Adiabatic spin-dependent momentum transfer in an SU(N) degenerate Fermi gas

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Our ultracold strontium experiment

Strontium 87 :

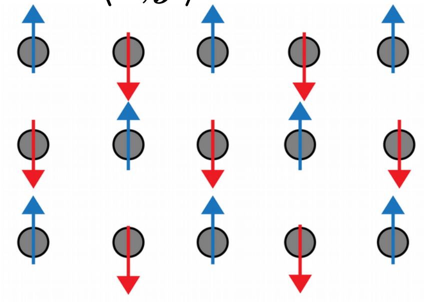
- Fermionic isotope of strontium
- Purely nuclear spin 9/2 → 10 spin states available in the ground state
- SU(N) symmetry : spin-rotation symmetry of the interactions
- Narrow lines : new methods for spin preparation and measurement

Goal of our experiment :

Ultracold Sr 87 in an optical lattice : studying ferromagnetism beyond spin ½

Effective Heisenberg model
Superexchange in an optical lattice :

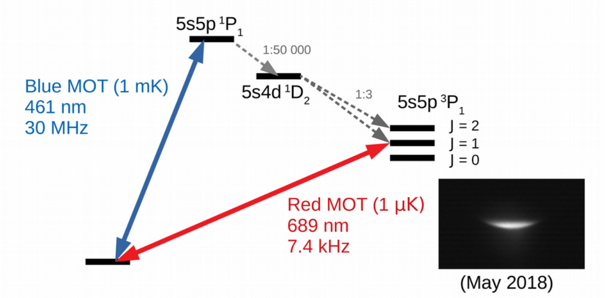
$$\hat{H}_{\text{eff}} = J \sum_{\langle i,j \rangle} \overrightarrow{S}_i . \overrightarrow{S}_j$$



Exploring magnetism in new regimes
N = 2 spin states: electron analogy (spin 1/2)
N = 3 spin states: 3 color quarks
N = 4 spin states: no equivalent

Our experimental setup

Narrow line cooling



(May 2018)

- Doppler limit: $k_B T = \hbar\Gamma$
  1 MHz: 50 µK
  1 kHz: 50 nK

- Recoil limit: $k_B T \sim \dfrac{h^2}{2m\lambda^2}$
  $\sim 500\text{nK}$

Optical dipole trap and Fermi sea

Evaporative cooling in a 1075 nm,
20W ODT with a dimple configuration.

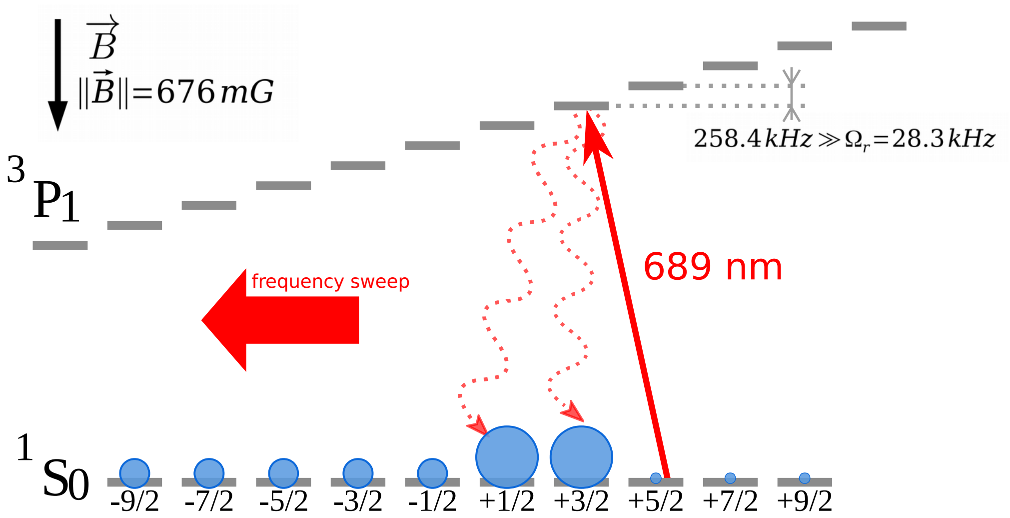
Fermi sea obtained in February 2019.
T/Tf ~ 0,2 with 10 spin states.

