Magnetization dynamics in chromium BECs at low and ultra-low magnetic field

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Interactions in BECs

Van der Waals / contact interactions :
short range and isotropic at low T

Effective potential $a_S\ \delta(R)$, with a_S = scattering length in channel S,
a_S is magnetically tunable through Feshbach resonances

Dipole-dipole interactions : long range and anisotropic
magnetic atoms **Cr,** Er, Dy; dipolar molecules; Rydberg atoms

Chromium atoms carry a magnetic moment of $6\mu_B$

Magnetic Dipole-Dipole Intereactions are 36 times bigger than in alkali BECs

We produce and study ^{52}Cr Bose-Einstein Condensates

PART ONE OF THE TALK :

DIPOLAR RELAXATION INHIBITION
at low magnetic field (few 10 mG) when the BEC is loaded into an optical lattice.

How a 2D lattice can stabilize an unstable BEC ?

Inelastic collisions - dipolar relaxation DR

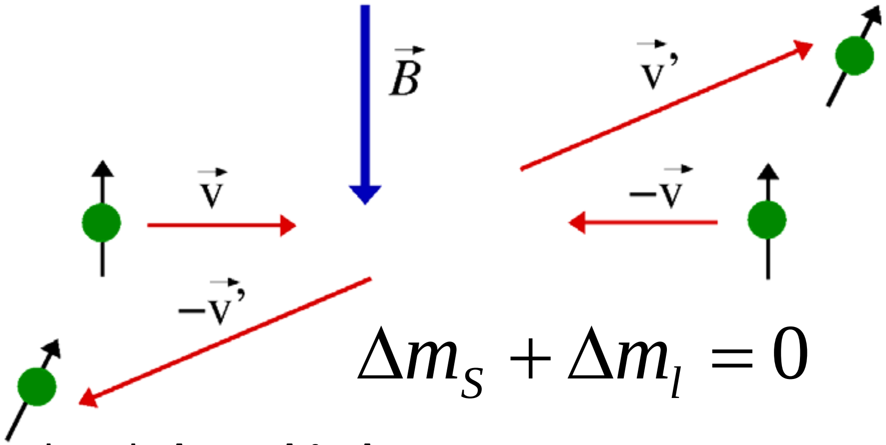
$$V_{dd}(\vec{r}) = \frac{\mu_0 (g_J \mu_B)^2}{4\pi} \frac{\hat{s}_1 \cdot \hat{s}_2 - 3(\hat{s}_1 \cdot \vec{u}_r)(\hat{s}_2 \cdot \vec{u}_r)}{r^3}$$

Conservation of the total angular momentum

- 2 channels : (S=3, m=+3 Cr atoms)

$$\left|+3,+3,\ell=0,m_\ell=0\right\rangle \overset{(1)}{\rightarrow} \frac{\left|+3,+2\right\rangle+\left|+2,+3\right\rangle}{\sqrt{2}}\left|\ell=2,m_\ell=1\right\rangle$$

$$\overset{(2)}{\rightarrow} \left|+2,+2,\ell=2,m_\ell=+2\right\rangle$$



$$\Delta m_S + \Delta m_l = 0$$

- During dipolar relaxation, Zeeman energy is released and **also orbital momentum** of the two collining particules is changed.

$$\frac{\hbar^2 k_f^{j\,2}}{m} = \frac{\hbar^2 k_i^{j\,2}}{m} + \Delta E^j$$

$$\Delta m_S = -1$$

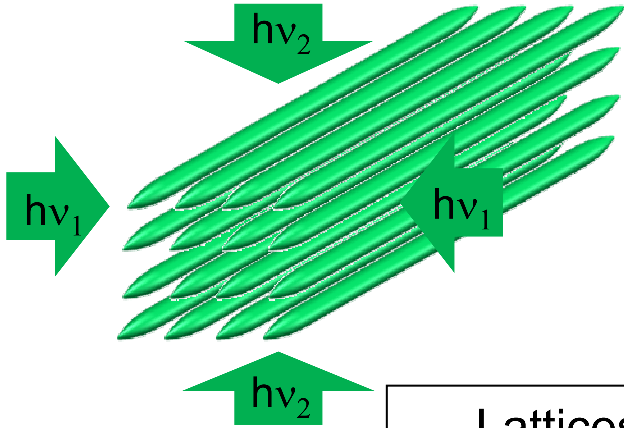
$$\Delta m_S = -2$$

$$\Delta E = g\mu_B B$$
$$\Delta E = 2g\mu_B B$$
$$\Delta\ell = 2$$

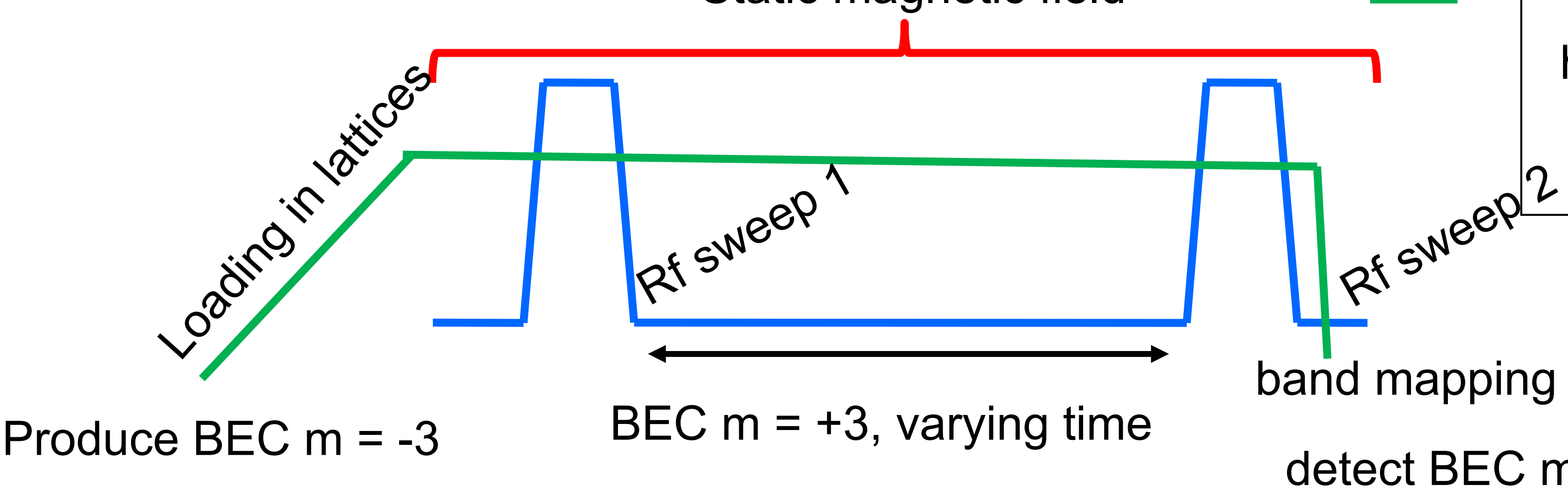
Angular conservation Induces rotation in the BEC ?
Spontaneous creation of vortices ?
Einstein-de-Haas effect
Ueda et al;**Phys. Rev. Lett. 96, 080405 (2006))**

