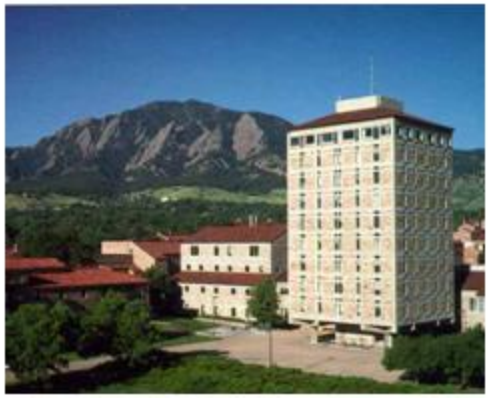
Making condensates with a Fermi gas of atoms

D. Jin

JILA, NIST and the University of Colorado



I. Introduction/ Motivation

II. Making ultracold molecules

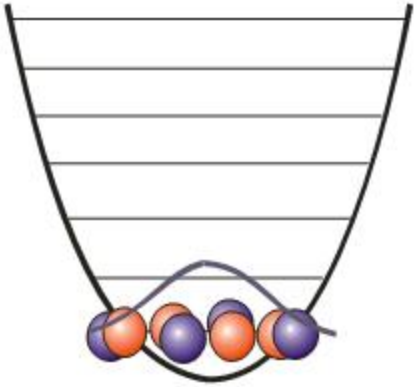
III. Molecular BEC

IV. Fermionic condensates

$$ NSF, NIST, Hertz

How do you get a condensate with fermions?

1. BEC of composite bosons
    1. Bind fermions together.
    2. BEC

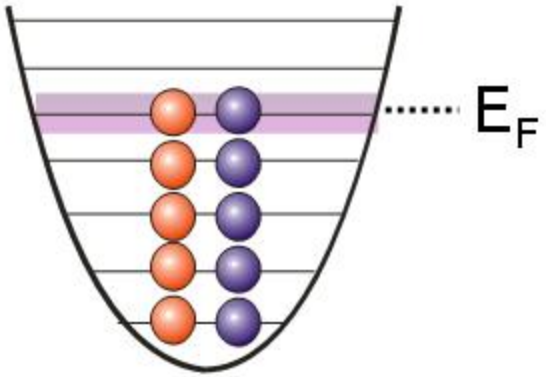


2. Superconductivity

    Also, superfluidity of liquid ^{3}He

    BCS theory: Cooper pairs

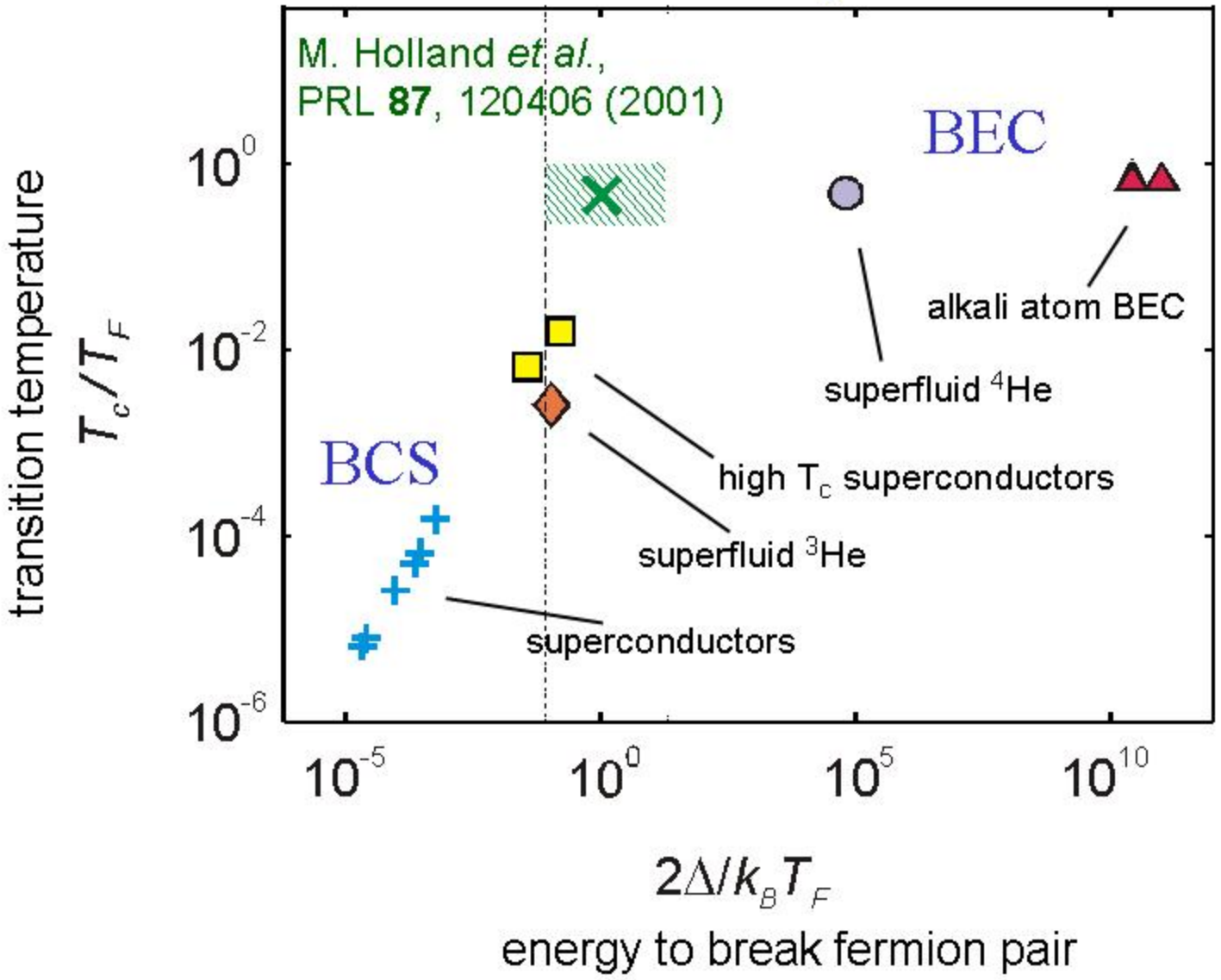
    quantum degenerate Fermi gas,
    weak attractive interactions



3. Something in between?

    Cooper pairs with stronger attraction, higher Tc

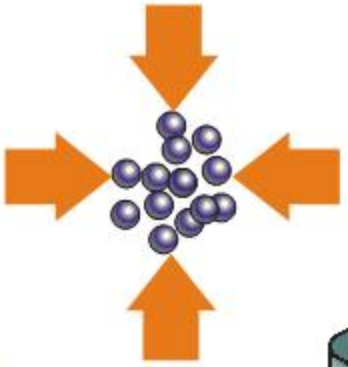
BCS-BEC landscape



Cooling a gas of ^{40}K atoms

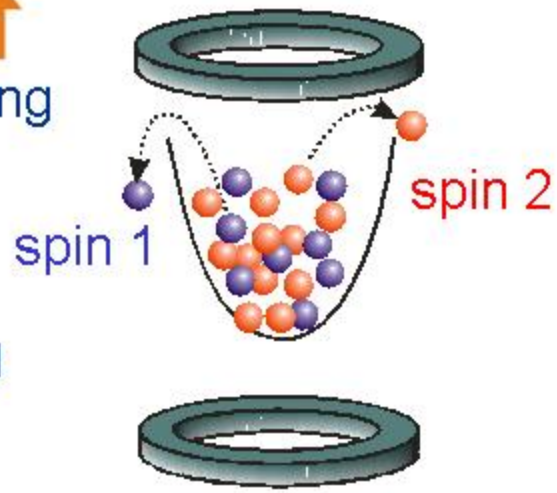
1. Laser cooling and trapping

   300 K to 1 mK, ~10^9 atoms



2. Magnetic trapping & evaporative cooling

   1 mK to 1 μK, ~10^8 . 10^6 atoms



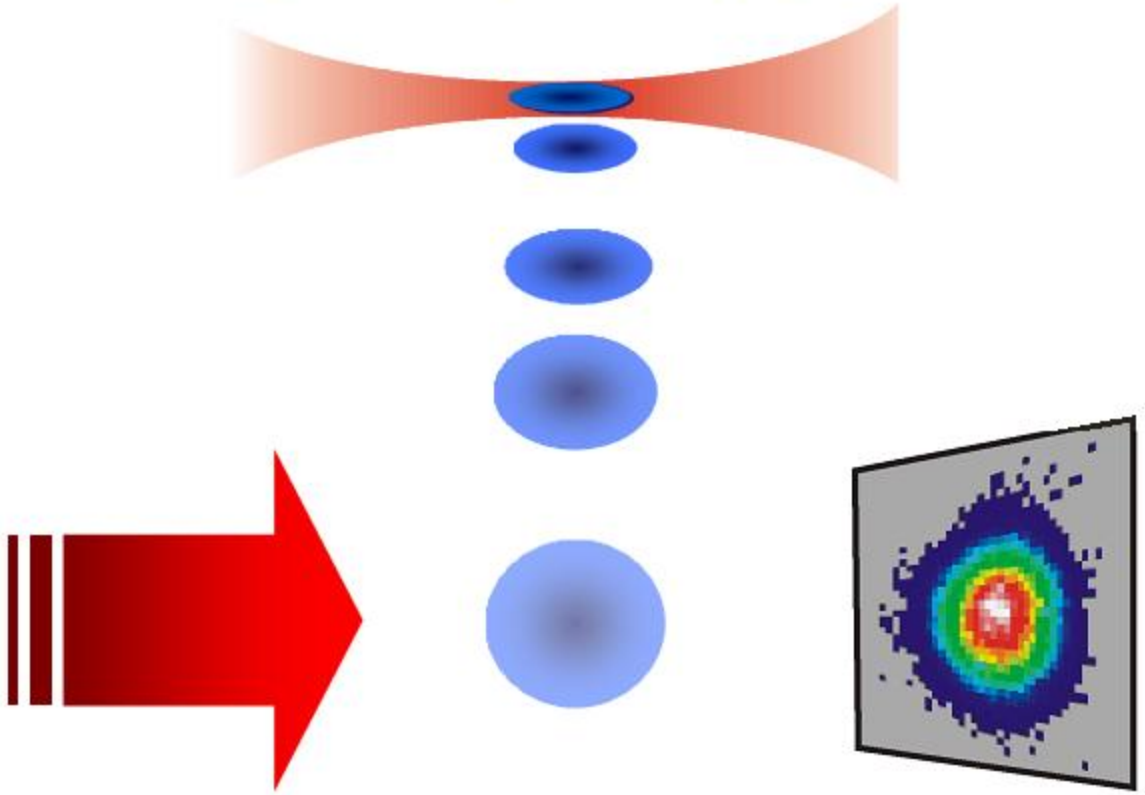
3. Optical trapping & evaporative cooling

