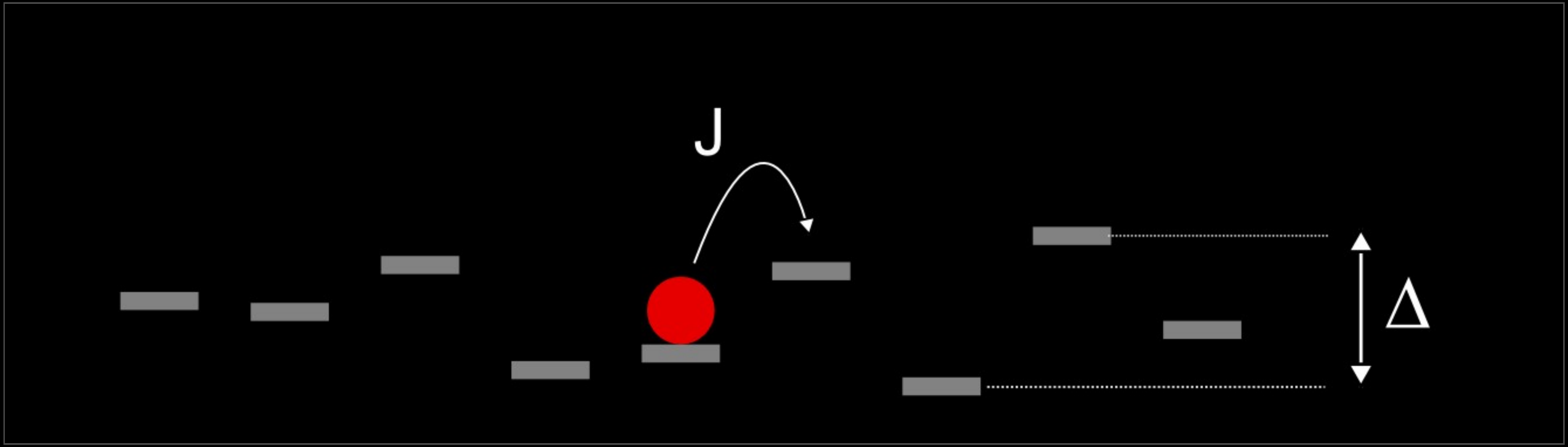
$$\hat{H} = -J \sum_{\langle i,j \rangle} \hat{b}_i^\dagger \hat{b}_j$$

Atoms trapped in the sites with a hopping probability $J \approx \exp\left(-2\sqrt{\frac{V_0}{E_R}}\right)$

Anderson model

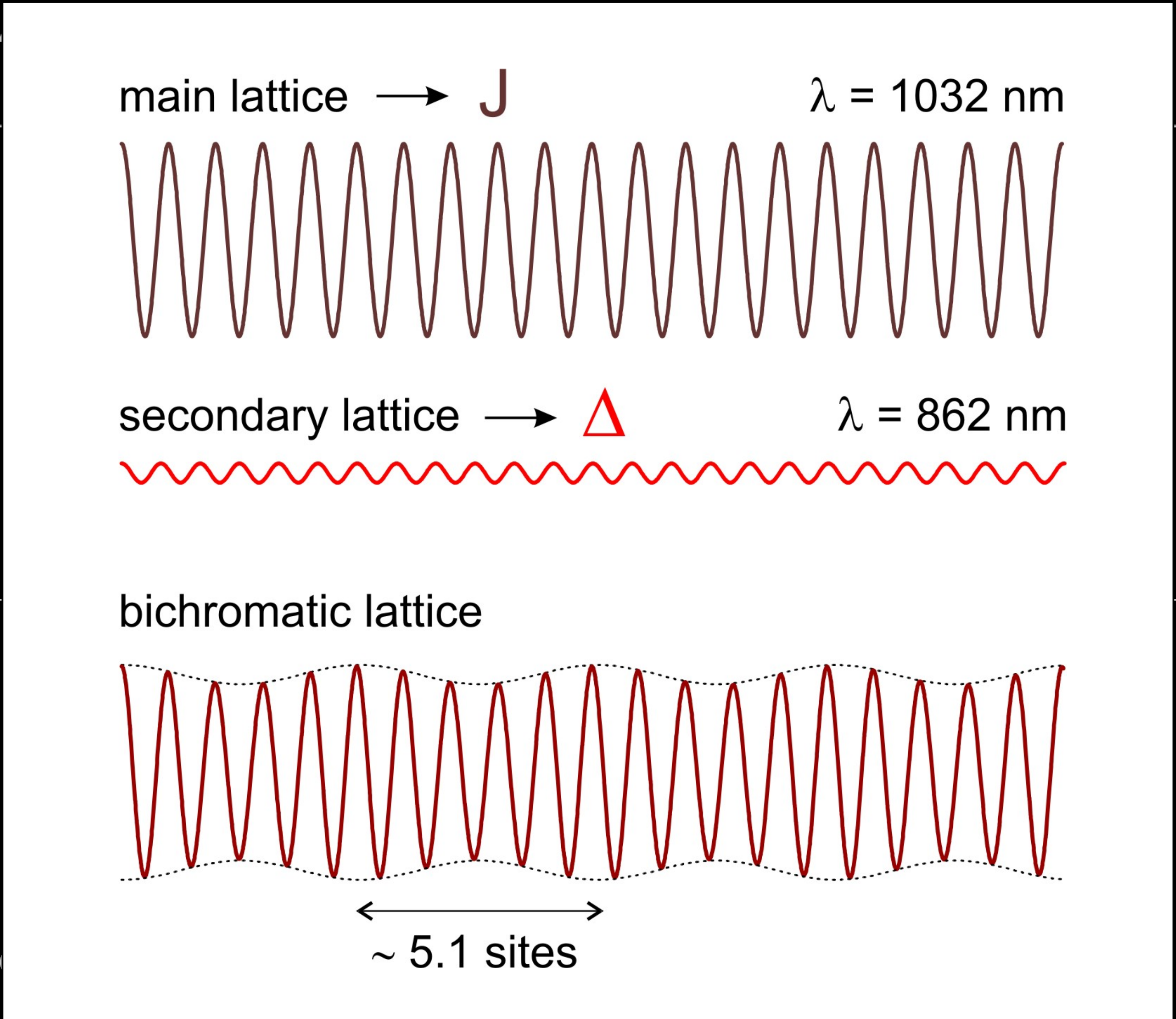
quantum particles hopping in a disordered lattice

$$\hat{H} = -J \sum_{\langle i,j \rangle} \hat{b}_i^\dagger \hat{b}_j + \sum_j \epsilon_j n_j$$



Aubry-André model with cold atoms!

Adding a w



The secon

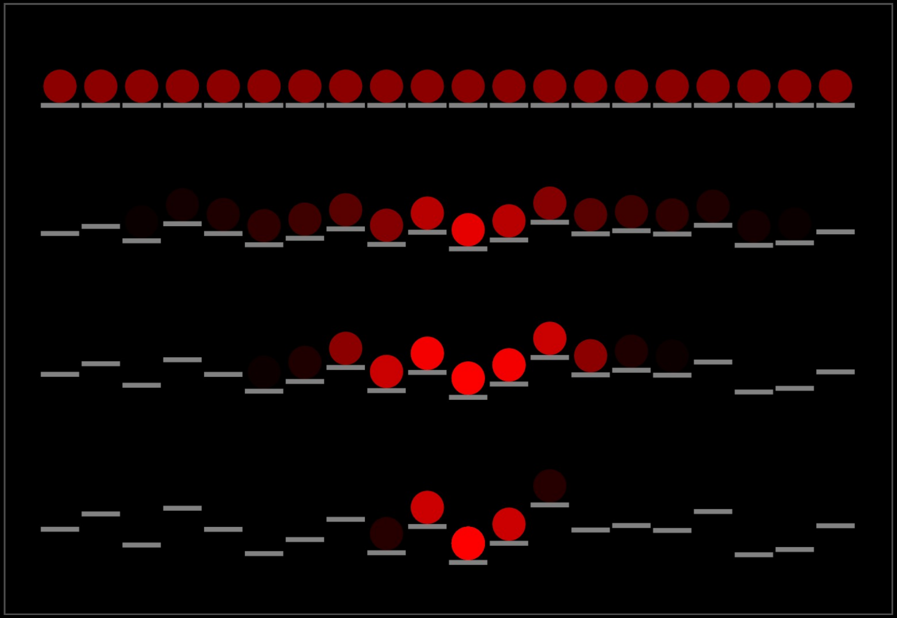
$(2\pi\beta j)$

Localization models

Localization depends on the kind of disorder and dimensionality!

1D Anderson model

$$\epsilon_j = \Delta \,\mathrm{Rand}(1)$$

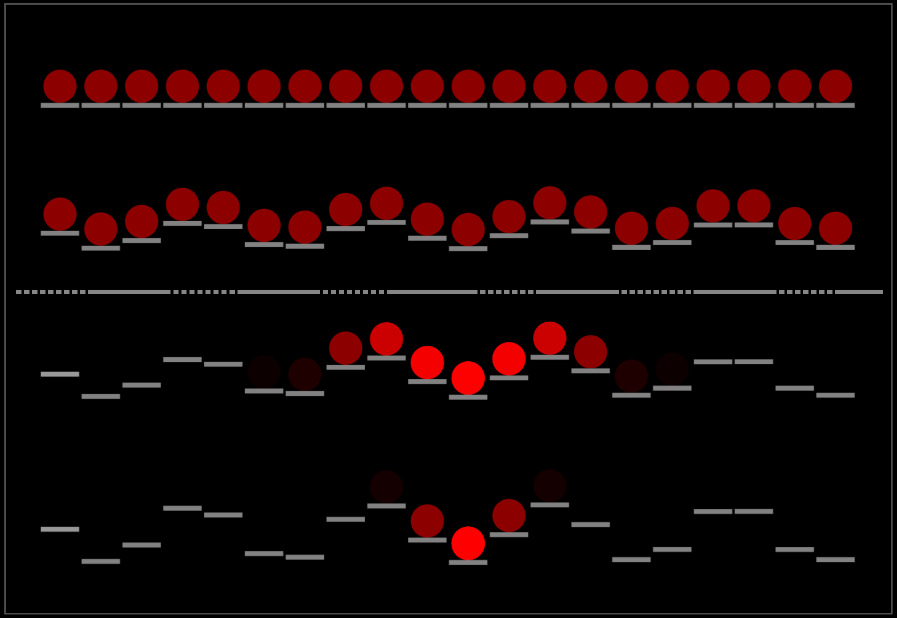


pure random

localization for any Δ

1D Aubry-André model

$$\epsilon_j = \Delta \cos\left(2\pi\beta j\right)$$



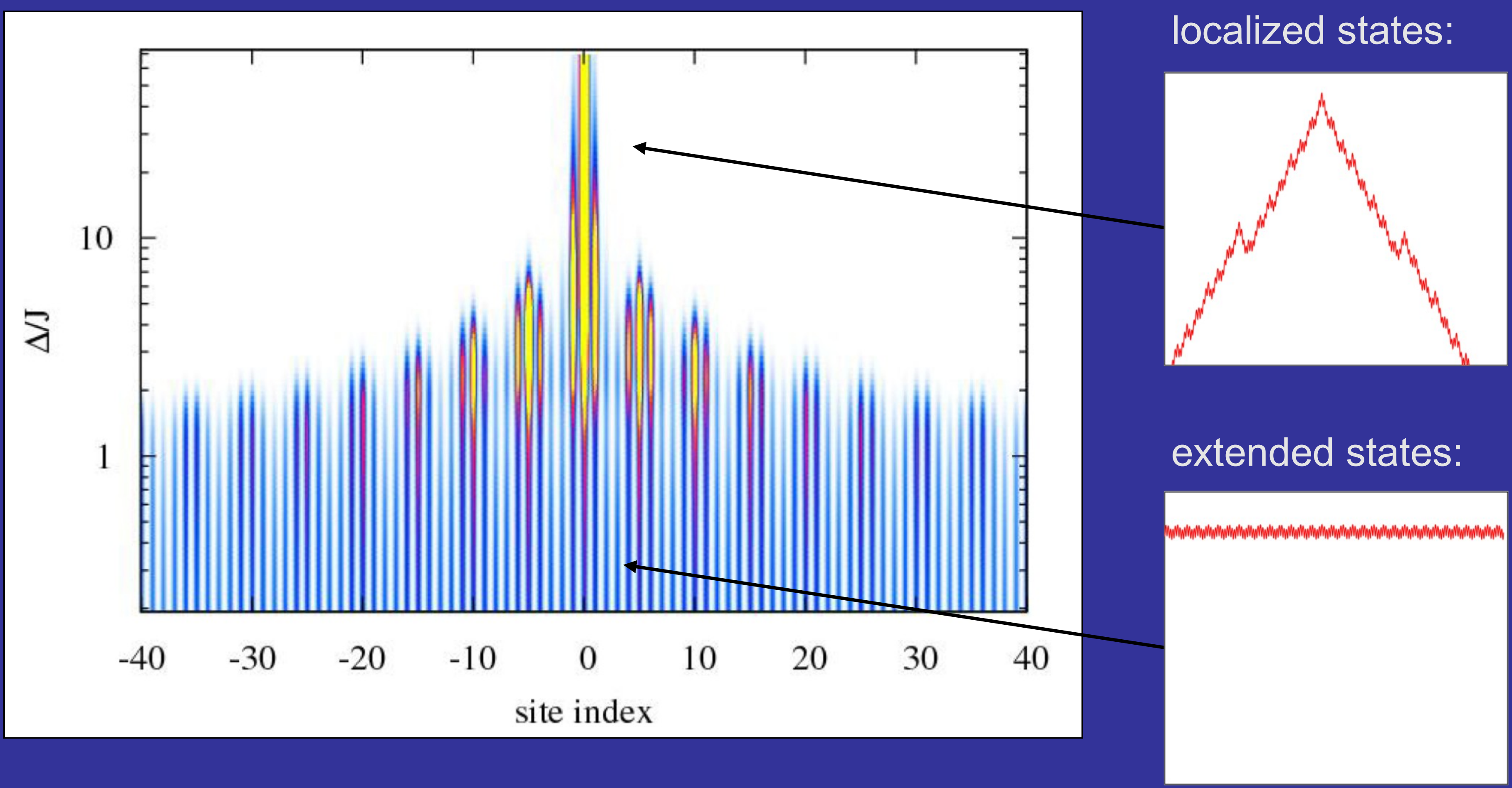
quasiperiodic

localization transition at finite $\Delta = 2J$

Extended and localized states

Localization transition in 1D incommensurate bichromatic lattice

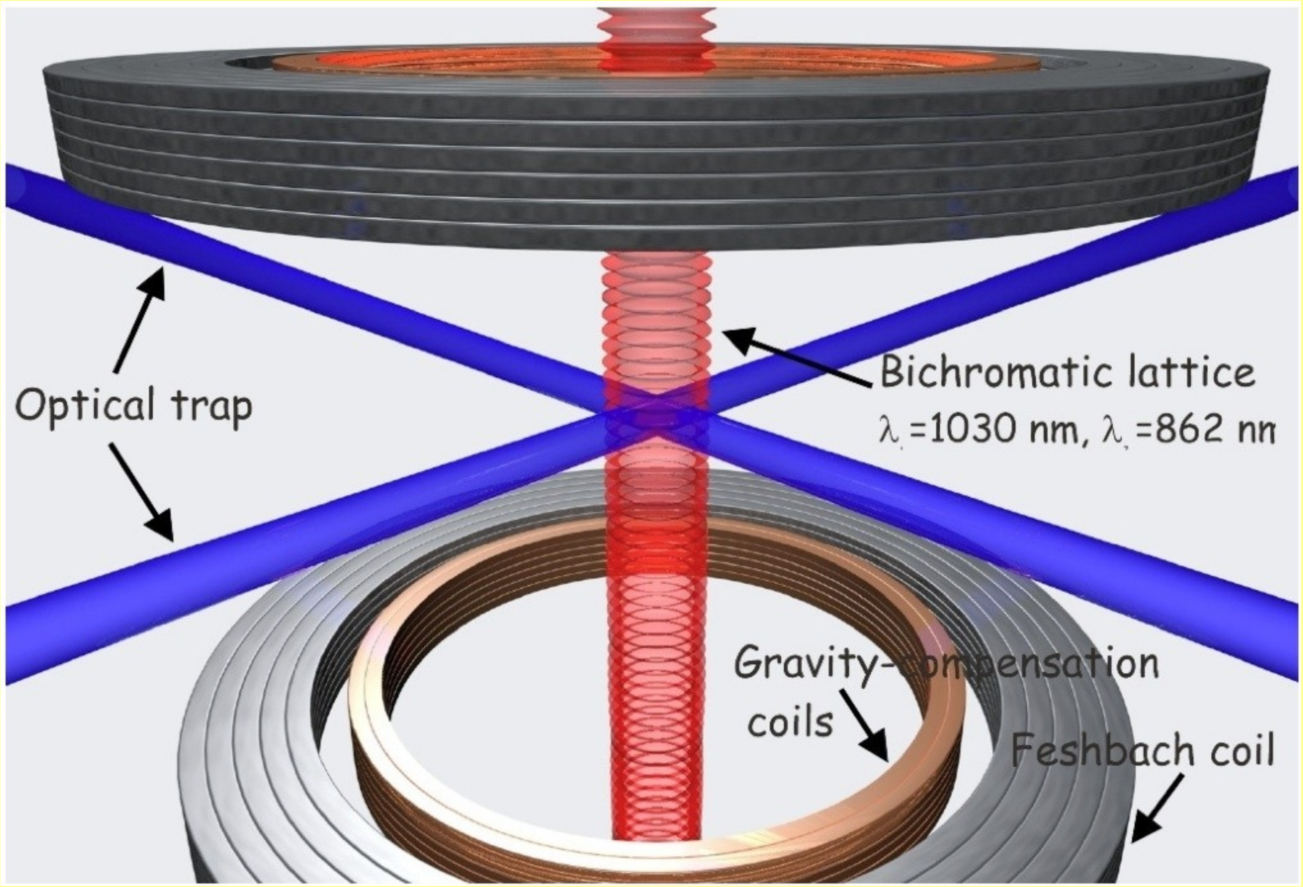
S. Aubry and G. André, Ann. Israel Phys. Soc. **3**, 133 (1980).



