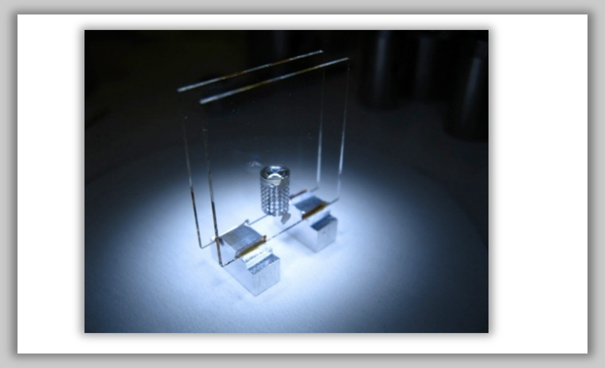
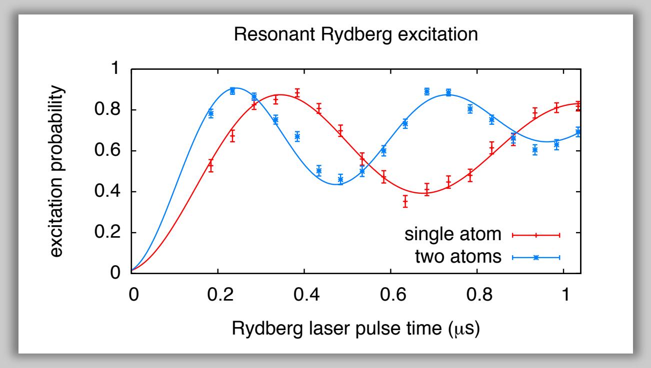
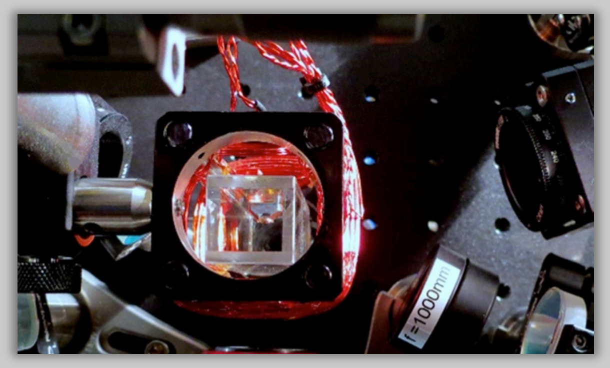
Exceptional service in the national interest

SAND2013-3162C

Sandia National Laboratories





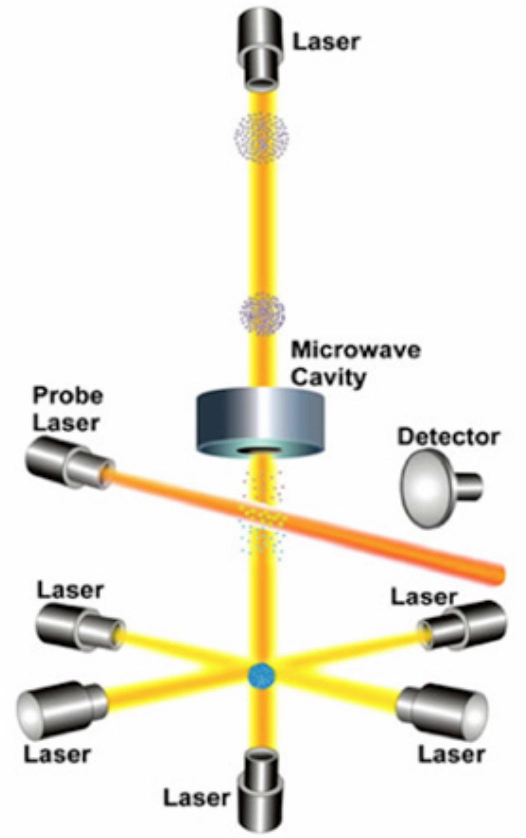


Neutral atom adiabatic quantum computation

Grant Biedermann

- Team Members: George Burns, James Chin-Wen Chou (Soon at Oregon), Rob Ellis, Andrew Ferdinand, Aaron Hankin, Yuan-Yu Jau, Cort Johnson, Shanalyn Kemme, L. Paul Parazzoli, Peter Schwindt, Amber Young, and Andrew Landahl
- Collaborators: Ivan Deutsch (U. New Mexico), and Mark Saffman (U. Wisconsin)

Quantum-Coherence



1 sec = 9,192,631,770 cycles of quantum oscillations in ^{133}Cs hyperfine states

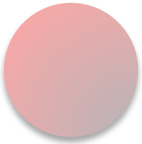
$$\left|6^2 S_{1/2}; F = 3, M_F = 0\right\rangle \leftrightarrow \left|6^2 S_{1/2}; F = 4, M_F = 0\right\rangle$$

$$\left|0\right\rangle \leftrightarrow \left|1\right\rangle$$

Typical accuracy now better than one part in 10^{15}

http://www.nist.gov/pml/div688/grp50/primary-frequency-standards.cfm

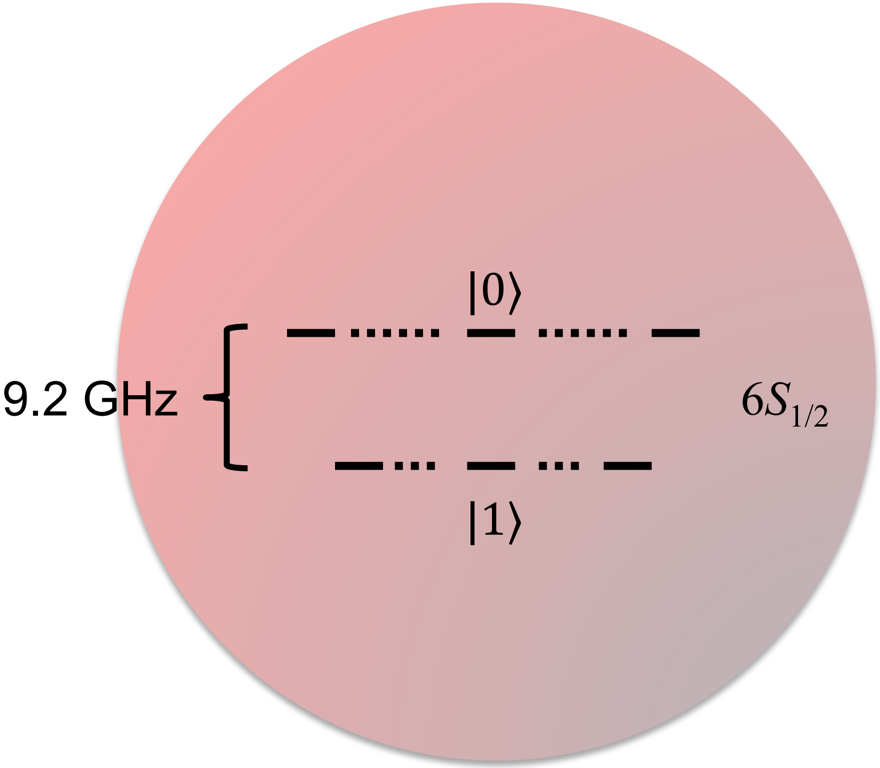
Many single-atom clocks

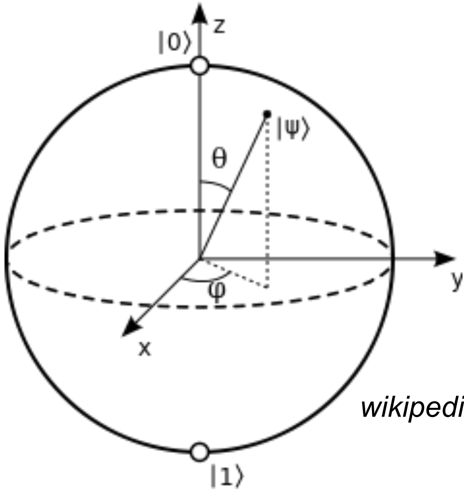


cesium atom

Many single-atom clocks

A look “inside”



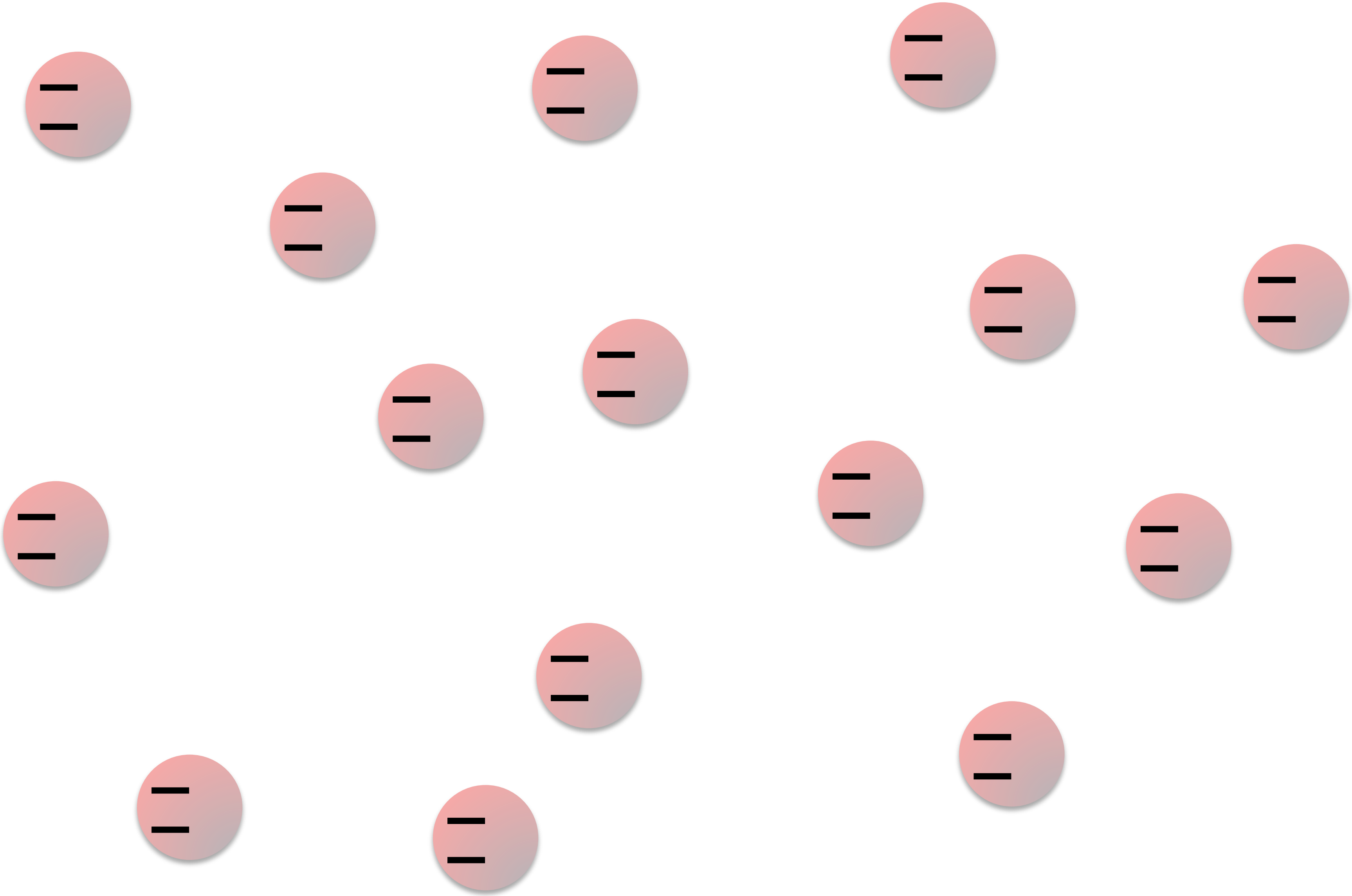


wikipedia

Bloch sphere

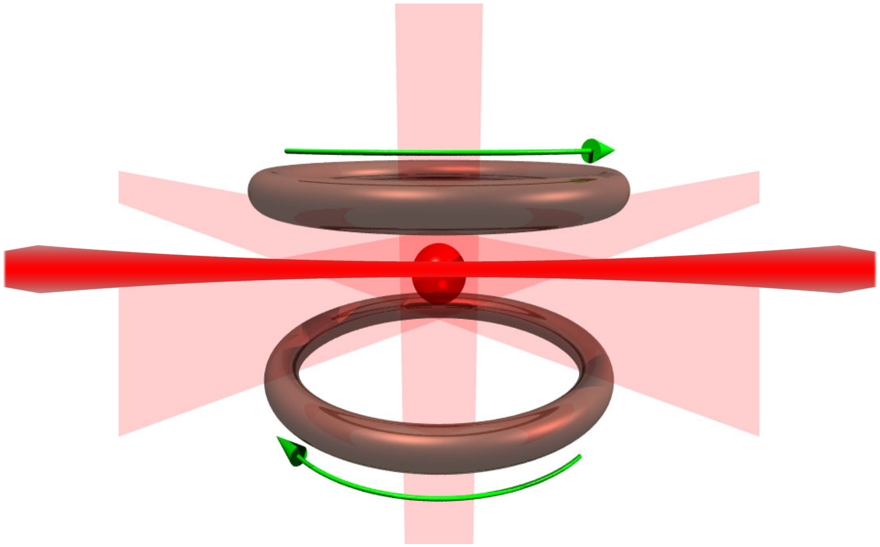
Long coherence times, state tomography

Many single-atom clocks



Single neutral atom control

- Optical tweezer for one atom [1]
- Red-detuned laser is focused tightly through the MOT
  - Waist at focal plane ~ 1 micron
  - Trap depth ~ 1 mK



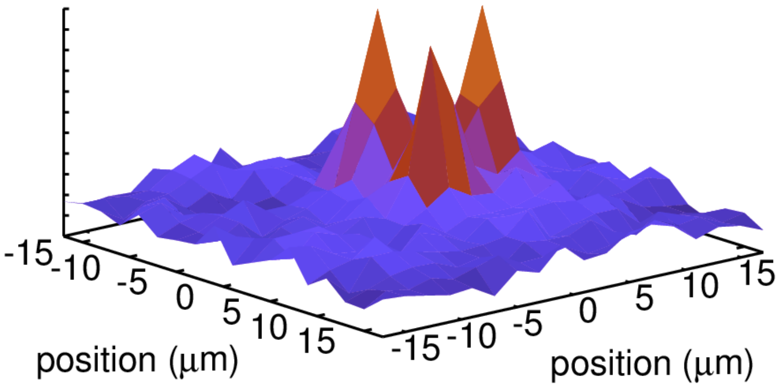
2D-arrays…

[1] N. Schlosser, et al., Sub-poissonian loading of single atoms in a microscopic dipole trap. *Nature*, **411**, 1024 (2001).

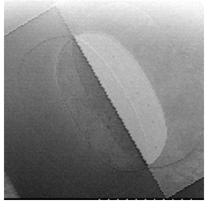
Single neutral atom control

Microfabricated optics for larger systems

single atoms in 3-spot trap



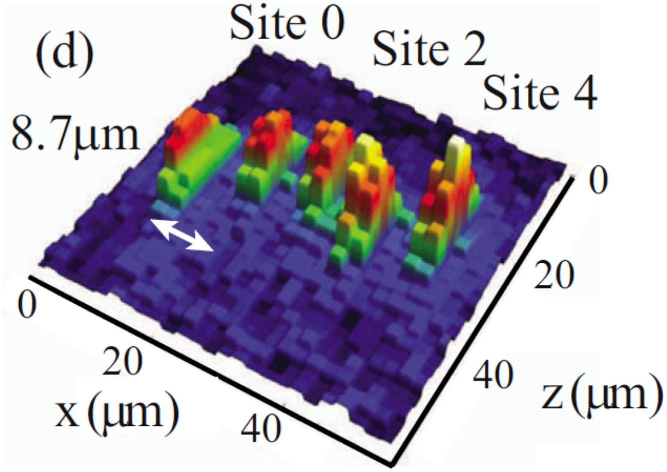
System for studying frustrated spins

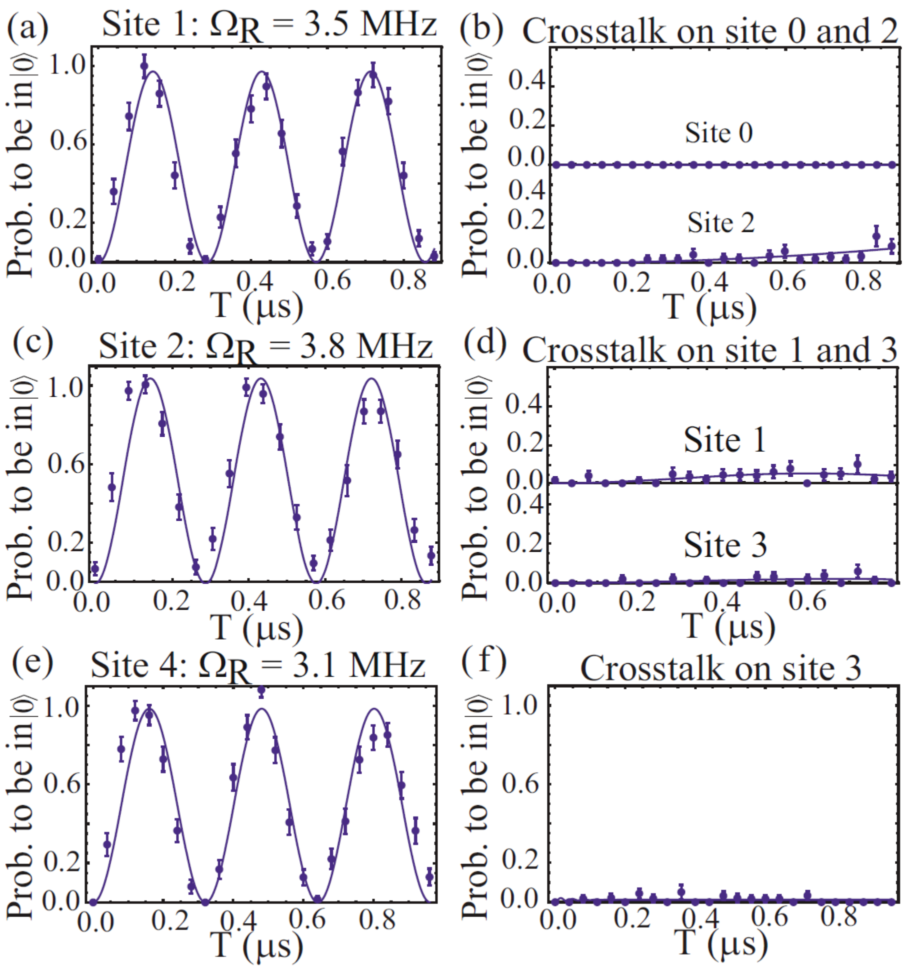


SEM image of 3-trap lens

2D-arrays…

Single neutral atom control

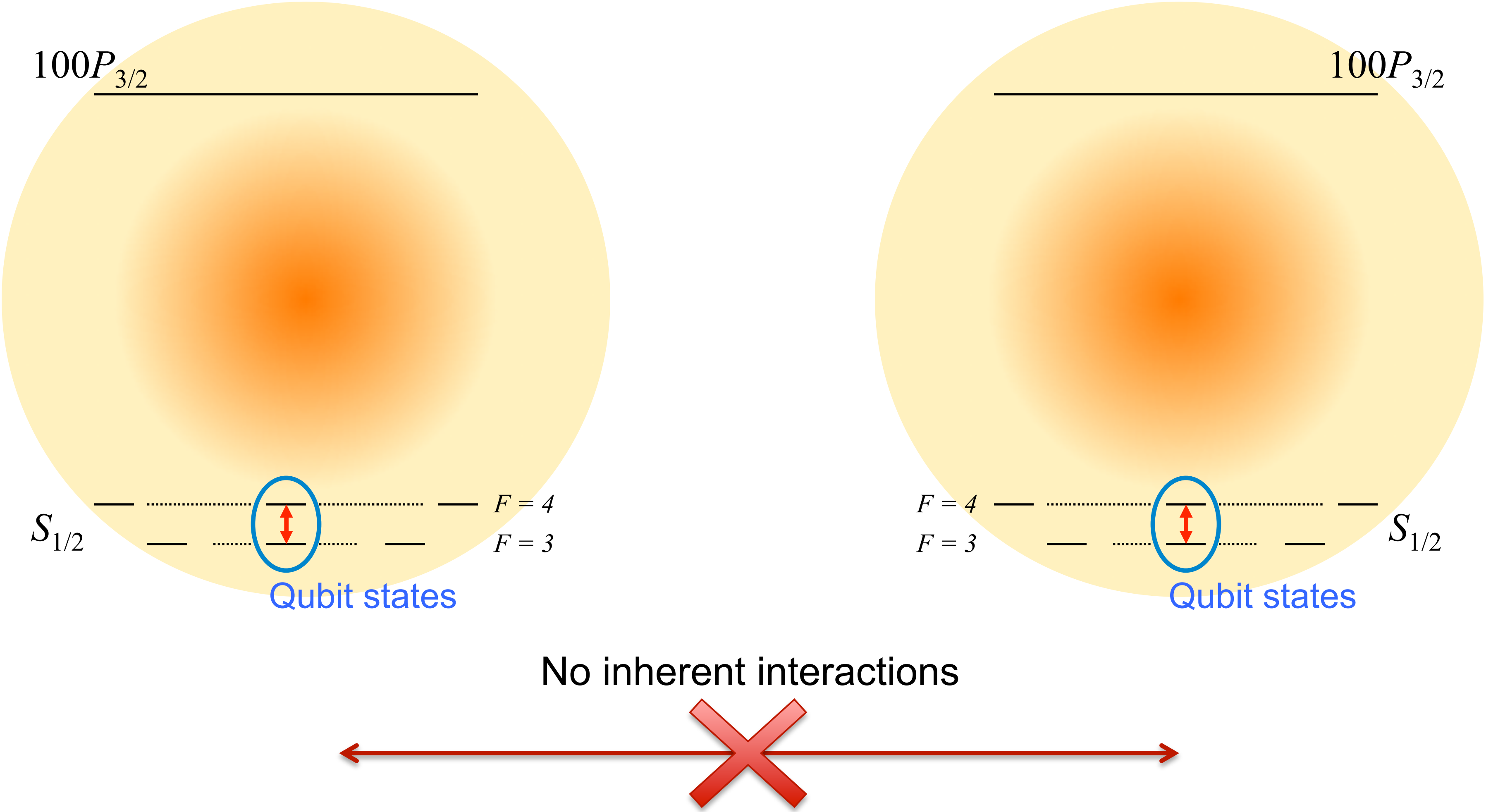




Individual addressing…

C. Knoernschild, et al., "Independent individual addressing of multiple neutral atom qubits with a micromirror-based beam steering system", APL **97**, 134101 (2010)

