Measuring Quantum Jumps of Ba 138+ in an Ion Trap

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Boris Blinov

Layout

I. The Measurement Problem

II. Ion Traps

III. Experimental Setup

IV. Results

Schrodinger's Equation is deterministic!

$$i\hbar \frac{d}{dt}\Psi(t) = \hat{\mathrm{H}}\Psi(t)$$

One can write:

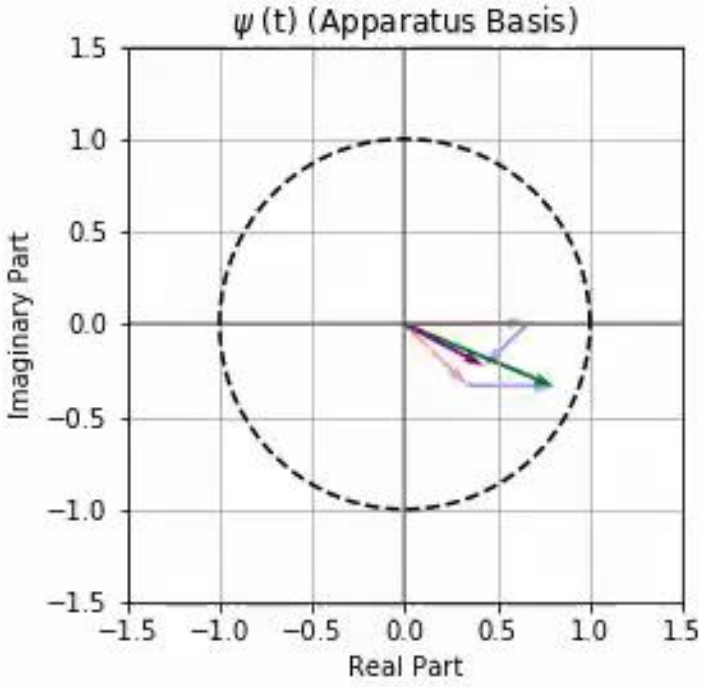
$$\Psi(t) = U(t)\Psi(0)$$

Where U is the (norm-preserving) time evolution operator

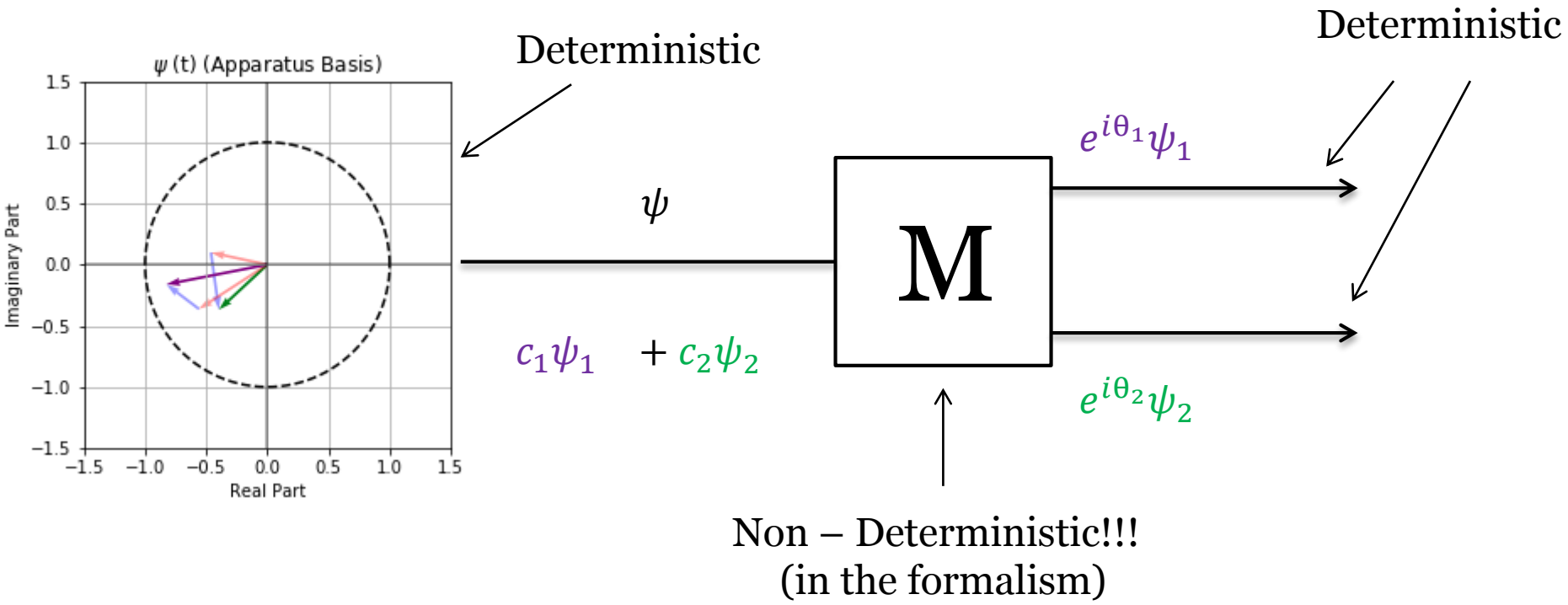
Thinking about U

- Take $\hat{H} = \begin{pmatrix} -5\hbar & 0 \\ 0 & 7\hbar \end{pmatrix}$, $\Psi(0) = c_1\psi_1 + c_2\psi_2$
- Then:

$$\Psi(t) = U(t)\Psi(0) = c_1\psi_1 + c_2\psi_2$$

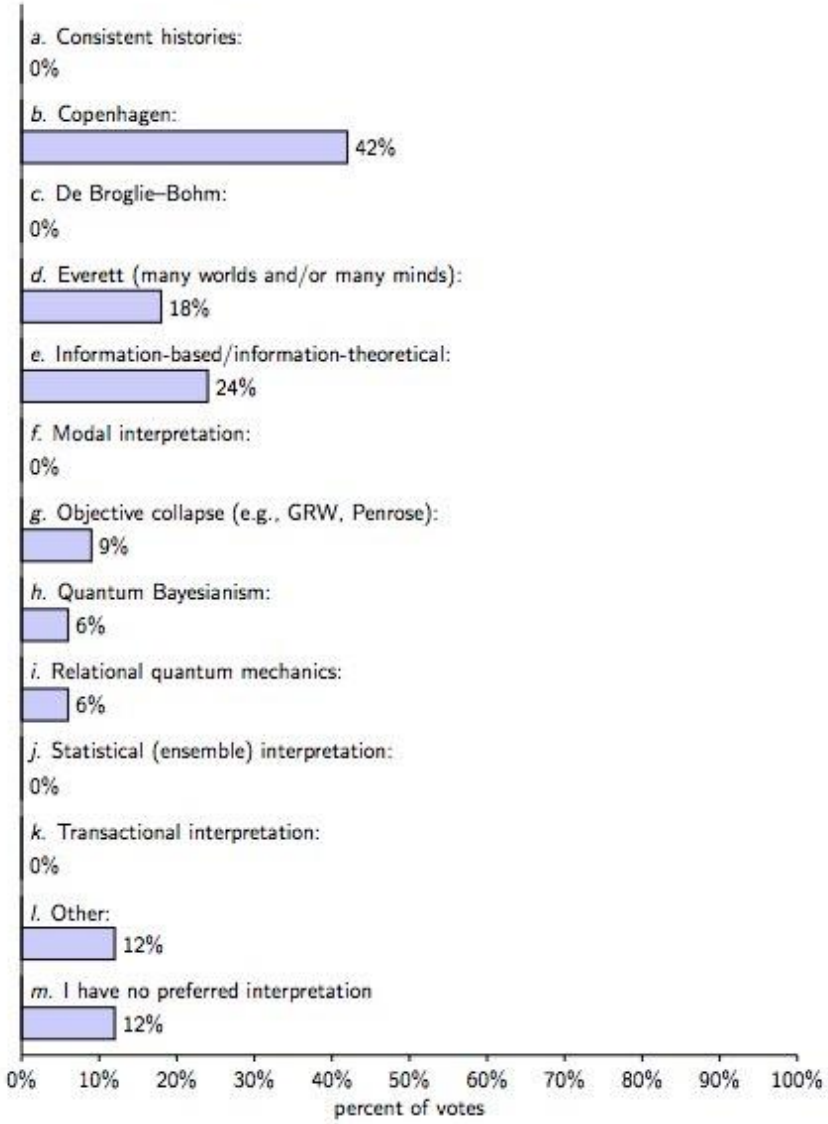


The Measurement Problem



- Projection is not unitary!!

Question 12: What is your favorite interpretation of quantum mechanics?



