Cooling stuff

Doppler molasses

Sisyphus and related

evaporation

expansion

Sideband cooling

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Marcell Jankovics

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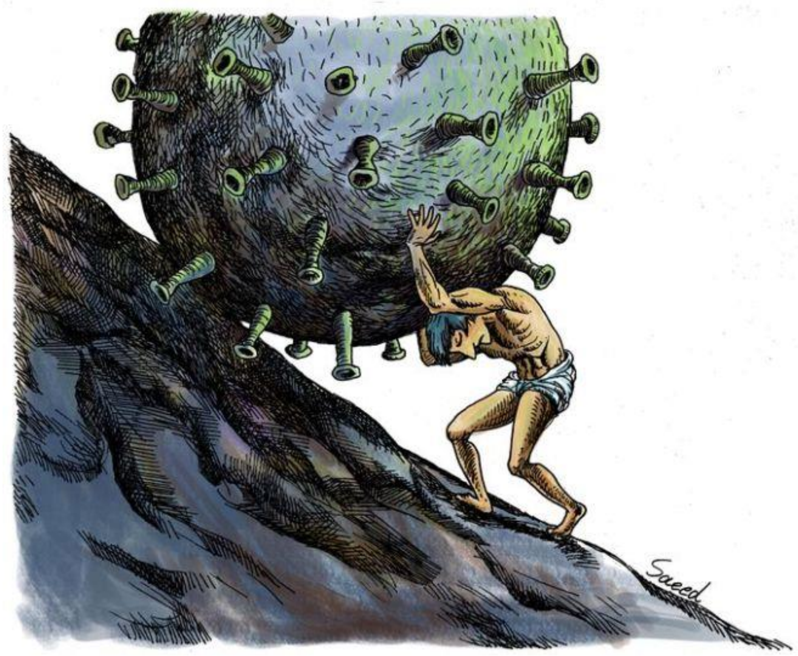

Saeed Sadeghi

Sisyphus and related

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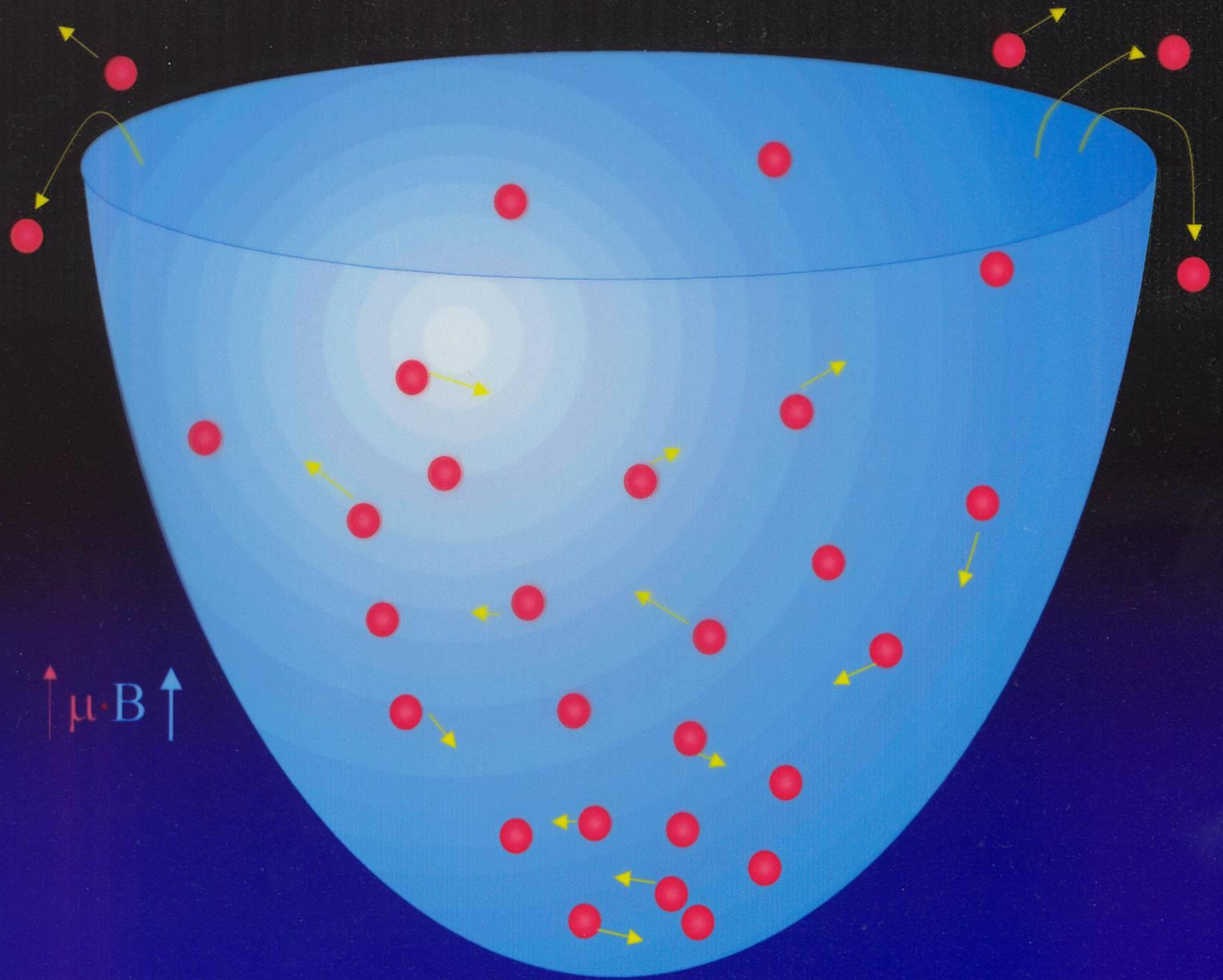
Sisyphus and related velocity and B-field limits.

Cooling efficiency. The Carnot limit

Black-body radiation and molecules

Can we do optical cooling to degeneracy?

Magnetic trapping and evaporative cooling



Evaporation.
Good, but large in volume,
complicated, expensive, slow.
Can we make BEC
small, cheap, fast?

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Tweezers!

many-body Schroedinger Equation.
The GPE mean-field solution.

