Thesis Committee Meeting 2001:

Pushing the envelope of high-precision mass comparisons

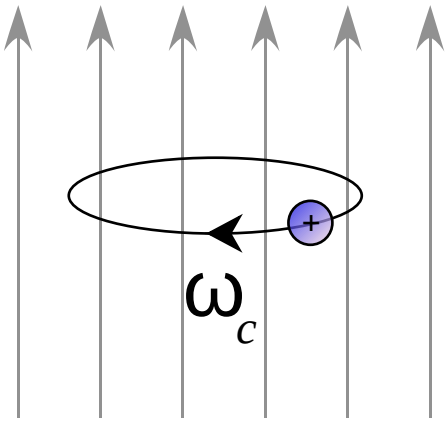
Part I. Introduction and First Results
—James K. Thompson

Part II. “Jump” into the Details
—Simon Rainville

Massachusetts Institute of Technology, Cambridge MA

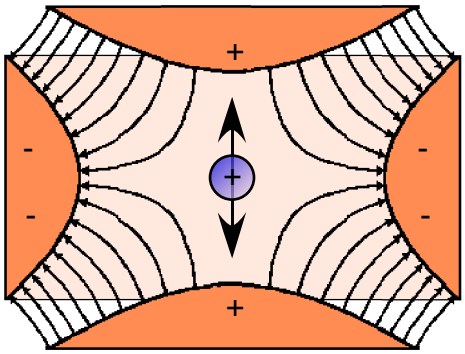
Single Ion Penning Trap Dynamics

Strong magnetic field



Cyclotron motion

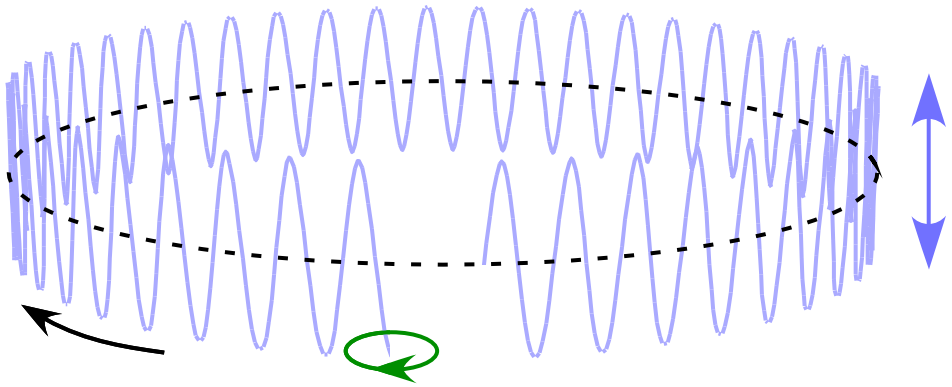
Weak electric field



Axial motion

Magnetron motion

$$q\left(\vec{v} \times B_0 \hat{z} + E_0 \frac{\vec{\rho}}{\rho_0} \hat{z}\right) = 0$$



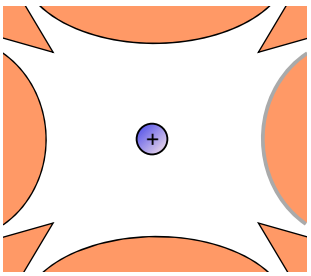
Magnetron
~ 5 kHz

Trap
Cyclotron
~ 5 MHz

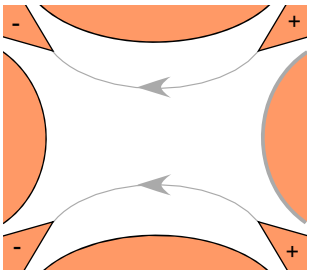
Axial
~ 200 kHz

Measuring the Cyc Freq

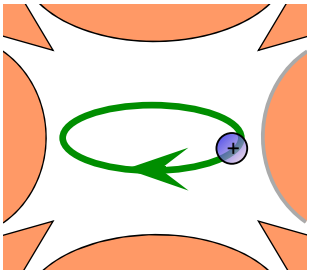
Time Sequence



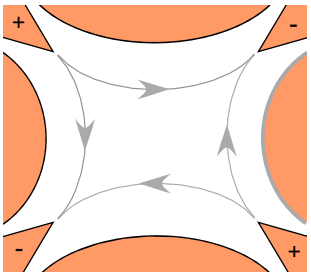
Start with “cold” ion
(i.e. $\rho_{mag} = \rho_{cyc} = a_z = 0$)



