Feshbach Resonances in Ultracold Atoms: The Ultimate Knob

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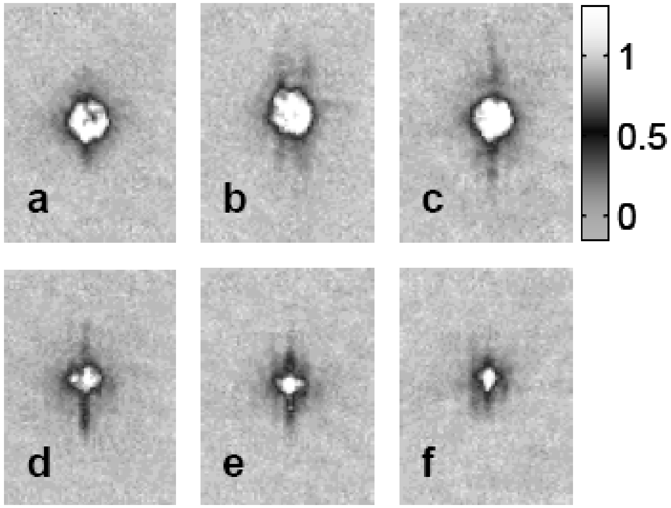
Physics 250, Spring 2006

Scattering Length

Outline

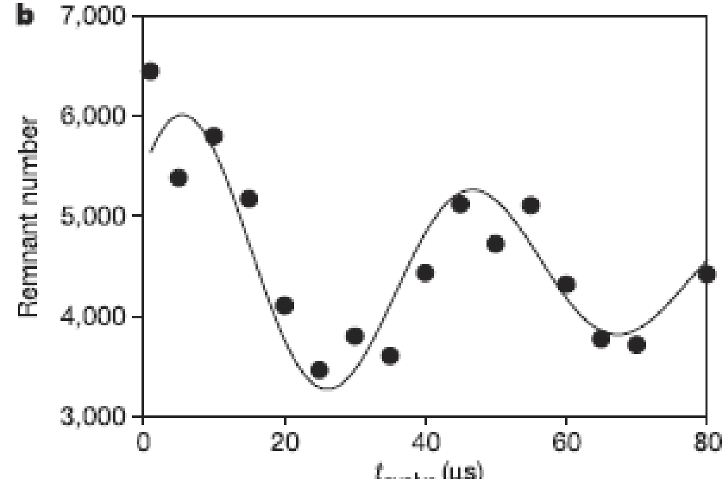
- Motivation
- Basic Scattering theory: s-wave scattering and scattering length
- The resonance
- Magnetic Field Dependence
- What’s hot in the ultracold

