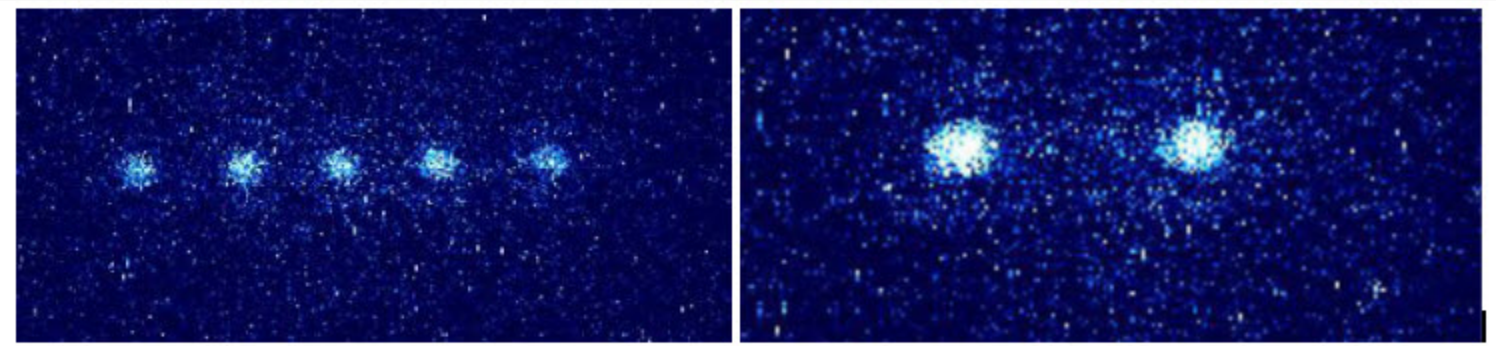
Lasers for Hyperfine State Detection and Cooling of Ytterbium Ions



Images of Trapped Ytterbium Ions from www.osti.gov

Sarah Innes-Gold
University of Washington INT REU 2014

Talk Outline

Motivation

- Quantum computing
- Why trapped ions?

Theory and Procedure

- System implementation

Project Specifics

- What we are actually working on

Talk Outline

Motivation

- Quantum computing
- Why trapped ions?

Theory and Procedure

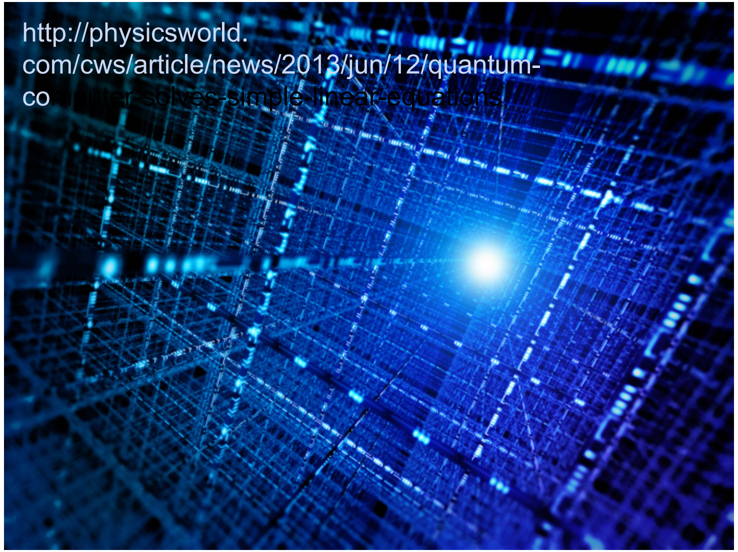
- System implementation

Project Specifics

- What we are actually working on

Quantum Computing

- Much faster calculations for difficult problems
  - Ex: Integer factorization, many-body problems
- Instead of traditional binary digits: qubits
  - make use of superposition states, entanglement
- Challenges
  - eliminate sources of decoherence, scale up systems

