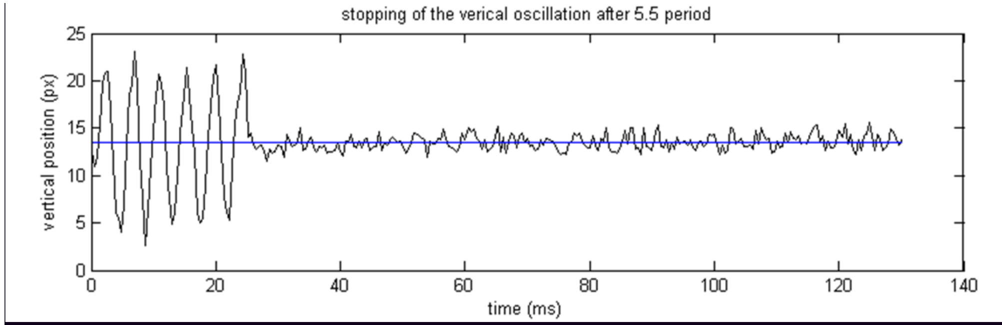
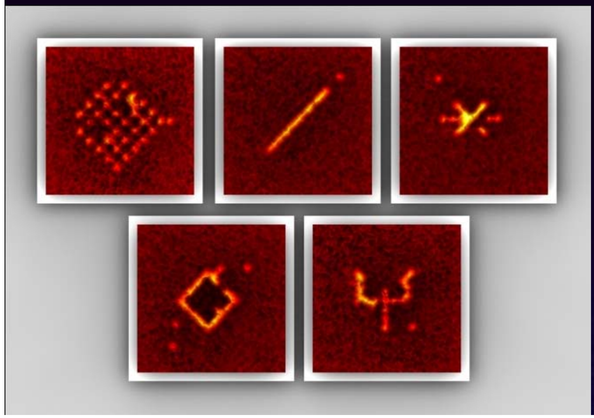


The Quantum Computer Game: Democratic Science and Game Based Learning



Jacob Sherson

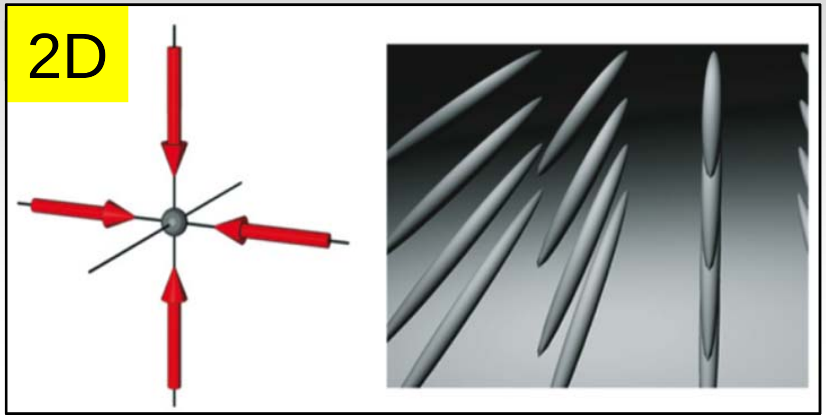
Paris 29/6-2012

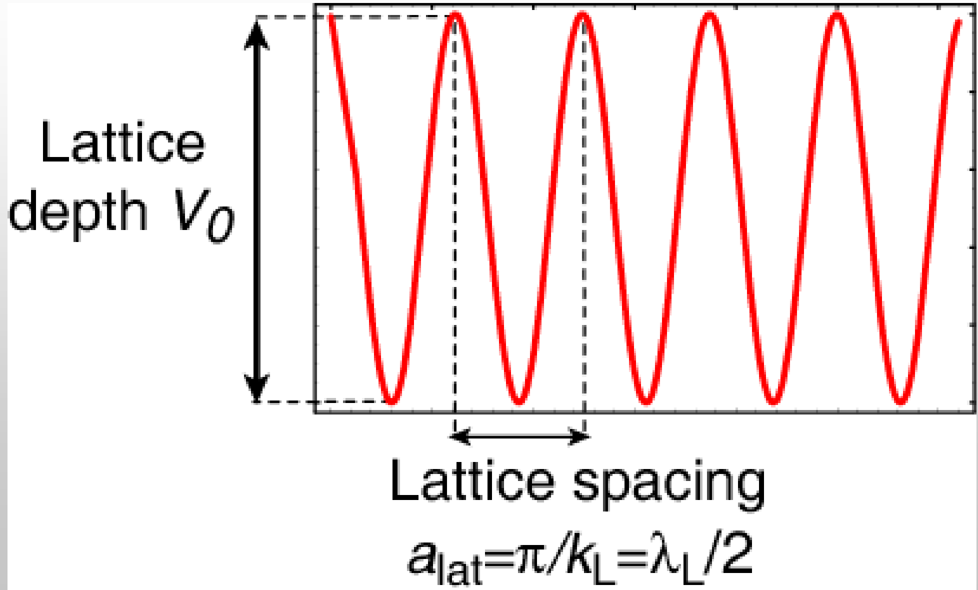
Outline

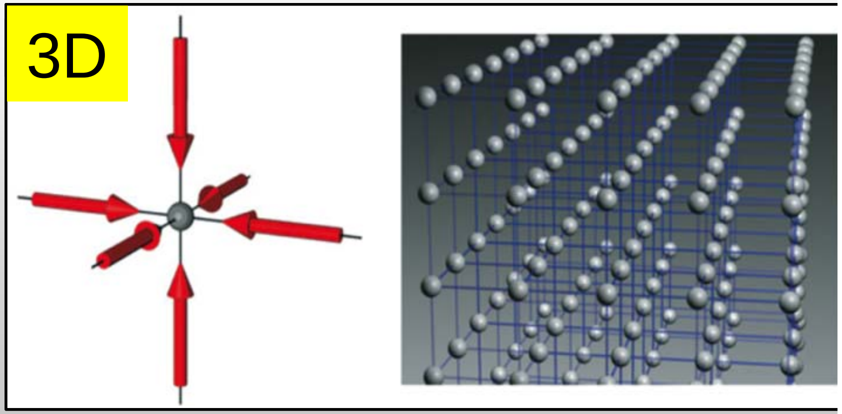
- Single site detection and manipulation in optical lattices
- Tweezer based q. computation architecture
- The quantum computer game
- Non-destructive imaging

Optical lattices

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





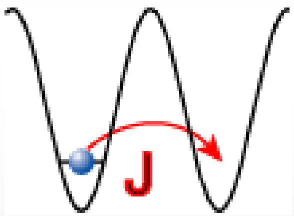


Bose-Hubbard Hamiltonian

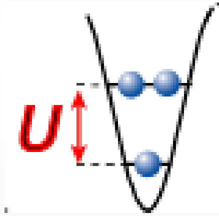
Expanding the field operator in the Wannier basis of localized wave functions on each lattice site, yields :

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

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

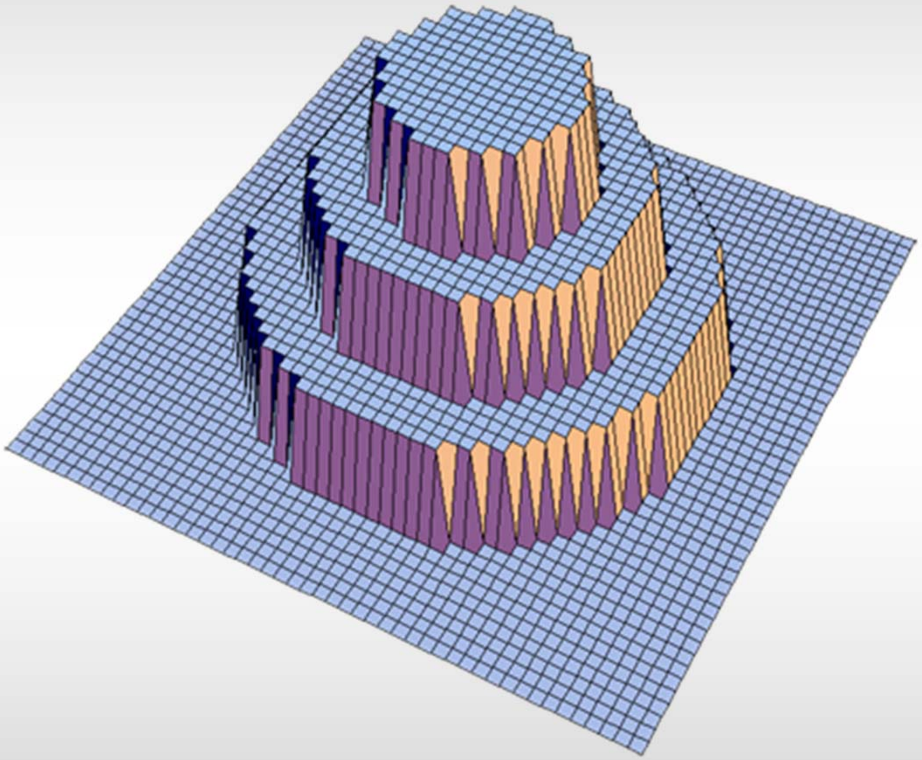
$$J = -\int d^3x \, w(\boldsymbol{x} - \boldsymbol{x}_i) \left(-\frac{\hbar^2}{2m} \nabla^2 + V_{lat}(\boldsymbol{x}) \right) w(\boldsymbol{x} - \boldsymbol{x}_j)$$

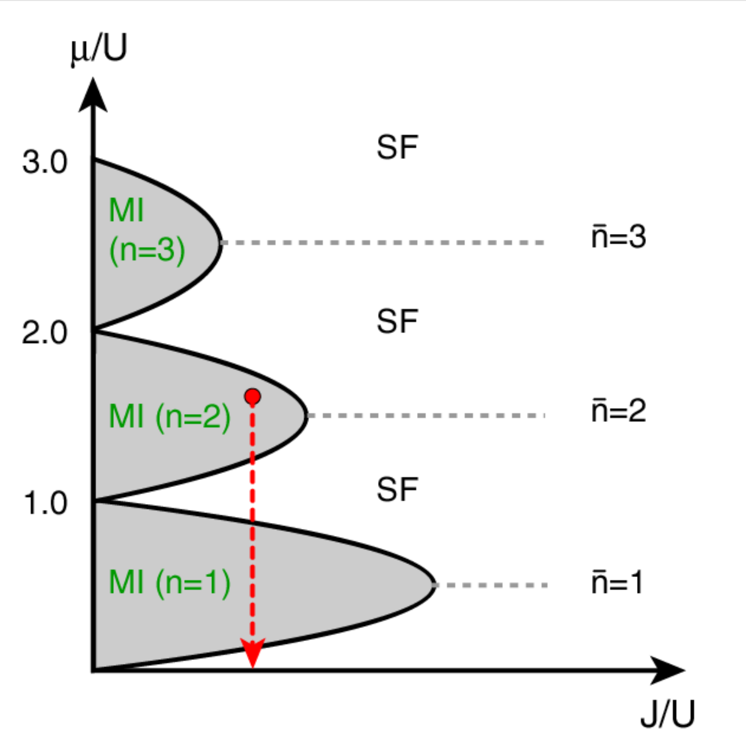
Onsite interaction matrix element

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

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

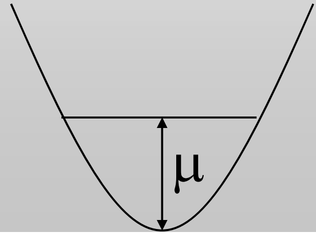
Superfluid – Mott-Insulator Phase Diagram





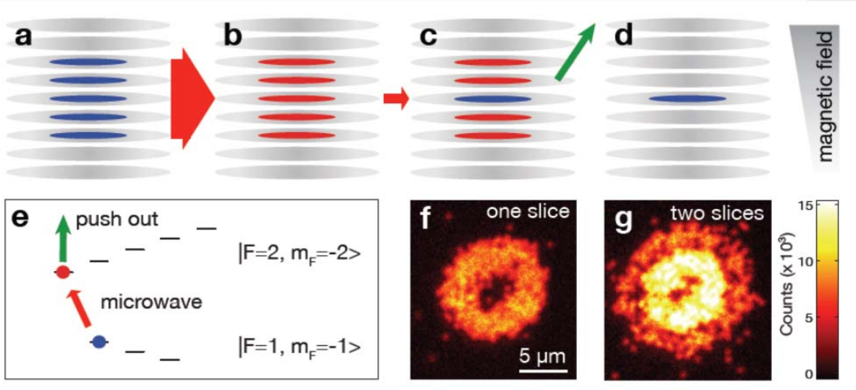
Inhomogeneous system:
effective local chemical potential

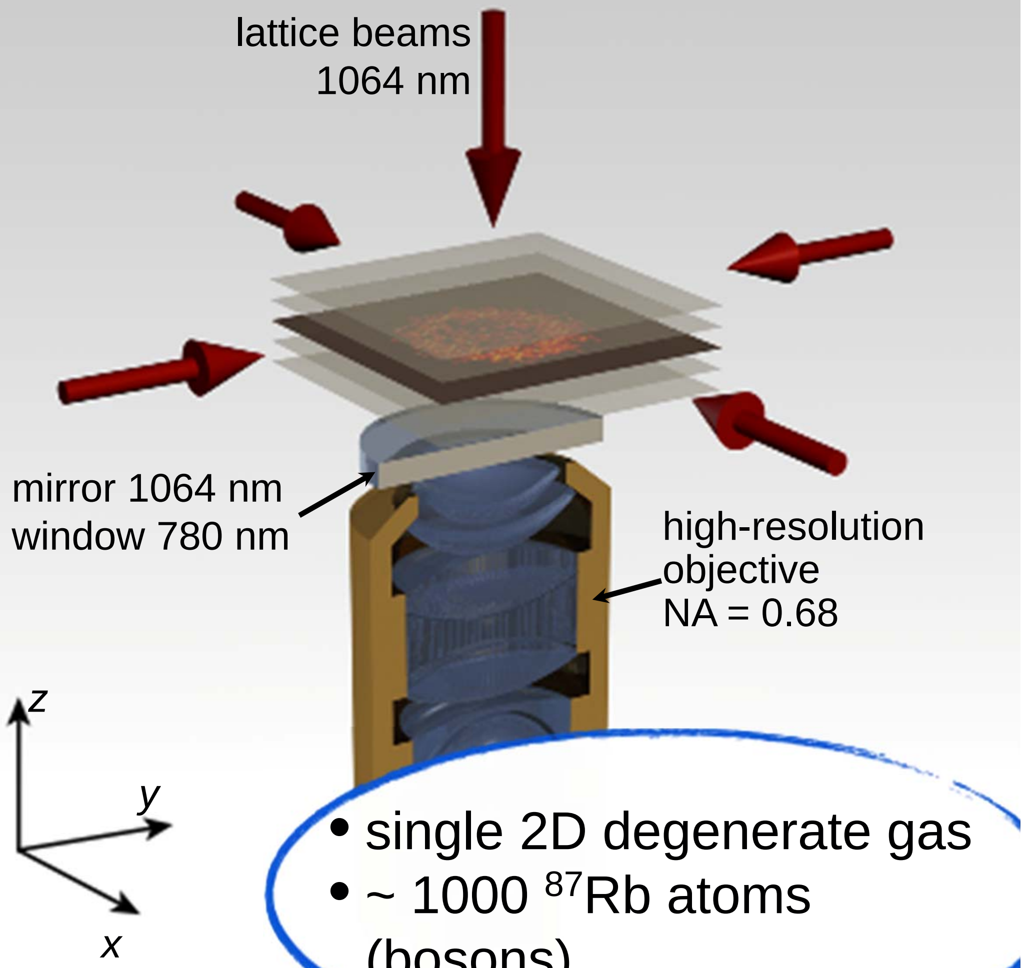
$$\mu_{loc} = \mu - \varepsilon_i$$



Experimental set-up

Preparation of a single 2D system:

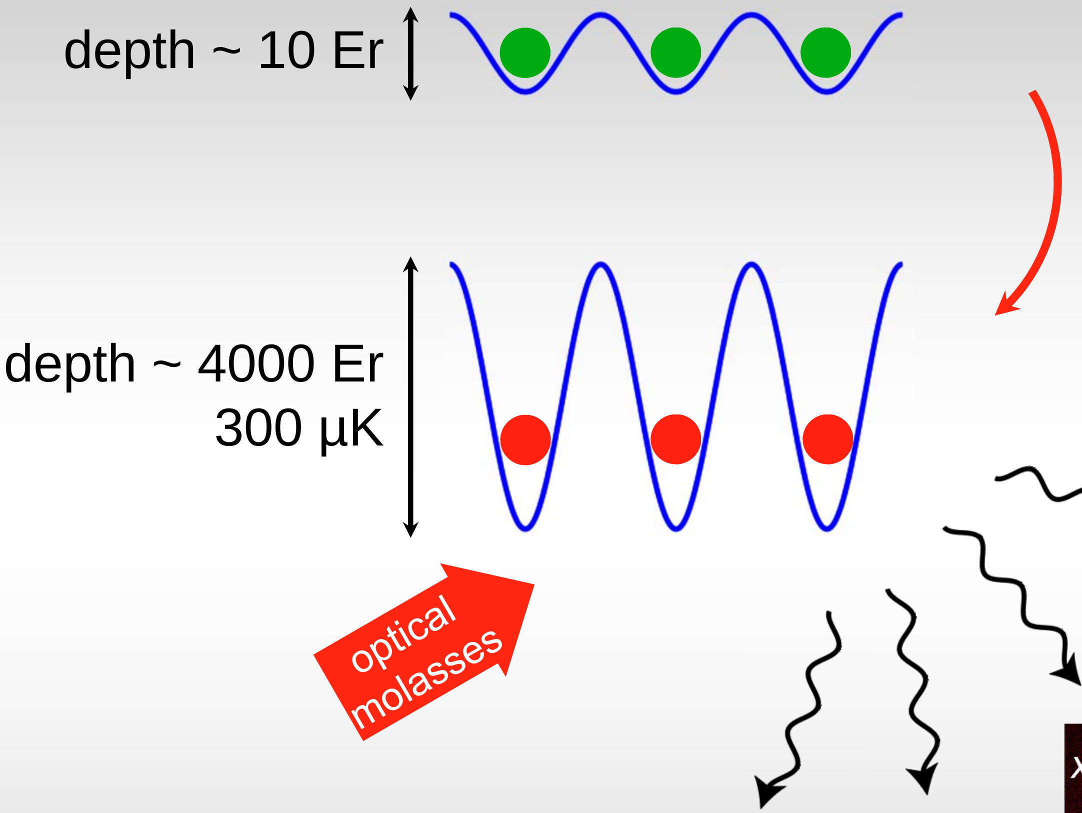




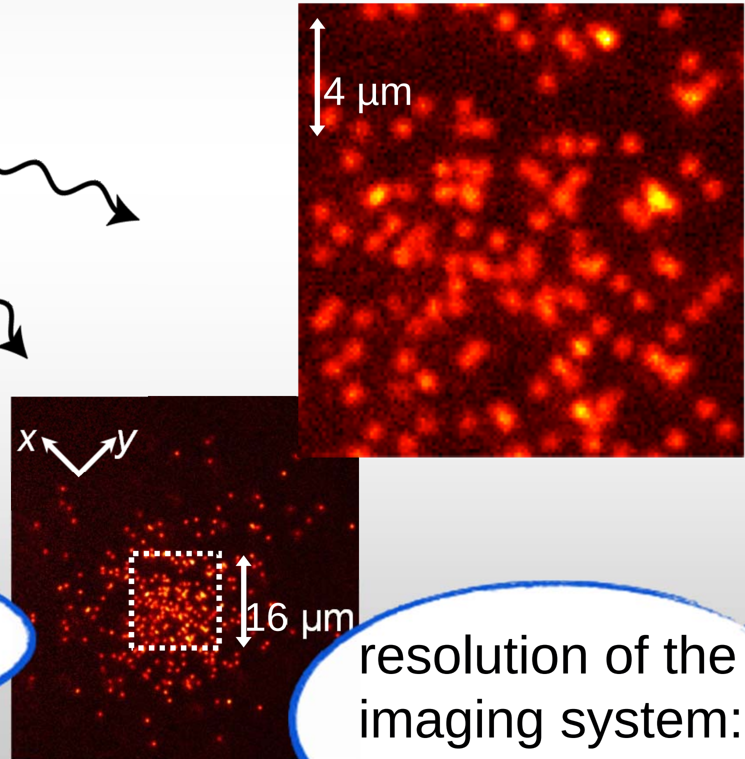
- single 2D degenerate gas
- ~ 1000 ^{87}Rb atoms (bosons)

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

Fluorescence imaging



- density distribution frozen
- phase coherence lost

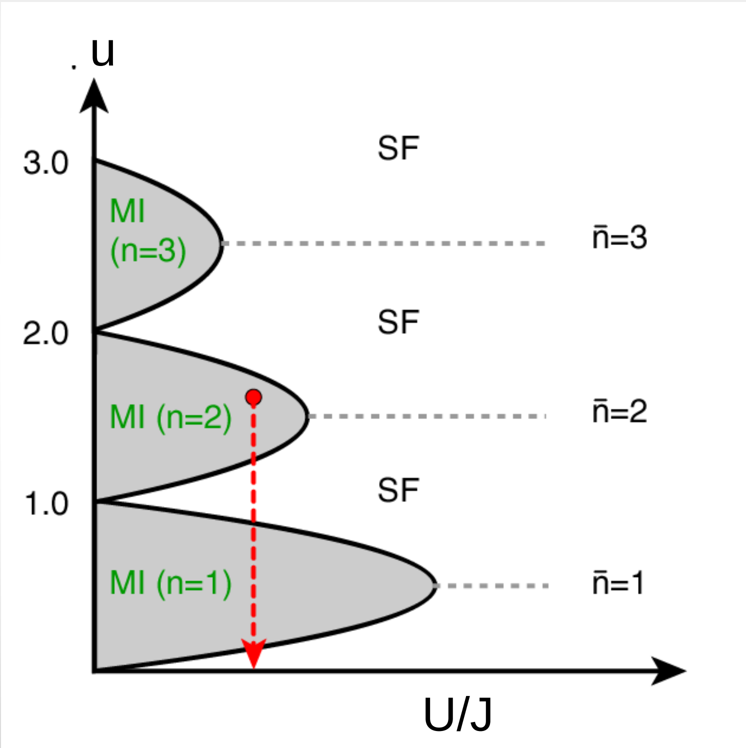


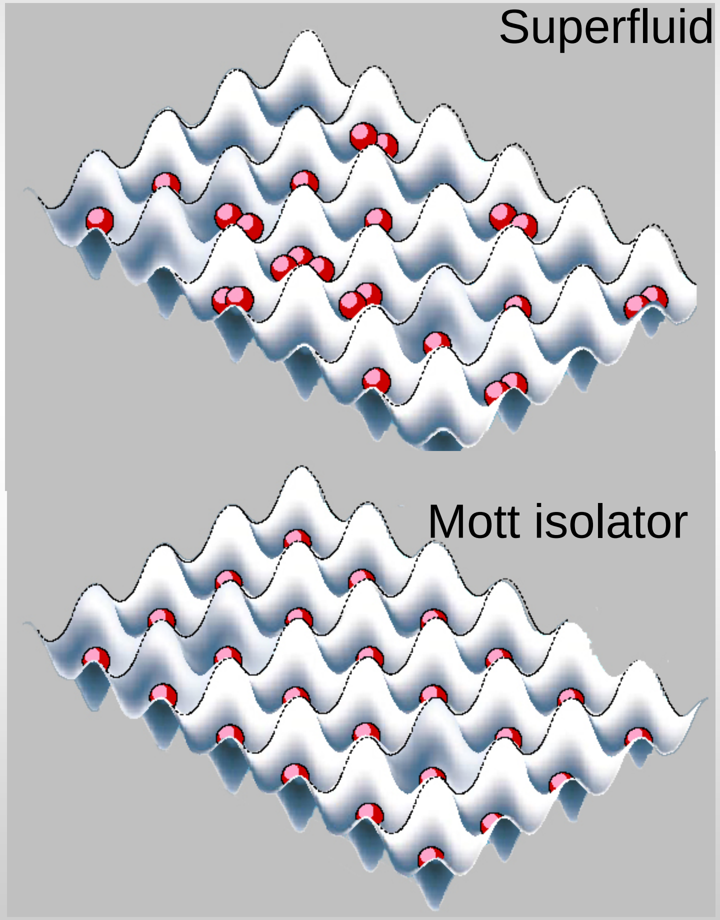
- fluorescence rate / atom: 60 kHz
- ~ 5000 photons / atom collected in 900ms

resolution of the imaging system: ~700 nm

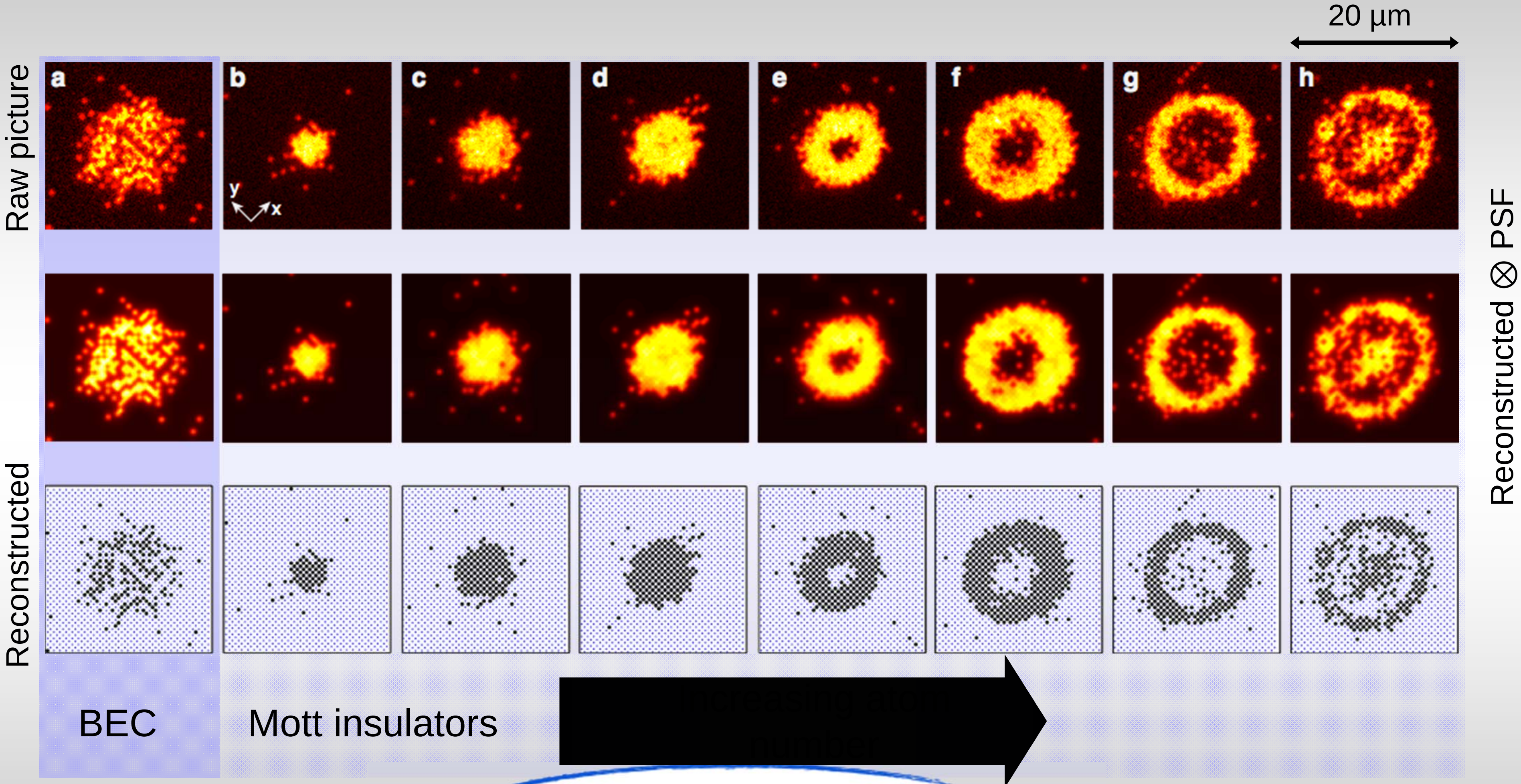
J. F. Sherson et al, **Nature, 467,** 68 (2010)

Superfluid – Mott-Isolator phase diagram





In-situ observation of a Mott insulator

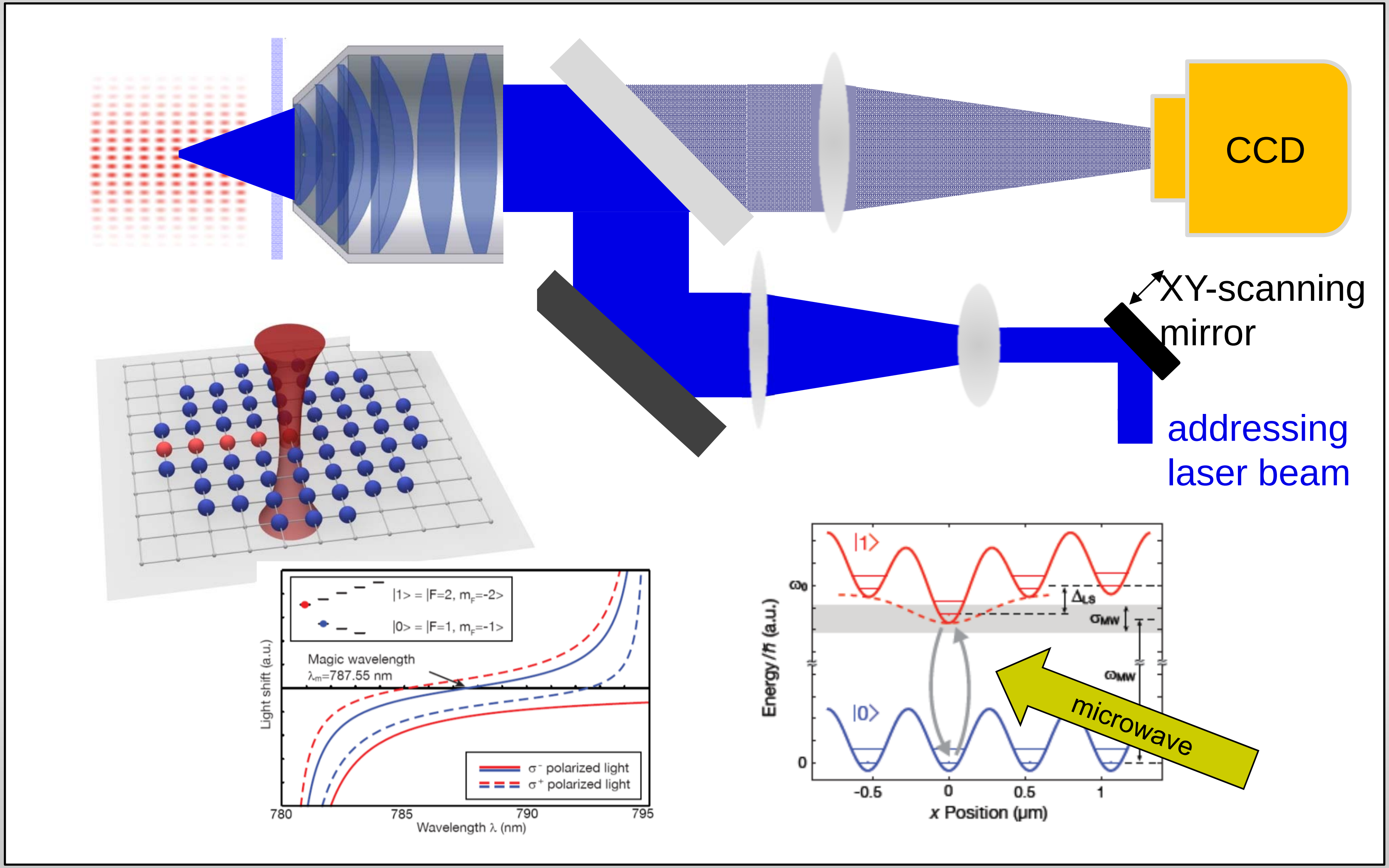


for the Mott insulators: U/J ~ 300 (critical U/J ~16)

