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QuAMP 2013

Towards large scale quantum information processing: Static magnetic field gradient quantum gates and microfabricated ion traps

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Talk Outline

- Ion Trapping and Ytterbium 171
- Use magnetic gradient induced coupling to produce . . . . . motional coupling: The key requirement for quantum . . . . gates.
- Reduce decoherence by 2 orders of magnitude using . . . . microwave dressed-states.
- The first 2-Dimensional ion trap array integrated on . . . . . microchip.
- Progress towards an operational homogeneous ring trap.

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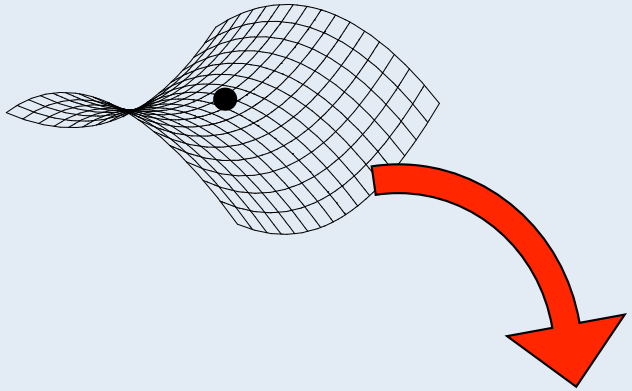
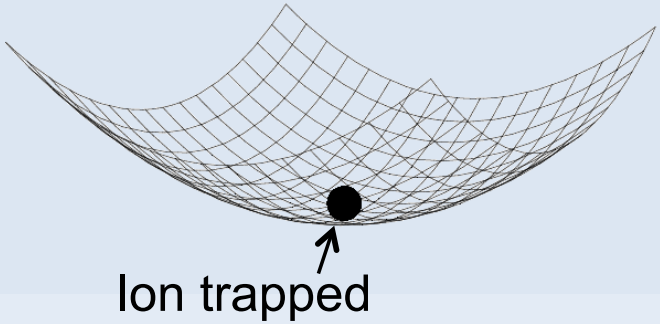
RF Paul Trap

- DC electrodes alone: Saddlepoint potential

$$\overline{\nabla} \cdot \overline{E} = 0$$



- DC and RF electrodes: Pondermotive potential



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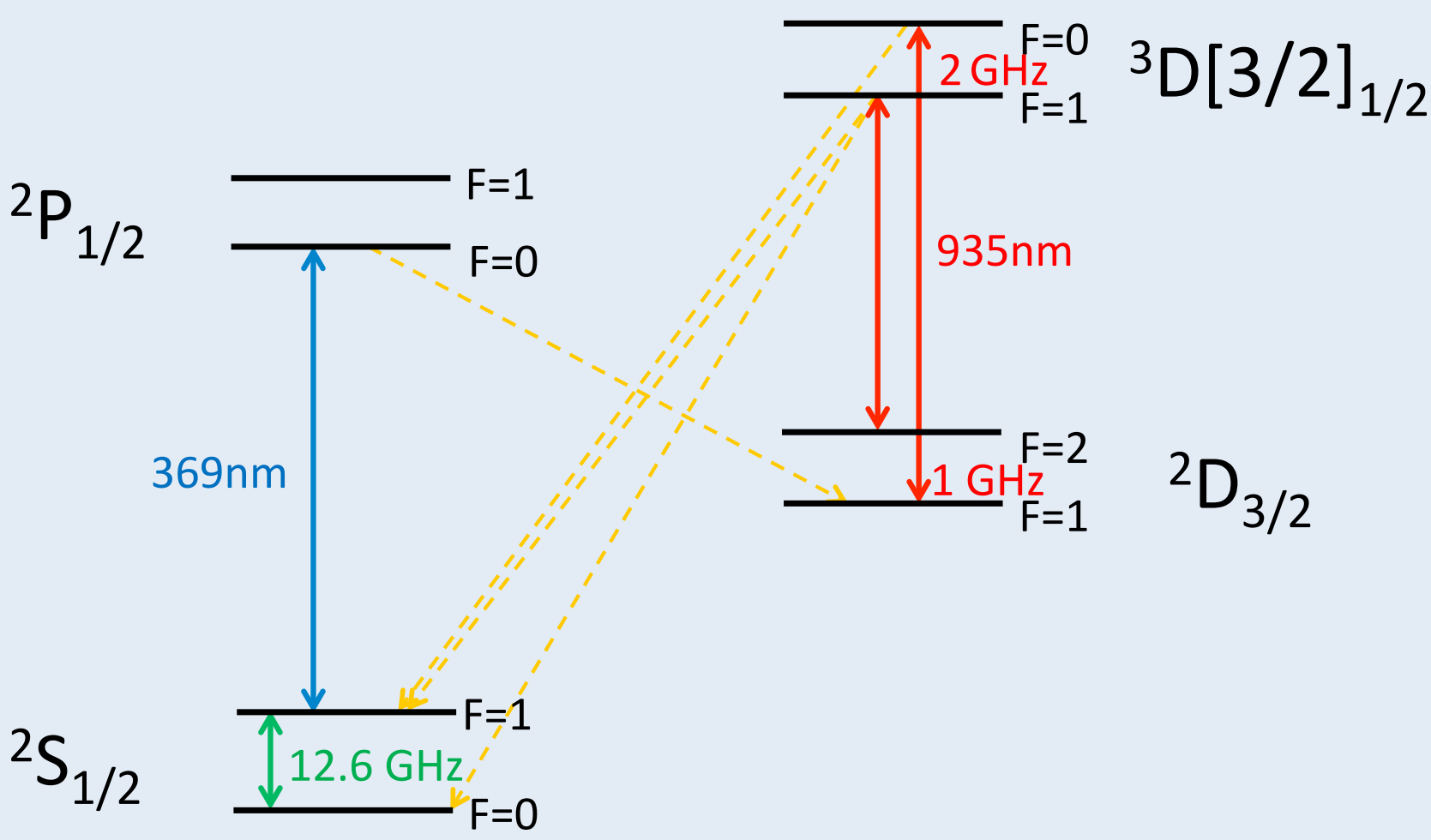
$^{171}Yb^{+}$: Cooling



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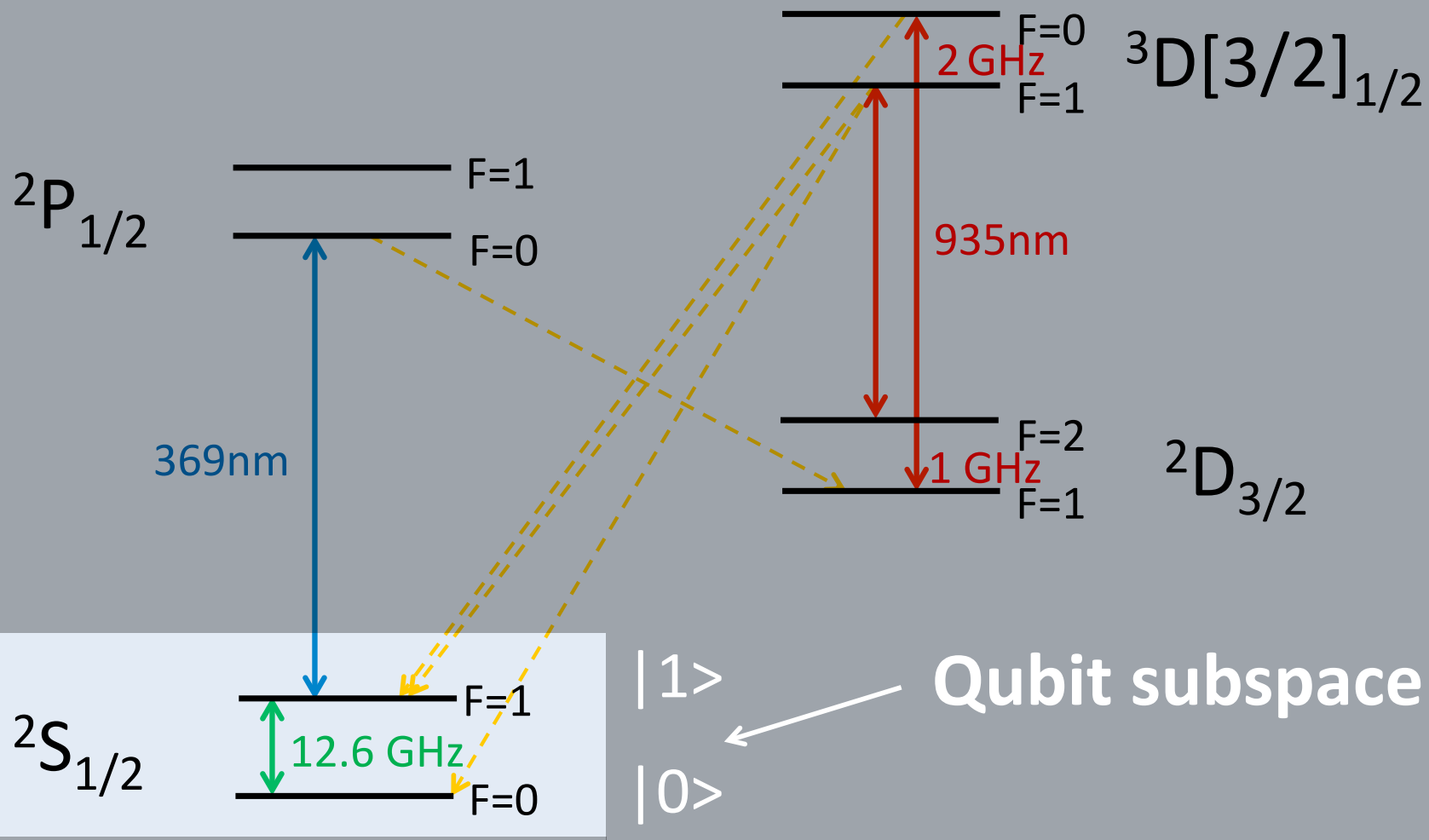
171Yb+ Qubit



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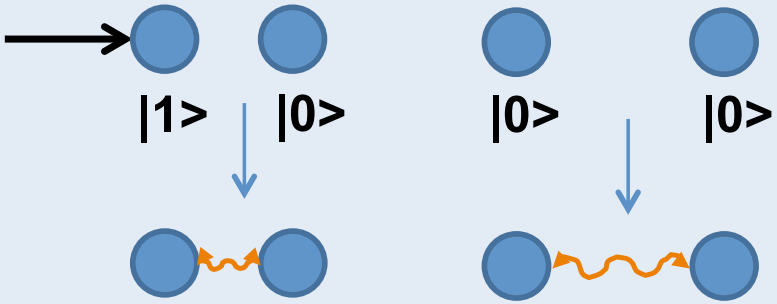
Gate operations

Ion-ion coupling achieved using state dependant force



State dependant force on ions

Coupling mediated via coulomb force

– State dependant force usually produced using laser beams

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Gate operations

The problems with lasers

- Noise
  - Intensity
  - spatial
  - frequency
  - phase

- Off resonant coupling

- Individual addressing

- Scalability

Solution – use microwaves with a static field gradient instead

Mintert, F. & Wunderlich, C. Phys. Rev. Lett. 87, 257904 (2001)

