An overview on Quantum Gases (II)

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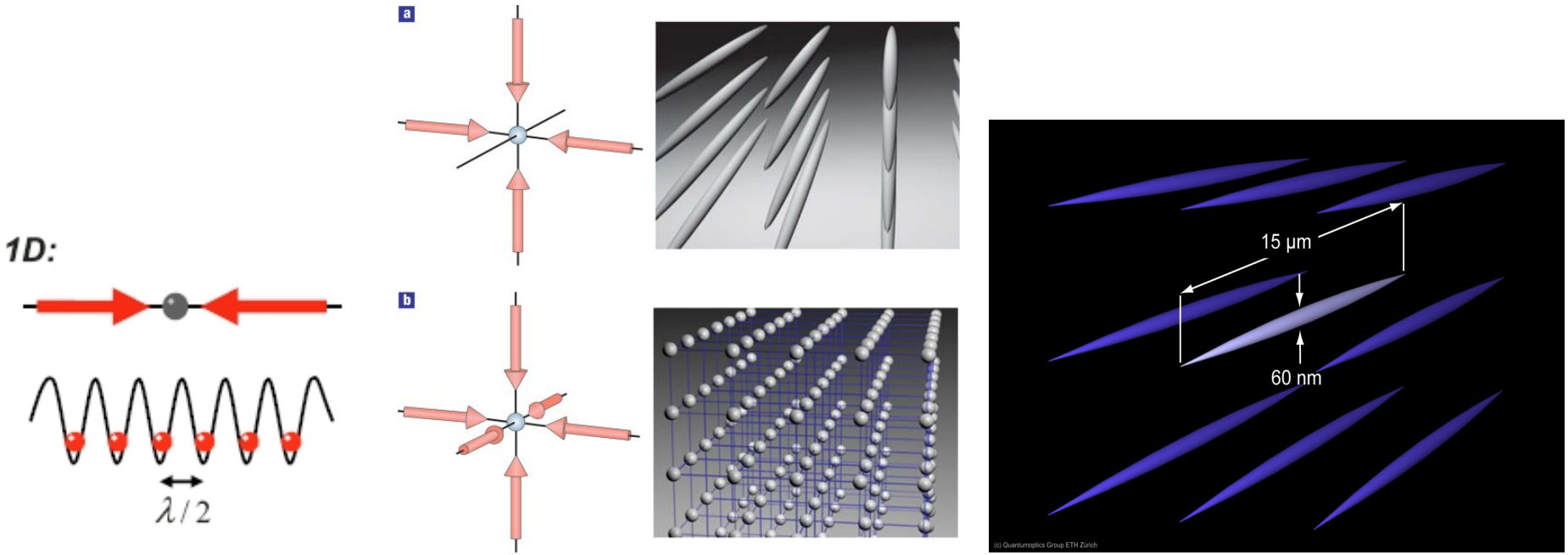
outline

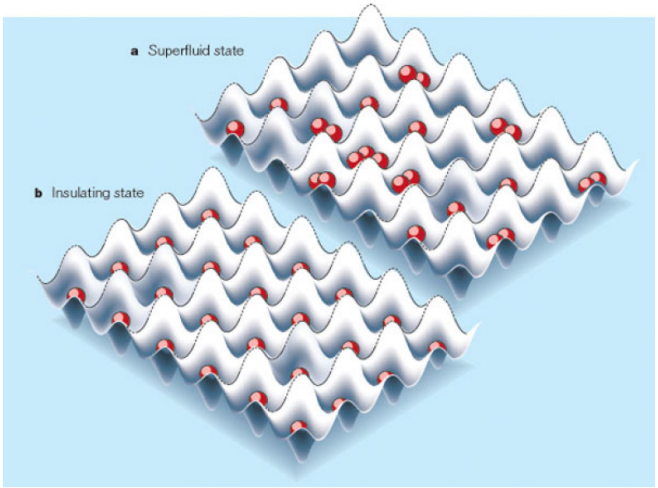
- optical lattices- artificial crystal with light and atoms!
- the breakthrow- Superfluid-Mott transition.
- Fermi gases- why intresting?
- BCS-BEC crossover- how related to high-T_c?
- Imbalanced Fermi gases- all about THE main question in condensed matter: pairing.

