Progress Towards Spatially Resolved Single-atom Imaging of ^{6}Li in a Multi-Well Potential

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Abstract

We prepare low-entropy samples of few atoms in a multi-well potential. To image them with spatial resolution we make them fluoresce by resonant laser beams, collect the emitted photons with a high-resolution objective and detect them on a sensitive camera.

Experimental apparatus

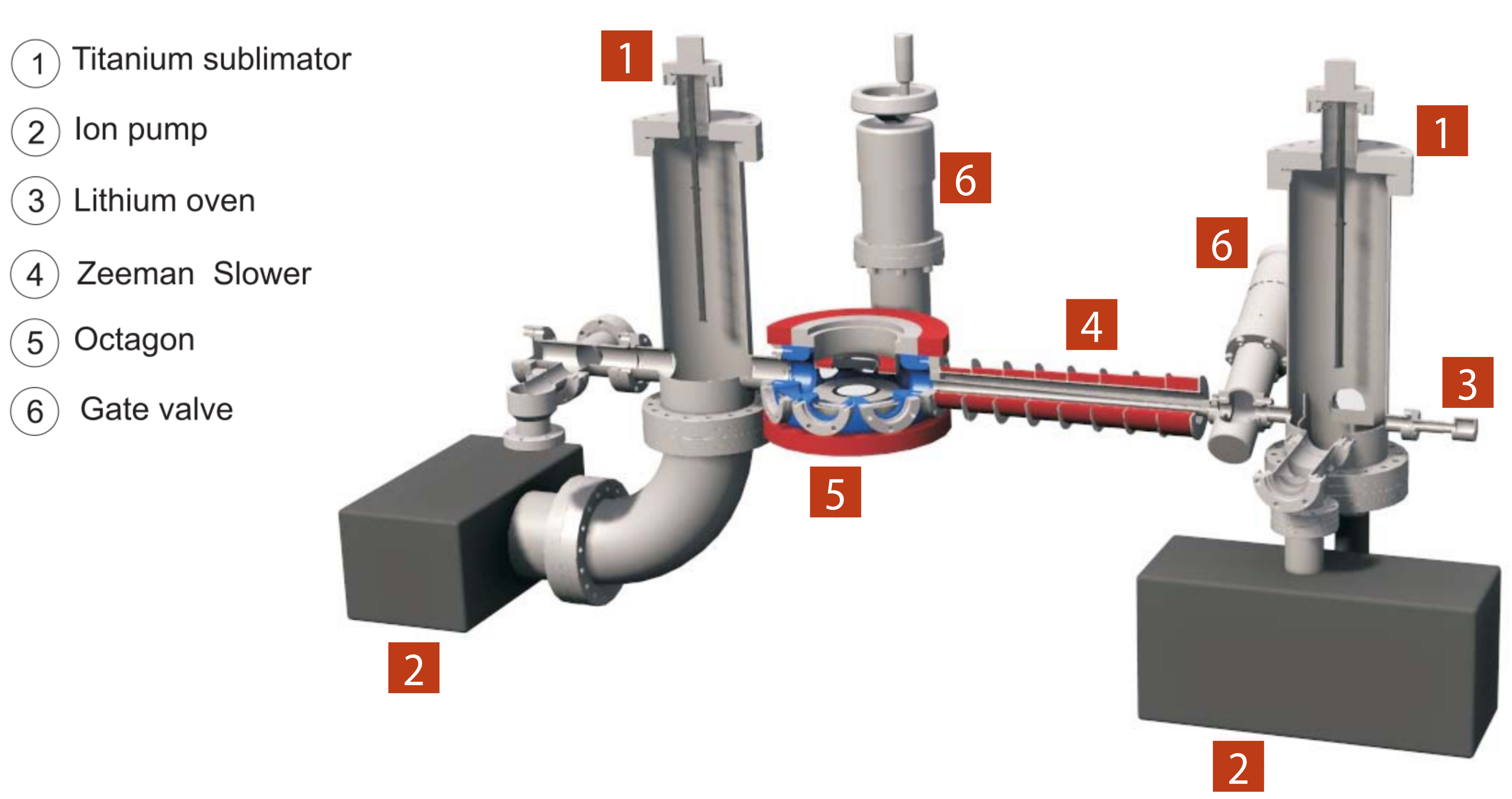