Reduction of dipolar relaxation in optical lattices

Load the BEC in a 2D Lattice



Experimental procedure:

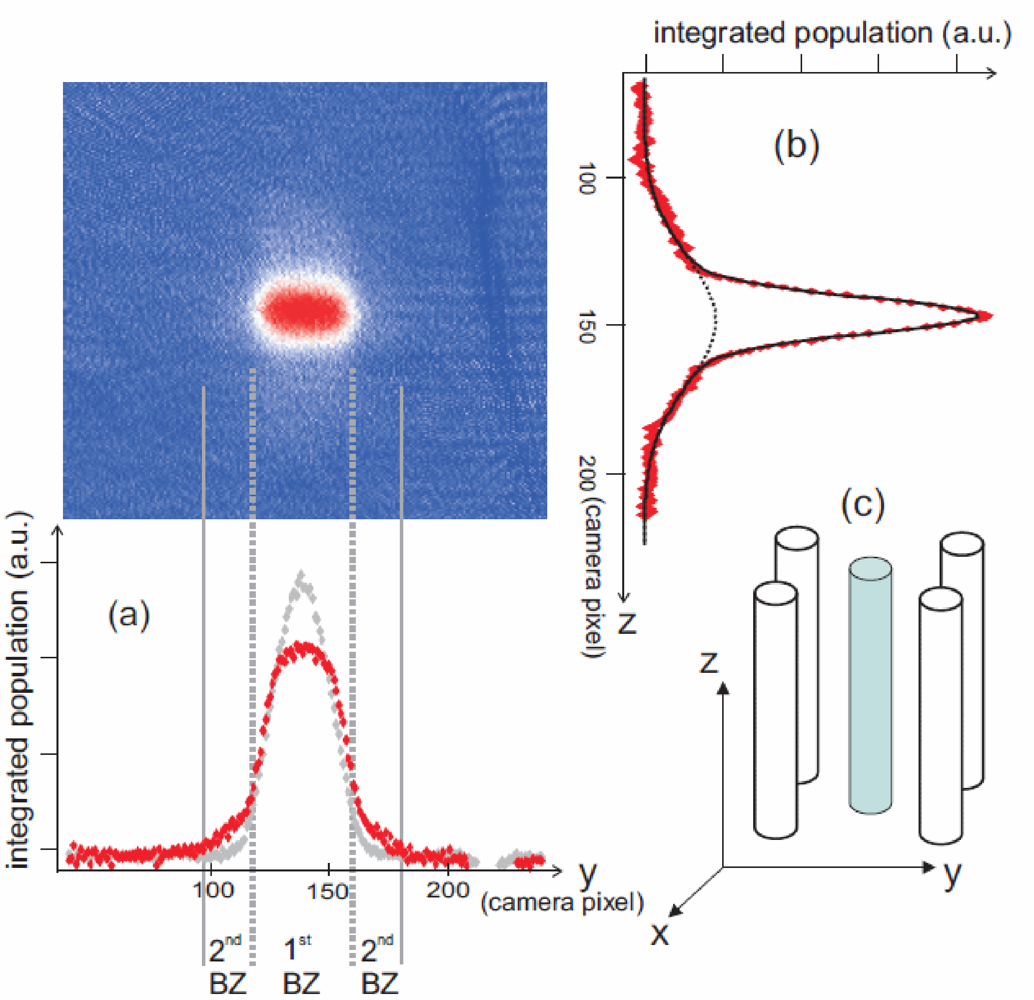


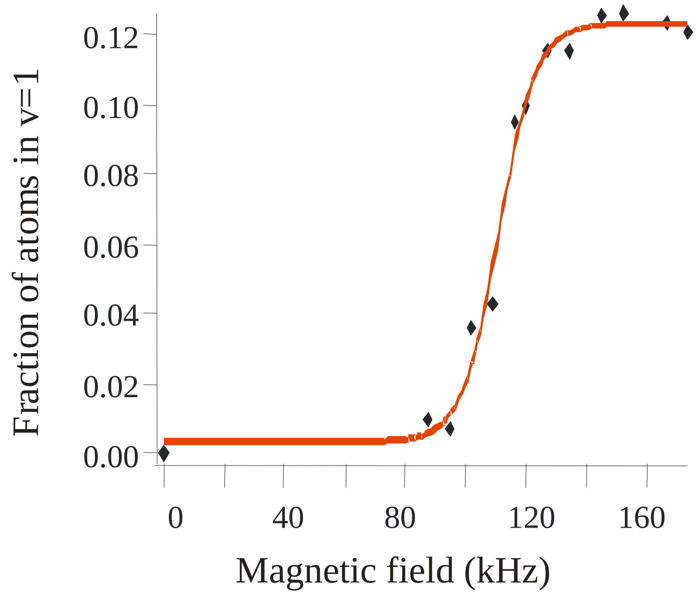
Lattices
height ~ 135 kHz
25 Er

$$\hbar\Gamma \approx \left|V_{dd}\right|^2 \rho\left(\varepsilon_f\right)$$

One expects a reduction of dipolar relaxation, as a result of the reduction of the density of states in the lattice

Dipolar relaxation inhibition in 1D (below B_c)

