Trapped ion system for multi-species quantum control

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Quantum logic spectroscopy

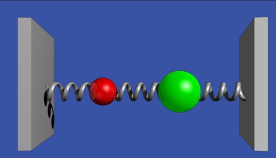
Leveraging quantum information processing techniques for precision measurement

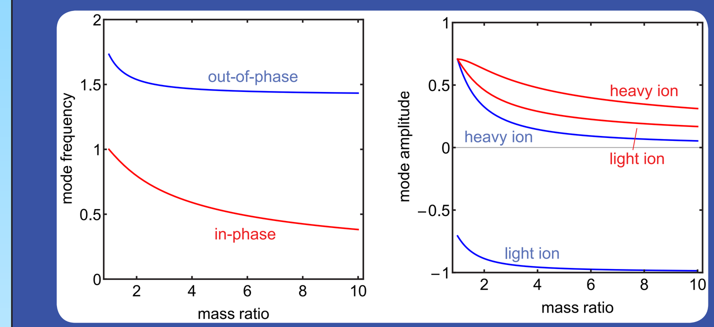
Atomic logic ion provides all dissipation
Target ion has an interesting spectroscopic transition

General procedure
- Co-trap ions
- External state preparation (sympathetic cooling)
- Internal state preparation (quantum projection)
- Spectroscopy probe of target ion
- State detection (non-destructive)

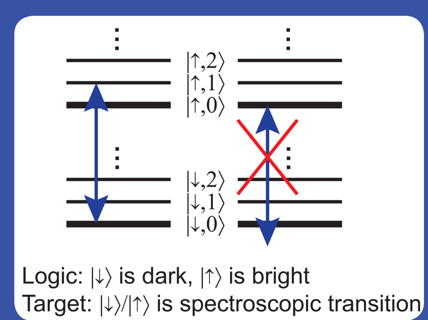
Our interest: molecules
- Quantum control of rotation states
- Rotation spectroscopy
- Quantum memory
- Tests of molecular quantum theory
- Time variation of fundamental constants
- Symmetry tests (P, T)

Normal modes:
an information bus shared by both ions





Conditional sideband excitation
read/write to info bus



Many atoms and molecules possess interesting spectroscopic transitions, but lack dissipative transitions useful for control and detection of internal states. In particular, molecules are useful candidates for quantum memories, low-temperature chemistry studies, tests of fundamental symmetries, and searches for time-variation of fundamental constants, but most lack a convenient cycling transition. By co-trapping a molecular ion with an atomic ion, the atom can provide all dissipation and detection.

Beryllium logic ion

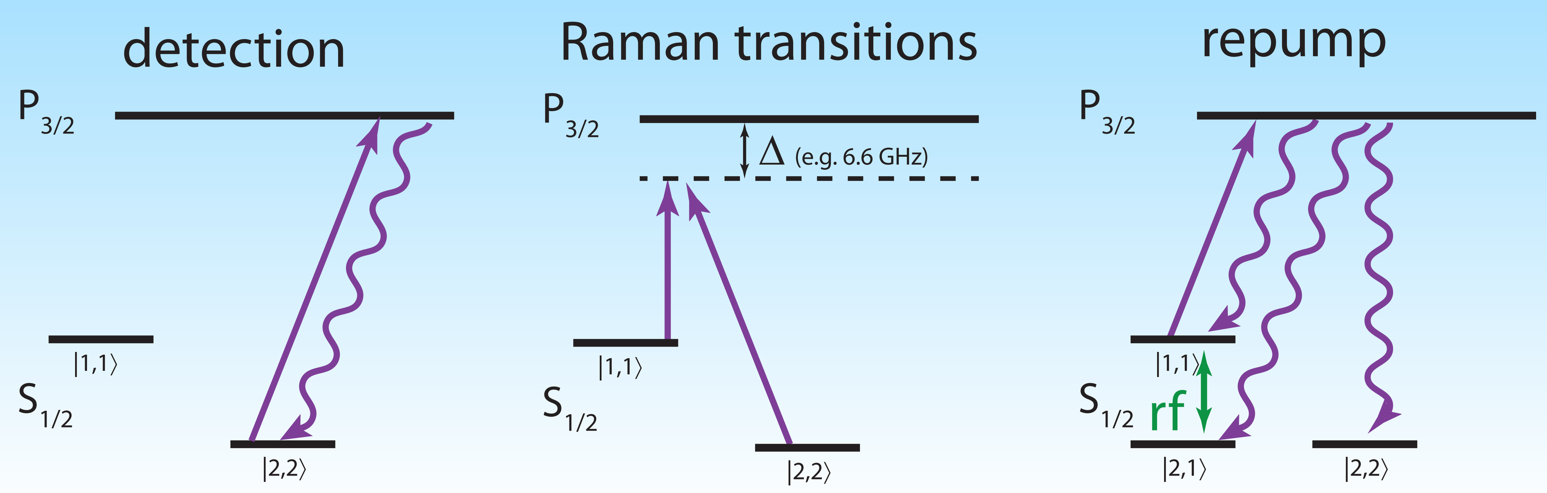
- Dissipation via photon scattering
- Hyperfine qubit
- Single isotope
- Ideal for lighter target ions

