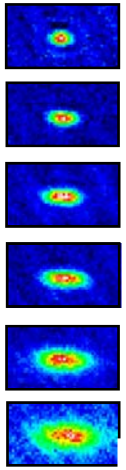
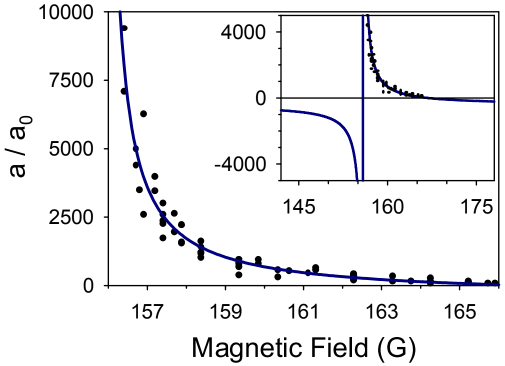
BEC research in Durham

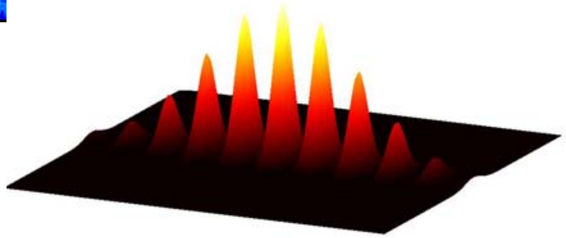
1. ^{85}Rb BEC Experiment

BEC with Tunable Interactions



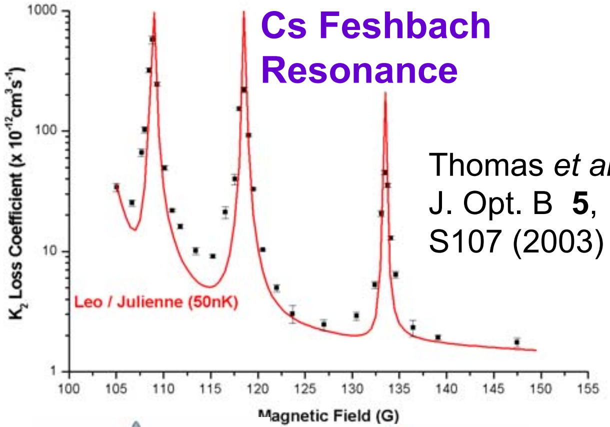


Cornish *et al,* PRL **85**, 1795 (2000)



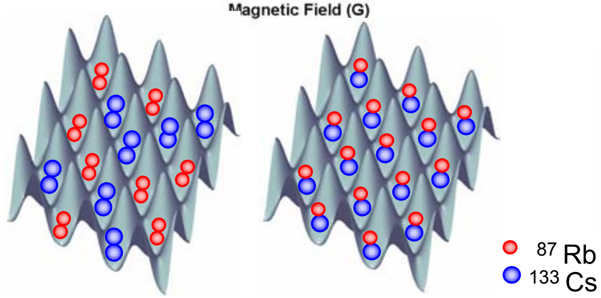
Staff:	**Simon Cornish, CSA**
Students:	**Margaret Harris**
	Malcolm Parks
	Patrick Tierney
Finance:	**Royal Society**
	EPSRC GR/S78339/01

2. Rb-Cs Mixtures

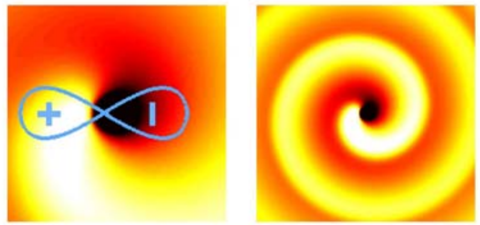


Cs Feshbach Resonance

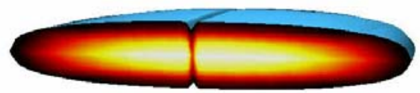
Thomas *et al,* J. Opt. B **5**, S107 (2003)



3. Theory: vortices, solitons, sound



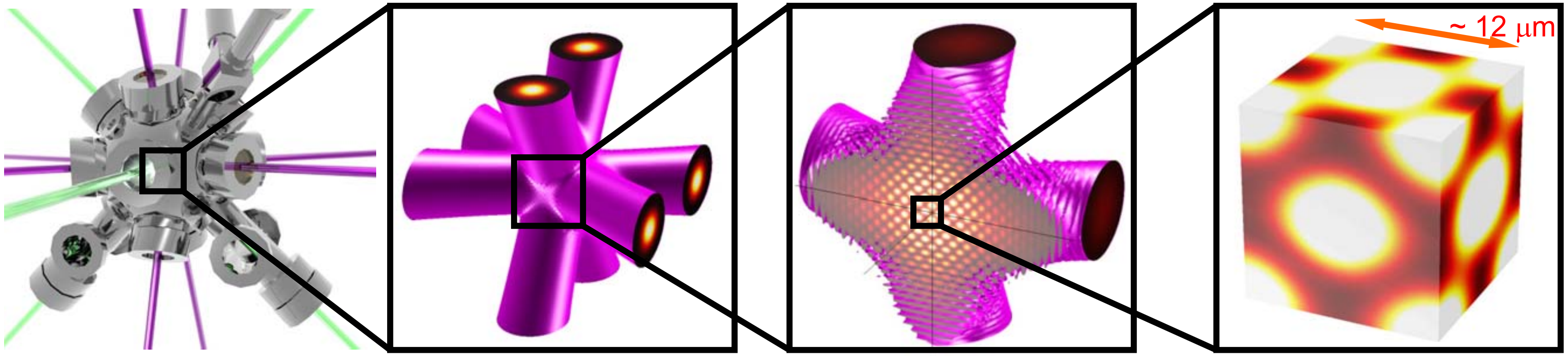
Parker et al. PRL **90**, 220401 (2003).
Parker et al. PRL **92**, 160403 (2004).



Staff:	**Nick Proukakis, CSA**
Students:	**Nick Parker**
	Eleni Sakallari (-07/04)
	Andrew Martin
Finance:	**EPSRC GR/S78339/01**

University of Durham

Neutral atom quantum computing in optical lattices: far red or far blue?



C. S. Adams

University of Durham

MESUMA 04

Dresden 2004

University of Durham

Outline

Good things for quantum computing

Scalability (optical lattices)

Low decoherence (large detuning)

Far-red

or

Far-blue

3D CO_2 single-site addressable

State-selective single-atom transport

Collisional gates

Experiment

Switchable inteactions

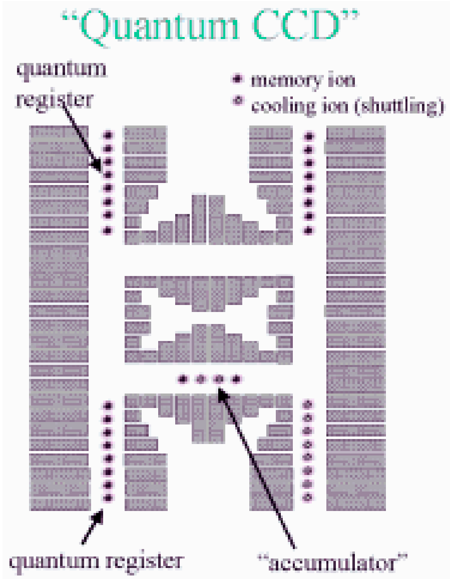
Magic Rydberg lattice

University of Durham

Quantum computing: atoms or ions?

1. Ions. (ENS, Caltech, MPQ, Sussex)

- Single-qubit addressable. ☺
- Switchable interactions. ☹
- Scaling to 2(3)D. 😐
- Low decoherence. ☺

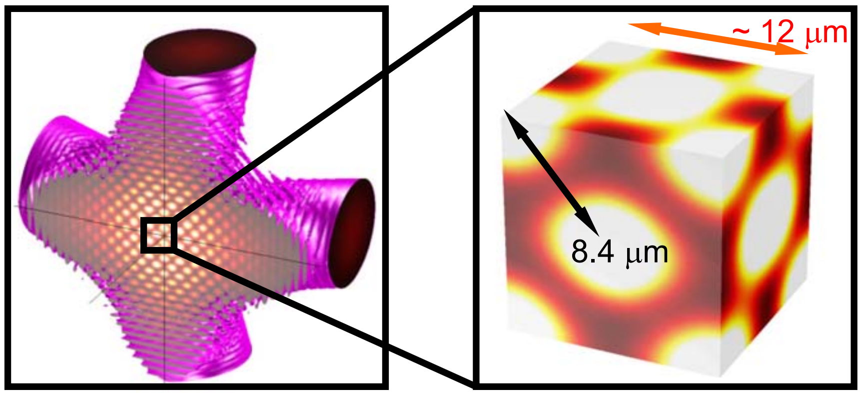


Architecture for a large-scale ion-trap quantum computer, D. Kielpinski, C. Monroe, D.J. Wineland Nature, **417**, 709 (2002).

2. Neutral atoms in optical lattice.

- Single-qubit addressable. ☺
  - Patterned loading
  - Cavity QED
  - Microtraps
- Switchable interactions. ☺
  - Rydberg
- Scaling to 2(3)D. ☺
- Low decoherence. 😐

3D CO_2 lattice 10 x 10 x 10 sites



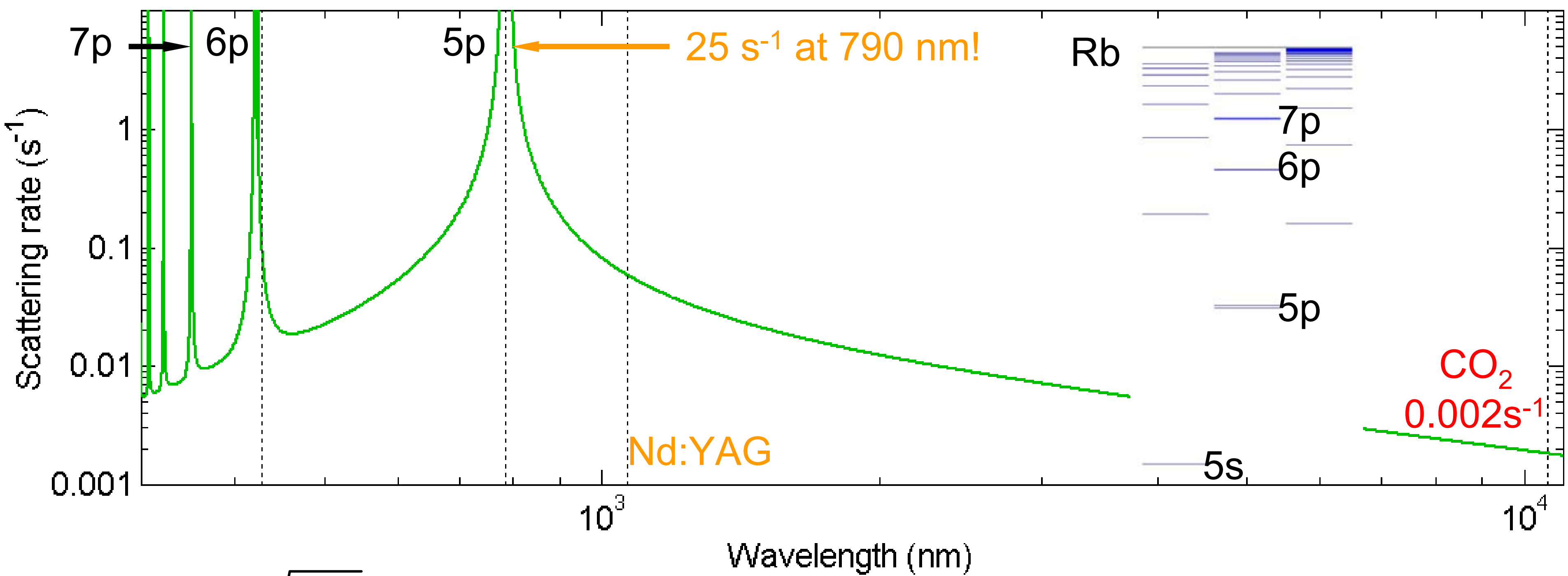
C. S. Adams et al. J. Phys. B. **36**, 1933 (2003).

