Mezinárodní centrum pro informaci a neurčitost

Registrační číslo: CZ.1.07/2.3.00/20.0060

evropský sociální fond v ČR

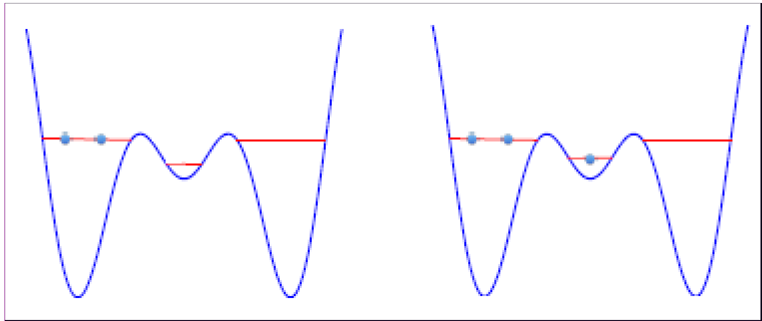
EVROPSKÁ UNIE

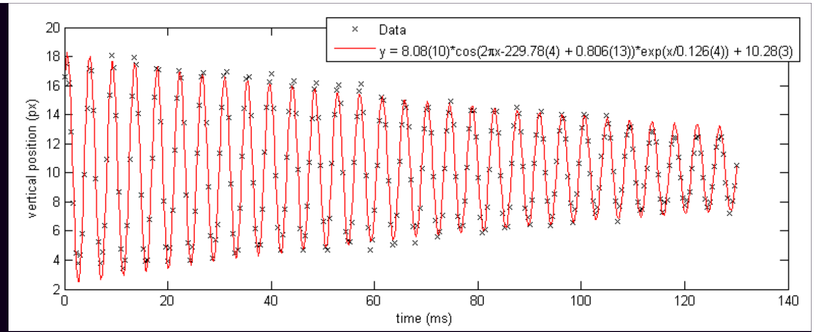
MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY

OP Vzdělávání pro konkurenceschopnost

INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

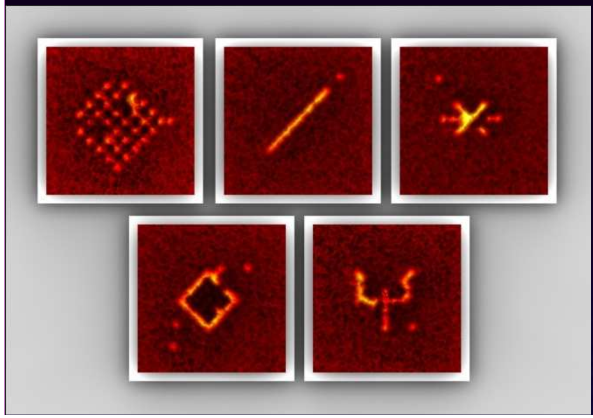
Tento projekt je spolufinancován Evropským sociálním fondem a státním rozpočtem České republiky.





Resources for quantum technologies

Jacob Sherson

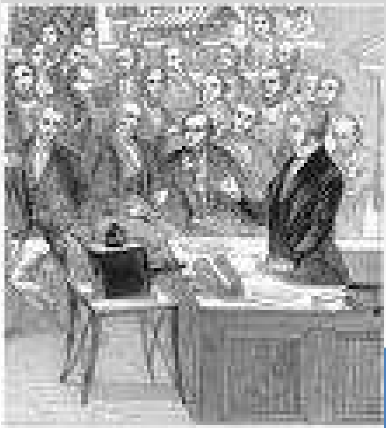


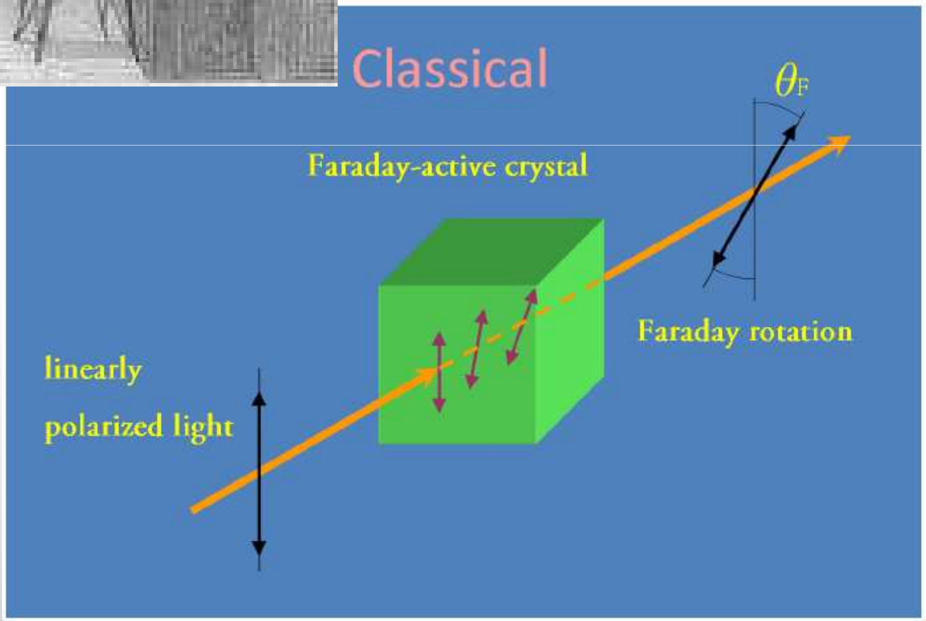
Olomouc 26/6-2012

Outline

- Non-destructive imaging
- Triple-well atomtronics
- The quantum computer game

Faraday rotation (1845)





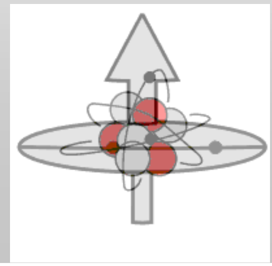
Different phase shift for the two circular components:

- Jones vector notation

$$\begin{pmatrix}1\\0\end{pmatrix}=\frac{1}{2}\left[\begin{pmatrix}1\\-i\end{pmatrix}+\begin{pmatrix}1\\i\end{pmatrix}\right]\rightarrow\frac{1}{2}\left[e^{i\theta_F}\begin{pmatrix}1\\-i\end{pmatrix}+e^{-i\theta_F}\begin{pmatrix}1\\i\end{pmatrix}\right]=\begin{pmatrix}\cos\theta_F\\ \sin\theta_F\end{pmatrix}$$

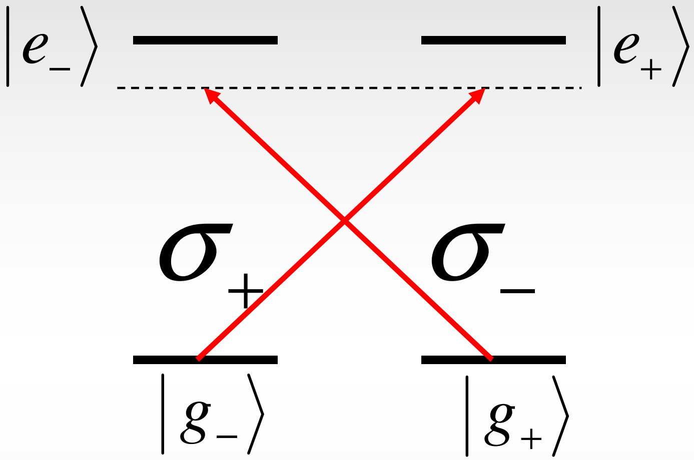
H. C. Ørsted (1820)

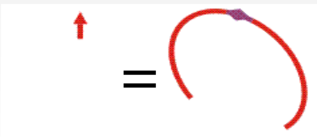
Moving charges generate magnetic fields.



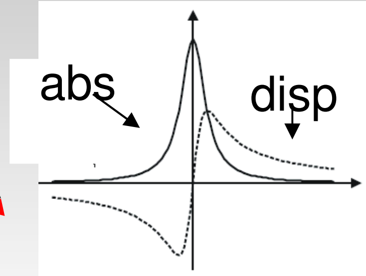
Faraday rotation, quantum version

Birefringence:



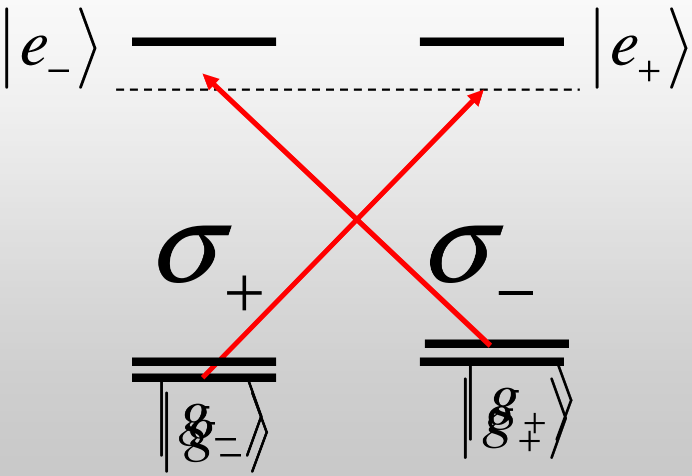


Linear polarization

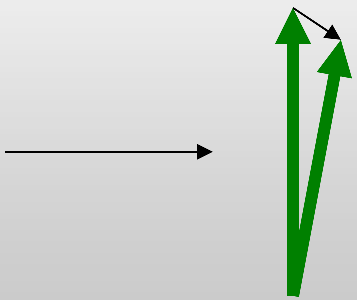


Linear polarization is rotated

AC-Stark shift:



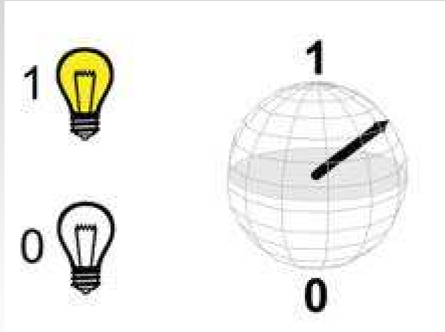
$$H = aJ_z S_z$$

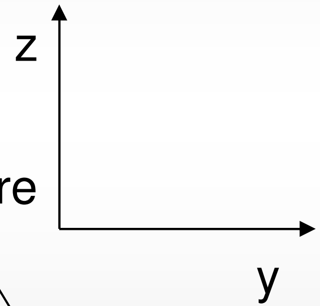


Atomic orientation is rotated

Complementarity

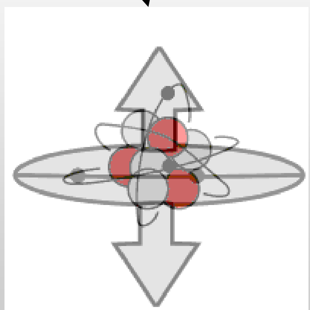
Single atom: 2 possible spins
in each direction



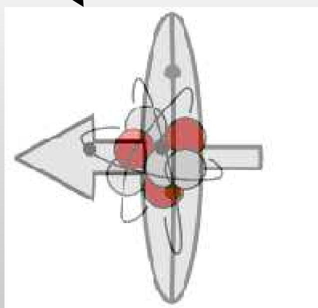


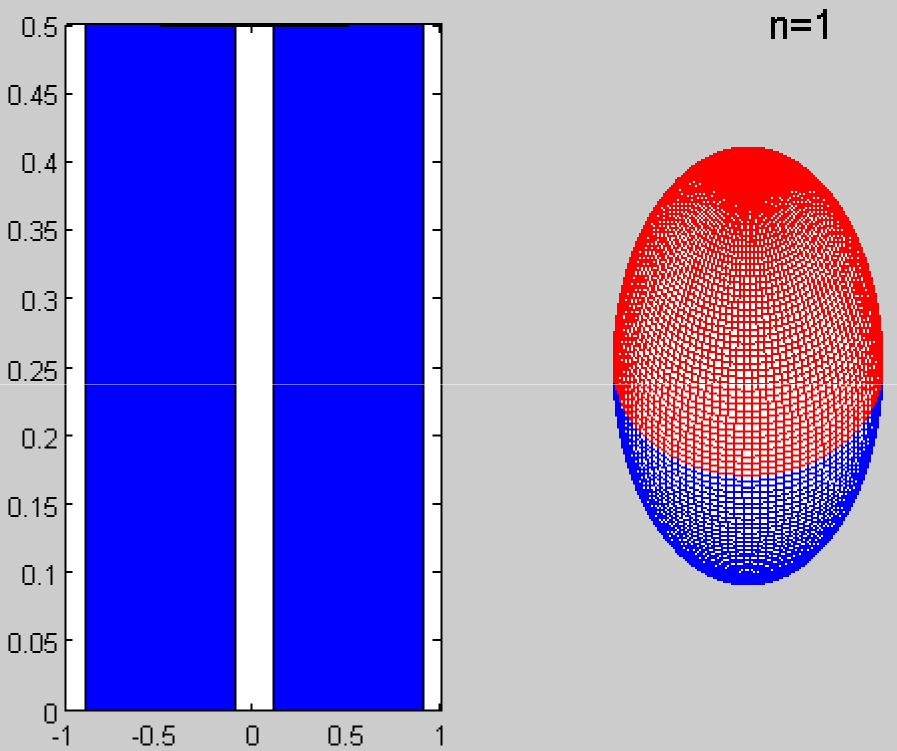
If two quantities are complementary, they cannot be known precisely at the same time

Prepare



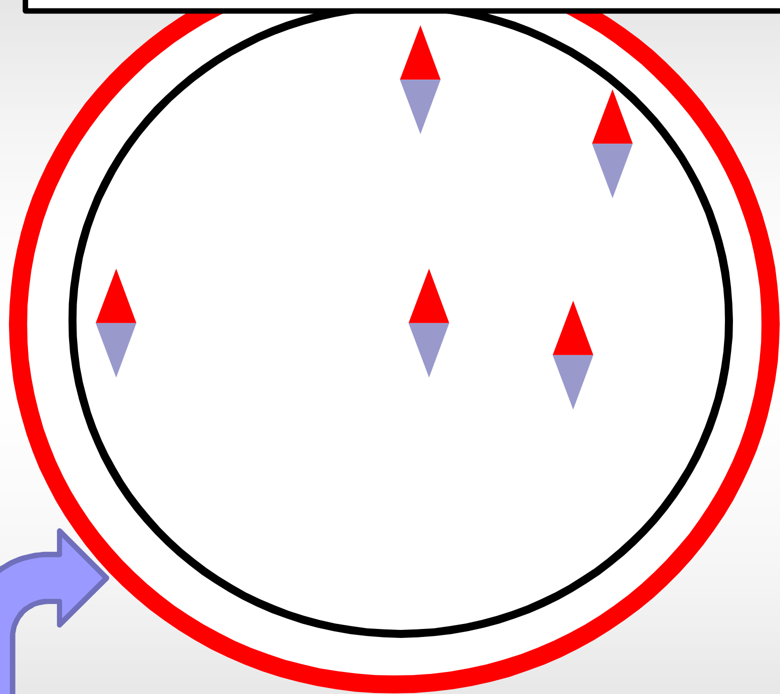
Measure





- Relative size of quantum fluctuations decreases
- discrete -> Continuous variables

Room temperature vapor cell ($N \sim 10^{12}$)

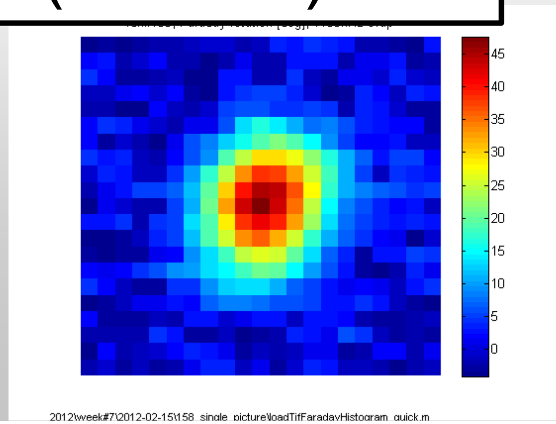


Polzik group

Nature 2004: Experimental demonstration of quantum memory for light

Nature 2006: Quantum teleportation between light and matter

Ultracold cloud ($N \sim 10^{5}$)



Two options:

- Longitudinal probing (classical)
- Transverse probing (quantum)

Århus experiment

Research group members:

Jan Arlt
Associate Prof

Jacob Sherson
Assistant Prof

Ultracold Bosons in Optical Lattices

Poul Pedersen

Miroslav Gajdacz

Multi Species Quantum Gases

Nils Winter

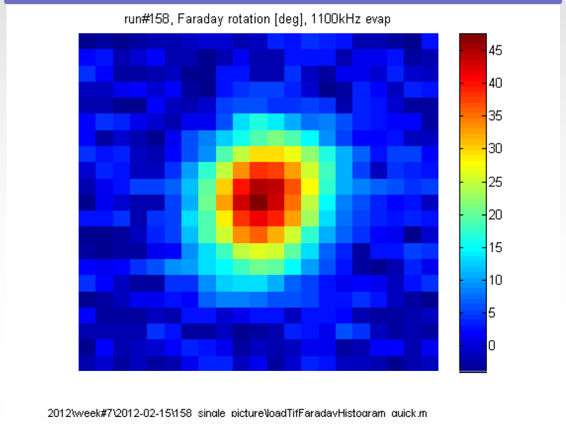
Lars Wacker

High resolution lab

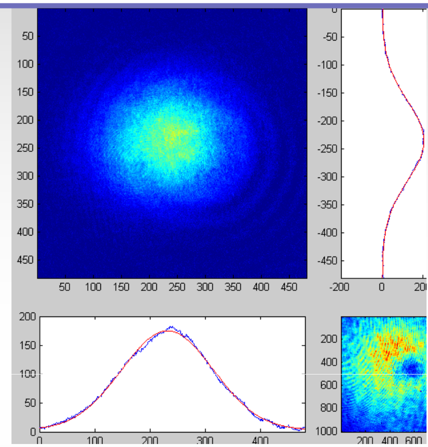
Romain Müller

Non-destructive imaging and feedback

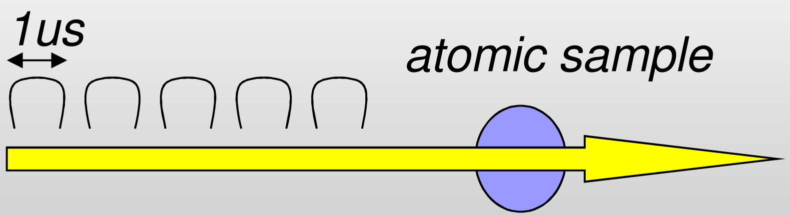
Faraday image of a thermal cloud



Absorption image (destructive)

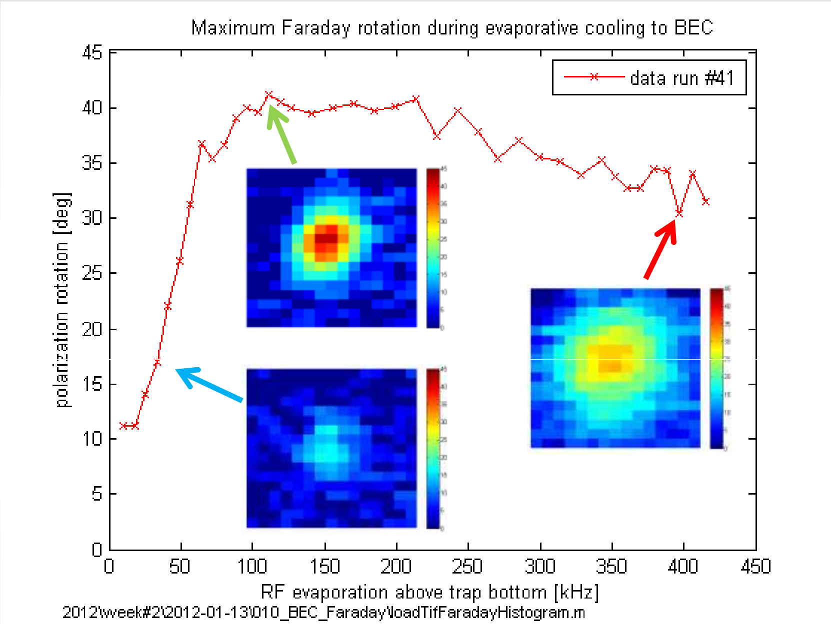


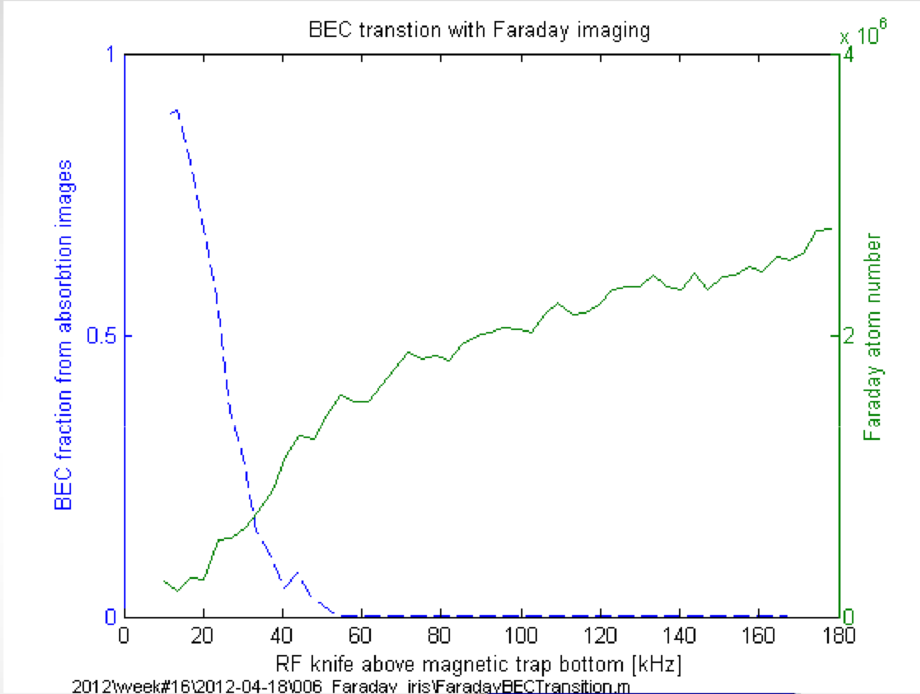
Absorption probability 0.003 per pulse!