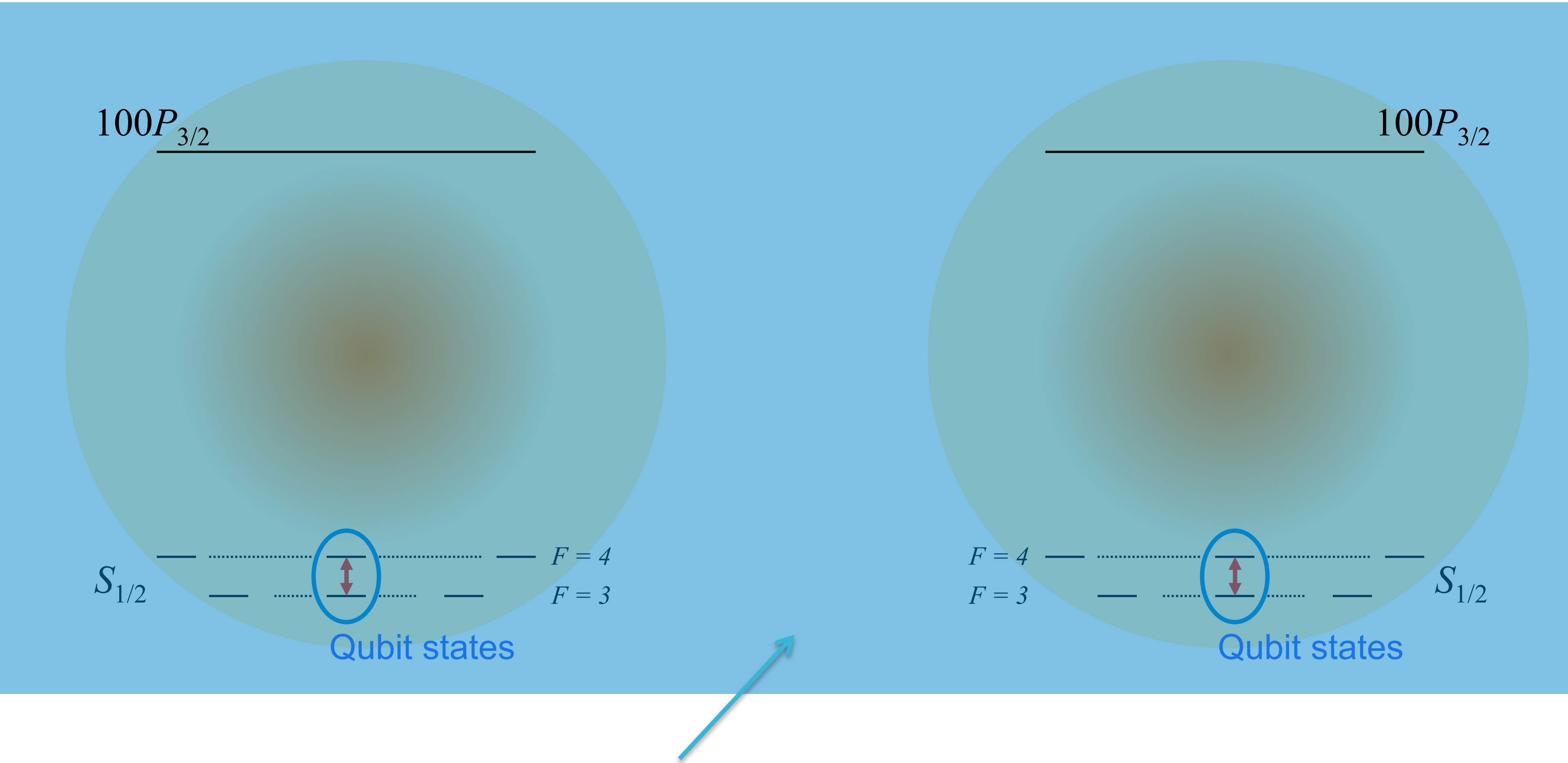
Single neutral atom control



No inherent interactions

C. Knoernschild, et al., “Independent individual addressing of multiple neutral atom qubits with a micromirror-based beam steering system”, APL **97**, 134101 (2010)

Single neutral atom control



Qubit states

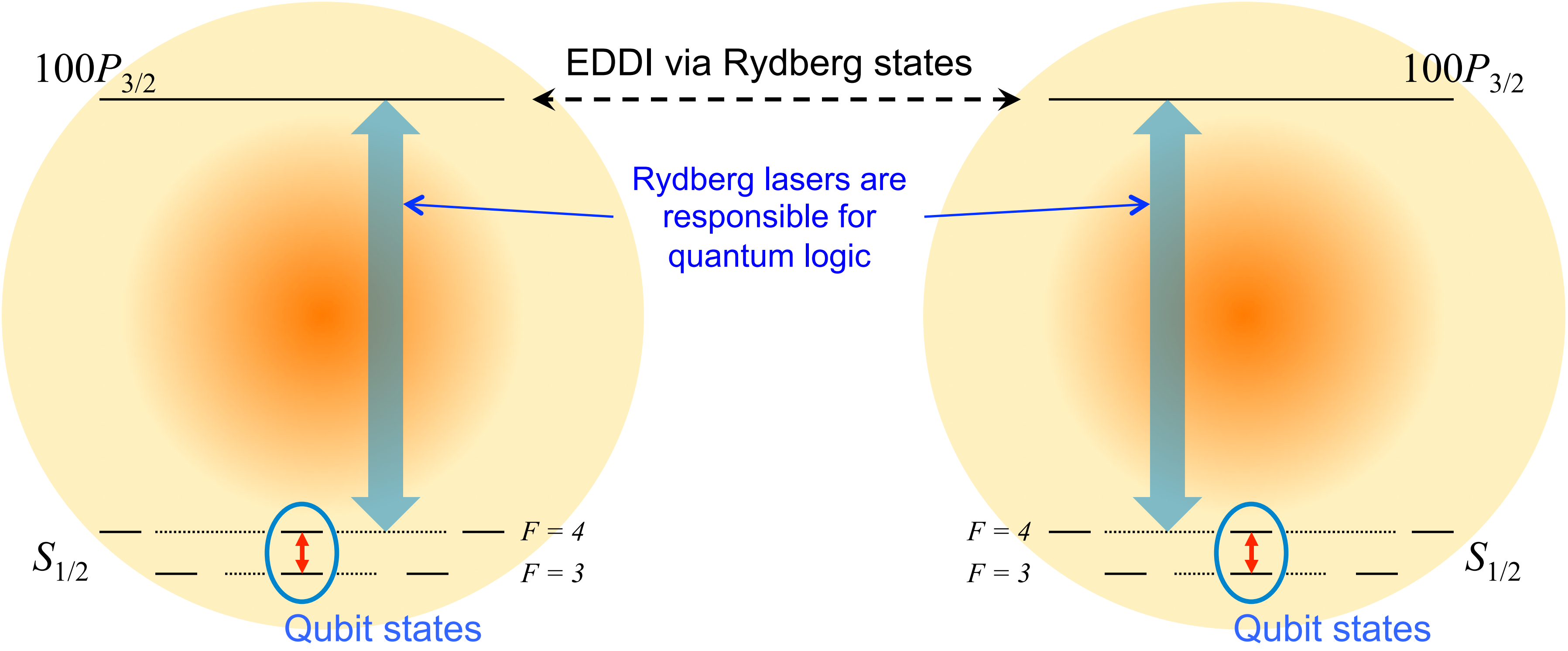
Qubit states

Laser light for excitation to Rydberg states

On-demand interactions…

C. Knoernschild, et al., “Independent individual addressing of multiple neutral atom qubits with a micromirror-based beam steering system”, APL **97**, 134101 (2010)

Single neutral atom control



On-demand interactions…

C. Knoernschild, et al., "Independent individual addressing of multiple neutral atom qubits with a micromirror-based beam steering system", APL **97**, 134101 (2010)

2-qubit QUBO problem

- We aim to solve the quadratic unconstrained binary optimization (QUBO) problem.
- This problem maps naturally onto adiabatic evolution.

Binary variables: $z_i = 0$ or 1

Minimize:

$$f(z_1,z_2) = h_1(t)\, z_1 + h_2(t)\, z_2 + j_{12}(t)\, z_1\, z_2$$

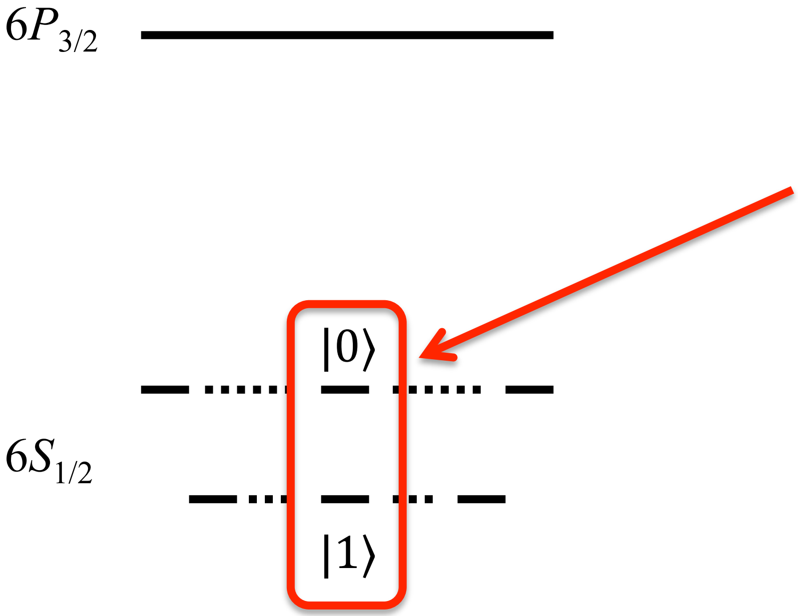
for a given set of h_1, h_2, and j_{12}

Independent control of terms: h_1, h_2, j_{12}

QUBO Hamiltonian for neutral cesium

$$\mathbf{H}(s) = (1 - s)\mathbf{H}_0 + s\mathbf{H}_Q$$

Cs energy level diagram



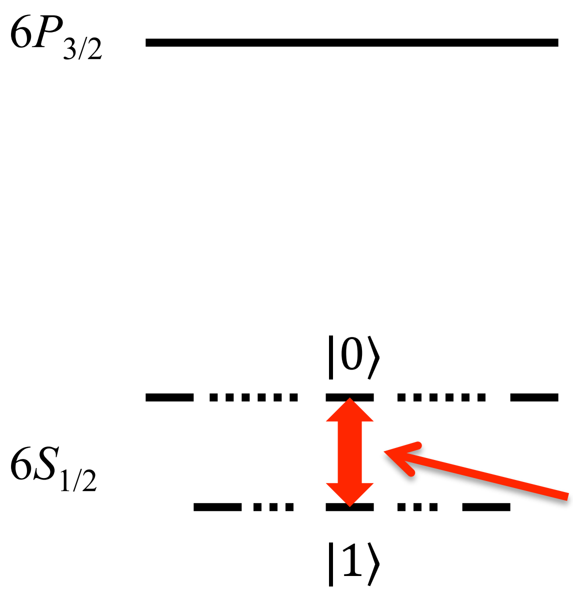
encode qubit in
Cesium's ground state

QUBO Hamiltonian for neutral cesium

$$\mathbf{H}(s) = (1-s)\mathbf{H}_0 + s\mathbf{H}_Q$$

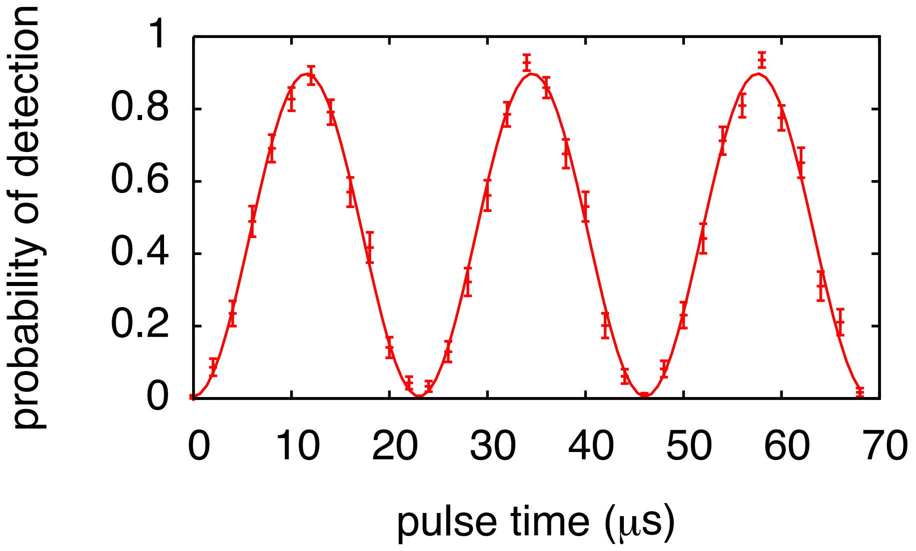
$$\boxed{\mathbf{H}_0 = \frac{b}{2}\left(\boldsymbol{\sigma}_x^{(1)} + \boldsymbol{\sigma}_x^{(2)}\right)}$$

Cs energy level diagram



Microwaves (9.2 GHz) or stimulated Raman transitions

Rabi flopping between qubit states



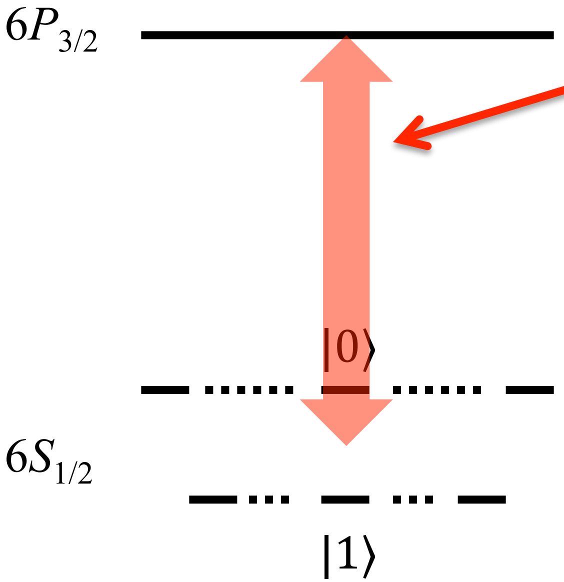
QUBO Hamiltonian for neutral cesium

$$\mathbf{H}(s) = (1-s)\mathbf{H}_0 + s\mathbf{H}_Q$$

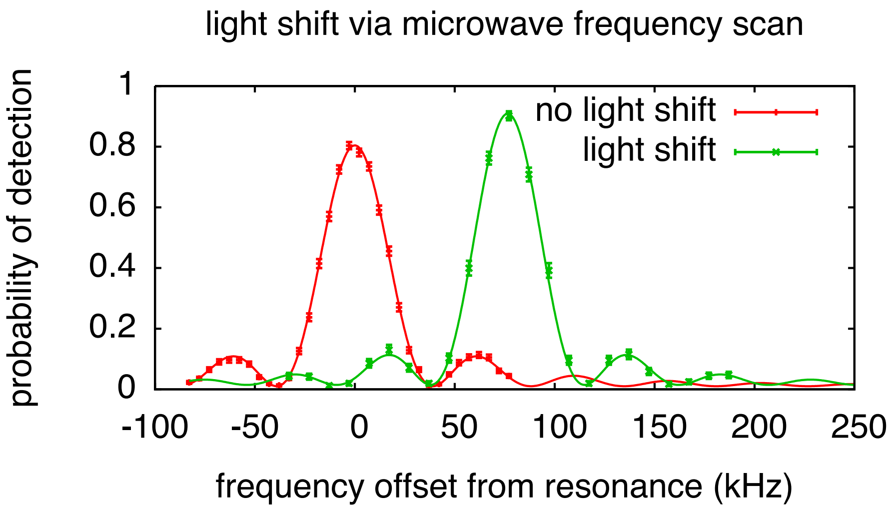
$$\mathbf{H}_0 = \frac{b}{2}\left(\boldsymbol{\sigma}_x^{(1)} + \boldsymbol{\sigma}_x^{(2)}\right)$$

$$\mathbf{H}_Q = \boxed{\frac{h_1}{2}\boldsymbol{\sigma}_z^{(1)} + \frac{h_2}{2}\boldsymbol{\sigma}_z^{(2)}} + \frac{j_{12}}{4}(1-\boldsymbol{\sigma}_z^{(1)})(1-\boldsymbol{\sigma}_z^{(2)})$$

Cs energy level diagram



Light-shift lasers (852 nm)