University of Durham

Low decoherence

Photon scattering rate for a trap frequency of 1 MHz

Far blue **Far red**



$$\nu_{\text{osc}} \propto \frac{\sqrt{U_0}}{\lambda}$$

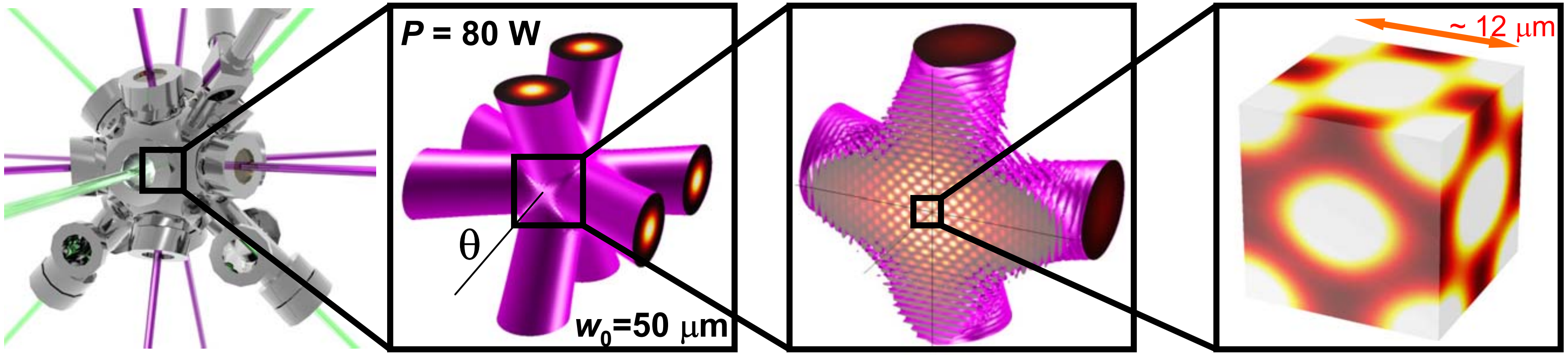
Blue: less power

Lamb-Dicke

$$\eta \propto \frac{2\pi a_0}{\lambda}$$

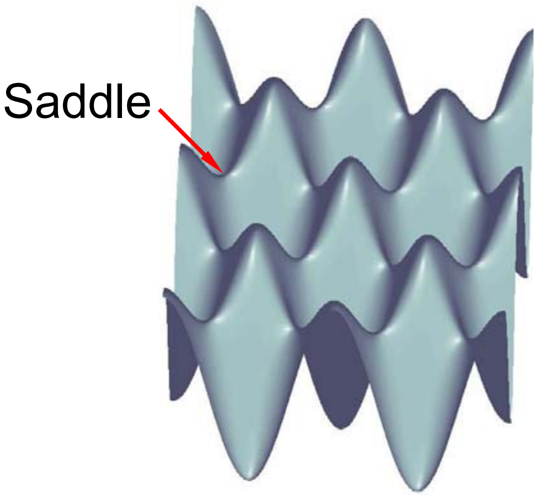
Far infrared: 3D CO_2 lattice

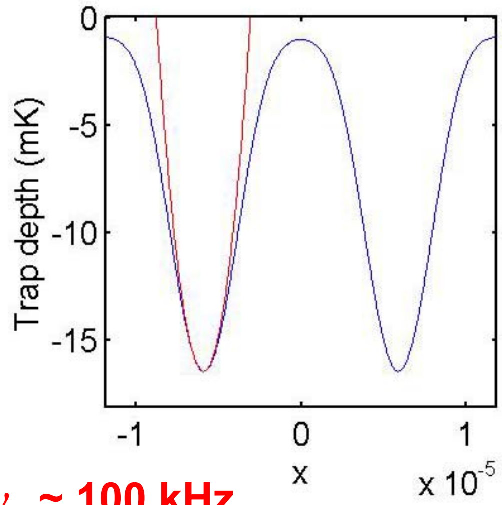
C. S. Adams et al. J. Phys. B. **36**, 1933 (2003).



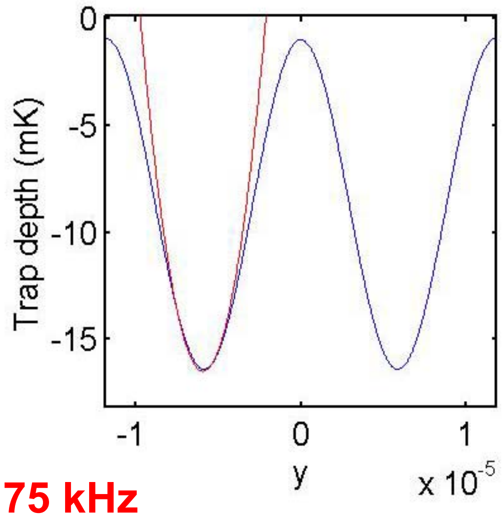
$\theta = \mathrm{atan}(2)$

1. **11.8 μm lattice constant: single-atom addressable.**
2. **Similar trap depths for most atoms (molecules).**



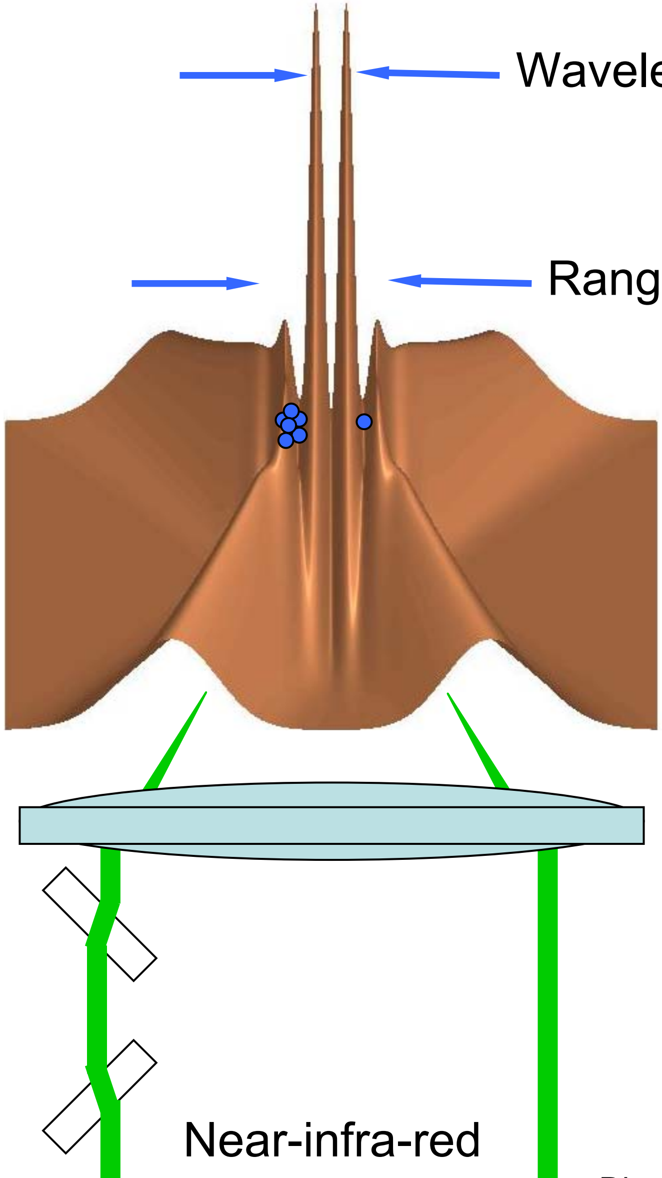


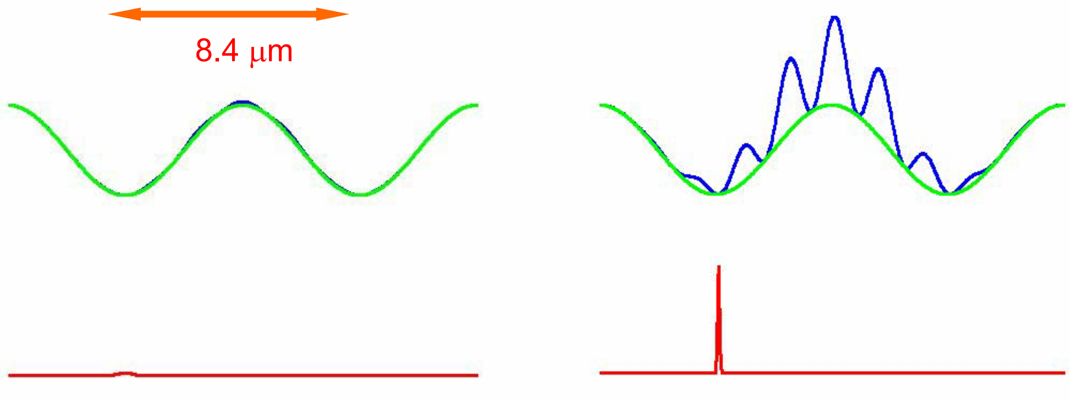
ν_x ~ 100 kHz



ν_y ~ 75 kHz

Single-atom conveyor



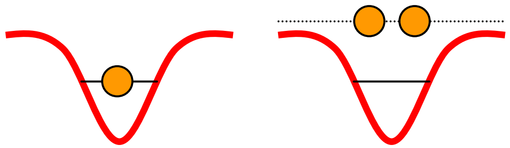


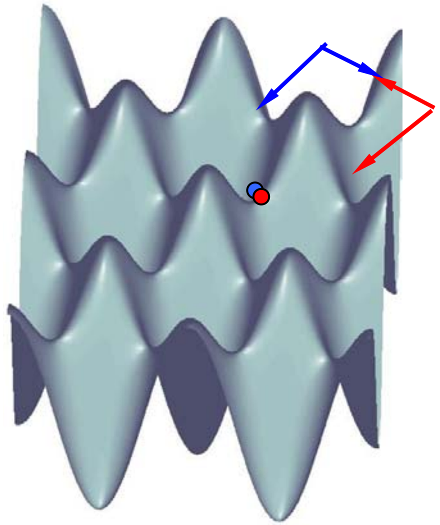
Photon scattering rate

Spin-dependent lattice

$$\frac{\text{‘Blue’}}{\text{‘Red’}} \qquad \frac{\frac{1}{4}\hbar\omega}{U_0} < 10^{-2}$$