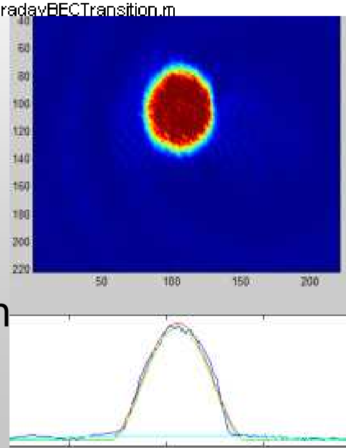
Continuous measurements

Single run monitoring of BEC transition





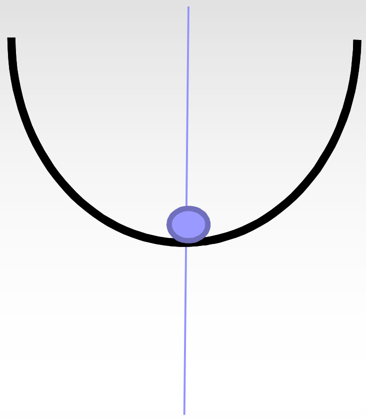
- multiple non-destructive pictures during cooling sequence
- sudden drop of maximum Faraday angle



- BEC confirmed by absorption image at the en

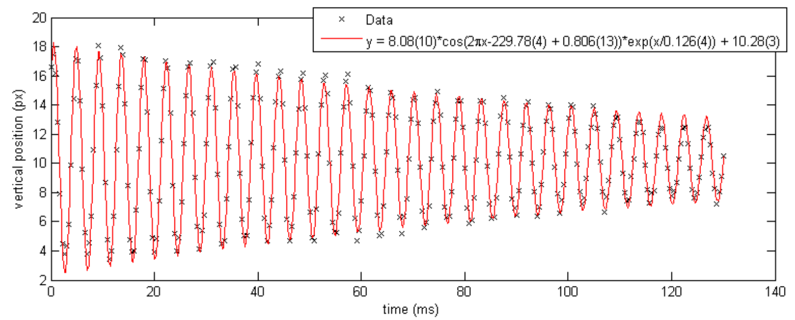
Non-destructive imaging and feedback

Suddenly shift the position of the trap

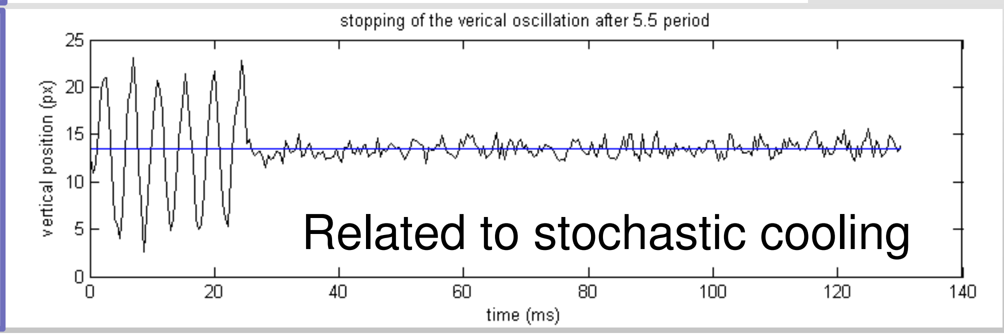


- Fast characterization of trap parameters
- Possibility for quantum (feedback) control

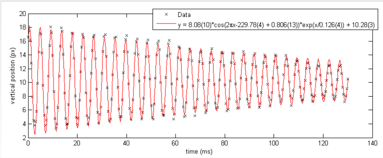
300 images of the same oscillating cloud



Stopping the motion of an oscillating cloud



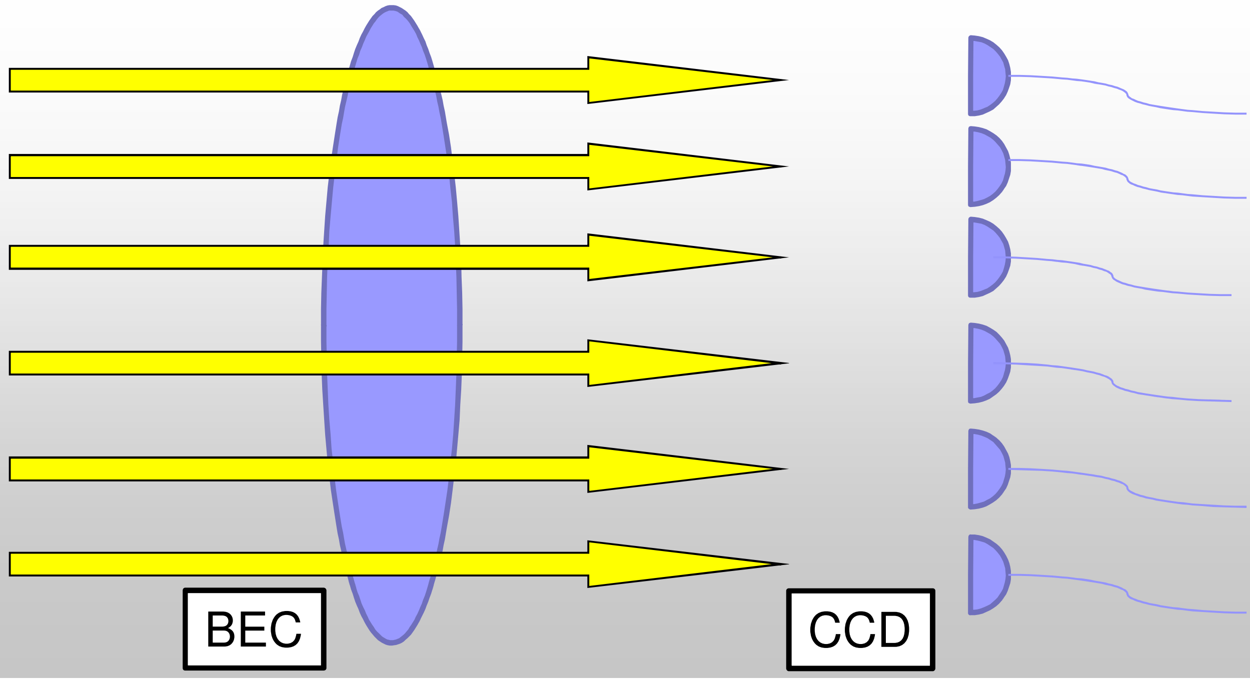
Some future perspectives



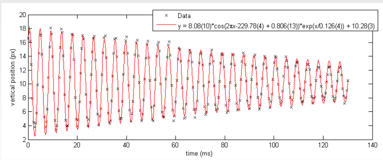
Measure and influence fundamental excitation modes of a BEC

- Squeezing
- Entanglement
- Fock- and Schrödinger cat states

Bogoluibov modes

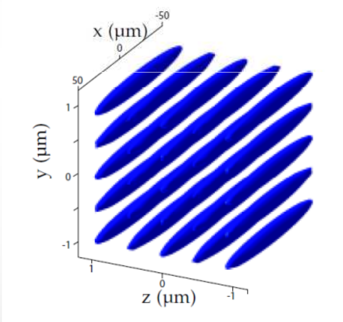


Some future perspectives



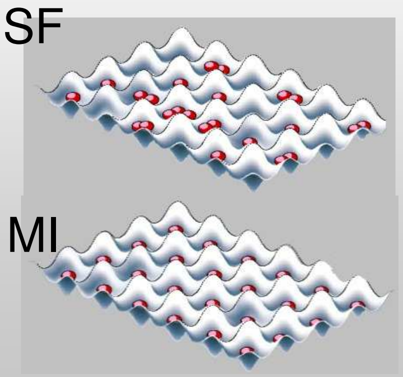
Measure and influence fundamental excitation modes of a BEC

- Squeezing
- Entanglement
- Fock- and Schrödinger cat states



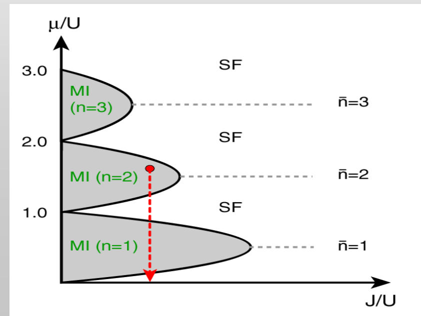
QND probing of a single 1D tube in a 2D optical lattice

- High capacity quantum memory
- Large Schrödinger cat states



QND probing of interacting quantum many-body states

- Modify quantum phase diagrams

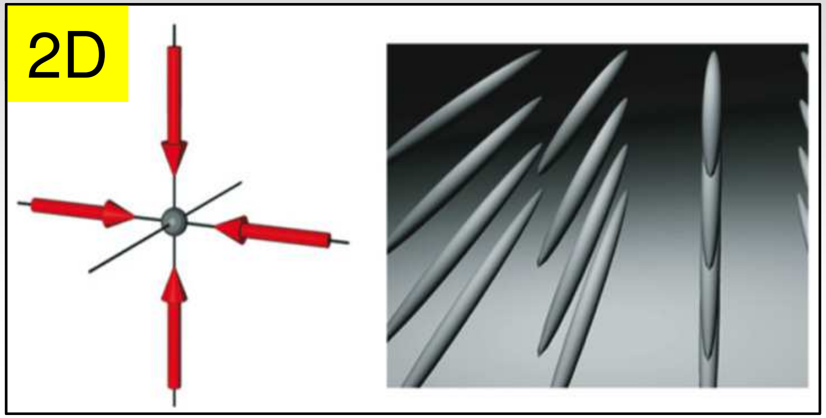


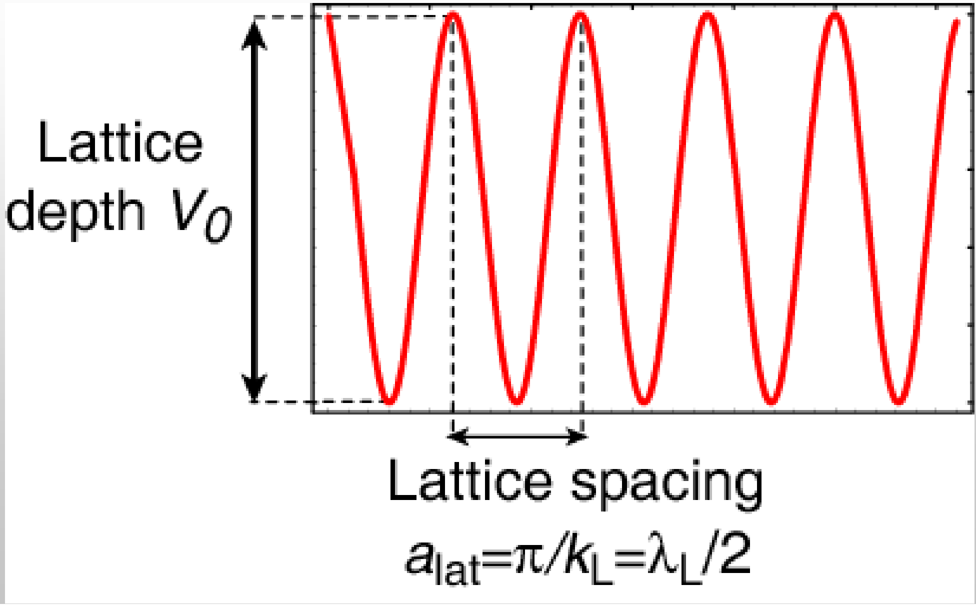
Outline

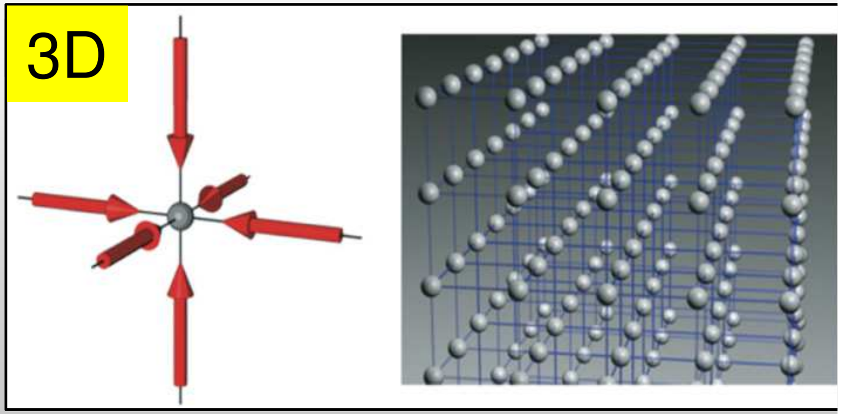
- Non-destructive imaging
- Triple-well atomtronics
- The quantum computer game

Optical lattices

Potential: $V(x) = V_0 \sin^2(k_L x)$





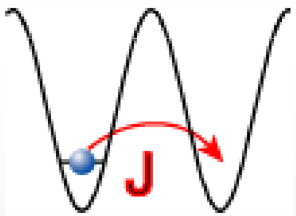


Bose-Hubbard Hamiltonian

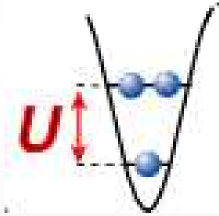
Expanding the field operator in the Wannier basis of localized wave functions on each lattice site, yields :

$$\hat{\psi}(\boldsymbol{x}) = \sum_i \hat{a}_i w(\boldsymbol{x} - \boldsymbol{x}_i)$$

Bose-Hubbard Hamiltonian



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



Tunnelmatrix element/Hopping element

$$J = -\int d^3x\, w(\boldsymbol{x} - \boldsymbol{x}_i) \left(-\frac{\hbar^2}{2m} \nabla^2 + V_{lat}(\boldsymbol{x}) \right) w(\boldsymbol{x} - \boldsymbol{x}_j)$$

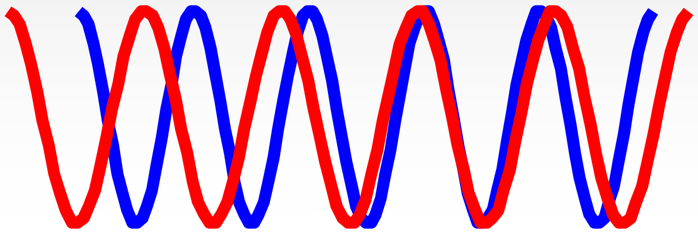
Onsite interaction matrix element

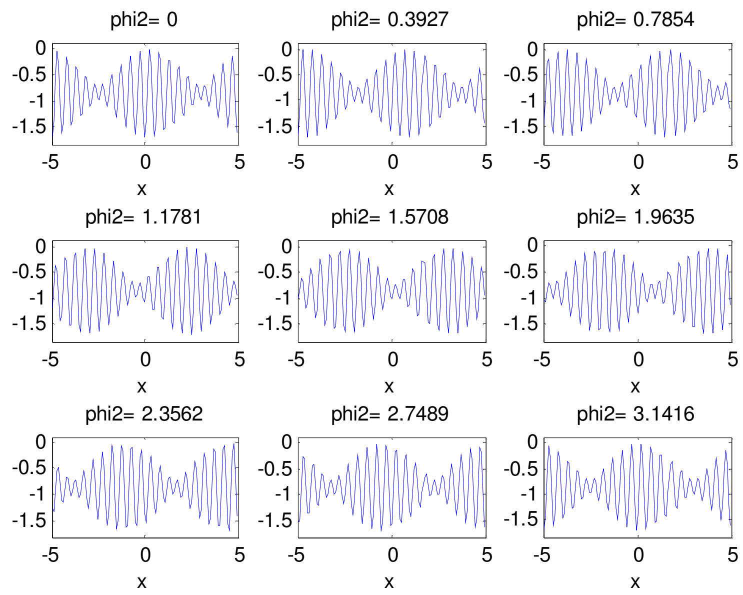
$$U = \frac{4\pi \hbar^2 a}{m} \int d^3x \left| w(\boldsymbol{x}) \right|^4$$

M.P.A. Fisher et al., PRB 40, 546 (1989); D. Jaksch et al., PRL 81, 3108 (1998)

