

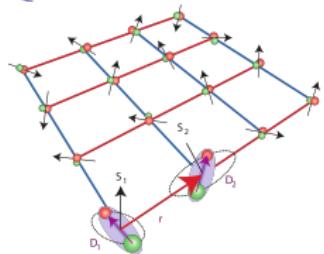
Building Single Molecules from Single Atoms

Yichao Yu

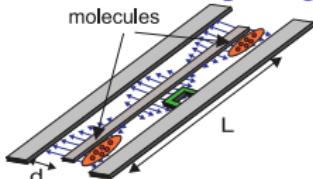
Ni Group/Harvard

Jul. 2020

Quantum Simulation



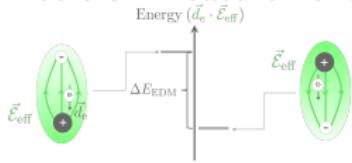
Quantum Computing



PRL. 97, 33003 (2006)

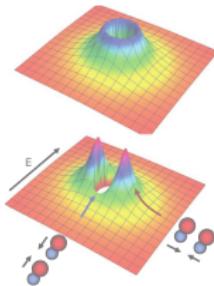
Nat. Phys. 2, 341 (2006)

Precision Measurement



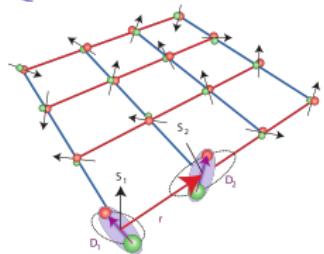
Science 343, p. 269-272 (2014)

Quantum Chemistry



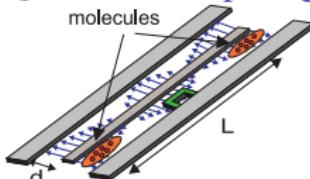
Nature 464, 1324 (2010)

Quantum Simulation



Nat. Phys. 2, 341 (2006)

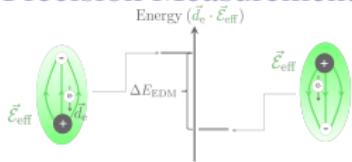
Quantum Computing



PRL. 97, 33003 (2006)

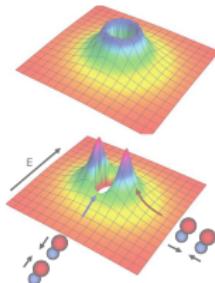
- Full quantum control
- Entanglement
- ...

Precision Measurement



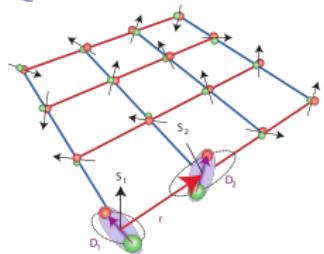
Science 343, p. 269-272 (2014)

Quantum Chemistry



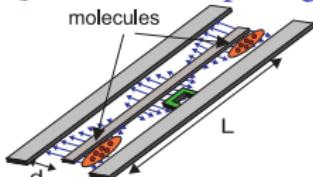
Nature 464, 1324 (2010)

Quantum Simulation



Nat. Phys. 2, 341 (2006)

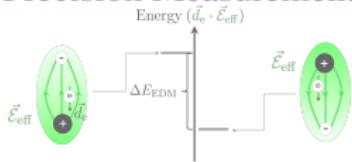
Quantum Computing



PRL. 97, 33003 (2006)

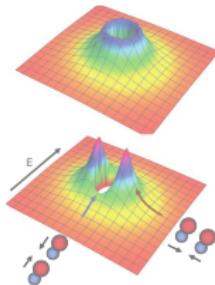
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Science 343, p. 269-272 (2014)

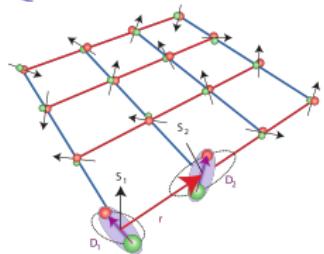
Quantum Chemistry



Nature 464, 1324 (2010)

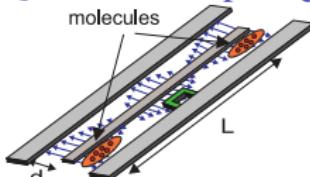
New Approach?

Quantum Simulation



Nat. Phys. 2, 341 (2006)

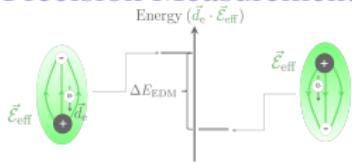
Quantum Computing



PRL. 97, 33003 (2006)

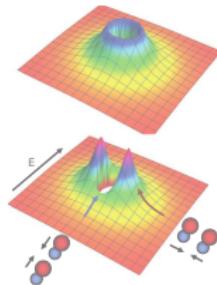
- Full quantum control
- Entanglement
- ...

Precision Measurement



Science 343, p. 269-272 (2014)

Quantum Chemistry



Nature 464, 1324 (2010)

New Approach!

Entanglement

Single particle control

Entanglement

i.e. interaction

Single particle control

Entanglement

i.e. interaction

Single particle control

Dipolar molecules

Dipolar molecules

- Strong and tunable interaction
($\approx k\text{Hz}$ at $\approx \mu\text{m}$ distance)
 - ▶ Fast gate operations
 - ▶ Long coherence time
- Rich internal structure
(Electronic, vibrational,
rotational, hyperfine, etc.)

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Single particle control

Optical tweezers

Entanglement

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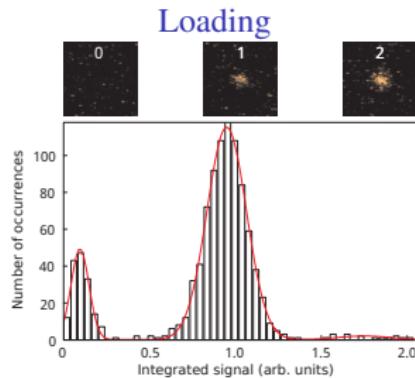
- Single site resolution



Entanglement

i.e. interaction

Dipolar molecules



Nat. Phys. 6, 951 (2010)

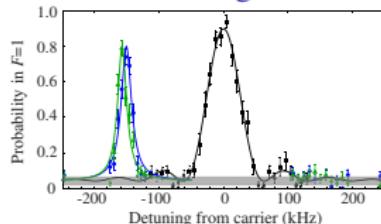
Single particle control

Optical tweezers

- Single site resolution

- ...

Cooling



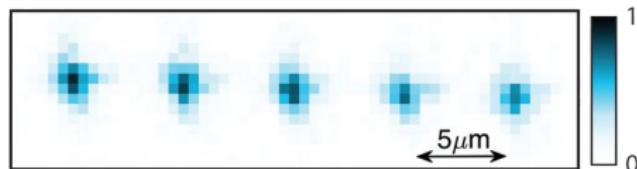
PRX. 2, 041014 (2012)

Rearranging



Ultracold molecule in tweezers

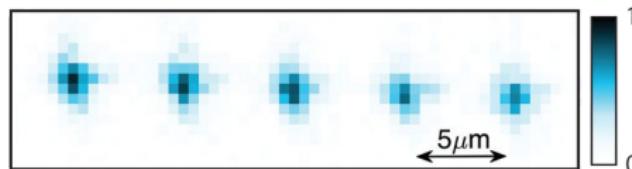
Direct cooling



Science 365, 1156 (2019)

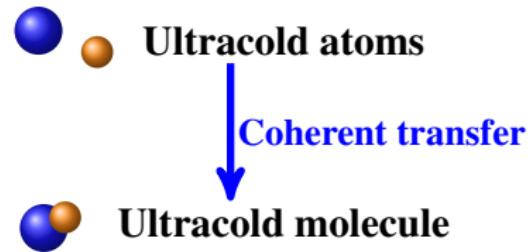
Ultracold molecule in tweezers

Direct cooling



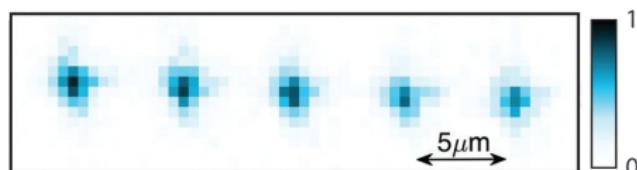
Science 365, 1156 (2019)

