p-wave Feshbach molecules

D. Jin

JILA, NIST and the University of Colorado

$ NSF, NASA, NIST

JILA AMO Physics Center

Outline

1. Motivation
2. A p-wave Feshbach resonance
3. Molecule energies and lifetimes
4. Future

Fermionic superfluidity

Cooper pairing:

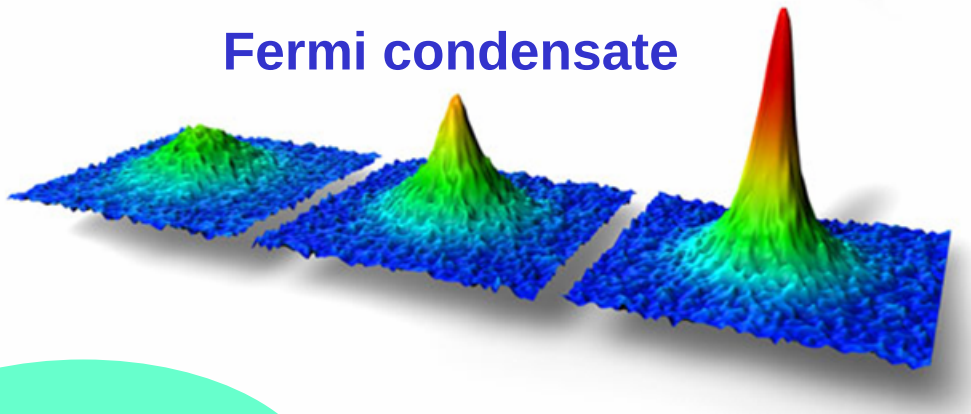
two correlated fermions act like a boson

Examples

Superconductivity:
Cooper pairs
of electrons

Superfluid ^{3}He:
^{3}He atom pairs

Superfluidity in
nuclear matter:
Nucleon pairs

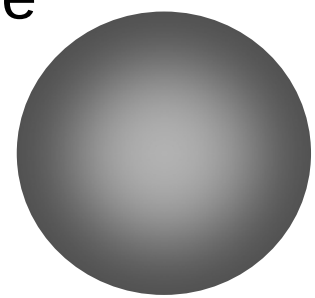


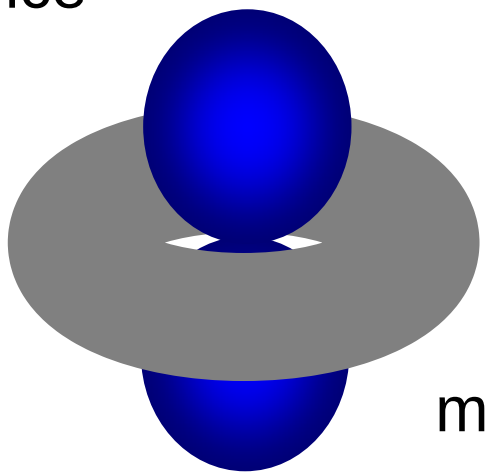
P-wave pairing?

Fermi condensates with non-s-wave pairing?

- Examples:
  - superfluid ^{3}He (p-wave)
  - high Tc superconductors (d-wave)
- Novel features:
  - anistropic gap
  - multiple superfluid phases,
  - narrow resonance

s-wave
L=0



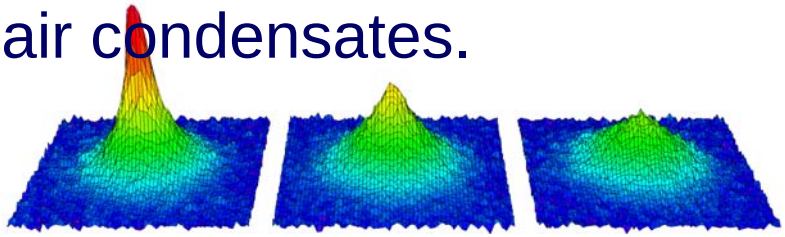


p-wave
L=1

m_l = -1,0,+1

Making molecules

- This is the first step toward making molecule condensates and fermion pair condensates.



- New possibilities: non-s-wave molecules, heteronuclear molecules, fermionic molecules, ground-state molecules, and polar molecules.

other non-s-wave Feshbach molecule studies:

Grimm (s- to g- wave), Salomon (p-wave)

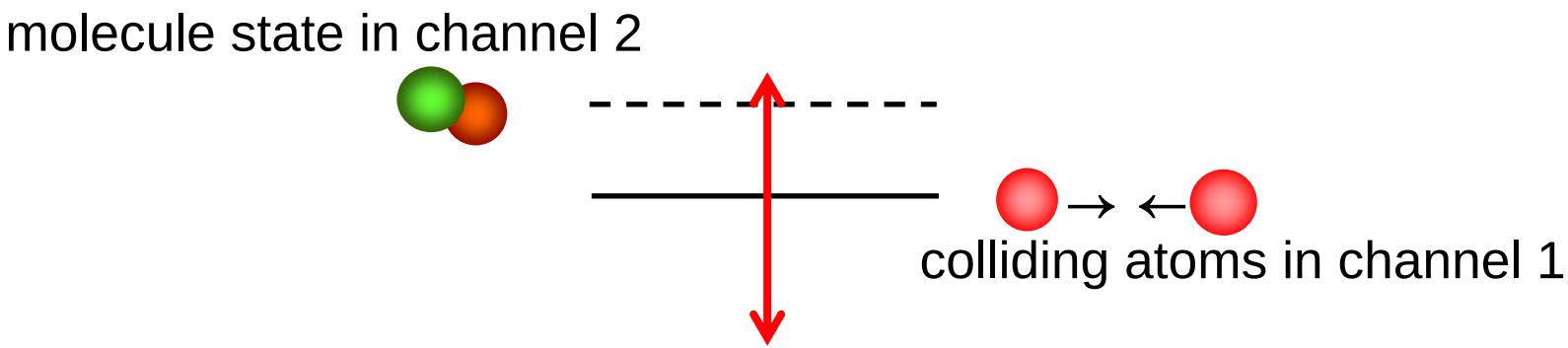
Making molecules

Molecules can be very efficiently created using a Feshbach resonance.

- magnetic-field sweep across resonance
- three-body collisions near a Feshbach resonance
- rf association
- magnetic-field modulation