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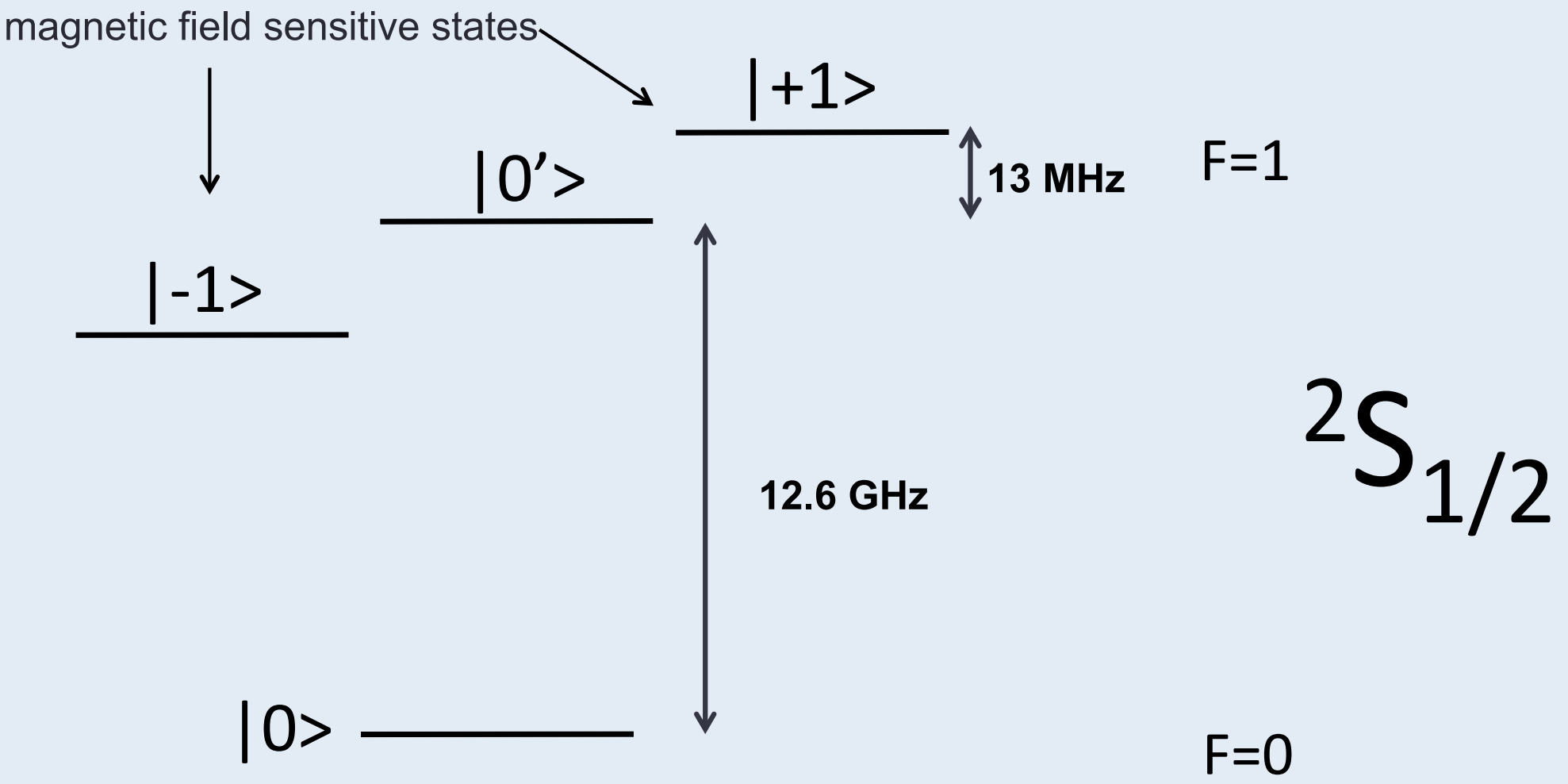
Qubit subspace



Mintert, F. & Wunderlich, C. Phys. Rev. Lett. 87, 257904 (2001)

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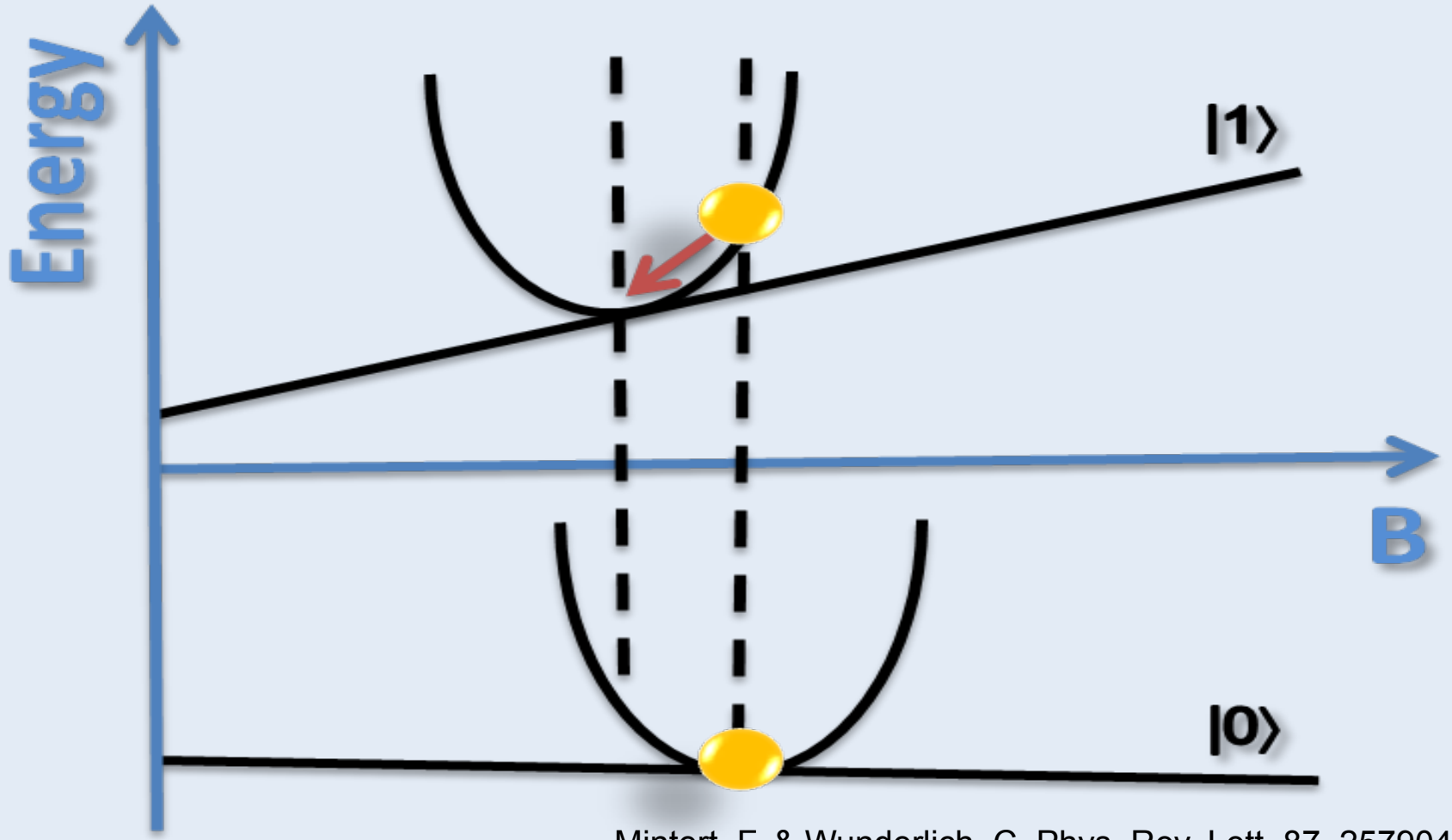
Motional coupling with a magnetic field gradient

Magnetic field gradient → shift in resultant trapping potential → state dependent force



Mintert, F. & Wunderlich, C. Phys. Rev. Lett. 87, 257904 (2001)

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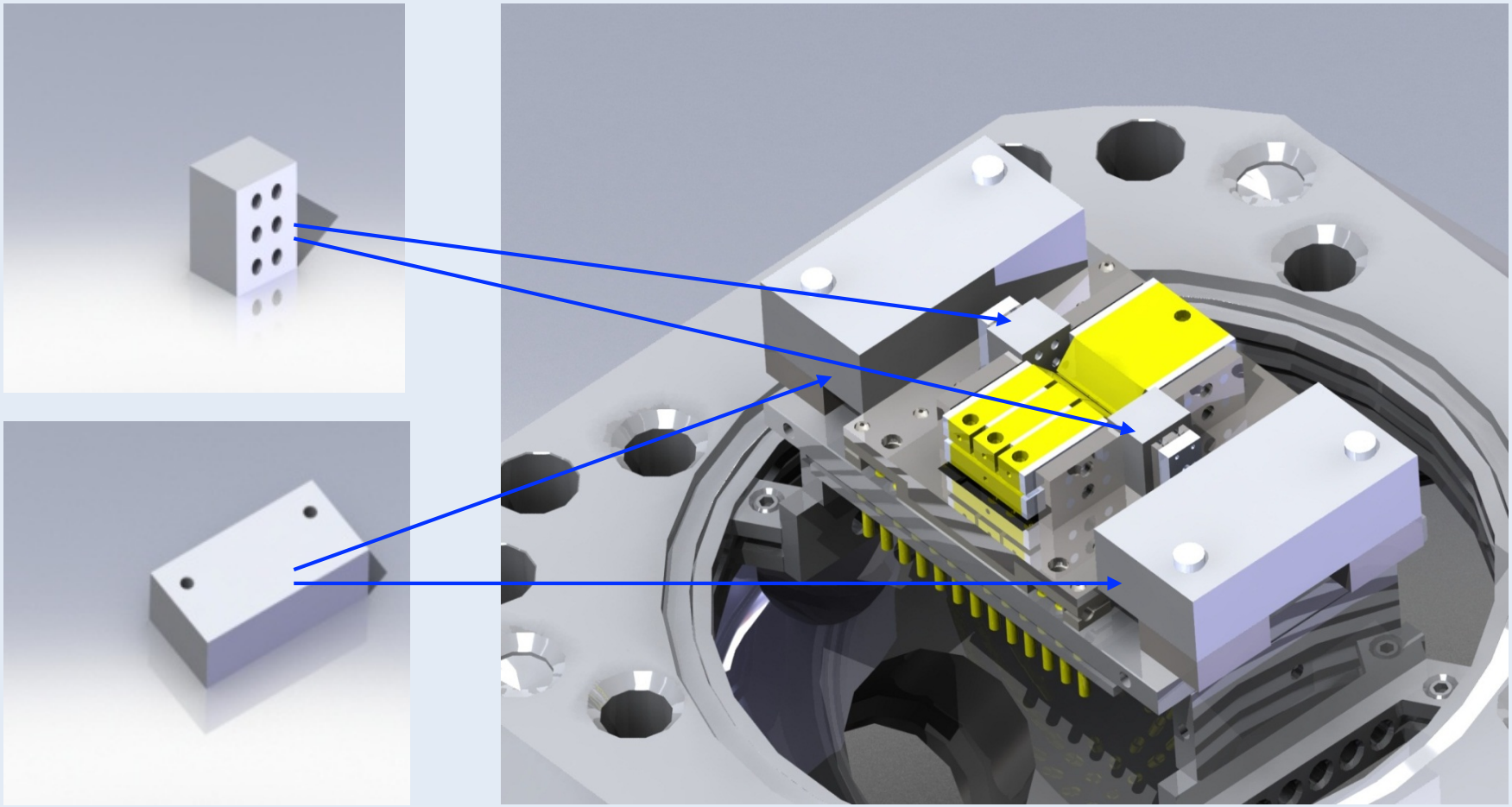
Creating a magnetic field gradient