-> only thermal fluctuations

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

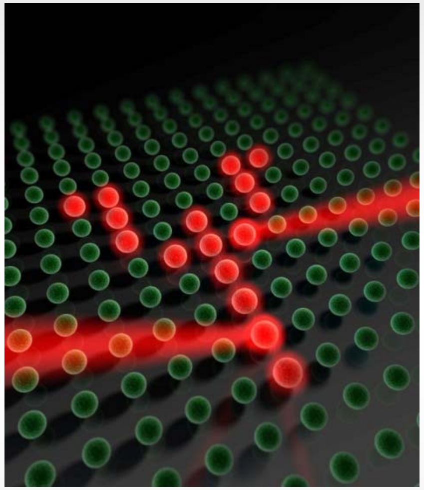
Addressing individual lattice sites

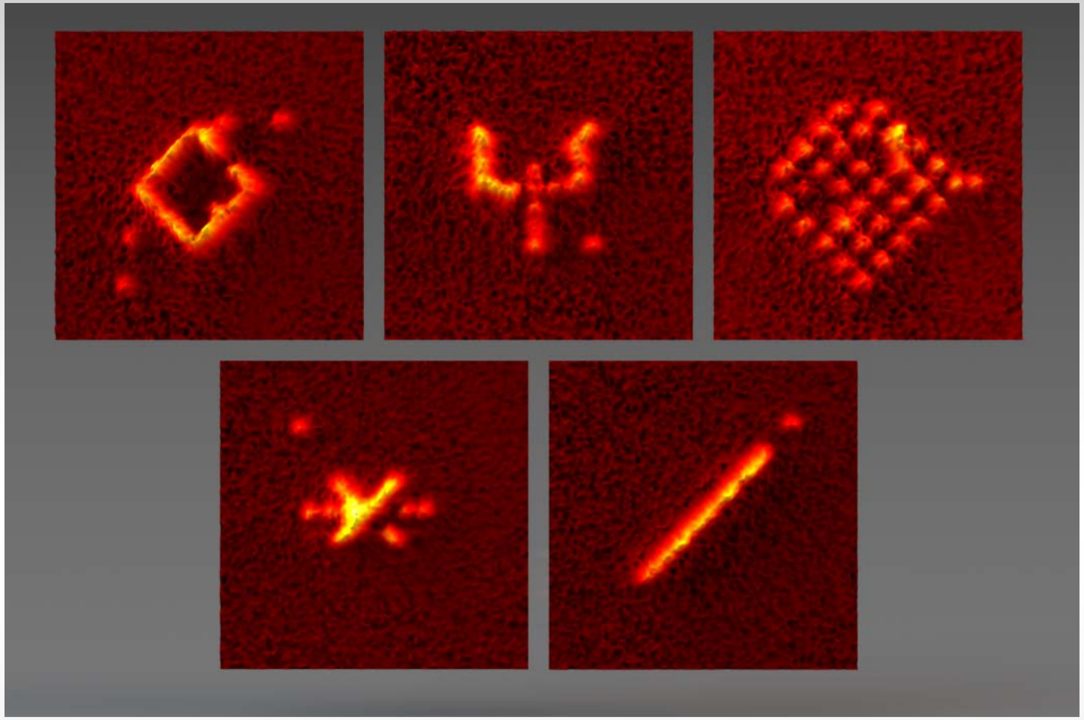


Weitenberg et al, **Nature, 471,** 319 (2011)

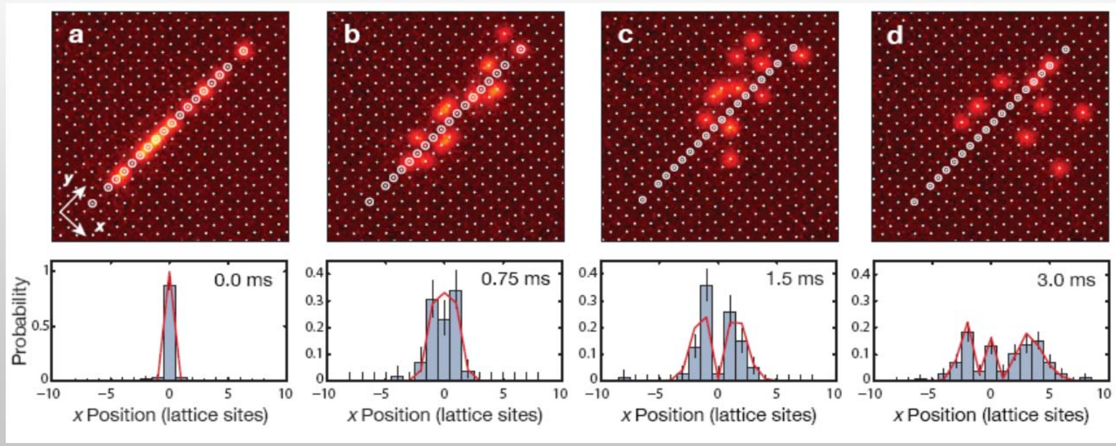
Addressing individual lattice sites

Writing arbitrary patterns





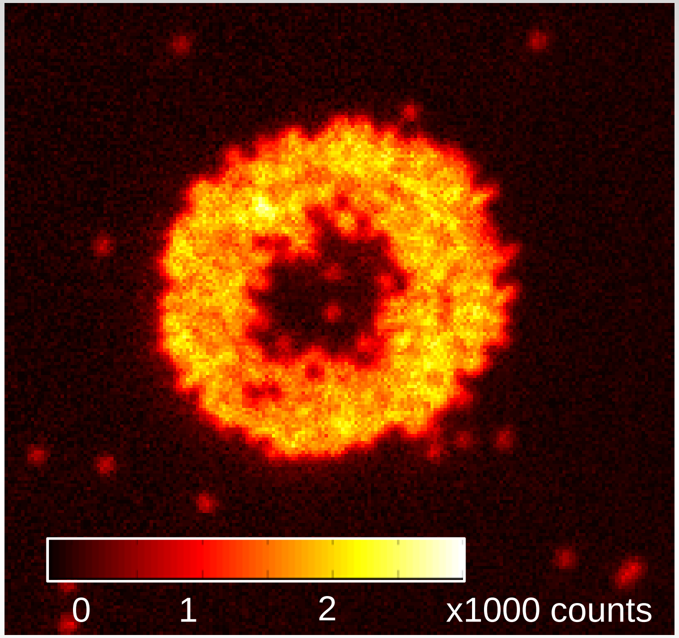
Single particle tunneling
”the horse track race”



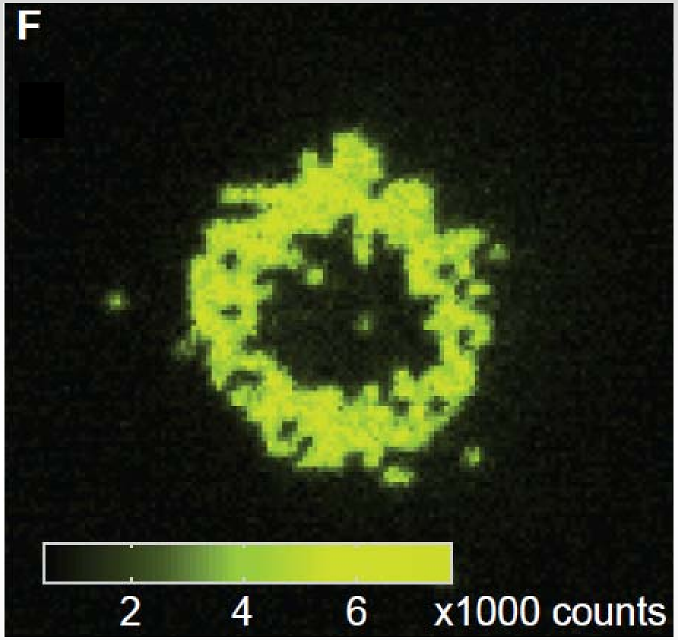
Weitenberg et al, **Nature, 471,** 319 (2011)

Mott Insulators

Garching:



Harvard: Bakr et al., Science 329, 547 (2010)



	Garching	Harvard
Feature	Intrinsic homogeneity	Disorder, phase correction
Focus	Single shot thermometry	SF-MI dynamics, averaged densities
Results	Global comparison with theory.	Observe fast (<t_{tunnel}) number squeezing Highest fidelty MI in thin MIs.
Temperature	0.071(5) U/kB	T ~ 0.16(3) U/kB

Detection of many-body physics

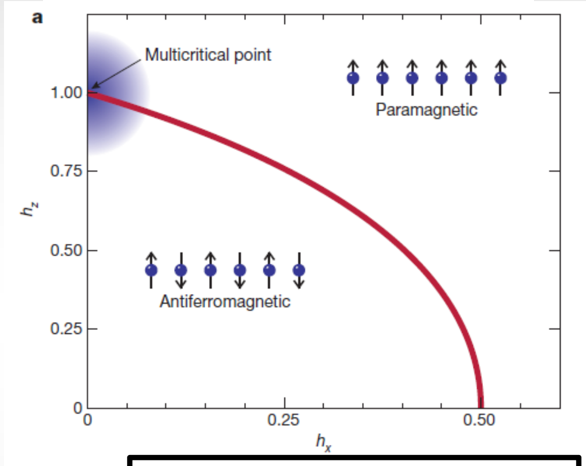
Quantum simulation of antiferromagnetic spin chains in an optical lattice

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

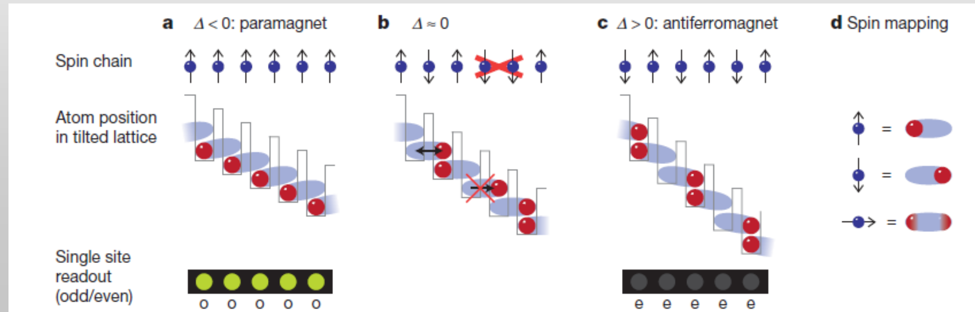
$$H = J\sum_i S_z^i S_z^{i+1} - h_z^i S_z^i - h_x^i S_x^i$$



Tilted optical lattice

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

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



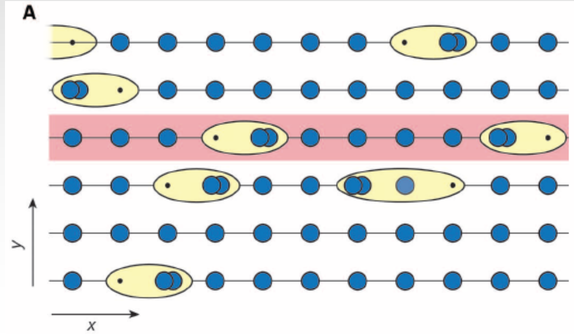
Detection of many-body physics

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 tunneling close to MI transition (particle-hole pairs)



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

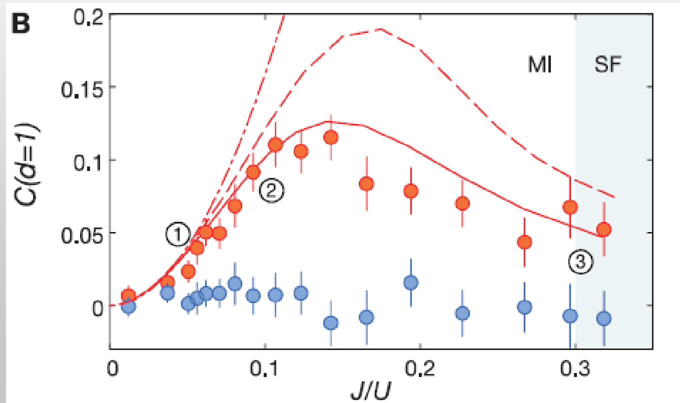
M. Endres,[1]* M. Cheneau,[1] T. Fukuhara,[1] C. Weitenberg,[1] P. Schauß,[1] C. Gross,[1] L. Mazza,[1] M. C. Bañuls,[1] L. Pollet,[2] I. Bloch,[1,3] S. Kuhr[1,4]

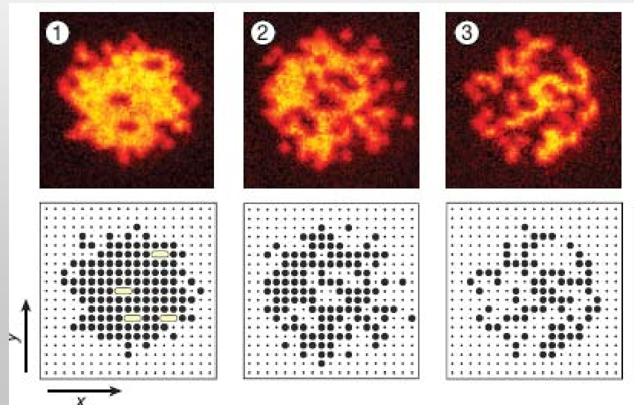
14 OCTOBER 2011 VOL 334 SCIENCE

Two-site parity correlation function

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

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





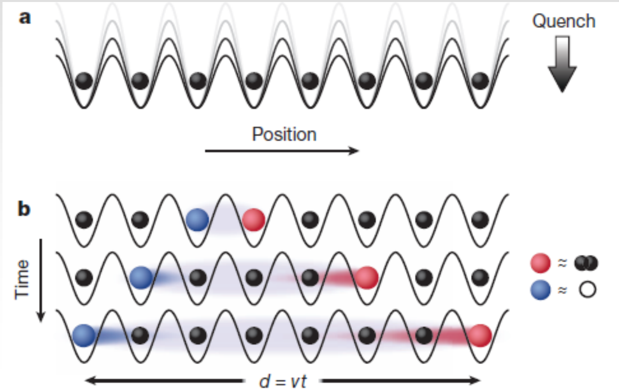
Detection of many-body physics

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

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



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

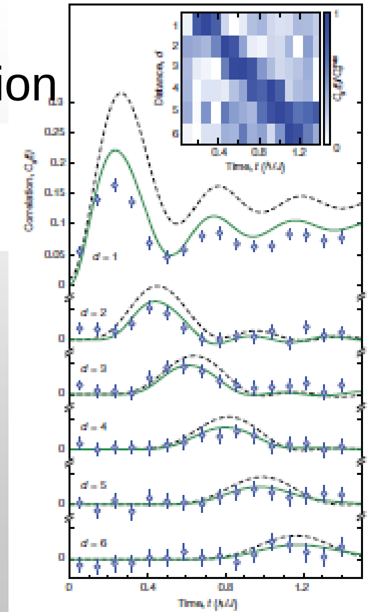
M. Endres,[1]* M. Cheneau,[1] T. Fukuhara,[1] C. Weitenberg,[1] P. Schauß,[1] C. Gross,[1] L. Mazza,[1] M. C. Bañuls,[1] L. Pollet,[2] I. Bloch,[1,3] S. Kuhr[1,4]

