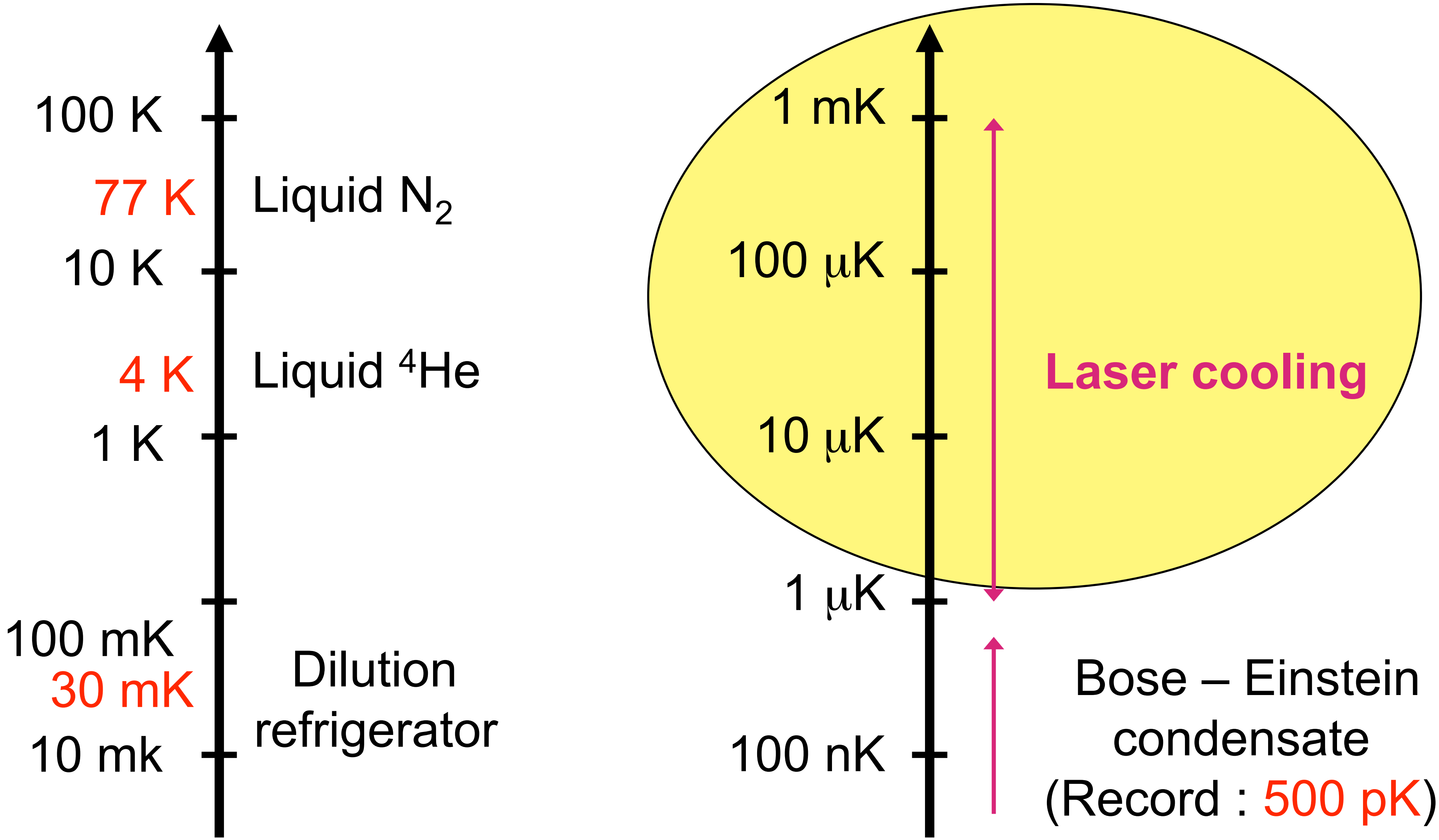
Laser cooling and trapping

Lecture 1	Light forces
Lecture 2	Doppler cooling
Lecture 3	Sub-Doppler cooling
Lecture 4	Magneto-optical trap Evaporative cooling

How cold?



100 K
77 K
Liquid N2
10 K
4 K
Liquid 4He
1 K
100 mK
30 mK
Dilution refrigerator
10 mk
1 mK
100 μK
Laser cooling
10 μK
1 μK
100 nK
Bose – Einstein condensate
(Record : 500 pK)

(Very…) short history

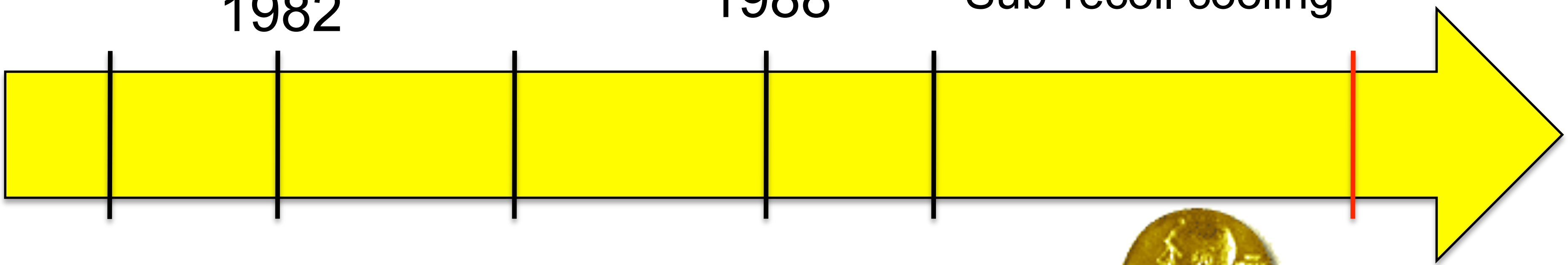
Sub-Doppler cooling

Beam slowing

1982

1988

Sub-recoil cooling



1980

1985

1990

1997

Optical molasses

1975
Hänsch, Schalow
Demhelt, Wineland

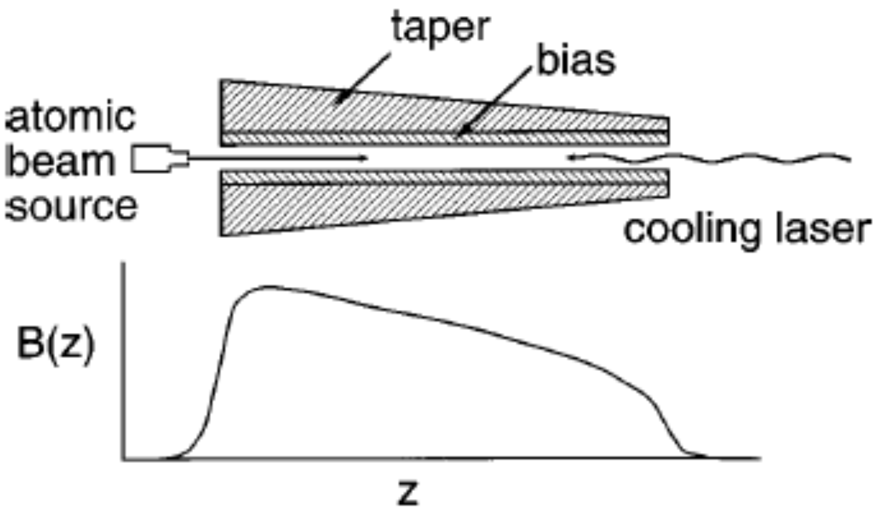
1980
Gordon, Ashkin

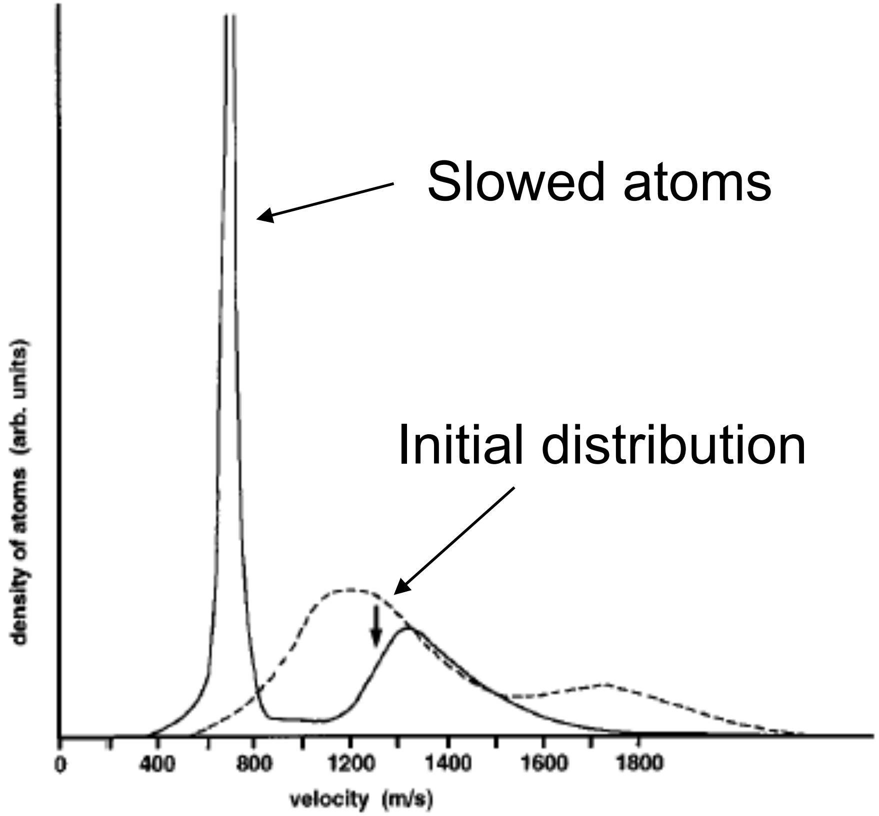
S. Chu

W. Phillips

C. Cohen-Tannoudji

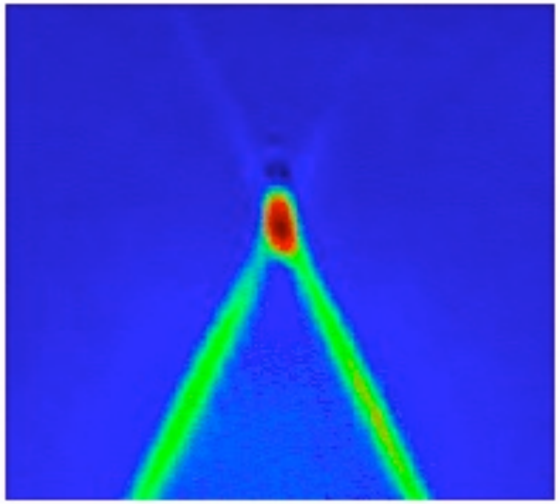
Zeeman slowing



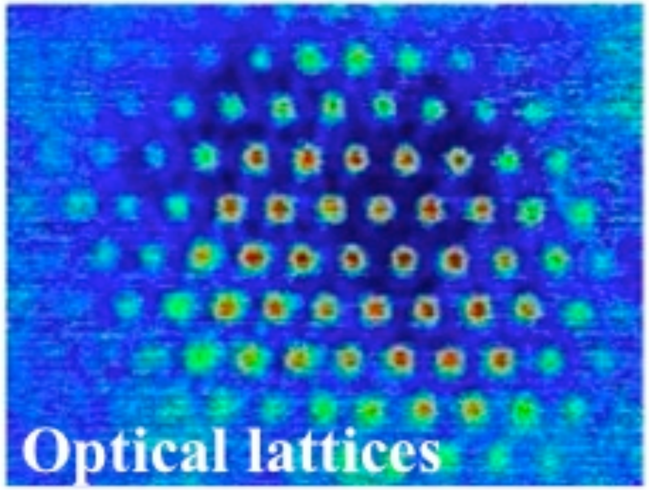


Phillips, PRL **48**, p. 596 (1982)