$^9Be^+$

$I = 3/2$

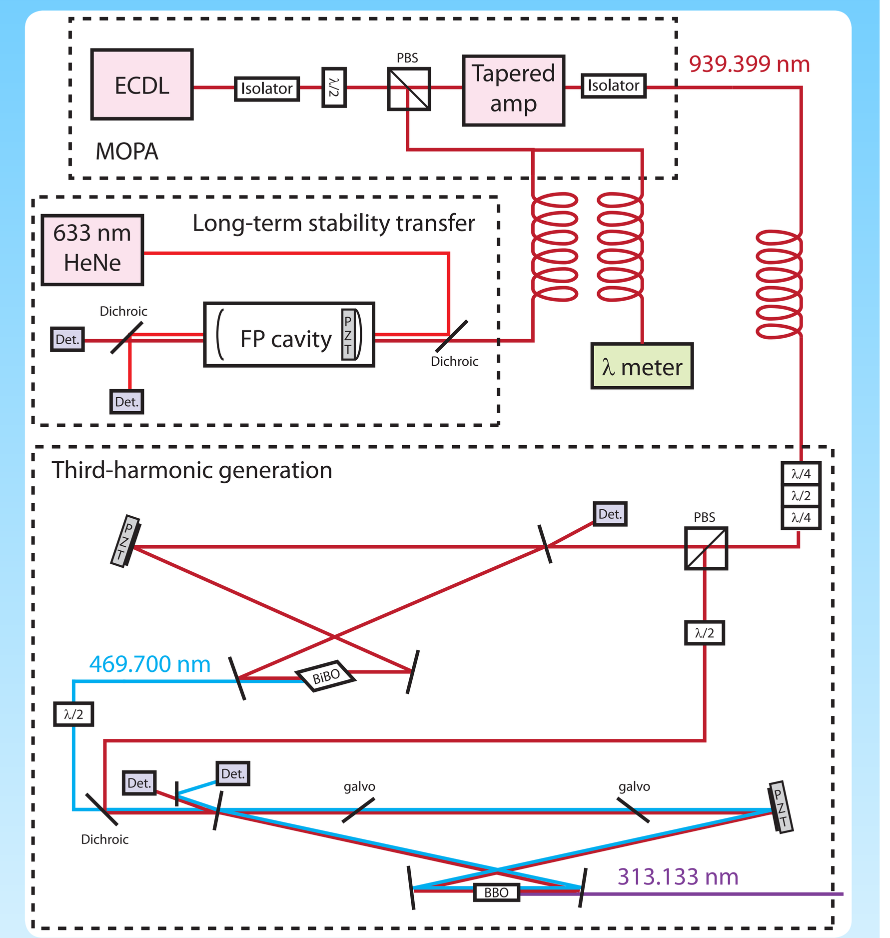
$\Gamma = 2\pi(19.4\text{ MHz})$

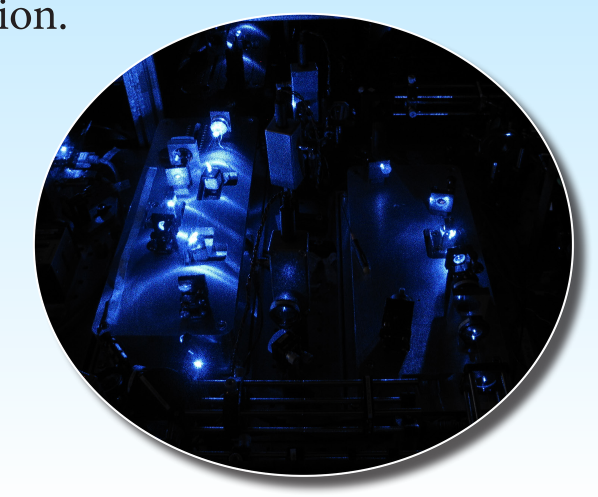
$\nu_{hfs} = 1.25\text{ GHz}$

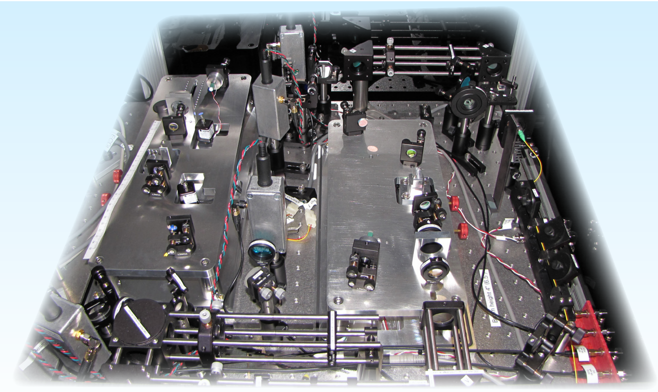


Be⁺ laser system

- Triple 939 nm diode laser to 313 nm (second-harmonic generation followed by sum-frequency generation)
- Transfer stability of HeNe to ECDL
- Both SHG and SFG cavities are locked with Pound-Drever-Hall technique (sidebands from ECDL modulation).
- In the SFG stage, quartz plates compensate for dispersion in BBO crystal and are tuned with galvos.
- Laser is 6.6 GHz off-resonance for Raman transitions, but modulating the ECDL adds a sideband on resonance for Doppler cooling and detection.

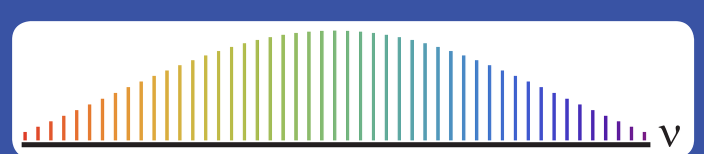






Raman transitions in the molecule

Pulsed laser
- Span rotation transitions
  100 fs pulse ~ 4 THz bandwidth
- Scan comb teeth with AOM
- No offset lock needed