Four Samarium Cobalt permanent magnets

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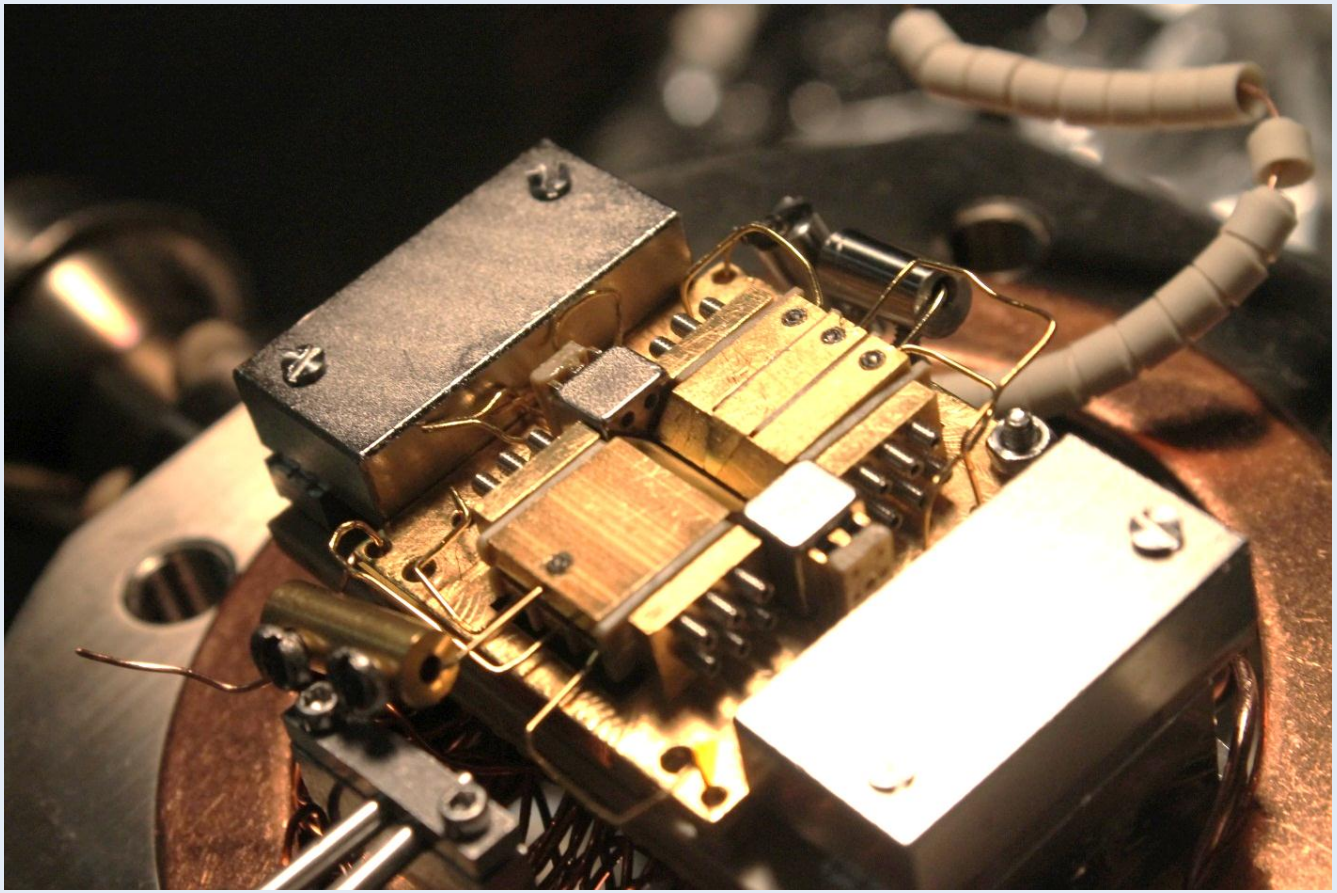
Creating a magnetic field gradient



Gradient: 24 T/m

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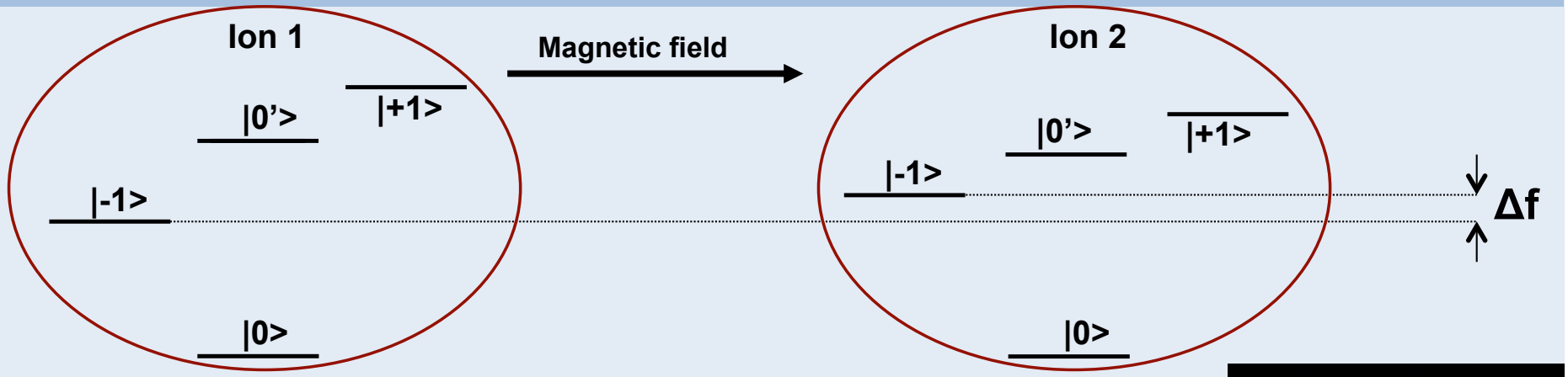
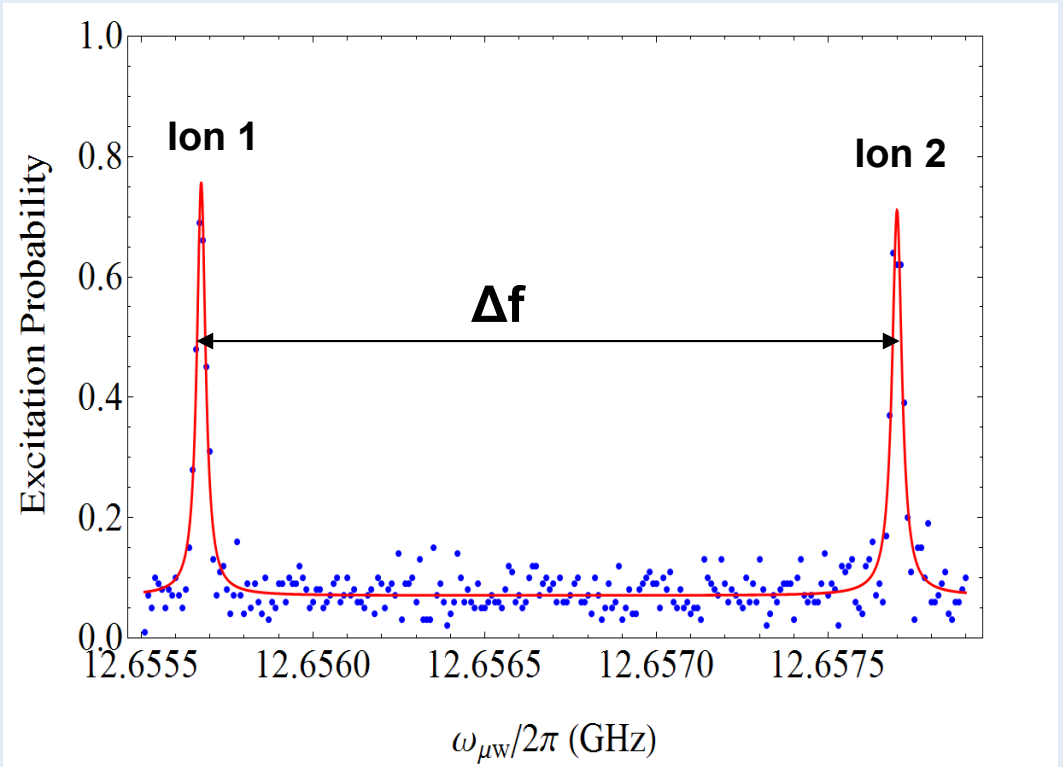
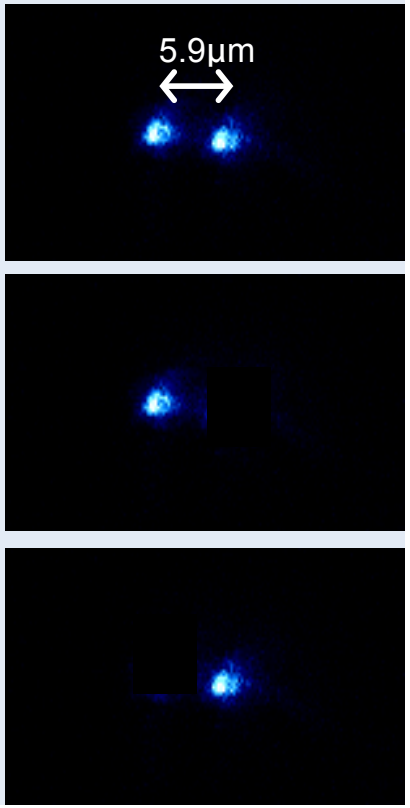
Individual addressing







