BCS-BEC Crossover in Cold Atoms

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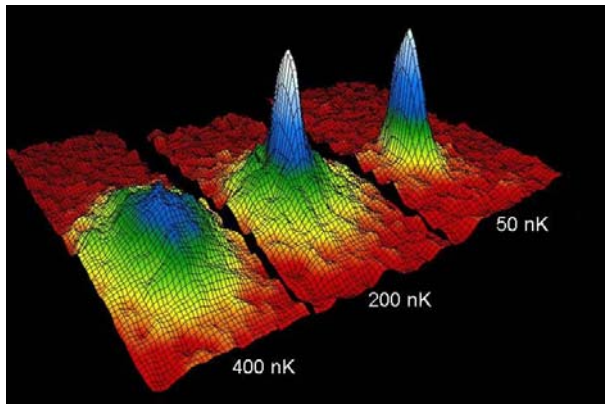
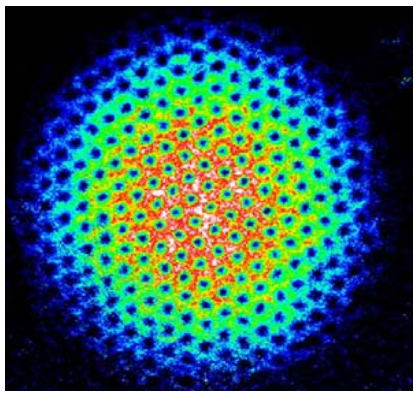
$ NSF, NASA, NIST

Motivation: Why study atomic gases?

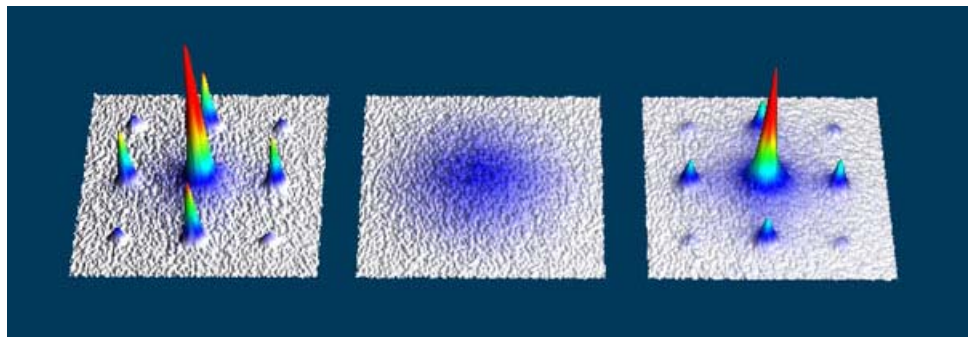
Investigate many-body quantum physics with a model system

BEC



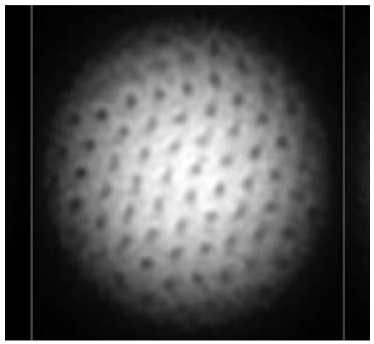


Rapidly rotating BECs



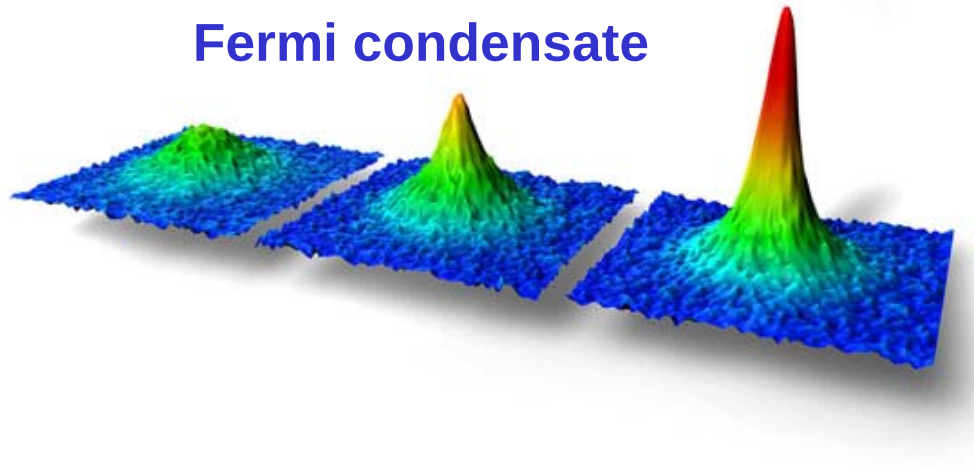
Mott insulator

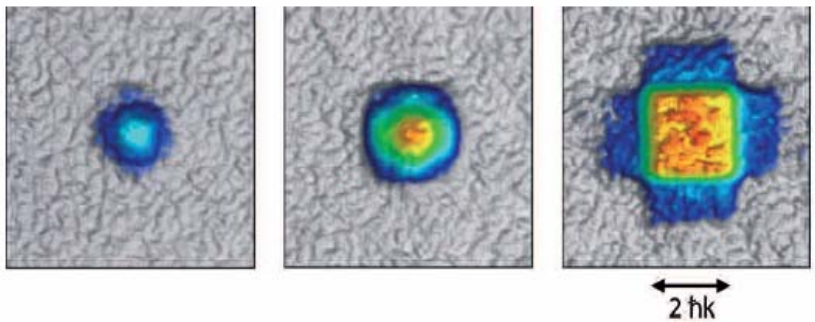
Fermi superfluidity



Vortices

Fermi condensate





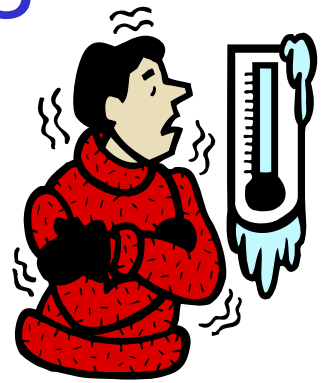
Fermi gas in an optical lattice

Challenges

1. Create an ultracold Fermi gas
2. Realize and detect Cooper pairing

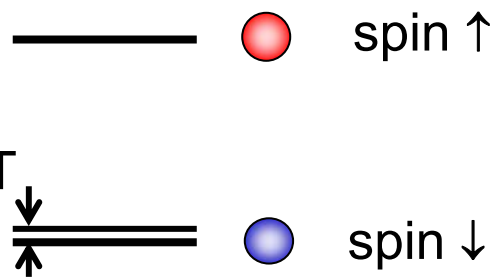
Creating an ultracold Fermi gas

Ultracold (100 nK!) gas challenges:



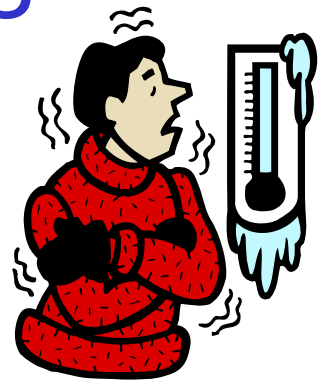
1. True ground state is a solid.