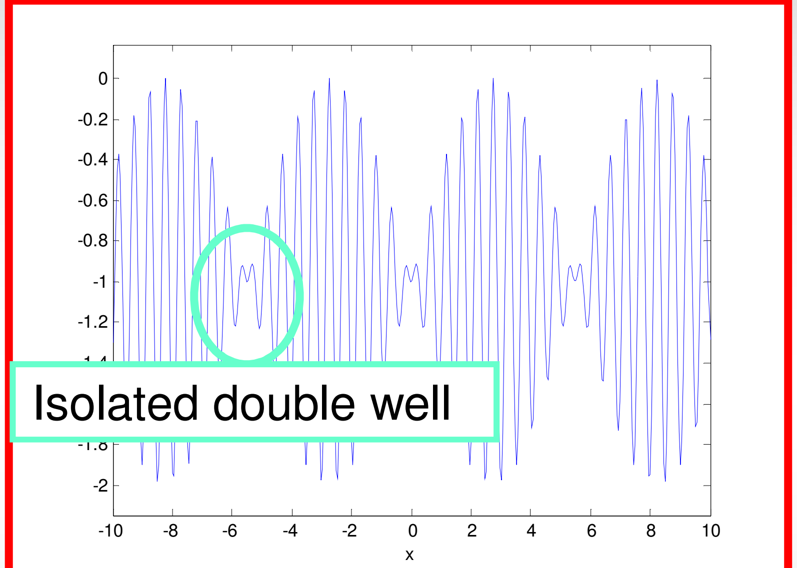
Large period superlattice

Overlap two standing waves of close lying frequency





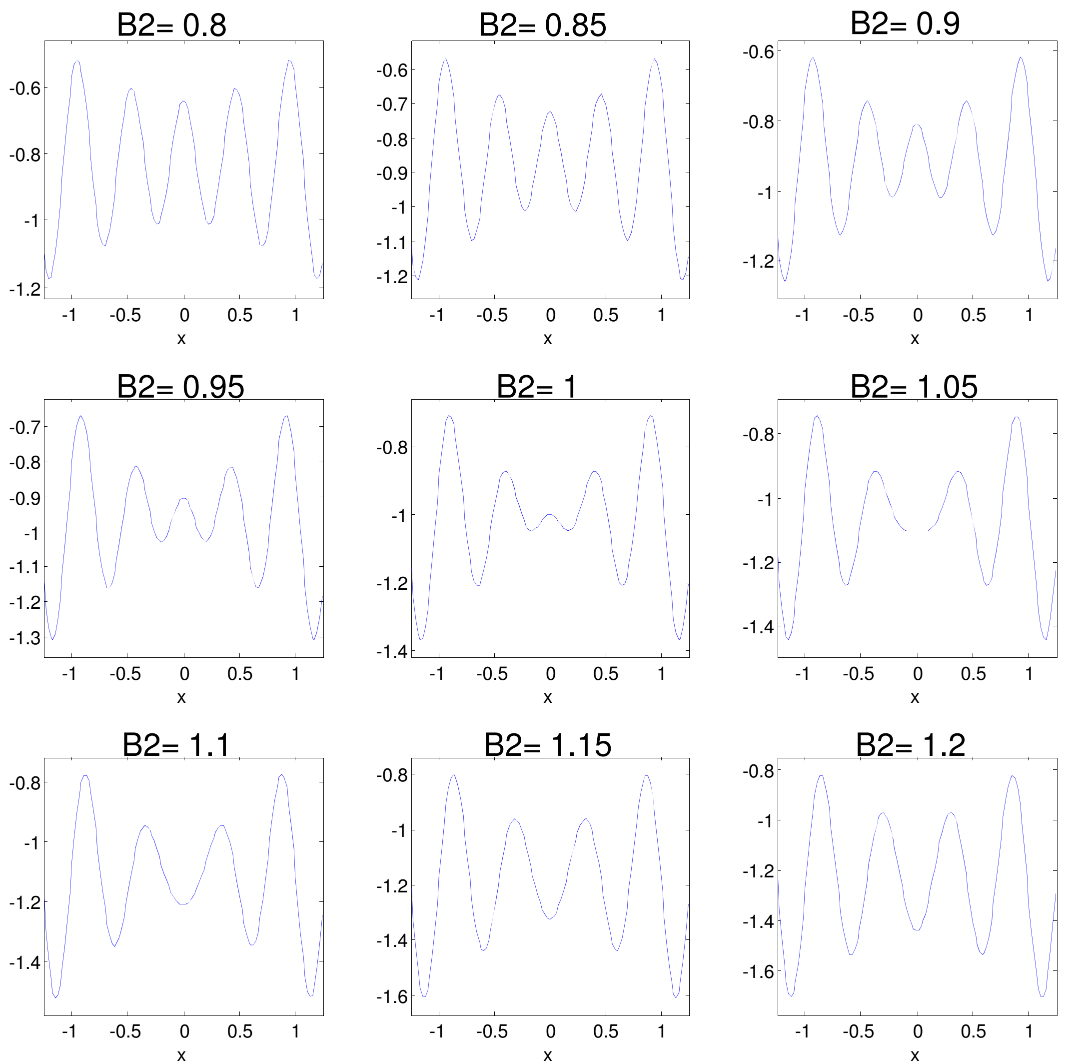
λ_1/λ_2=1.055



Scanning the relative phase using frequency adjustment allows for ultra-precise addressing of individual sites

Double well dynamics

- The relative amplitude gives full control of the barrier height
- The relative phase controls the asymmetry of the double well



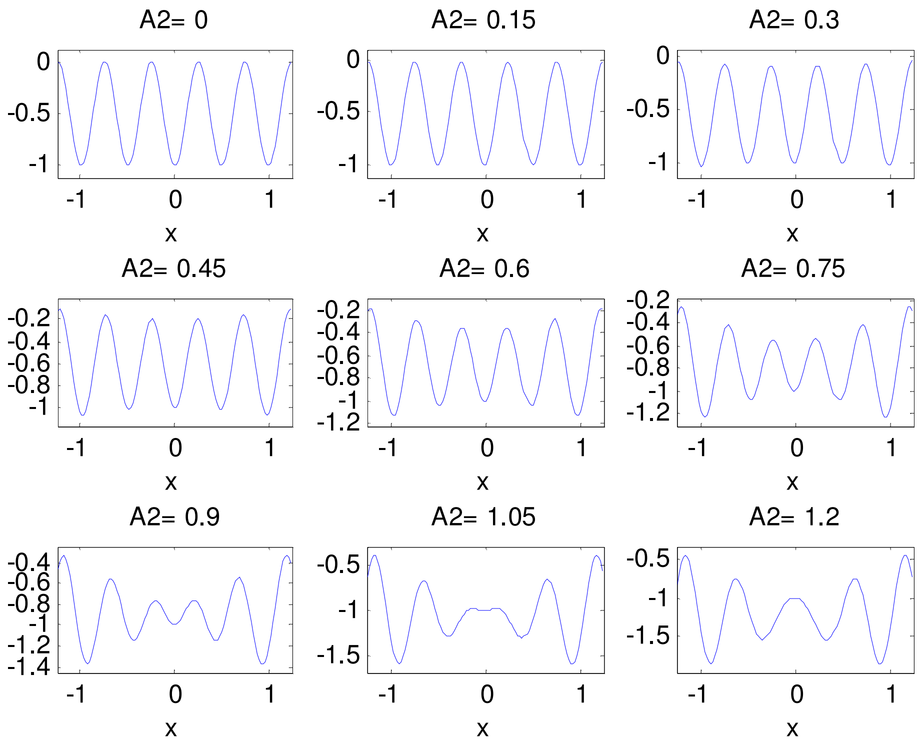
$\lambda_1/\lambda_2=1.055$

Perspectives

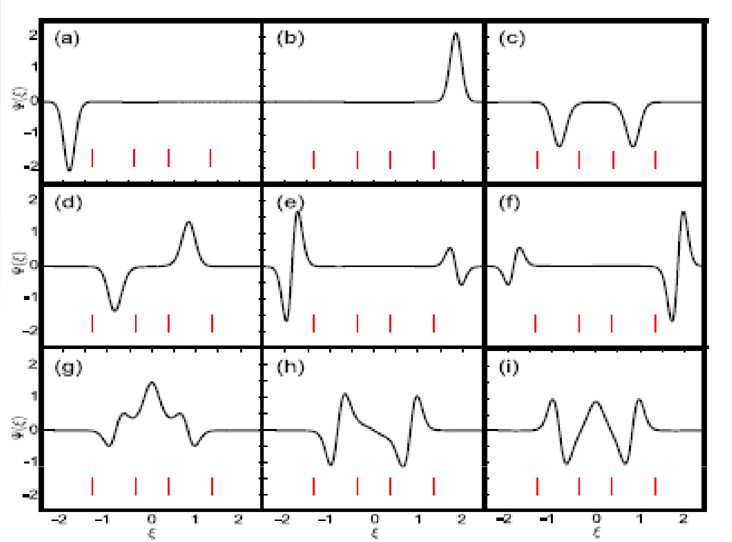
- Local double well merger
- Local directed transport

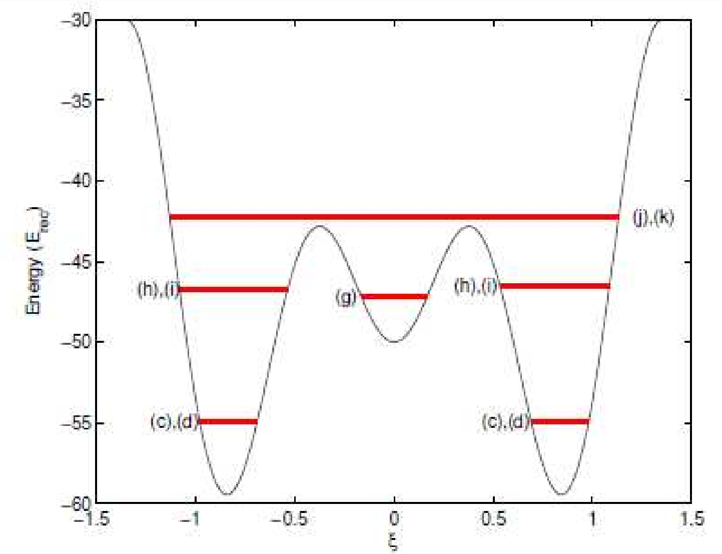
Triple well dynamics: towards atomtronics

Different choice of relative phase: triple well



$\lambda_1/\lambda_2=1.1$

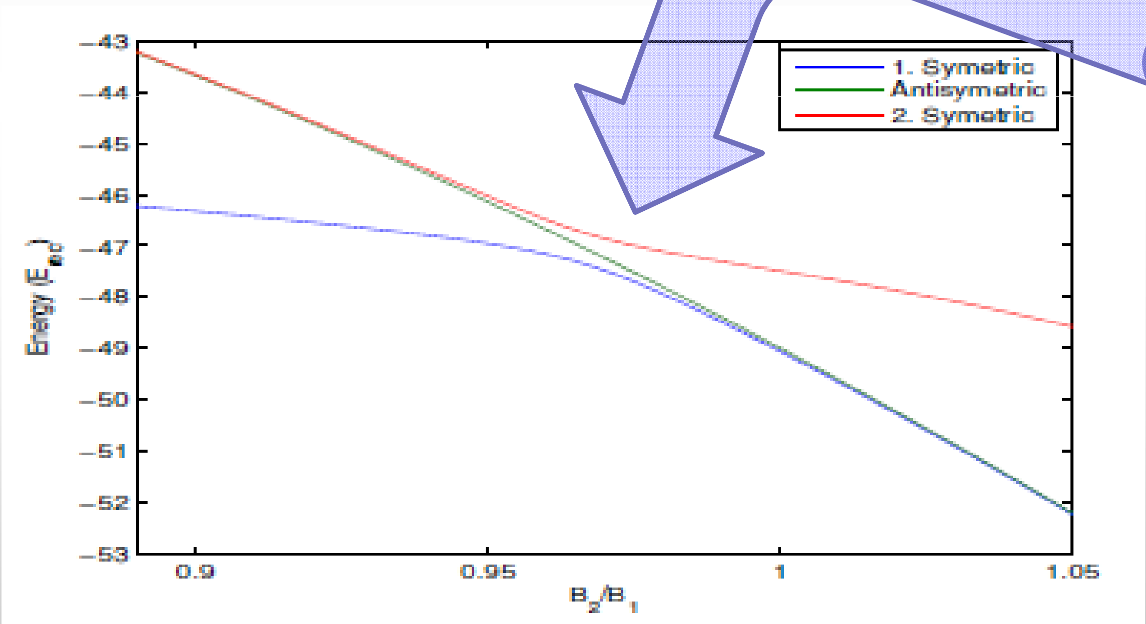


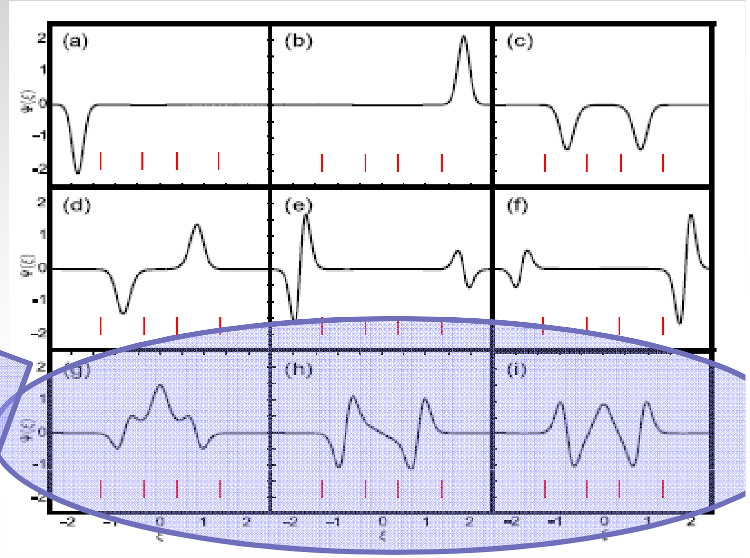


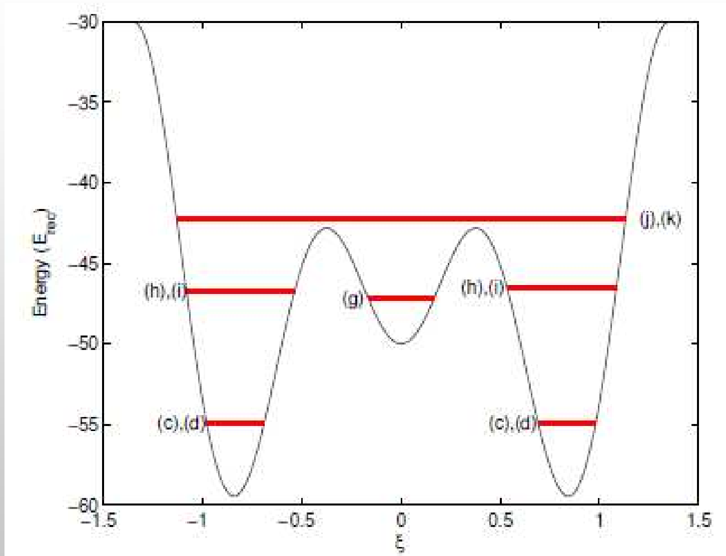
Adjusting the relative amplitude gives full control of the middle well depth

Triple well dynamics: towards atomtronics

Spectrum vs relative amplitude

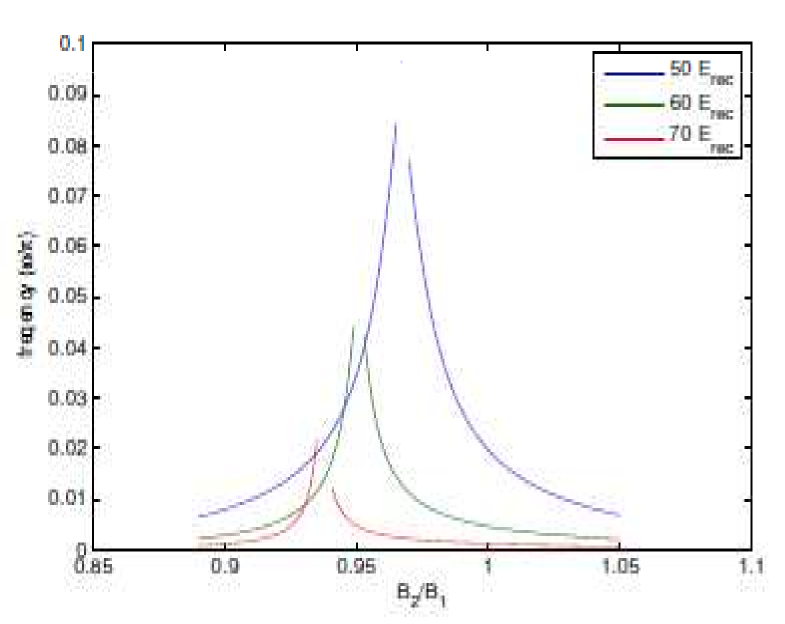




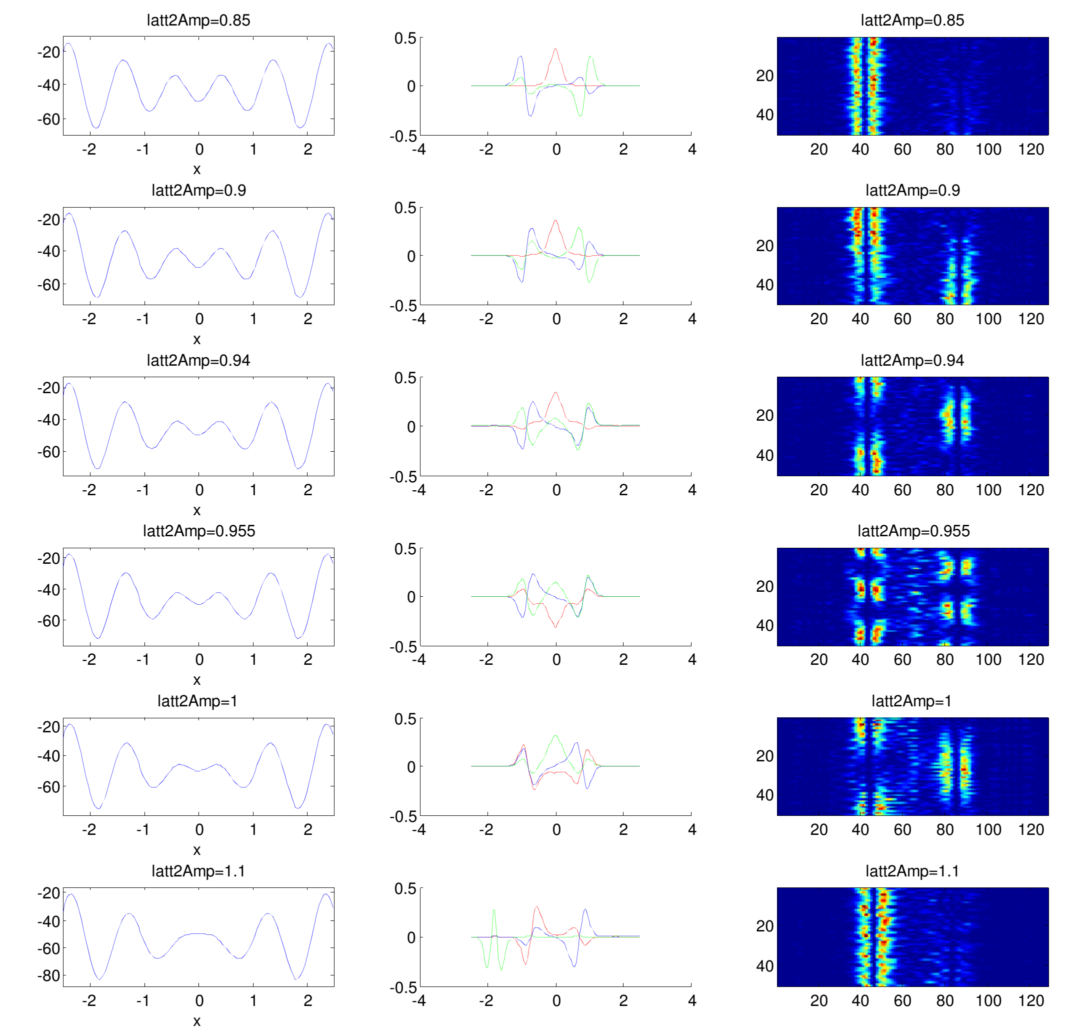


Triple well dynamics

- Place an atom in the 1st excited state of the left well (200 Erec)
- Quench to 50 Erec
- Evolve in time



