Fermi-Bose mixtures in optical lattices

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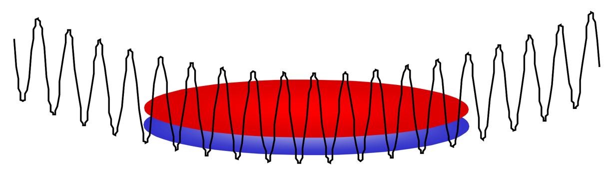
Abstract

We present our experiments on trapping ^{40}K-^{87}Rb degenerate mixture in 1-D optical lattices. In presence of additional quadratic confinement we observe spatial localization of the particles, which can be directly observed by radio-frequency spectroscopy.
In case of an external linear potential we can follow Bloch oscillations of Fermi gas and we determine accurately the Bloch period and therefore the acceleration of gravity. It constitutes the first interferometer with degenerate atomic Fermi gases.
We can also study the interactions properties of the mixture by confining it in a very tight optical lattice. In particular we can tune the interspecies scattering length with an external magnetic field (Feshbach resonances). This is the first step towards the detection of heteronuclear ultracold molecules.

Optical lattice and parabolic potential: localization

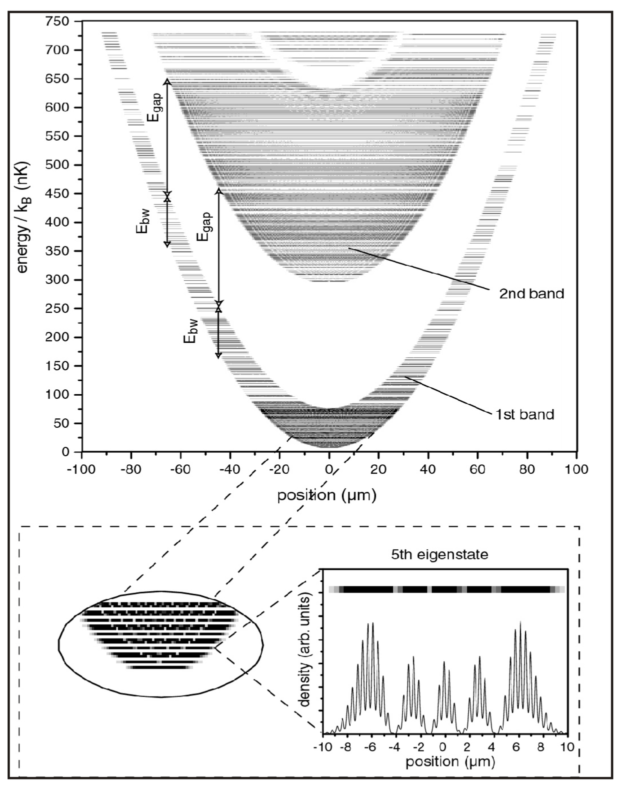
We prepare a Fermi gas of ^{40}K in |F=9/2, m_F=9/2> by sympathetic cooling with ^{87}Rb atoms in |F=2>, m_F=2> [1]. We transfer the mixture in the combined potential of the parabolic magnetic trap and a one-dimensional optical standing wave [2].

N_K=3 10^4
N_{Rb}= 1 10^5
T/T_F=0.3
=830 nm
E_R/k_B=340 nK



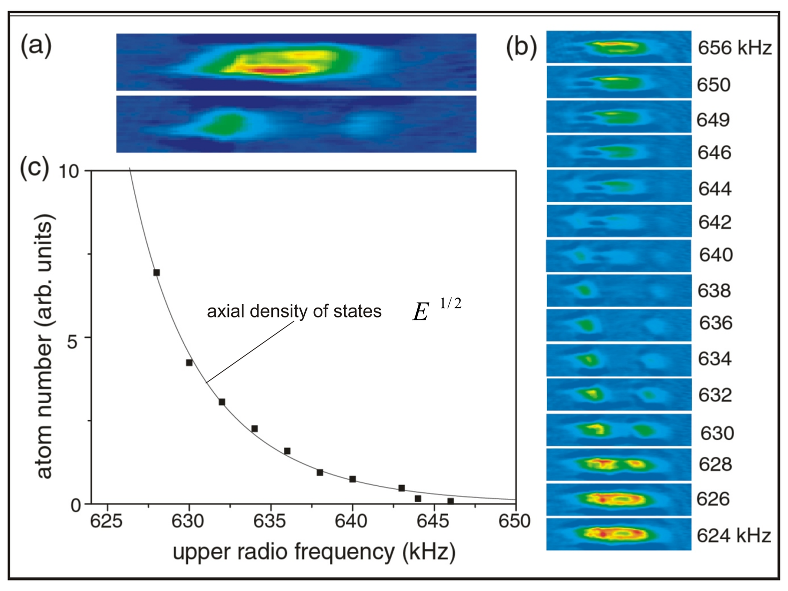
Numerical Solution of the 1D Schrödinger equation

$$\frac{p^2}{2m} \quad \frac{1}{2}m\,{}^2x^2 \quad \frac{s}{2}E_r(1 \quad \cos(4\,x/\;))$$



Observation of Localized States:

We selectively remove the atoms from the trap with a radio frequency field [3]. Atoms that are trapped in localized states remain in the potential.