   1 μK to 50 nK, 10^6 . 10^5 atoms

- can confine any spin-state
- can apply arbitrary B-field

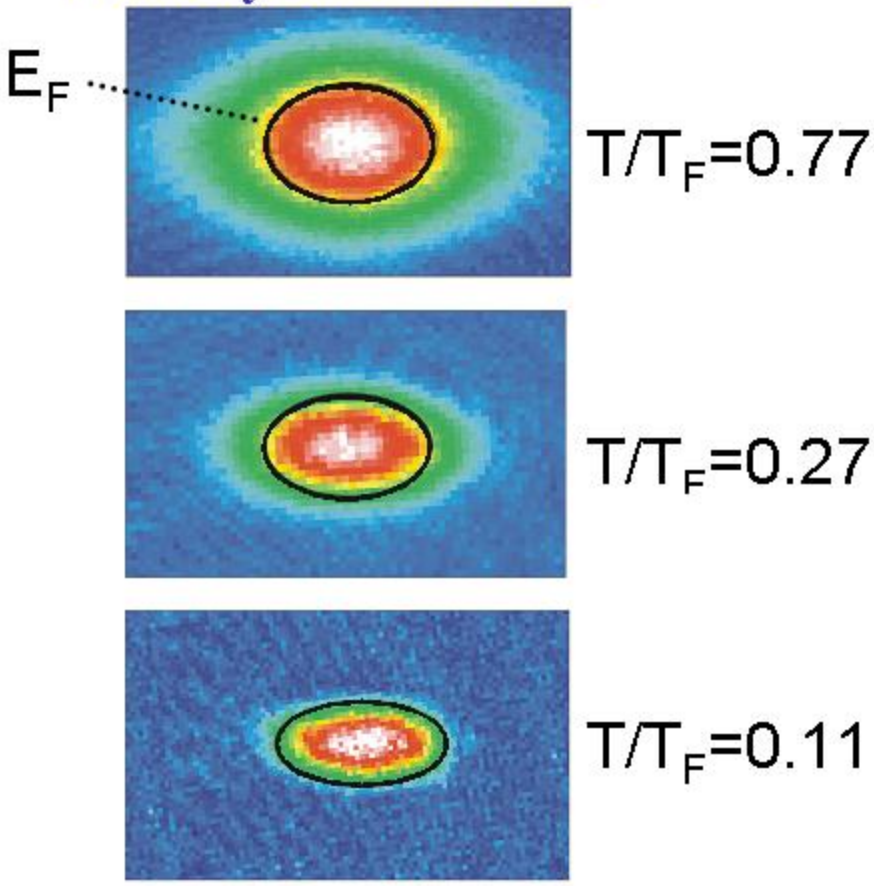
Probing the ultracold gas

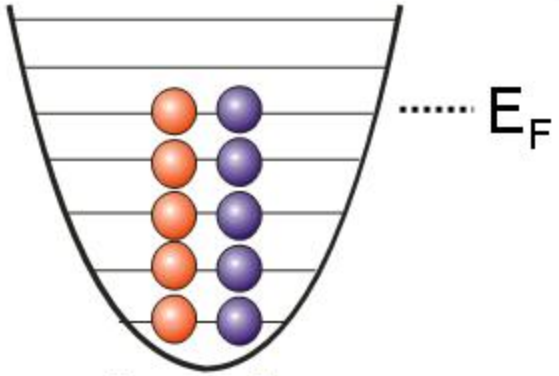
Time-of-flight absorption imaging



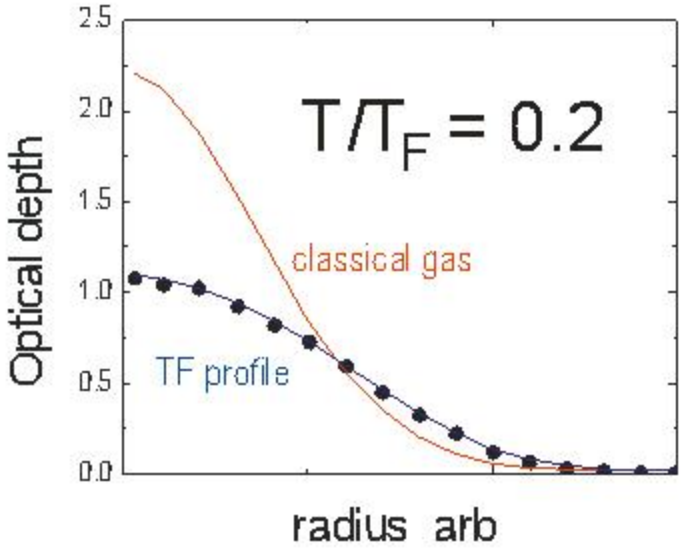
Quantum degeneracy

velocity distributions



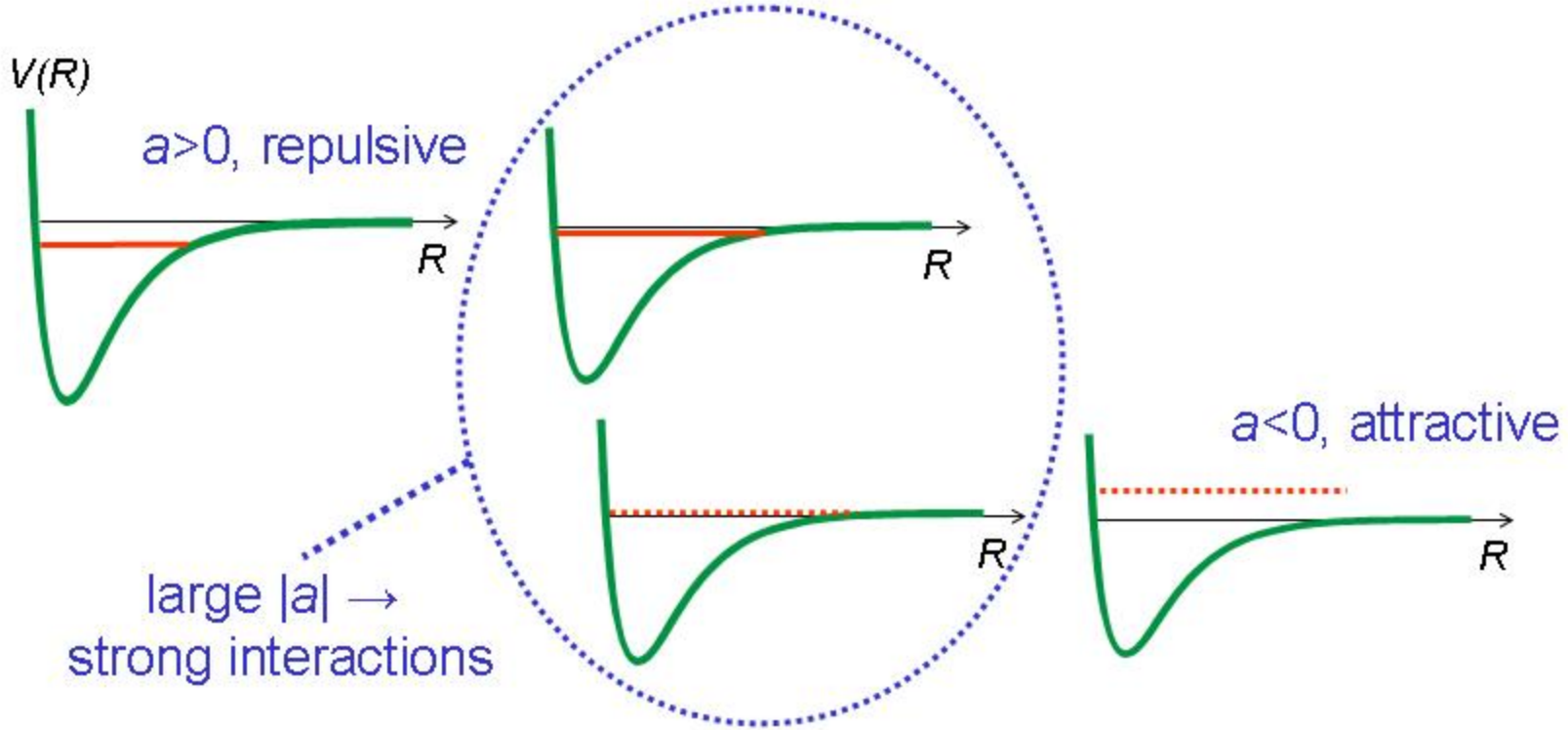


Fermi sea of atoms

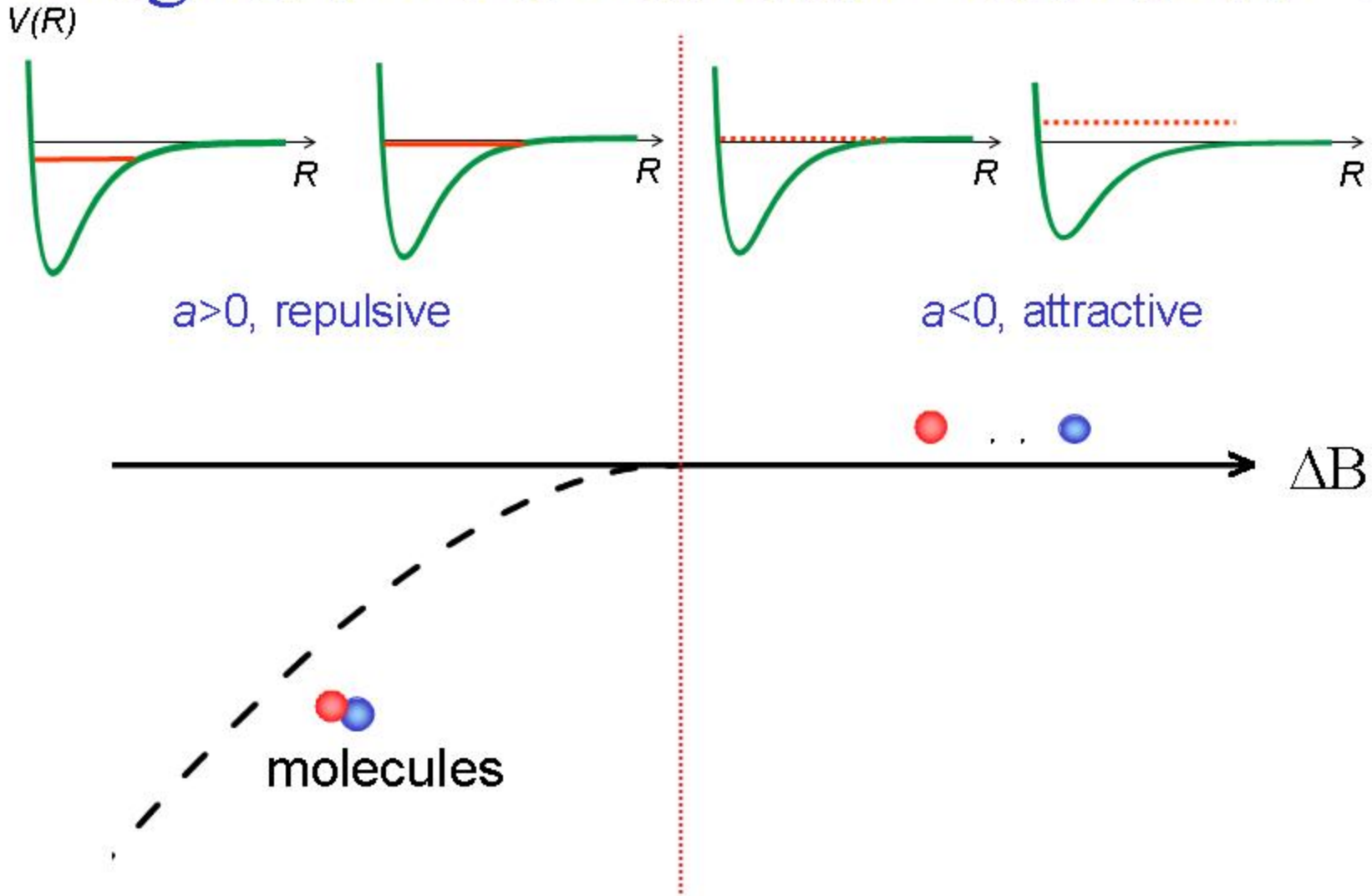


Controlling interactions

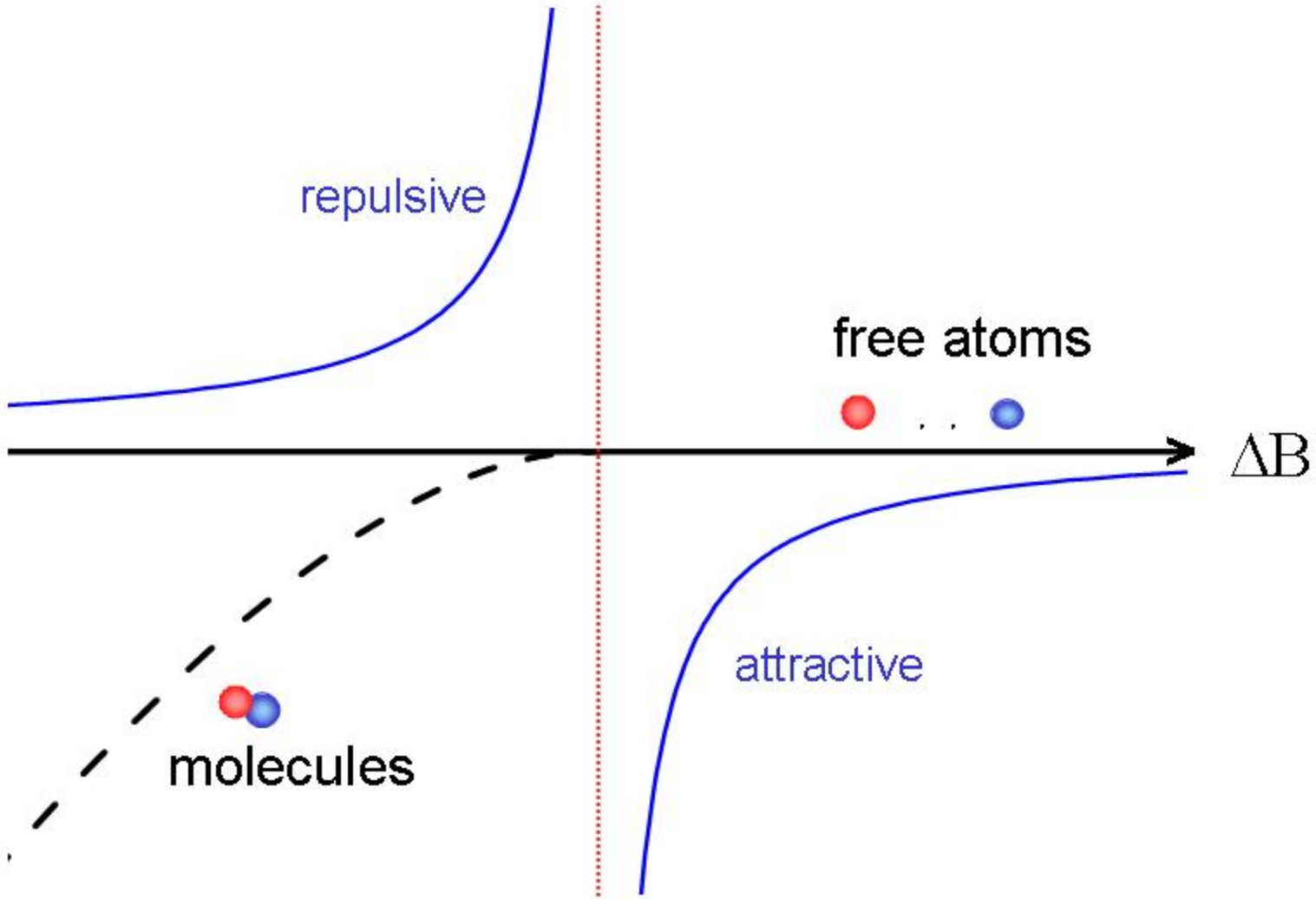
- Interactions are characterized by the s-wave scattering length, *a*
- *a* depends sensitively on the depth of the potential