Single-atom tweezer

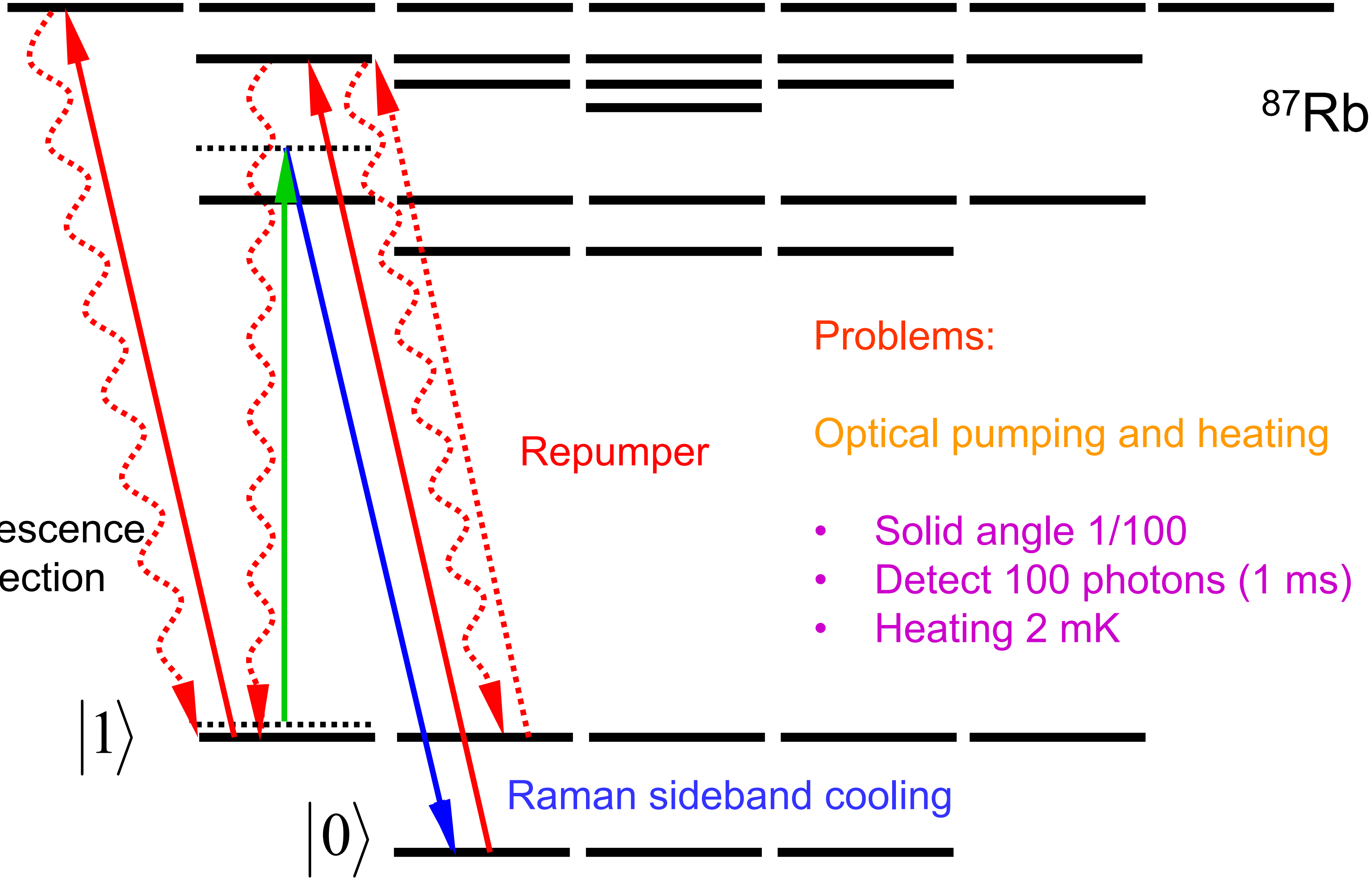




Diener et al. Phys. Rev. Lett. **36**, 1933 (2003).

University of Durham

Single-atom cooling and detection



Problems:

Optical pumping and heating

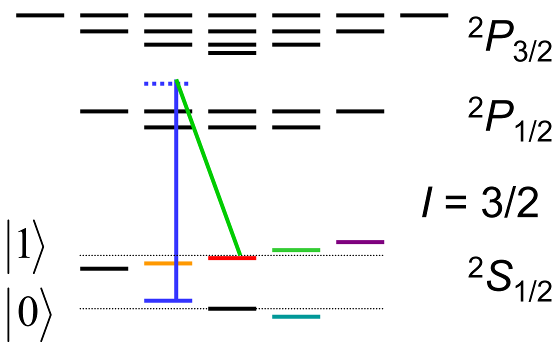
- Solid angle 1/100
- Detect 100 photons (1 ms)
- Heating 2 mK

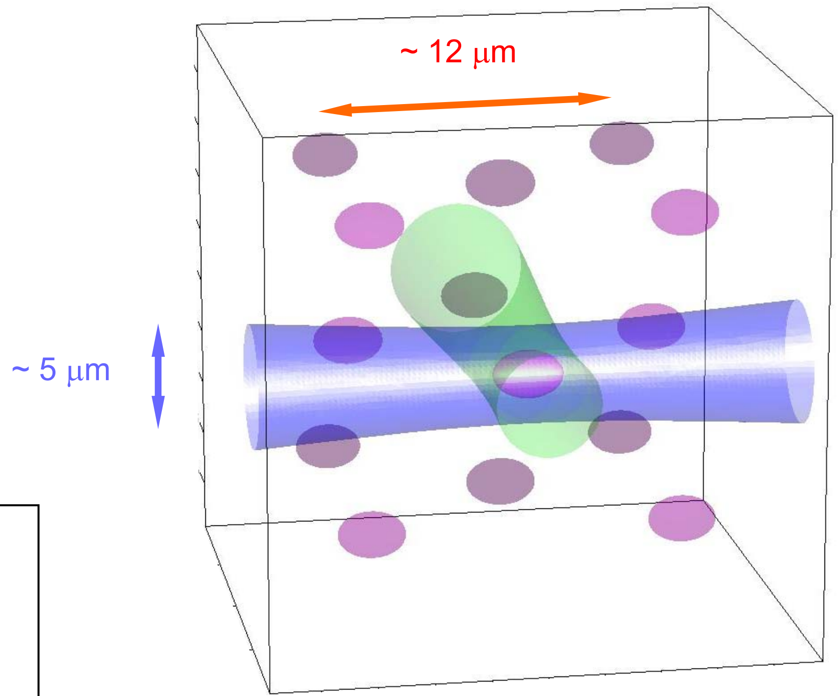
C. Monroe, D.M. Meekhof, B.E. King, S.R. Jefferts, W.M. Itano, D.J. Wineland, and P. Gould,
Resolved-sideband Raman cooling of a bound atom to the 3D zero-point energy, Phys. Rev. Lett. **75**, 4011 (1995).

University of Durham

Single-atom addressability

^{87}Rb



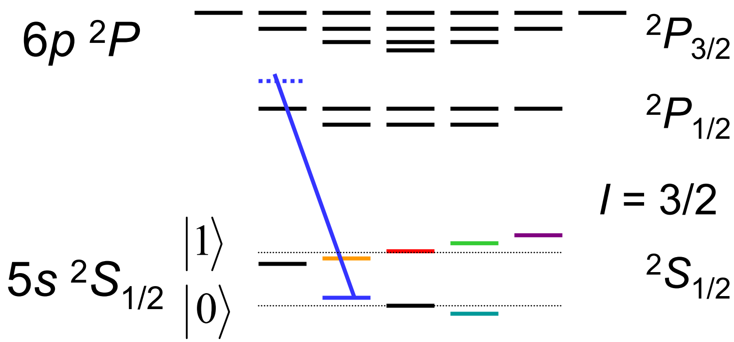


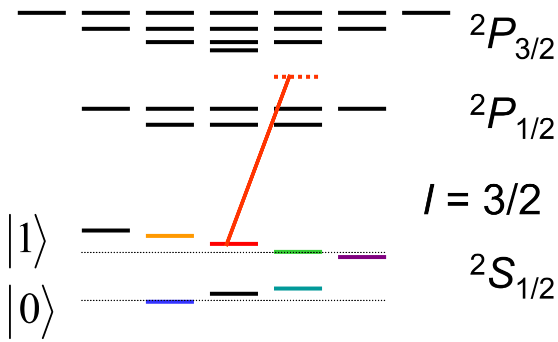
Stimulated Raman transitions.

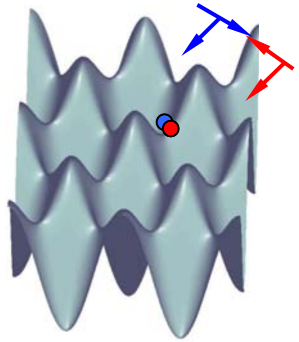
- Single-site addressable.
- Single-qubit rotations.
- State-selective single atom transport.
- Single-atom cooling and detection.