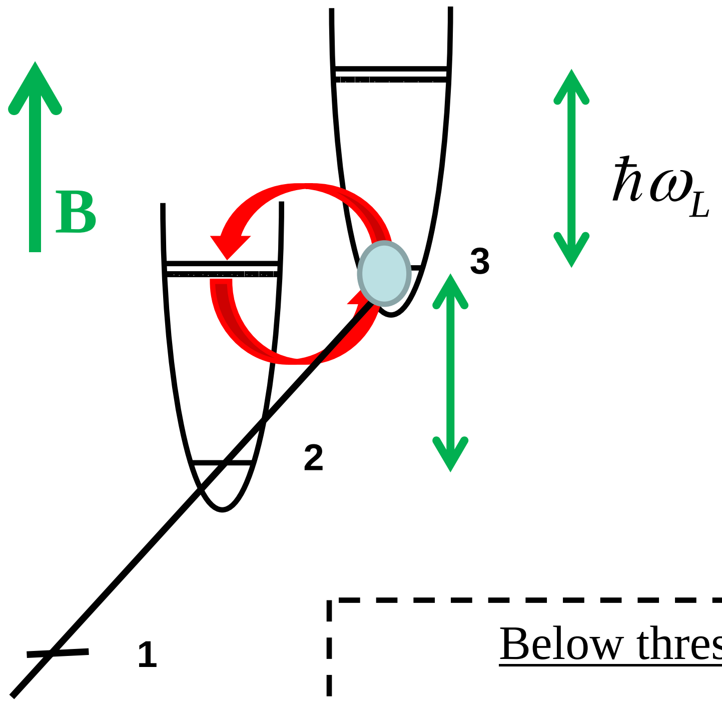




Below Bc the dipolar relaxation rate is reduced by 10^3 compared with 3D

Spin relaxation and band excitation in 1D

Bc ≈ 40 mG



Spin-flipped atoms get promoted from the lowest band to the excited bands when B is over the threshold set by

$$g\mu_B B = \hbar\omega_L$$

Below threshold:

a (spin-excited) metastable 1D quantum gas ;

Interest for spinor physics, spin excitations in 1D…

Above threshold :

should produce vortices in each lattice site (EdH effect) (problem of tunneling)

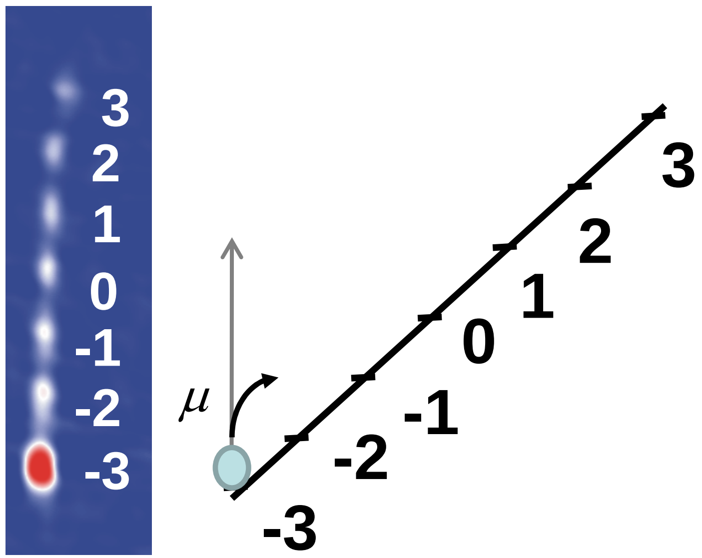
Towards coherent excitation of pairs into higher lattice orbitals ?

PART TWO OF THE TALK

SPONTANEOUS DEMAGNETIZATION OF A SPINOR BEC

What happens at extremely low magnetic fields ?
ie when $g\mu_B B \langle \mu_B$

This happens for **B < few 100 microG**

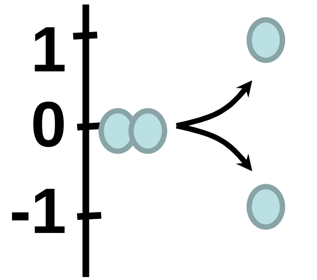


S=3 Spinor physics with free magnetization

- To date, spinor studies have been restricted to S=1 and S=2

-Up to now, all spinor dynamics studies were restricted to constant magnetization

As required by contact interactions

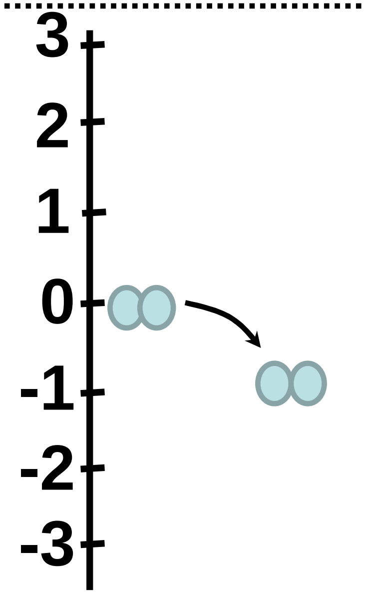


- eg in Rb a pair of colliding atoms stays in the $M = m_{S1}+m_{S2} = 0$ multiplicity

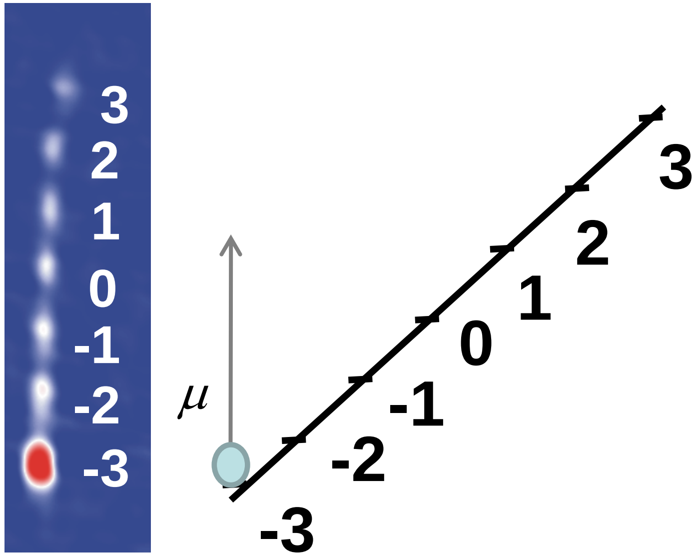
New features with Cr

-First **S=3 spinor**

- Dipole-dipole interactions **free** the **magnetization**
- Possible investigation of the true many-body ground state of the system (which requires **stable and very small** magnetic fields)



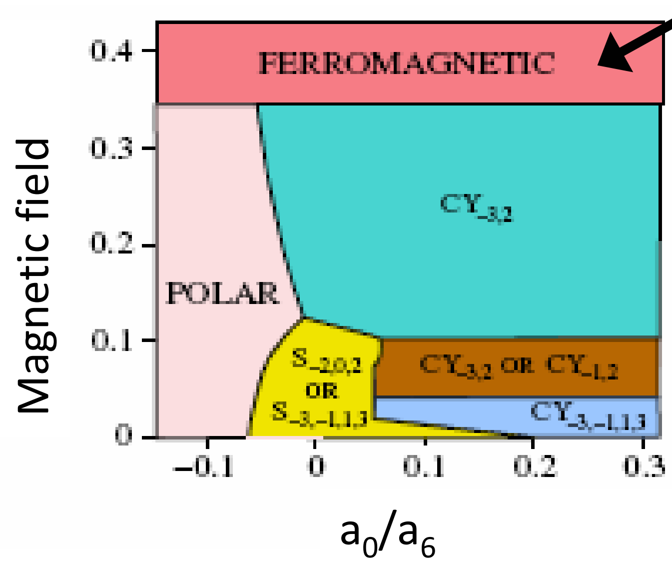
S=3 Spinor physics with free magnetization