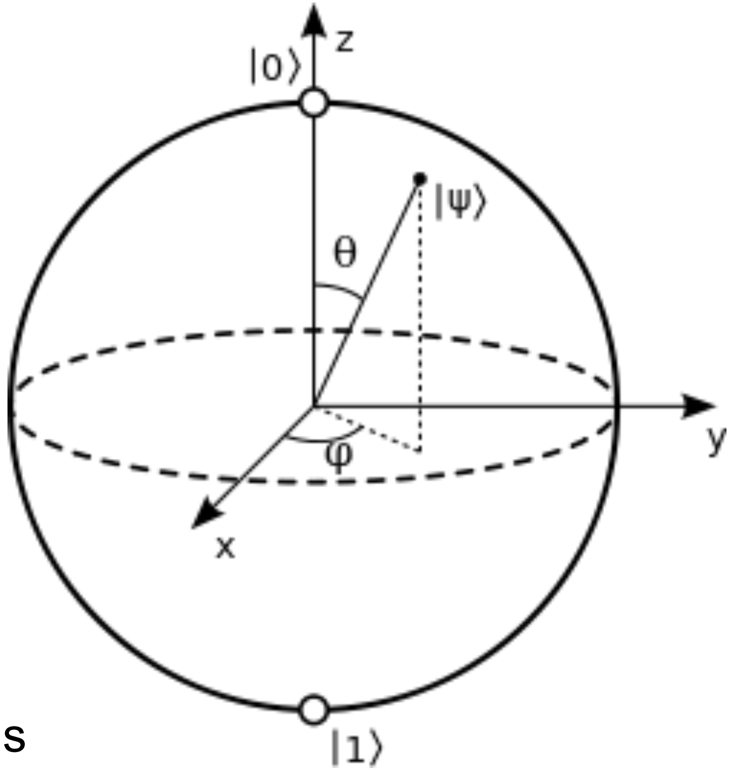


Google Image result for “quantum computer”

Qubits

- What makes a good qubit?
  - two-level quantum system
  - can be individually addressed
  - states can be entangled
  - long coherence time
  - decoupled from environment

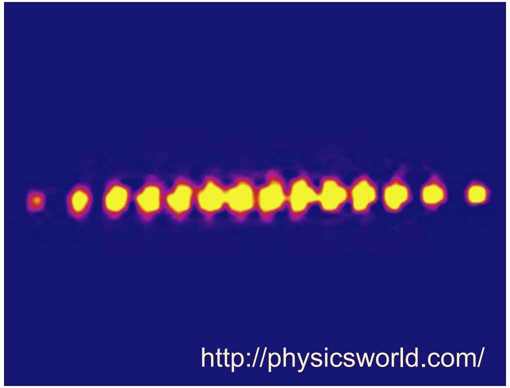
- A few possible candidates...
  - Photons
  - Superconducting Josephson junctions
  - Quantum dots
  - Trapped ions and atoms



http://upload.wikimedia.org/wikipedia/commons/thumb/6/6b/Bloch_sphere.svg/250px-Bloch_sphere.svg.png

Trapped Ions as Qubits

- Advantages
  - ions in trap well-isolated from environment
  - long coherence times
  - two energy levels can act as qubit states
  - motional levels used for information transfer

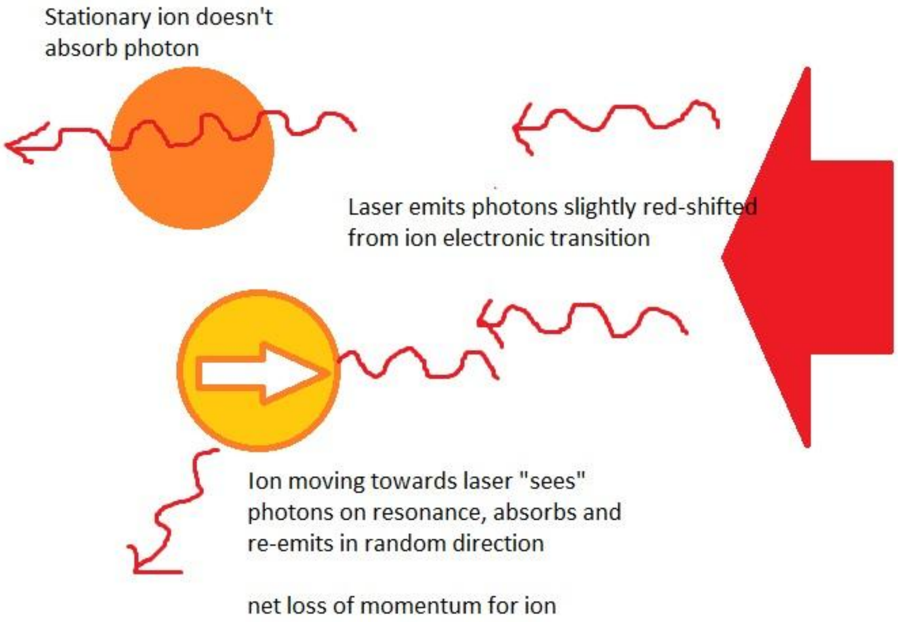


- Problems
  - scalability
  - ions heat up, move
    - causes decoherence, as motional energy levels are used for information processes between ions