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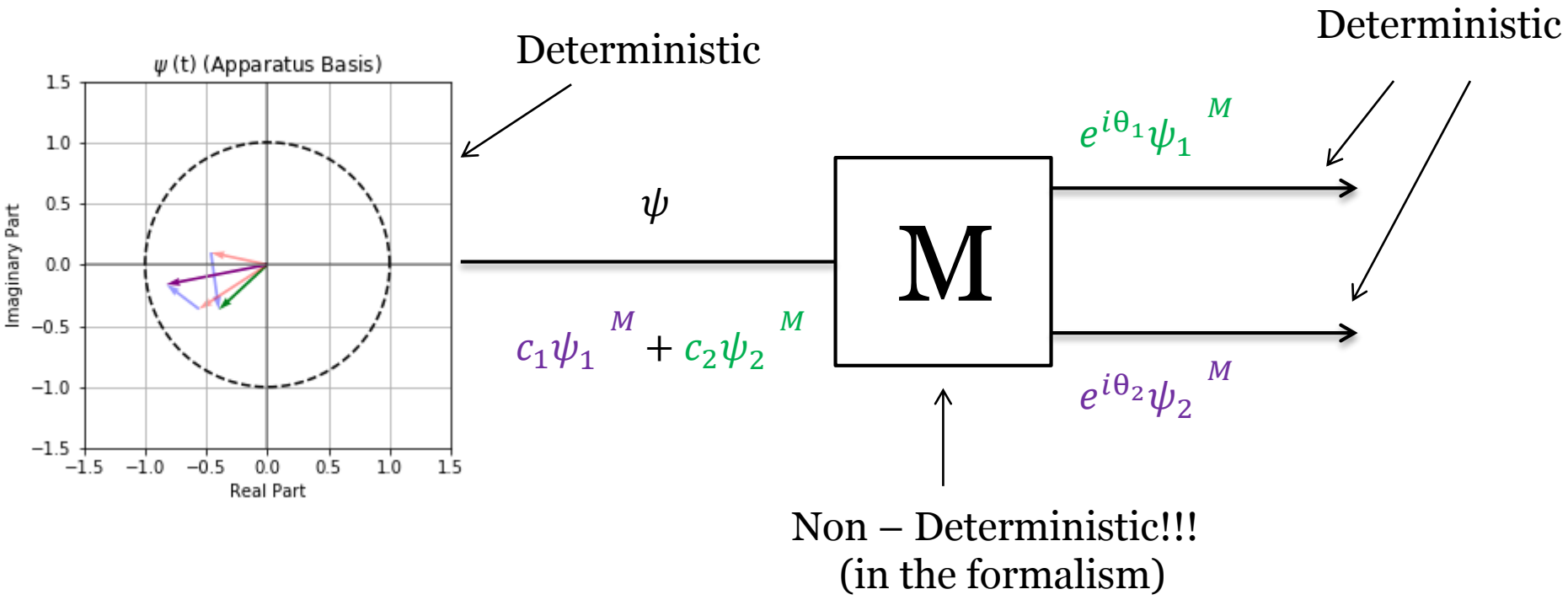
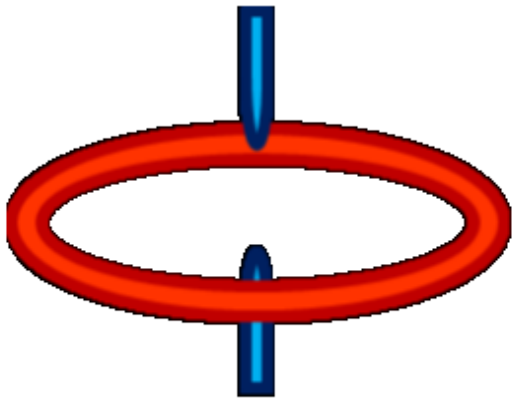
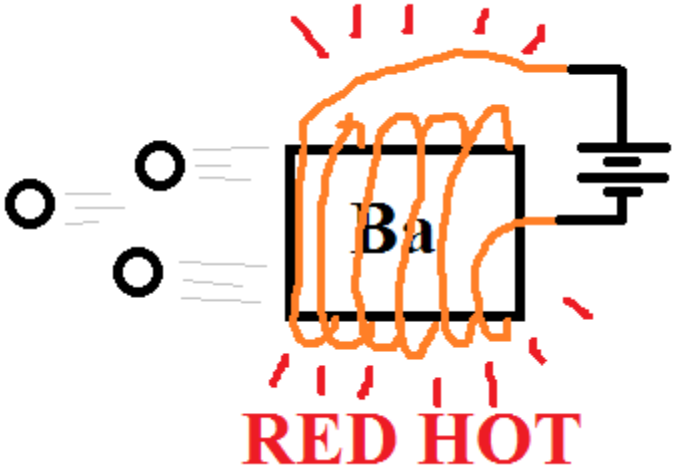


- Projection is not unitary!!
- What is the time scale Δt of collapse?

$$(\psi \rightarrow \psi_m{}^M)$$

Ion Traps





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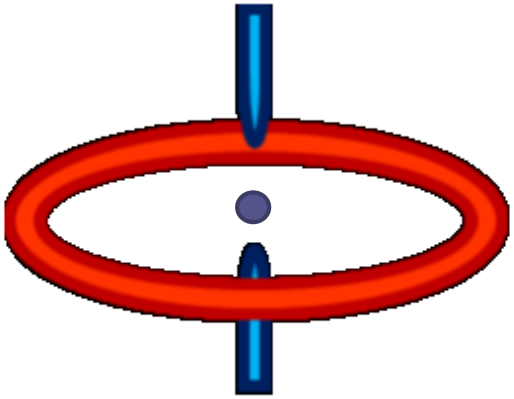
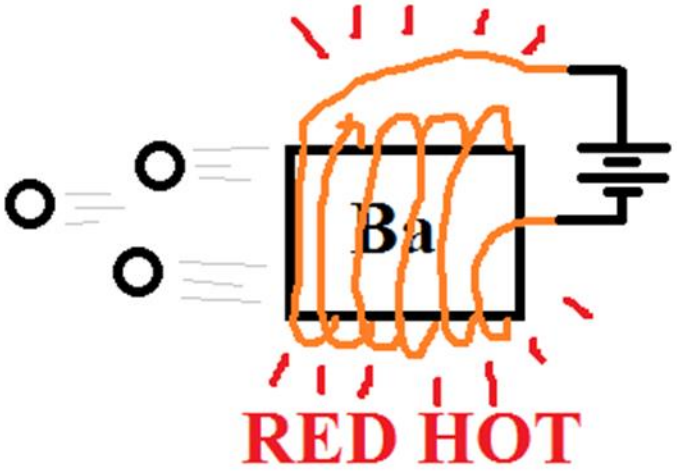
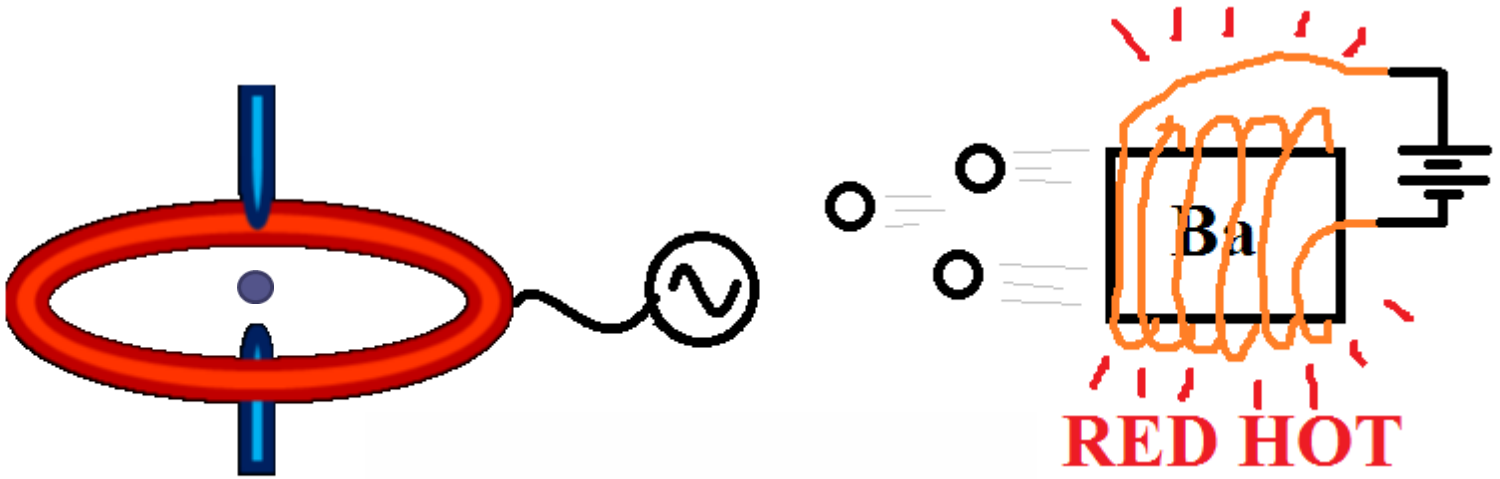
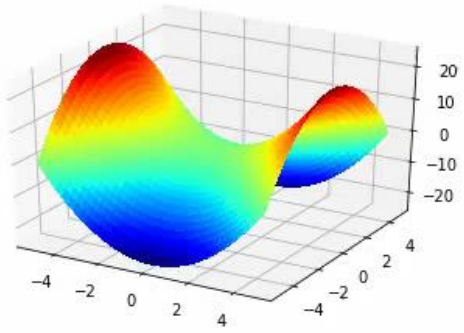