Crossed dipole trap – crystal of light



attraction towards
large intensity
regions

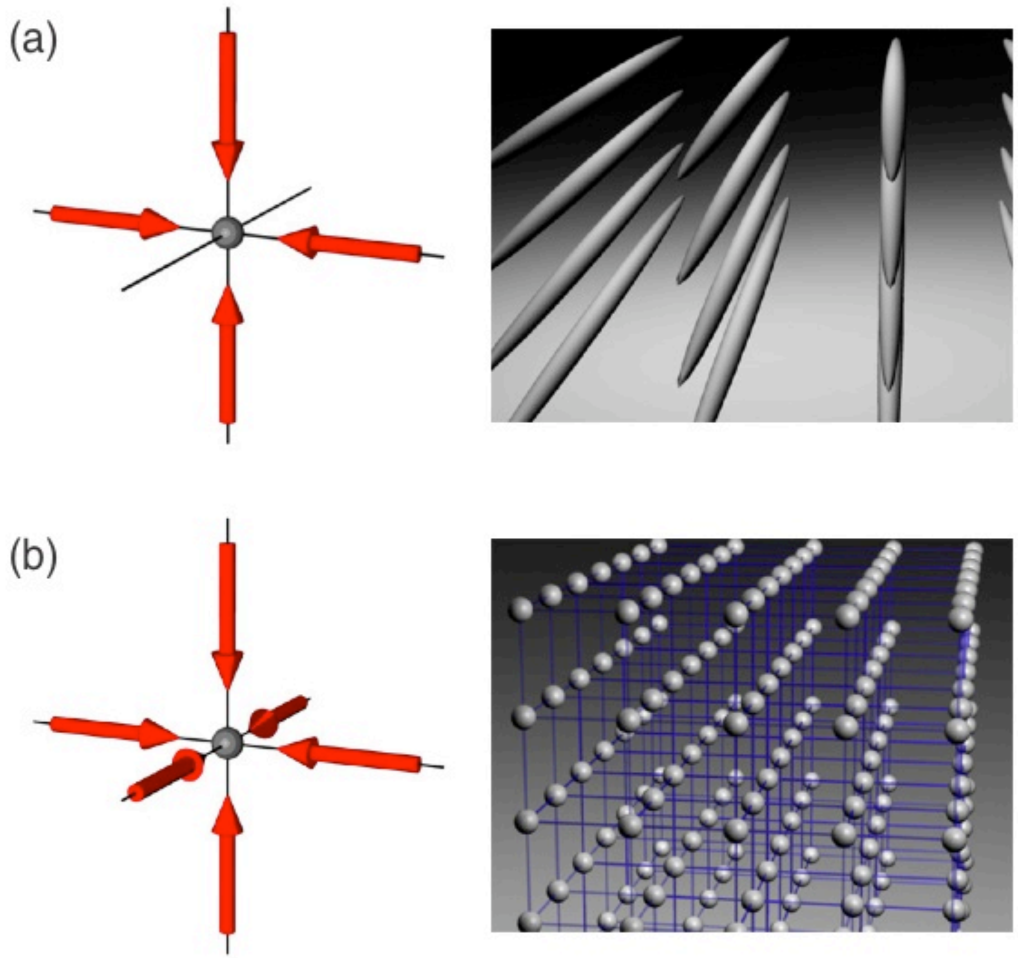


pictures from C. Salomon et al.

Optical lattices

1 - d

2 - d



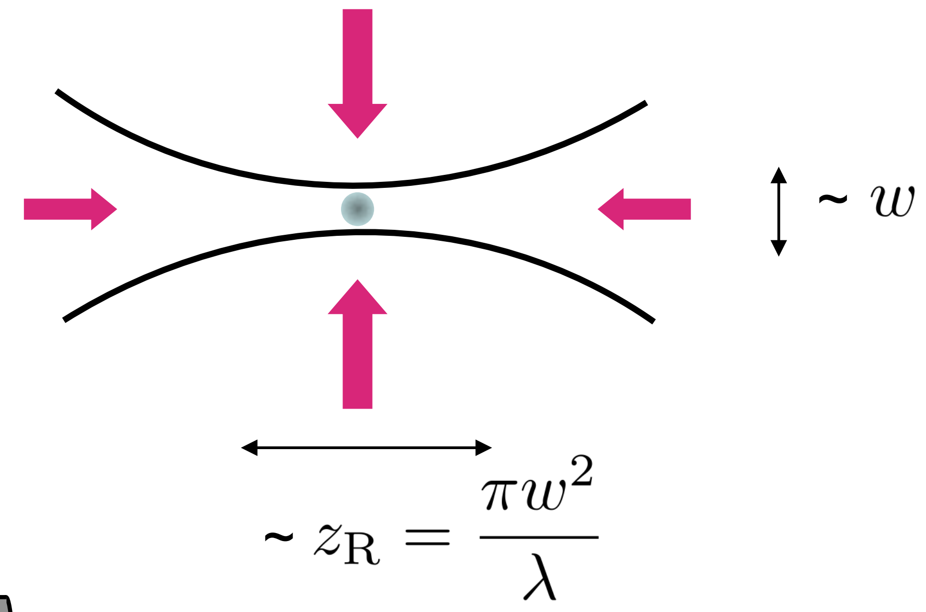
3 - d

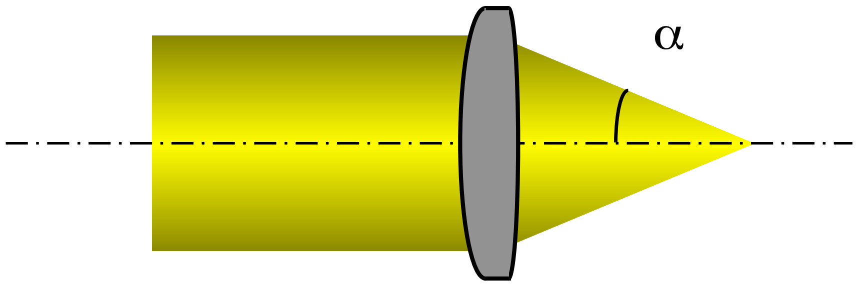
(M. Greiner)