QM: Particle described by Schrödinger equation

$$\left(-\frac{\hbar^2}{2m}\Delta + V_{extern}\right)\psi(\vec{r}) = E\psi(\vec{r})$$

BEC: many weakly interacting particles

→ Gross-Pitaevskii equation

$$\left(-\frac{\hbar^2}{2m}\Delta + V_{extern} + \underbrace{\frac{4\pi\hbar^2 a}{m}\left|\psi(\vec{r})\right|^2}\right)\psi(\vec{r}) = \mu\psi(\vec{r})$$

The condensate is
self-interacting (usually self-repulsive)

BEC: many weakly interacting particles
→ Gross-Pitaevskii equation

$$\left(-\frac{\hbar^2}{2m}\Delta + V_{extern} + \frac{4\pi\hbar^2 a}{m}\left|\psi(\vec{r})\right|^2\right)\psi(\vec{r}) = i\hbar\frac{\partial\psi(\vec{r})}{\partial t}$$

Can be solved in various approximations.

The Thomas-Fermi approximation:
ignore KE term, look for stationary states

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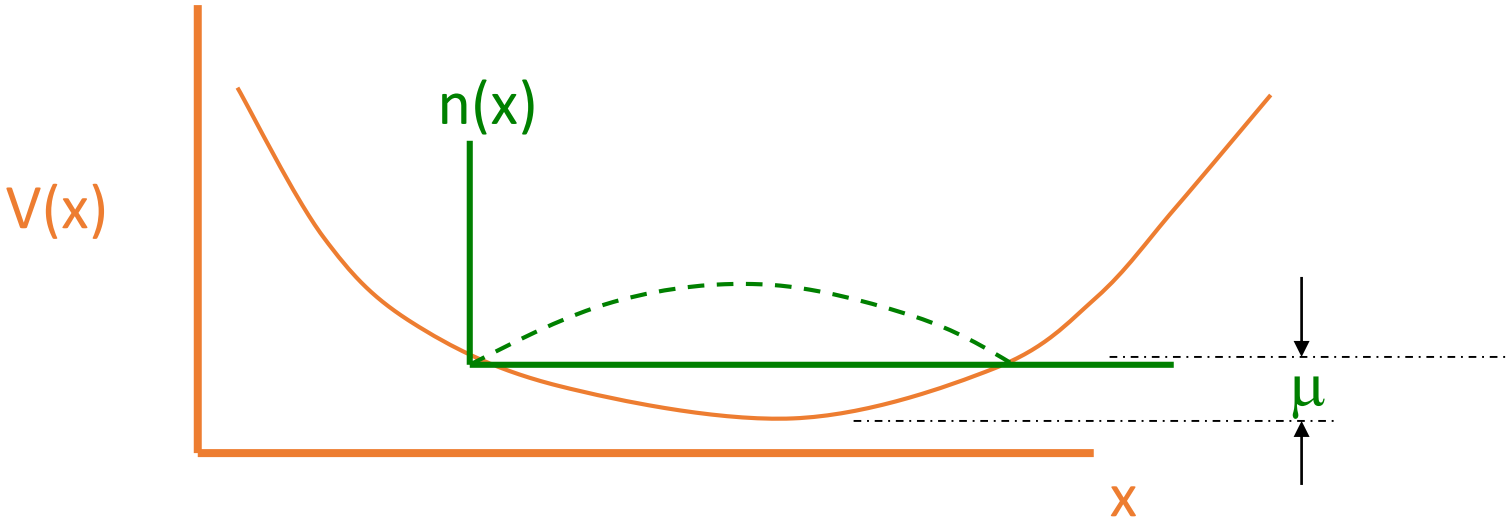

Self-interacting condensate
expands to fill confining potential
to height μ

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Ignore external potential, look for plane-wave excitations

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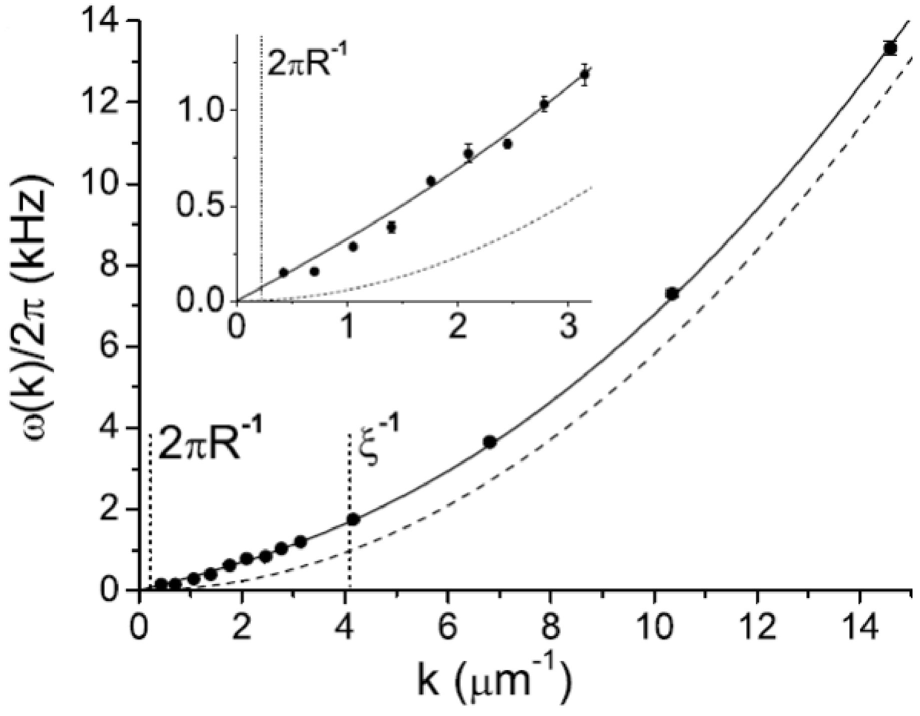


Data from Nir Davidson

speed of sound:

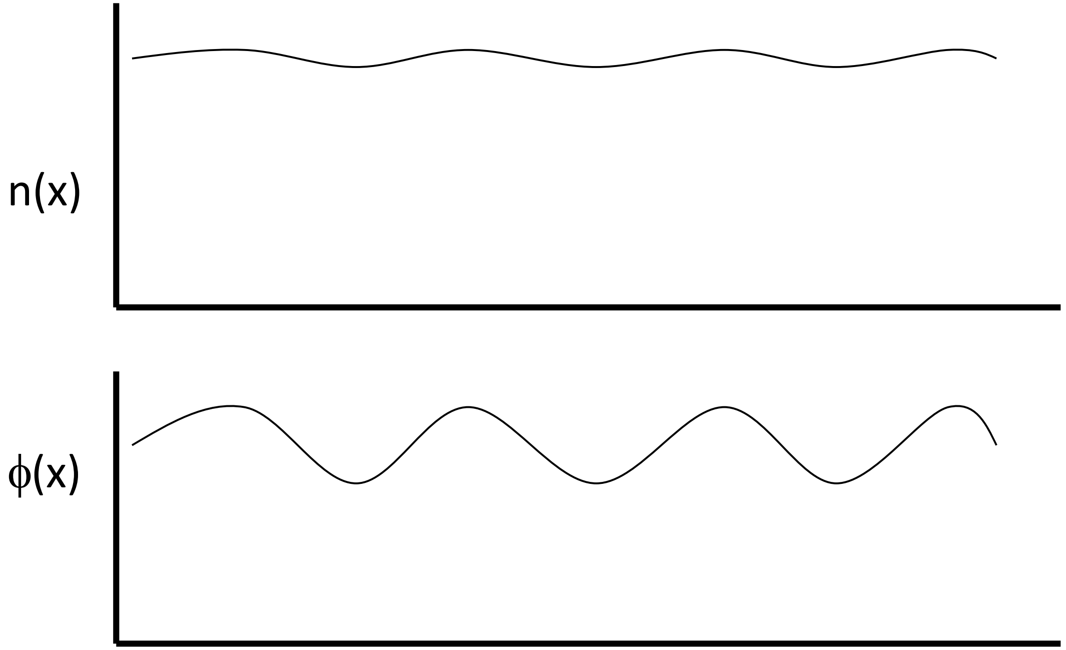
$c = (\mu/m)^{1/2}$

Healing length:

$\xi = (\hbar^2/ m \mu)^{1/2}$

Chemical potential:

$\mu = 4 \pi \hbar^2 a n /m$



Long wavelength excitations
($k \ll 1/\xi$)

relatively little density fluctuation, large phase fluctuation (which we can't directly image).

coherent breathing

limits to GPE

fluctuations at low d

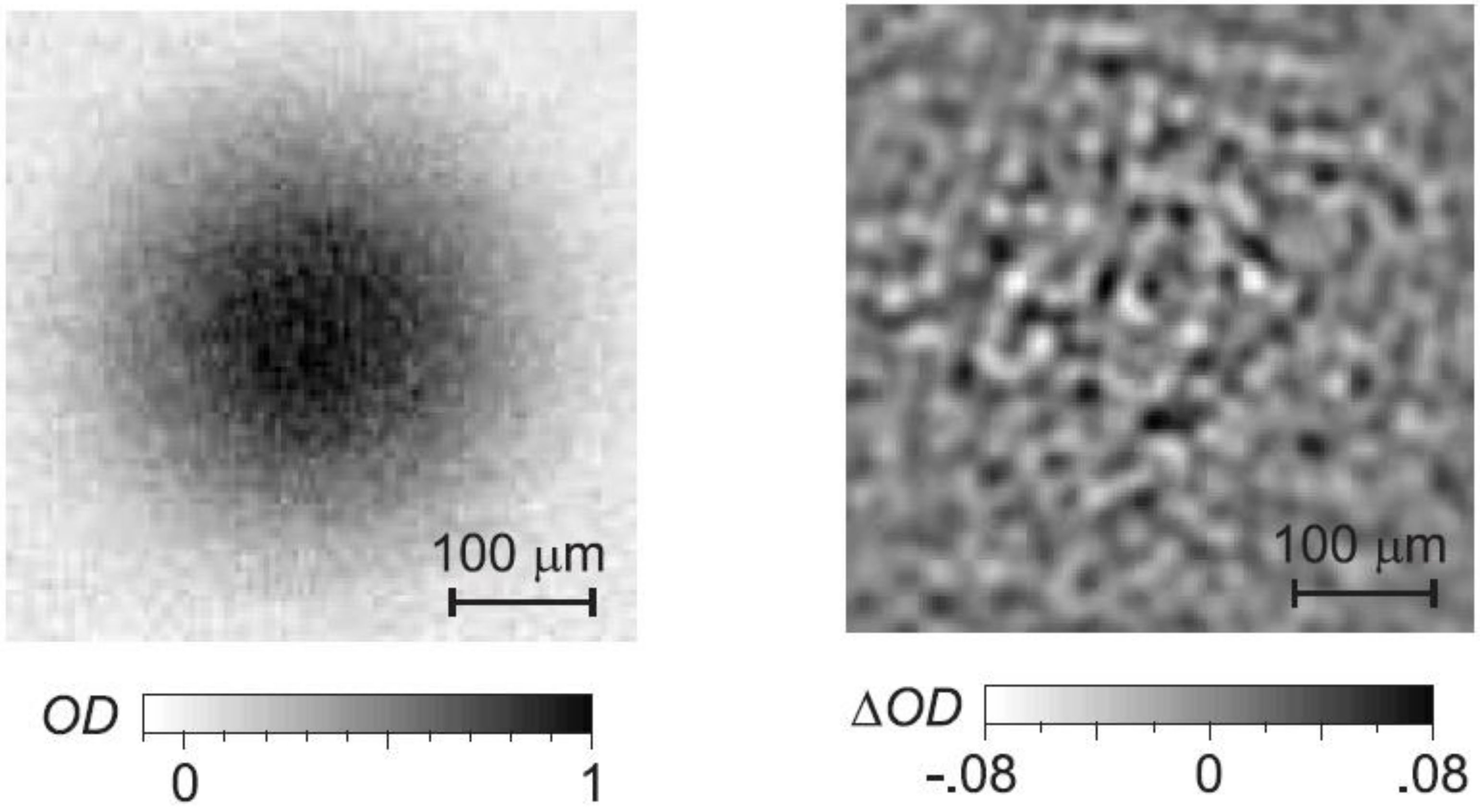
finite T damping

T ~ Tc

$na^3 > 1/4pi$

discrete-atom density fluctuations

Atom shot noise limited imaging



Data from lab of Debbie Jin.

limits to GPE

fluctuations at low d
finite T damping
T ~ Tc
na^3 > 1/4pi (for na^3 < ¼ pi, perturbative corrections exist)
discrete-atom density fluctuations

Hard to study strong interactions in atomic BEC, because of 3-body recombination.
But for “s=1/2” fermions, yes, possible.