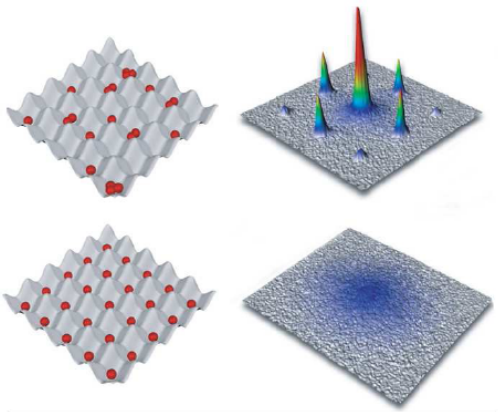
opticall lattices: artificial crystal with light and atoms!



$$V(\mathbf{r}) \propto \sin^2(kx) + \sin^2(ky) + \sin^2(kz)$$

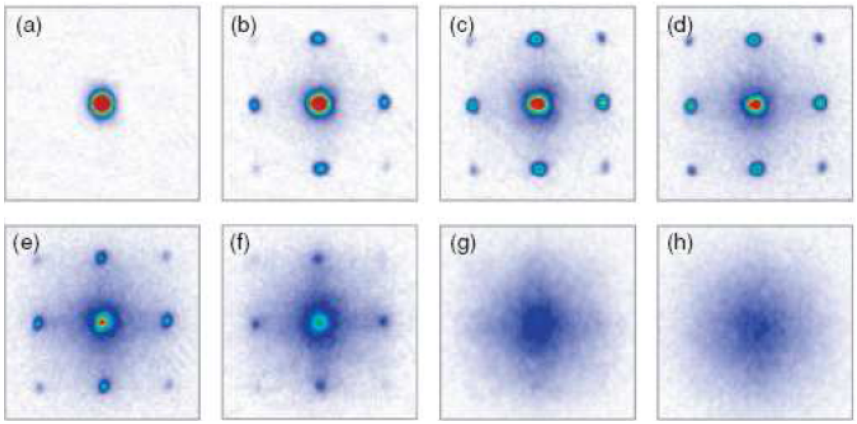
Superfluid-Mott transition





Quantum phase transition from a superfluid to a Mott insulator in a gas of ultracold atoms

Markus Greiner*, Olaf Mandel*, Tilman Esslinger†, Theodor W. Hänsch* & Immanuel Bloch*



$t_{hop} \gg U_{on-site}$ superfluid

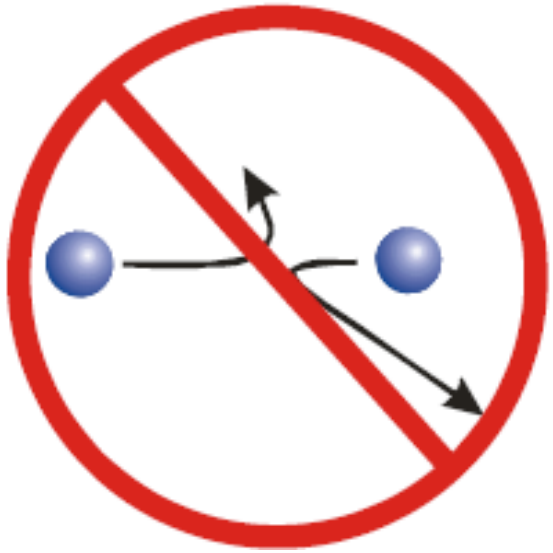
$t_{hop} \ll U_{on-site}$ Mott

Why study ultracold Fermi gases?