14 OCTOBER 2011 VOL 334 SCIENCE

Two-site parity correlation function

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

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



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

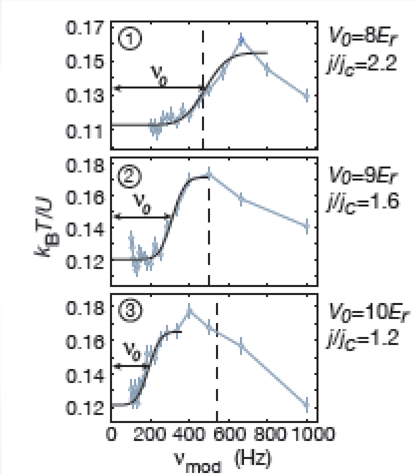
The 'Higgs' Amplitude Mode at the Two-Dimensional Superfluid-Mott Insulator Transition

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

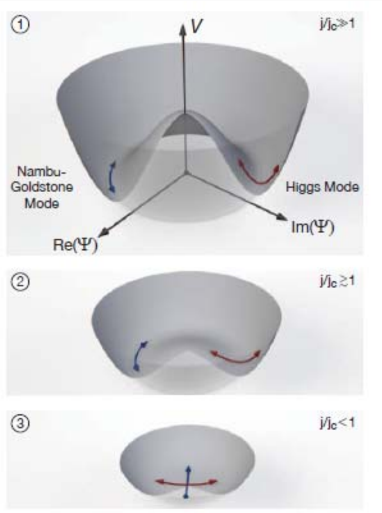
SF-MI phase transition has a complex order parameter

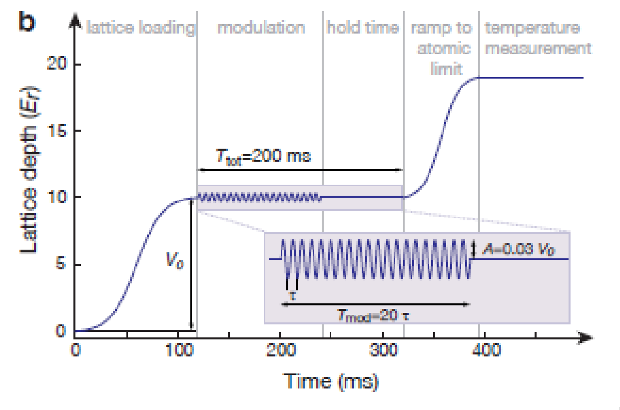
$$\Psi = |\Psi| e^{i}$$

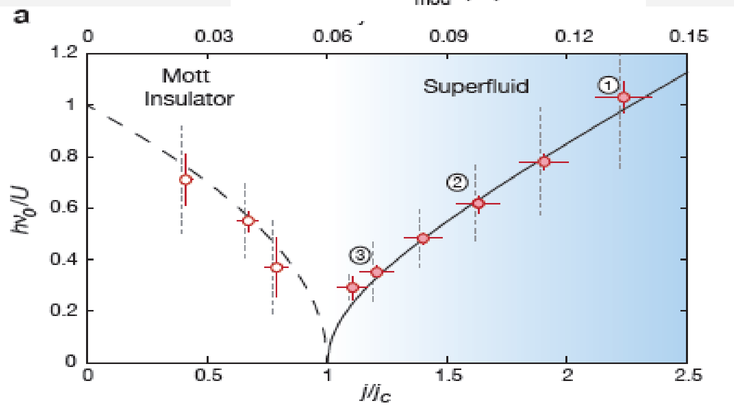


Spontaneous symmetry breaking in the SF phase

Using weak amplitude modulation detect a gap in the response





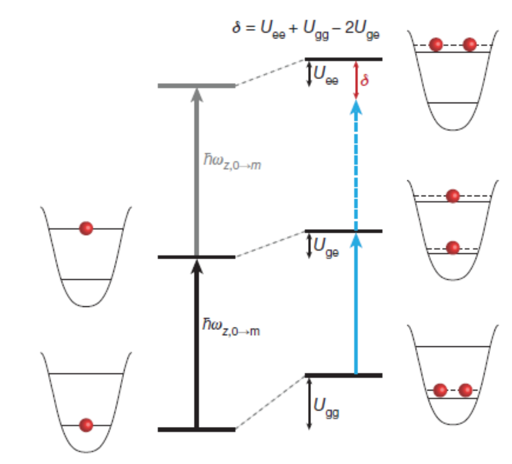


Global manipulation

Orbital excitation blockade and algorithmic cooling in quantum gases

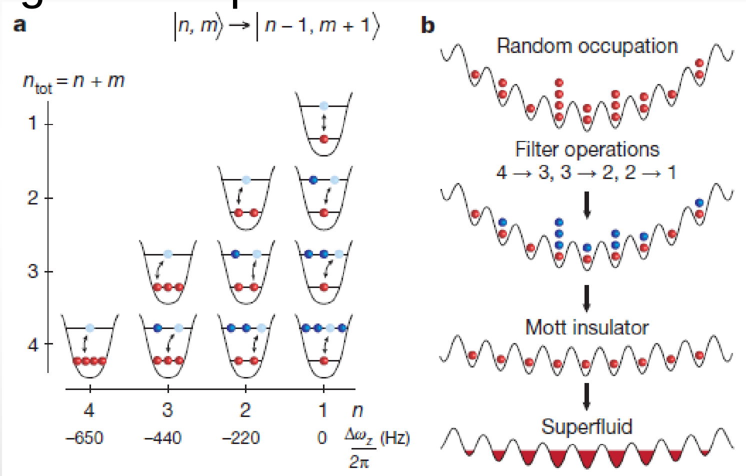
Waseem S. Bakr[1], Ph 500 | NATURE | VOL 480 | 22/29 DECEMBER 2011 ıer[1]

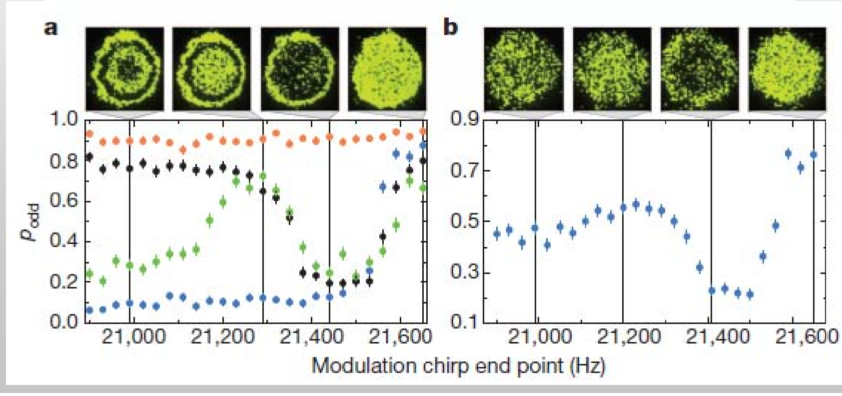
Two-particle interaction energy depends on the vibrational state



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

Filtering: sequentially excite and remove higher occupational numbers





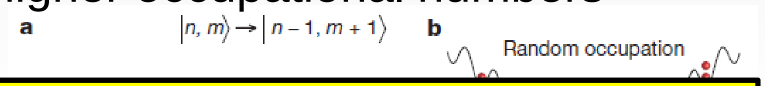
Global manipulation

Orbital excitation blockade and algorithmic cooling in quantum gases

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

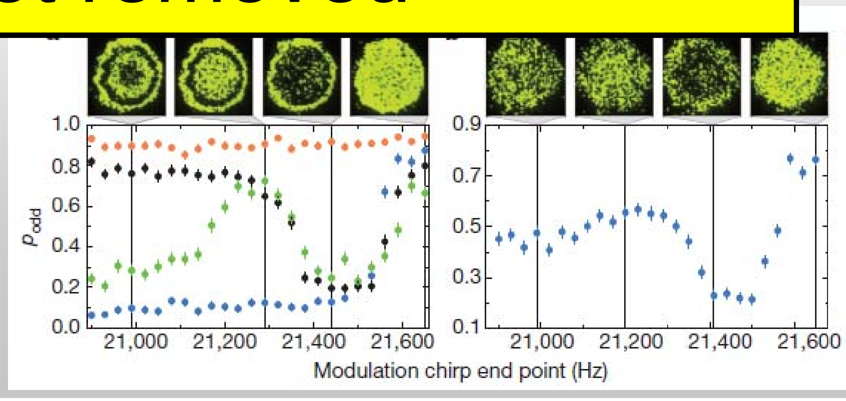
Two-particle interaction energy depends on the vibrational state

Filtering: sequentially excite and remove higher occupational numbers



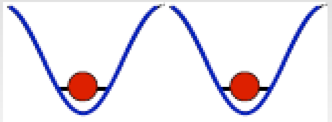
- Entropy per particle is reduced dramatically in the center but not globally
- Vacancies are not removed

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



Shaking the entropy out of an optical lattice: removing vacancies

Would like to realize an "OR" operation between 2 sites
Forbidden due to unitarity

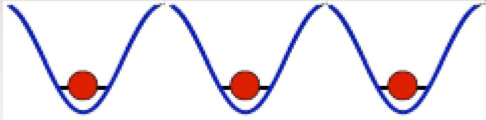


Vacancy probability: ε

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

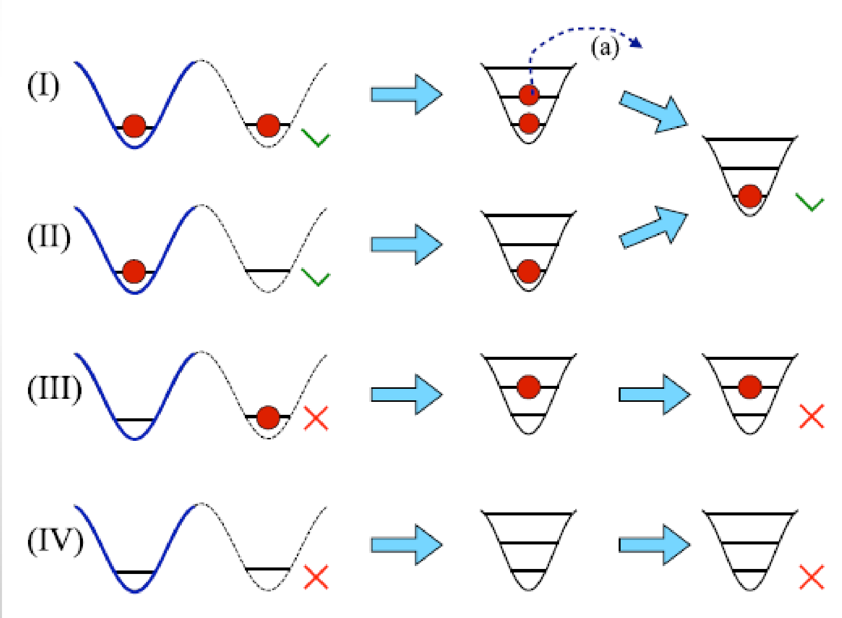
Shaking the entropy out of an optical lattice: removing vacancies

Need 3 sites:
Target well + 2 aux wells

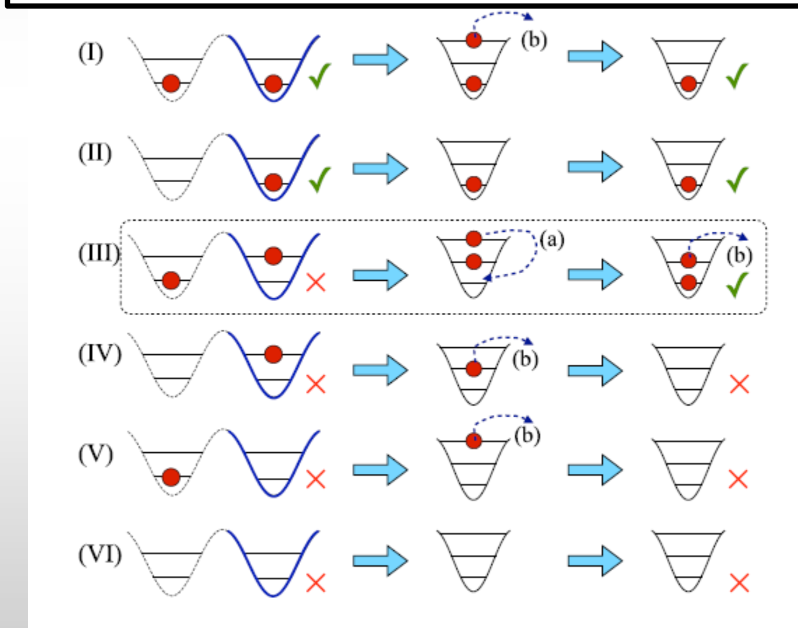


Vacancy probability: ε

Step 1: merge middle and left well



Step 2: merge middle and right well



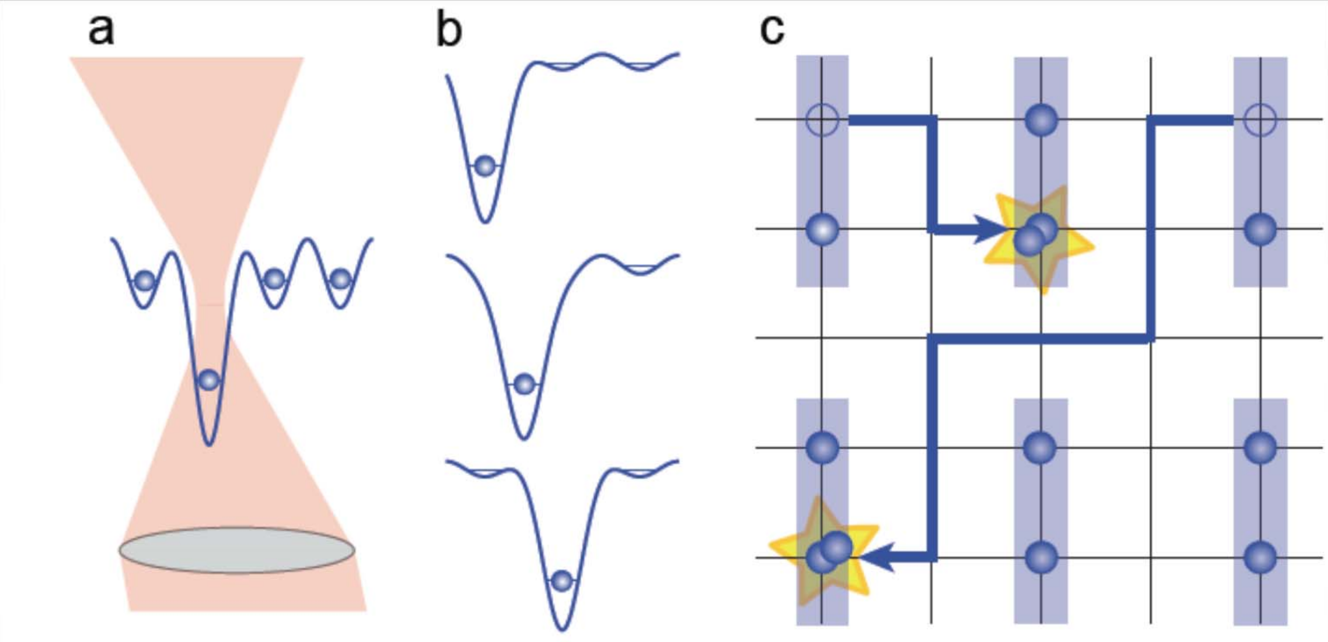
Final vacancy probability: $2\varepsilon^2 - \varepsilon^3$