Figure 1. (right) Schematics of the vacuum chamber. The lithium atoms move through the Zeeman slower (4) to the main chamber (5), where they are trapped by a Magneto-Optical Trap (MOT).

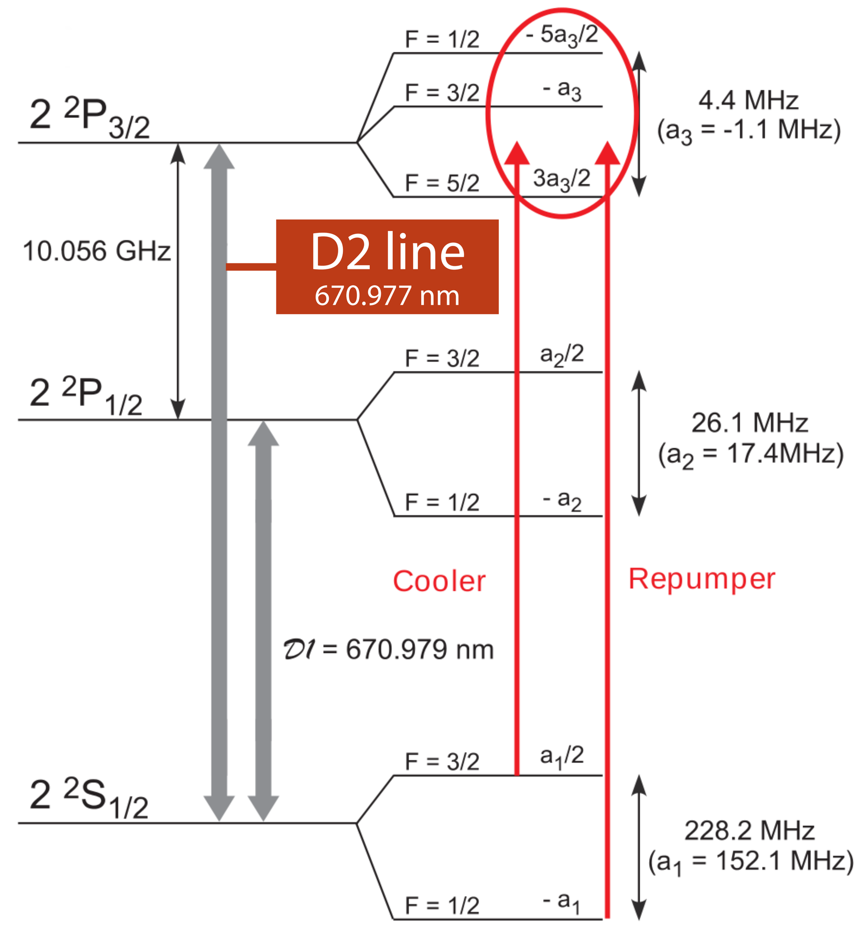

Figure 2. Electronic scheme of ^{6}Li (energy splittings not to scale). We perform laser cooling on the D2-line.

The excited state hyperfine splitting is not resolved due to it being smaller than the transition's natural linewidth of 6 MHz.

A repumper beam is added to close the cooling cycle.