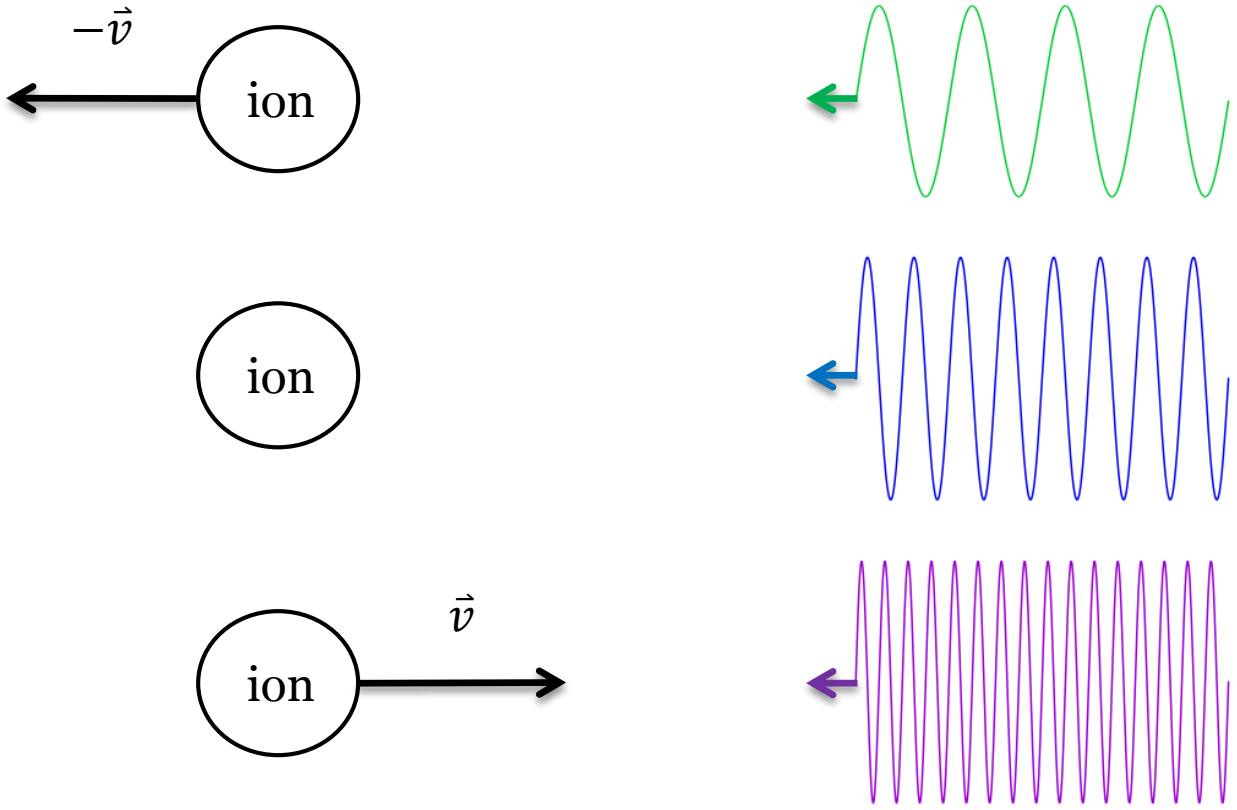
Ion Traps

$$\varphi(x,y,z) = \varphi_0 + (U_0 + V_0\cos(\omega t)\left(\frac{x^2 + y^2 - 2z^2}{r^2 + 2z^2}_0\right)$$





Doppler Cooling (Doppler Effect)



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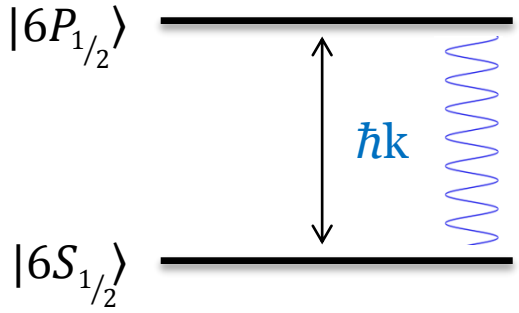
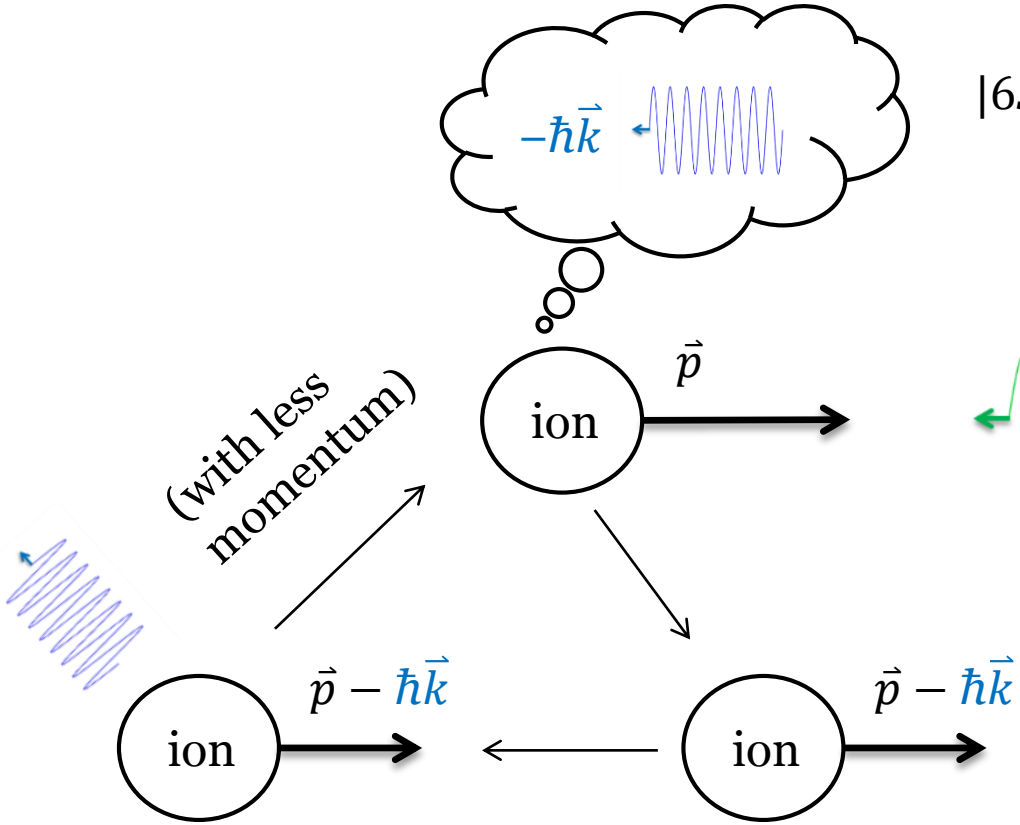
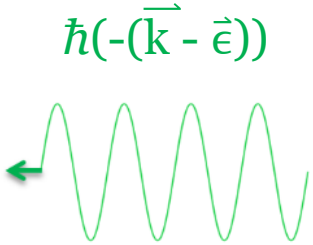
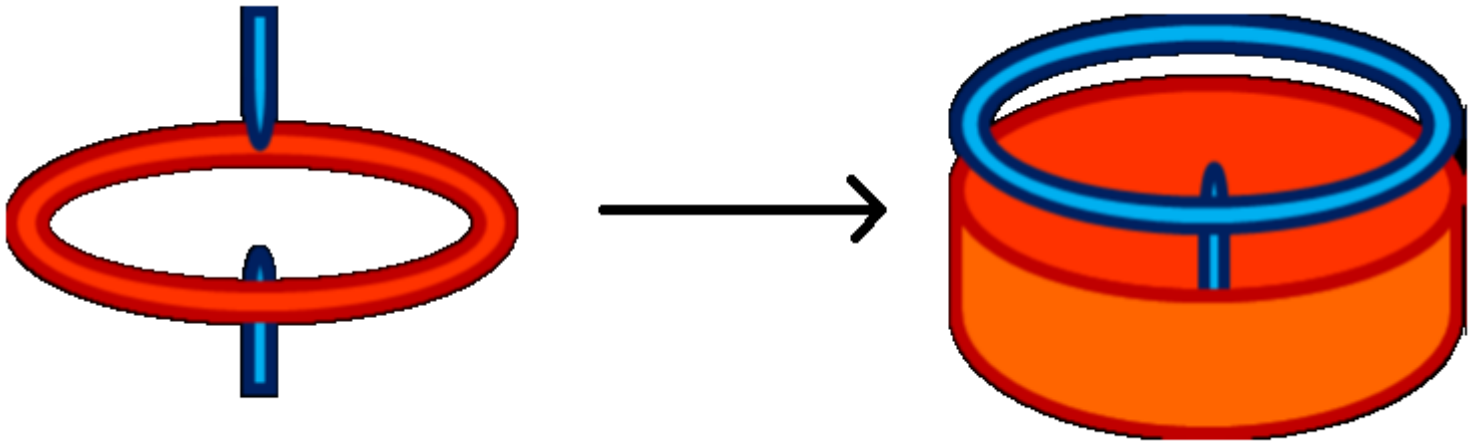


