Magnetic properties of a dipolar BEC loaded into a 3D optical lattice

Quantum magnetism with atomic quantum magnets

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Interplay between contact and long range interactions

Relative strength of dipole-dipole and Van-der-Waals interactions

$$\varepsilon_{dd} = \frac{\mu_0 \mu^2 m}{12\pi\hbar^2 a} \propto \frac{V_{dd}}{V_{contact}}$$

^{52}Cr $\quad \varepsilon_{dd} = 0.16 \quad (\mu = 6\mu_B)$

^{87}Rb $\quad \varepsilon_{dd} = 0.007 \quad (\mu = 1\mu_B)$

The basics

Chromium (S=3)

Permanent magnetic moment of **6 µB**
7 Zeeman states, linear Zeeman structure
4 Scattering lengths, a_6=103 a.u, a_4=64 a.u, a_2, a_0

Spin operators

$$\hat{S}_{1z}\hat{S}_{2z} + \frac{1}{2}\left(\hat{S}_{1+}\hat{S}_{2-} + \hat{S}_{1-}\hat{S}_{2+}\right)$$
$$-\frac{3}{4r^2}\left(2\hat{z}\hat{S}_{1z} + \hat{r}_-\hat{S}_{1+} + \hat{r}_+\hat{S}_{1-}\right)\left(2\hat{z}\hat{S}_{2z} + \hat{r}_-\hat{S}_{2+} + \hat{r}_+\hat{S}_{2-}\right)$$

Elastic collisions.

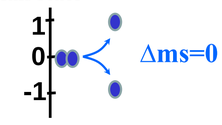
Spin exchange. Magnetization is conserved.

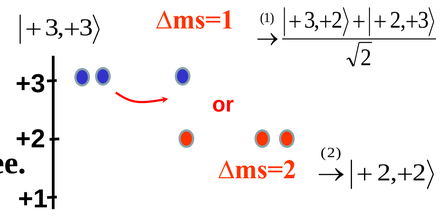
Inelastic collisions. Magnetization is free.

Dipole-dipole interactions: detailed contributions

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

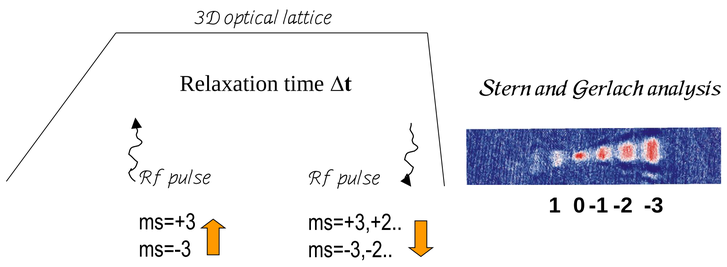
Zeeman state

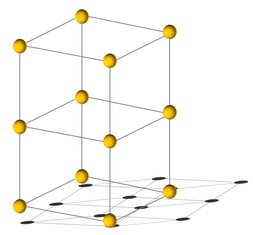




Dipolar Relaxation

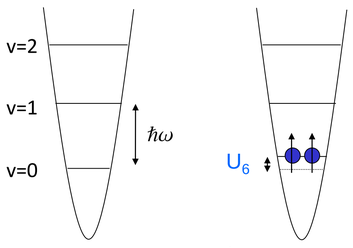
Relaxation rates depend on the confining geometry



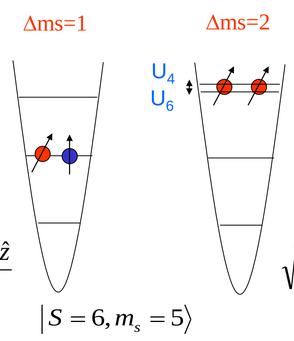


What happens?