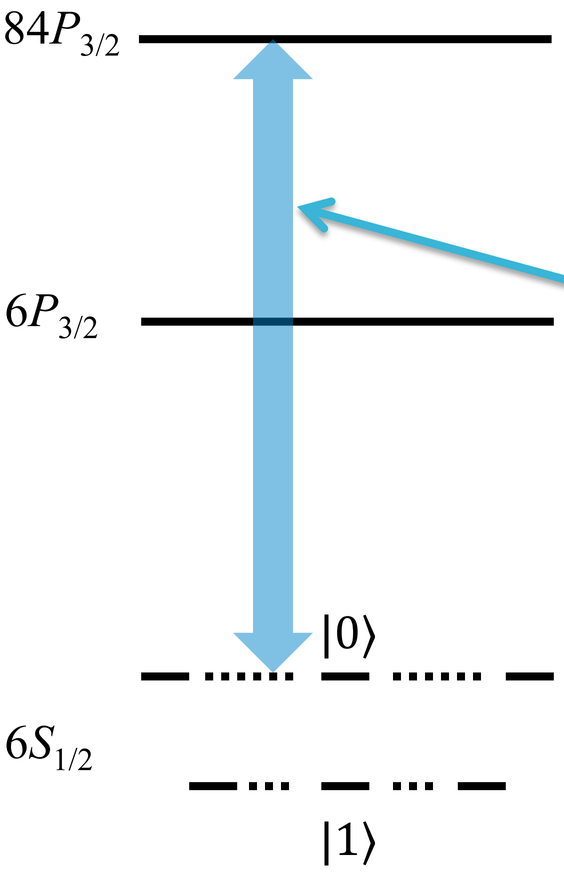


QUBO Hamiltonian for neutral cesium

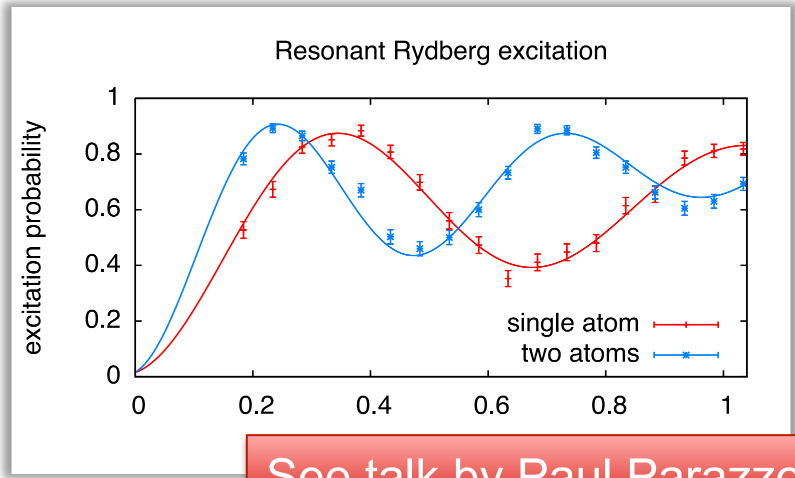
$$\mathbf{H}(s) = (1-s)\mathbf{H}_0 + s\mathbf{H}_Q$$

$$\mathbf{H}_0 = \frac{b}{2}\left(\boldsymbol{\sigma}_x^{(1)} + \boldsymbol{\sigma}_x^{(2)}\right)$$

$$\mathbf{H}_Q = \frac{h_1}{2}\boldsymbol{\sigma}_z^{(1)} + \frac{h_2}{2}\boldsymbol{\sigma}_z^{(2)} + \boxed{\frac{j_{12}}{4}(1-\boldsymbol{\sigma}_z^{(1)})(1-\boldsymbol{\sigma}_z^{(2)})}$$



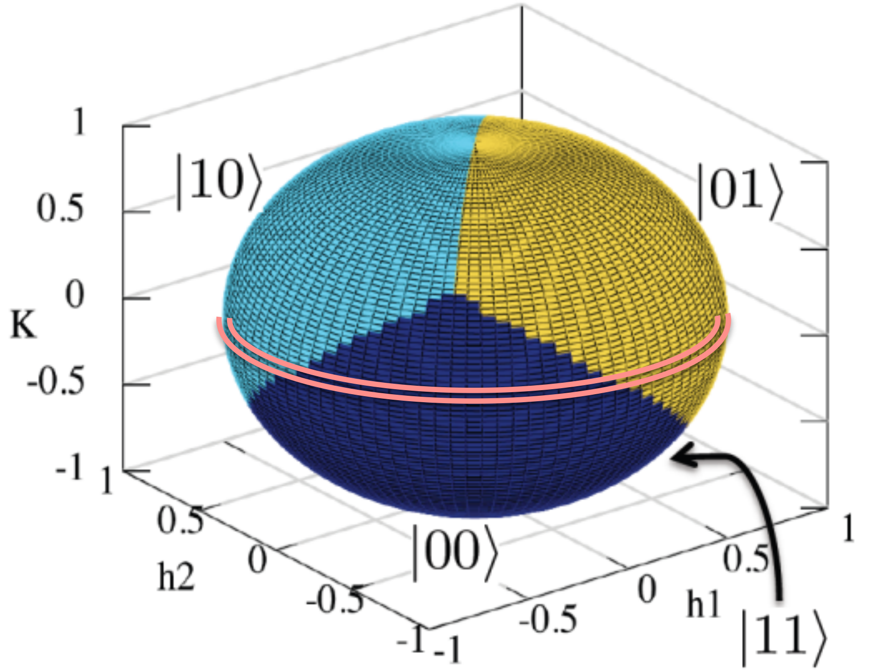
Rydberg-dressing laser (318 nm)



See talk by Paul Parazzoli

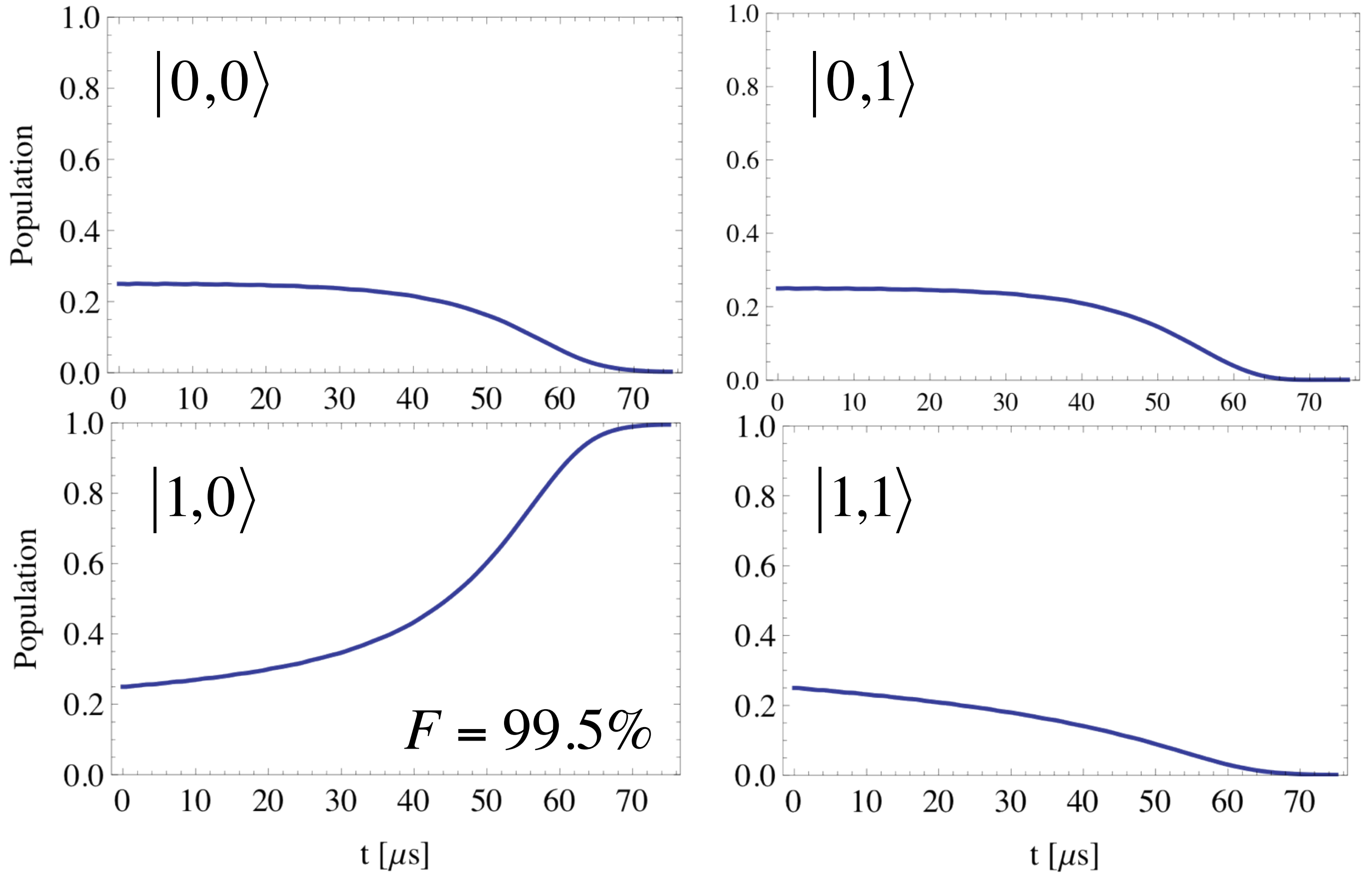
J. E. Johnson and S. L. Rolston. Interactions between rydberg-dressed atoms. *Phys. Rev. A*, 82:033412, Sep 2010.

2-qubit QUBO—solution space



$$H = h_1 \sigma_z^{(1)} + h_2 \sigma_z^{(2)} + K \sigma_z^{(1)} \sigma_z^{(2)}$$

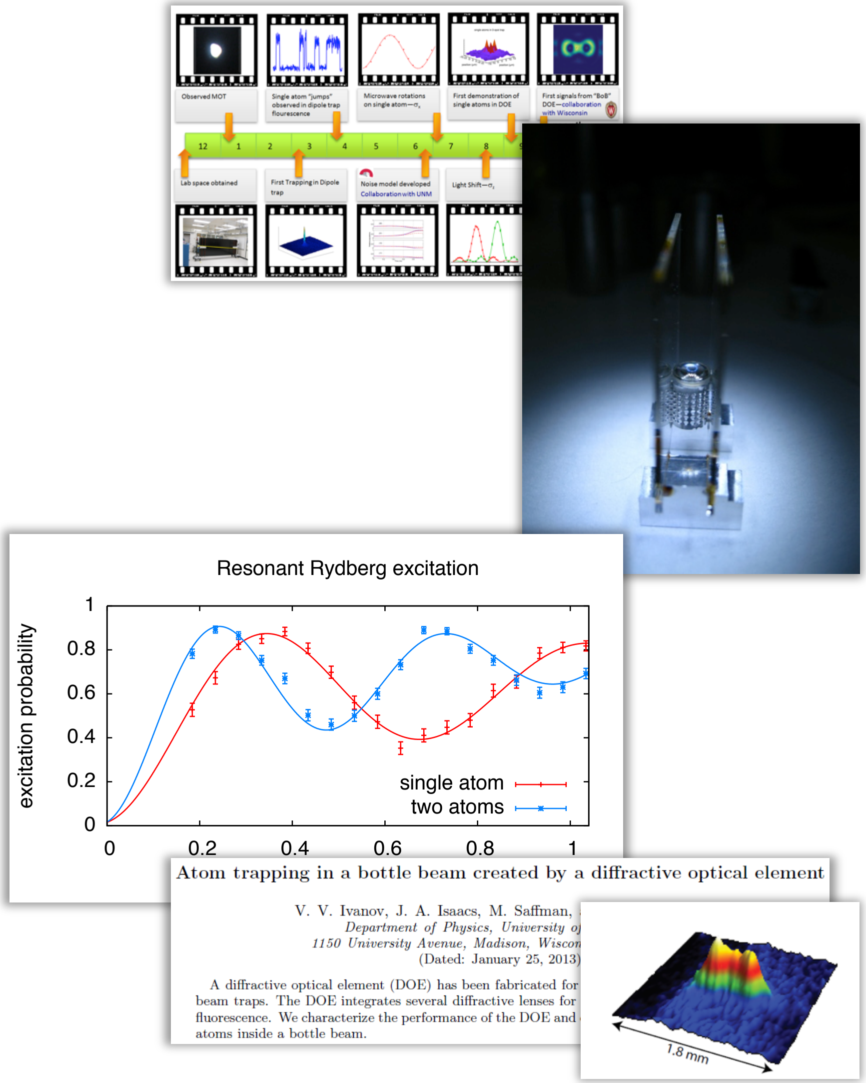
2-qubit QUBO



Keating, et al., arXiv:1209.4112

Outline

- Project overview and progress
- Capabilities development
- Rydberg experiments
- Diffractive optics development



Atom trapping in a bottle beam created by a diffractive optical element

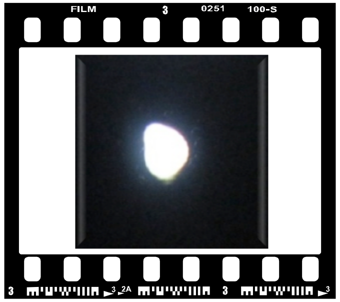
V. V. Ivanov, J. A. Isaacs, M. Saffman,
Department of Physics, University o
1150 University Avenue, Madison, Wiscon
(Dated: January 25, 2013)

A diffractive optical element (DOE) has been fabricated for
beam traps. The DOE integrates several diffractive lenses for
fluorescence. We characterize the performance of the DOE and
atoms inside a bottle beam.

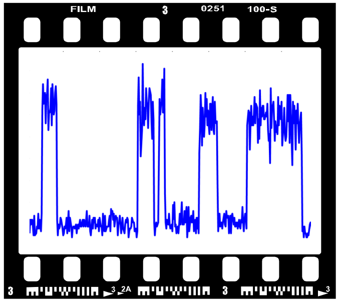
PROJECT OVERVIEW AND PROGRESS

Timeline-Year 1

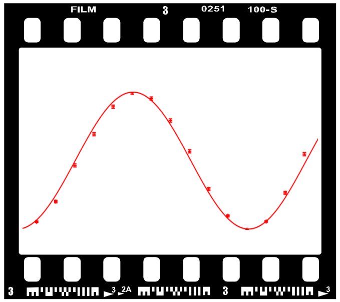
Sandia
National
Laboratories



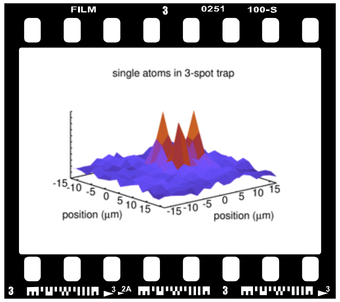
Observed MOT



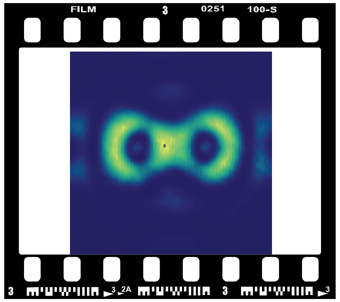
Single atom "jumps" observed in dipole trap flourescence



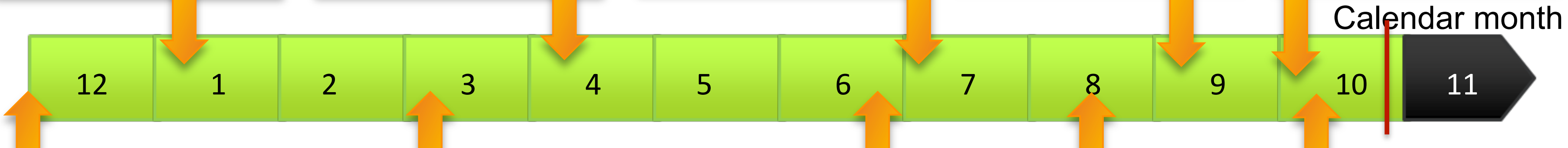
Microwave rotations on single atom—σ_x



First demonstration of single atoms in DOE



First signals from "BoB" DOE—collaboration with Wisconsin



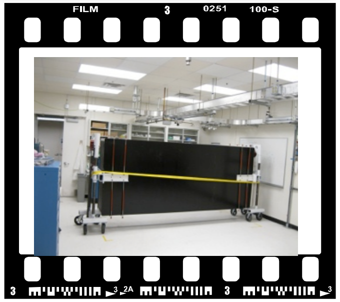
Lab space obtained

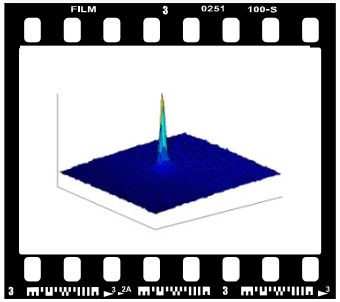
First Trapping in Dipole trap

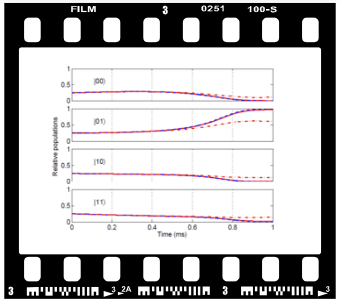
Noise model developed
Collaboration with UNM

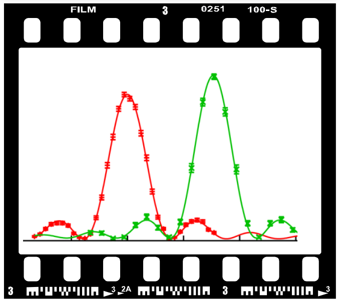
Light Shift—σ_z

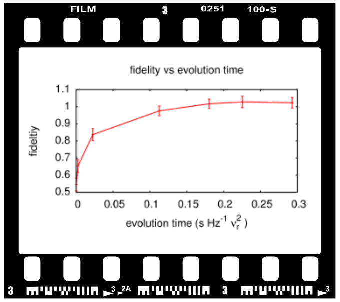
Single atom adiabatic evolution



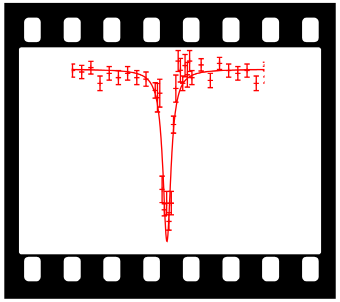




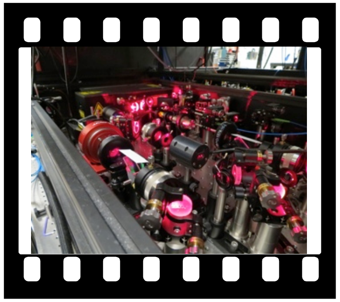




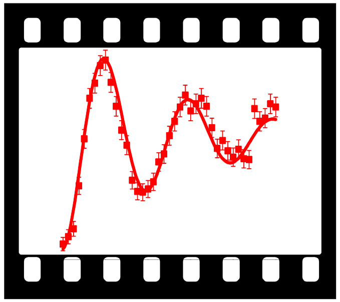
Timeline-Year 2



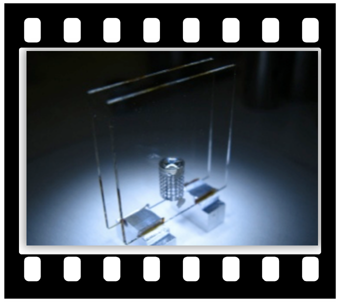
First Rydberg signals



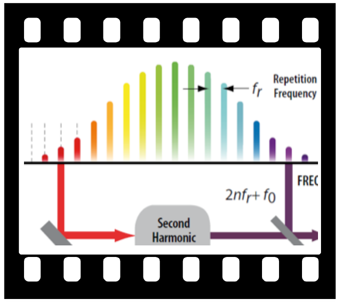
318 nm Rydberg laser



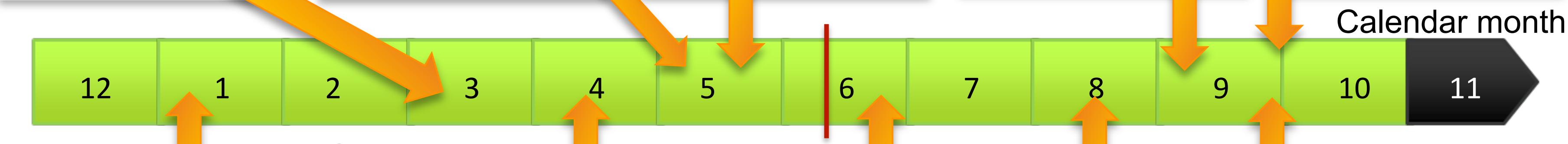
S-state Rydberg Rabi oscillations



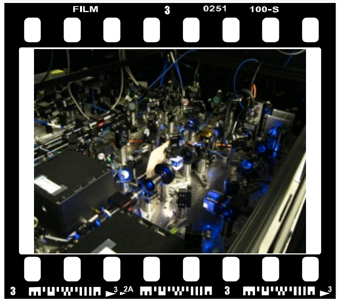
E-field mitigation



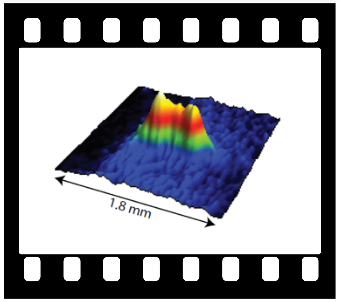
Frequency comb



2-photon Rydberg laser

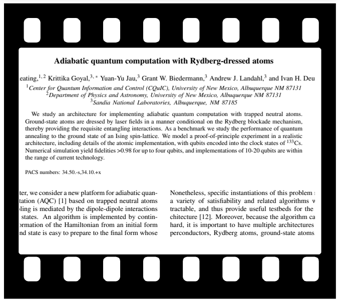


Atoms trapped in BoB



Collection lens testing

AQC paper



Adiabatic quantum computation with Rydberg-dressed atoms

eating,[1,2] Krittika Goyal,[3,*] Yuan-Yu Jau,[3] Grant W. Biedermann,[3] Andrew J. Landahl,[3] and Ivan H. Deu