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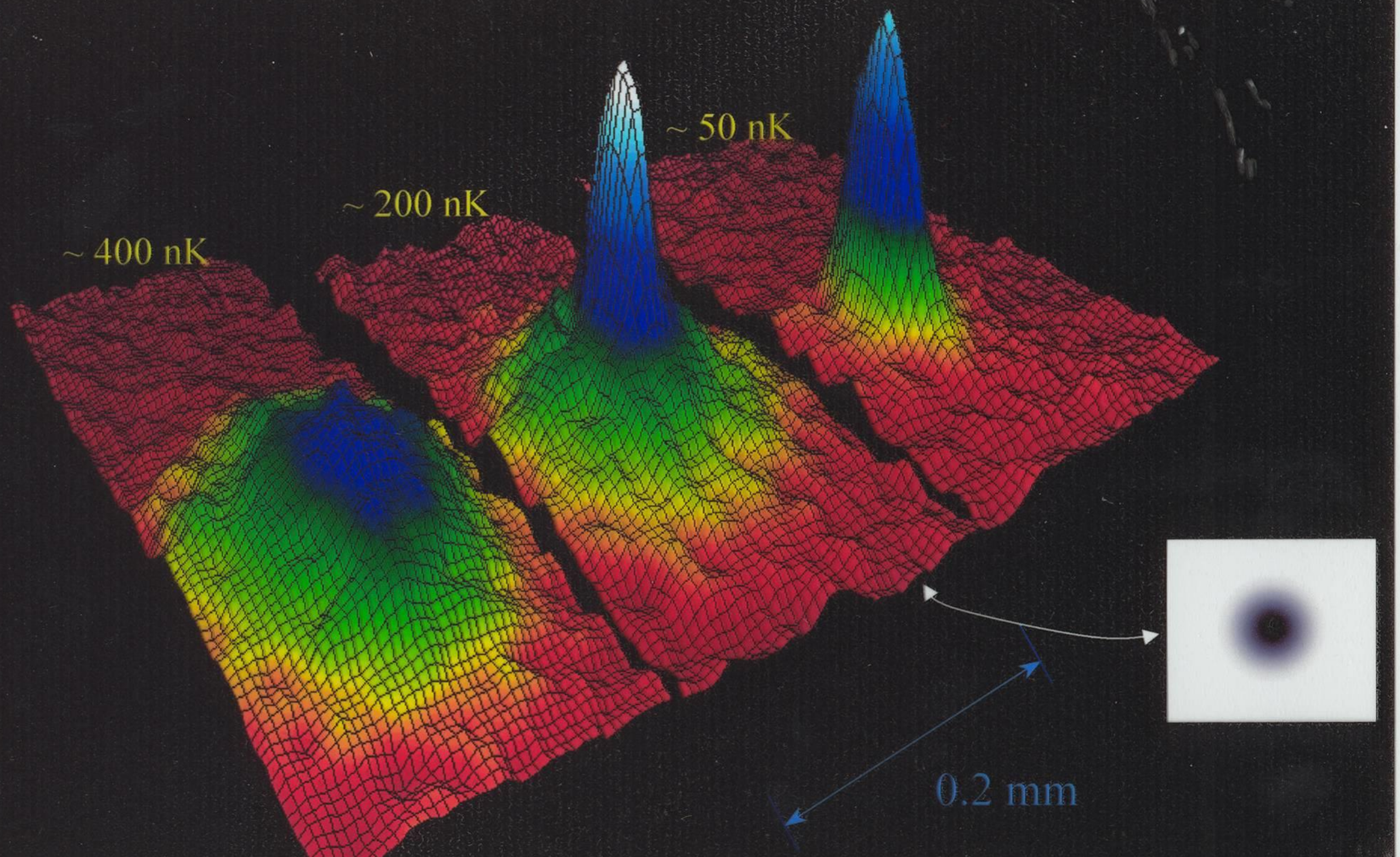
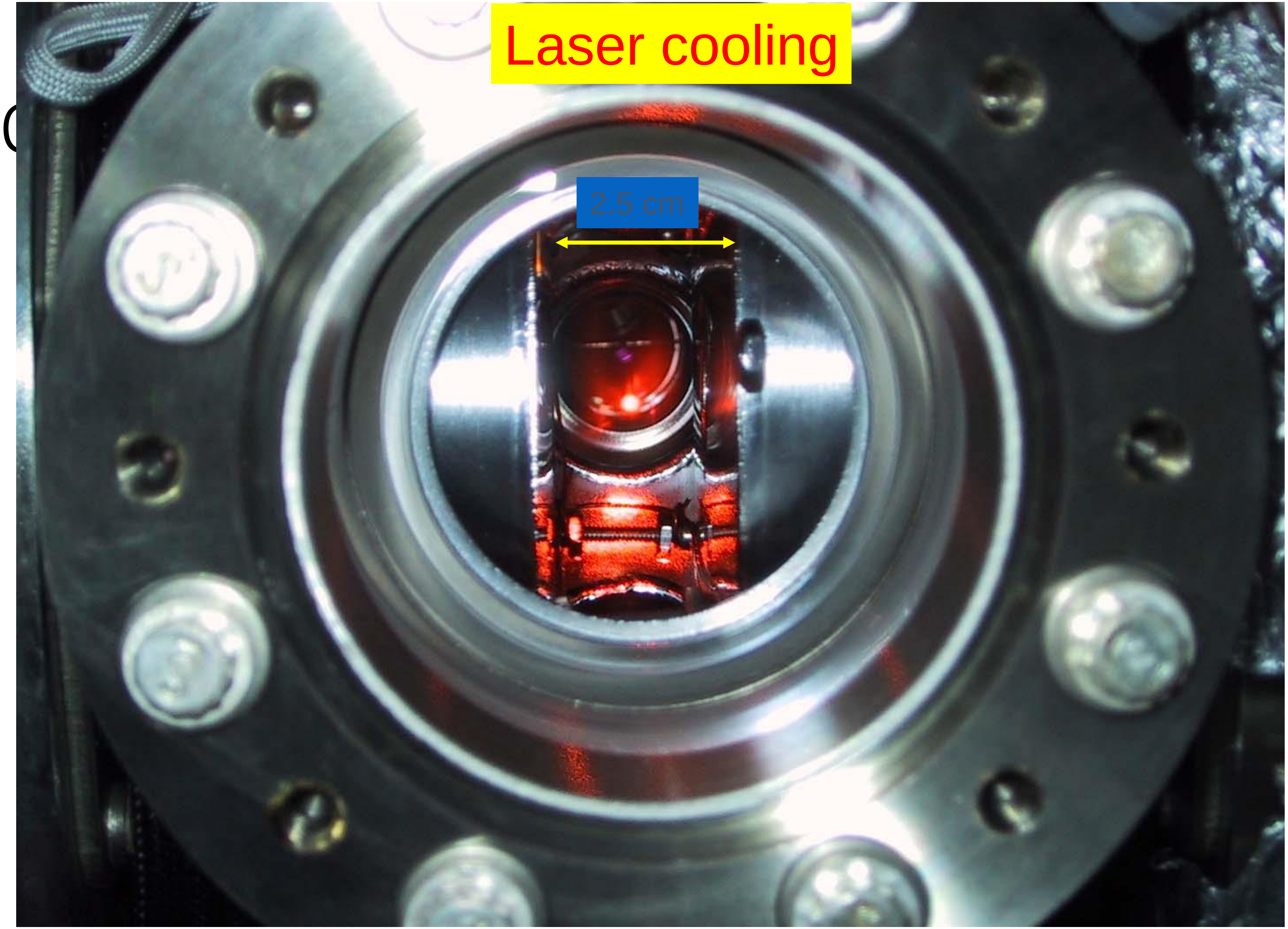
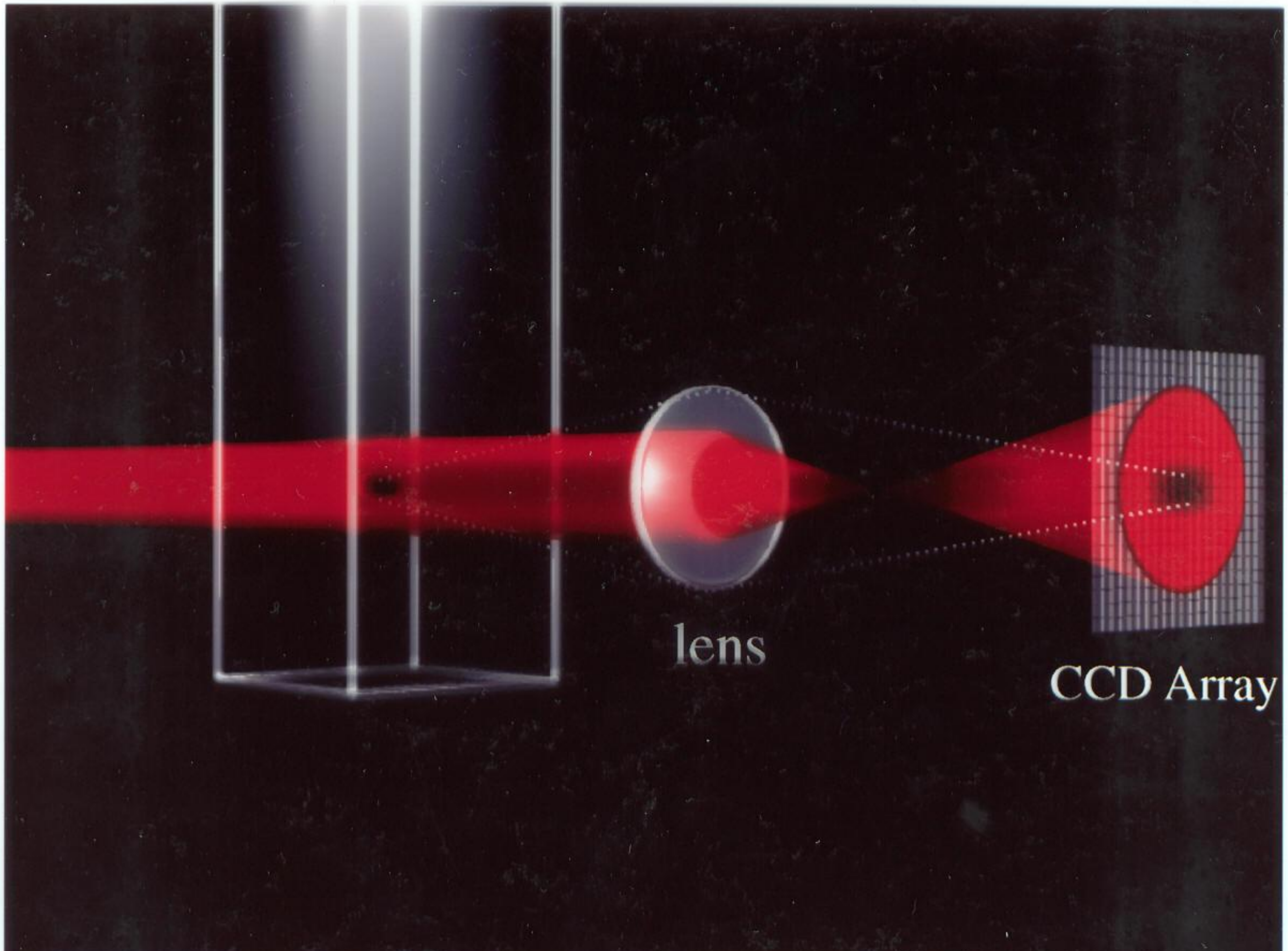
cf work of Deborah Jin 1967-2016.

