

# Building Single Molecules from Single Atoms

Yichao Yu

Lee Liu, Kenneth Wang, Lewis Picard, Jonathan Hood  
Jessie T. Zhang, Eliot Fenton, Yen-Wei Lin

Ni Group/Harvard

Sep 5, 2019

# Atom

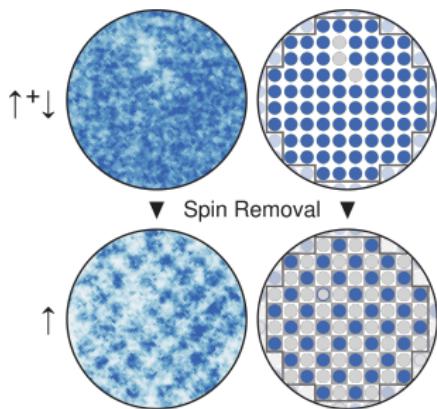
- Laser cooling/trapping
- Internal state control
- High fidelity imagining

⋮

## Atom

- Laser cooling/trapping
- Internal state control
- High fidelity imagining

⋮

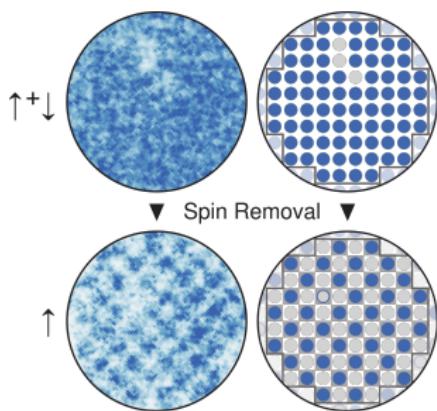


Nature 545, 462-466 (2017)

## Atom

- Laser cooling/trapping
- Internal state control
- High fidelity imagining

⋮



Nature 545, 462-466 (2017)

