Probing the Limits of Quantum Mechanics with Ion Traps.

My interest in the foundations of quantum mechanics goes back to my days as a graduate student at the Rockefeller University, where I studied superfluidity. I wondered at that time whether a macroscopic quantum system could be used to turn the tables on the uncertainty principle, If the quantum system is bigger than the observer would there be a surprise? Alas, the macroscopic manifestations of quantum mechanics in superfluid helium were limited to the 'old quantum theory' and did not contain the wave-function- superposition issues that are fundamental to 'wave function collapse'. At that time I also became disenchanted with the huge literature on 'quantum measurement' whose authors were merely describing their personal interpretation of quantum mechanics rather than providing an experimental prediction for a new phenomenon.

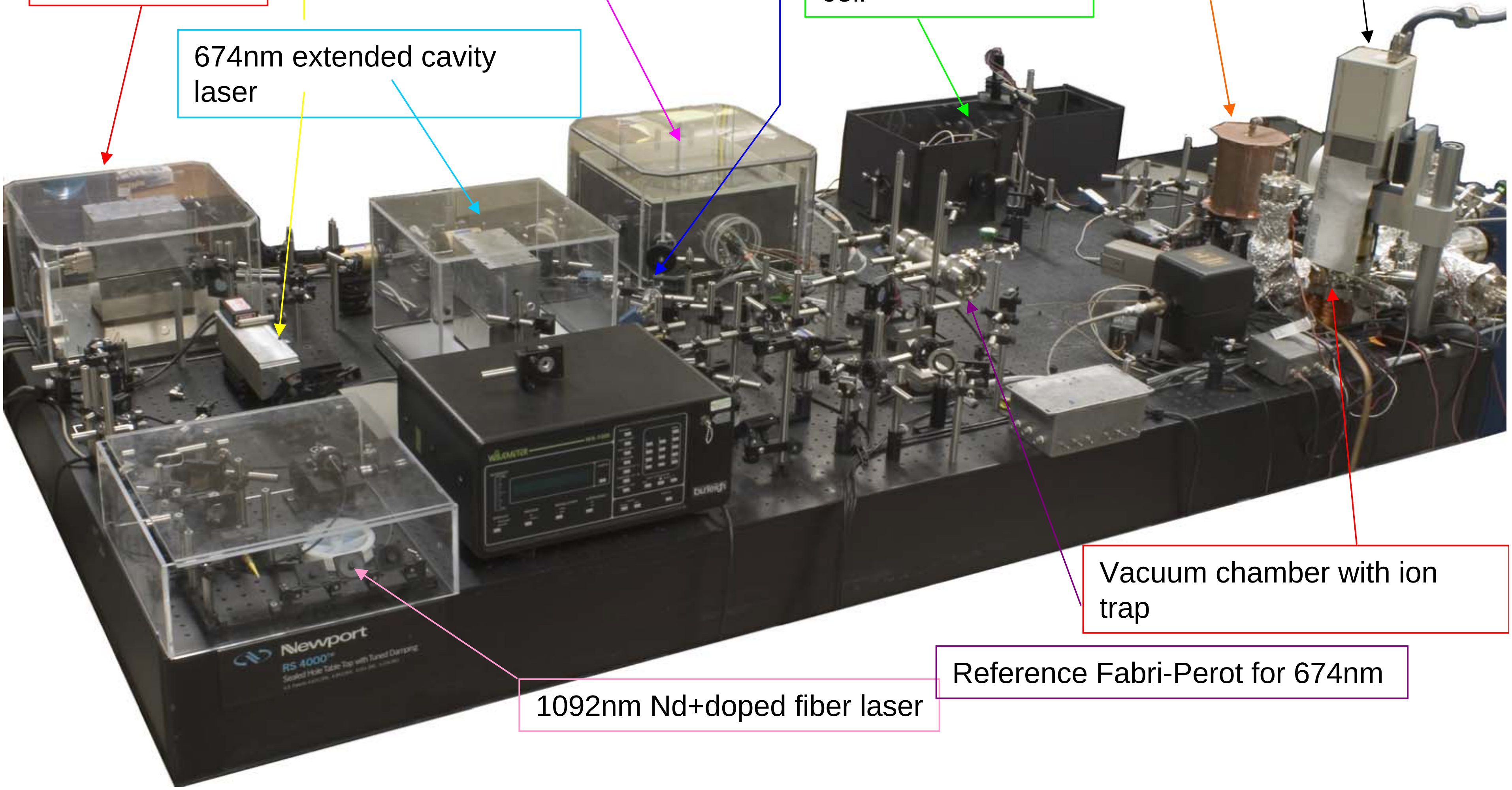
The advent of the ability to study trapped single ions and probe individual quantum jumps using the Dehmelt shelving scheme again interested me in the experimental foundations of quantum mechanics. In this arrangement the ground state '0' of an ion is coupled to two excited states one of which '1' is a short lived state [with ~ nanosecond lifetime] and the other '2' a metastable state [with a long lifetime ~ 1 second]. If these transitions are both illuminated Dehmelt envisioned that from time to time the rapid-repetitive emission from the 1-0 transition will turn off [in this example for about 1 second] when the atom shelves itself in level 2. This intermittency in fluorescence enables one to observe successive quantum jumps in a single resettable degree of freedom. Tom Erber and I, proposed that in this arrangement randomness characteristic to ensembles is avoided and that therefore a trapped ion provides the best opportunity to test the fundamental randomness postulate of quantum mechanics[1]. In order to ascribe quantum mechanical meaning to randomness in intermittent fluorescence of the 3 level ion, the effect must exist in the limit of **coherent** illumination. If chaos in the light source is the cause of intermittency then one is not probing intrinsic quantum mechanics of the jumps. Our proposition that the quantum telegraph exists in the limit of coherent illumination turned out to be controversial [for just this reason] but was resolved –in our favor-by our publications [2,3]. We showed that a photo-detector which can record outgoing photons also records the duration of null emission between photon arrivals and in so doing changes the wave function into a state where the quantum telegraph is observed The introduction to our 1989 paper provides an accessible summary of the key issues.

