Realization of a Crossed-Beam Dipole Trap for Investigation of Spin-Dependent Forces on Ultracold Atoms

Tiago Correia and Nathan Lundblad
Bates College, Lewiston, ME 04240

Abstract

We prepare ultracold samples of rubidium-87 and transfer them to a crossed-beam dipole trap formed by a tunable Ti:shappire laser along one direction and a 1060 nm laser along another. We model and measure trap parameters such as lifetime and characteristic frequencies.

Experimental Setup

Our BEC apparatus reliably produces Bose-Einstein Condensates (BECs) of rubidium-87 with temperatures ~100 nK and densities in the order of 10^{13} cm^{-3}. The process of BEC production is as follows:

- Hot atoms exit the effusive oven, go through a Zeeman Slower and are trapped in a conventional six-beam magneto-optical trap (MOT).
- The trapped sample in the $|F=1; m_F = -1\rangle$ state is transferred into a magnetic quadrupole trap and subject to rf evaporation. This process is limited by spin-flip Majorana losses as the sample gets colder.
- Atoms are transferred to a single-beam optical dipole trap aligned slightly below the field zero. Forced evaporation by lowering the trap depth achieves sufficiently high density and low temperature.

Optical Dipole Force

Atoms placed in an oscillating electric field, e.g. the focus of a laser, will have an induced dipole moment and experience a force proportional to the intensity of the beam [1].

The general approximate expressions for dipole potential and the scattering rate are

$$U_{dip}(\mathbf{r}) = \frac{3\pi c^2}{2\omega_0^3}\frac{\Gamma}{\Delta} I(\mathbf{r})$$

$$\Gamma_{sc}(\mathbf{r}) = \frac{3\pi c^2}{2\hbar\omega_0^3}\left(\frac{\Gamma}{\Delta}\right)^2 I(\mathbf{r})$$

There are two main takeaways:

- Sign of the detuning Δ: below an atomic resonance ("red" detuning) the potential is negative. Potential minima are at regions of maximum beam intensity.
- Scaling with intensity and detuning: while the potential scales as I/Δ, the scattering rate is proportional to I/Δ^2. As such it's advantageous to use a large detuning and high beam intensity to minimize scattering.

Alkali atoms such as rubidium have the well-known D line doublet $^2S_{1/2} \rightarrow {}^2P_{1/2}, {}^2P_{3/2}$ [2]. Taking into account the detuning relative to each transition and the laser polarization, the potential of a ground state with total angular momentum F and magnetic quantum number m_F is

$$U_{\mathrm{dip}}(\mathbf{r}) = \frac{\pi c^2 \Gamma}{2\omega_0^3}\left(\frac{2+\mathcal{P}g_F m_F}{\Delta_{2,\,F}} + \frac{1-\mathcal{P}g_F m_F}{\Delta_{1,\,F}}\right) I(\mathbf{r})$$

► Atoms in different m_F states experience different light shifts.

Crossed-Beam Optical Trap

An all optical trap opens a new avenue in control of neutral atoms which can not be trapped by electric fields. For a more detailed study of our trap's characteristics, we use our model of beam shape and waist to predict its size and depth.