- lots of interesting and challenging high density Fermi system: metals,semiconductor, liquid ^{3}He, white dwarf and neutron stars
- Fermionic superfluidity: superfluidity of ^{3}He, superconductivity.
- "new" dream: high-T_c

The difficulty in cooling Fermions

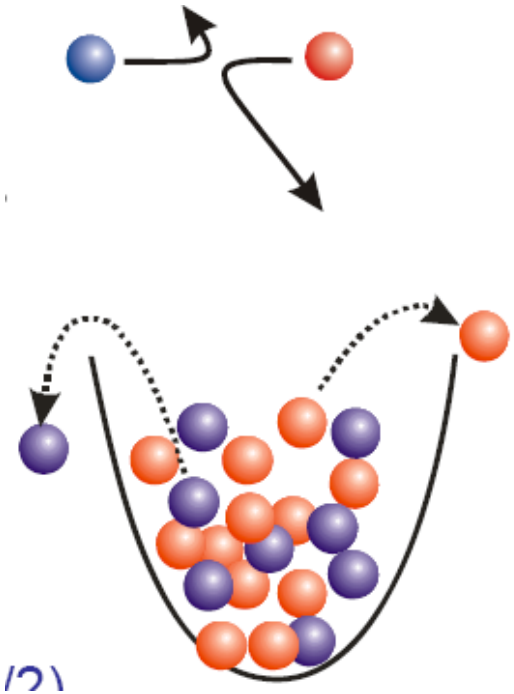
Collisions are required for cooling, but at low T spin-polarized fermions stop colliding.



Fermions are identified with **Pauli principle**. so, what to do?

A new cooling strategy

Simultaneous cooling: evaporate atoms in two spin-states



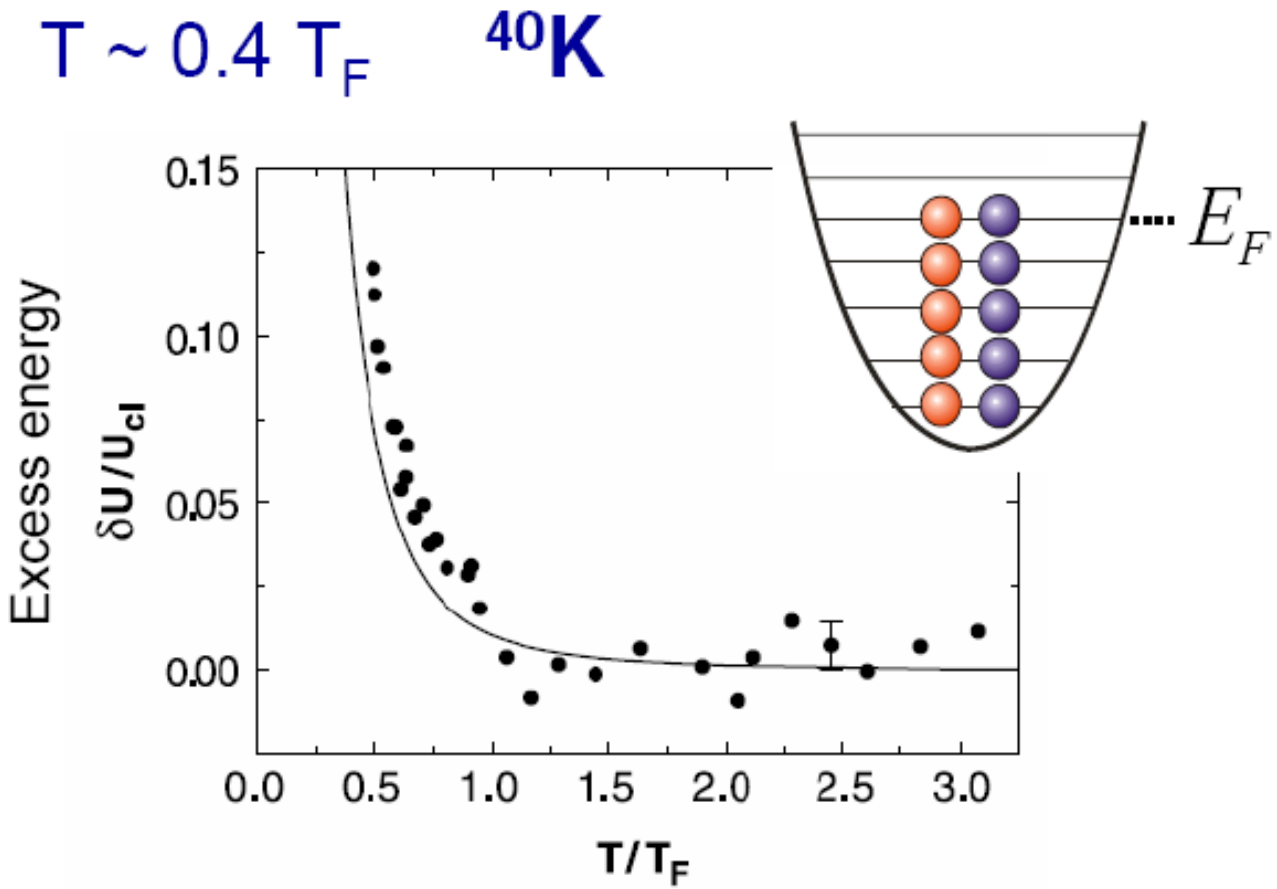
Onset of Fermi Degeneracy in a Trapped Atomic Gas