2. Spin degree of freedom is frozen out.



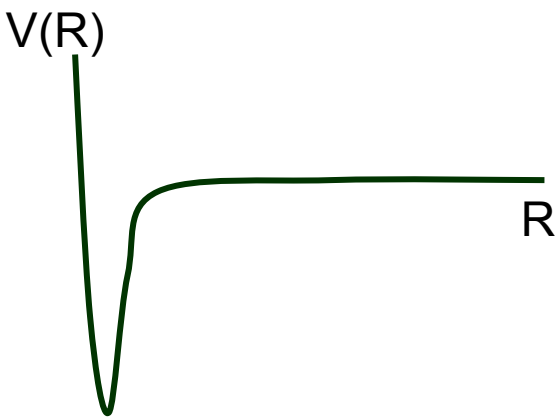
3. Collisions/interactions are only s-wave.

Creating an ultracold Fermi gas

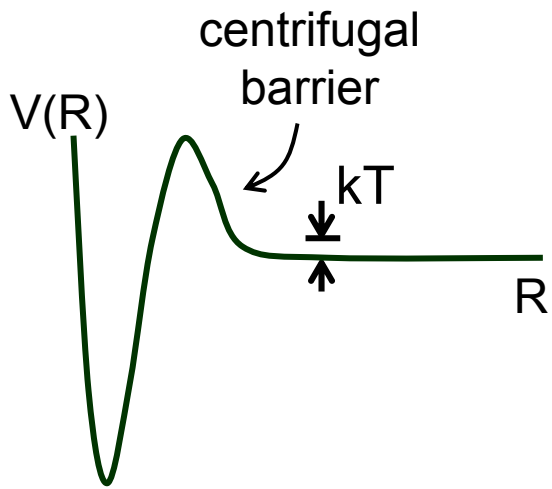


Collisions/interactions are only s-wave.

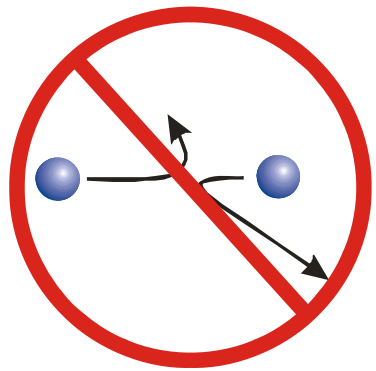
s-wave



non-s-wave



Spin-polarized fermions stop colliding.

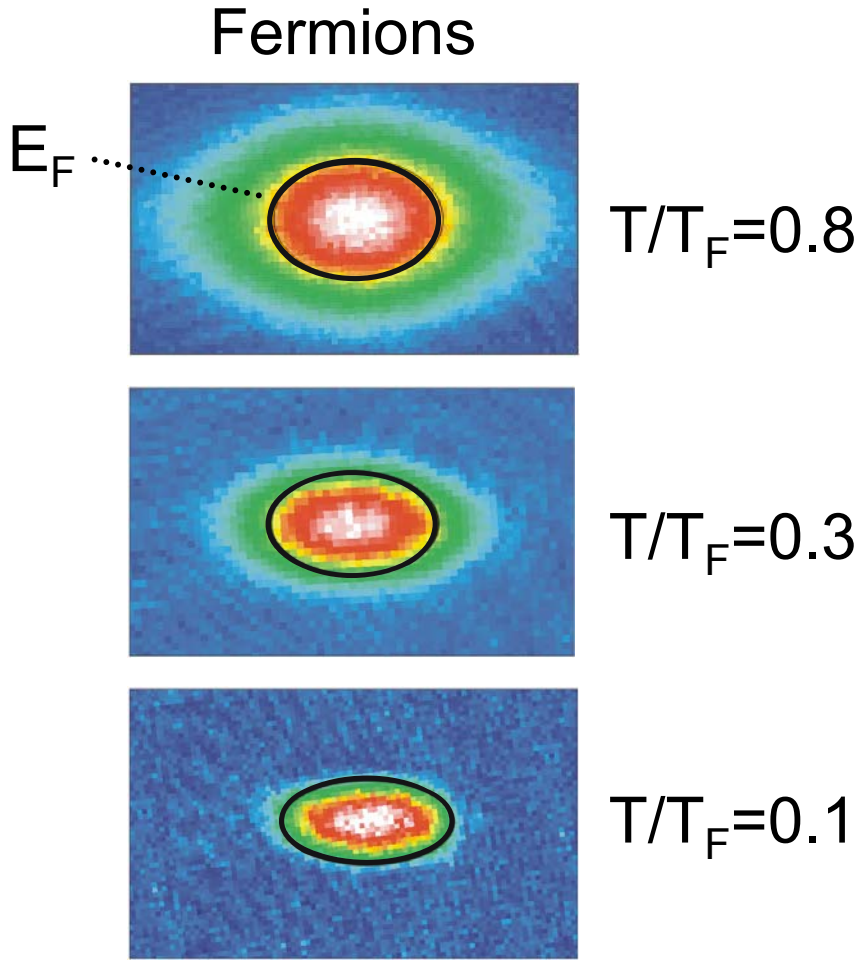


Creating an ultracold Fermi gas

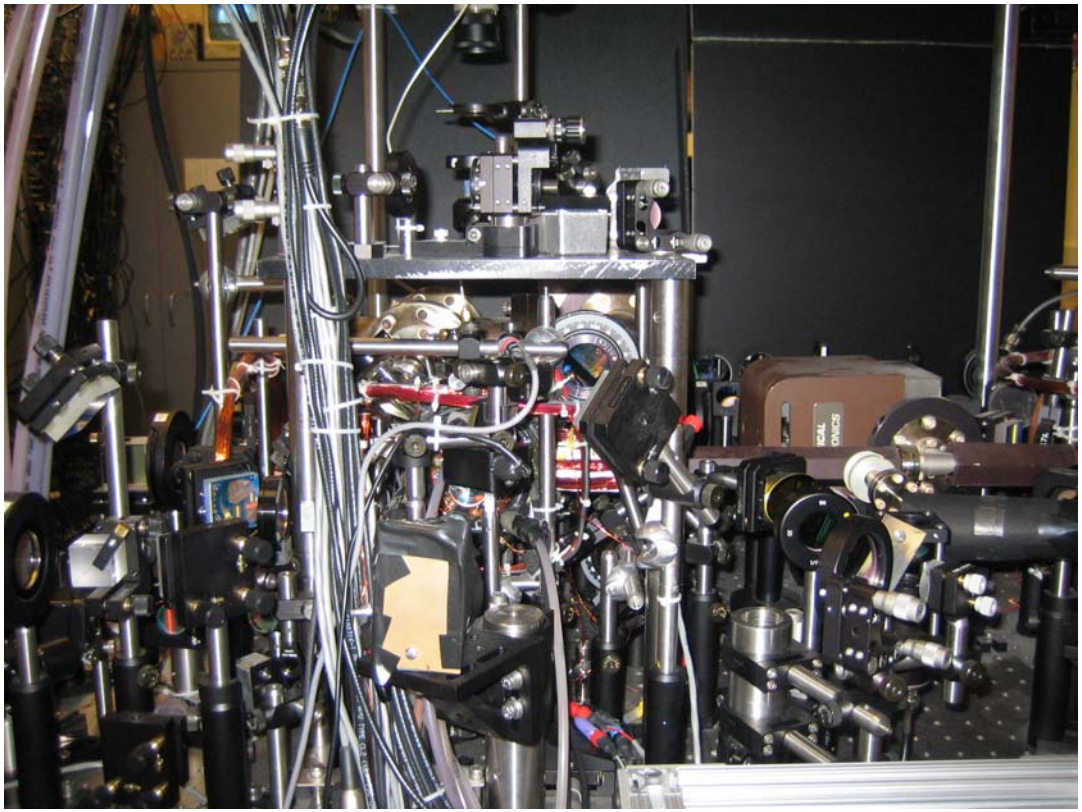
Use a stable mixture of two spin-states.