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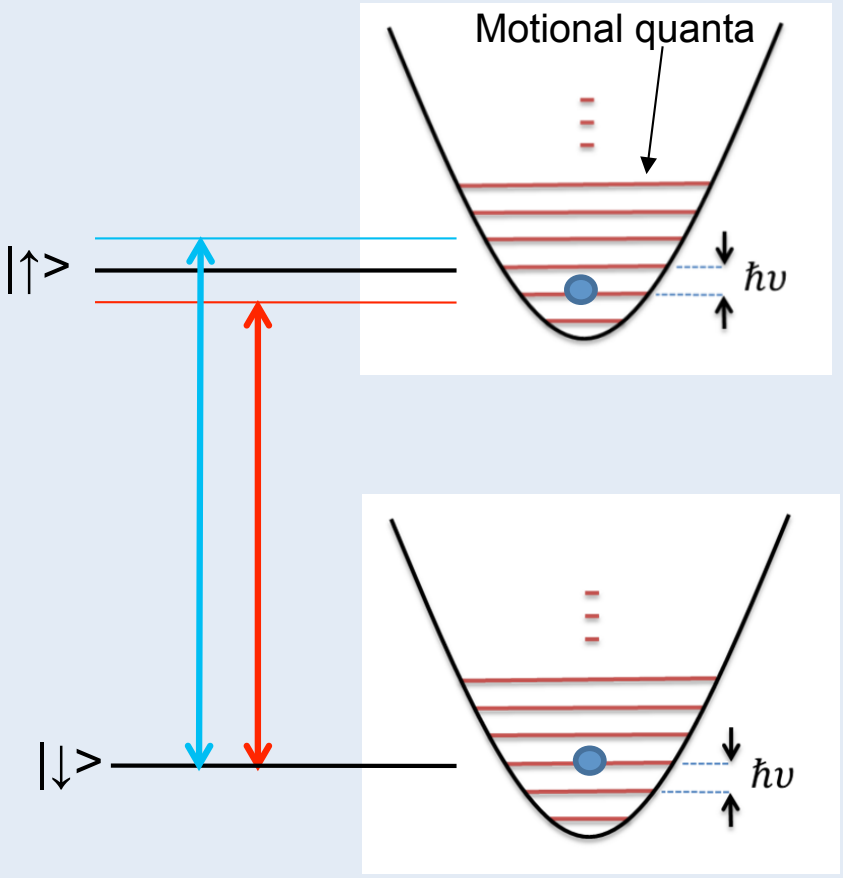
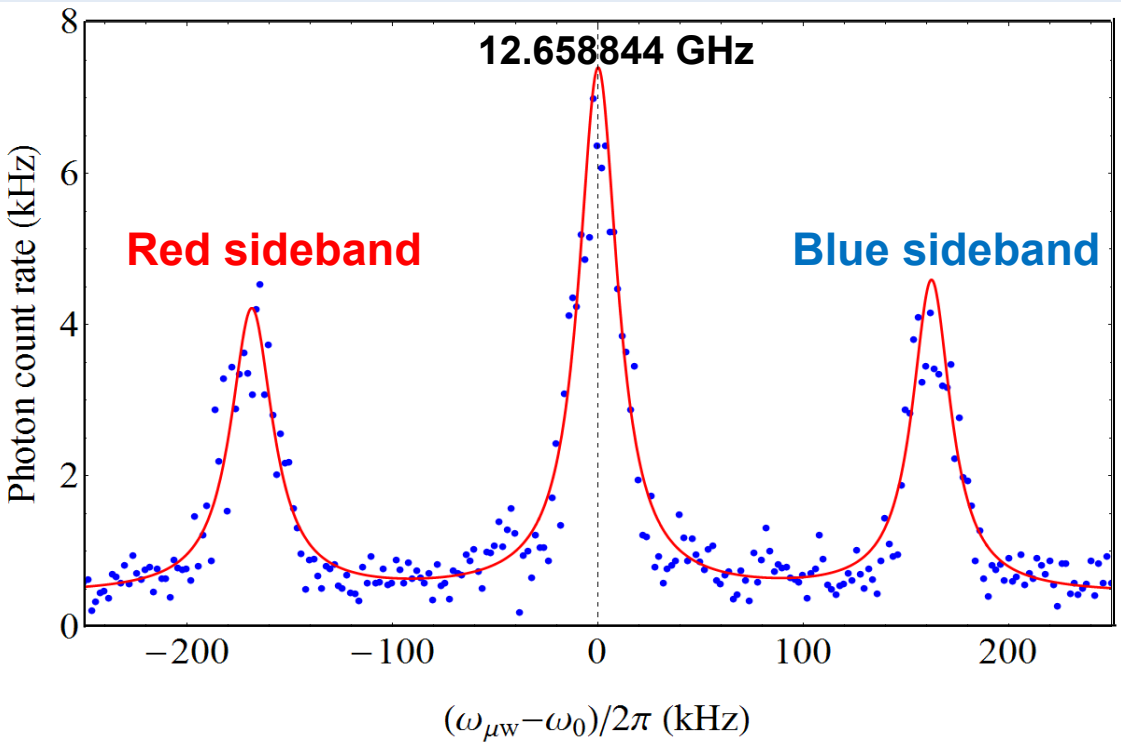
Resolving motional sidebands



Blue sideband – adds one motional quanta

Red sideband – takes one motional quanta



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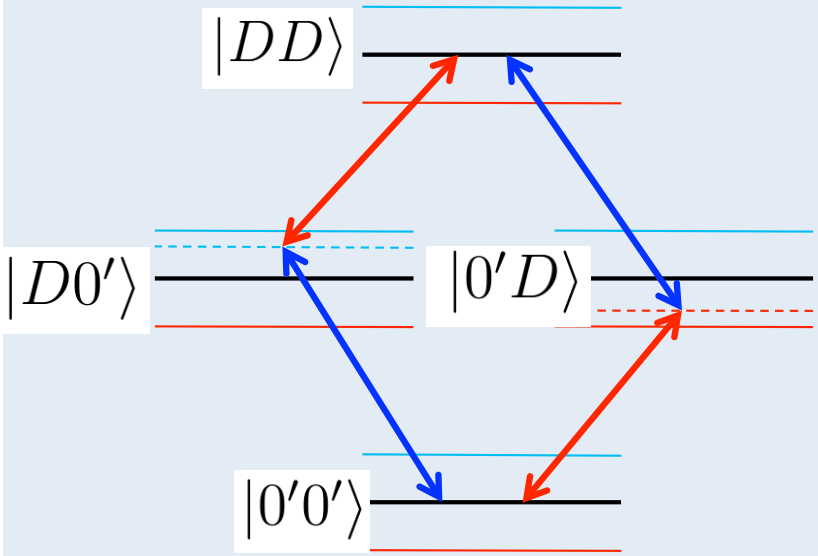
Resolving motional sidebands

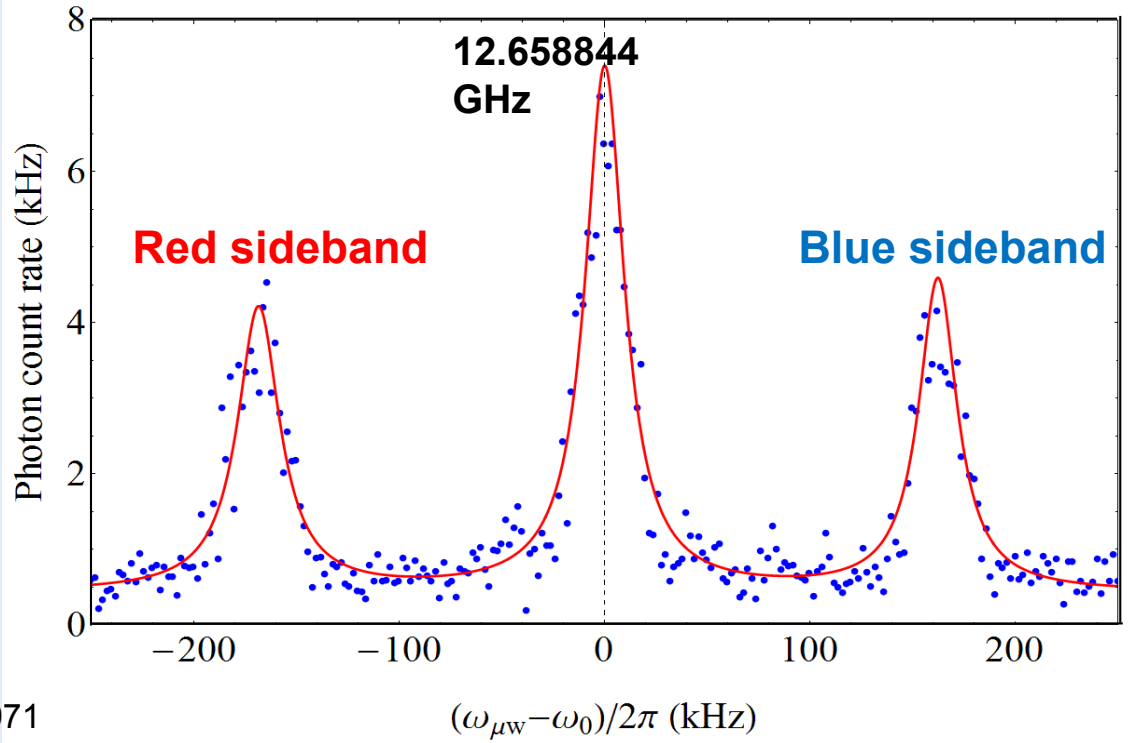
Red and blue motional sidebands = key requirement for entanglement gates



Mølmer and Sørensen gate

Apply red and blue sidebands together

→ Coherent two qubit transition which puts the ions in an entangled state



Sørensen, A., Mølmer, K., 1999. Phys. Rev. Lett. 82, 1971

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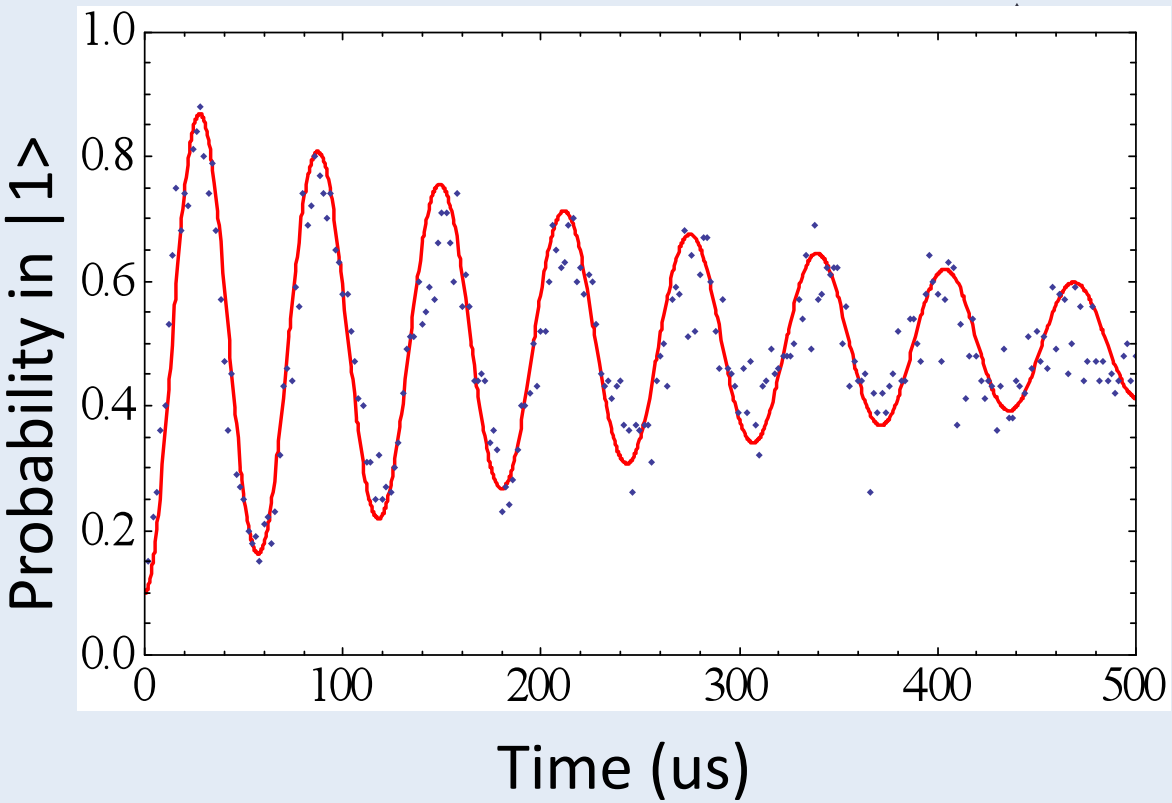
Decoherece