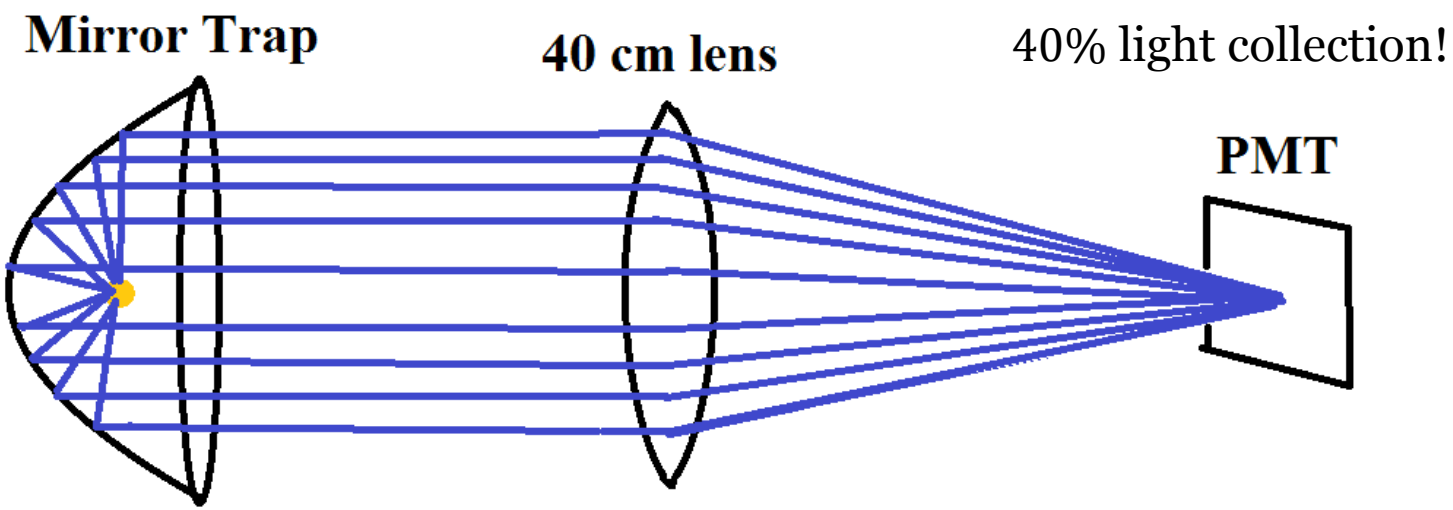




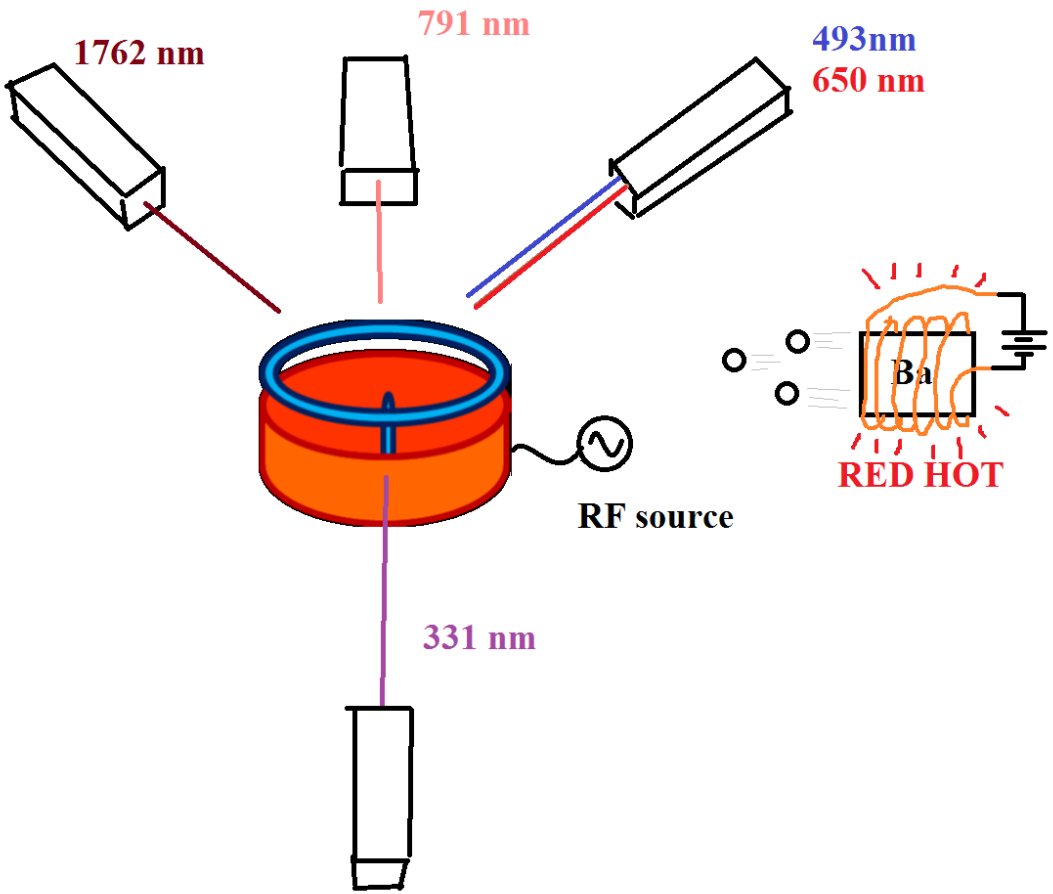
Parabolic Mirror Trap



Parabolic Mirror



Full Trap Setup



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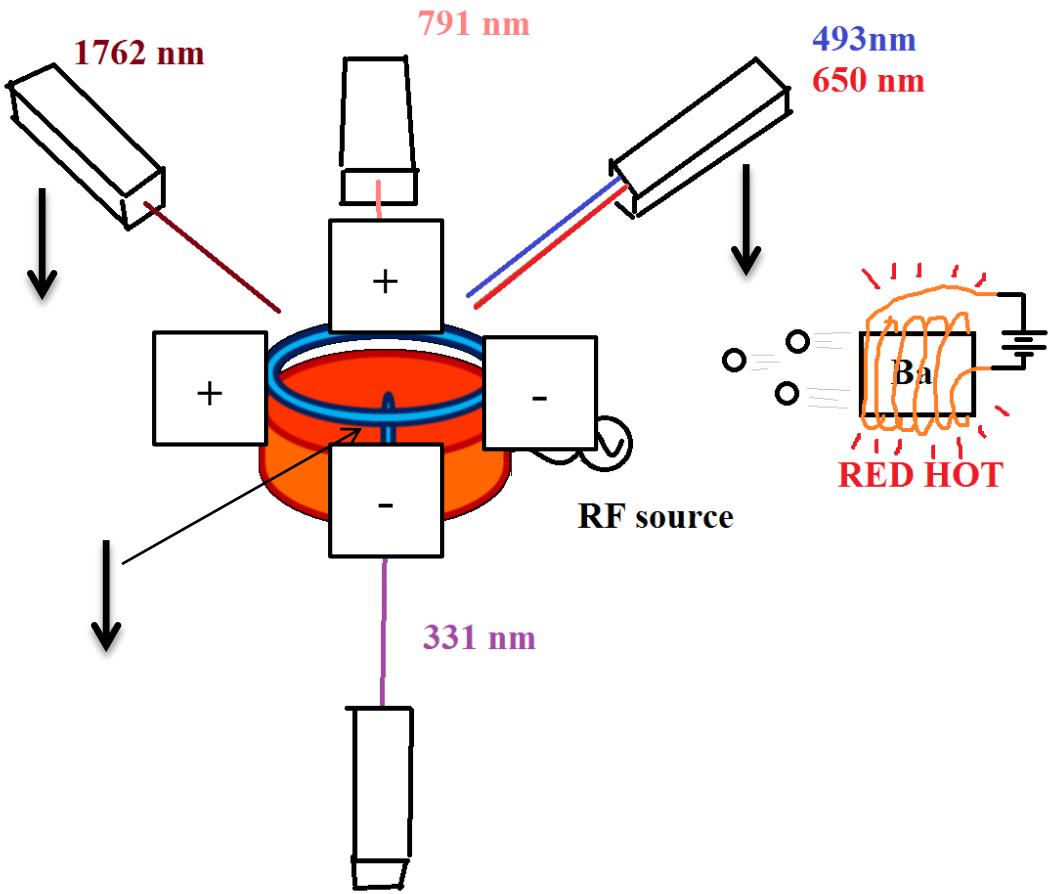
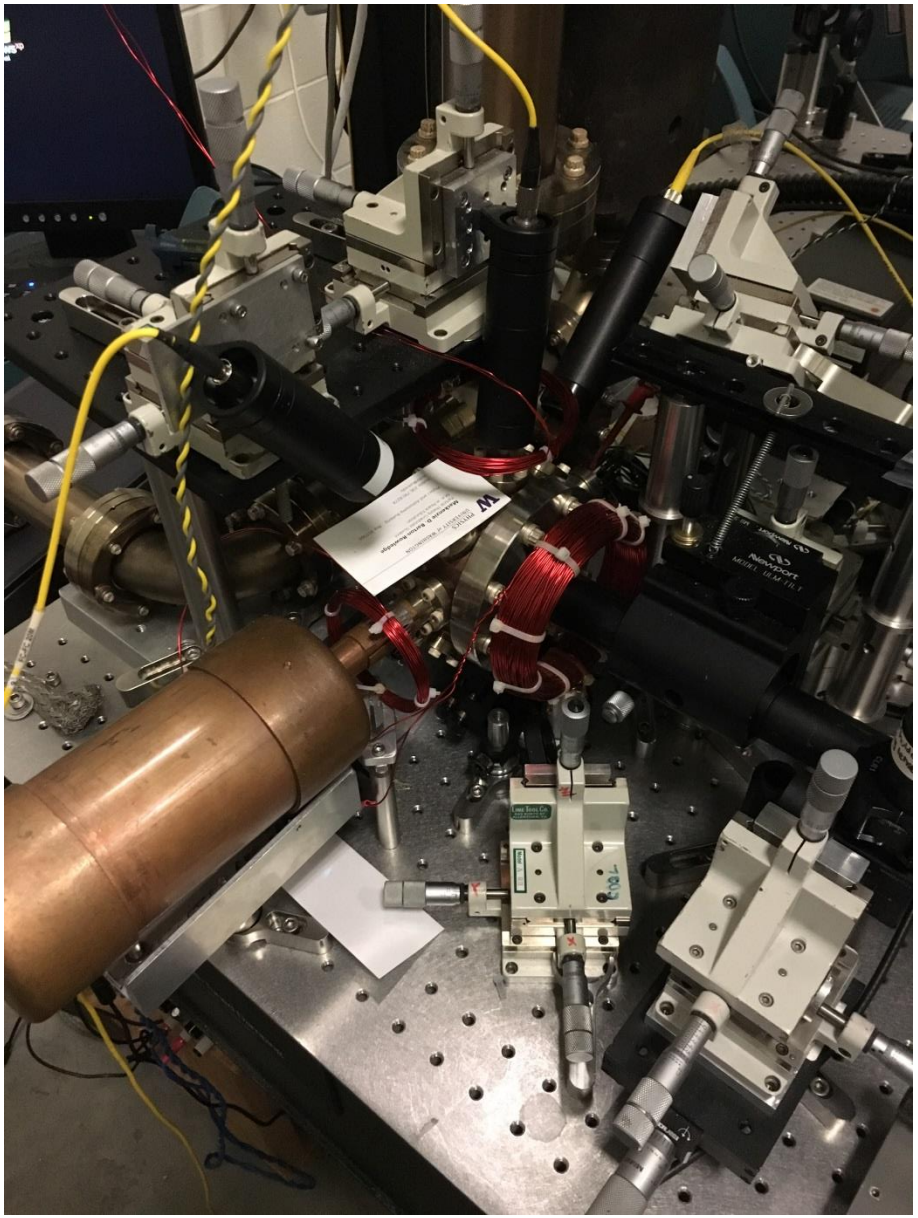
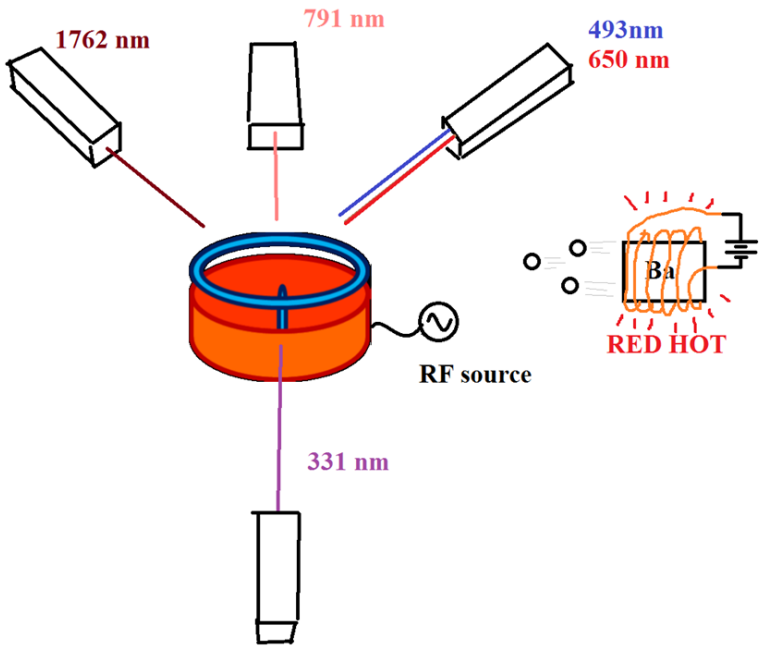
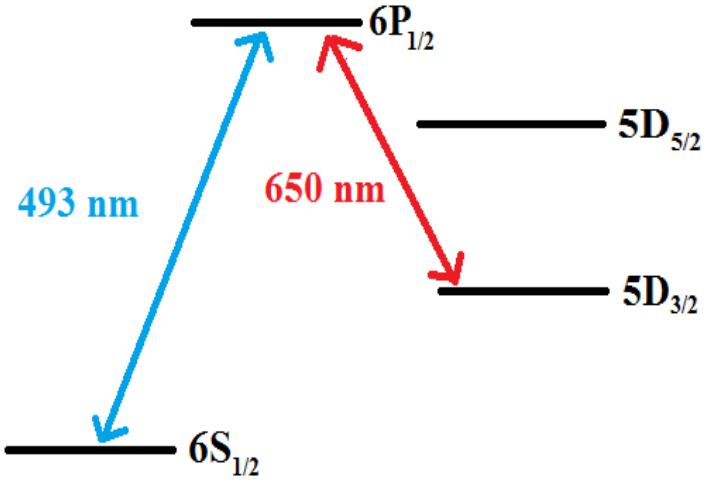