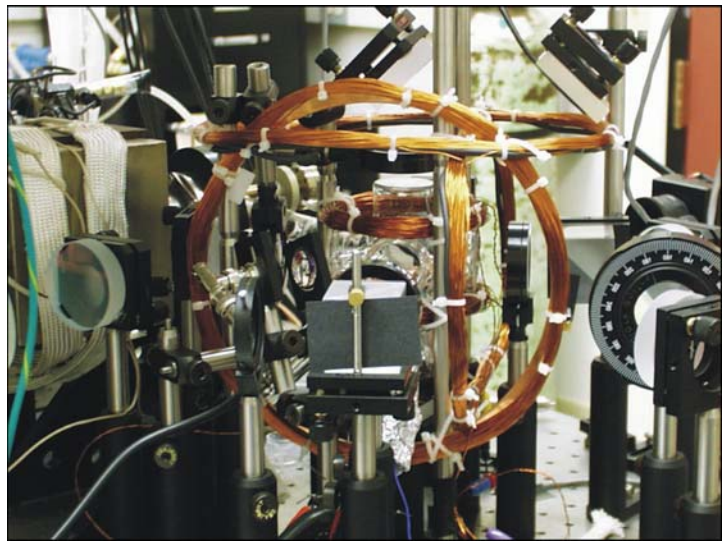
^{40}K

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



Apparatus





Cooper pairing of atoms

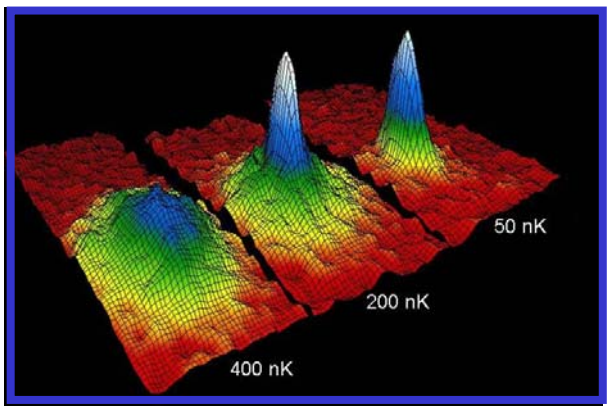
Cooper pairing challenges:

1. T/T_F is not that low.

2. ^{40}K atoms have weak, repulsive interactions.

3. Detecting the phase transition is not so easy.

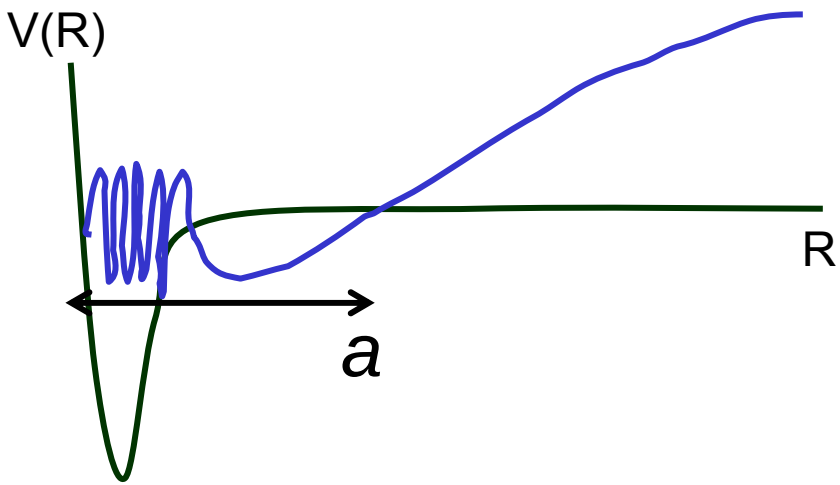
BEC



BCS?

Interactions

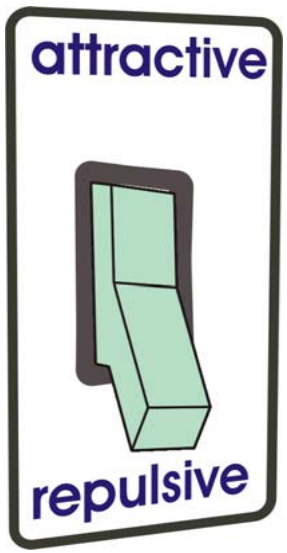
s-wave scattering length, a

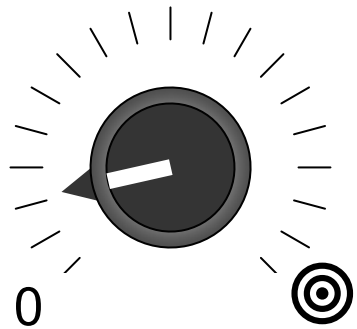


$a > 0$ repulsive, $a < 0$ attractive
Large $|a| \rightarrow$ strong interactions

Controlling interactions

$a > 0$ repulsive, $a < 0$ attractive
Large $|a| \rightarrow$ strong interactions