## Molecule

- Strong interaction
- Rich internal structure

## Direct molecule cooling

# Path to Ultracold Molecules

**Direct molecule cooling**

**Making molecule from atoms**

# Path to Ultracold Molecules

**Assemble molecule in tweezers**

**Making molecule from atoms**

# Outline

1 System Overview

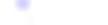
2 Trapping and Cooling of Atoms

3 Atom-Atom Interaction and Molecule Formation

# Steps



Loading



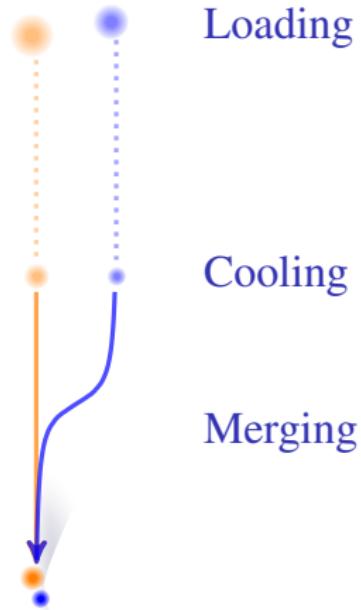
# Steps



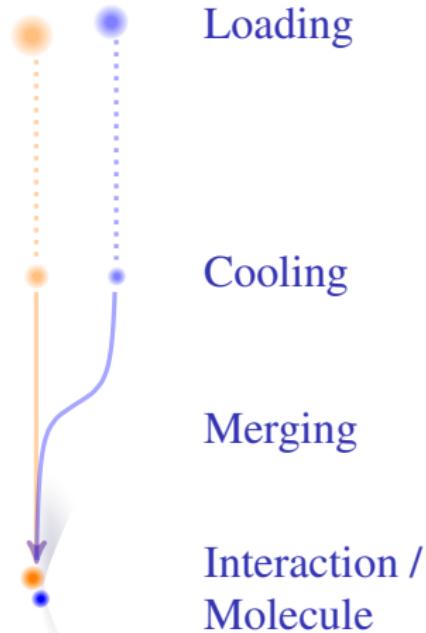
Loading

Cooling

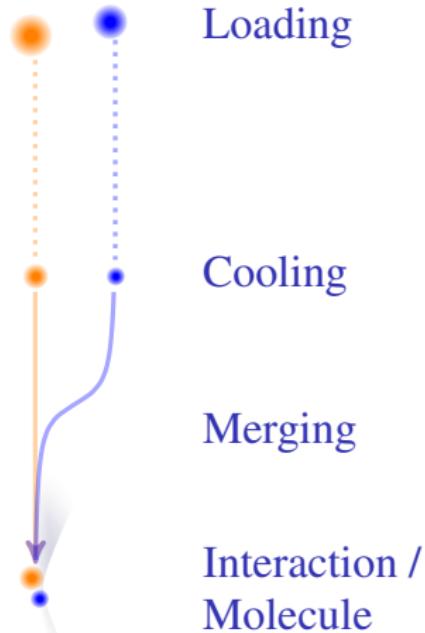
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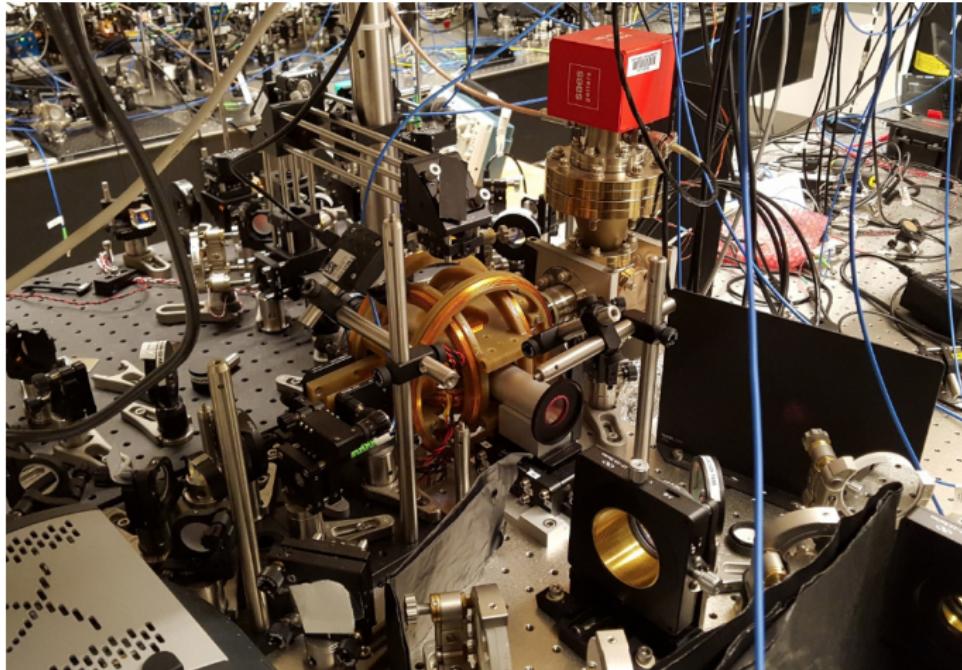
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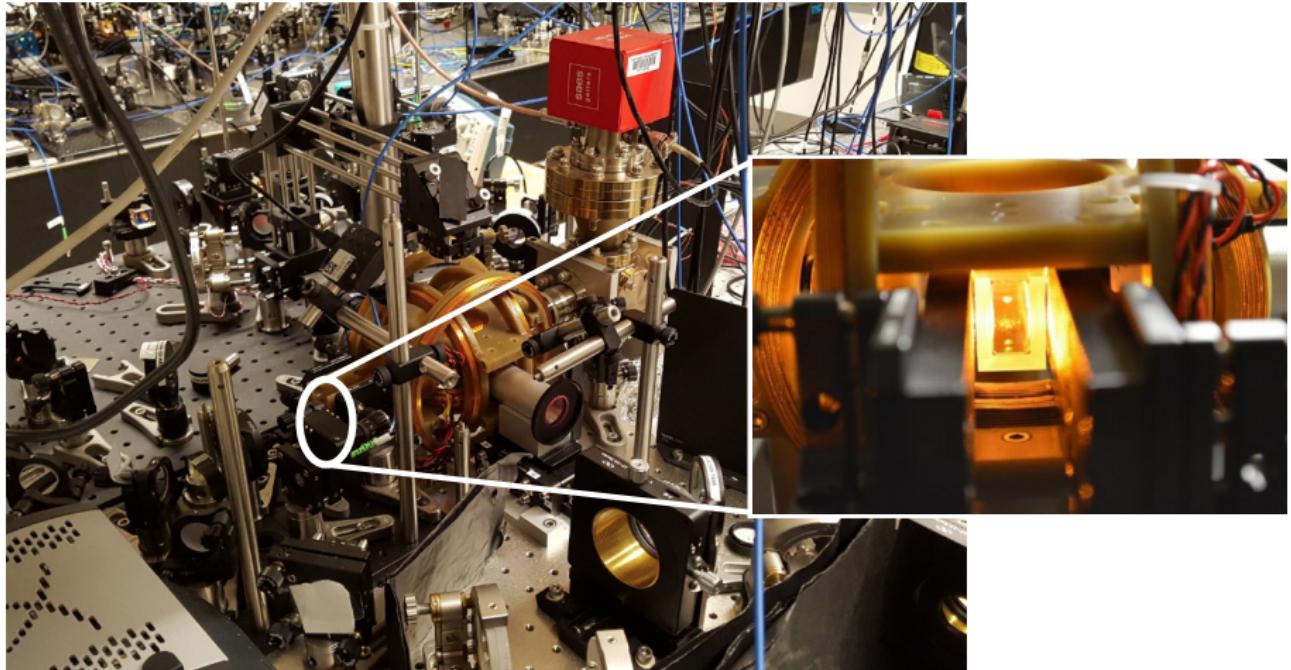


# Steps



Science 360 6391, 2018





# Single Atom in Tweezer

# Raman Sideband Cooling

# Outline

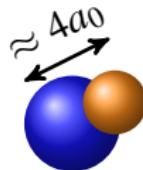
1 System Overview

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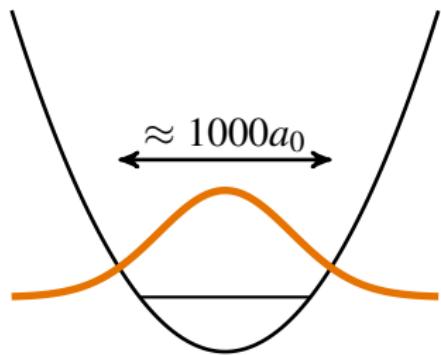
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# Optical Transfer to Molecular State