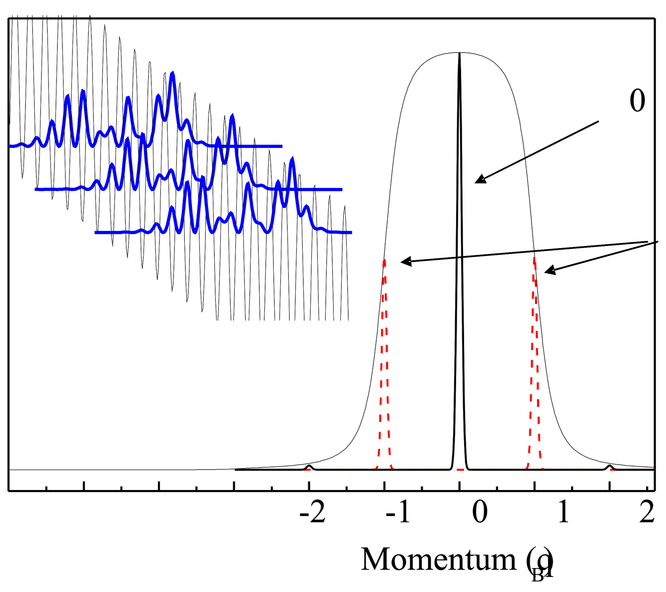


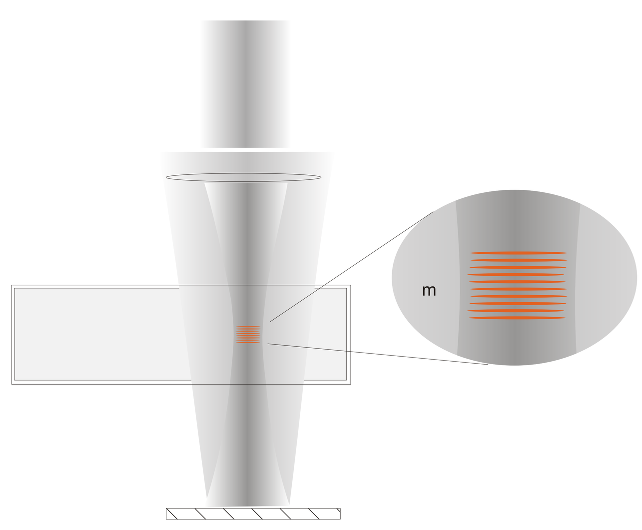
Atom interferometry with trapped Fermi gases

We load the degenerate Fermi gas in a far detuned 1-D optical lattice aligned along gravity .

N=3 10^4
T/T_F=0.3
=873 nm
q 0.75q_B
E_R/k_B=310 nK

$$H \quad \frac{P^2}{2m} \quad \frac{1}{2}sE_R(1 \quad \cos\frac{4\,z}{\;}) \quad mgz$$