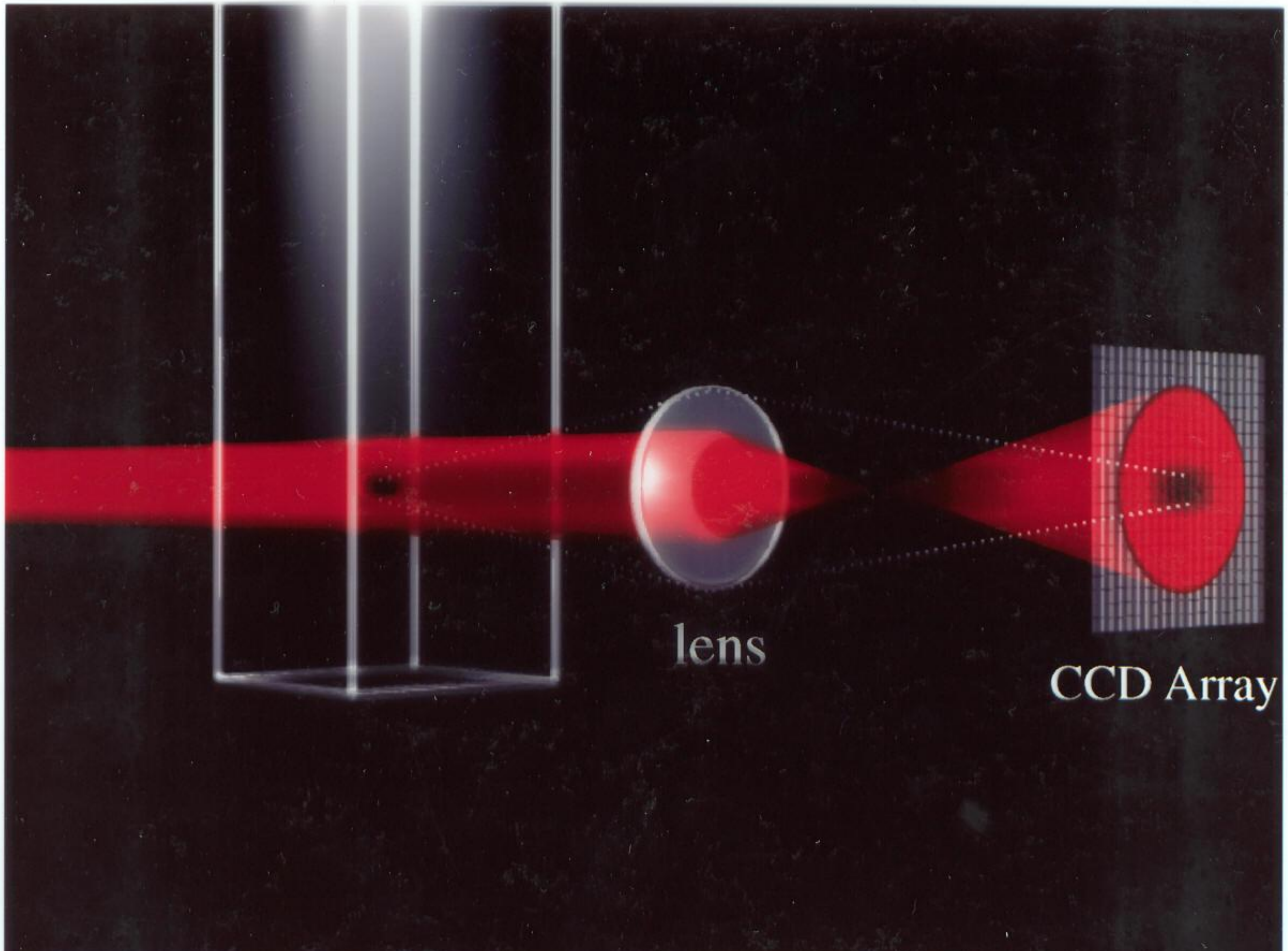
2 D velocity/density distributions



MO




lens
CCD Array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