Feedback control of a single trapped ion's motion

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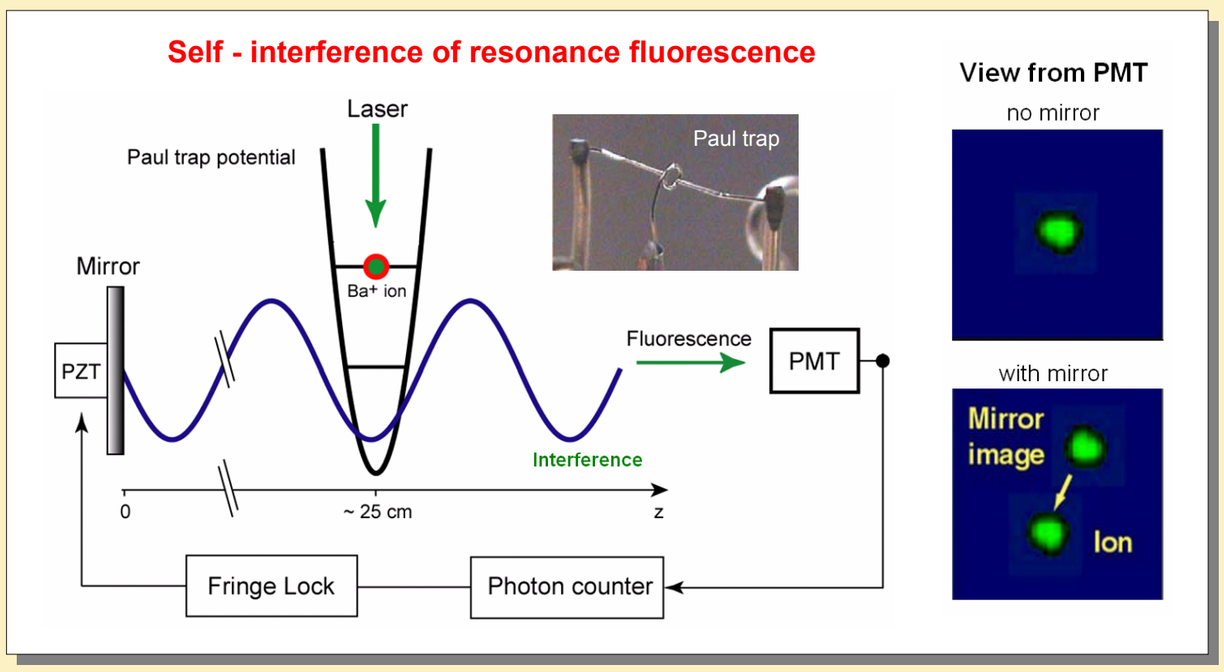
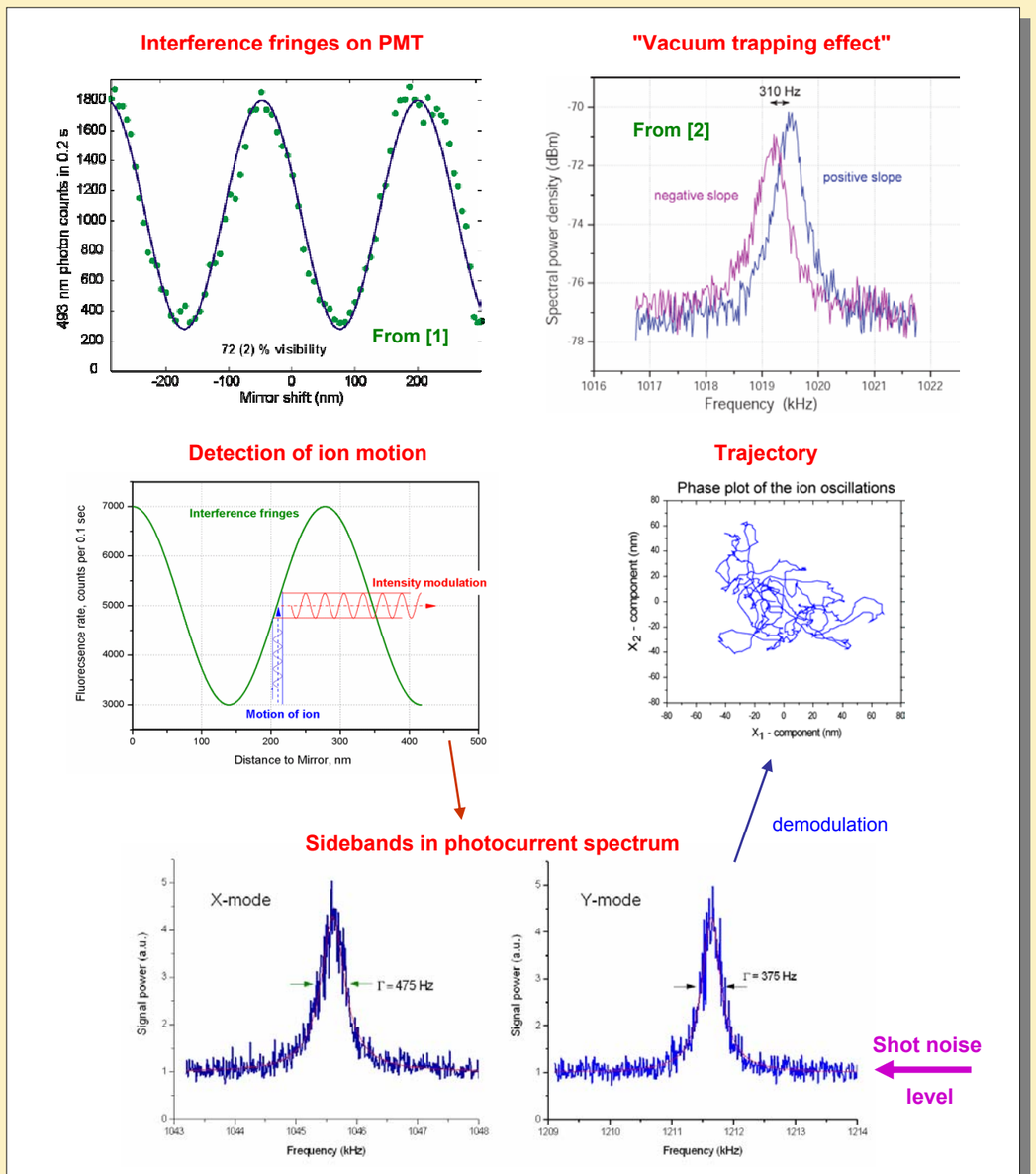
Real-time observation of a single trapped ion's trajectory