Fluctuations in the magnetic field cause uncontrolled phase rotations

$$\frac{1}{\sqrt{2}}(|+1\rangle + e^{i\phi(t)}\,|-1\rangle)$$

Gives rise to fast decoherence

Coherence time of magnetic field sensitive transition ~ 200us

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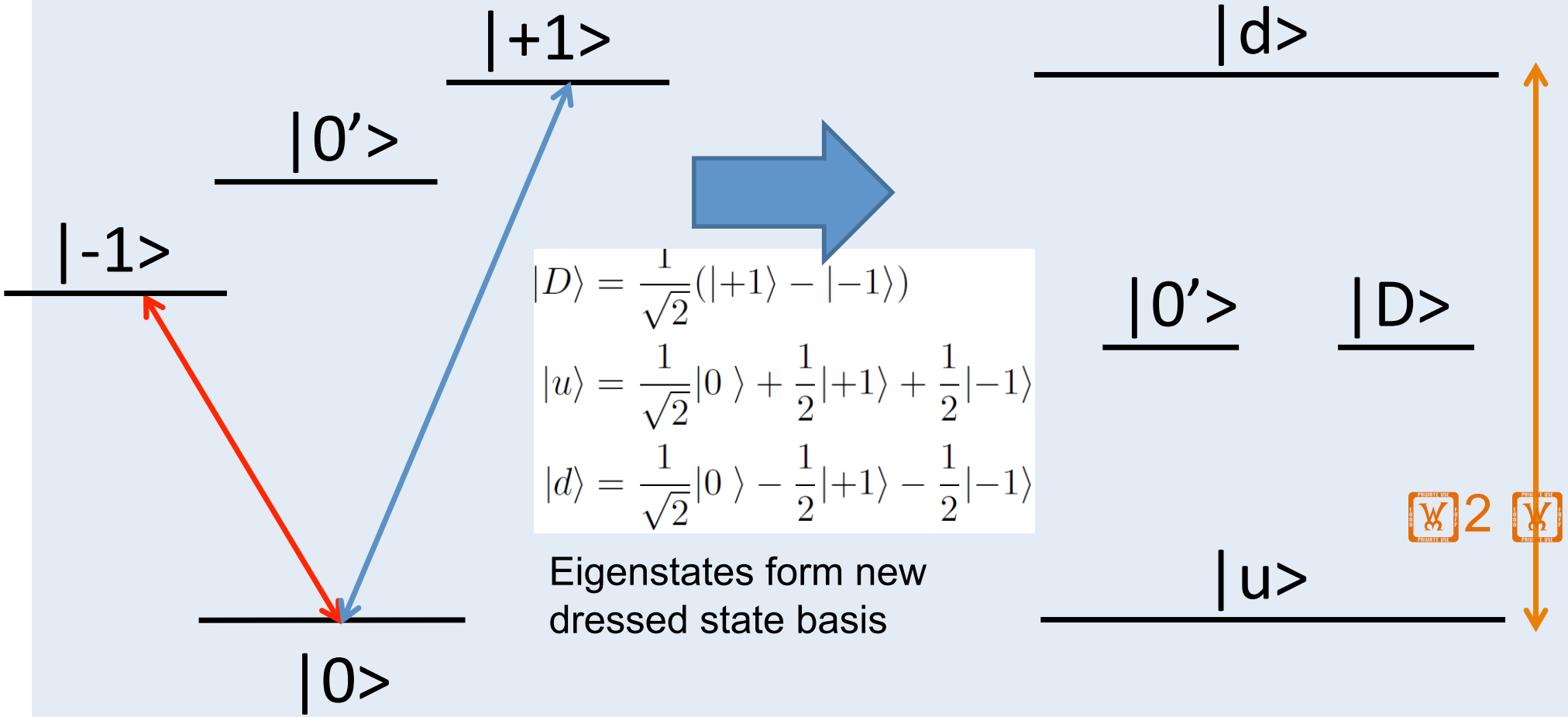
Microwave dressed states

Solution = Use microwave dressed-states

Microwave dressed-states: Superposition states between bare states and photons



$$|D\rangle = \frac{1}{\sqrt{2}}(|+1\rangle - |-1\rangle)$$

$$|u\rangle = \frac{1}{\sqrt{2}}|0\rangle + \frac{1}{2}|+1\rangle + \frac{1}{2}|-1\rangle$$

$$|d\rangle = \frac{1}{\sqrt{2}}|0\rangle - \frac{1}{2}|+1\rangle - \frac{1}{2}|-1\rangle$$

Eigenstates form new dressed state basis

*N. Timoney, I. Baumgart, M. Johanning, A. F. Varon, M. B. Plenio, A. Retzker, and C. Wunderlich, Nature 476, 185 (2011)

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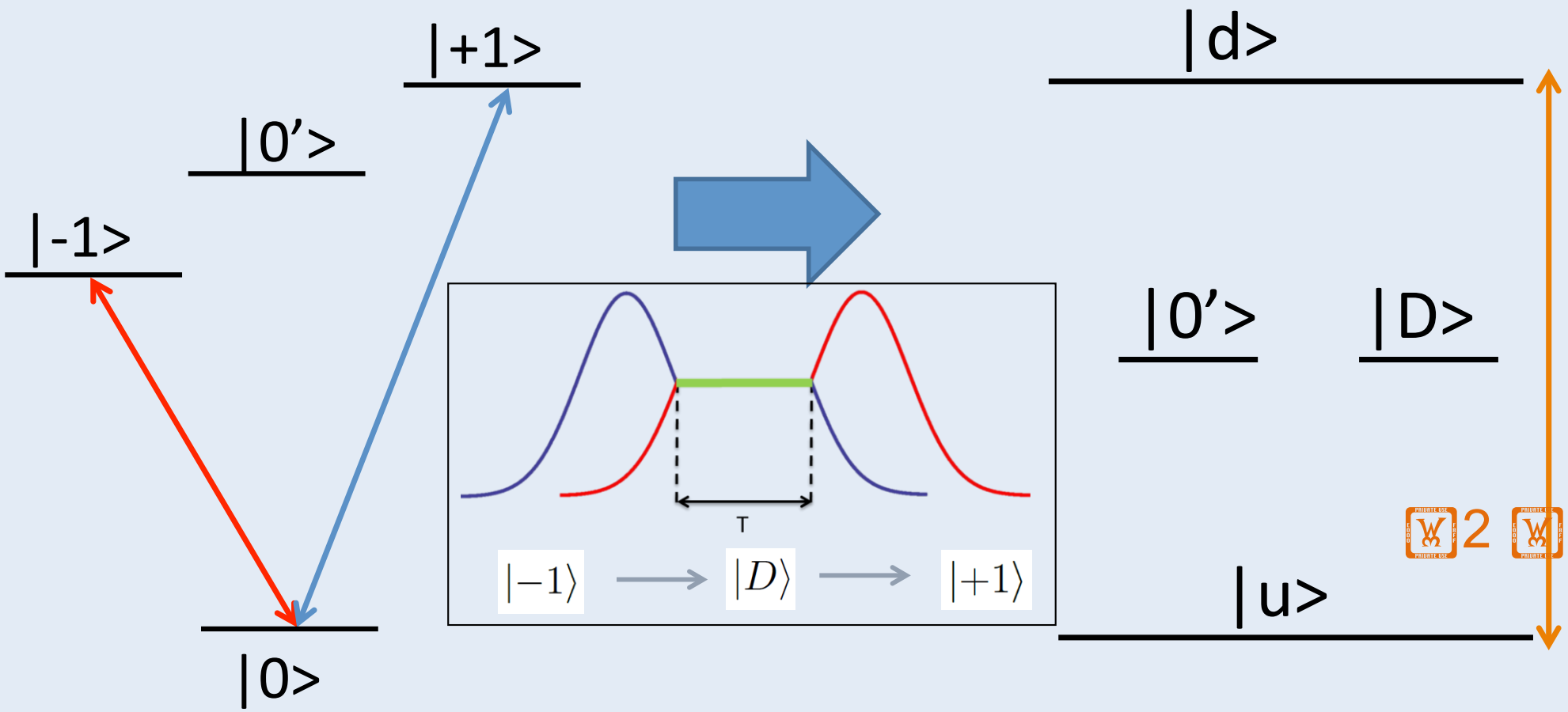
Microwave dressed states



Bare states mapped to dressed states using STIRAP pulses

*N. Timoney, I. Baumgart, M. Johanning, A. F. Varon, M. B. Plenio, A. Retzker, and C. Wunderlich, Nature 476, 185 (2011)

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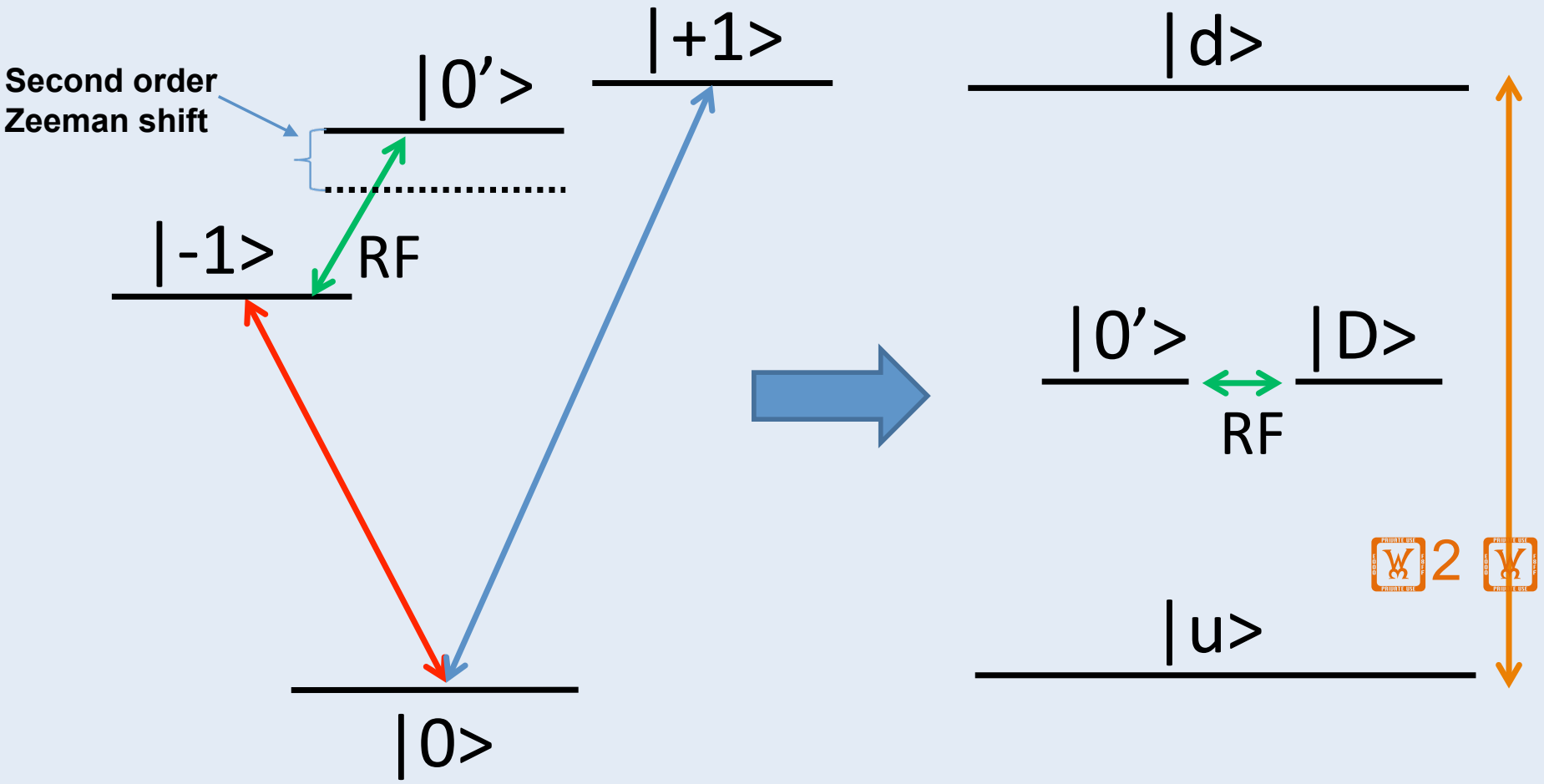
Coherent manipulation within microwave dressed states