Binding energy  
 $\approx 150\text{THz}$



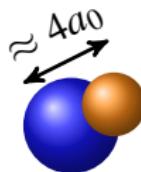
Molecule



Atoms

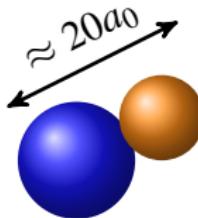
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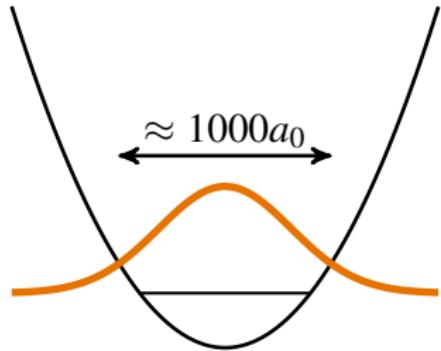


Molecule

Binding energy  
 $\approx 300\text{MHz}$

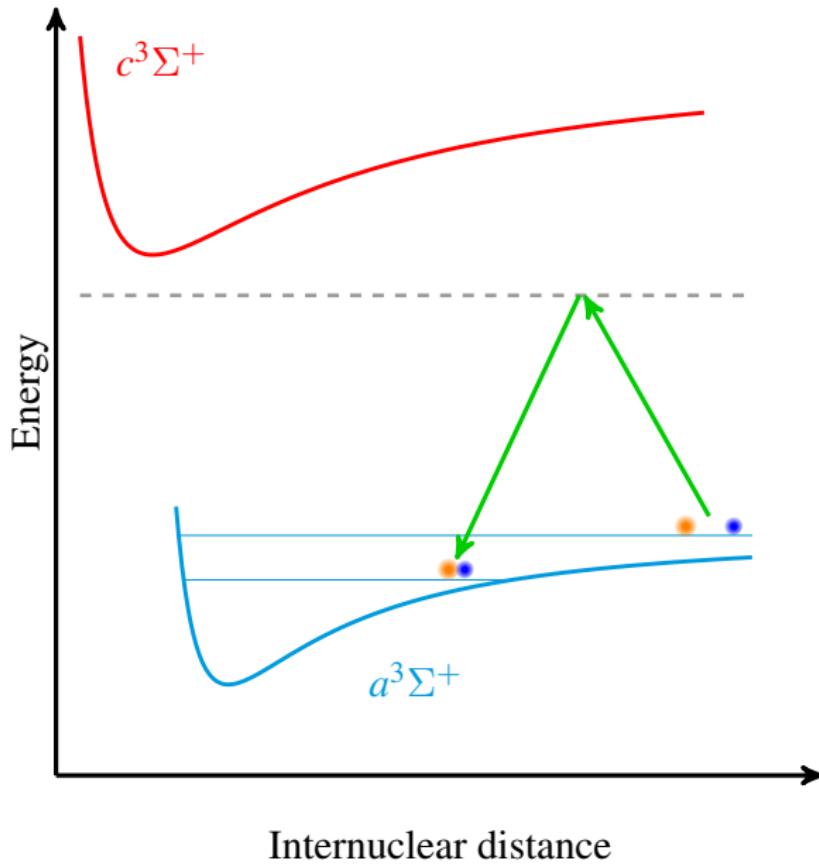


Weakly-Bound  
Molecule



Atoms

# Optical Transfer to Molecular State

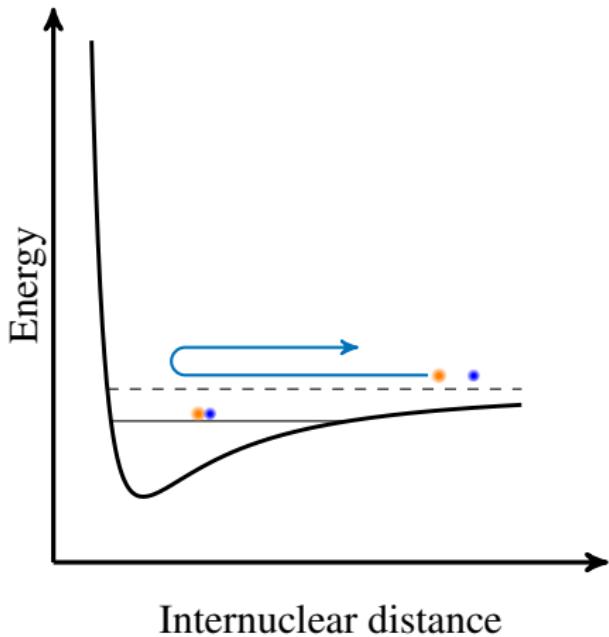