Optical tweezers: trapping in 3 D

High field seekers $\omega < \omega_0$

Gaussian beam





NA = sin α

w ~ λ/**NA**

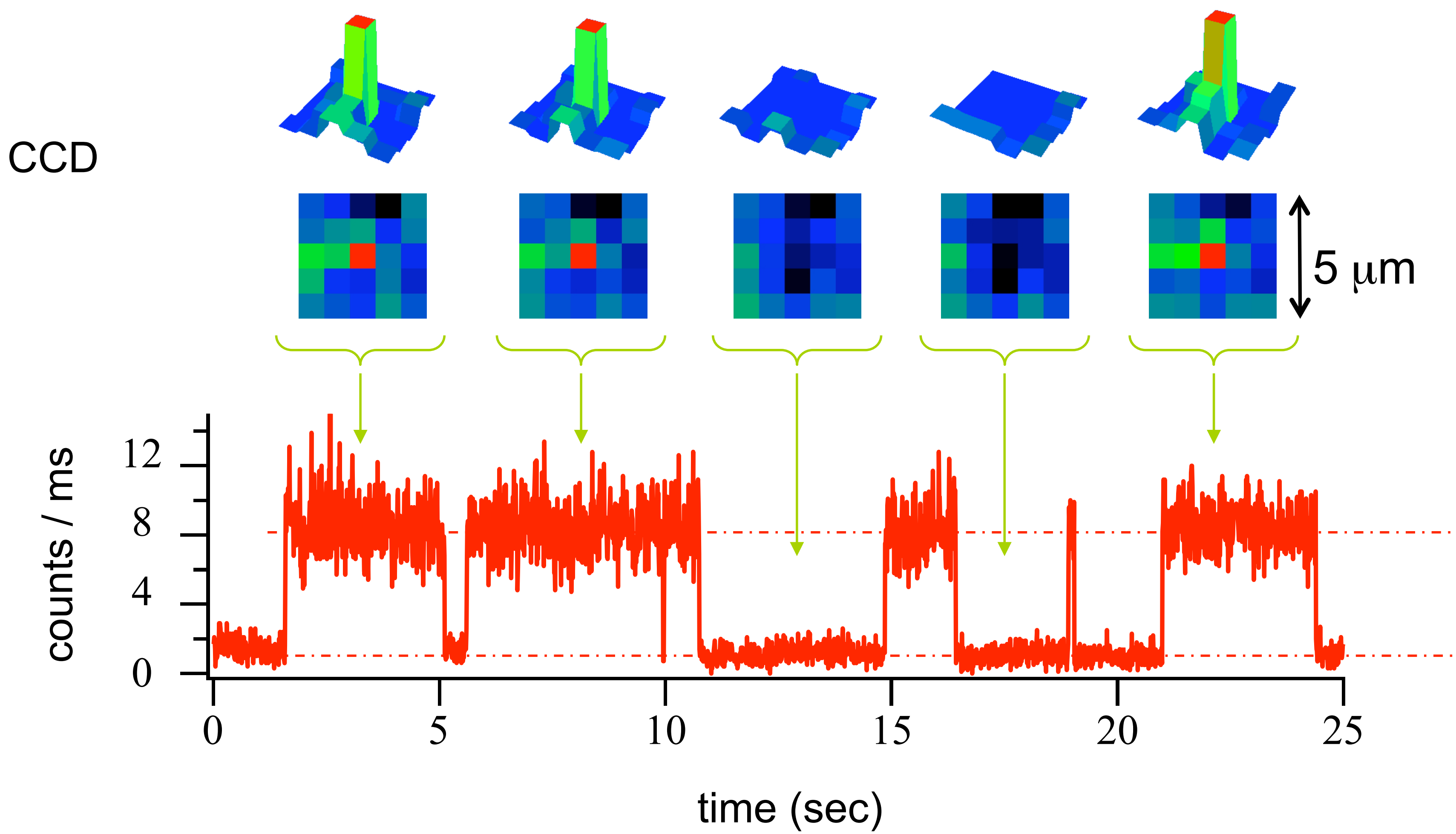
Diffraction limited optics w ~ λ

Trapping volume ~ $\pi \lambda^3$

Ex: 1 mW on 1 μm

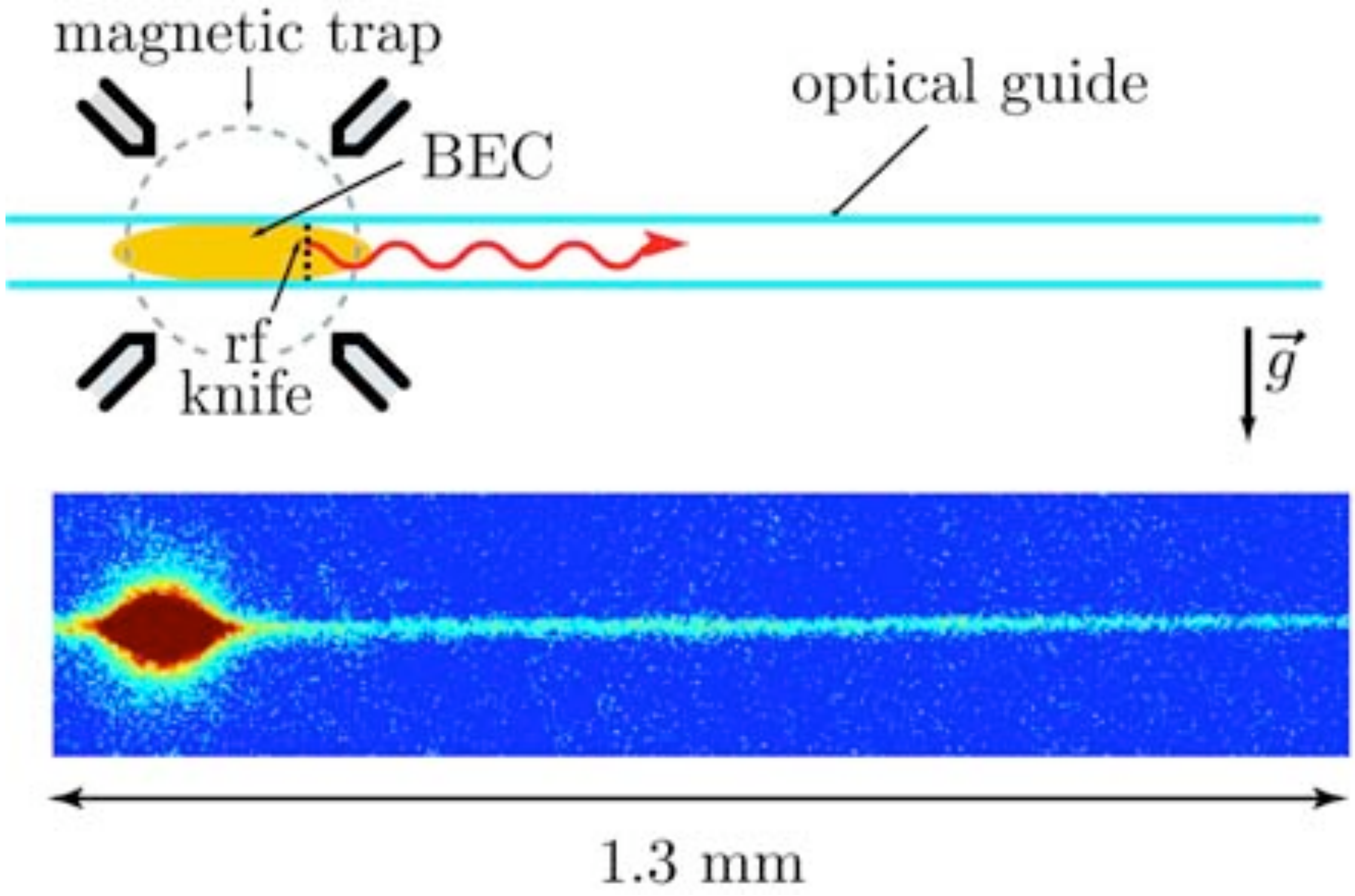
Trap depth = 1 mK

Detecting a single atom



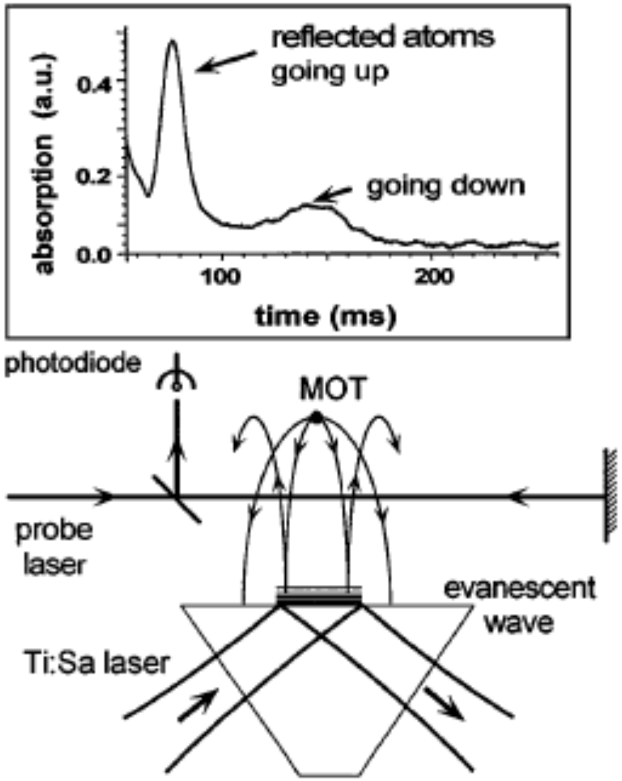
Institut d'Optique, France

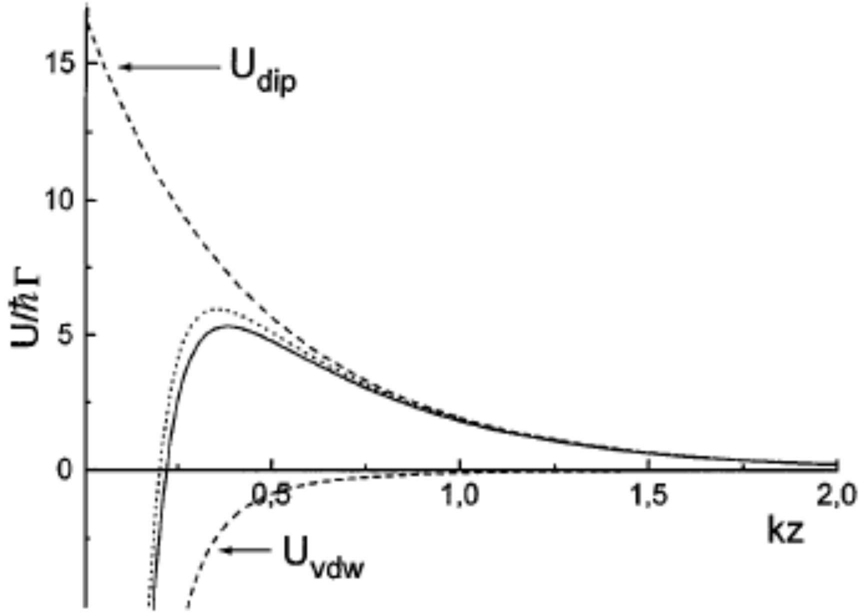
Guiding an atom laser