[1]*Center for Quantum Information and Control (CQuIC), University of New Mexico, Albuquerque NM 87131*
[2]*Department of Physics and Astronomy, University of New Mexico, Albuquerque NM 87131*
[3]*Sandia National Laboratories, Albuquerque, NM 87185*

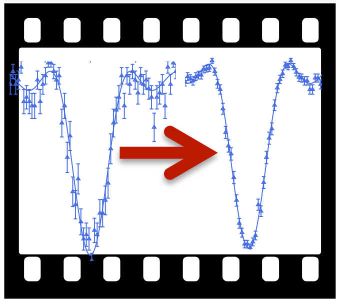
We study an architecture for implementing adiabatic quantum computation with trapped neutral atoms. Ground-state atoms are dressed by laser fields in a manner conditional on the Rydberg blockade mechanism, thereby providing the requisite entangling interactions. As a benchmark we study the performance of quantum annealing to the ground state of an Ising spin-lattice. We model a proof-of-principle experiment in a realistic architecture, including details of the atomic implementation, with qubits encoded into the clock states of ^{133}Cs. Numerical simulation yield fidelities >0.98 for up to four qubits, and implementations of 10-20 qubits are within the range of current technology.

PACS numbers: 34.50.-s,34.10.+x

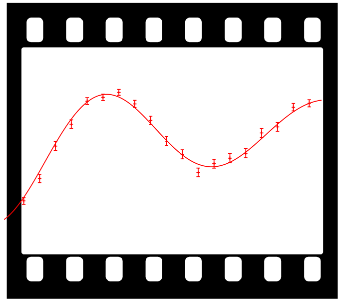
ter, we consider a new platform for adiabatic quan-
tation (AQC) [1] based on trapped neutral atoms
ling is mediated by the dipole-dipole interactions
states. An algorithm is implemented by contin-
rmation of the Hamiltonian from an initial form
nd state is easy to prepare to the final form whose

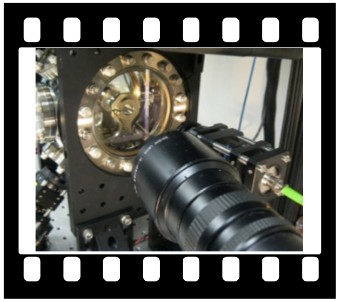
Nonetheless, specific instantiations of this problem
a variety of satisfiability and related algorithms
tractable, and thus provide useful testbeds for the
chitecture [12]. Moreover, because the algorithm ca
hard, it is important to have multiple architectures
perconductors, Rydberg atoms, ground-state atoms

High data rate



Timeline-Year 3

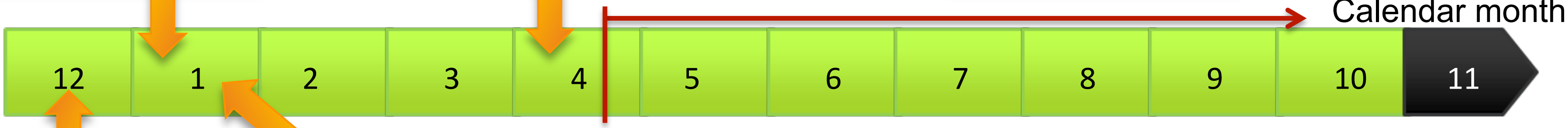




P-state Rabi oscillations

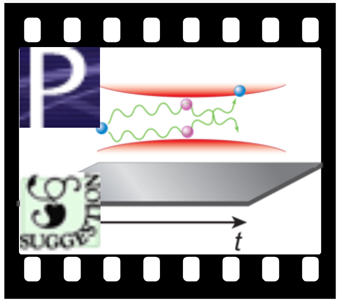
Proximity experiment

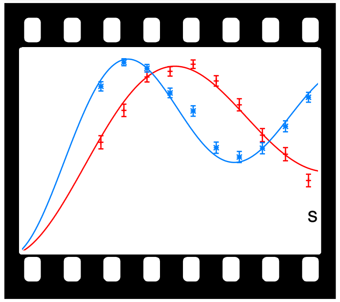
Blue skies



Single atom
Interferometer PRL

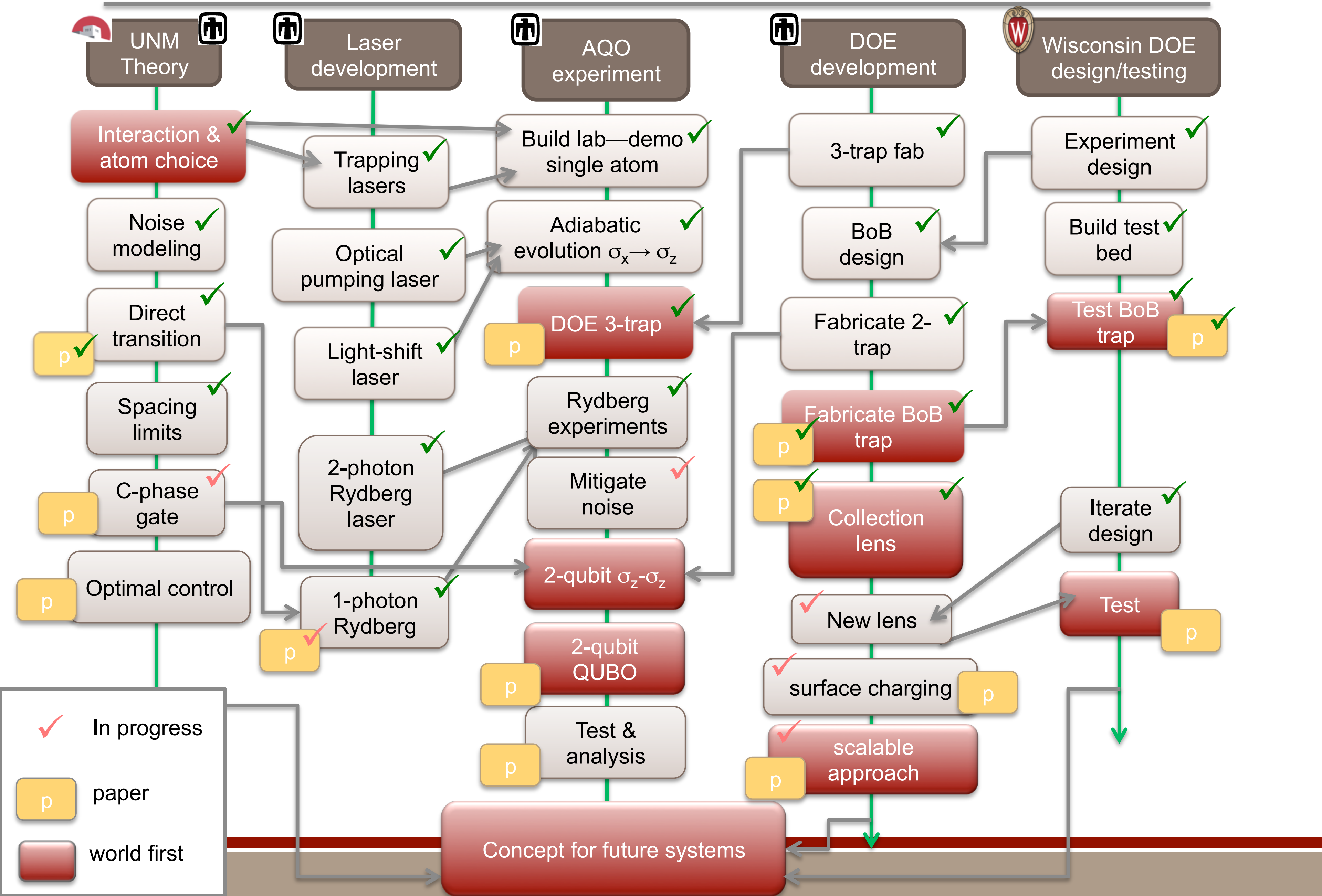
Rydberg blockade





Project flow chart

Sandia National Laboratories



UNM Theory
- Interaction & atom choice ✓
- Noise modeling ✓
- Direct transition ✓ p ✓
- Spacing limits ✓
- C-phase gate ✓ p
- Optimal control p

Laser development
- Trapping lasers ✓
- Optical pumping laser ✓
- Light-shift laser ✓
- 2-photon Rydberg laser ✓
- 1-photon Rydberg ✓ p ✓

AQO experiment
- Build lab—demo single atom ✓
- Adiabatic evolution $\sigma_x \to \sigma_z$ ✓
- DOE 3-trap ✓ p
- Rydberg experiments ✓
- Mitigate noise ✓
- 2-qubit σ_z-σ_z
- 2-qubit QUBO p
- Test & analysis p

DOE development
- 3-trap fab ✓
- BoB design ✓
- Fabricate 2-trap ✓
- Fabricate BoB trap ✓ p ✓
- Collection lens ✓ p ✓
- New lens ✓
- surface charging ✓ p
- scalable approach ✓ p

Wisconsin DOE design/testing
- Experiment design ✓
- Build test bed ✓
- Test BoB trap ✓ p ✓
- Iterate design ✓
- Test p

Concept for future systems

✓ In progress

p paper

🟥 world first

Publications and presentations

1. D. A. Scrymgeour, S. A. Kemme, R. R. Boye, A. R. Ellis, T. R. Carter, J. D. Hunker, “Micro-optical grayscale collection lenses for atom and ion trapping,” Proc. Of the SPIE– The International Society for Optical Engineering, San Francisco, CA, vol. 8249, Feb 2013.
2. A. L. Young, S. A. Kemme, J. R. Wendt, T. R. Carter, S. Samora, “High numerical aperture diffractive optical elements for neutral atom quantum computing,” Proc. Of the SPIE– The International Society for Optical Engineering, San Francisco, CA, vol. 8249, Feb 2013.
3. S. A. Kemme; G. R. Brady; A. R. Ellis; J. R. Wendt; D. W. Peters; G. W. Biedermann; T. R. Carter; S. Samora; J. A. Isaacs; V. V. Ivanov; M. Saffman, “Ultrafast diffractive optical micro-trap arrays for neutral atom quantum computing,” Proc. of the SPIE – The International Society for Optical Engineering, San Francisco, CA, vol. 8249, Jan 2012.
4. V. V. Ivanov, J. A. Isaacs, M. Saffman, S.A. Kemme, A.R. Ellis, G.R. Brady, J.R. Wendt, G. Biederman, S. Samora, “Atom trapping in a bottle beam created by a diffractive optical element,” to be submitted to App. Phys. B, 2013.
5. A. Ferdinand, et al., “Adiabatic Quantum Computation with Rydberg Atoms,” Southwest Quantum Information and Technology Workshop, Santa Barbara, CA, February 2013
6. T. Keating, K. Goyal, Y. Jau, G. W. Biedermann, A. Landahl, I. H. Deutsch, “Adiabatic quantum computation with Rydberg-dressed atoms”, arXiv quant-ph 1209.4112, submitted to Phys. Rev. A (RC) (2013)
7. L. P. Parazzoli, A. H. Hankin, G. W. Biedermann, “Observation of Free-Space Single-Atom Matterwave Interference”, Phys. Rev. Lett. 109, 230401 (2012)
8. G. Biedermann, “Adiabatic quantum computation with neutral atoms,” Second International Workship on Adiabatic Quantum Computing (invited tutorial), London, England, March 6-8, 2013
9. A. Hankin, “Adiabatic quantum computation with neutral cesium,” Southwest Quantum Information and Technology (SQuInT), 15th Annual Meeting, Santa Barbara, California, February 21-23, 2013
10. L. P. Parazzoli, “Experimental Demonstration of Adiabatic Quantum Computation with Neutral Atoms,” First International Workshop on Adiabatic Quantum Computing, Albuquerque New Mexico, March 2012
11. L. P. Parazzoli, “Adiabatic Quantum Computation with Neutral Atoms,” Southwest Quantum Information and Technology Conference, Albuquerque New Mexico, February 2012
12. G. Biedermann, "Adiabatic Quantum Computing with Dressed Rydberg Atoms," Gordon Research Conference on Atomic Physics, West Dover, VT, June 2011
13. K. Goyal, I. Deutsch, “Adiabatic Quantum Computation with Neutral Atoms Via the Rydberg Blockade,” 42nd Annual Meeting of the APS Division of Atomic, Molecular, and Optical Physics, Atlanta, GA, June 2011
14. P. Parazzoli, "Adiabatic quantum computing with neutral atoms," International Conference on Laser Spectroscopy, Hameln, Germany, May 2011
15. L. P. Parazzoli, “Adiabatic quantum computation with neutral atoms,” International Conference on Atomic Physics, Paris, France, July 2012
16. G. W. Biedermann, “Observation of Free-Space Single-Atom Matterwave Interference,” International Conference on Atomic Physics, Paris, France, July 2012
17. A. H. Hankin, “Adiabatic quantum computation with Neutral atoms”, Division of Atomic, Molecular and Optical Physics conference, Anaheim, CA, June 2012
18. I. Deutsch, “Adiabatic quantum computing with trapped neutral atoms,” First International Workshop on Adiabatic Quantum Computing, Albuquerque New Mexico, March 2012
19. G. Biedermann, “Coherent manipulations with single cesium atoms”, Physics colloquium, University of Nevada, Reno, November 30, 2012
20. G. Biedermann, “Single-atom matterwave interferometry in free space”, Winter Colloquium on the Physics of Quantum Electronics, Snowbird, UT, January 8, 2013
21. G. Biedermann, “Matterwave interferometry, indistinguishable faces in a crowd”, Physics seminar, University of Hannover, Germany, February 2013.
22. G. Biedermann, “Matterwave interferometry, indistinguishable faces in a crowd”, Physics seminar, Imperial College, London, England, March 2013.
23. G. Biedermann, “Matterwave interferometry, indistinguishable faces in a crowd”, Physics seminar, University of Birmingham, England, March 2013.
24. G. Biedermann, “Adiabatic quantum computation with neutral atoms,” APS March Meeting (invited talk), Baltimore, MD, March 18, 2013
25. L. P. Parazzoli, “Adiabatic quantum computation with neutral atoms,” Second International Workship on Adiabatic Quantum Computing, London, England, March 6-8, 2013
26. T. Keating, "Adiabatic Quantum Computing via the Rydberg Blockade", Division of Atomic, Molecular and Optical Physics conference, Anaheim, CA, June 2012
27. T. Keating, et al, "Quantum Information Processing with Rydberg-Dressed Atoms", Southwest Quantum Information and Technology (SQuInT), 15th Annual Meeting, Santa Barbara, California, February 21-23, 2013

Milestones

Sandia National Laboratories

Year 1

- Select atom-atom interaction and species—Rydberg in cesium
- Establish neutral atom lab space
- Develop neutral atom AQO scheme—2-qubit QUBO
- Ship 1st generation DOE to collaborators
- Demonstrate conventional optical trapping
- Create control & noise model
- Trap single atom in DOE trap

Year 2

Detect two-level Rabi oscillations on ground states	
Develop Rydberg laser system	
Implement Rydberg excitation	
Demonstrate trapping and single qubit rotations of 2 qubits	
Fabricate DOE collection lens	
Build dedicated DOE experimental evaluation system	09/30/2012
Document known challenges to physical realization of a scalable system	09/30/2012
Demonstrate Rydberg “J” coupling	09/30/2012
Demonstrate C-phase gate	09/30/2012
Demonstrate individual Z control of 2 qubits	09/30/2012
Demonstrate 2-qubit QUBO	09/30/2012
Update control & noise model	09/30/2012

Accelerated goals

Green – satisfactory
Yellow – in progress
Red – pending

Milestones (new goals!)