Add a single additional RF field to perform Rabi flopping between qubit states

* S. C. Webster, S. Weidt, K. Lake, J. J. McLoughlin and W. K. Hensinger, arXiv:1303.3798, accepted for publication into PRL (2013)

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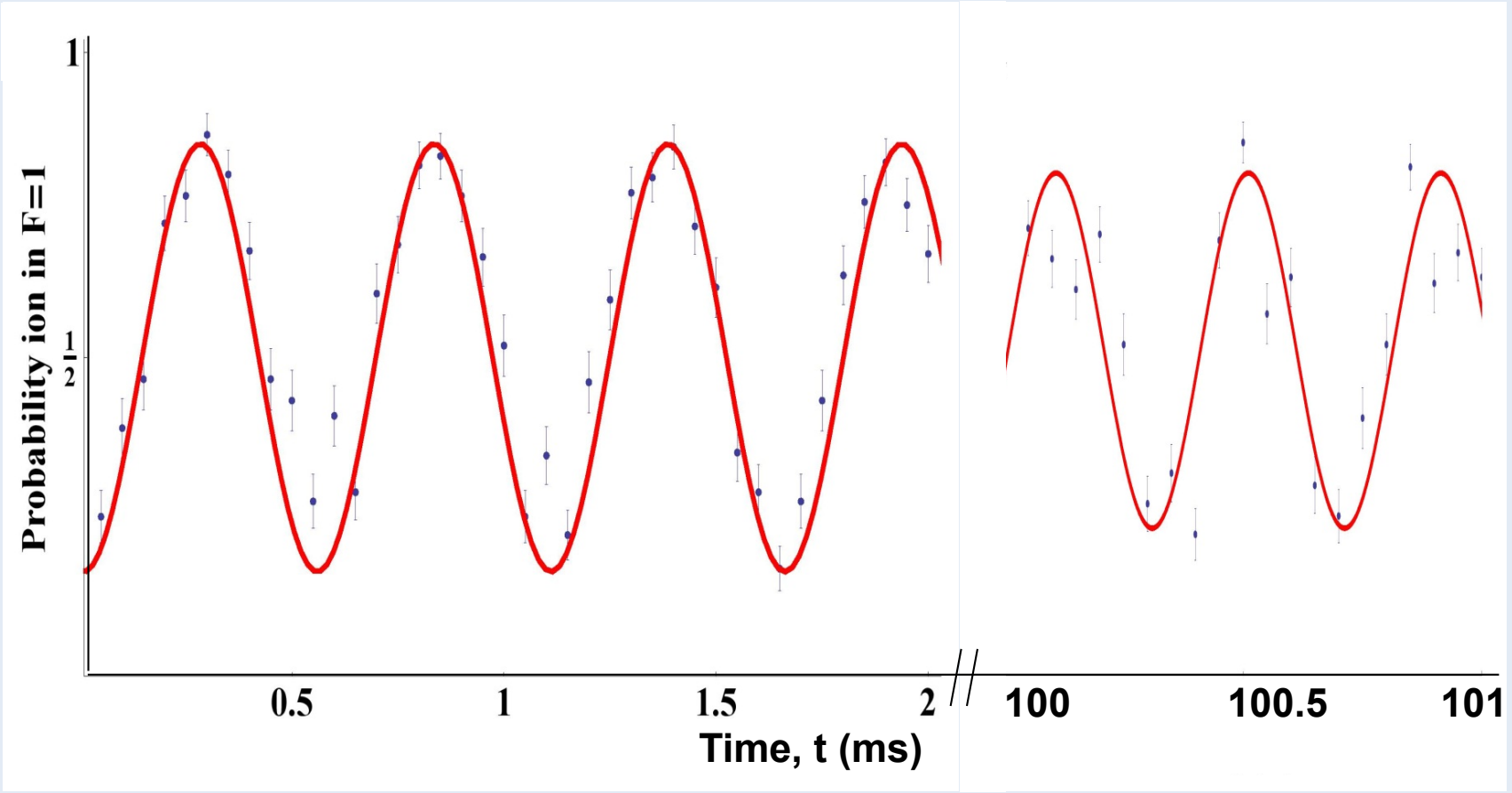
Coherent manipulation within microwave dressed states

Coherence measurement within dressed-state



Coherence time ~500 ms

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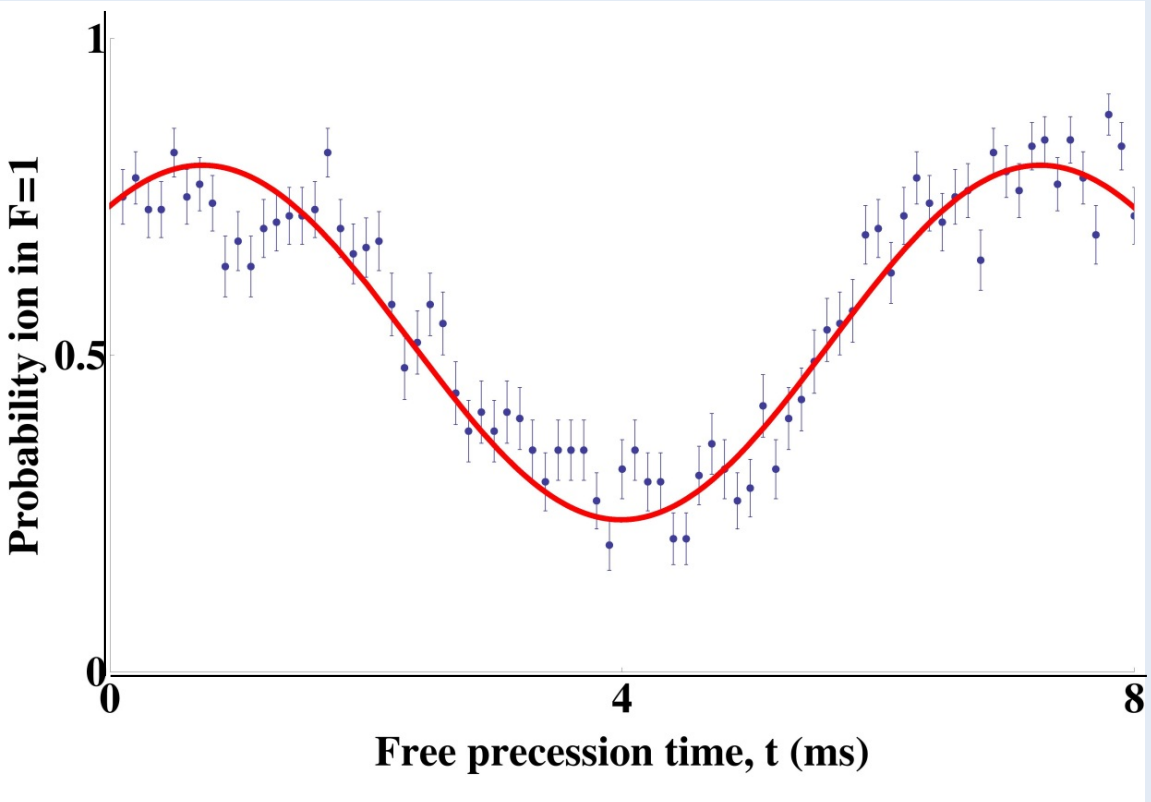
Coherent manipulation within microwave dressed states

Ramsey fringes



Demonstrates ability to fully manipulate Bloch sphere within dressed state

* S. C. Webster, S. Weidt, K. Lake, J. J. McLoughlin and W. K. Hensinger, arXiv:1303.3798, accepted for publication into PRL (2013)

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2-Dimensional ion trap lattice

Uses

- E/B-field sensing
- Force sensing
- Quantum simulations
- Cluster state quantum computing
- Protein sorting