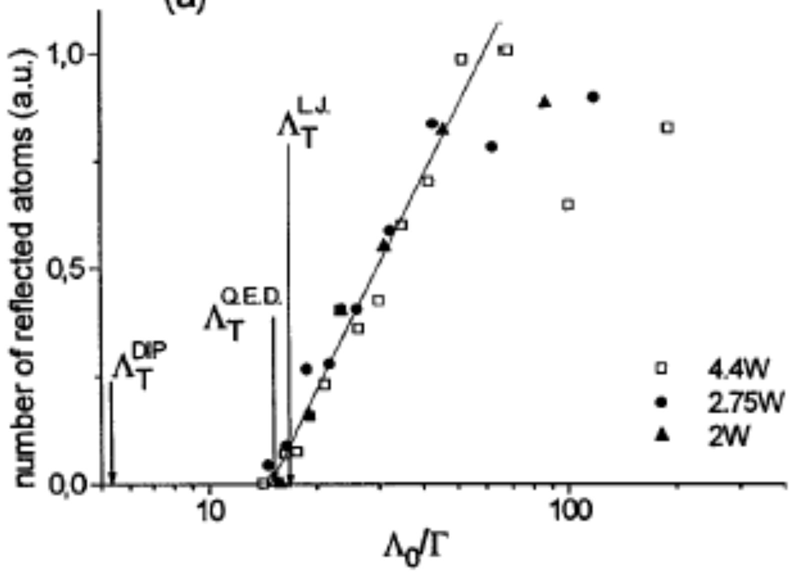
Institut d'Optique, France

Bouncing atoms on a surface



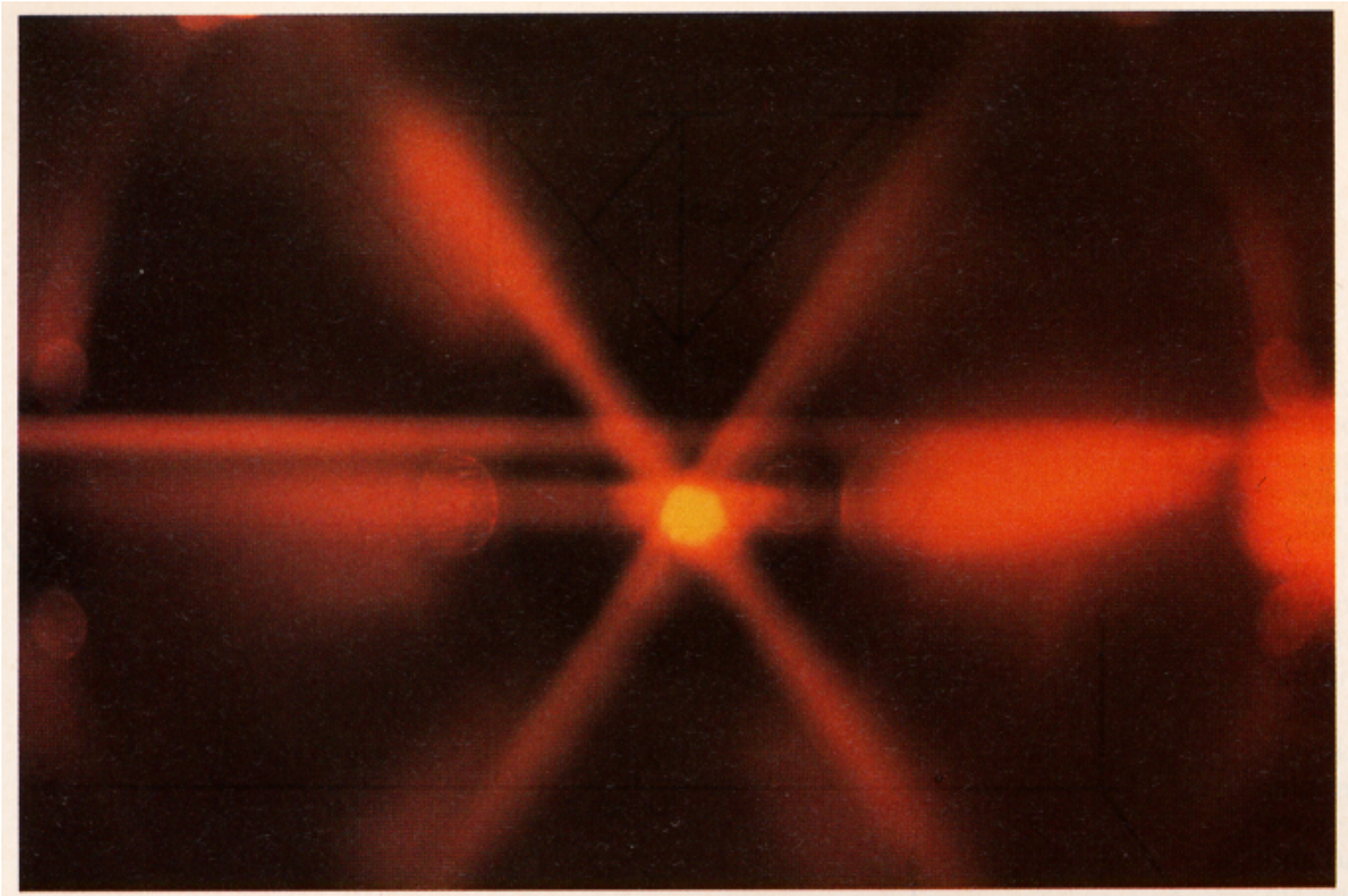


(a)



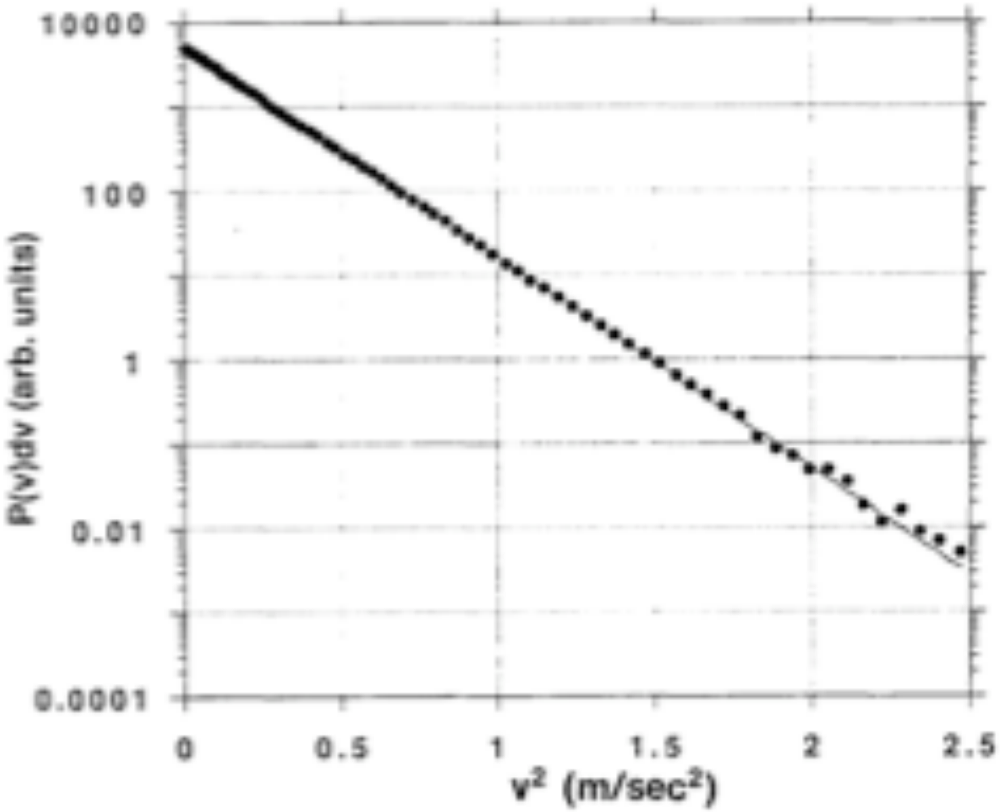
Institut d'Optique, 1996

3D optical molasses



Chu (1985)

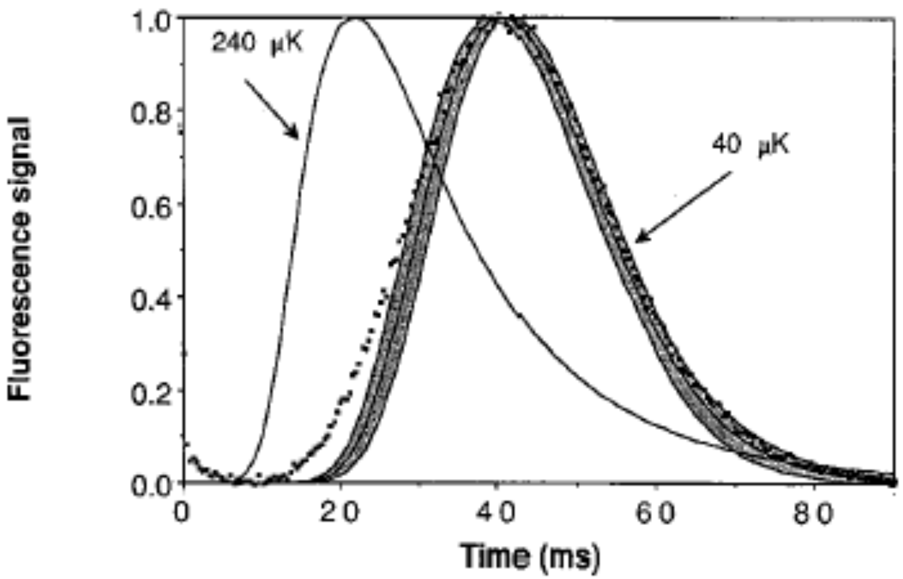
Laser cooling and Maxwell Boltzman distribution



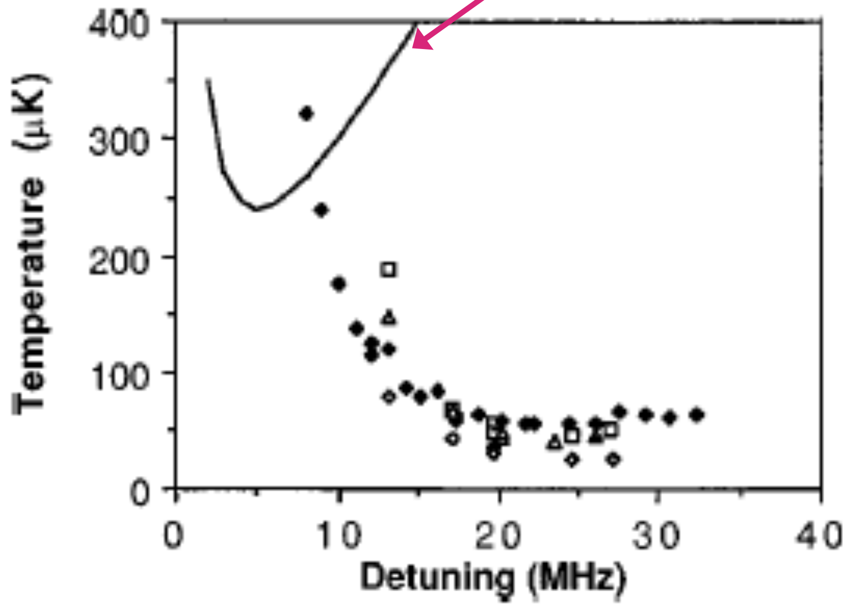
Lett *et al.*, JOSA B **11**, p. 2024 (1989)

The results of Phillips *et al.* (1988)