Year 3

Experiment goals

• Maximize fidelity of 2-qubit QUBO	12/01/2012
• Program all four outputs of 2-qubit QUBO	12/01/2012
• Test 2-atom interaction resonance dependence on spacing	01/01/2013
• Address detection challenge to enable high data rate (100 Hz)	01/01/2013
• ~~Model and test deterministic loading challenge to enable large array~~	~~03/01/2013~~
• Experimentally compare 1-photon and 2-photon Rydberg excitation	03/01/2013
• ~~Use DOE or conventional approach for controllable 3-qubit system~~	~~09/30/2013~~
• ~~Implement three-qubit AQO~~	~~09/30/2013~~
– ~~Linear~~	
– ~~Triangular~~	

DOE goals

• Ship 2nd generation DOEs to Mark Saffman	12/01/2012
• Characterize collection DOE with atom	10/01/2012
• Develop and down select notional DOE designs addressing identified primary challenges	03/01/2013
• Design, fab, and test evaluation DOE 1	12/01/2012
• ~~Design, fab, and test evaluation DOE 2~~	~~05/01/2013~~
• ~~Design, fab, and test evaluation DOE 3~~	~~09/30/2013~~

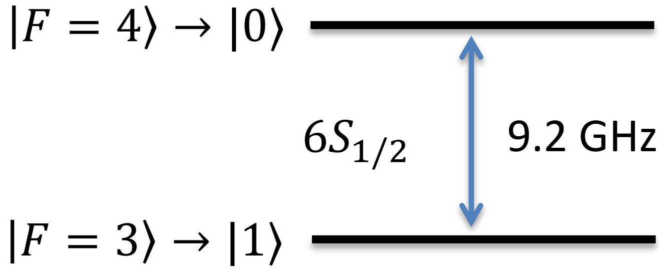
Green – satisfactory
Yellow – in progress
Red – pending

Detection

CAPABILITIES DEVELOPMENT

Detection overview

qubit basis:



$|F = 4\rangle \rightarrow |0\rangle$

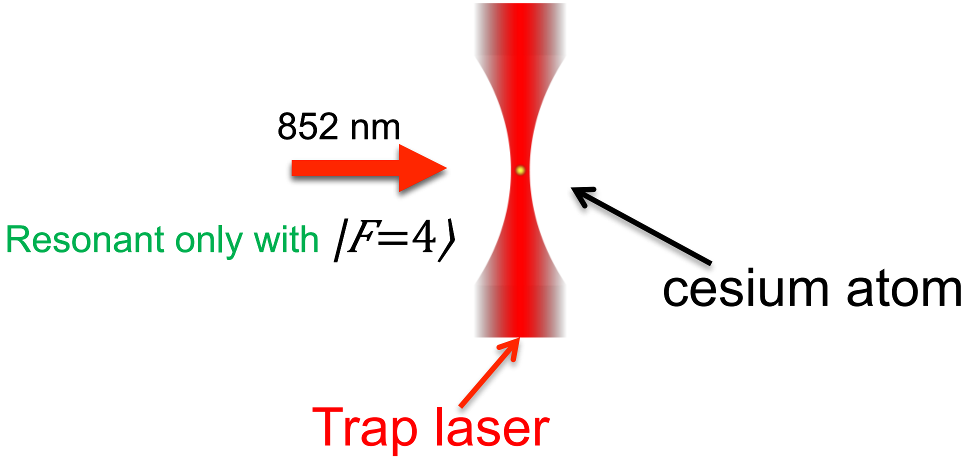
$6S_{1/2}$

9.2 GHz

$|F = 3\rangle \rightarrow |1\rangle$

Imagine a 50% superposition: $\frac{1}{\sqrt{2}}(|0\rangle + e^{-i\emptyset}|1\rangle)$

Destructive detection technique—blast $|F{=}4\rangle$



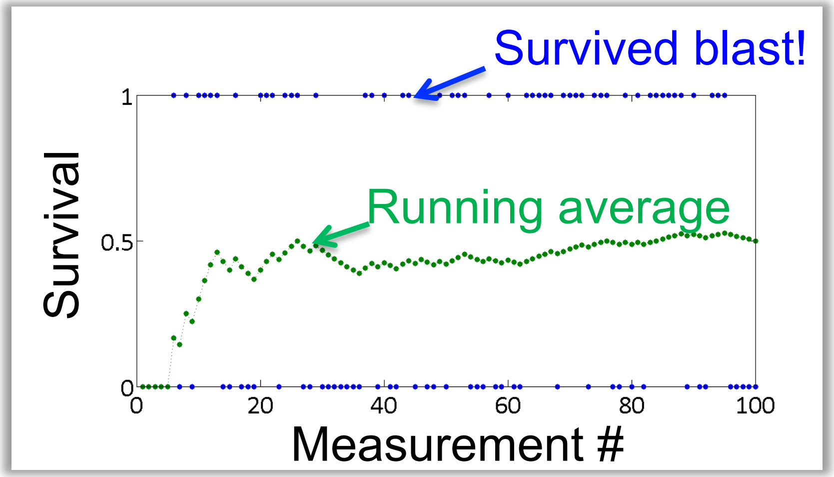
852 nm

Resonant only with $|F{=}4\rangle$

cesium atom

Trap laser

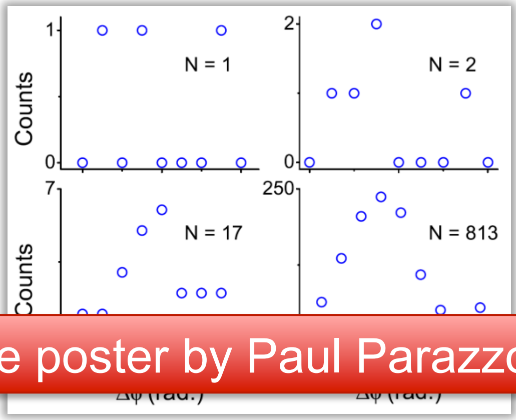
One state measurement



Survived blast!

Running average

Appearance of a fringe

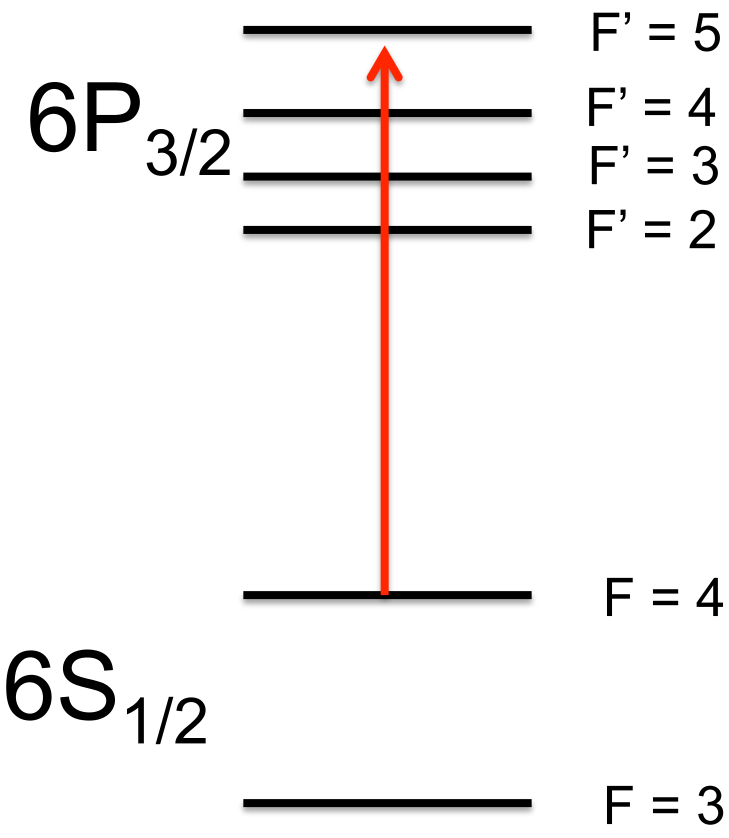


See poster by Paul Parazzoli

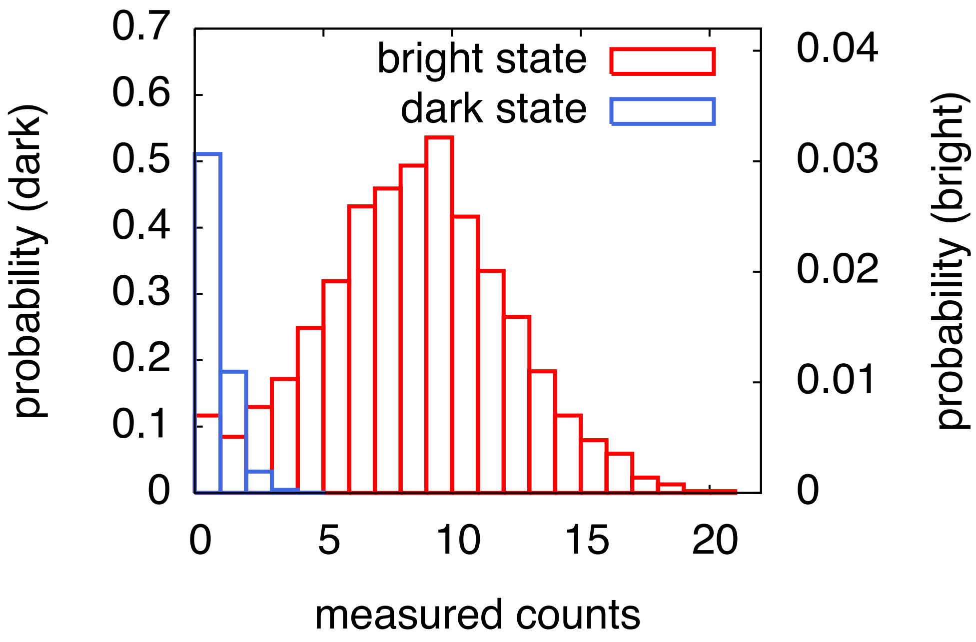
Parazzoli, et al., “Observation of free-space single-atom matterwave interference”, Phys. Rev. Lett. **109**, 230401 (2012)

Lossless two state detection

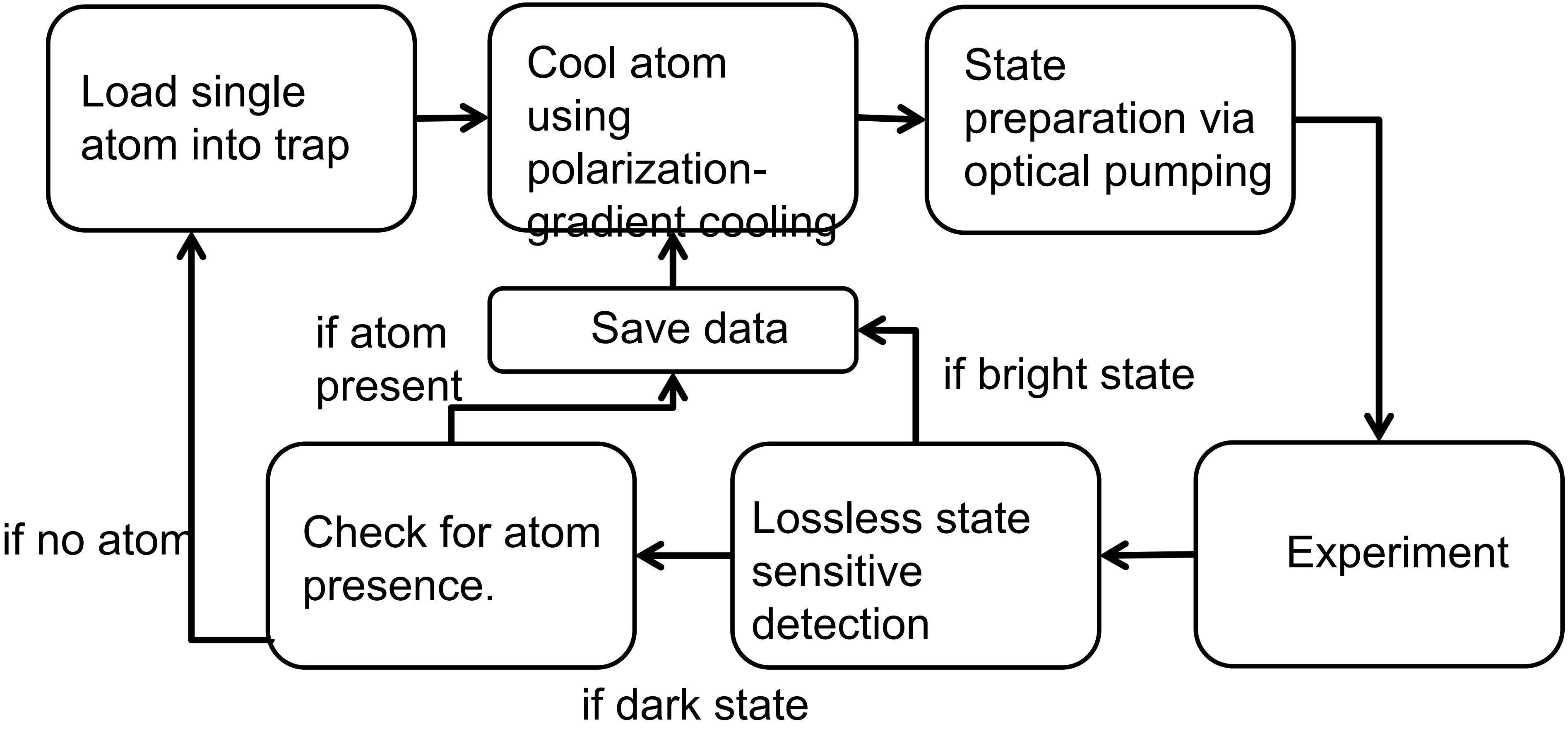
Cesium energy level diagram



Fluorescence histogram for two states



Experimental sequence



Load single atom into trap

Cool atom using polarization-gradient cooling

State preparation via optical pumping

Experiment

Lossless state sensitive detection

if bright state

Save data

if dark state

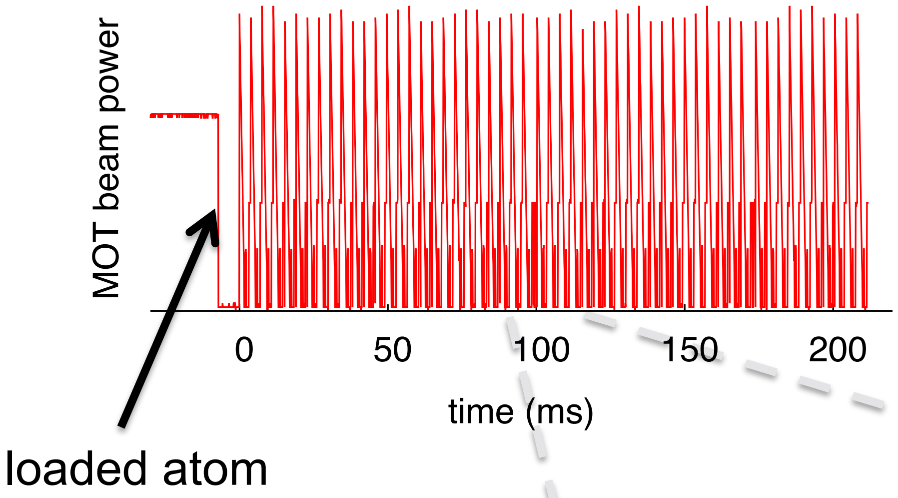
Check for atom presence.

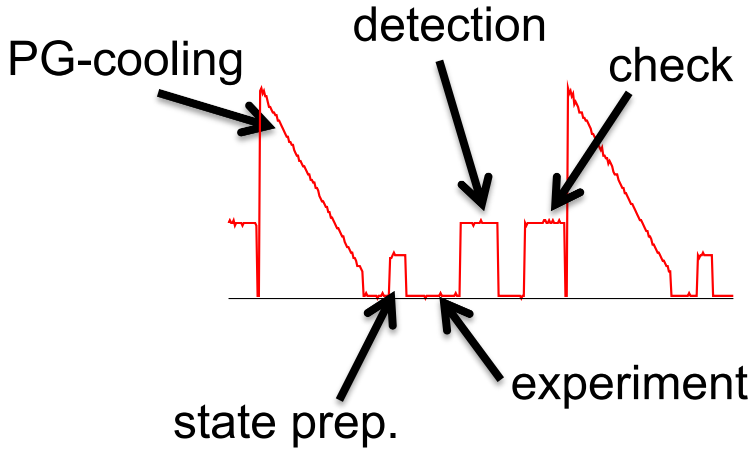
if atom present

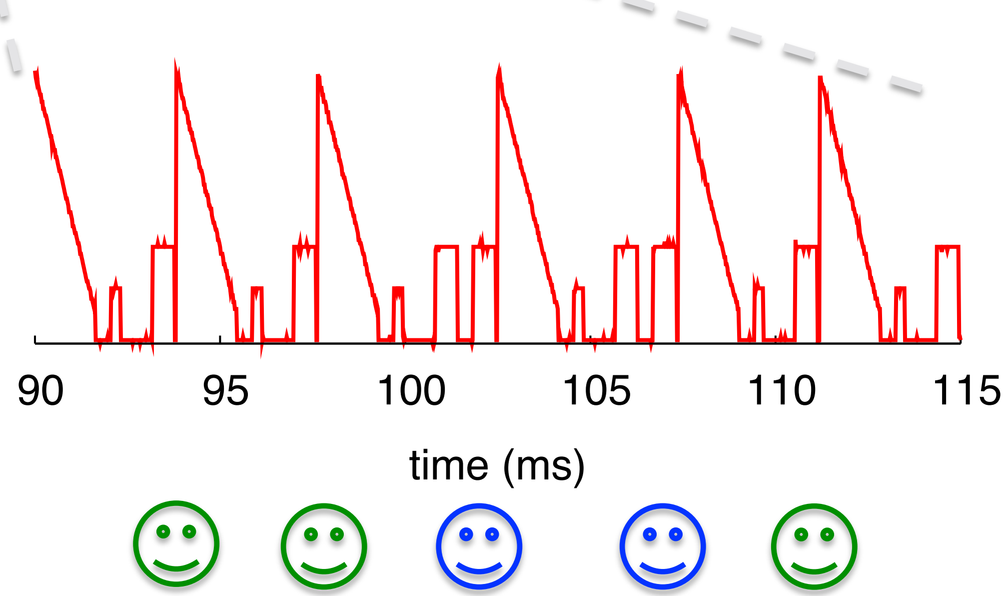
if no atom

Using this method, we can reuse atoms 20-40 times on average when lossless detection is possible.

High data rate detection via atom reuse



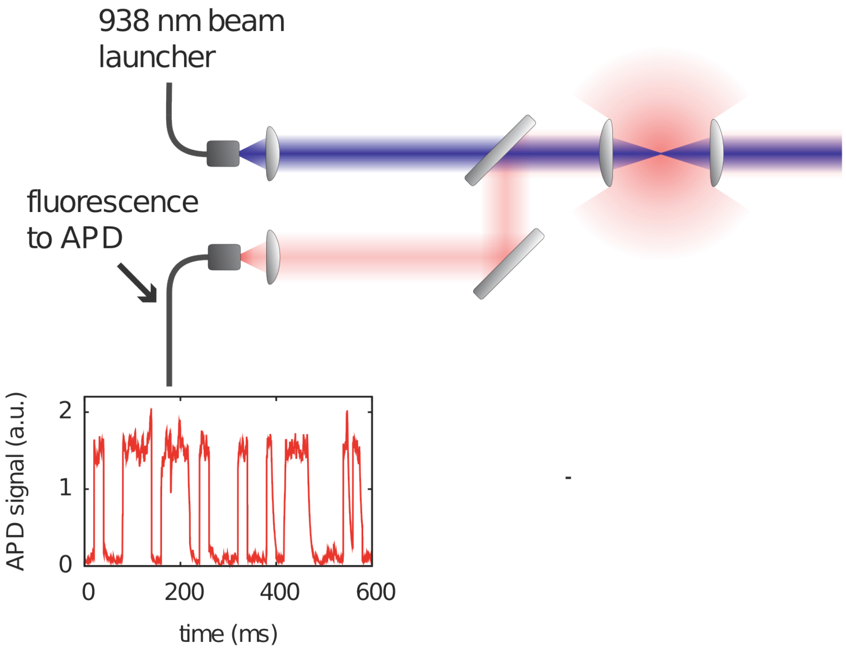




🙂 - bright state

🙂 - dark state

Improving photon collection efficiency



We found that our estimated fiber coupling efficiency was well below what would be expected for the coupling of a well mode matched Gaussian beam profile.

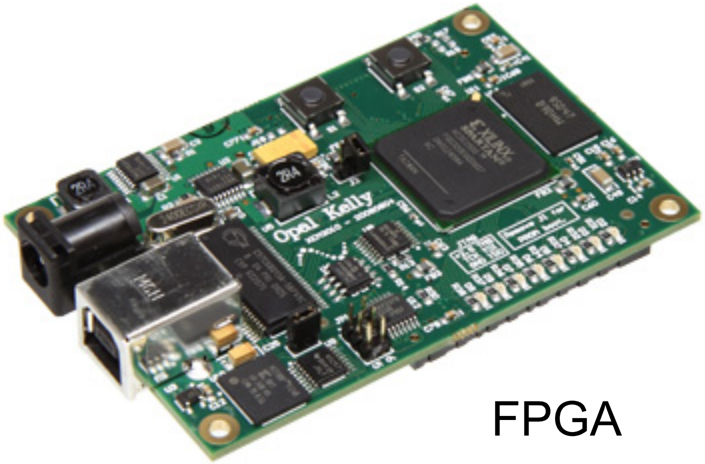
Fiber core size (μm)	**Single mode?**	**Typical photon collection rate (ms^{-1})**	**Estimated fiber coupling efficiency**
5	852 nm	6	2.5%
9	1550 nm	16	6 %
65	multimode	70	29 %

We find that the 9 μm core fiber offers a good compromise in the measured signal to noise ratio.