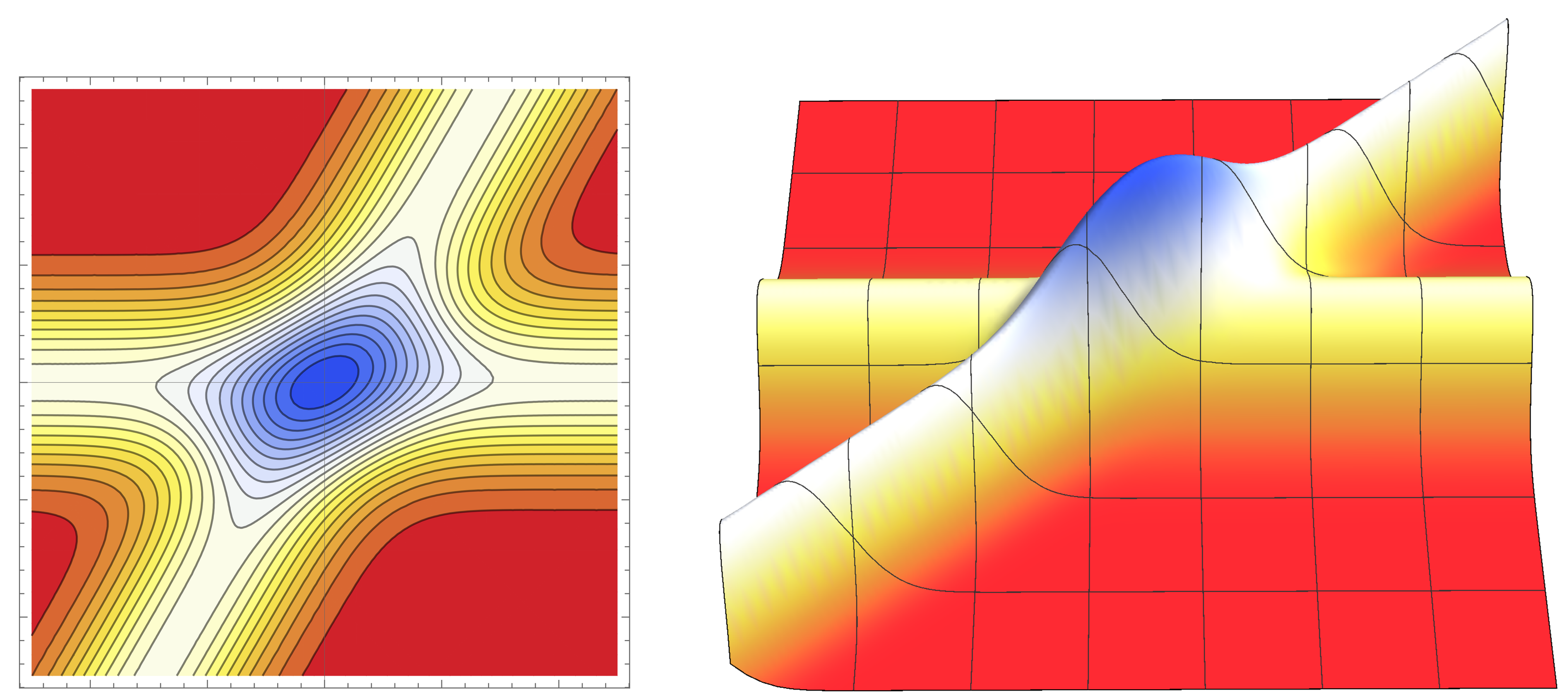

Figure 1. Intensity profile of two overlaping Gaussian beams at an angle of 62º. In a red-detuned trap the regions of higher intensity correspond to a lower potential.

