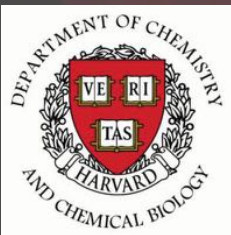


# Assembled molecules in optical tweezers for quantum science

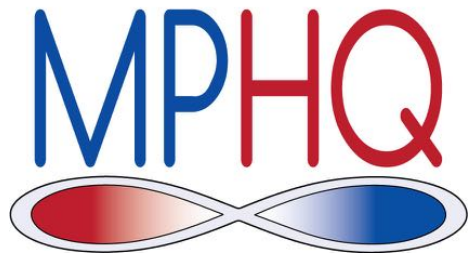
**William Cairncross**

MPHQ Postdoctoral Fellow, Ni group

Department of Chemistry & Chemical Biology, Harvard University  
and MIT-Harvard Center for Ultracold Atoms

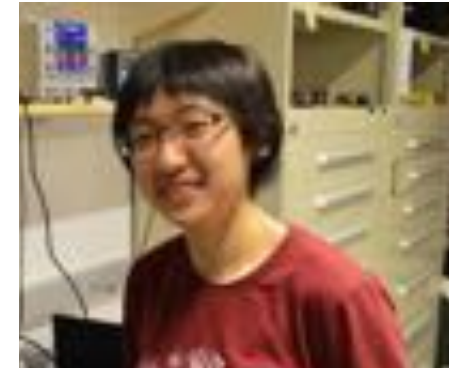


# Acknowledgements

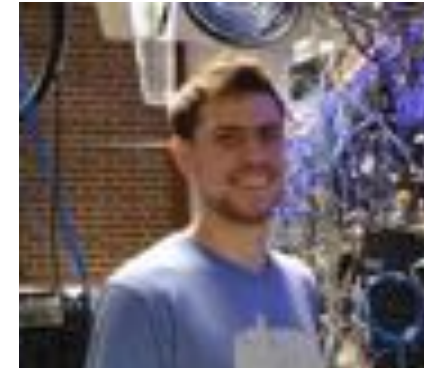


**Prof. Kang-Kuen Ni**

## Graduate students



**Jessie Zhang**



**Lewis Picard**



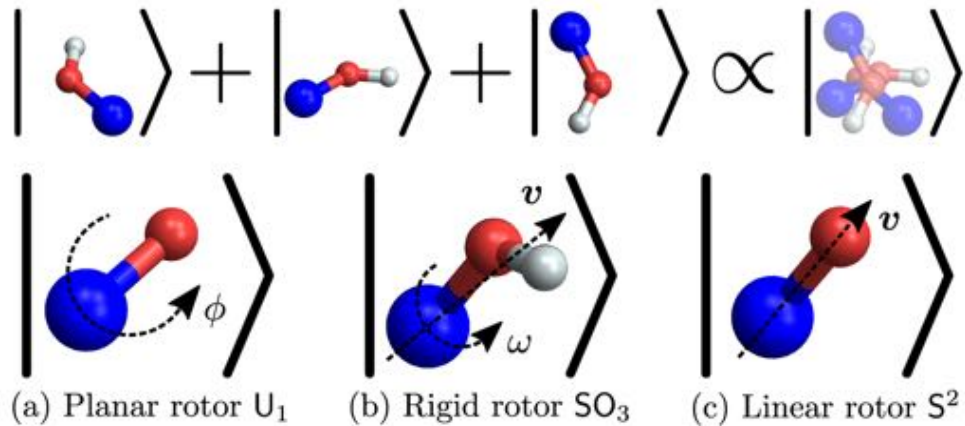
**Yichao Yu**



**Kenneth Wang**

**Past members: Prof. Nick Hutzler (Caltech), Prof. Jonathan Hood (Purdue U.), Dr. Lee Liu (CU Boulder)**

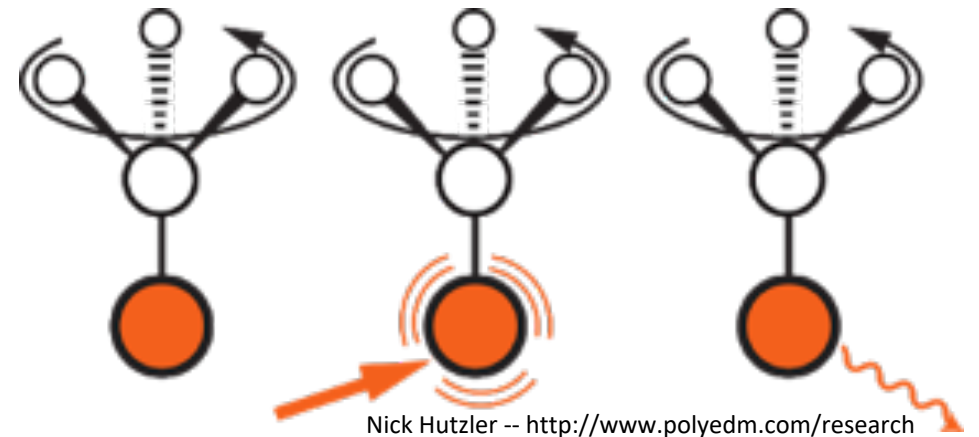
# Ultracold molecules



## Quantum computation & simulation

DeMille, PRL **88**, 067901 (2002)

Albert, Covey & Preskill, PRX **10**, 031050 (2020)



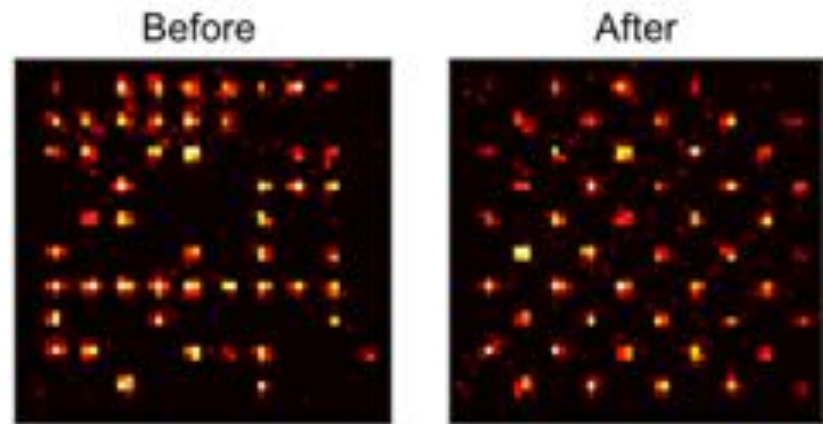
## Precision measurements

Kozyryev & Hutzler, PRL **119**, 133002

DeMille (Yale), Nagerl et al. (Innsbruck), Doyle (Harvard), Ye (JILA), Hinds + Tarbutt (Imperial), Vutha (U of T), Hessels (York U), Jayich (UCSB), Cornell (JILA), Campbell + Hudson (UCLA), Hoekstra et al. (Groeningen), Narevicius (Weizmann), & many more