Transistor like tunneling behavior

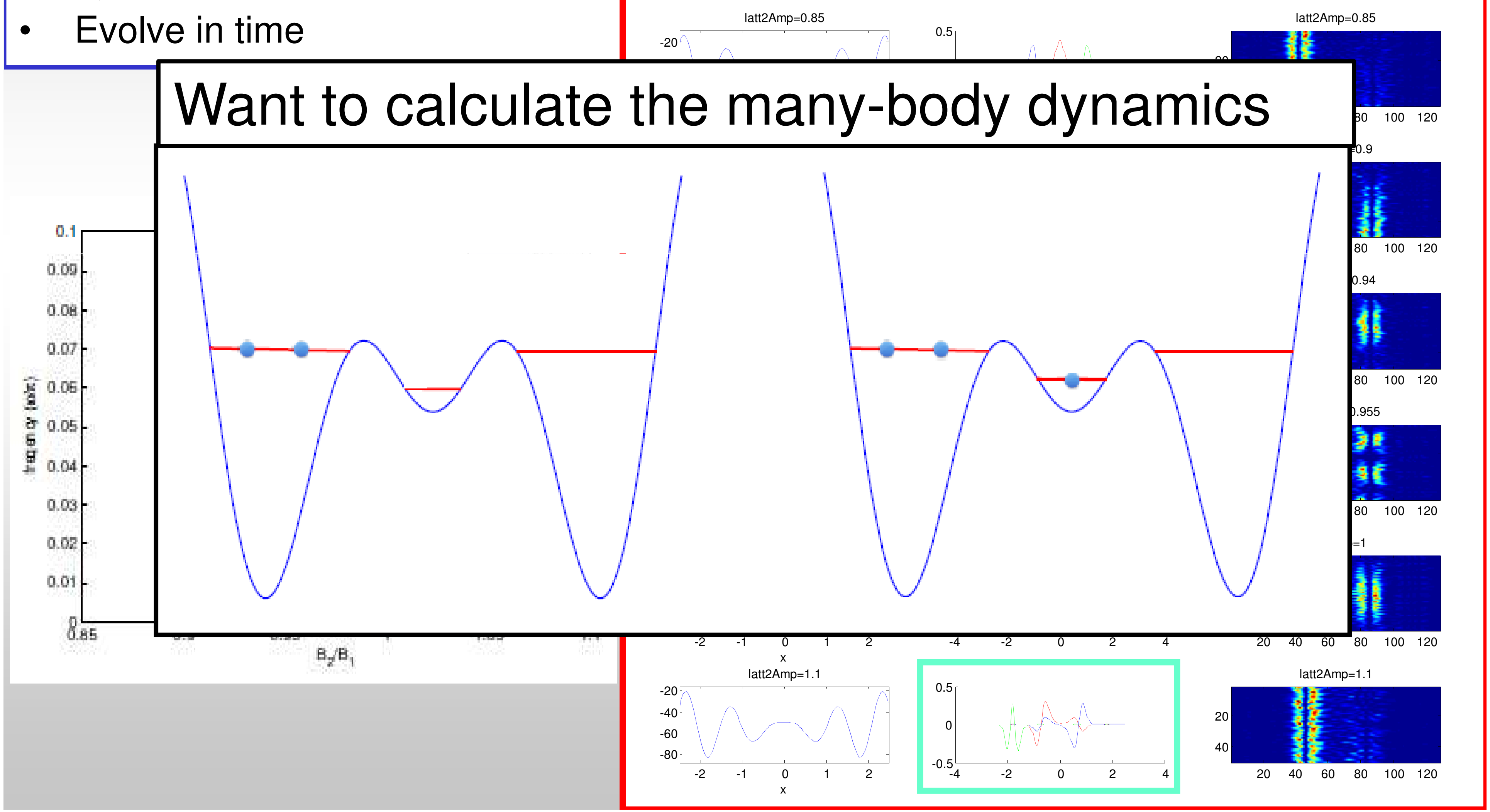


Triple well dynamics

- Place an atom in the 1st excited state of the left well (200 Erec)
- Quench to 50 Erec
- Evolve in time

Transistor like tunneling behavior

Want to calculate the many-body dynamics



Creating localized initial states

- Place an atom in the 1st excited state of the left well (120-50 Erec)
- Quench to 50 Erec

Calculate overlap with eigenstates

$$p_{\mathrm{L},i} = \langle \Phi_i | \psi_\mathrm{L} \rangle$$

$$p_{\mathrm{R},i} = \langle \Phi_i | \psi_\mathrm{R} \rangle$$

Define "localized states"

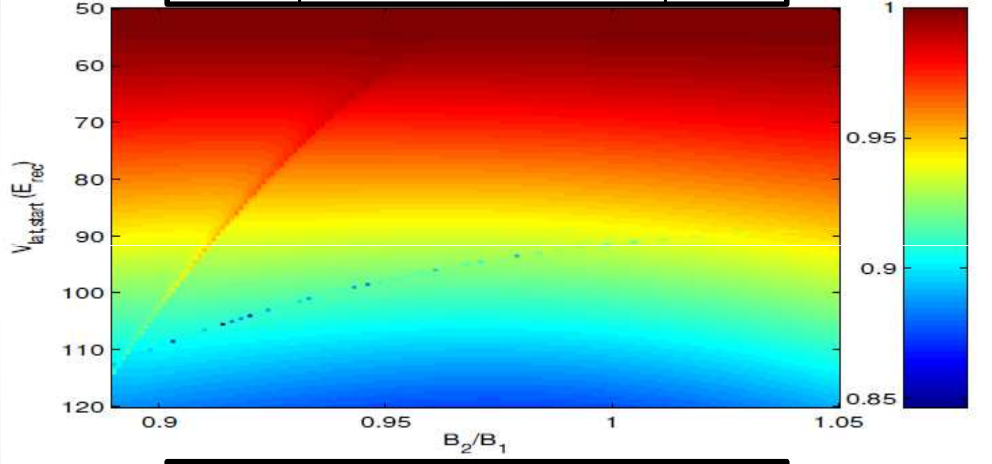
$$\Psi_\mathrm{L} = \sum_{i \in \{\mathrm{a,s,g}\}} p_{\mathrm{L},i} \Phi_i$$

$$\Psi_\mathrm{R} = \sum_{i \in \{\mathrm{a,s,g}\}} p_{\mathrm{R},i} \Phi_i$$

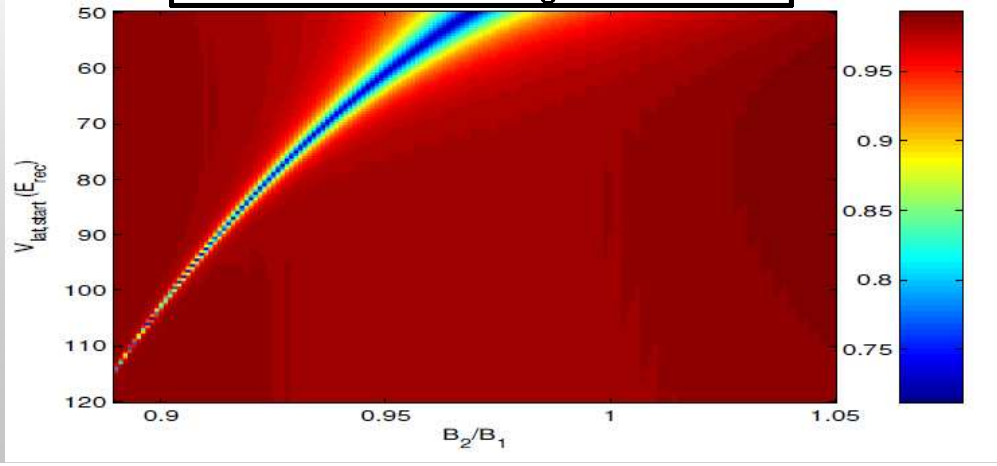
$$\mathbf{p}_\mathrm{M} = \mathbf{p}_\mathrm{L} \times \mathbf{p}_\mathrm{L}$$

$$\Psi_\mathrm{M} = \sum_{i \in \{\mathrm{a,s,g}\}} \mathbf{p}_{\mathrm{M},i} \Phi_i$$

Overlap: initial state to final space



Localization of eigenstates



Creating localized initial states

- Projection from deep lattice (below)
- Projection from lattice 1 highest power (left)
- Projection from lattice 2 highest power (right)

Calculate overlap with eigenstates

$$p_{\mathrm{L},i} = \langle \Phi_i | \psi_{\mathrm{L}} \rangle$$

$$p_{\mathrm{R},i} = \langle \Phi_i | \psi_{\mathrm{R}} \rangle$$

$$B_2/B_1 = 0.969$$

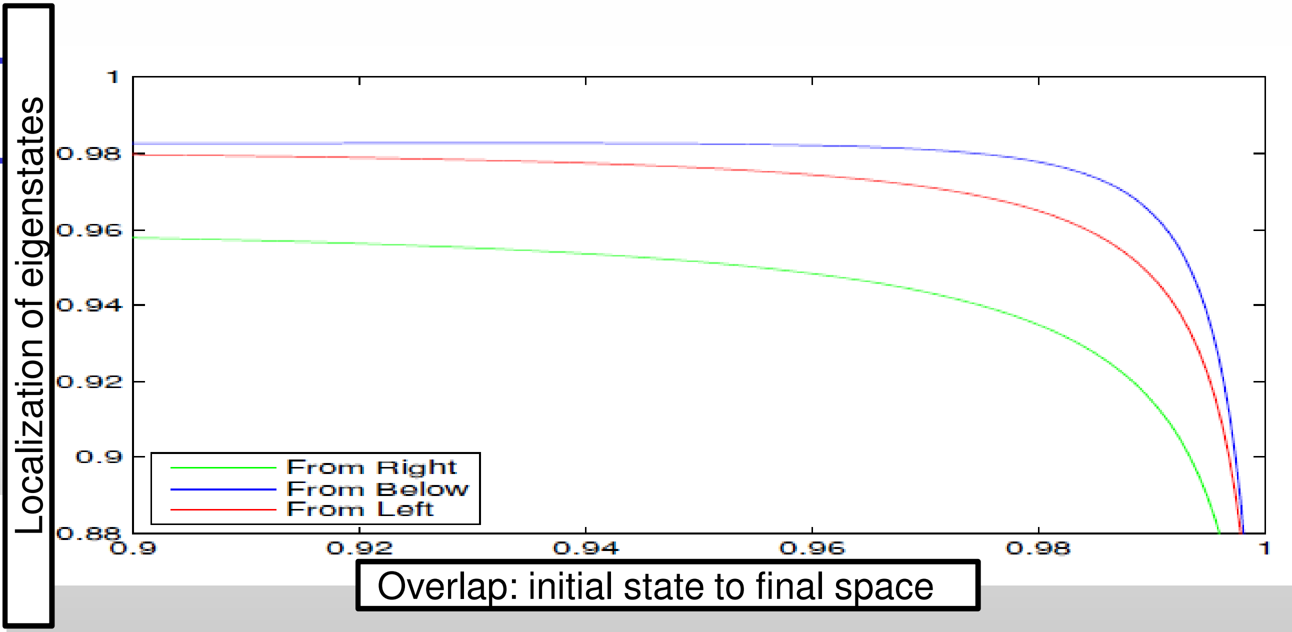
Define "localized states"

$$\Psi_{\mathrm{L}} = \sum_{i\in\{\mathrm{a,s,g}\}} p_{\mathrm{L},i}\Phi_i$$

$$\Psi_{\mathrm{R}} = \sum_{i\in\{\mathrm{a,s,g}\}} p_{\mathrm{R},i}\Phi_i$$

$$\mathbf{p}_{\mathrm{M}} = \mathbf{p}_{\mathrm{L}} \times \mathbf{p}_{\mathrm{L}}$$

$$\Psi_{\mathrm{M}} = \sum_{i\in\{\mathrm{a,s,g}\}} \mathbf{p}_{\mathrm{M},i}\Phi_i$$



Many body simulations

Define Fock states

$$|n_1, n_2, n_3\rangle = \left(\prod_{i \in \{1,2,3\}} \frac{1}{\sqrt{n_i!}} (\hat{a}_i^\dagger)^{n_i} \right) |0,0,0\rangle$$

Bose-Hubbard Hamiltonian

$$H = -\sum_{\langle i,j \rangle} J_{i,j} \hat{a}_i^\dagger \hat{a}_j + \frac{1}{2} \sum_i U_{i,i} \hat{n}_i (\hat{n}_i - 1) + \frac{1}{2} \sum_i \sum_j U_{i,j} \hat{n}_i \hat{n}_j + \sum_i \epsilon_i \hat{n}_i,$$

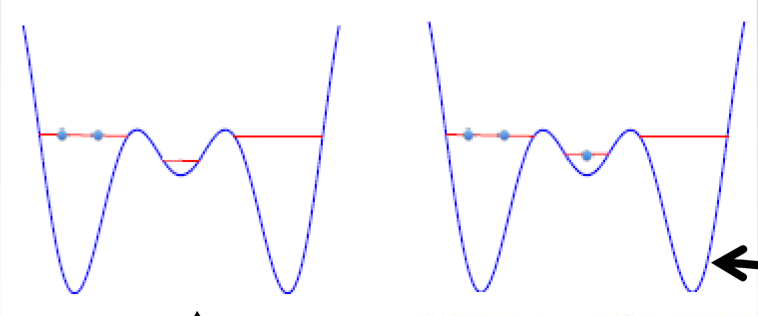
nxn matrix

$$H_{i,j} = \langle F_i | H_{\mathrm{BH}} | F_j \rangle$$

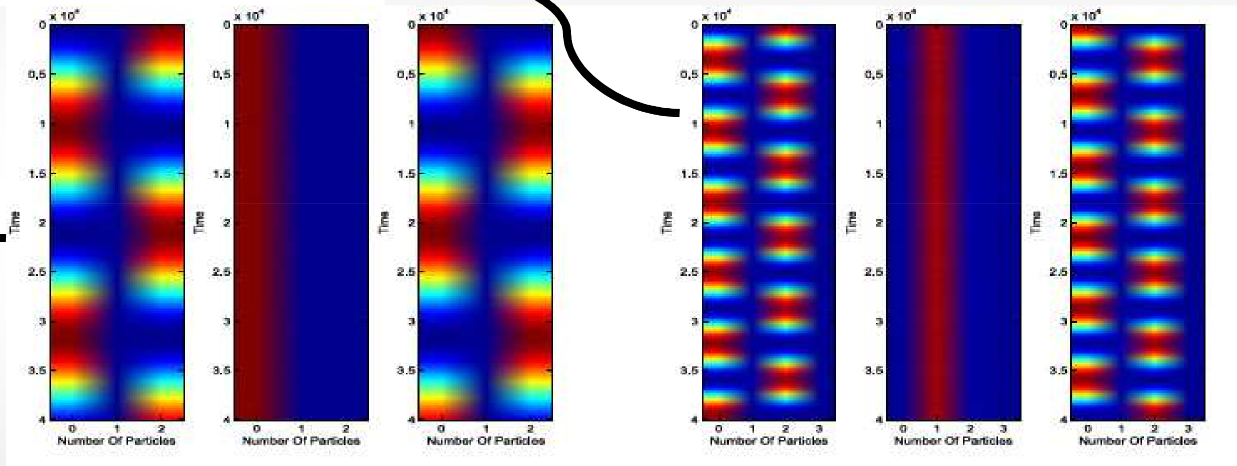
Evolve according to

$$|\Psi(t)\rangle = e^{\frac{iHt}{\hbar}} |\Psi_0\rangle$$

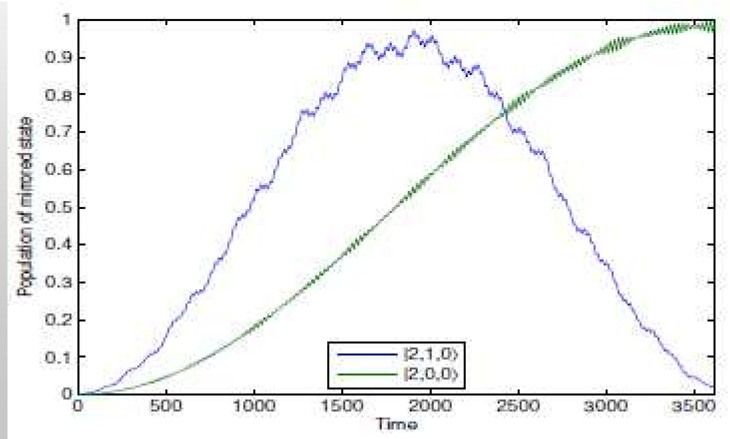
Many body simulations



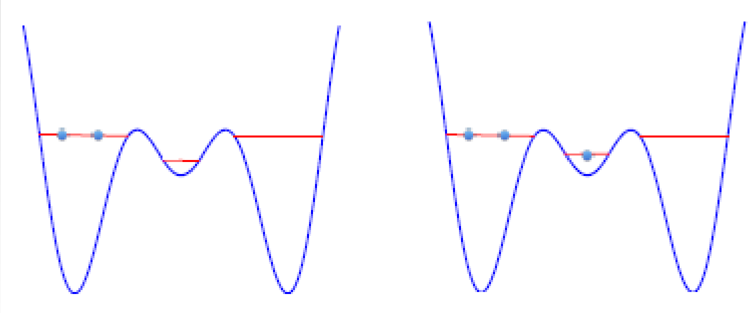
"Timed oscillations"



N_{left}=1-9

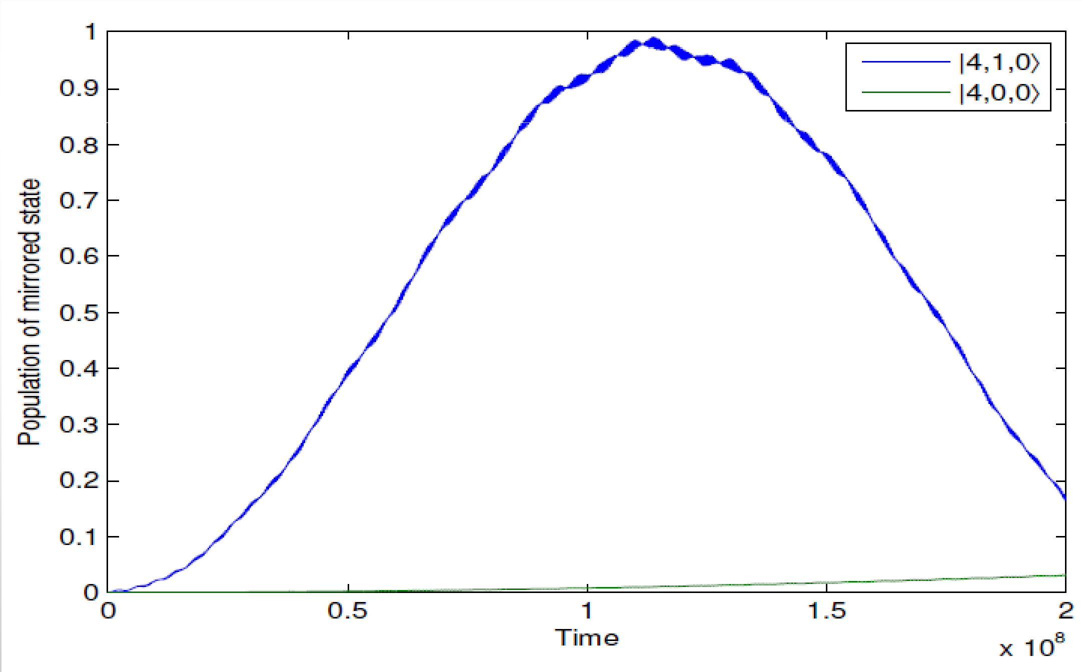


Many body simulations

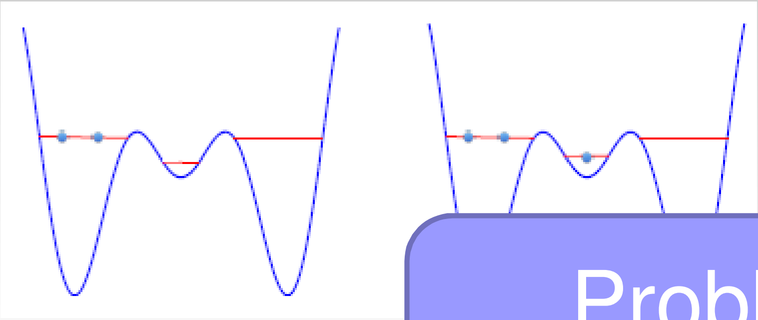


"Blocked oscillations" (high interaction)

$N_{left}=4$

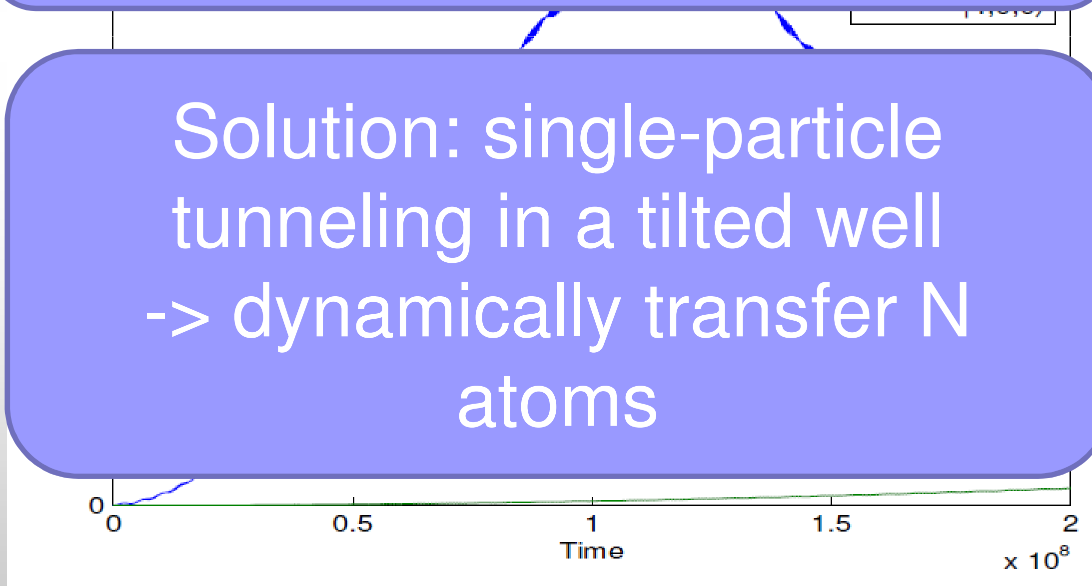


Many body simulations



"Blocked oscillations"