Time-of-flight measurement



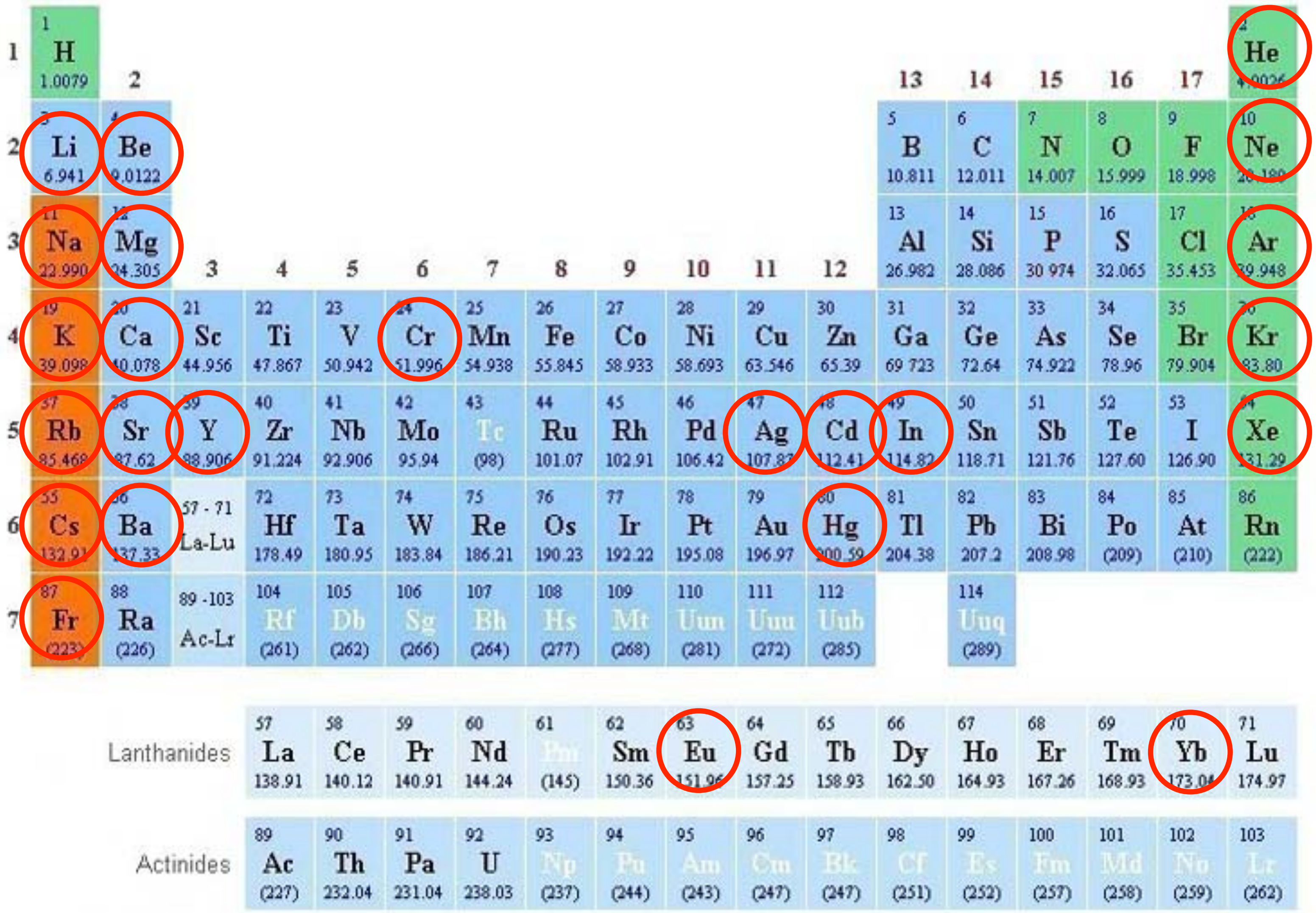
Doppler theory



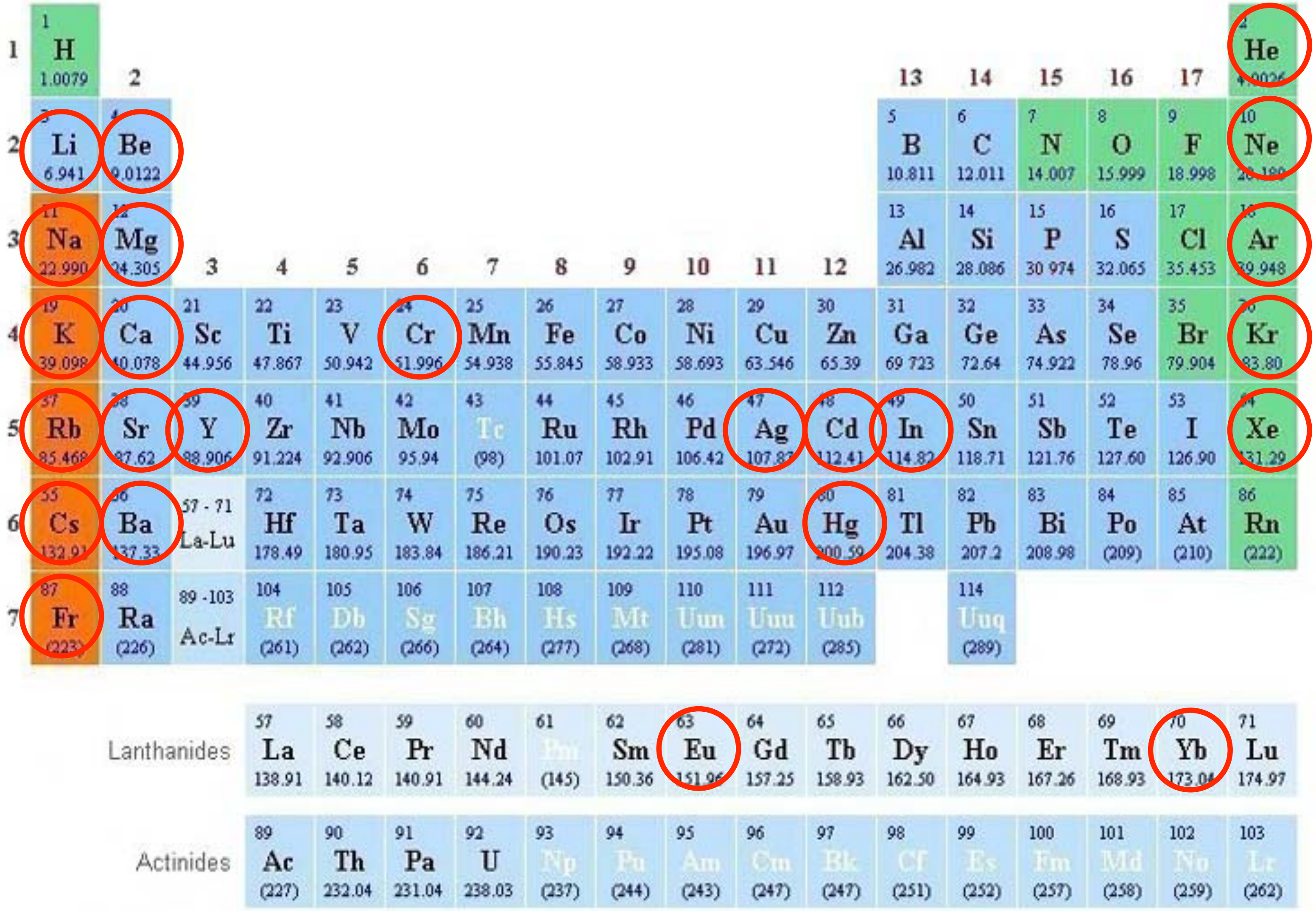
For Na, T_D = 240 μK

Lett, PRL **61**, p. 169 (1988)

Laser cooled atoms (2010)

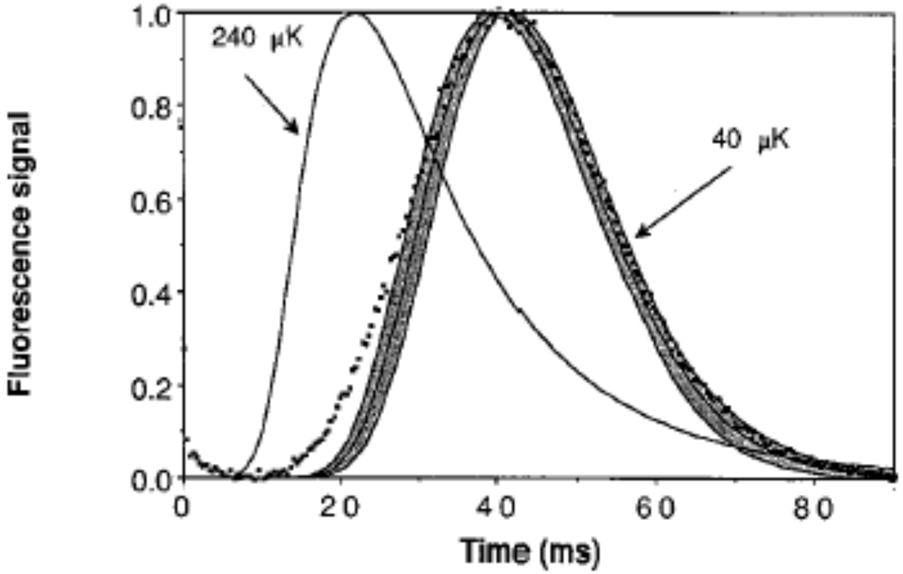


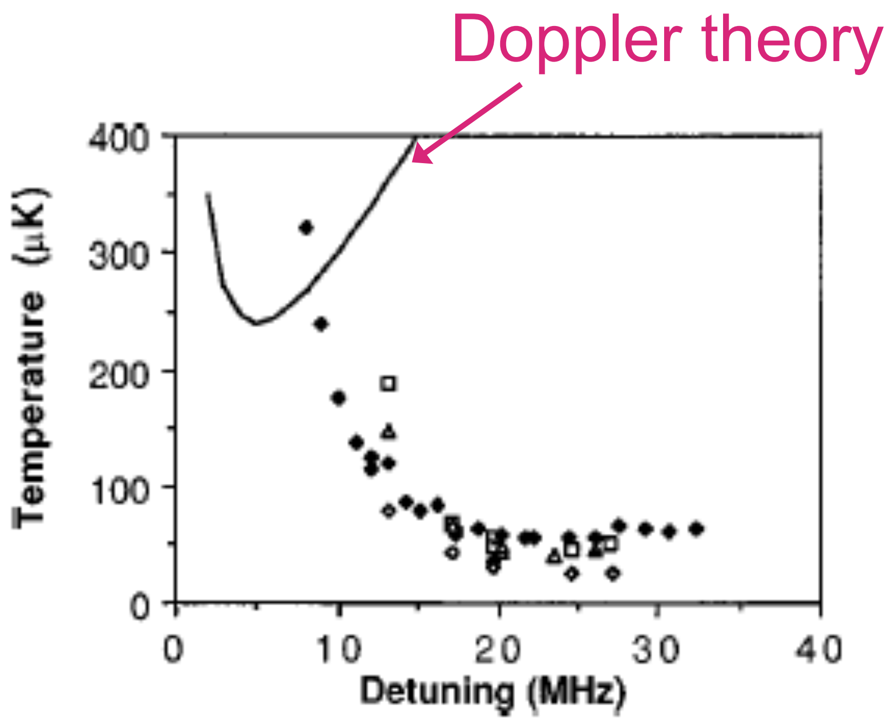
Laser cooled atoms (2010)