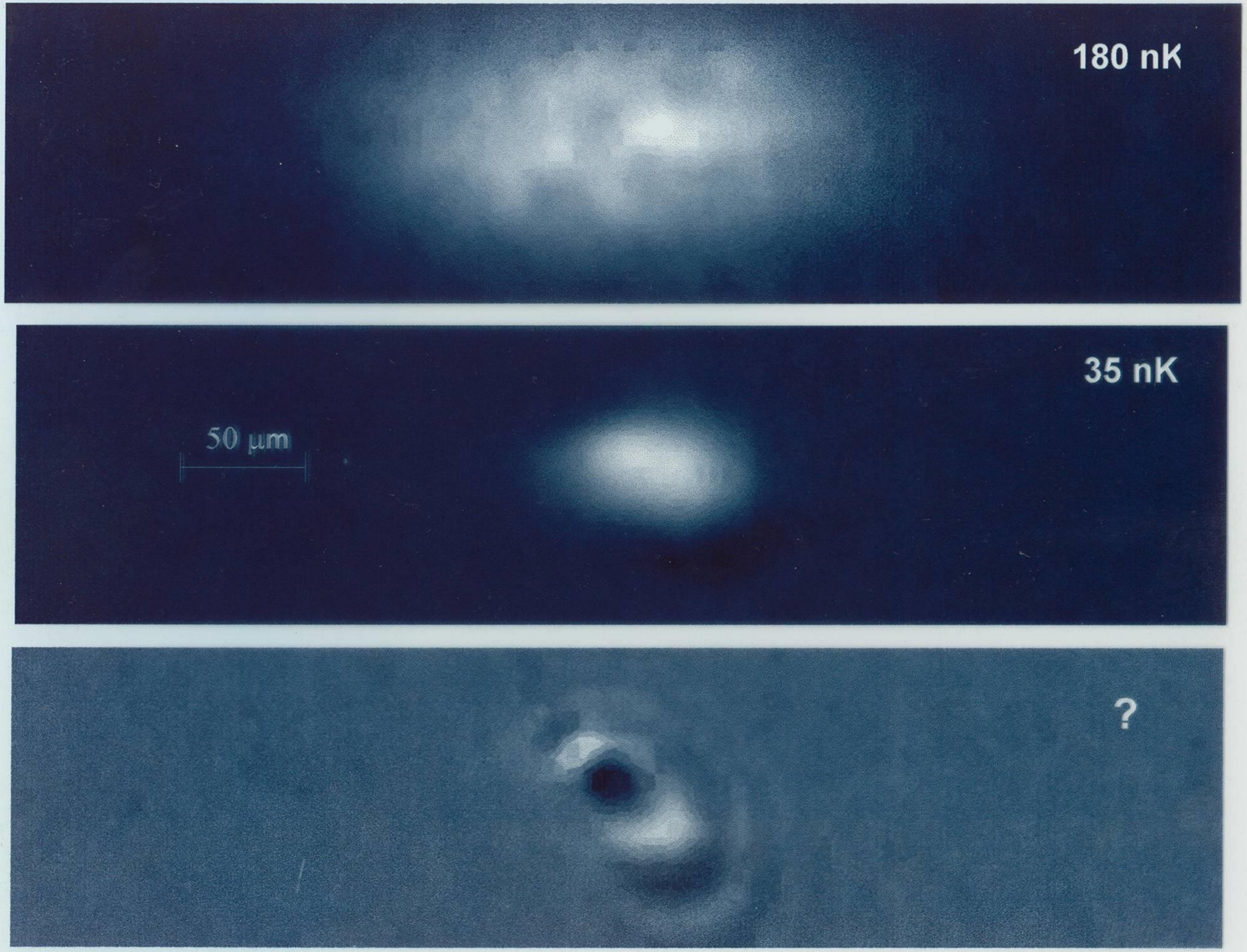
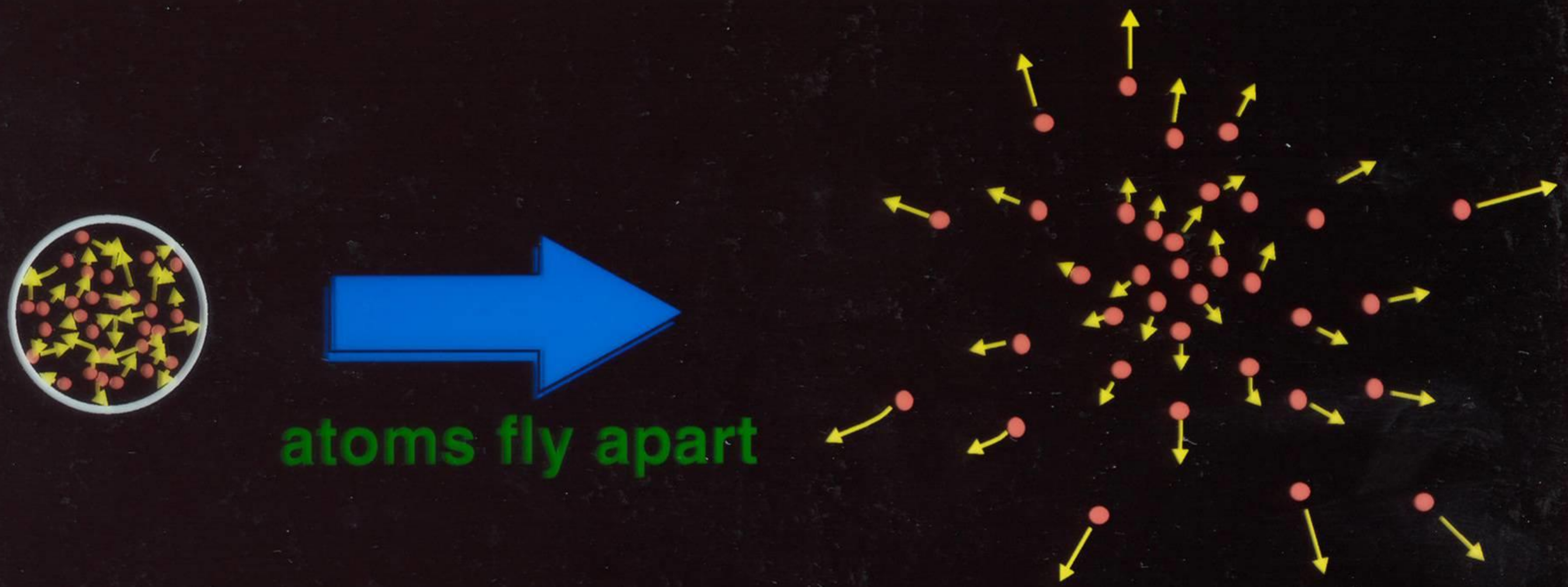
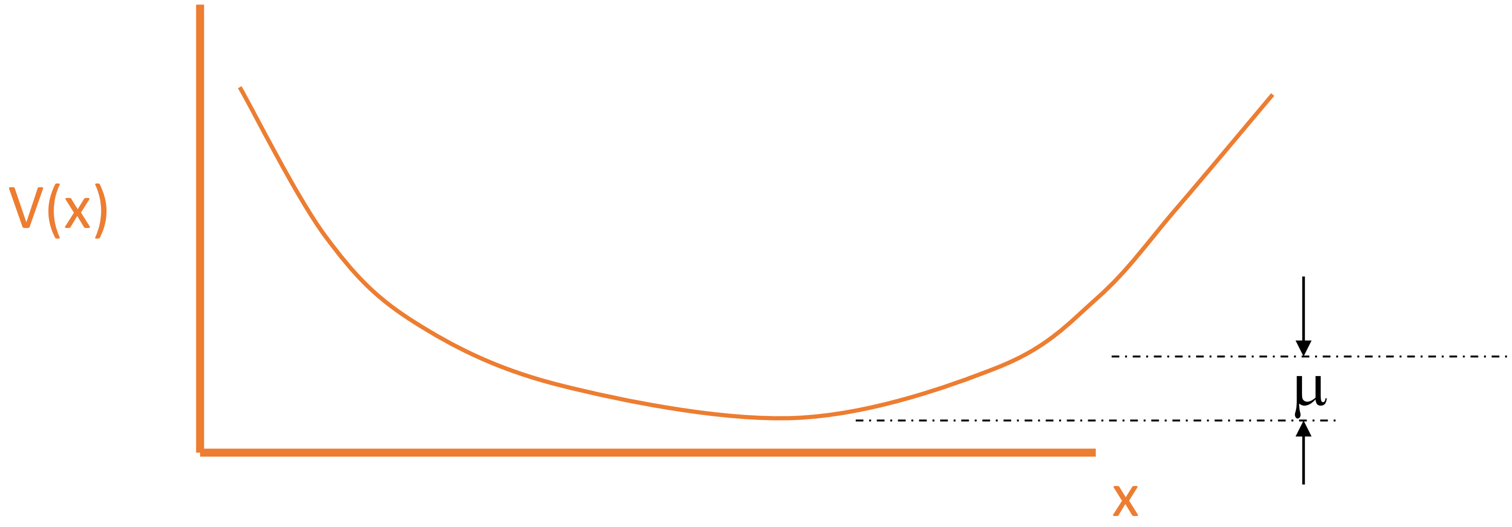

