EXPERIMENTS WITH SINGLE TRAPPED YTTERBIUM IONS AT JPL

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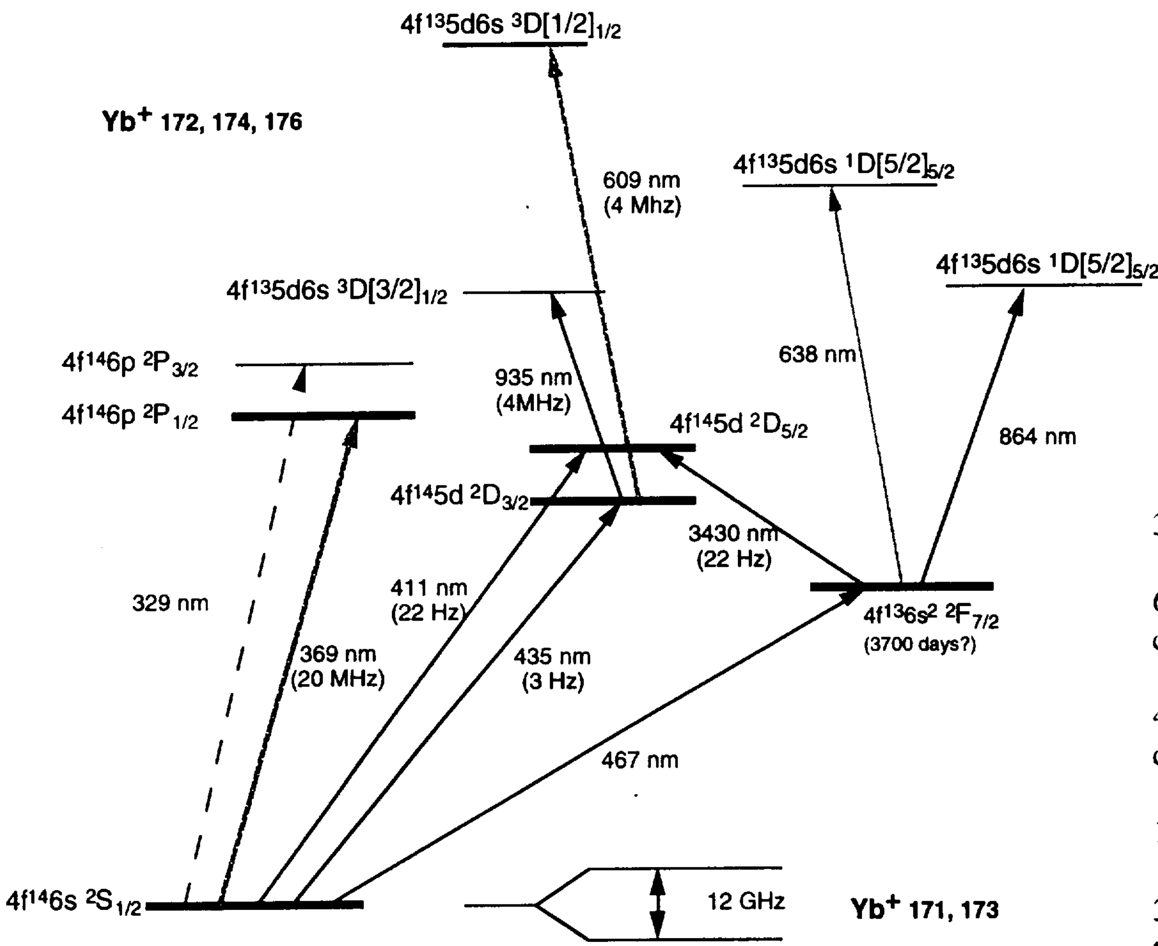
Ytterbium ion level scheme



369 nm cooling transition.