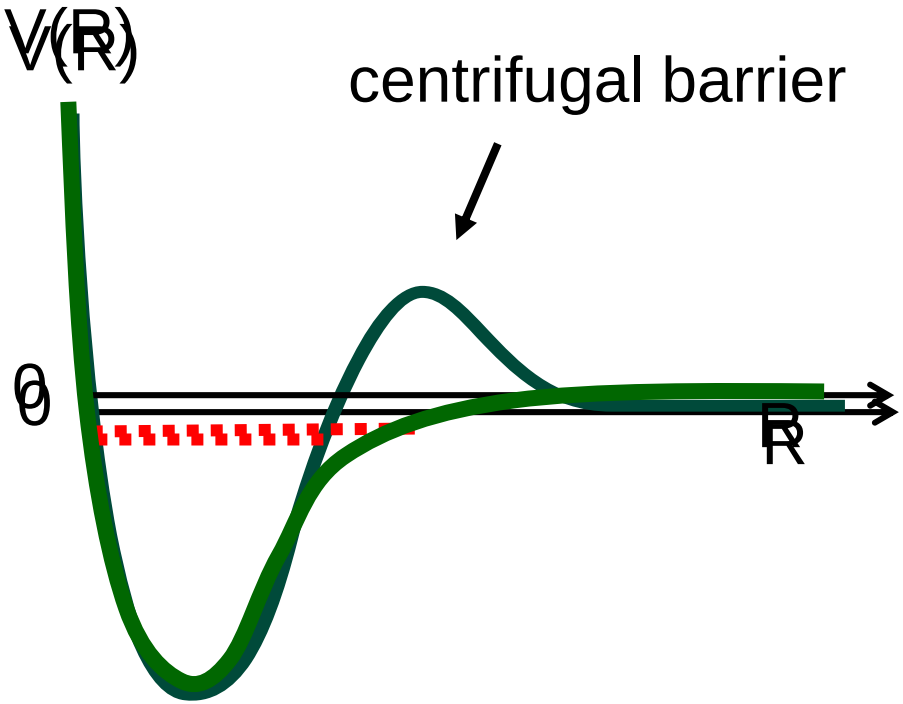
Feshbach resonance

A magnetic-field tunable atomic scattering resonance



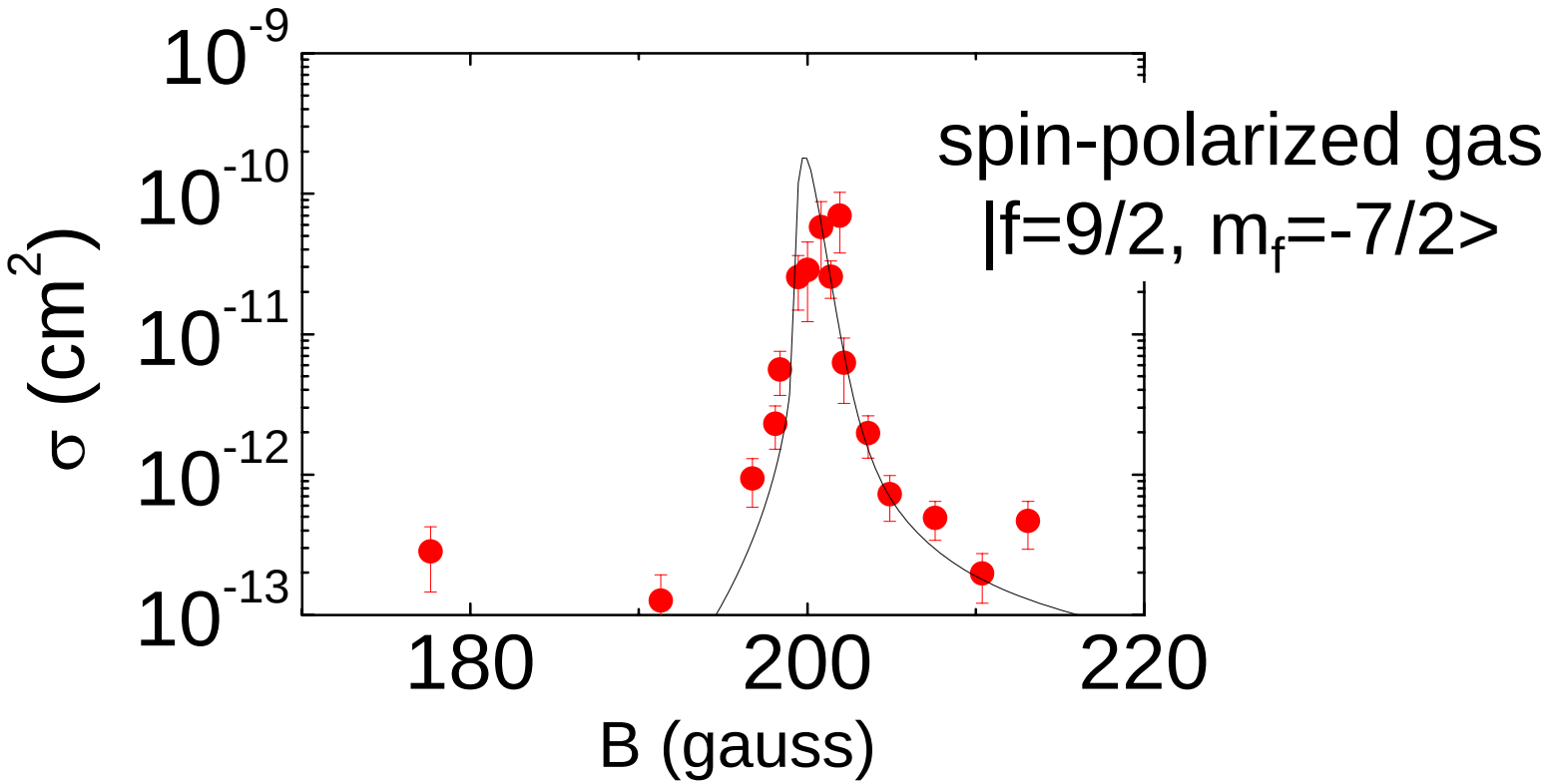
Channels are coupled by the hyperfine interaction.