Assembly



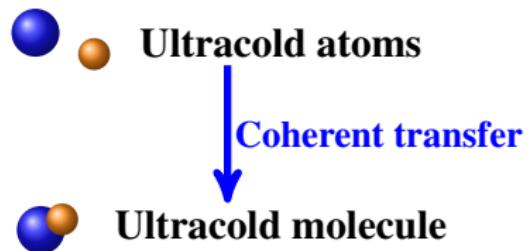
Ultracold molecule in tweezers

Direct cooling



Science 365, 1156 (2019)

Assembly

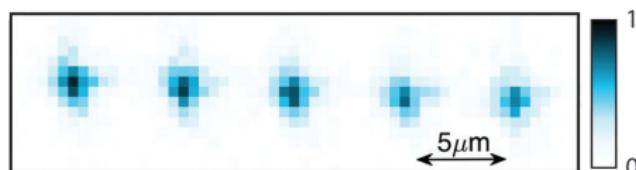


Challenges

- Temperature in tweezers
- Quantum control

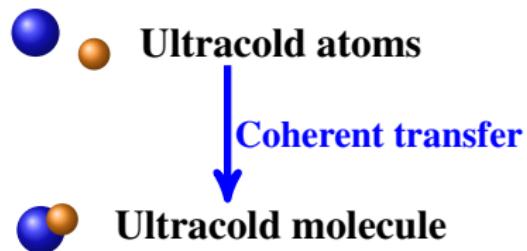
Ultracold molecule in tweezers

Direct cooling



Science 365, 1156 (2019)

Assembly



Challenges

- Temperature in tweezers
- Quantum control
- Creating molecules
- Maintain coherence

Outline

1 Experiment overview

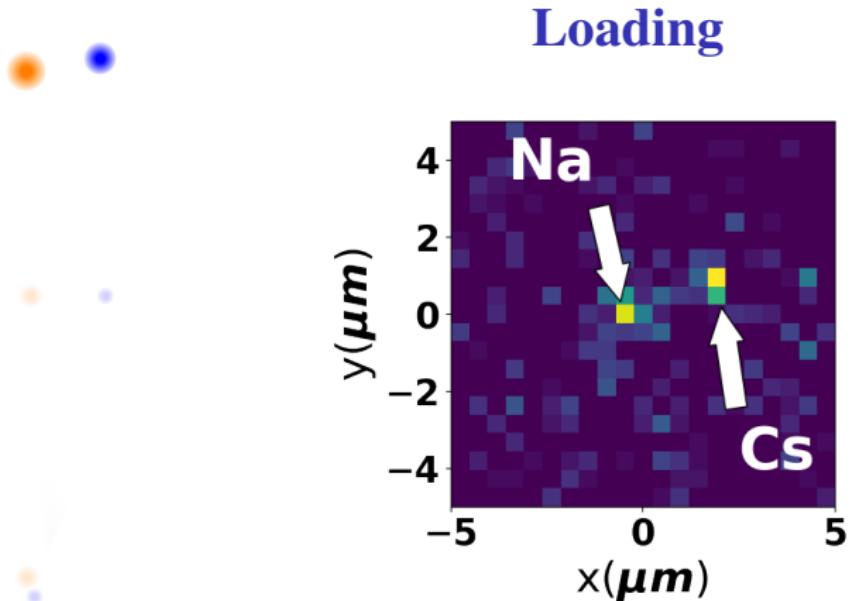
2 Atom state control

- Raman sideband cooling of Na atoms

3 Optical molecule creation

4 Conclusion

Experiment overview

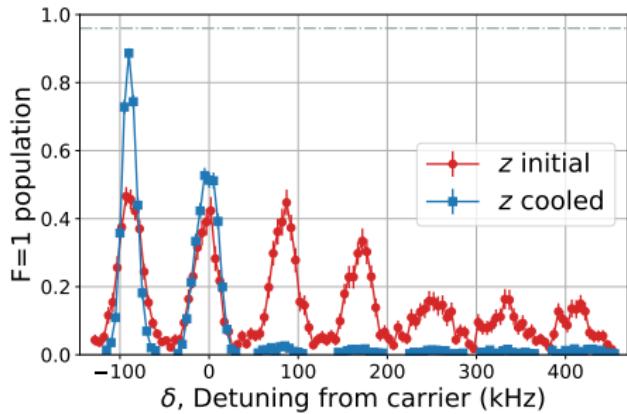


Loading probability per site: 60%
Post select on initial and final state.

