Trapping Ions on a Shoestring?

WABASH COLLEGE
A LIBERAL ARTS COLLEGE FOR MEN

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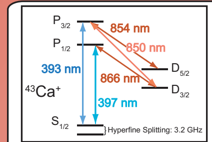
As a proven architecture for quantum information experiments, it would be invaluable to establish a research program at an undergraduate liberal-arts college, building the opportunity for students to participate in state-of-the-art research in quantum information and quantum control. There are currently a number of research opportunities at undergraduate institutions that utilize laser cooling and that provide experiences in atomic physics, notably with Bose-Einstein Condensates. This project is trying to extend the research opportunity for undergraduate students in the field of trapped ion quantum information as well as covers the experimental implementation of a new type of quantum control using long-wavelength radiation.

Why Calcium?

The table at right is an inventory of all the trappable, single-electron atomic ions used in quantum information experiments. The different resonant transitions needed for Doppler-cooling and resonance fluorescence detection are shown. Simple Doppler cooling experiments for loading and detecting a single ion can currently be done most directly for calcium ions. Although some of the blue and UV diode lasers exist, the availability and price of those lasers are not consistent.

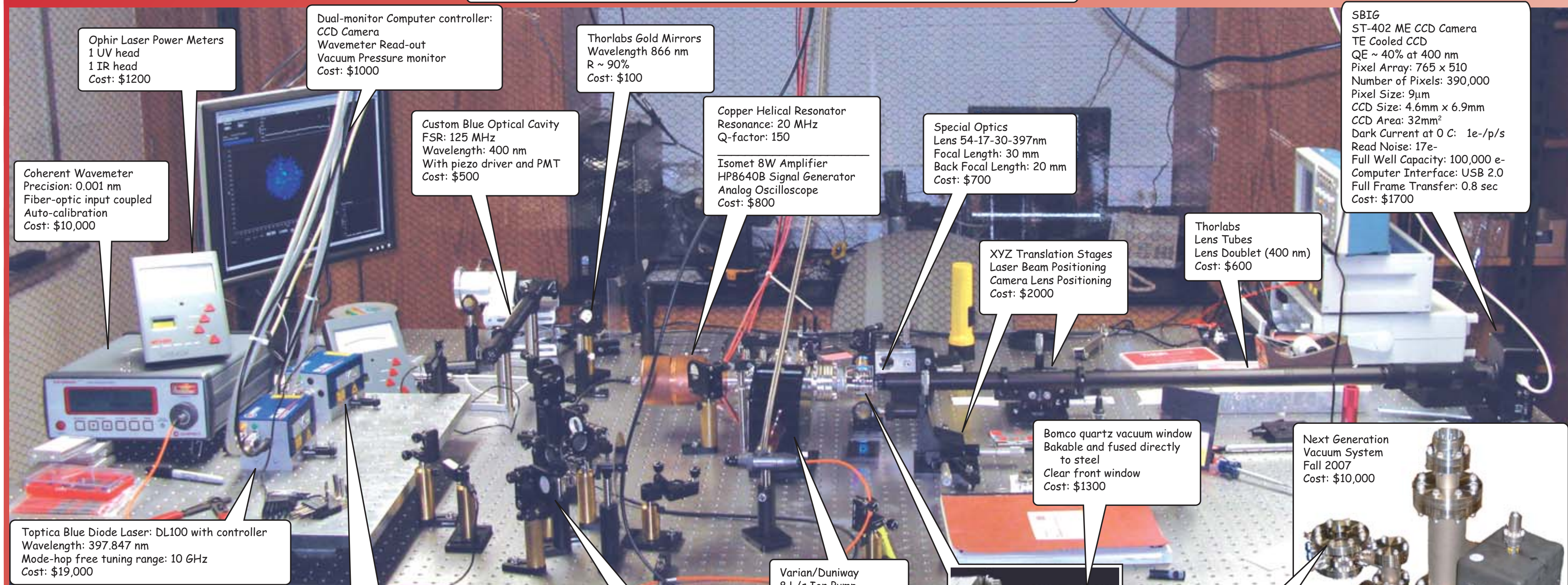
Ion	$S_{1/2}\rightarrow P_{1/2}$	$S_{1/2}\rightarrow P_{3/2}$	$P_{1/2}\rightarrow D_{3/2}$	$P_{3/2}\rightarrow D_{3/2}$	$P_{3/2}\rightarrow D_{5/2}$	$S_{1/2}\rightarrow D_{5/2}$	$S_0\rightarrow P_1$	$P_1 \rightarrow$ Continuum
Ca	***397***	***393***	***866***	***850***	***854***	***729***	*423*	***390***
Sr	*422*	***408***	1092	1004	1033	***674***	*460*	***412***
Ba	*493.5*	*455.5*	***650***	*585.5*	***614***	1760	553	455
Be	313	313	-	-	-	-	235	-
Cd	226	215	-	-	-	-	229	-
Mg	280	279	-	-	-	-	285	-
Yb	*369*	-	***935***	-	-	-	***399***	***395***
Hg	194	164	-	-	-	-	185	-
Zn	203	206	-	-	-	-	213	-

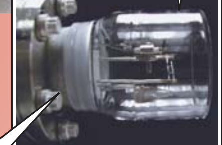
Laser wavelengths (in nm) are given for the possible trapped ion quantum information atomic species. The ***BOLD ITALIC*** wavelengths are accessible via direct diode lasers, while the *ITALIC* wavelengths can be reached by frequency doubled diode lasers.



Calcium has also been proven in trapped ion quantum research. There are several groups including the Steane Group at Oxford, the Blatt Group at Innsbruck, and Drewsen Group at Arhauus that currently work with trapped calcium ions. In addition, there has been work done with both $^{40}Ca^+$ and $^{43}Ca^+$ qubits.

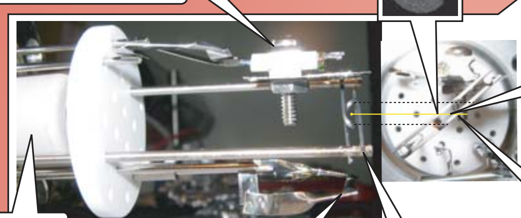
Experiment Setup

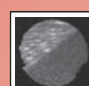




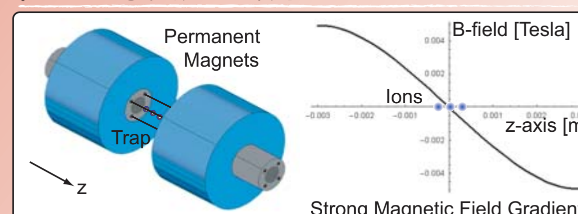
Budget to Date

Lasers:	$30,000
Laser Measurement and optics:	$16,100
Vacuum System and RF:	$5,200
Imaging System:	$4,000
Total Cost to Date:	$55,300
Working on trapping ions at an undergraduate liberal-arts college:	*Priceless*





Future Direction: Magnetic Field Gradients



One research objective is to combine a line of ions with a strong magnetic field gradient. The magnetic field shifts the ground state energy levels in an odd-numbered isotope like $^{43}Ca^+$. This makes the line of ions look like a molecule for Nuclear Magnetic Resonance (NMR) studies. But the interactions in this "molecule" can be tuned and adjusted and more ions can be added, unlike the real chemical molecules in NMR. By controlling the characteristics of the ion "molecule", it will be possible to build a designer entangled system.