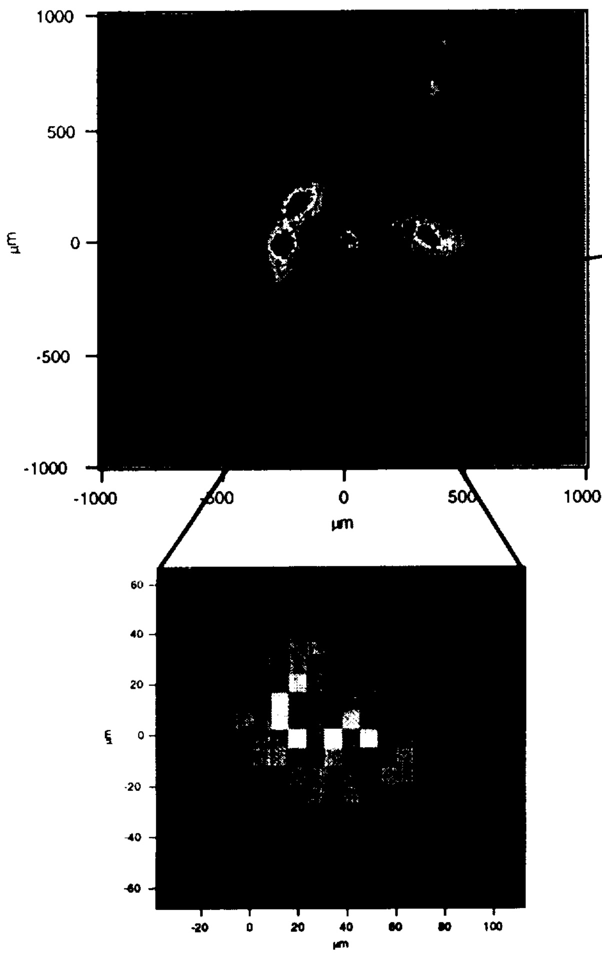
609nm 935nm, 638 nm clearing transitions.

411nm, 467nm, 3.43um clock transitions.

12 GHz microwave trans.

329 nm auxiliary shelving transition.

Paul-Straubel rf trap and single ion image



Single Yb+ ion fluorescence image

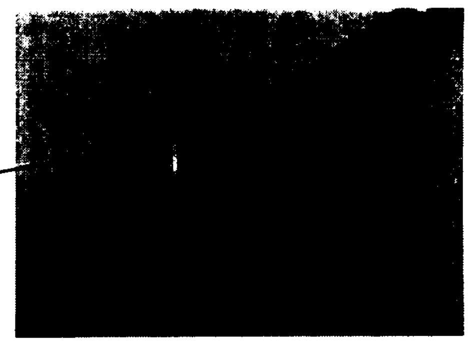
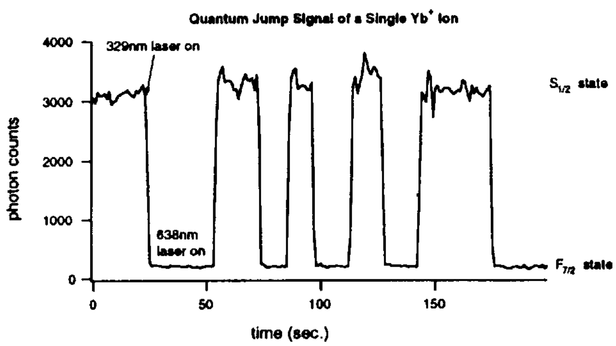


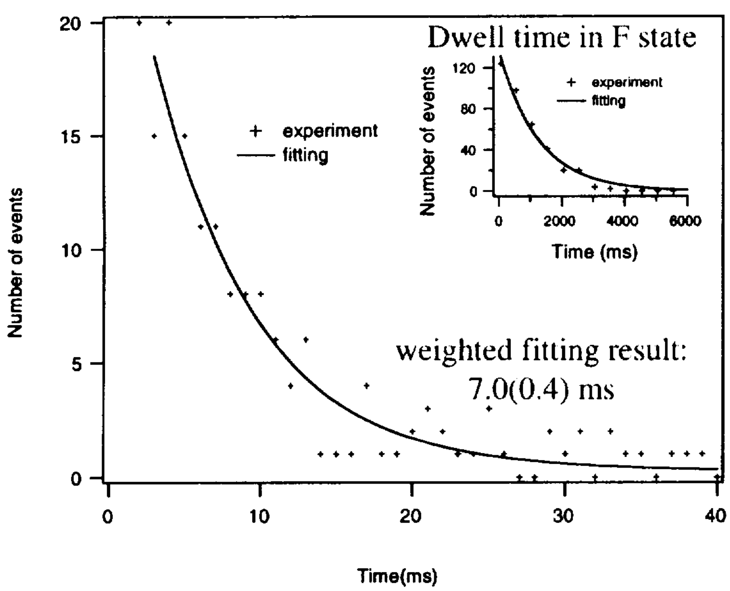
Photo of a Paul-Straubel trap

The trap is made of twisted Ta wire loop of 1.0 mm diameter.