Experiment overview



Cooling



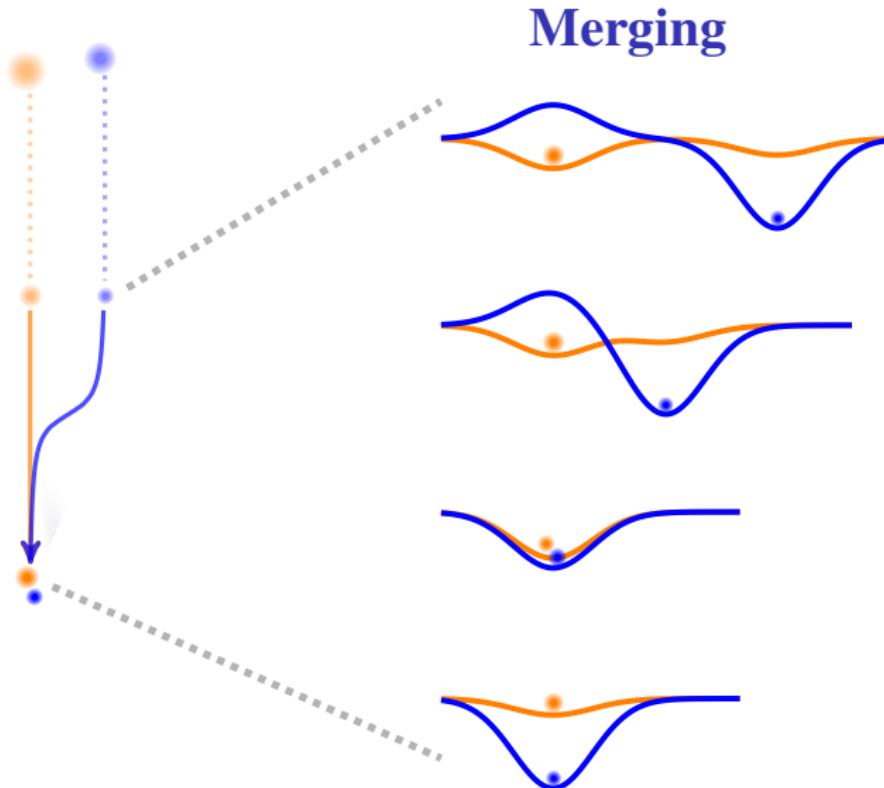
Cs: 96% ground state¹

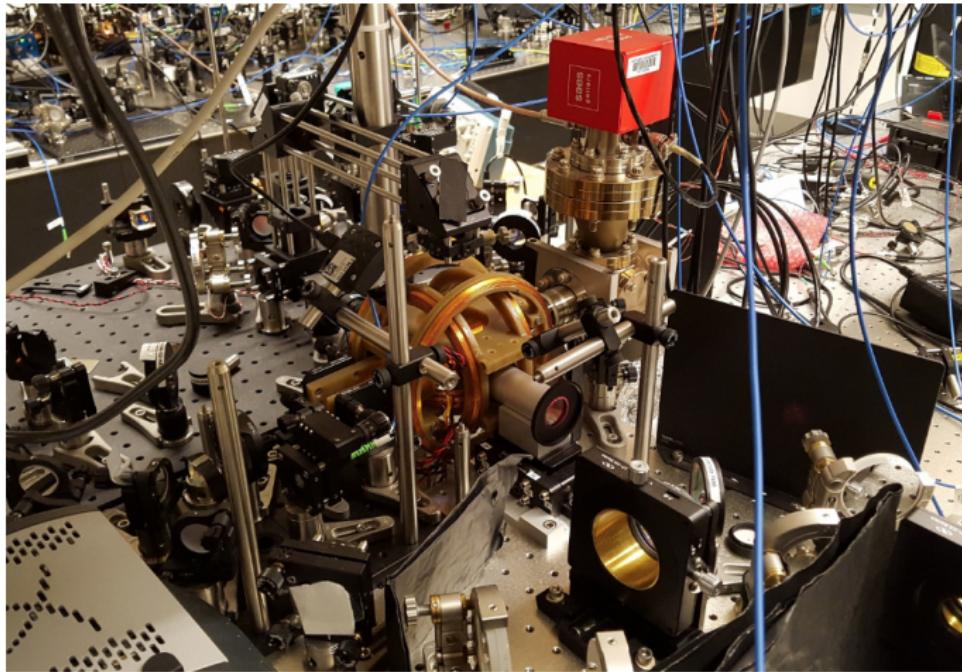
Na: 94% ground state²

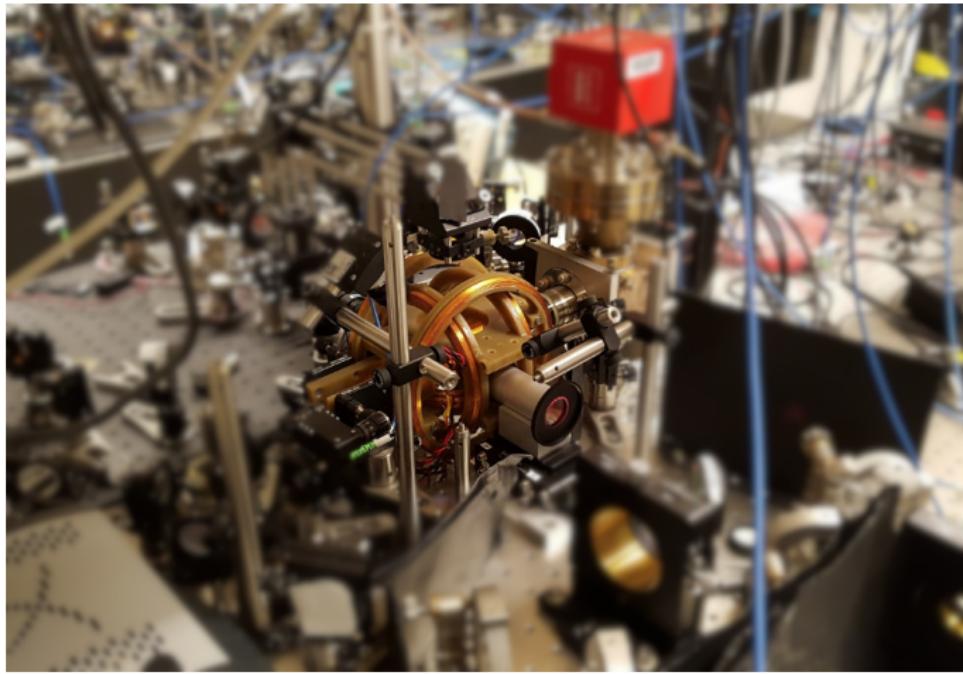
¹Phys. Rev. X 9, 021039

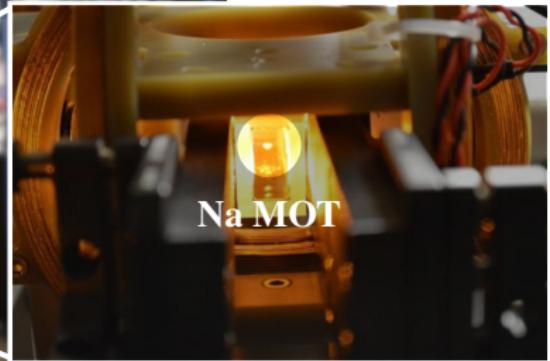
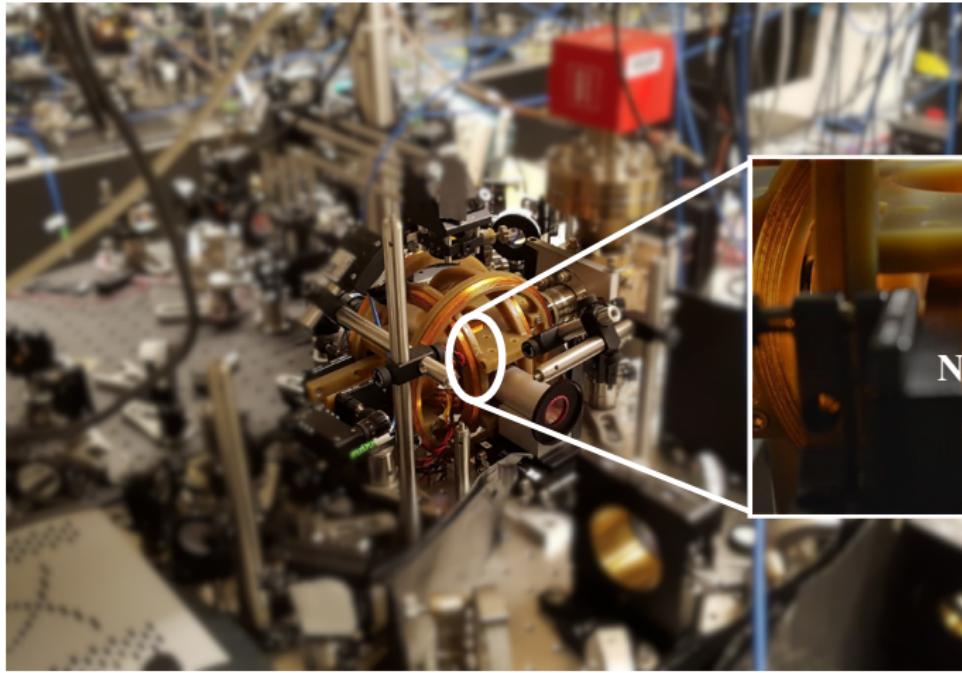
²Phys. Rev. A 97, 063423