Anderson localization of a non-interacting Bose-Einstein Condensate

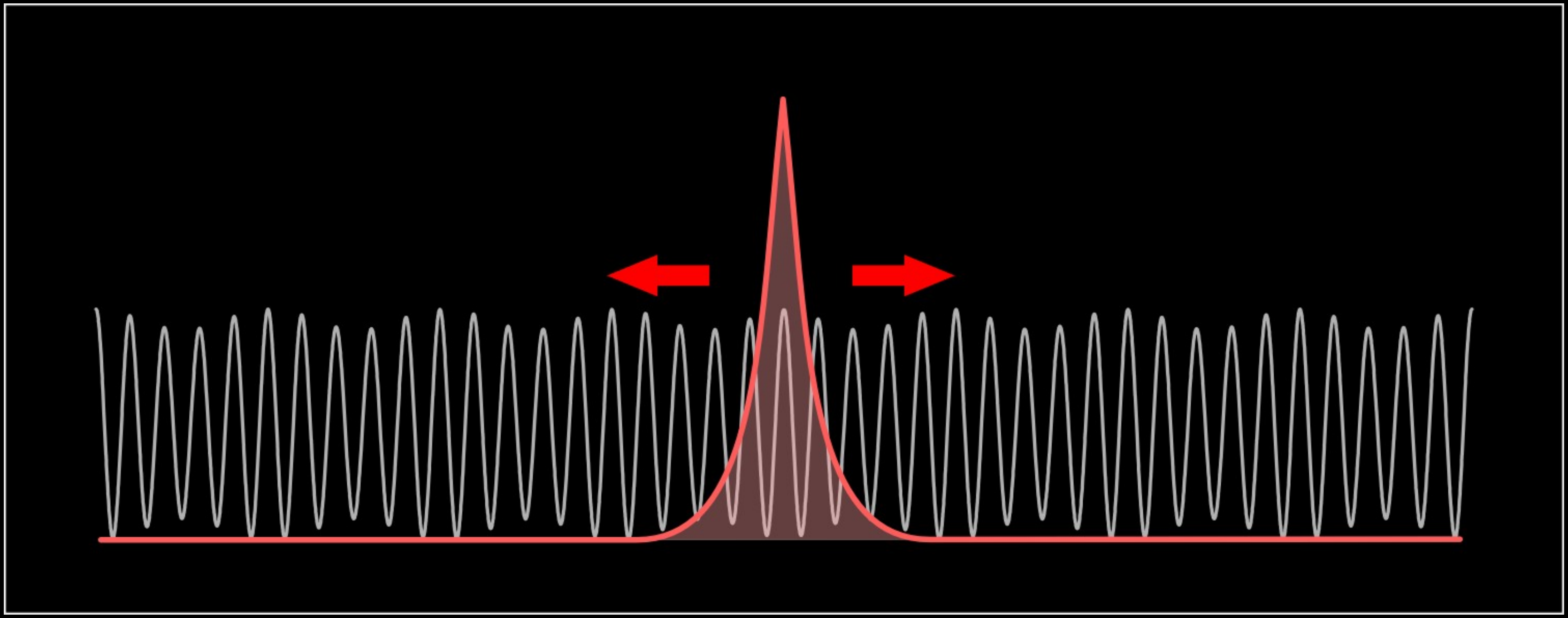
Roati et al., *Nature* 453, 895-898 (2008)

EXPERIMENTAL SCHEME

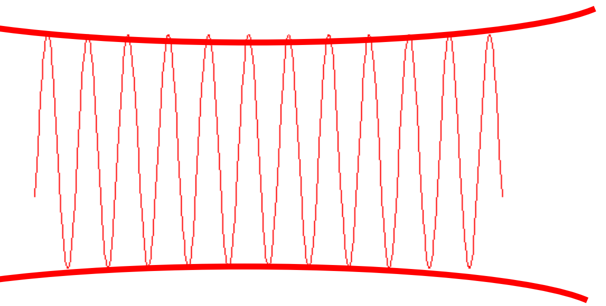


Probing the transport properties

The noninteracting BEC is initially confined in a harmonic trap and then left free to expand in the bichromatic lattice

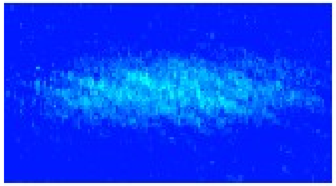


$\Delta=0$

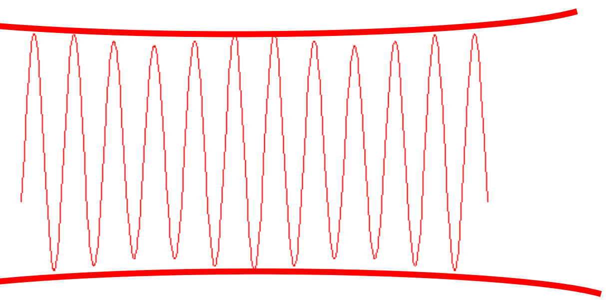


Ballistic expansion:

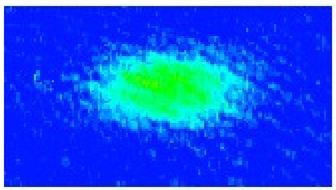
$$\langle r^2\rangle(t) \propto t^2$$



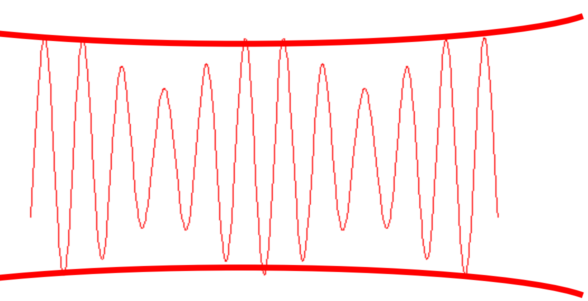
$\Delta/J=1$



Ballistic expansion with reduced velocity

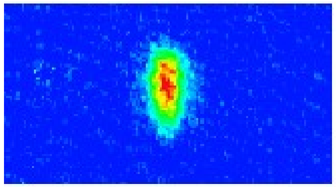


$\Delta/J=7$



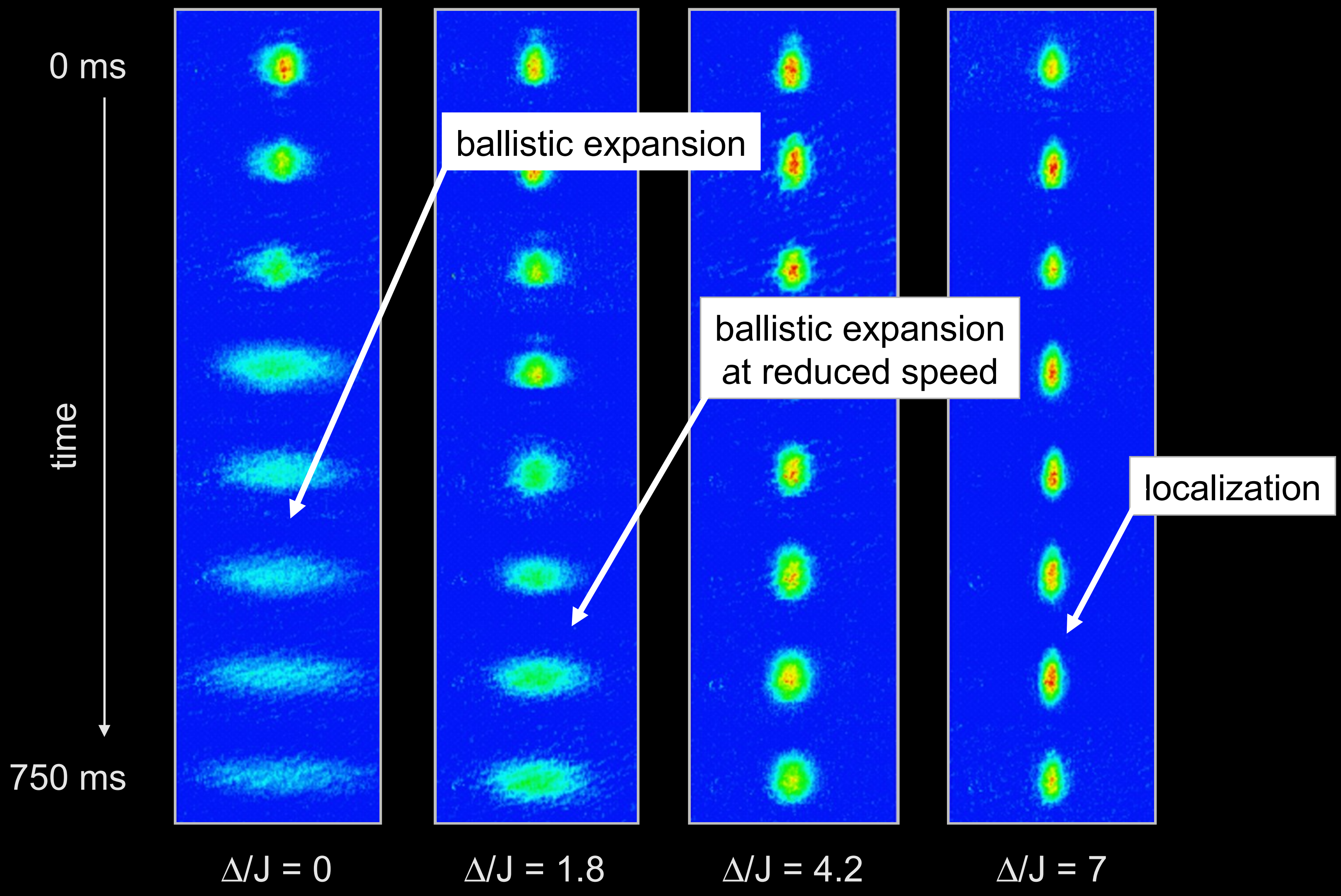
Absence of diffusion:

$$\langle r^2\rangle(t) \propto \langle r^2\rangle(0)$$



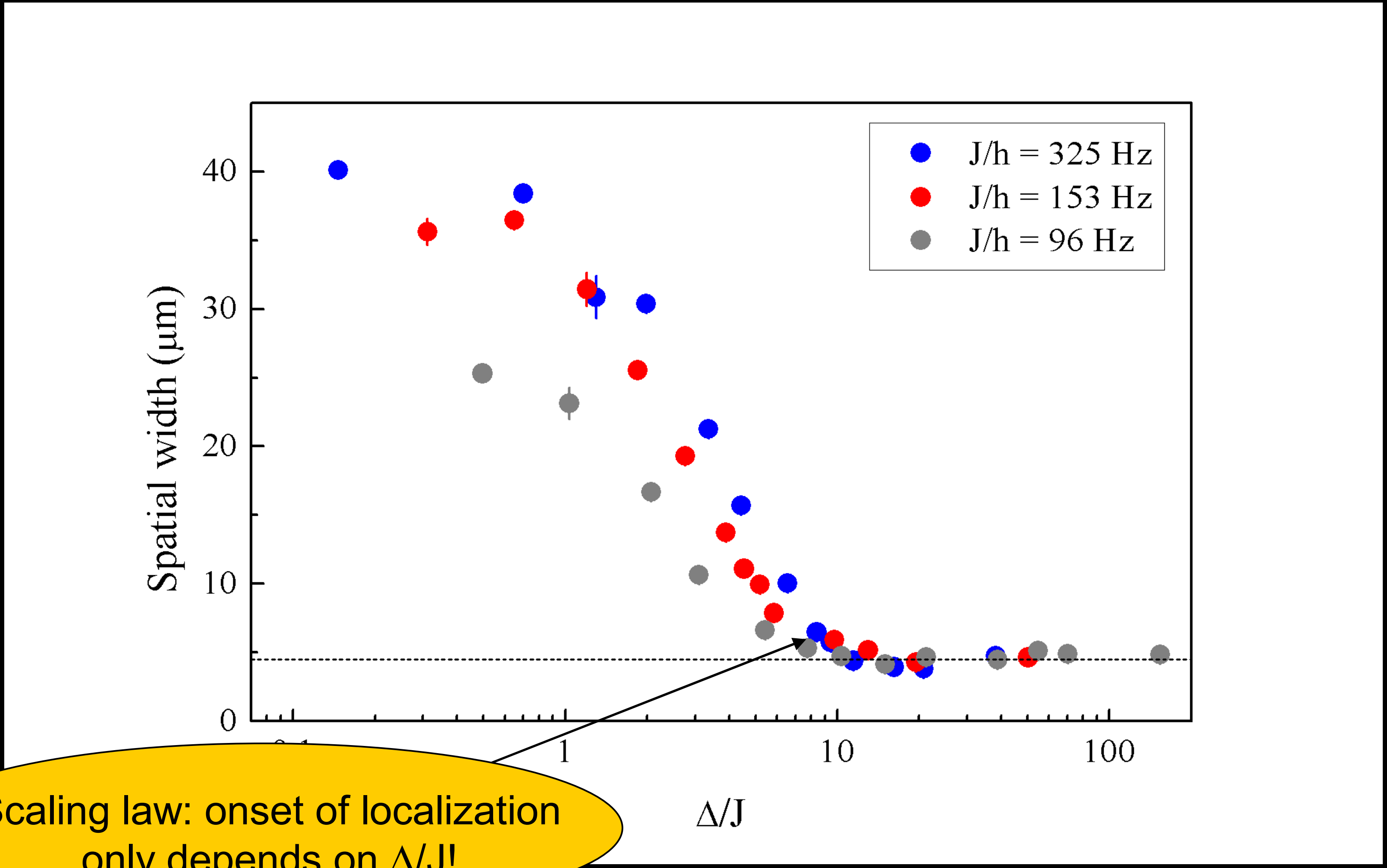
Expansion in the bichromatic lattice

G. Roati et al., *Nature* 453, 895-898 (2008)



Expansion in the bichromatic lattice

Size of the condensate after 750 ms expansion in the bichromatic lattice:

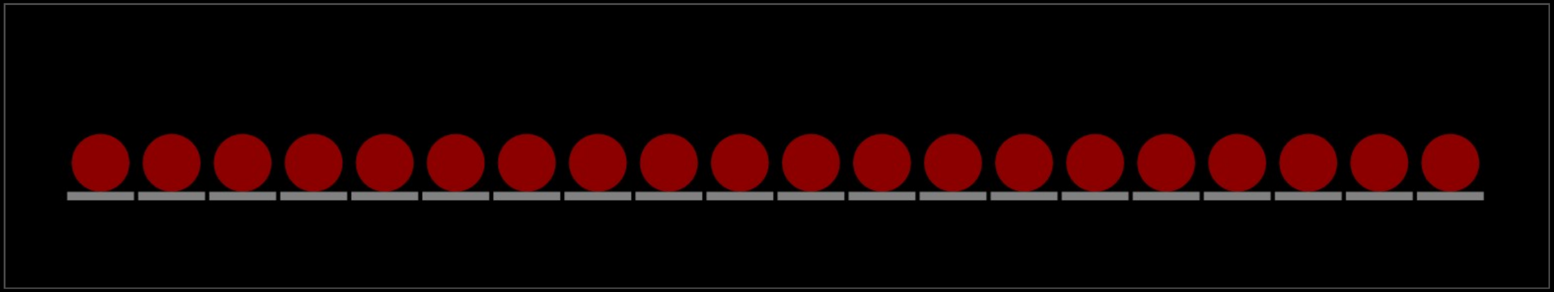


Scaling law: onset of localization only depends on Δ/J!