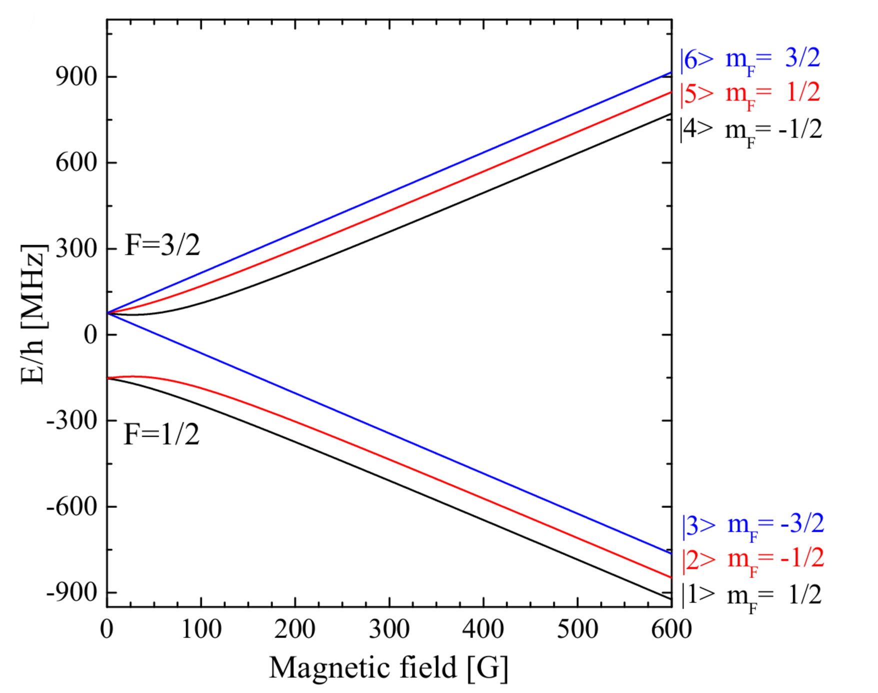

Figure 3. Magnetic-field dependence of the F = 3/2 and F = 1/2 states of ^{6}Li.

Optimal loading rate and atom number in the MOT is achieved with red detuning of about 6Γ for the pumper and repumper beams at a magnetic field gradient of 20 G/cm.

References

M. E. Gehm. *Preparation of an Optically-Trapped Degenerate Fermi Gas of 6Li: Finding the Route to Degeneracy*. PhD thesis, Duke University, 2003.

A. Bergschneider. *Ultracold few-fermion systems in multiwell potentials.* Master thesis, University of Heidelberg, 2013.

G. Zürn. *Realization of an Optical Microtrap for a Highly Degenerate Fermi Gas*. Diploma thesis, Max-Planck Institue for Nuclear Physics, 2009.