Experiment overview

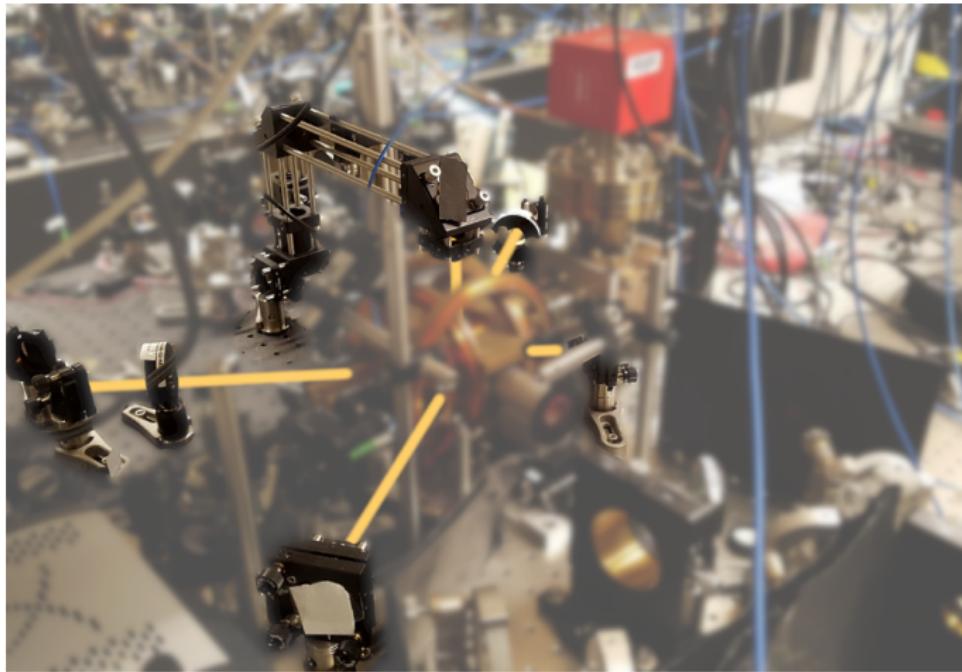




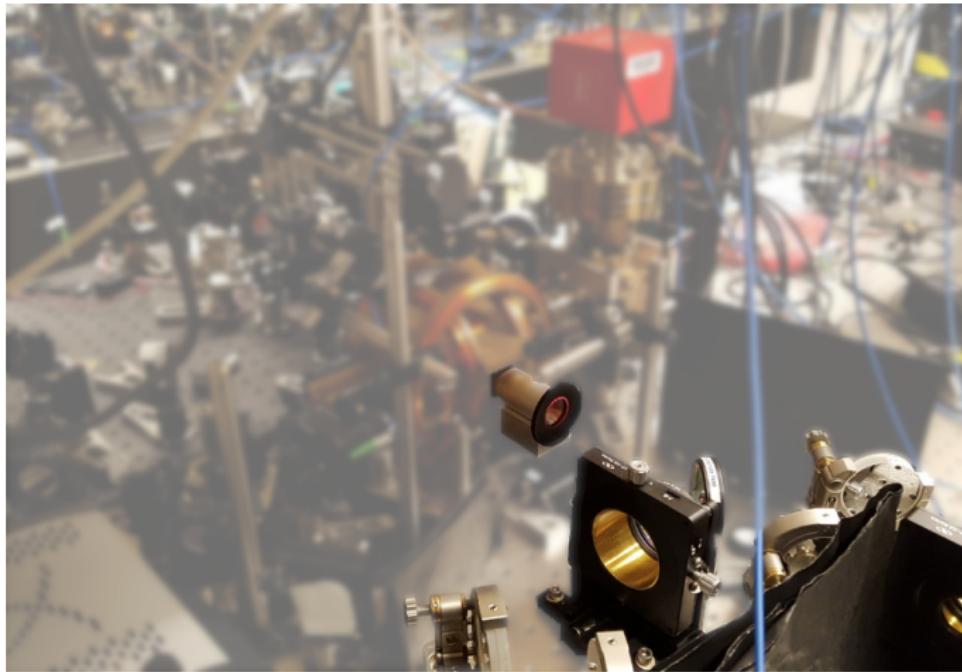




MOT beam path



Tweezer beam path



Outline

1 Experiment overview

2 Atom state control

- Raman sideband cooling of Na atoms

3 Optical molecule creation

4 Conclusion

Raman sideband cooling

Outline

1 Experiment overview

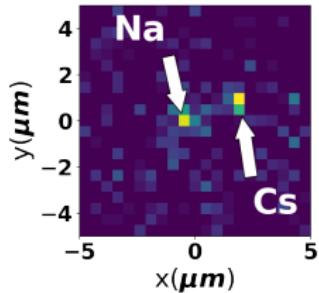
2 Atom state control

- Raman sideband cooling of Na atoms

3 Optical molecule creation

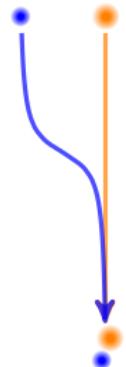
4 Conclusion

Loading

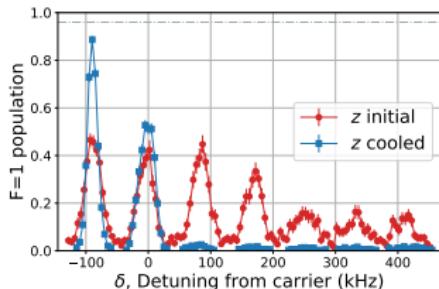


NJP. 19, 023007 (2017)

Merging

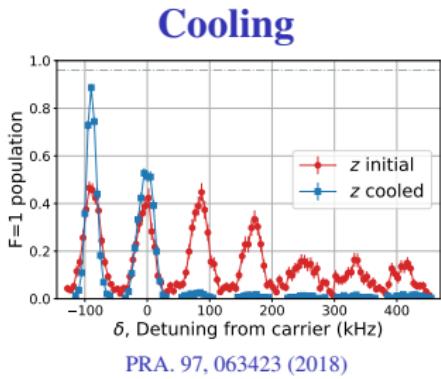
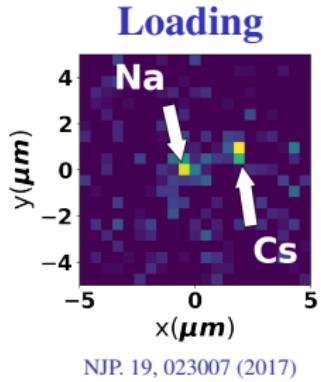


Cooling

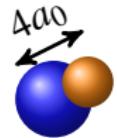
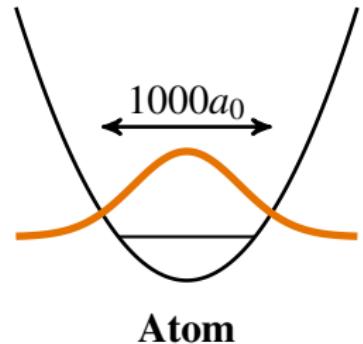
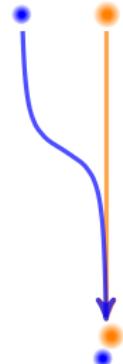


PRA. 97, 063423 (2018)

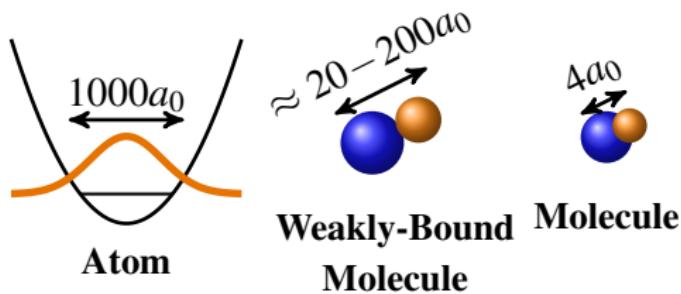
PRX. 9, 021039 (2019)

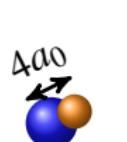
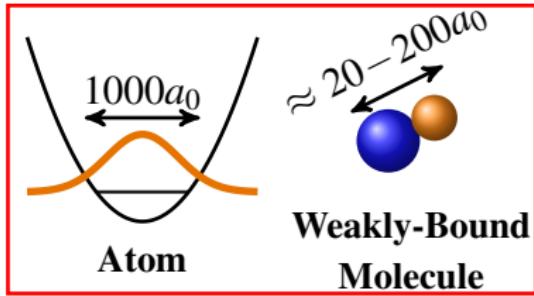