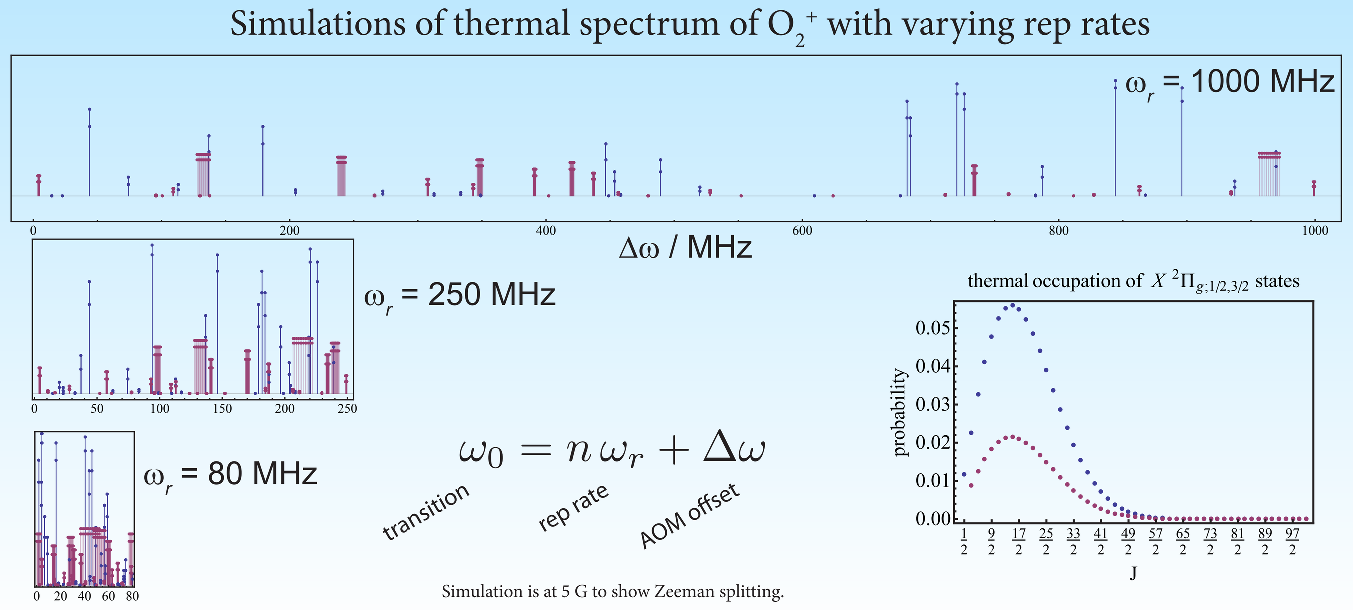


Rabi rate

$$\Omega \sim \frac{1}{\Delta}$$

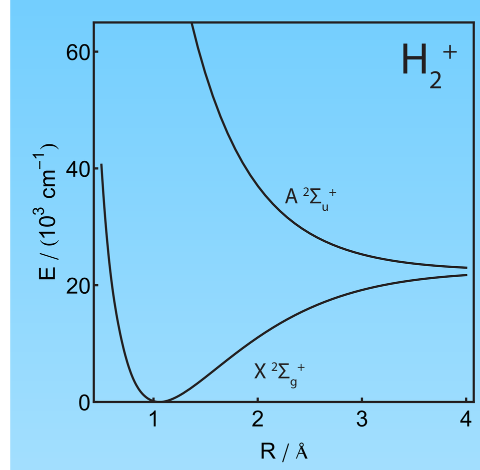
Can detune very far
(800 nm = 12500 cm⁻¹)

Simulations of thermal spectrum of O_2^+ with varying rep rates



Simulation is at 5 G to show Zeeman splitting.

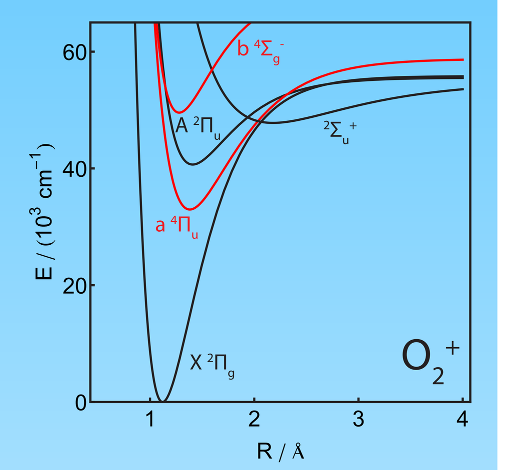
Candidate molecules



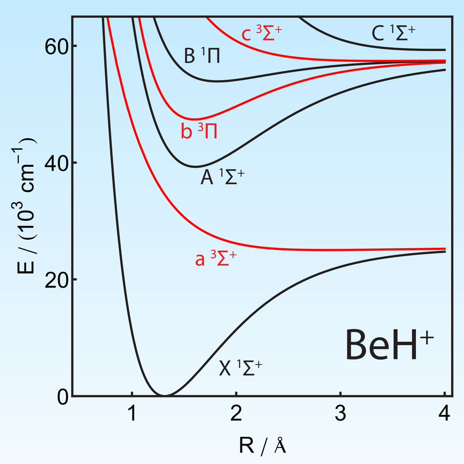
B = 905 GHz (H_2^+)
670 GHz (HD^+)
450 GHz (D_2^+)
300 GHz (T_2^+)

Our techniques are applicable to a wide variety of molecules. Choosing a target includes both science interest (e.g. sensitivity to me/mp variation or availability of high-precision theory calculations) and practical considerations such as ease of loading and systematic effects (e.g. apolar molecules insensitive to trap rf).