Feshbach Resonances in the News



Donley, E. *et.al*. Nature 412, 295

Bosenova

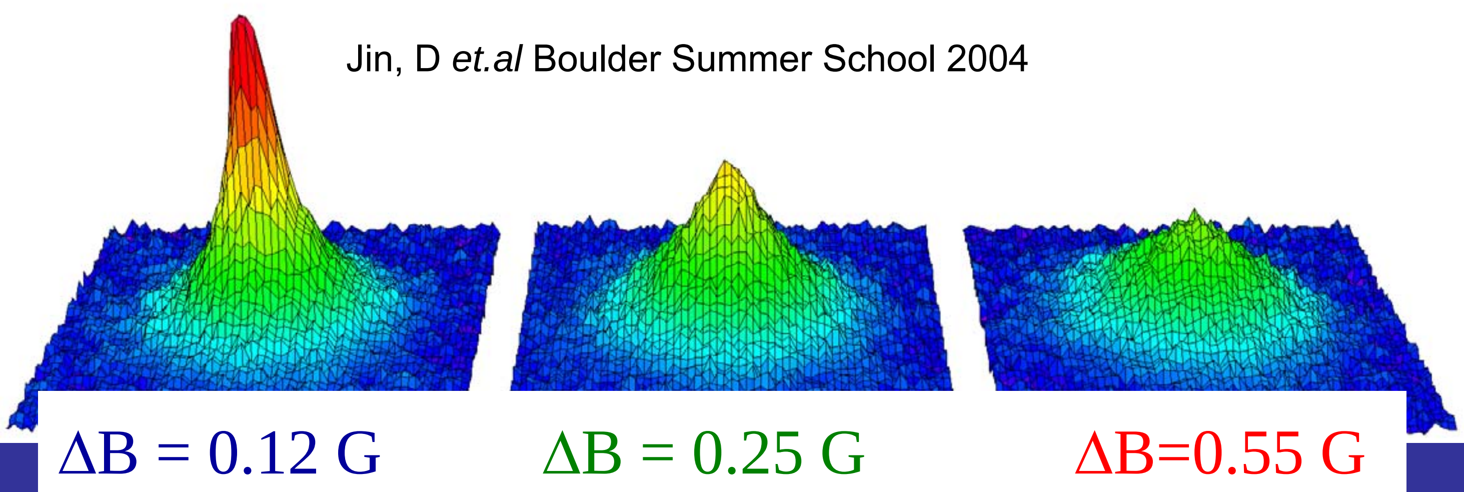


Donley, E. et.al. Nature 417, 529

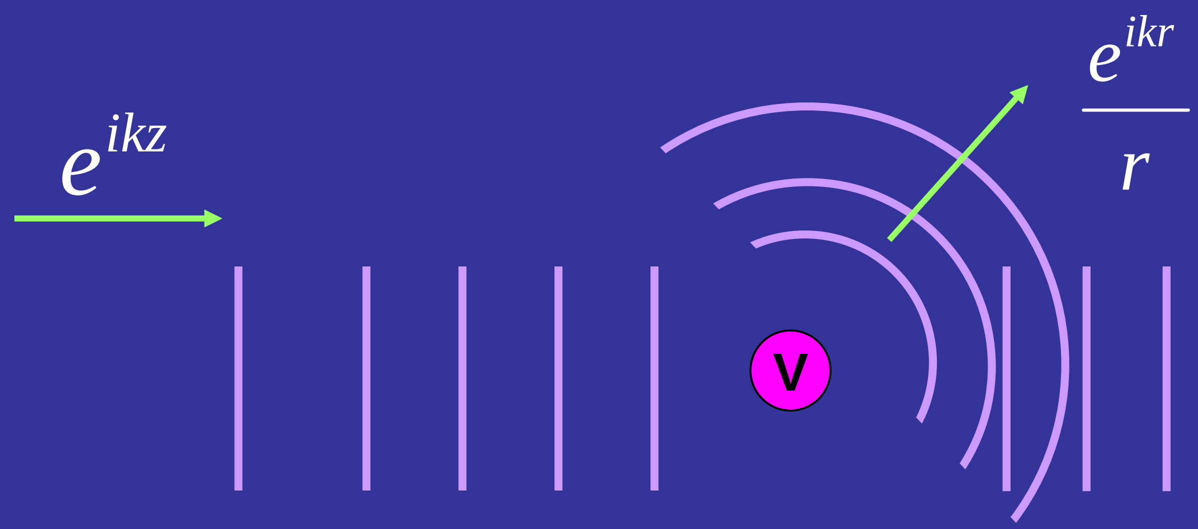
Ultra-Cold Molecules

BEC-BCS crossover

Jin, D *et.al* Boulder Summer School 2004



Spherically Symmetric Potential



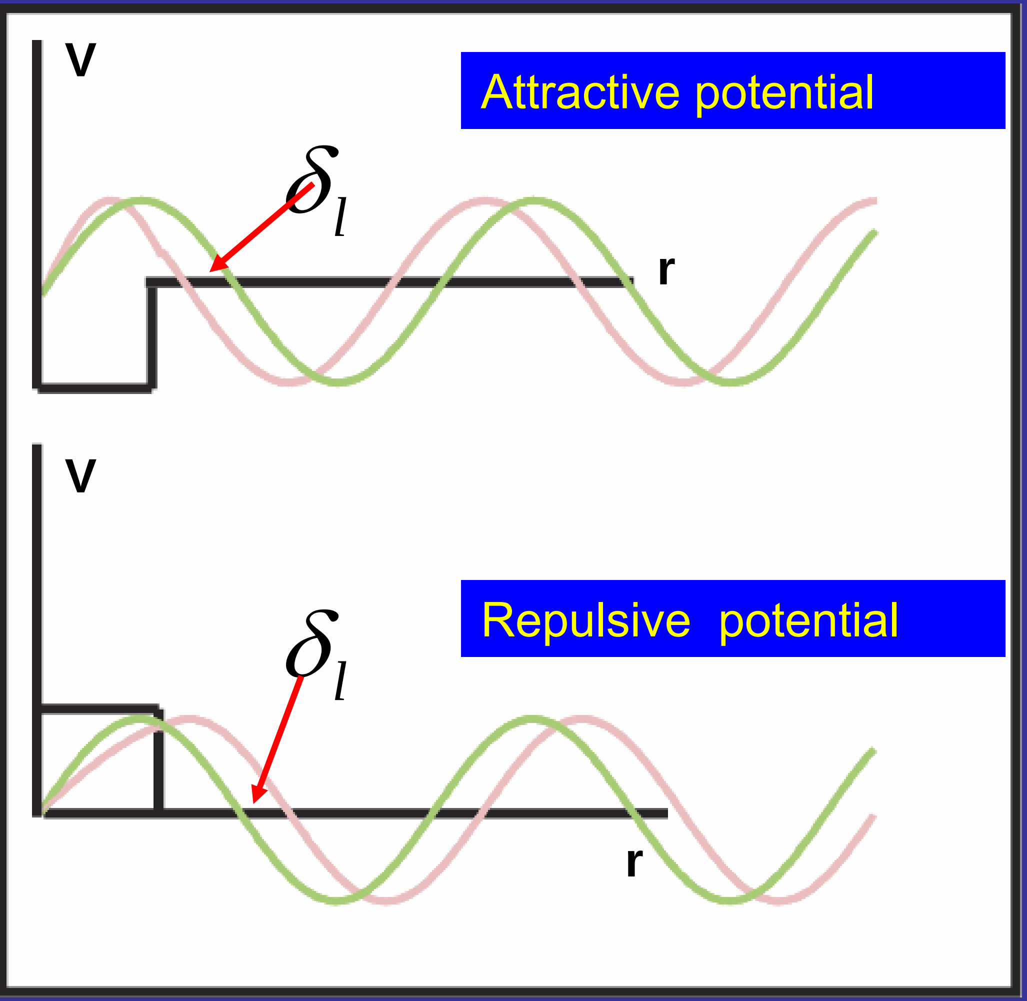
For a spherically symmetric potential :

$$\Psi(r,\theta,\phi) = R(r)Y_{lm}(\theta,\phi)$$

As R→∞

$$\Psi = Ae^{ikz} + Af(\theta)\frac{e^{ikr}}{r}$$

Phase Shifts



$$f(\theta) = \frac{1}{k}\sum_{l=0}^{\infty}(2l+1)e^{i\delta_l}\sin\delta_l P_l(\cos\theta)$$

$$\frac{d\sigma}{d\Omega} = |f(\theta)|^2$$

$$\sigma = \frac{4\pi}{k}\,\mathrm{Im}(f(0))$$

For low T, only ℓ=0 is important
→ s-wave scattering

$$\sigma = \frac{4\pi}{k^2}\sin^2\delta_0 = 4\pi a^2$$

The importance of being "a"