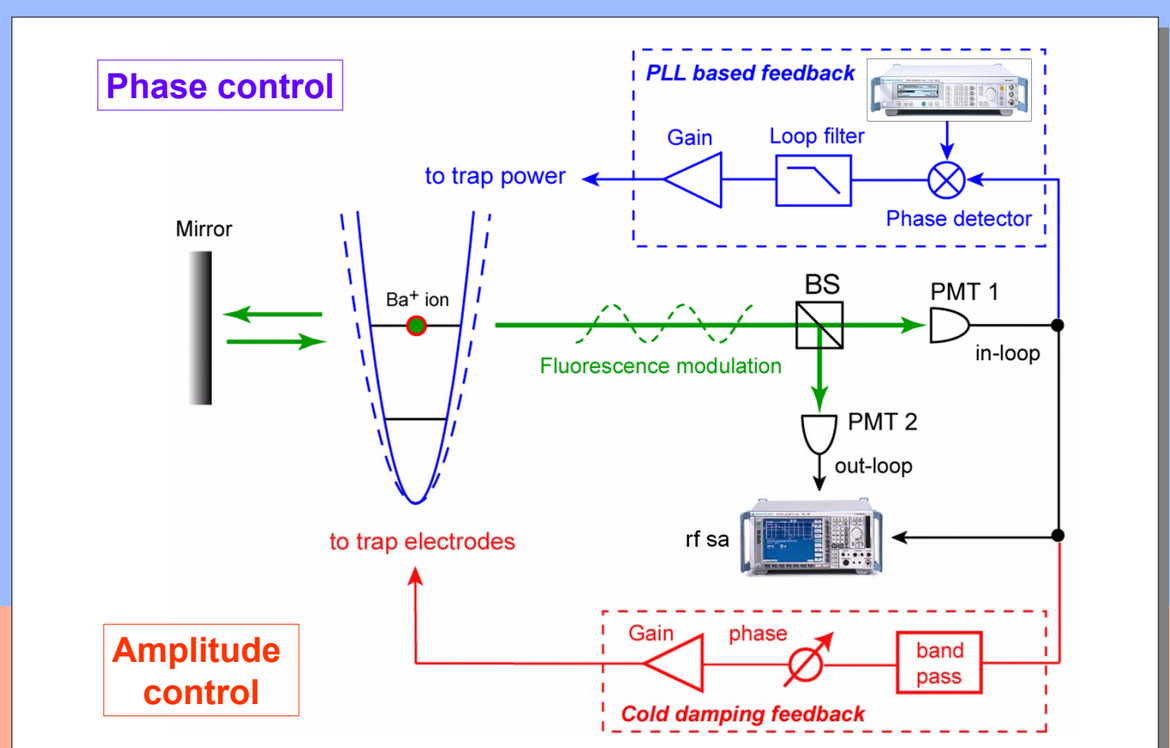
- **Single Ba^+ ion in Paul trap, laser-excited, Doppler cooled**
- **Residual thermal (r.m.s.) vibration ~ 35 nm @ ~ 1 MHz.**
- **Retro-reflecting distant mirror creates interference in fluorescence on photomultiplier [1].**
- **Amplitude and phase of the ion's motion are detected with high SNR as vibrational sideband in fluctuation spectrum of photo counting signal.**
- **Demodulation allows to track the ion's trajectory.**

