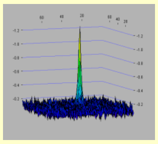
Studying dipolar effects in degenerate quantum gases of chromium atoms



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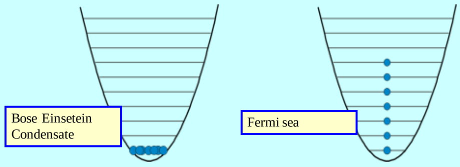
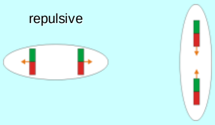
Scientific goals : Production and study of dipolar quantum gases made of chromium atoms. Generation of strongly correlated systems of bosons and fermions

Why is chromium interesting ?

- large magnetic moment $6\mu_B$
- ➢ large dipole - dipole interactions
- ➢ physics of a Spinor condensate (multi component BEC with F=3)
- Cr has a fermionic (^{53}Cr) and a bosonic (^{52}Cr) isotope with a large abundance (resp. 10% and 84 %)
- ➢ Possibility to reach a Fermi sea by sympathetic cooling
- ➢ Possibility to study a degenerate mixture BEC- Fermi sea



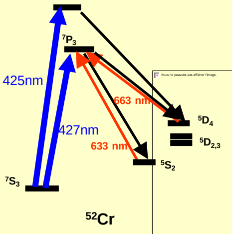


- Dipole-dipole interaction :
  - long range ($1/r^3$)
  - anisotropic

Specific properties of chromium atoms

- difficult to obtain an atomic beam: high melting point (1700°)
- chromium MOTs are small and have a relatively small number of atoms (large light assisted inelastic losses)
- presence of metastable states adds difficulties but solutions as well !
- large inelastic collisions in the ground state (spin exchange/dipolar) makes the condensation in Magnetic Traps impossible

Chromium atom level scheme



^{53}Cr

I = 3/2

Hyperfine structures

All trapping frequencies achievable from one laser with AOMs

Lasers used in the setup

- Verdi 18W + cw Ti:Sa laser + external doubling cavity -> 350 mW @ 425 nm for cooling.
- Two extended cavity red laser diodes close to 650 nm as repumpers.
- A frequency doubled laser diode for spin polarization (427 nm).
- Yb-doped fiber-laser for optical trapping 50W @ 1075nm.

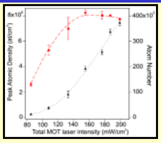
^{52}Cr/^{53}Cr Dual isotope Magneto-Optical Traps

Atom number ^{52}Cr: 4.10^6

Atom number ^{53}Cr: 4.10^5

limited stationary numbers but reasonably high loading rates

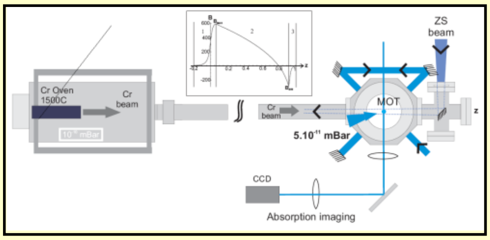
MOT temperature:110 µK



See R. Chicireanu et al., Phys. Rev. A **73**, 053406 (2006)

Experimental apparatus

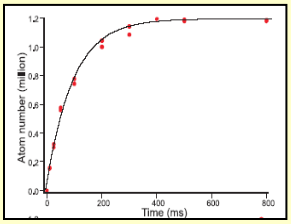
- An oven operated at 1500 °C inside an UHV chamber.
- A one meter long Zeeman slower to stop the atom.
- A 2nd UHV chamber at P=5.10^{-11} mBarr houses the traps in which we reach BEC.
- Detection and imaging devices.



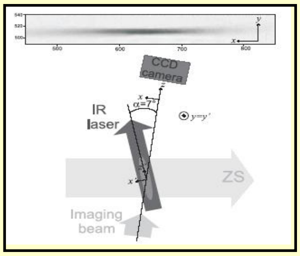
Optical trapping of chromium metastable atoms: a step further towards BEC

In order to reach degeneracy, we use the following cycling procedure:

- The atoms are first trapped in the MOT at 100 μK. The high light assisted inelastic collisions rate is responsible for the low atom number (~ $5\ 10^6$).
- By spontaneous emission, the atoms accumulate in metastable states where there are no more light assisted collisions. The atoms are then to be optically trapped. A weak 427nm beam is used to depump atoms towards $^5S_2$, which is favorable to optical trapping.
- The atoms in the metastable states are trapped in a 1D FORT (Far Off Resonance optical Trap) superimposed on the MOT (trap depth: 500 μK). This loading is improved by a "dark spot" 633nm repumper which cancels the depumping beam in the MOT trapping region but doesn't excite atoms in the optical trap.



Trapped atom absorption image



At the end of the loading :
- we switch off the MOT gradient
- we repump the atoms towards the ground state
- we optically pump them to the high field seeking $m_J = -3$ absolute ground state in order to avoid dipolar relaxation and to have a long atomic lifetime (~15s).

see
- Q. Beaufils, et al, Phys. Rev. A, **77**, 053413 (2008)
- R. Chicireanu, et al., Euro Phys J D **45**, 189 (2007)

Now:

- Study of ground state degeneracy obtained with rf field (arXiv:0808.3931).
- Study of a Feshbach resonance with an open channel in l=2.

Prospects:

Transfer of the Cr-BECs in optical lattices

Looking for dipolar interaction induced effects in reduced dimensionality (1D ou 2D)

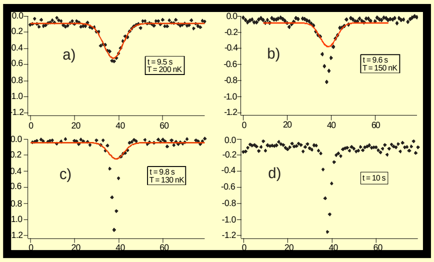
Study of thermalisation issues in dipolar polarized fermionic ensembles

Long term goal:

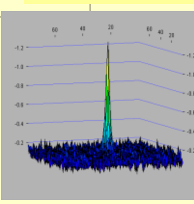
Creation of a dipolar Fermi sea and dipolar boson-fermion mixtures

All-optical Bose-Einstein Condensation of Chromium

- After the 1D OT loading we form a **crossed optical trap** (use of a $\lambda/2$ + pbs)
- We lower the IR laser power from 35 W to 500 mW in 10 s



BEC transition at **110 nK**



First signals -17 novembre 2007

- After « dimple » formation, the trap beam power is lowered from 35W to 500 mW within 10s.
- Overall cycle duration is around 14s.
- TF radii on the order of 4 to 5 µm, peak density $6.\ 10^{13}$ cm^{-3} and chemical potential 800Hz.
- Optical trap frequencies 110Hz, 100Hz et 150 Hz
- Typical atom number in the BEC ~15 000

- Q. Beaufils, et al, Phys. Rev. A, 77, 061601® (2008)

(*) Work supported by : Conseil Régional Ile-de-France (contrat Sesame), Ministère de l'Enseignement Supérieur et de la Recherche (CPER 2001-2006), European Union (Fonds Européen de Développement Régional) and IFRAF.