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Laser Setup

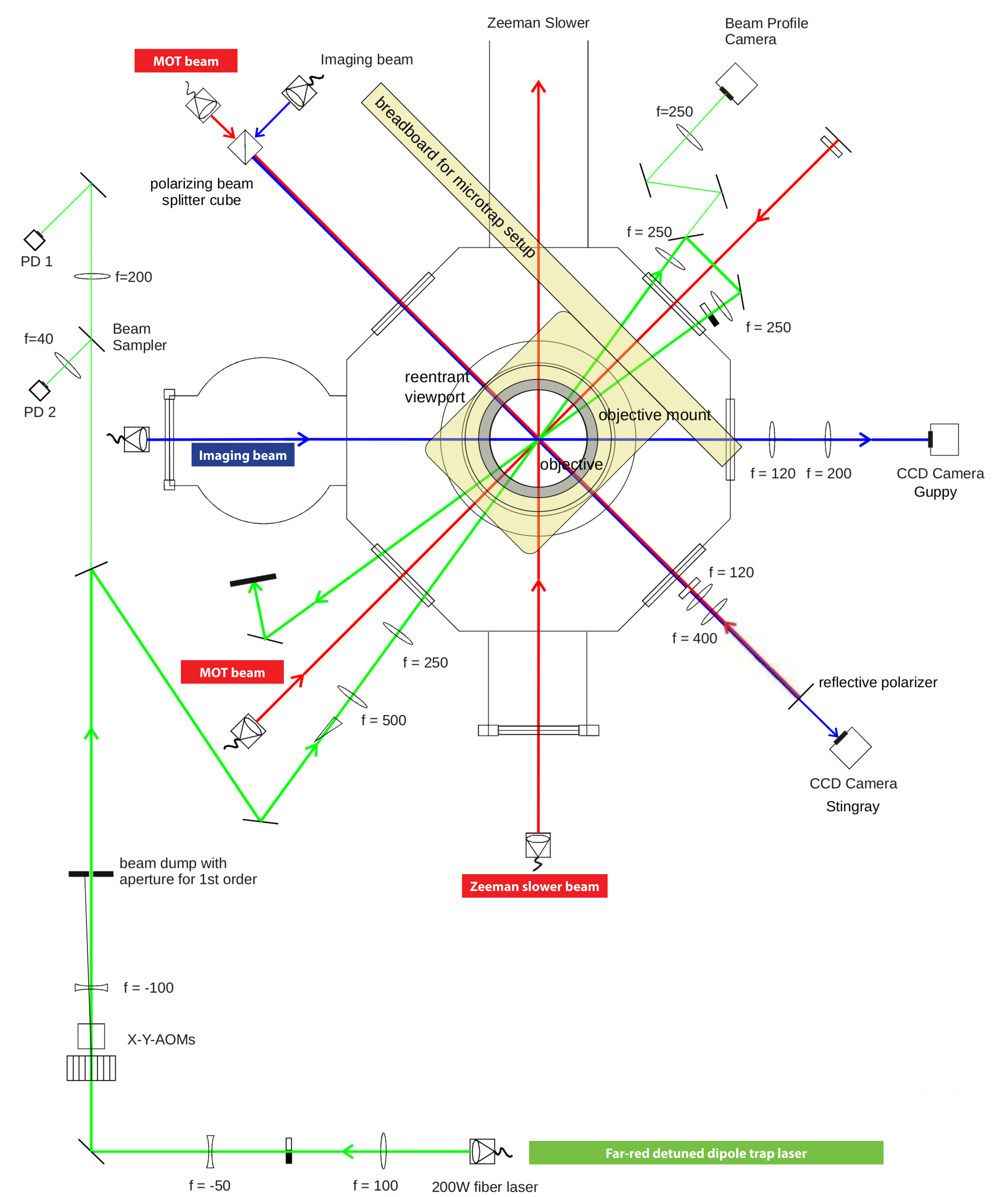

Figure 4. Top view of the experimental setup before changes were made to the imaging beam. The MOT and Zeeman slower beams are colored in red, absorption imaging beams in blue and the far-red detuned dipole trap beam in green. The microtrap beam comes in from underneath the vacuum chamber.

Crossed Beam Optical Dipole Trap (ODT)

- Atoms are loaded directly from the MOT to the dipole trap.
- Depth of 1 mK made possible by using a 200 W fiber laser (YLR-200-LP, IPG Photonics) at λ = 1070 nm.
- Cigar-shaped trap created by crossing two beams with a waist of $\omega_0 \approx 40$ μm.