180 nK
35 nK
50 µm
?

Turn magnetic trap off





Self-interacting condensate
expands to fill confining potential
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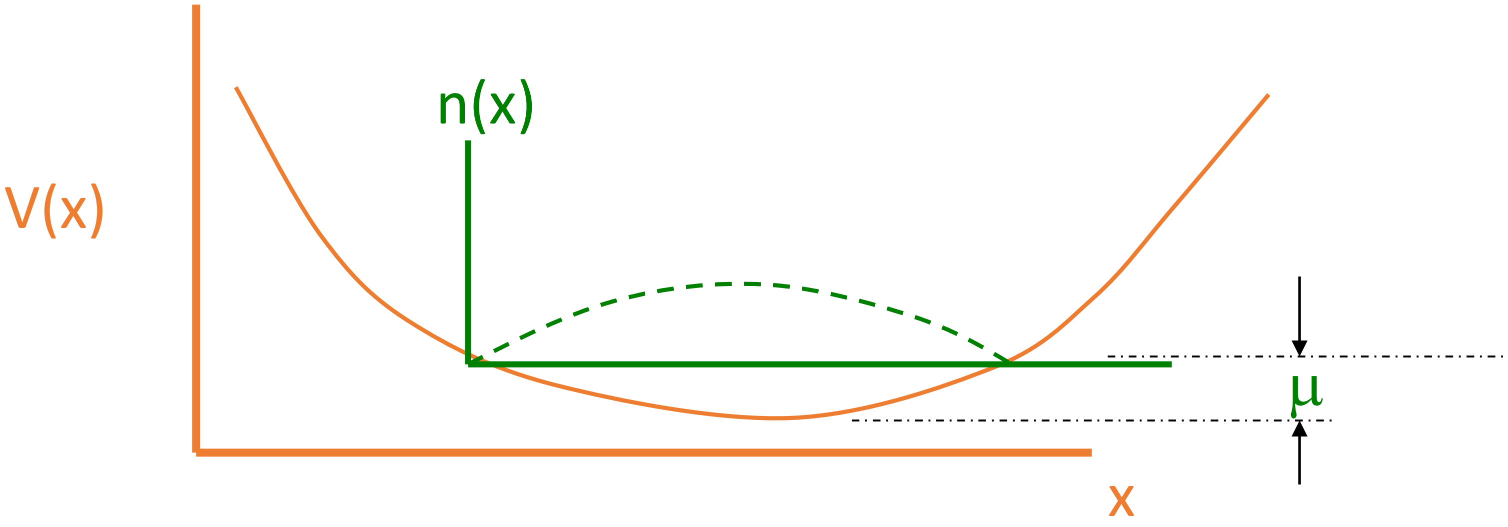