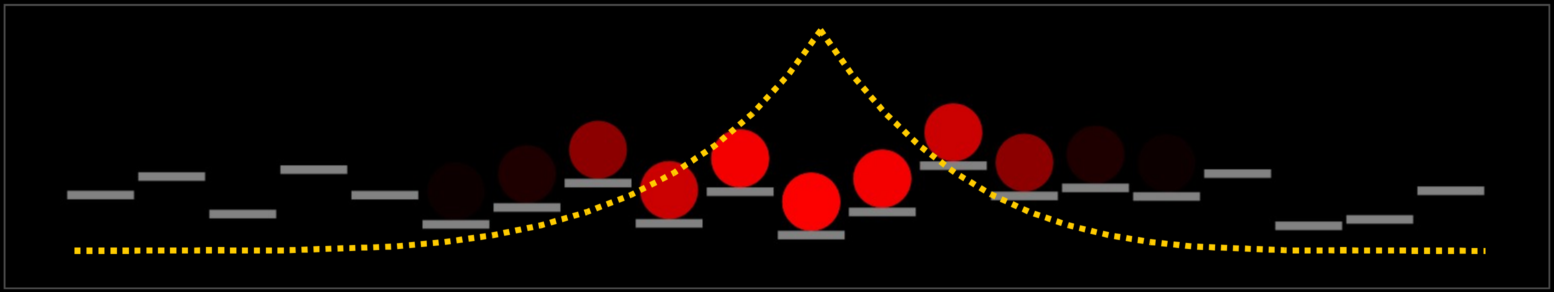
Localized states

Diffusion stops because the eigenstates are localized!

Periodic: wavefunction is delocalized on the whole system size



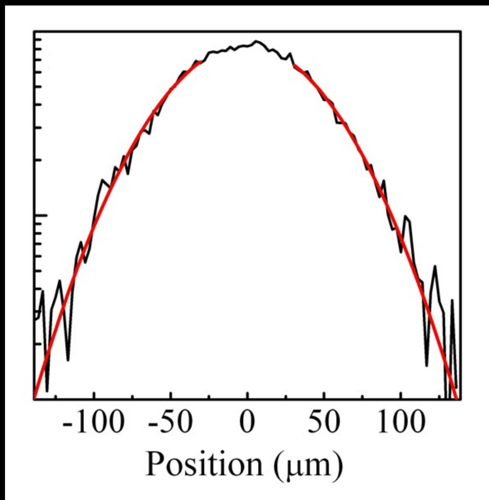
Disordered: eigenstates are localized in a finite region of space



exponentially decaying amplitude of wavefunction

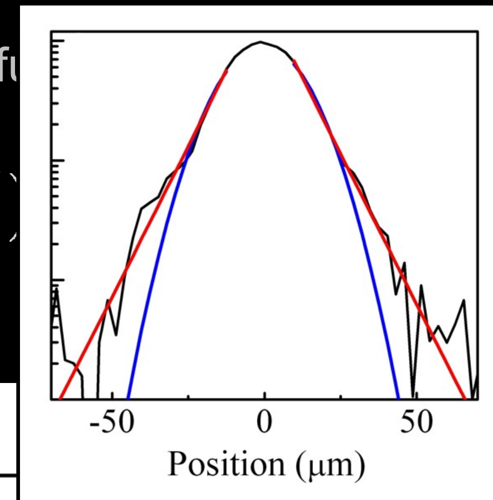
Exponential localization

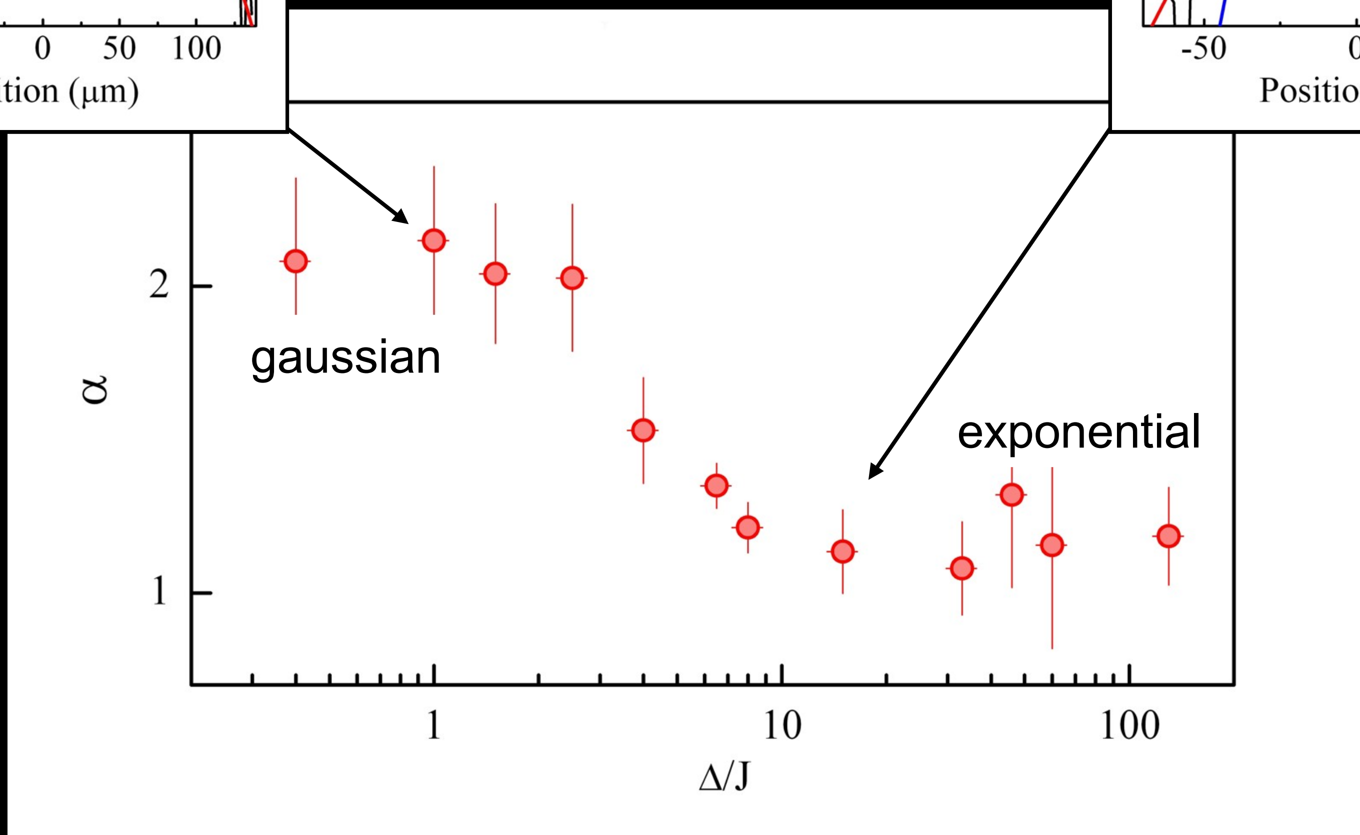
Roati et al, *Nature*, 453, 895-898 (2008)



