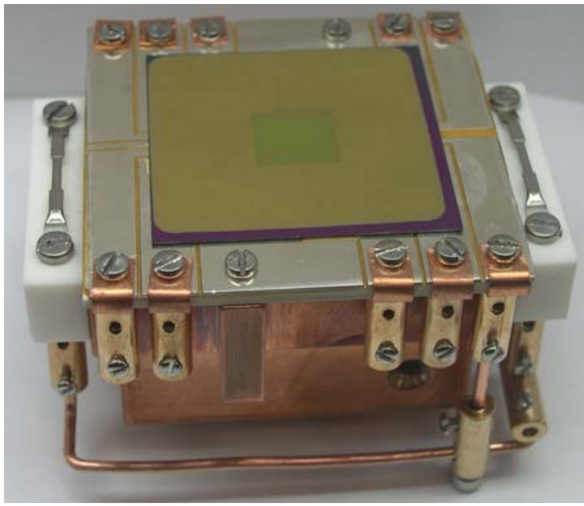
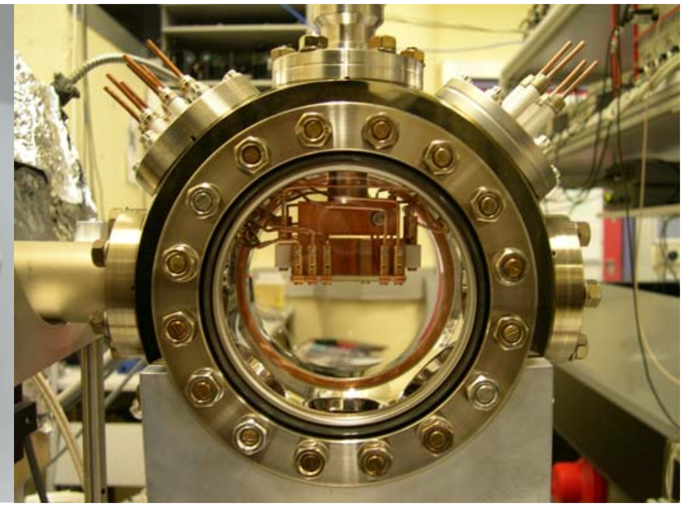
Interaction of a Bose Einstein Condensate with a Permanent Magnetic Lattice on an Atom Chip





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Outline

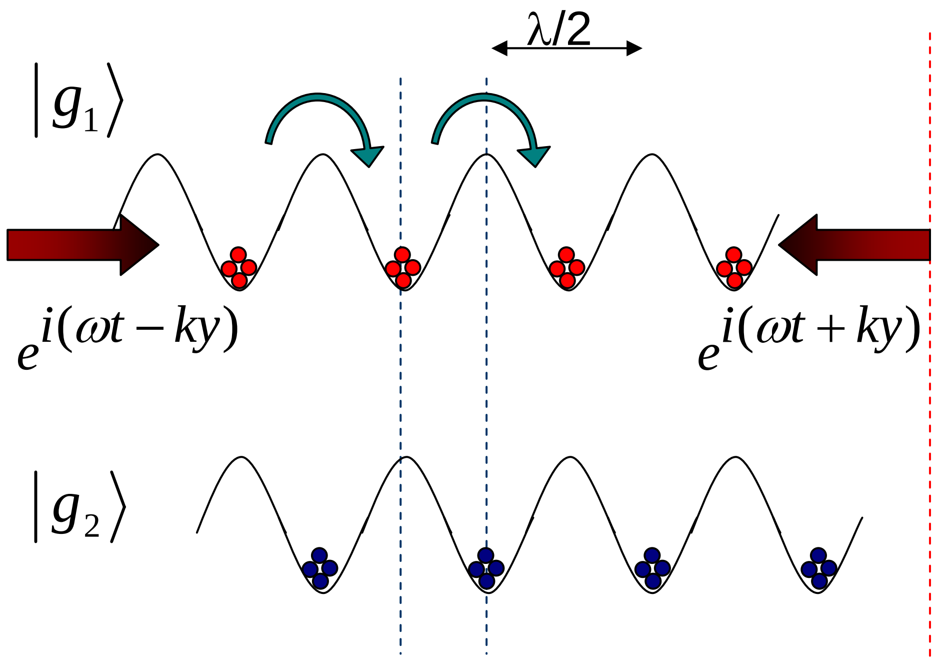
- Introduction
- Permanent Magnetic Lattice Construction on an Atom Chip
- Effect of the Lattice on a Bose Einstein Condensate