# Optical tweezer arrays

## Rearrangement for defect-free arrays



D. Barredo et al., *Science* 10.1126/science.aah3778 (2016).

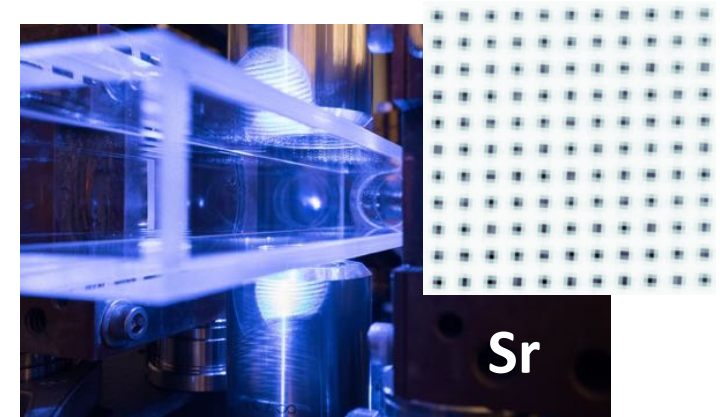
## Browaeys group, Universite Paris-Saclay

H. Bernien et al., *Nature* **551**, 579 (2017)

## Lukin group, Harvard



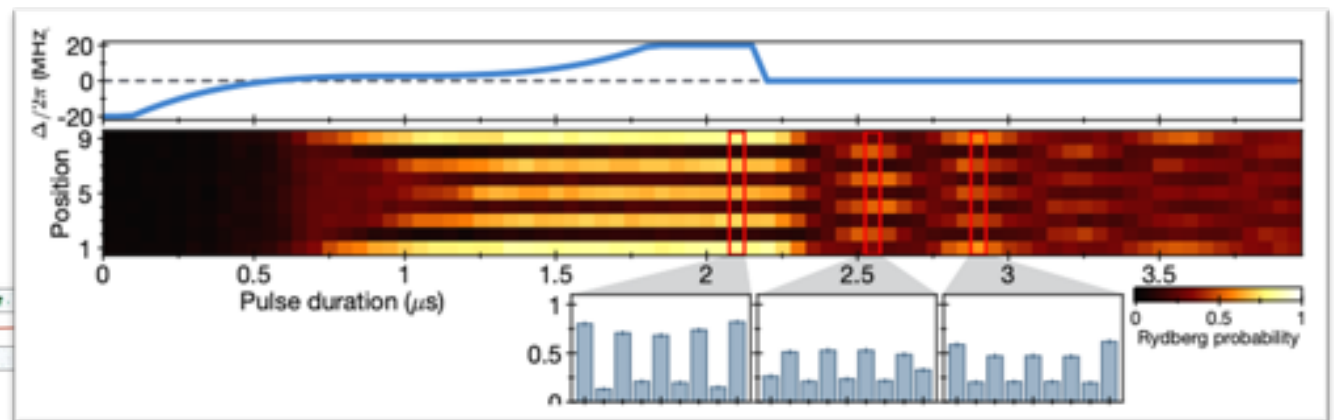
## Alkaline earth atoms



## Endres group, Caltech Kaufman group, JILA

Madjarov et al., *Nature Physics* **16**, 857 (2020)

Young et al., arXiv:2004.06095

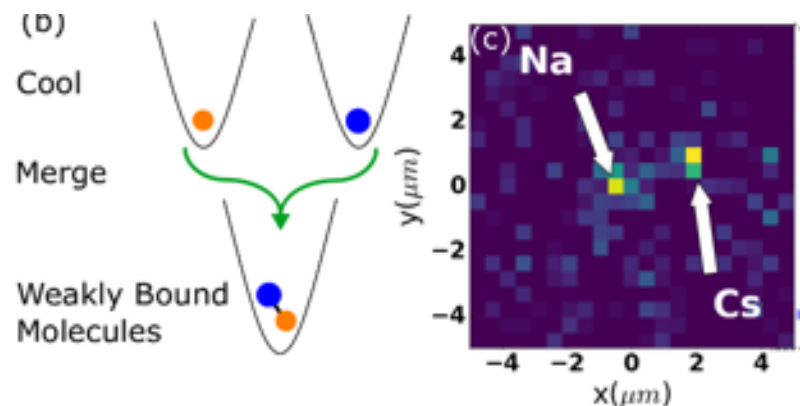


H. Bernien et al., *Nature* **551**, 579 (2017)

# Ultracold molecules in optical tweezers

Bringing complete quantum state control offered by optical tweezers to molecules

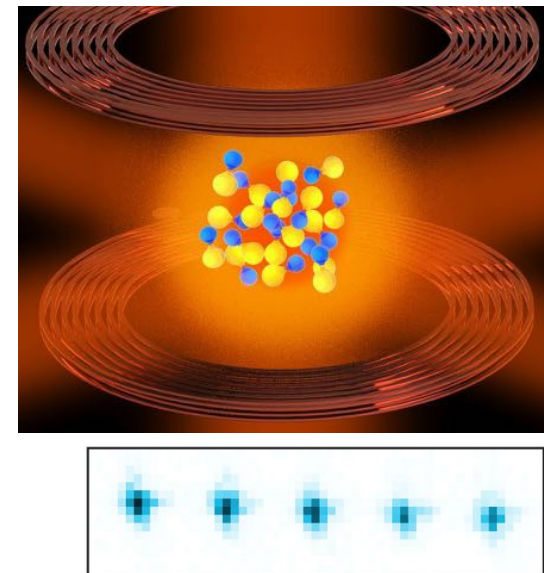
## Assembly from laser-cooled atoms



Liu, Hood, Yu et al., Science 360, 900 (2018)  
Zhang, Yu, Cairncross et al., PRL 124, 253401 (2020)  
Yu, Wang et al. (in preparation)  
Cairncross, Zhang, Picard et al., (in preparation)

**Ni group, Harvard**

## Directly cooled molecules



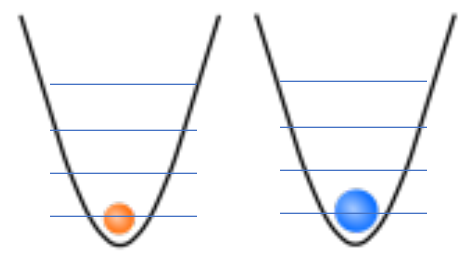
L. Anderegg et al., Science **365**, 1156 (2019)