The image resolution is limited by the photon collection optics (x4.5).

$D_{5/2}$ state lifetime measurement



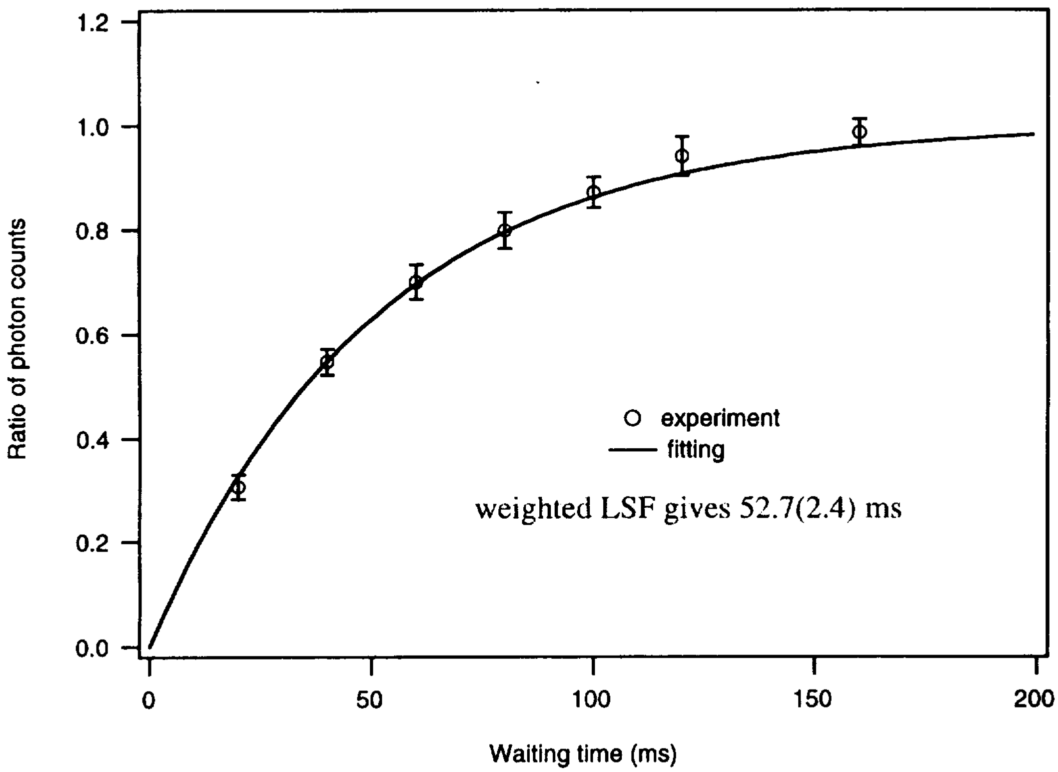


The lifetime of the $D_{5/2}$ state can be determined using the quantum jump technique. In this technique, continuous fluorescence photons are detected when the ion is in the ground state. An excitation of the ion into the $D_{5/2}$ state will quench the fluorescence completely until it decays spontaneously back to the ground state and the fluorescence resumes.

The on or off state of the fluorescence signal indicates whether the ion is in the $S_{1/2}$ or $D_{5/2}$ state. The average fluorescence off-time(dark period) gives the lifetime of the $D_{5/2}$ state.

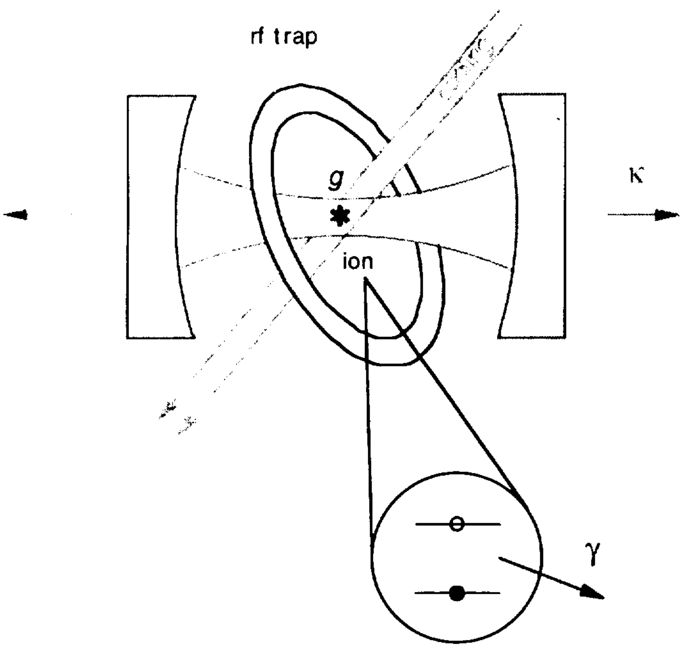
$D_{3/2}$ state lifetime measurement

decay histograph



On average, 207 photons at 369nm are scattered before the ion is repumped into $D_{3/2}$ state again, yielding the $P_{1/2}$ branching ratio to be 0.0483.