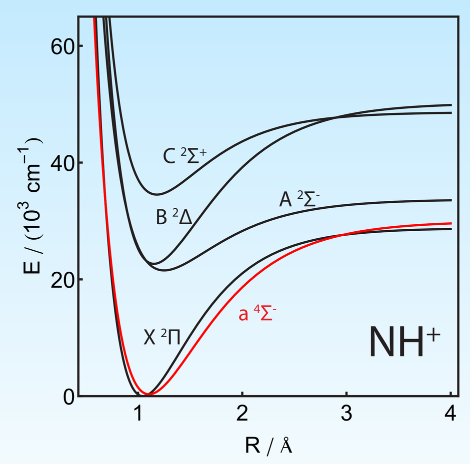
Here are some candidates we are considering and their ground-state rotation constants.



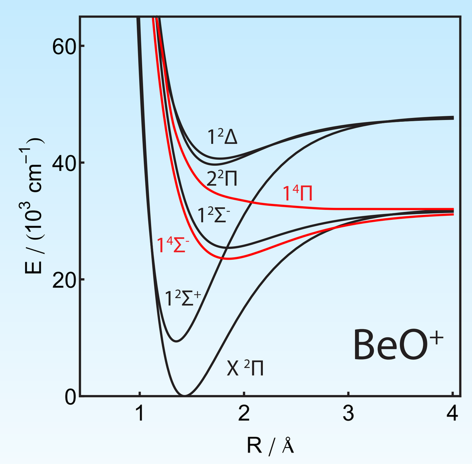
B = 50 GHz



B = 324 GHz (BeH^+)
179 GHz (BeD^+)



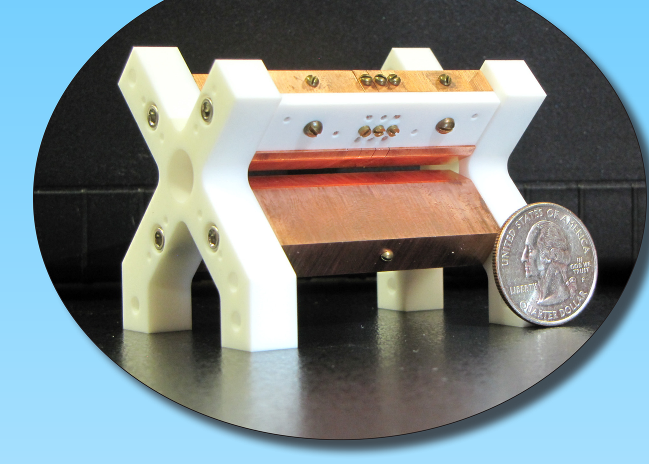
B = 460 GHz



B = 43 GHz

The apparatus

- UHV chamber with laser, imaging, and electrical access
- Beryllium wire ovens
- Precision leak valve for gas introduction
- Electron emitter for impact ionization of beryllium and background gas

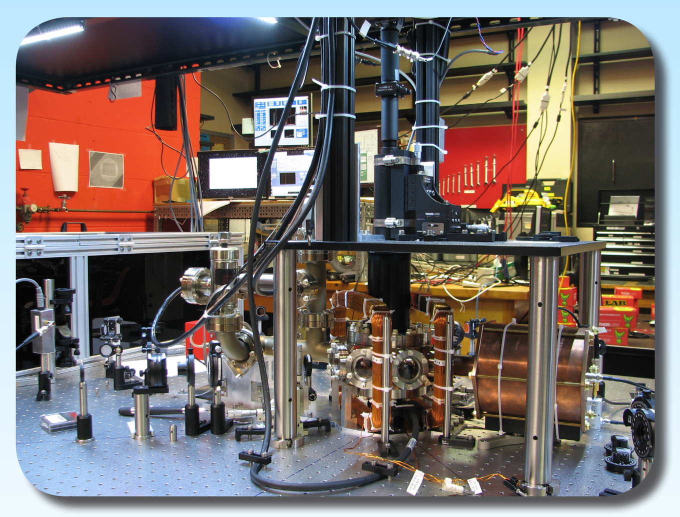


Trap parameters

$r_0 = 1.2$ mm

$z_0 = 1.5$ mm

$\Omega = 2\pi(15.2\text{ MHz})$



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