7 Zeeman states; all trapped
four scattering lengths, a_6, a_4, a_2, a_0

Phases are set **by contact interactions** (a_6, a_4, a_2, a_0)
– differ by total magnetization

ferromagnetic i.e. polarized in lowest energy single particle state



*Santos PRL **96**, 190404 (2006)*
*Ho PRL. **96**, 190405 (2006)*

Critical magnetic field

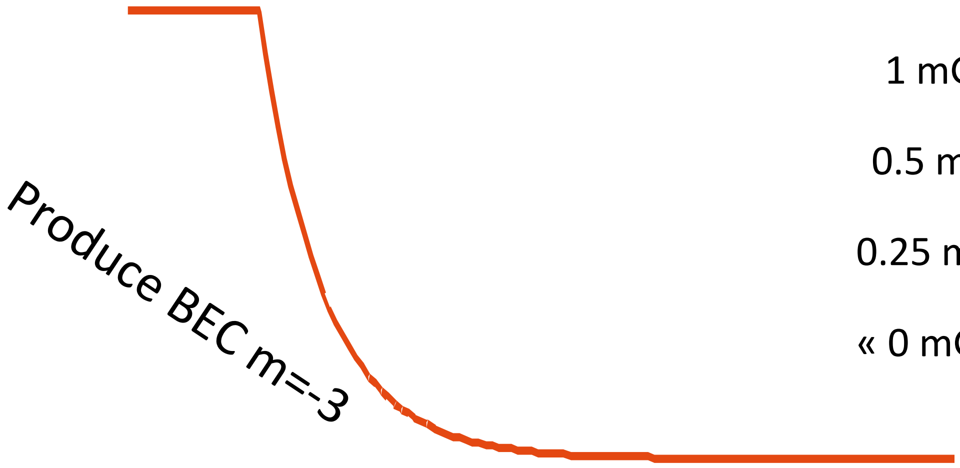
$$g_J \mu_B B_c \approx \frac{2\pi\hbar^2 n_0 \left(a_6 - a_4\right)}{m}$$

(at B_c, it costs no energy to go from m=-3 to m=-2 : difference in interaction energy compensates for the loss in Zeeman energy)

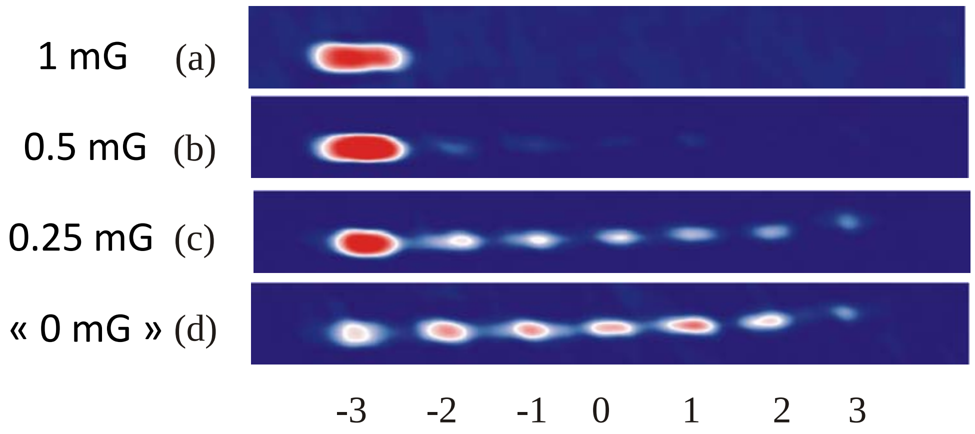
DDI **ensure the coupling between** states with different magnetization

At VERY low magnetic fields,
spontaneous depolarization of 3D and 1D quantum gases

Experimental procedure



Rapidly lower magnetic field

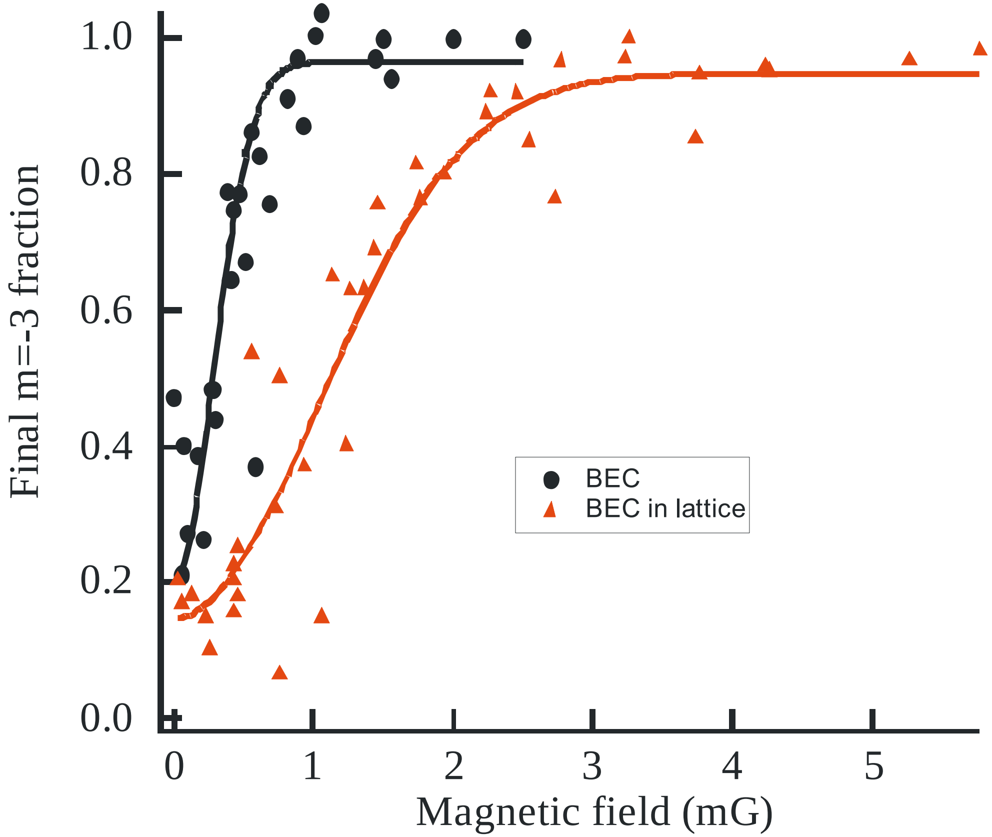


Stern Gerlach experiments

Magnetic field control below .5 mG
(dynamic lock, fluxgate sensors)
(50 Hz noise fluctuations, earth Magnetic field, …)