**Doyle/Ketterle/Ni, MIT-Harvard CUA**

1. Trap



2. Cool



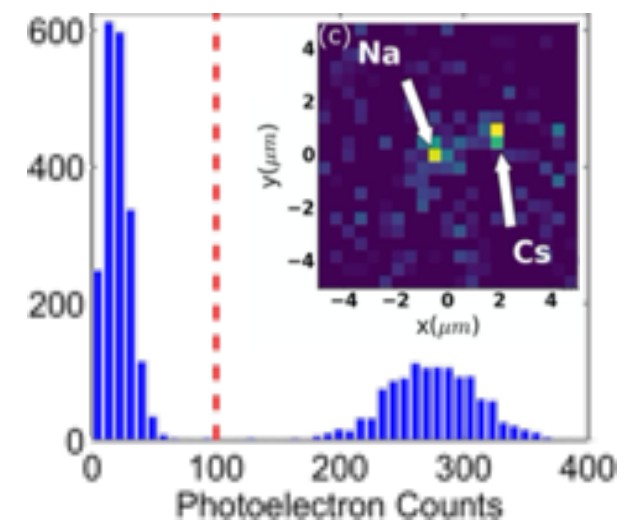
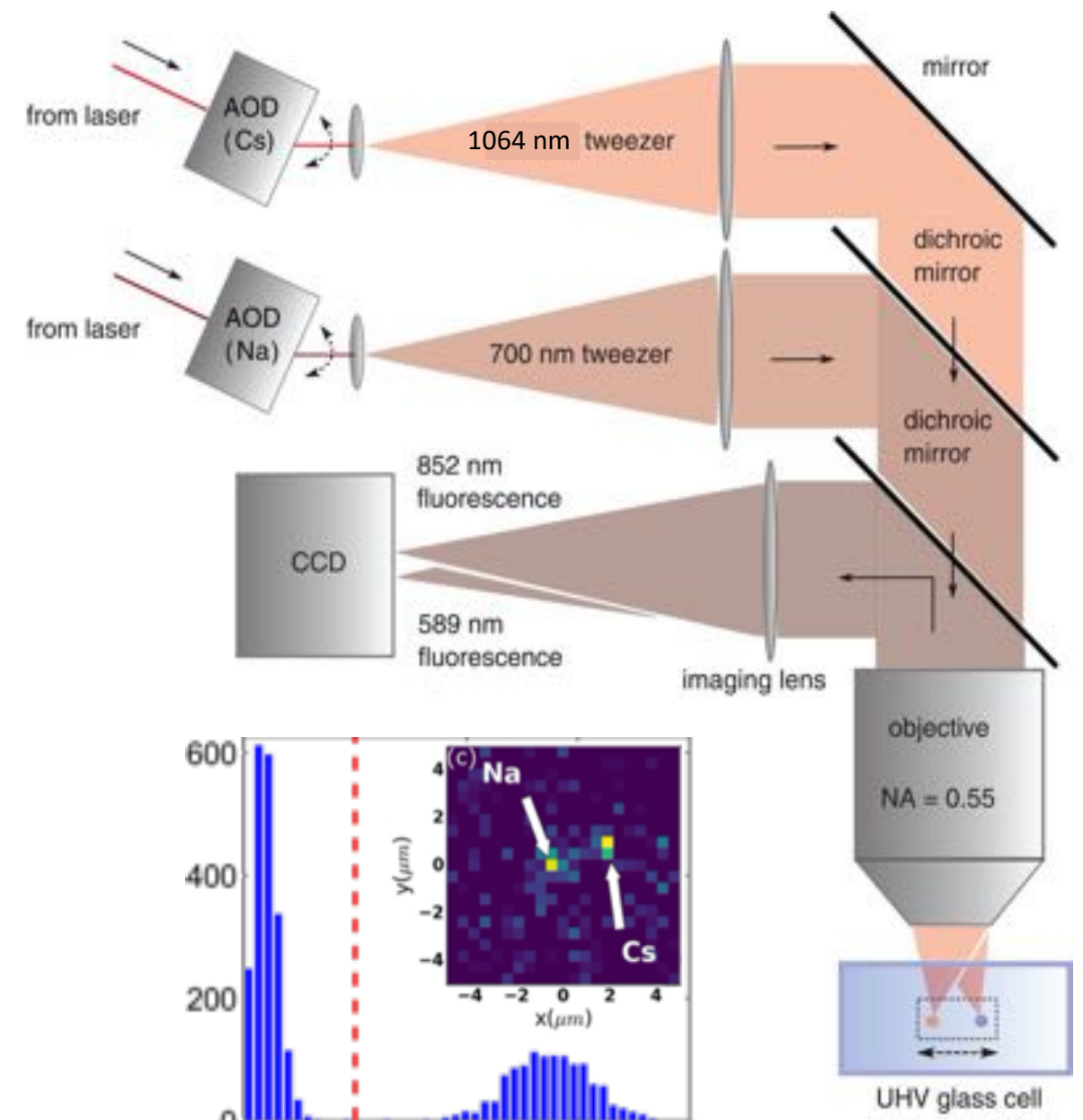
3. Merge