Optical Lattice vs Magnetic Lattice

A Lattice is a Periodic Potential

Optical Lattice

- Based on electric dipole force
- Requires phase stability
- State manipulative

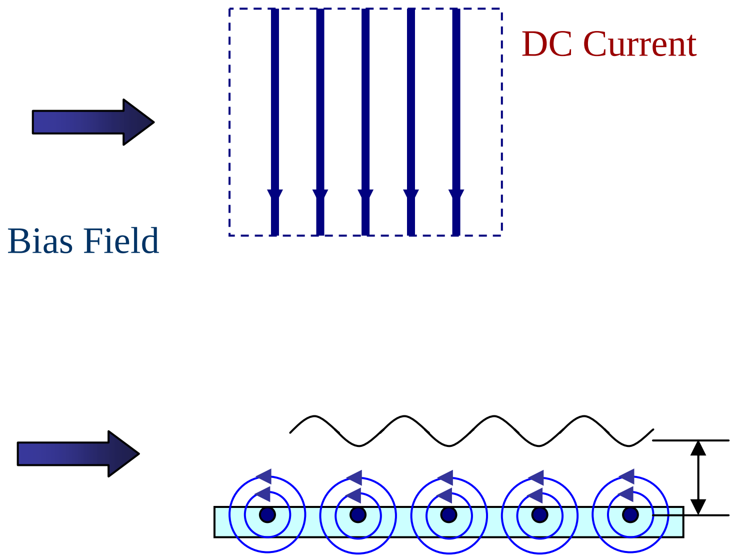


Magnetic Lattice

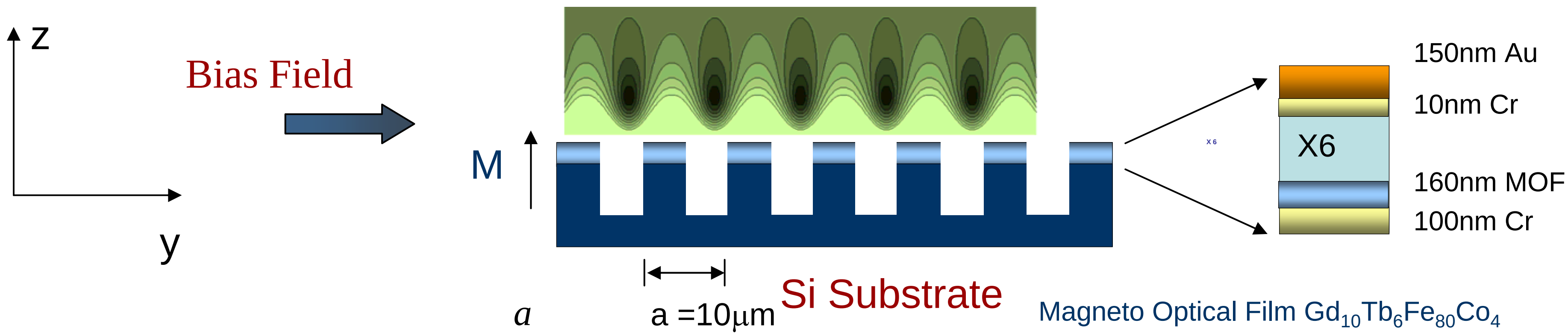
- Based on magnetic dipole force

$$V(r) = m_F g_F \mu_B B(r)$$

- Weak field seeking states are trapped
- Potential can be perturbed with RF
- Easily integrated on an atom chip



A Permanent Magnetic Lattice



Field for z large compared with $\frac{a}{4\pi}$

$$B_y = B_{0y} Sin(ky) e^{-kz} + B_{by}$$
$$B_z = B_{0y} Cos(ky) e^{-kz} + B_{bz}$$