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

Outline

- Single site detection and manipulation in optical lattices
- Tweezer based q. computation architecture
- The quantum computer game
- Non-destructive imaging

Quantum computation with optical tweezers

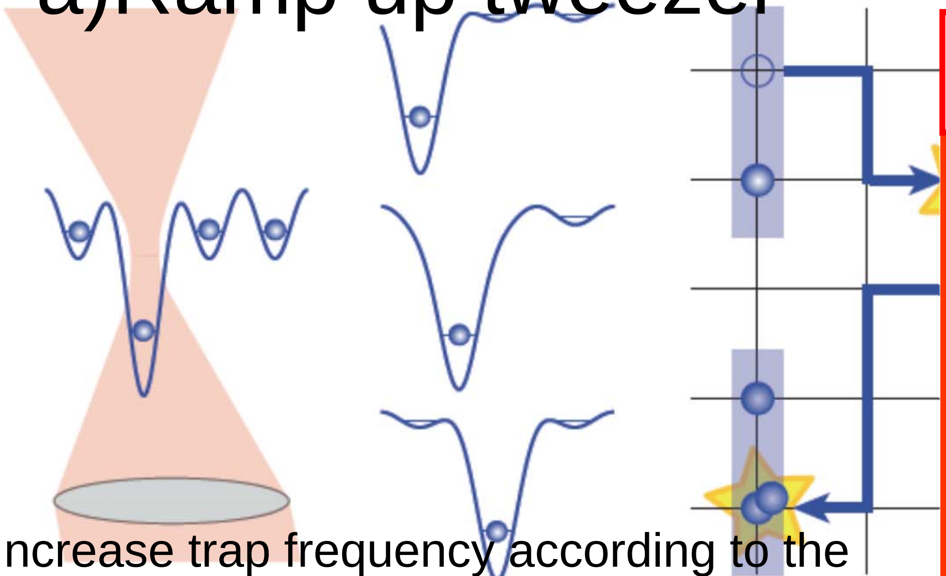


a) Ramp up tweezer
b) Transport atom by translating tweezer
c) Collisional gate by merging atoms

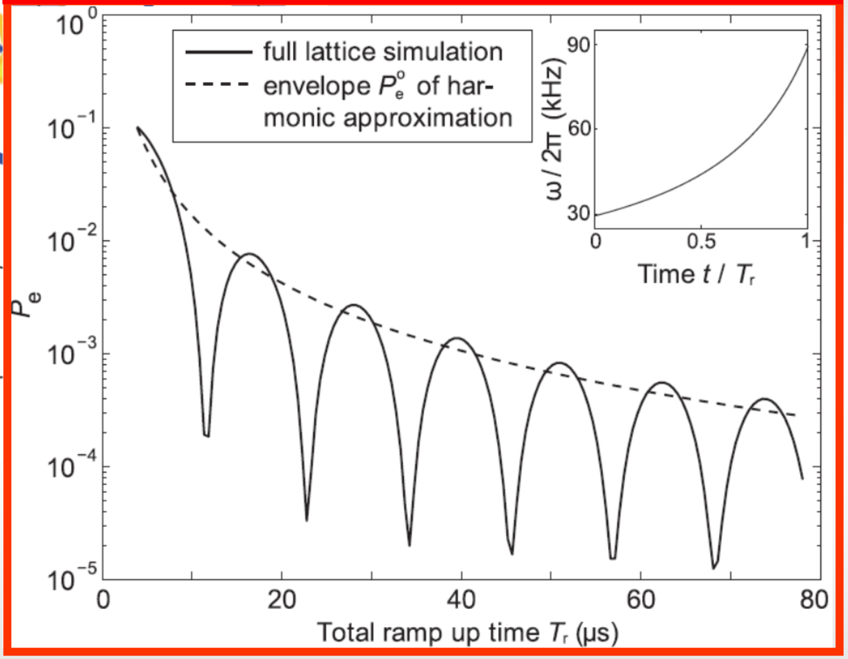
Weitenberg et al, PRA (2011)

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:

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

Solve analytically in a two-state harmonic oscillator model

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

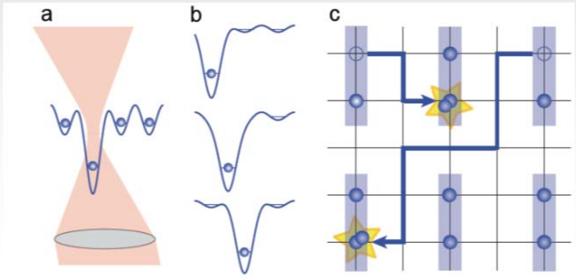
With envelope:

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

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:

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

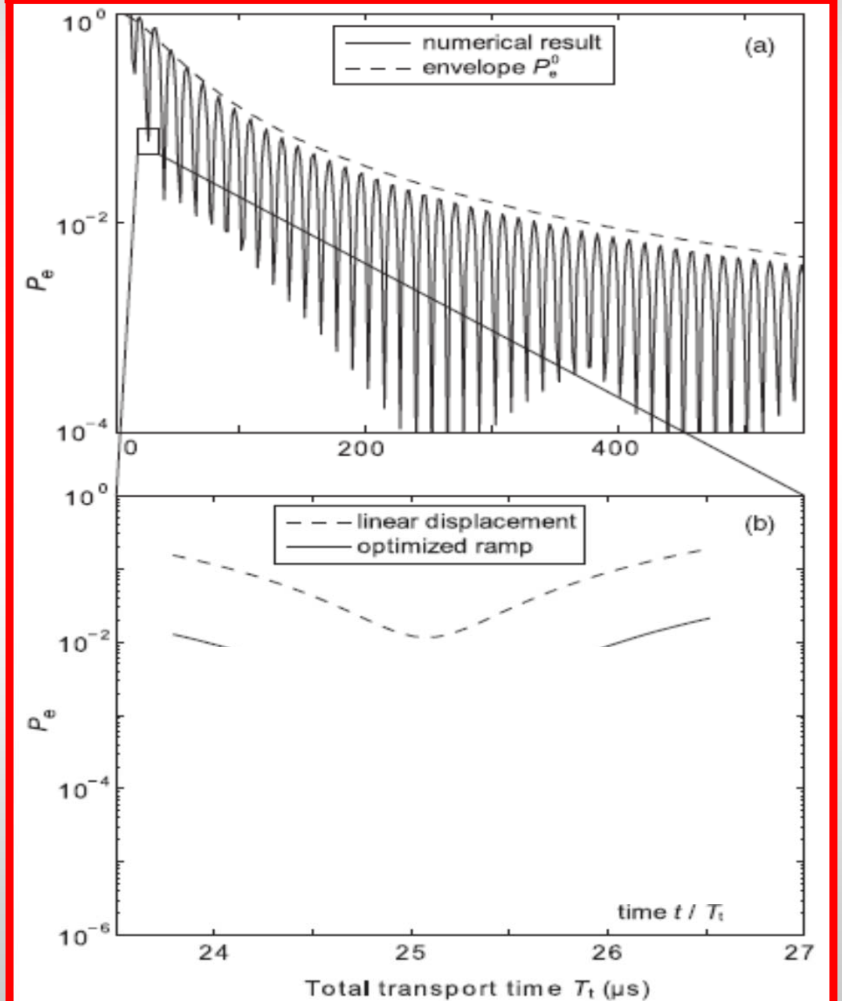
Solve analytically in a two-state harmonic oscillator model

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

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

Weitenberg et al, PRA (2011)

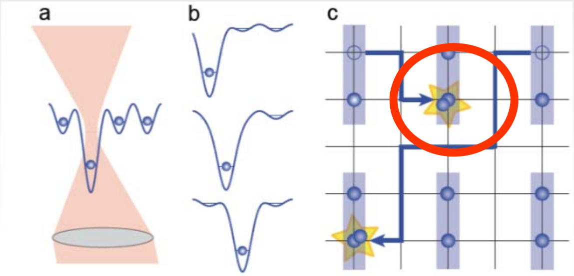
Numerical solution of the time-dependent Schrödinger equation

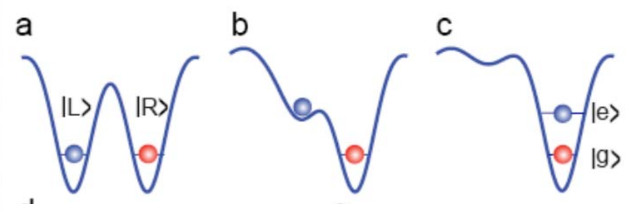


Numerical optimization of the translation profile

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

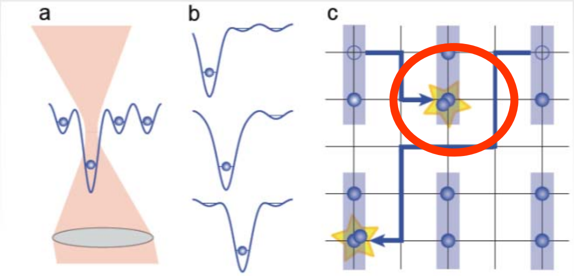
$$\Psi(t=0) = |s\rangle + |t_0\rangle \sim |\uparrow\rangle_g |\downarrow\rangle_e,$$
$$\Psi(t) = |s\rangle + e^{iU_{eg}t/\hbar} |t_0\rangle,$$
$$\Psi(t=T_{\text{swap}}) = |s\rangle - |t_0\rangle \sim |\downarrow\rangle_g |\uparrow\rangle_e,$$
$$\Psi(t=T_{\text{swap}}/2) = |s\rangle + i|t_0\rangle \sim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

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

Weitenberg et al, PRA (2011)

Quantum computation with optical tweezers

c)2-qubit exchange gate

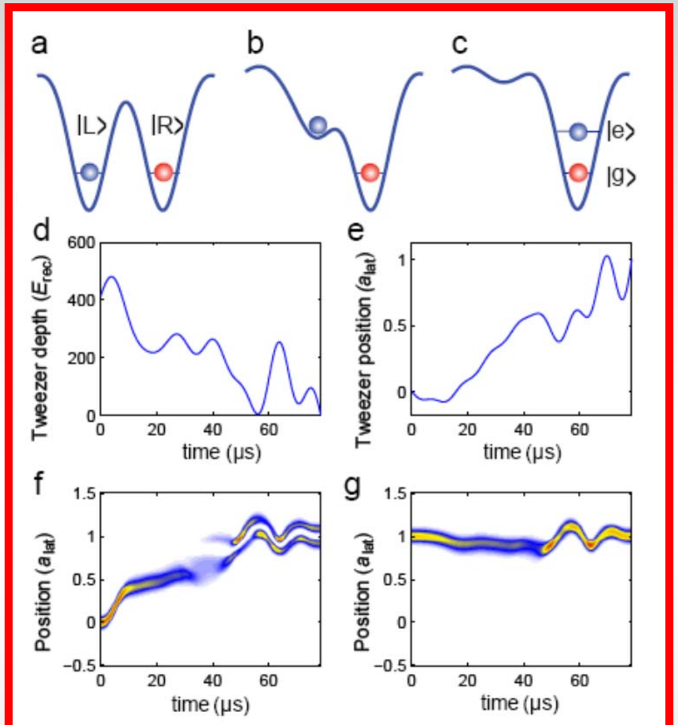


- Map left well atom to first excited state of the right well
- The atom is now in a superposition of the singlet and triplet combinations

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

- Interactions in the triplet state

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



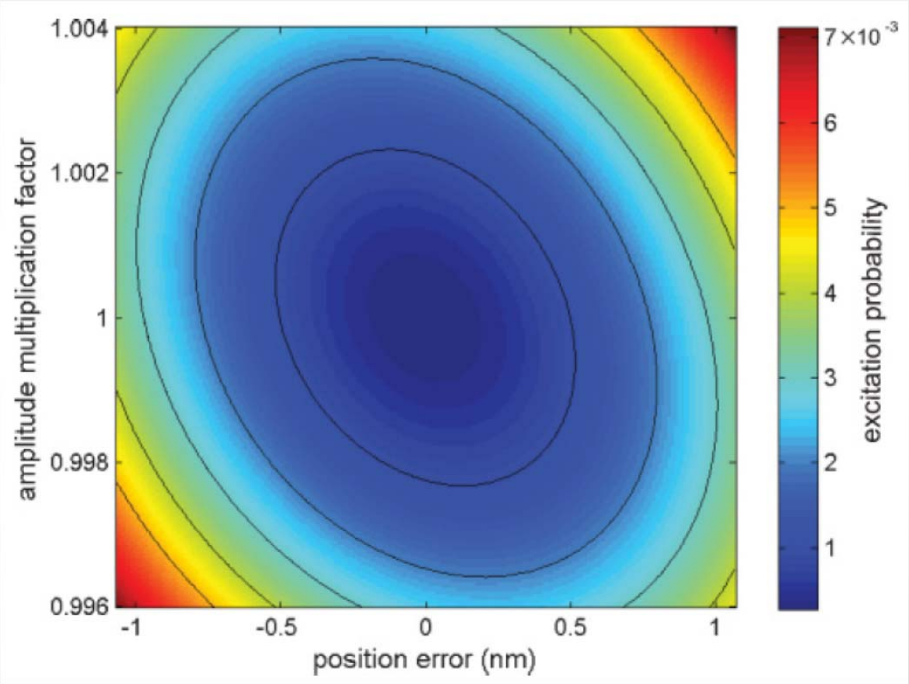
99.97% fidelity in 75 us

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

Outline

- Single site detection and manipulation in optical lattices
- Tweezer based q. computation architecture
- The quantum computer game
- Non-destructive imaging

Human Computing

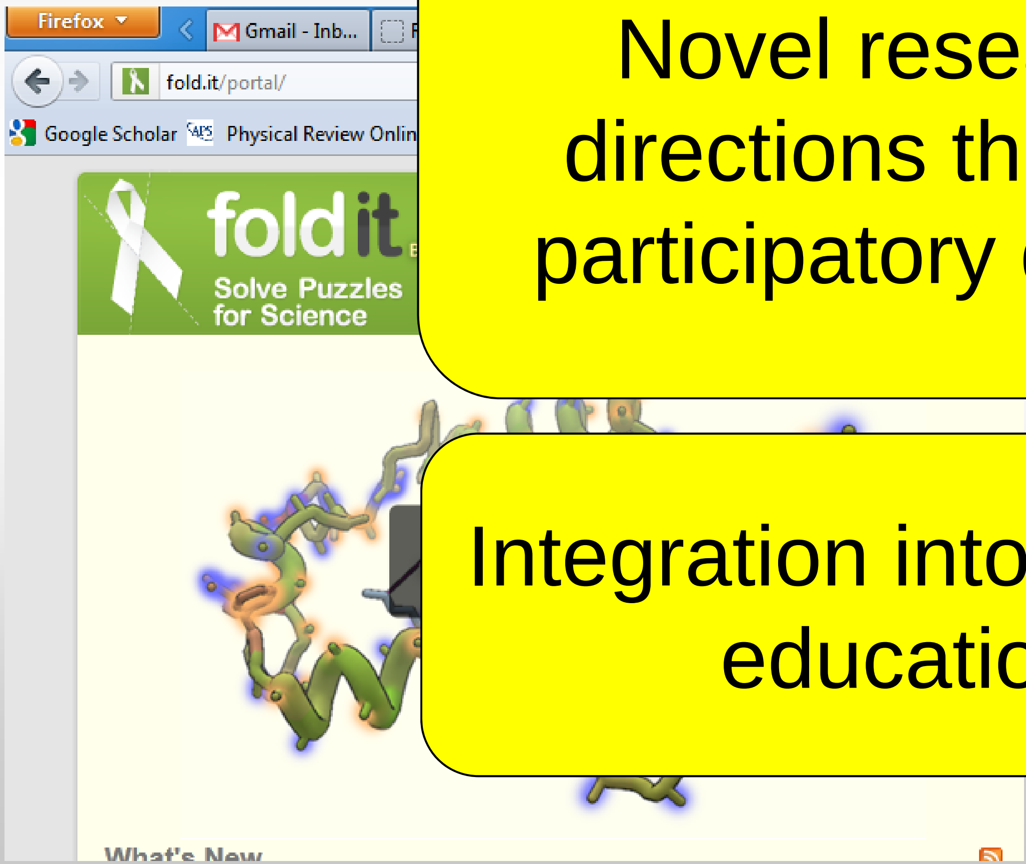
9 billion man-hours spent on solitaire per year!