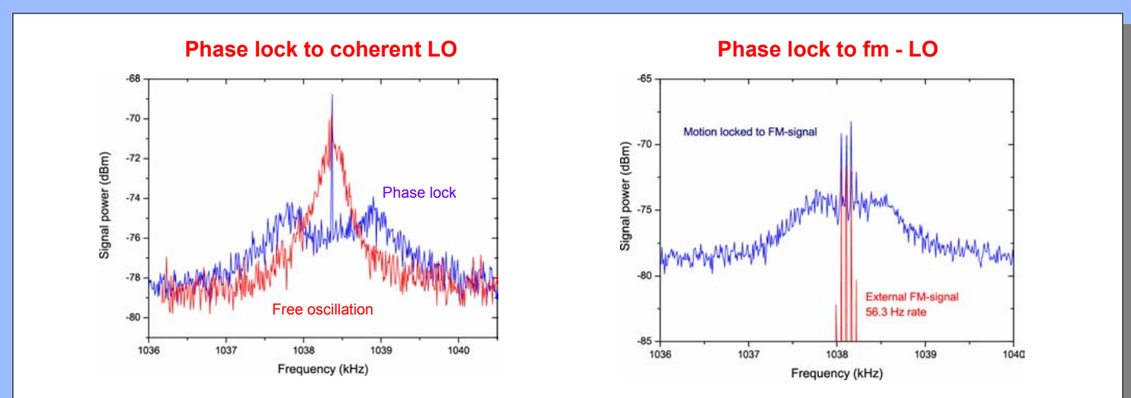
We use the information about the ion's motion to control it with various feedback techniques.
A quantum mechanical model [3] based on a master equation describes the measurements well.

[1] J. Eschner et al., Nature 413, 495 (2001). [2] P. Bushev et al., PRL 92, 223602 (2004).
[3] V. Steixner et al., t.b.p.
[4] J.M.W. Milatz et al., Physica XIX, 181(1953); S. Mancini et al., PRL 80, 688 (1998); P. F. Cohadon et al., PPL 83, 3174 (1999).