where $B_{0y} = B_0 (e^{kt} - 1)$ $\quad B_0 = 4M$

and $k = \frac{2\pi}{a}$

Features of Permanent Magnetic Traps

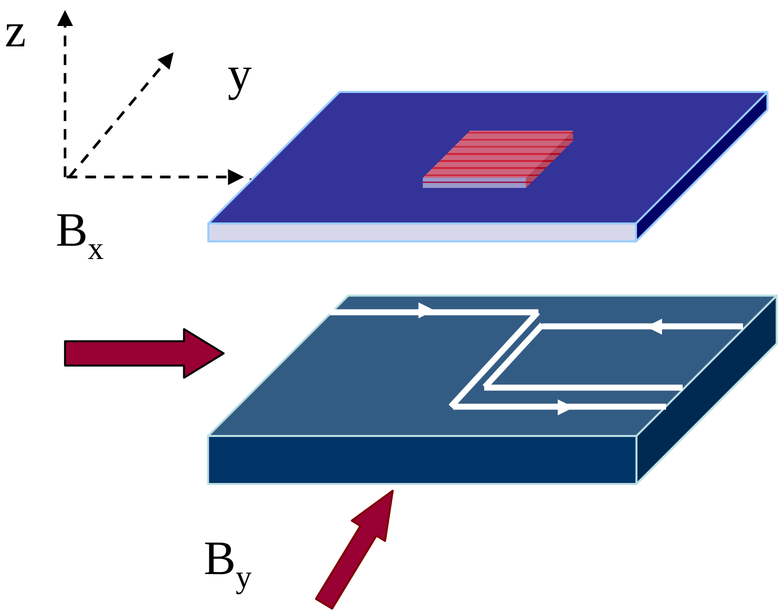
- **No need of current carrying wires**
- **Low Technical Noise**
- **Low Heating Rates ~ 3.2 nK/s** (S. Whitlock, Thesis, 2007)

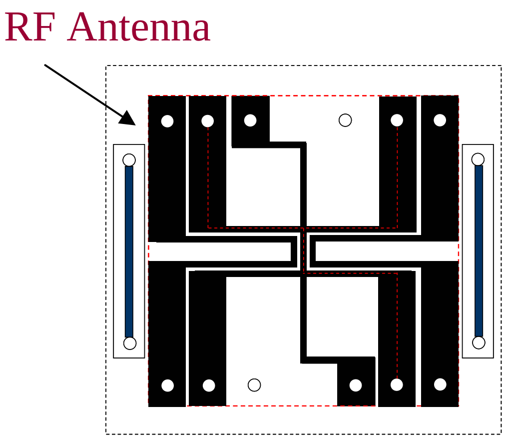
However, less flexibility in context of switching of the lattice potentials or trap

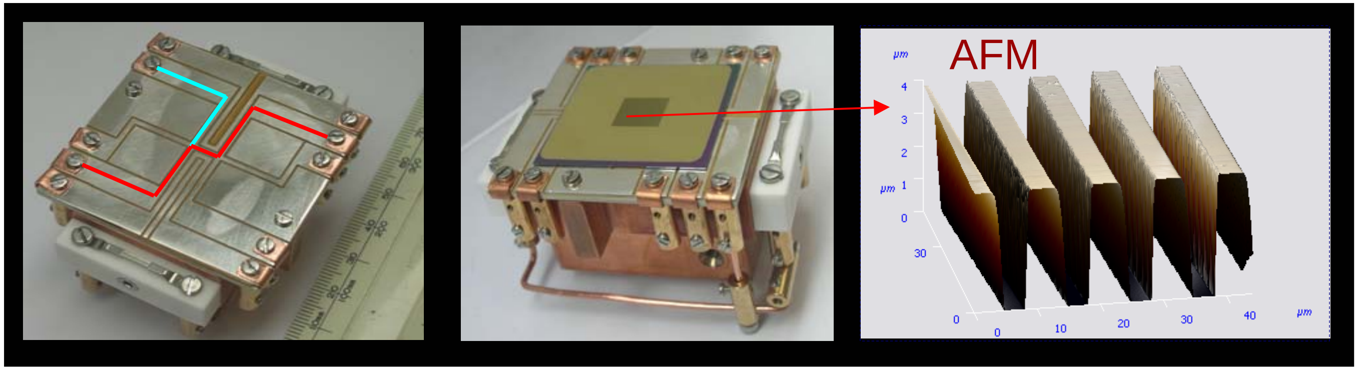
E. A. Hinds et al., J. Phys. D: Appl. Phys., 32, R119 (1999)