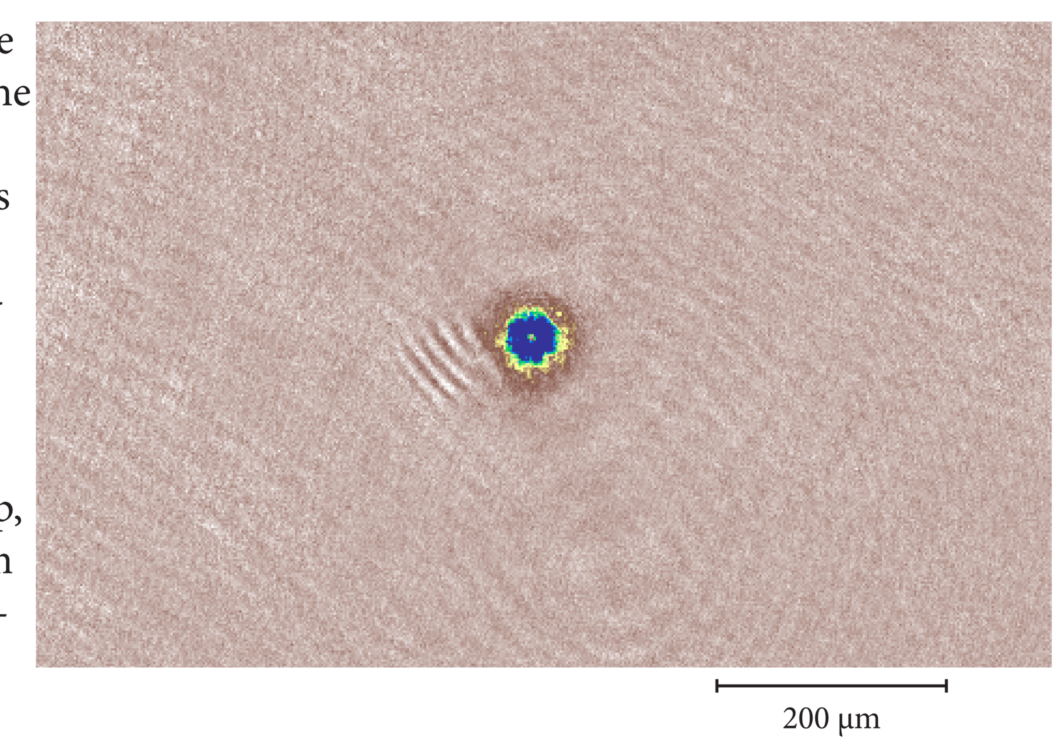

Figure 2. Absorption image taken of a partial BEC in the pure crossed-beam dipole trap with around 10^5 atoms at ~100 nK. The atoms are first loaded into the single-beam dipole trap, where they undergo evaporative cooling. The Ti:shappire intensity is then ramped up, transferring the cloud from a single-beam to a crossed-beam trap.

Spin-Dependent Forces

- Ti:saphire laser wavelength between D1 and D2 transitions originates a state dependent light shift.
- At the tune-out wavelength of 790.06 nm the light shift is opposite for $m_F = 1$ and $m_F = -1$ states.