- Dipolar relaxation channels are Δms=1,2.
- Resonant process: the Zeeman energy is equal to the band gap. $m_s g \mu_B B = n\hbar\omega_L$
- The band gap depends on the lattice depth and on contact interactions.



$$|S=6, m_s=6\rangle$$



$$V_2 = \frac{3}{2} S \frac{\mu_0 (g_s \mu_B)^2}{4\pi} \frac{(\hat{x}+i\hat{y})^2}{r^2}$$

Unresolved splitting

$$\frac{4\pi\hbar^2}{m_{Cr}}(a_6 - a_4)\frac{1}{V_{ho}} \approx 1\text{kHz}$$

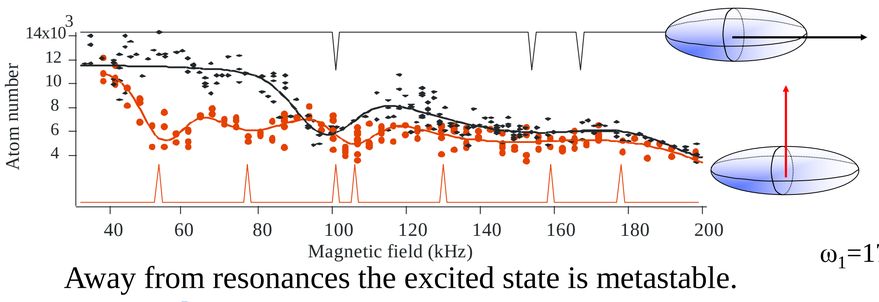
$$V_1 = 3S^{\frac{3}{2}} \frac{\mu_0 (g_s \mu_B)^2}{4\pi} \frac{1}{r^3} \frac{(\hat{x}+i\hat{y})\hat{z}}{r^2}$$

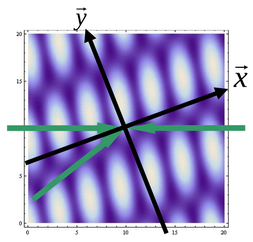
$$\sqrt{\frac{6}{11}}|S=6, m_s=4\rangle + \sqrt{\frac{5}{11}}|S=4, m_s=4\rangle$$

$$|S=6, m_s=5\rangle$$

Probing dipolar relaxation resonances

along two axis of the non degenerate 3D lattice.

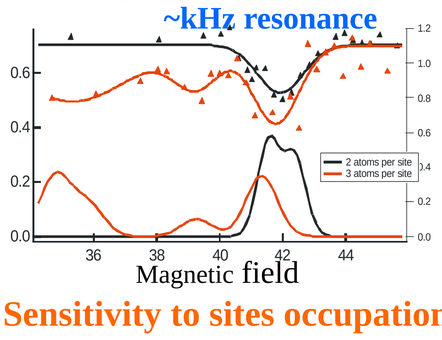




ω_1=170kHz, ω_2=45kHz, ω_3=110kHz

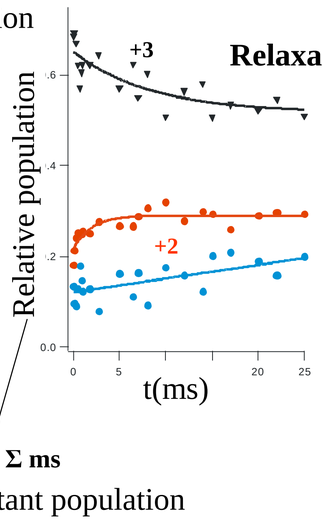
Away from resonances the excited state is metastable.

~kHz resonance



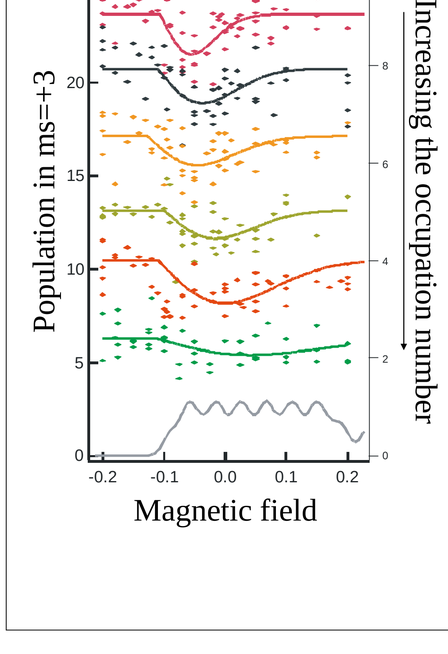
In agreement with the calculated 2 atoms resonance width.
Squeezed states: Mott plateau with 2 atoms per lattice site.