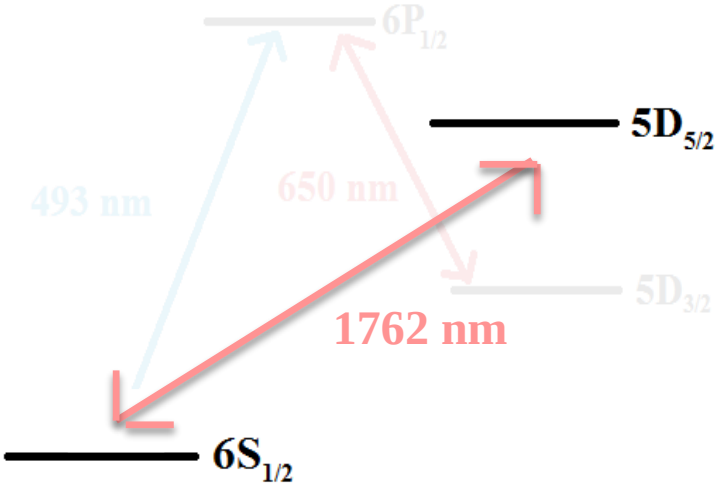



1762 nm
791 nm
493nm
650 nm
Ba
RED HOT
RF source
331 nm

Barium Energy Structure



Shelving



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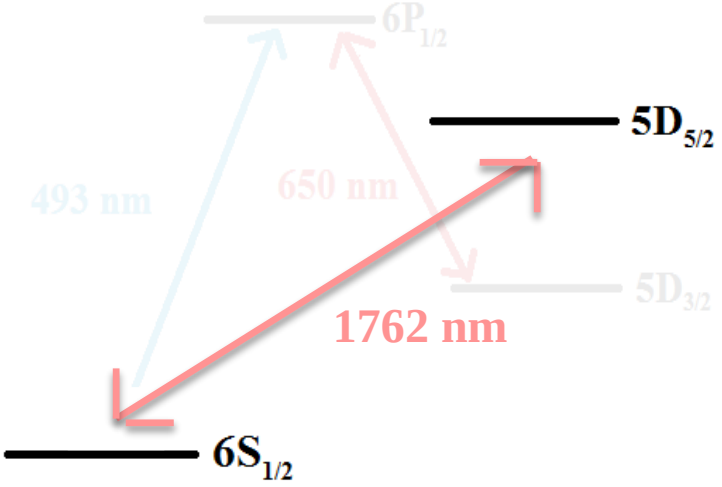
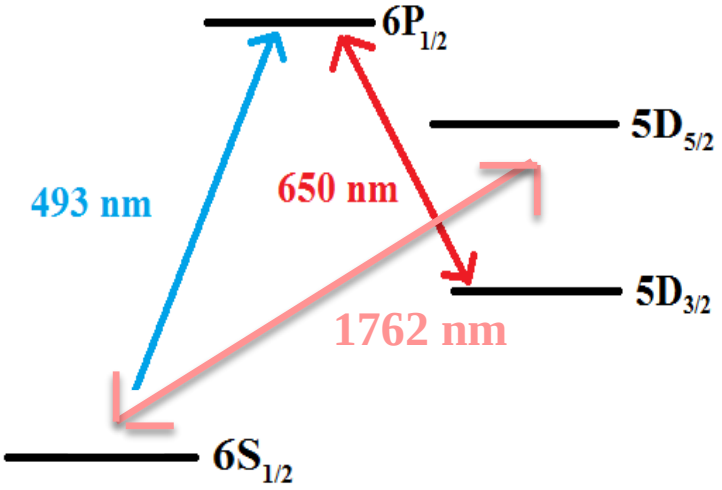


Detection

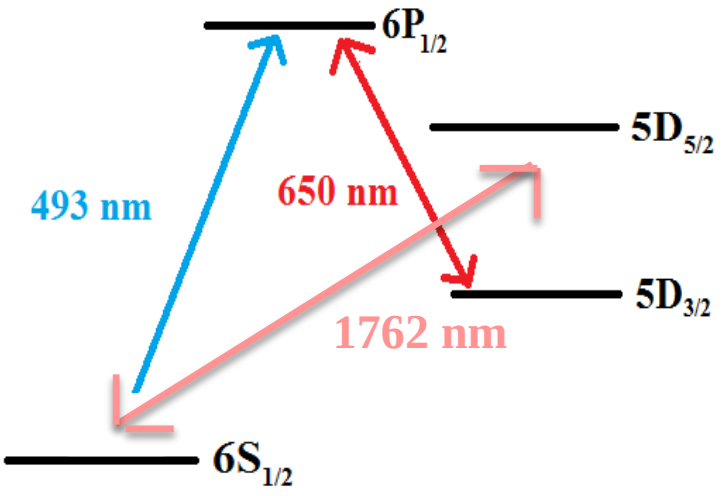


Superposition Scheme

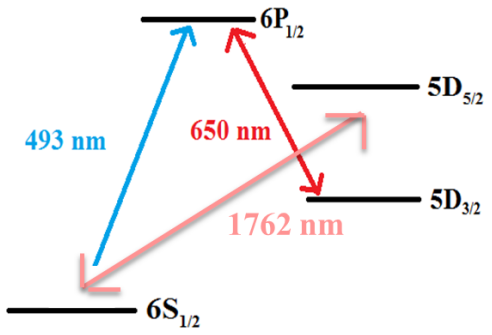
- Dipole Forbidden (30 s)
- Semiclassical treatment

$$H = H_0 + H_I$$
$$H_I(\mathrm{t}) = e\mathbf{r} \cdot \boldsymbol{E}_0 \cos(\omega t)$$

Solve SE:



Rabi Oscillations



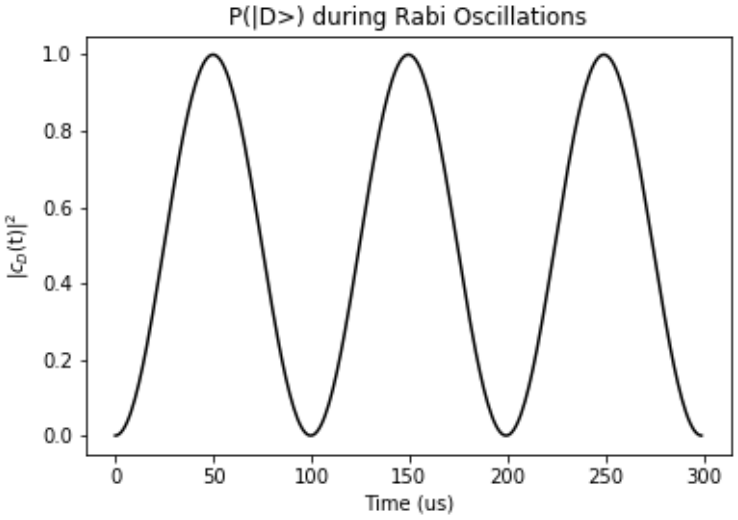
- $\Psi(t) = c_D(t)|5D_{5/2}\rangle + c_S(t)|6S_{1/2}\rangle$