Magnetic-field Feshbach resonance

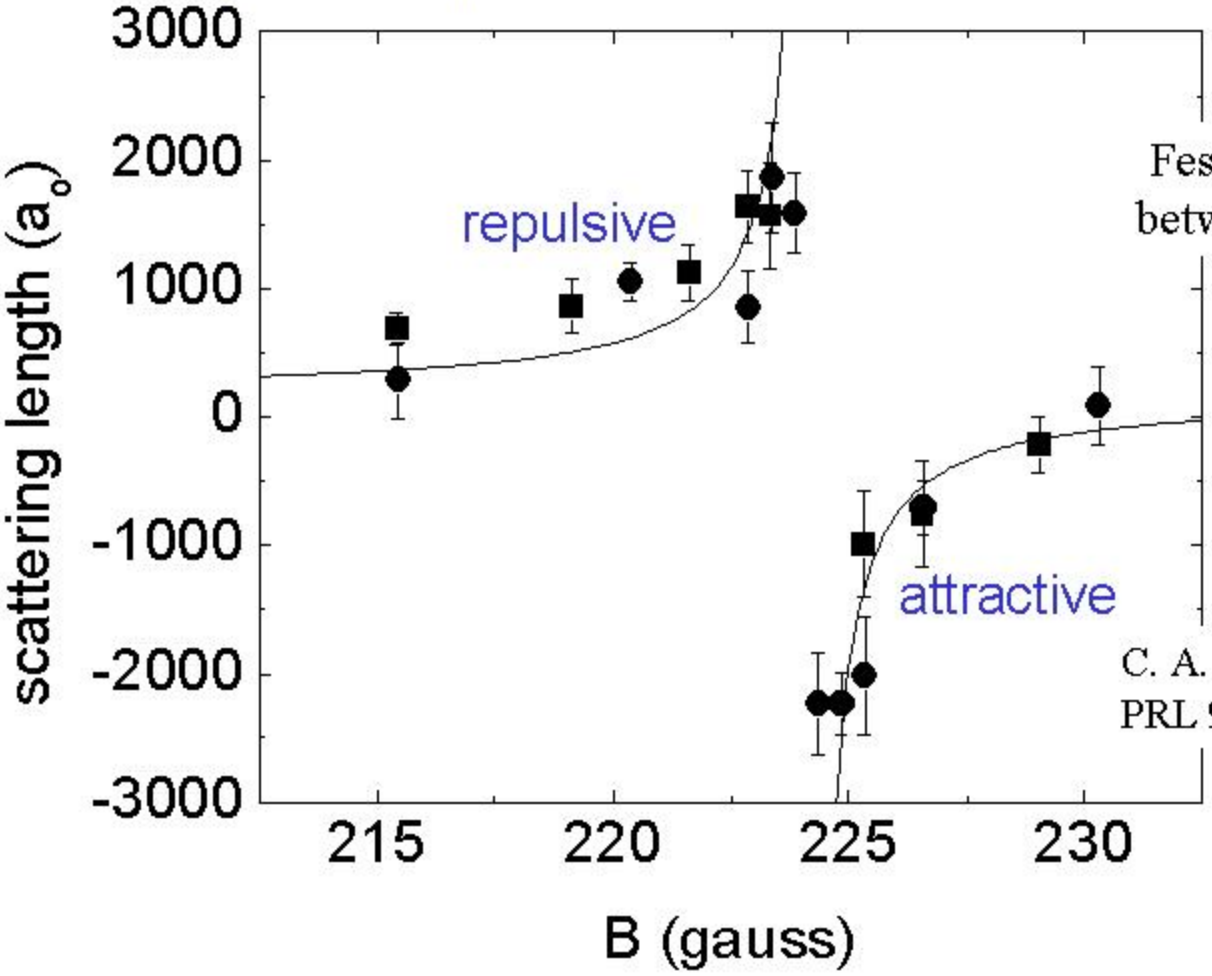


Magnetic-field Feshbach resonance

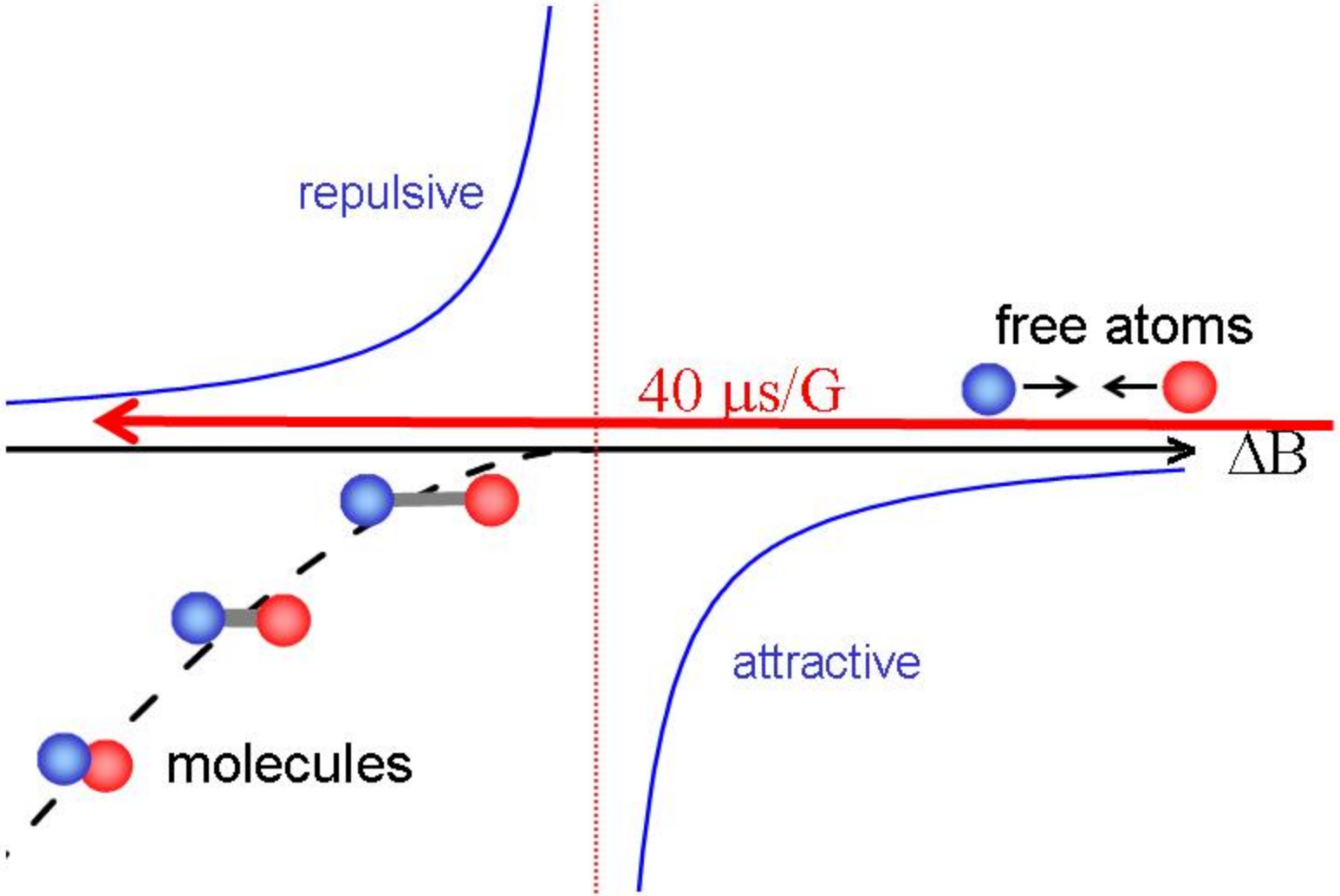


Controlling interactions

- spectroscopic measurement of the mean-field energy shift



Turning atoms into molecules



Turning atoms into molecules

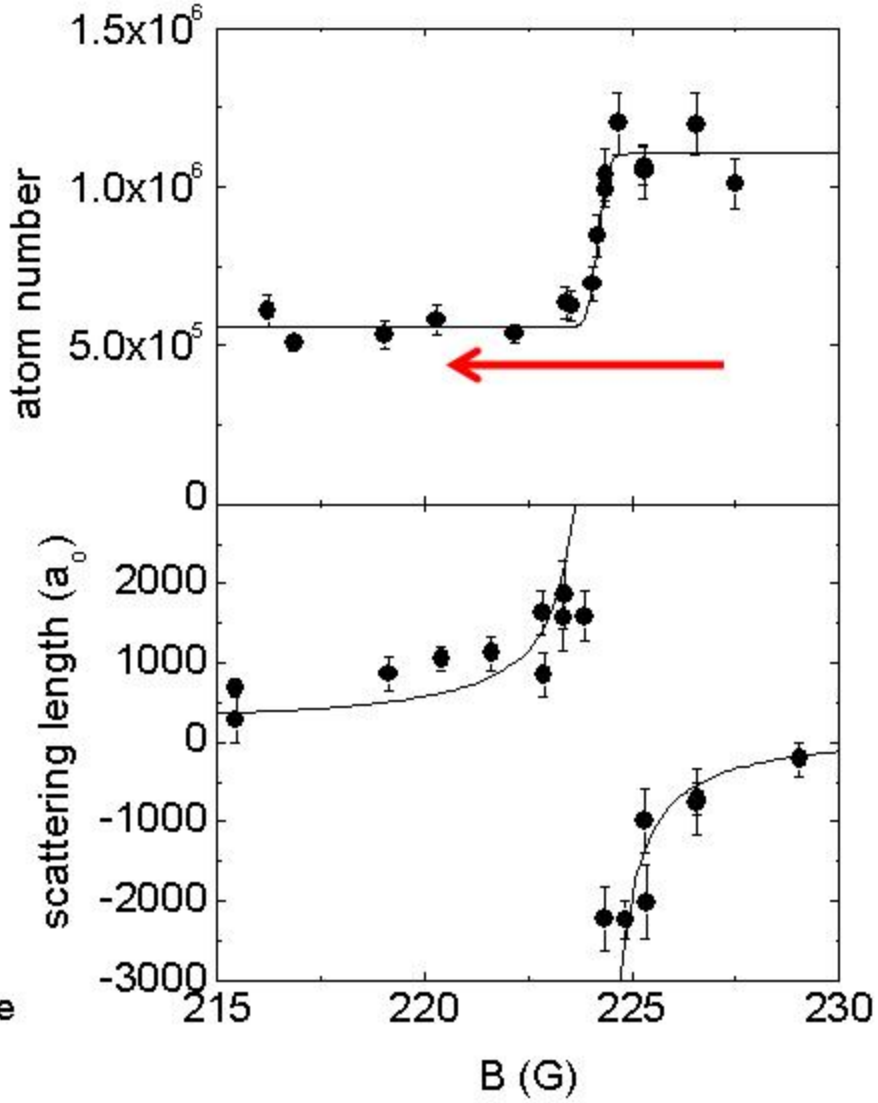
Ramp across Feshbach resonance from high to low B