S-wave resonance



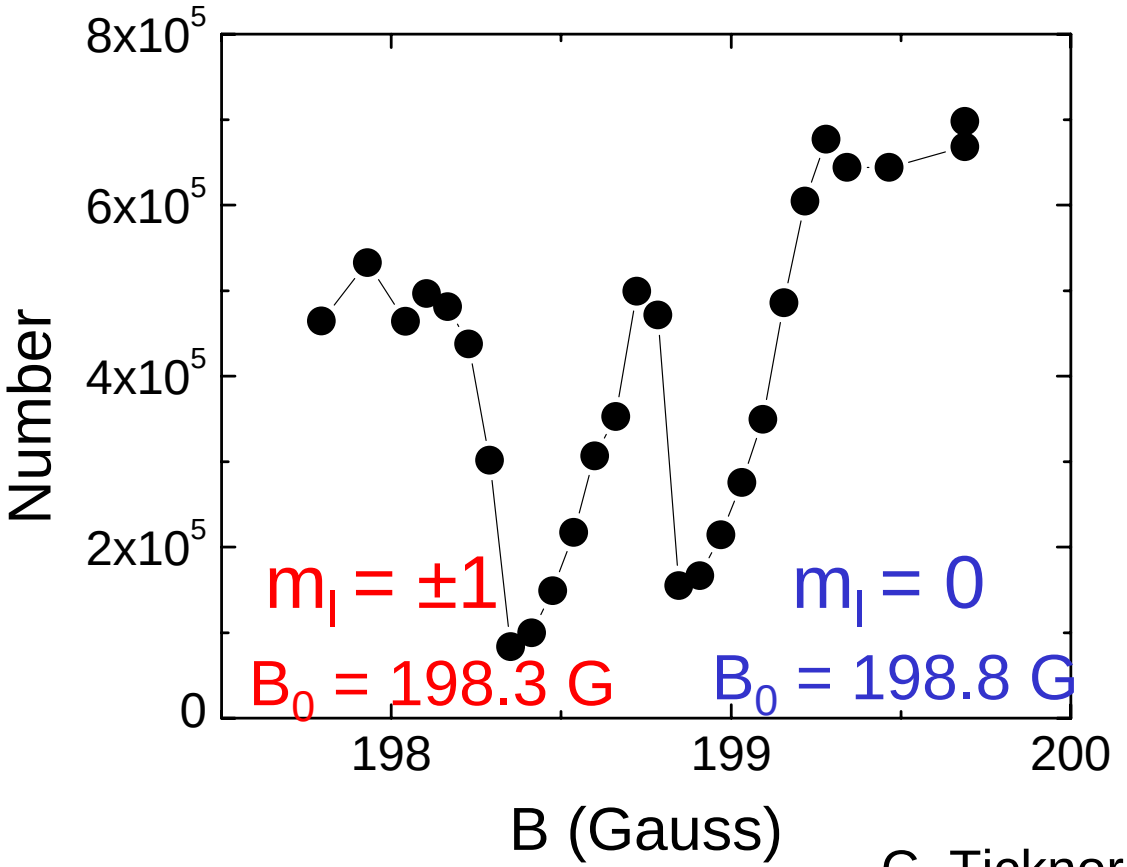
P-wave resonance

^{40}K



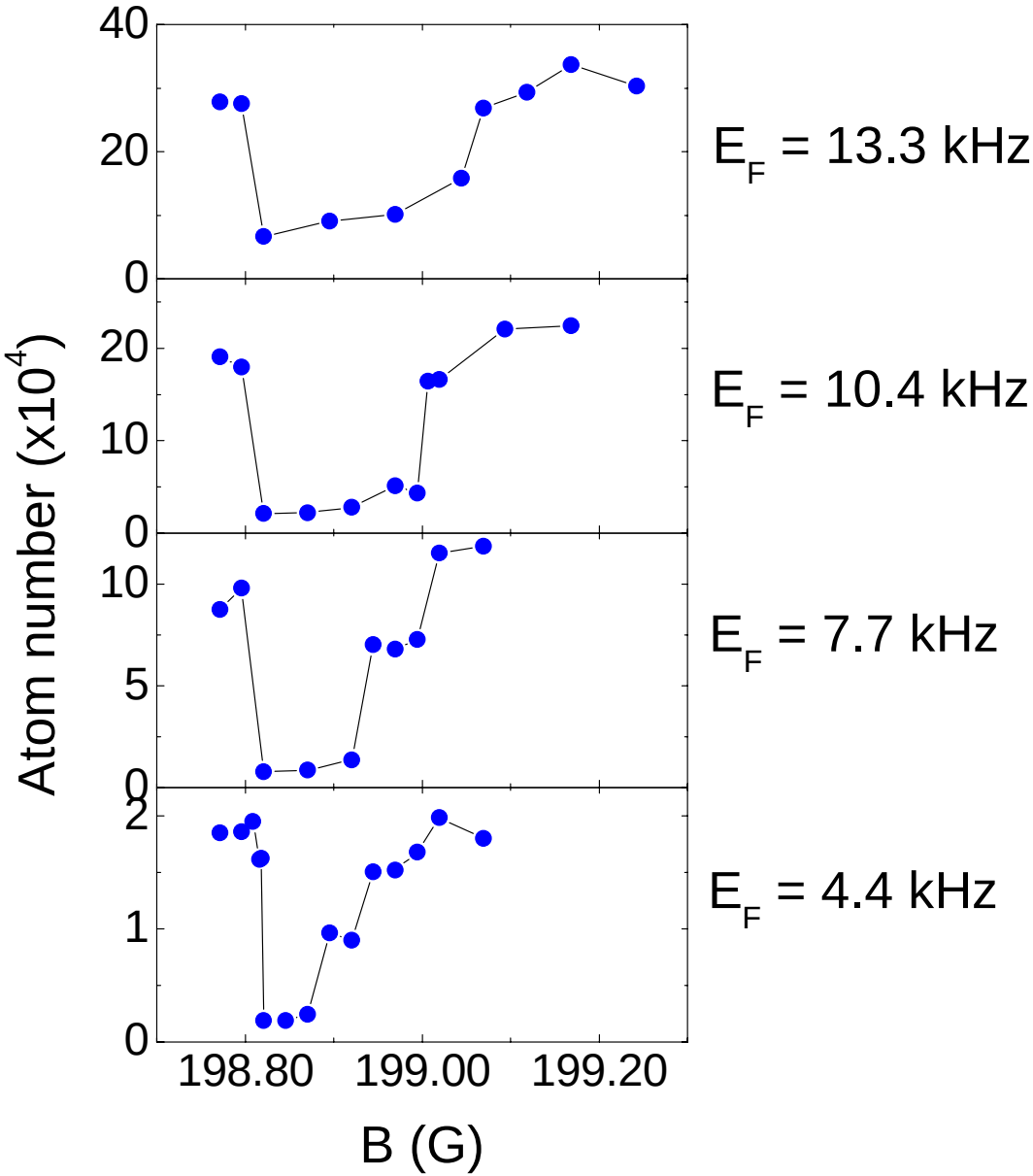
C.A. Regal, C. Ticknor, J.L. Bohn, & D.S. Jin, PRL **90**, 053201 (2003)