Problem: time scales become very long



Solution: single-particle tunneling in a tilted well -> dynamically transfer N atoms

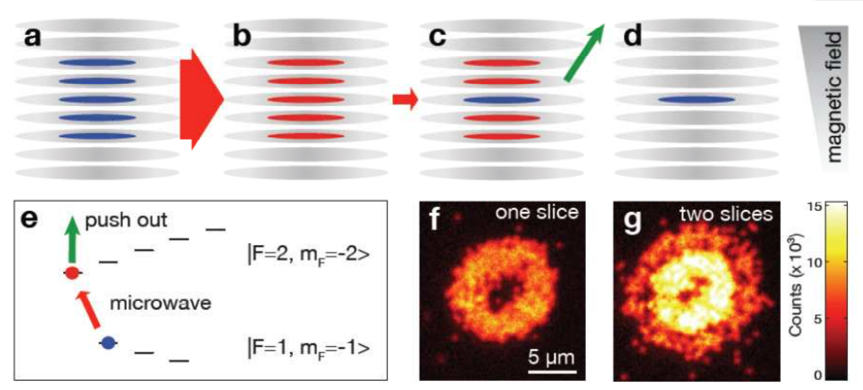
$N_{left}=4$

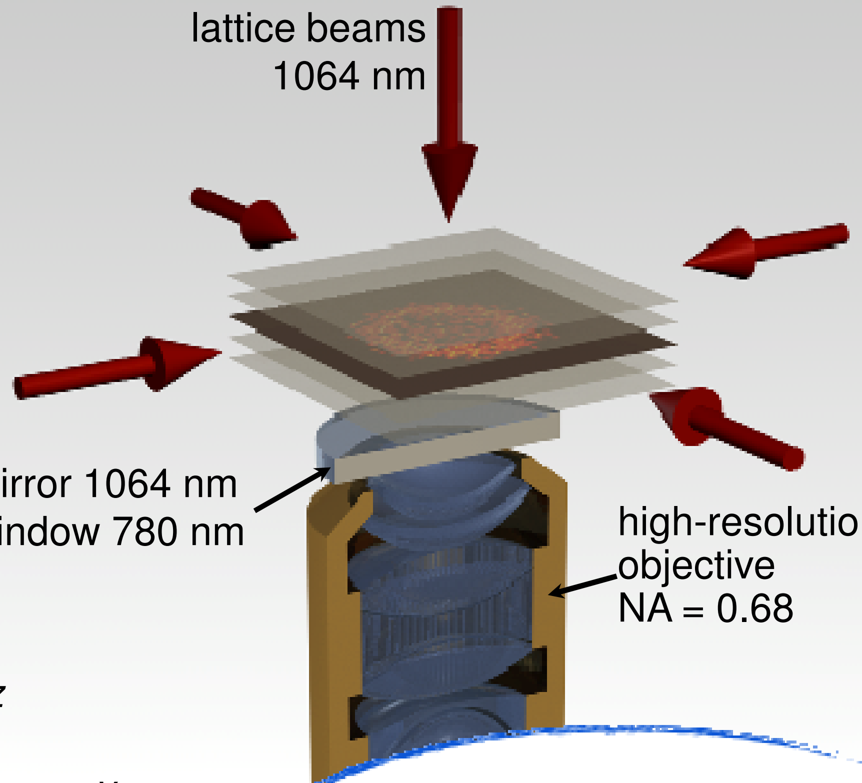
Outline

- Non-destructive imaging
- Triple-well atomtronics
- The quantum computer game

Experimental set-up

Preparation of a single 2D system:

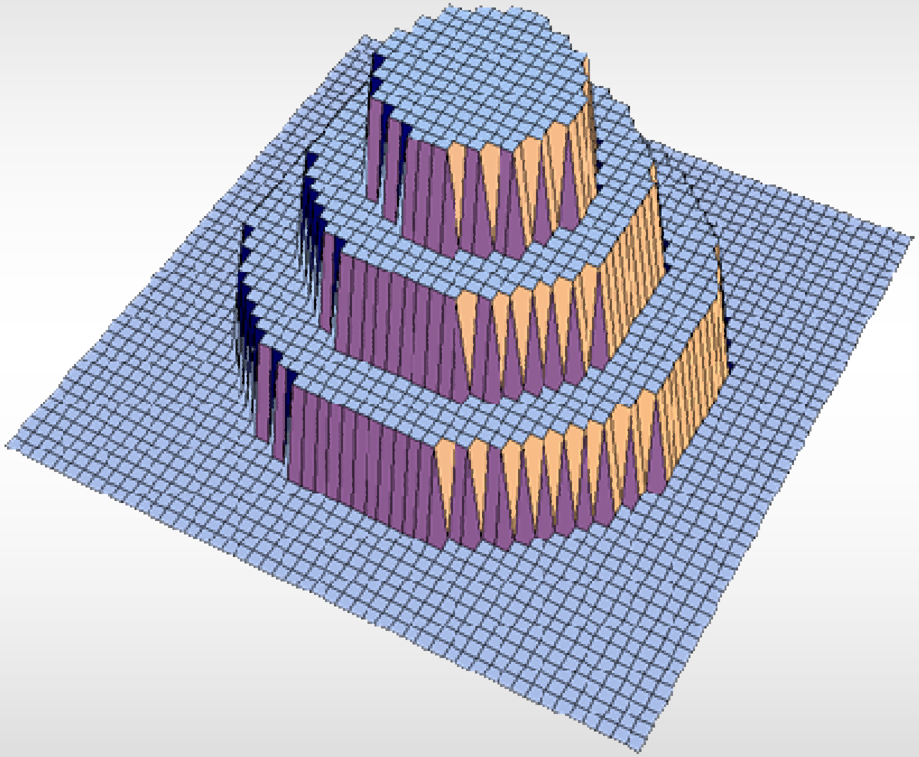


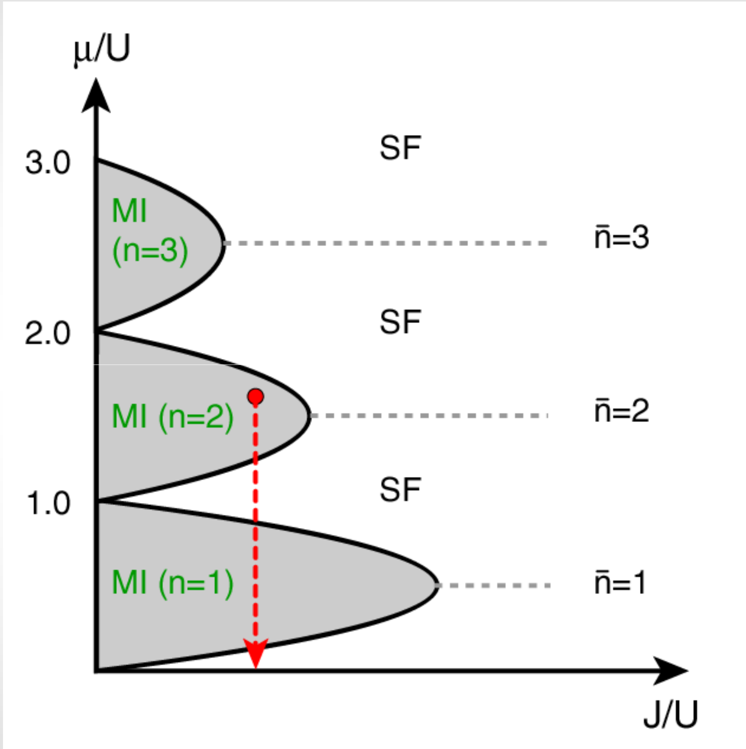


- single 2D degenerate gas
- ~ 1000 ^{87}Rb atoms (bosons)

J. F. Sherson et al, **Nature, 467,** 68 (2010)

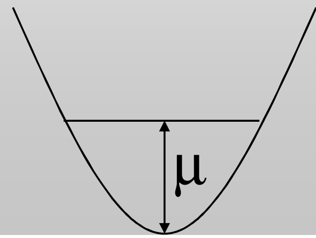
Superfluid – Mott-Insulator Phase Diagram



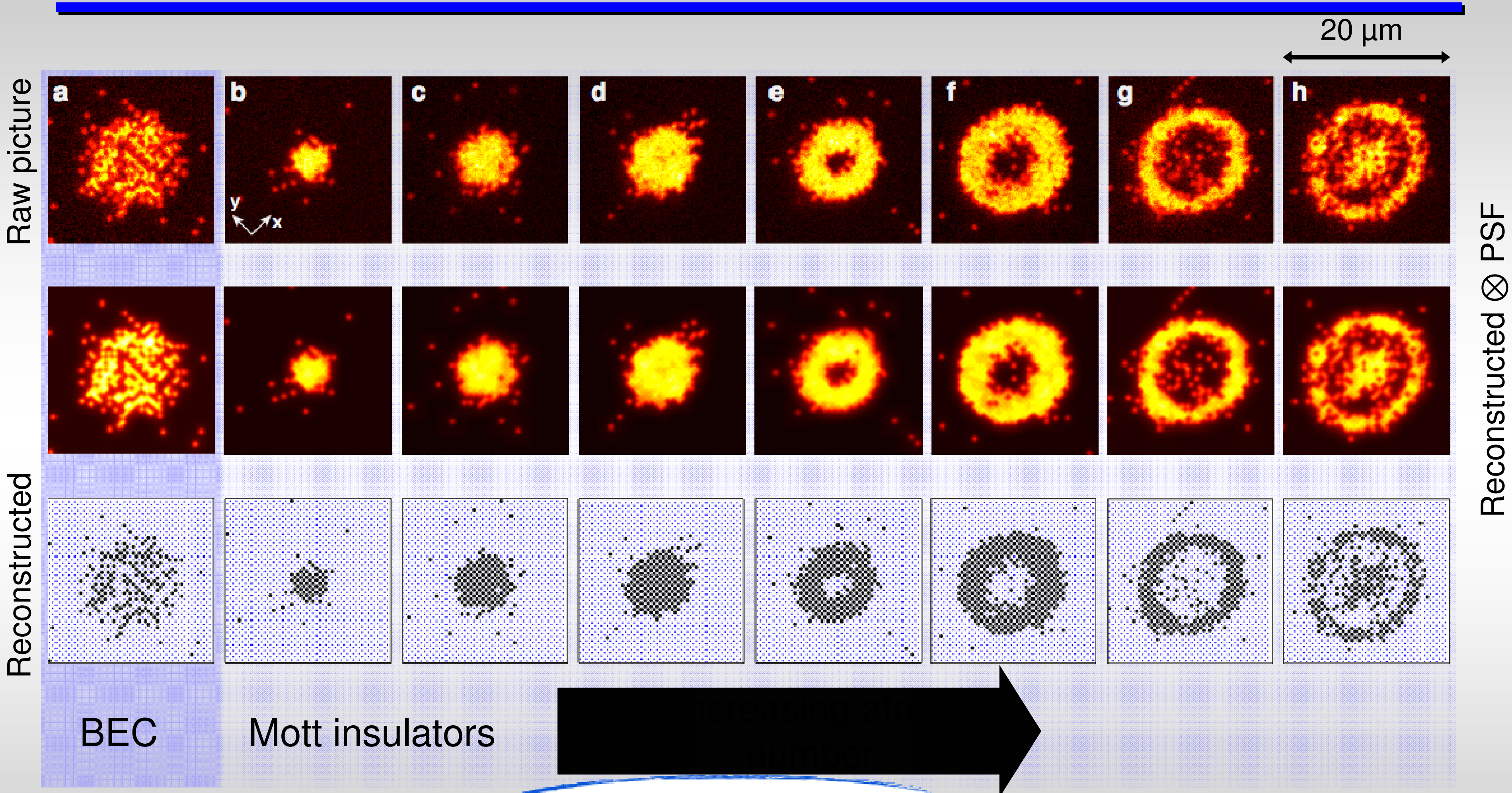


Inhomogeneous system:
effective local chemical potential

$$\mu_{loc} = \mu - \varepsilon_i$$



In-situ observation of a Mott insulator



for the Mott insulators: U/J ~ 300 (critical U/J ~16)

-> only thermal fluctuations

J. F. Sherson et al, **Nature, 467,** 68 (2010)

Detection of many-body physics

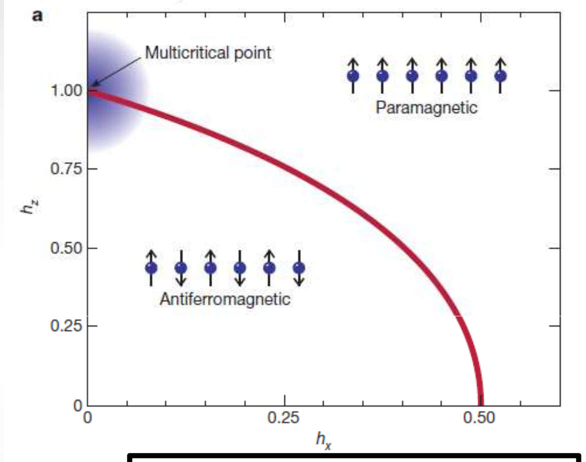
Quantum simulation of antiferromagnetic spin chains in an optical lattice

Jonathan Simon[1], Waseem S. Bakr[1], Ruichao Ma[1], M. Eric Tai[1], Philipp M. Preiss[1] & Markus Greiner[1]

21 APRIL 2011 | VOL 472 | NATURE | 307

1D Ising chain

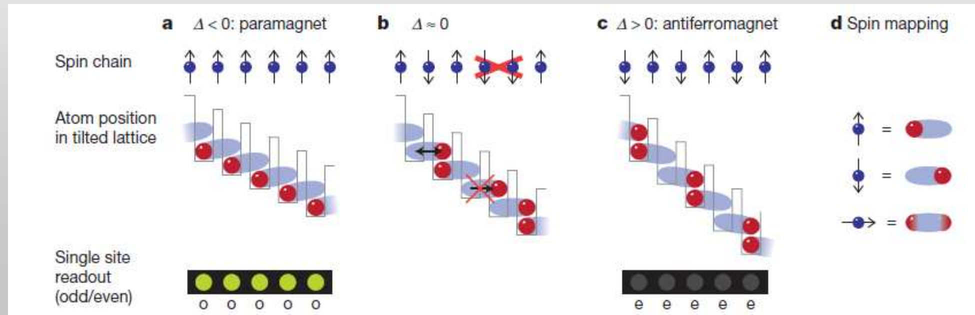
$$H = J\sum_i S_z^i S_z^{i+1} - h_z^i S_z^i - h_x^i S_x^i$$



Tilted optical lattice

$$(h_z, h_x) = (1 - \tilde{\Delta}, 2^{3/2}\tilde{t})$$

$$\tilde{t} = t/J, \quad \tilde{\Delta} = \Delta/J = (E - U)/J$$



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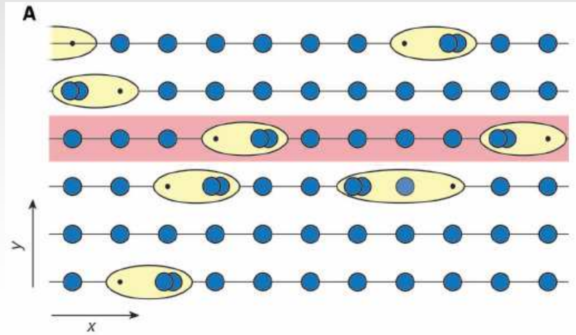
21 APRIL 2011 | VOL 472 | NATURE | 307

1D tunneling close to MI transition (particle-hole pairs)



Observation of Correlated Particle-Hole Pairs and String Order in Low-Dimensional Mott Insulators

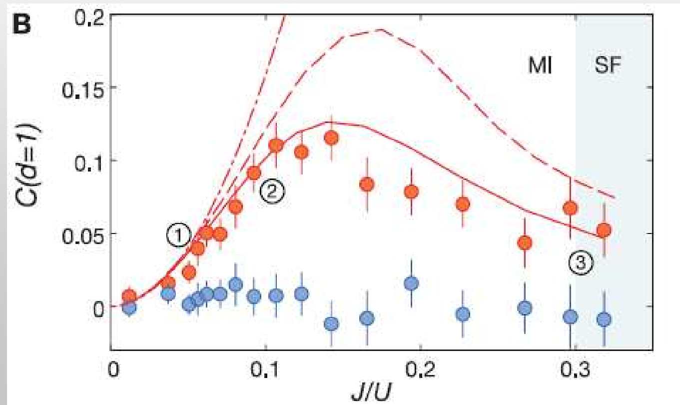
M. Endres,[1*] M. Cheneau,[1] T. Fukuhara,[1] C. Weitenberg,[1] P. Schauß,[1] C. Gross,[1] L. Mazza,[1] M. C. Bañuls,[1] L. Pollet,[2] I. Bloch,[1,3] S. Kuhr[1,4]

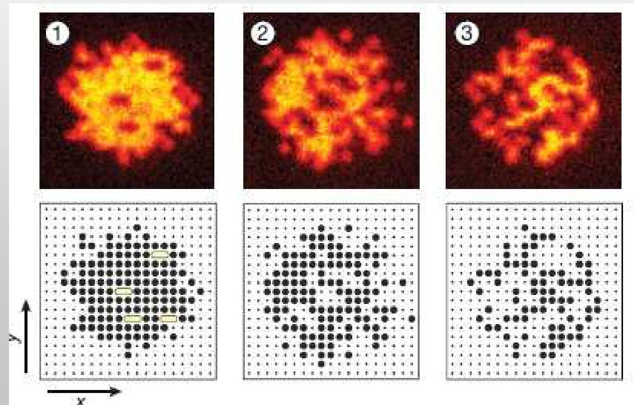
14 OCTOBER 2011 VOL 334 SCIENCE

Two-site parity correlation function

$$C(d) = \langle \hat{s}_k \hat{s}_{k+d} \rangle - \langle \hat{s}_k \rangle \langle \hat{s}_{k+d} \rangle$$

$$\hat{s}_k = e^{i\pi\delta\hat{n}_k}$$





Detection of many-body physics

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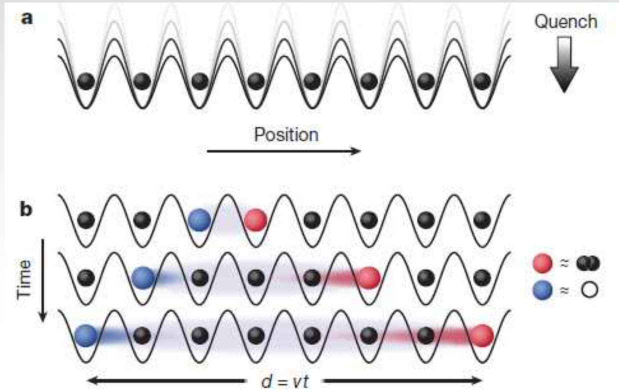
Jonathan Simon[1], Waseem S. Bakr[1], Ruichao Ma[1], M. Eric Tai[1], Philipp M. Preiss[1] & Markus Greiner[1]

21 APRIL 2011 | VOL 472 | NATURE | 307

Quench from U/J=40 to U/J=9



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14 OCTOBER 2011 VOL 334 SCIENCE