Phase lock of ion motion and feedback cooling





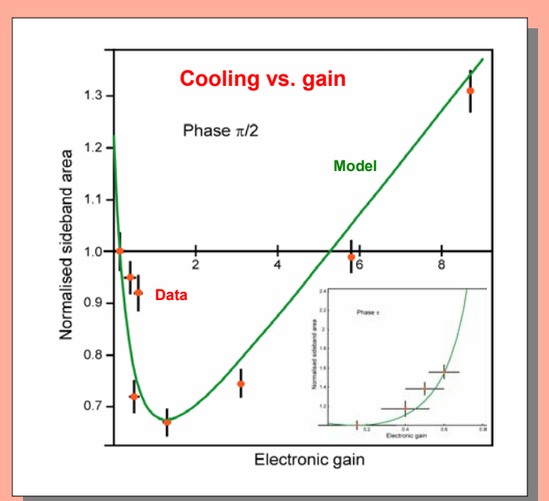
PLL operation: **measured phase deviations between the ion's motion and a reference oscillator (LO) are fed back to the of the rf trap drive power, thus controlling the trap stiffness.**

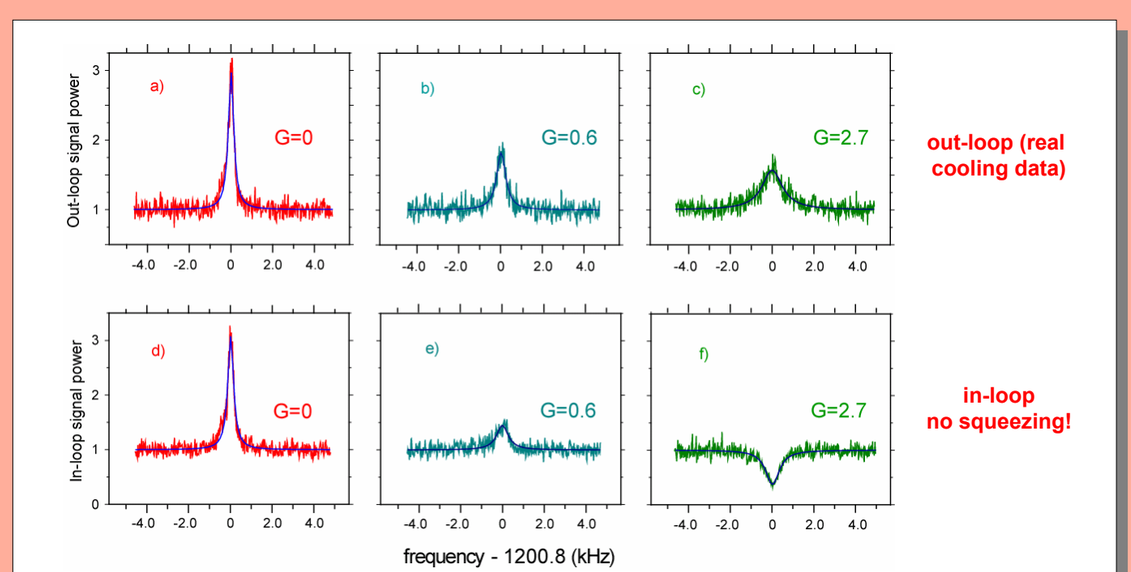
Shot noise limit: The bandwidth of the bandpass filter must capture recoild-induced phase fluctuations but allows shot noise to enter.

Feedback cooling **(cold damping) [4]: additional friction force proportional to the instantaneous velocity of the ion, by supplying electric fields which are -90° phase-shifted against the measured amplitude of the motion.**

A quantum mechanical model has been derived from first principles, describing the system by a master equation, including gain, phase, and noise [3].

Shot noise limit: At high gain the motion is driven by the shot noise, which overcompensates the cooling and leads to heating.





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