Multiplet structure



C. Ticknor, C.A. Regal, D.S. Jin, and J.L. Bohn, PRA 69, 042712 (2004).

Width of loss feature



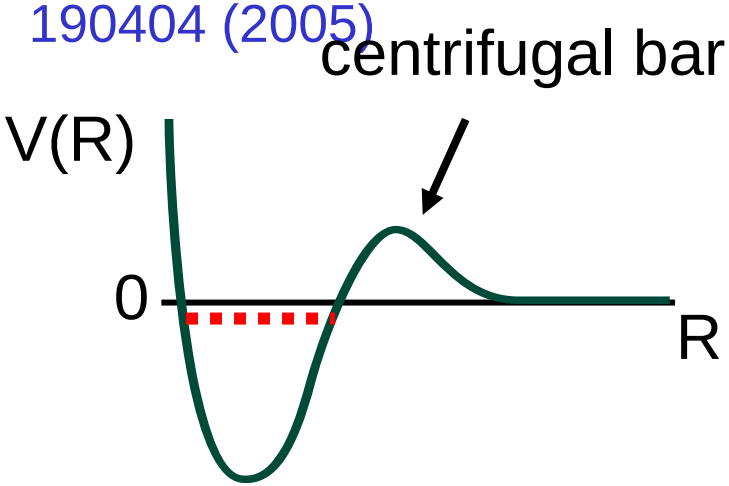
$m_l = 0$ resonance

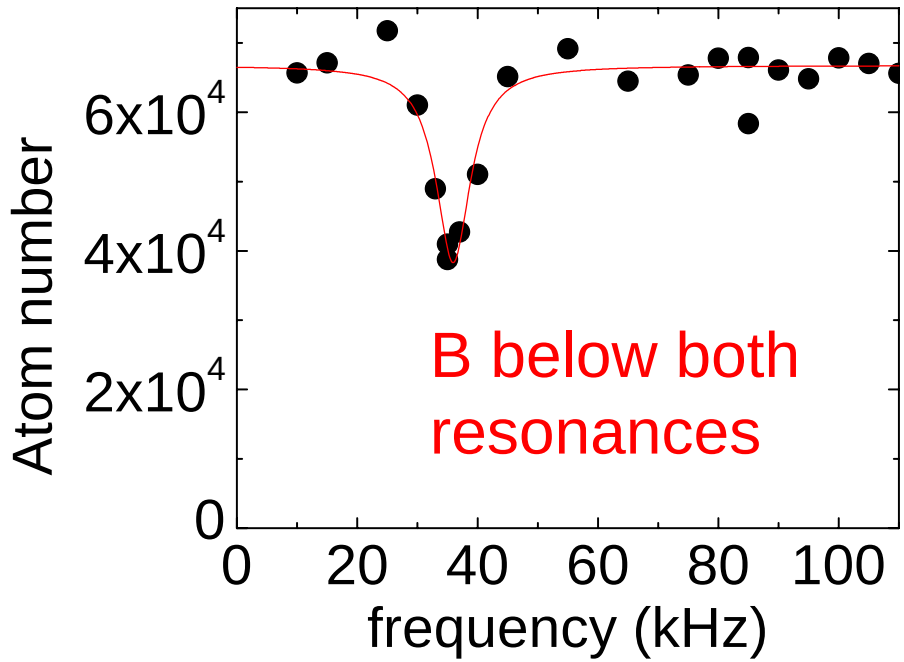
Feature of a narrow resonance

B-field modulation

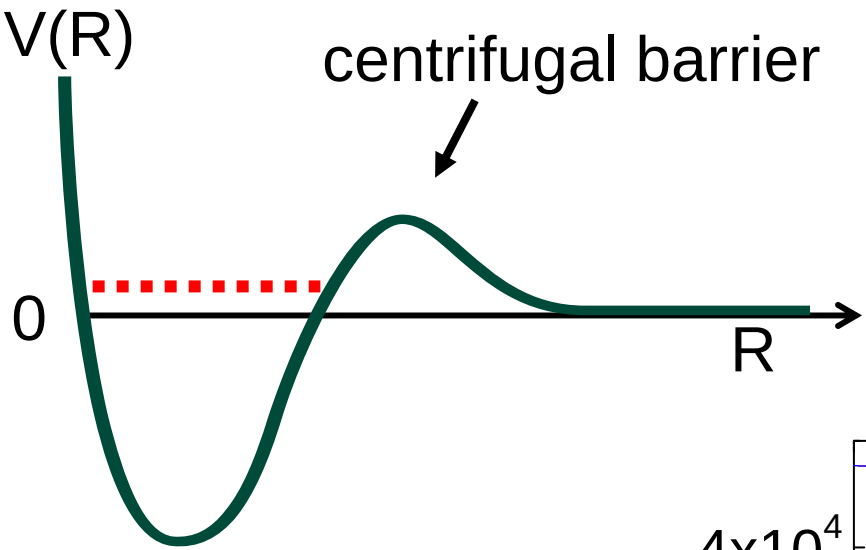
Near a Feshbach resonance, a resonant oscillating B-field can create molecules.

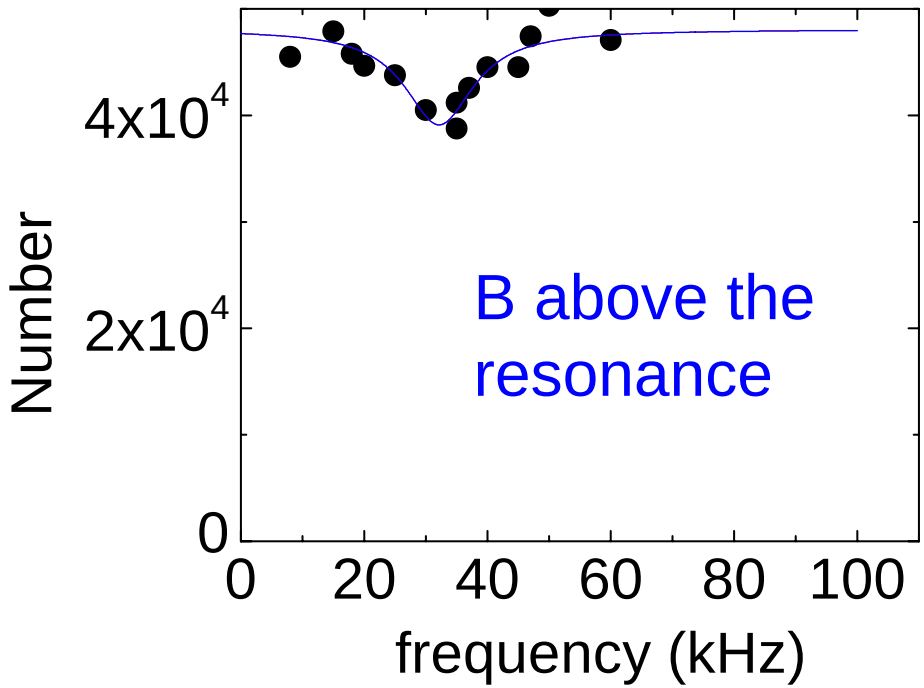
dissociation M. Greiner, C.A. Regal, & D.S. Jin, PRL 94, 070403 (2005)
association S.T. Thompson, E. Hodby, & C.E. Wieman, PRL 94, 190404 (2005)