bution with a generalized exponential fu

$$n(x) = A\exp\left(-\gamma\,(x - x_0)^{\alpha}\right.$$





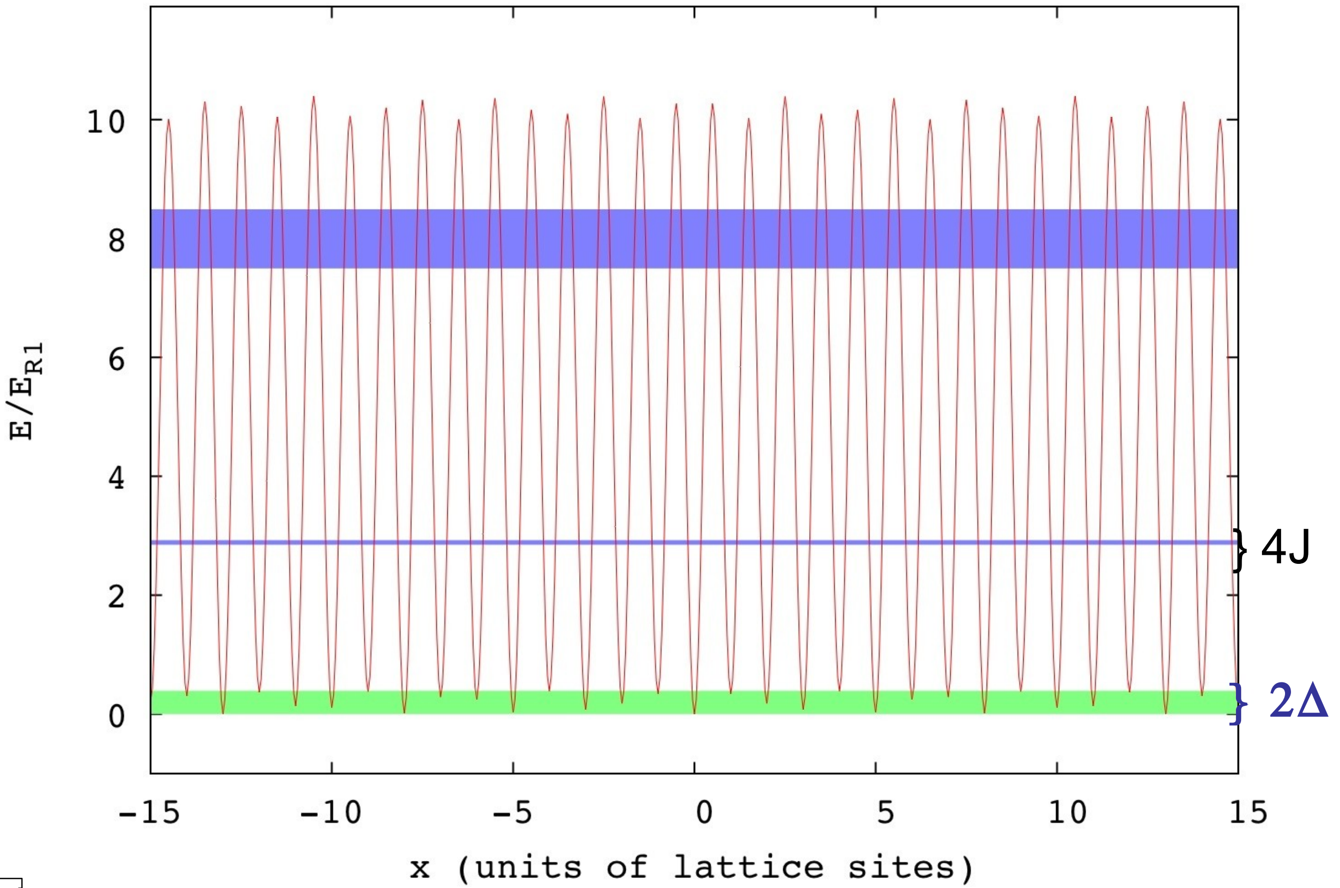
Bloch waves

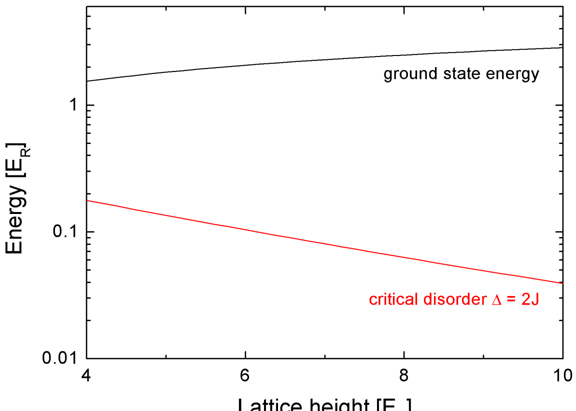
with energy

E

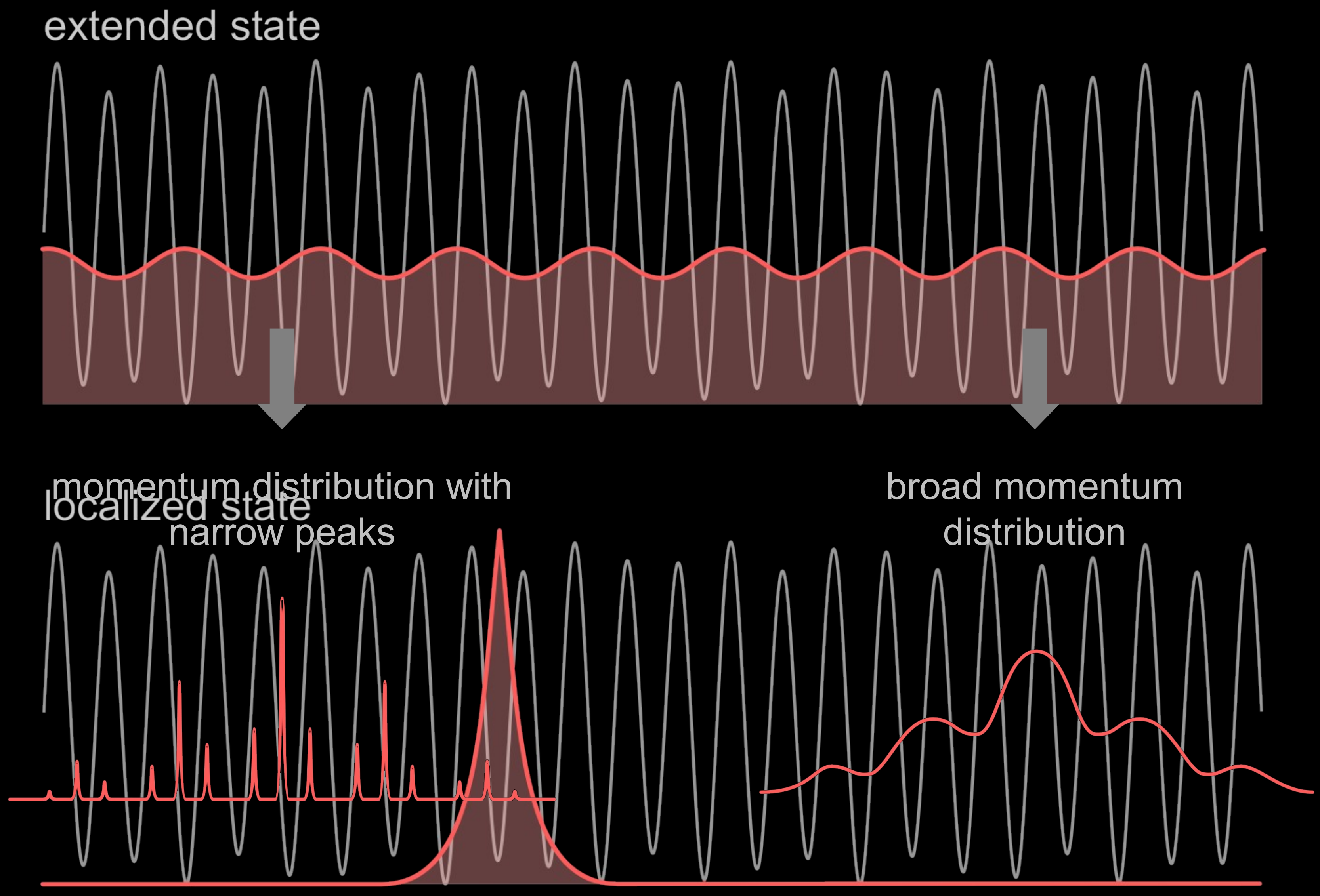
larger than

Δ



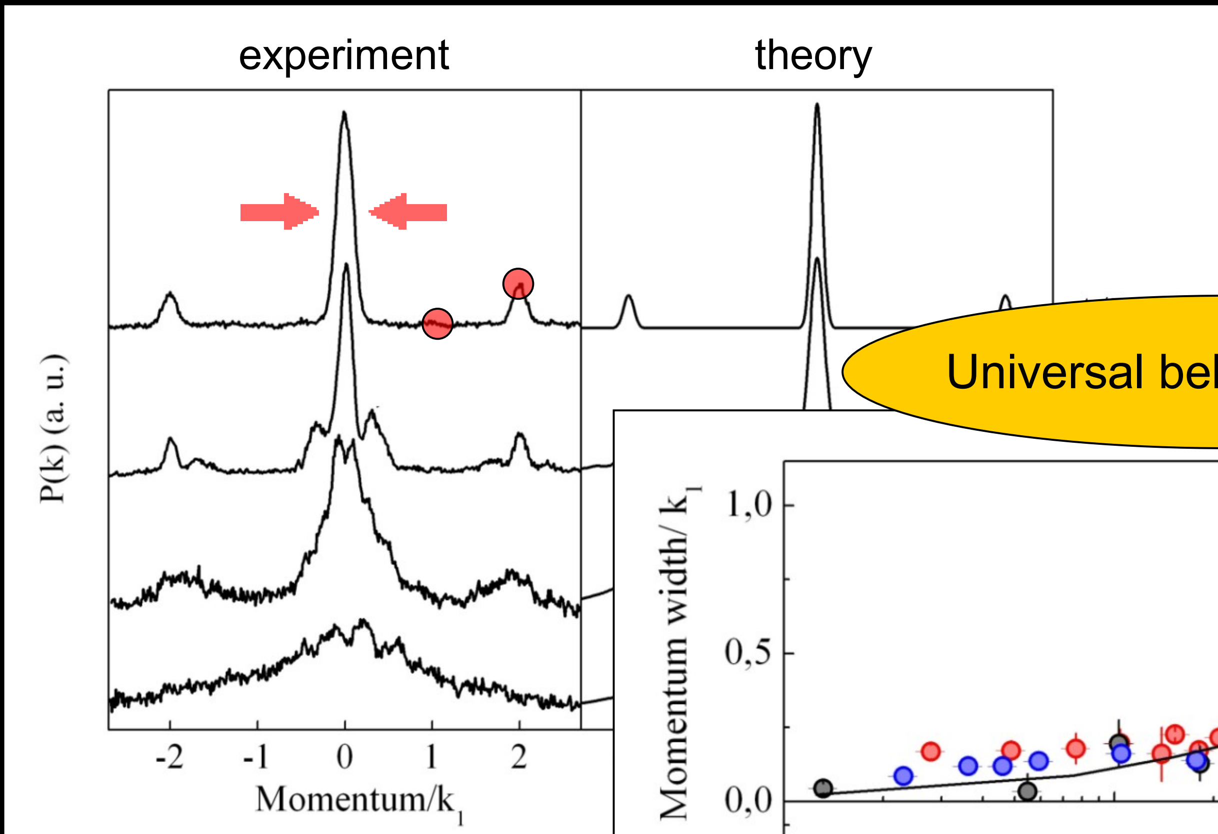


from Momentum distribution



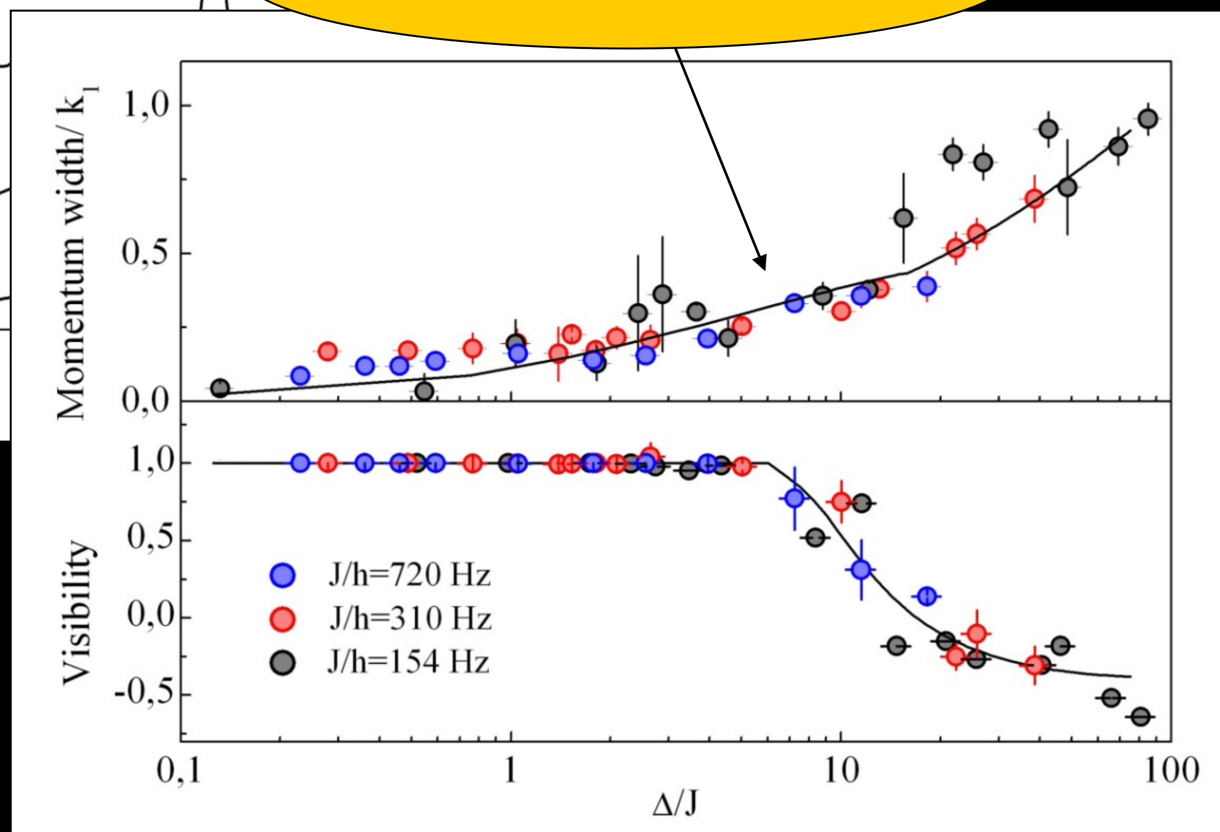
from momentum distribution

G. Roati et al., Nature, 453, 895-898 (2008)



Density distribution after time-of-flight of the initial stationary state

Universal behavior with Δ/J!



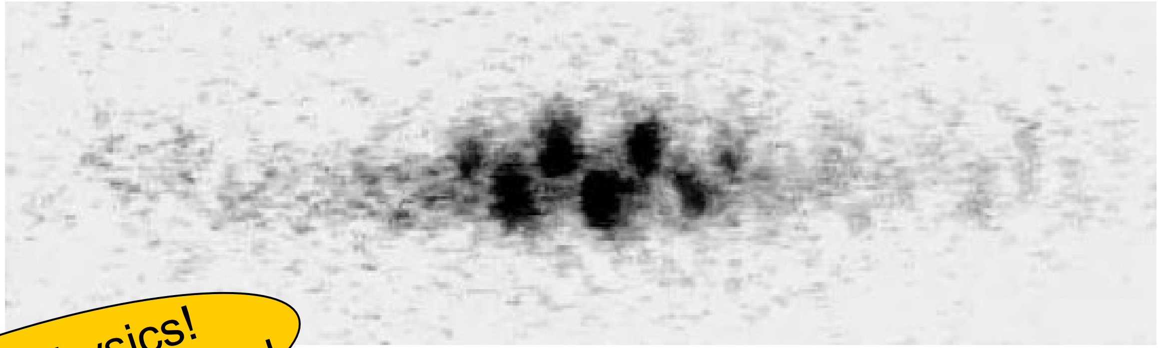
Width of the central peak

Visibility $$\frac{P(2k_1) - P(k_1)}{P(2k_1) + P(k_1)}$$

Interference between multiple localized states

Changing the harmonic confinement allows to load multiple localized states

Interference between two independent localized states
one of which contains a thermally-activated vortex



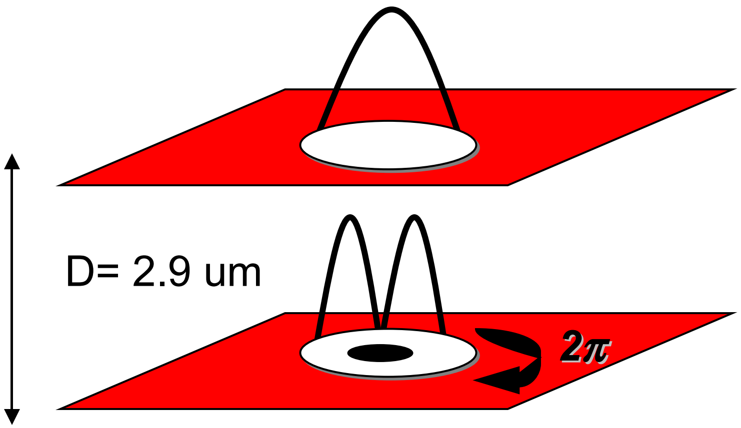
Quasi-2D physics!
Lens, ENS, NIST, Stanford…

S. Stock et al., Phys. Rev. Lett. **95**, 190403 (2005)

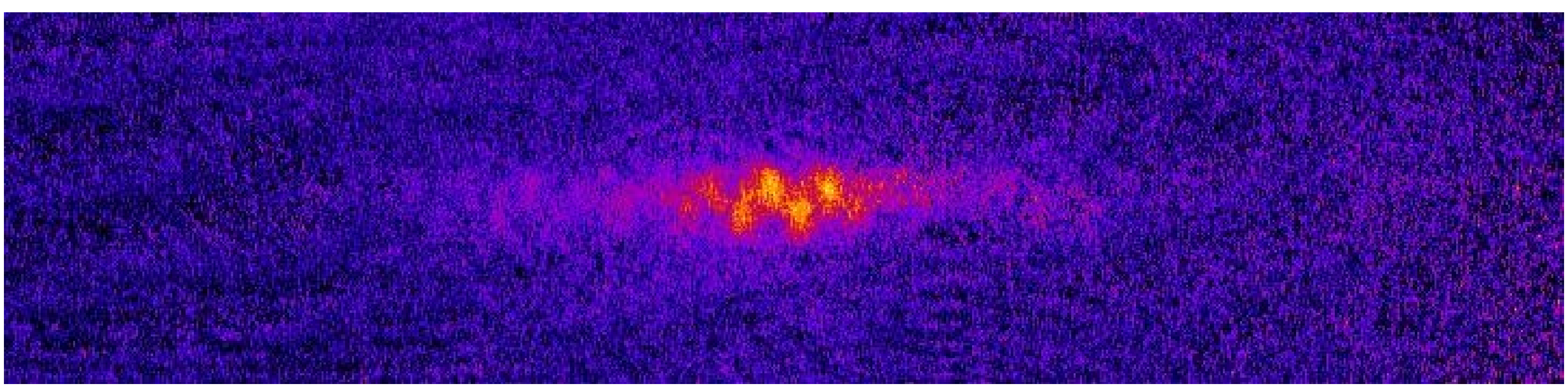
No fixed phase of the interferogram ⟶ **Localized states are independent!**

T≠0 -> the 2D is no more superfluid: BKT transition

- Proliferation of vortices no superfluidity
- Phase-correlation function decays exponentially



Thermal fluctuations -> creation of vortices



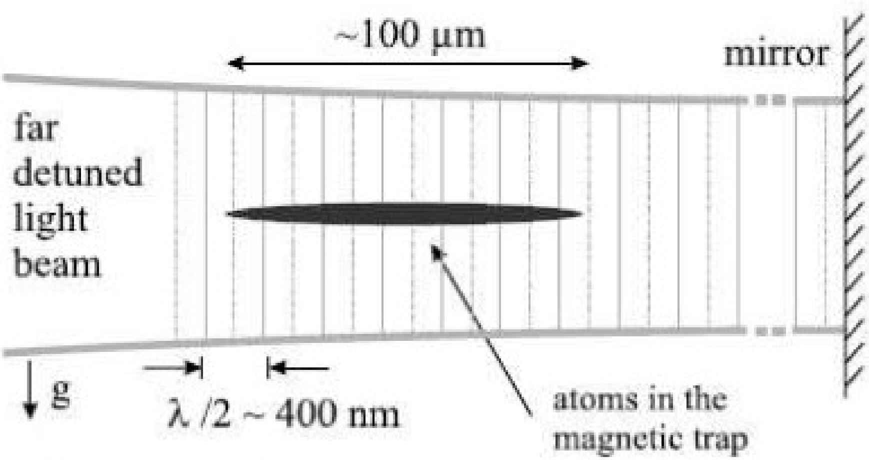
BEC in 2D

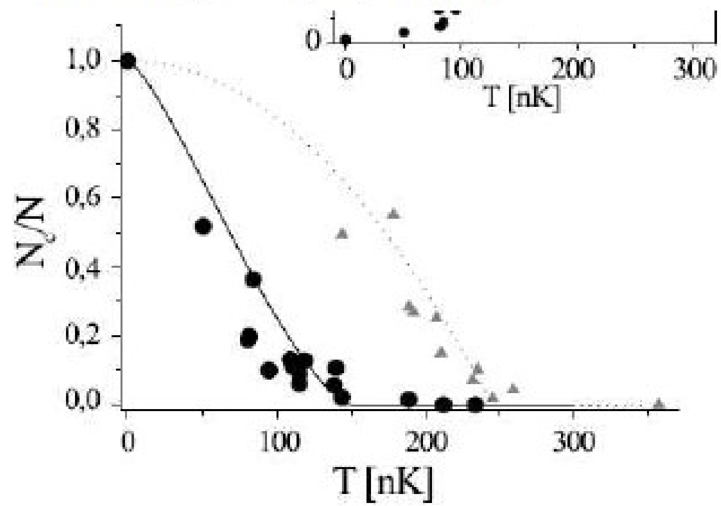
In 2D BEC possible for ideal gases + harmonic confinement
Semiclassical results:

$$N\left[1-\left(\frac{T}{T_c}\right)^2\right] = N_0 - \left(\frac{k_B T}{\hbar\omega}\right)^2 \frac{1+\ln N_0}{N_0}$$

$$k_B T_c = \sqrt{\frac{6N}{\pi}}\hbar\omega$$

For large atom numbers in the condensate $N_0 \simeq N[1-(T/T_c)^2]$

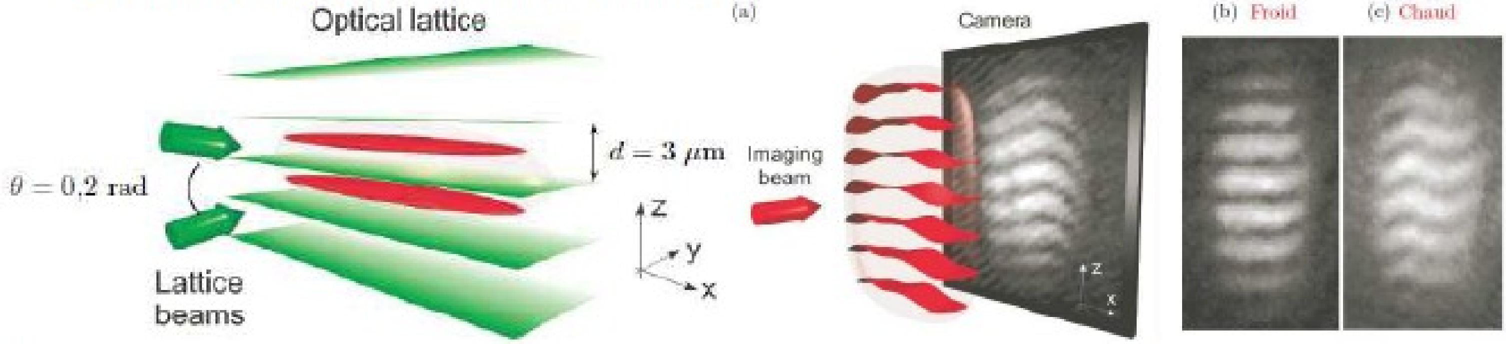




S. Burger et al. 2002

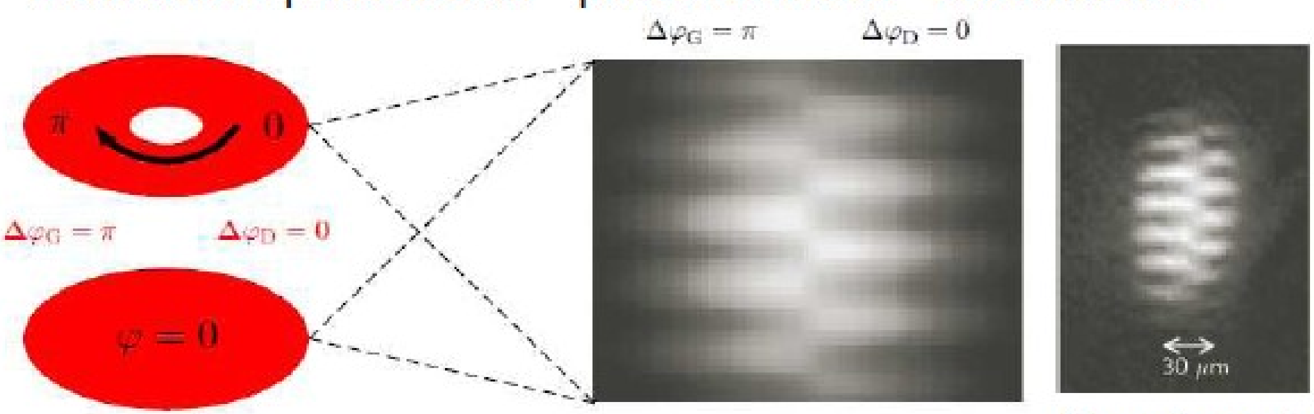
Experimental realization with atomic gases, ENS

Elongated Rb condensate split like a sandwich, by blue-detuned optical lattice
$\rightarrow$ two independent 2D-condensates



Upon expansion the two condensates overlap and interfere

Atomic heterodyne technique: a vortex in condensate 1 detected by interference pattern with "phase-reference" condensate 2