Merging

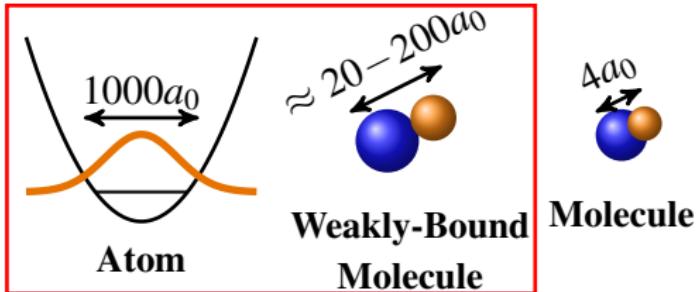


Molecule

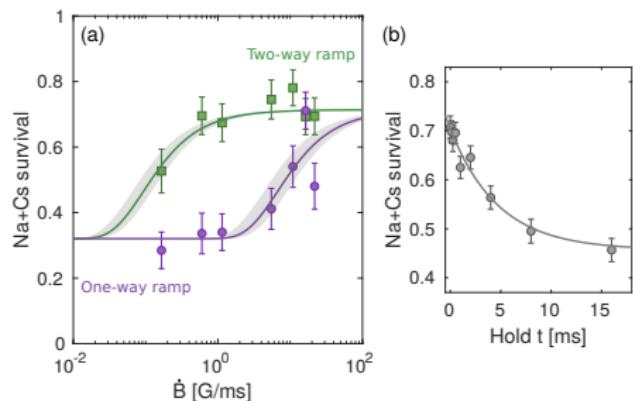




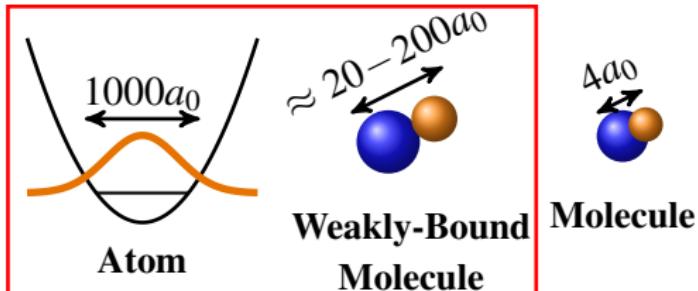
Molecule



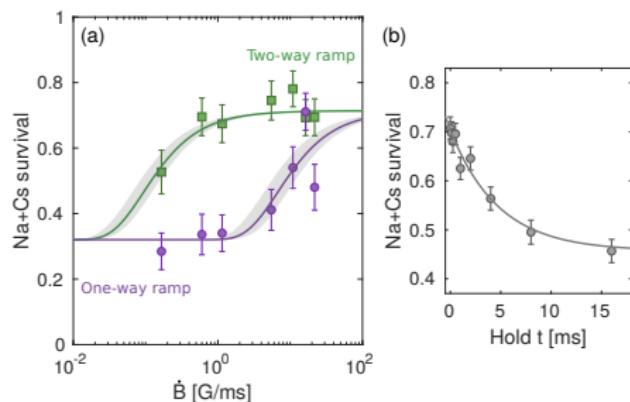
Feshbach molecule



PRL. 124, 253401 (2020)

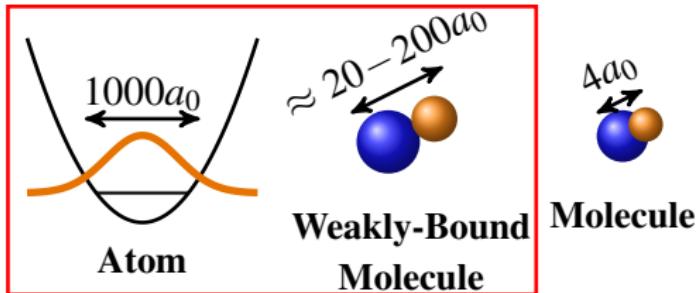


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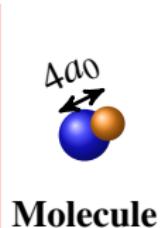
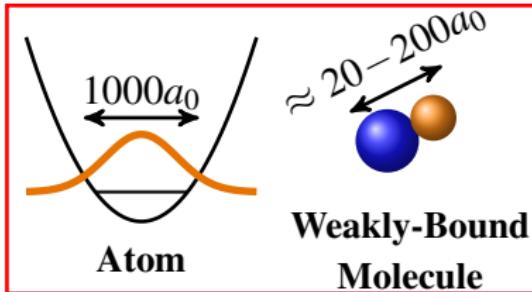
- Requires Feshbach resonance
- Usually large magnetic field

PRL. 124, 253401 (2020)



Optical transfer

- More general
- Faster

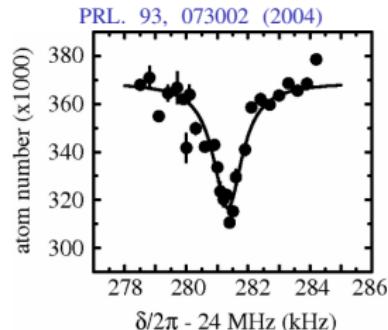


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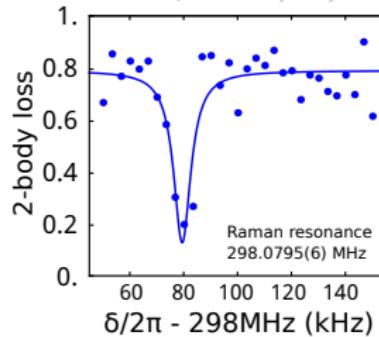
Previous results

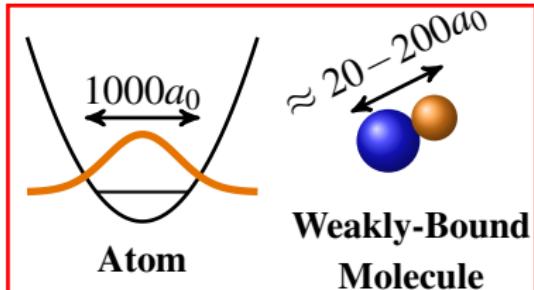
Rb_2 Science 287, p. 1016-1019 (2000)



Sr_2 PRL. 109, 115302 (2012)

NaCs PRX. 9, 021039 (2019)





Optical transfer

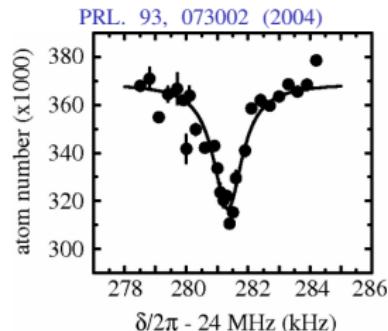
- More general
- Faster

Limitations so far

- Incoherent due to scattering
- Rely on narrow line optical transition

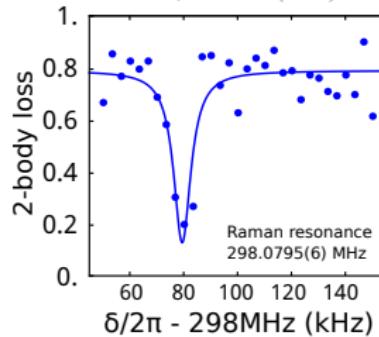
Previous results

Rb_2 Science 287, p. 1016-1019 (2000)

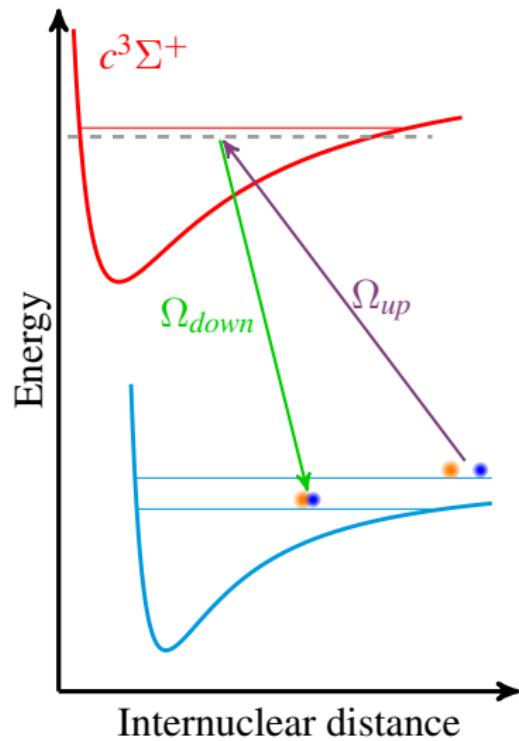


Sr_2 PRL. 109, 115302 (2012)

NaCs PRX. 9, 021039 (2019)