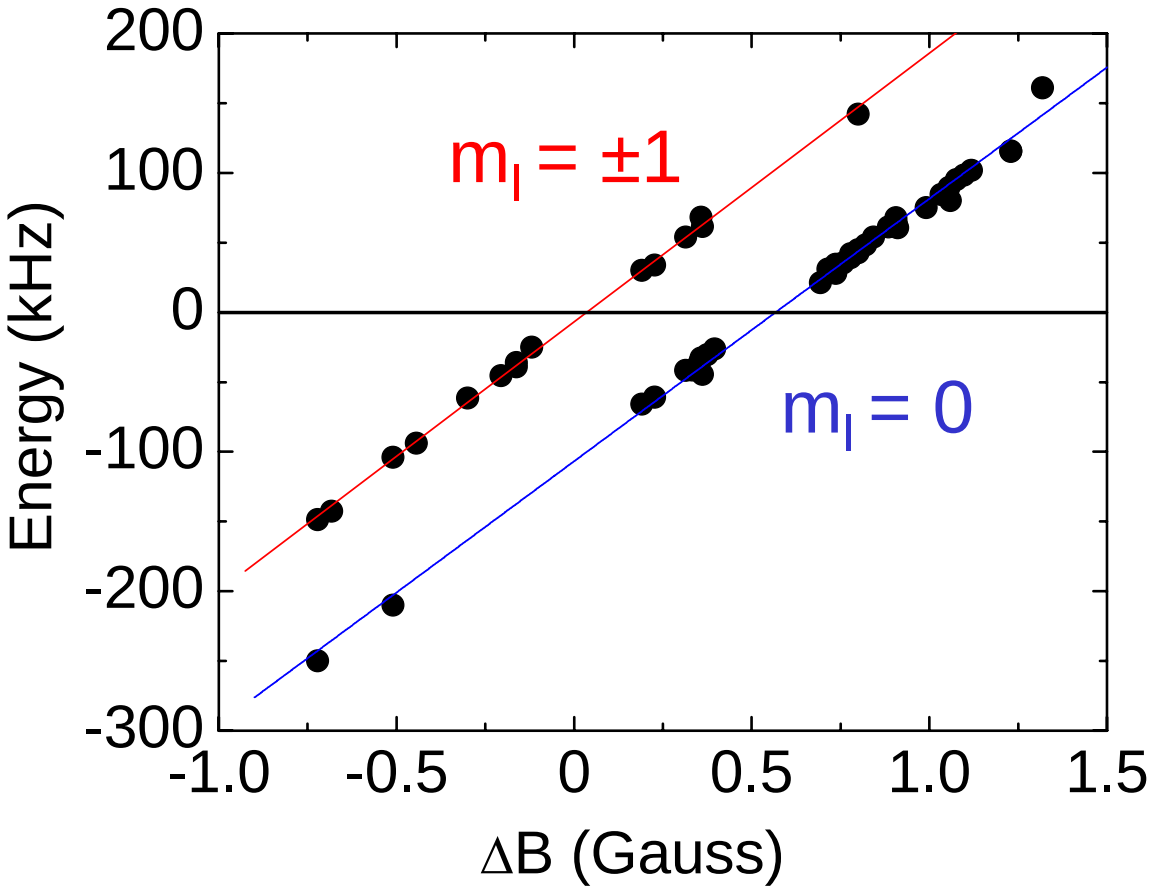


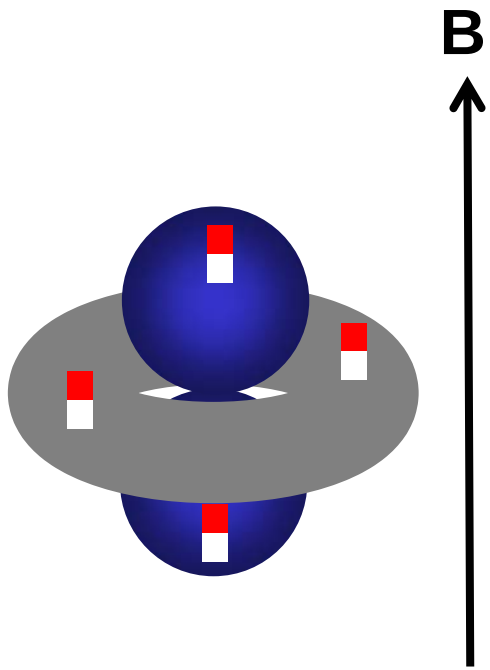
Quasi-bound molecules





P-wave molecule energy

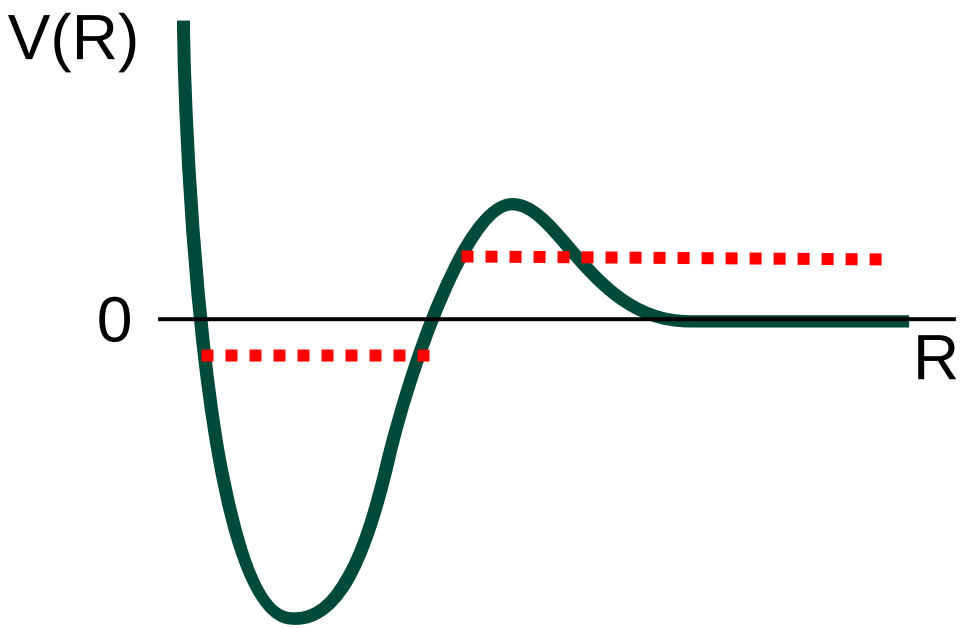




J.P. Gaebler, J.T. Stewart, J.L. Bohn, & D.S. Jin, cond-mat/0703087

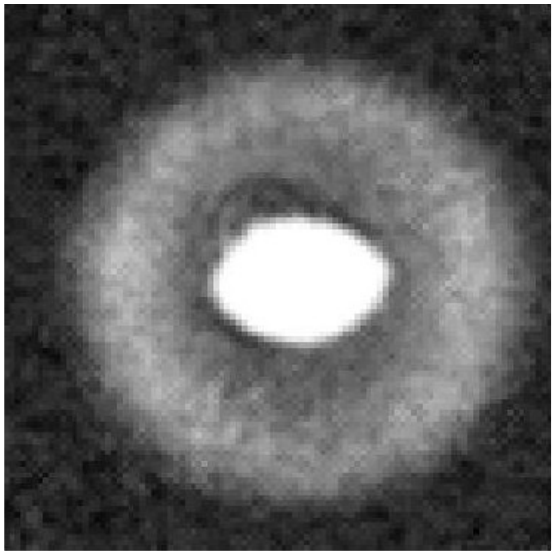
A way to “see” molecules

Create molecules

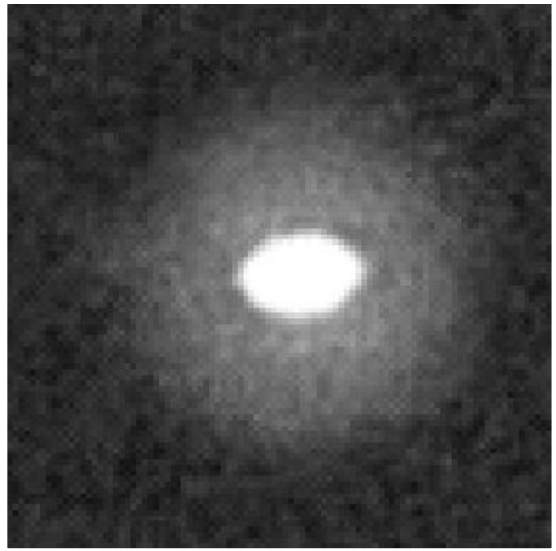


Look for energetic atoms created by tunneling

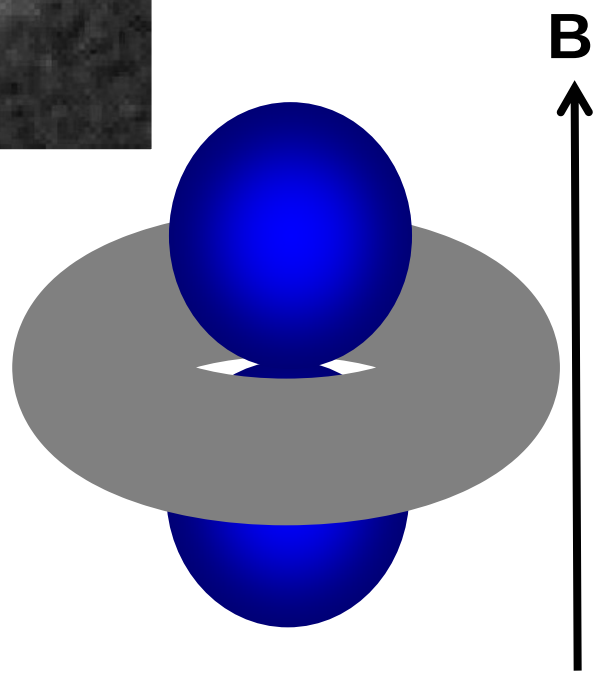
A way to “see” molecules