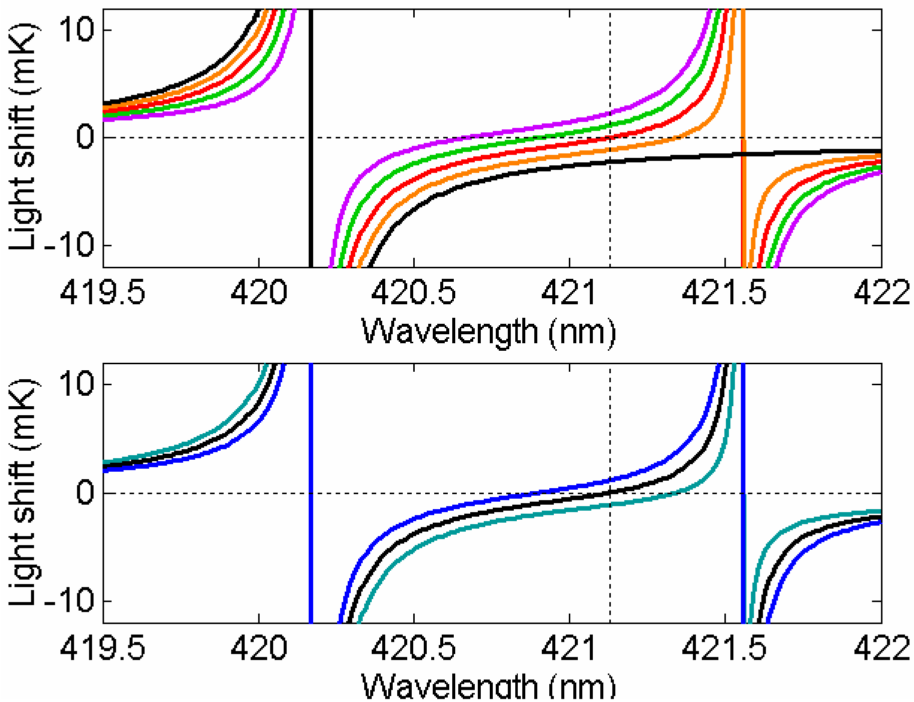
University of Durham

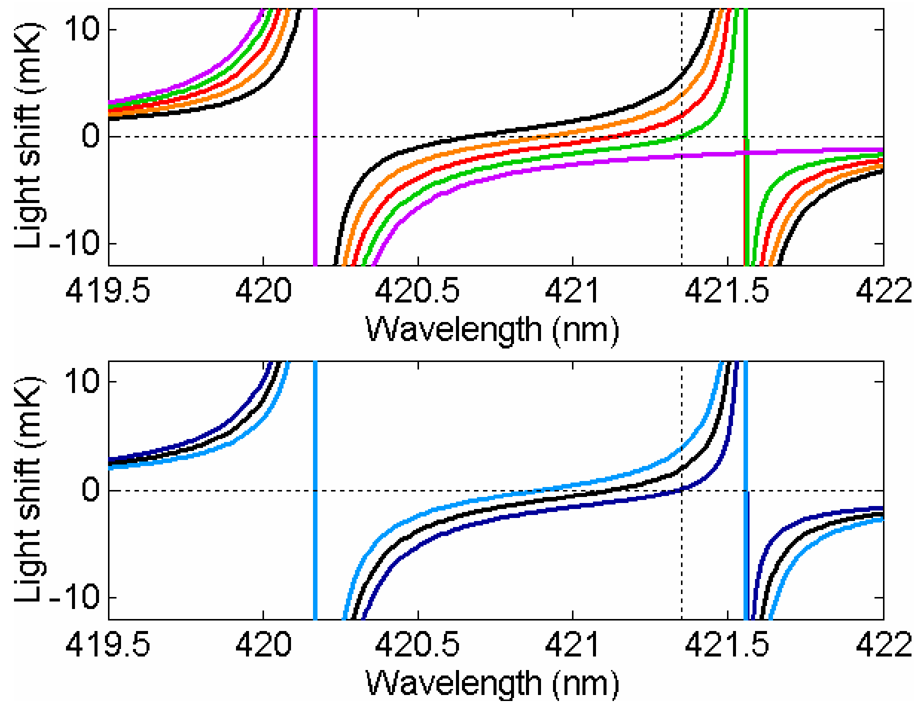
State-selective transport









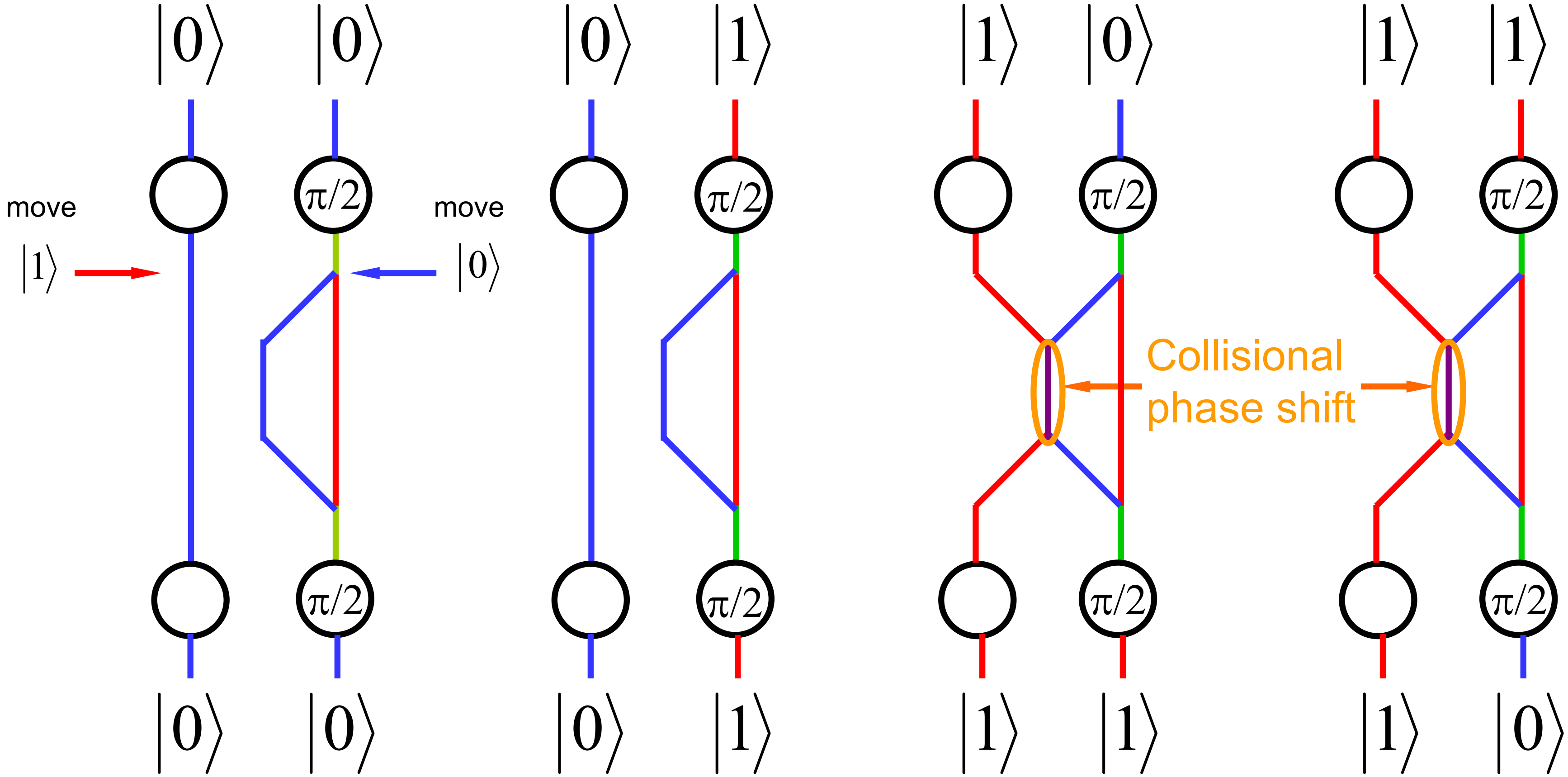


Left circular 421.1 nm selects $|0\rangle$

Right circular 421.4 nm selects $|1\rangle$

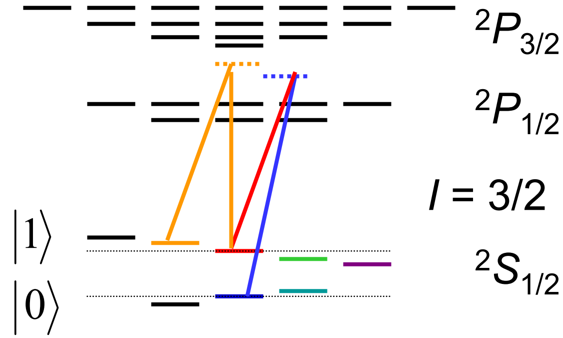
University of Durham

Collisional gates

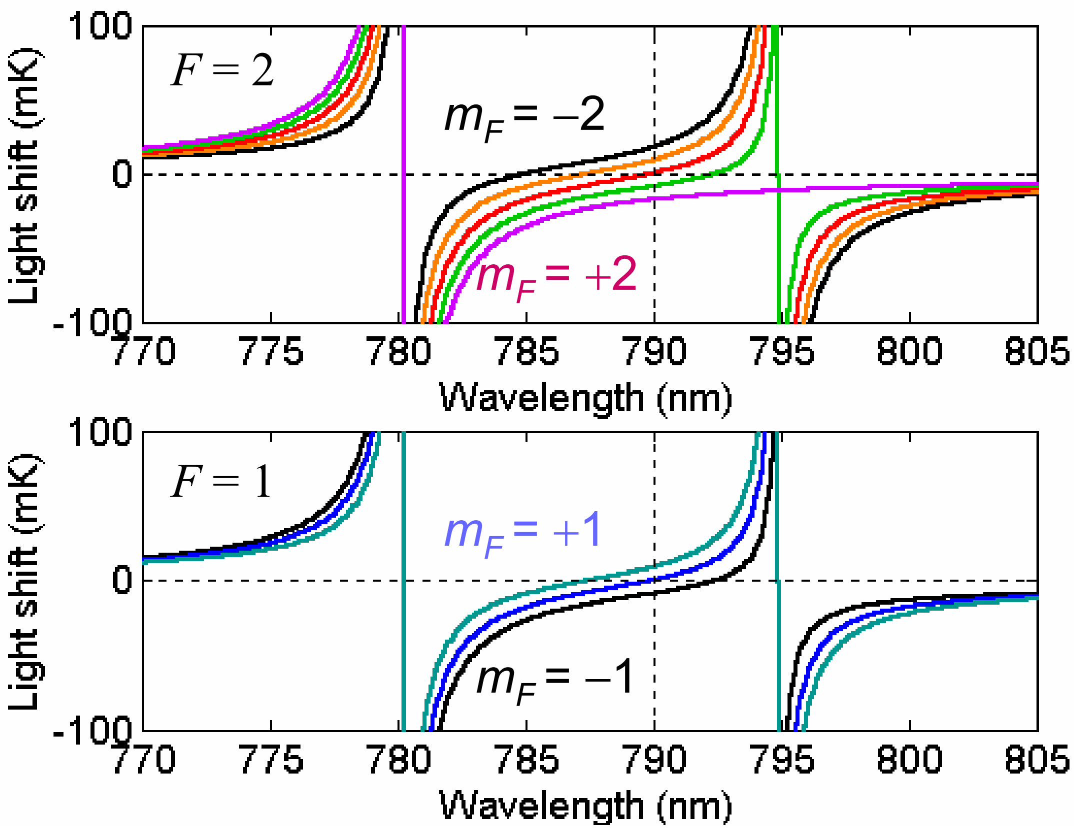


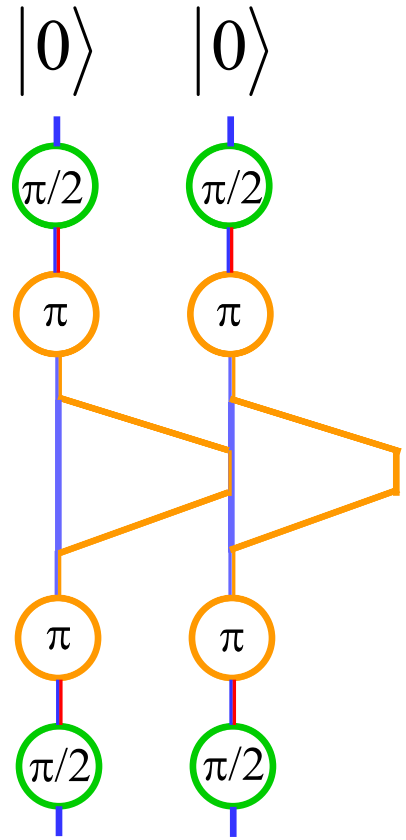
University of Durham

Magnetically insensitive storage