Where, with $\Psi(0) = |6S_{1/2}\rangle$:

$$|c_S(t)|^2 = cos^2\left(\frac{\Omega t}{2}\right)$$

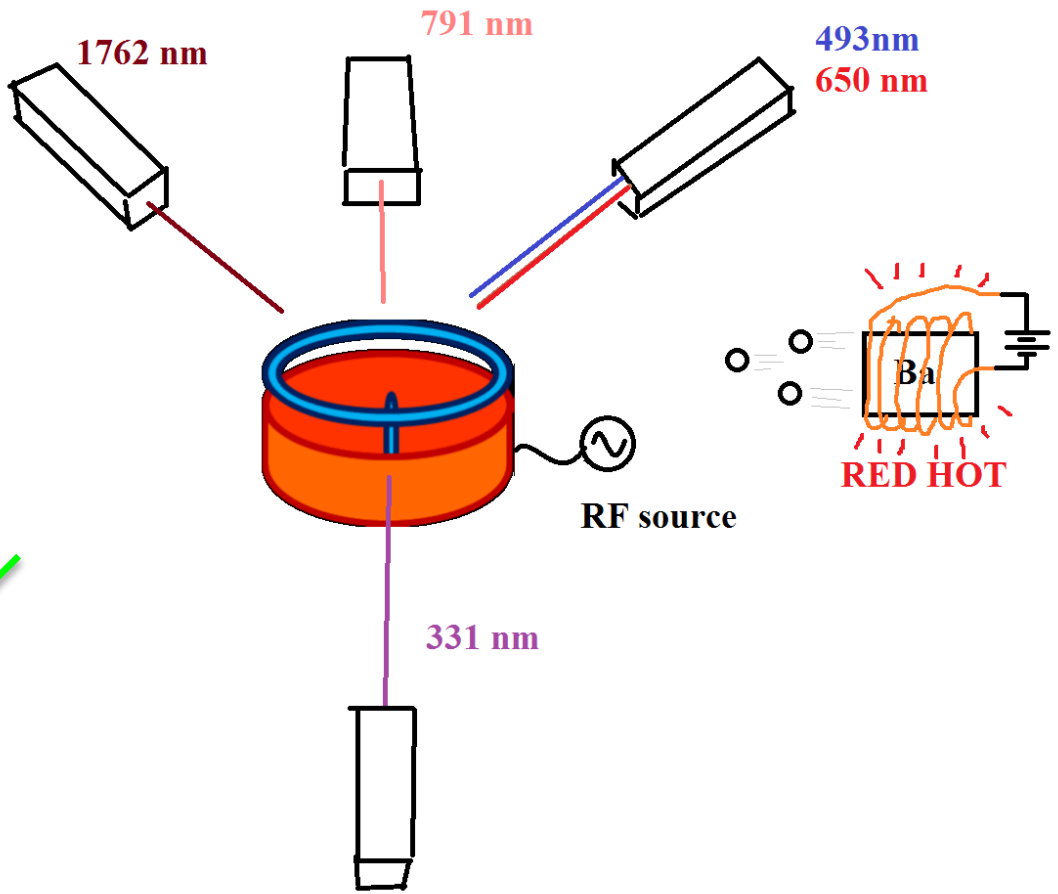
$$|c_D(t)|^2 = sin^2\left(\frac{\Omega t}{2}\right)$$

$$\Omega = \frac{e\langle S|\boldsymbol{r}\cdot\boldsymbol{E}_0|D\rangle}{\hbar}$$

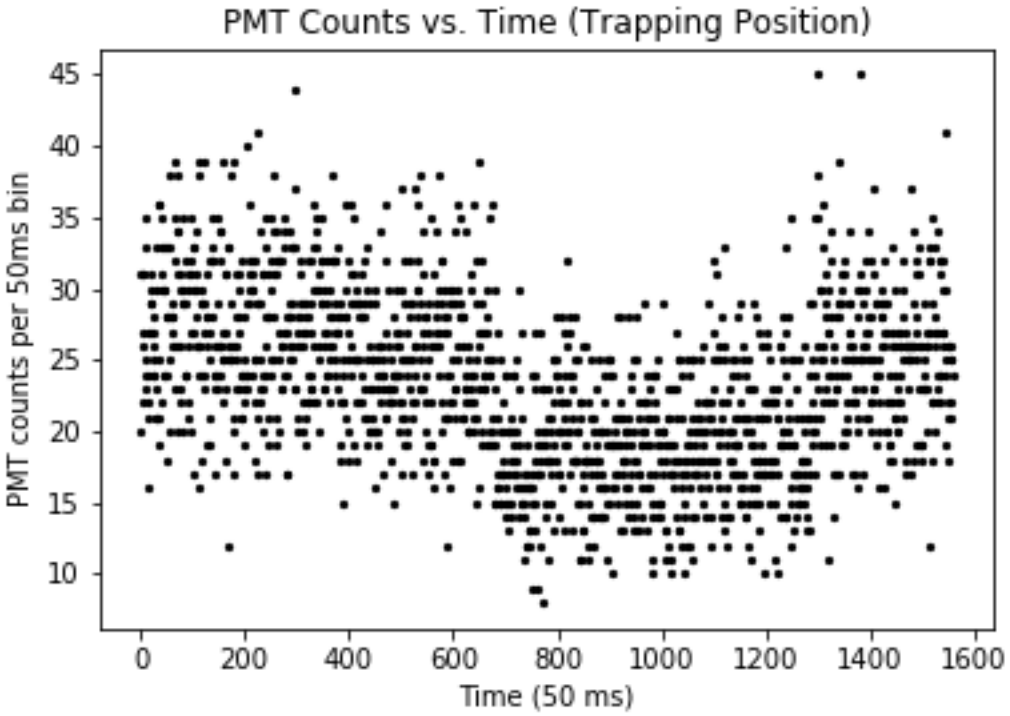


Procedure

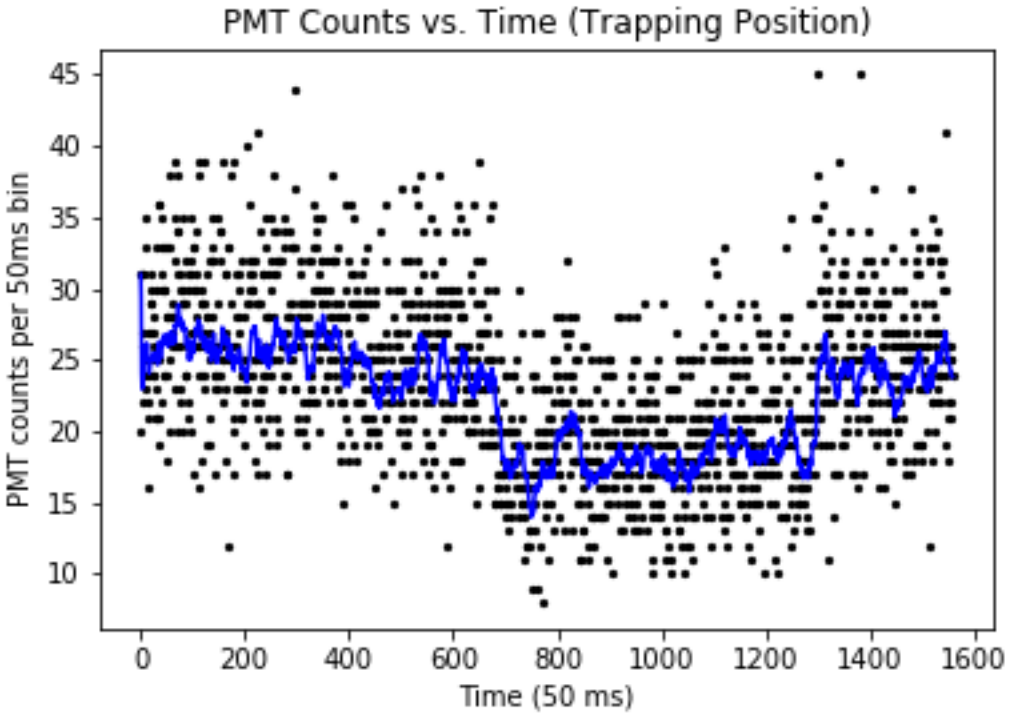
1. Send barium in ✓
2. Ionize Ba 138 ✓
3. Doppler Cool ✓
4. Single Ion ✓
5. ~~Pull Ion into focus~~
6. Shine 1762 ✓
7. Measure Photons ✓
8. Analyze Results
9. (Nobel Prize)



Progress


PMT Counts vs. Time (Trapping Position)
PMT counts per 50ms bin
45
40
35
30
25
20
15
10
0
200
400
600
800
1000
1200
1400
1600
Time (50 ms)

Progress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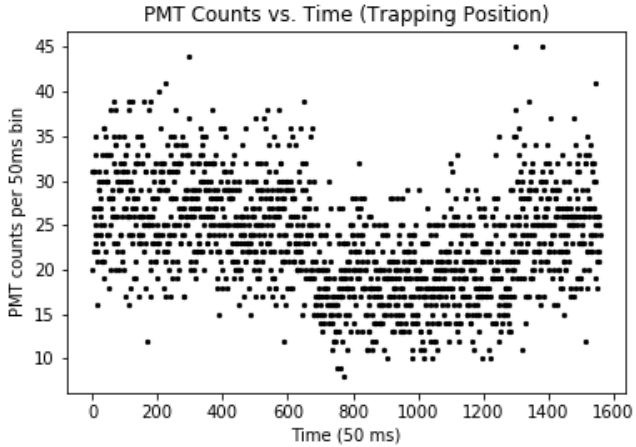
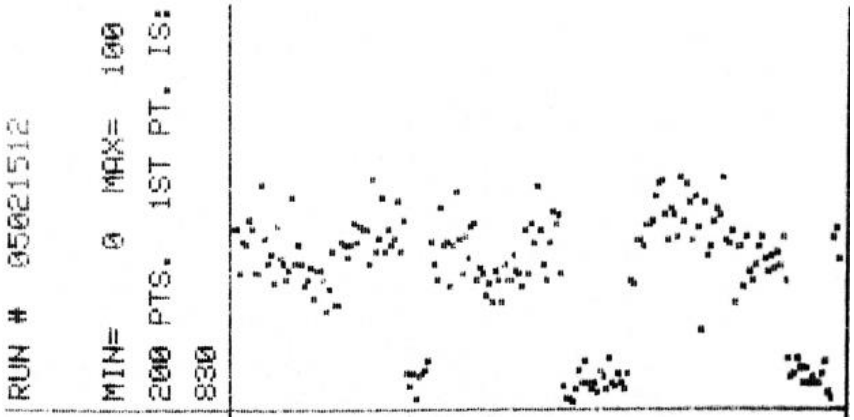
Time (50 ms)