# Photoassociation (PA) Spectroscopy

# Optical Transfer to Weakly-Bound Molecular

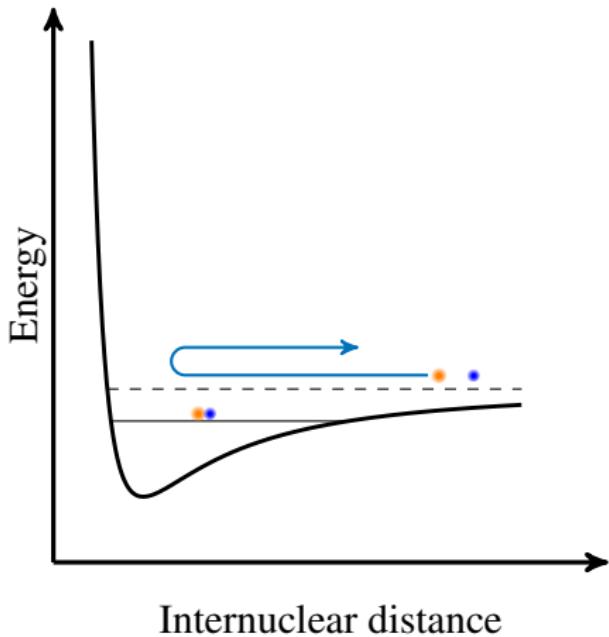
## Scattering length $a$

- Binding energy
- Molecular potential
- Feshbach resonance
- Molecule formation
- ⋮



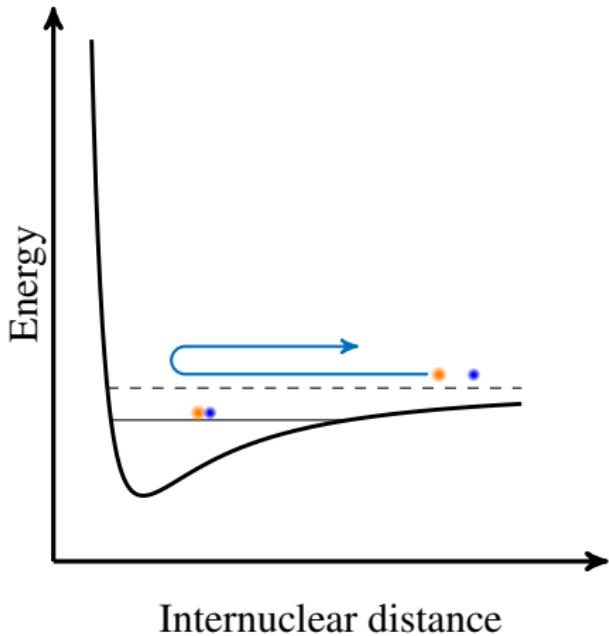
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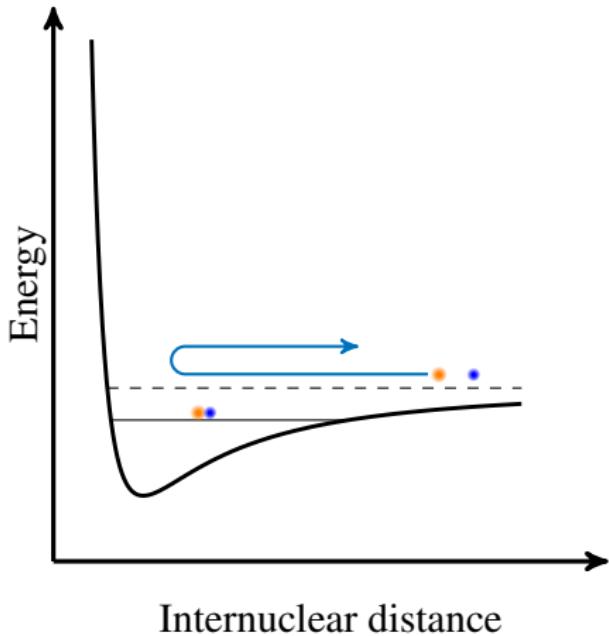
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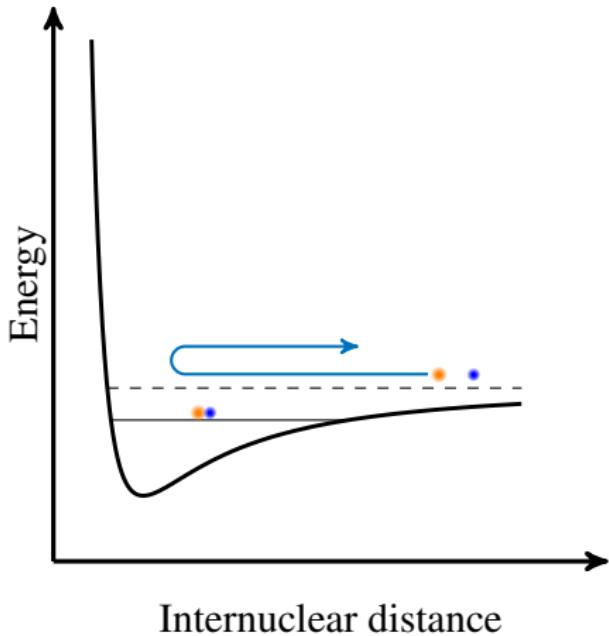
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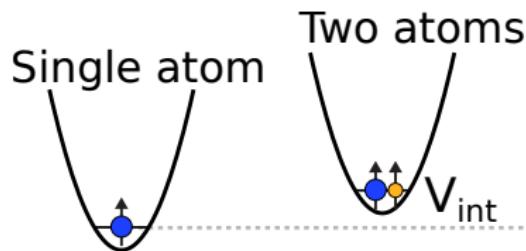