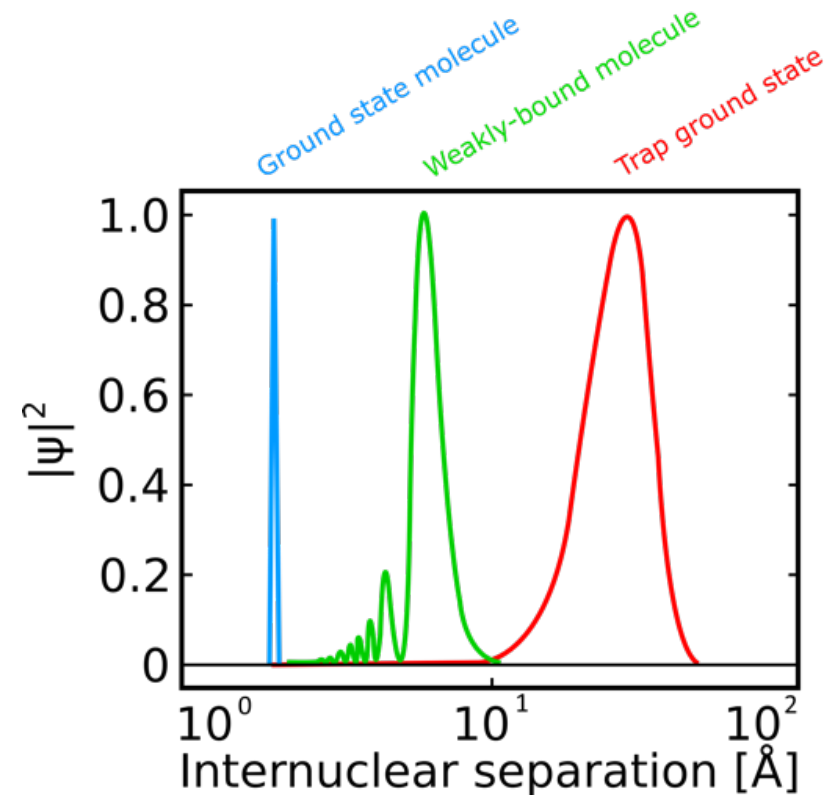
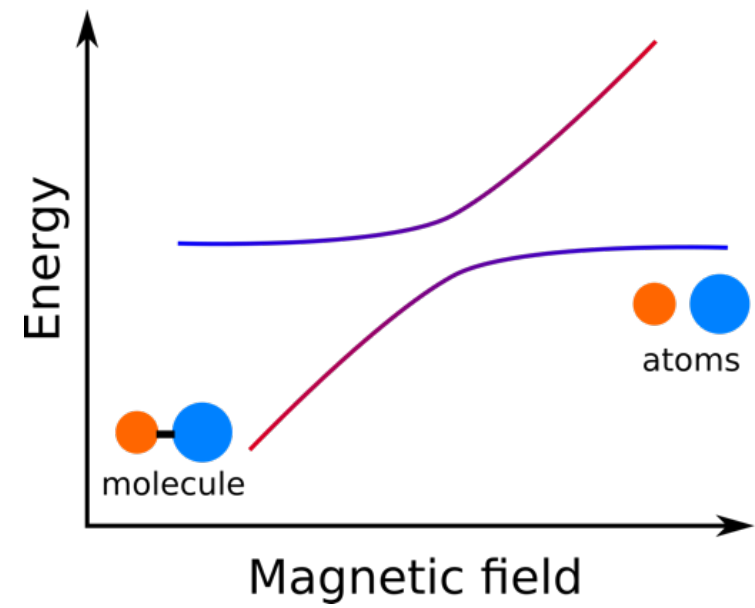
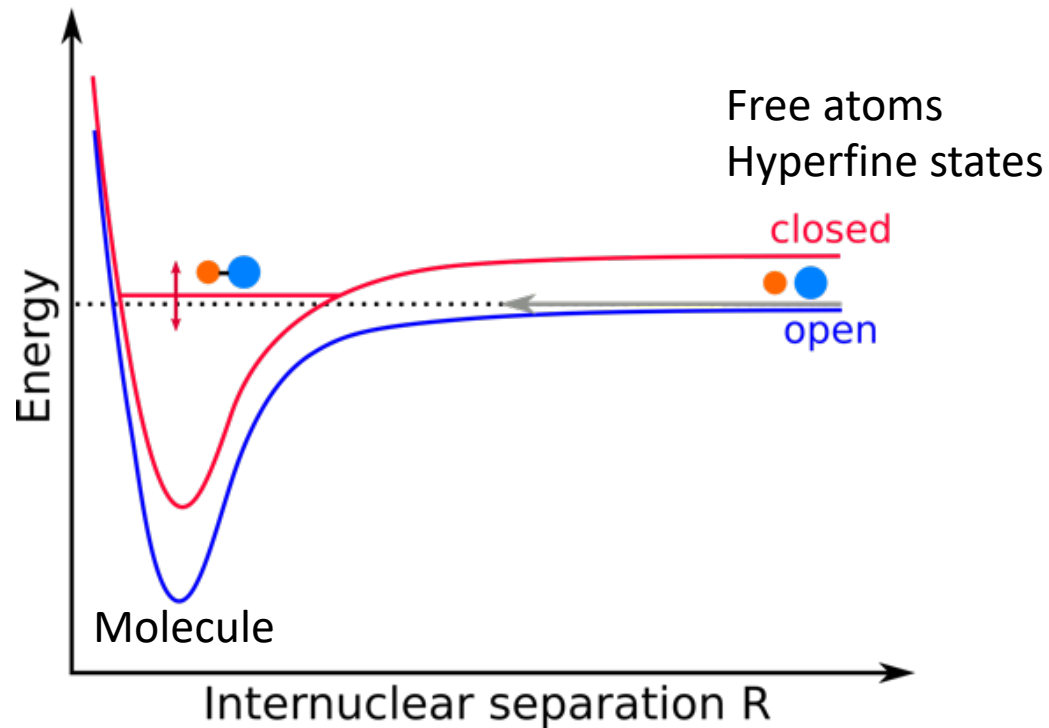