Raman selection pulse
+ 790.0 nm move beam

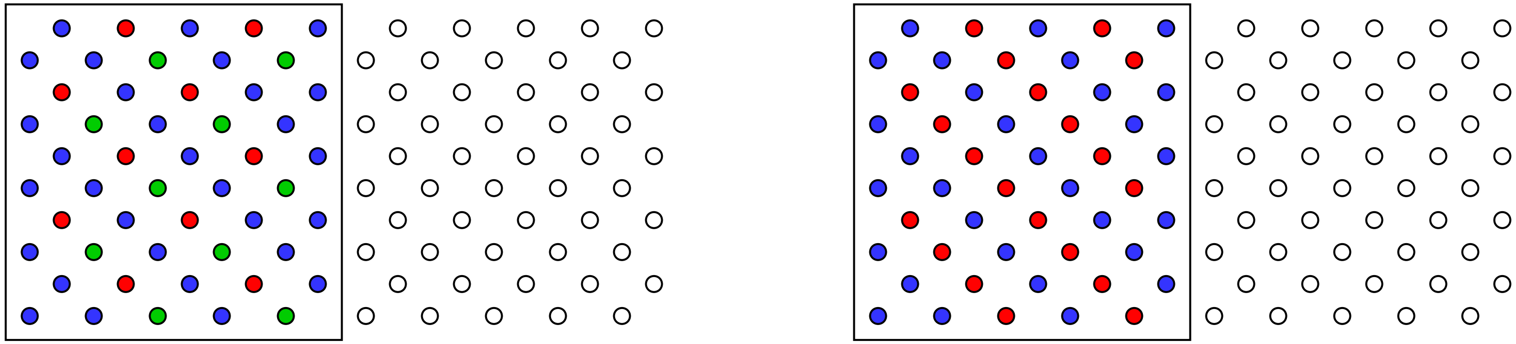




University of Durham

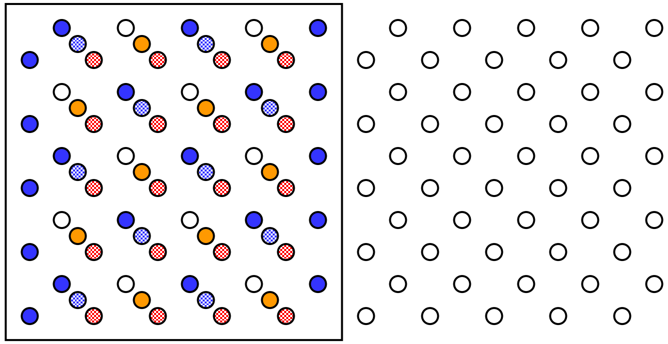
Scalable neutral atom quantum computer

1. Initialisation

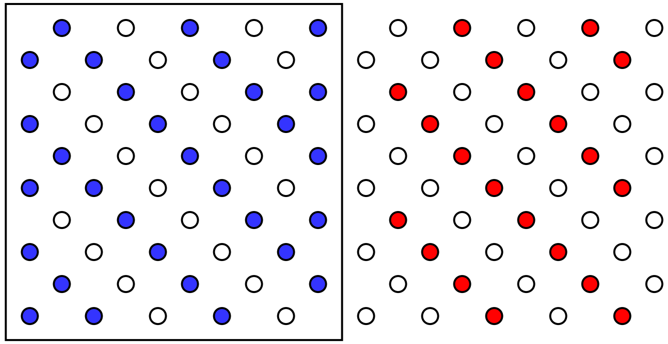


Detection is not state specific but transport is!

2. Computation



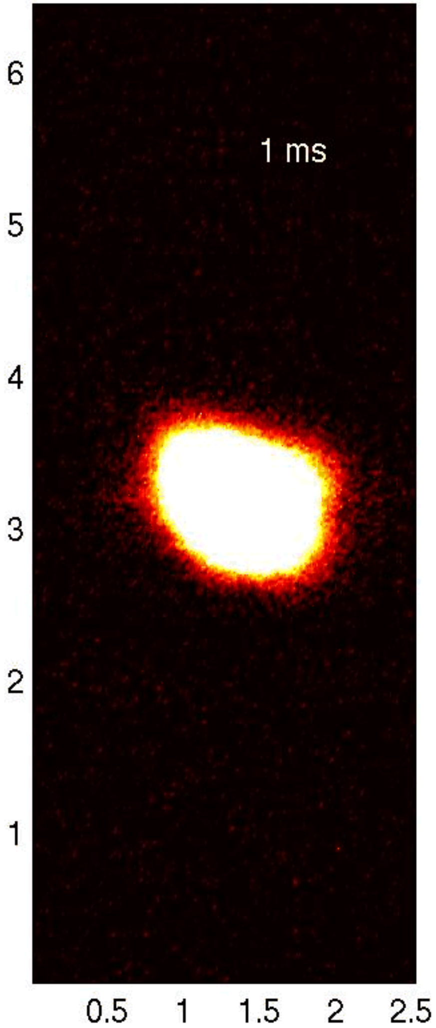
3. Read-out

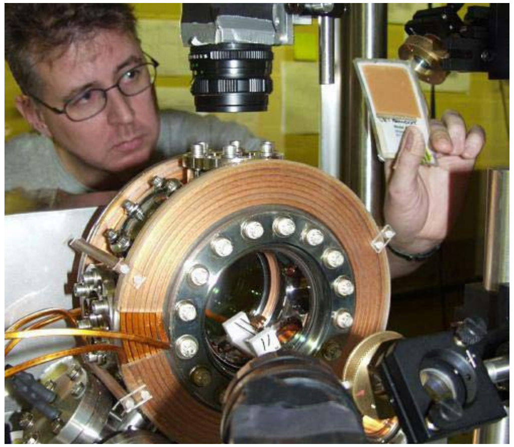


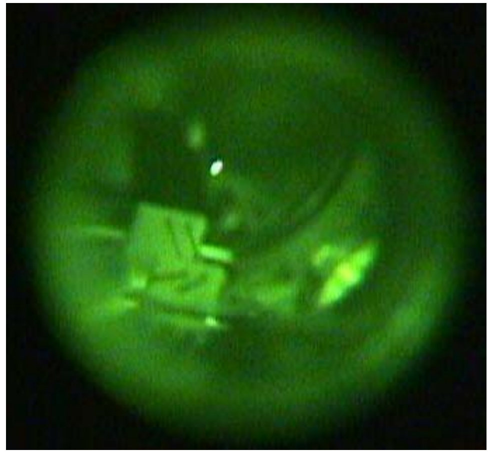
$|0\rangle$ detection $|1\rangle$ detection