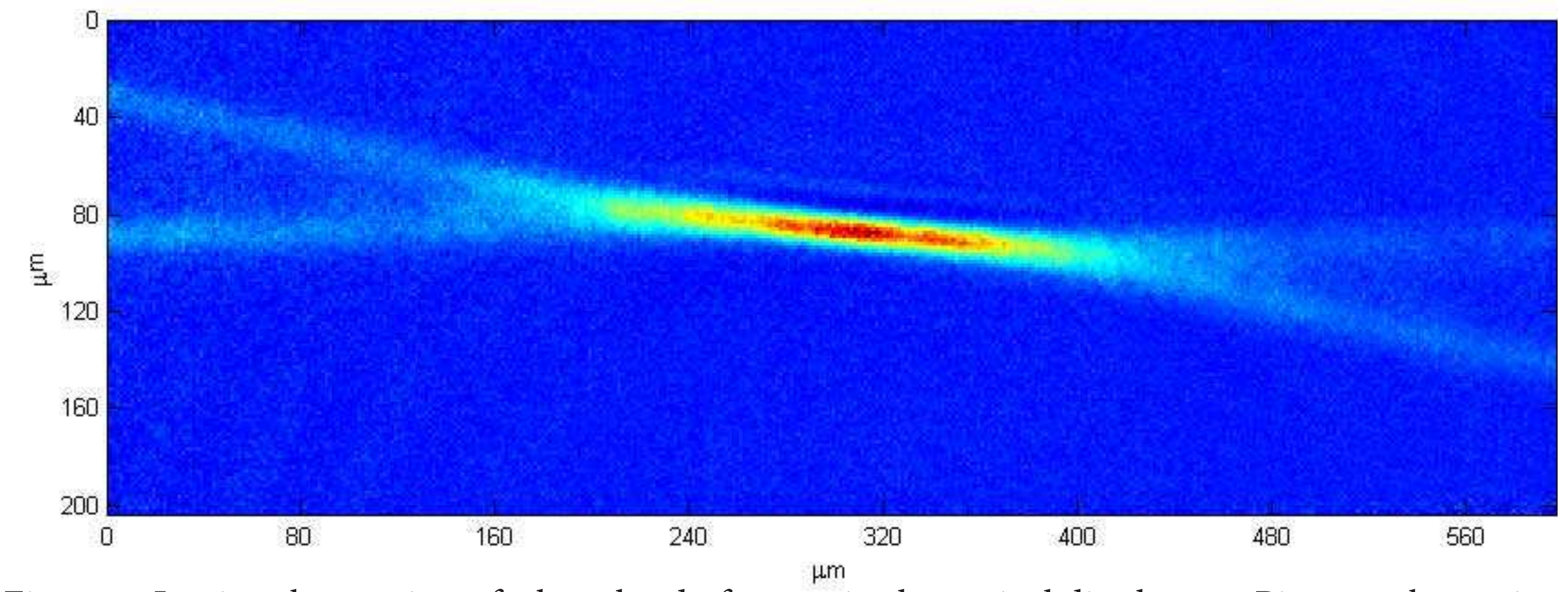

Figure 5. In-situ observation of a hot cloud of atoms in the optical dipole trap. Picture taken using absorption imaging on the vertical axis.

Microtrap

- Trap dimensions of 1x1x5 μm^3 superimposed with 10x10x100 μm^3 ODT.
- High quantum degeneracy - occupation probability of almost unity for the lowest trap levels.
- In order to avoid heating the sample we quadratically ramp up the microtrap potential.