B. DeMarco and D. S. Jin*†

Science **285**,1703 (1999)

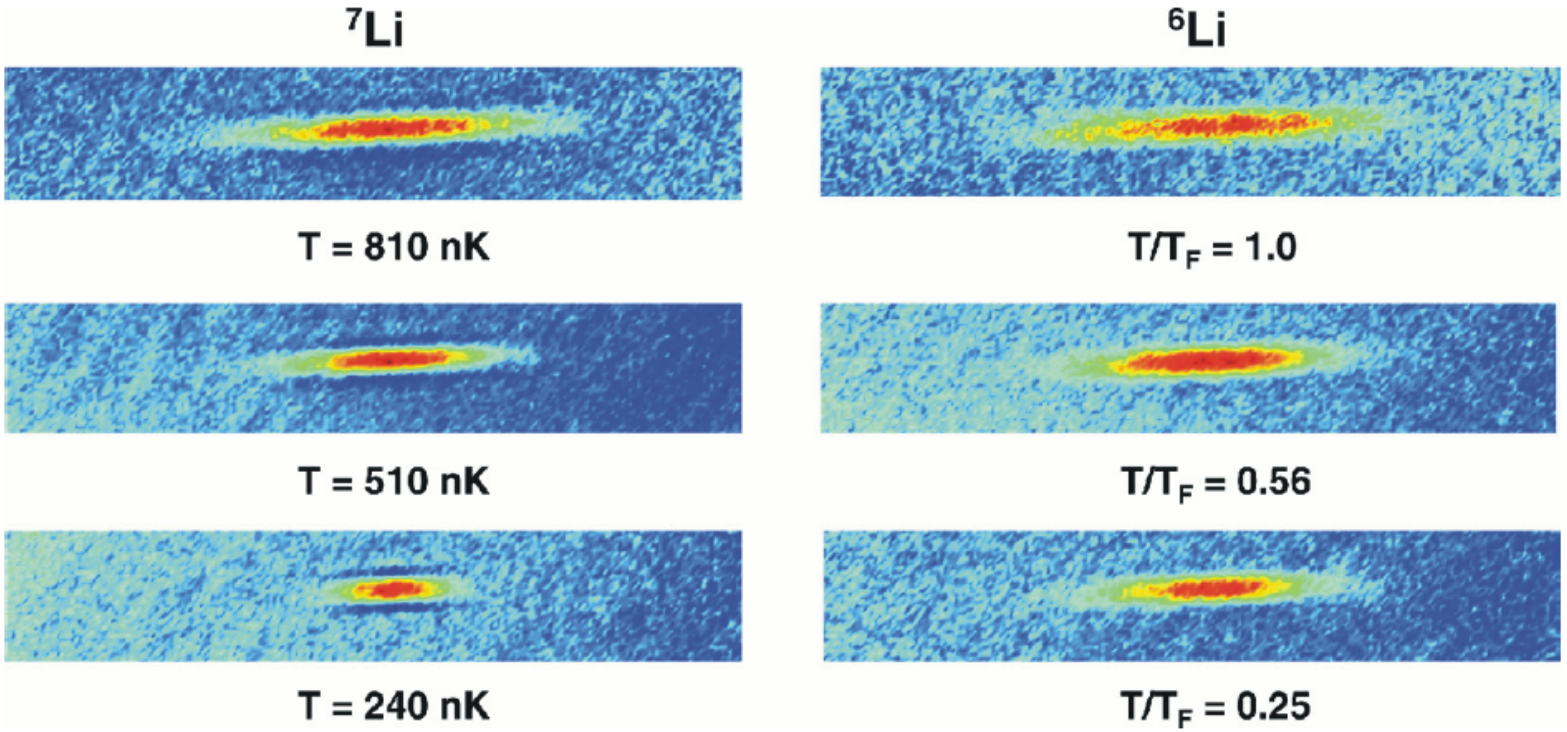
The first 'cool' fermion was ^{40}K.