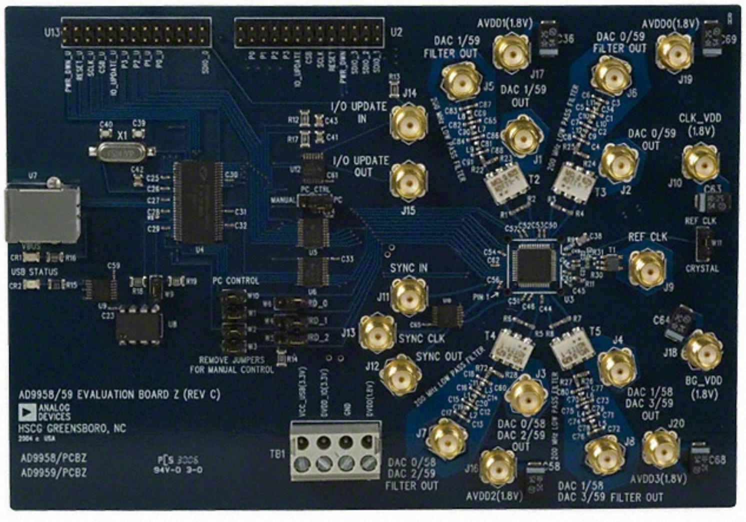
FPGA-based experiment control

- User-programmable experimental sequence is uploaded into onboard memory
- Micro-controller accesses the memory at each clock cycle and carries out the instructions such as turning on or off laser beams, varying laser frequencies, changing coil currents, and counting number of pulses from the APDs
- Operations can be programmed to be conditioned upon photon counts
- Currently using USB 2.0 48 MHz clock ⇒ decision making time << 1 μs
- Commercial USB interface for easy programming and communication

- Originally designed for trapped-ion experiments at MIT (Chuang group)
- Revised in Georgia Tech (Brown group)
- Hardware and software (user interface) revised at Sandia and adapted for neutral atom experiments

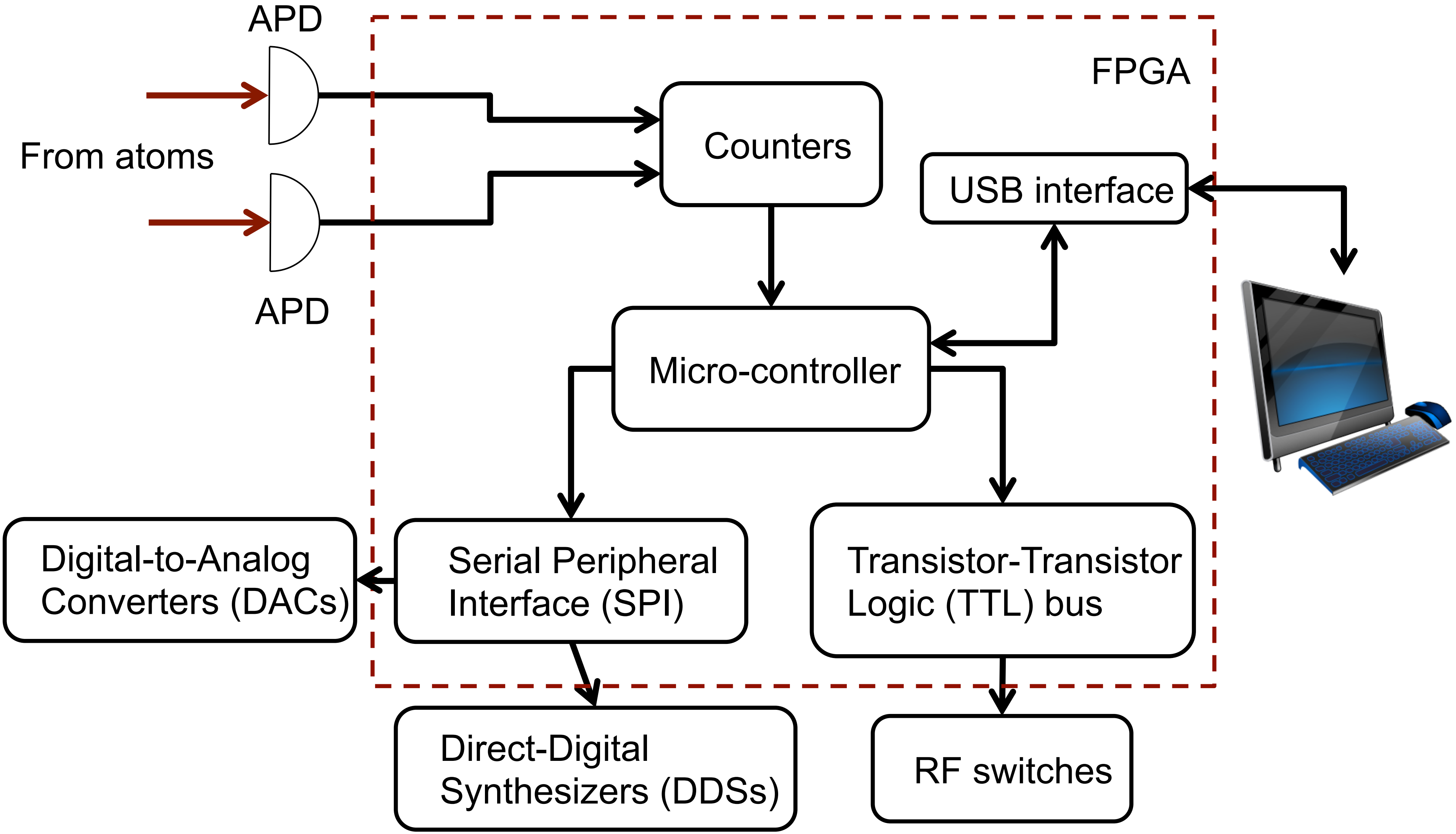


FPGA



DDS

FPGA-based experiment control—II



APD

FPGA

Counters

From atoms

USB interface

APD

Micro-controller

Digital-to-Analog Converters (DACs)

Serial Peripheral Interface (SPI)

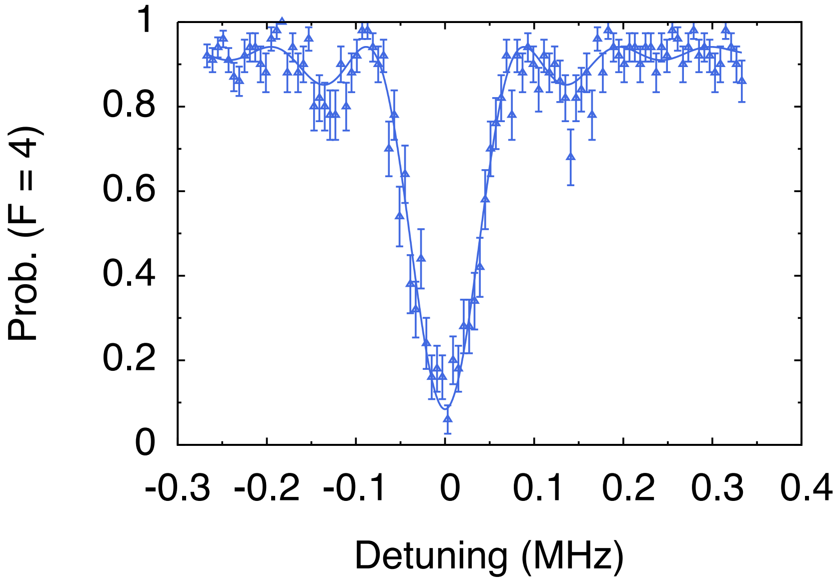
Transistor-Transistor Logic (TTL) bus

Direct-Digital Synthesizers (DDSs)

RF switches

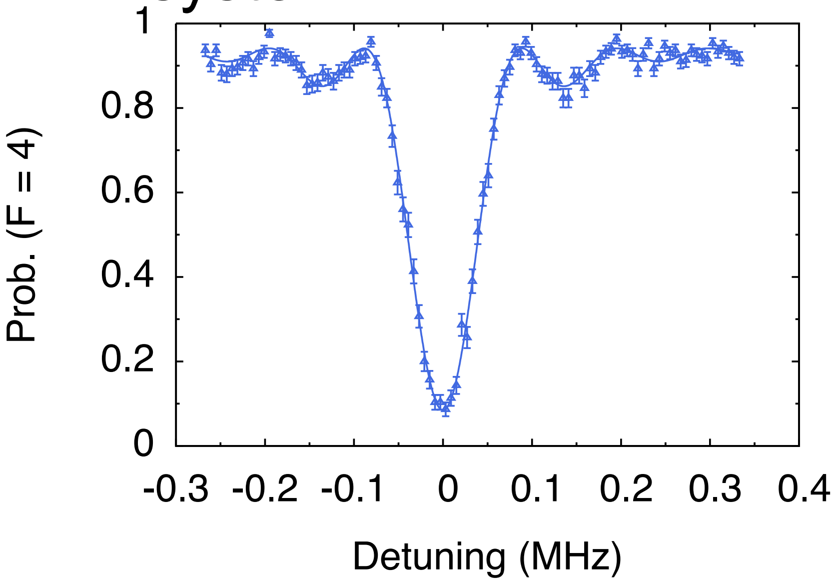
High data-rate single atom detection

Old control system data rate



average data rate = 10 Hz

FPGA control system

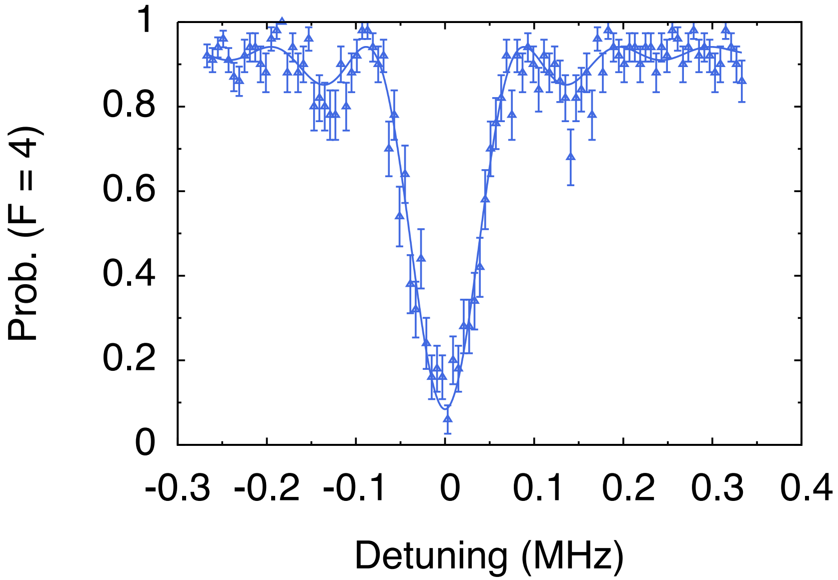


average data rate = 70 Hz

7 minutes of data collection

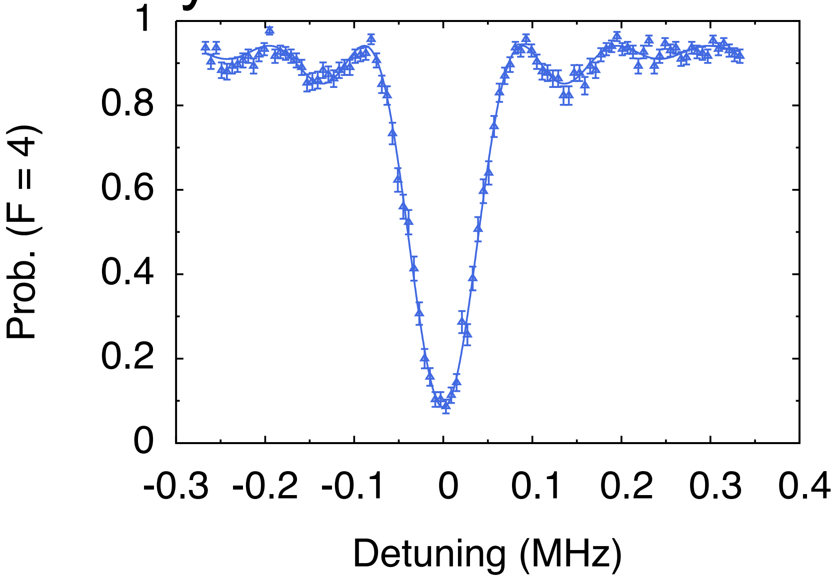
High data-rate single atom detection

Old control system data rate



average data rate = 10 Hz

FPGA control system



average data rate = 70 Hz

factor of 7 improvement

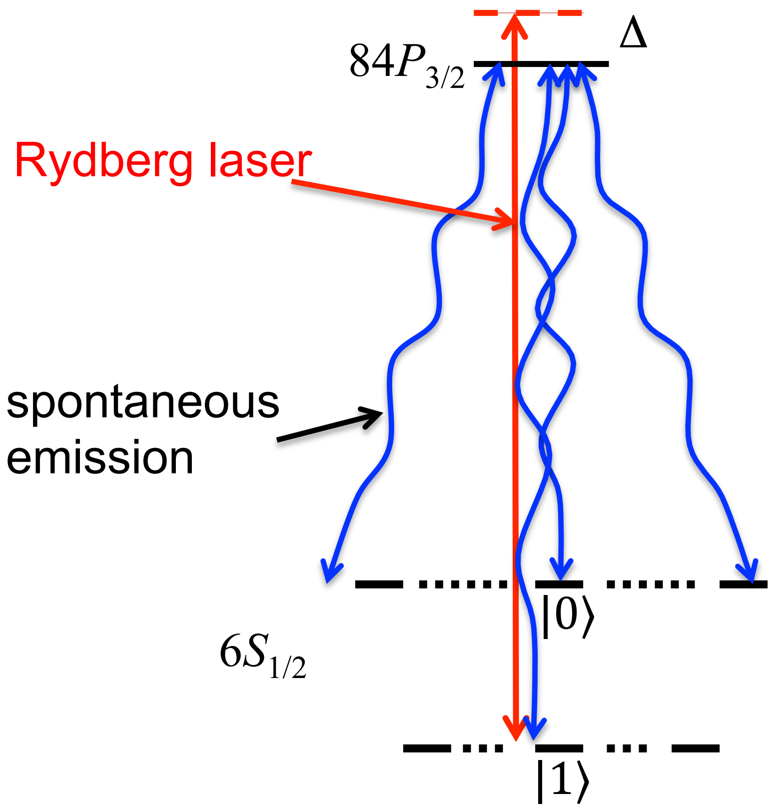
And 46 times better than at last EAB

Rydberg lasers

CAPABILITIES DEVELOPMENT

Upper limit on the evolution time

Photon scattering

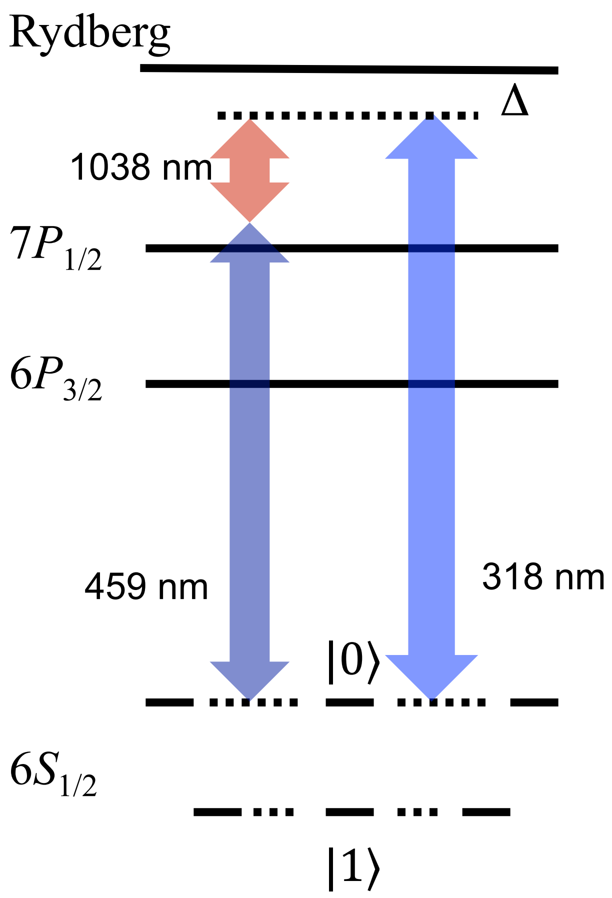


Limits on evolution time

- Though reduced, the atom still scatters photons off-resonance.
- This adds leakage from the qubit space.
  - Debilitating for AQC
  - Manageable in circuit model and quantum simulation
- Forecast for our parameters
  - J ~ 100 kHz
  - γ_s ~ 100 Hz

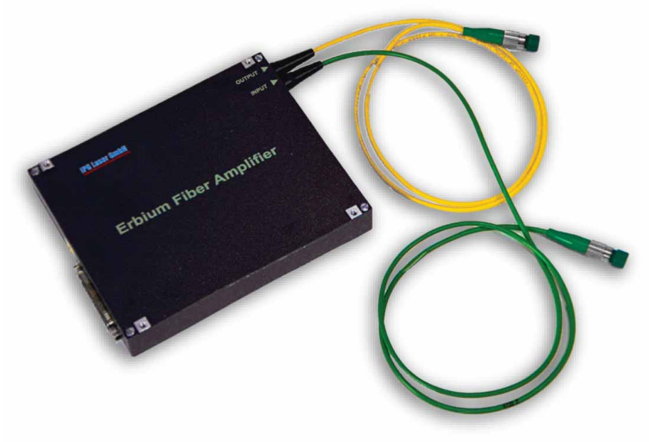
Two approaches for risk mitigation

Cs energy level diagram



- 1-photon
  - 318 nm
  - Reduced photon scatter
  - currently our favored option
- 2-photon
  - 1038nm + 459 nm
  - Conventional…less risk
  - ~10x worse scattering

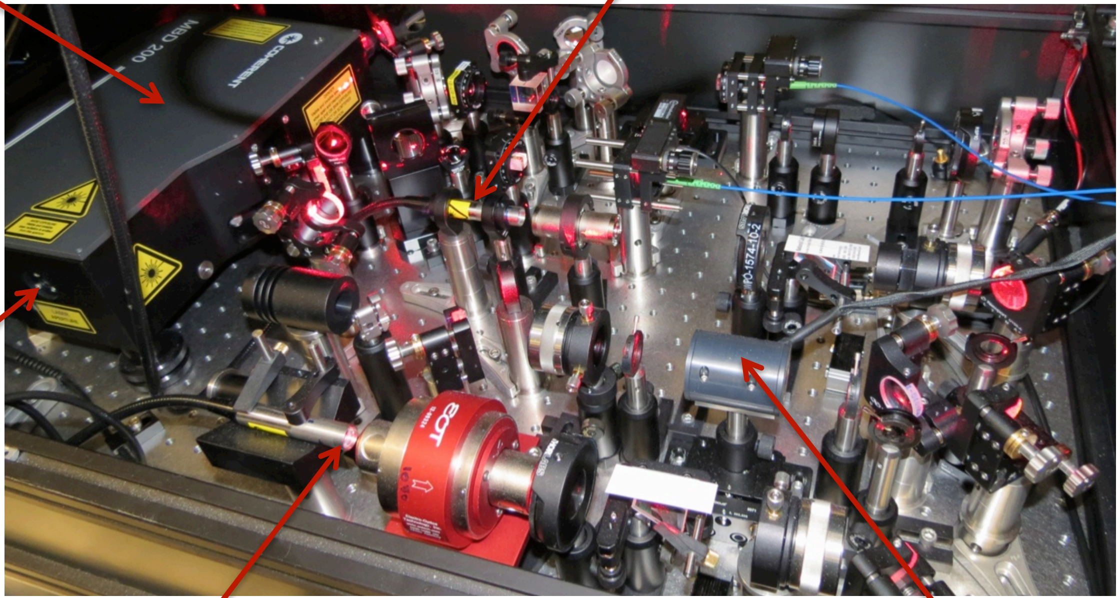
2-photon Rydberg laser—status



- PolarOnyx amplifier
  - Out for repair since November
  - 2nd time…
  - fool me once…