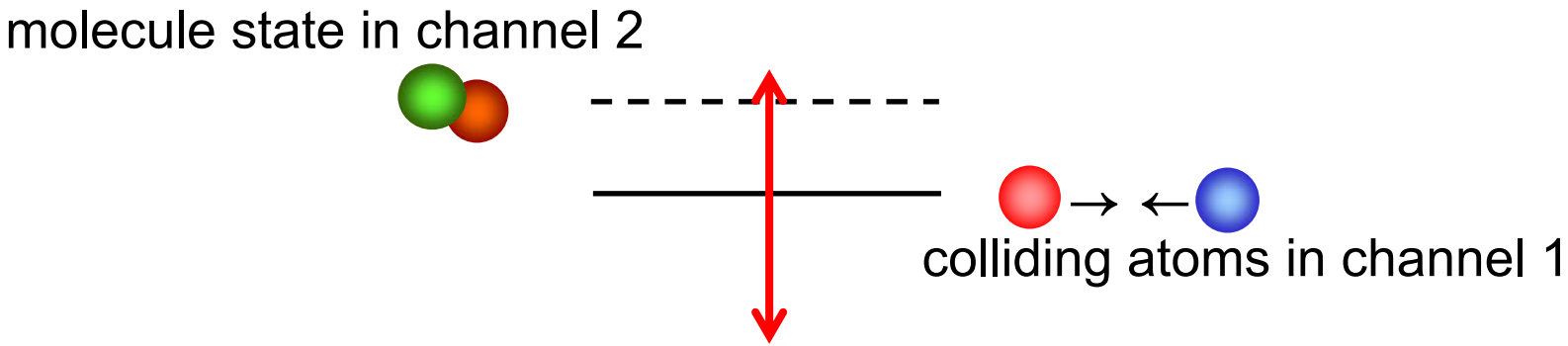


scattering length, a

^{40}K

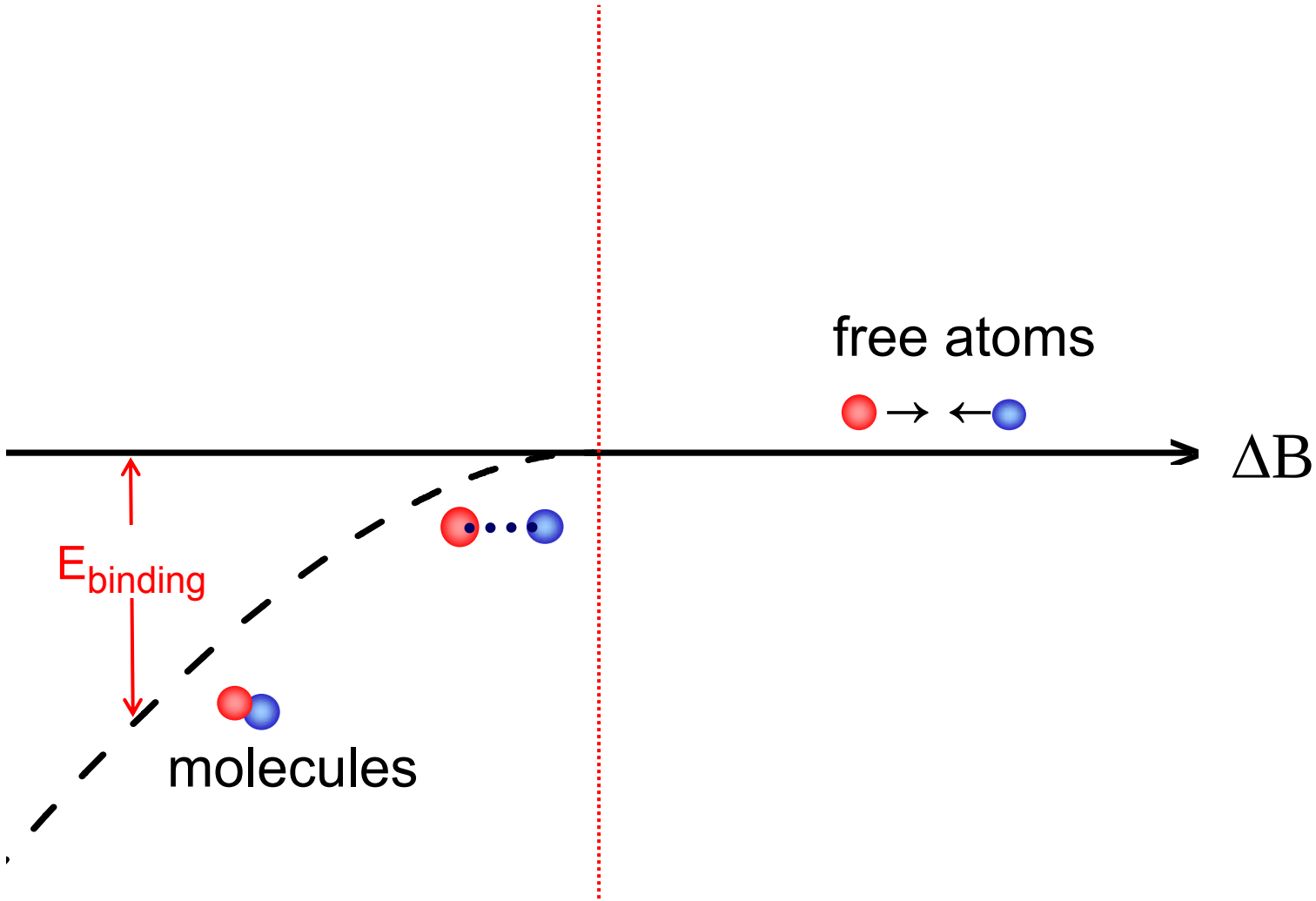
Magnetic-field Feshbach resonance

A magnetic-field tunable atomic scattering resonance

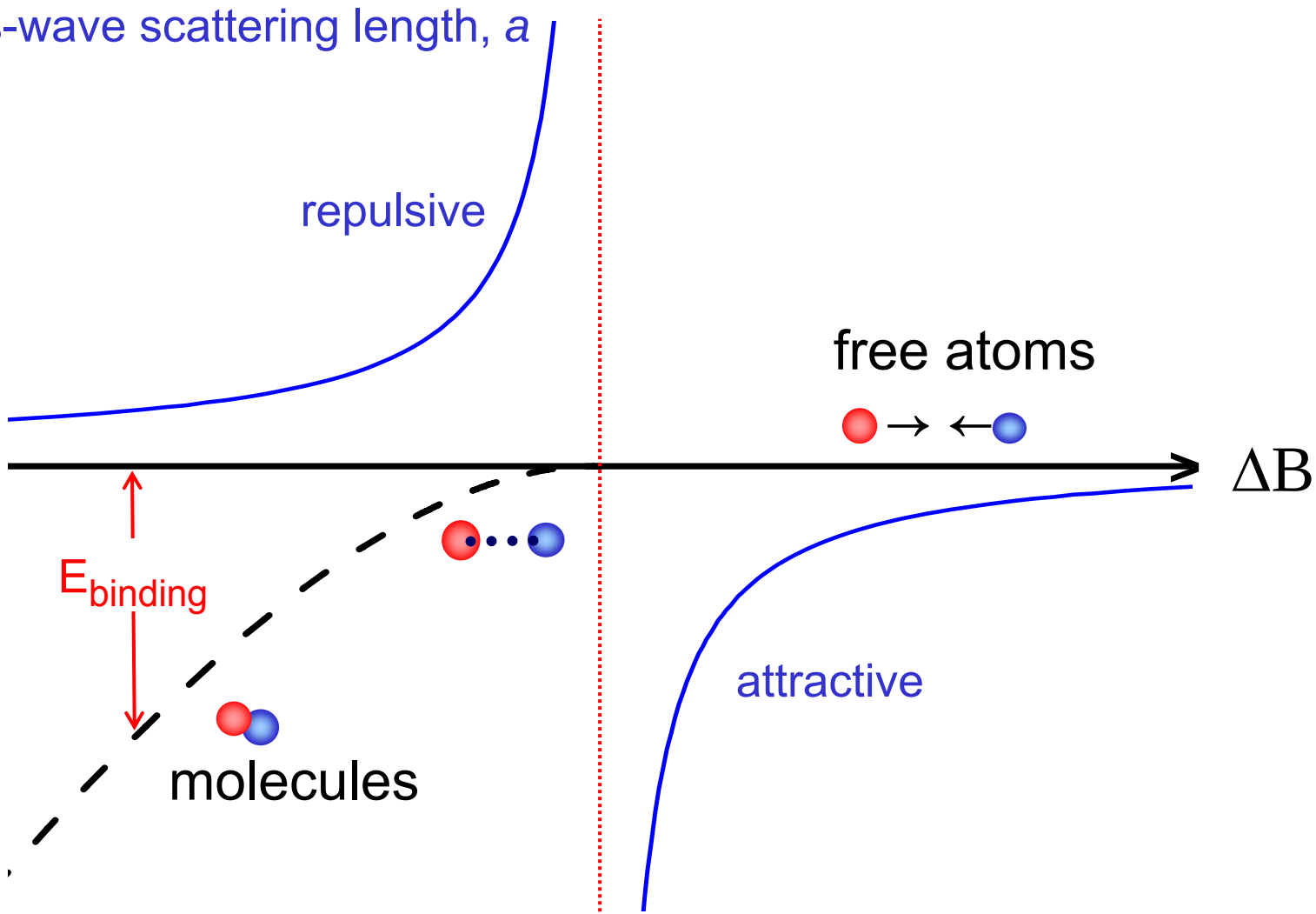


Channels are coupled by the hyperfine interaction.