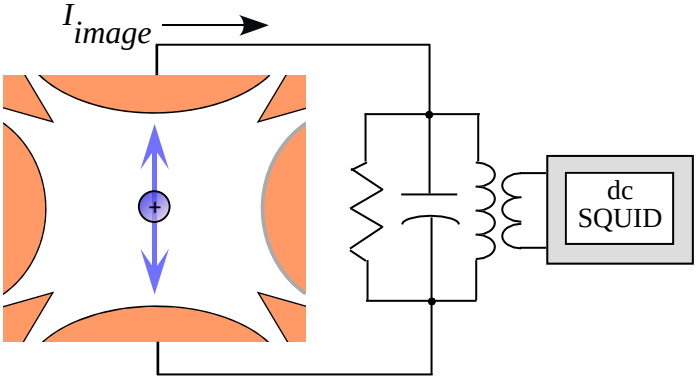
Cyclotron Drive
(dipole rf E-field)



Cyclotron motion accumulates phase at ~5MHz

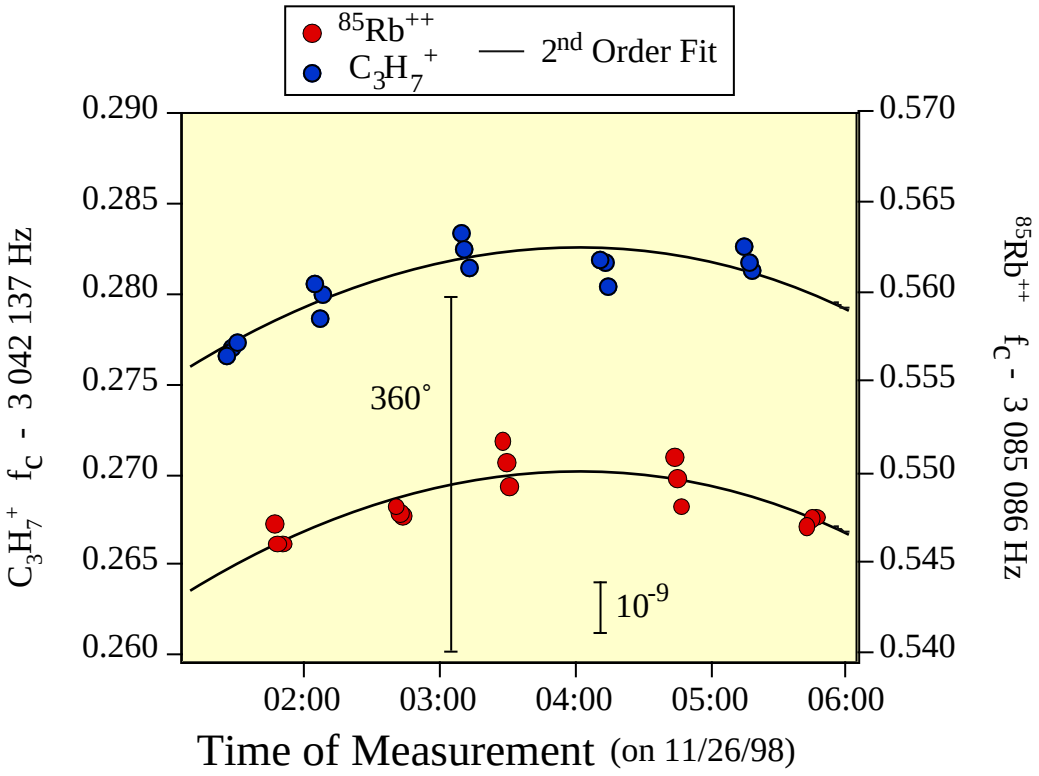


π-pulse cyclotron - axial (quadrupole rf E-field). Transfers the phase of motion as well!



Measure Phase of image current induced between endcaps.