C. Regal, C. Ticknor, J.L. Bohn and D. S. Jin, Nature **424**, 47

The atoms reappear if we sweep back to high B

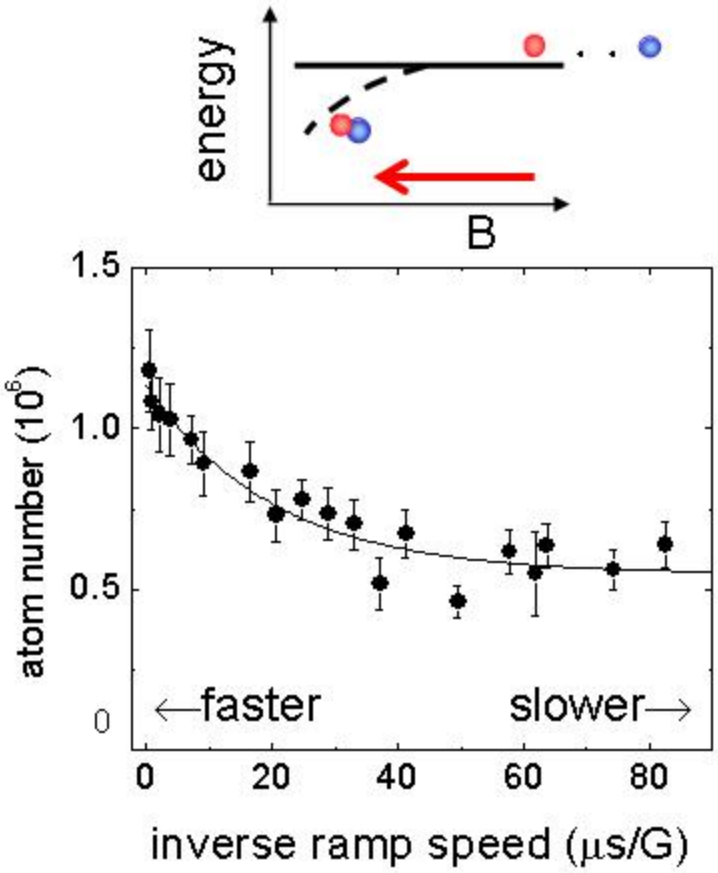
Other expts: Wieman

Hulet, Salomon, Grimm, Rempe, Ketterle



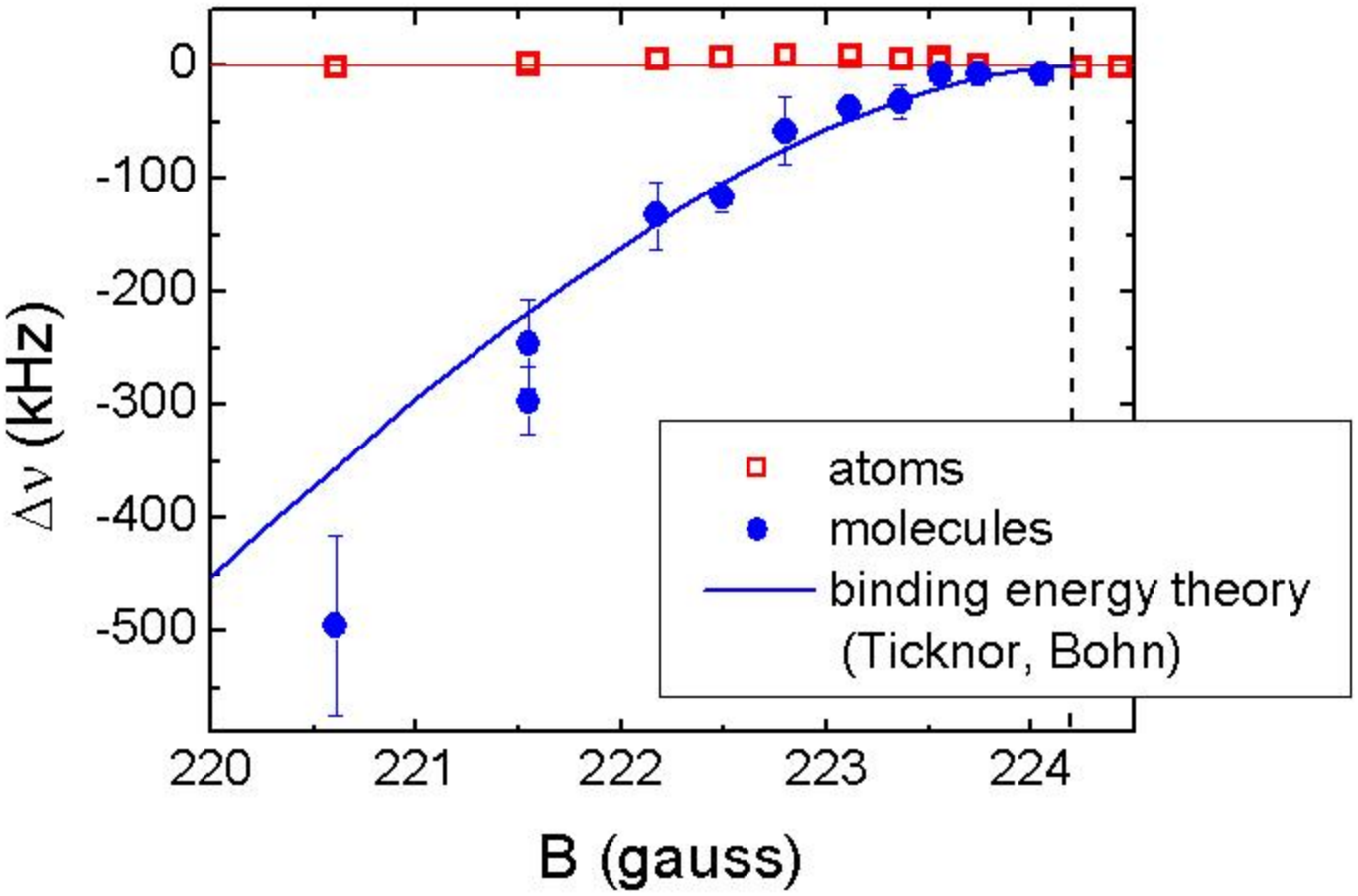
Timescale

Creating molecules



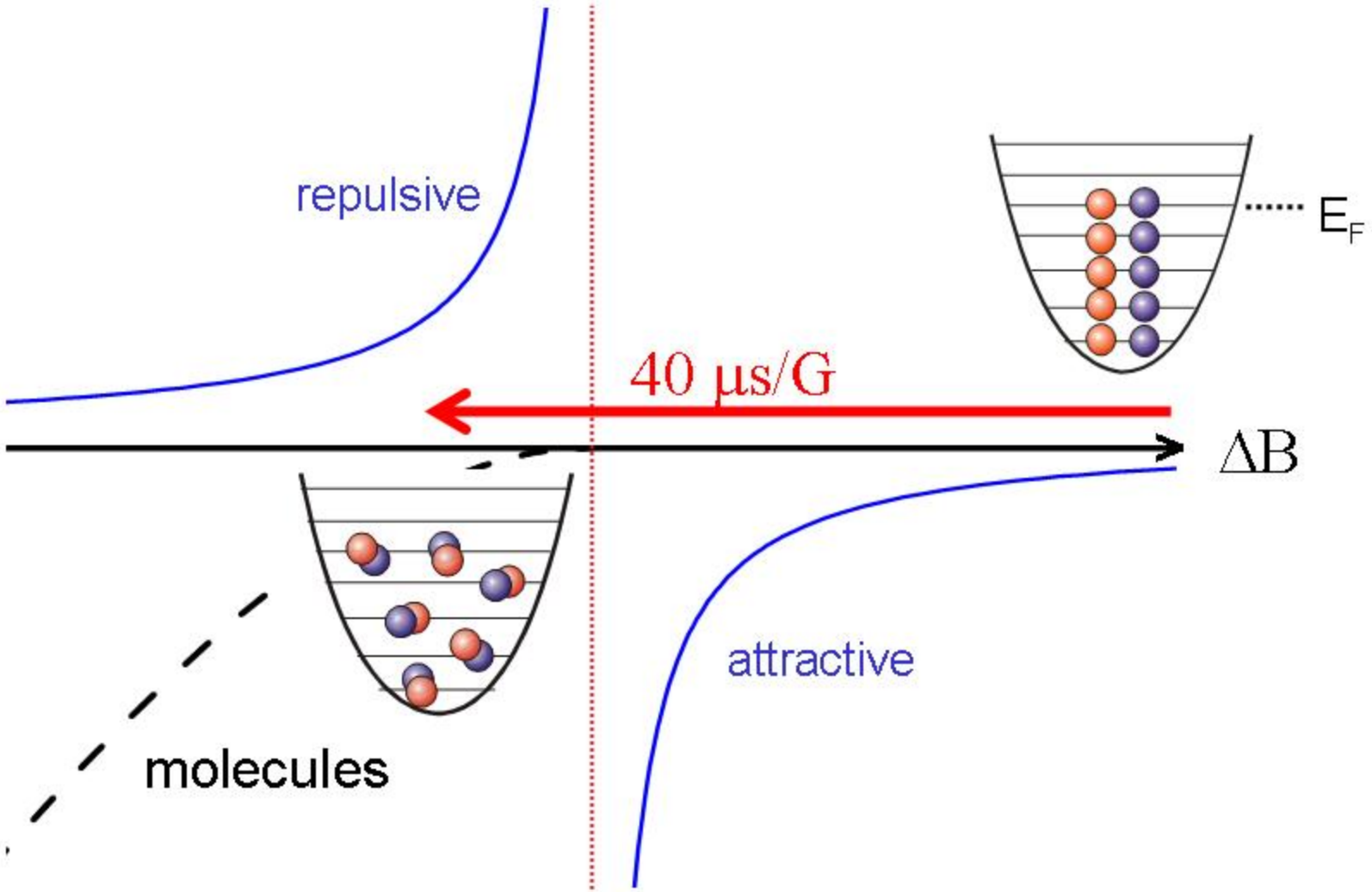
Molecule binding energy

- rf photodissociation spectroscopy