Preliminary tests of randomness have been conducted by Wineland [see ref 3] and Berkeland [4]. In my lab at UCLA Emil Kirilov has also built an ion trap for Strontium ions [the figures shows a photo of the current experimental arrangement and a version of the ion trap]. One goal is to build a trap where the quantum efficiency for detecting quantum jumps is increased by at least a factor of 100 over previous efforts with the goal of making critical tests of quantum randomness. There is more to randomness than a fit to the Poisson distribution. Especially interesting will be checks for the ordering or cycling of ‘shelving’ times. As the randomness criteria are honed and extended we envision using randomness to learn about the observer and the external macroscopic means of excitation. How far can this be pushed?.

At a deeper level experimental research with ion traps will probe intricate arrangements where the entanglement of quantum states is realized. Perhaps ion traps present an opportunity to create a conundrum for quantum mechanics as we know it. In particular can one use feedback between quantum entangled systems and the coherent state of the laser which excited them to push beyond the current limits of quantum mechanics? We do not propose to contradict Schrödinger’s equation, but rather aim to create a situation where Schrödinger’s equation cannot easily supply an answer.

References

[1] T. Erber , S. Putterman, Nature 318, 41 (1985).
[2] M. Porarati, S. Putterman Phys. Rev. A36, 929 (87); Phys. Rev. A39, 3010 (89)
[3] T. Erber et al. Annals of Physics, l90, 254 (1989).
[4] Dana Berkeland, Physical Review A69, 52103-1-4 (2004).