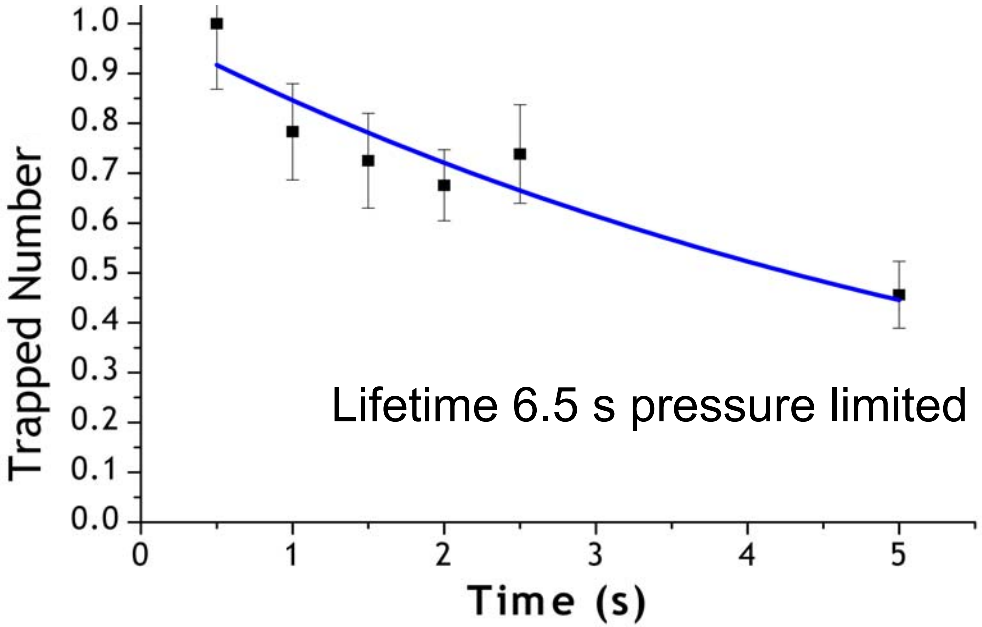
University of Durham

CO_2 trap experiment





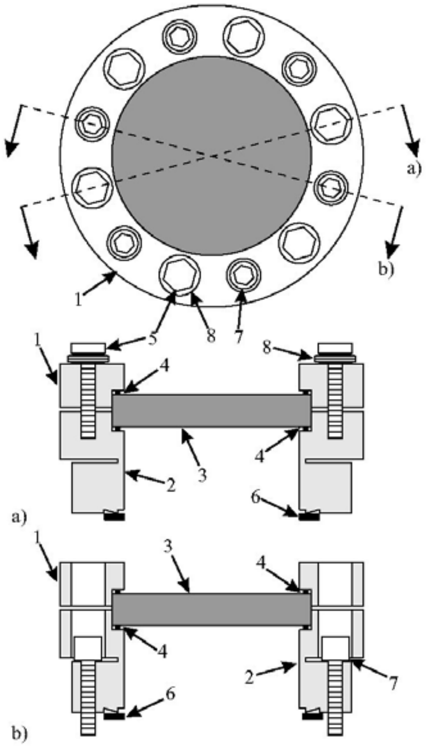


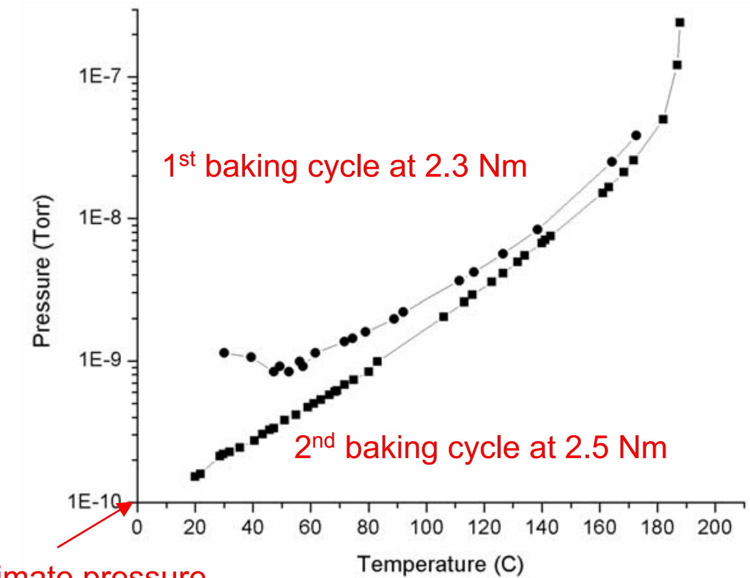


University of Durham

Solder seal windows

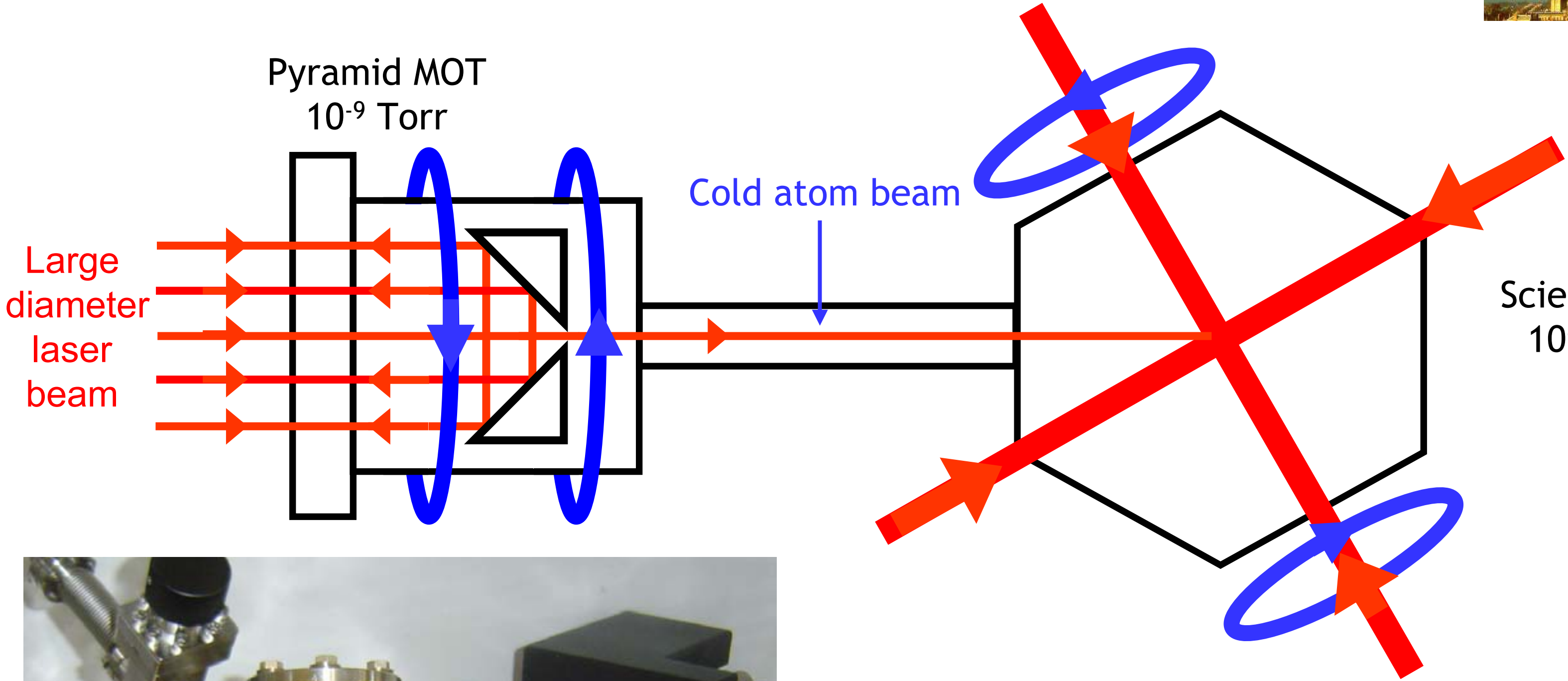
1. **Hard solder: melting point 309 ^{o}C**
2. **Tested to 275 ^{o}C.**
3. **Reusable.**
4. **Flexibility: high optical quality, any substrate, any coating.**
5. **ZnSe saving – £750 per window!**

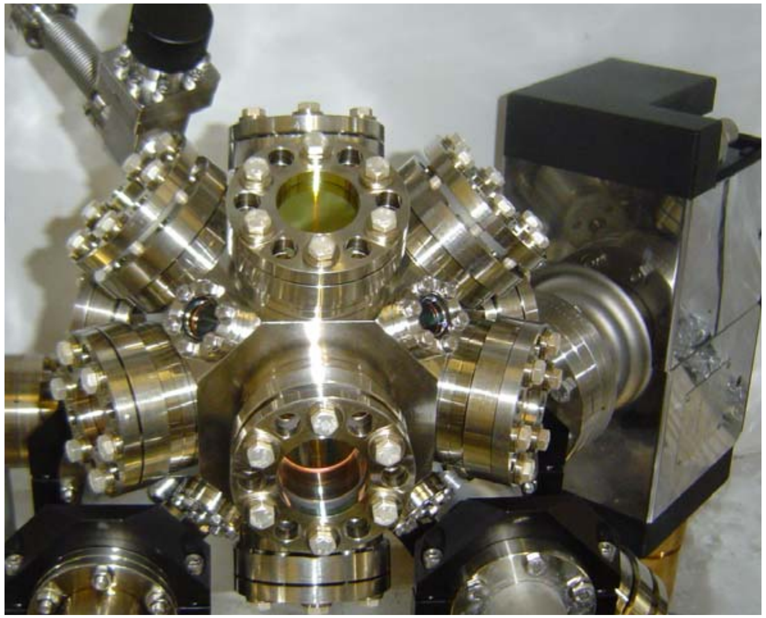




S. G. Cox et al. Rev. Sci. Instrum. **74**, 1311 (2003); K. J. Weatherill et. al. in preparation

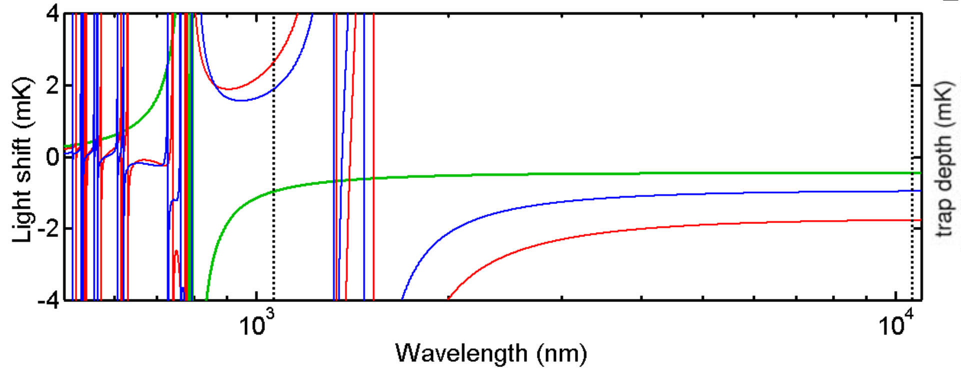
3D chamber

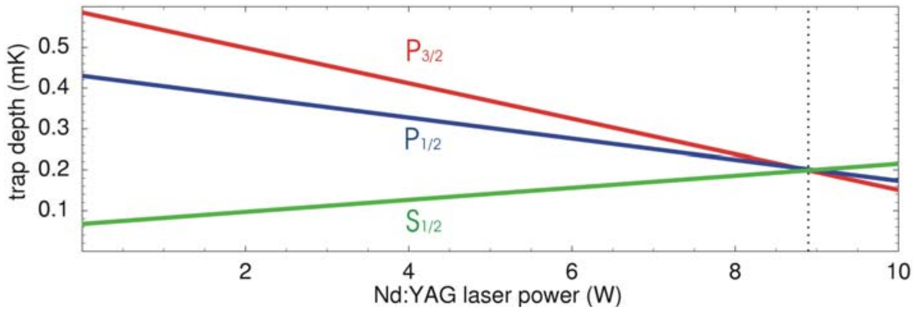

Pyramid MOT
10-9 Torr
Large
diameter
laser
beam
Cold atom beam
Science MOT
10-11 Torr

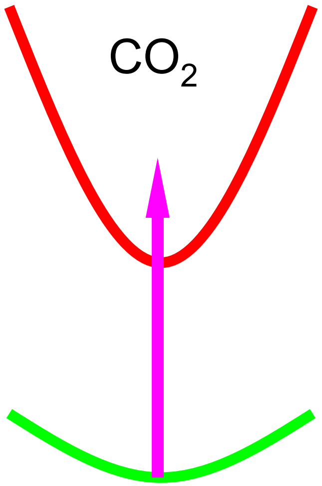


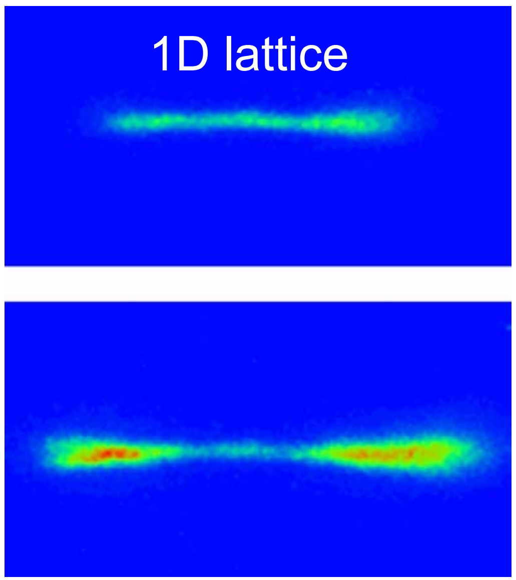
University of Durham

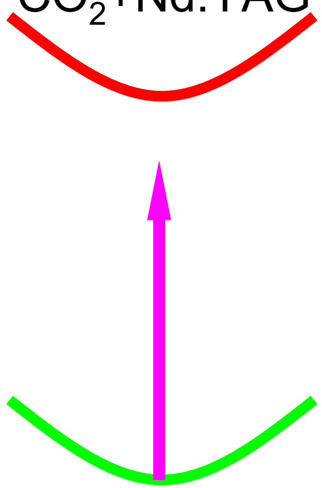
Loading CO_2 lattices

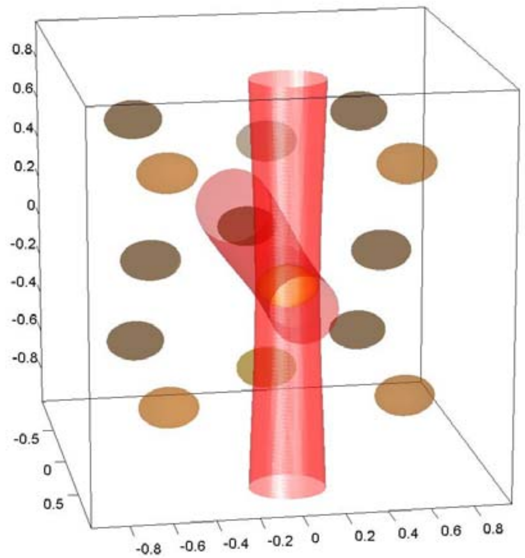












An optical lattice with single lattice site optical control for quantum engineering
R Scheunemann, F S Cataliotti, T W Hänsch and M Weitz, J. Opt. B **2**, 645 (2000).