Single Ion data



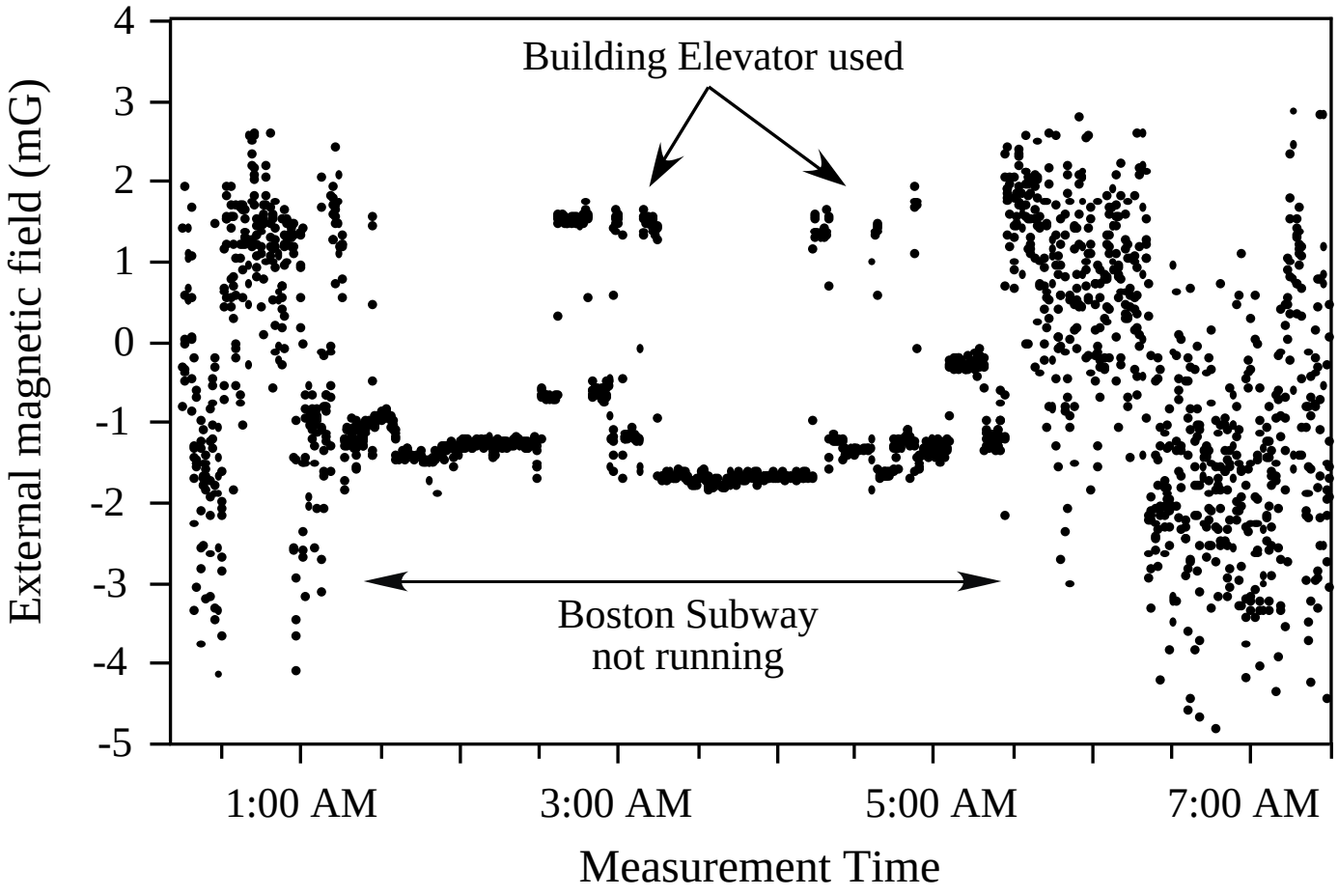
- 5 - 30 minutes to isolate a new single ion
- Precision of 10^{-10} for a full run (4 hours)
- Magnetic Field Noise Limits Precision

MIT Mass Table

Element	Δm/m (x 10^{-10})	Factor of improvement	Element	Δm/m (x 10^{-10})	Factor of improvement
H	5.0	24	^{23}Na	1.2	93
^{2}H	2.5	48	^{28}Si	0.7	350
^{13}C	0.8	17	^{40}Ar	0.8	424
^{14}N	0.9	22	^{85}Rb	1.6	193
^{15}N	0.7	36	^{87}Rb	1.7	187
^{16}O	1.3	24	^{133}Cs	2.0	111
^{20}Ne	1.2	957			