(.1mG stability)
(no magnetic shield…)
(up to 1H stability)

Mean-field effect: when does the transition take place ?



$$g_J \mu_B B_c \approx \frac{2\pi\hbar^2 n_0 (a_6 - a_4)}{m}$$

	BEC	Lattice
Critical field	0.26 mG	1.25 mG
Demag time	3ms	10ms

Critical field for depolarization depends on the density **(exp check for linearity)**

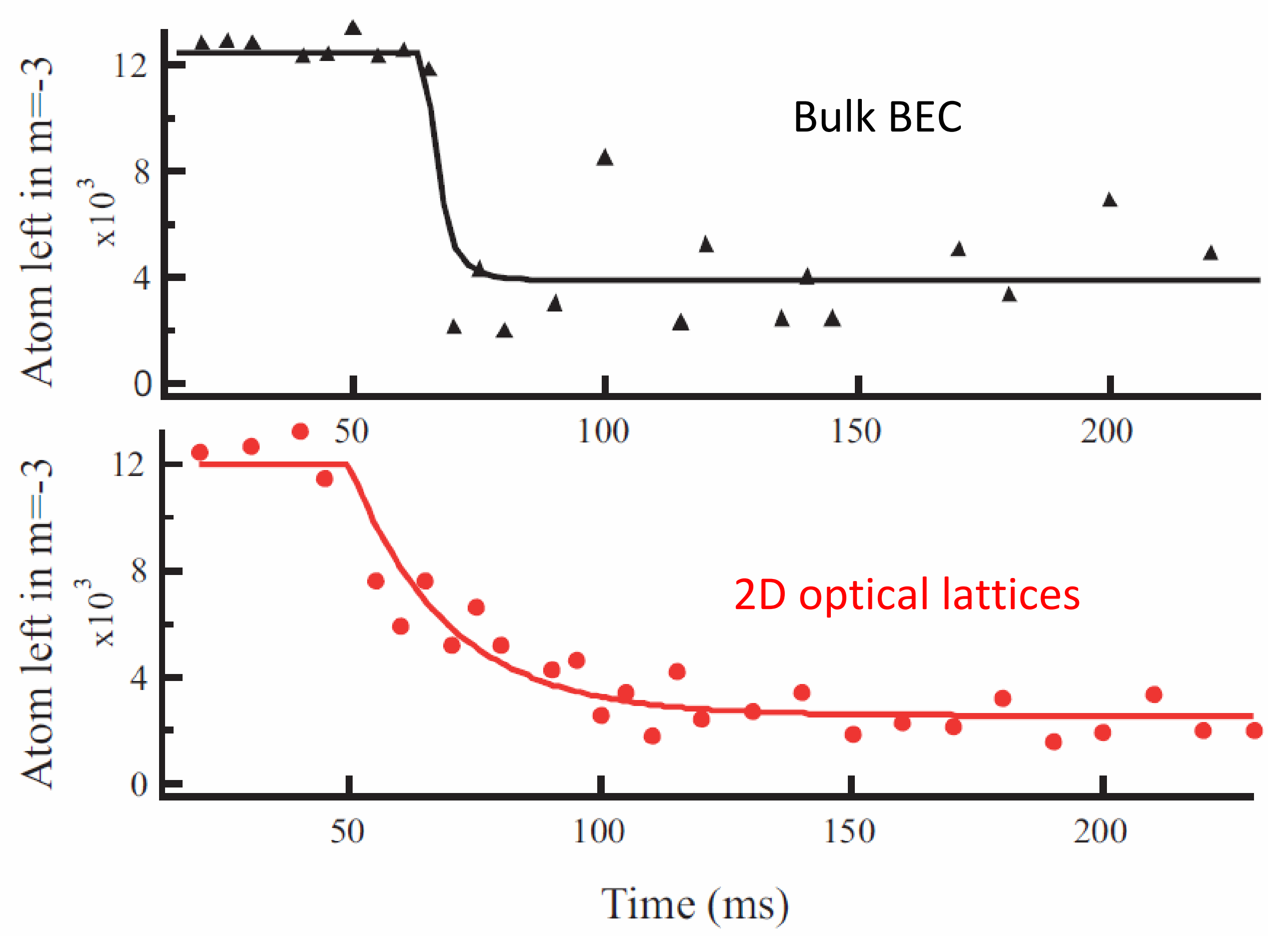
Magnetic field control below 0.5 mG (actively stabilized)

(0.1mG stability)
(no magnetic shield…)

Dynamics analysis

In lattices (in our experimental configuration), the volume of the cloud **is multiplied by 3** → Mean field due to dipole-dipole interaction **is reduced**

