Robust Chains of Trapped Ions

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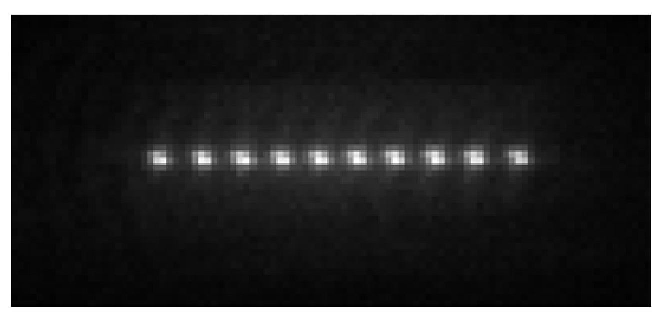
Analog Quantum Simulation

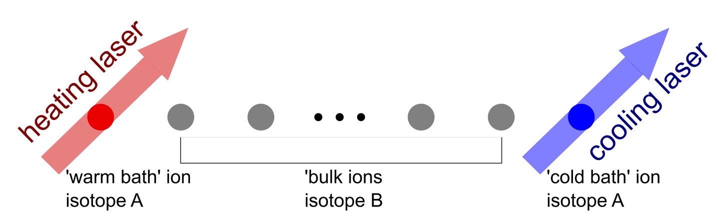
Motivation:

Many interesting quantum systems cannot be solved analytically, nor be simulated on a classical computer. However, one can infer the dynamics of a complex system by analogy to a well-controlled quantum system in a lab.

As an example, the dynamics of heat flow on an atomic scale requires quantum mechanical considerations, but the system is too complicated to compute analytically.



Chain of trapped $^{40}\mathrm{Ca}^+$

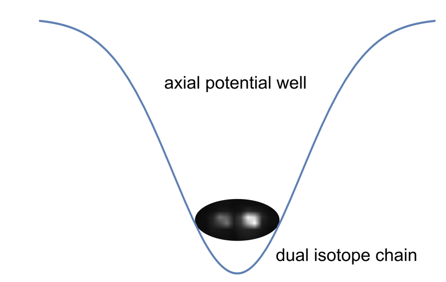


Goal: Simulate heat transfer in a linear chain of two isotopes of Ca$^+$

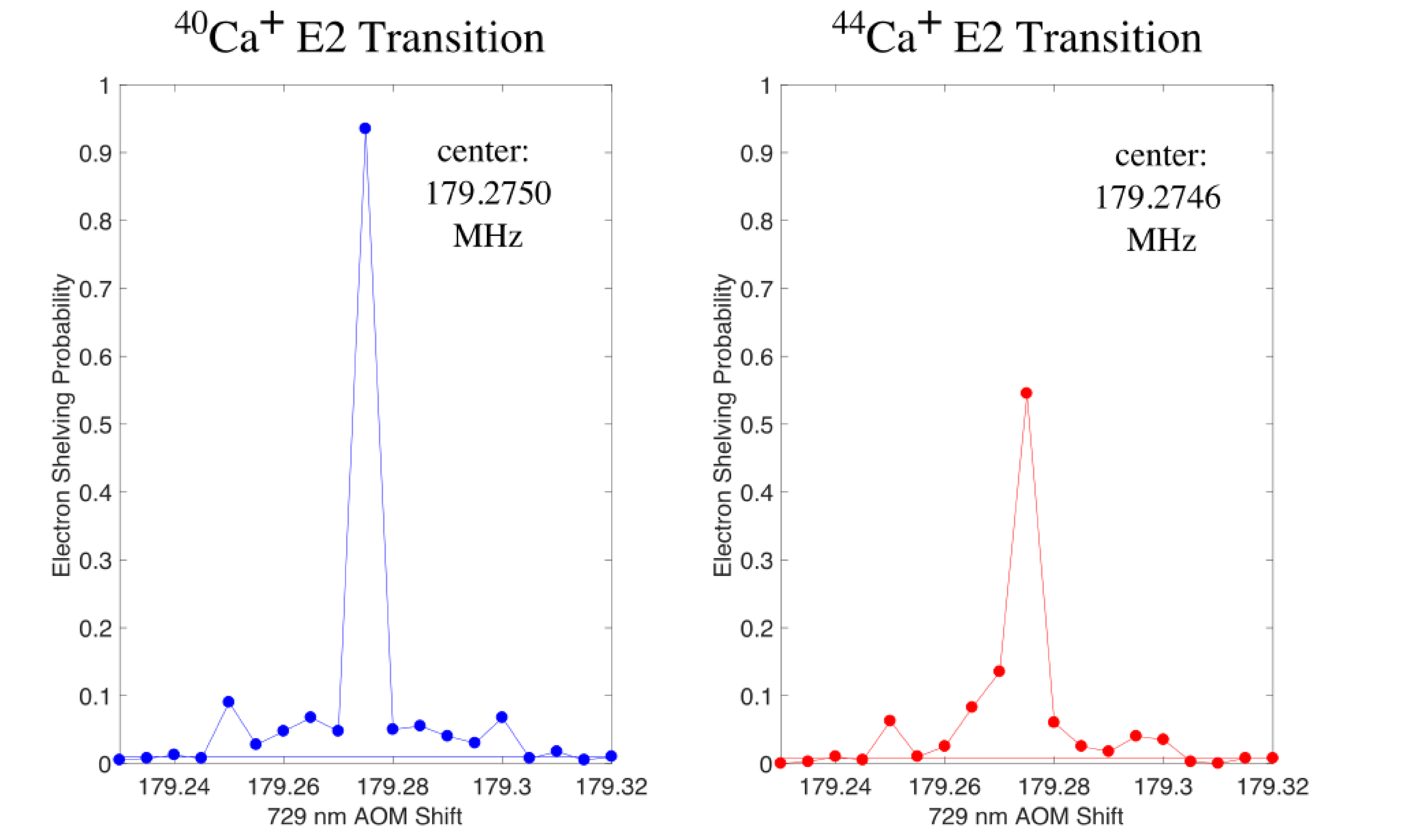
First, need to:

- Precisely measure the *isotope shift* between our target isotopes, $^{40}\mathrm{Ca}^+$ and $^{4x}\mathrm{Ca}^+$
- Trap dual-species ion chains and hold onto them for significant time

We took preliminary isotope shift data back in Bronfman, but found that we cannot hold on to ion chains as long as necessary for the experiment. **This poster details steps to increase our chain lifetime.**



Potential well trapping a dual isotope chain of $^{40}\mathrm{Ca}^+$ and $^{44}\mathrm{Ca}^+$

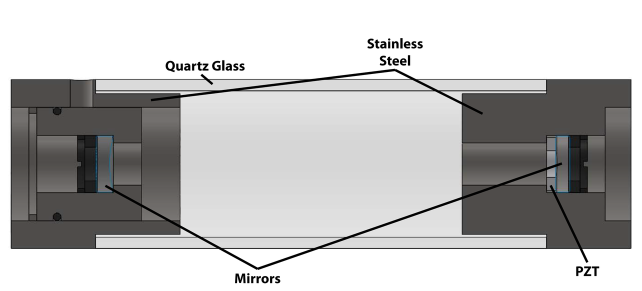


EOM shift: 2670.445 MHz

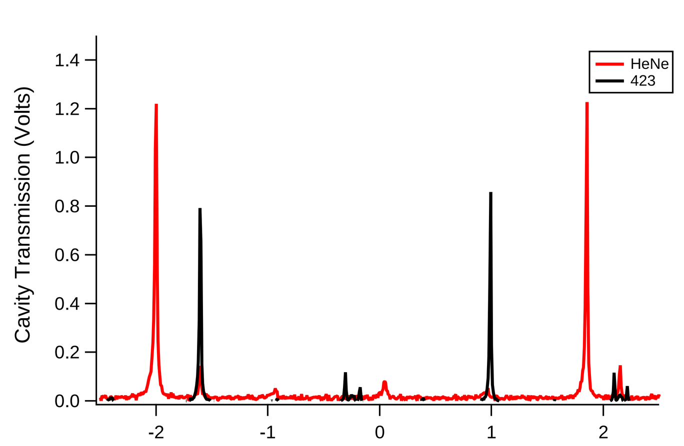
Preliminary data on the $^{40-44}\mathrm{Ca}^+$ $4S_{1/2} \rightarrow 3D_{5/2}$ transition isotope shift using simultaneous measurement of a dual isotope chain

Fabry-Pérot Stabilization

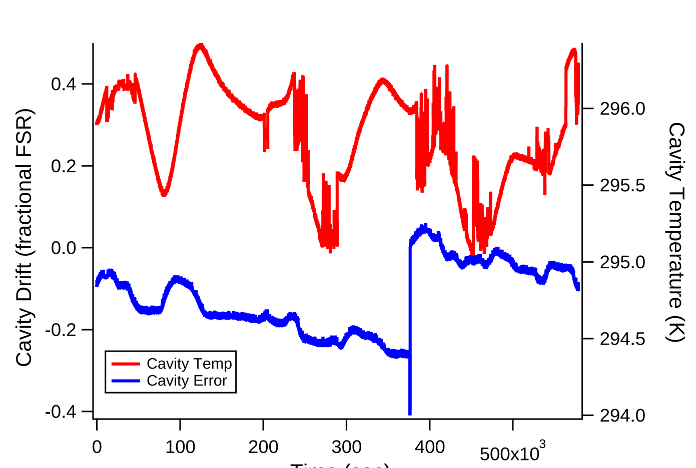
We use a Fabry-Pérot cavity to frequency stabilize our lasers. A commercial stabilized HeNe laser provides a stable frequency reference. The diode lasers are compared to the HeNe using a scanning optical cavity. We lock the relative position of a diode laser cavity transmission fringe to that of the HeNe, thus transferring its stability onto the diode laser.