what to probe?



B. DeMarco and D.S. Jin, Science **285**, 1703 (1999)

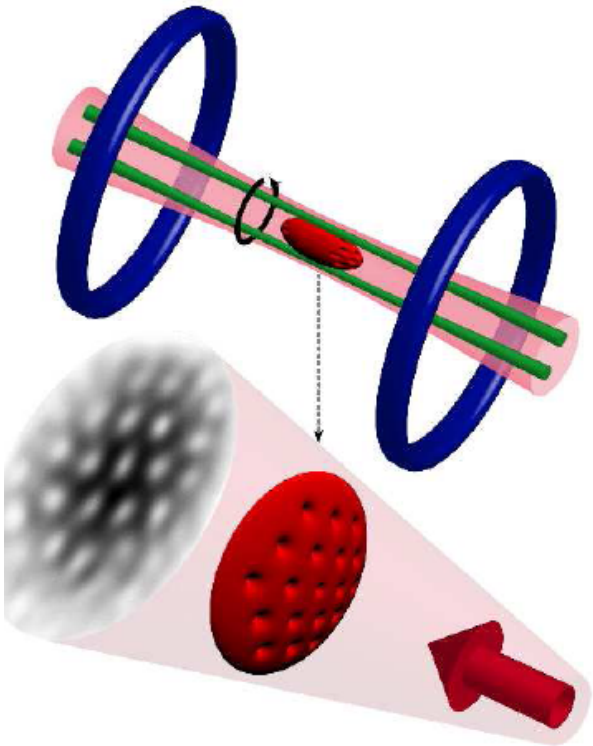
clear fingerprint of quantum statistic: Fermi pressure



A.G. Truscott *et al.*, Science **291**, 2570 (2001)

This is purely quantum many-body effect.