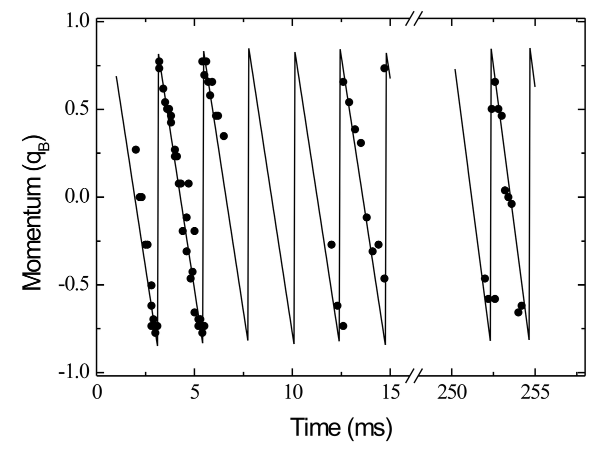


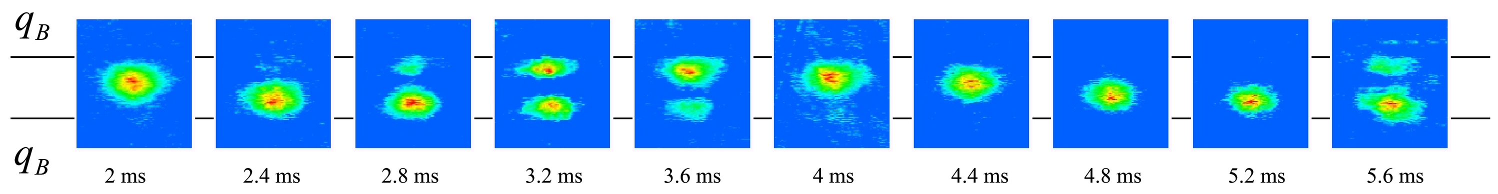


The energy spectrum is given by the Wannier-Stark ladder of states which are equally spaced by E mg /
The spatial extension of each of these states is few lattice sites while in momentum space it occupies the whole Brillouin zone.
Neighboring states evolve in time with a phase difference = Et/h
giving rise to an interference pattern periodic in time with T_B=h/ E The interference between Wannier-Stark states results in equally spaced peaks in momentum space. In particular the peaks spacing is the inverse of the spatial period of the lattice, and it can be defined as 2q_B, where q_B=h/ is the Bragg momentum.

Observing fermionic interference

To observe the interference, we let the atoms evolve in the lattice plus the gravitational potential for holding times T_1. We adiabatically release the atoms at different instants and we study the oscillation of the interference pattern.
We observe the interference peaks oscillating with the Bloch period.



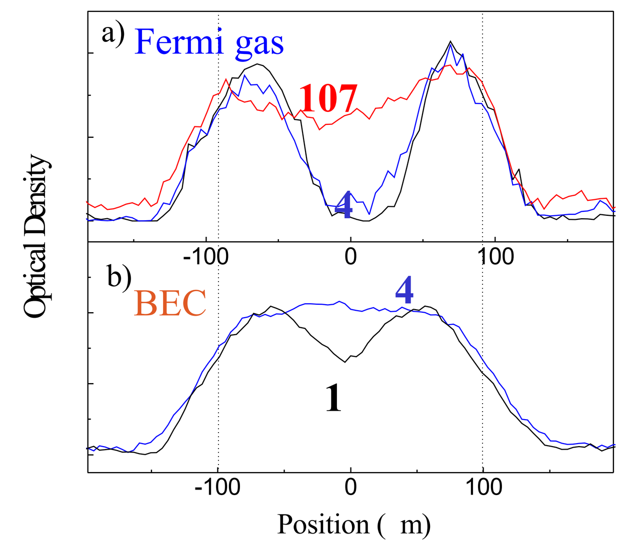


By following the vertical position of the peak of the distribution, we get the periodic motion expected for Bloch oscillations.
The absence of interactions allows us to follow more than 100 Bloch periods with high contrast and to measure accurately the Bloch period:

T_B=2.32789 (22) ms

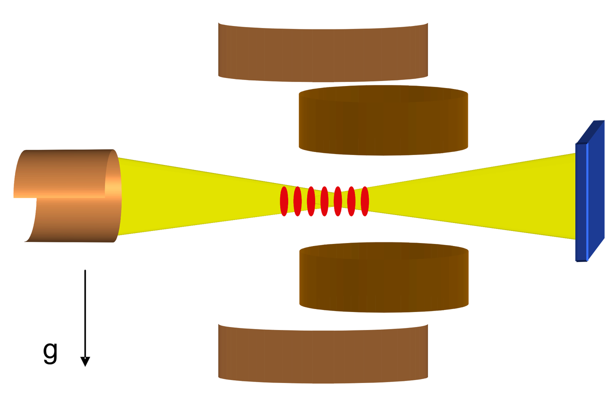
From the Bloch period, assuming that the only external force acting on the samples is gravity, we can determine a local gravitational acceleration as

g=9.7372 (9) m/s^2

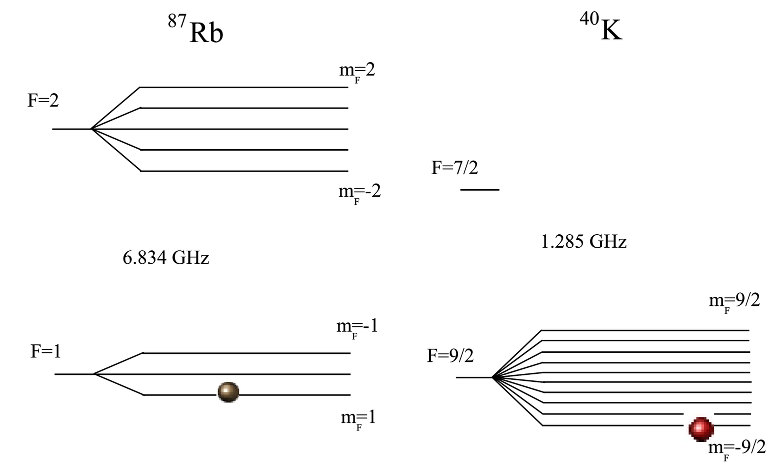


We repeat the experiment using a BEC of rubidium atoms (T<0.6 T_C, N=5 10^4). Collisions between atoms in the BEC destroy the coherent superposition of Wannier-Stark states, reducing the visibility of the interference fringes,