Trapped individual ions in an optical cavity



Interaction Hamiltonian:

$$\hat{H}_s = \frac{\hbar\omega_A}{2}\hat{\sigma}^z + \hbar\omega_c\hat{a}^\dagger\hat{a} + i\hbar[g(\vec{r})\hat{a}^\dagger\hat{\sigma}^- - g^*(\vec{r})\hat{a}\hat{\sigma}^+].$$

$$g(\vec{r}) = \left(\frac{\mu^2\omega_c}{2\hbar\epsilon_0 V_m}\right)^{1/2} U(\vec{r}) = g_0 U(\vec{r}).$$

The strong coupling condition:

$$g_0 > (\gamma, \kappa).$$

Experimental challenges:
* protecting mirror coating,
* avoid/circumvent dielectric charge-up,
* reducing cavity volume,
* ....

Initial exploratory system: experimental goals

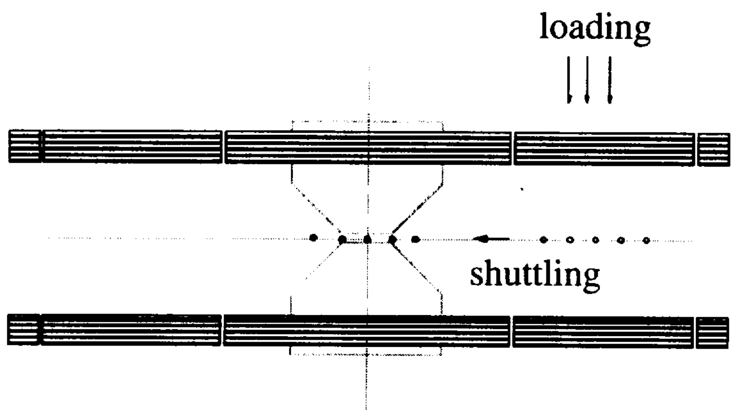
Feasibility demonstration:

- effects of atom beam collimation/contamination
- pulsed electron beam ion-loading/surface charge up problem
- ion translation capability, trap stability
- QED cavity locking/stabilization
- possible *insitu* surface discharge

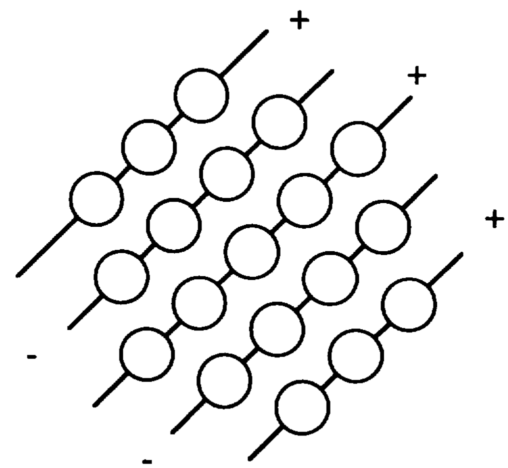
Interesting physics to investigate:

- sw cooling
- cavity field mapping
- ion orbital size measurement
- laser transmission of occupied cavity
- QND atom state measurement through off resonance phase shift

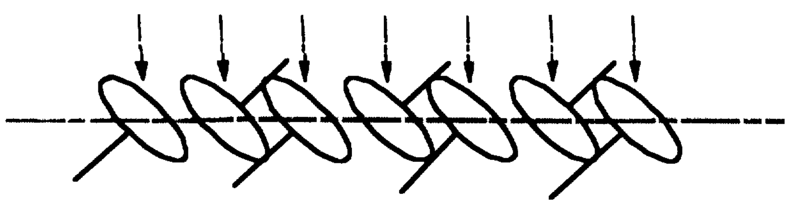
Future systems: trap-cavity integration II



linear trap ion loading and ion addressing



planar ring trap array



serial ring trap array