Discovery of sub-Doppler cooling (1988)

Time-of-flight measurement

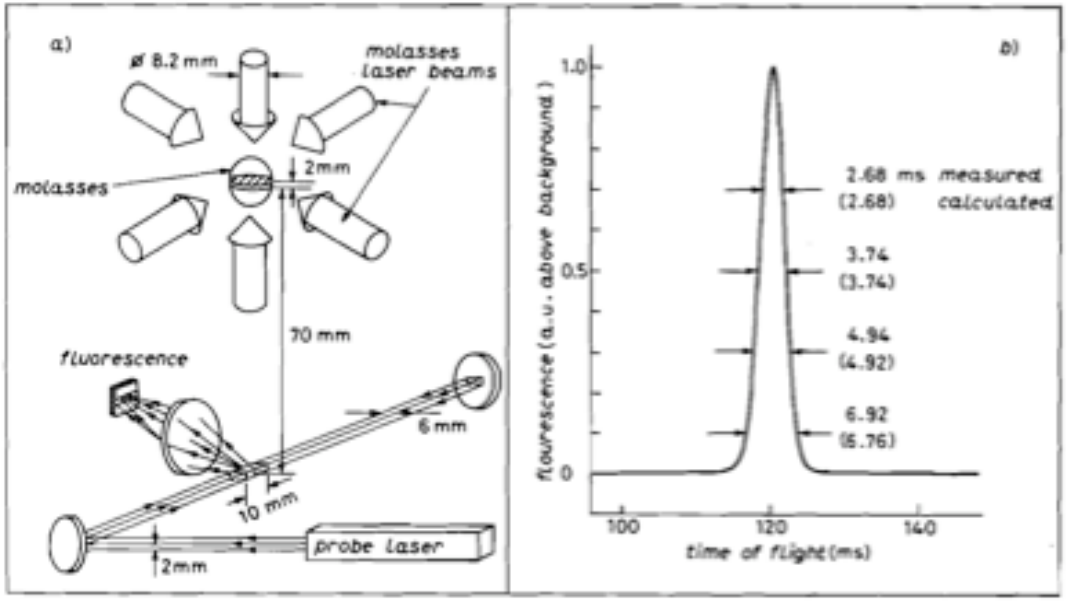




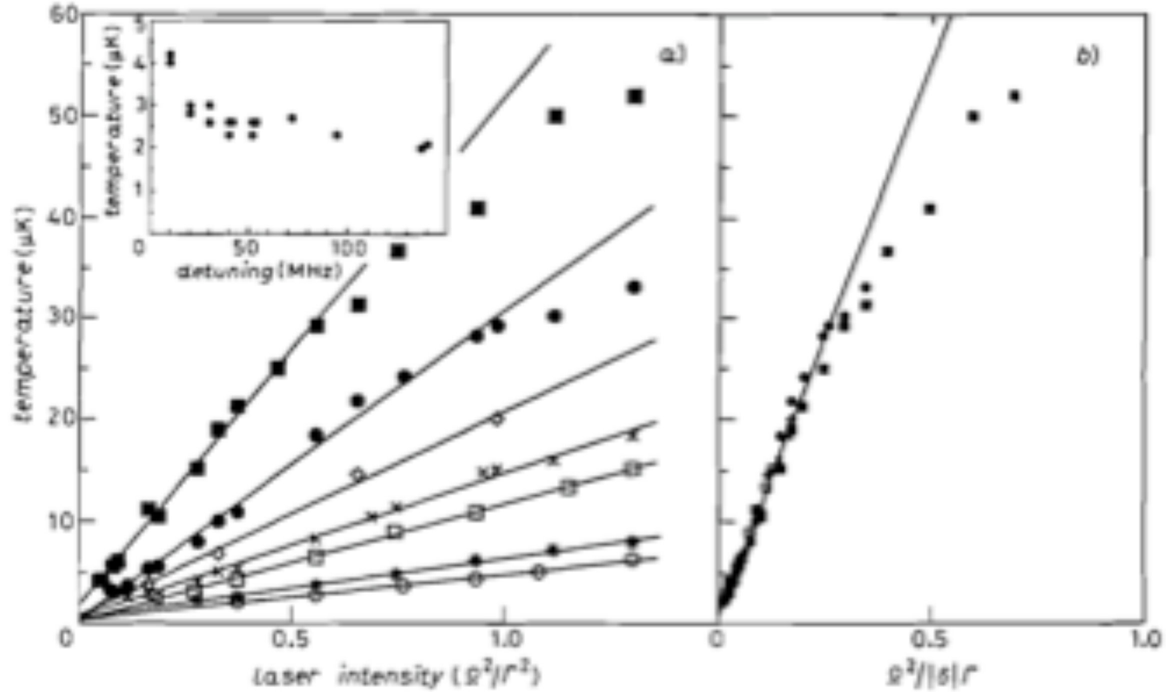
For Na, T_D = 240 µK

Lett, PRL **61**, p. 169 (1988)

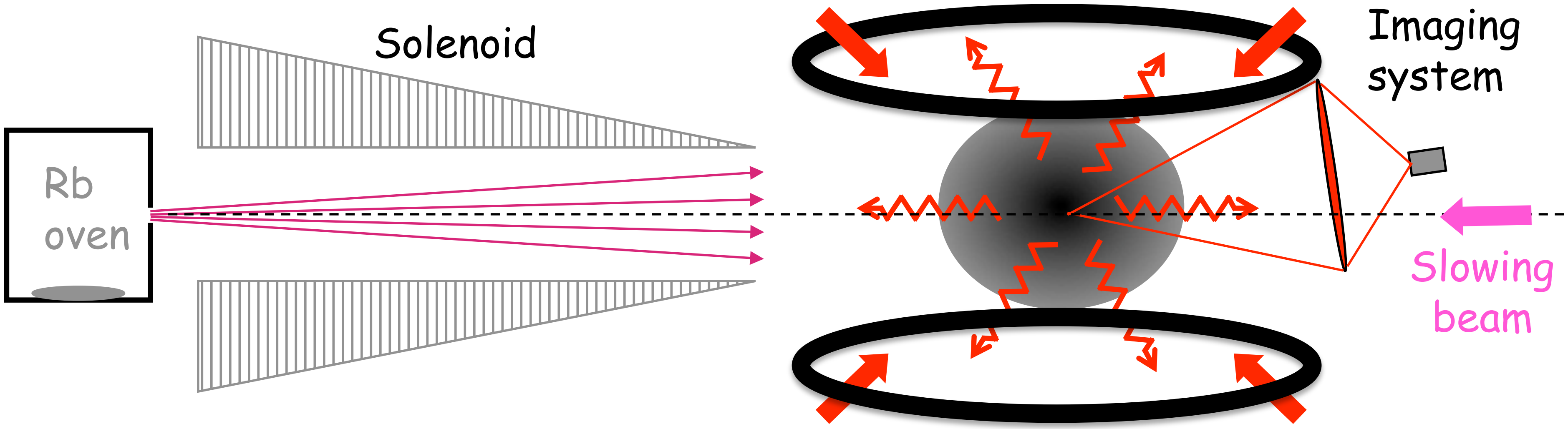
Experimental verifications



Salomon *et al.*,
Euro. Phys. Lett. **12**, p. 683 (1990)