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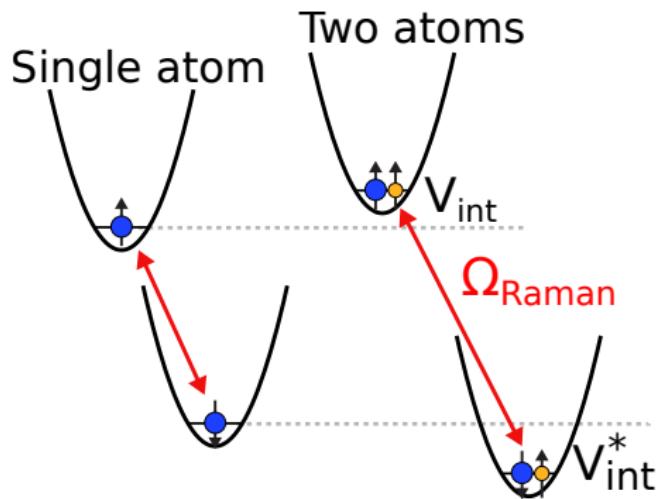
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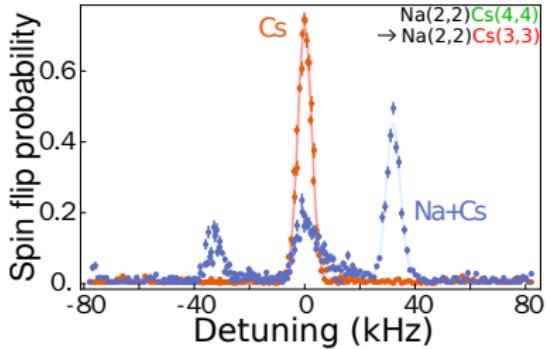
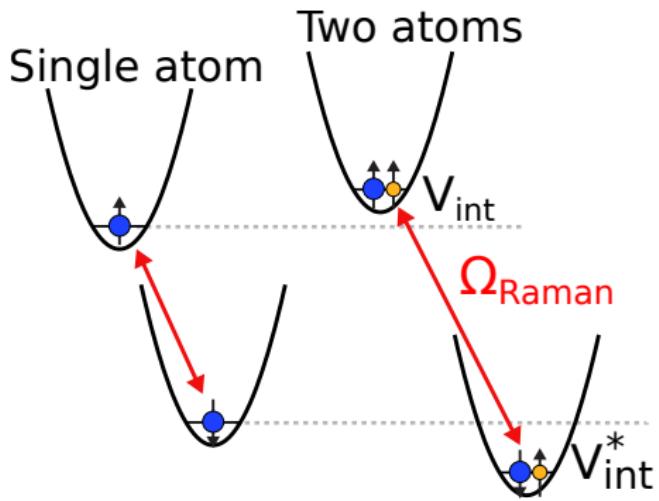
## Interaction shift



## Interaction shift



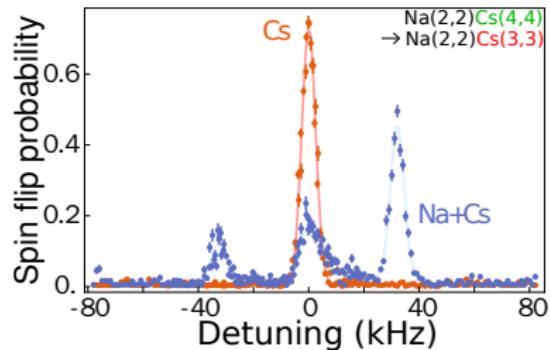
## Interaction shift



## Interaction shift

$$H = \underbrace{\sum_{i=x,y,z} \left( \frac{m_1 \omega_{1,i}^2 x_{1,i}^2}{2} + \frac{p_{1,i}^2}{2m_1} \right)}_{\text{Na}} + \underbrace{\sum_{i=x,y,z} \left( \frac{m_2 \omega_{2,i}^2 x_{2,i}^2}{2} + \frac{p_{2,i}^2}{2m_2} \right)}_{\text{Cs}} + V_{int}(\vec{r}_1 - \vec{r}_2)$$