However, this lock stabilizes the *wavelength* of the lasers, while we require the *frequency* to be stable. As such, we need to stabilize the environment inside the cavity to ensure that the relationship between frequency and wavelength remains constant, thereby ensuring that we are always making comparisons to the same set of transmission fringes.



To improve stability, we built a vacuum sealed enclosure to protect the cavity from humidity and pressure fluctuation. The cavity itself is comprised of a quartz spacer and stainless steel endcaps, with coefficients of thermal expansion matched to make the cavity close to athermal.



Ultra-Low Pressure Measurement

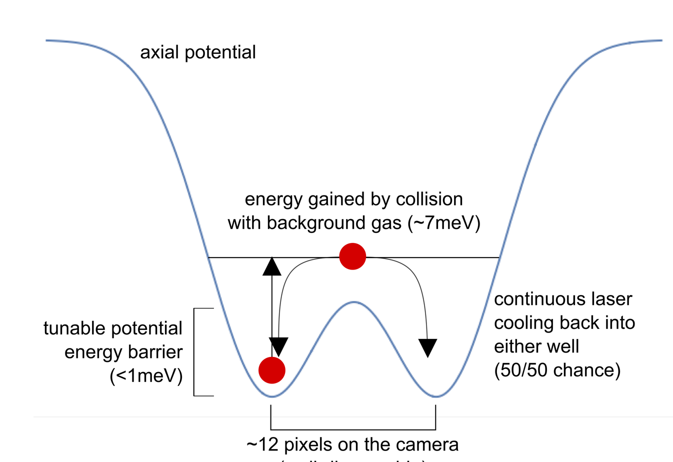
Trapping ion chains requires incredibly low background pressure. For, collisions heat the chain and decrease chain lifetime.

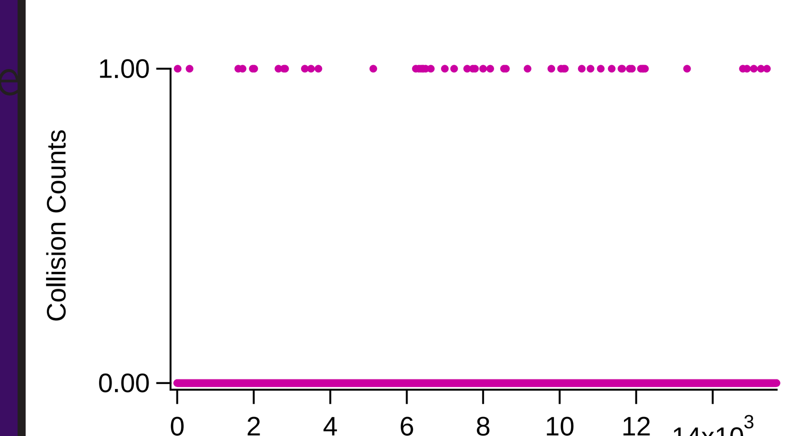
Problem:

- Gauges don't work well at ultra high vacuum
- Care about the pressure at the ion

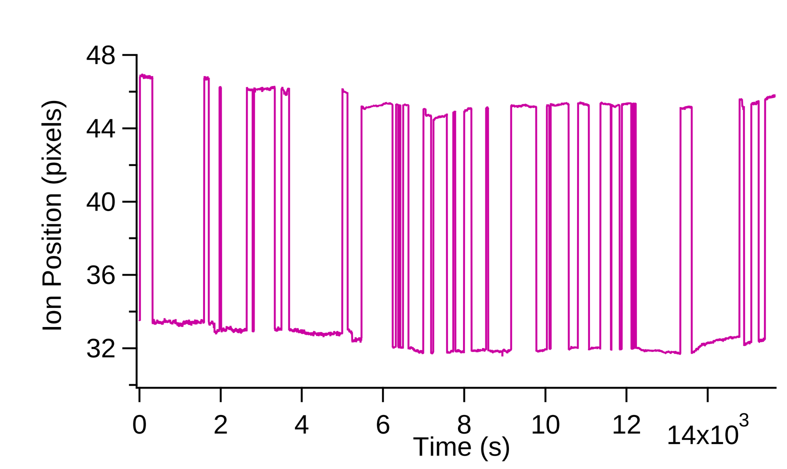
Solution: Use the ion itself to measure pressure.

Trap ion in a double well potential with a barrier small enough that a collision gives the ion enough energy to slosh freely between the wells. As the ion is continuously laser-cooled it probabilistically falls back into one of the wells => it hops for 50% of collisions.