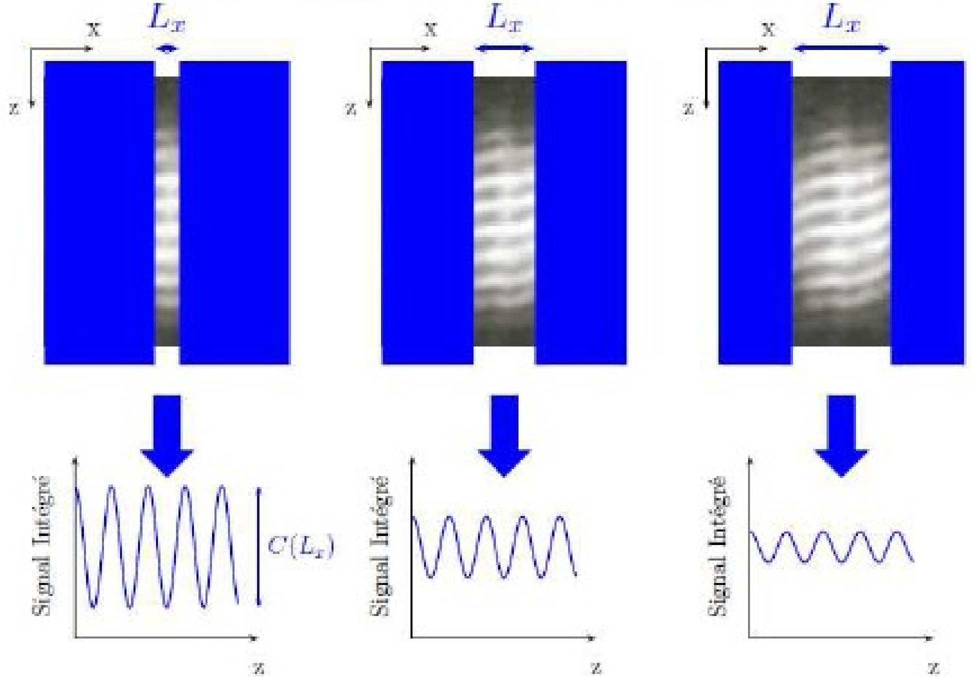
Experimental

Simulated (B. Battelier, 2007)

Decay of interference

BKT crossover detected by analysis of decay of interference contrast (Polkonvikov et al. 2006)

For each position x, fit fringes along vertical direction, extract contrast $c(x)$ and phase $\phi(x)$, integrate and average over multiple images



$C(L_x) = \frac{1}{L_x} \left| \int_{L_x} c(x) \exp(i\phi(x)) \mathrm{d}x \right|$

$\langle C^2(L_x) \rangle \approx \int dx [g_1(x,0)]^2 \propto L_x^{-2\alpha}$

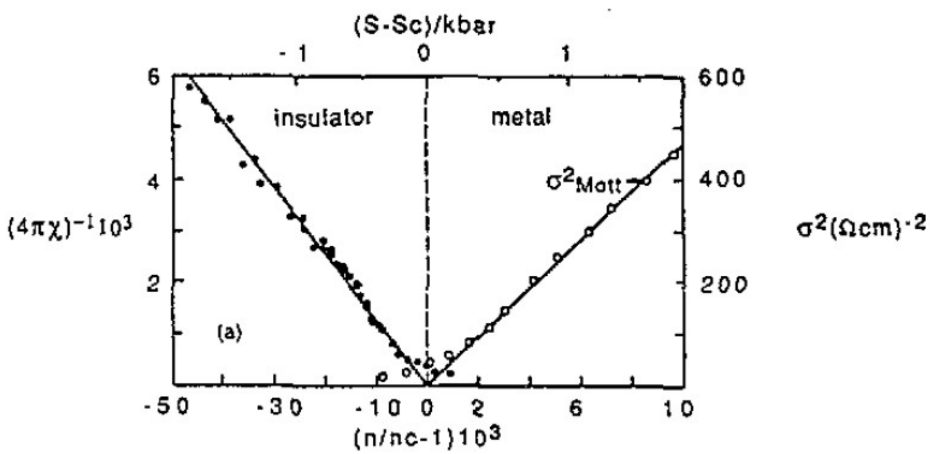
Fit for α

AUBRY- ANDRE Hamiltonian

$$
\begin{aligned}
H &= J \sum_j \left(|w_j\rangle \langle w_{j+1}| + |w_{j+1}\rangle \langle w_j| \right) \\
&+ \Delta \sum_j \cos\left(2\pi\beta j + \phi\right) |w_j\rangle \langle w_j|
\end{aligned}
$$

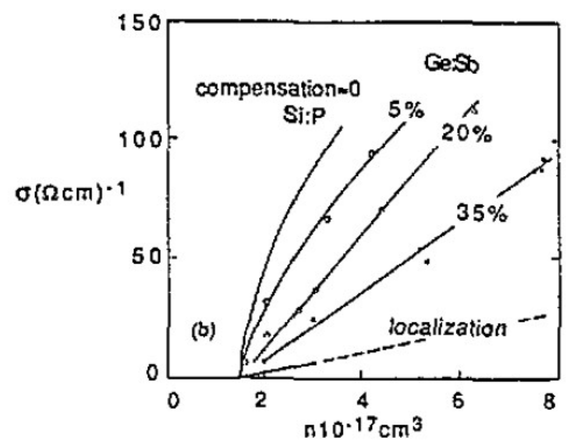
The Anderson transition in solid state physics

see: Kramer & MacKinnon, Localization: theory and experiment, Rep. Prog. Phys. 56, 1469–1564 (1993).



Metal-insulator transition in doped silicon (Si:P): conductivity (right) and inverse of dielectric susceptibility (left) *vs* concentration of the dopant atoms (P).

DC conductivity *vs* concentration of dopant atoms for different degrees of compensation in Ge:Sb

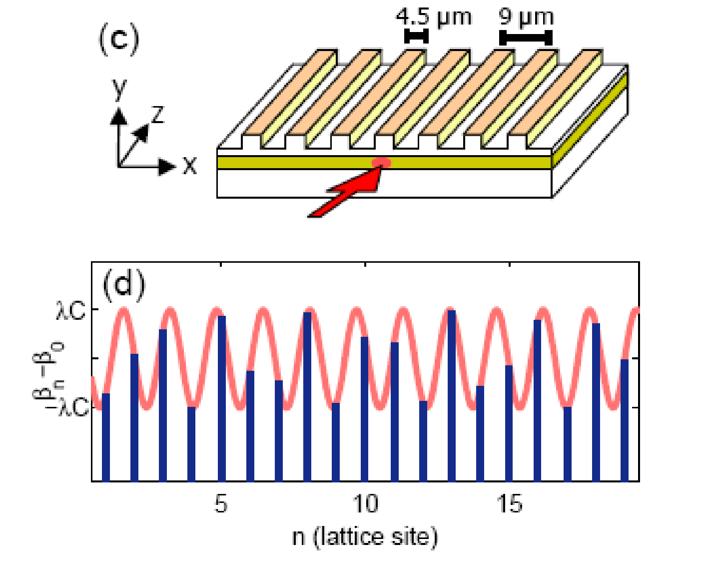


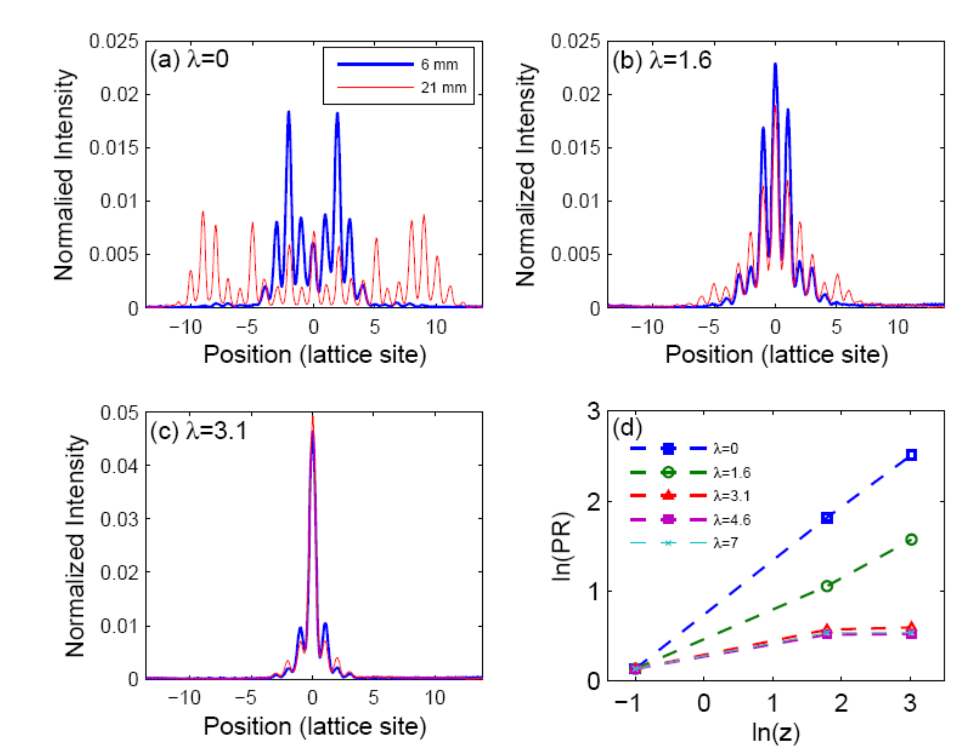
[Paalanen and Thomas, 1983]

LIGHT in PHOTONIC LATTICES

Direct observation of a localization transition in quasi-periodic photonic lattices

Y. Lahini[1], R. Pugatch[1], F. Pozzi[2], M. Sorel[2], R. Morandotti[3], N. Davidson[1] and Y. Silberberg[1]



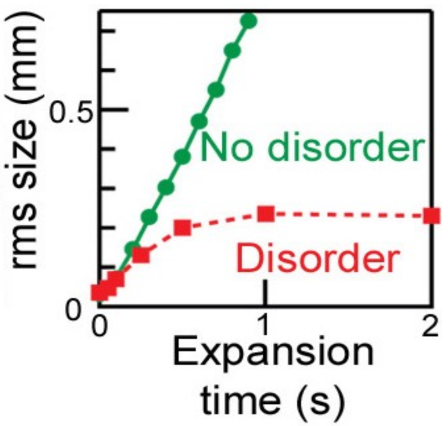


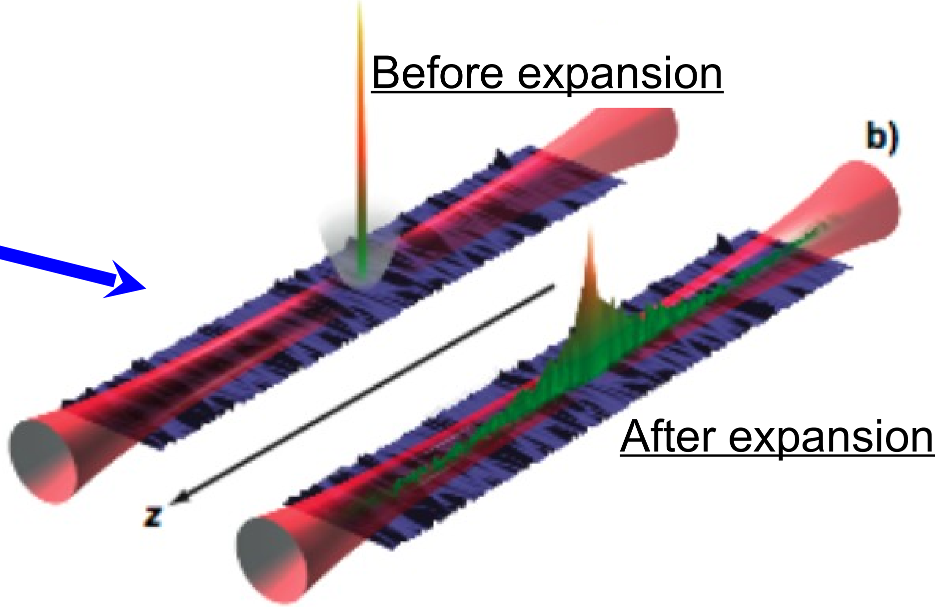
Only the beginning...

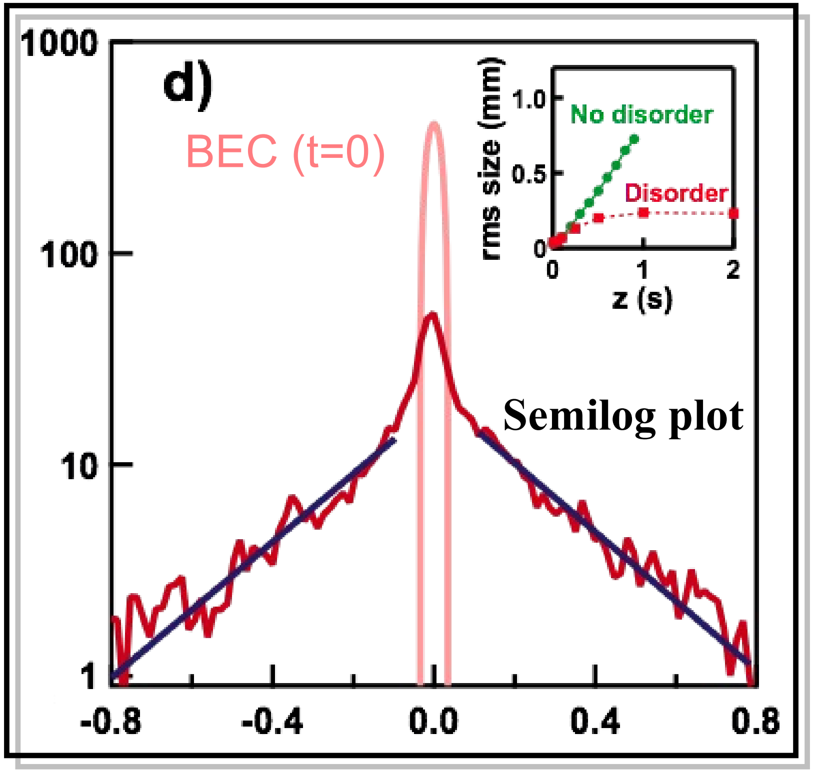
also Institute d’Optique

Hannover, Rice, Illinois …

Signature of Anderson Localization







J. Billy et al., ***Nature,*** 891 – 894 (2008)

Complementary experiment at
INSTITUTE D'OPTIQUE

Aspect

P.W.Anderson, Nobel lecture (1977)

… about the role of interactions.

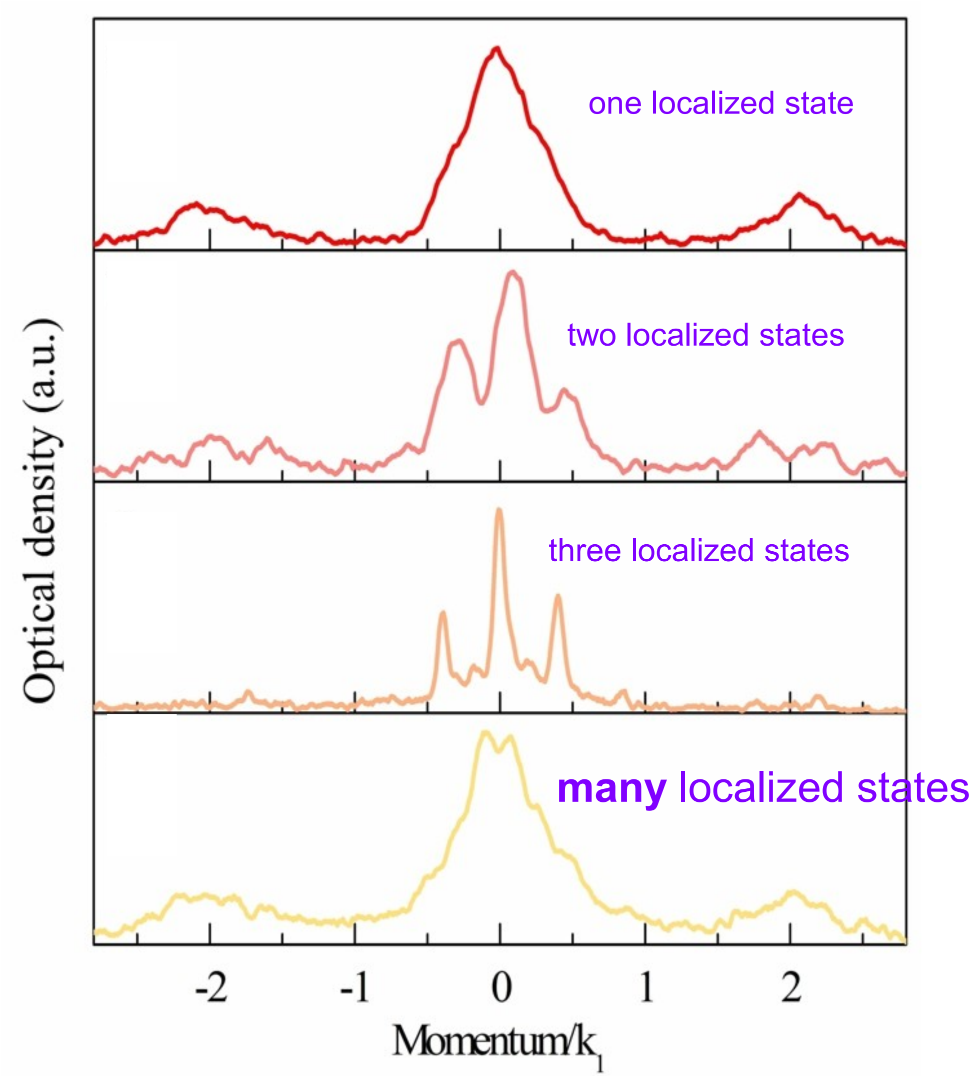
A second reason why I felt discouraged in the early days was that I couldn't fathom how to reinsert *interactions*, and I was afraid they, too, would delocalize.