For cold gases a determines interactions

In BEC, $\mu = \frac{4\pi\hbar^2 a}{m} n$

a>0 $\delta<0$ repulsive interaction → Stable, large BEC eg. ^{87}Rb

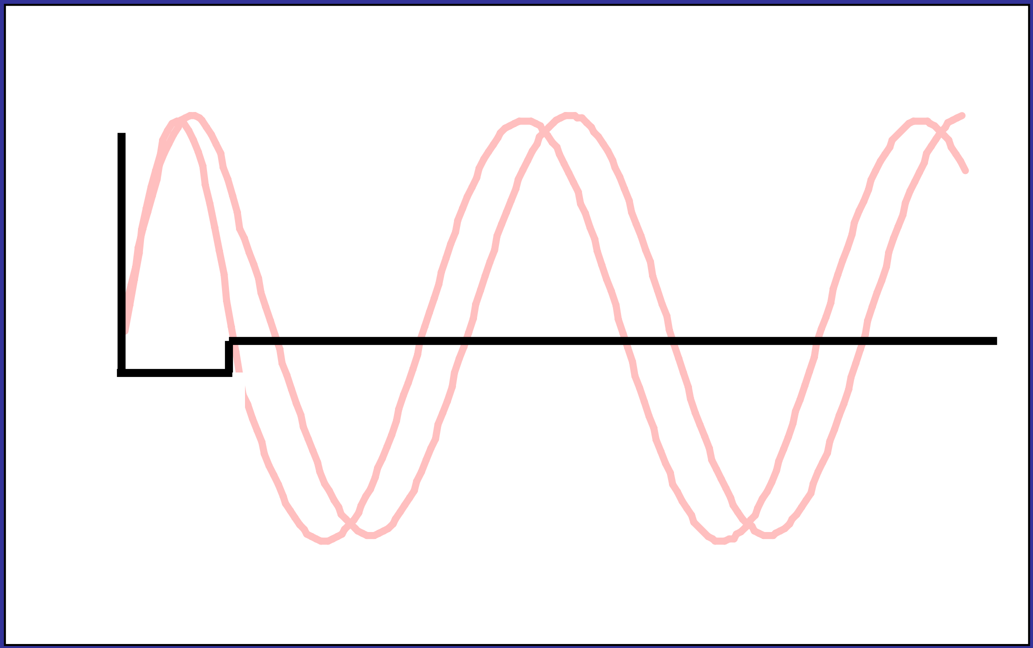
a<0 $\delta>0$ attractive interaction → Unstable, small BEC eg. ^{85}Rb

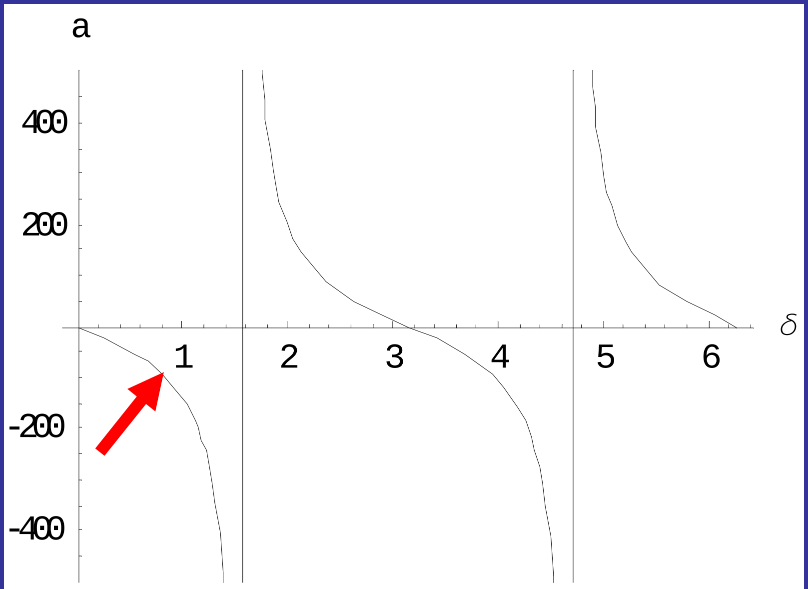
In fermions:

a>0 → weakly bound bosonic molecules

a<0 → Cooper pairing

Bound States

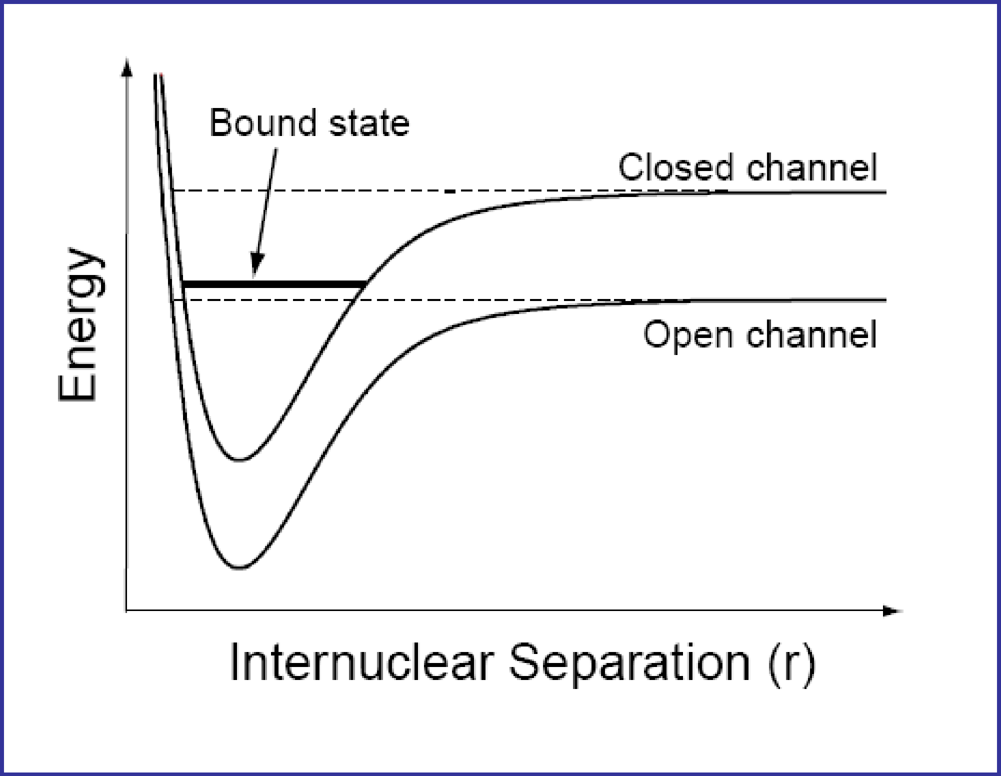




$a \sim -\tan\delta_0/k$

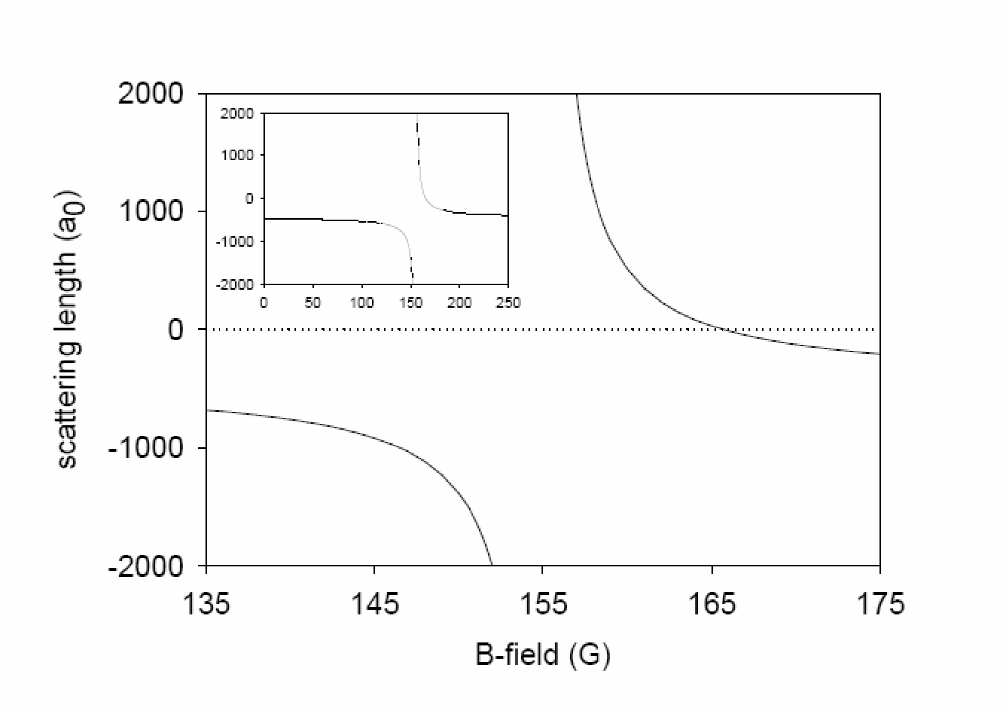
limit $k \to 0$

Feshbach Resonance



- $KE_{\text{atoms}} = Energy_{\text{bound state}}$
- Channels coupled by Hyperfine interaction
- Total spin not conserved
- Total m_F is conserved