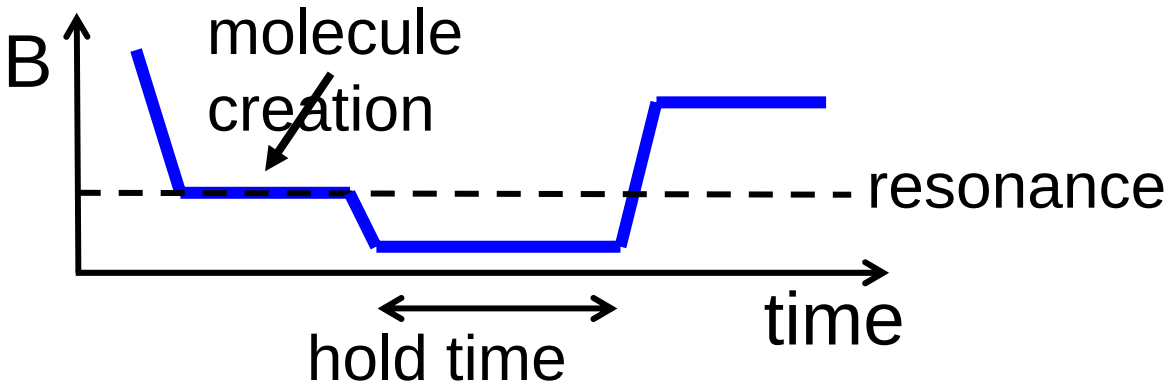
$m_l = \pm 1$

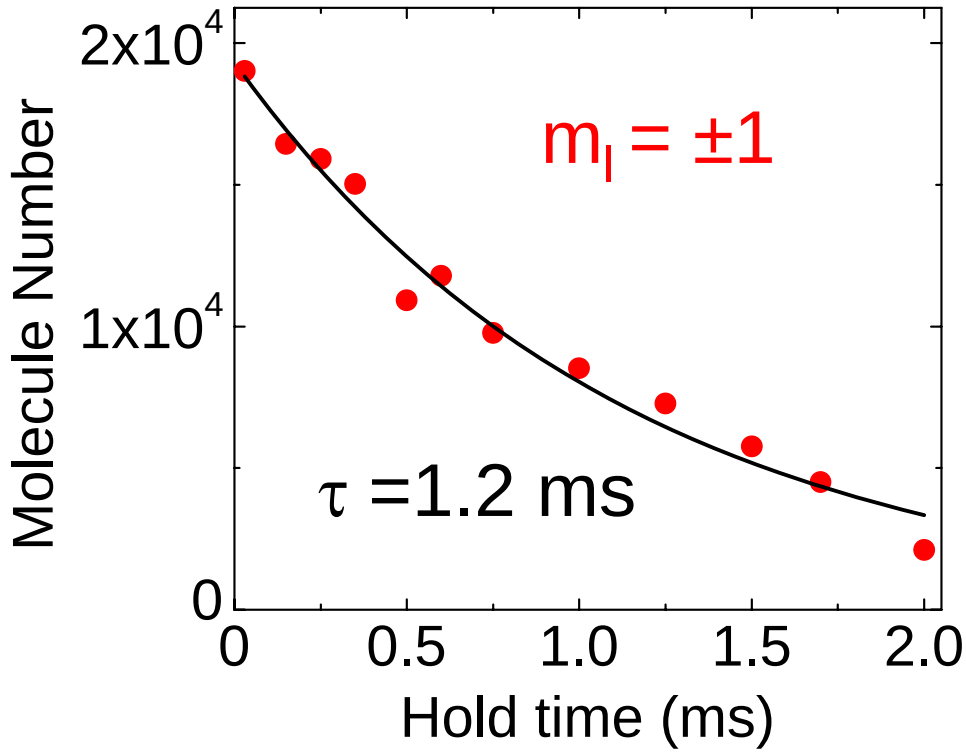


$m_l = 0$

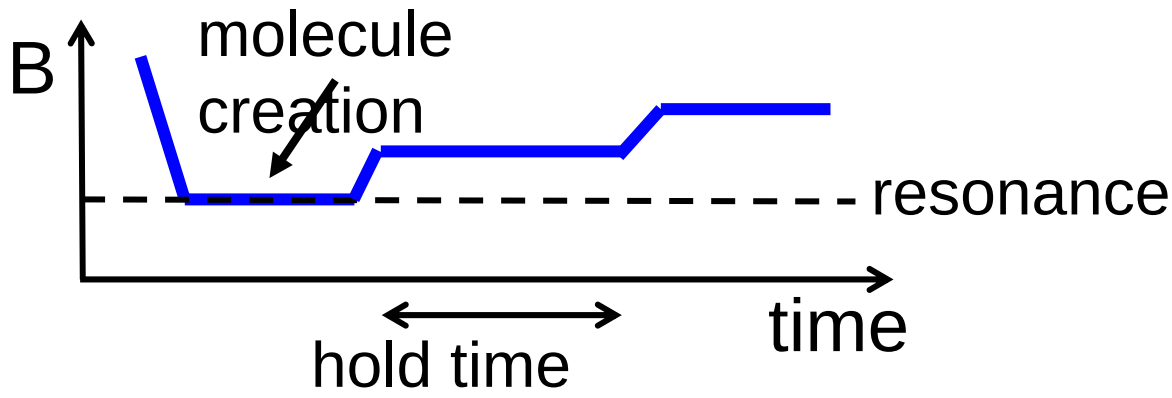


Molecule lifetime

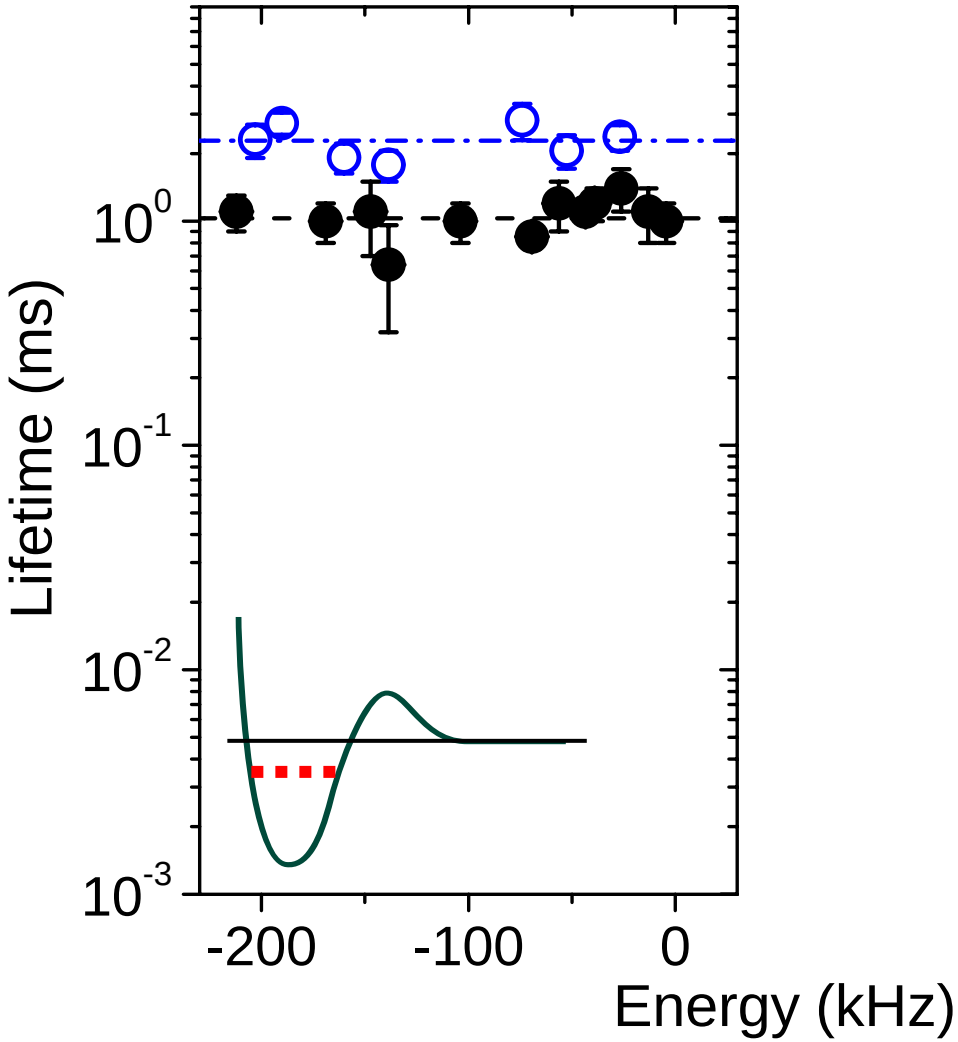




Quasi-bound molecule lifetime



Molecule Lifetimes



$m_l = 0$

$m_l = \pm 1$

J.P. Gaebler, J.T. Stewart, J.L. Bohn, & D.S. Jin, cond-mat/070308

Dipolar relaxation

Since our atoms are not in the lowest energy spin state, the molecules can undergo “one-body” decay.