Laser Cooling

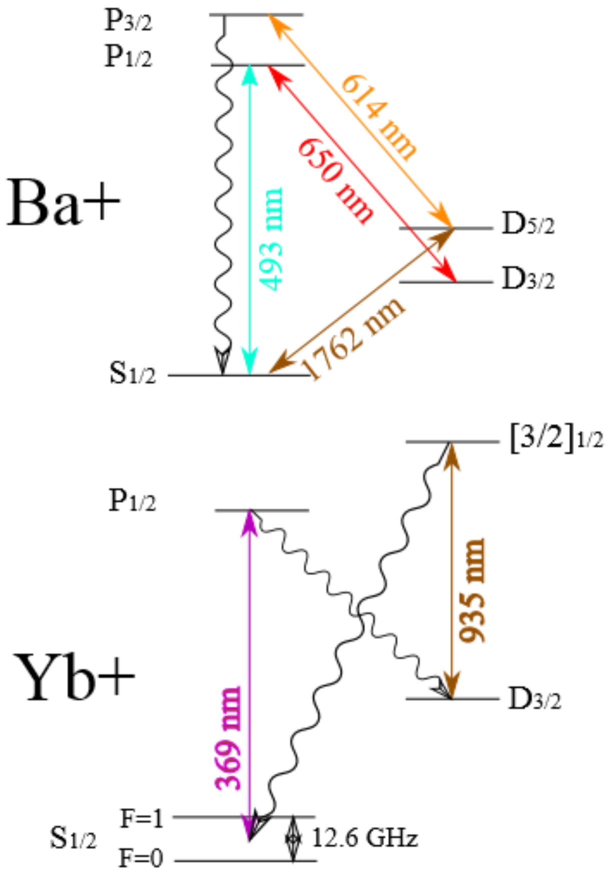
- Prevents decoherence caused by heating

- Problems:
  - laser excites internal electronic transitions
  - those levels also needed for information processes
  - difficult to cool single ion w/o exciting transitions in neighbours



Sympathetic Cooling

- two species of ions
  - whose internal transition energies do not overlap
- one as the qubit, one to be laser-cooled
- interactions between them cause qubit ions to be cooled as well



Talk Outline

Motivation

- Quantum computing
- Why trapped ions?