4. Weakly-bound molecule



5. Ground-state molecule

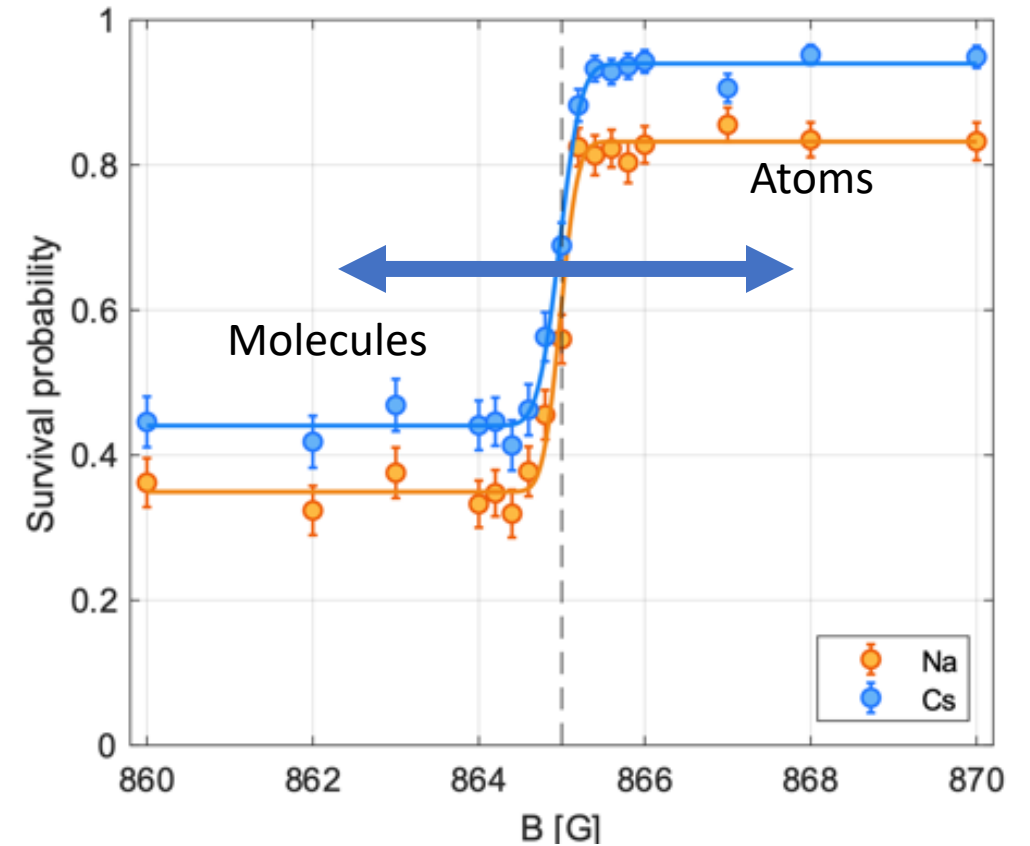
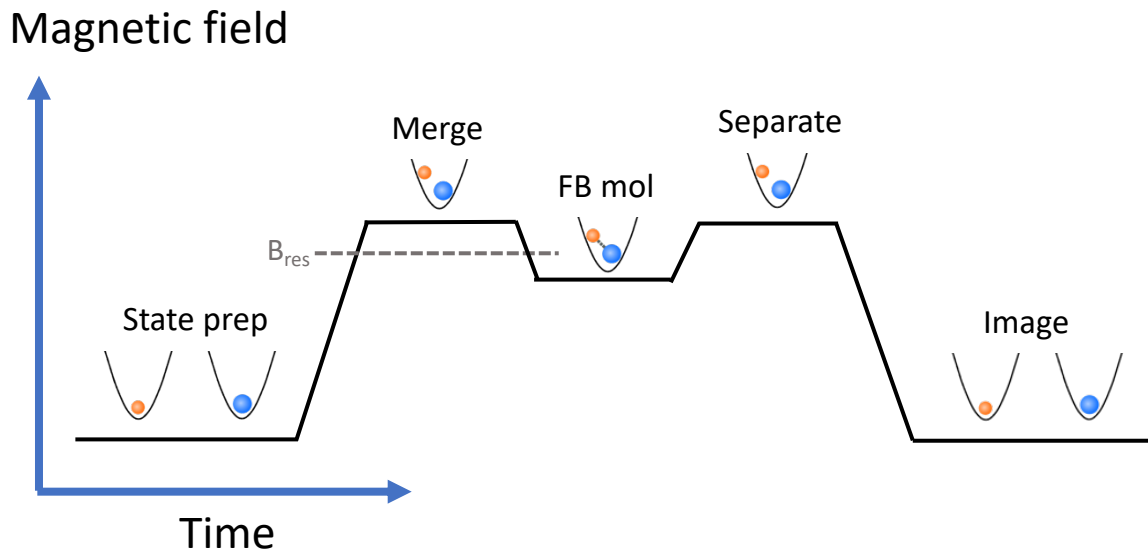