Interaction



## Interaction shift

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To center of mass  
and relative coordinates

$$M = m_1 + m_2$$

$$\mu = \frac{m_1 m_2}{m_1 + m_2}$$

$$\Omega_i^2 = \frac{m_1 \omega_{1,i}^2 + m_2 \omega_{2,i}^2}{m_1 + m_2}$$

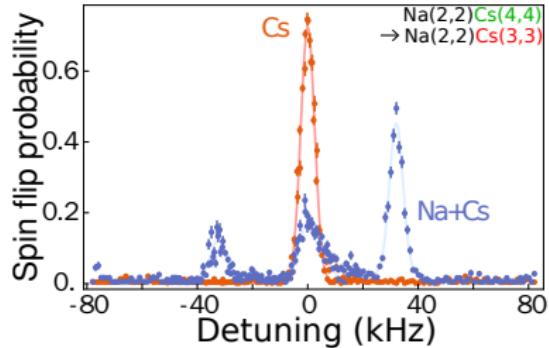
$$\omega_{R,i}^2 = \frac{m_2 \omega_{1,i}^2 + m_1 \omega_{2,i}^2}{m_1 + m_2}$$

$$X_i = \frac{m_1 x_{1,i} + m_2 x_{2,i}}{m_1 + m_2}$$

$$x_{R,i} = x_{1,i} - x_{2,i}$$

$$P_i = p_{1,i} + p_{2,i}$$

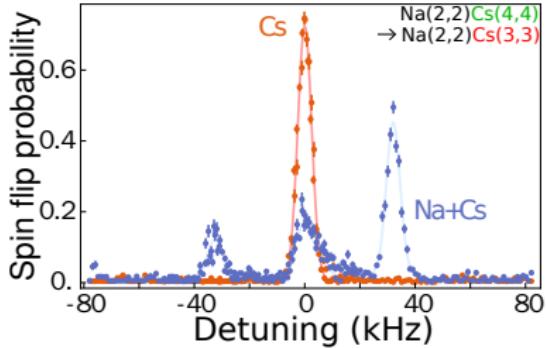
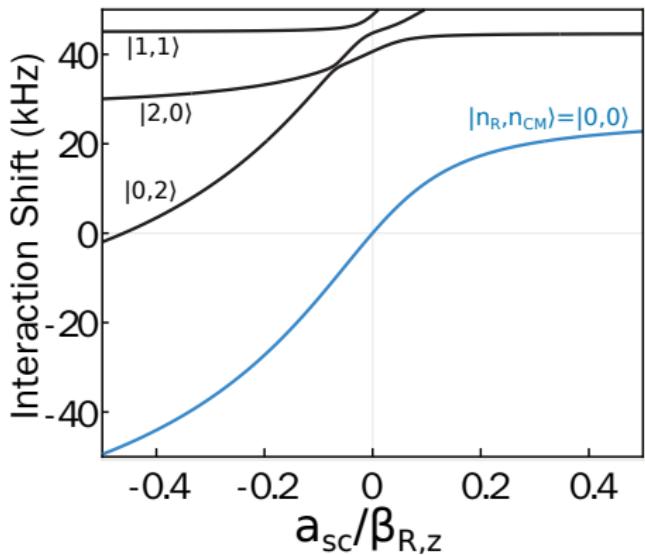
$$p_{R,i} = \frac{m_2 p_{1,i} - m_1 p_{2,i}}{m_1 + m_2}$$



Center of mass

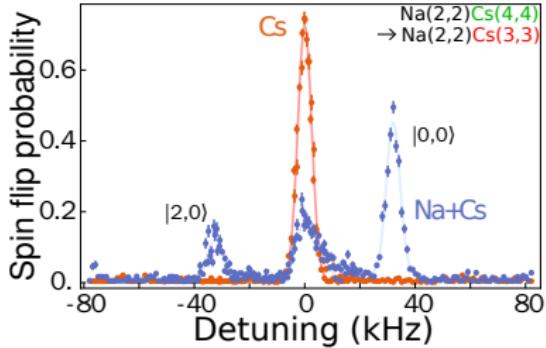
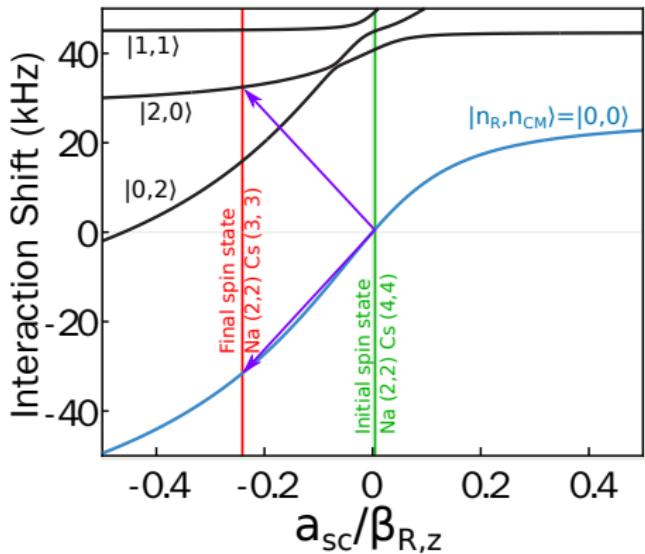
$$H = \underbrace{\sum_{i=x,y,z} \left( \frac{M \Omega_i^2 X_i^2}{2} + \frac{P_i^2}{2M} \right)}_{\text{Center of mass}} + \underbrace{\sum_{i=x,y,z} \left( \frac{\mu \omega_{R,i}^2 X_{R,i}^2}{2} + \frac{p_{R,i}^2}{2\mu} \right) + V_{int}(\vec{r}_R)}_{\text{Relative}} + \underbrace{\sum_{i=x,y,z} \mu (\omega_{1,i}^2 - \omega_{2,i}^2) X_i x_{R,i}}_{\text{Mixing}}$$