Magnetic-field Feshbach resonance

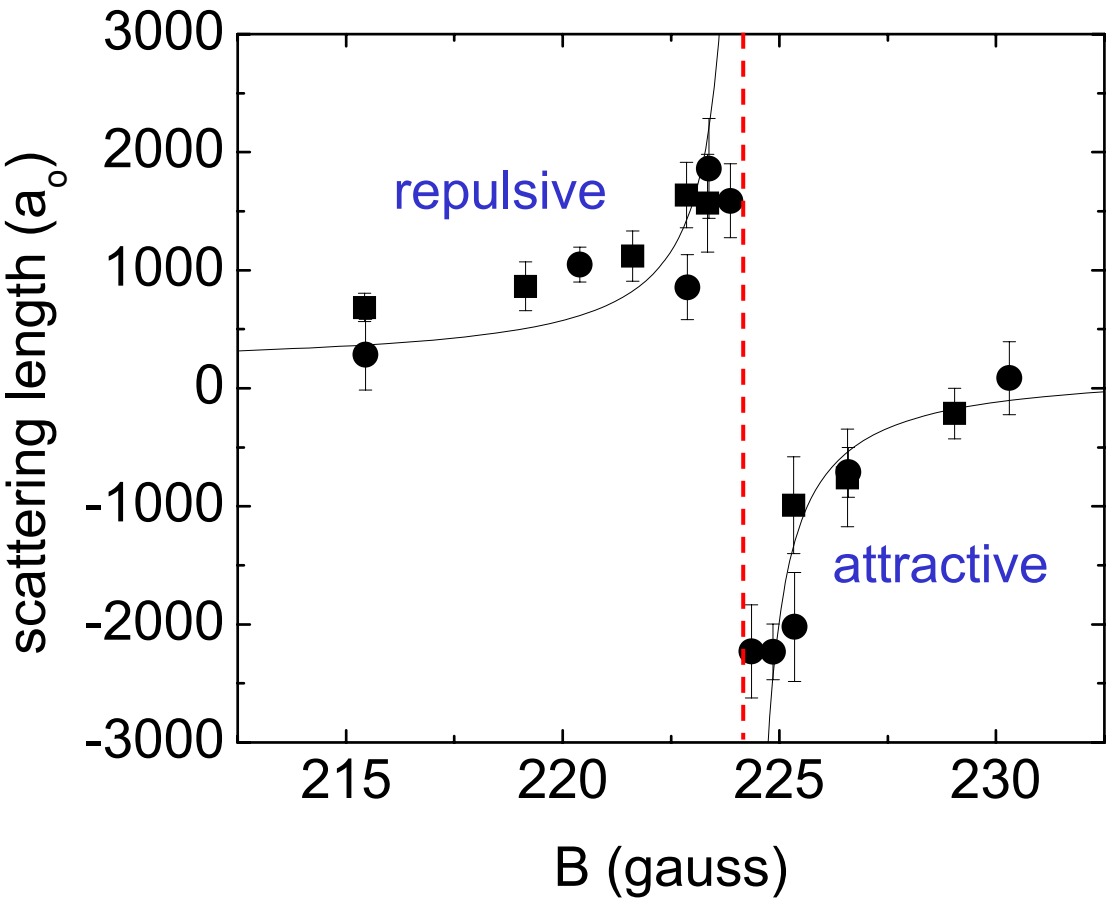


Magnetic-field Feshbach resonance



Magnetic-field Feshbach resonance

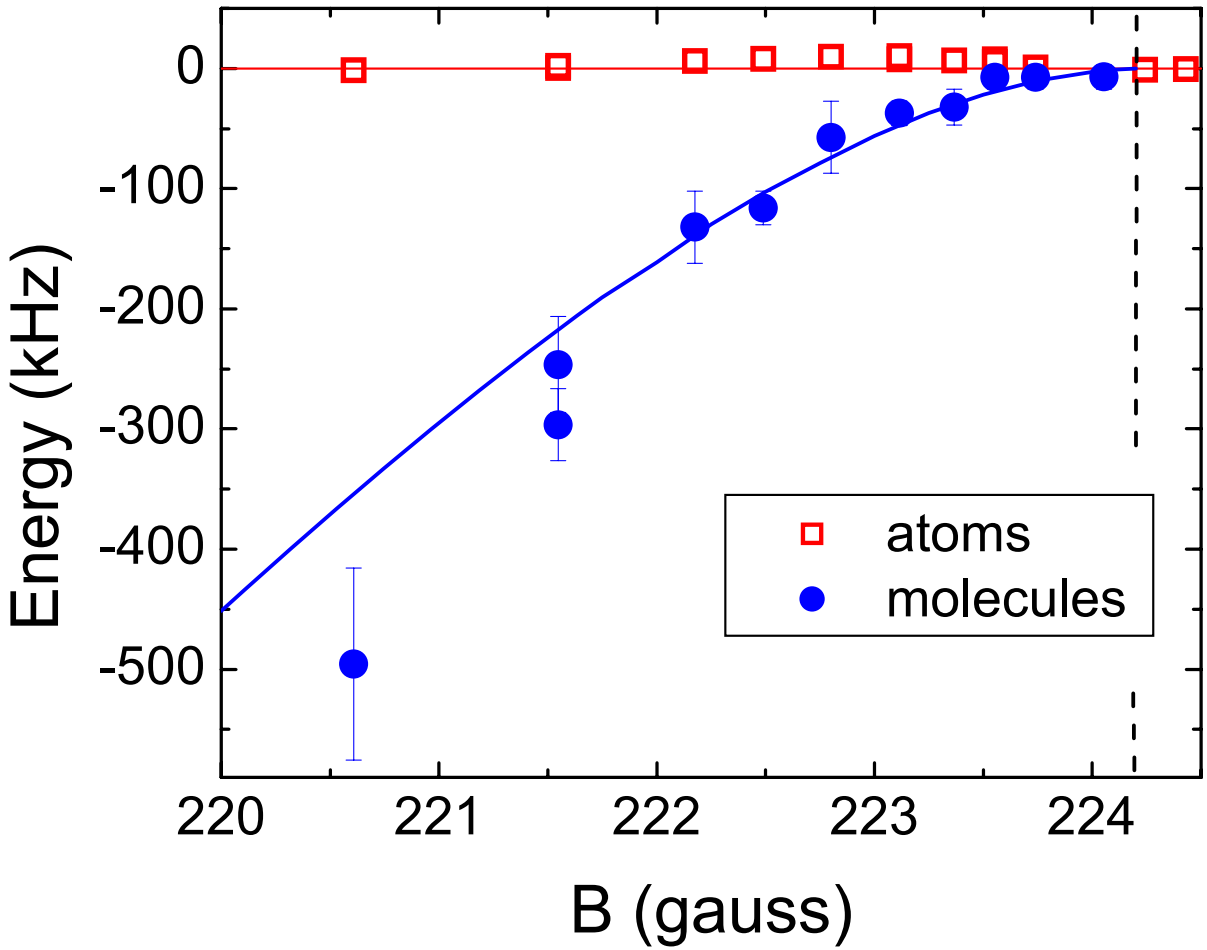