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!



Novel research directions through participatory design

0 players
nvent new
s (15 year
super-player)
elped the
win the
09 protein
allenge

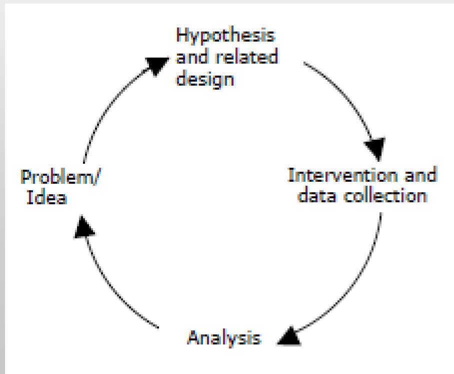
Integration into science education

First phase timeline

Nov. 2011 - Jan, 2012	Feb, - marts 2012	April – June 2012

<u>Development of first concept and prototype</u>

- Design-based research
- Create first rough prototype for testing:
    - Motivational factors
    - Function and Integration in a school context
    - Potentials for community building structures



<u>Tests: first prototype</u>

Tests in two Danish high school classes

<u>Video observations</u>

- Video observations and focus group interviews with one class and teachers
- Survey both classes

<u>First analysis of data</u>

- Publication of papers
- Communicating concept

<u>Pre-produktion online beta test:</u>

- Reward structure: high-score, badges, co-authorship
- Social game structures vs. competition
- Community building structures, expert groups
- Learning approach

<u>Survey</u>

- 77 VIP invited online gamers
- Open for gamers inviting each other

The quantum computer game

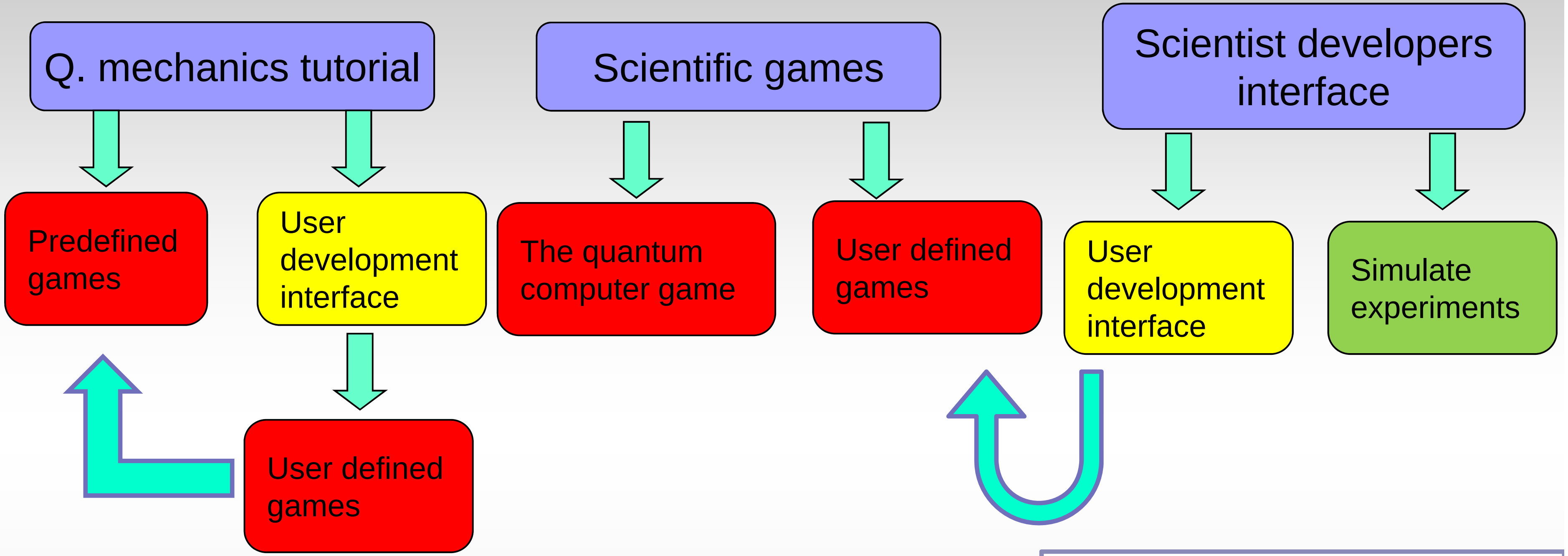
Design goals

- 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

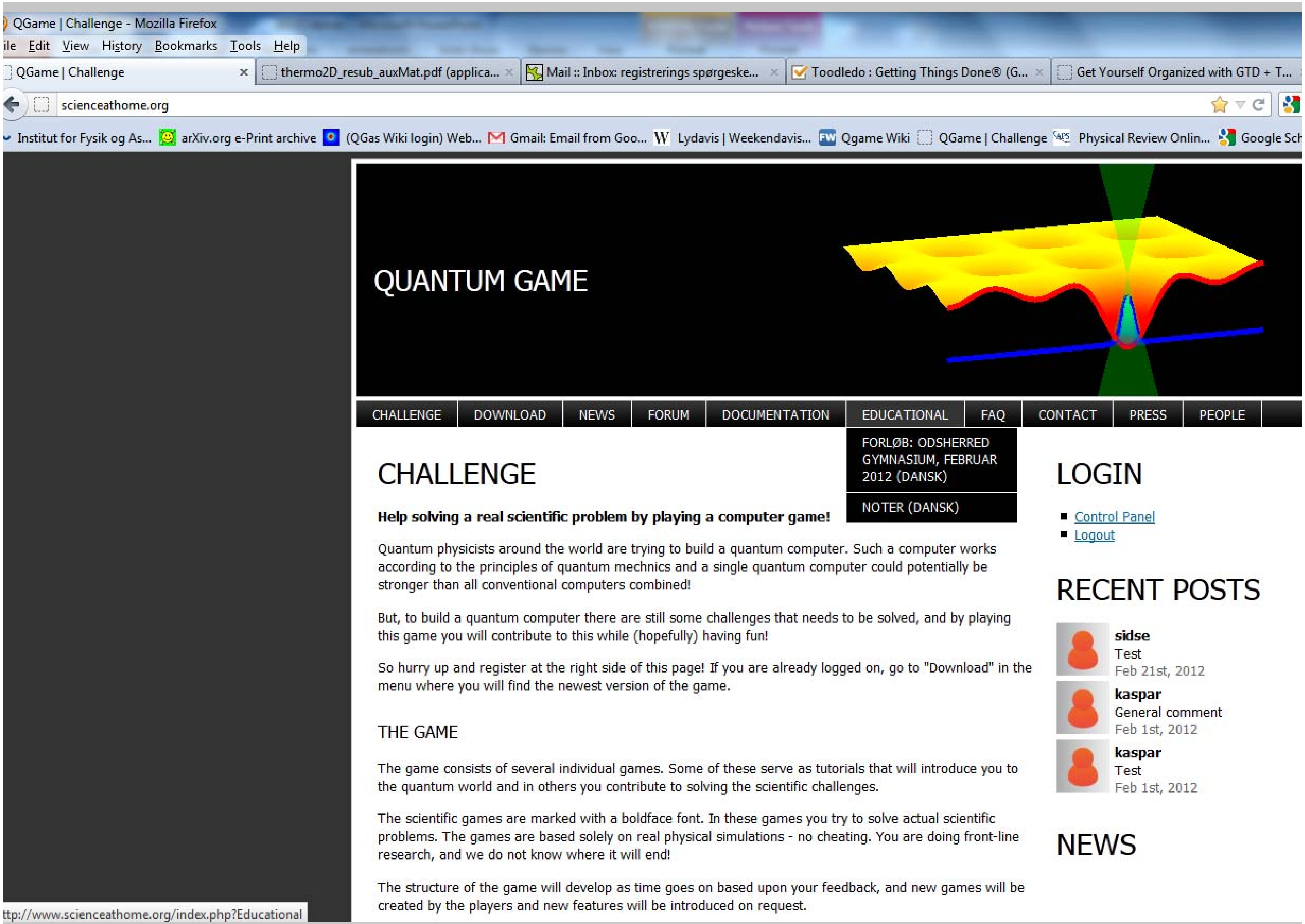
- Fun and easy arcade type game
- Individual competition on a global high score
- Competition and cooperation in groups, eg. classes, cities countries...
- Players contribute to actual science

Quantum games: software overview



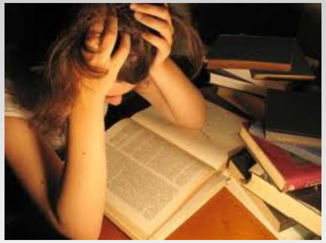
Different codes available

- Schrödinger (TDSE)
- Gross-Pitaevskii
- Bose-Hubbard
- …


QGame | Challenge - Mozilla Firefox
File Edit View History Bookmarks Tools Help
QGame | Challenge
thermo2D_resub_auxMat.pdf (applica...
Mail :: Inbox: registrerings spørgeske...
Toodledo : Getting Things Done® (G...
Get Yourself Organized with GTD + T...
scienceathome.org
Institut for Fysik og As...
arXiv.org e-Print archive
(QGas Wiki login) Web...
Gmail: Email from Goo...
Lydavis | Weekendavis...
Qgame Wiki
QGame | Challenge
Physical Review Onlin...
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

Why gamification of education?

Two types of students



Mastery:

- Become proficient in a topic to the best of his/her ability
- Learning matters
- Intrinsic motivation
- Engagement
- Risk taking

Performance :

- Desire to achieve highly on external indicators of success
- Grades matter
- Extrinsic motivation
- Anxiety
- Reluctance to take risks

Computer games

What is the defining difference between the two?

The view on failure!

a learning process vs a stigmatisation

Players iteratively add content/strategies by repeatedly failing

Why gamification of education?

<u>Main goal: increase scientific literacy</u>

Give students a sense of accomplishment by mastering a complex topic + hope to get transfer to other areas by changing the mind set of the student

Mastery:
- Becor the be
- Learn
- Intrins
- Engag
- Risk t

n
ess
ames

What is the defining difference between the two?

The view on failure!

a learning process vs a stigmatisation

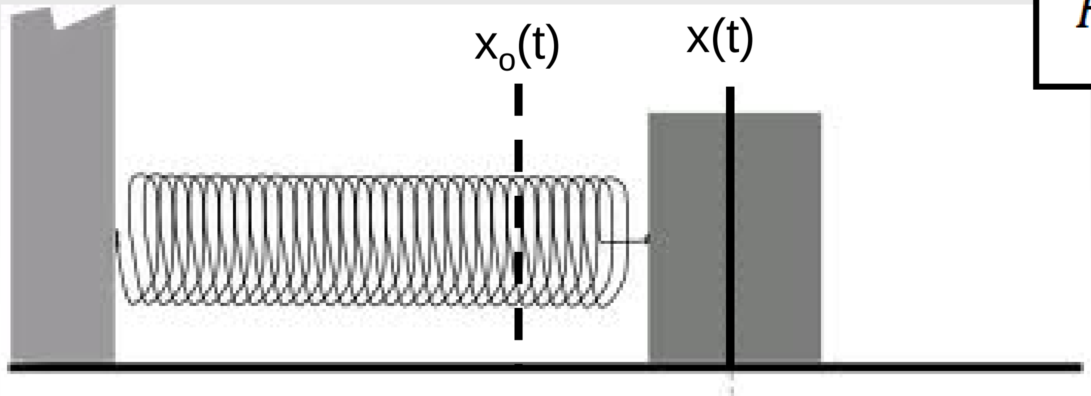
Players iteratively add content/strategies by repeatedly failing

Classical example: Harmonic motion

Move the wall according to $x_o(t)$

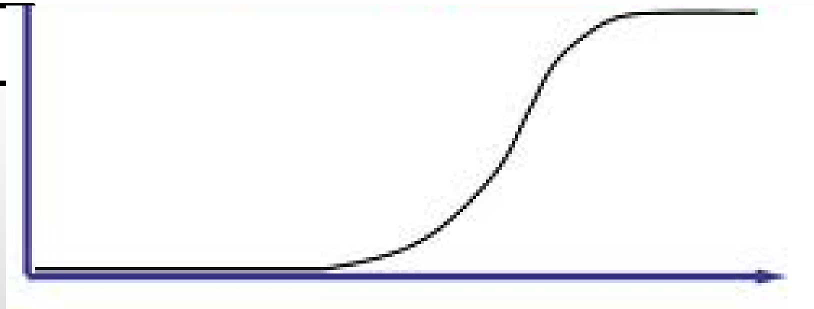
Newtons 2nd lov:

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



Exercise: the mass has to move according to:

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

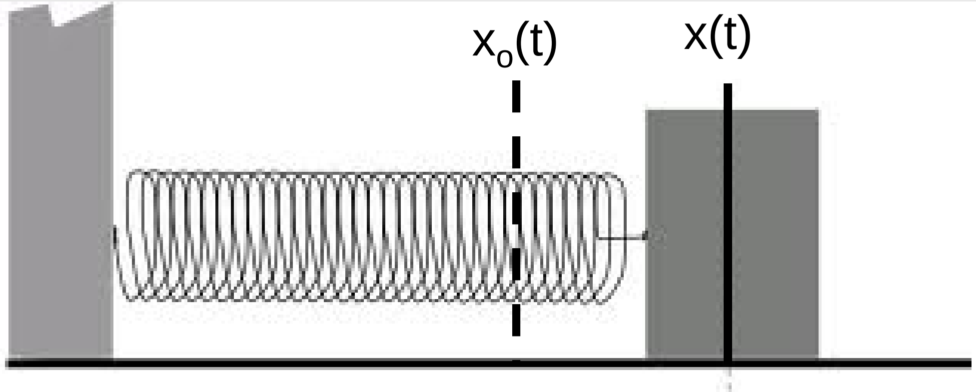


Classical example: Harmonic motion

Move the wall according to $x_o(t)$

Newtons 2nd lov:

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

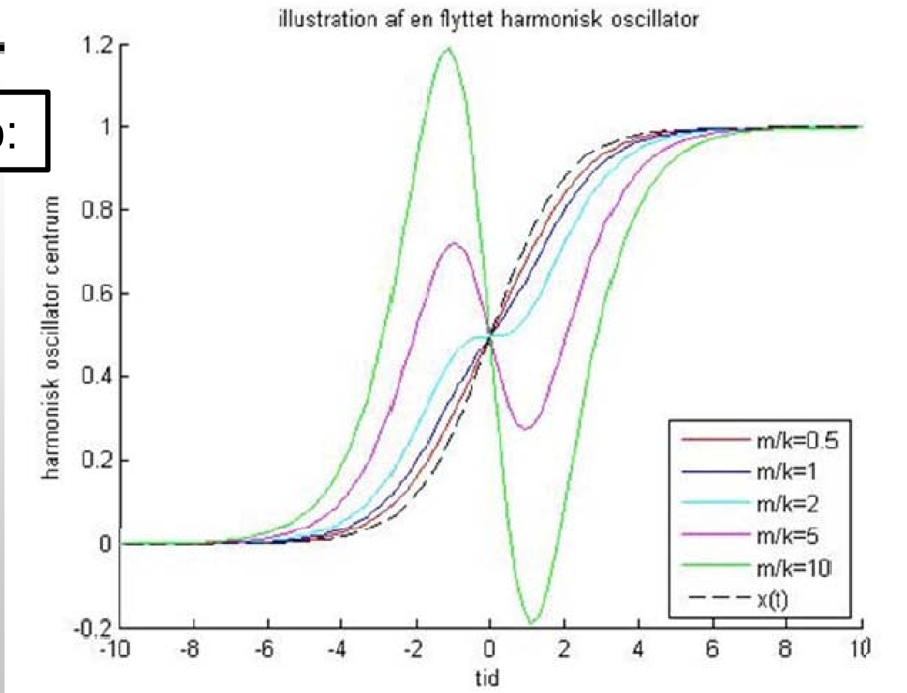


Exercise: the mass has to move according to:

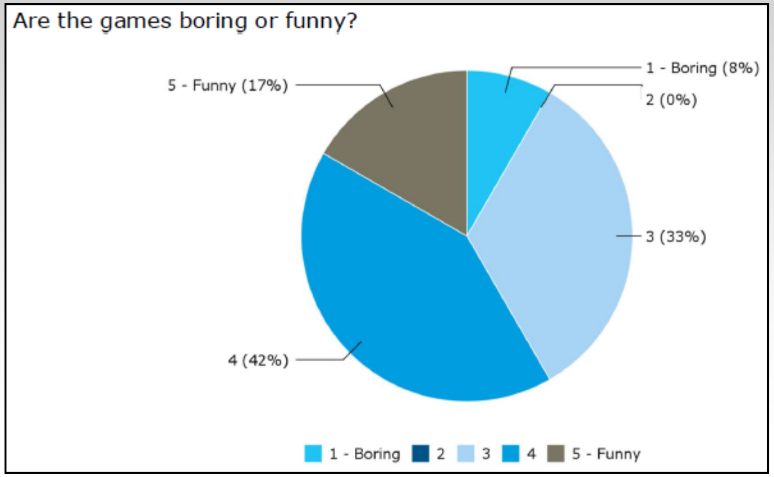
$$x(t) = \frac{1}{1+e^{-t}}$$

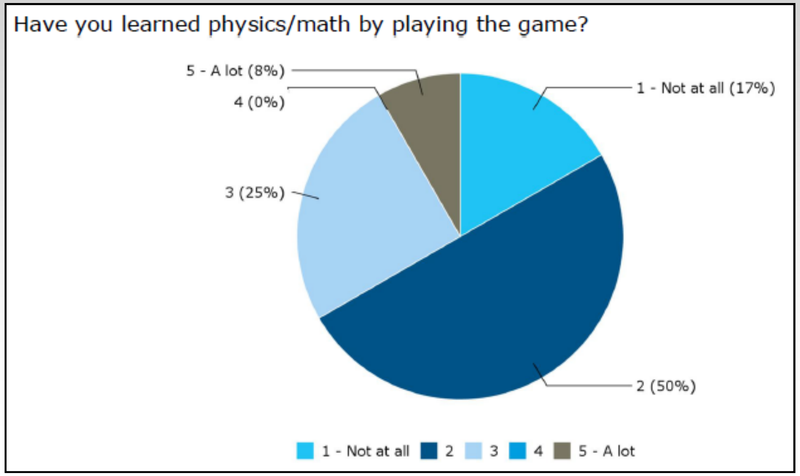
What should $x_o(t)$ be?

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



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"

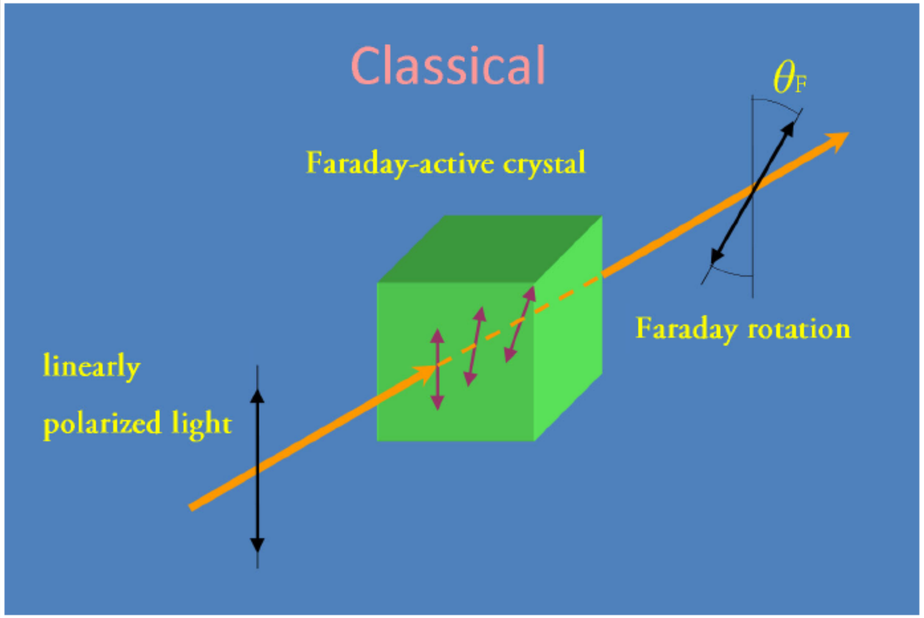
"Quantum physics seems suddenly more tangible, something which is not a dangerous monster you can't work out. It should be in every school!"

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

Outline

- Single site detection and manipulation in optical lattices
- Tweezer based q. computation architecture
- The quantum computer game
- Non-destructive imaging

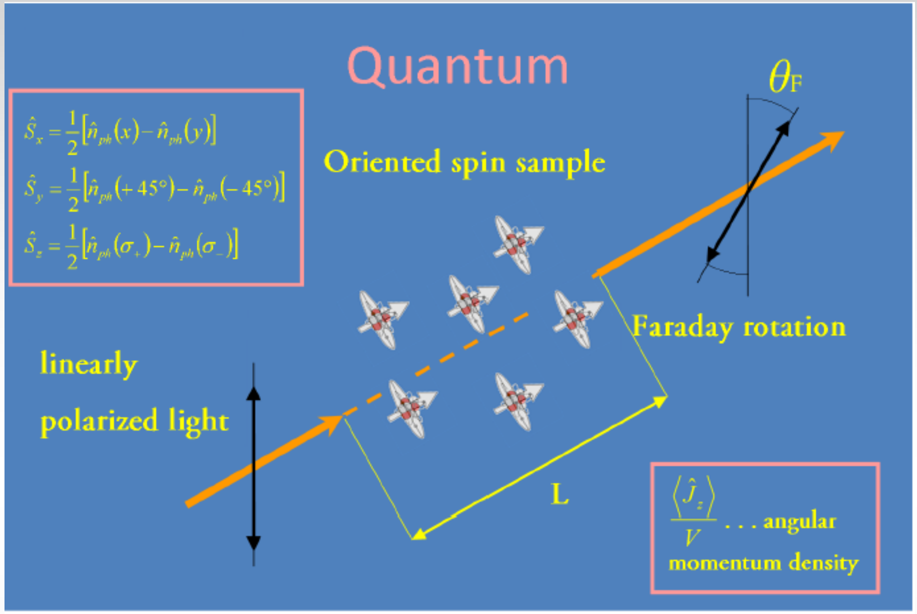
Non-destructive imaging: Faraday rotation



Different phase shift for the two circular components:

- Jones vector notation

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



Quantum mechanical interaction:

- rotation and mixing of atomic and light variables

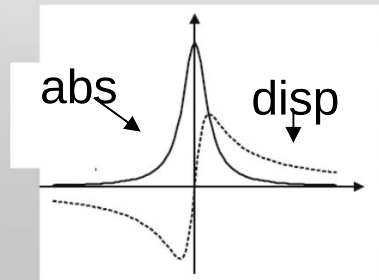
$$\hat{H}_I=\frac{b}{\Delta}\hat{J}_z\hat{S}_z \qquad b=a_0\frac{\hbar\Gamma\lambda^2c}{4\pi V}$$

off-resonantly: $a_0\rightarrow 1$ and $\Theta_F=\frac{\Gamma\lambda^2L}{8\pi\Delta}\frac{\langle\hat{J}_z\rangle}{V}$

Polzik group

Nature 2006: Quantum teleportation between light and matter

Nature 2004: Experimental demonstration of quantum memory for light



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

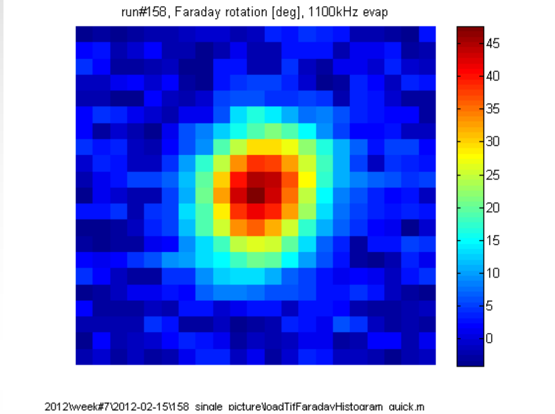
Lars Wacker

High resolution lab

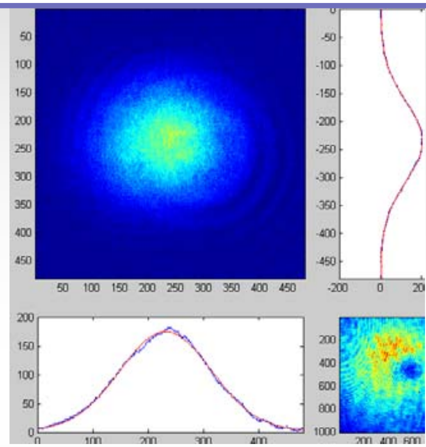
Romain Müller

Non-destructive imaging and feedback

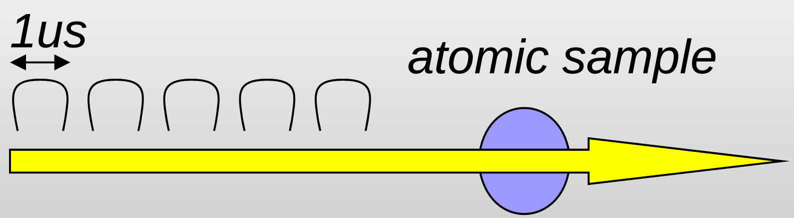
Faraday image of a thermal cloud



Absorption image (destructive)

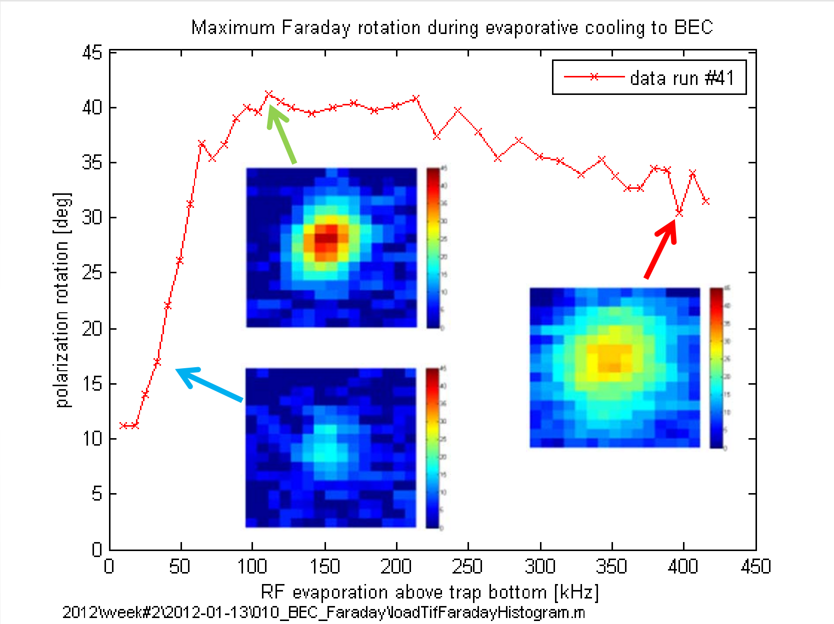


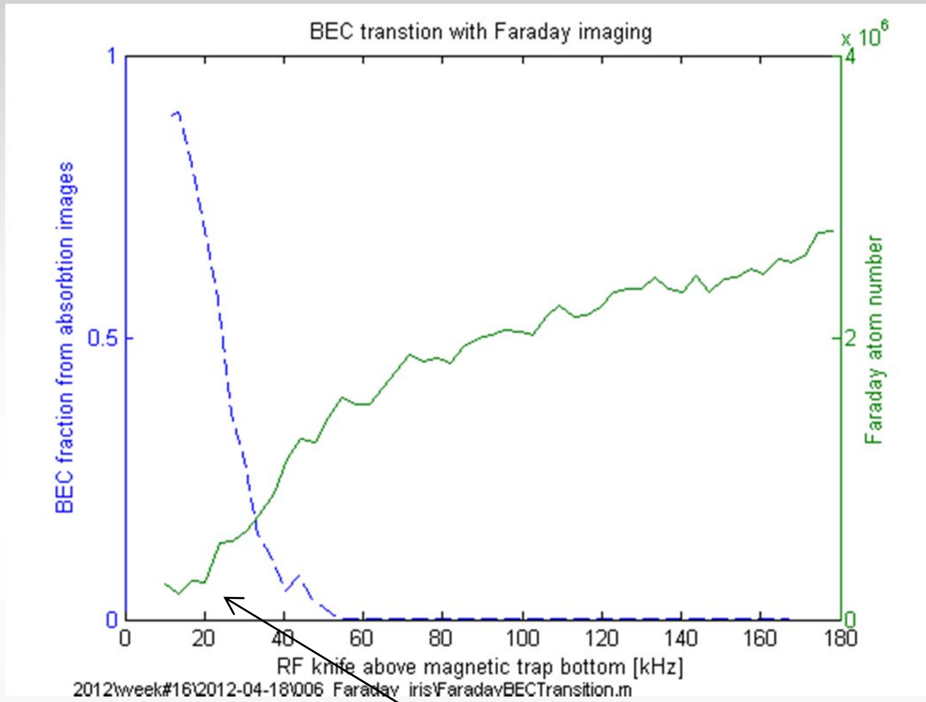
Absorption probability 0.003 per pulse!

