Interferometric analysis and modification of a single ion's fluorescence

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We analyse the resonance fluorescence of a single Ba^+ ion in a 1 mm diameter Paul trap using various interferometric techniques. By superimposing the collimated fluorescence at 493 nm (see level scheme in Fig. 1) and a fraction of the exciting laser light on a beam splitter [1] and analyzing their interference with a double-balanced heterodyne detector (Fig. 1), we observe a bandwidth-limited 61 mHz wide Rayleigh peak [2]. With the same resolution we observe the sidebands caused by the driven micromotion of the ion, when the analyzer frequency is shifted by the 18 MHz rf frequency of the Paul trap. We also observe sidebands due to the macromotion of the ion, by weak electric excitation of the ion at a frequency around one of the macromotion resonances, and by shifting the analyzer to that frequency, see Fig. 2. The broadening of the macromotion resonance is caused by the laser cooling that goes along with the $S_{1/2}$ to $P_{1/2}$ optical excitation [3].

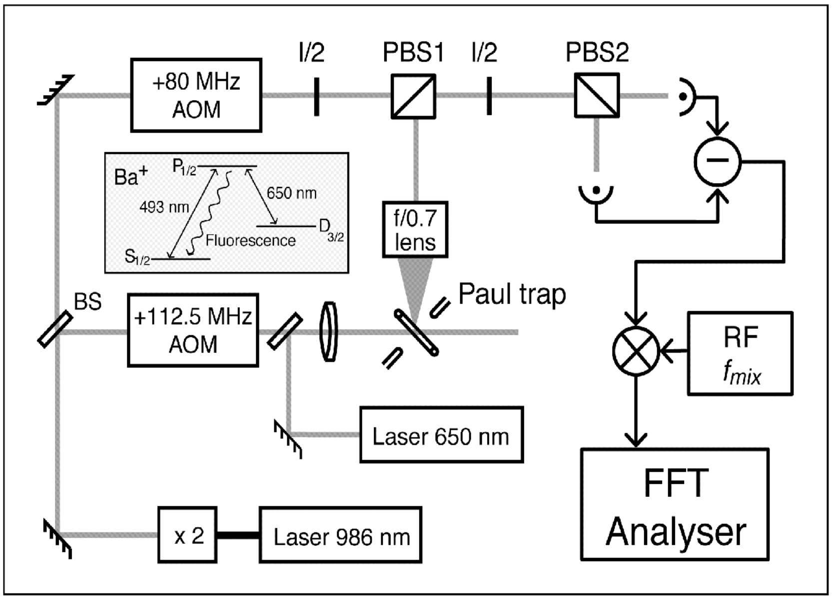

Figure 1: Heterodyne setup. The inset shows the relevant levels and transition wavelengths of Ba^+. With f_{mix} set to the difference frequency of the two AOMs, we observe the Rayleigh (carrier) peak of elastic scattering. With f_{mix} shifted by the frequency of one of the ion's vibrational modes, the corresponding sideband of the fluorescence spectrum is observed.

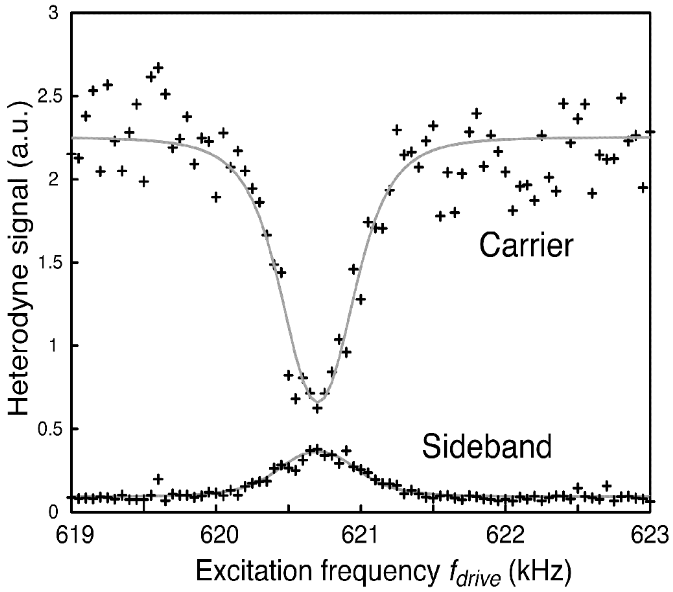

Figure 2: Carrier and sideband signal for weakly driven macromotion vs. drive frequency f_{drive}. Each data point corresponds to f_{mix} set to either the carrier or shifted by f_{drive}, and f_{drive} is scanned over the 620.5 kHz macromotion resonances.

From the Bessel function fit in Fig. 2 we find a cooling rate of 0.75 kHz in agreement with the value of 0.64 kHz calculated from optical Bloch equations [2]. Since the oscillation amplitude is smaller than the laser wavelength, i.e. the driven ion remains in the Lamb-Dicke regime, the determined cooling rate corresponds to the one without external excitation of the motion.

We also observe interference of the ion's fluorescence with itself in both a Mach-Zehnder interferometer and by refocusing the emitted light onto the ion with a high quality lens and a mirror. The latter experiment corresponds to modifying the vacuum fluctuations around a single ion by a mirror 40 cm away. Suppression and enhancement of spontaneous emission is observed with more than 20% contrast. The signal is sensitive to the position of the ion at the nm-level. With the same resolution we can also determine, from the signal contrast, the ion's motional amplitude in the direction of observation.

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[1] J. T. Höffges et al., Optics Commun. 133, 170 (1997).
[2] C. Raab et al., quant-ph/0003009.
[3] J. I. Cirac et al., Phys. Rev. A 48, 2169 (1993).