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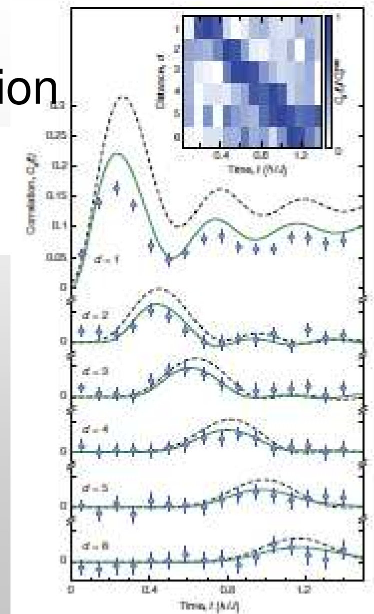


Light-cone-like spreading of correlations in a quantum many-body system

Marc Cheneau[1], Peter Barmettler[2], Dario Poletti[2], Manuel Endres[1], Peter Schauß[1], Takeshi Fukuhara[1], Christian Gross[1], Immanuel Bloch[1,3], Corinna Kollath[2,4] & Stefan Kuhr[1,5]

484 | NATURE | VOL 481 | 26 JANUARY 2012

Global manipulation

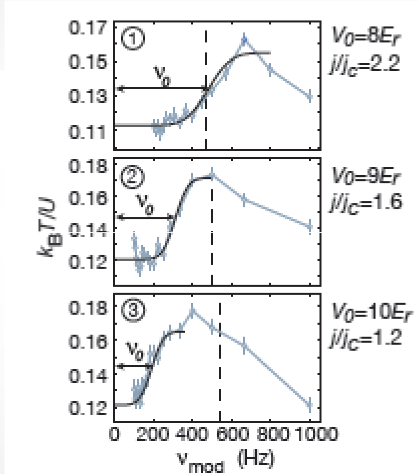
The 'Higgs' Amplitude Mode at the Two-Dimensional Superfluid-Mott Insulator Transition

Manuel Endres[1,*], Takeshi Fukuhara[1], David Pekker[2], Marc Cheneau[1], Peter Schauß[1], Christian Gross[1], Eugene Demler[3], Stefan Kuhr[4], and Immanuel Bloch[1,5]

arXiv:1204.5183v2 [cond-mat.quant-gas] 25 Apr 2012

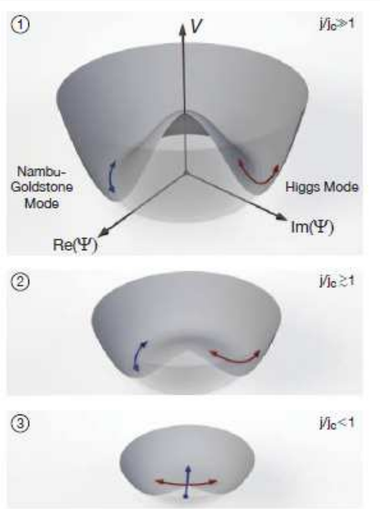
SF-MI phase transition has a complex order parameter

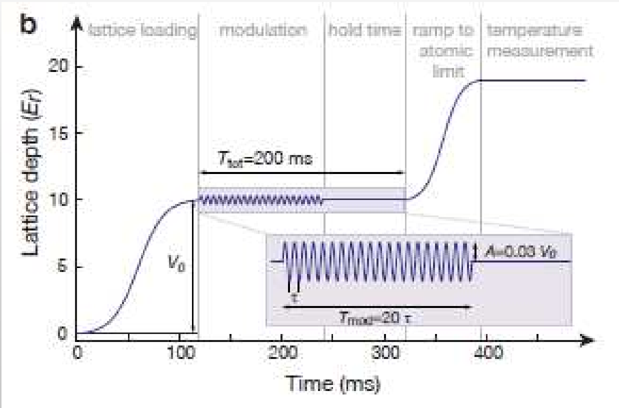
$$\Psi = |\Psi| e^{i}$$

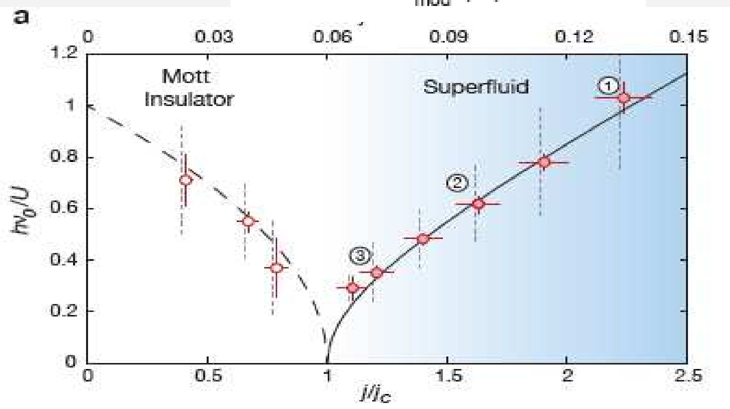


Spontaneous symmetry breaking in the SF phase

Using weak amplitude modulation detect a gap in the response





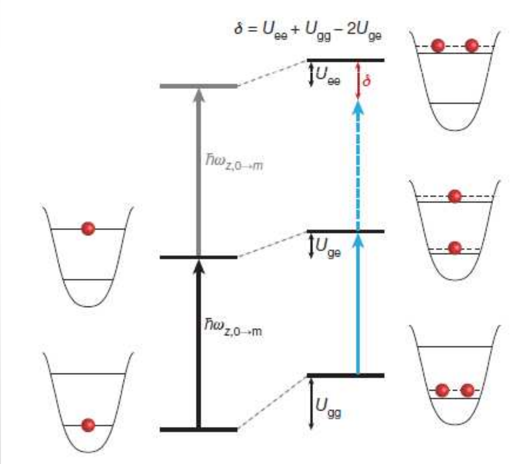


Global manipulation

Orbital excitation blockade and algorithmic cooling in quantum gases

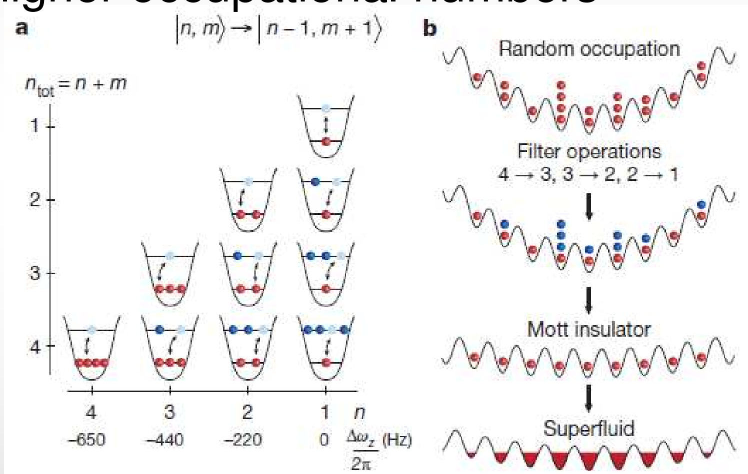
Waseem S. Bakr[1], Ph 500 | NATURE | VOL 480 | 22/29 DECEMBER 2011 ıer[1]

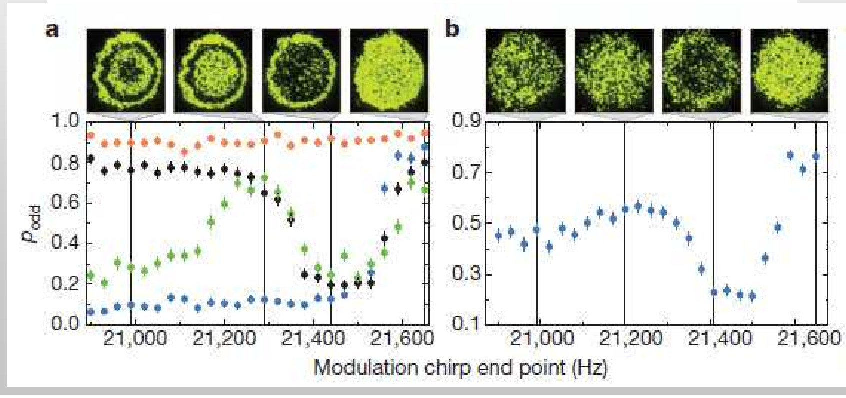
Two-particle interaction energy depends on the vibrational state



$$U_{\nu,\mu} = U_{00}\begin{pmatrix} 1 & 1 & 0.75 & \dots \\ 1 & 0.75 & 0.875 & \dots \\ 0.75 & 0.875 & 0.64 & \dots \\ \vdots & \vdots & \vdots & \ddots \end{pmatrix}$$

Filtering: sequentially excite and remove higher occupational numbers





Global manipulation

Orbital excitation blockade and algorithmic cooling in quantum gases

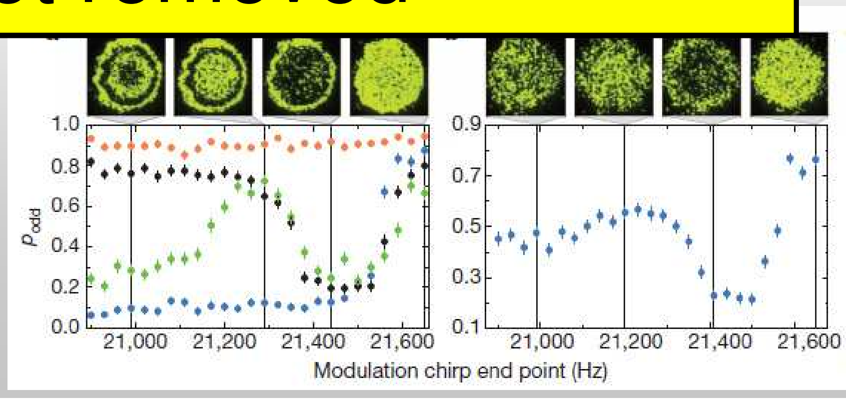
Waseem S. Bakr[1], Ph 500 | NATURE | VOL 480 | 22/29 DECEMBER 2011 ıer[1]

Two-particle interaction energy depends on the vibrational state

Filtering: sequentially excite and remove higher occupational numbers

- Entropy per particle is reduced dramatically in the center but not globally
- Vacancies are not removed

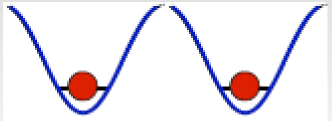
$$U_{\nu,\mu} = U_{00}\begin{pmatrix} 1 & 1 & 0.75 & \dots \\ 1 & 0.75 & 0.875 & \dots \\ 0.75 & 0.875 & 0.64 & \dots \\ \vdots & \vdots & \vdots & \ddots \end{pmatrix}$$



Shaking the entropy out of an optical lattice: removing vacancies

Would like to realize an "OR" operation between 2 sites

Forbidden due to unitarity

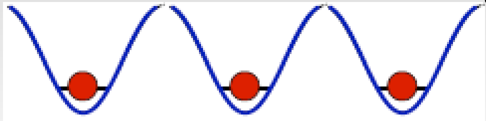


Vacancy probability: ε

Malte Tichy, Klaus Mølmer, and JFS, arxiv:1012.1457v2 (2010)

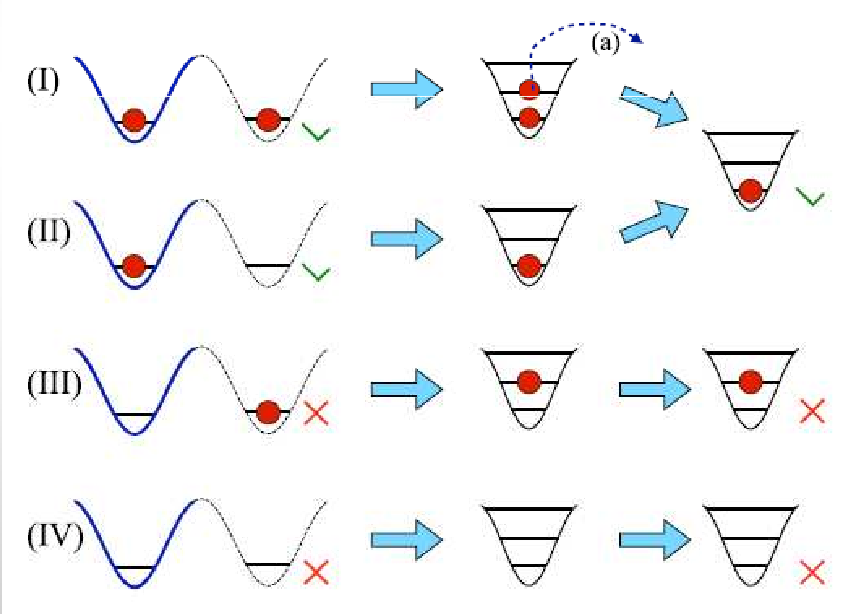
Shaking the entropy out of an optical lattice: removing vacancies

Need 3 sites:
Target well + 2 aux wells

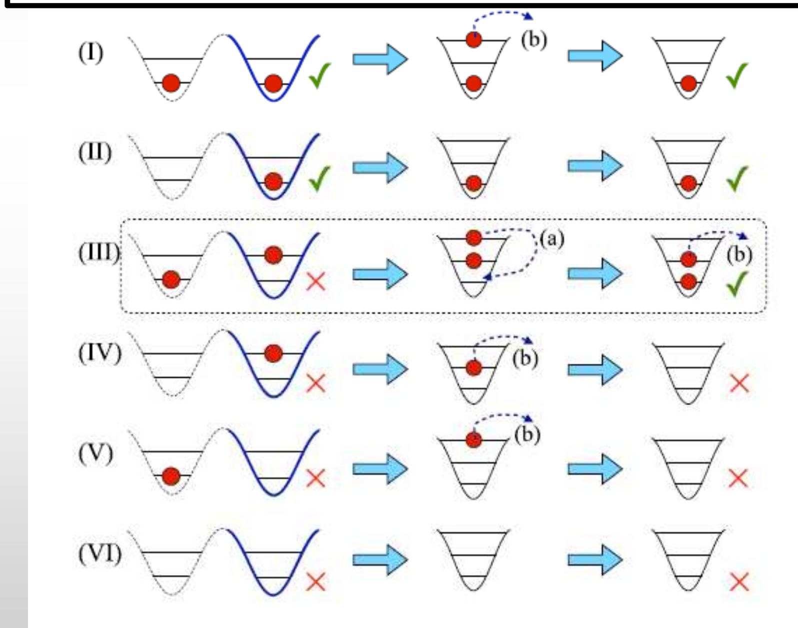


Vacancy probability: ε

Step 1: merge middle and left well



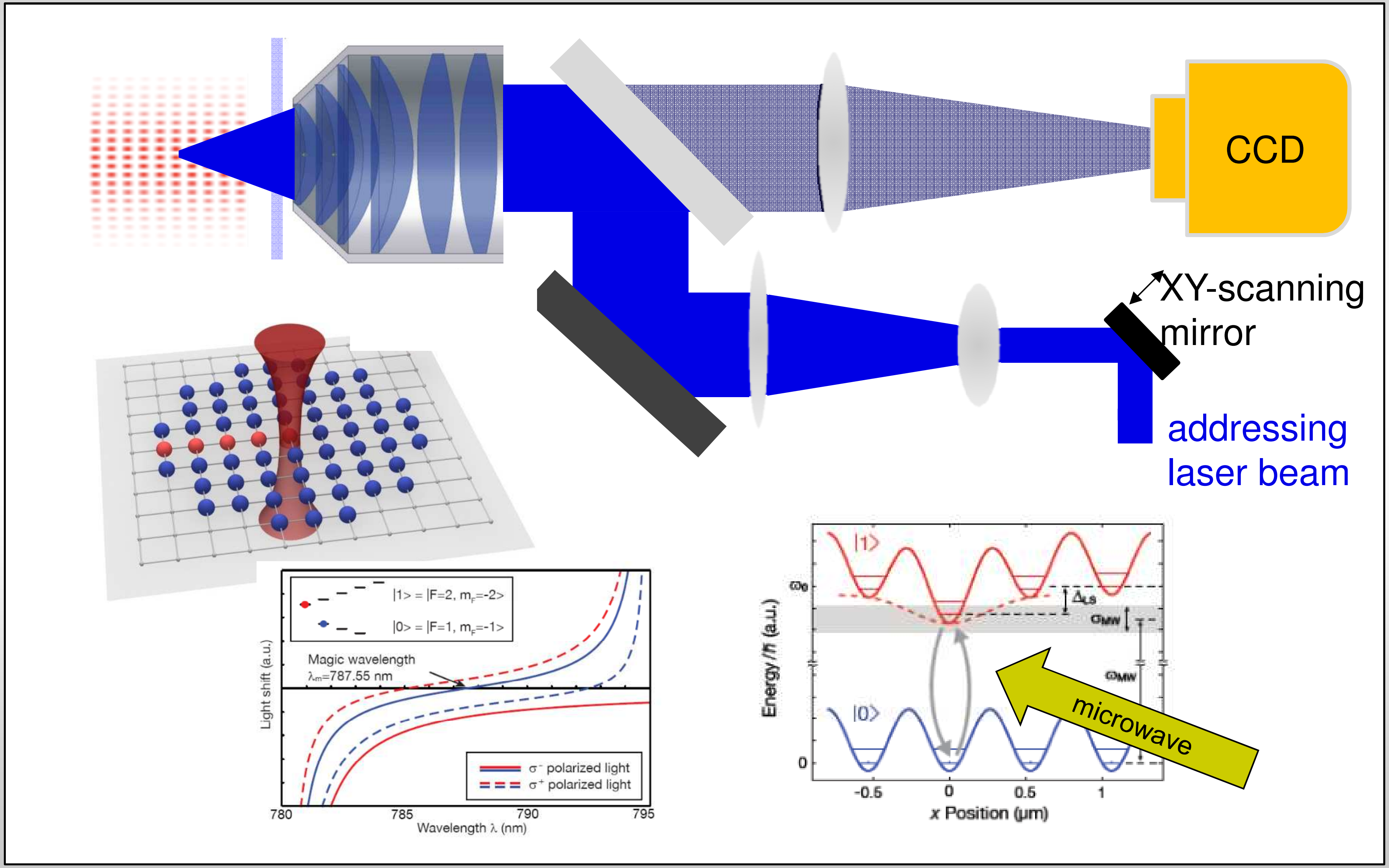
Step 2: merge middle and right well



Final vacancy probability: $2\varepsilon^2 - \varepsilon^3$

Malte Tichy, Klaus Mølmer, and JFS, arxiv:1012.1457v2 (2010)

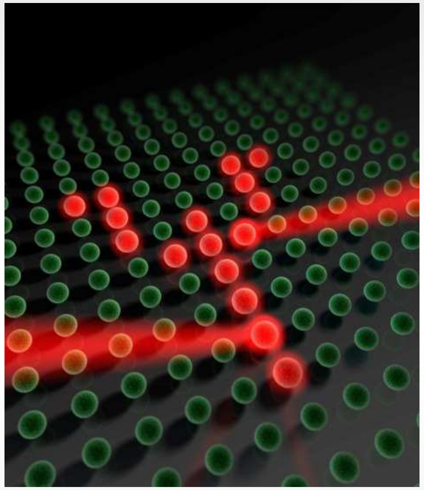
Addressing individual lattice sites

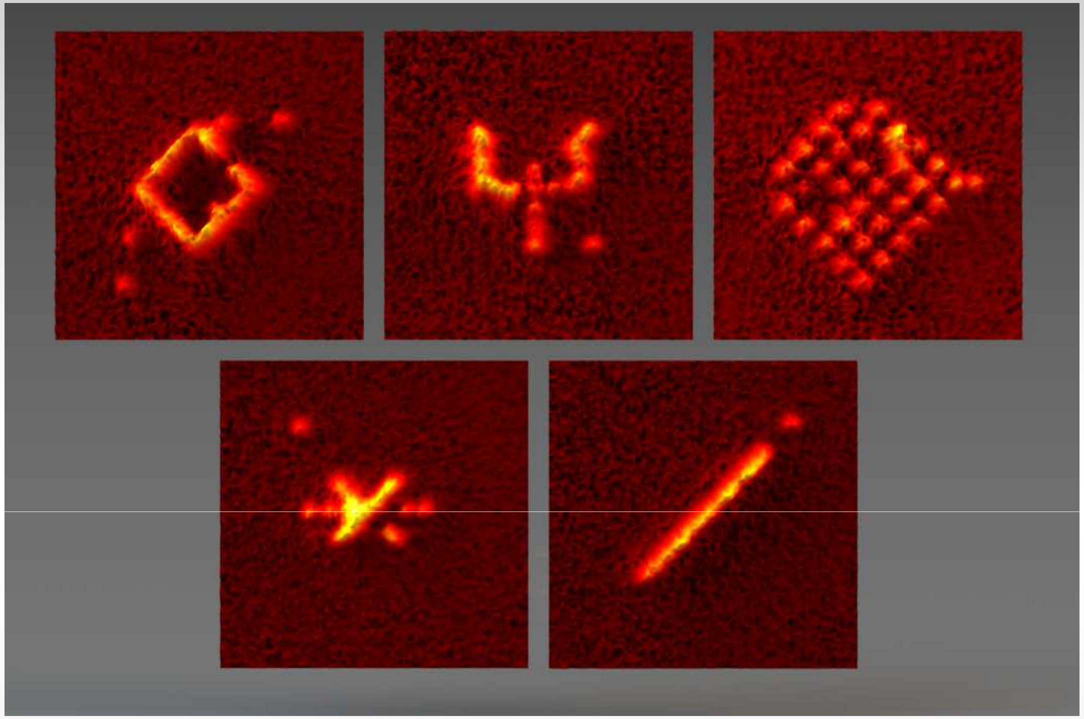


Weitenberg et al, **Nature, 471,** 319 (2011)