- spectroscopic measurement of the mean-field energy shift



C. A. Regal and D. S. Jin, PRL **90**, 230404 (2003)

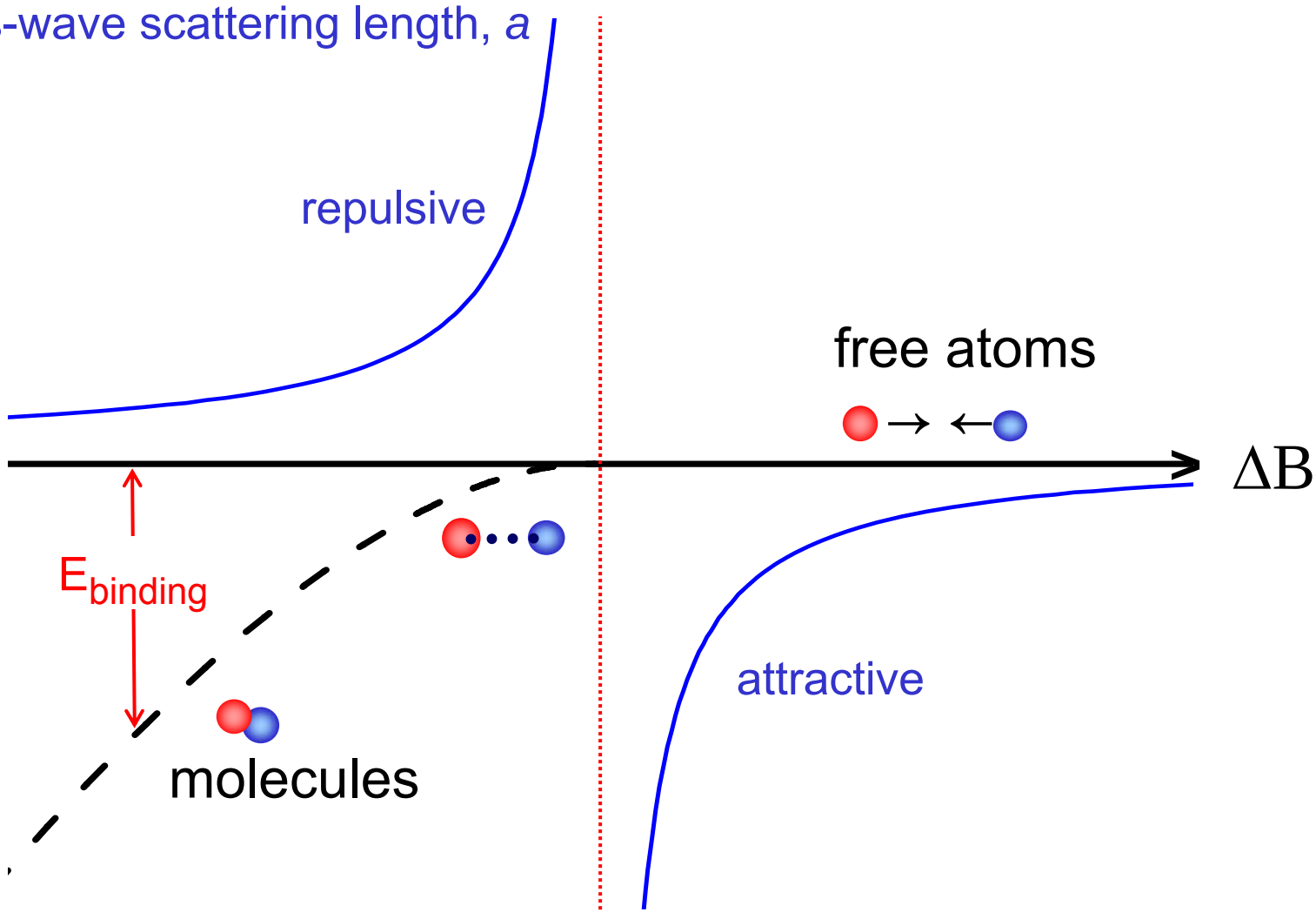
Molecules!