Deja Vu



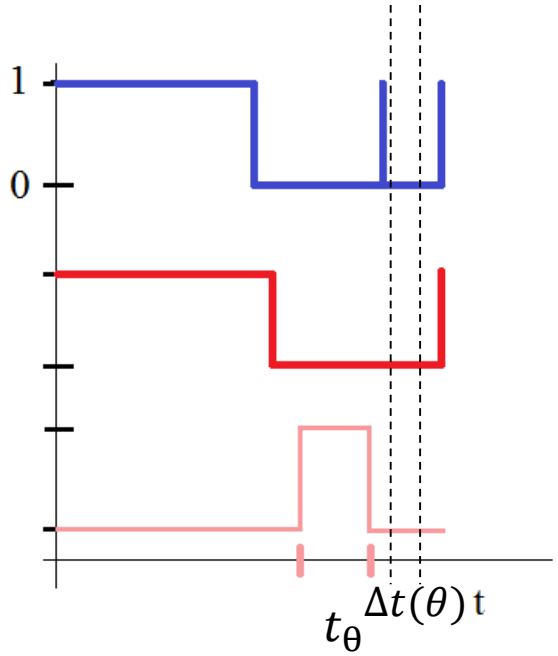
Clancy, Lilieholm, Blinov
2017

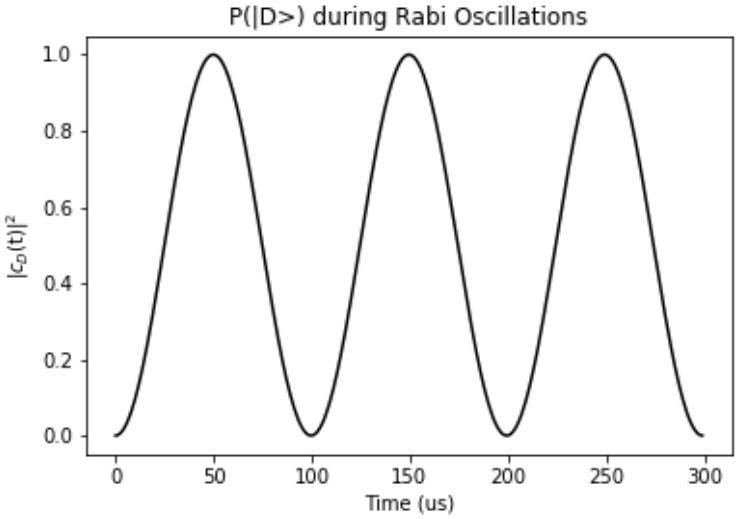


Dehmelt, Other groups
1986

Future Work

- Apply t_θ pulse
- Measure time dependence $\Delta t(\theta)$

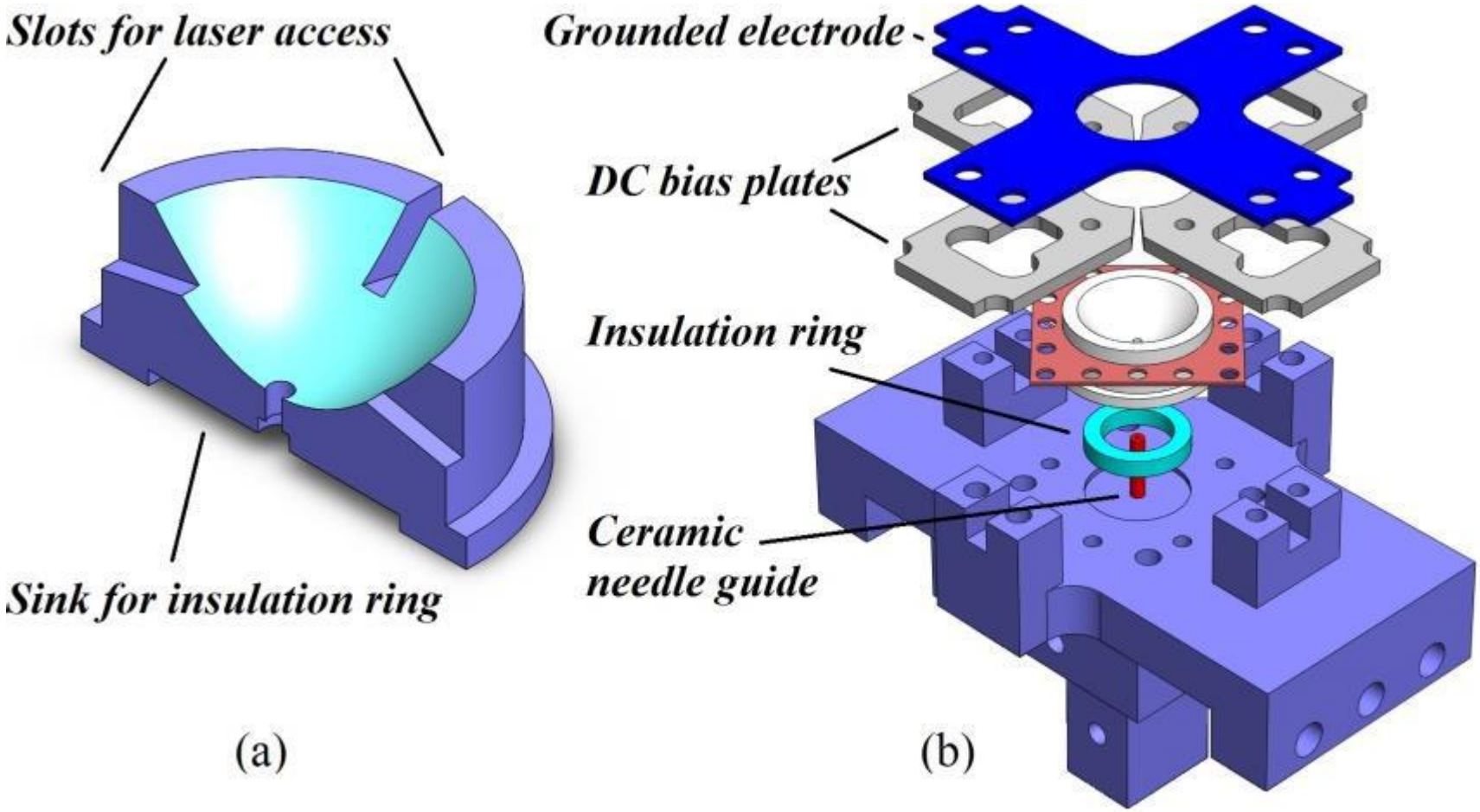




Acknowledgements

- Jennifer Lilieholm, Liudmila Zhukas, Tomasz Sakrejda
- Boris Blinov
- NSF
- UW REU program: Cheryl McDaniel, Linda Vilett, Deep Gupta, Gray Rybka
- Viewers like you

Ion Trap (Full)



Quantum Mechanical Digression

$$i\hbar \frac{d}{dt}\Psi(t) = \hat{\mathrm{H}}\Psi(t)$$

Replace with:

$$i\hbar \frac{d}{dt}U = \hat{\mathrm{H}}U$$

Where:

$$\Psi(t) = U(t)\Psi(0)$$

And U is given by:

$$U(t) = exp\left(\frac{-i\hat{\mathrm{H}}t}{\hbar}\right)$$

Unitary Time Evolution

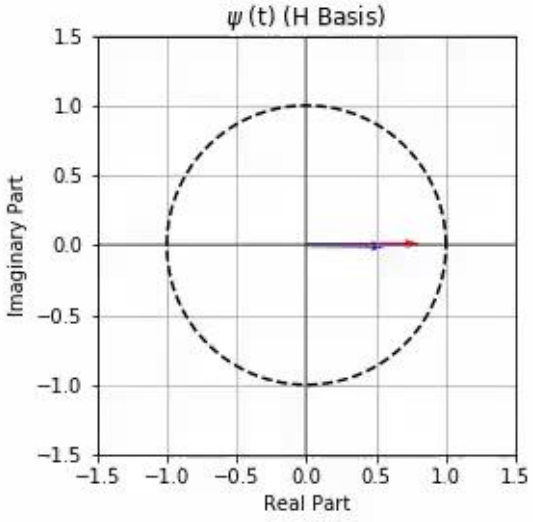
$$\hat{\mathrm{H}} = \begin{pmatrix} E_1 & & \\ & E_2 & \\ & & \ddots \end{pmatrix} \rightarrow U(t) = \begin{pmatrix} e^{\frac{-iE_1 t}{\hbar}} & & \\ & e^{\frac{-iE_i t}{\hbar}} & \\ & & \ddots \end{pmatrix}$$

$$U(t)\psi = \sum_i \langle \psi_i | \psi \rangle e^{\frac{-iE_i t}{\hbar}} \psi_i$$

Thinking about U

- Take $\hat{\mathrm{H}} = \begin{pmatrix} -5\hbar & 0 \\ 0 & 7\hbar \end{pmatrix}$, $\Psi(0) = c_{-5}\psi_{-5} + c_7\psi_7$
- Then:

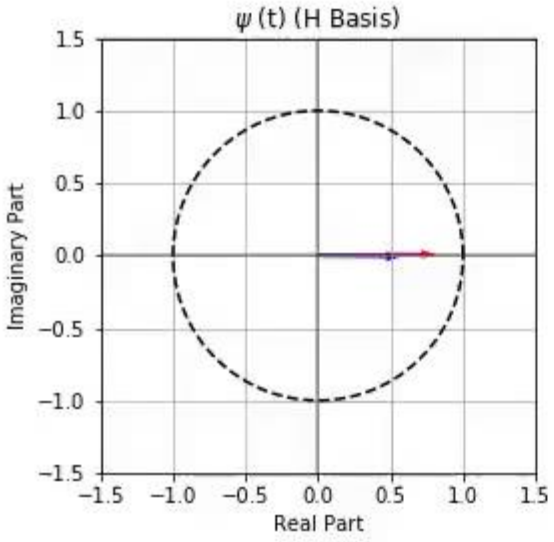
$$\Psi(t) = U(t)\Psi(0) = c_{-5}e^{i5t}\psi_{-5} + c_7e^{-i7t}\psi_7$$