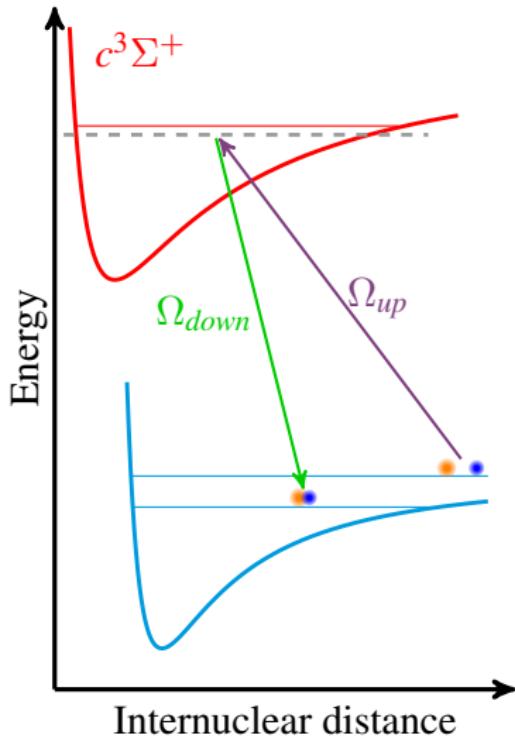
Raman transfer



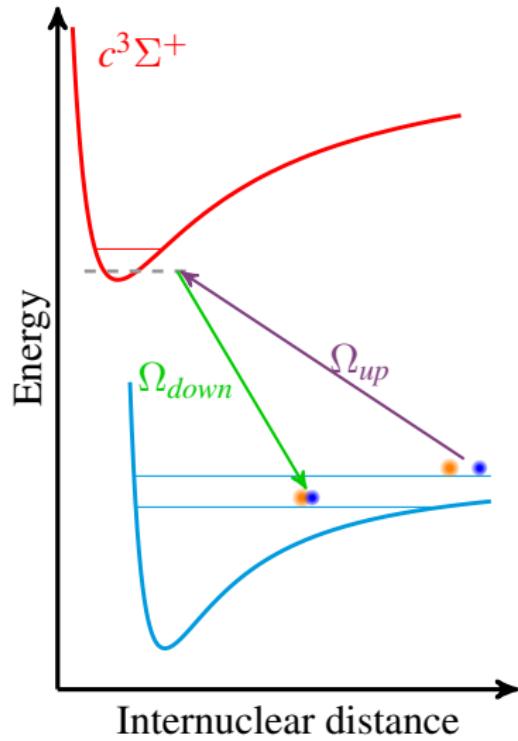
Raman transfer

Near threshold states

- Stronger coupling (Ω_{up} and Ω_{down})
- Closely spaced
- Fast scattering



Raman transfer



Near threshold states

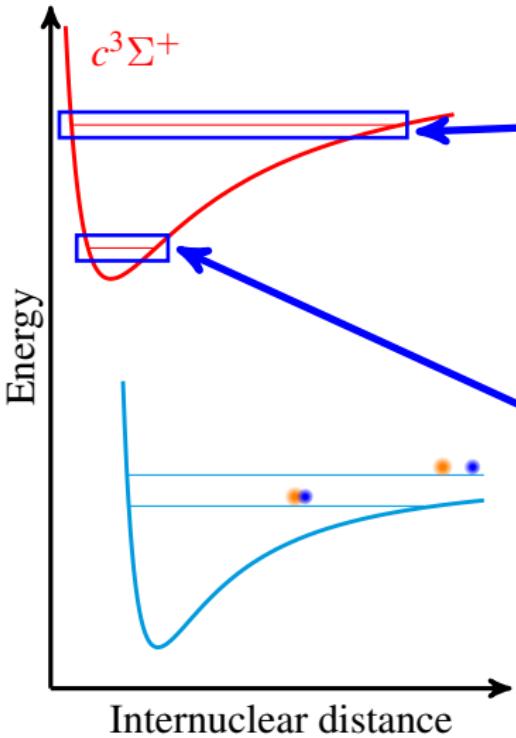
- Stronger coupling (Ω_{up} and Ω_{down})
- Closely spaced
- Fast scattering

Deeply bound states

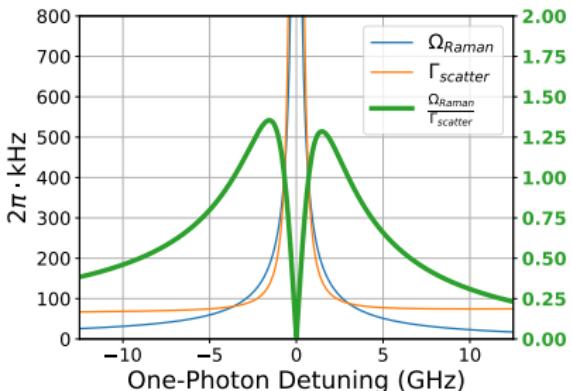
- Weaker coupling
- Sparsely spaced
- Allow larger detuning
- Slower scattering

arXiv:1701.03121(2017)

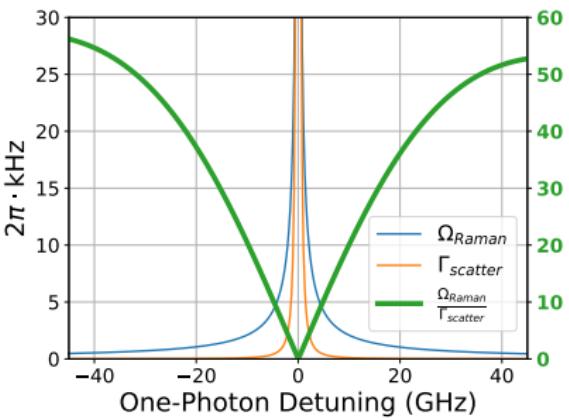
Raman transfer



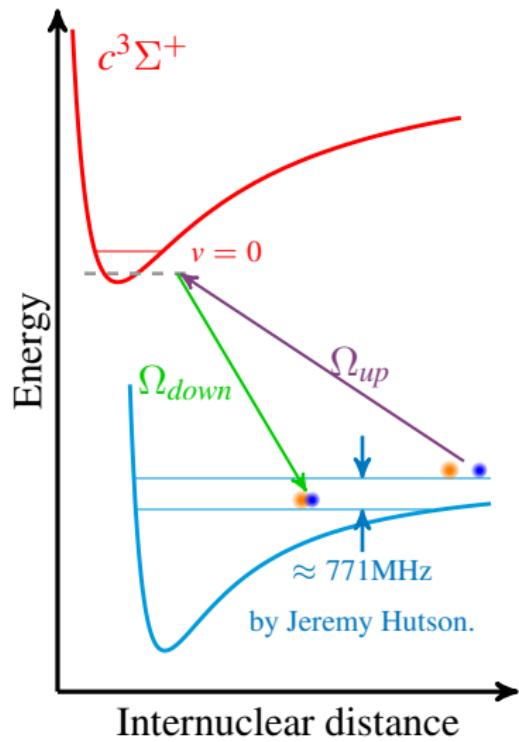
Near threshold states



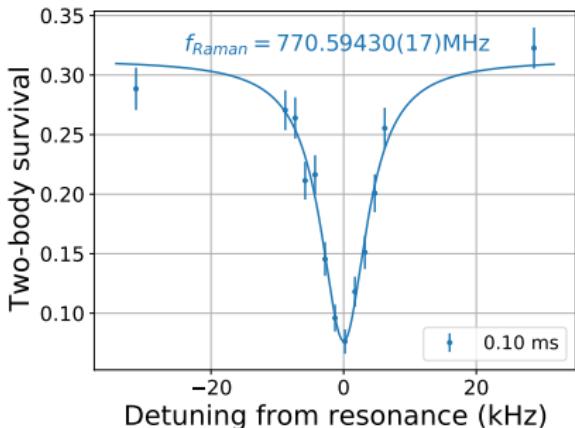
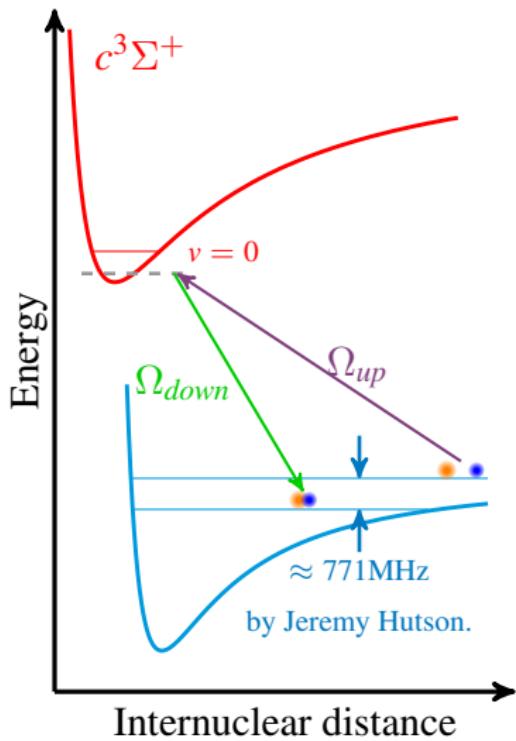
Deeply bound states