S. Ghanbari et al. J. Phys. B : At. Mol. Opt. Phys., 39, 847 (2006)

Magnetic Lattice on an Atom Chip



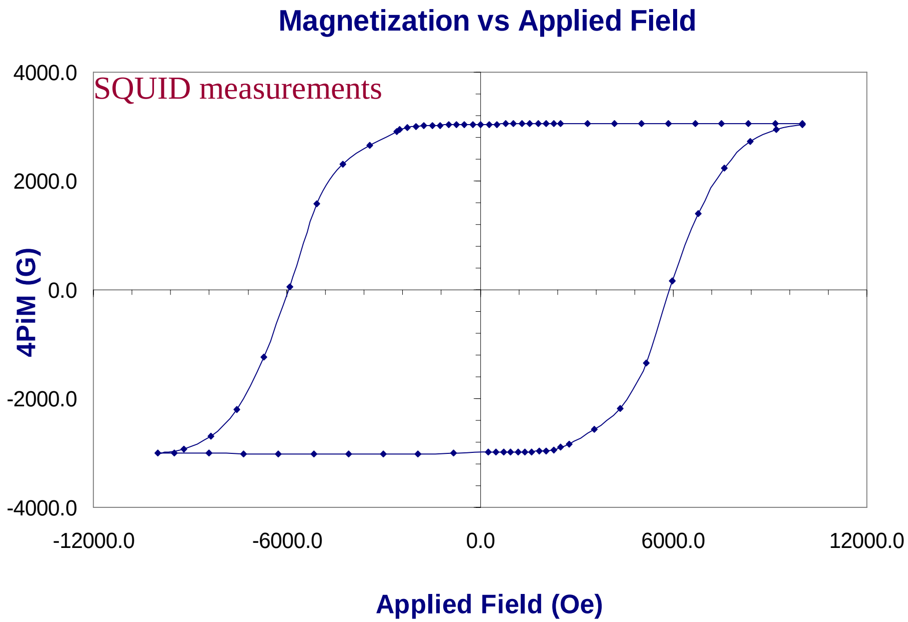


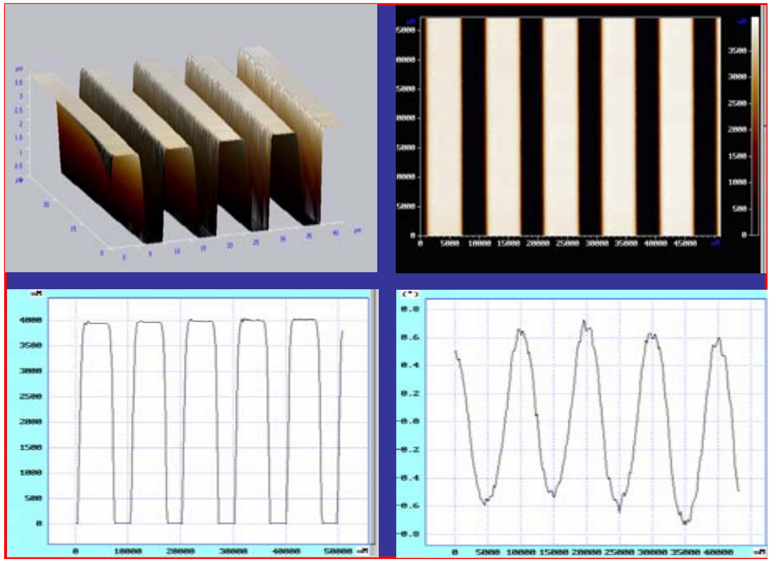


B. V. Hall., et al. J. Phys. B, 39, 27 (2006)

Magnetic Film Quality

DC sputtered on Si grooved substrate

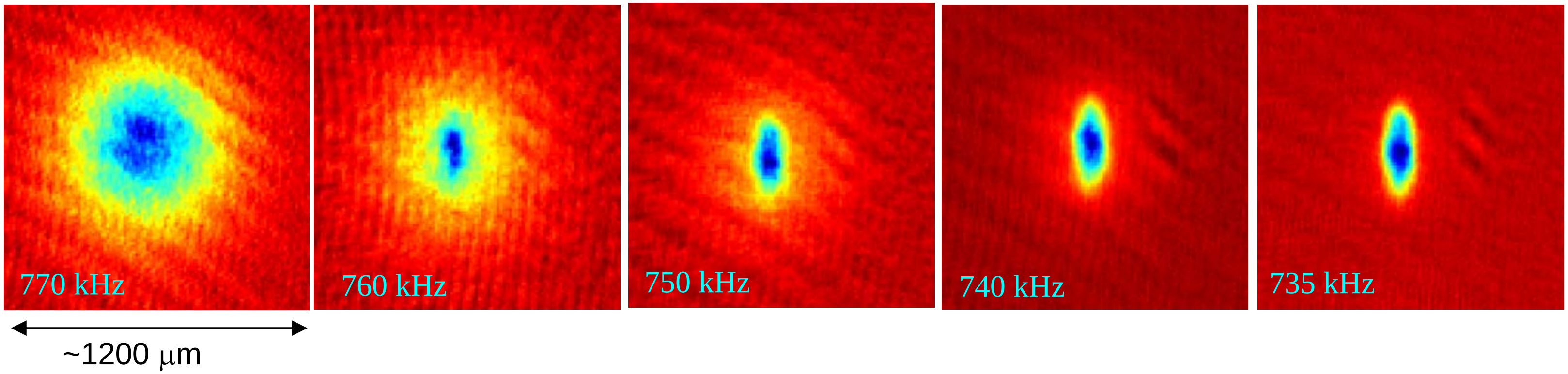


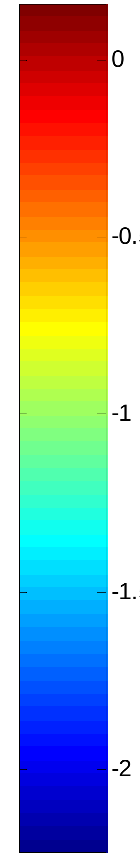


AFM MFM

- Magneto optical Film GdTbFeCo, thickness ~1 μm
- Curie Temperature ~ 300°C, Roughness ~ 20 nm
- Remanent Magnetization $4\pi M \approx 3$ kG
