Single neutral atoms as impurities in a BEC

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Application Note

Introduction

Single neutral atoms immersed in quantum gases allow studying impurity physics in a highly controlled system. In our experiment, we combine single Cesium-133(Cs) with a quantum gas of Rubidium-87 (Rb) atoms. Both species are independently trapped and cooled down to ultracold temperatures by applying laser cooling techniques.

Experiment

All experiments are performed in a glass cell under ultra-high vacuum. A magneto-optical trap (MOT) is used to capture and cool both Rubidium and Cesium atoms. For Rb, a standard low gradient MOT captures up to 10^9 atoms, which are subsequently loaded into a crossed dipole trap, formed by two orthogonal laser beams at 1064 nm.

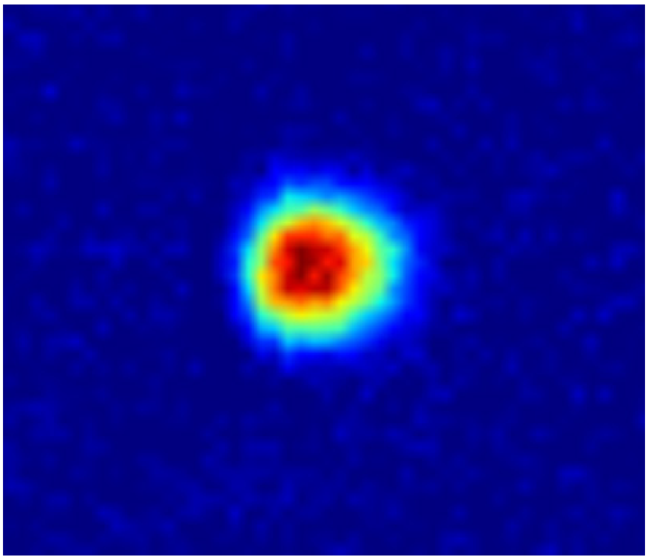

Fig 1: Absorption image of the Rubidium BEC containing about 50.000 atoms at a temperature of a few 100 nK

Here, the Rb atoms are evaporatively cooled down to temperatures of a few 100 nK, where they start forming a Bose-Einstein condensate (BEC). We image the BEC by standard absorption imaging employing an Andor iXon3 DU885-KCS-VP EMCCD Camera, see figure 1. From such images the atomic density and thus the atom number as well as atom temperature are deduced.

For the cesium atoms instead a high gradient MOT having a very small trapping volume captures only few or single atoms. Photons from six resonant laser beams are scattered by the atoms into the full solid angle. An objective (NA=0.36) placed beneath the glass cell collects 3.36% of the fluorescence photons, which we then detect on an Andor iXon3 DU897-ECS-BV EMCCD camera. The number of photons i.e. the total counts on the camera chip is proportional to the atom number in the trap.

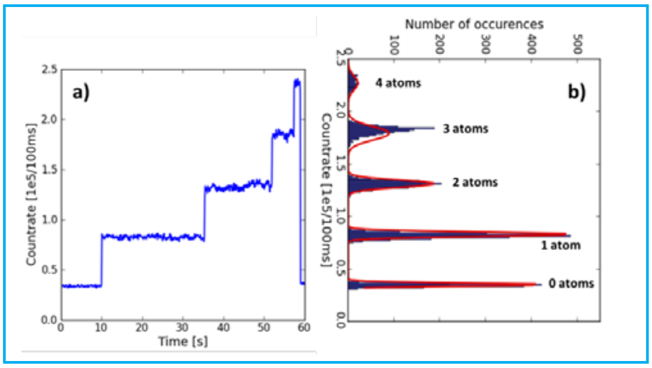

Fig 2: a) A typical fluorescence trace of the Cesium MOT detected over about 1 minute with an exposure time of 100 ms. Each step is the loading event of a single atom. b) A histogram calculated from 30 fluorescence traces. Each peak corresponds to a certain atom number.

We continuously detect the photons binned in periods of the exposure time, yielding an in-trap image of the atoms. A typical trace of the total fluorescence per image is shown in figure 2a. From a series of these traces we calculate a histogram (fig. 2b) revealing the total counts per atom, allowing us to calculate the atom number from the electron count rate of the EMCCD chip. After the MOT phase the Cesium atoms are stored in an optical lattice composed of two counter propagating laser beams at a wavelength of 790 nm, superimposed to a dipole trap beam (λ_{YAG}=1064 nm). Here we can detect the atoms close to single site resolution, revealing their exact position. High quantum efficiency (60%) of the iXon 897 camera is crucial, since the illumination in the lattice is very small and only very few photons are scattered.

Performance

Since the detected light intensities originating from single fluorescing atoms is very low, the background noise i.e. the dark counts of the detector chip is an important factor. If the noise level is too high, the numerical routine for counting the atom numbers becomes unreliable. In order to check the performance of our imaging, we therefore first investigate the camera dark counts by repeating the standard measurement procedure with camera shutter closed. The signal of the chip

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is then only determined by the dark counts. The measurements were performed for two different EM-Gains and different temperatures (fig.3). For an EM-Gain of 1000 the camera software does not allow for higher temperatures than -50 °C. In general the noise level for the EM-Gain = 1000 is larger than the one for EM-Gain = 275 by a factor of 2. In the case of EM-Gain = 1000 the noise level increases for decreasing temperature, whereas for an EM-Gain of 275 the noise level for small temperatures is approximately lowest. As most of the measurements are performed with high EM-gains a temperature of -70 °C is used as recommended in the performance data sheet. The noise level of about 1.4×10^3 counts/100 ms is quite small compared to signal count rates of 1×10^5counts/100 ms and hence don't pose a limit for our experiment. Example images of single atoms for exemplary values are shown in fig.3.

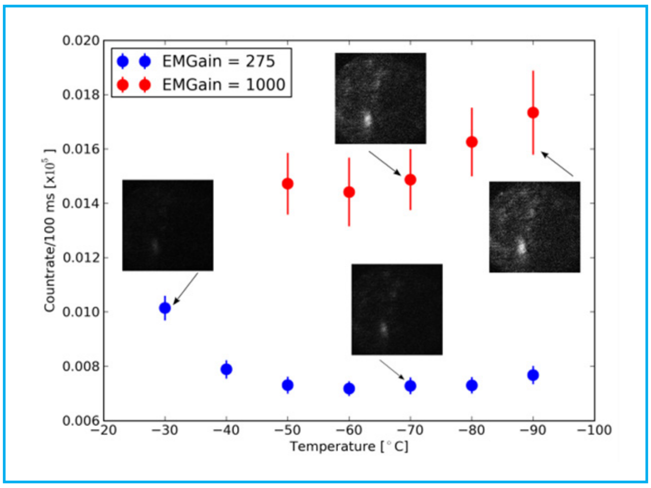

Fig 3: Dark count rate versus temperature for two different EM-Gains and an exposure time of 100 ms. The inset pictures show single atom MOT images taken with the same settings as for the measurement.

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