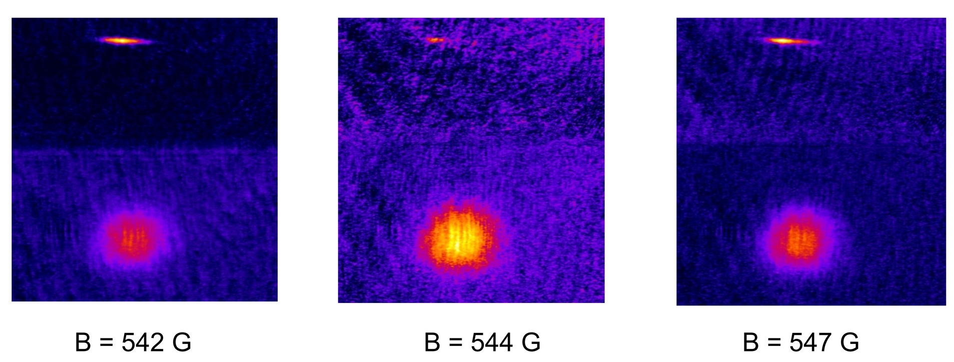
Interspecies Feshbach resonances



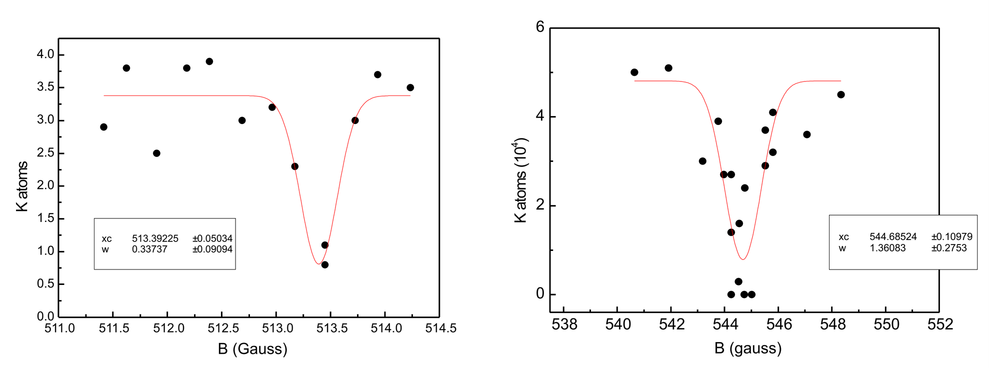
We transfer the mixture in a tight 1-D optical lattice and we spin polarize K in |F=9/2, m_F=-9/2> and with Rb atoms in |F=1>, m_F= 1>. We apply an homogenous magnetic field and we observe losses in potassium sample ($N_K \ll N_{Rb}$) [5].



N_K= 6 10^4
N_{Rb}= 4 10^5
T =2 K
=822 nm
P = 600 mW
= 390 Hz
= 130 KHz
n = 10^{12} cm^{-3}



The observed losses are due to the formation of heteronuclear K-Rb molecules near the Feshbach resonance.



References

[1] G. Roati, F. Riboli, G. Modugno, and M. Inguscio Phys. Rev. Lett. **89**, 150403 (2002).
[2] L. Pezzè, L. Pitaevskii, A. Smerzi, S. Stringari, G. Modugno, E. de Mirandes, F. Ferlaino, H. Ott, G. Roati, and M. Inguscio Phys. Rev. Lett. **93**, 120401 (2004).
[3]H. Ott, E. de Mirandes, F. Ferlaino, G. Roati, V. Türck, G. Modugno, and M. Inguscio Phys. Rev. Lett. **93**, 120407 (2004).
[4] G. Roati, E. de Mirandes, F. Ferlaino, H. Ott, G. Modugno, and M. Inguscio Phys. Rev. Lett. **92**,230402 (2004).
[5] S. Inouye, J. Goldwin, M. L. Olsen, C. Ticknor, J. L. Bohn, D. S. Jin, cond-mat/0406208 (2004).