In progress: optical lattices

- Square 2D 532 nm lattice (ALS laser)
- 1064 nm 1D vertical lattice (ALS laser)
- 689 nm 1D lattice (MOGLabs laser) superimposed on the 532 nm 2D lattice to create a disordered potential
- 2D superlattice (1064 nm lattice multiplexed with the 532 nm 2D lattice)

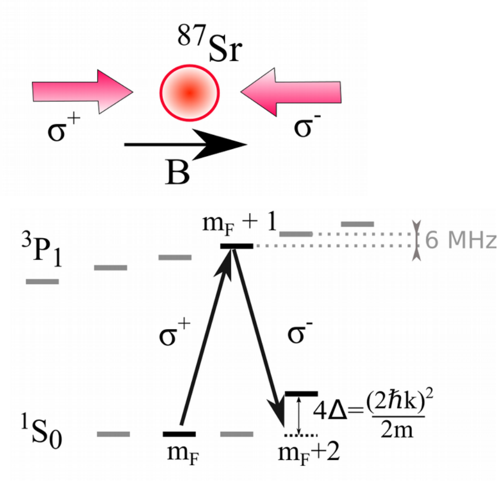
Spin state preparation

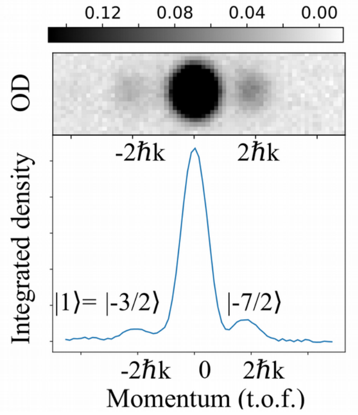
We can arbitrarily populate 2 to 10 spin states of our choice thanks to the 7 kHz wide $^1S_0 \rightarrow {}^3P_1$ transition.



Adiabatic spin momentum transfer

Beam configuration and diffraction process



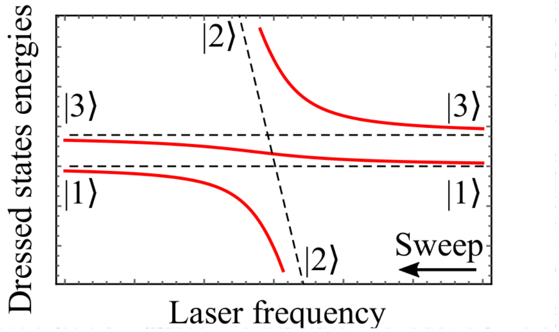


The diffraction process is completely adiabatic: the retroreflected laser is swept through the transition.

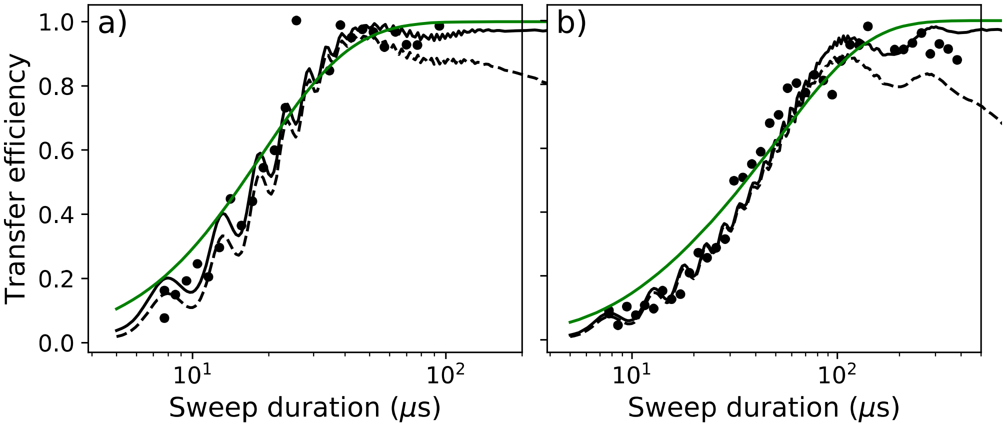
$|1\rangle = |m_F, 0\hbar k\rangle$ $|m_F+2, 0\hbar k\rangle$

$|2\rangle = |^3P_1, m_F + 1, \hbar k\rangle$ or $|^3P_1, m_F + 1, -\hbar k\rangle$

$|3\rangle = |m_F+2, 2\hbar k\rangle$ $|m_F, -2\hbar k\rangle$



Adiabatic transfer dynamics



a) from $|-3/2, 0\hbar k\rangle$ to $|+1/2, 2\hbar k\rangle$ at -3 MHz

b) from $|-7/2, 0\hbar k\rangle$ to $|-3/2, 2\hbar k\rangle$ at -15 MHz

● : measured transfer efficiencies as a function of ramp duration (assuming a 10% occupation of the spin states)

━ : simulation accounting for the atoms collecting two recoils or having undergone spontaneous emission.

