A boson-fermion atom interferometer for inertial sensing

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We are building a new-generation apparatus for cooling a boson-fermion mixture to quantum degeneracy.
The resulting coherent matter wave will be used for inertial sensing by atom interferometry (accelerometry, gyrometry).

Bosonic ^{87}Rb and fermionic ^{40}K

^{40}**K** A fermion with a natural isotopic abundance of **1 : 10 000**. Trapping and cooling transitions at **767 nm**.

^{87}**Rb** A well-known boson. Trapping and cooling transitions at **780 nm**. Strong tunable interactions with potassium ⇒ good buffer gas for thermalisation of fermions during evaporation.

Laser sources for potassium and rubidium

AR-Coated Extended Cavity Laser Diodes (ECDL)

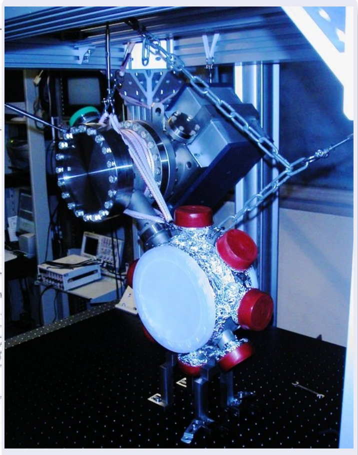
- Laser diodes at 780 nm (for Rb): standard technology, but they are not tunable down to 767 nm.
- In a laser diode a high intracavity photon density reduces the number of charge carriers, thus lowering the gap between the quasi-Fermi levels.
- By AR-coating the output facet of our laser diodes we reduced the feedback, thus lowering the photon density.

⇒ Increased band-gap that allows for higher energy transitions, thus tunability far to the blue of a normal ECDL, down to 766 nm.

Tapered Amplifiers

After frequency shifting, each beam is injected in a Tapered Amplifier
⇒ 200 mW of fibered light per species, for each MOT.

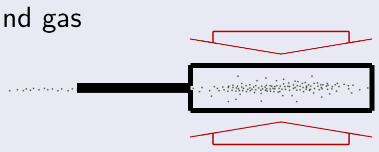
R. Nyman, G. Varoquaux, B. Villier, D. Sacchet, F. Moron, Y. Le Coq, A. Aspect, and P. Bouyer, Rev. Sci. Instrum. **77**, 033105 (2006)



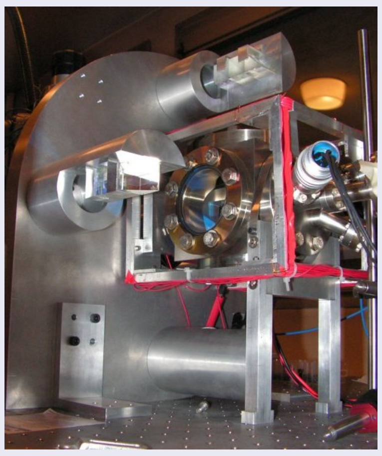
The vacuum chamber is suspended from a frame for improved optical-access.

A two-species atomic jet created by a 2D-MOT

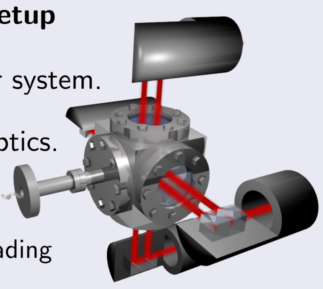
- Doppler cooling and trapping of the background gas in the 2 lateral directions
  ⇒ A thin 1D cloud of trapped atoms.



- A long thin tube as an exit path
  ⇒ selection of the atoms with a small lateral velocity, ie that have spent a long time in the trapping region, thus with a small longitudinal velocity.
  ⇒ a slow collimated beam of atoms.