bound **free**

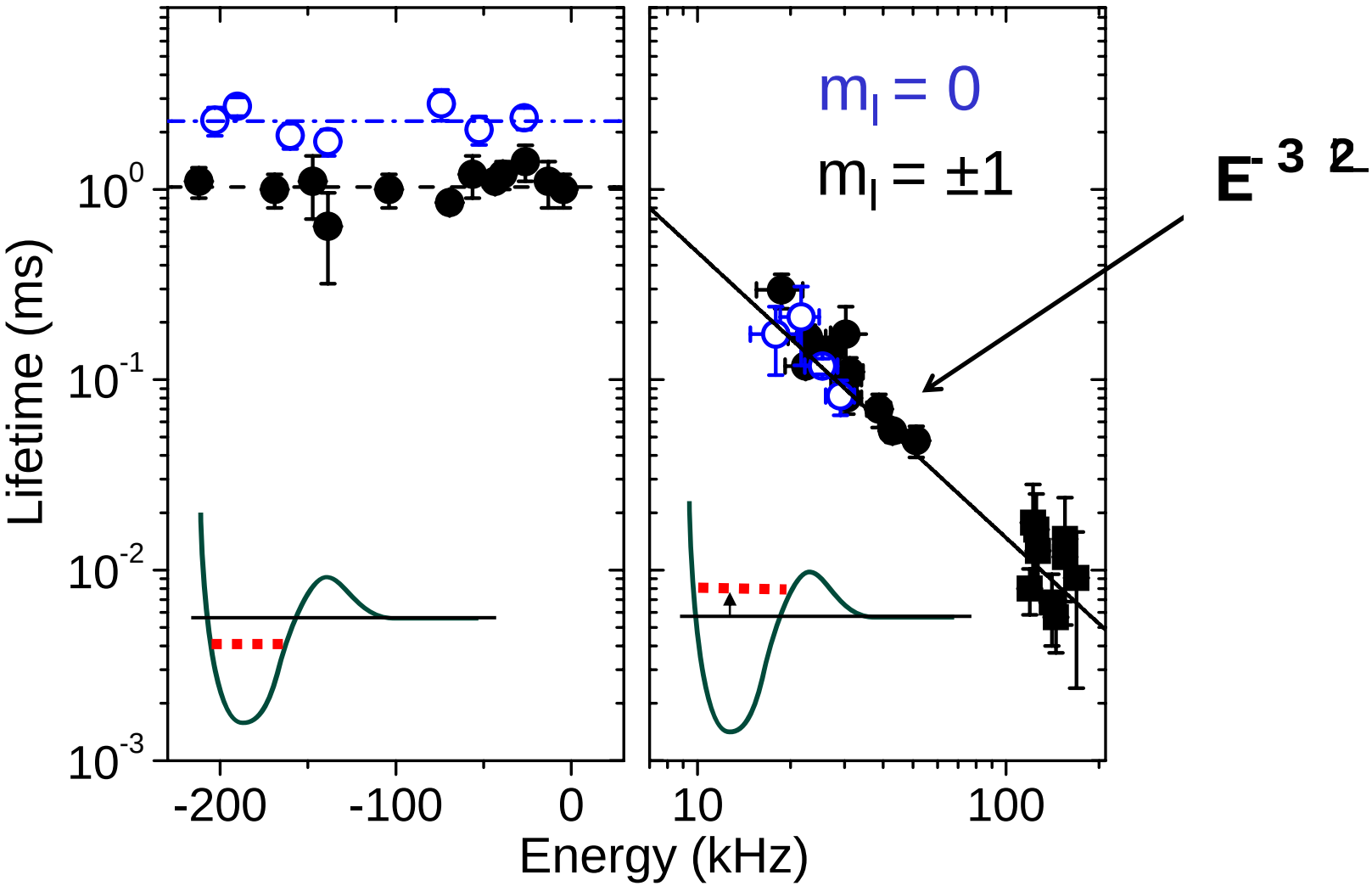
$$\left|\frac{9}{2},\frac{-7}{2}\right\rangle+\left|\frac{9}{2},\frac{-7}{2}\right\rangle\longrightarrow\left|\frac{9}{2},\frac{-9}{2}\right\rangle+\left|\frac{9}{2},\frac{-9}{2}\right\rangle$$

$$\longrightarrow\left|\frac{9}{2},\frac{-7}{2}\right\rangle+\left|\frac{9}{2},\frac{-9}{2}\right\rangle$$

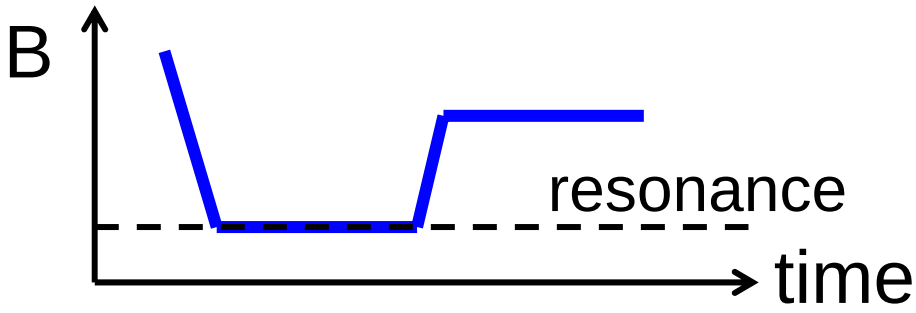
This decay process would not exist for atoms in the lowest energy spin state.