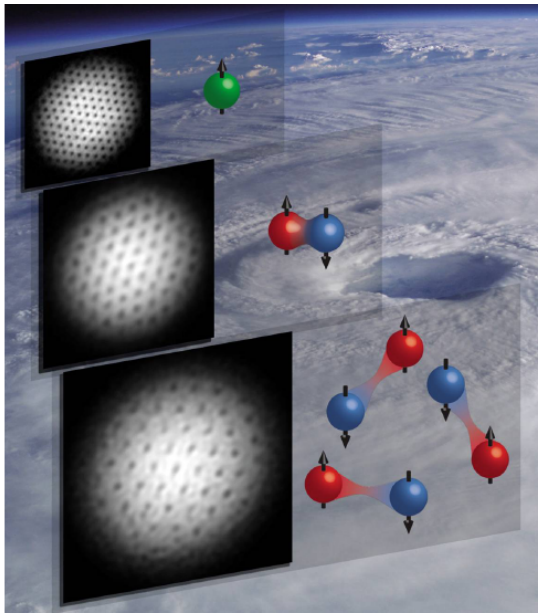
fermionic superfluidity

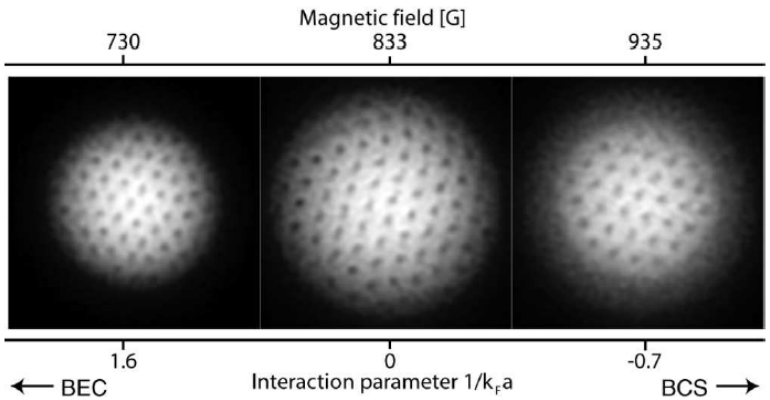


Atomic Bose-Einstein condensate (sodium)

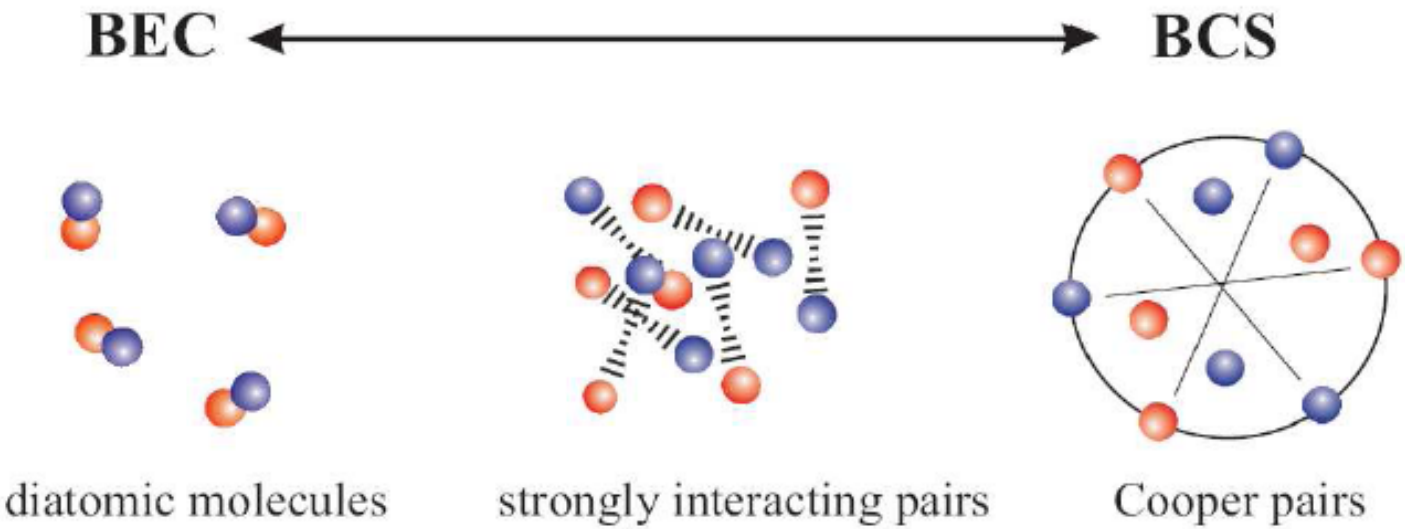
Molecular Bose-Einstein condensate (lithium $^6Li_2$)

Pairs of fermionic atoms (lithium-6)





BEC-BCS crossover



The size of the [cuprate] pairs pairs (from 10-30 angstrom) puts us in the intermediate regime of the so-called BEC to BCS crossover.