- IPG photonics
  - Replacement
  - Under contract
  - Expected in March

318 nm Rydberg excitation laser



Doubling cavity

1580 nm input

360 mW, 318 nm

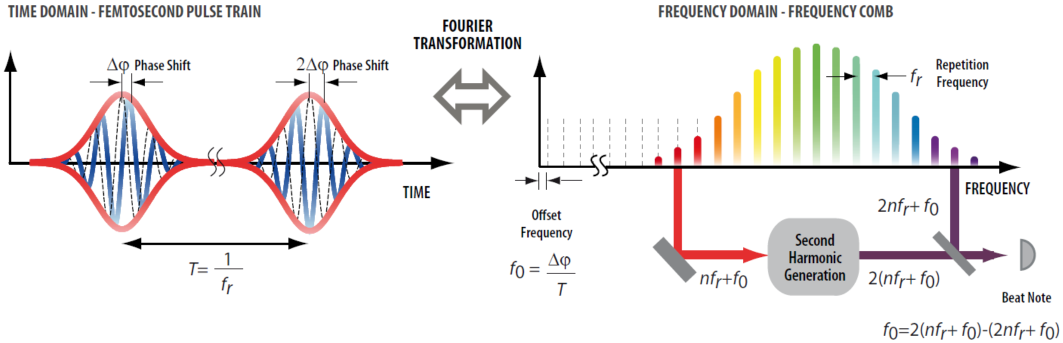
1064 nm input

Sum-frequency mixing

- Upon failure of 2-photon system, began 1-photon investigations
- Reconfigured system to maximize power to atom

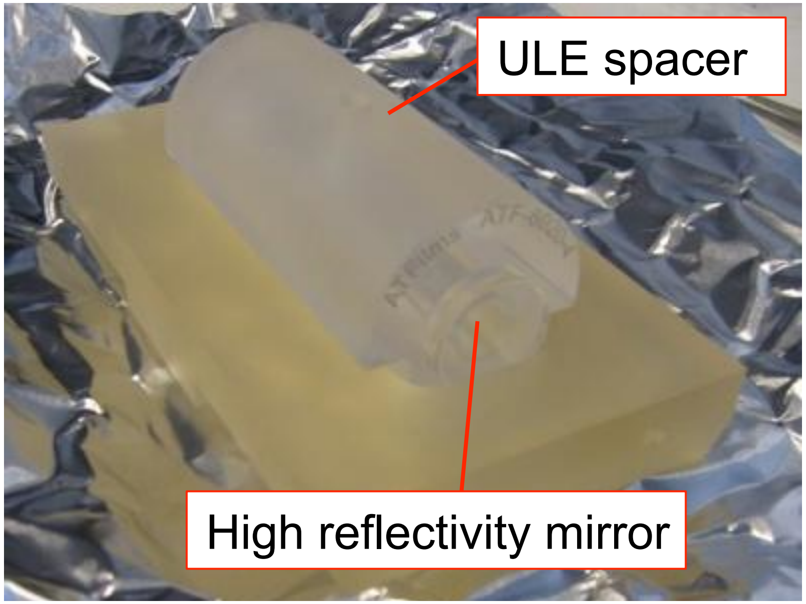
Infrastructure

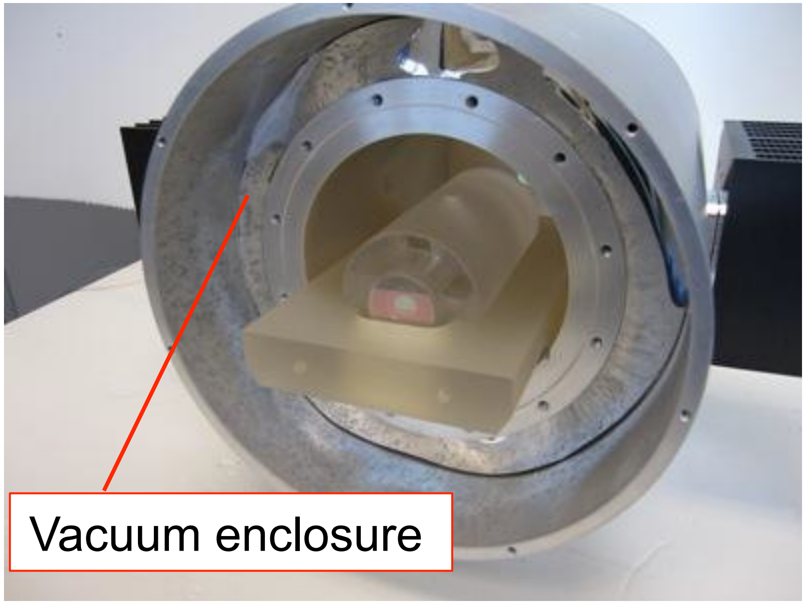
- Optical frequency synthesizer
- Calibration of Rydberg spectroscopy
- Laser frequency characterization



High-finesse cavity with ULE spacer

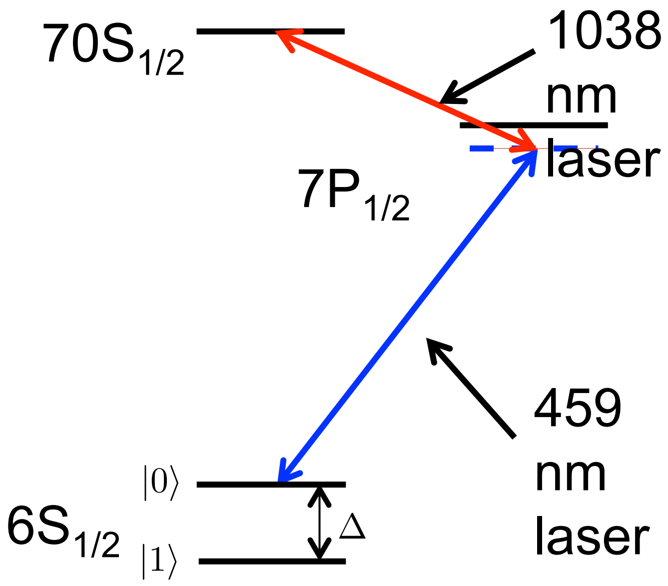
- Suspect laser frequency noise and drift as next limit to fidelity
- ULE: Ultra-Low Expansion material
- Coating for end mirrors designed for high finesse (~20,000) and narrow linewidth (<75 kHz) at 459, 636, and 1038 nm
- Locking the laser frequency to 1/50 of the cavity linewidth narrows the laser linewidth to <2 kHz
- Kept under vacuum to minimize the temperature dependence of the effective cavity length due to air



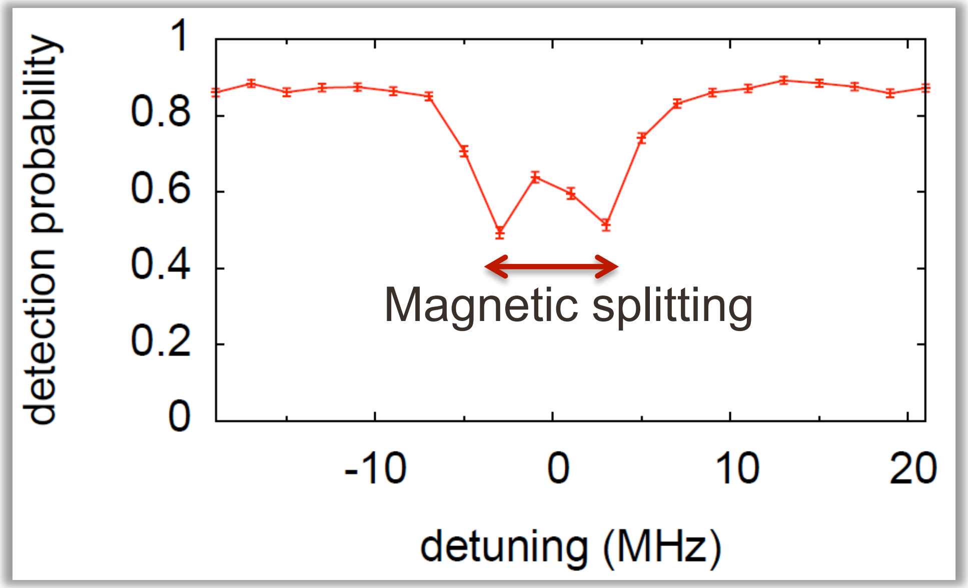


RYDBERG EXPERIMENTS

1st signals (from last EAB)



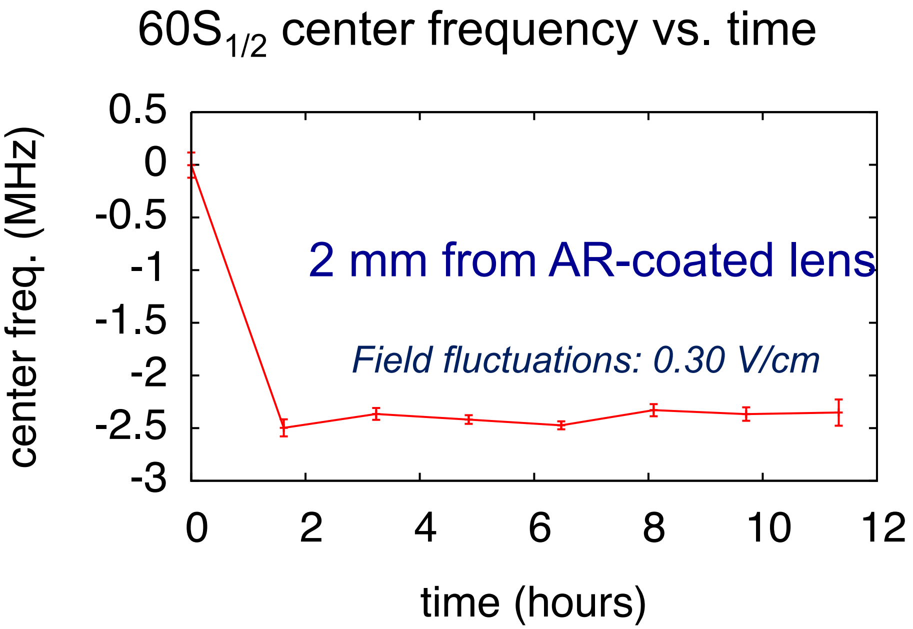
2-photon Rydberg system



Rydberg frequency scan

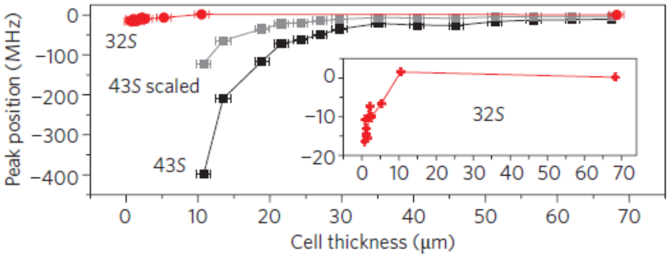
Suspected electric field fluctuations

Frequency stability of Rydberg states

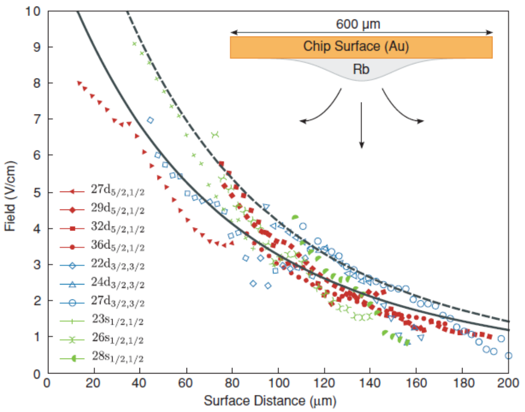


Other known issues

Kubler, et al., Nature, **4**, (2010)



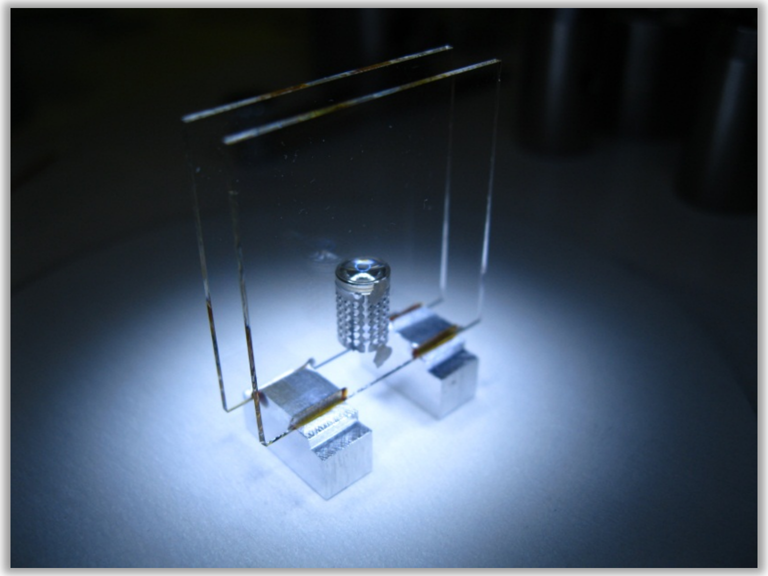
Tauschinsky, et al., PRA, **81**, (2010)



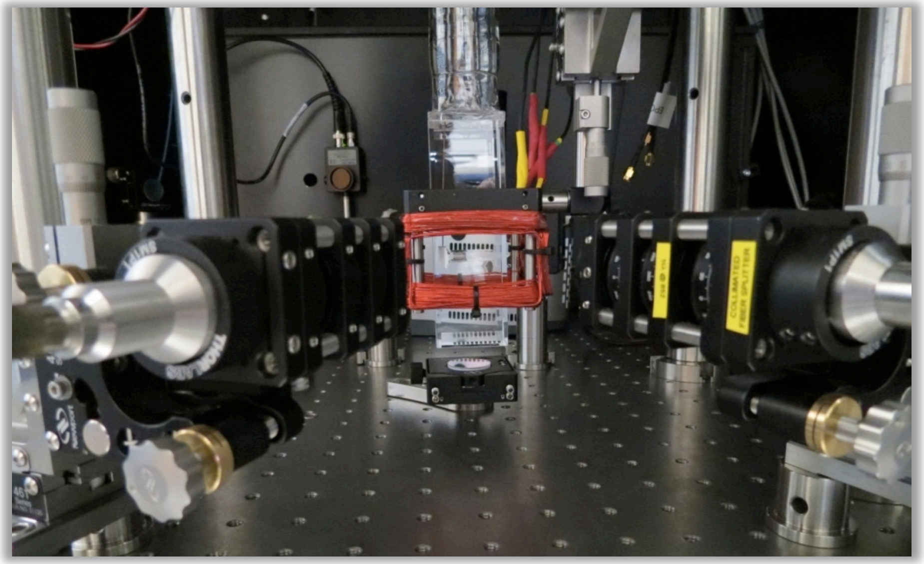
Also: charging of AR-coated surface, private communications with A. Browaeys