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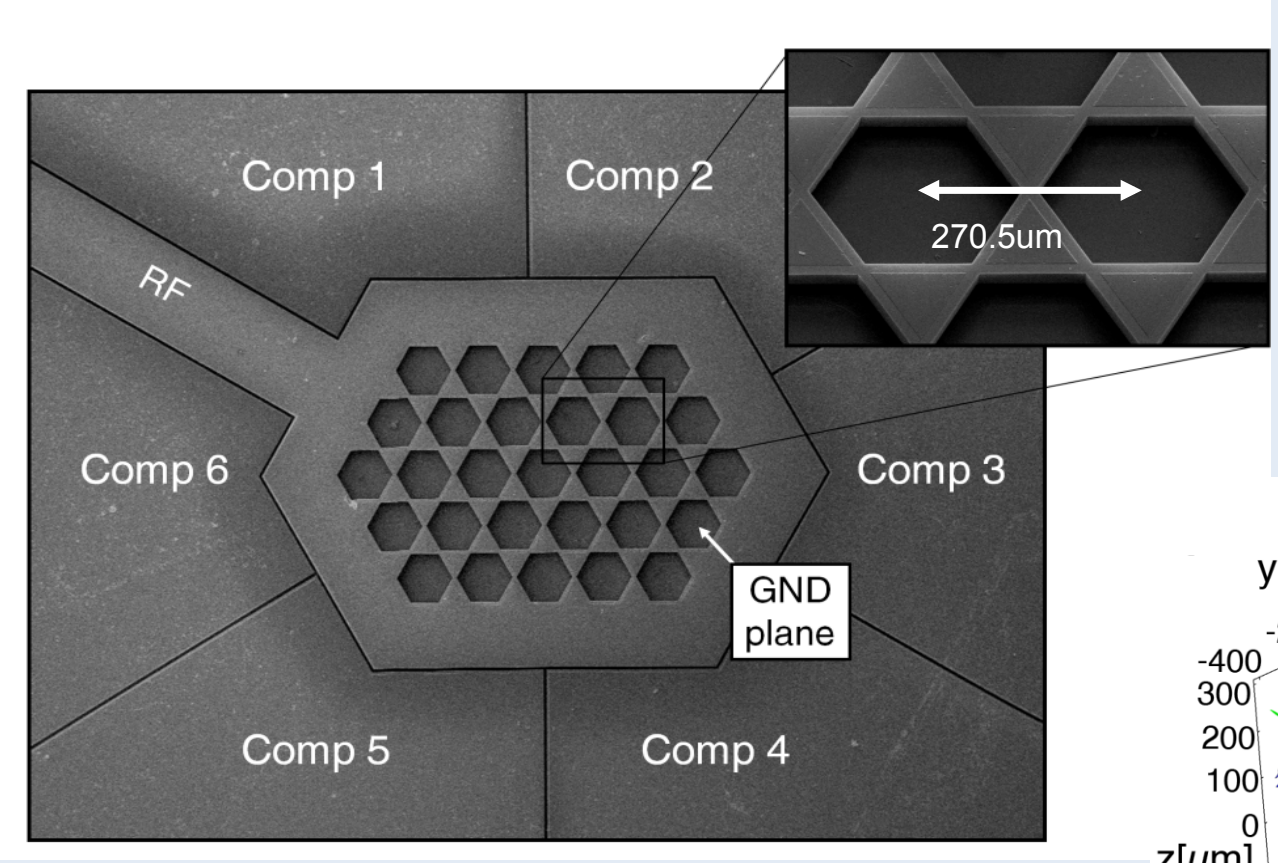
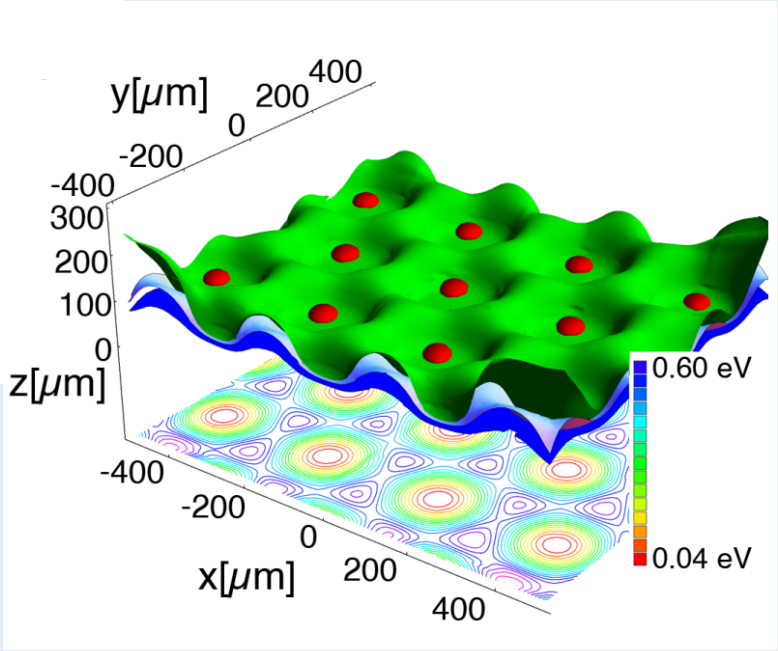
2-Dimensional ion trap lattice





*R. C. Sterling, H. Rattanasonti, S. Weidt, K. Lake, P. Srinivasan, M. Kraft and W. K. Hensinger, arXiv:1302.3781v4 (2013)

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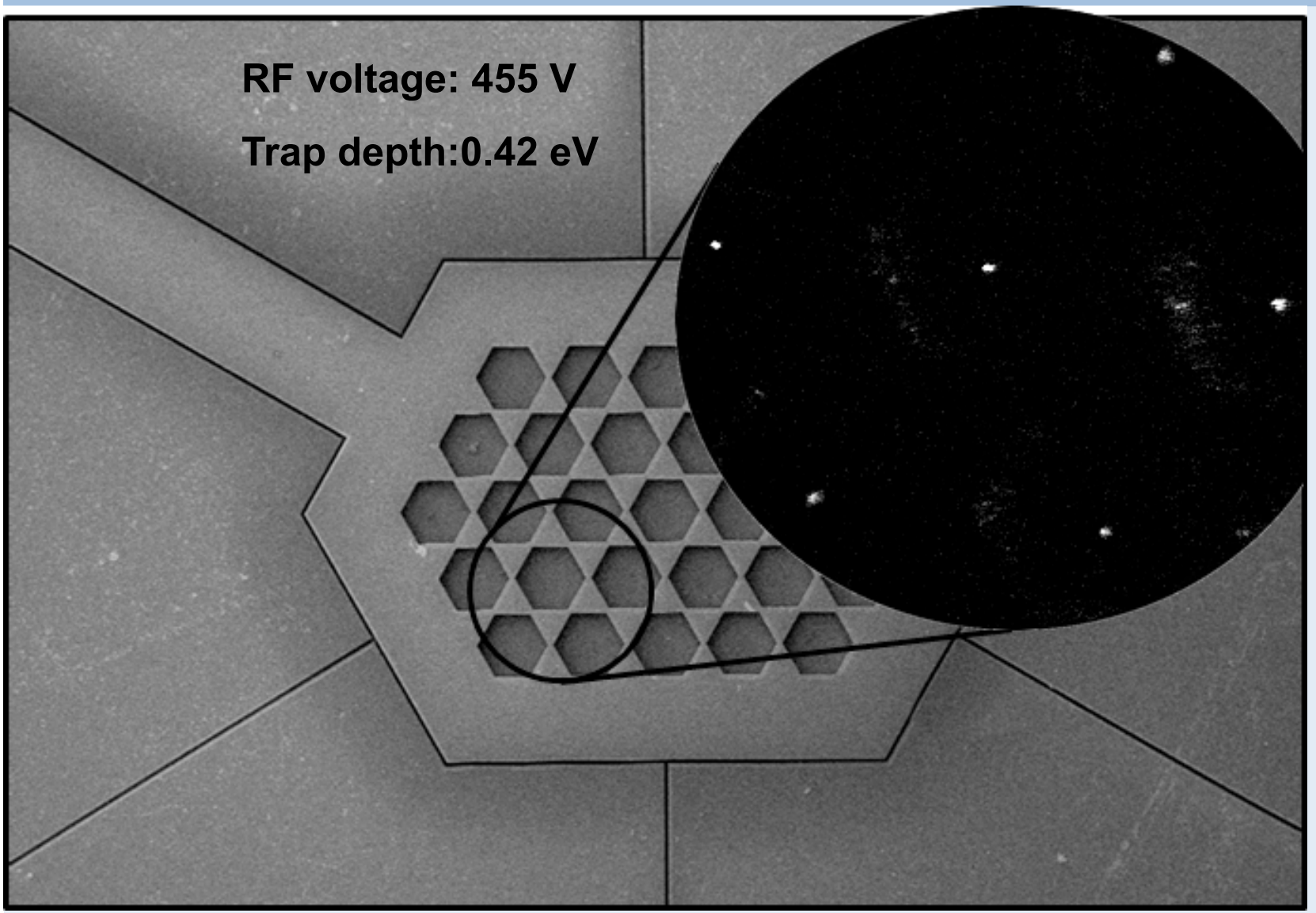
2-Dimensional ion trap lattice



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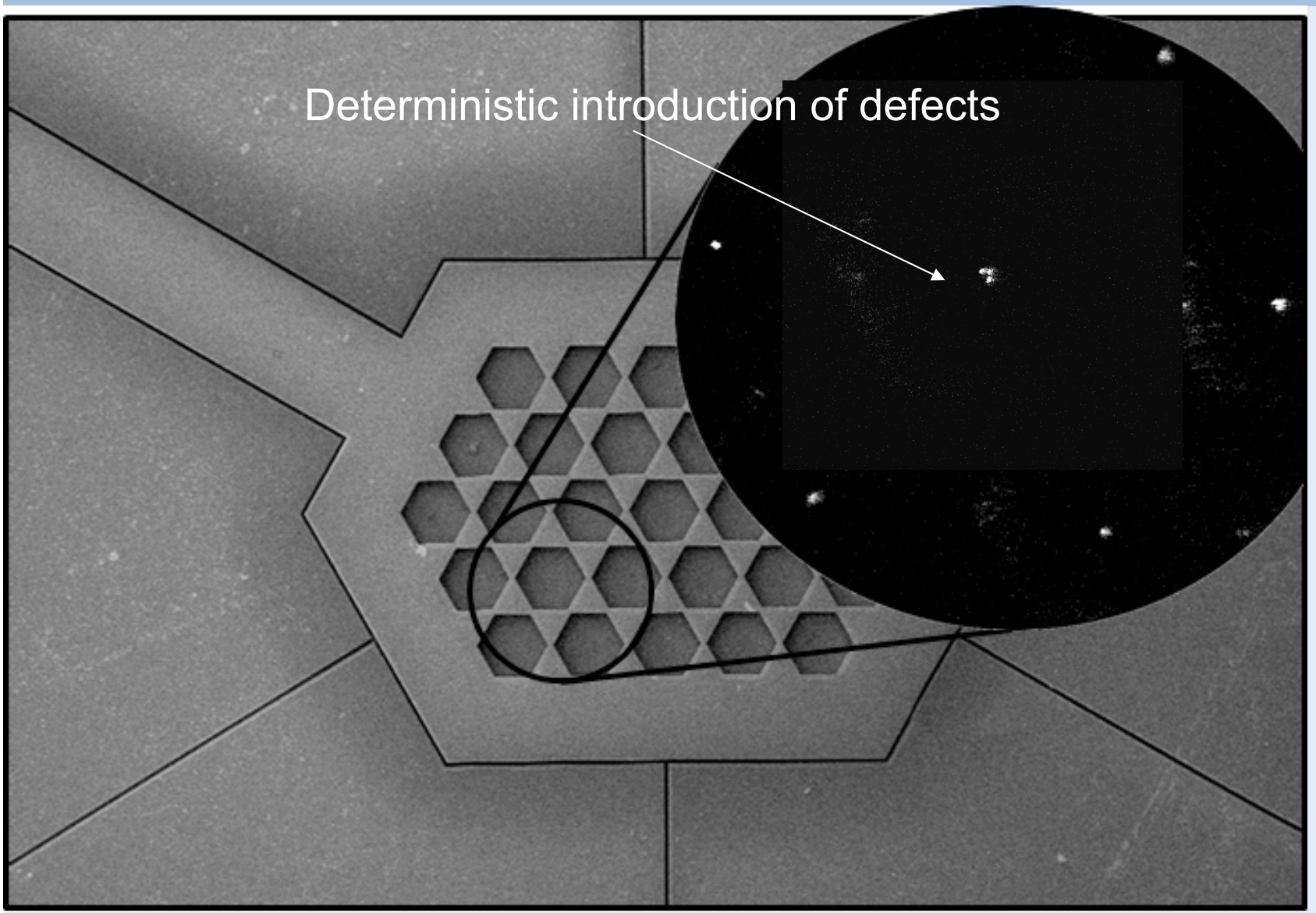
2-Dimensional ion trap lattice