↓



Slower dynamics, even with higher peak densities

↓

Non local character of DDI

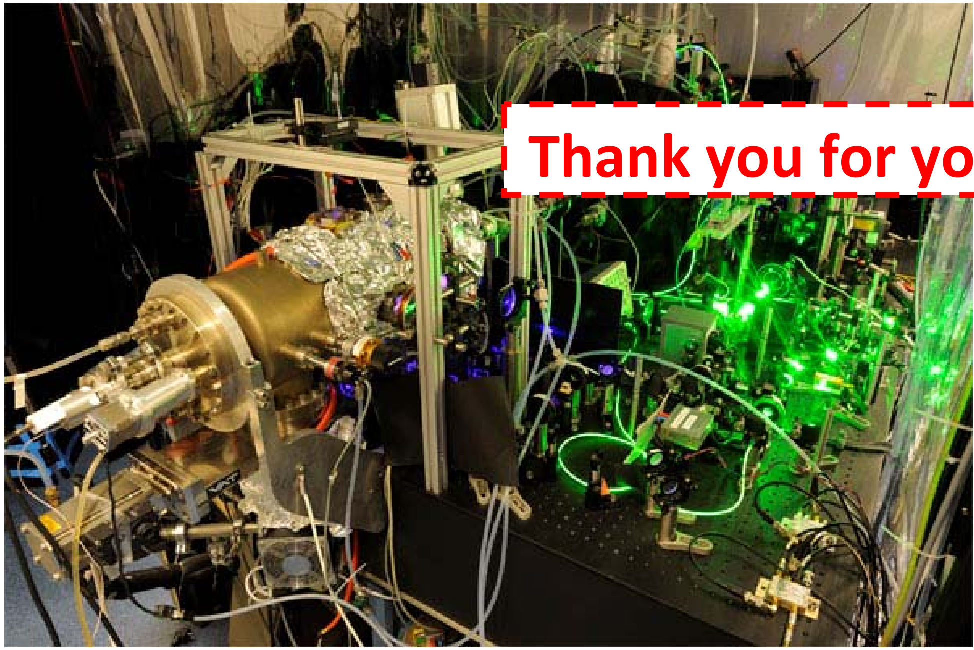
Conclusion

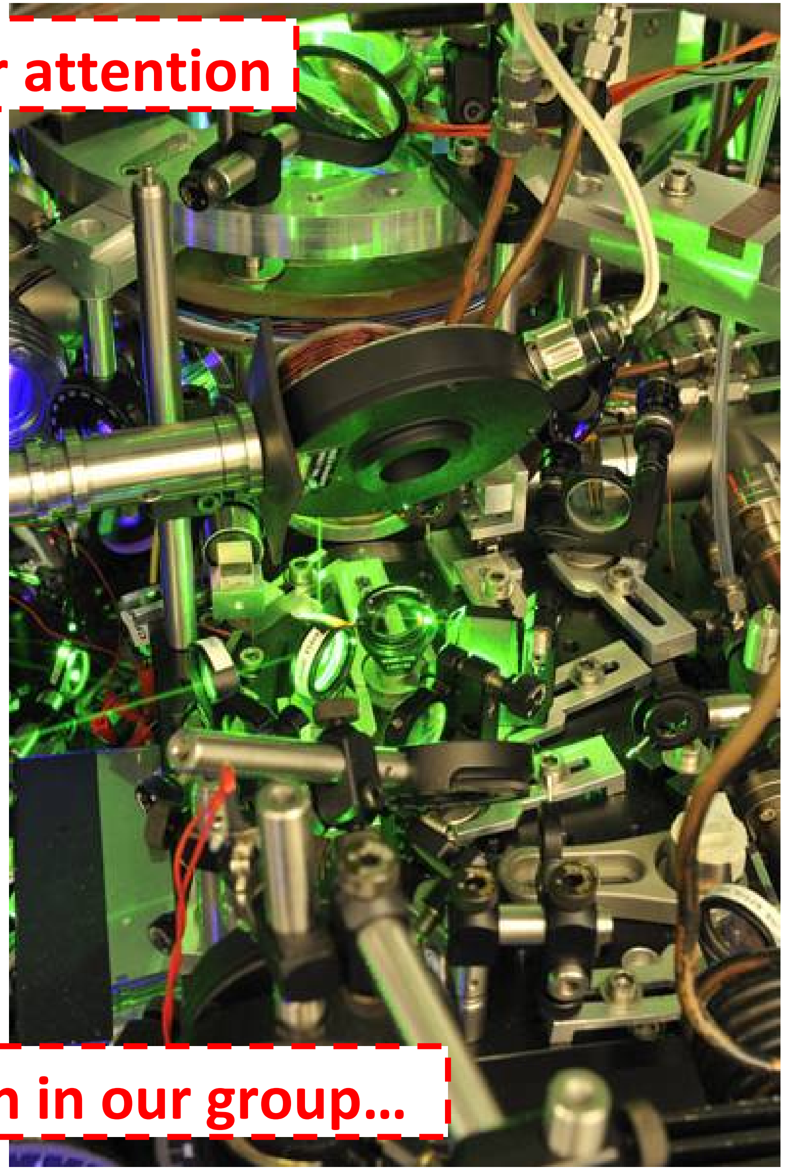
Dipolar relaxation in reduced dimensions:

- almost-suppression of DR
- towards Einstein-de-Haas rotation in lattice sites
(PRL 106, 015301 (2011))

Spontaneous demagnetization in a quantum gas:

- phase transition
- first steps towards spinor ground state**(**
PRL 106, 255303 (2011))
- Spinor thermodynamics with free magnetization
(see POSTER session)





Thank you for your attention

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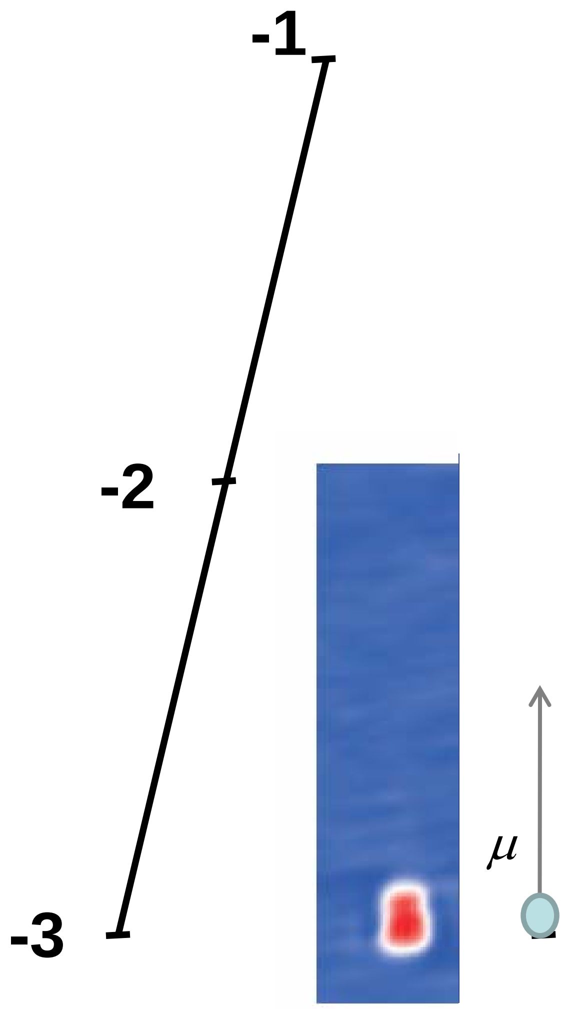
Ferromagnetic phase of the spinor condensate

when B ≈ 4 mG the chemical potential
is much smaller than the Zeeman splittings

Starting point :
BEC in the m= -3 single particle ground state
Procedure:
lower B for example to 1mG
Detection TOF + Stern-Gerlach