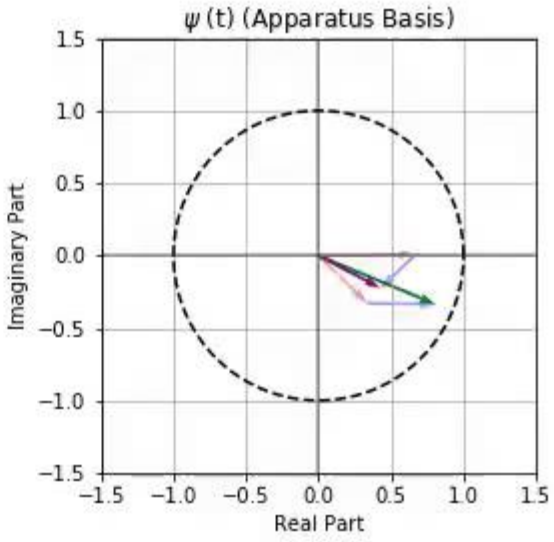


Apparatus Basis

- Apparatus M yields eigenstates ${\psi_1}^M, {\psi_2}^M, \ldots$ with corresponding real eigenvalues $m_1, m_2, \ldots$

$$\psi = \sum_i \langle {\psi_i}^M | \psi \rangle {\psi_i}^M$$





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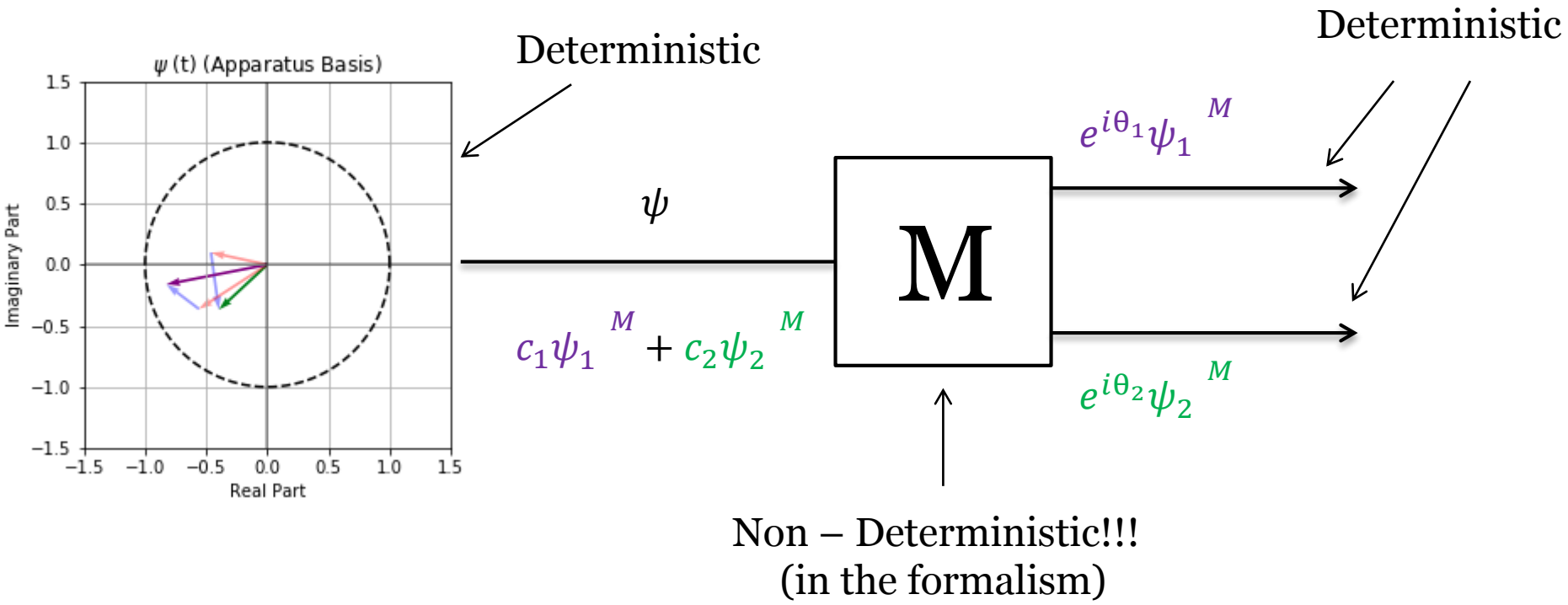

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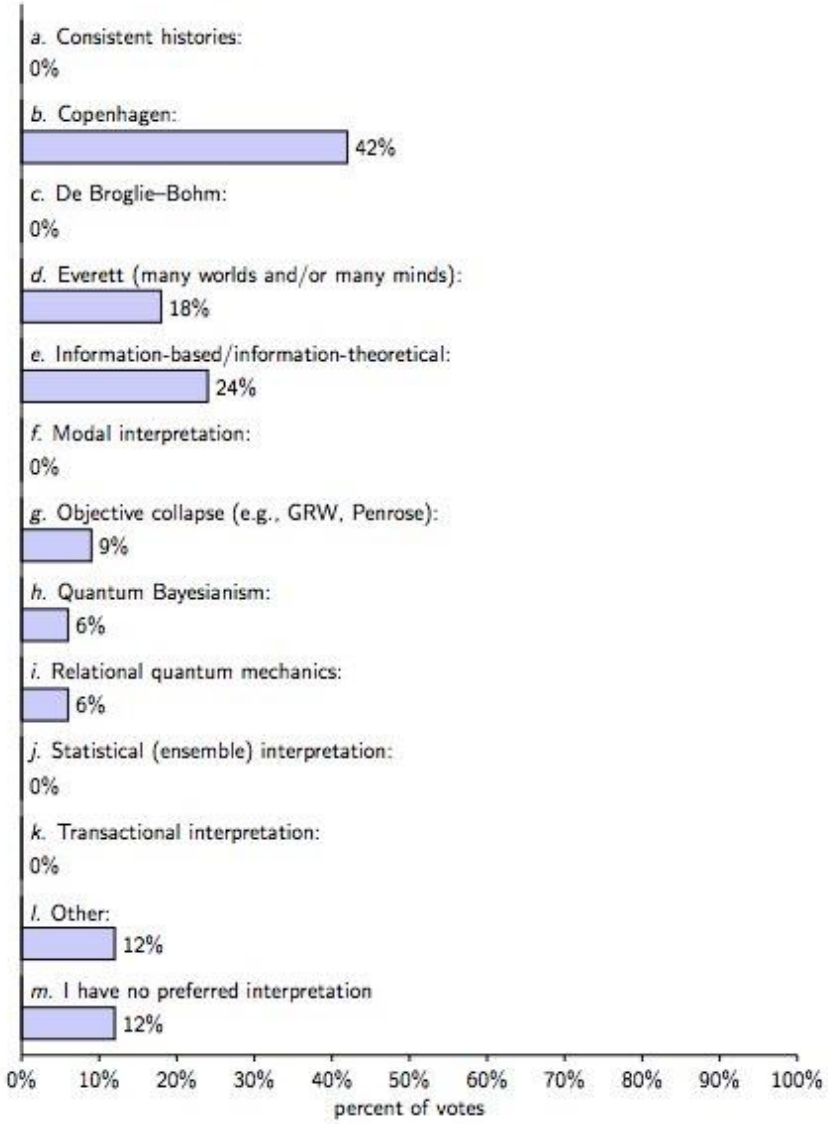

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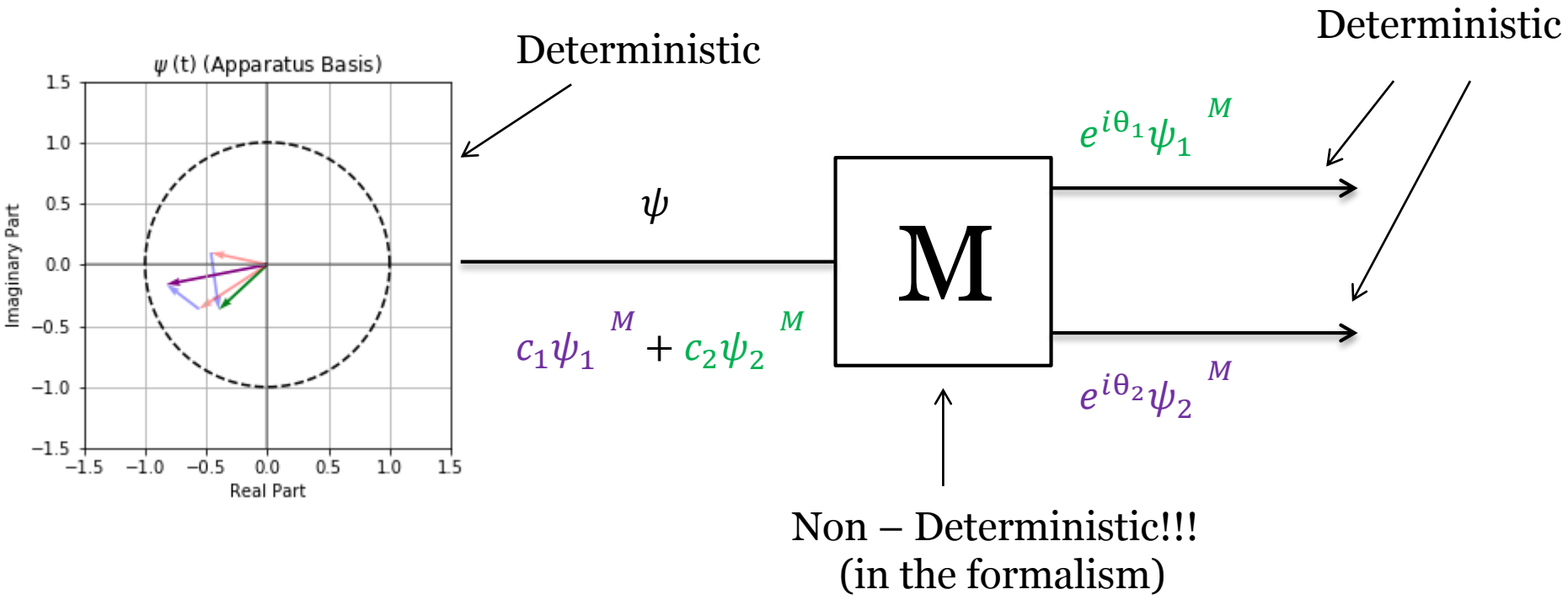

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