- Even 7 mm away is an issue
- Suggested ITO coating

Mitigating the electric field

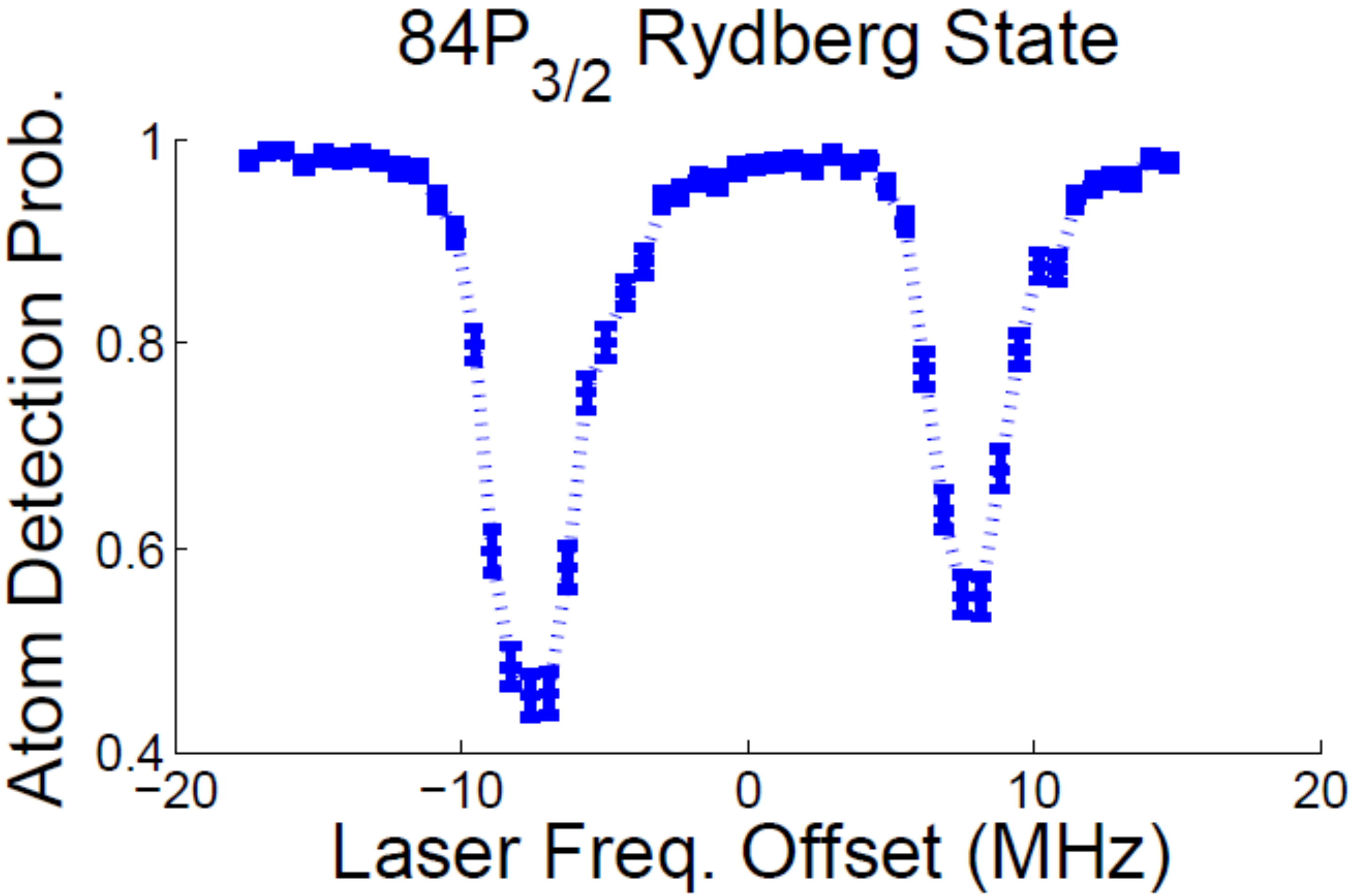


Indium Tin Oxide (ITO) coatings
Approximates Faraday cage

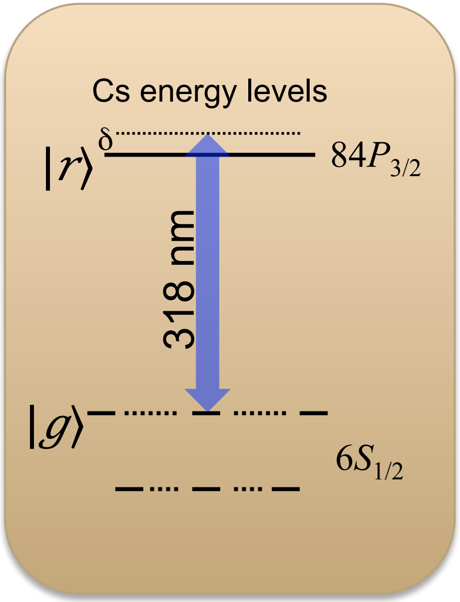


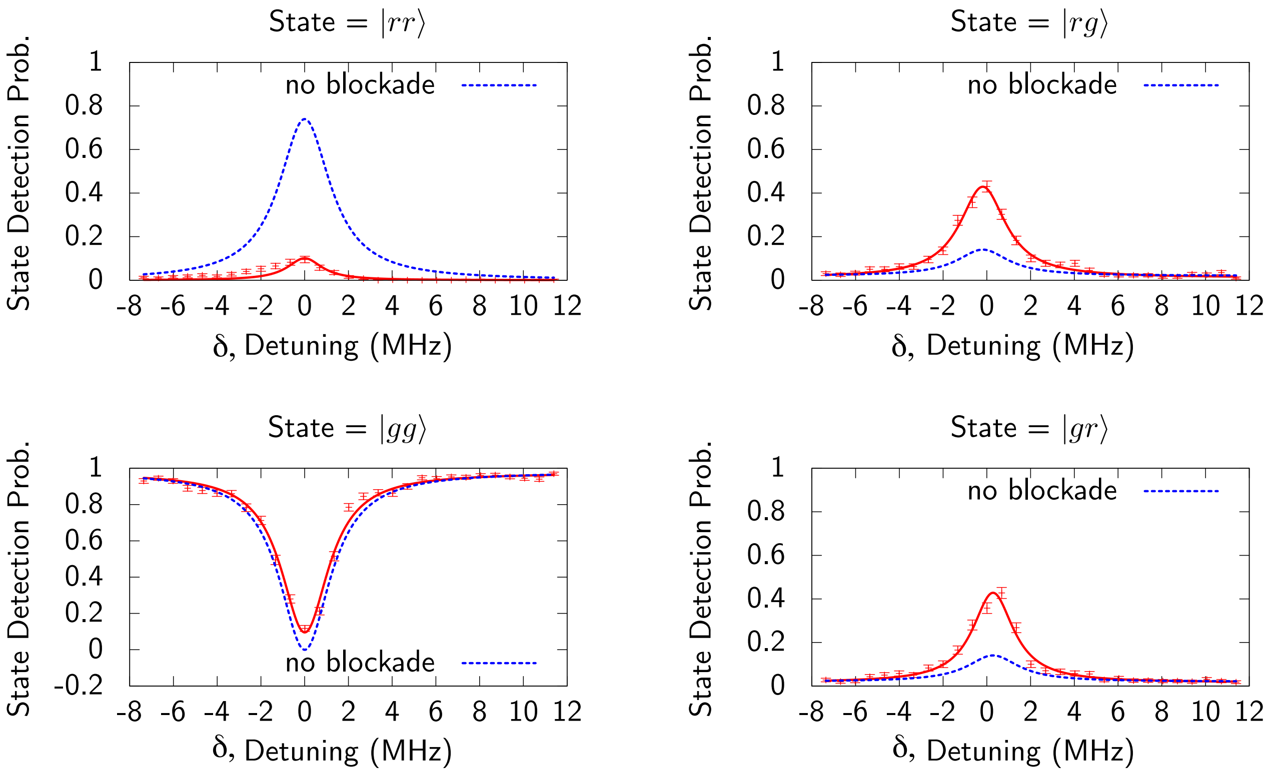
New setup: 4th generation

Stable P-state spectroscopy



Rydberg blockade demonstration

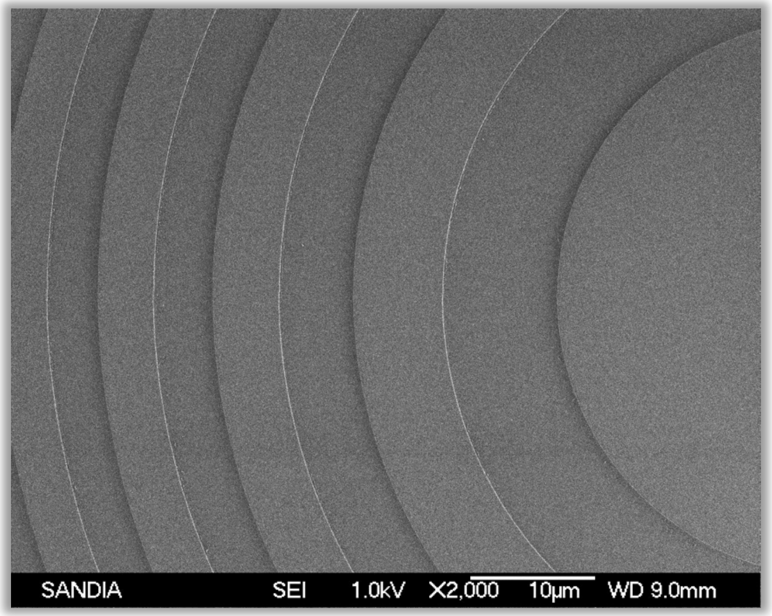




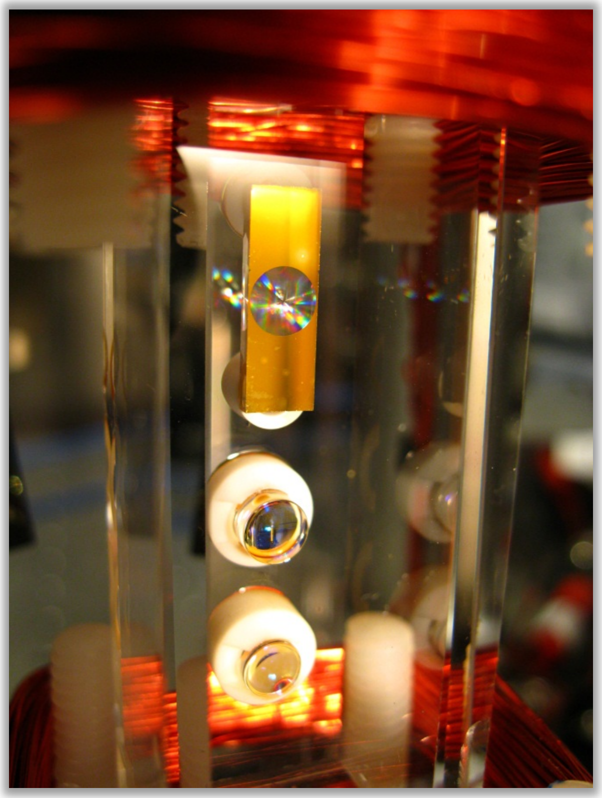
See talk by Paul Parazzoli & poster by Aaron Hankin

DIFFRACTIVE OPTICS DEVELOPMENT

DOE collection lens



SEM of collection lens



- Finished DOE test platform
- Characterized with single atom
- Scanned atom position to optimize
- Performance at least comparable to commercial lens

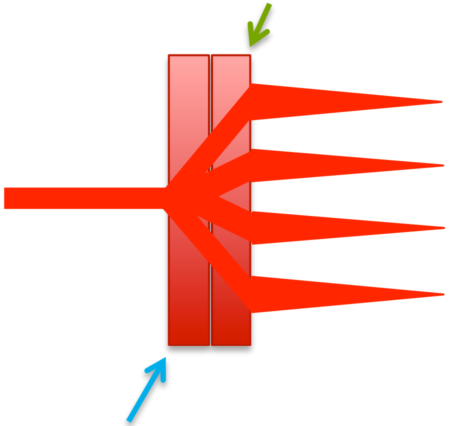
Optical Tasks

A DOE is an encoded phase plate for each point in x and y for an on-axis lens:

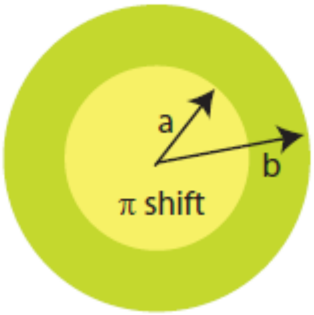
Priority	Task	Impact	Wavelength (nm)	Polarization	Power (nW)	Spot Size (microns)	Irradiance (nW/ micron^2)
1	Trap	holds for ~15sec, posn important	938	linear	5000	2-4	300 - 1300
6	State Prep	no size rqmt => flood, orientation important	895	linear			0.01
1'	σz	Adjust (decrease) trap power to set	938	linear			
2	J	Rydberg, **k** same direction for all atoms	318	linear		30	1000
4	σx	**k** same direction for all atoms	852 or 895 or 459	circular			100
5	Readout		852	circular			0.01
3	Collection	efficiency impacts speed => **hi NA**	852				

Saffman 4X4 DOE Design

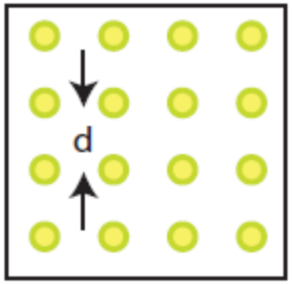
2D Bottle Beam Trap DOE Array



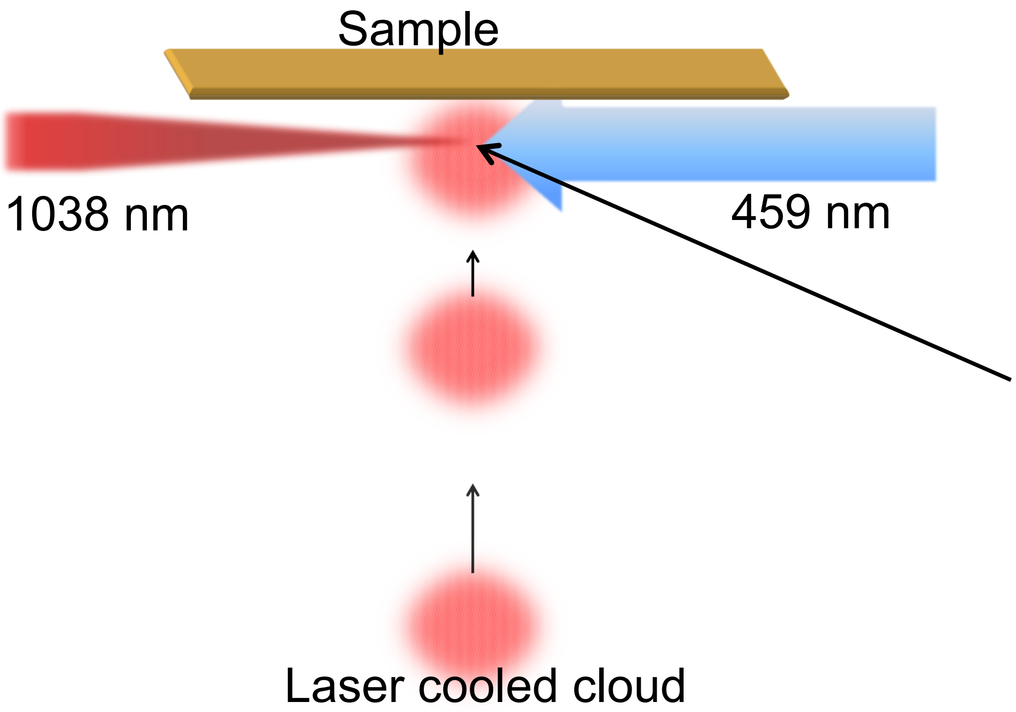
2D Dammann grating



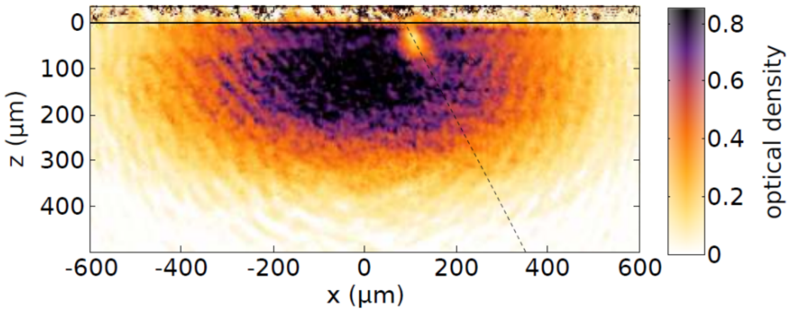
16 BBL with center to center spacing d

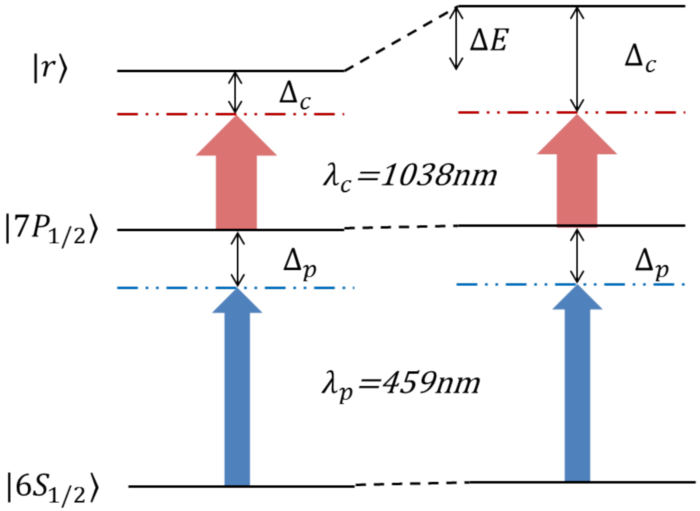


Testing proximity effects



Demonstration of Rydberg atom EIT near surface [1]



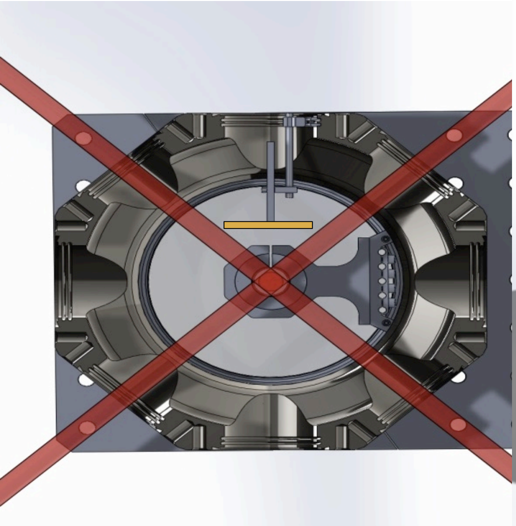


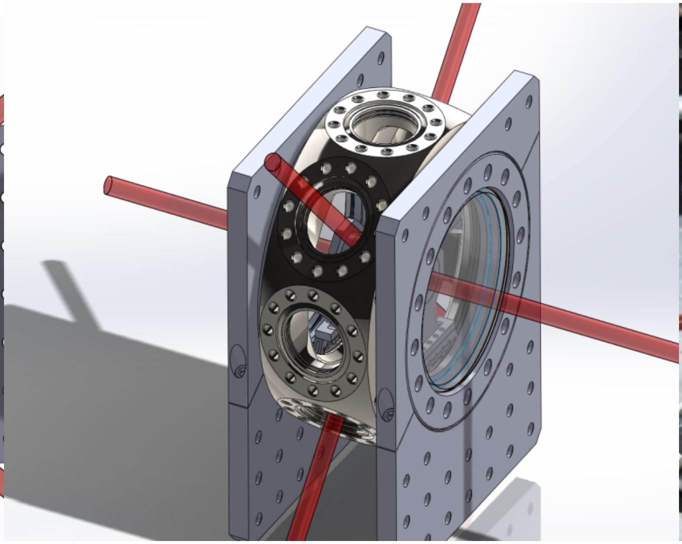
- Scanning the frequency of the probe beam gives a measure of the absorption profile
- Imaging the cloud using λ_p=*459nm* gives spatial dependence of EIT parameters

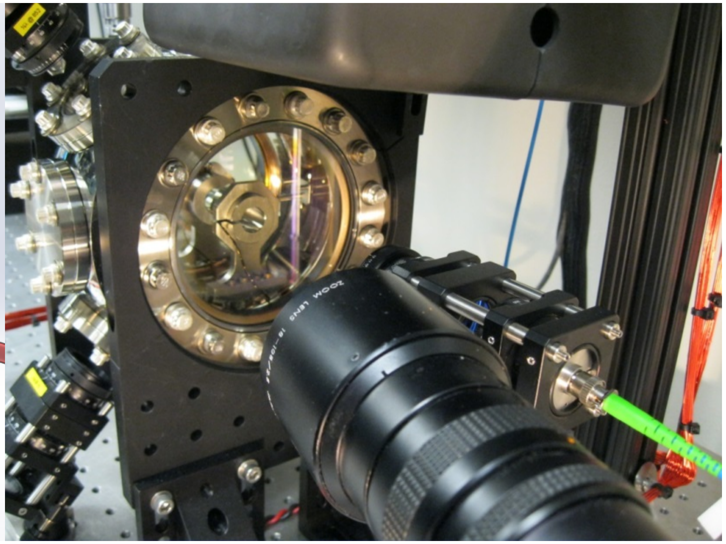
[1]Tauschinsky *et al.* Spatially resolved excitation of Rydberg atoms and surface effects on an atom chip. Phys. Rev. A (2010)

Apparatus for testing

- Vacuum chamber contains material samples to probe
- Progress
  - Laser cooled sample
  - EIT lasers inherited from main experiment
- Goal
  - Explore material effects
  - Explore geometry effects—simulate lenses







Going forward

- Mitigate Technical noise
- Demonstrate “J” term with 2 atoms
- Demonstrate QUBO
- Finalize scaled DOE layout
- Finalize c-phase gate

Conclusion

- Neutral atoms present a tantalizing system for 2D computation/ simulation arrays

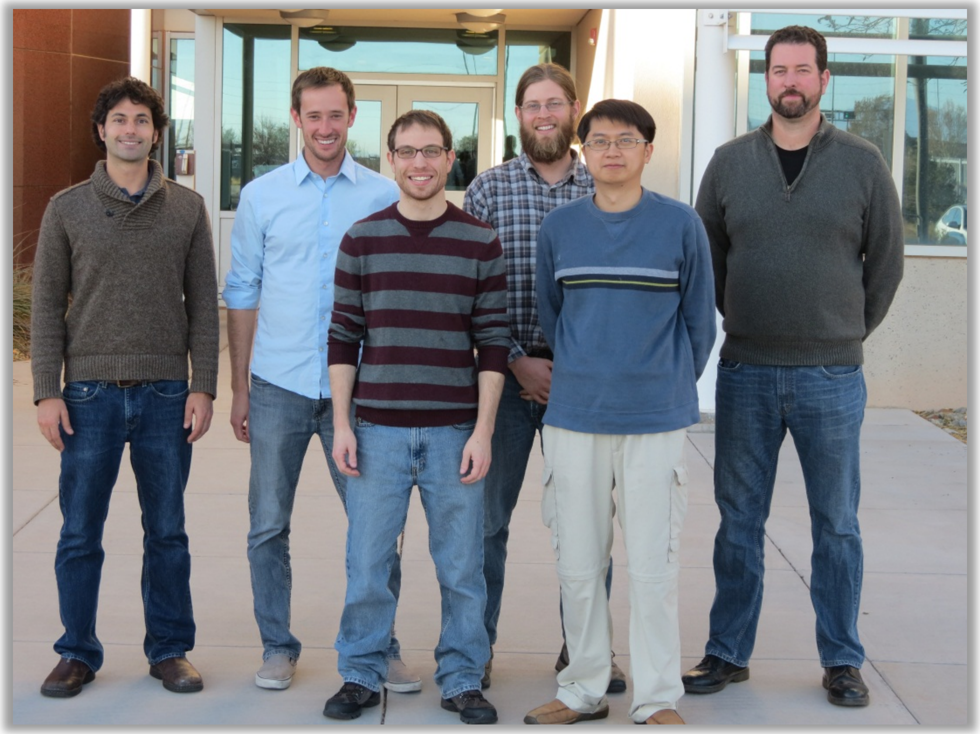
- Near-surface scaling requires careful attention to proximity effects

- Viability of Rydberg-dressed approach requires further investigation

- 2-qubit QUBO on track

- Large scale AQC with neutrals requires innovation

Neutral atom work at Sandia



L. Parazzoli, G. Biedermann, A. Hankin, A. Ferdinand, J. Chou, G. Burns

Not pictured:
- A. Landahl
- I. Deutsch
- T. Keating
- R. Cook
- K. Goyal
- M. Saffman
- P. Schwindt
- C. Johnson
- Y. Jau
- S. Kemme
- A. Young
- R. Ellis

Final thoughts