The realization that, of course, the Mott insulator localizes without randomness, because of interactions, was my liberation on this: one can see easily that Mott and Anderson effects supplement, not destroy, each other …

The present excitement of the field for me is that a *theory of localization with interactions* is beginning to appear, …It is remarkable that in almost all cases **interactions play a vital role** , yet many results are not changed too seriously by them.

non interacting atoms in a disordered optical lattice

production of different localized states



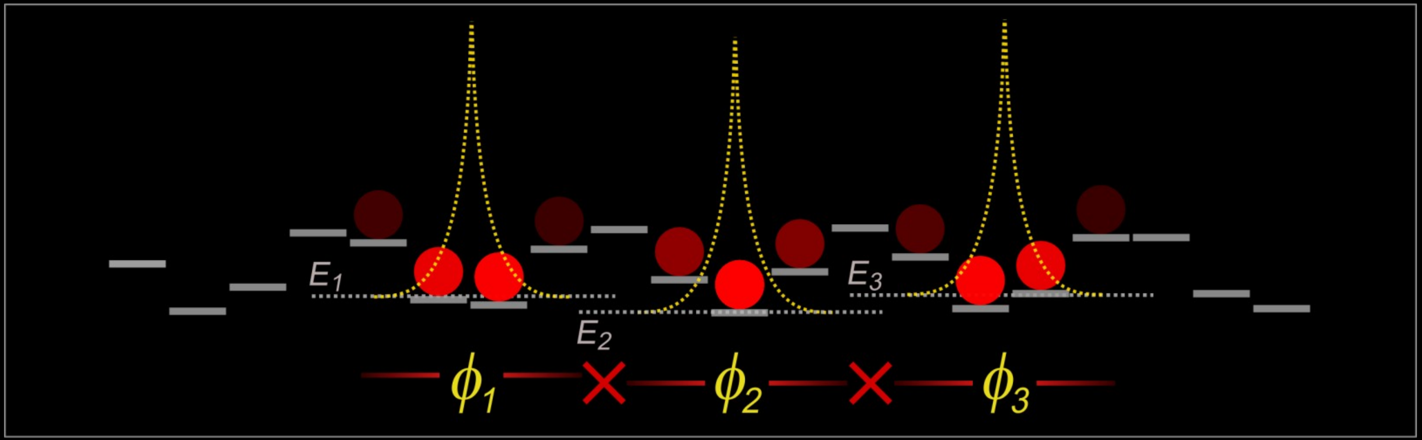
also 2D physics!

see Michele Modugno

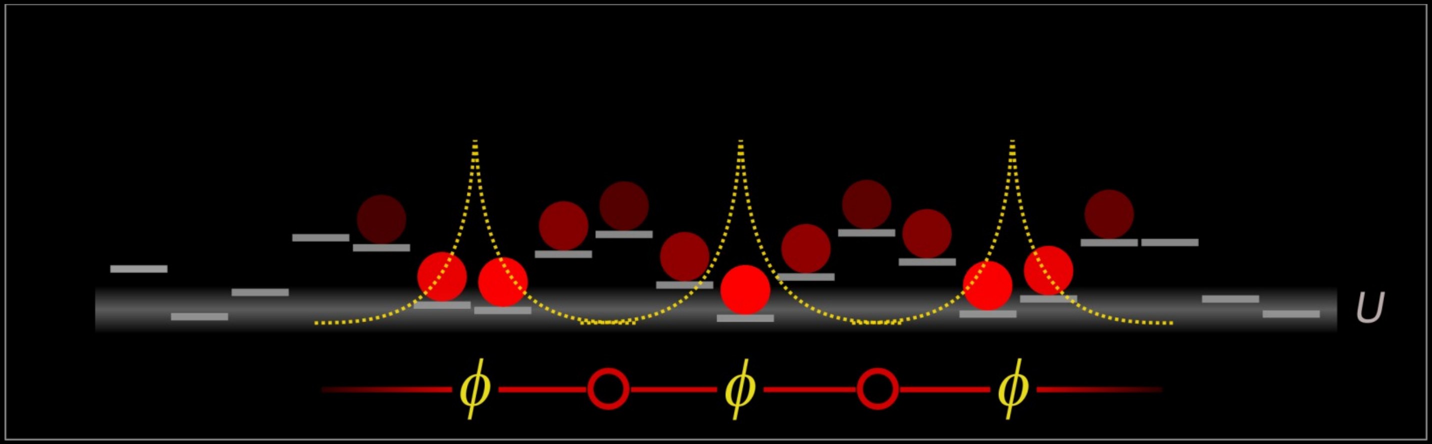
Tuesday Poster session

Disorder and interaction

No interaction: few independent localized states



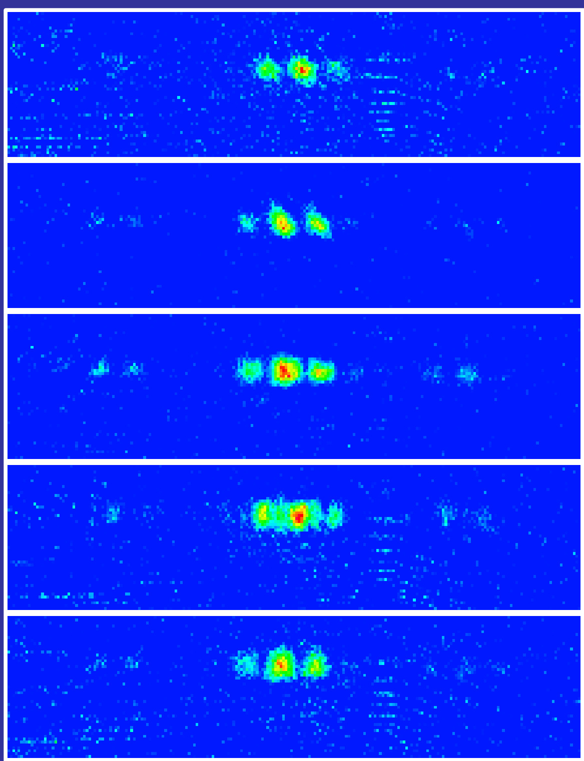
With interaction: localized states get more extendend and lock in phase



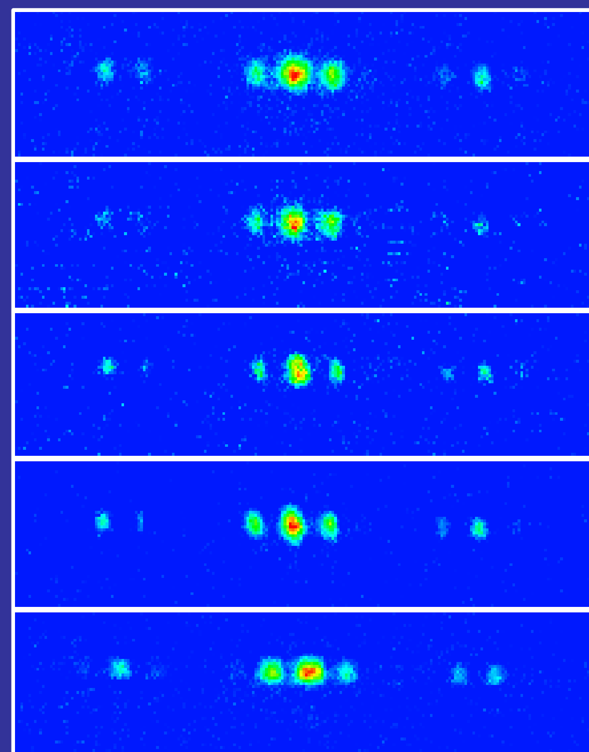
Adding interactions – several shots

Interferogram of multiple localized states:

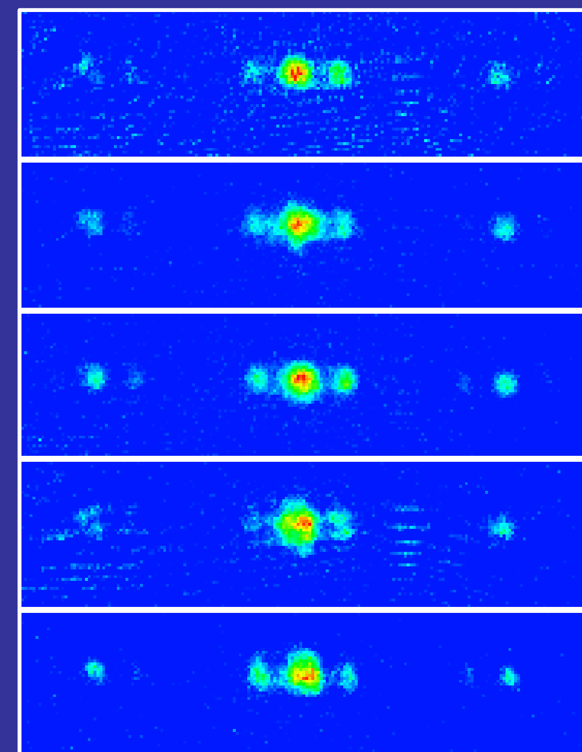
$a = 1.7a_0$



$a = 9.4a_0$

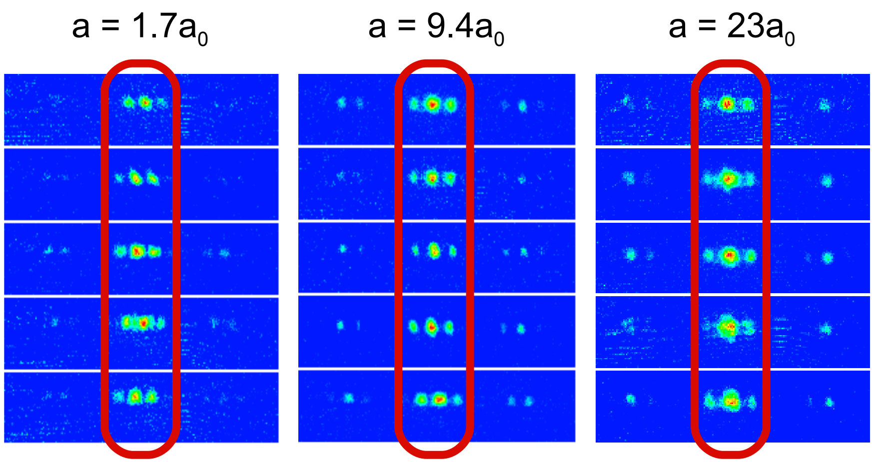


$a = 23a_0$

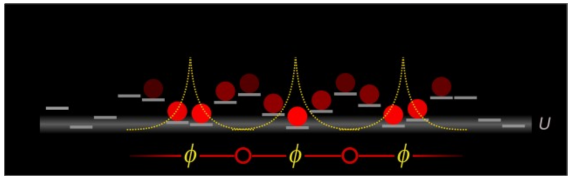


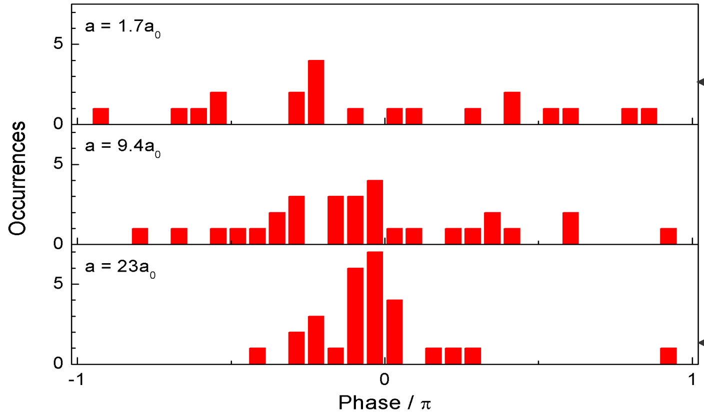
Preliminary results

First effects of the interactions on the interference pattern of multiple localized states:



fluctuating phase → fixed phase

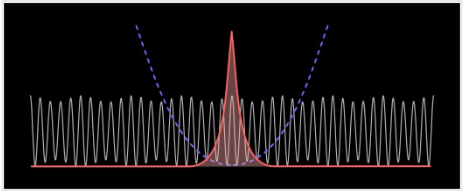




Non interacting regime: independent localized states (large separation with respect to their axial extent) → the phase of the interference pattern varies randomly in the range [0, 2π], from shot to shot.

Weakly interacting regime: the eigenstates of the system become a superposition of an increasing number of noninteracting eigenstates, and the effective tunneling between them increases→ the phase is locked.

Momentum distribution and interference



tight trapping (~100Hz)
[previous preliminary measurements]

a=0: interference between few localized states:

random phase (from shot to shot)

a>0: interacting groundstate
interference peaks but locked phase

☹ critical threshold affected by the harmonic potential

weak trapping (< 10Hz)

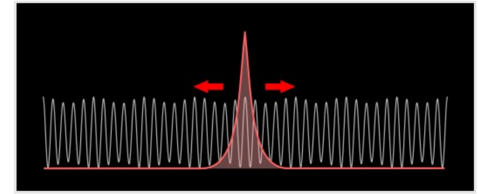
a=0: interference between many localized states:

no interference pattern

a>0: interference peaks

☺ critical threshold weakly perturbed

Quantum diffusion



PRL **100,** 094101 (2008) PHYSICAL REVIEW LETTERS week ending 7 MARCH 2008

Destruction of Anderson Localization by a Weak Nonlinearity

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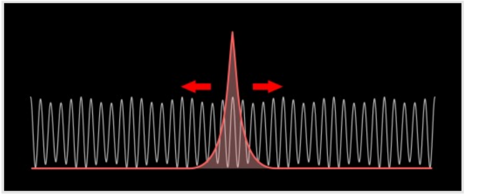
(Received 24 August 2007; published 4 March 2008)

We study numerically the spreading of an initially localized wave packet in a one-dimensional discrete nonlinear Schrödinger lattice with disorder. We demonstrate that above a certain critical strength of nonlinearity the Anderson localization is destroyed and an unlimited subdiffusive spreading of the field along the lattice occurs. The second moment grows with time $\propto t^{\alpha}$, with the exponent α being in the range 0.3–0.4. For small nonlinearities the distribution remains localized in a way similar to the linear case.

Quantum diffusion



PRL **100**, 084103 (2008) PHYSICAL REVIEW LETTERS week ending 29 FEBRUARY 2008

Absence of Wave Packet Diffusion in Disordered Nonlinear Systems

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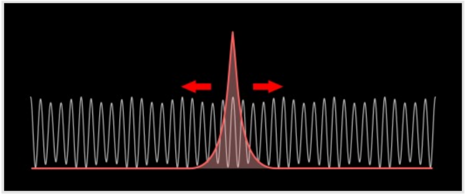
[1]*Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Strasse 38, D-01187 Dresden, Germany*
[2]*Department of Materials Science and Technology, University of Crete, 71003 Heraklion, Greece*
[3]*Laboratoire Léon Brillouin (CEA-CNRS), CEA Saclay, 91191-Gif-sur-Yvette, France*
(Received 11 October 2007; published 27 February 2008)

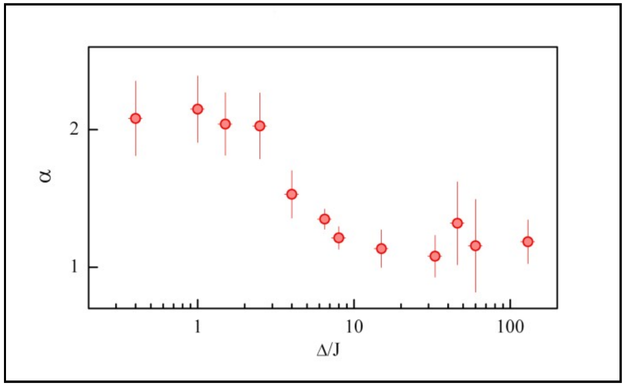
We study the spreading of an initially localized wave packet in two nonlinear chains (discrete nonlinear Schrödinger and quartic Klein-Gordon) with disorder. Previous studies suggest that there are many initial conditions such that the second moment of the norm and energy density distributions diverges with time. We find that the participation number of a wave packet does not diverge simultaneously. We prove this result analytically for norm-conserving models and strong enough nonlinearity. After long times we find a distribution of nondecaying yet interacting normal modes. The Fourier spectrum shows quasiperiodic dynamics. Assuming this result holds for any initially localized wave packet, we rule out the possibility of slow energy diffusion. The dynamical state could approach a quasiperiodic solution (Kolmogorov-Arnold-Moser torus) in the long time limit.