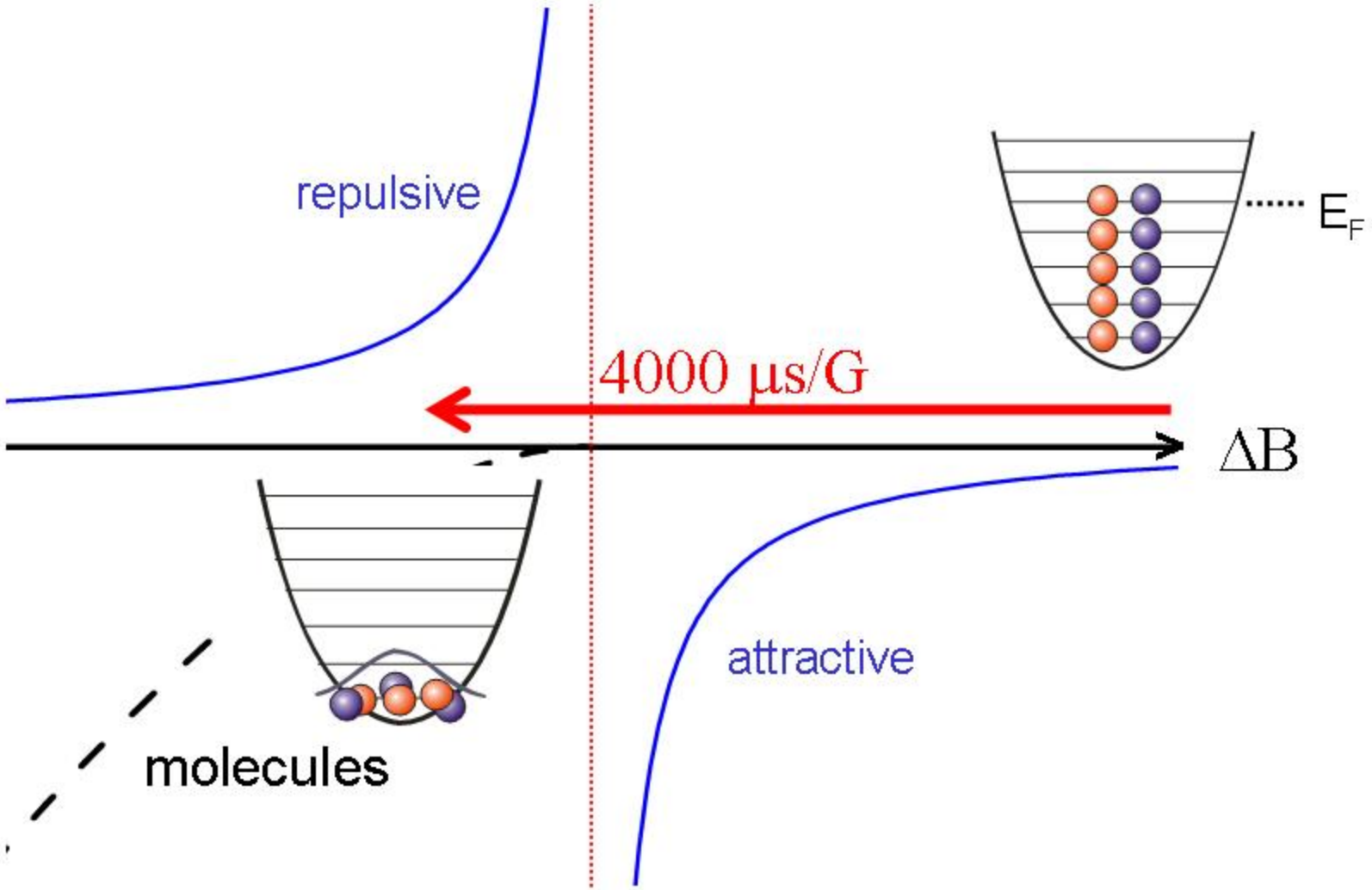


- We observe that the molecules can survive many collisions!

Turning a Fermi gas into a molecular BEC



Turning a Fermi gas into a molecular BEC

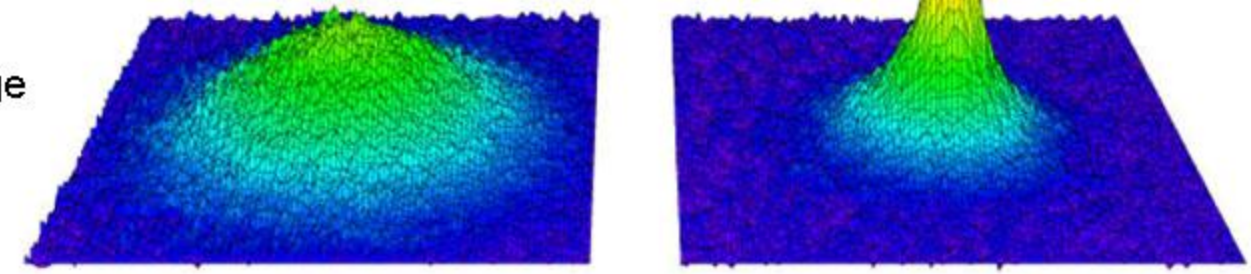


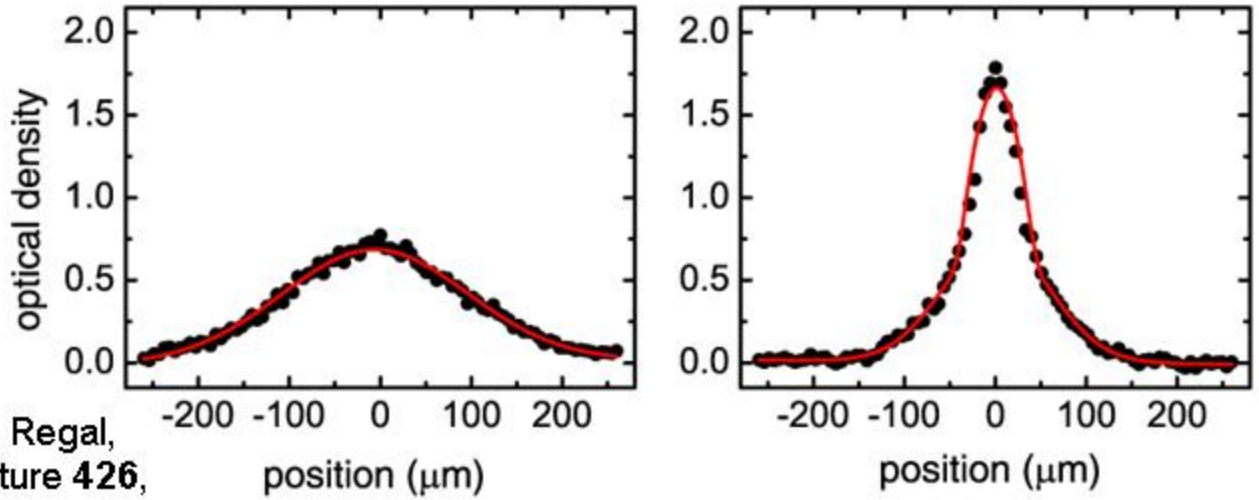
Cubizolles *et al.*, PRL **91**, 240401 (2003); L. Carr *et al.*, cond-mat/0308306