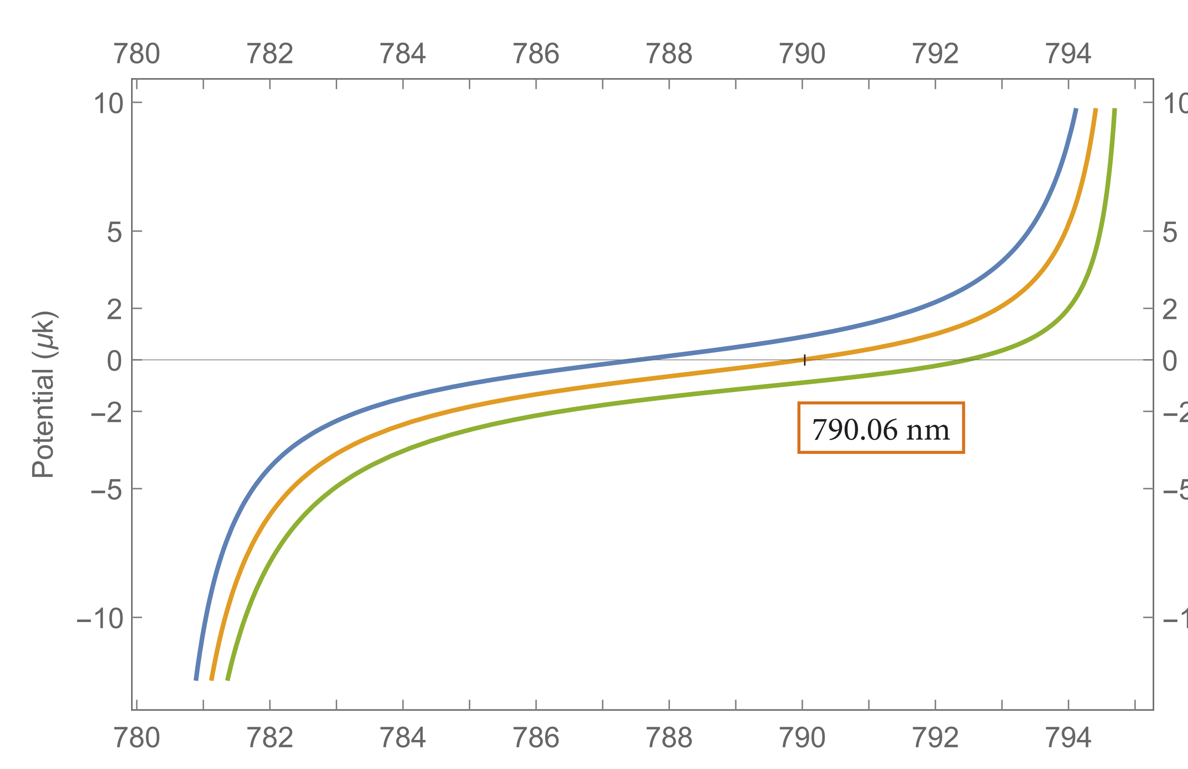

Figure 3. Light shift as a function of wavelength between the D1 and D2 lines (laser power of 10 mW and a waist of 100 μm) for $m_F = 1$ (blue), $m_F = 0$ (orange) and $m_F = -1$ (green) states.

Trap Dynamics

To quantify our atom loss over time we investigate the lifetime of the crossed-beam trap by plotting atom number versus hold time in the trap prior to imaging.

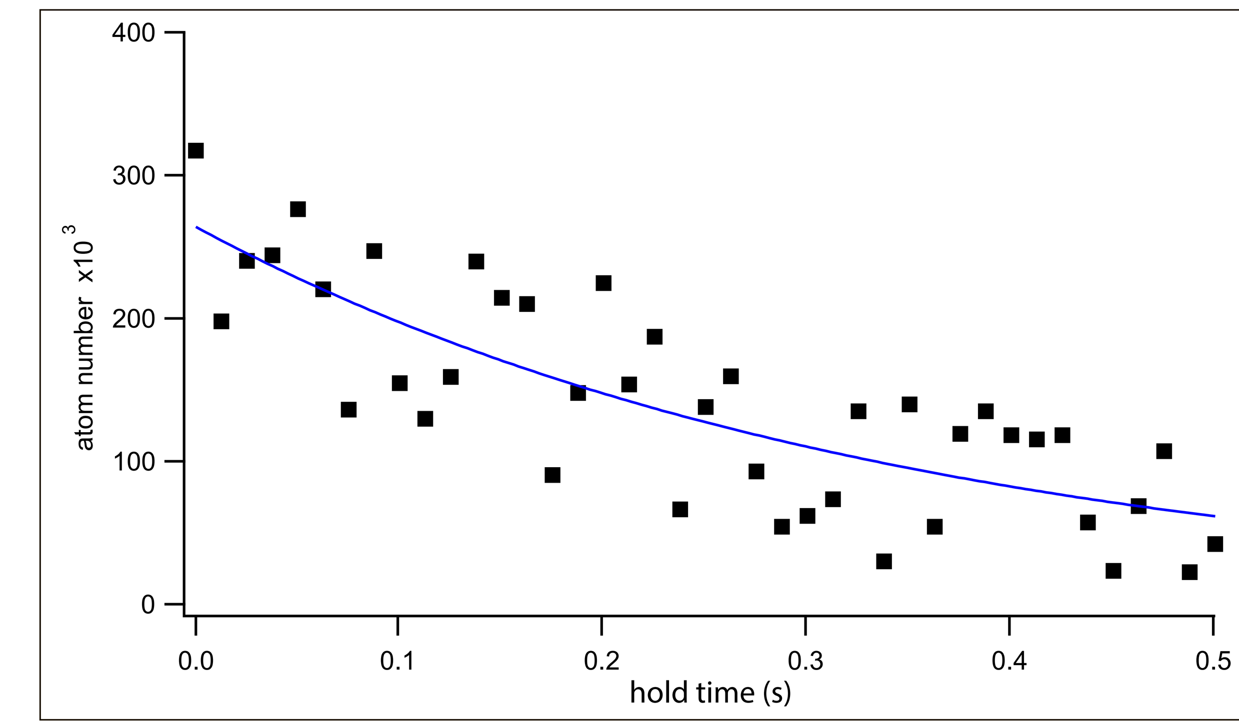

Figure 4. Atom number vs. hold time fitted with a decaying exponential for ~80 mW of Ti:sapphire power. Fit curve has time constant of 0.35 seconds.