# Magnetic Feshbach resonance



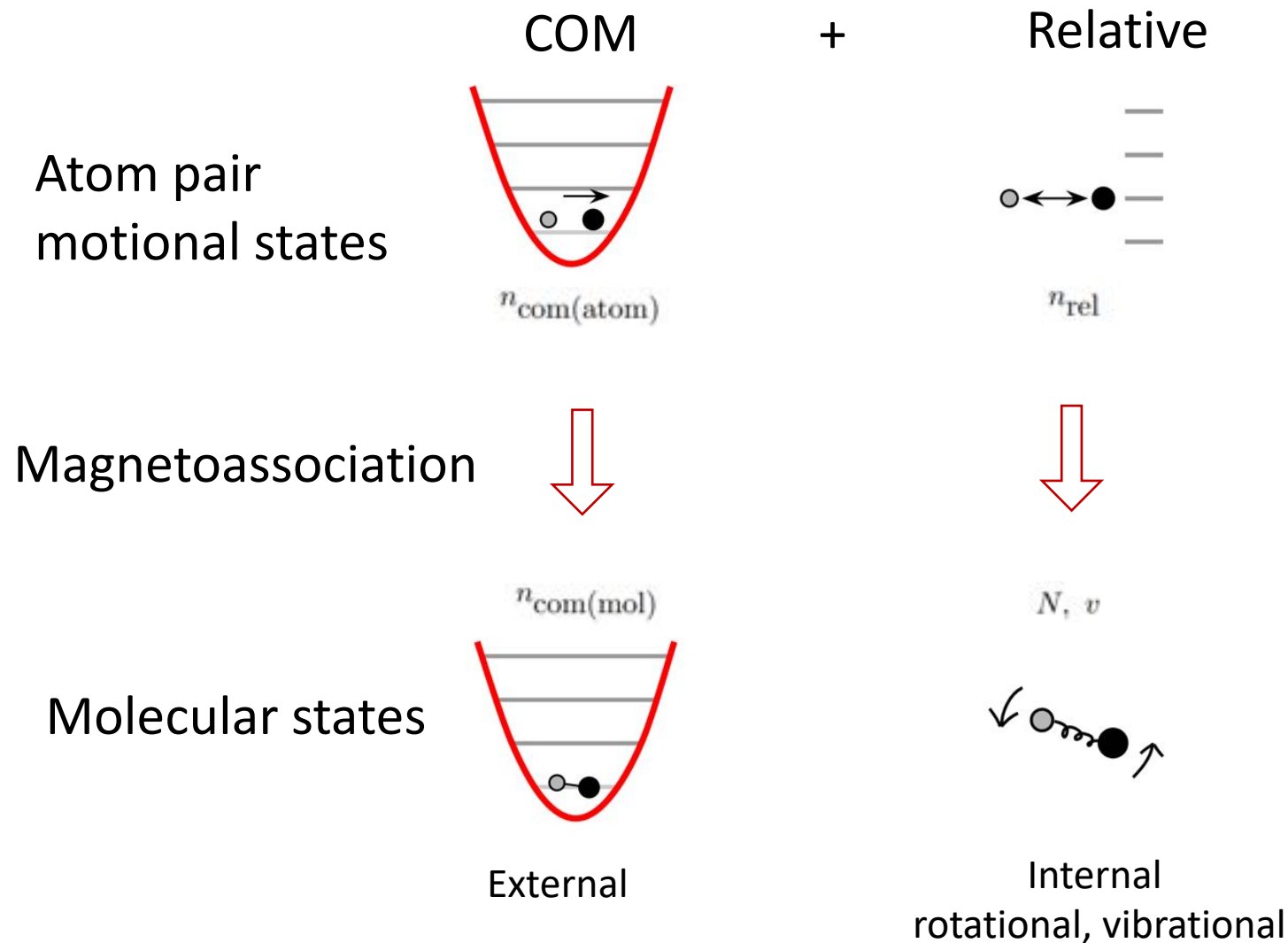
# Forming Feshbach molecules

- Detect with correlated loss of Na + Cs
- Adiabatic, reversible

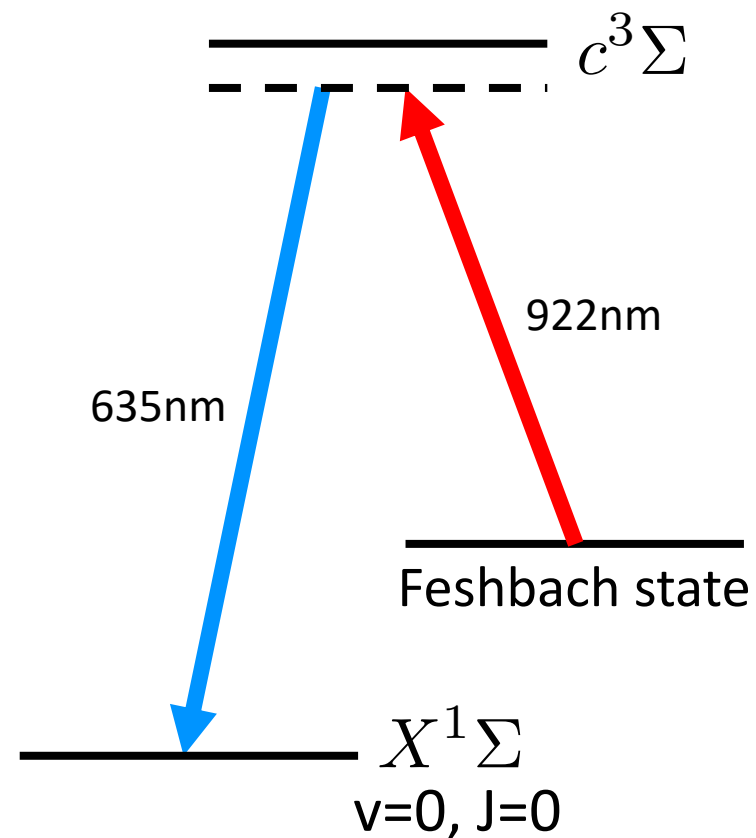
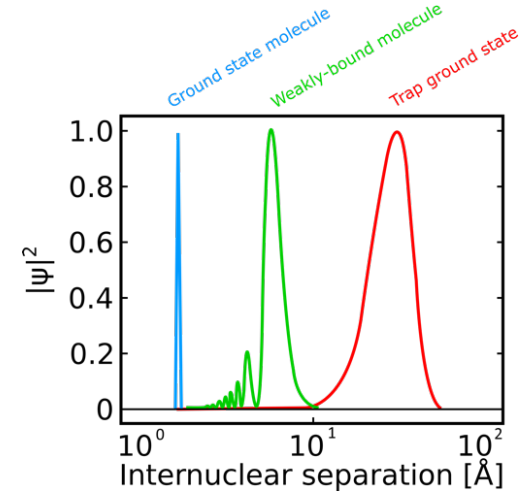
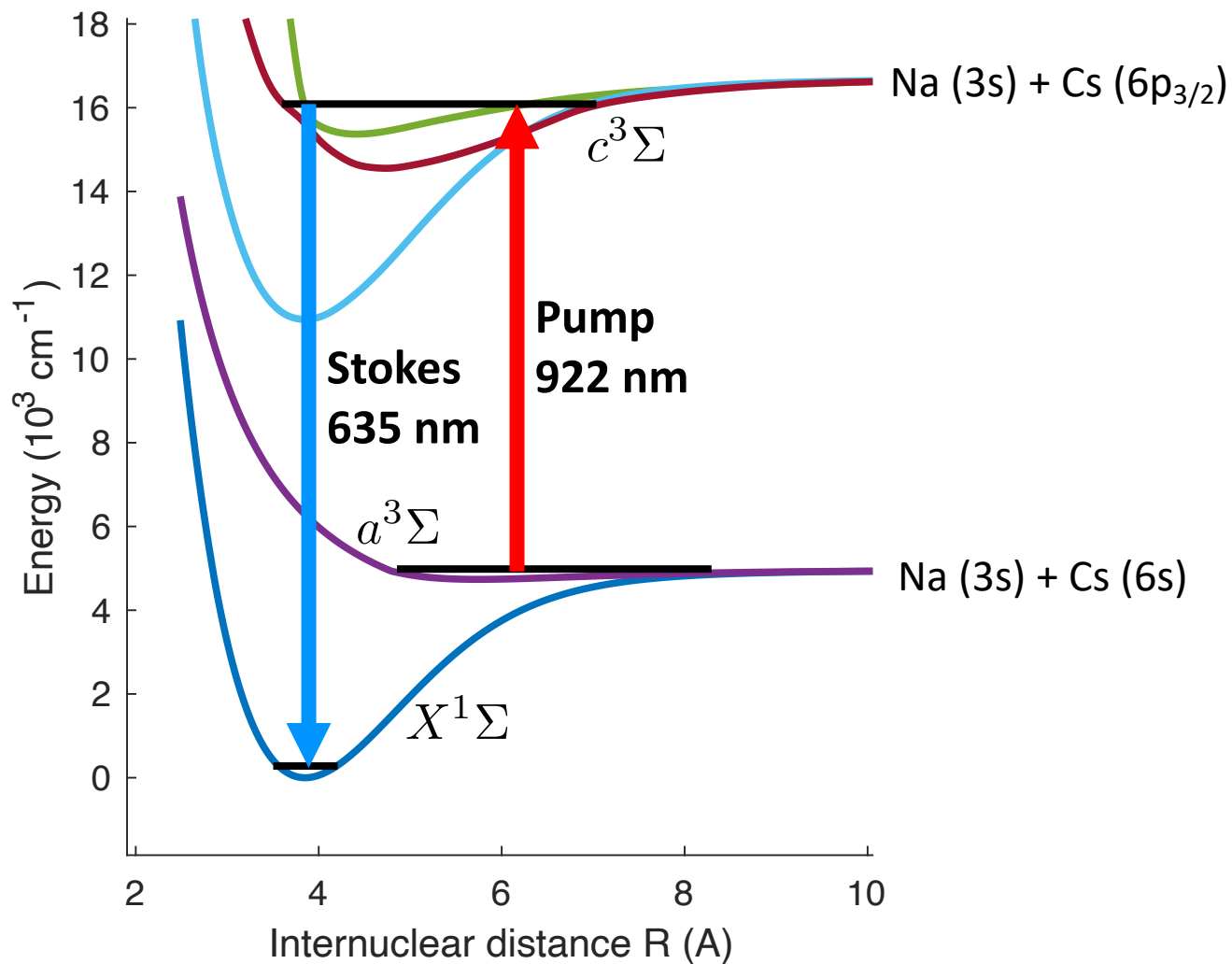