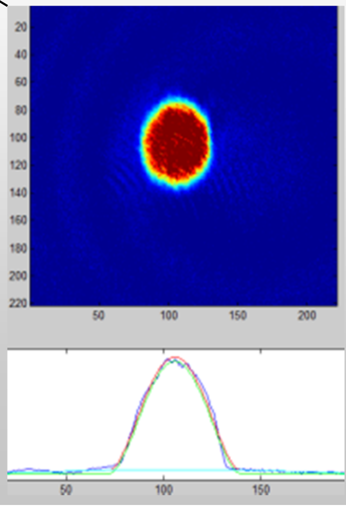


Continuous measurements

Single run monitoring of BEC transition



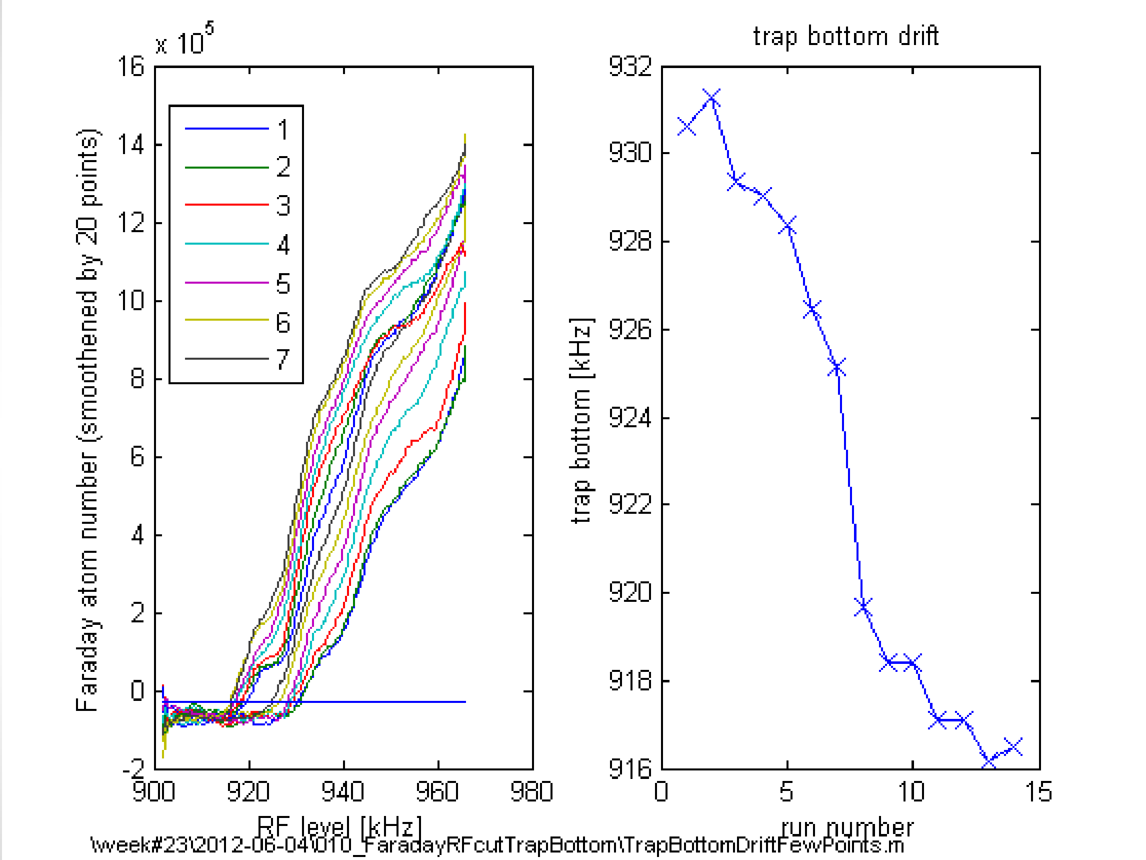




- multiple non-destructive pictures during cooling sequence
- sudden drop of maximum Faraday angle

  - BEC confirmed by absorption image at the end of the run

Single shot measurement of the trap bottom



Atom number calibration

November 1, 2007 / Vol. 32, No. 21 / OPTICS LETTERS

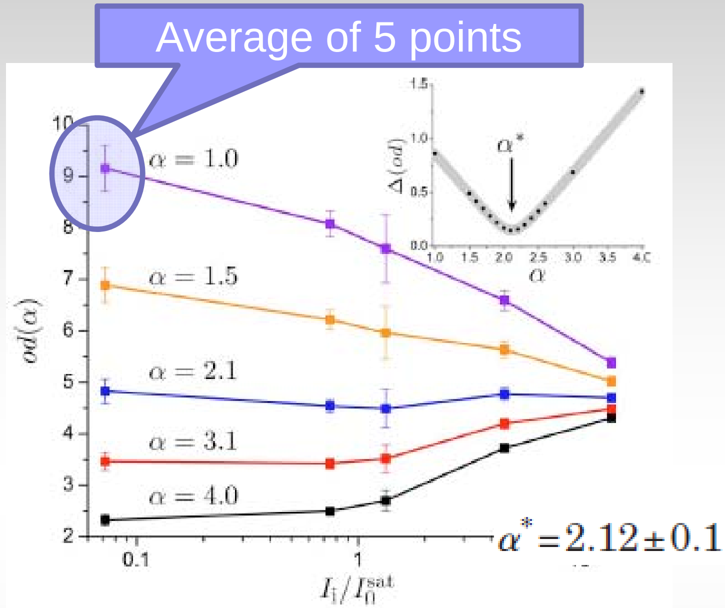
Strong saturation absorption imaging of dense clouds of ultracold atoms

G. Reinaudi,[1] T. Lahaye,[1,2] Z. Wang,[1,3] and D. Guéry-Odelin[1,*]

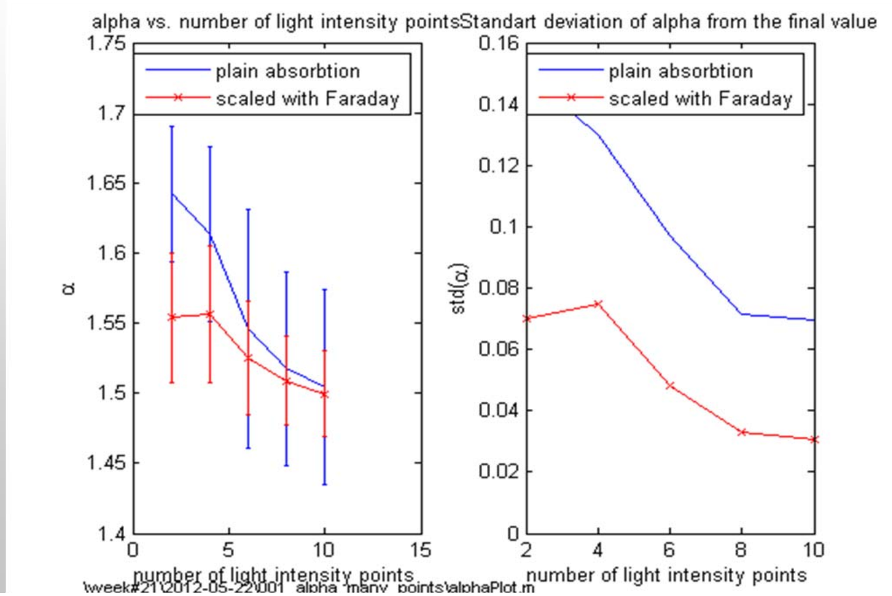
$$\frac{\mathrm{d}I}{\mathrm{d}z} = -n\frac{\sigma_0}{\alpha^*}\frac{1}{1+I/I_{\mathrm{eff}}^{\mathrm{sat}}}I \equiv -n\sigma(I)I,$$

$$od_0(x,y) \equiv \sigma_0 \int n(x,y,z)\mathrm{d}z = f(x,y;\alpha^*),$$

$$f(x,y;\alpha^*) = -\alpha^* \ln\left(\frac{I_{\mathrm{f}}(x,y)}{I_{\mathrm{i}}(x,y)}\right) + \frac{I_{\mathrm{i}}(x,y) - I_{\mathrm{f}}(x,y)}{I_0^{\mathrm{sat}}}.$$



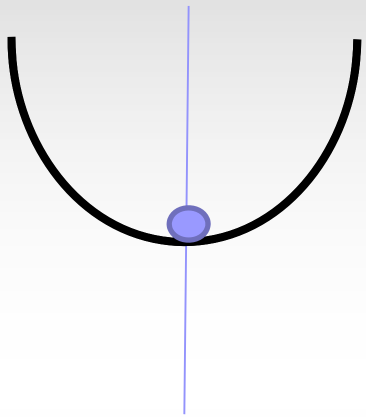
Faraday assisted atom number calibration



We get better precision in 2 points than Guery-Odelin in 25 points!

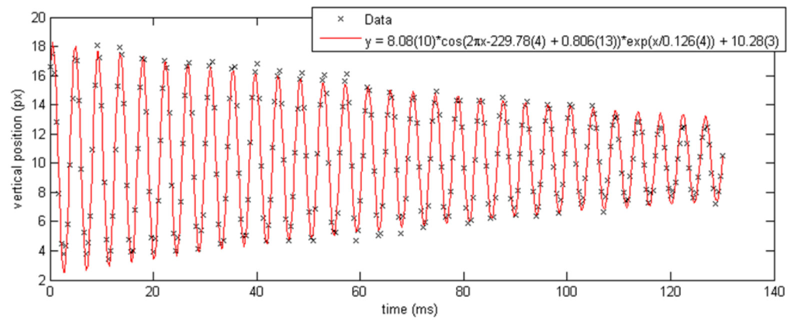
Non-destructive imaging and feedback

Suddenly shift the position of the trap

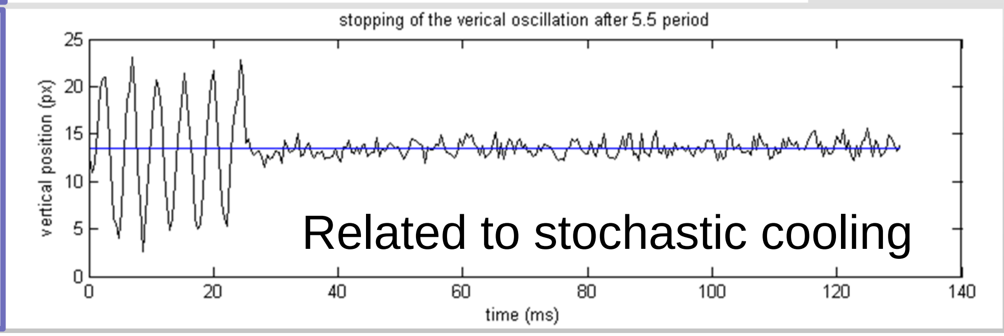


- Fast characterization of trap parameters
- Possibility for quantum (feedback) control

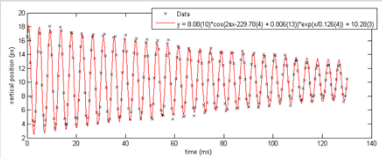
300 images of the same oscillating cloud



Stopping the motion of an oscillating cloud



Some future perspectives



Measure and influence fundamental excitation modes of a BEC

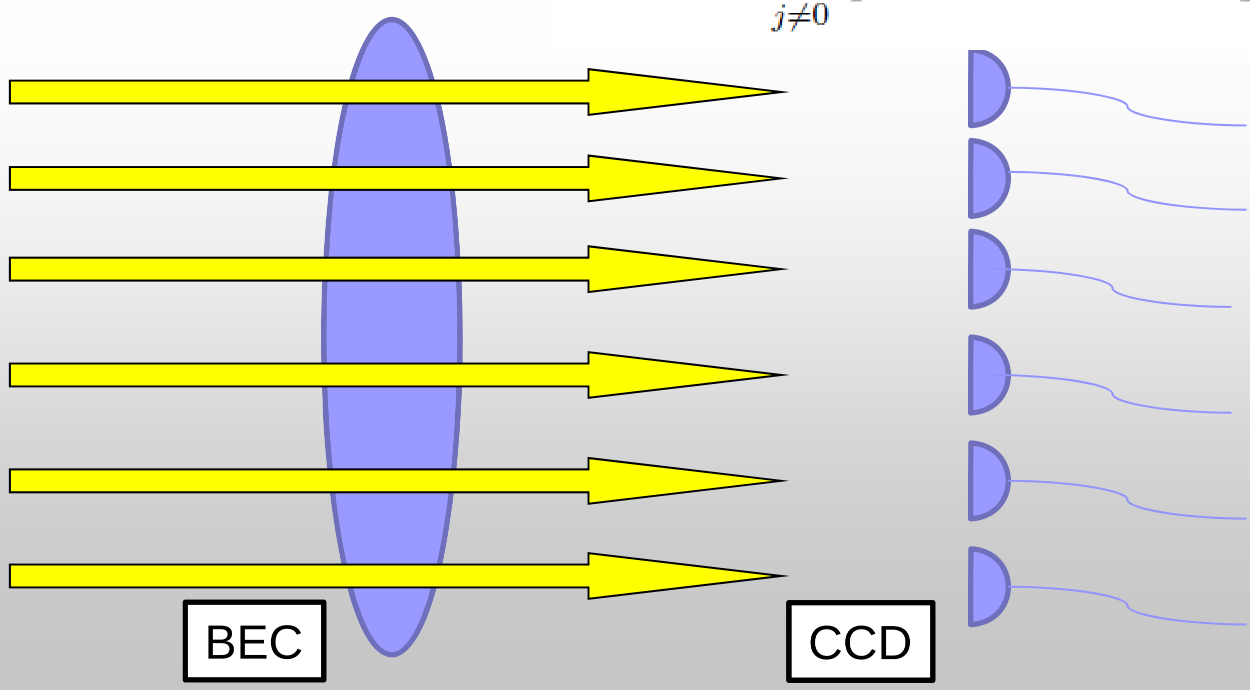
- Squeezing
- Entanglement
- Fock- and Schrödinger cat states

Bogoluibov modes

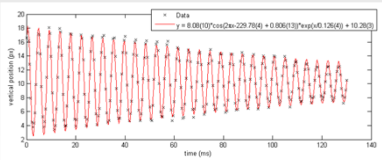
$$\hat{\psi}(z) = \psi(\mathbf{r})\,\hat{\alpha}_0/\sqrt{N_0} + \delta\hat{\psi}(z)$$

$$\delta\hat{\psi}(z) = \sum_{j\neq 0}\left[u_j(z)\,\hat{\alpha}_j - v_j^*(z)\,\hat{\alpha}_j^\dagger\right]$$

$$\delta\hat{\psi}^\dagger(z) = \sum_{j\neq 0}\left[u_j^*(z)\,\hat{\alpha}_j^\dagger - v_j(z)\,\hat{\alpha}_j\right]$$

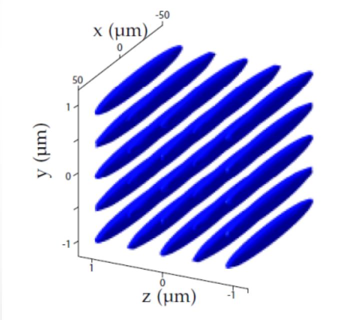


Some future perspectives



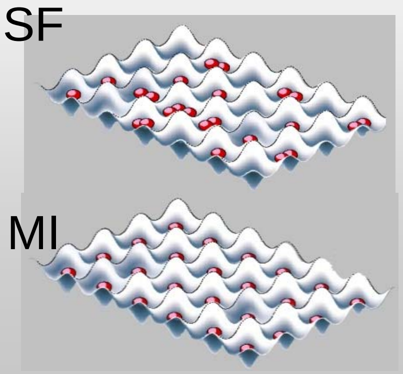
Measure and influence fundamental excitation modes of a BEC

- Squeezing
- Entanglement
- Fock- and Schrödinger cat states



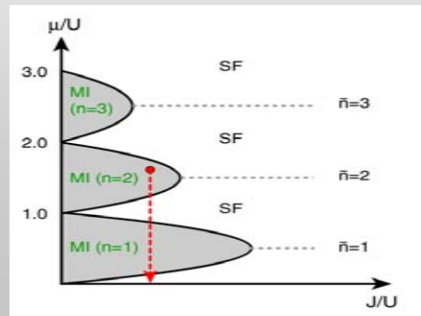
QND probing of a single 1D tube in a 2D optical lattice

- High capacity quantum memory
- Large Schrödinger cat states



QND probing of interacting quantum many-body states

- Modify quantum phase diagrams



Thank you very much