Ferromagnetic / polarized phase



Above threshold

Spontaneous demagnetization of the spinor condensate

when the final B ≈ 0.4 mG

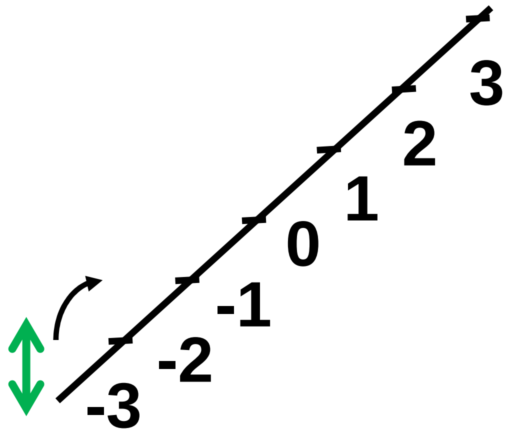
then the chemical potential becomes on the order of Zeeman splittings

Starting point : BEC in the m= -3 single particle ground state

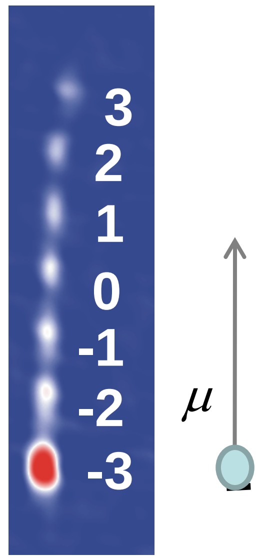
Procedure: lower the magnetic field

Detection TOF + Stern-Gerlach

Above threshold



…spin-flipped atoms *gain* energy



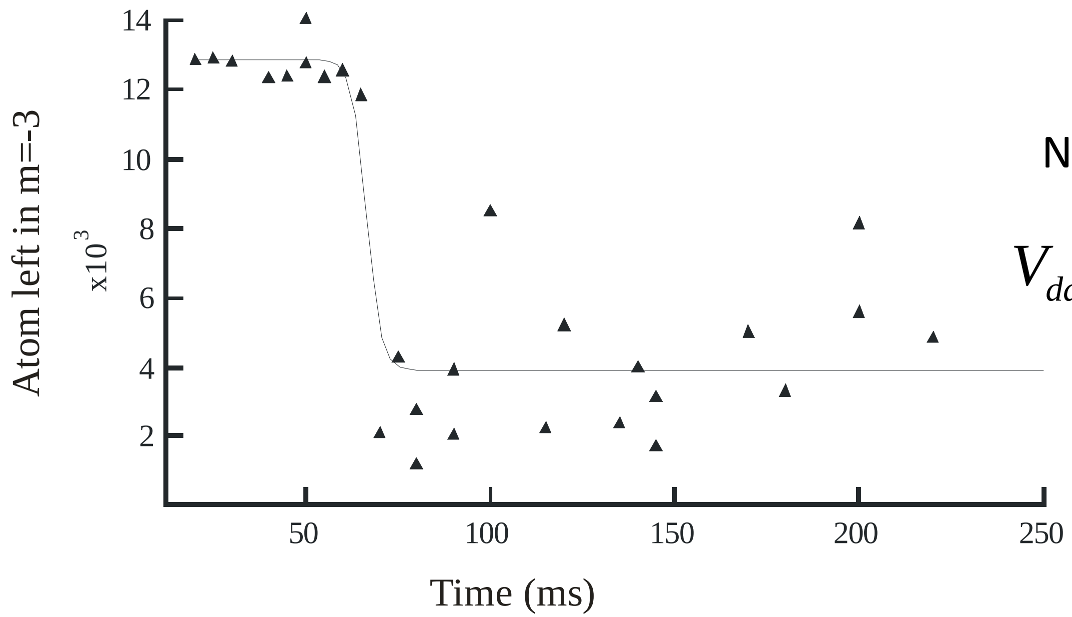
Below threshold

Dynamics analysis

At short times, transfert between m_S = -3 and m_S = -2

~ a two level system coupled by V_{dd}

few atoms in m_S = -2, so collision only in a_6



Natural timescale for depolarization:

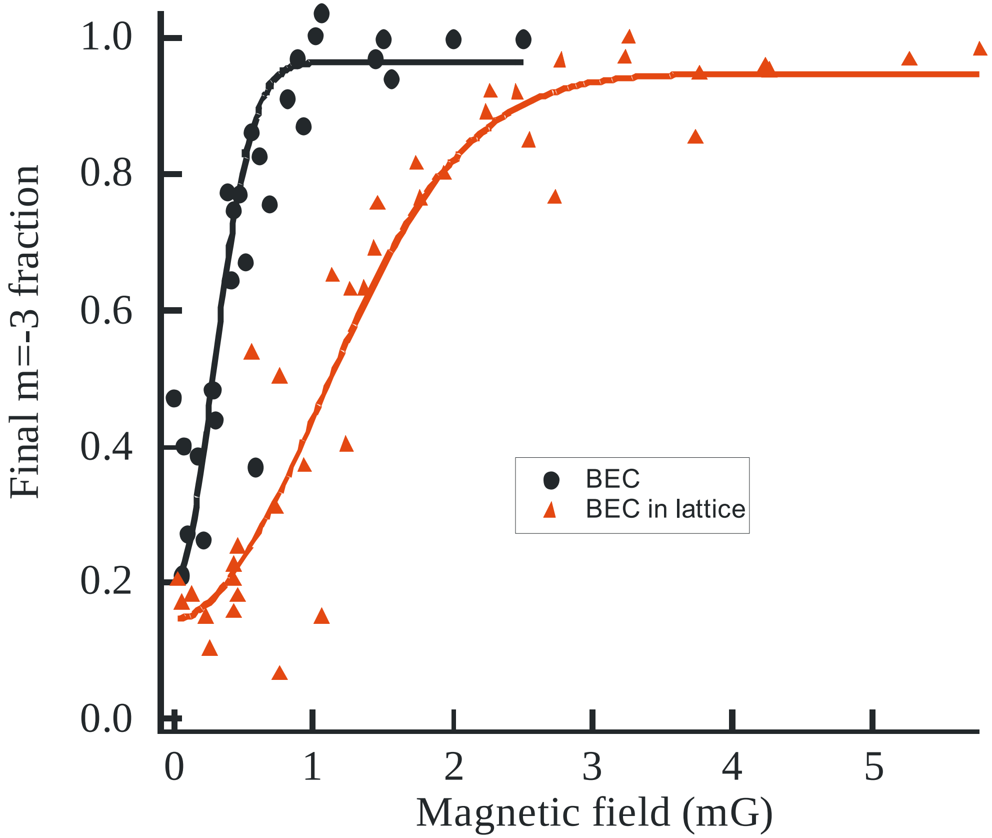
$$V_{dd}\left(r = n^{-1/3}\right) \propto \frac{\mu_0}{4\pi} S^2 \left(g_J \mu_B\right)^2 n$$

(a few ms)

But still unaccounted for B above dipolar meanfield → Influence of the trap / temperature ???