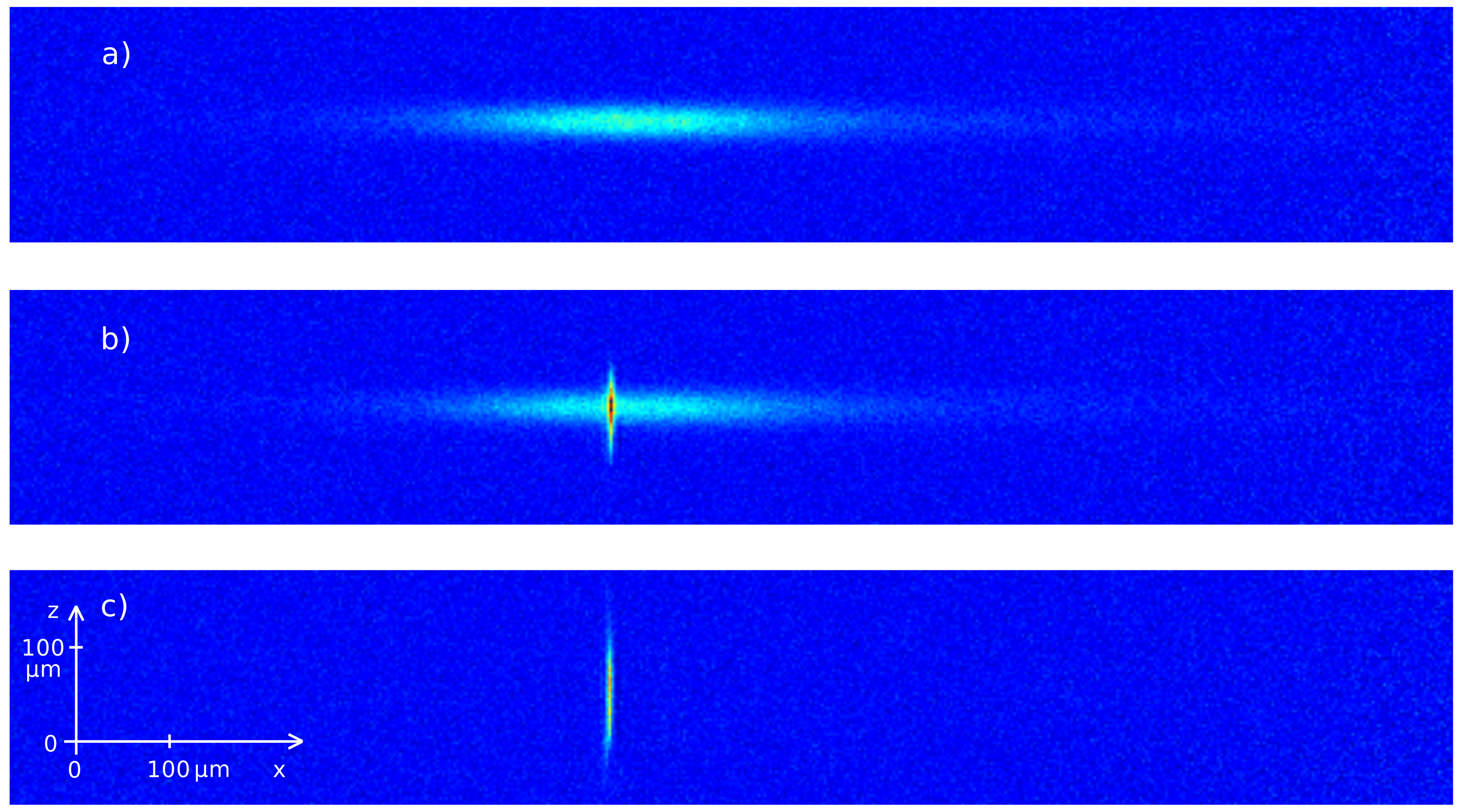

Figure 6. Transfer of atoms from the ODT to the microtrap. (a) Large cloud in the ODT with the microtrap switched off. (b) By switching on the microtrap we can see a considerable increase in atom density within its trapping potential. (c) The shallow trap is switched off.

Motivation for Spatially Resolved Imaging

If we have a double well instead of a single microtrap we want to be able to extract spatial information from pictures we take. To image one or few atoms the fluorescent time is small which leads to very few photons being scattered. Based on our need for a high-resolution camera with single-photon sensibility we used the Andor iXon Ultra 897 (EMCCD mode). Other changes:

1. Developed and implemented an optical scheme to focus the fluorescent signal onto the camera objective.
2. Using the microtrap laser we analyzed the focus of the beam at the Andor in order to assess the quality of our optical system.
3. Built an interlock that prevented the Andor from taking a picture when there is too much light incident on the objective. This helps protect the camera chip from overexposure.
4. Maximized the photon count by tweaking the detuning, intensity and position of the imaging beam.