- Coercivity ≈ 6 kOe

Bose-Einstein Condensate on an Atom Chip

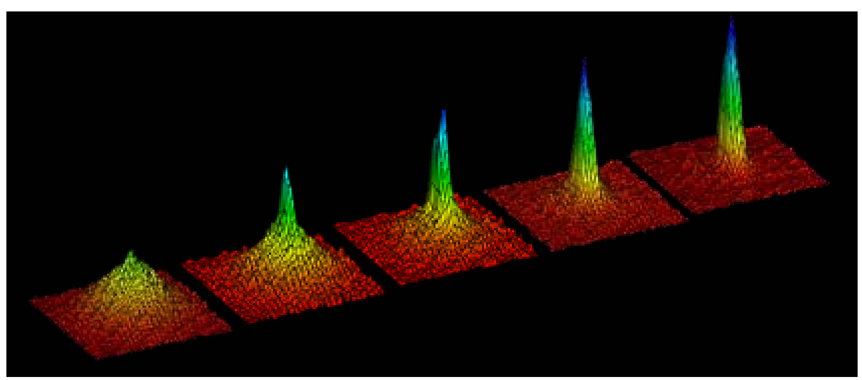




- BEC in a Z-wire magnetic trap about 250 μm from the lattice
- Lattice effect is negligible at such a distance
- Number of atoms ~ 2 x 10^5

Axial Trap Frequency ~ 23 Hz

Radial Trap Frequency ~ 420 Hz



Diffraction of a BEC from a Magnetic Lattice

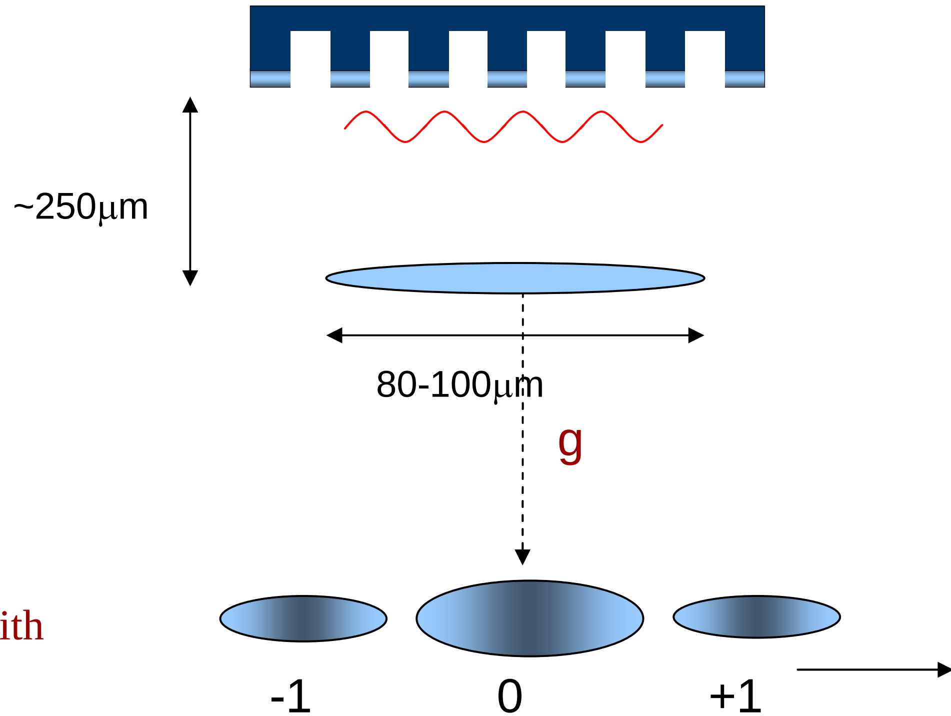
- Phase modulation of the condensate generates momentum states in quantum superposition