Opto-galvanic reference for 1092nm

Error signal----
polarization method

Helical resonator

844nm
extended cavity
laser

KNbO3 cavity doubler

Absolute reference
for the 422nm,
AOM with Rb vapor
cell

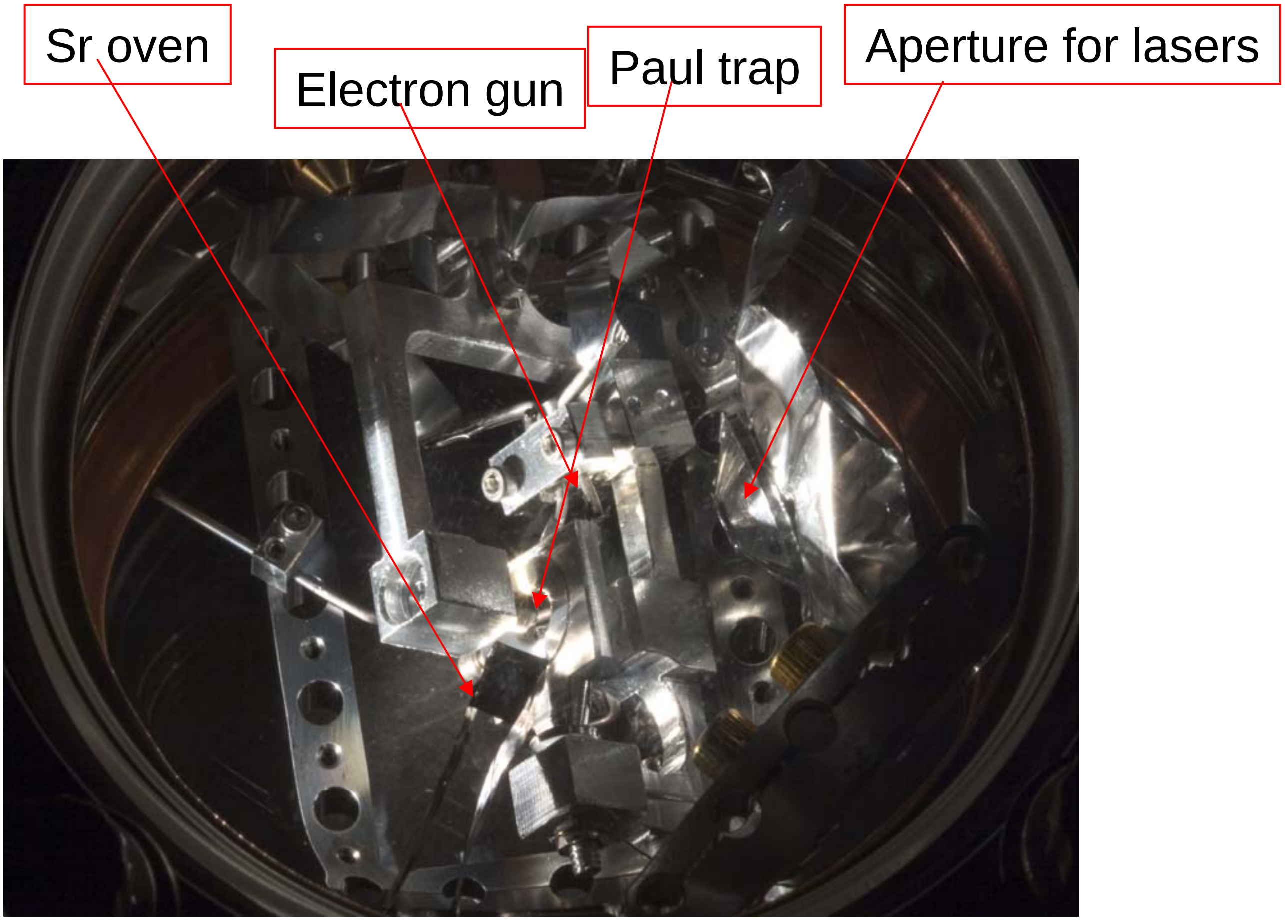
Detection
optics

674nm extended cavity
laser