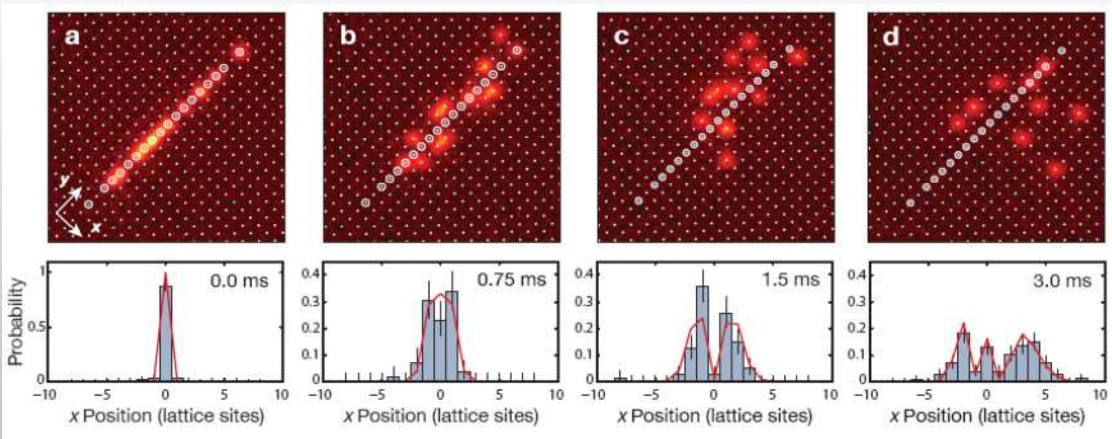
Addressing individual lattice sites

Writing arbitrary patterns



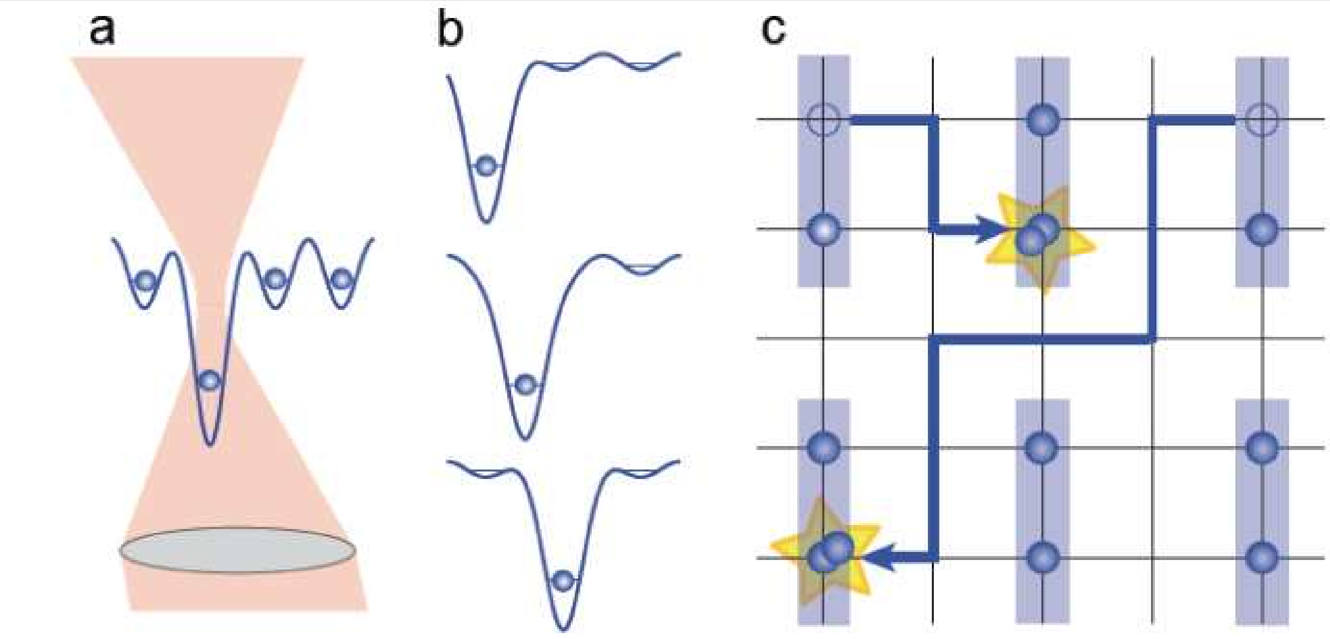


Single particle tunneling
"the horse track race"



Weitenberg et al, **Nature, 471,** 319 (2011)

Quantum computation with optical tweezers

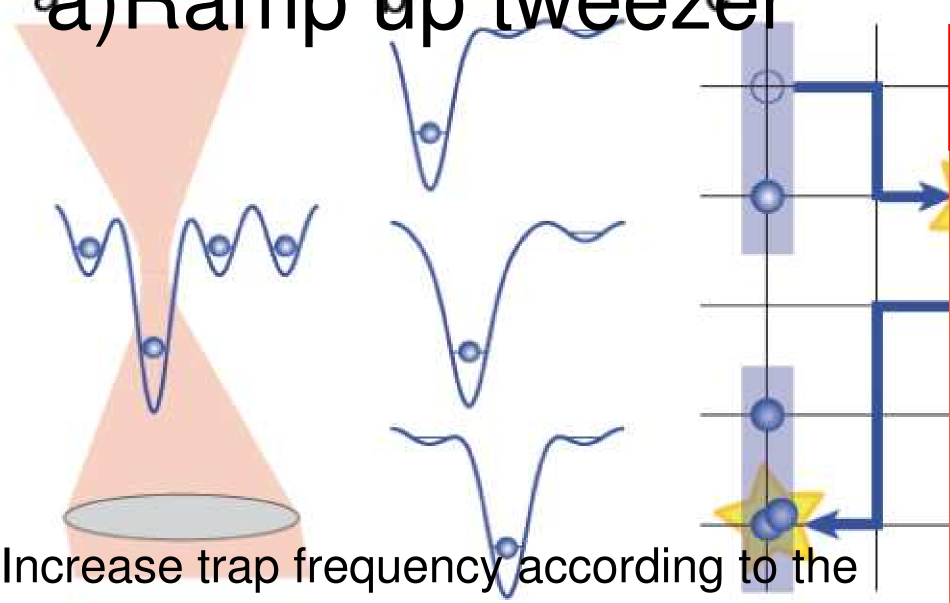


a)Ramp up tweezer
b)Transport atom by translating tweezer
c)Collisional gate by merging atoms

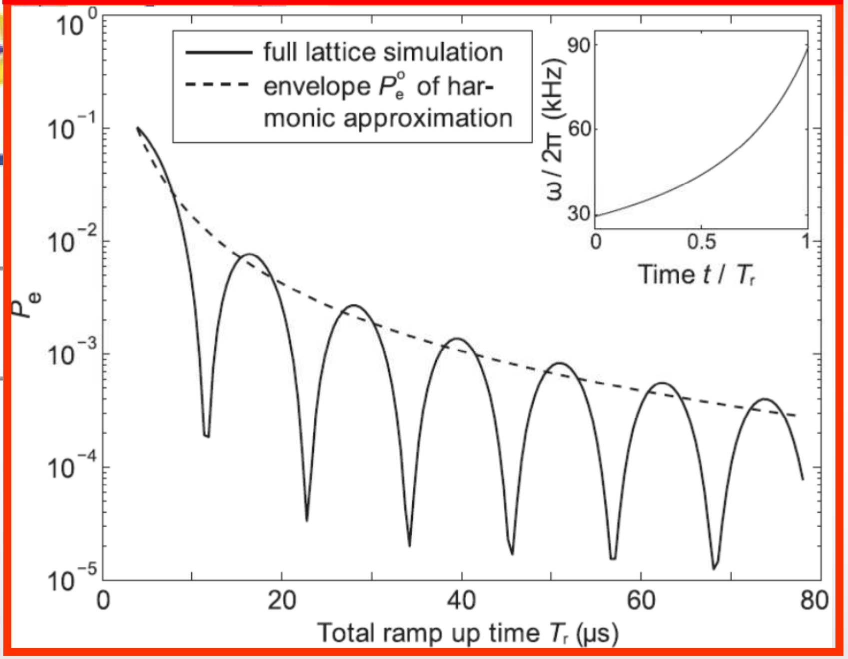
Weitenberg et al, PRA (2011)

Quantum computation with optical tweezers

a)Ramp up tweezer



Numerical solution of the time-dependent Schrödinger equation



Increase trap frequency according to the adiabaticity criterion:

$$\hbar\left|\frac{d\omega(t)}{dt}\right| = \xi\,\frac{(\Delta E_{ge})^2}{\left|\langle\phi_e|\frac{\partial H}{\partial\omega}|\phi_g\rangle\right|}$$

Solve analytically in a two-state harmonic oscillator model

$$P_e^{\mathrm{harm}}(t) = P_e^0 \sin^2\left[\frac{\sqrt{2\xi^2 + \frac{1}{2}\log[1 - 4\sqrt{2}t\xi\omega_o]}}{4\xi}\right]$$

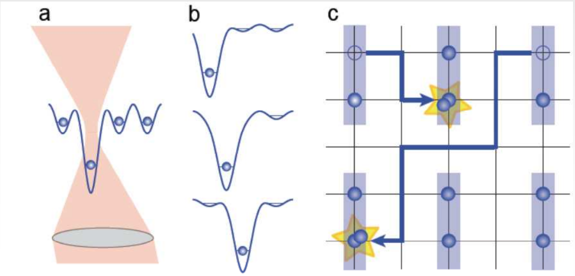
With envelope:

$$P_e^0 = 4\xi^2/(1 + 4\xi^2)$$

C. Zhang, V. W. Scarola, and S. Das Sarma, Phys. Rev. A 75, 060301(R) (2007).

Quantum computation with optical tweezers

b)Transport atom



Shift tweezer position (linearly) according to the adiabaticity criterion:

$$\hbar \left| \frac{\mathrm{d}x_o(t)}{\mathrm{dt}} \right| = \xi \frac{(\Delta E_{ge})^2}{\left| \langle \phi_e | \frac{\partial H}{\partial x_o} | \phi_g \rangle \right|}$$

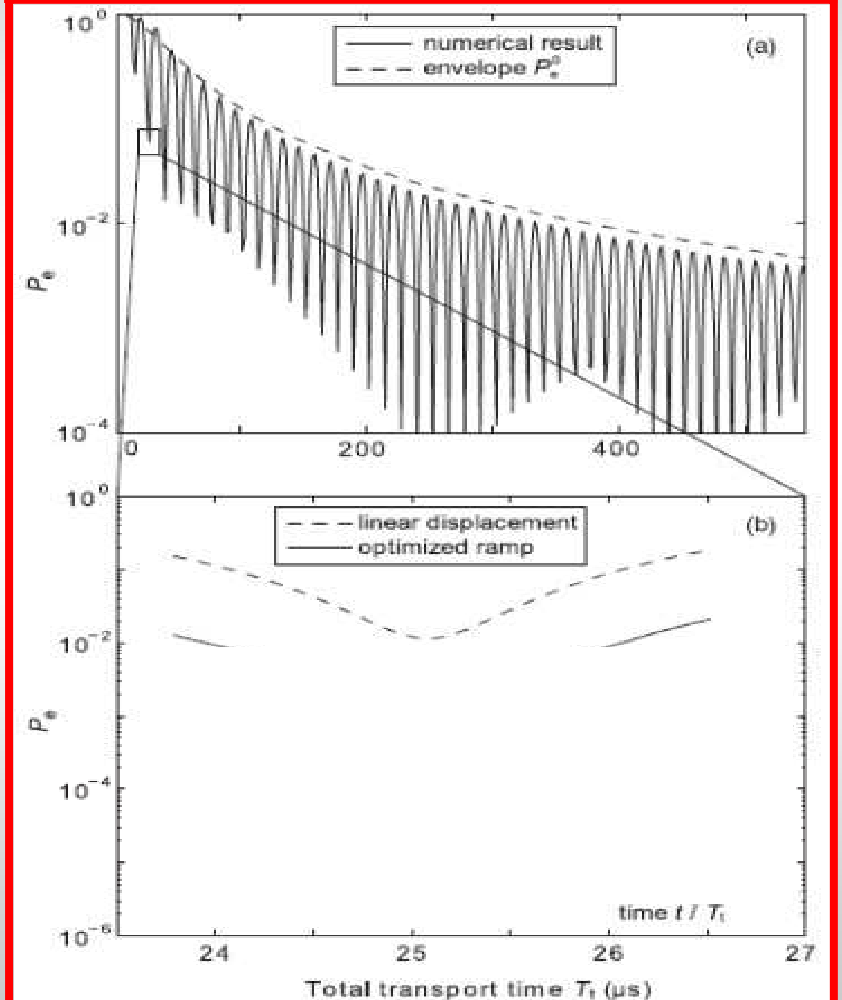
Solve analytically in a two-state harmonic oscillator model

$$P_e^{\mathrm{harm}}(t) = P_e^0 \sin^2[\sqrt{1 + 4\xi^2}\omega t/2]$$

With envelope: $P_e^0 = 4\xi^2/(1 + 4\xi^2)$

Weitenberg et al, PRA (2011)

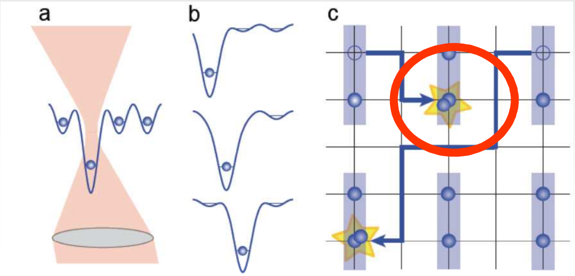
Numerical solution of the time-dependent Schrödinger equation

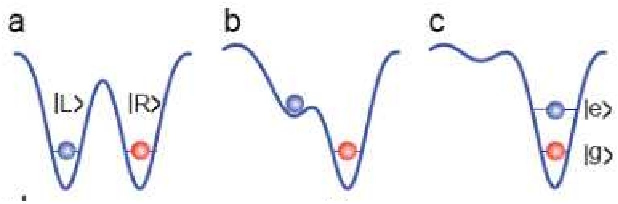


Numerical optimization of the translation profile

Quantum computation with optical tweezers

c)2-qubit exchange gate





99.97% fidelity in 75 us

- Map left well atom to first excited state of the right well
- The atom is now in a superposition of the singlet and triplet combinations

$$|s\rangle = |\uparrow\rangle_g |\downarrow\rangle_e - |\downarrow\rangle_g |\uparrow\rangle_e,$$
$$|t_0\rangle = |\uparrow\rangle_g |\downarrow\rangle_e + |\downarrow\rangle_g |\uparrow\rangle_e,$$
$$|t_{-1}\rangle = |\downarrow\rangle_g |\downarrow\rangle_e,$$
$$|t_{+1}\rangle = |\uparrow\rangle_g |\uparrow\rangle_e.$$

- Interactions in the triplet state drive oscillations

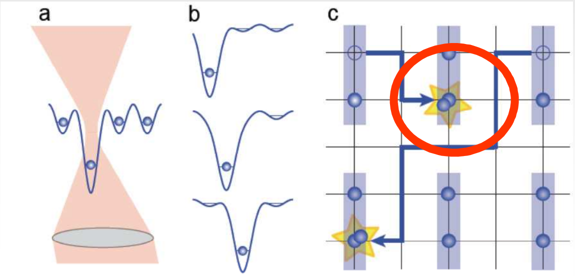
$$\Psi(t=0) = |s\rangle + |t_0\rangle \sim |\uparrow\rangle_g |\downarrow\rangle_e,$$
$$\Psi(t) = |s\rangle + e^{iU_{eg}t/\hbar}|t_0\rangle,$$
$$\Psi(t = T_{swap}) = |s\rangle - |t_0\rangle \sim |\downarrow\rangle_g |\uparrow\rangle_e,$$
$$\Psi(t = T_{swap}/2) = |s\rangle + i|t_0\rangle \sim |\uparrow\rangle_g |\downarrow\rangle_e + i|\downarrow\rangle_g |\uparrow\rangle_e.$$

$\sqrt{\text{swap}}$ gate

Weitenberg et al, PRA (2011)

Quantum computation with optical tweezers

c)2-qubit exchange gate



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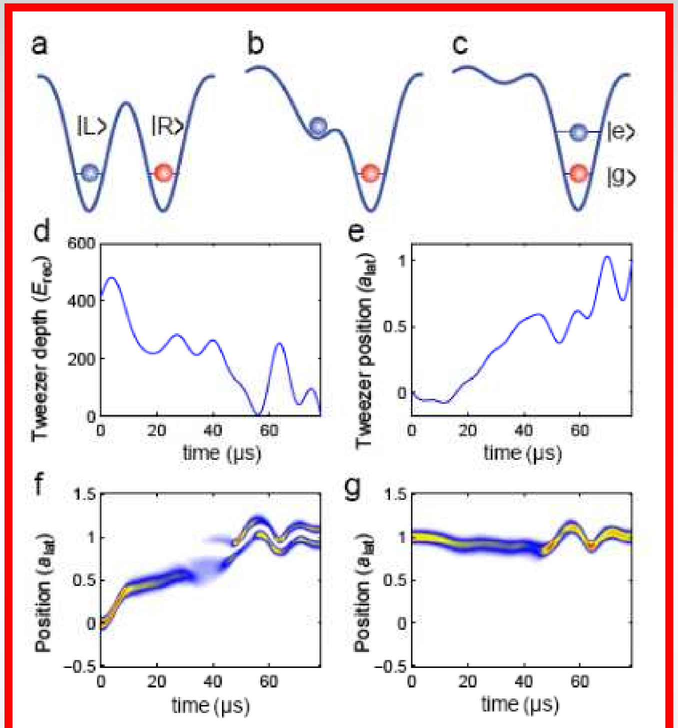
$$\Psi(t=T_{swap}) = |s\rangle - |t_0\rangle \sim |\downarrow\rangle_g |\uparrow\rangle$$
$$\Psi(t=T_{swap}/2) = |s\rangle + i|t_0\rangle \sim |\uparrow\rangle_g |\downarrow\rangle_e + i$$