Theory and Procedure

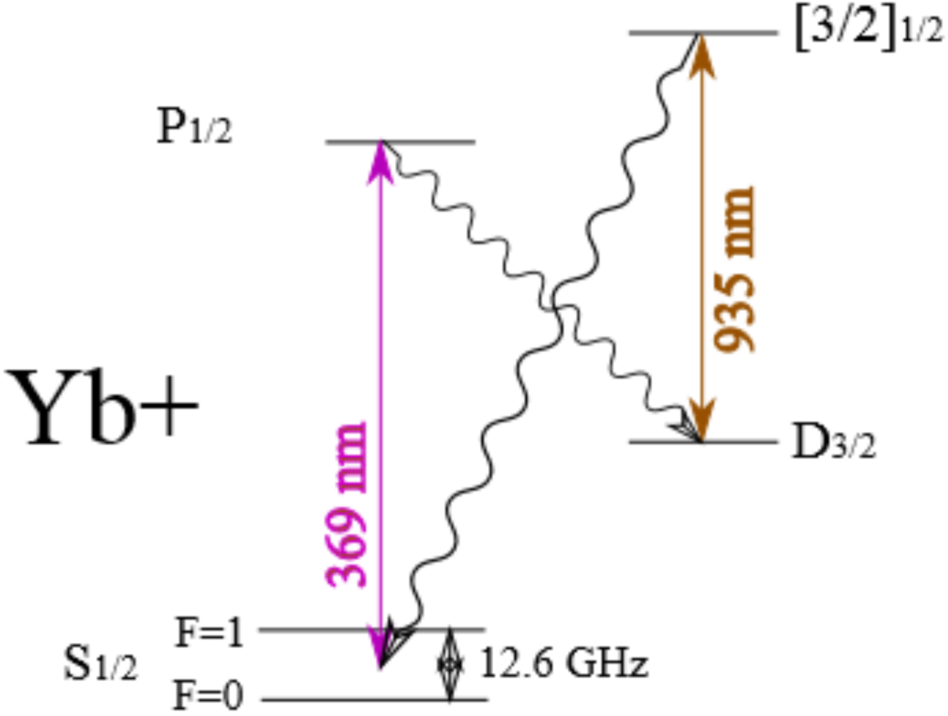
- System implementation

Project Specifics

- What we are actually working on

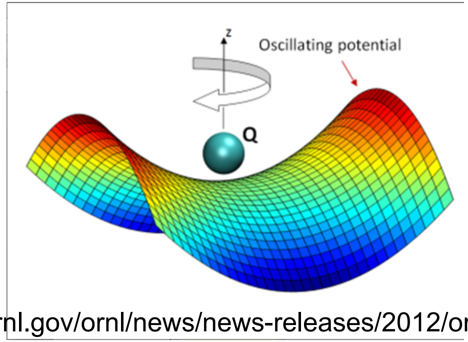
State Detection in Yb^+

- Hyperfine structure allows us to select for one level
- In one state, ion fluoresces as it emits photon
- Other level is outside the cooling cycle

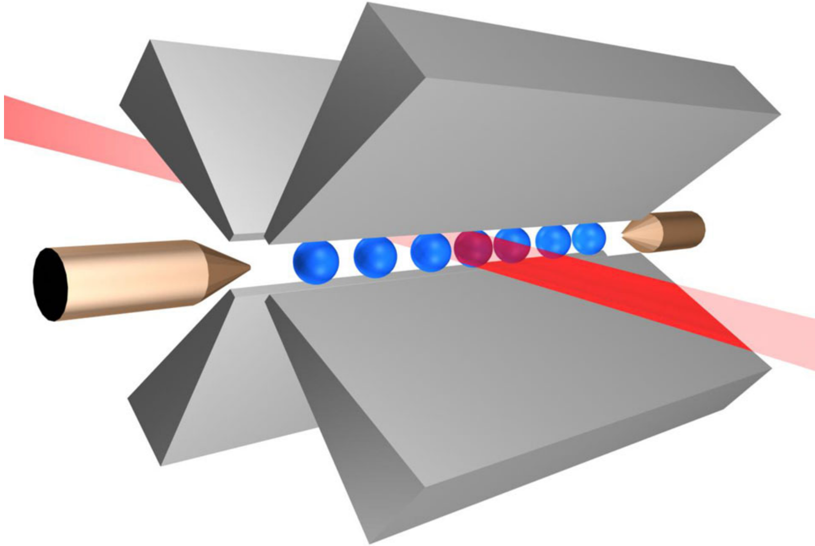


Trapping Ions in Linear RF-Paul Trap

- uses combination of DC voltages and oscillating rf voltage
- forms (almost) harmonic 3D potential well



http://www.ornl.gov/ornl/news/news-releases/2012/ornl--yale-take-steps-toward-fast--low-cost-dna-sequencing-device



http://www.uibk.ac.at/th-physik/qo/research/trappedions.html

Talk Outline

Motivation

- Quantum computing
- Why trapped ions?