Measured using rf photodissociation

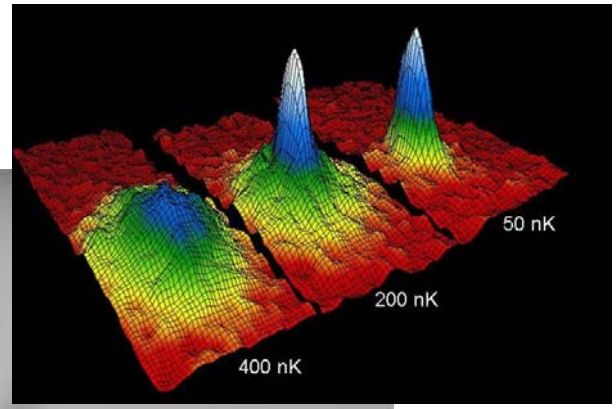


C. Regal *et al.*, Nature **424**, 47 (2003)

Magnetic-field Feshbach resonance

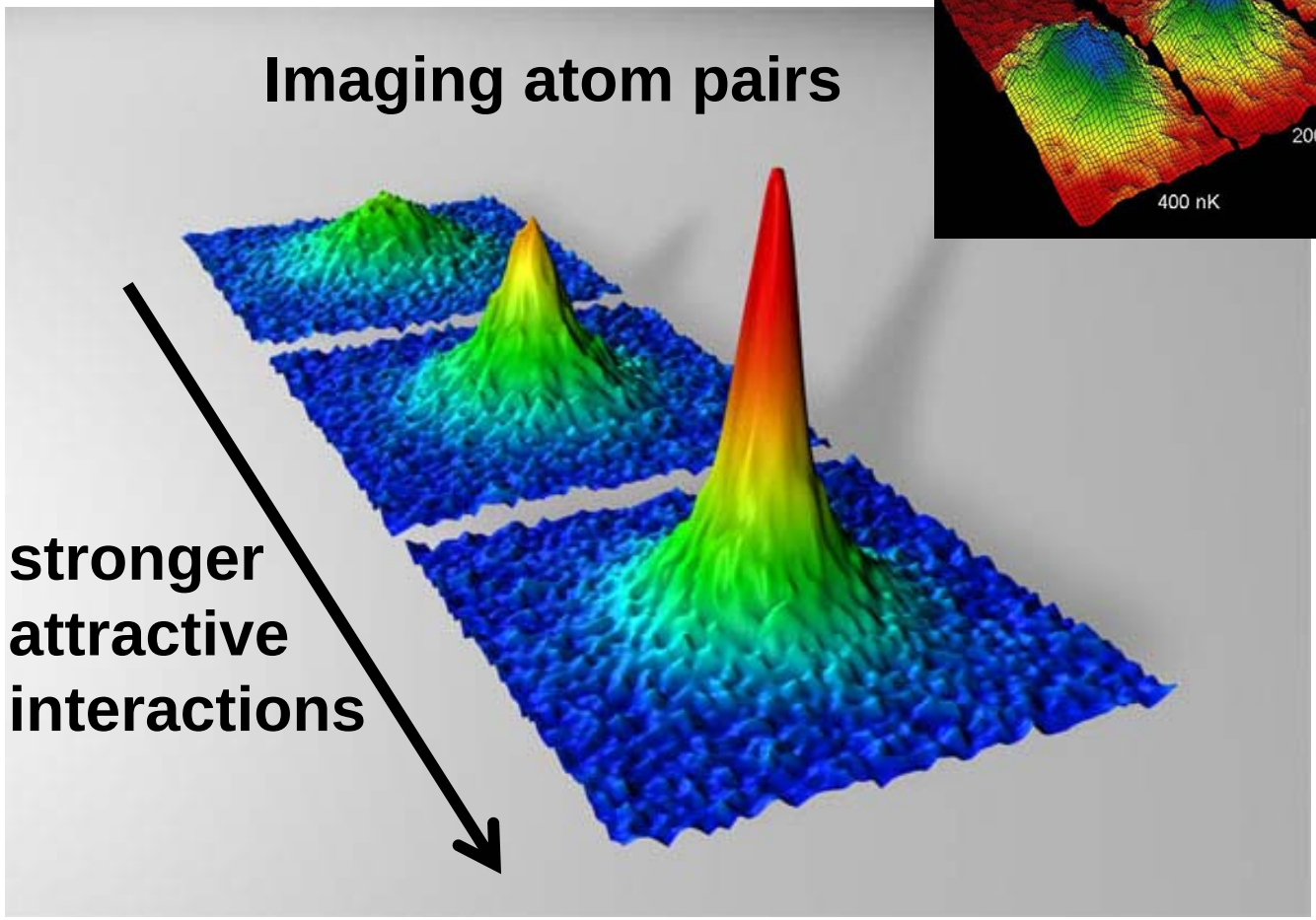


Bose-Einstein Condensate



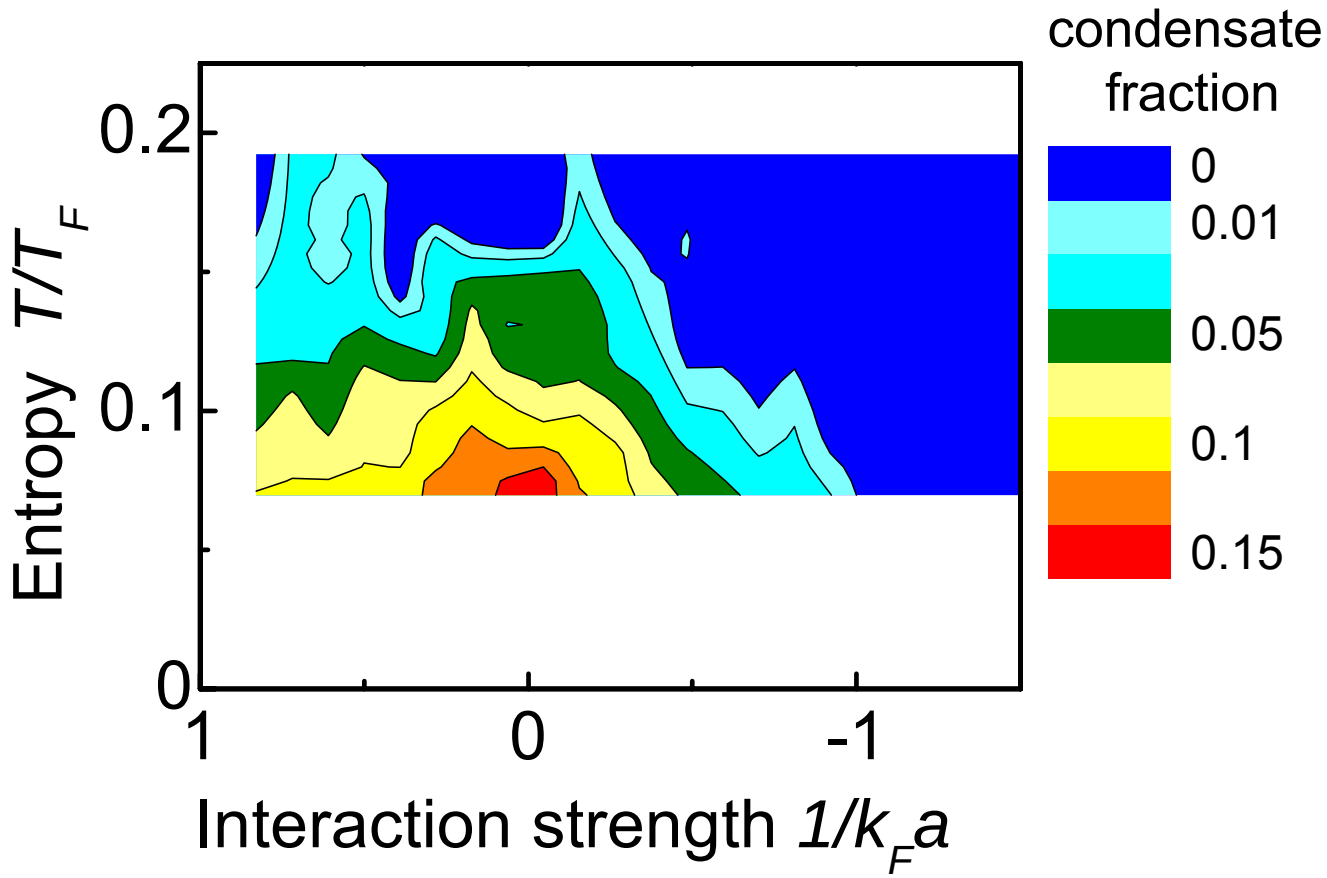
Fermi Condensate

2004



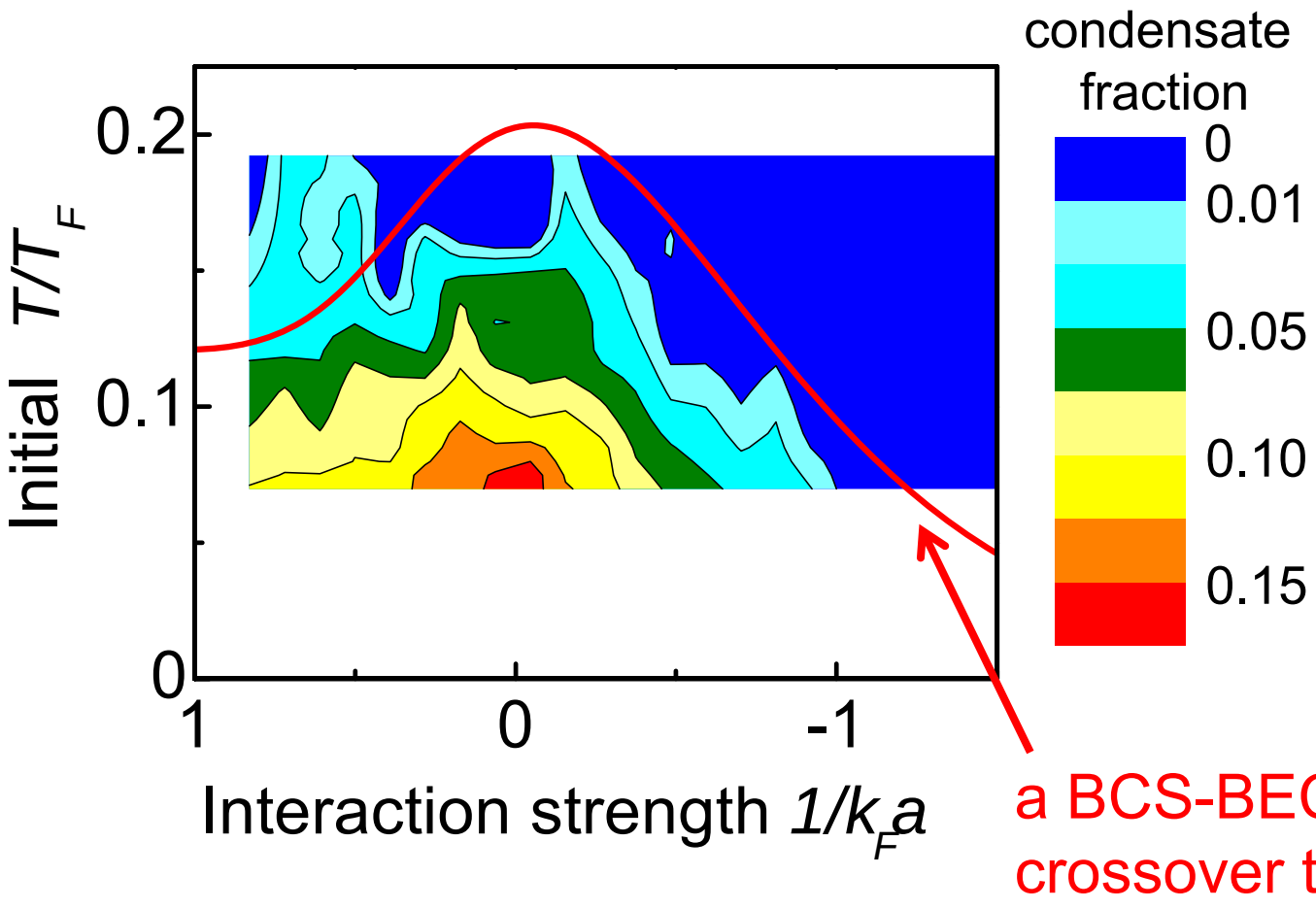
C. A. Regal, M. Greiner, and D. S. Jin, PRL 92, 040403 (2004)

BCS-BEC Crossover



C.A. Regal, M. Greiner, and D. S. Jin, PRL **92**, 040403 (2004)