# Interaction shift



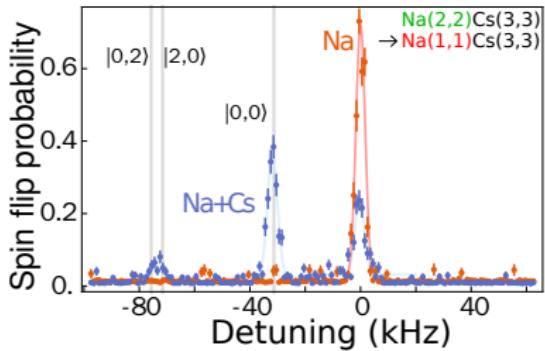
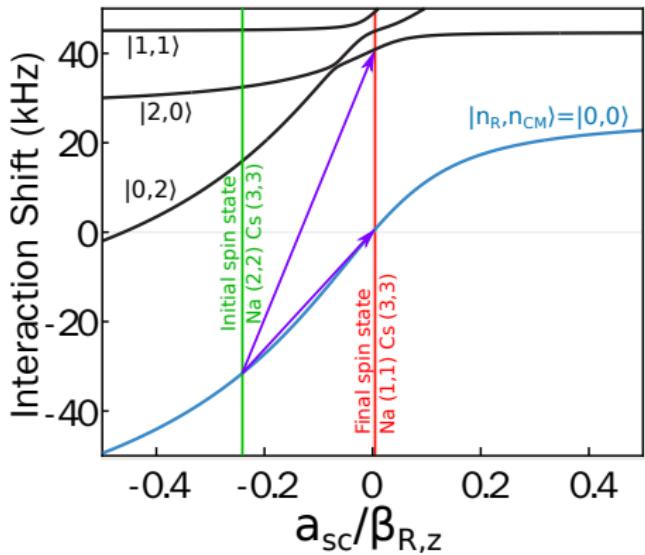
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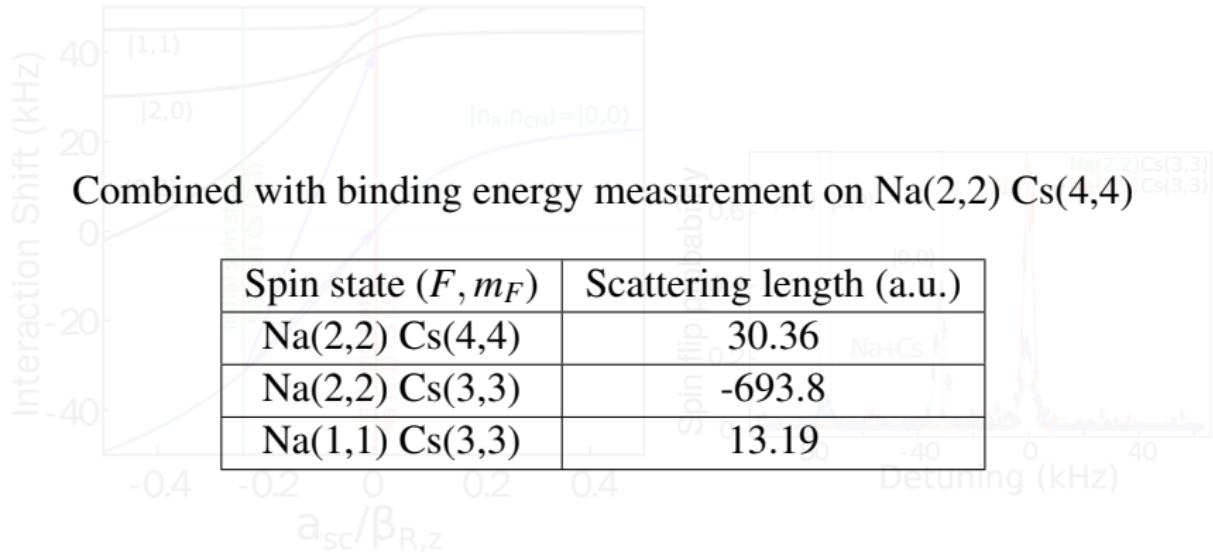
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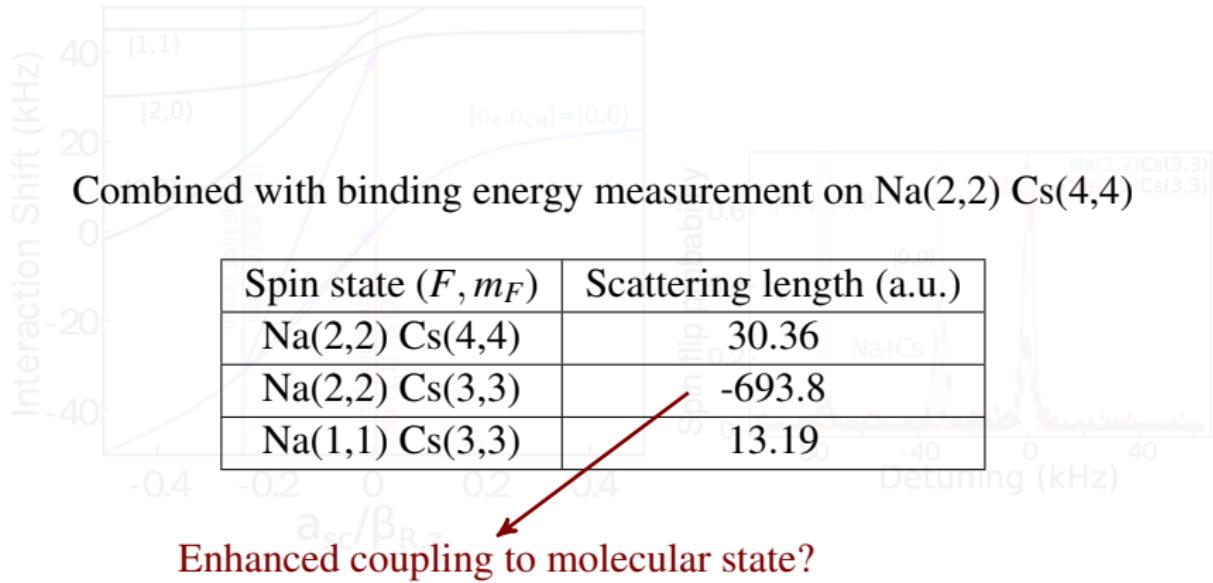
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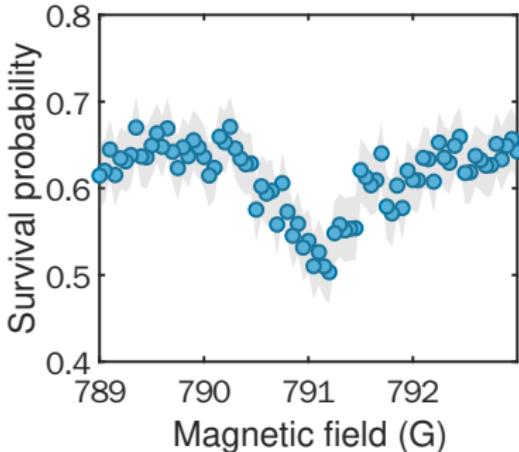
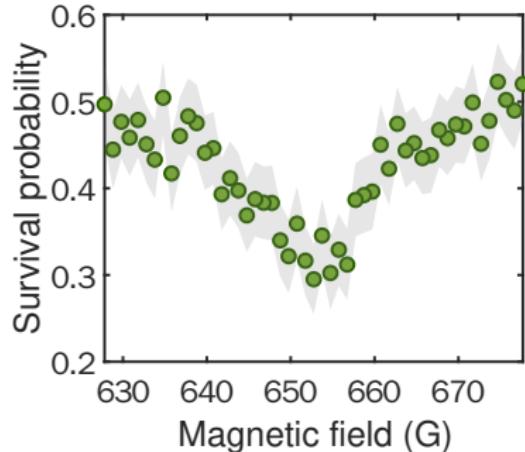