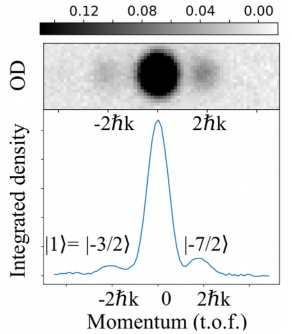
╍ : simulation accounting only for the fraction that underwent precisely two recoils.

━ : the LZ scaling $P^{\mathrm{LZ}}_{\mathrm{adiab}}(\Omega_1) \times P^{\mathrm{LZ}}_{\mathrm{adiab}}(\Omega_2)$

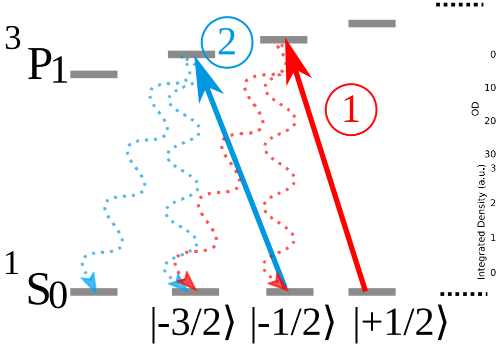
Adiabatic spin momentum transfer

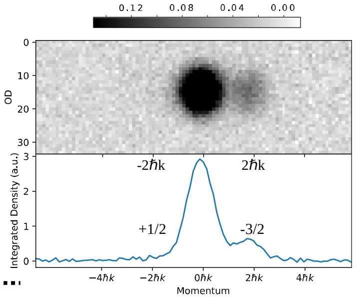
Single shot image

- without spin preparation:



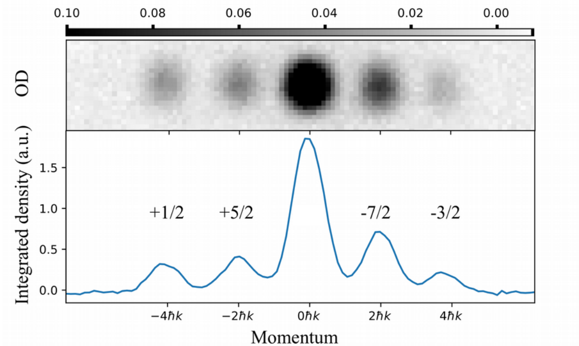
- with spin preparation:



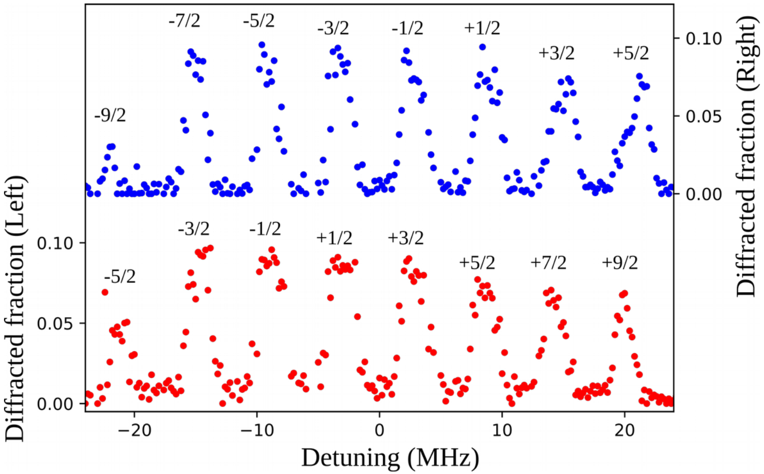


- Measuring 4 spins states at once:

3 consecutive pulses connecting:
-3/2 and +1/2; +1/2 and 5/2; −7/2 and −3/2.



Complete spectrum reconstitution



In a nutshell:

- Population of the 10 spin states measured in 6 shots when the standard single shot protocol, 4 shots when measuring 4 spin states at once.

- Conservation of the momentum distribution of the diffracted spin states (enables momentum-resolved spin correlation measurements).

- Fully coherent process.

- Inhibition of spontaneous emission due to the “dark” state:
$P_{\rm sp} \propto \gamma\Delta/\Omega^2$