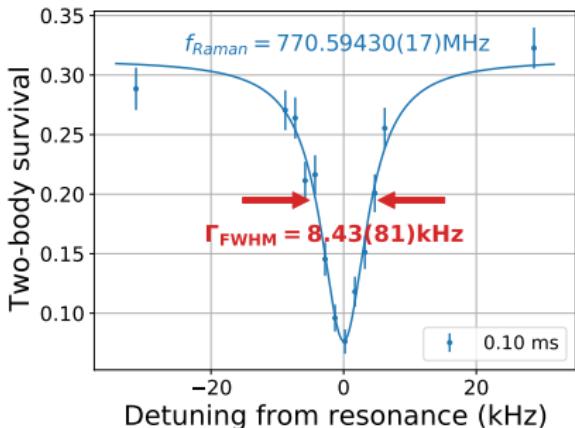
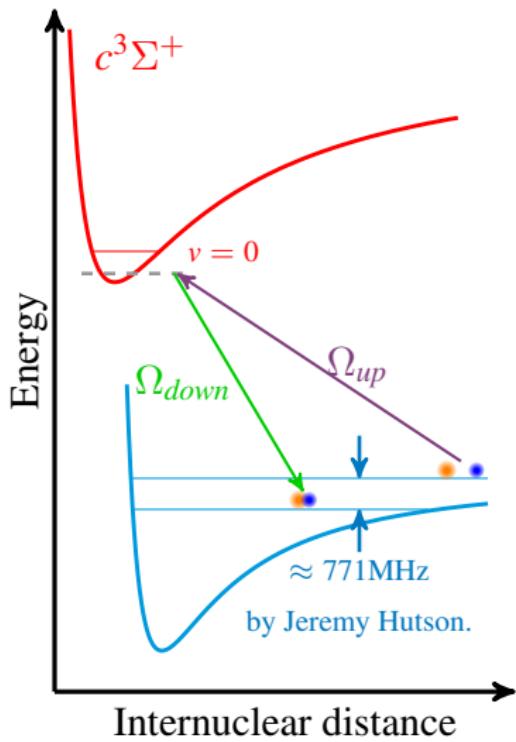
Experiment



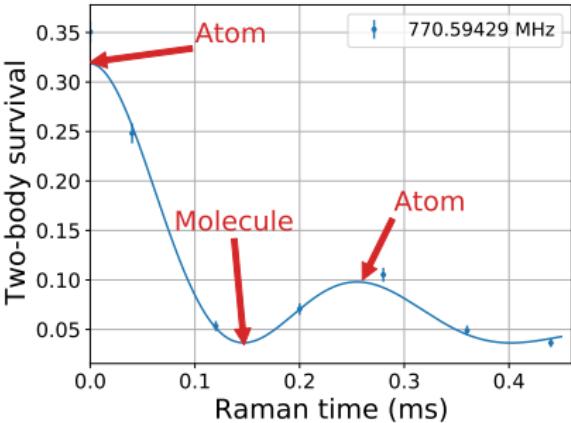
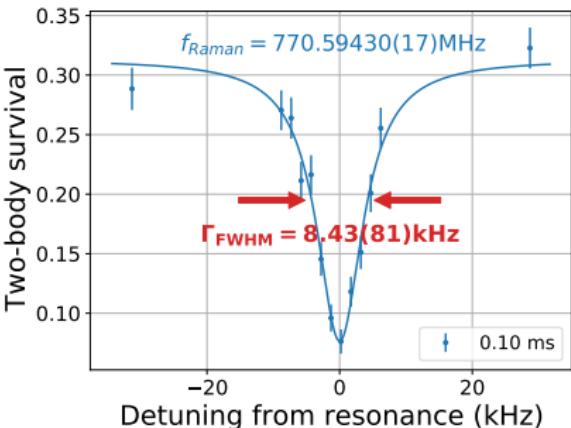
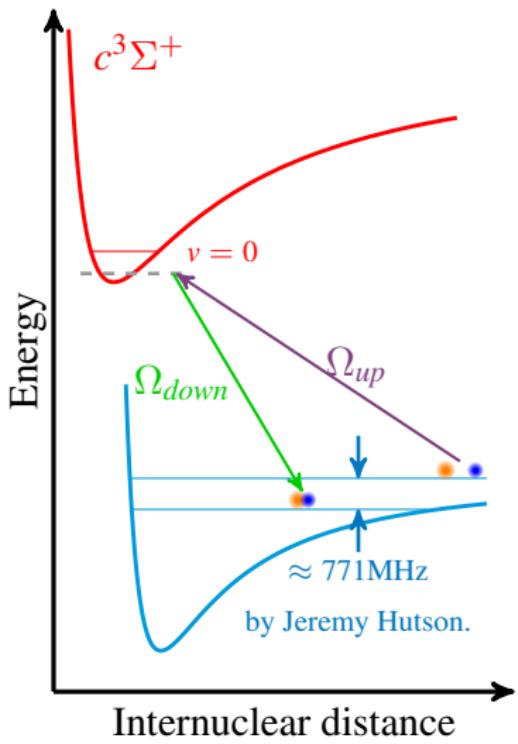
Experiment



Experiment

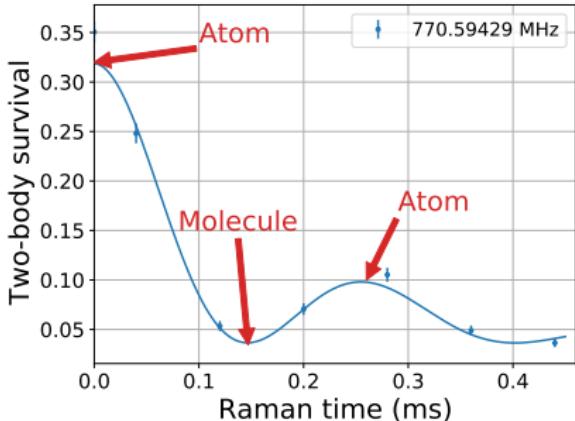
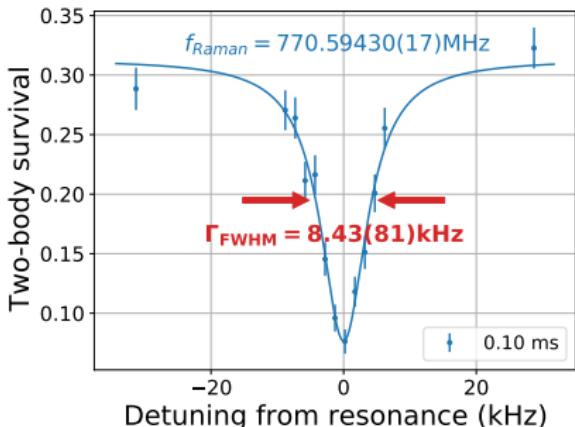
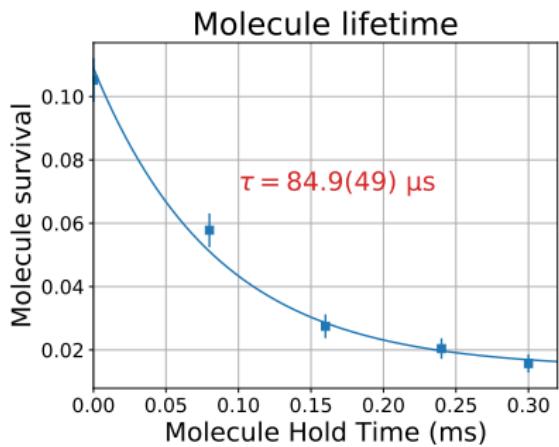