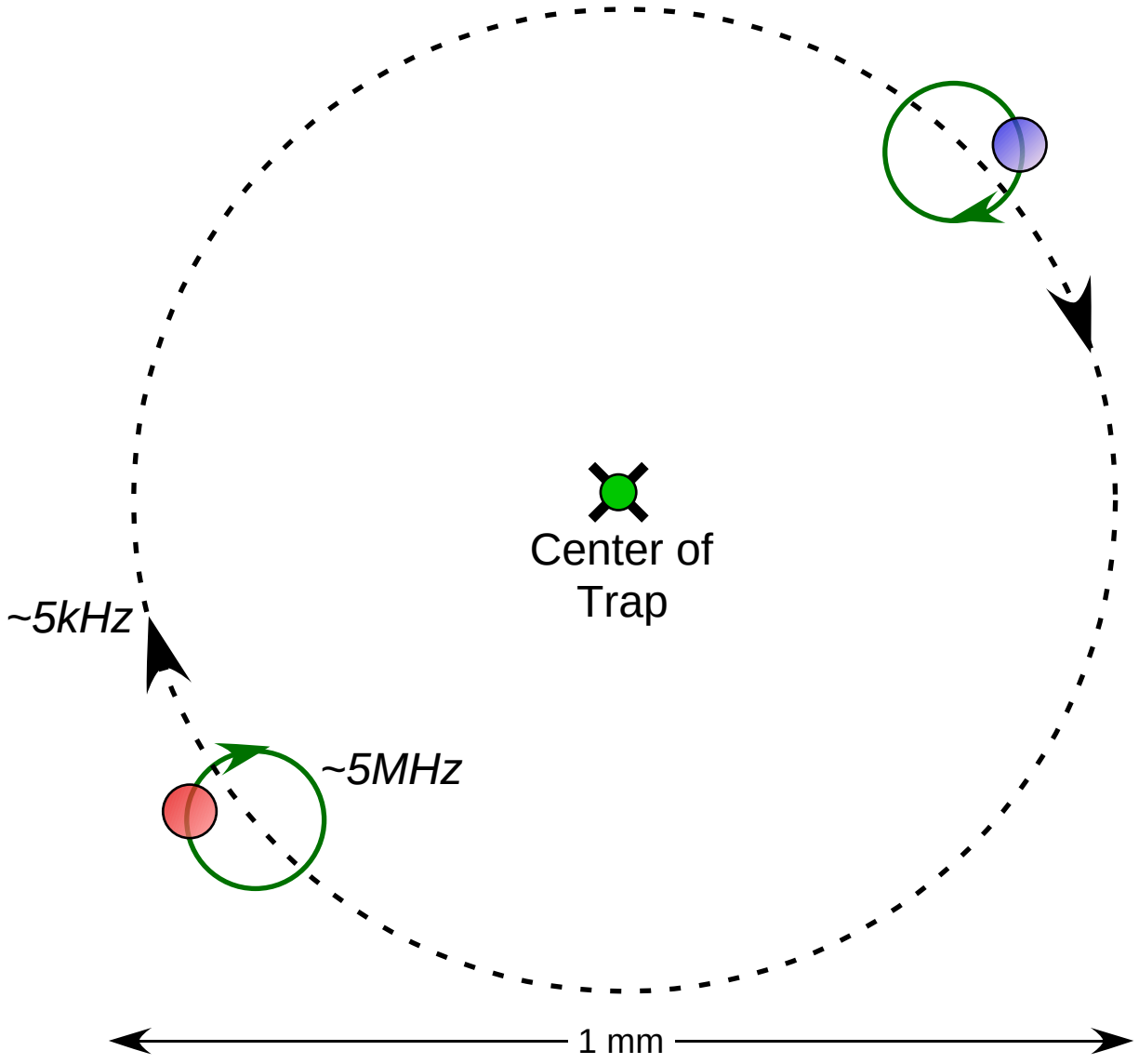
Main Limitation of Single Ion Technique:

Magnetic Field Noise



Want to make SIMULTANEOUS measurements

Exploit Magnetron Motions



$\Delta f_{cyclotron}$ *2000.000 Hz*

Δf_{axial} *40.000 Hz*

$\Delta f_{magnetron}$ *0.001 Hz*

Radial *Ion-Ion Coulomb Int.* *0.050 Hz*

Axial *Ion-Ion Coulomb Int.* *1.000 Hz*

Expect: independent cyclotron & axial motions
coupled magnetron motion

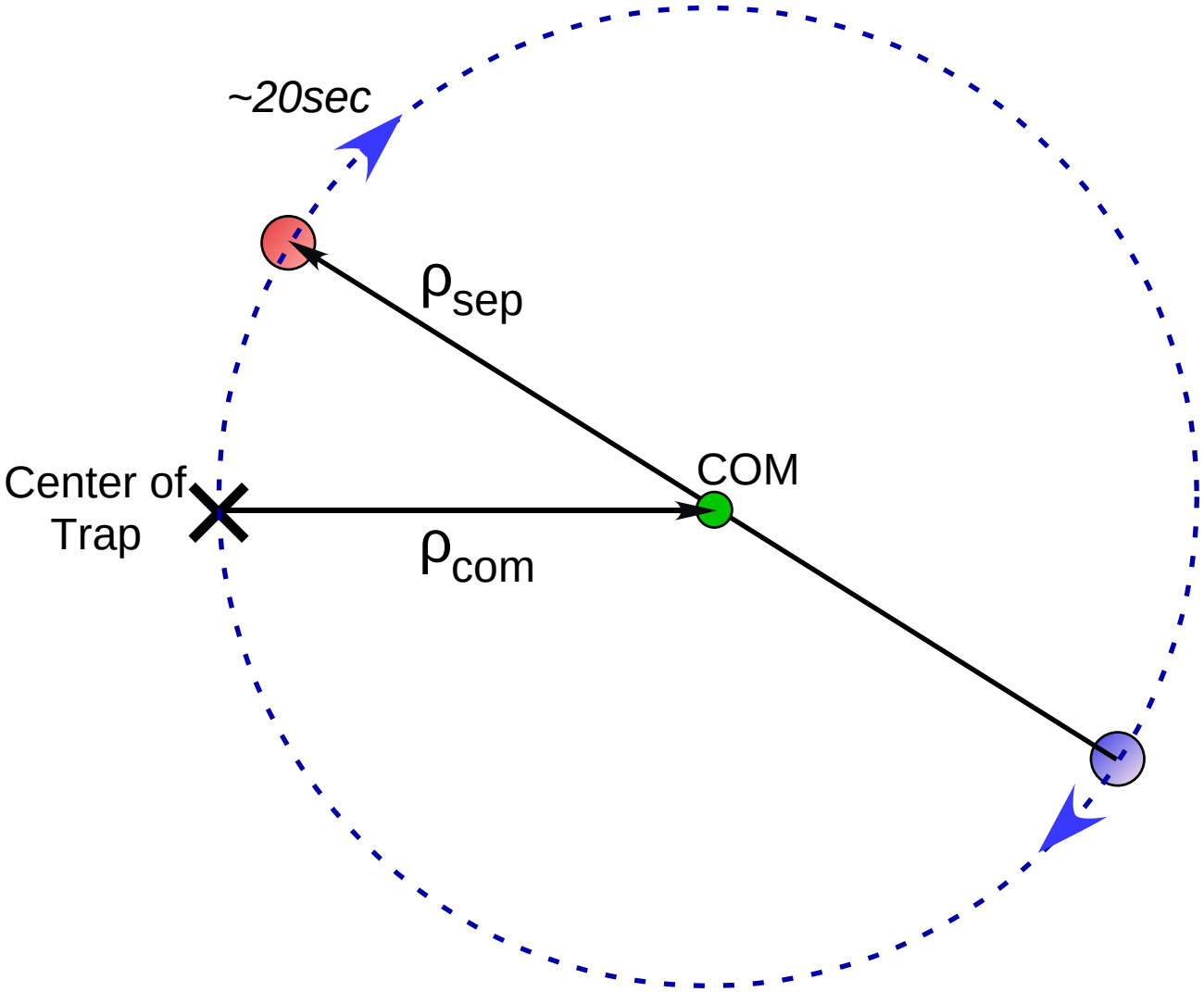
Magnetron Mode Mixing

$$L_z \approx \frac{qB}{c}\left(\rho_1^2 + \rho_2^2\right)$$

$$E \approx -\frac{qV_{trap}}{4d^2}\left(\rho_1^2 + \rho_2^2\right) + \frac{q^2}{\rho_{sep}}$$