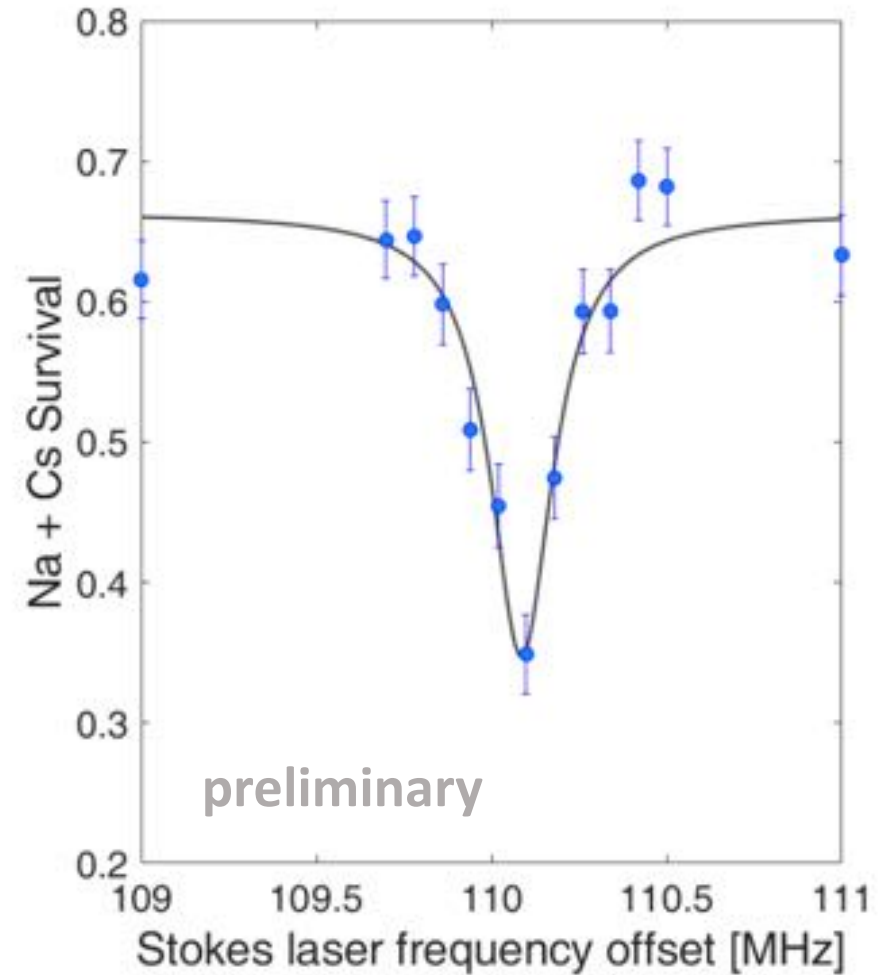
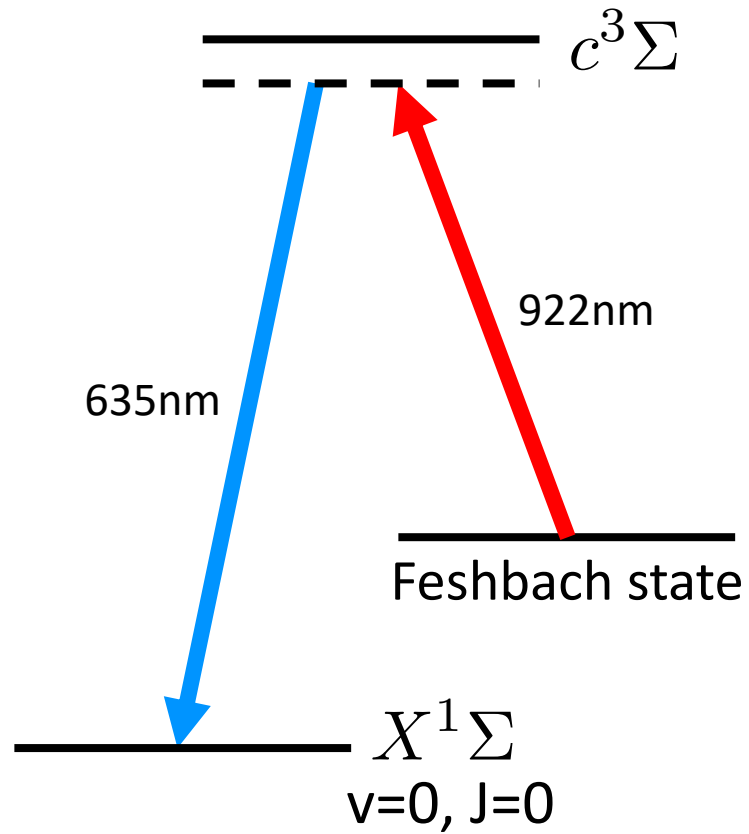
# Mapping complete control of atomic states to single molecules