Experiment



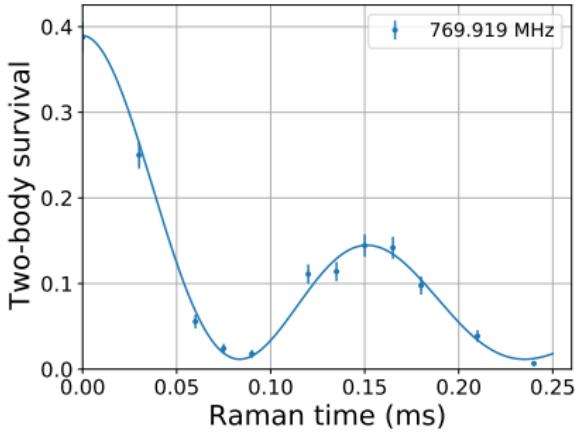
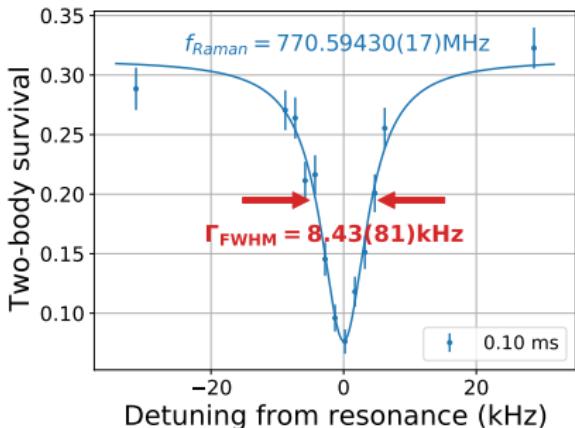
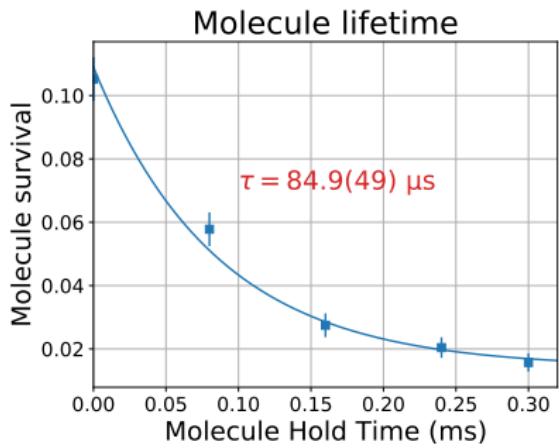
Experiment

- Transferred 50% of ground state atom to molecule.
- Single molecule spin state
- > 50% of molecule in motional ground state.



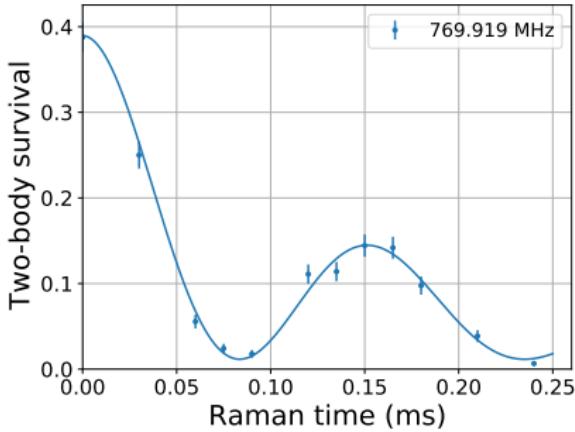
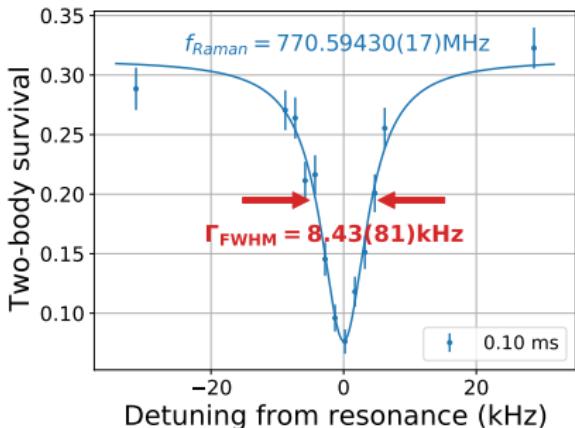
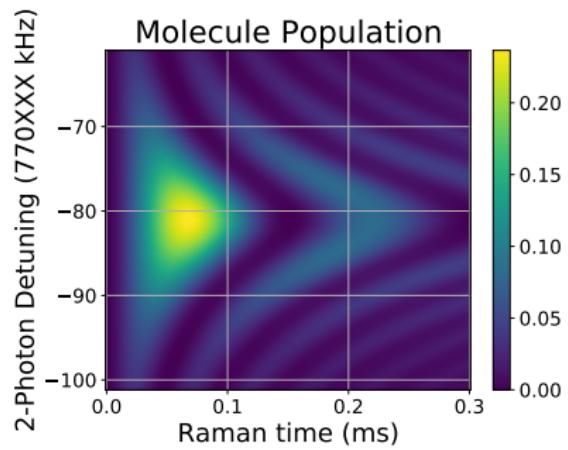
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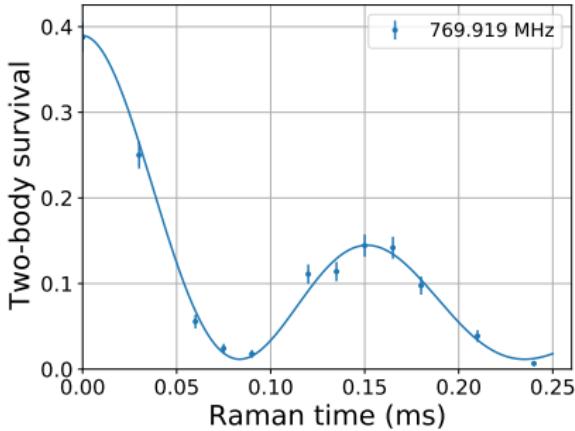
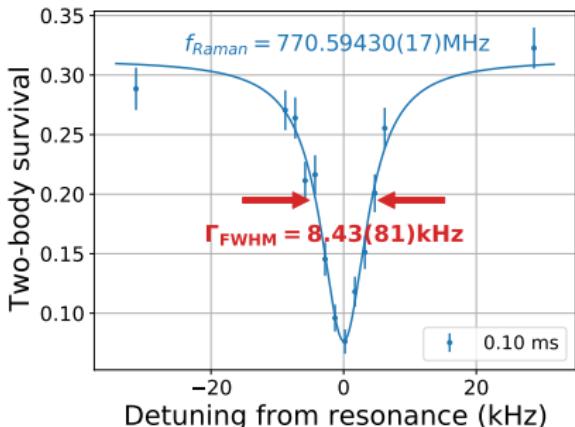
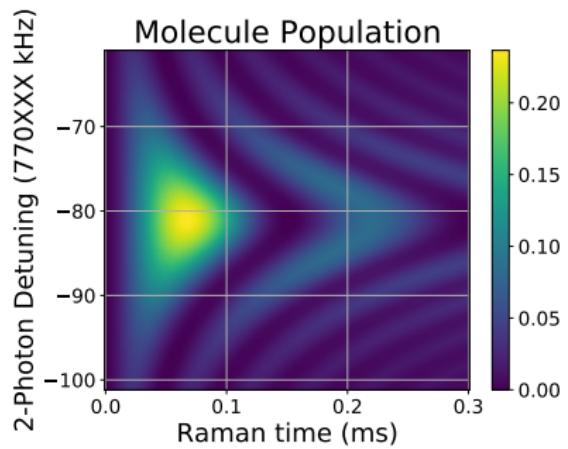
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Conclusion and outlook

- Full quantum control of atoms in optical tweezers
- Coherent all-optical creation of single molecule
- Improve molecule lifetime and signal contrast
- Feshbach molecule ($\tau = 4.7(7)$ ms)

Conclusion and outlook

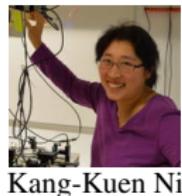
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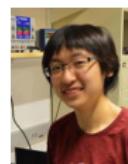


Kang-Kuen Ni

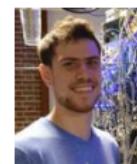
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Kenneth
Wang



Jessie
Zhang



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William
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Asstn Prof @Caltech

Theory



Jeremy Hutson