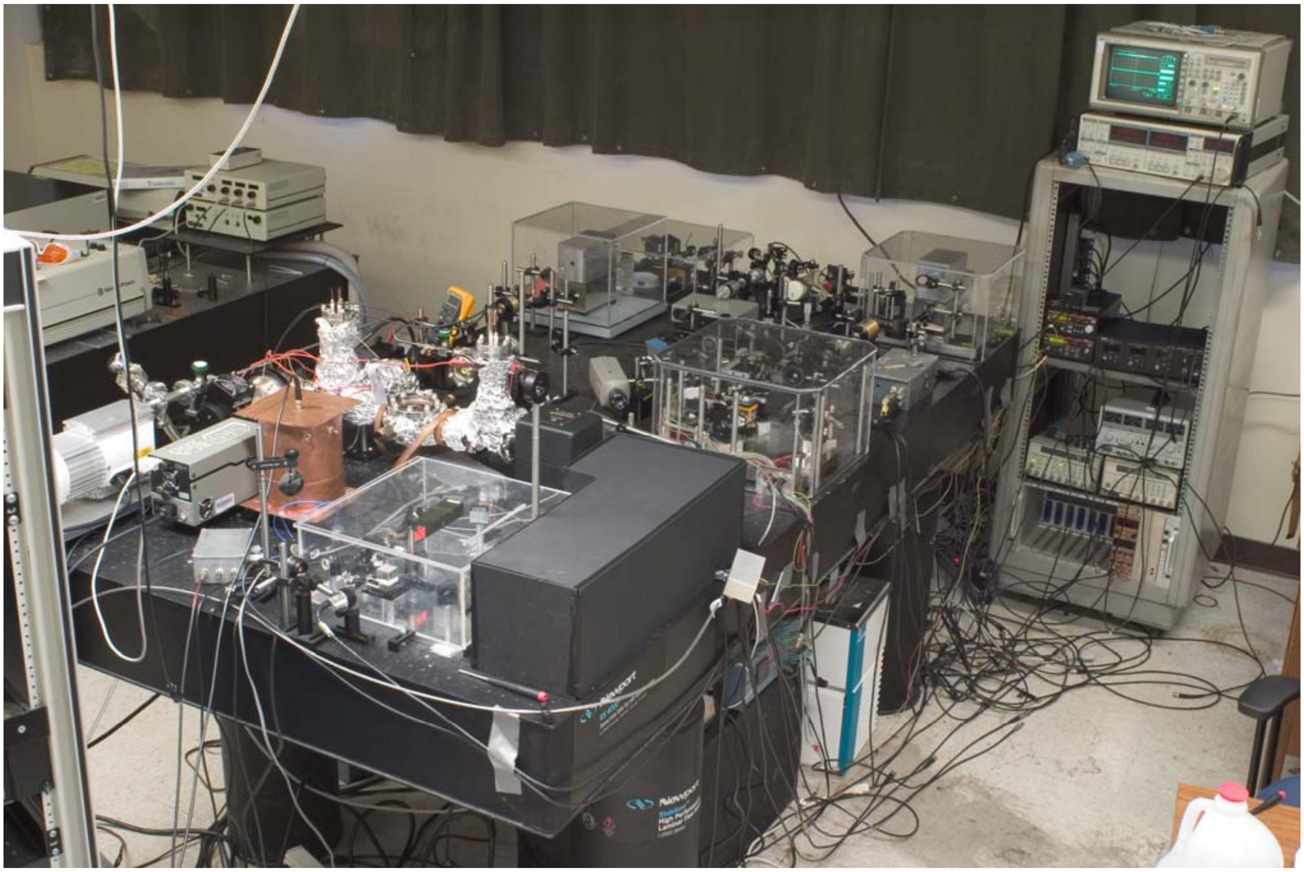
Vacuum chamber with ion
trap

Reference Fabri-Perot for 674nm

1092nm Nd+doped fiber laser



Above is a photo of a Paul trap used to trap a cloud of Strontium ions shown to the left. The ion cloud is the short Horizontal line of light.



Trapped cloud of ions