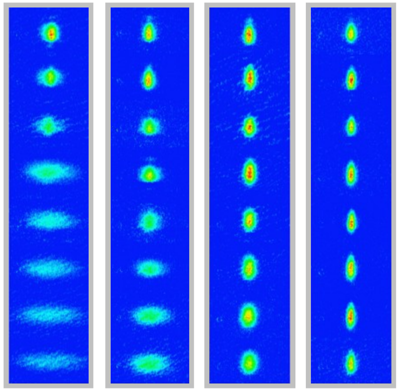
+ role of initial conditions (width of the wavepacket)

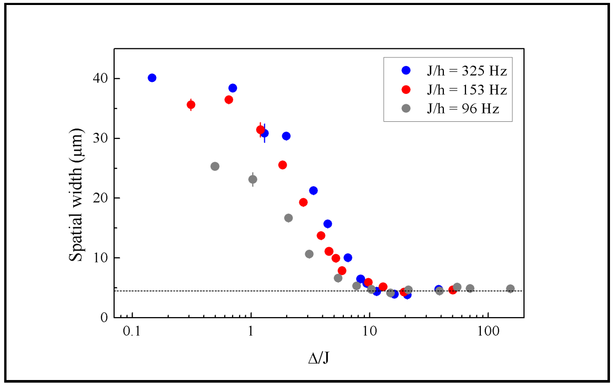
Quantum diffusion



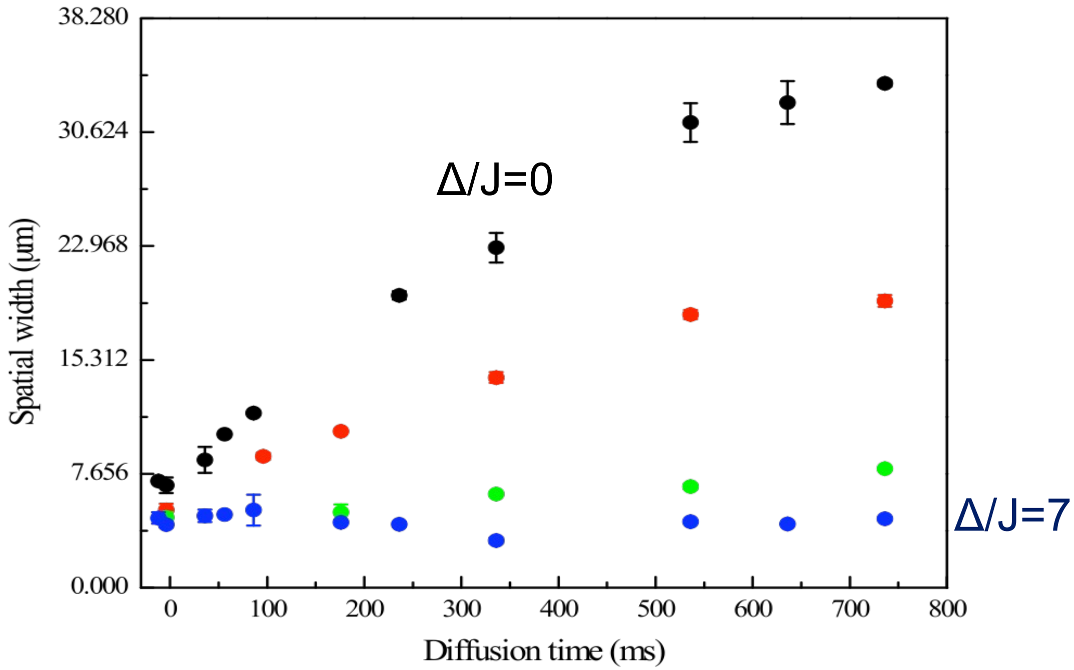
Diffusion at fixed s_1 for different values of the interaction?



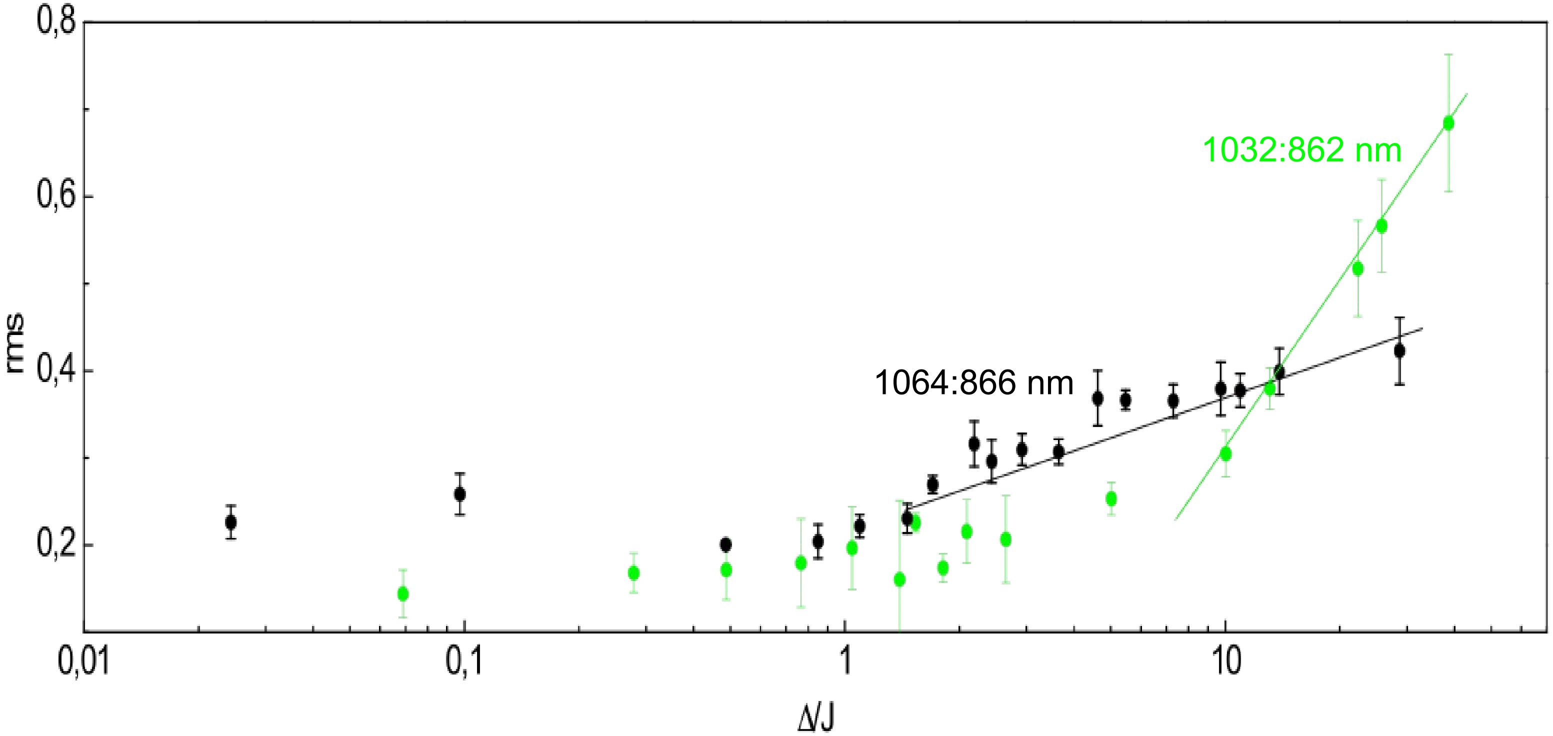




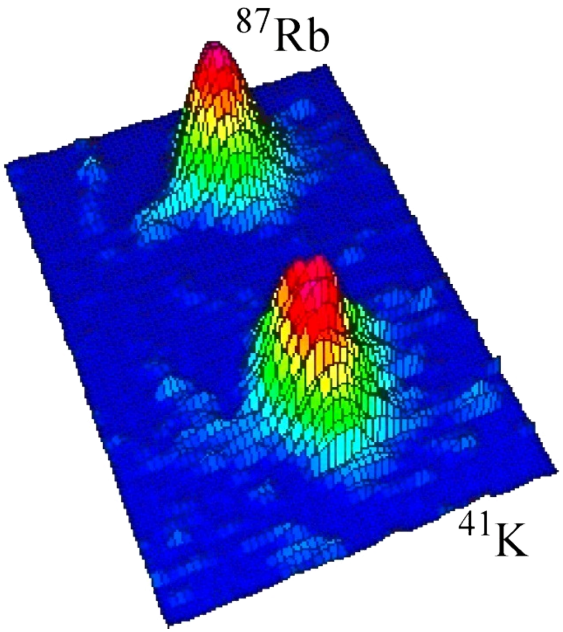
From diffusive to localized behaviour

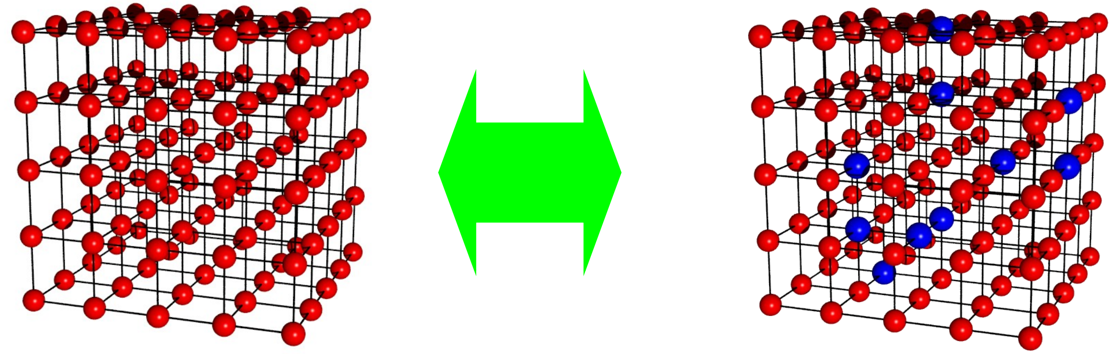


Changing the lattice wavelenghts

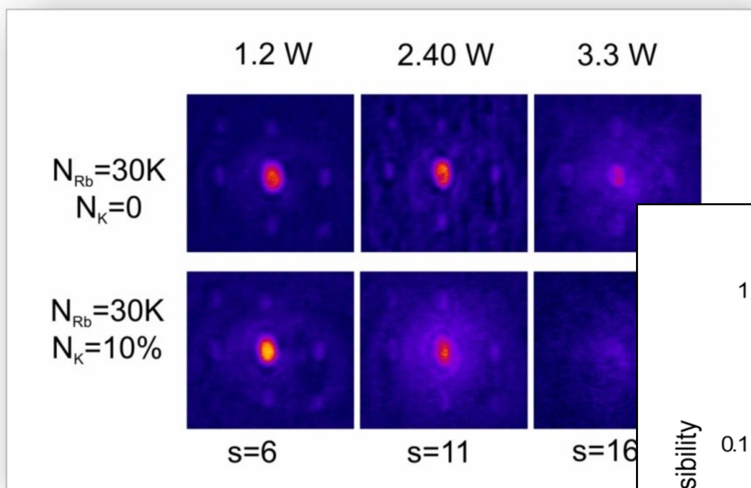


…different strategy

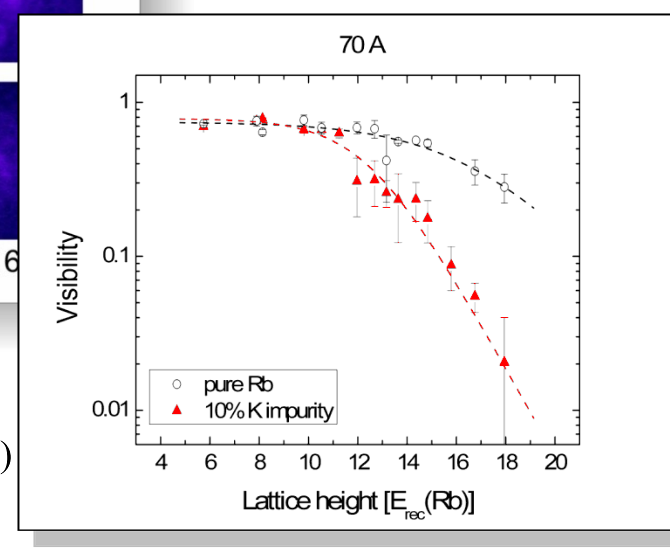




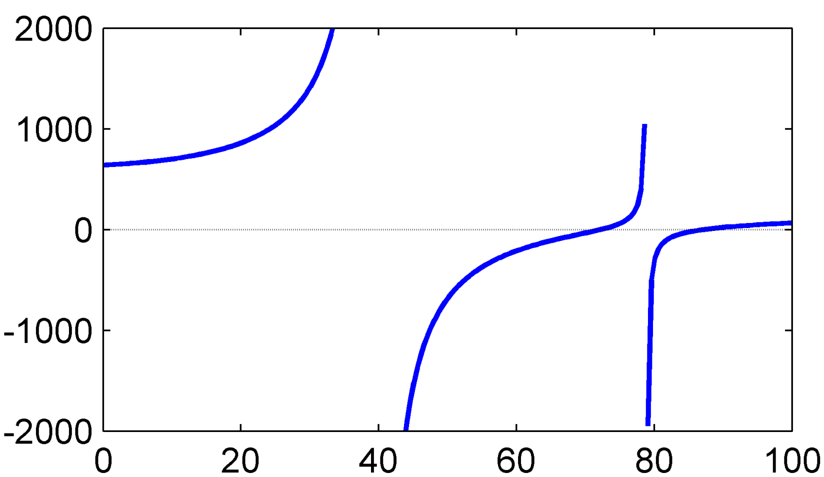
^{41}K/^{87}Rb mixture



Shift of the "Mott-insulator" transition.

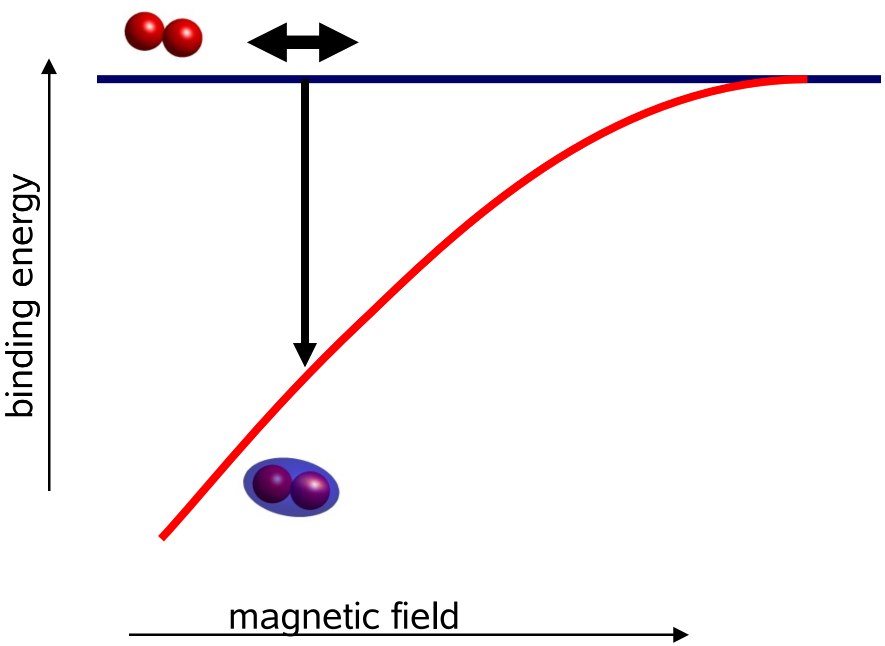


Degenerate Bose-Bose mixture in a 3D optical lattice
J. Catani, L. De Sarlo, G. Barontini, F. Minardi and M.I. PRA77, 011603R (2008)
Hamburg and Zurich with Fermions



Feshbach resonances

Thalhammer et al. PRL 100, 210402 (2008)