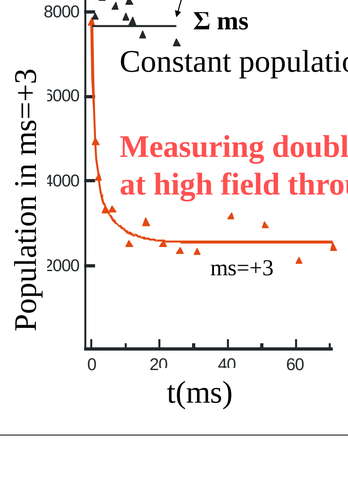
No contribution from triplons



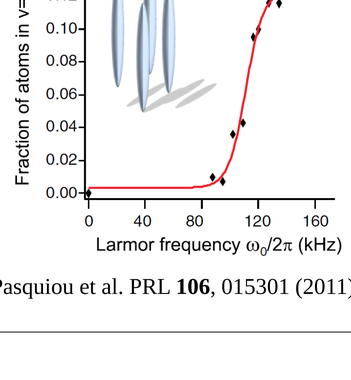
Relaxation Dynamics

Sensitivity to sites occupation





In 2D: dipolar relaxation shows a threshold.

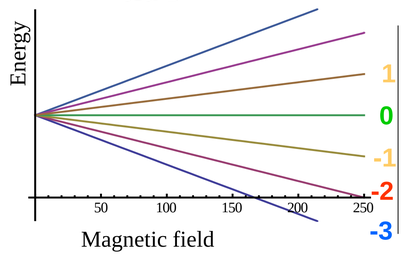


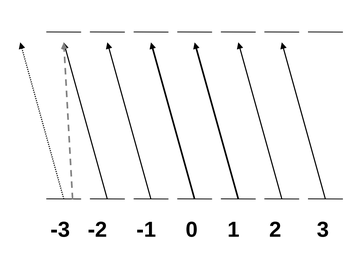
B. Pasquiou et al. PRL **106**, 015301 (2011)

Spinor physics

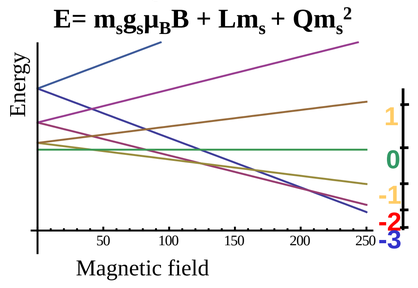
Opening new relaxation channels with the quadratic Zeeman effect

Linear Zeeman effect
E = $m_s g_s \mu_B B$





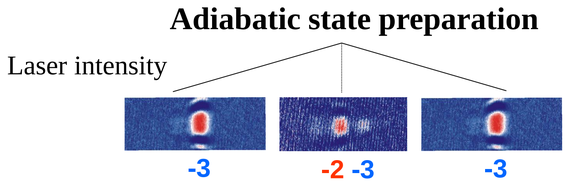
Linear+Quadratic Zeeman effect
E= $m_s g_s \mu_B B + L m_s + Q m_s^2$



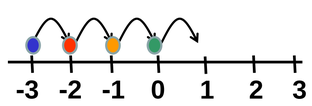
A σ– polarized laser close to a J→J transition (100 mW 427.8 nm).
Some π component remains.