$$\Psi(x,y,z) = \sqrt{n(x,y,z)}\,e^{-i\phi_0(d)Cosky}$$

where $k = \dfrac{2\pi}{a}$

or

$$\Psi(x,y,z) = \sqrt{n(x,y,z)}\sum_n (-1)^n J_n(\phi_0(d))e^{inky}$$



$$v_r = \frac{h}{ma}$$

- Wavefunction collapses after a measurement with a probability distribution

$$P_n = \left|J_n(\phi_0(d))\right|^2$$

Or the density distribution

$$\rho_{cond}(y) = A\sum \rho_0(y - nv_r t)\left|J_n(y)\right|^2$$

For $a = 10\mu m$

Recoil velocity $v_r = 0.46mm/\sec$

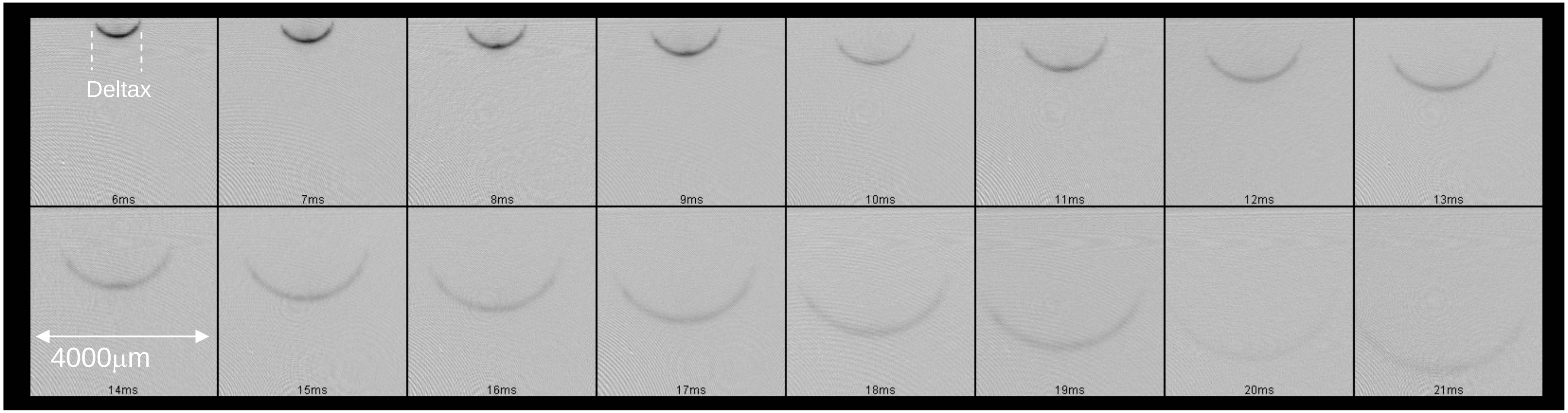
Demands longer time of flight

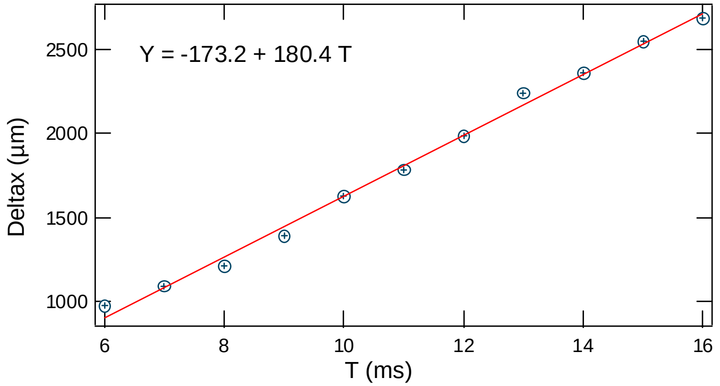
Chemical Potential ~ 1KHz

A. Gunther et al., PRL 95,170405 (2005)

Condensate Evolution in Free Fall
(Lattice Effect)

- BEC is prepared far away from the lattice
- Gradually brought closer to the lattice in 25 ms and released after 200 μs