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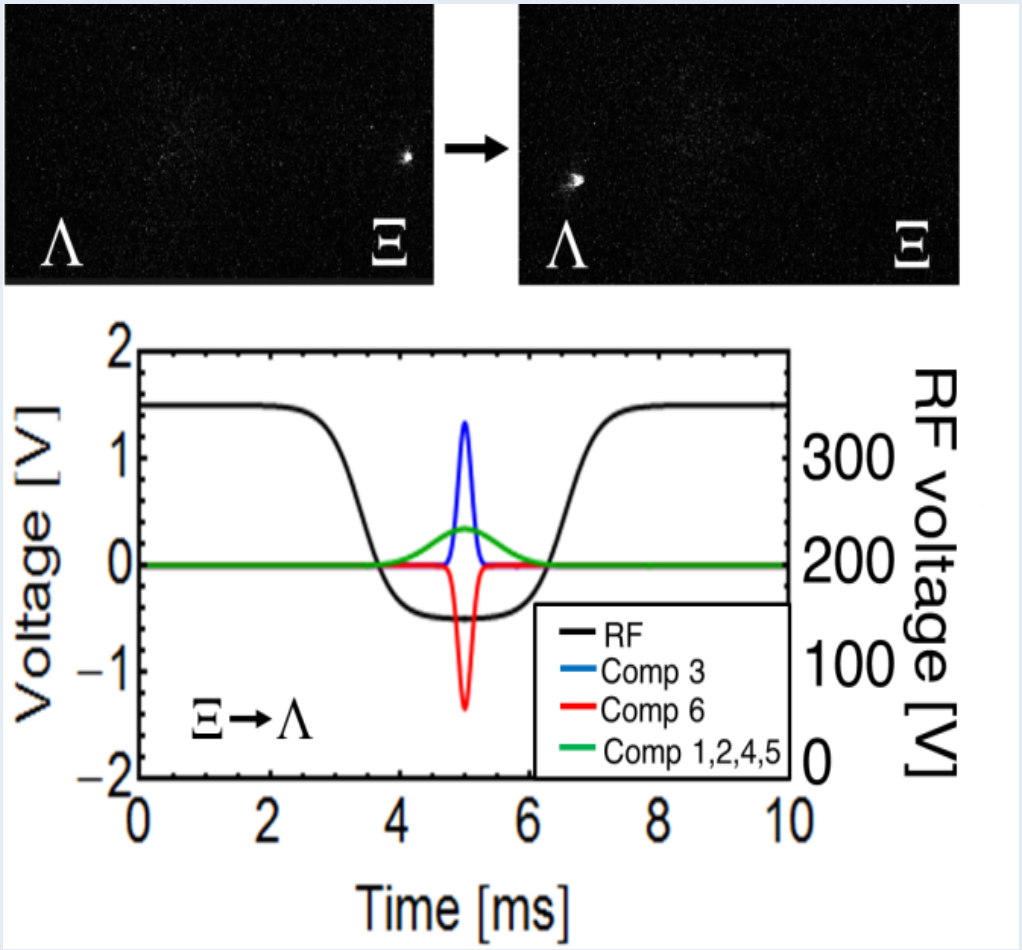
2-Dimensional ion trap lattice

- Site to site shuttling



*R. C. Sterling, H. Rattanasonti, S. Weidt, K. Lake, P. Srinivasan, M. Kraft and W. K. Hensinger, arXiv:1302.3781v4 (2013)

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2-Dimensional ion trap lattice

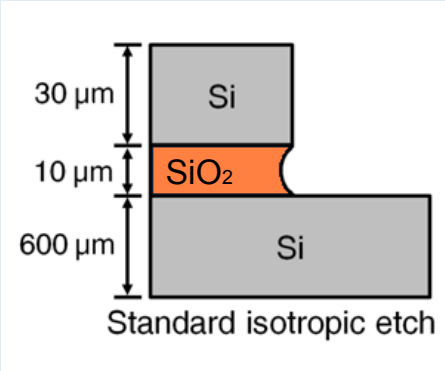
Ultra-high breakdown voltages

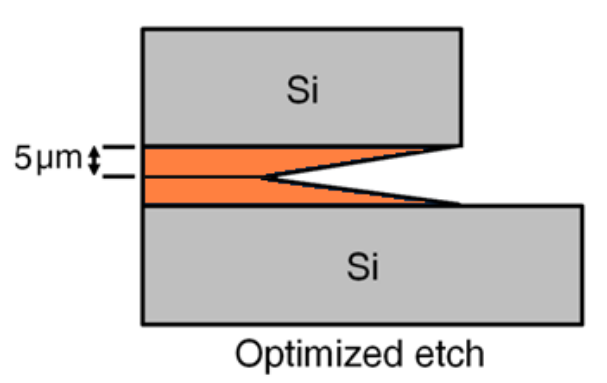
- Voltage breakdown occurs ver . . . . . insulator surface.
- Use two SiO2 insulator layers together . instead of one layer.
- Increased etch rate along interface . . . . when exposing handle layer.

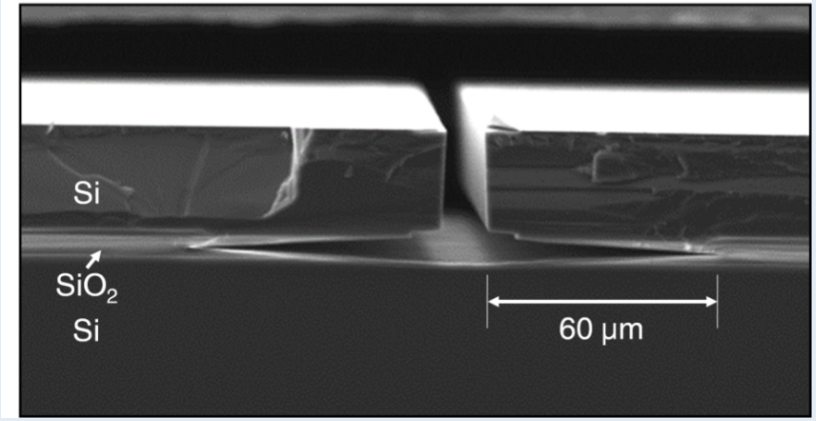
Vdc = 1298(5) V

Vrf = 1061(32) V

Order of magnitude greater than previously achieved







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Vdc = 1298(5) V

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Order of magnitude greater than previously achieved

Applications

- MEMS devices
- Larger trap depths
- Lower heating rates
- Thrusters arrays
- Protein sorting

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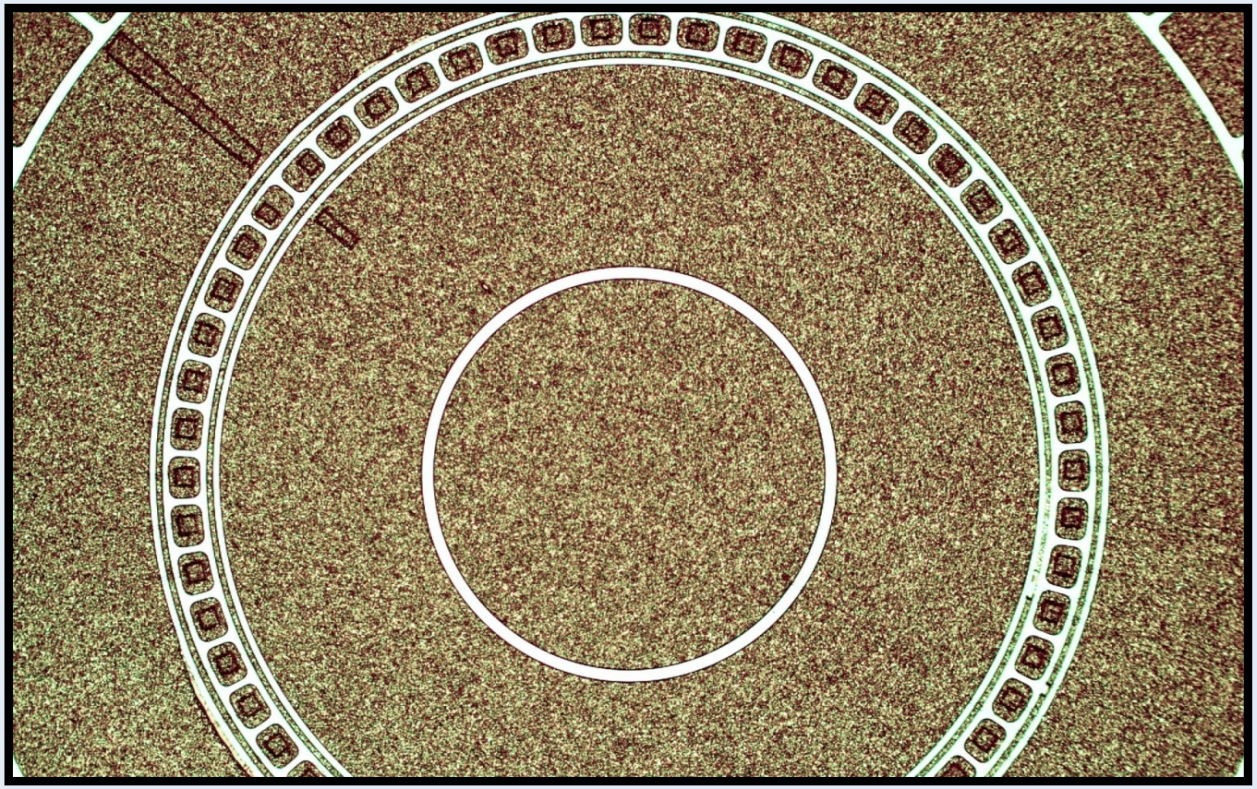
Ring Trap

Uses - Quantum simulations eg - Homogeneous Kibble-Zurek mechanism.
- Space time crystals
- Hawking's radiation



- Inner segmented static . . . . . electrodes
- Buried static and rf wires

- Periodic boundary . . . . . conditions
- No RF field mismatch

Marcus Hughes (Sussex), Jessica Maclean (Nottingham), Seb Weidt (Sussex),
Chris Mellor (Nottingham), Winfried Hensinger (Sussex)

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Summary

- Realised magnetic gradient induced coupling.
- Reduced our decoherence by 2 orders of nagnitude . . . . . using microwave dressed-states.
- New method of dressed state coherent nanipulation . . . . which allows for full manipulation o e Bloch sphere.

Demonstrated first 2-Dimensional ion trap array on a . . . . microchip.

- Progress towards an operational homogeneous ring trap.

We gratefully acknowledge funding from

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EPSRC
Engineering and Physical Sciences Research Council

Department of the Army · United States of America · 1775

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SEVENTH FRAMEWORK PROGRAMME

European Commission

MARIE CURIE ACTIONS

IOTA
ION TRAPS FOR TOMORROW'S APPLICATIONS

cost
European Science Foundation

The Nuffield Foundation