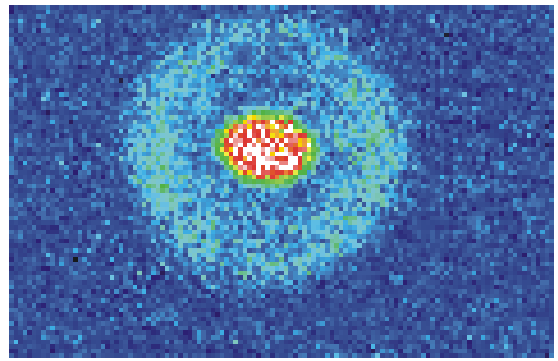
(^{6}Li has such a p-wave resonance).

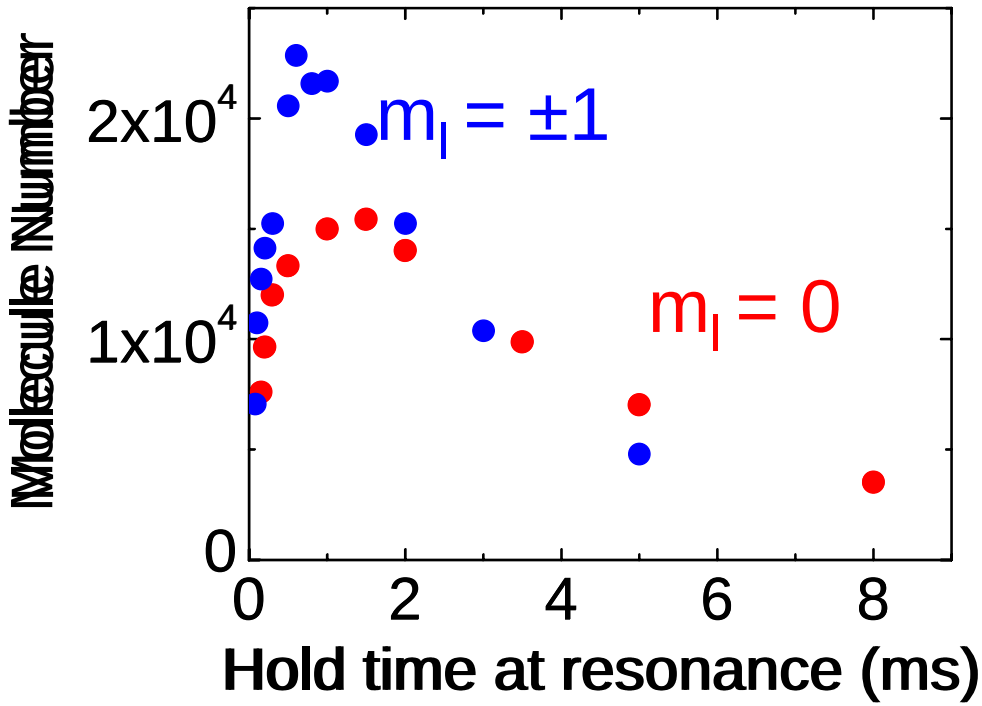
What's next?


$m_l = 0$
$m_l = \pm 1$
$E^{-3/2}$
Lifetime (ms)
10^0
10^{-1}
10^{-2}
10^{-3}
-200
-100
0
10
100
Energy (kHz)

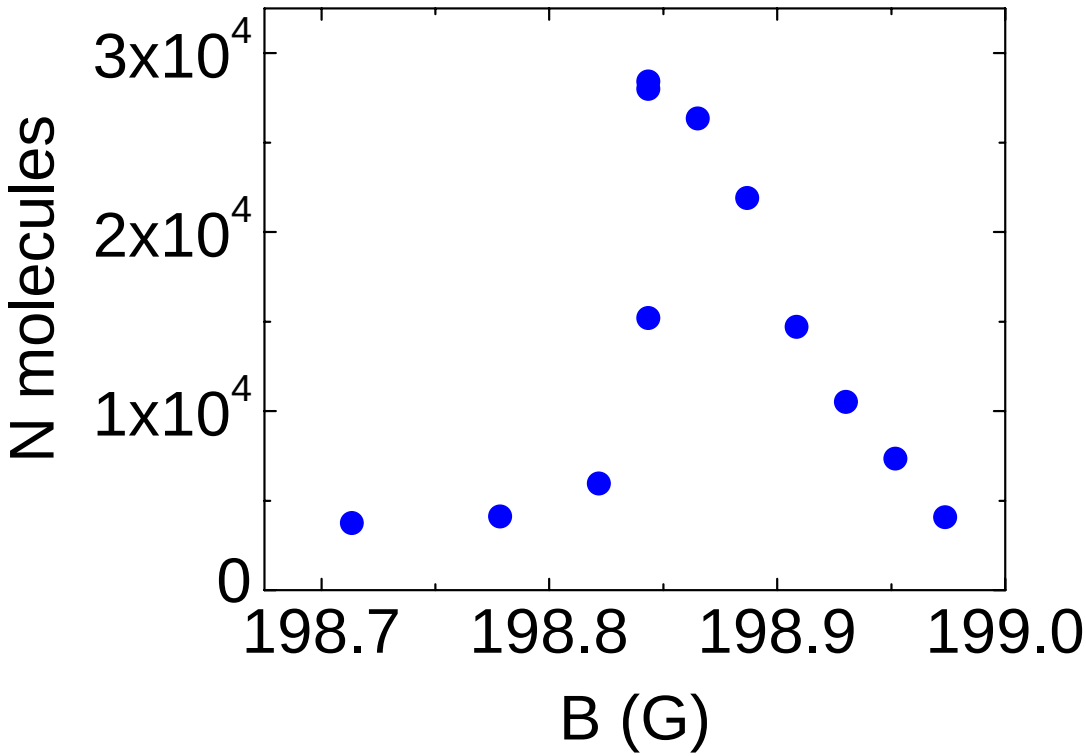
Molecule Creation







Molecule Creation

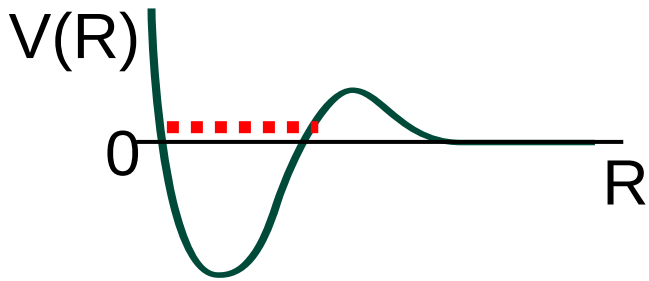


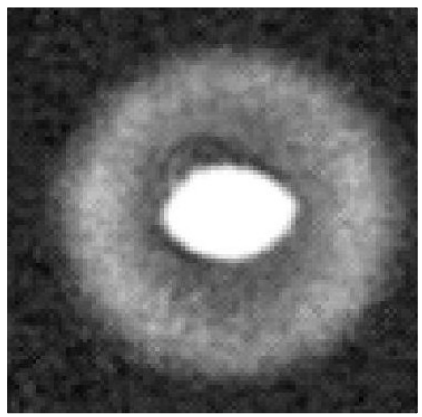
Conclusion:

We can create and detect p-wave Feshbach molecules
in our Fermi gas of atoms.

Novel aspects include:

- Centrifugal barrier
- Quasi-bound state
- Narrow resonance





Group Members

P-wave molecule work: Jayson Stewart, John Gaebler