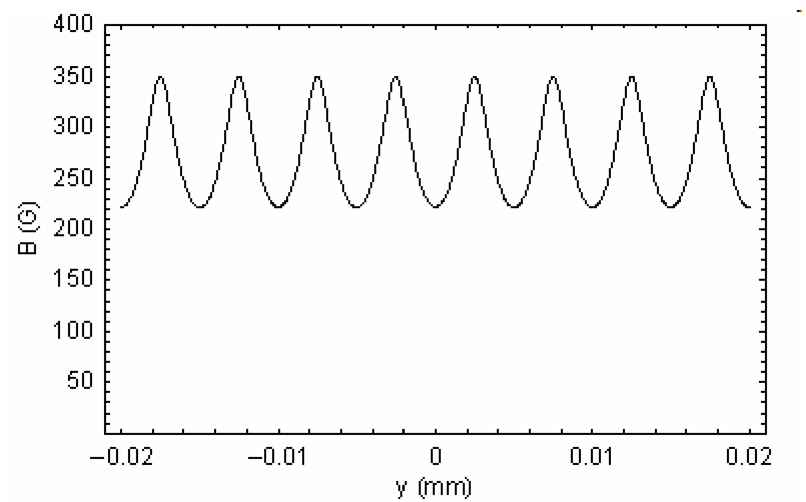
- Maximum Horizontal Velocity = 90.2 mm/sec

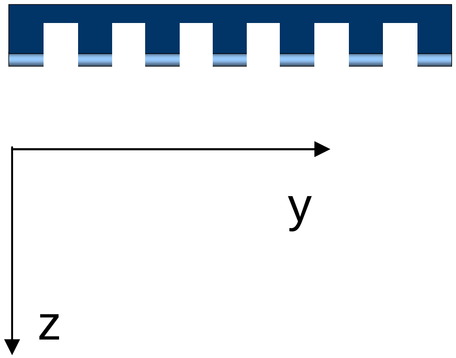
Corrugation near the Lattice

- For d < 2 μm (a = 10 μm)

$$B = B_{0y} e^{-kz}$$

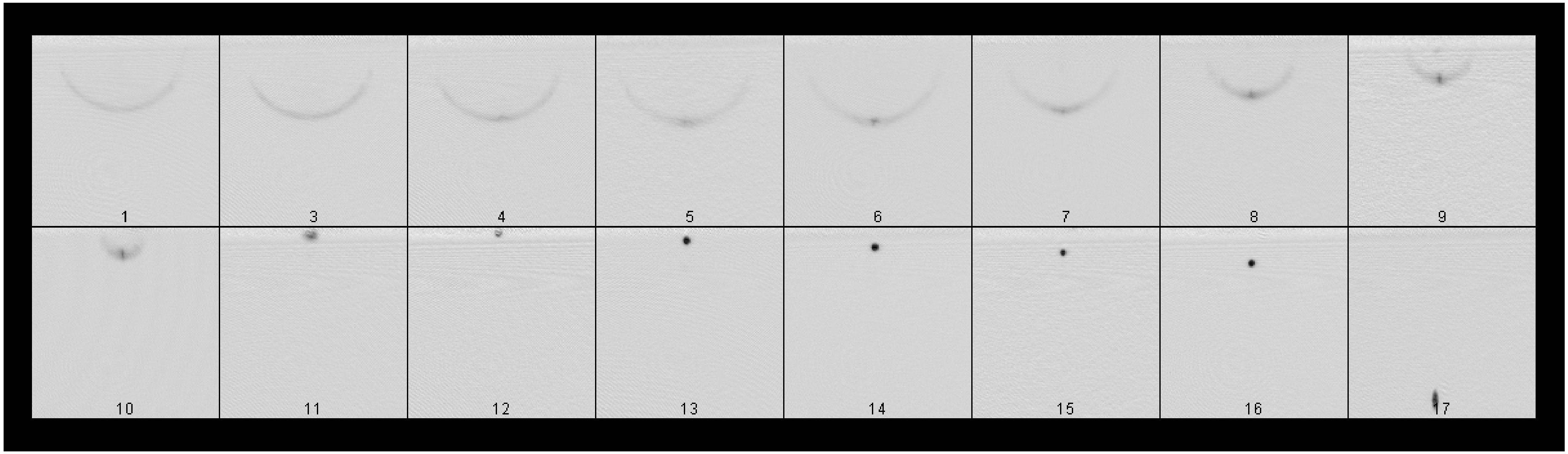
- Structure effect of the lattice dominates and higher harmonics should be considered