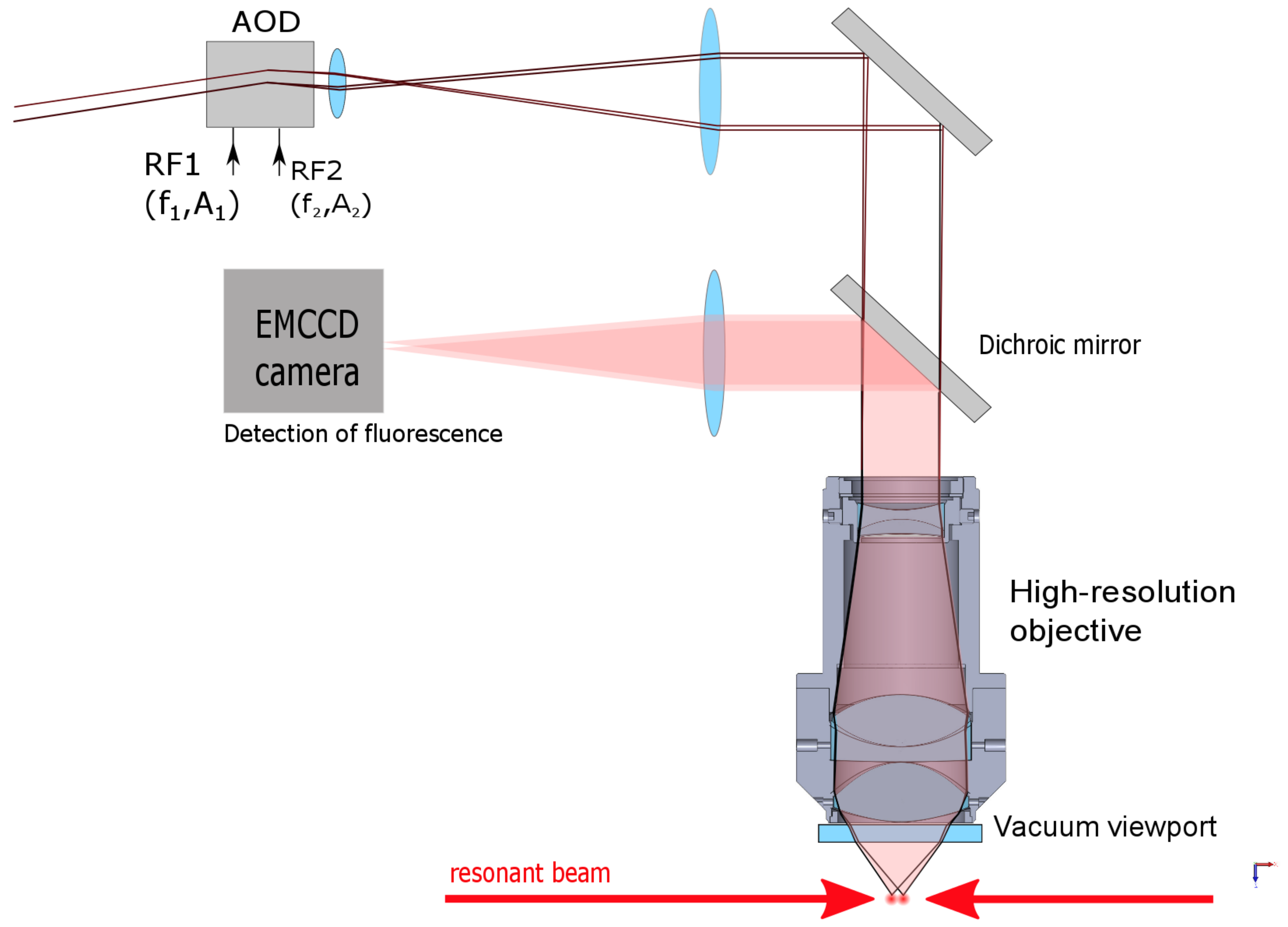

Figure 7. Generation of the multi-well potential.