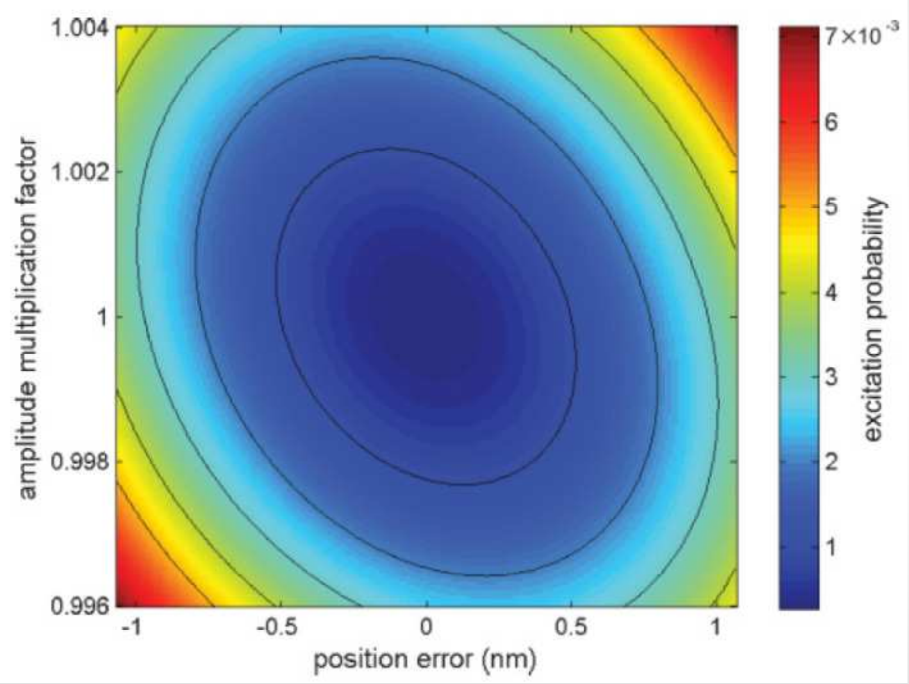
99.97% fidelity in 75 us

Total gate time a few 100us with 10^{-3} error

Weitenberg et al, PRA (2011)

Quantum computation with optical tweezers

Include intensity and beam pointing instabilities



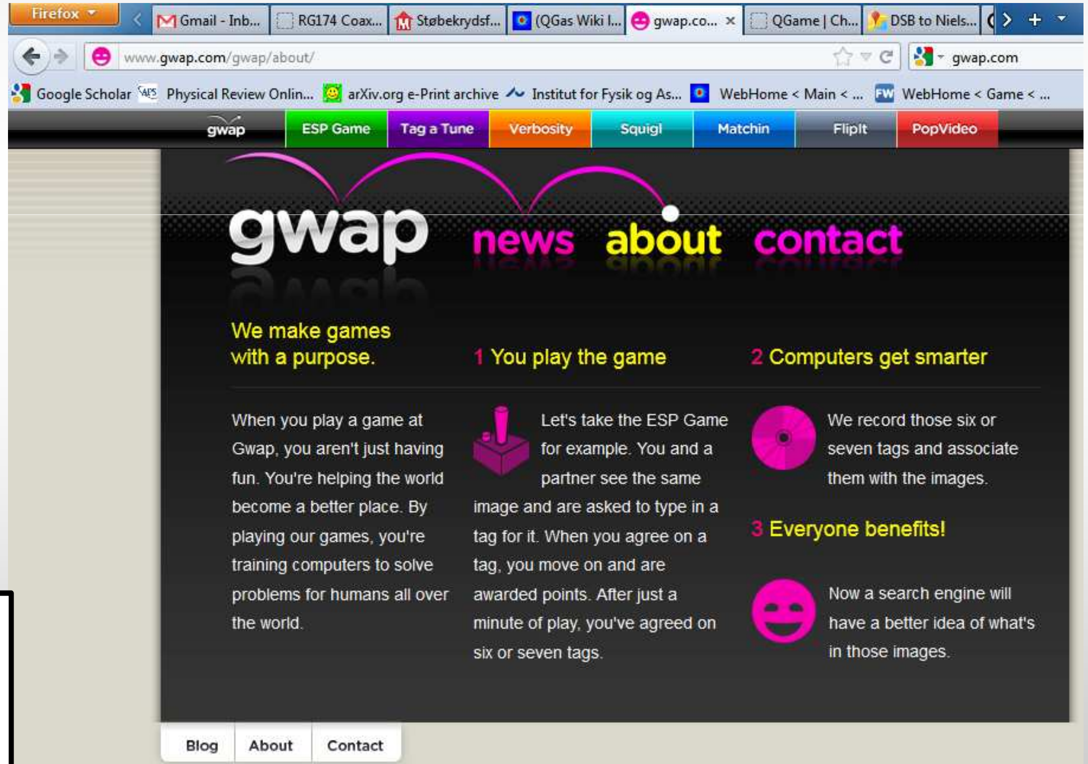
Current state-of-the-art of 50nm beam pointing accuracy yields considerably higher errors!

Three solutions:
- Improve state-of-the-art a la LIGO
- The quantum computer game
- A fundamentally new method for addressing

Human Computing

9 billion man-hours spent on solitaire per year!

Luis Von Ahn



ESP game:
22,000 players
Over 3,2 mio image-labels

Human Computing

9 billion man-hours spent on solitaire per year!

- >100.000 players
- Players invent new algorithms (15 year super-player)
- Players helped the scientists win the CASP 2009 protein folding challenge

The quantum computer game

Design goals

- Parameter search by thousands of players
- Unique players with extraordinary optimization techniques
- Novel research directions through participatory design
- Science education to the general public

Incentives

- Fun and easy arcade type game
- Individual competition on a global high score
- Competition and cooperation in groups, eg. classes, cities countries...
- Players contribute to actual science

Quantum games: software overview

Q. mechanics tutorial
- Predefined games
- User development interface
  - User defined games → Predefined games

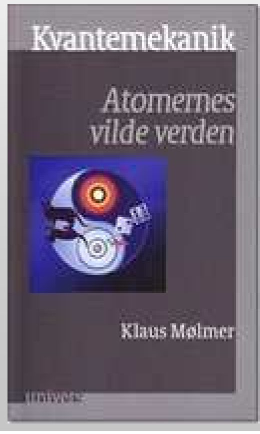
Scientific games
- The quantum computer game
- User defined games

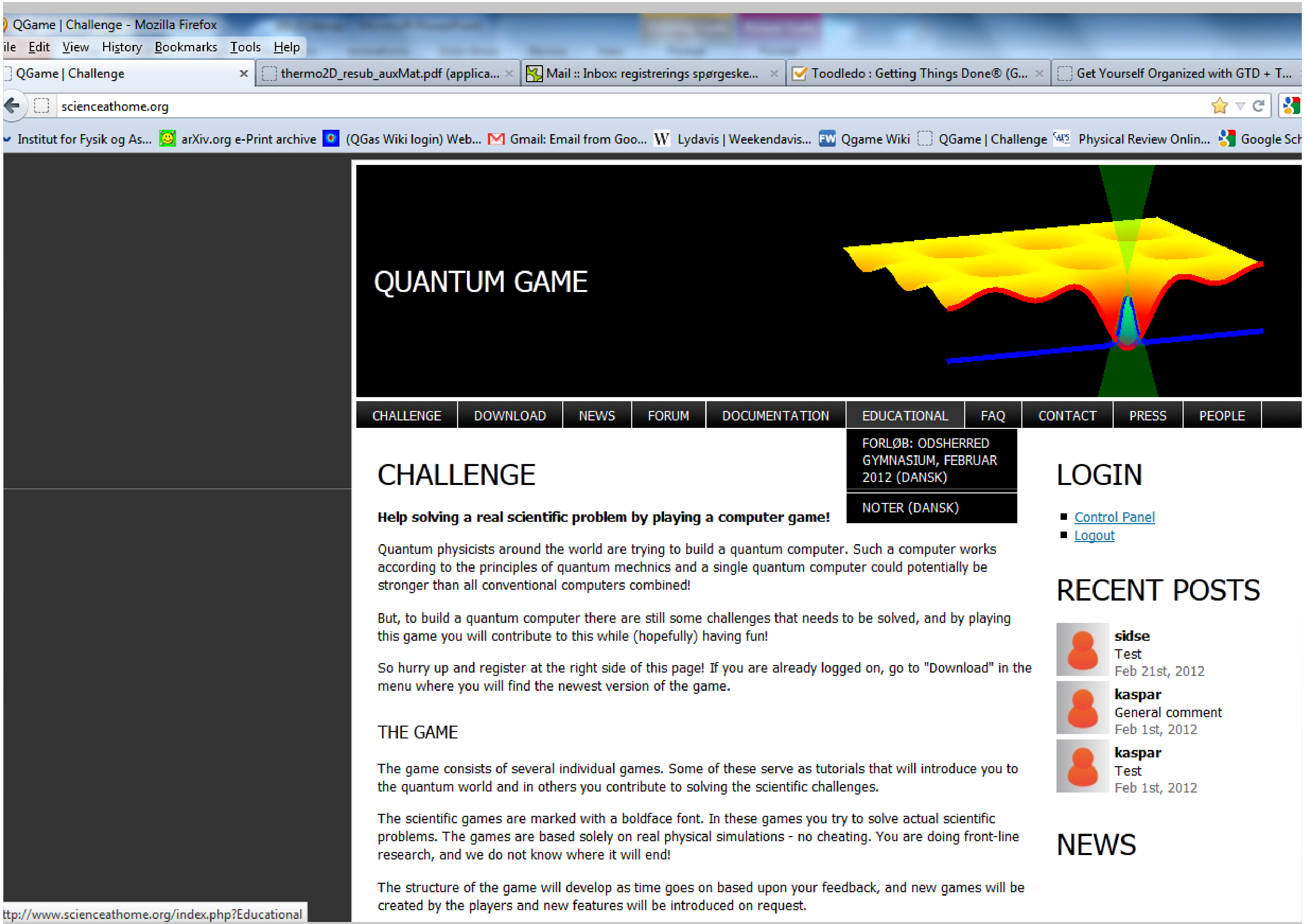
Scientist developers interface
- User development interface
- Simulate experiments

es available
r (TDSE)
evskii
ard

Feb 2012: first successful high-school project

High school / university projects:
- 1-2 week course
- Combined with q. mechanics book of Klaus Mølmer





QGame | Challenge - Mozilla Firefox

sciencеathome.org

QUANTUM GAME

CHALLENGE | DOWNLOAD | NEWS | FORUM | DOCUMENTATION | EDUCATIONAL | FAQ | CONTACT | PRESS | PEOPLE

FORLØB: ODSHERRED GYMNASIUM, FEBRUAR 2012 (DANSK)

NOTER (DANSK)

CHALLENGE

Help solving a real scientific problem by playing a computer game!

Quantum physicists around the world are trying to build a quantum computer. Such a computer works according to the principles of quantum mechnics and a single quantum computer could potentially be stronger than all conventional computers combined!

But, to build a quantum computer there are still some challenges that needs to be solved, and by playing this game you will contribute to this while (hopefully) having fun!

So hurry up and register at the right side of this page! If you are already logged on, go to "Download" in the menu where you will find the newest version of the game.

THE GAME

The game consists of several individual games. Some of these serve as tutorials that will introduce you to the quantum world and in others you contribute to solving the scientific challenges.

The scientific games are marked with a boldface font. In these games you try to solve actual scientific problems. The games are based solely on real physical simulations - no cheating. You are doing front-line research, and we do not know where it will end!

The structure of the game will develop as time goes on based upon your feedback, and new games will be created by the players and new features will be introduced on request.

LOGIN

- Control Panel
- Logout

RECENT POSTS

sidse
Test
Feb 21st, 2012

kaspar
General comment
Feb 1st, 2012

kaspar
Test
Feb 1st, 2012

NEWS

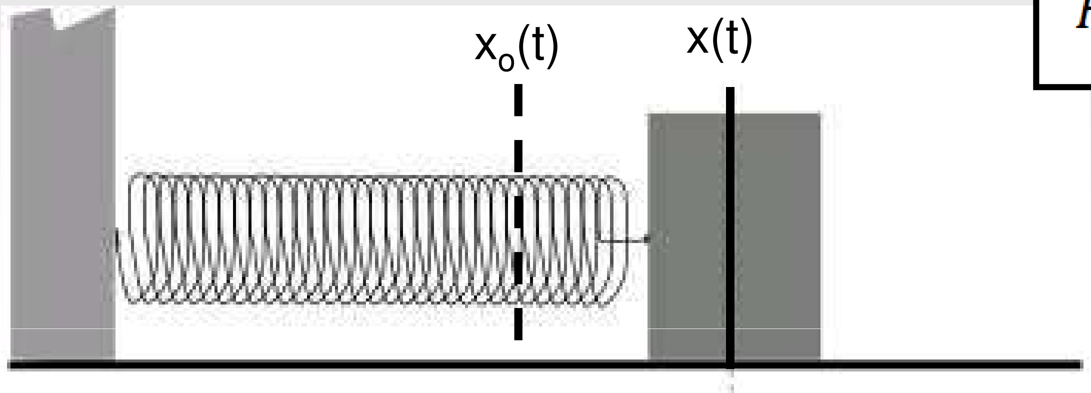
ttp://www.scienceathome.org/index.php?Educational

Classical example: Harmonic motion

Move the wall according to $x_o(t)$

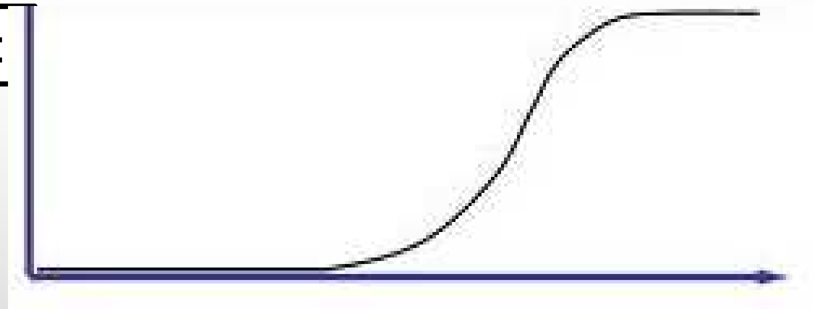
Newtons 2nd lov:

$$F = m\,\ddot{x} = -k\,(x(t) - x_o(t))$$



Exercise: the mass has to move according to:

$$x(t) = \frac{1}{1 + e^{-t}}$$



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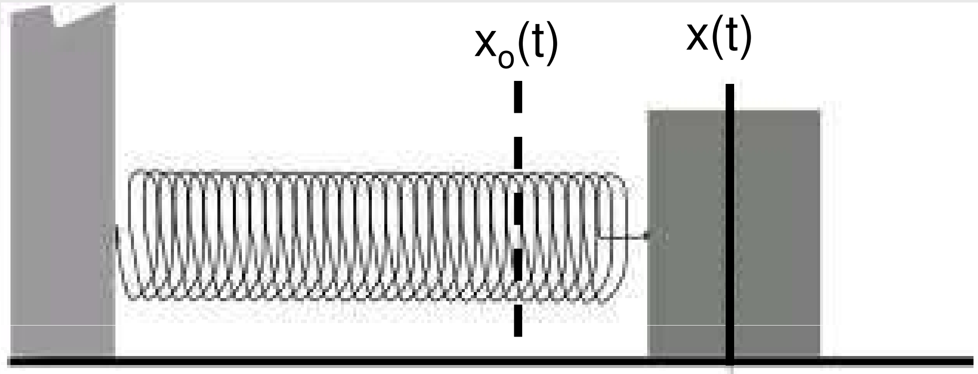
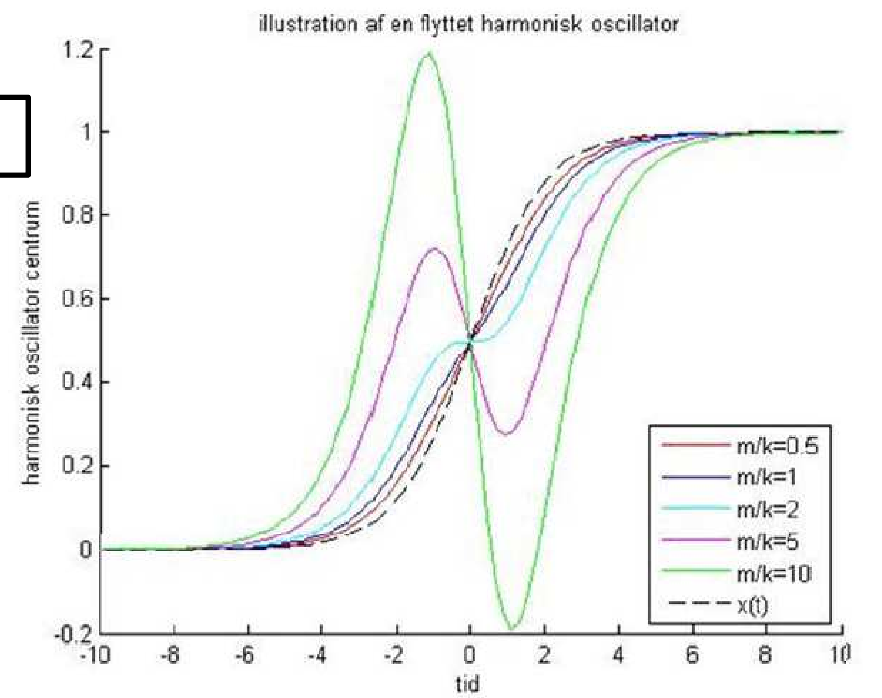


Exercise: the mass has to move according to:

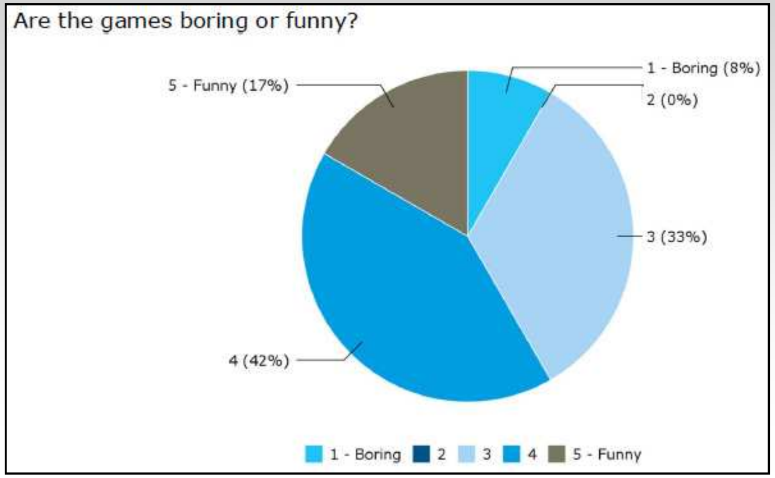
$$x(t) = \frac{1}{1+e^{-t}}$$

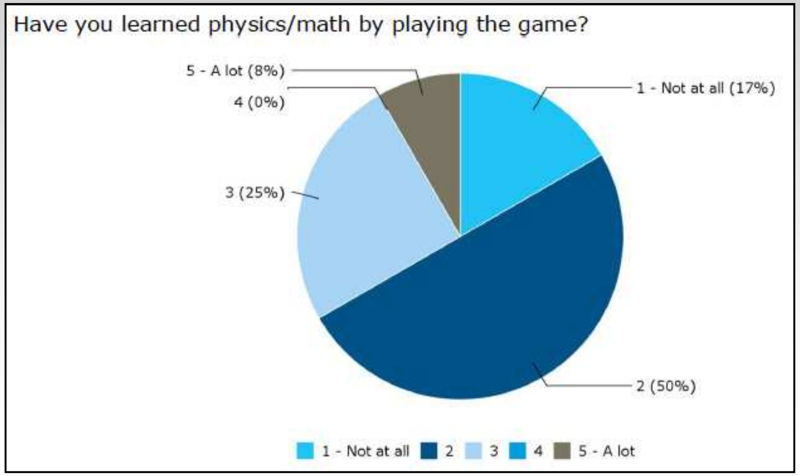
What should $x_o(t)$ be?

$$x_o(t) = x(t) + \frac{m}{k}\,\ddot{x}$$



Evaluation results





"Especially competitive aspect of the game is a scoop. It's almost like taking advantage of the most primal part of humans to explore science."

"In the normal teaching you calculate it only while you in the game get the feeling of directly doing the experiment"

"Quantum physics seems suddenly more tangible, something which is not a dangerous monster you can't work out. It should be in every school!"

"I think you have found a super mix of tutorial games and difficult scientific games.

Thank you very much