Trap frequencies for different beam powers can be calculated if the exact trap geometry is known. Therefore, measurements of trap frequencies are a good way of testing our theoretical model. Below is an example of such measurement.

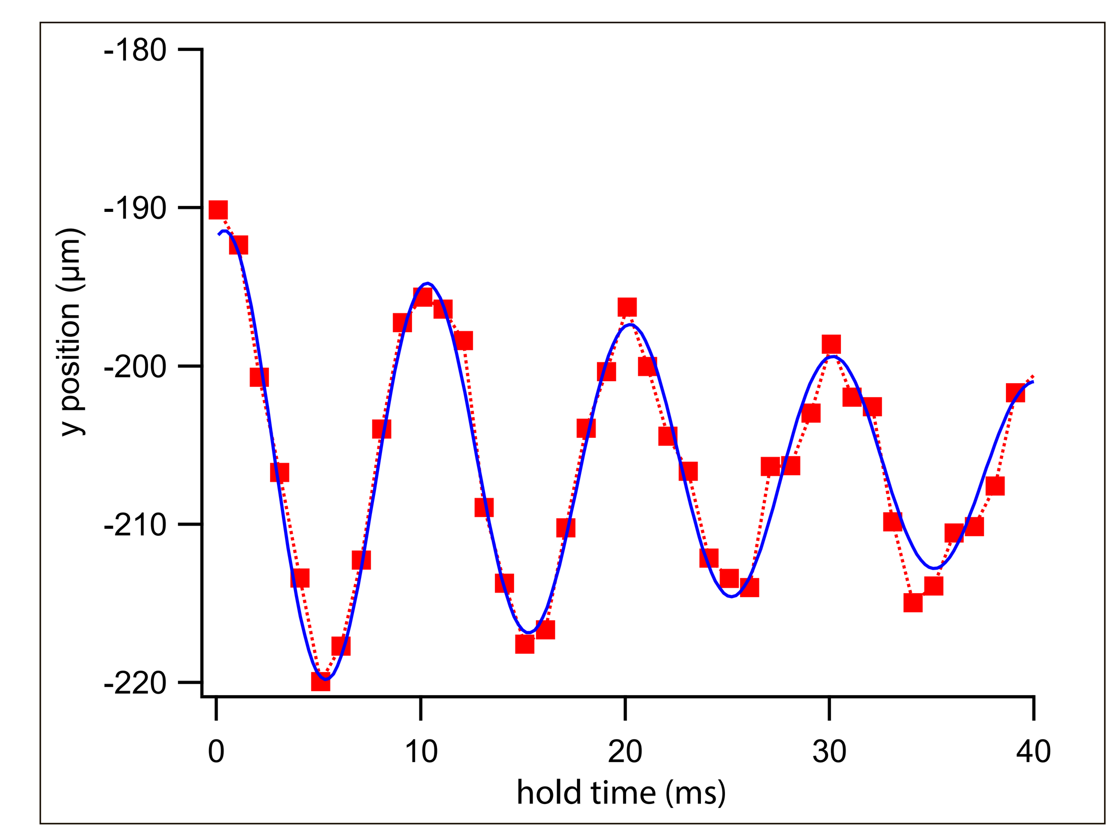

Figure 5. Trap frequency measurement (in the y-direction). The Ti:sapphire laser is turned off for 2 ms while the other beam remains at normal power. Measurements of cloud position are then made for a variable hold time in the combined trap. Atom-atom interactions cause the oscillation to decay over time.

Future work

- Analyze trap frequency data to improve estime of beam waists
- Geometry is not orthogonal - what are the characteristic directions?
- RF dressing of spin-dependent optical potential

References

[1] R. Grimm, et al. *Optical Dipole Traps for Neutral Atoms.* Advances in Atomic, Molecular and Optical Physics Vol. 42, 95-170 (2000)
[2] Daniel A. Steck *Rubidium 87 D Line Data*. Los Alamos National Laboratory, 2001.

Acknowledgements

- Work funded by the Sherman Fairchild Foundation through Bates College.
- Special thanks the Bates College Physics Department and to the members of the Lundblad lab.