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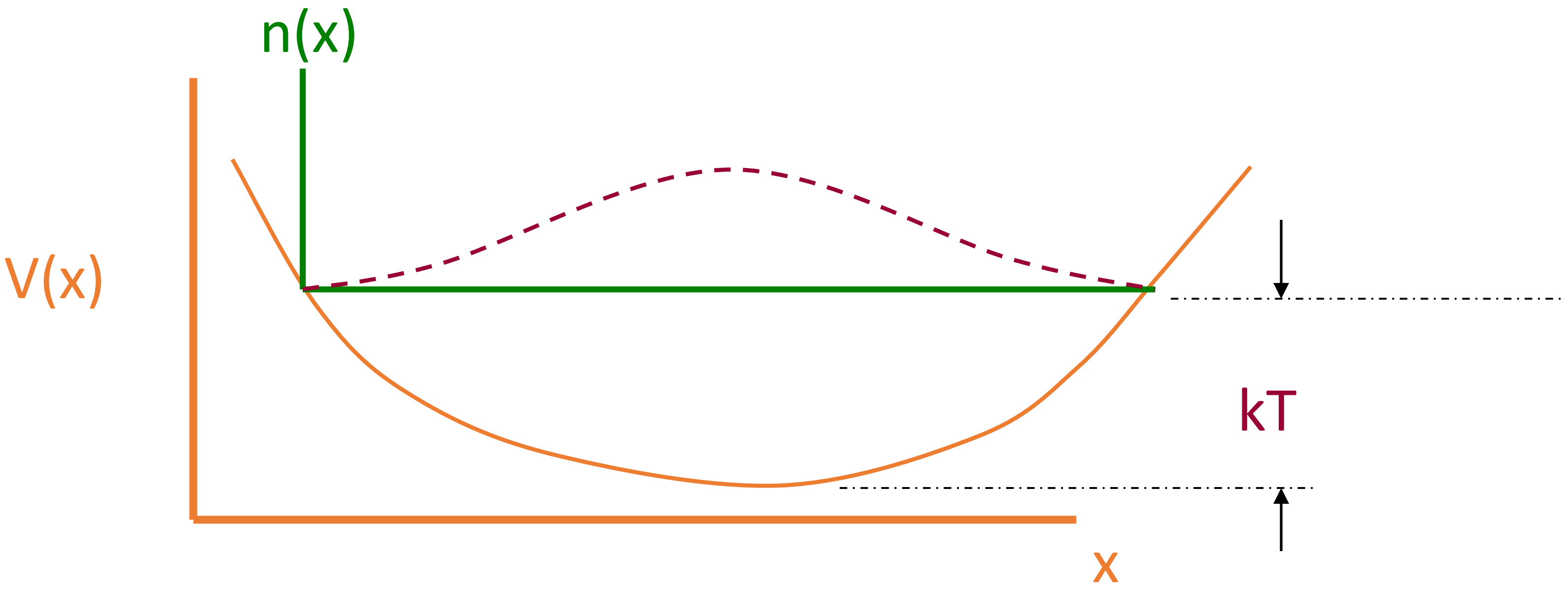
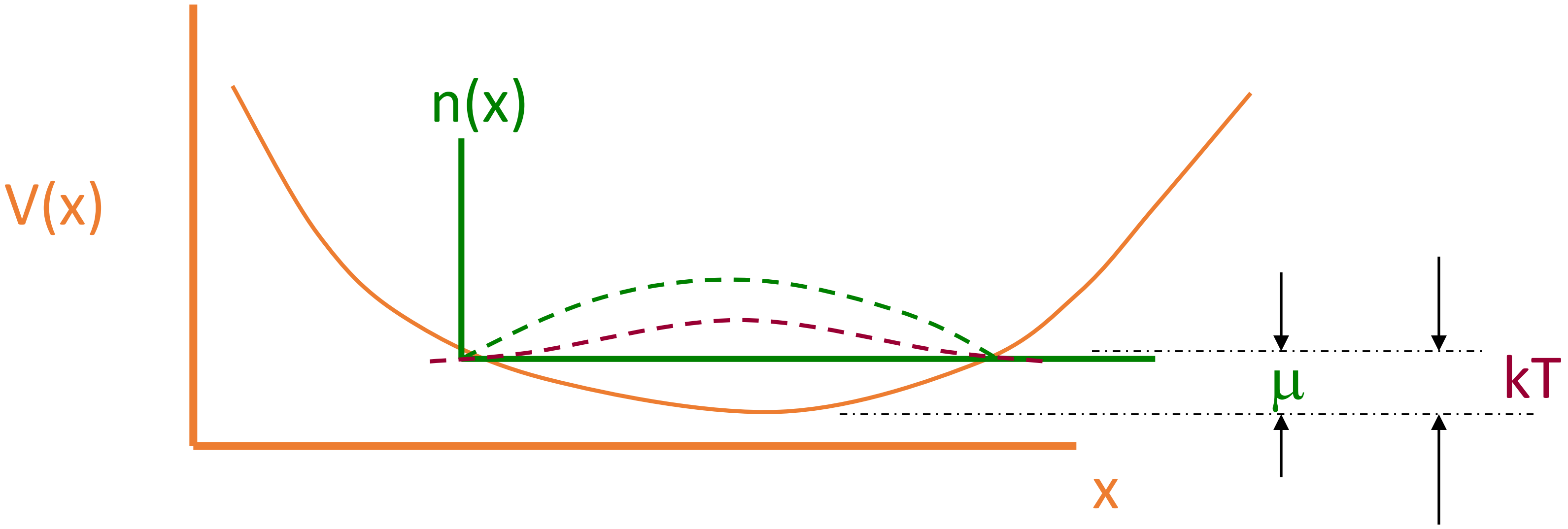


Cloud of thermal excitations
made up of atoms on trajectories
that go roughly to where the
confining potential reaches kT



When kT < μ then there are very few thermal excitations extending outside of condensate. Thus evaporation cooling power is small.

2 D velocity/density distributions