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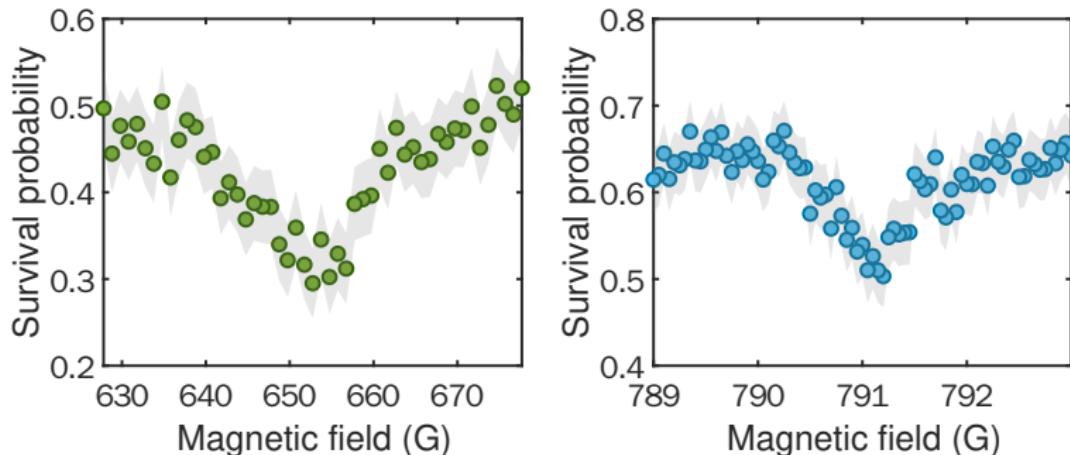
## Na (1, -1) Cs (3, -3) Feshbach resonance



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	<i>s</i> -wave	<i>p</i> -wave
Predicted (based on interaction shift) <sup>1</sup>	663 G	799 G
Measured	652(3) G	791.2(2) G

<sup>1</sup>In collaboration with Bo Gao