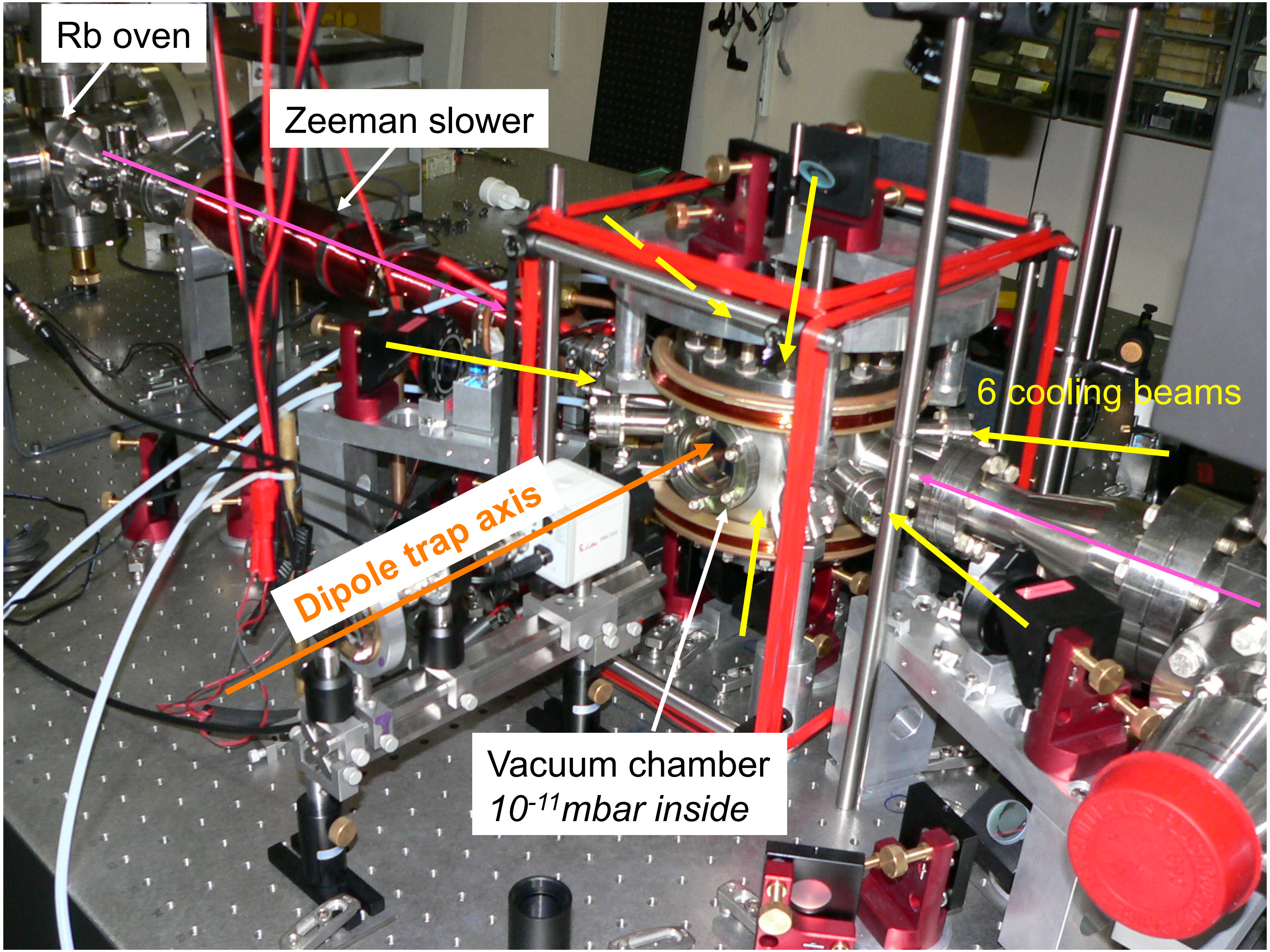
Loading a MOT from a slowed beam



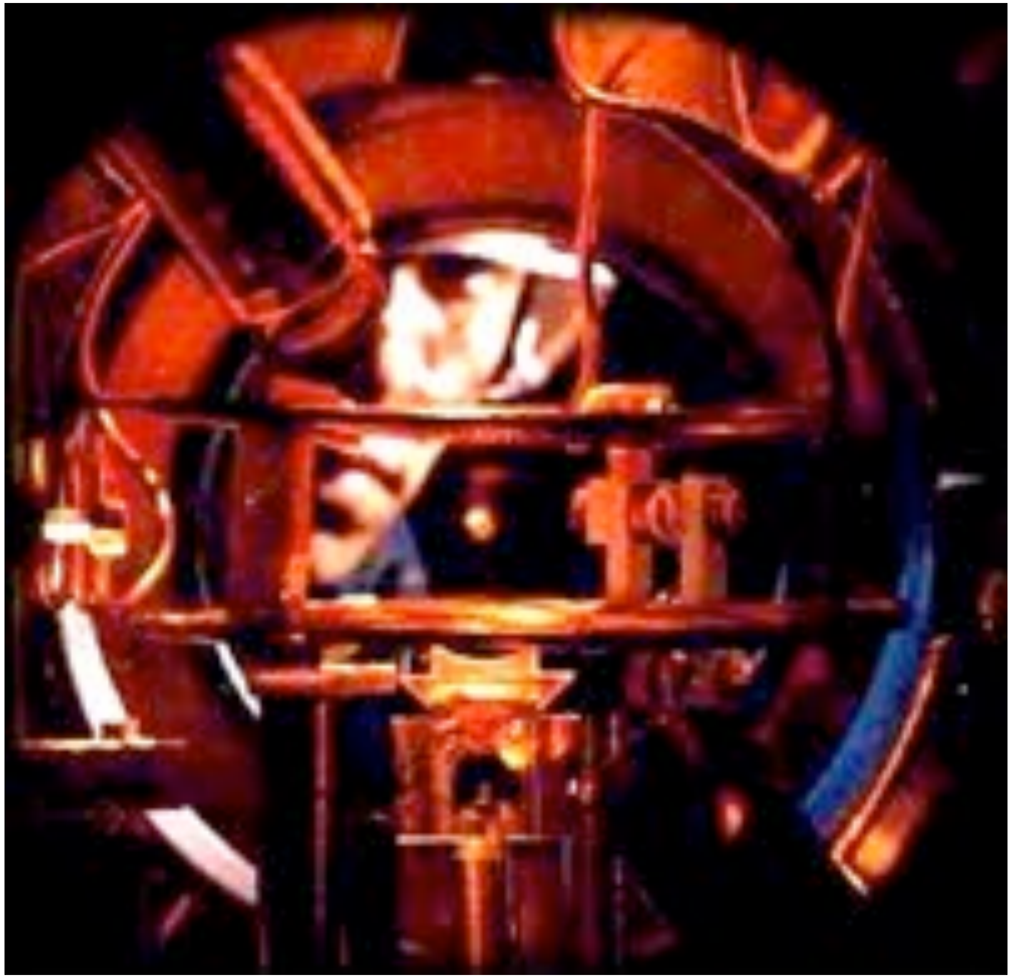
Oven
200 m/s

Slowing
200 m / s → ~ 1 m / s

Dilute atomic cloud

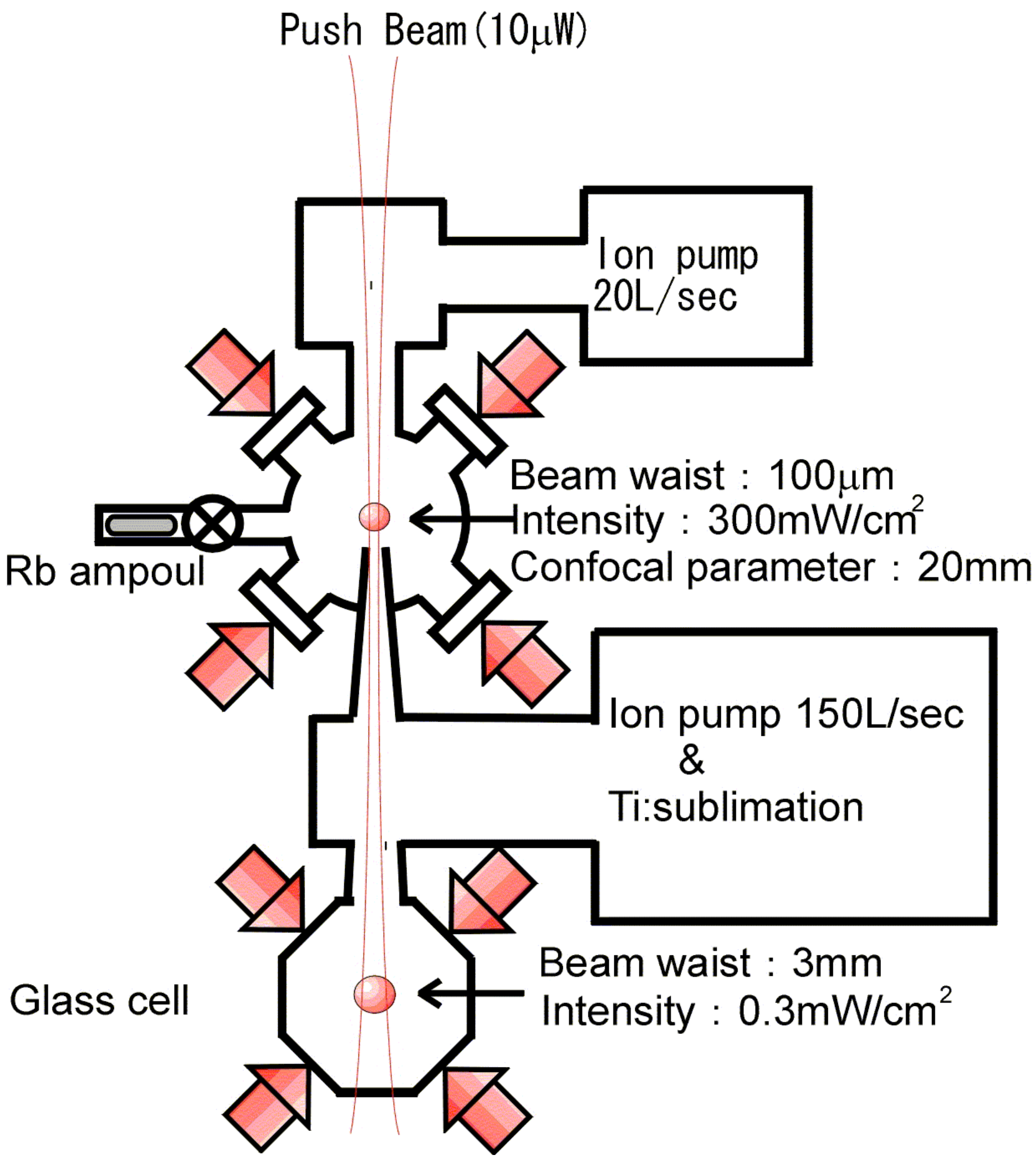

Rb oven
Zeeman slower
6 cooling beams
Dipole trap axis
Vacuum chamber
10^{-11}mbar inside