ρ_{sep} and ρ_{com} are constant

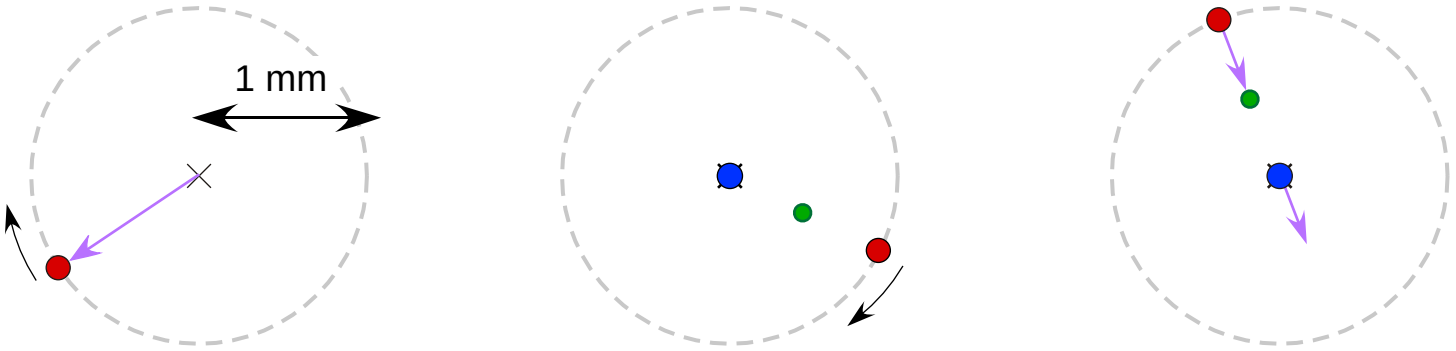
In frame corotating with COM (~5kHz)



$$\left|\vec{v}\right| \quad \left|\vec{E}_{12}\right| \quad \frac{1}{\rho_{sep}^2} \qquad T_{swap} \quad \rho_{sep}^3$$