*Ueda, PRL **96**, 080405 (2006) / Kudo Phys. Rev. A **82**, 053614 (2010)*

Mean-field effect



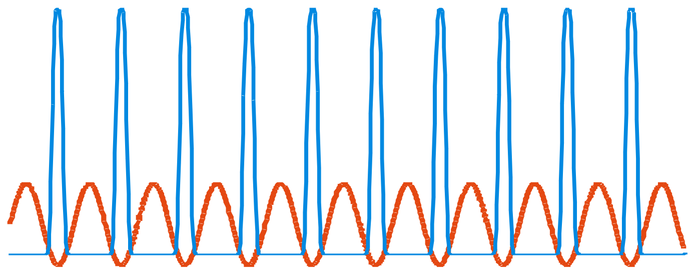
$$g_J \mu_B B_c \approx \frac{2\pi\hbar^2 n_0 \left(a_6 - a_4\right)}{m}$$

	BEC	Lattice
Critical field	0.26 mG	1.25 mG
1/e fitted	0.4 mG	1.45 mG

Critical field value for depolarization depends on density

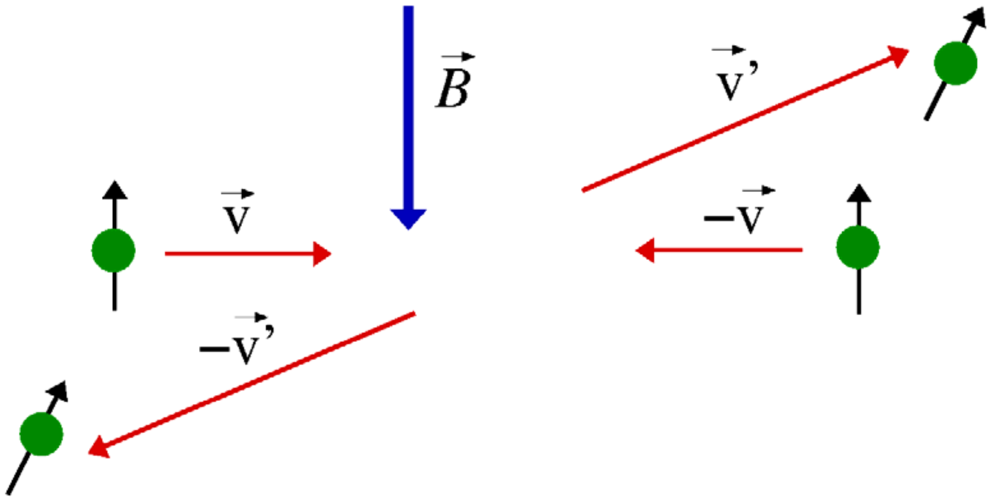
Optical lattices : change only the density, not the symetry for DDI

$$R_c > a_\perp$$



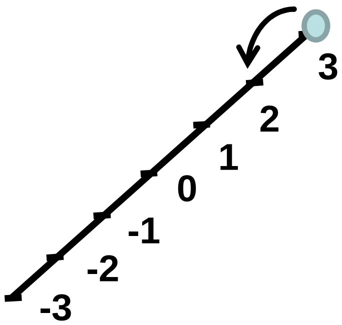
Inelastic collisions - dipolar relaxation DR

$$V_{dd}(\vec{r}) = \frac{\mu_0 (g_J \mu_B)^2}{4\pi} \frac{\hat{s}_1 \cdot \hat{s}_2 - 3(\hat{s}_1 \cdot \vec{u}_r)(\hat{s}_2 \cdot \vec{u}_r)}{r^3}$$



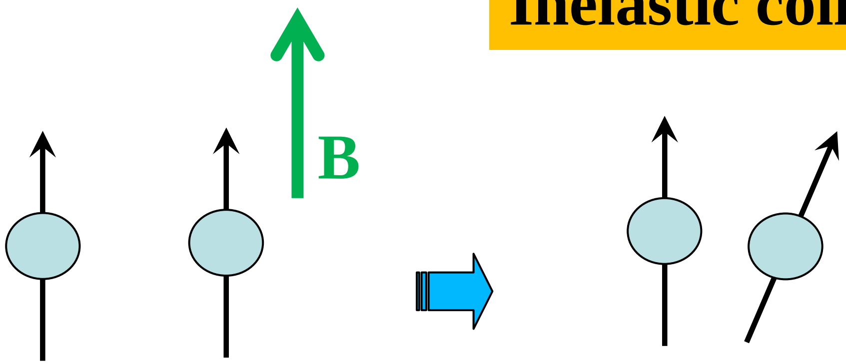
$$\Delta E_{Zeeman} = \Delta m_S g \mu_B B$$

Zeeman energy ladder in B



DR causes heating then losses and the magnetic field strength controls DR

Inelastic collisions - dipolar relaxation DR



Conservation of the total angular momentum

$$\Delta m_S + \Delta m_l = 0$$

2 possible channels for initialy (S=3, m_s=3= atoms)

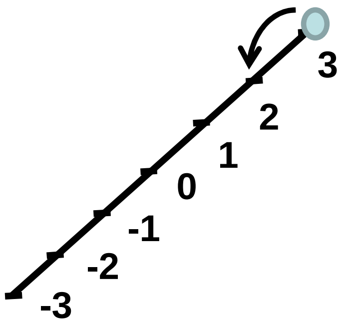
$$\left|+3,+3,\ell=0,m_\ell=0\right\rangle \xrightarrow{(1)} \frac{\left|+3,+2\right\rangle + \left|+2,+3\right\rangle}{\sqrt{2}} \left|\ell=2,m_\ell=1\right\rangle$$

$$\xrightarrow{(2)} \left|+2,+2,\ell=2,m_\ell=+2\right\rangle$$

$$\Delta E = g\mu_B B$$

$$\Delta E = 2g\mu_B B$$

$$\Delta\ell = 2$$



Angular momentum conservation

Induces rotation in the BEC ?

Spontaneous creation of vortices ?

Einstein-de-Haas effect

Ueda et al;

Phys. Rev. Lett. 96, 080405 (2006)