A MOT trap of sodium



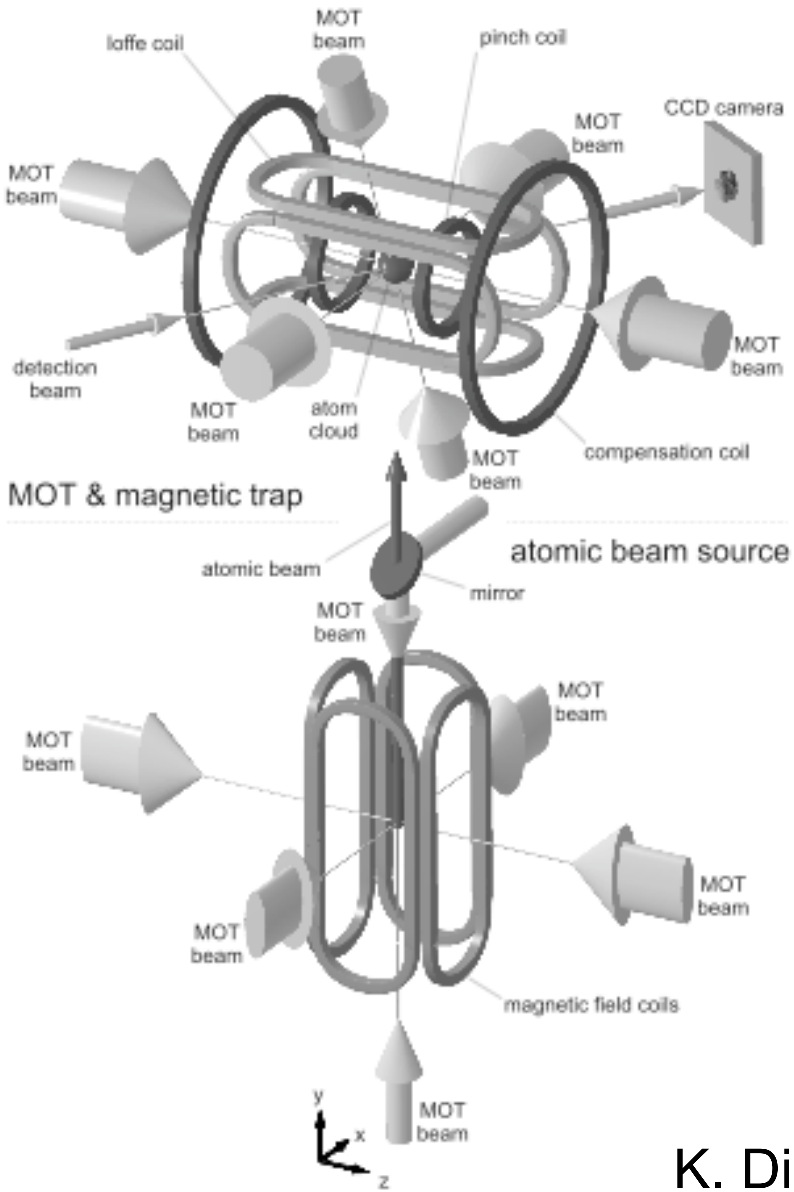
NIST, USA

Double MOT system



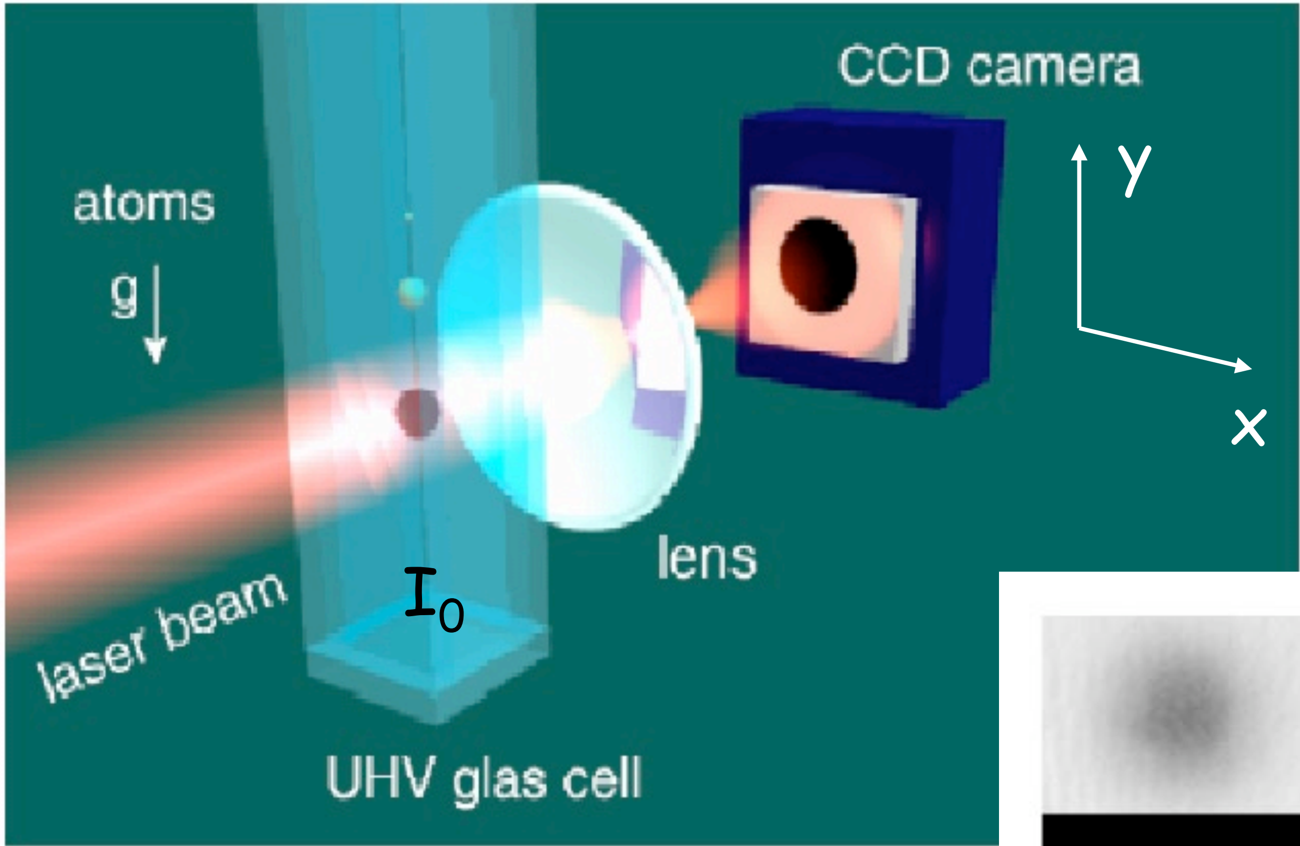
Gakushuin, Japan

Loading from a 2D MOT

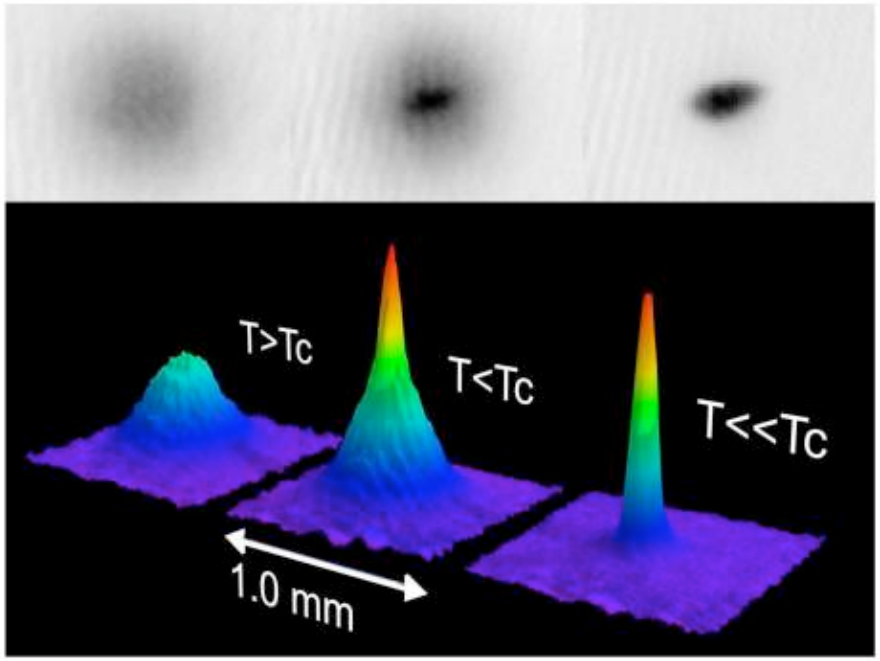


Amsterdam,
K. Dieckmann thesis (2001)

Absorption imaging

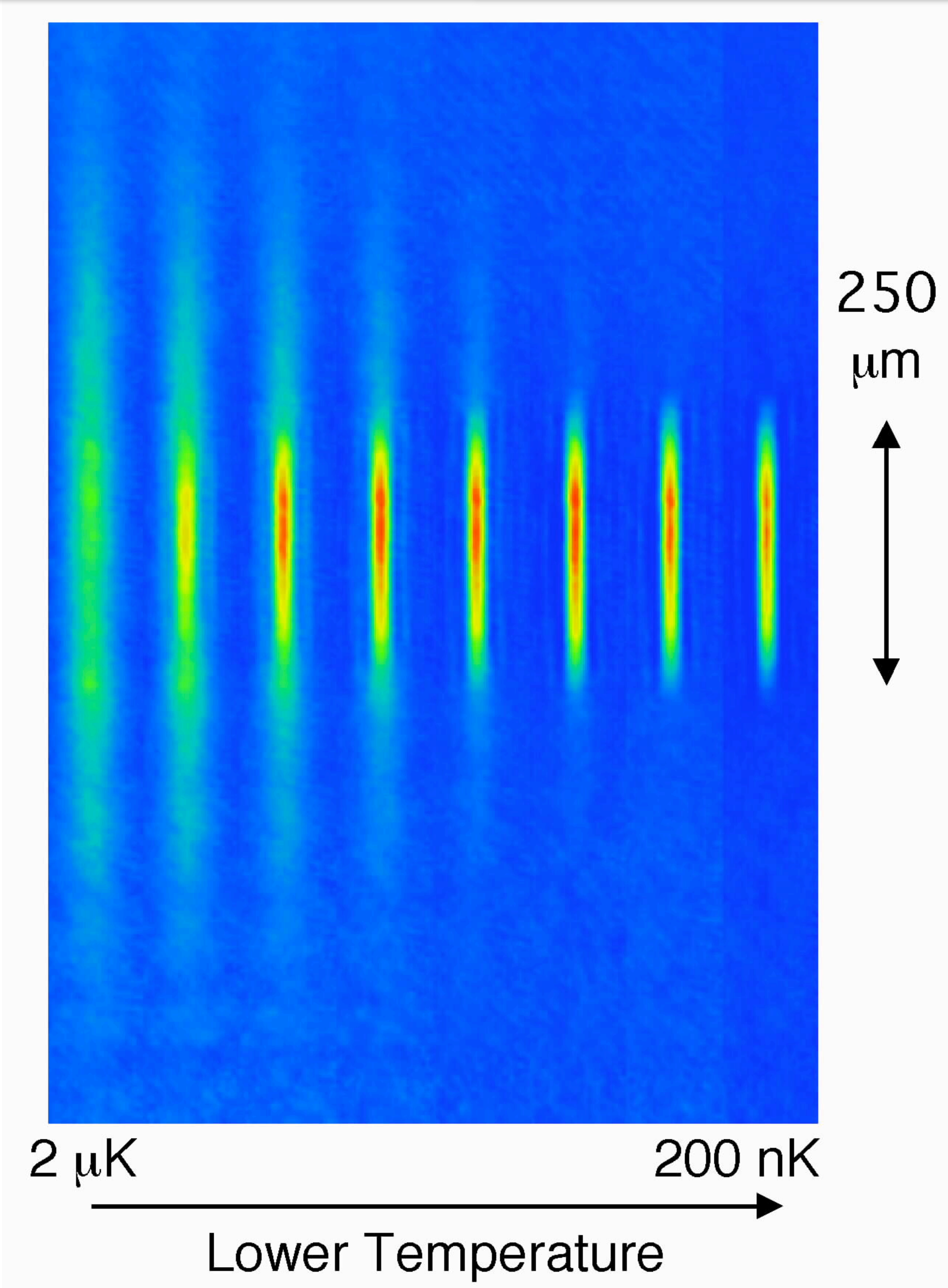


MIT



$$I(x,y) = I_0\, e^{-n(x,y)\,\sigma L}$$

Phase contrast imaging



MIT