Below a critical magnetic field ms=-2 is the ground state

Adiabatic state preparation



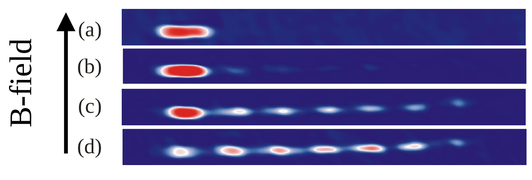
Changing the ground state



New phases appear at extremely low field

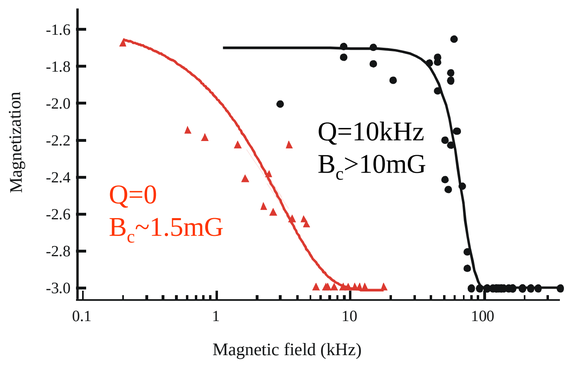
$$g_J \mu_B B_c \approx \frac{2\pi\hbar^2 n_0 (a_6 - a_4)}{m}$$

Spontaneous depolarization in a dipole trap.



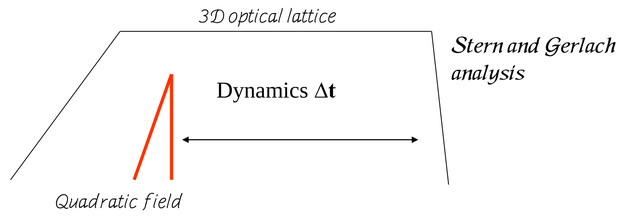
B. Pasquiou *et al.*, Phys. Rev. Lett **106**, 255303 (2011).

Depolarization in a 3D lattice

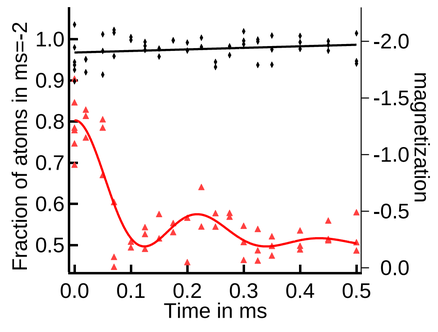


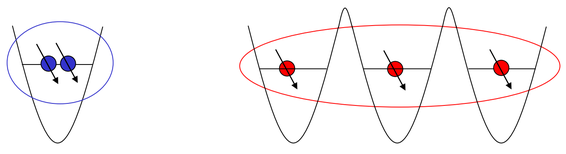
Coherent Spin dynamics in a 3D lattice

Preliminary data

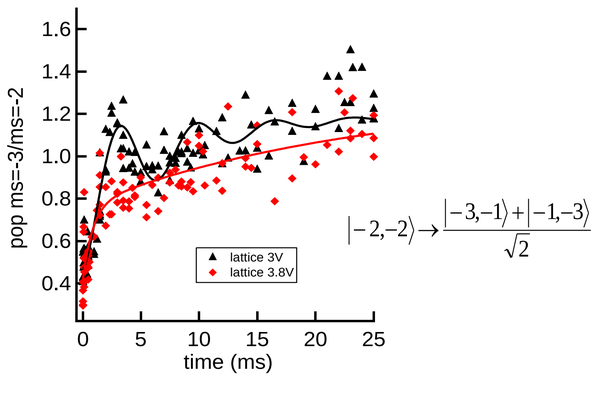


Short time scale Δt <1ms:
Spin exchange driven by **contact interactions**





Long time scale Δt >10ms:
Spin exchange driven by **dipole-dipole interactions ?**



$$|-2,-2\rangle \rightarrow \frac{|-3,-1\rangle + |-1,-3\rangle}{\sqrt{2}}$$

Correlations between the lattice depth and the amplitude of the coherent dynamics