BCS-BEC Crossover



C.A. Regal, M. Greiner, and D. S. Jin, PRL **92**, 040403 (2004)

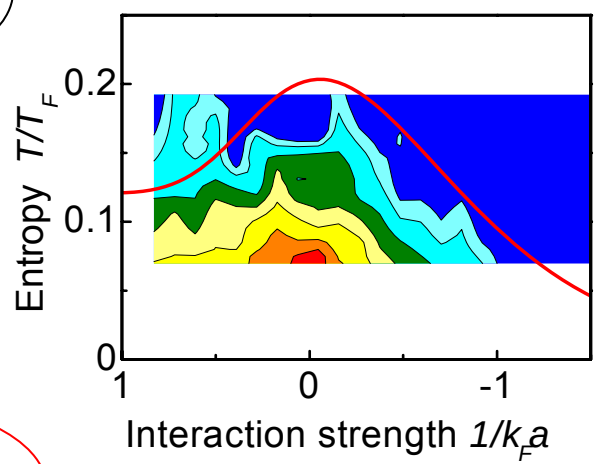
Q. Chen, C.A. Regal, M. Greiner, D.S. Jin & K. Levin, PRA **73**, 041601 (2006).

Probing the BCS-BEC crossover

Condensate fraction

Collective excitations

Unbalanced spin population



Vortices

Unitarity and Universality

Probes of pairing

Thermodynamic measurements

Correlations in atom shot noise

People

Brian DeMarco

Cindy Regal

Markus Greiner