BEC at one site:
- reservoir for extracting single atoms

University of Durham

3D CO_2 trap collisional gates

Advantages: single-site addressable

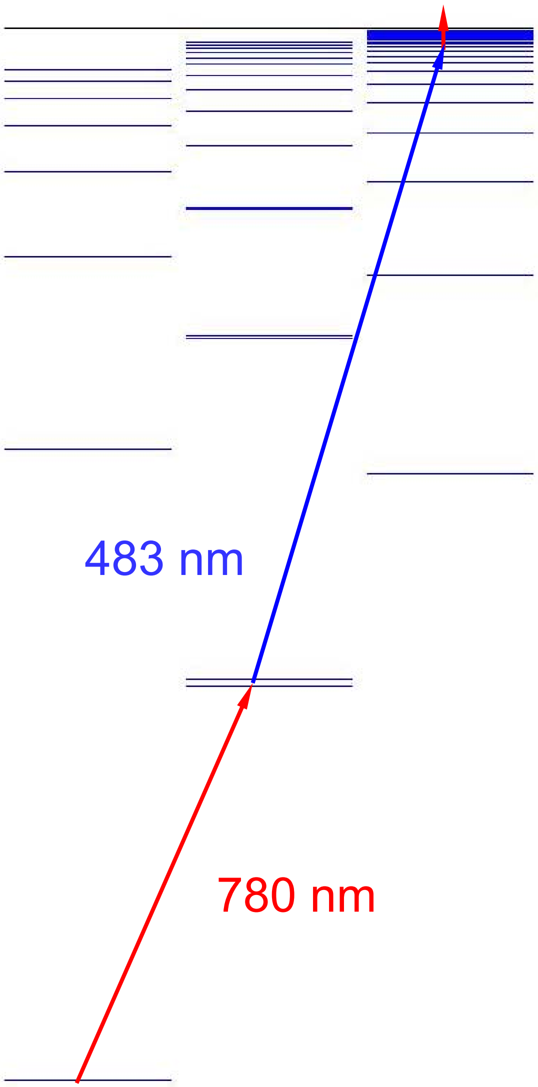
1. State-selective (site-specific) transport:
   blue detuning: low scattering
   high trap frequency
   faster gates
   magnetically insensitive storage.

Disadvantages: CO_2 laser

1. Collisional interactions: slow (not switchable)
   motional decoherence.

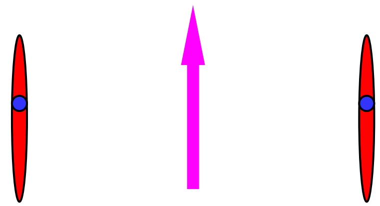
Rydberg gates

D. Jaksch, J.I. Cirac, P. Zoller, S.L. Rolston, R. Cote, M.D. Lukin,
Fast quantum gates for neutral atoms, Phys. Rev. Lett. **85**, 2208 (2000).



$$|V_{\rm dd}| = \frac{d_1 d_2}{4\pi\varepsilon_0 r^3} \propto n^4 \qquad \tau \propto \frac{1}{n^3}$$

~ 10 μm



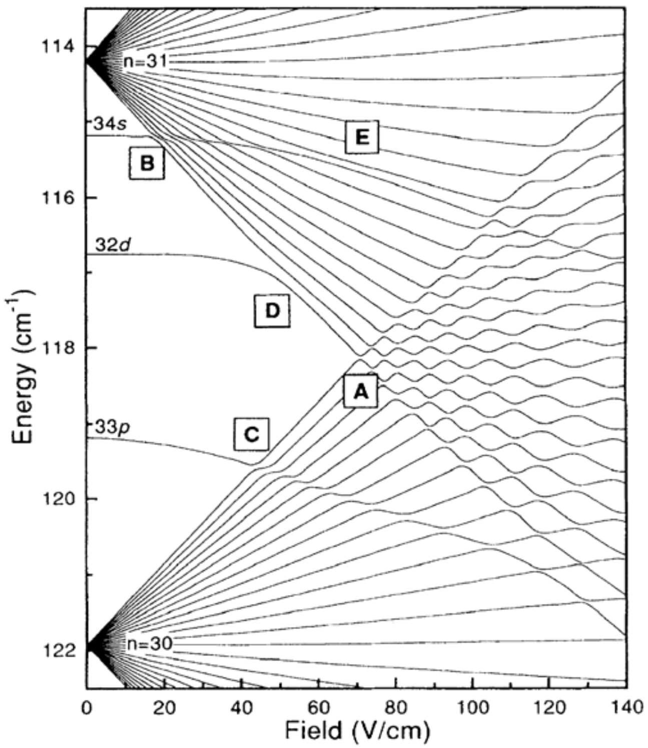
n	V_{dd}(kHz)	τ (μs)	Γ (x 2π kHz)
15	50	2.5	50
20	160	10	16
25	400	20	8
30	800	30	5
40	2600	50	3

$$|V_{\rm dd}| > 100\Gamma$$

Ionisation rate

λ (μm)	10.6	1.06
n	25	16
I (Wcm^{-2})	5×10^5	5×10^4
τ (μs)	0.01	10

R. M. Potvliege, private communication

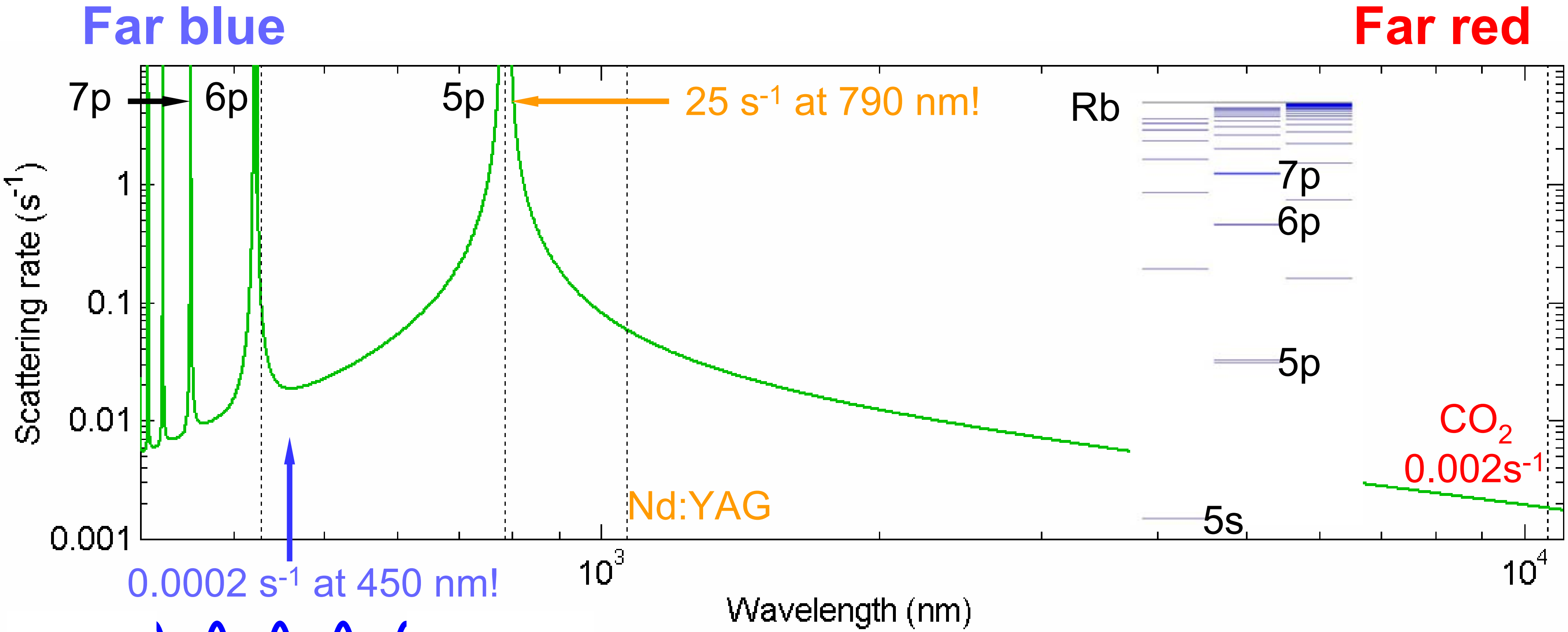


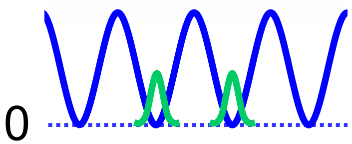
G.M. Lankhuijzen and L.D. Noordam, Phys. Rev. Lett. **74**, 355 (1995).