Legget, **What do we Know about high-T_c?**, Nature Phys. March 2006

Fermi systems with imbalanced spin population

Breakdown of superconductivity in a magnetic field:

The standard BCS phase could, at most, resist to a magnetic field:

$$\mu_B H \approx \Delta \qquad\qquad Pauli\ \ limit$$

Clogstone PRL,**9**, 266 (1962)

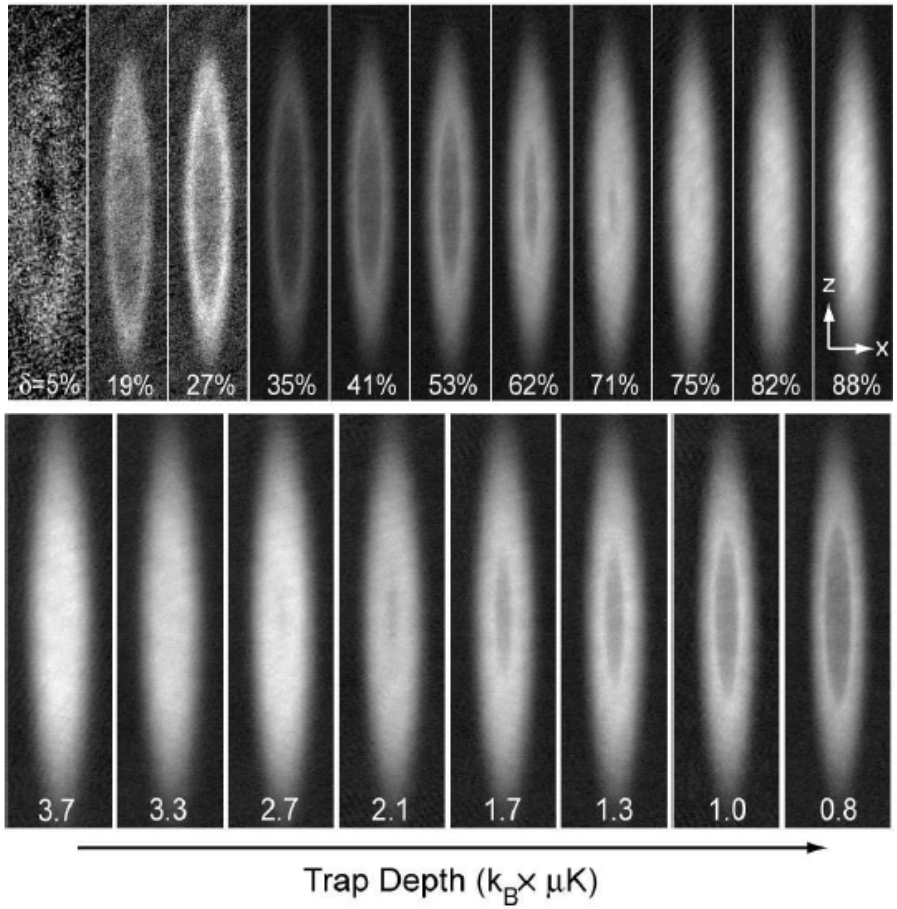
non-BCS pairing

- FFLO (Fulde-Ferrel-Larkin-Ovchinikov) state: non-uniform order parameter

$$\Delta(\mathbf{r}) = \Delta_0 e^{i\,2\mathbf{q}.\mathbf{r}}$$

- observation in superconductors is under debate:
  - H.A. Radovan *et.al*, Nature **425**, 51 (2003).
  - A. Bianchi *et.al*, PRL **91**, 187004 (2003).
  - K. Kakuyanagi *et.al*, PRL **44**, 047602 (2005).

Experimental realization of Imbalanced Fermi gases



M.W. Zwierlein *et.al*, Science **311**, 492 (2006)
M.W. Zwierlein *et.al*, Nature **442**, 54 (2006)
Y. Shin *et.al*, PRL **97**,030401 (2006).