Keeping track of ion hops



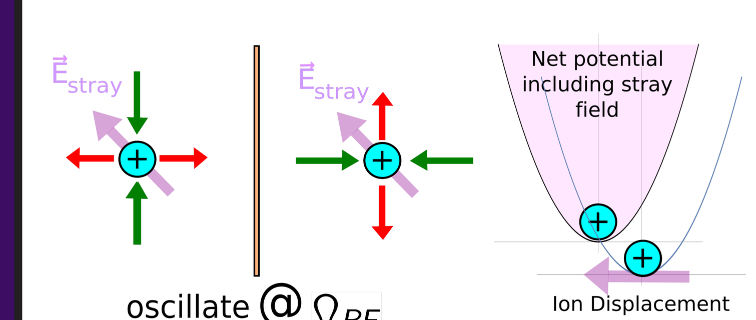
Ion position vs time

The true collision rate is double the measured rate. Since the background gas consists almost exclusively of H_2 molecules, one can use the collision rate to calculate the pressure from first principles.

Y-Field Compensation

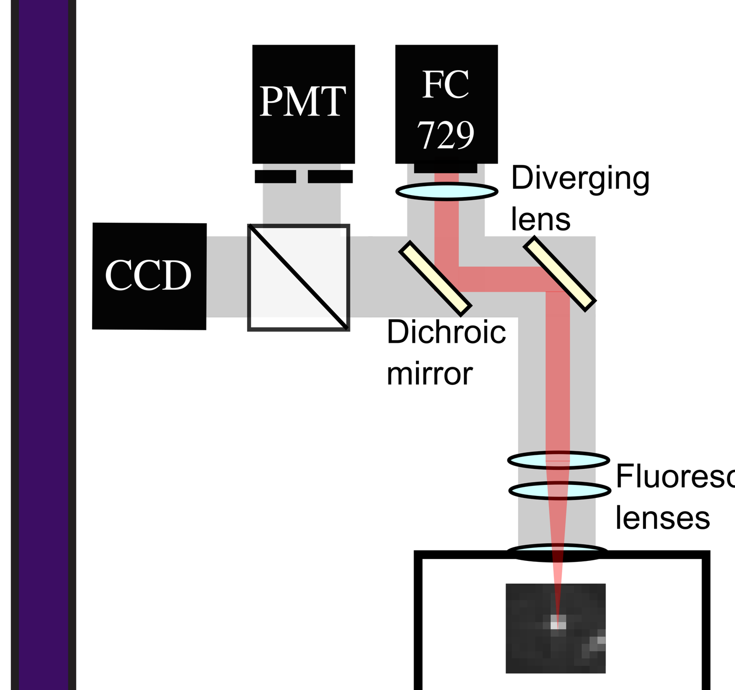
Our trap has stray electric fields. They had been compensated for in the x- and z-directions (horizontal), but not in the y-direction (vertical). Stray fields push the ion from the pseudopotential null => oscillations at the RF frequency.

This causes heating and shorter chain lifetimes.

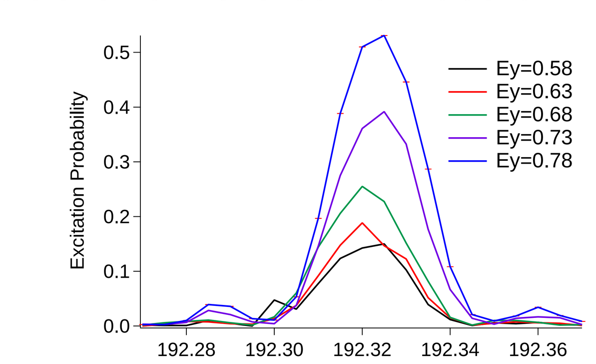


Micromotion is measured by its effective Doppler shift, so the beam path must overlap with the direction of motion.

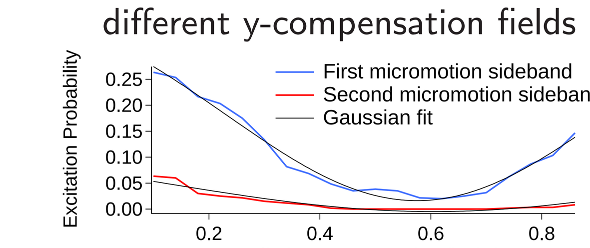
=> created a new beam path to probe the vertical direction.



Beampath of the 739nm light through the fluorescence stack.



Scanning over the micromotion sideband for different y-compensation fields



Excitation probability at the sideband frequency as a function of the applied y-compensation

We measured the stray fields in the y-direction and applied appropriate compensation voltages. The remaining stray fields in the y-direction are now <100 V/m in the regions of the trap used to build ion chains.