University of Durham

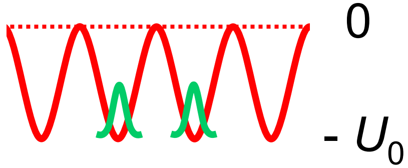
Low decoherence

Photon scattering rate for a trap frequency of 1 MHz





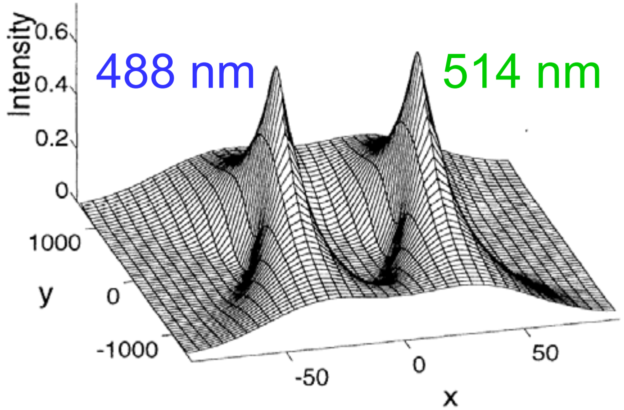
$$\frac{\text{'Blue'}}{\text{'Red'}} \qquad \frac{\frac{1}{4}\hbar\omega}{U_0} \sim 10^{-2}$$

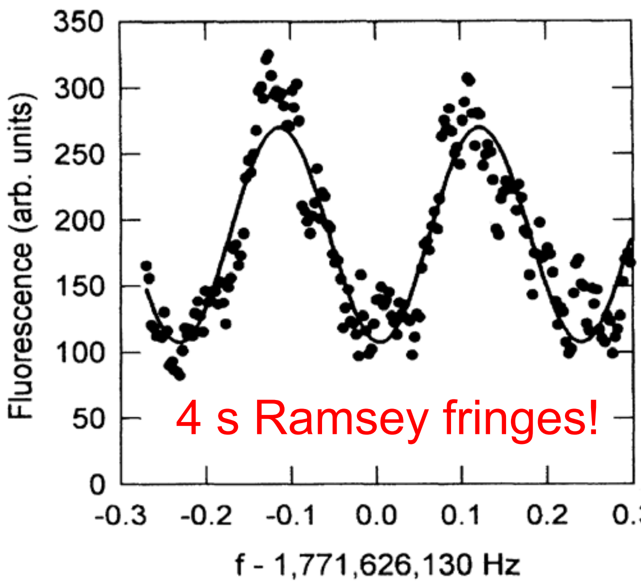


University of Durham

More blue!

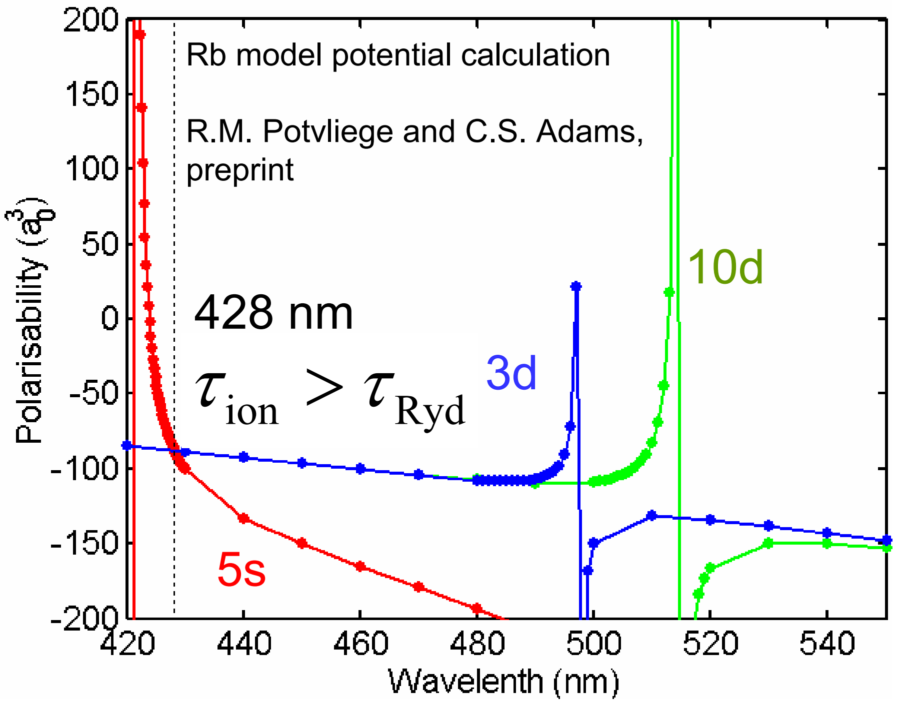
Long coherence

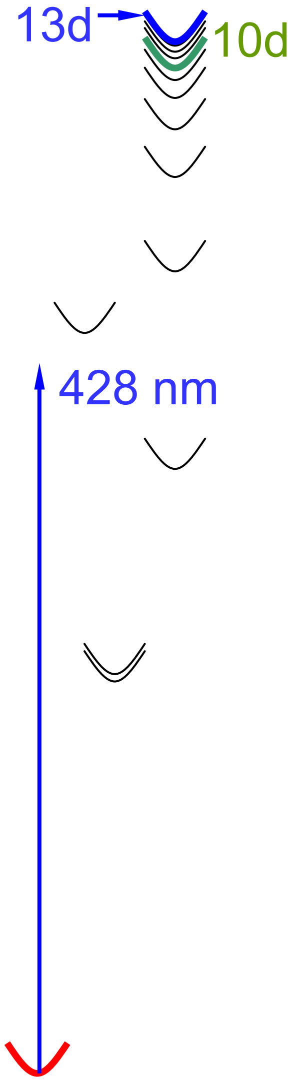




Davidson, Lee, Adams, Kasevich, and S. Chu, PRL. **74**, 1311 (1995).

Magic Rydberg lattice



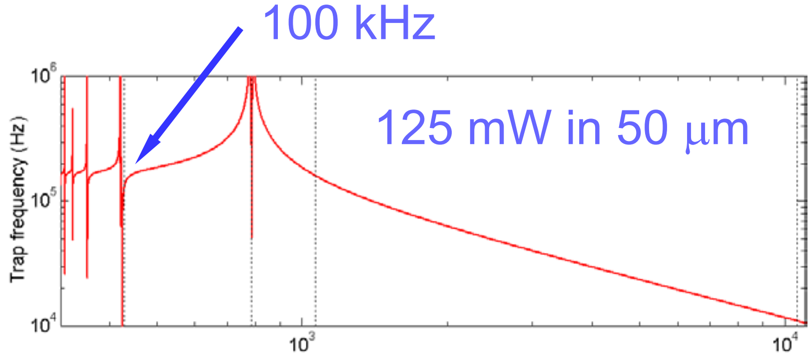


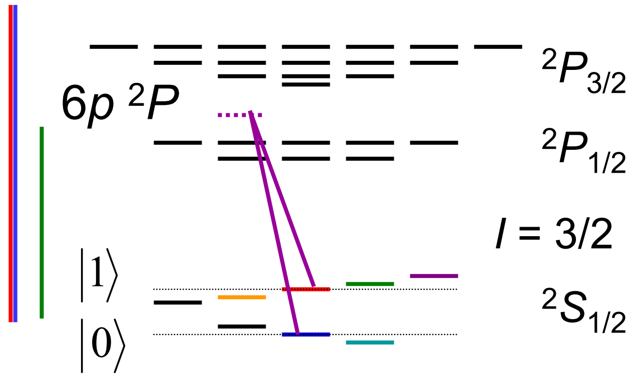
University of Durham

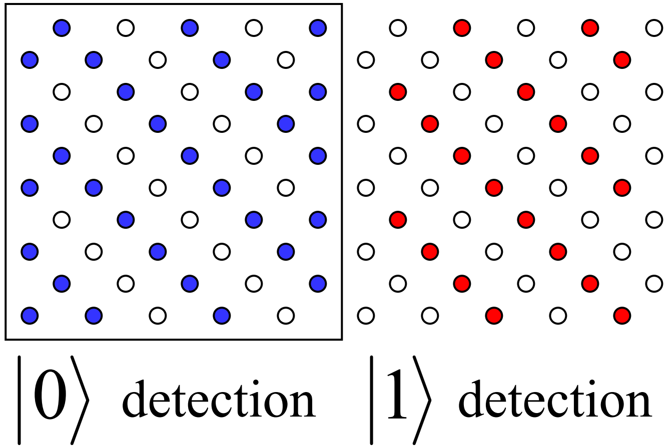
428 nm lattice proposal

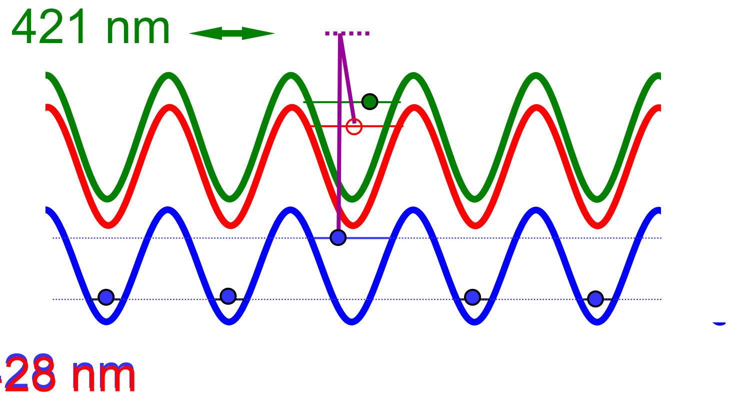
R.M. Potvliege and C.S. Adams, preprint

1. **Doubled 856 nm: 3 orthogonal beam pairs. phase stable**
2. **Mott insulator**
3. **Local addressing with a 'pointer'**
   T. Calarco *et al*. quant-ph/0403197
4. **Transfer to expandable lattice + state selective transport to perform read-out**









University of Durham

Conclusions

Optical lattices: scalability

Low decoherence

Far-red

$3D\ CO_2$ single-site addressable

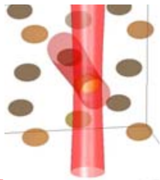
State-selective single-atom conveyor

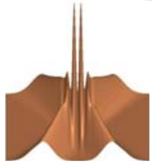
Collisional gates

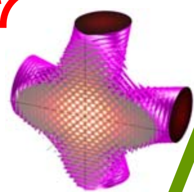
Spatially discriminated parallel read-out

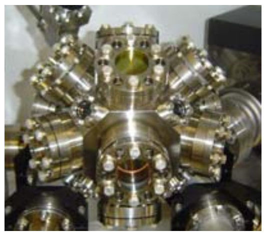
Scalable up to 10^3 qubits

Experiment



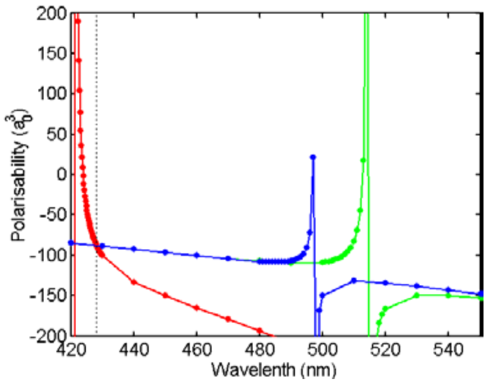


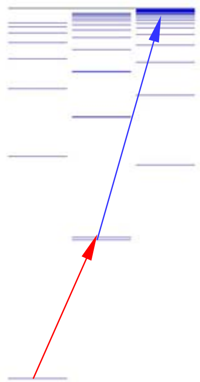




Far-blue

Magic Rydberg lattice





Switchable interactions

University of Durham

Acknowledgements

Collaborators: Robert Potvliege (Rydberg theory)

Graduate students: Paul Griffin
Kevin Weatherill
Matt Pritchard

Research assistants: Simon Cox (up to 08/04)

Collaborators: Erling Riis (Strathclyde)
Ifan Hughes, Simon Cornish

Technical support: Robert Wylie (Strathclyde)

Financial support: Previously EPSRC

http://massey.dur.ac.uk/