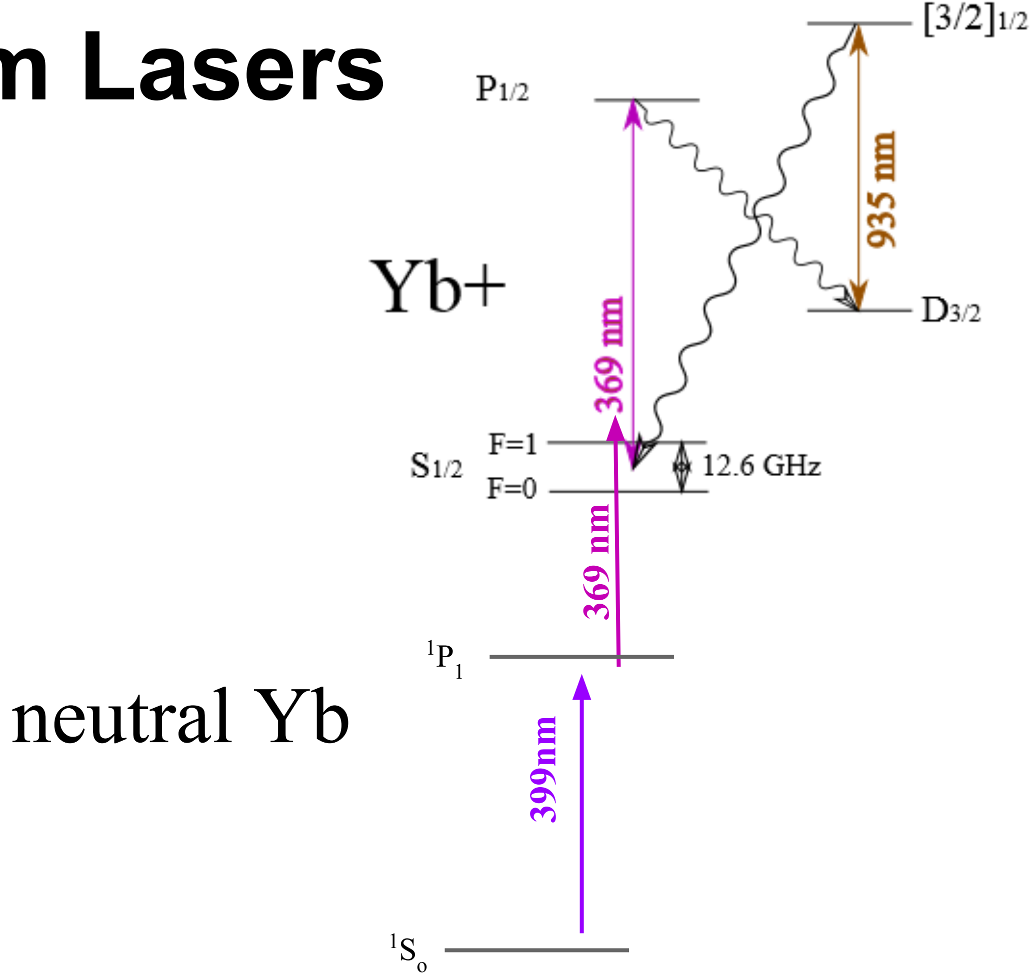
Theory and Procedure

- System implementation

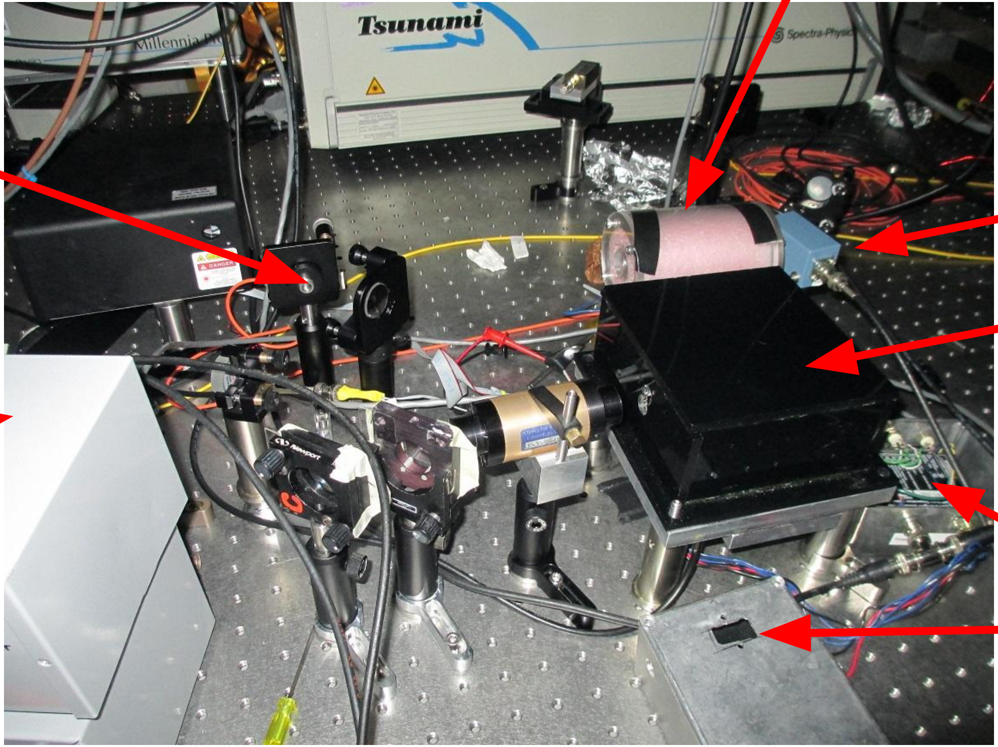
Project Specifics

- What we are actually working on

Ytterbium Lasers