2Mag Pulses: Parking 2 Ions

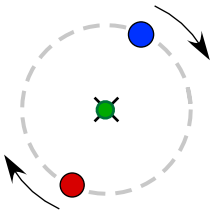
Time Sequence



Mag Drive 1

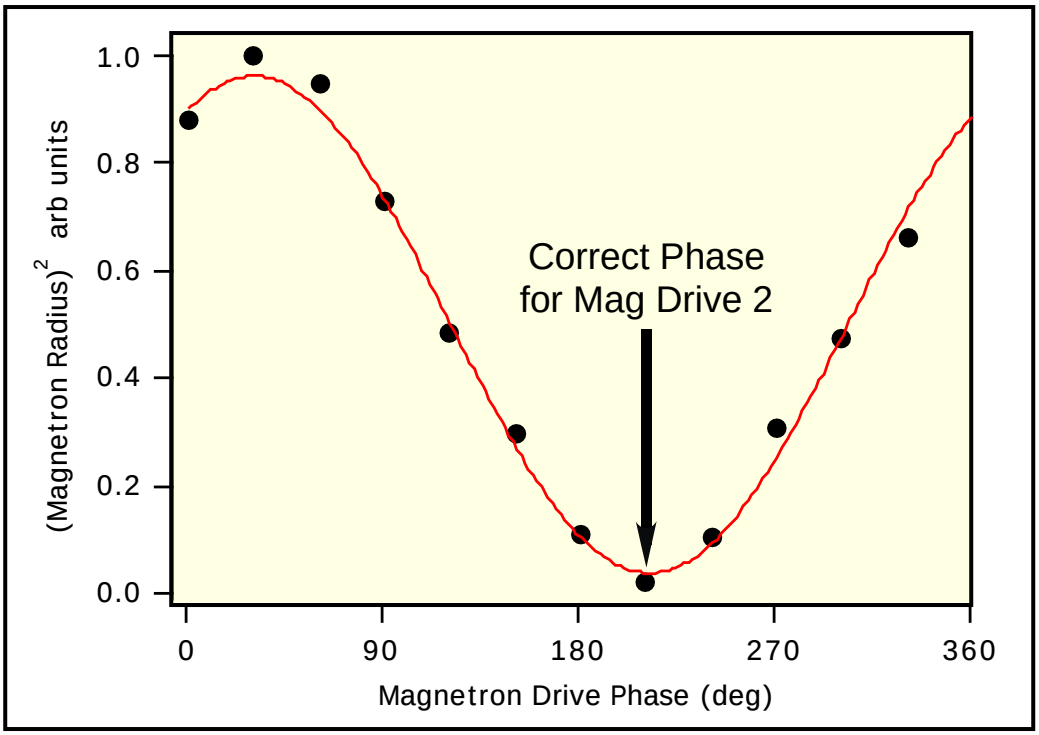
Ionize Atom
Near Trap Center

Mag Drive 2

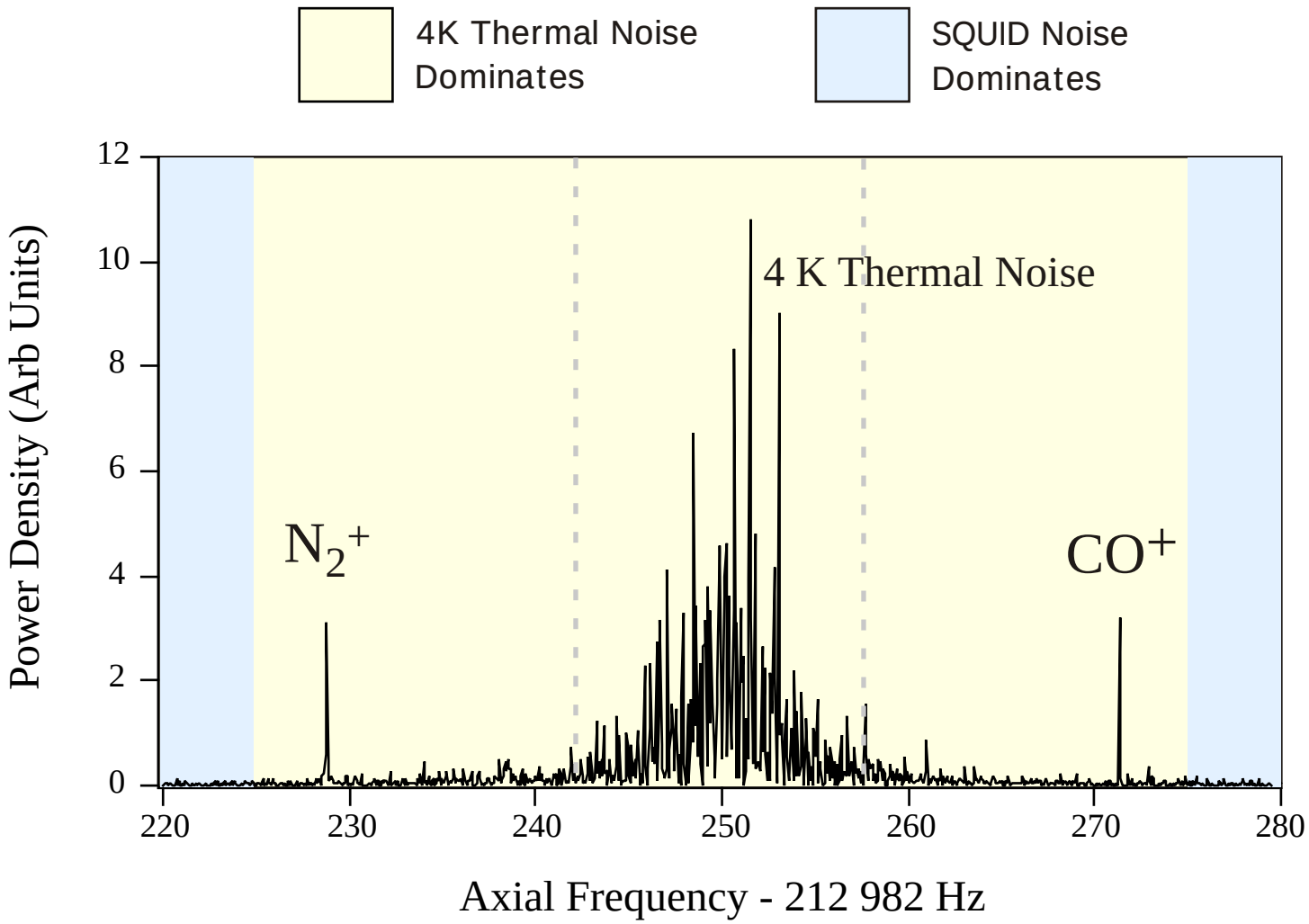


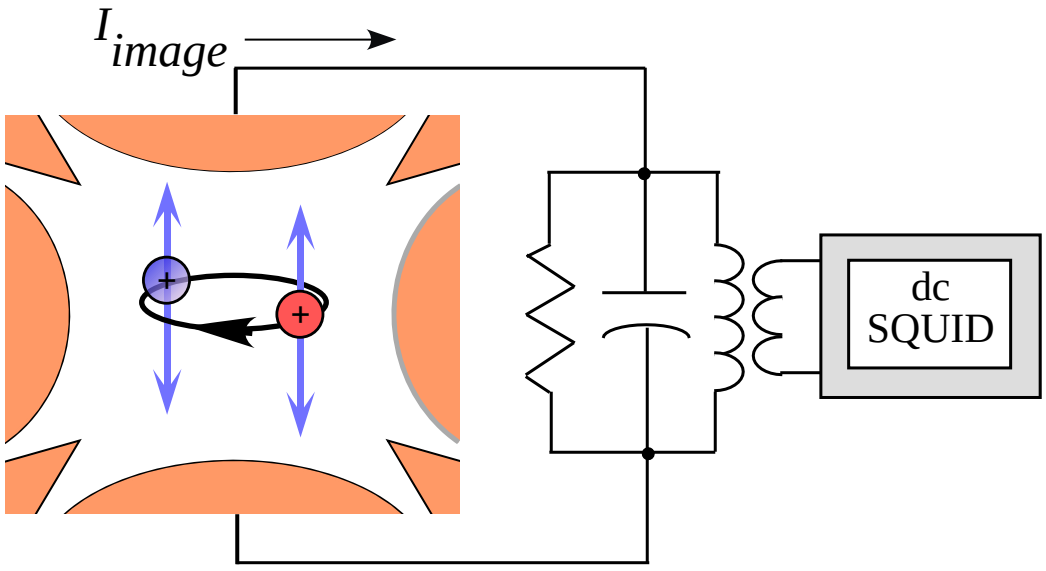