Molecular Condensate

initial T/T_F: 0.19 0.06

Time of flight absorption image

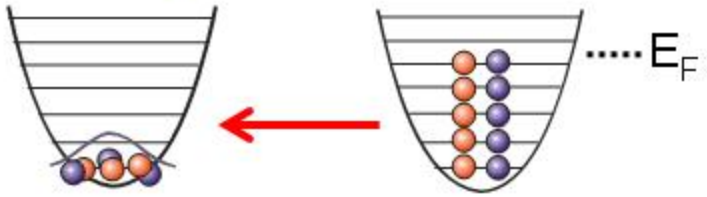


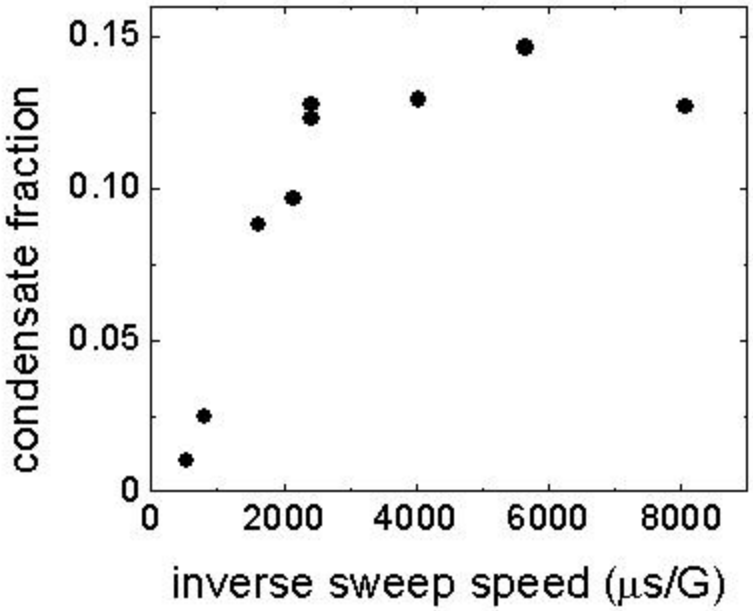


M. Greiner, C.A. Regal, and D.S. Jin, Nature **426**, 537 (2003).

Timescales

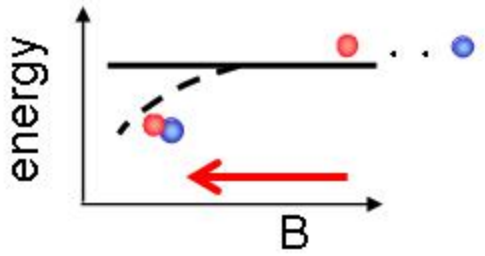
Creating molecular BEC

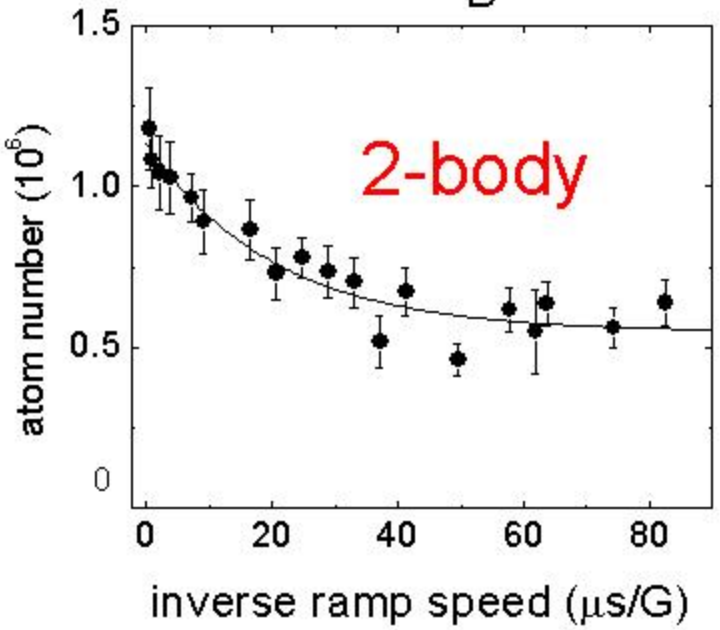




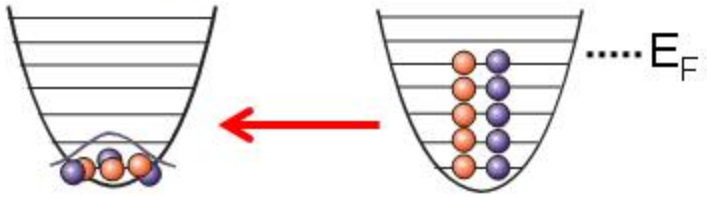
Timescales

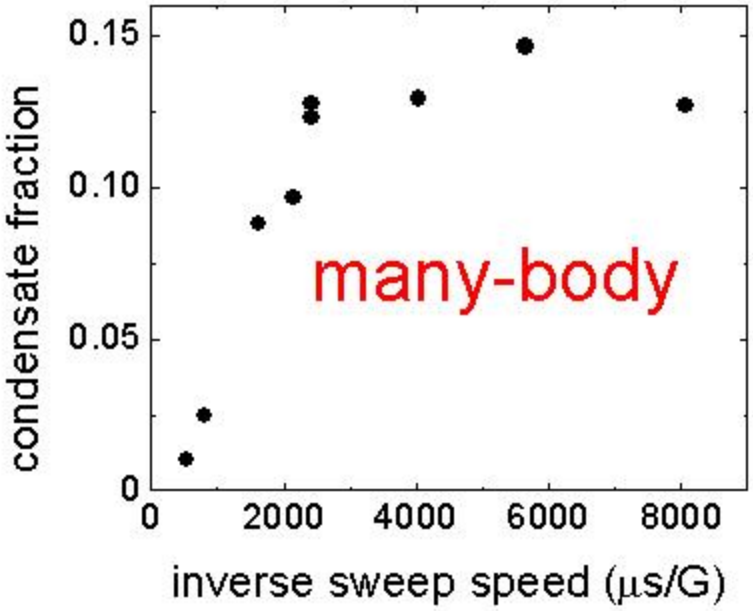
Creating molecules