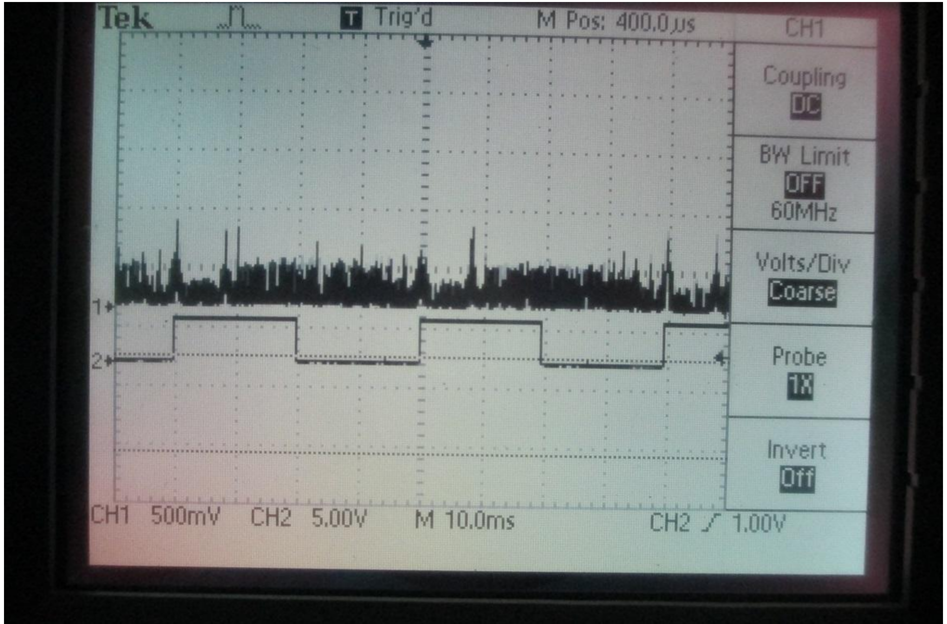


935 nm Laser Setup



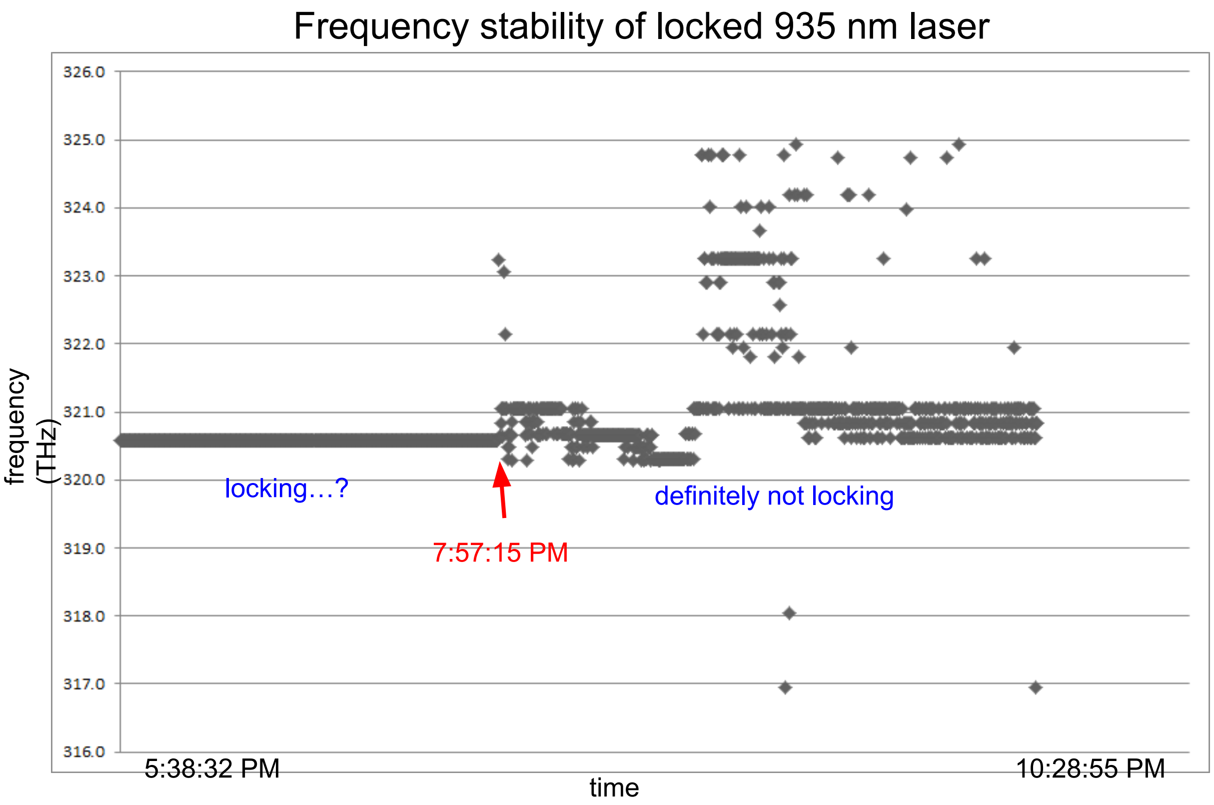
Frequency Stability

- scan laser over range of frequencies
- peaks correspond to modes of the cavity
- lock laser to a peak