Magnetic Field Dependence



Different magnetic moments between atoms/molecules

$$a(B) = a_n\left(1 + \frac{\Delta}{B - B_0}\right)$$

Δ width of resonance

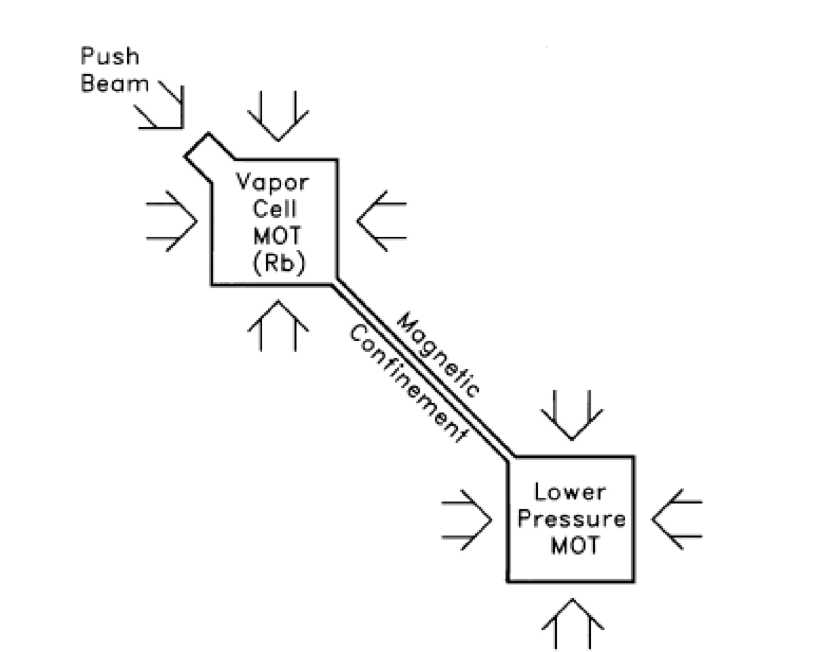
B_0 resonant magnetic field

155 G Feshbach Resonance ^{85}Rb

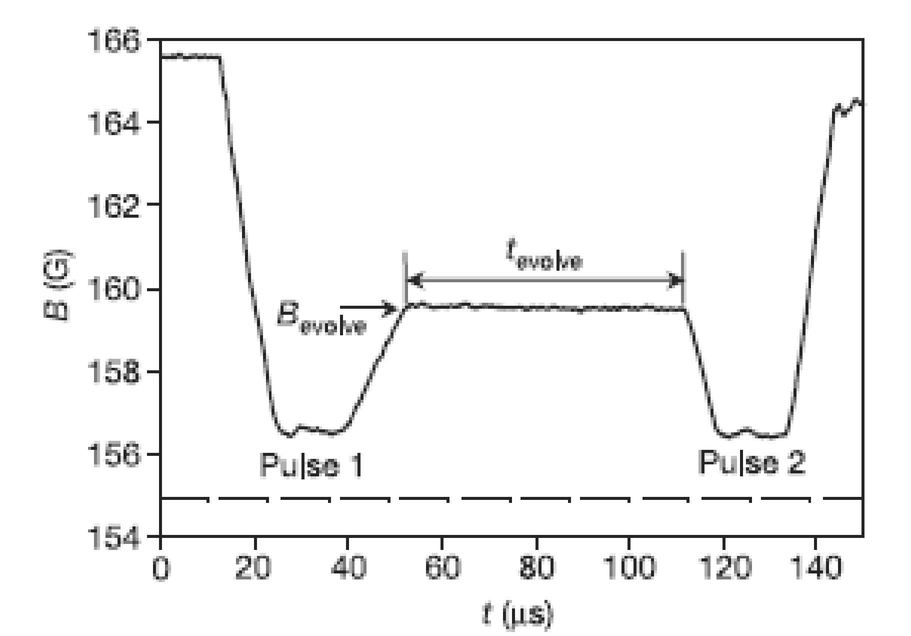
Claussen Thesis

http://jilawww.colorado.edu/pubs/thesis/claussen

Atom-Molecular Coherence in a BEC: Experimental setup