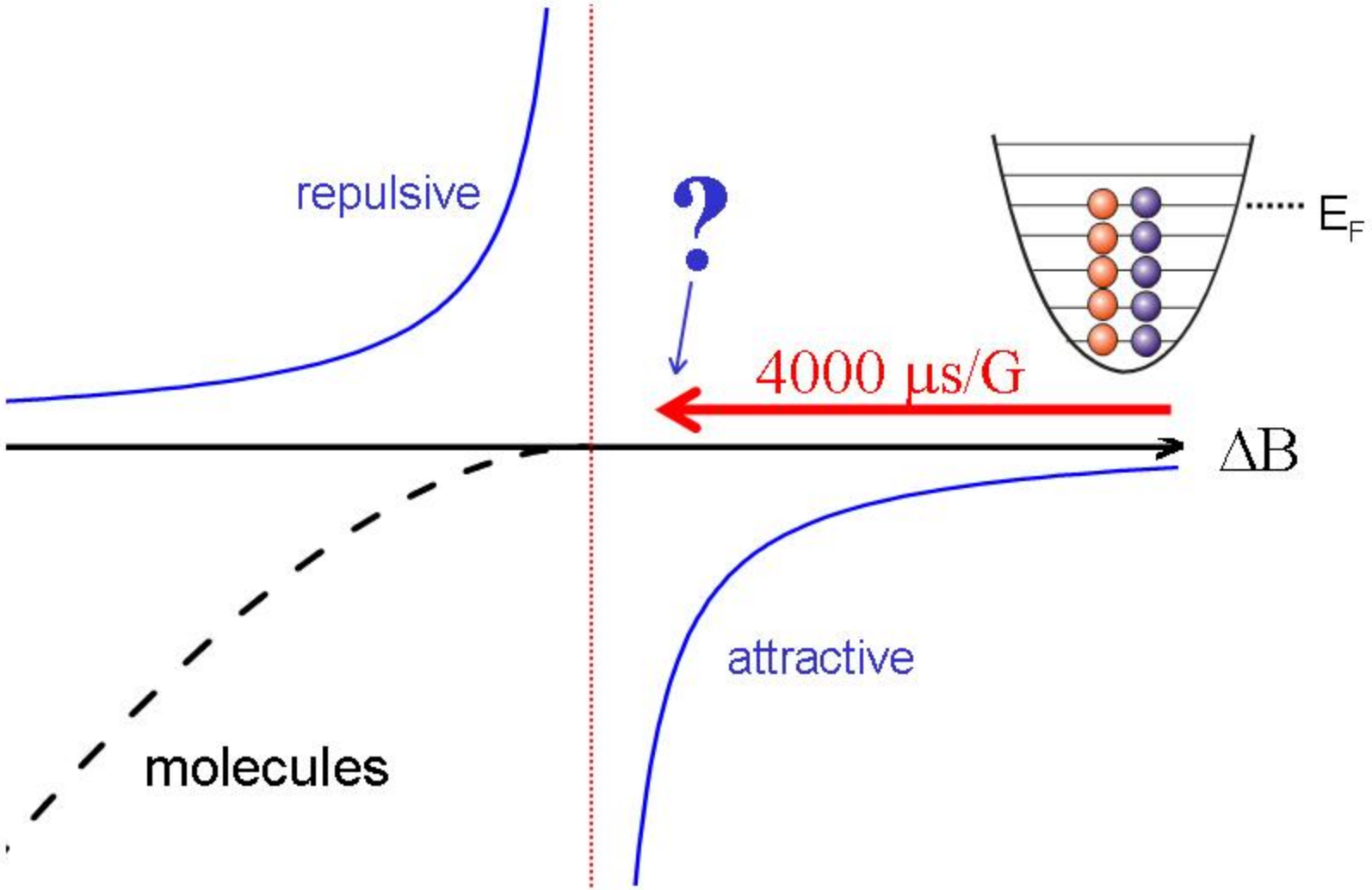
Creating molecular BEC



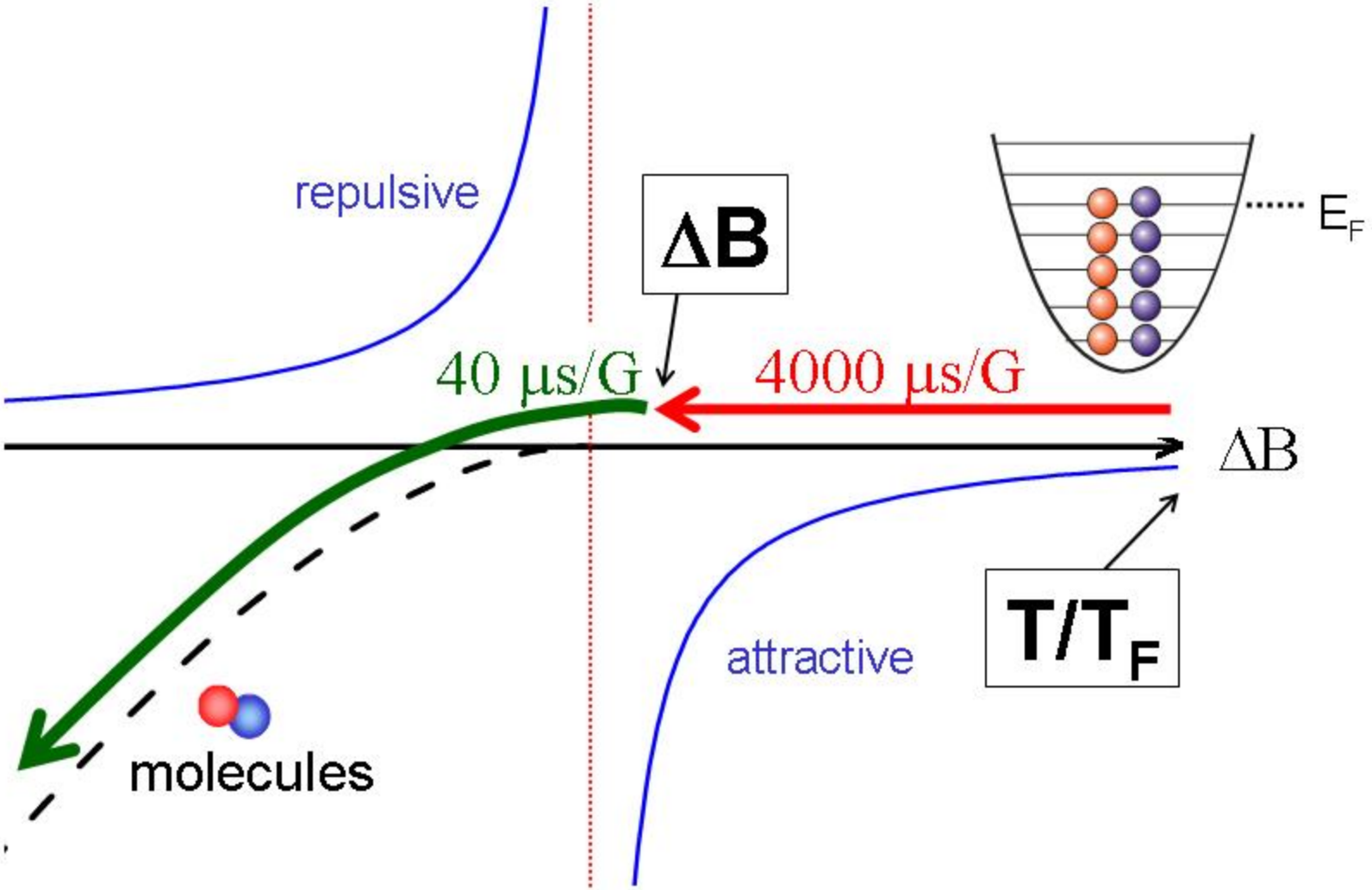


➢ two orders of magnitude difference in timescales!

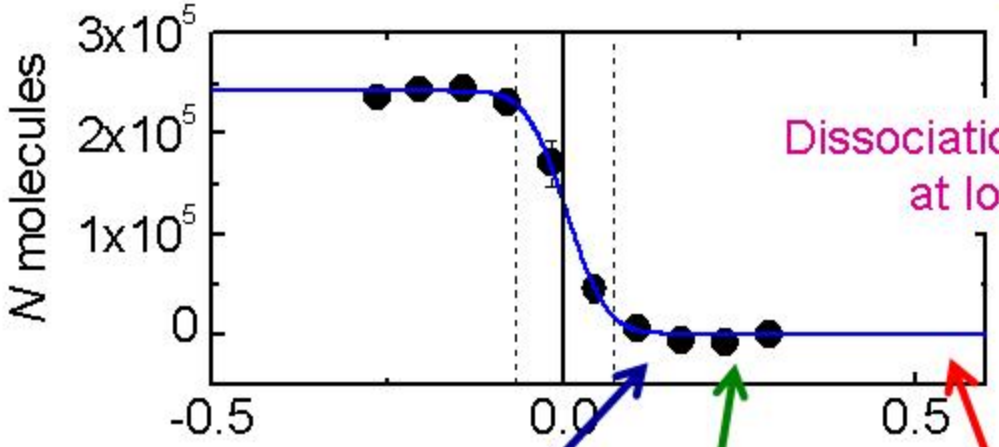
Observing a Fermi condensate



Observing a Fermi condensate

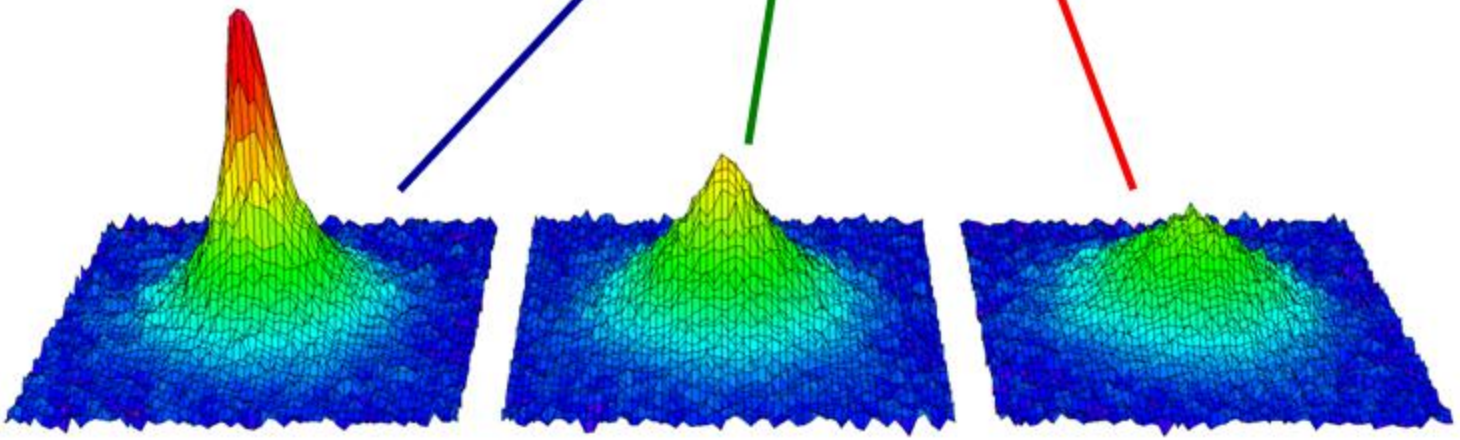


Condensates w/o a two-body bound state



Dissociation of molecules at low density

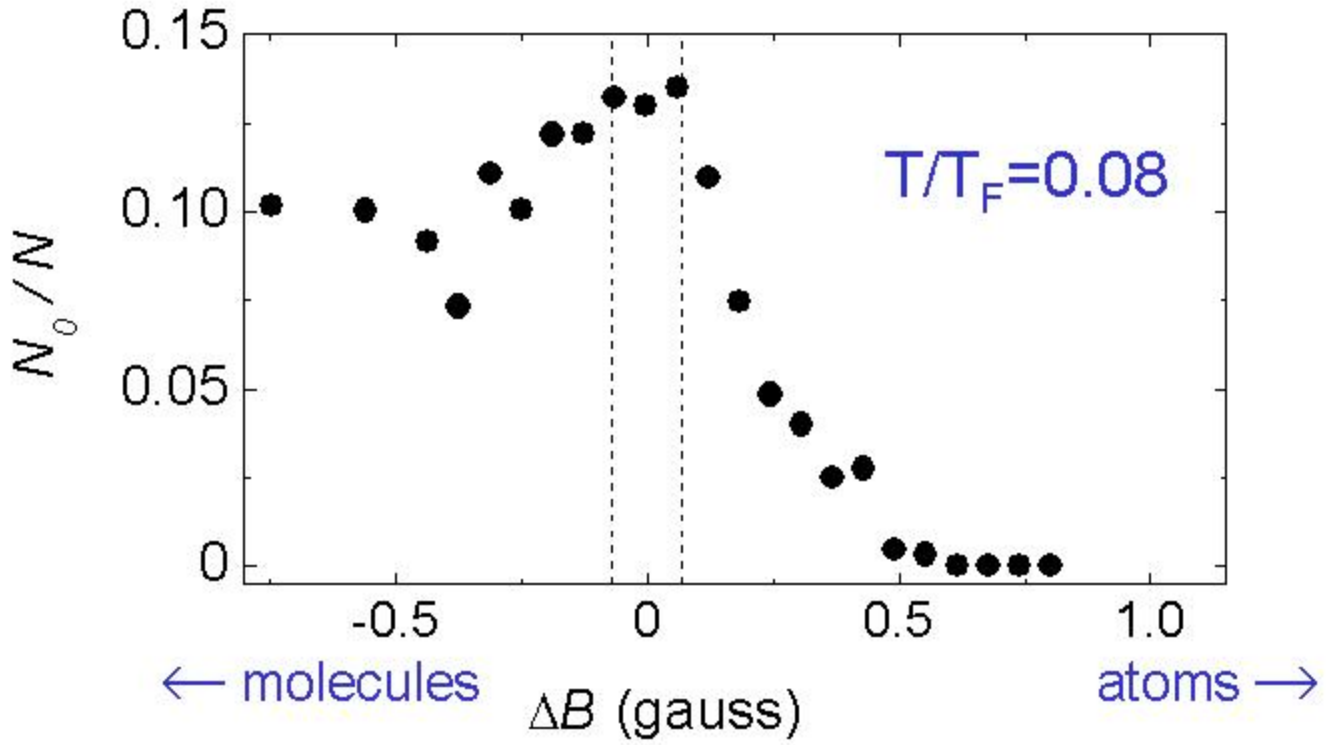
C. Regal, M. Greiner, and D. S. Jin, PRL **92**, 040403 (2004)