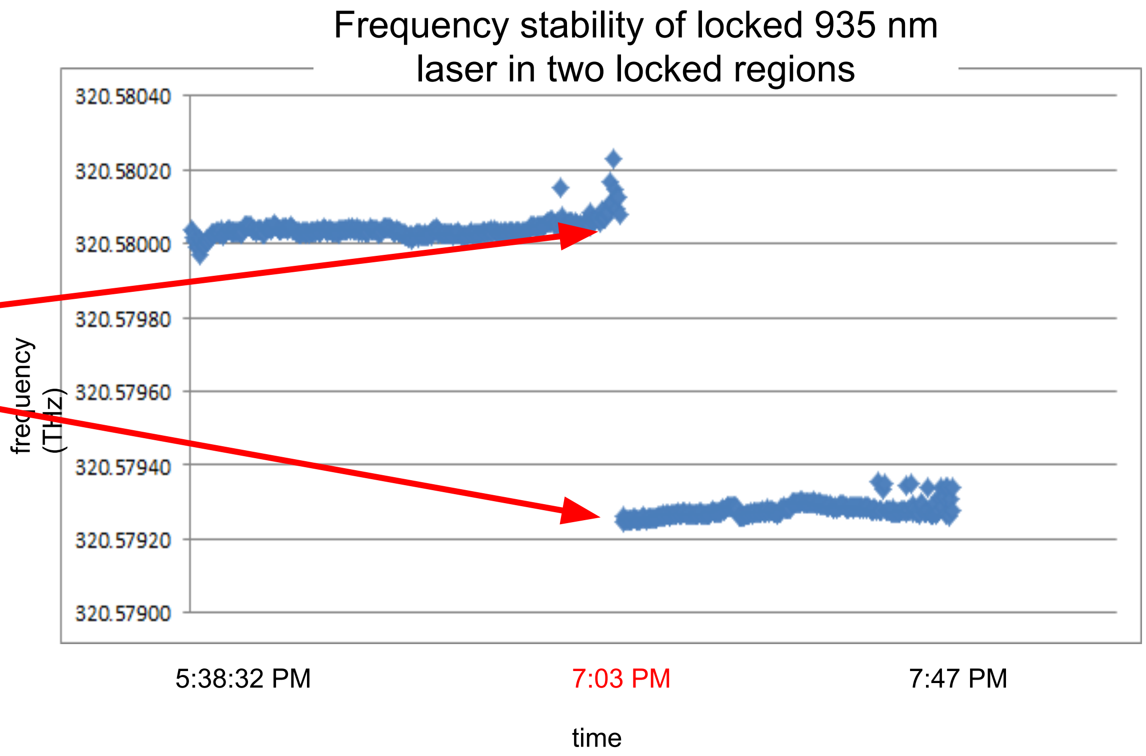
Poorly resolved but visible peaks

Locking the Laser



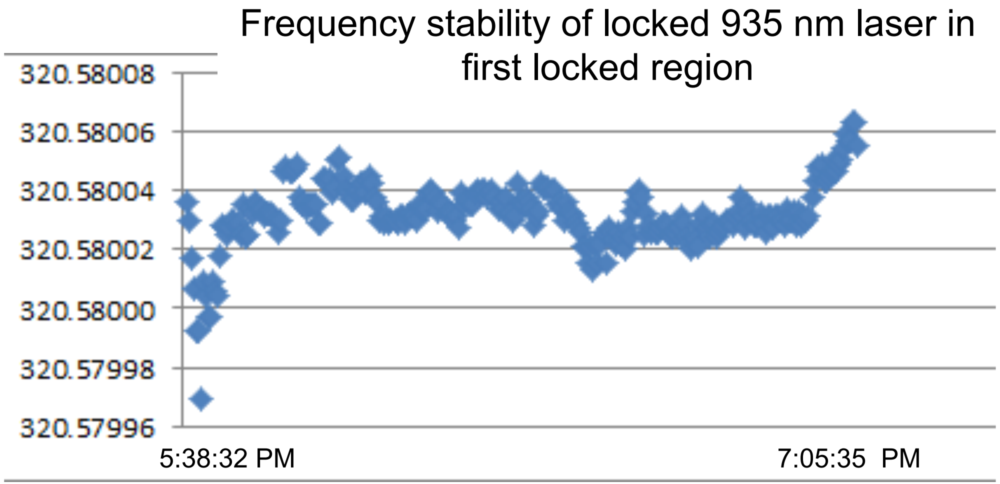
Locking the Laser

Laser jumps, locks to a different peak



Locking the Laser

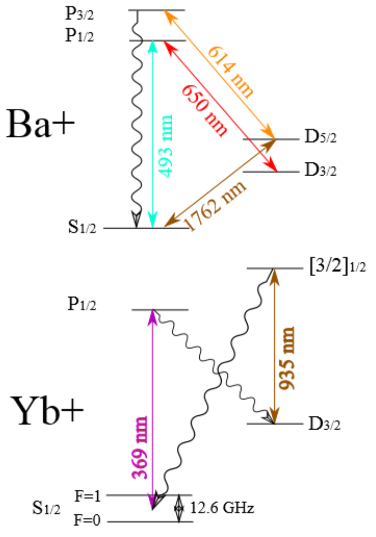
- Stable to ~80 MHz for the first 90 minutes
- Oscillations expected due to temperature

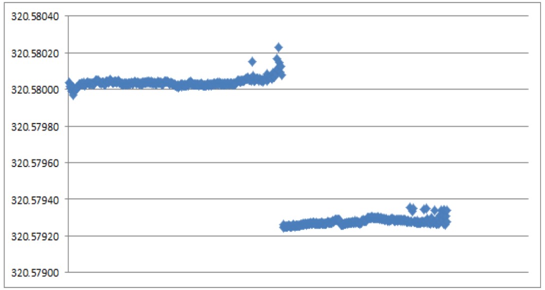


In Summary...

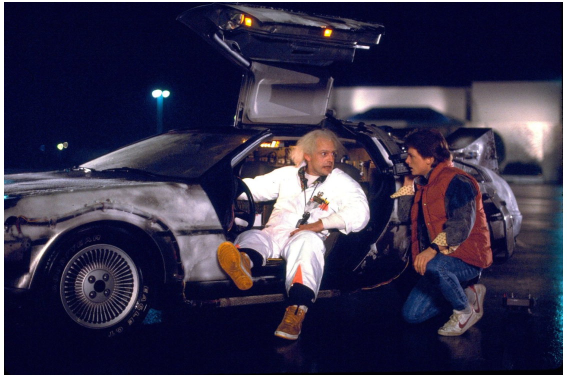
- Trapped ions offer a promising architecture for the long-term goal of a quantum computer
- Right now: development and refinement of techniques for trapping, cooling, and manipulating
- Yb^+ ions as a qubit candidate, cooled sympathetically

- System of lasers to read out hyperfine state
- 935 nm laser for Yb^+ now set up with lock
- Frequency stability within 80 MHz over long enough time scale





In the Future...



- Trap, cool Yb^+ ions using new lasers
- Further experiments with two-species sympathetic cooling
- Pulsed lasers to drive narrow transitions in Barium ions
- More experiments on processes used for quantum information

Thank you!

Thanks very much to:

Boris Blinov, John, Tomasz, and the rest of the trapped ion group!

Alejandro, Deep, Shih-Chieh, Janine, and Linda

Ron Musgrave for a wonderful machine shop class

The University of Washington and the NSF

References

Blatt, Wineland. Entangled states of trapped atomic ions. *Nature Vol. 453* (19 June 2008).

Hayes. Remote and Local Entanglement of Ions using Photons and Phonons. (2012).

Olmschenk, Younge, Moehring, Matsukevich, Maunz, Monroe. Manipulation and detection of a trapped Yb^+ qubit. *Physical Review A* ***76,*** 052314 (2007).

Wineland, Monroe, Itano, Leibfried, King, Meekhof. Experimental Issues in Coherent Quantum-State Manipulation of Trapped Atomic Ions. *Journal of Research of the NIST. Vol. 103 Number 3* (May-June 1998).