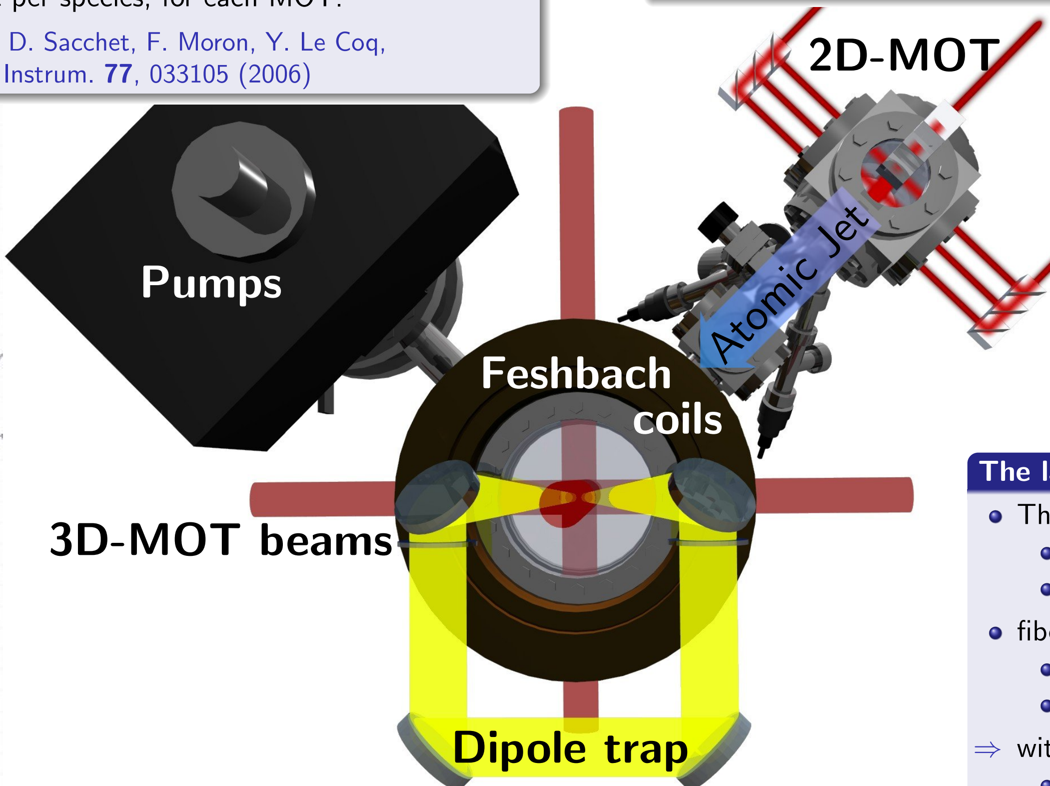


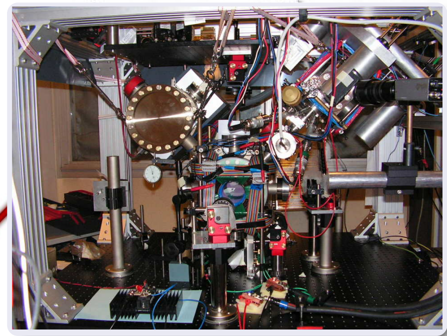
2D-MOT setup



- Fully fibered laser system.
- Non adjustable optics.
- 2 sets of beams
  ⇒ 2 mutually loading 1D clouds.
- Magnetic field bias coils to control the position of the output flux.

07/02/06: Atomic jet captured by 3D-MOT





The laser for the dipole trap

- The wavelength: a trade-off between
  - depth $U_0 \propto (\omega - \omega_0)^{-1}$
  - and photon scattering $\Gamma_{sc} \propto (\omega - \omega_0)^{-2}$
- fibered erbium laser:
  - telecom wavelength: **1565 nm**
  - high power: **50 W**

⇒ with a waist of 0.1 mm
- for rubidium: $U_0 \sim 130\,\mu$K $\Gamma_{sc}^{-1} \sim 11.5$ s
- for potassium: $U_0 \sim 160\,\mu$K $\Gamma_{sc}^{-1} \sim 13.0$ s

Transfering atoms from the MOT to the dipole trap

Need to cool in the dipole trap

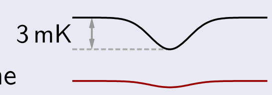
		MOT/Molasses	Dipole trap	
Rb	Temperature	$\sim 10\,\mu$K	Depth	$\sim 150\,\mu$K
	Density	$\sim 10^9$ at.cm^{-3}	Volume	$\sim 10^{-4}$ cm^3
K	Temperature	$\sim 100\,\mu$K		
	Density	$\sim 10^8$ at.cm^{-3}		

⇒ Poor matching between the MOT and the dipole trap.

Dipole trap inhibits MOT

- The excited state of the MOT transition has a transition at 1529 nm:

⇒ The excited state is trapped by the dipole trap.



\+ The atoms are shifted off resonance by 400 MHz, the MOT-laser can become blue detuned in the center!

Can we alternate molasses and dipole trap, or adjust the detunings to do sub-Doppler cooling in the dipole trap ?

Atom interferometry with a boson-fermion mixture

Using fermions reduces the interaction shift

A BEC is a dense gas. The inter-particle interactions give rise to a phase shift that can lead to loss of contrast or systematic errors in atom interferometry. Due to Pauli blocking cold fermions interact very little.

G. Roati, E. de Mirandes, F. Ferlaino, H. Ott, G. Modugno, and M. Inguscio, *Phys. Rev. Lett.* **92**, 230402 (2004)

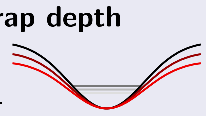
Feshbach resonances allow for control of the interaction strength

Interspecies and Rb-Rb interactions can be tuned via feshbach resonances.

Evaporation to degeneracy in the dipole trap

Evaporation in the dipole trap by lowering the trap depth

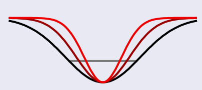
⇒ Removal of the hottest atoms
- The trap frequencies go to zero, so does the collision rate.



Using a compressible trap

- Starting from a very large trap to match the MOT

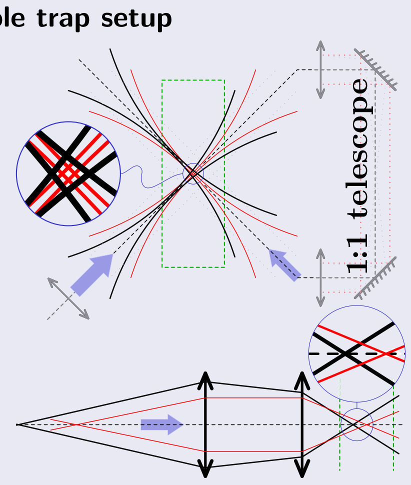
… ending in a tight trap for high collision rates.



Variable size cross-dipole trap setup

The trapping volume is defined by the intersection of two beams.
Changing the position of the waist varies confinement: the strongest trap is for beams intersecting at waist.

To translate the waist along the beam path we use an image transport system that images in the chamber an outer focus on which we have mechanical control.
The beam goes through the chamber, and is then reinjected through a 1:1 telescope at 90°.



T. Kinoshita, T. Wenger, and D. S. Weiss, *Phys. Rev. A.* **71**, 011602 (2005)

I.C.E.: a Transportable Atomic Inertial Sensor for Test in Microgravity RA Nyman, G Varoquaux, F Lienhart, D Chambon, S Boussen, J-F Clément, T Muller, G Santarelli, F Pereira Dos Santos, A Clairon, A Bresson, A Landragin, P Bouyer cond-mat/0605057