ΔB = 0.12 G ΔB = 0.25 G ΔB=0.55 G

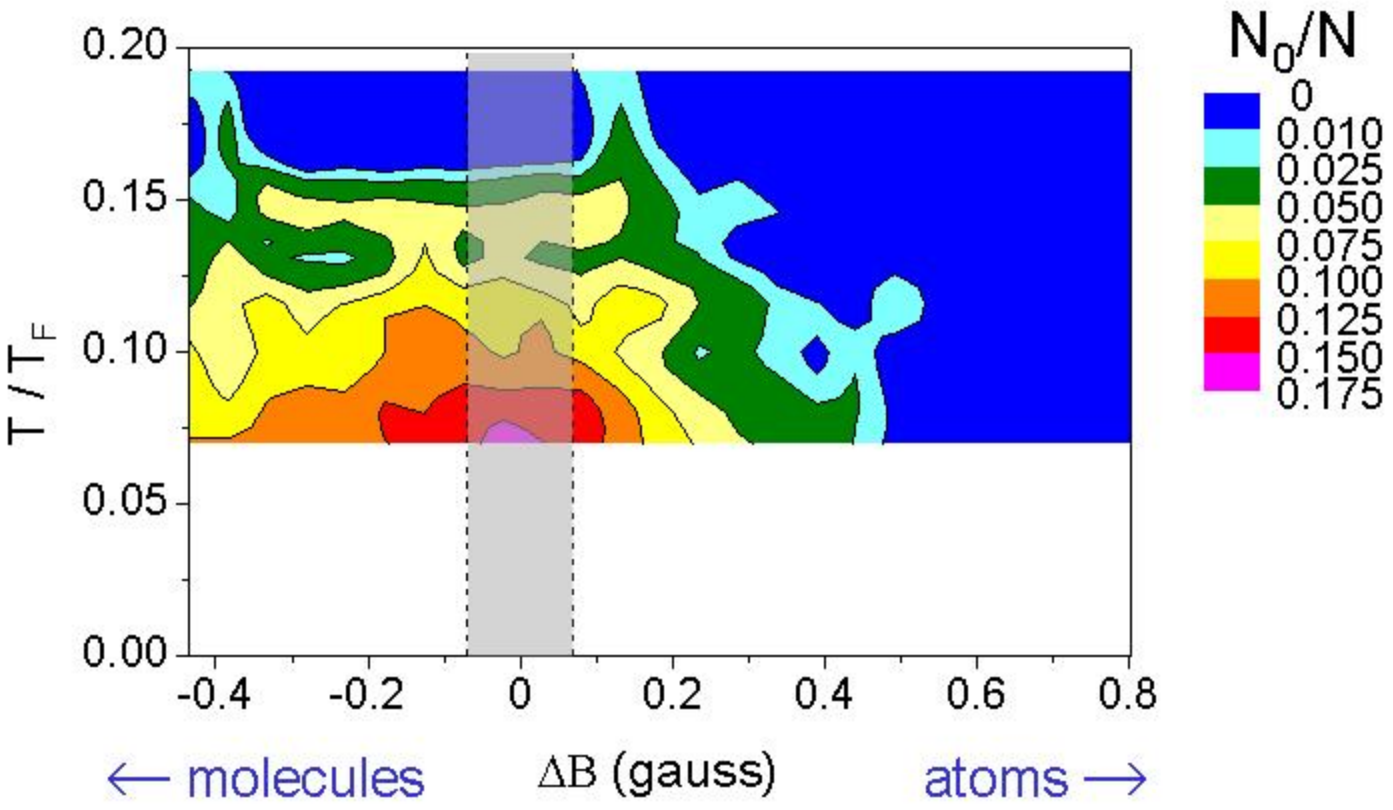
T/T_F=0.08

Fermionic condensate



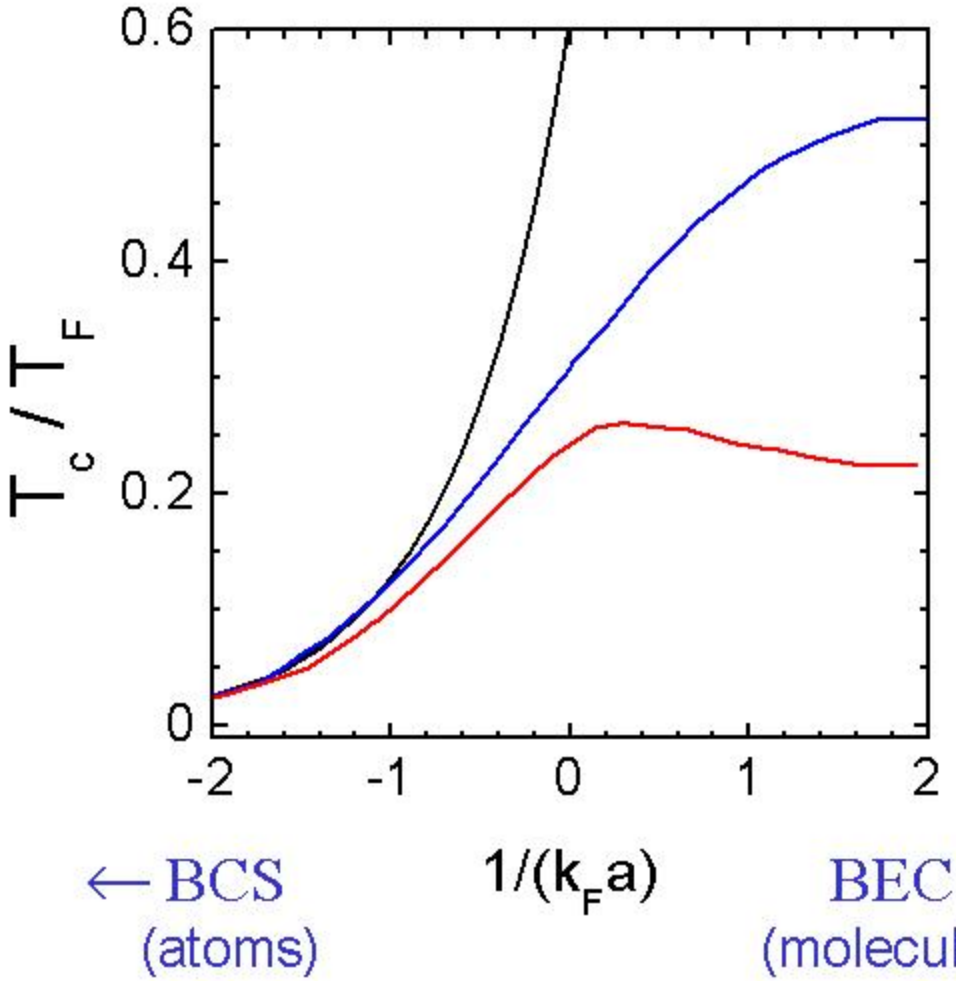
- Clearly see condensation on the "atom-side" of the resonance!

Phase diagram



- consistent with larger T_c closer to resonance

BCS-BEC crossover



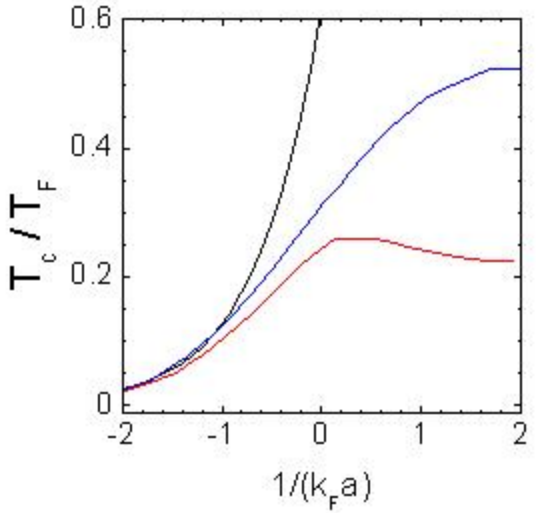
$$T_{c,BCS} \propto T_F e^{-\frac{\pi}{2k_F|a|}}$$

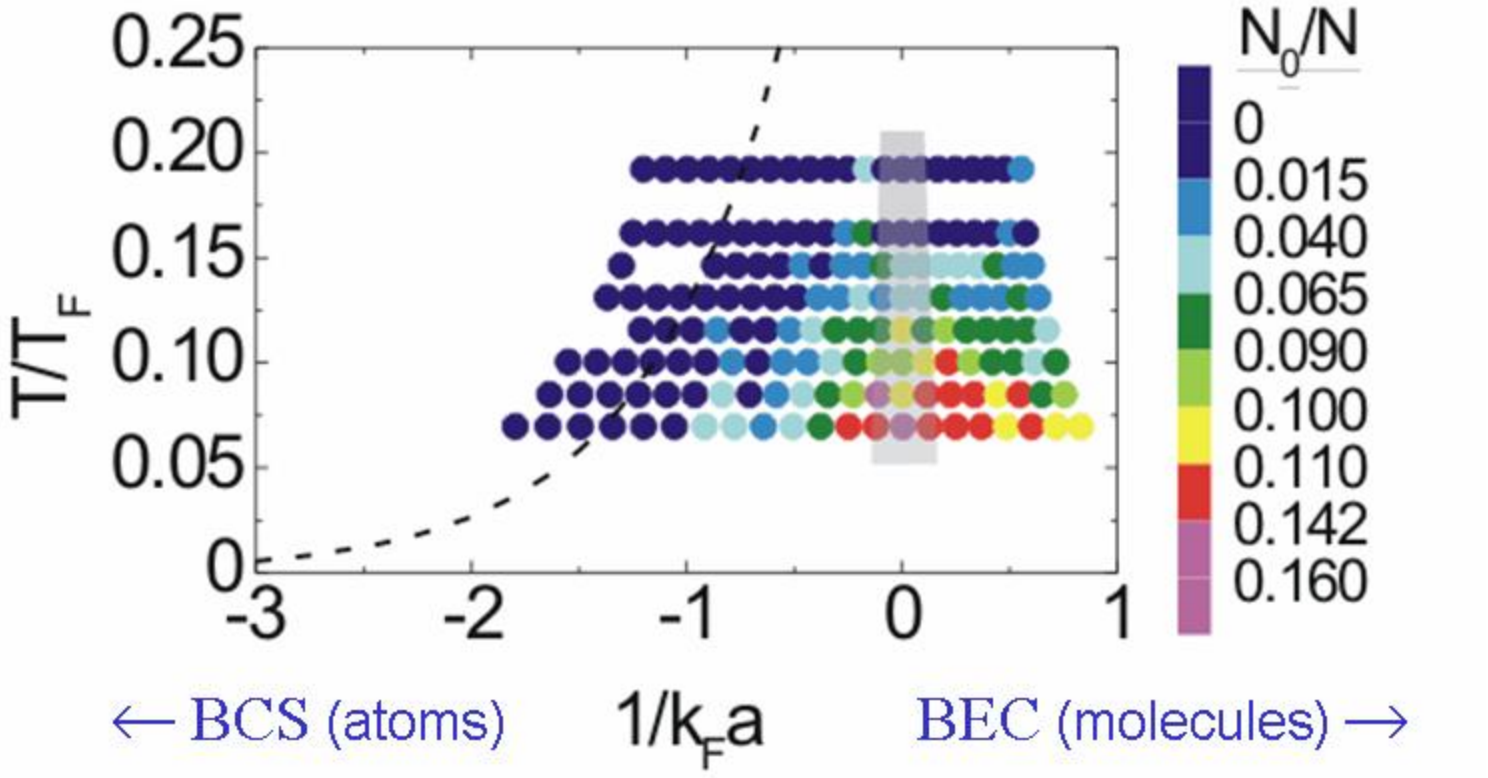
A. Perali, P. Pieri, L. Pisani, and G. C. Strinati, cond-mat/0311309

C. A. R. Sa de Melo, M. Randeria, J. R. Engelbrecht, PRL **71**, 3202 (1993).

partial list: Eagles, Leggett, Nozieres and Schmitt-Rink, Randeria, Haussman, Strinati, Holland, Timmermans, Griffin, Levin, …

BCS-BEC Crossover





Conclusion

- We have created condensates of fermionic atom pairs in the BCS-BEC crossover regime!
  - "Cooper pairs" with strong interactions
  - "BEC" with extremely weakly bound molecules

Next…

Many opportunities for experimental and theoretical work …

Current group members:

M. Greiner
J. Goldwin
S. Inouye
C. Regal
J. Smith
M. Olsen