Myatt, C.. *et.al* Optics Letters 21 290



Ramsey Experiment

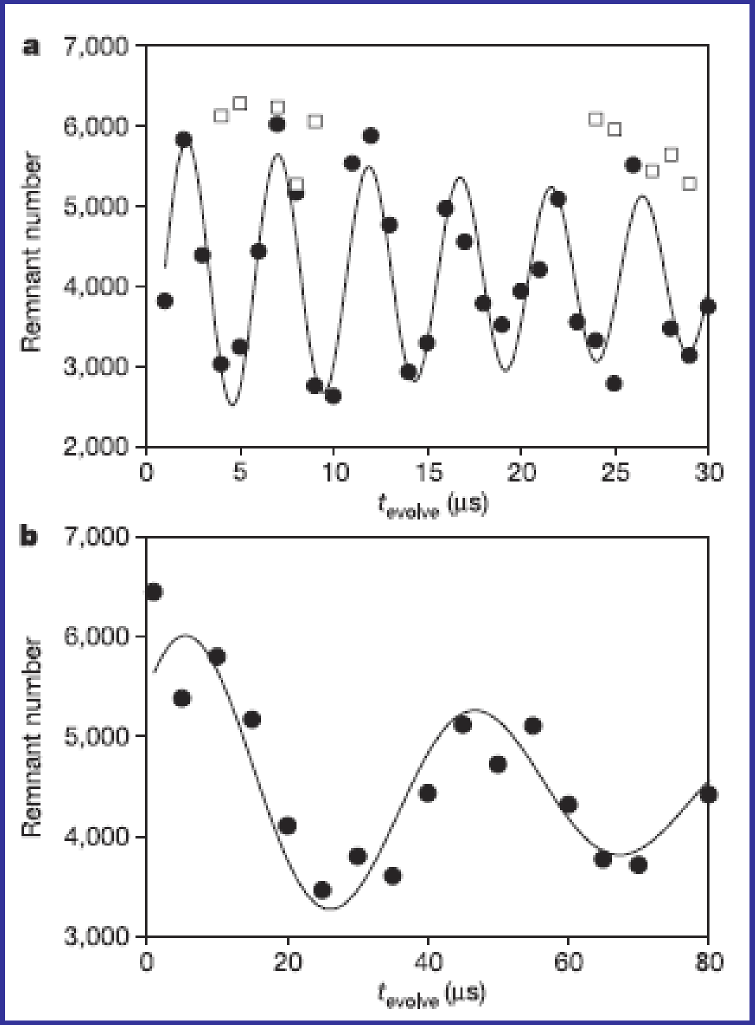
16,000 ^{85}Rb nearly pure BEC in F=2 m_F=-2 state

a_{init}~$10a_0$

a_{evolve}~$570a_0$

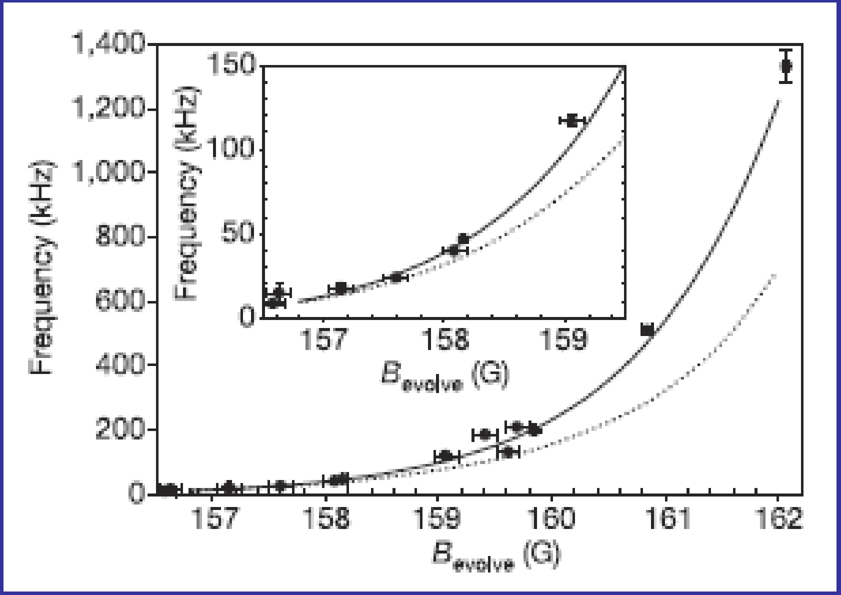
Donley, E. *et.al* Nature 417 529

Molecular Conversion



Approximate potential as : $\varepsilon = -\hbar^2 / ma^2$

Oscillation frequency given as : $\nu \sim \varepsilon / h$



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