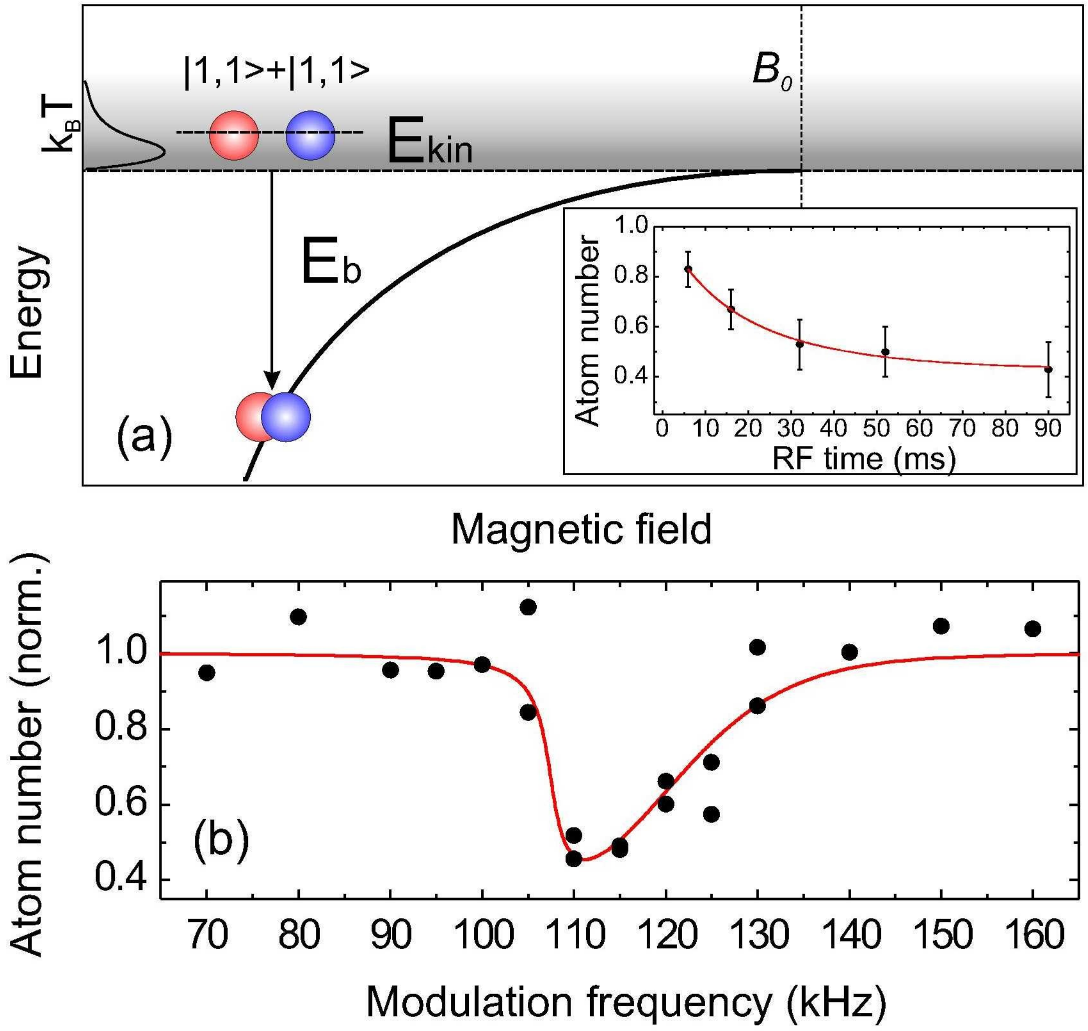


RF-association

associate molecules by modulating magnetic field near strong Feshbach resonance

inelastic molecule-atom collisions

Feshbach molecules, rf association



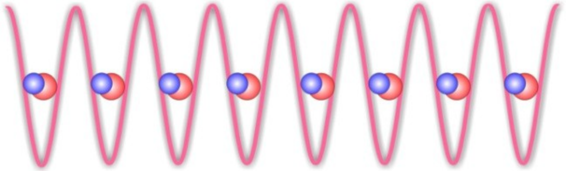
Molecules associated by resonant modulation of the Feshbach magnetic field

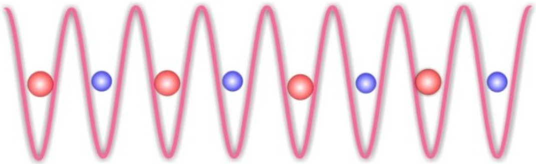
Weber et al cond mat 0808.4077

Quantum Phases in Optical Lattices

EFFECTIVE SPIN formalism can map a mixture of different species in OL on a Spin-like system , thus allowing the employment of Bosonic Mixtures for investigation on QUANTUM MAGNETISM.

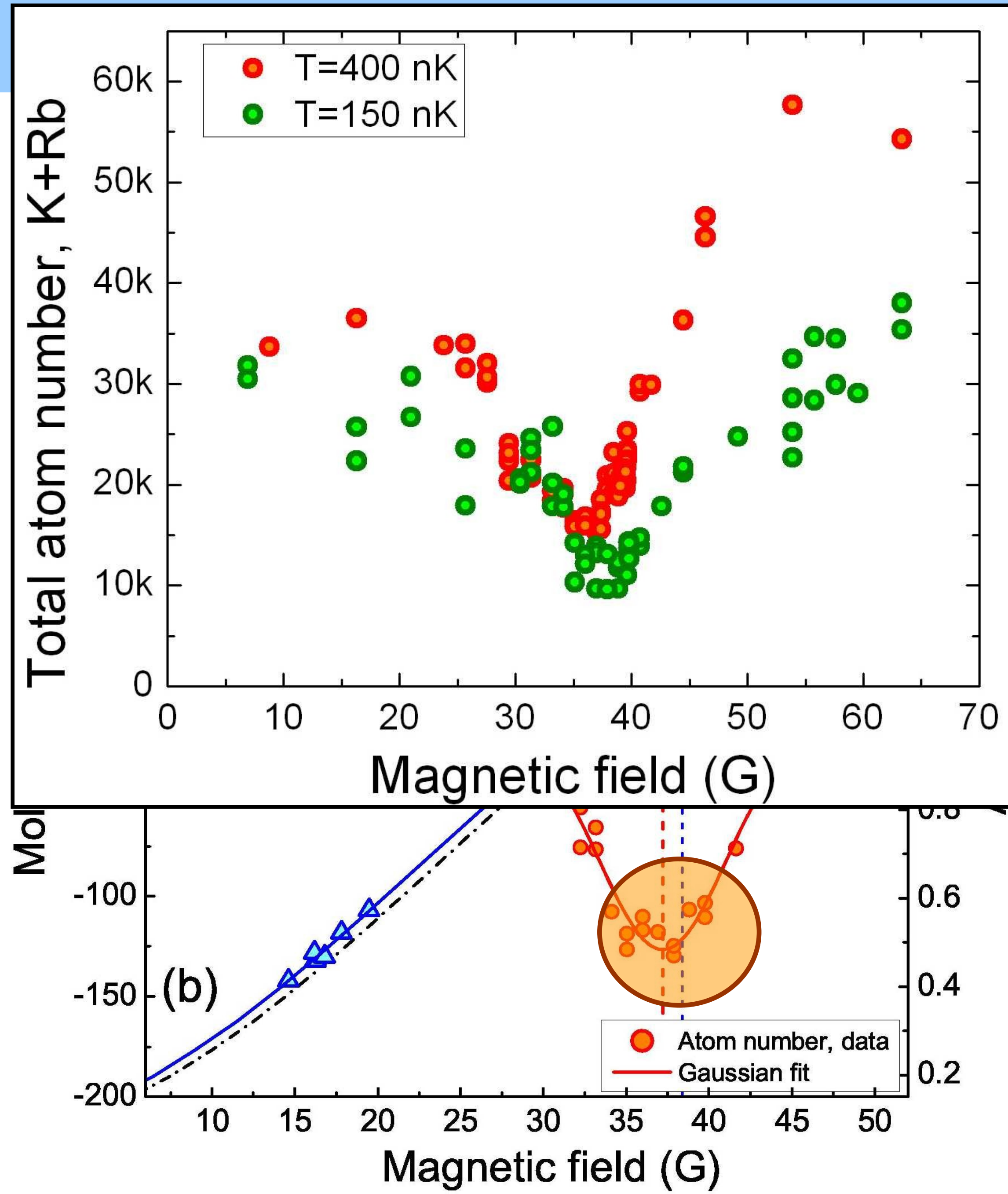
Depending on relative filling factor (equivalent to magnetization), and relative interaction, different magnetic phases in the deep lattice are expected, ranging from FERROMAGNETIC to Néel (or ANTIFERROMAGNETIC) ordered states.





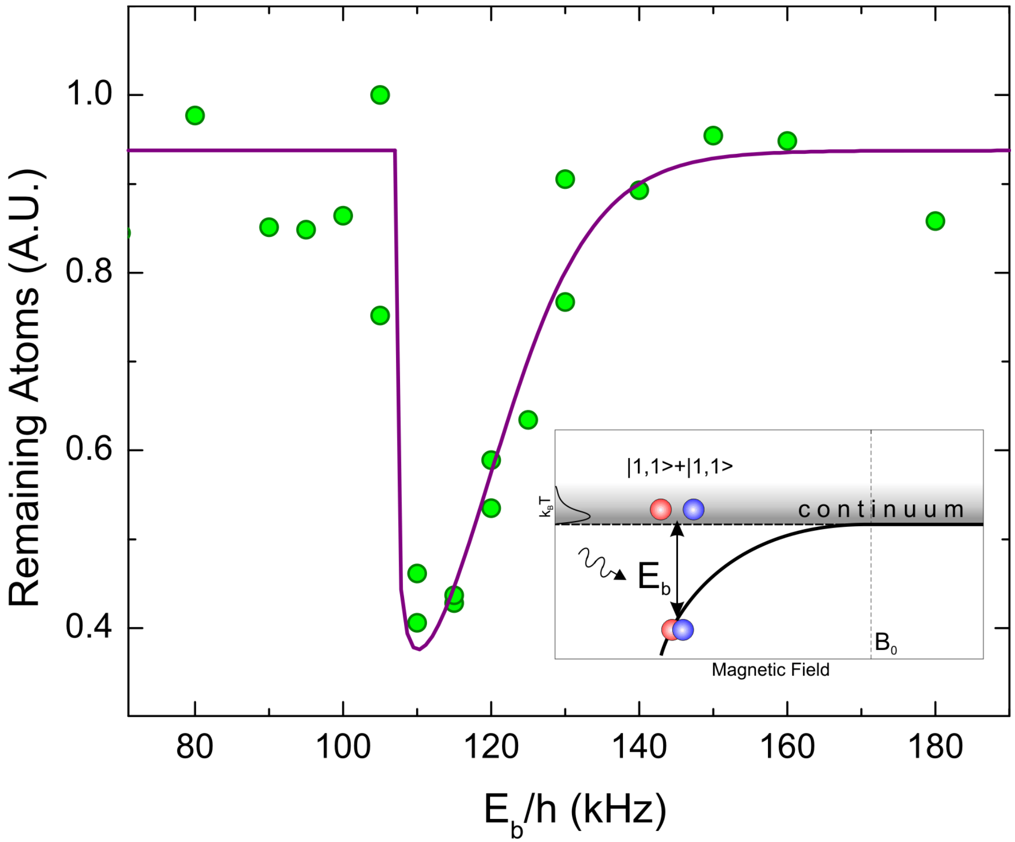
Strongly correlated systems in a highly controllable environment

py

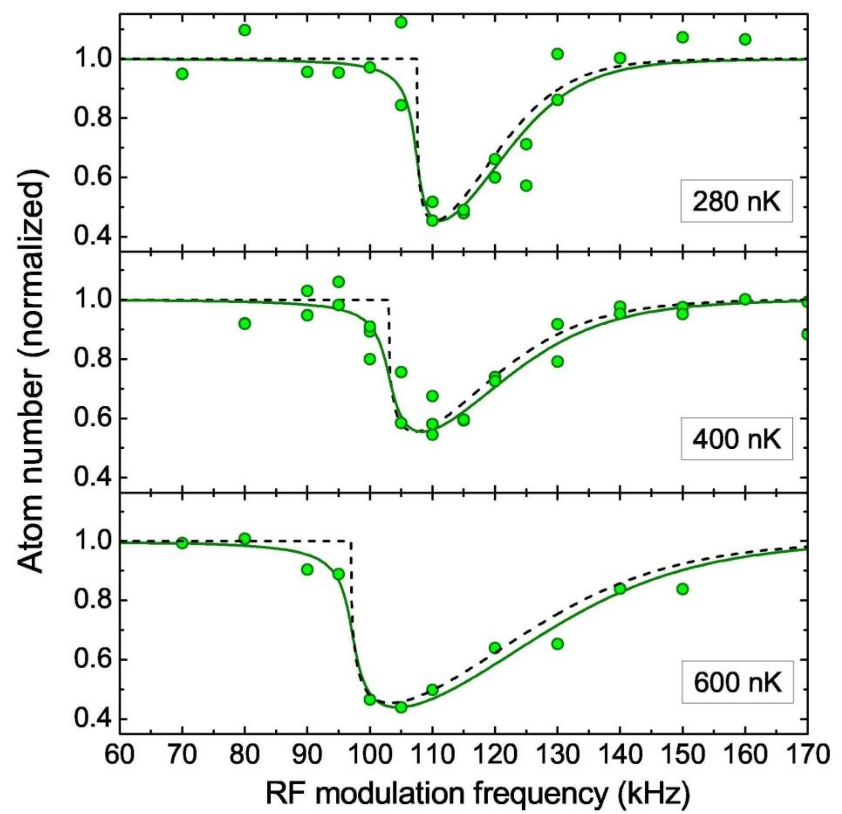


Feshbach position precisely determined by measuring the molecular binding energy vs magnetic field

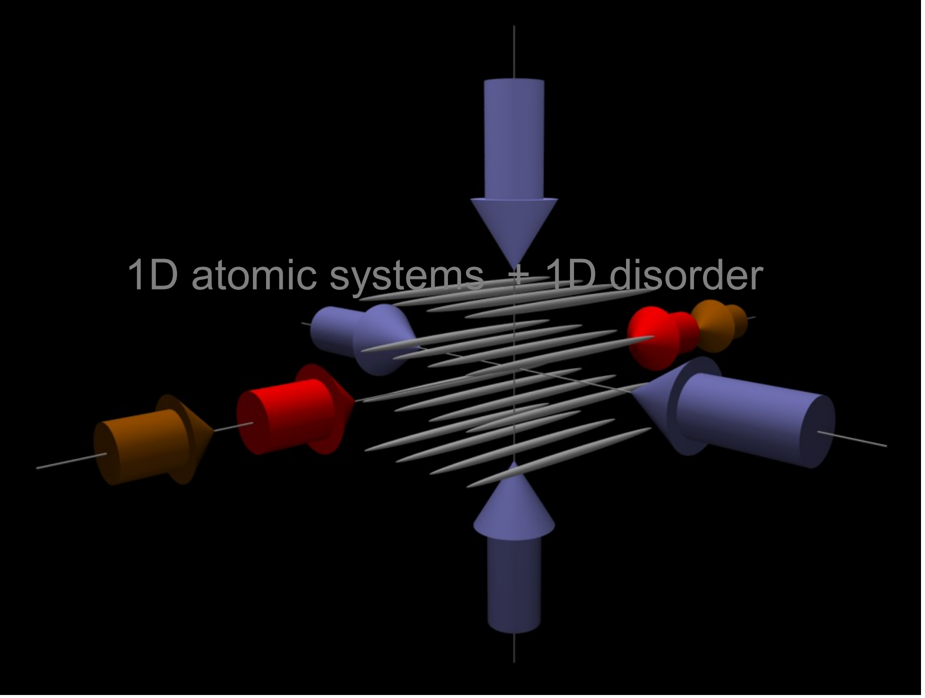
Three-body losses have a peak that depends on the sample temperature, complicated dynamics of trapped atoms and dimers



Remaining Atoms (A.U.)
1.0
0.8
0.6
0.4
80
100
120
140
160
180
E_b/h (kHz)
|1,1>+|1,1>
k_BT
continuum
E_b
B_0
Magnetic Field

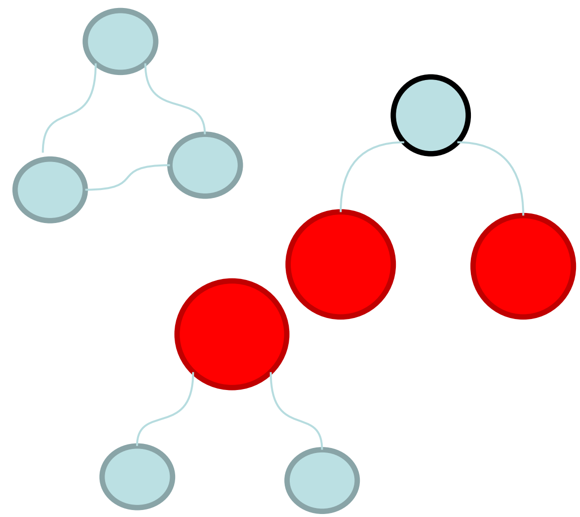


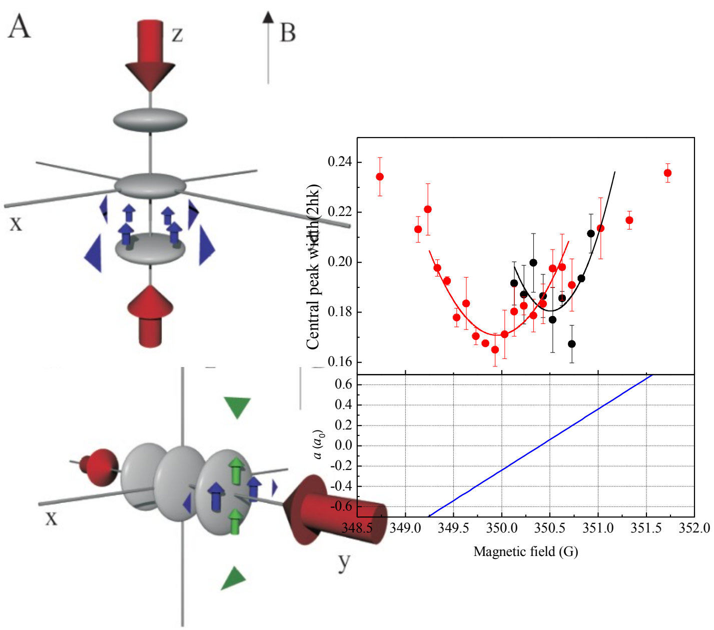
Atom number (normalized)
1.0
0.8
0.6
0.4
280 nK
400 nK
600 nK
60
70
80
90
100
110
120
130
140
150
160
170
RF modulation frequency (kHz)



BRAGG

EFIMOV





Bloch oscillations
Dipolar effects

Microtraps. Photonic crystals…