2 μm to 0.4 μm

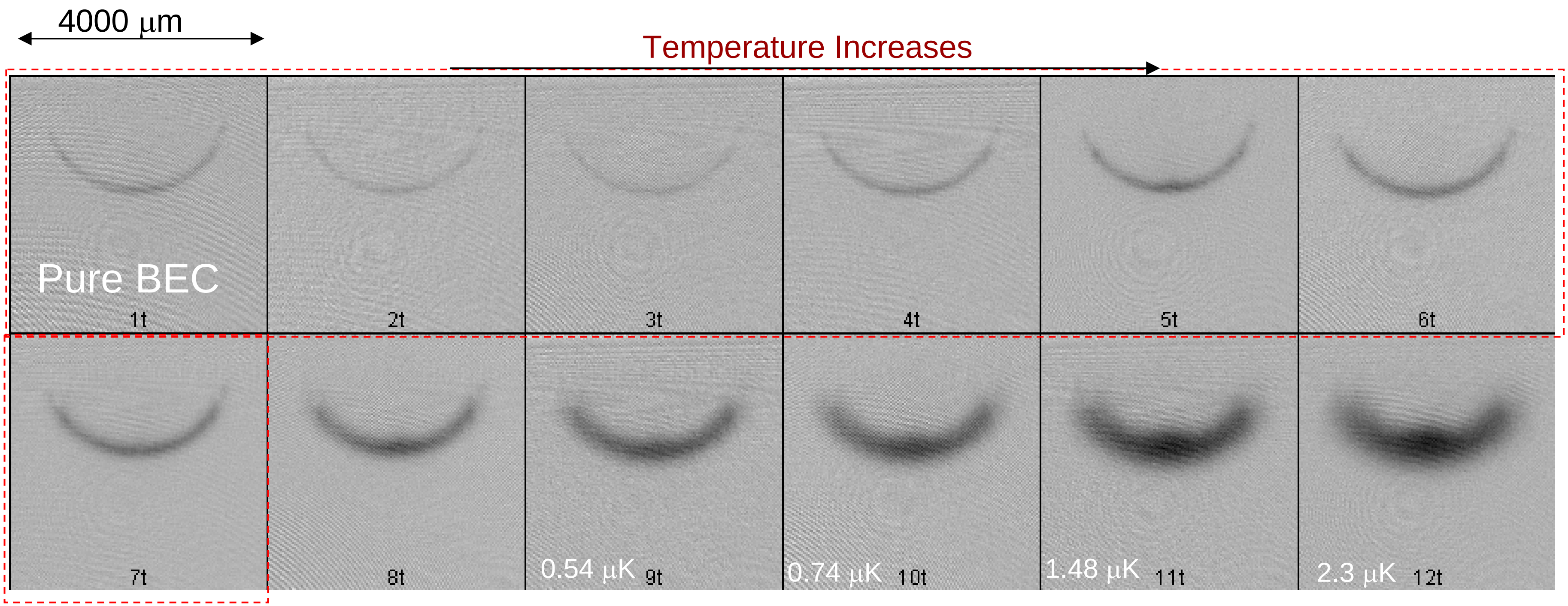
Effect of Distance from the Lattice



Distance from surface increases

- At smaller distance there is a large initial velocity due to repulsion from the lattice (magnetic mirror effect)

Effect of Temperature



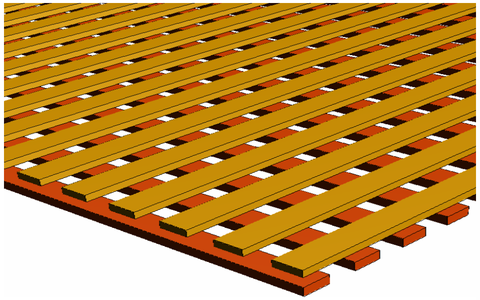
For TOF = 8 ms

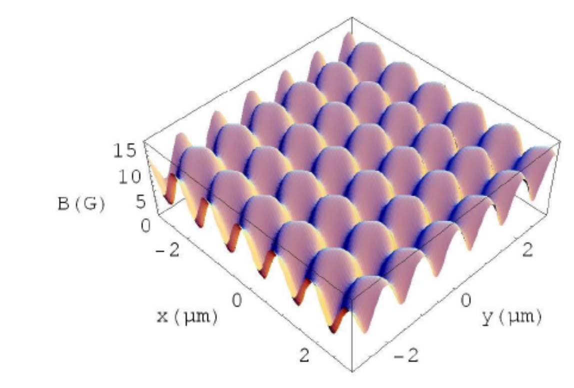
- As temperature increases the trap volume increases which means some atoms are further away from the lattice

  → Therefore they are not affected as strongly by the lattice potential

Future Directions

- Load magnetic lattice (homogeneity of magnetic potential?)
- Two dimensional magnetic lattice





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- BEC coherence in magnetic lattice
- BEC to Mott Insulator Transition ?