Reduced COM

Practice with 1 Ion in Trap

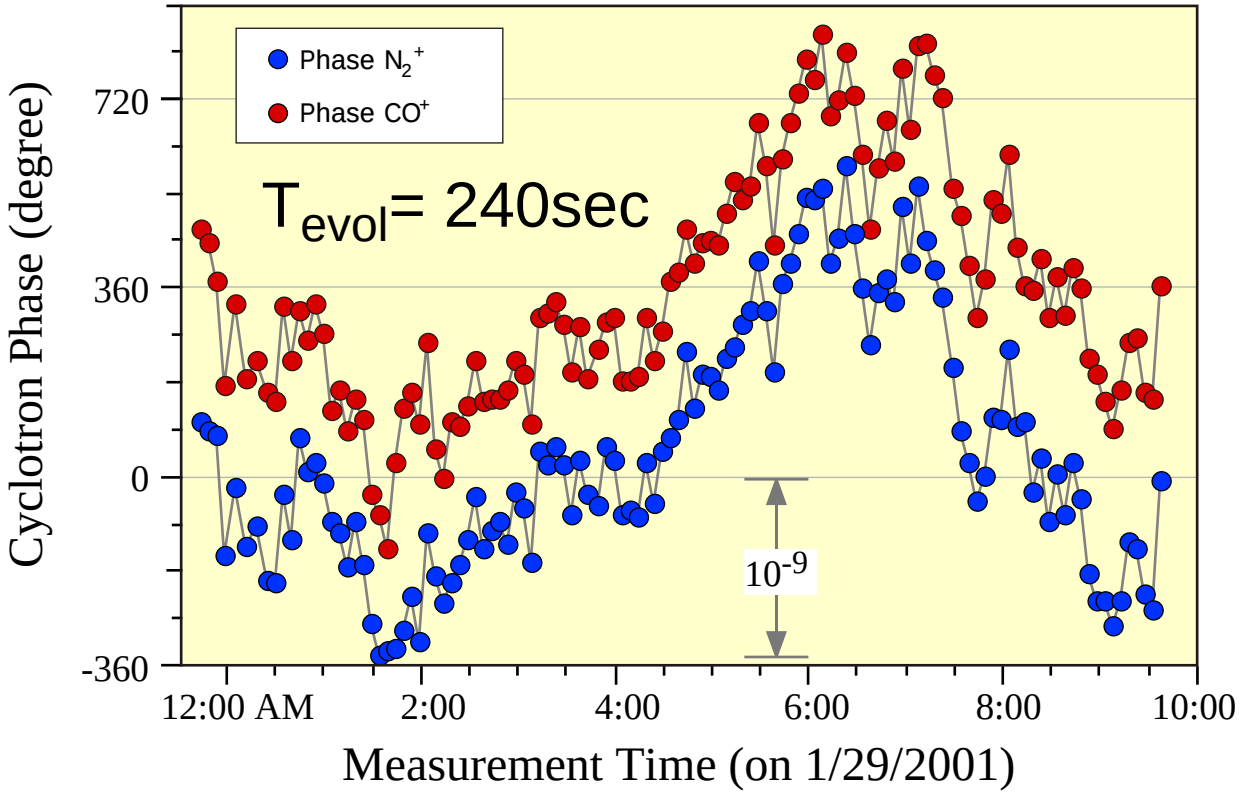


Two Ion Axial Signal





Simultaneous Cyc Meas



~10^{-10} Precision in Cyclotron Ratio
in 4 minutes and even during the day!!
(~2 x10^{-11} in 1 hour)