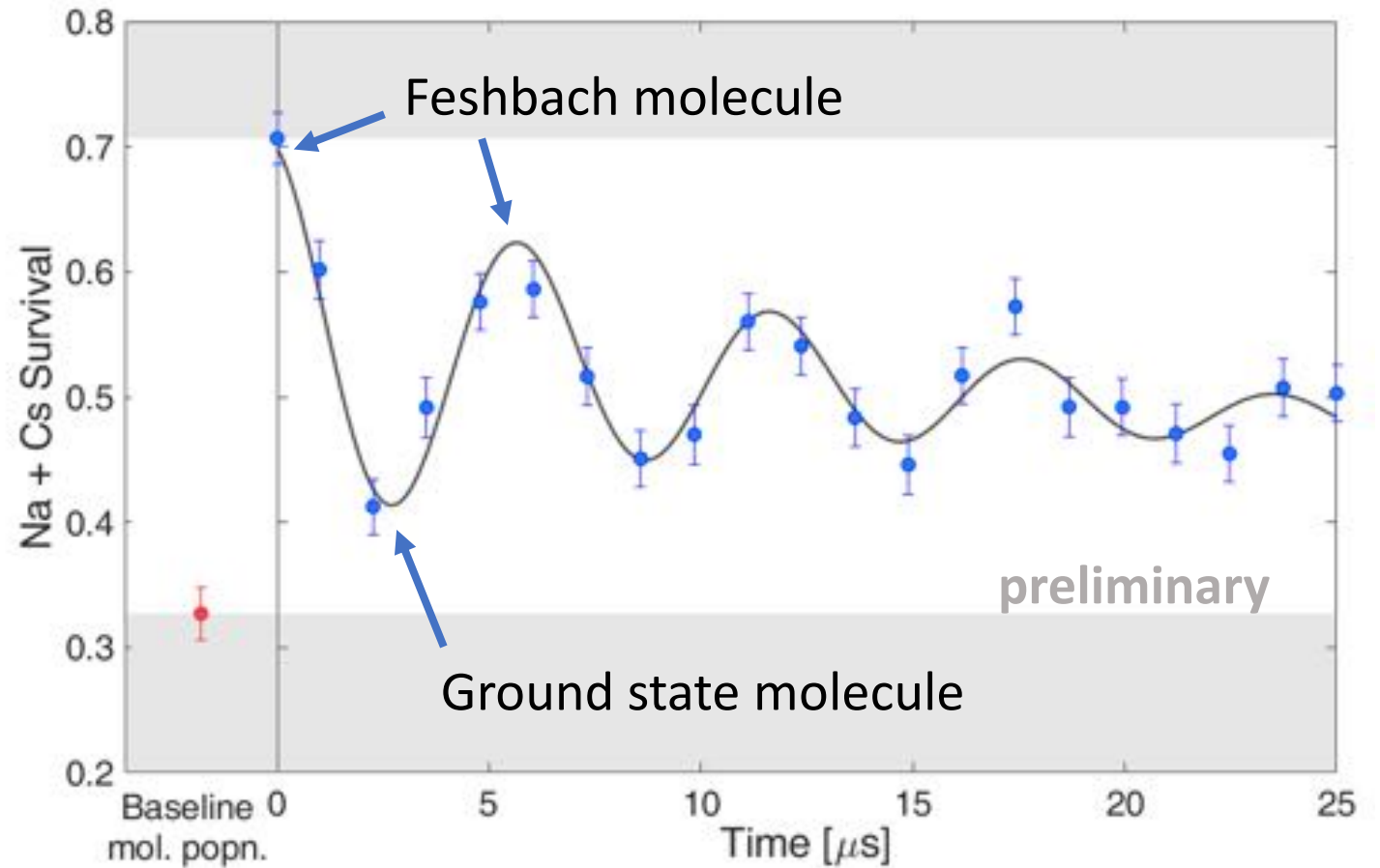
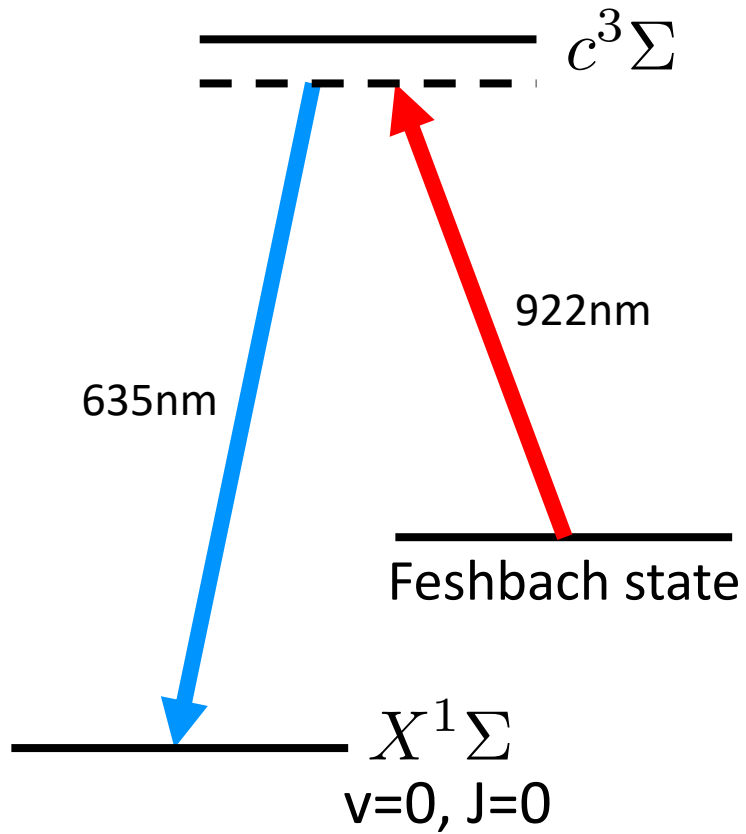
# Pathway to NaCs ground state



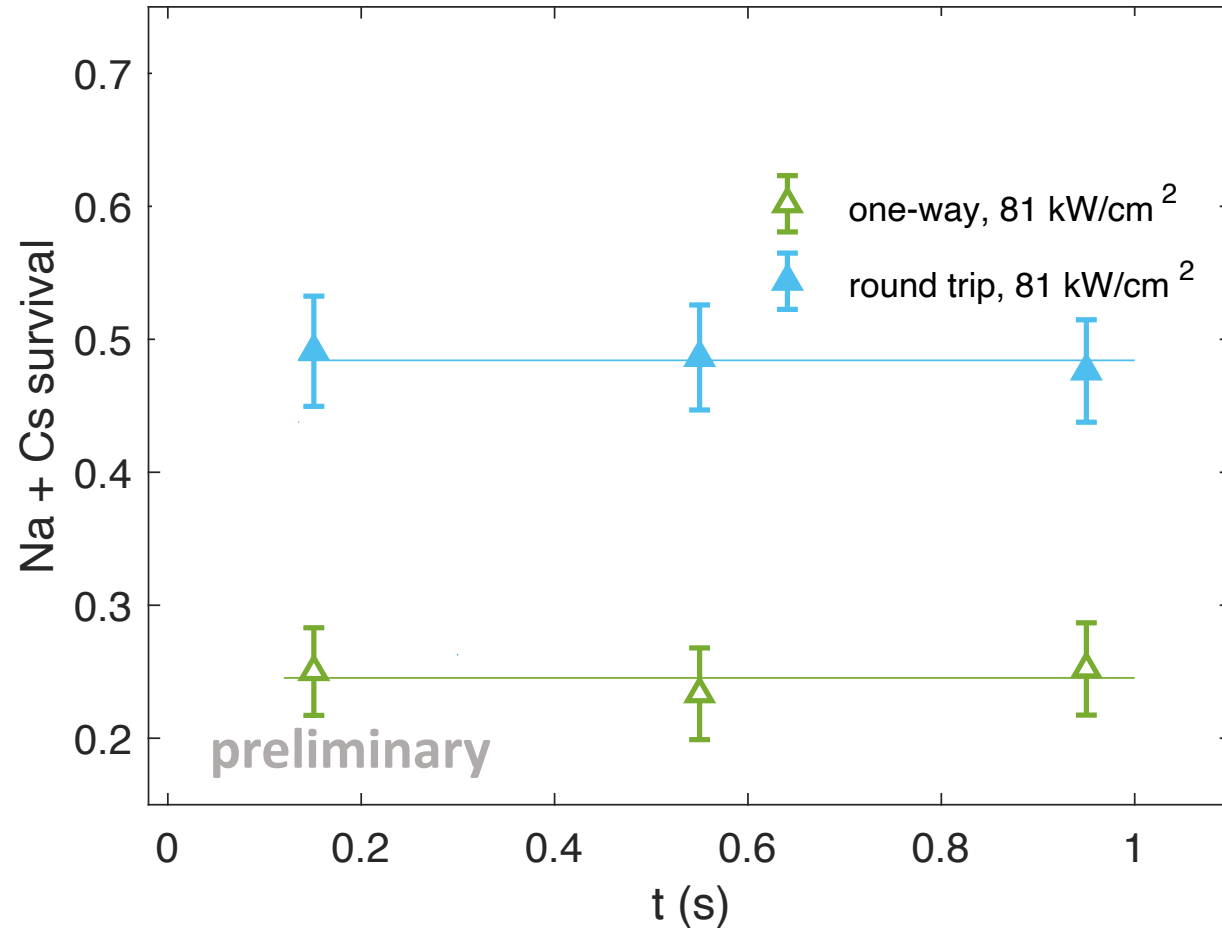
# Creation of ground-state molecules



# Creation of ground-state molecules



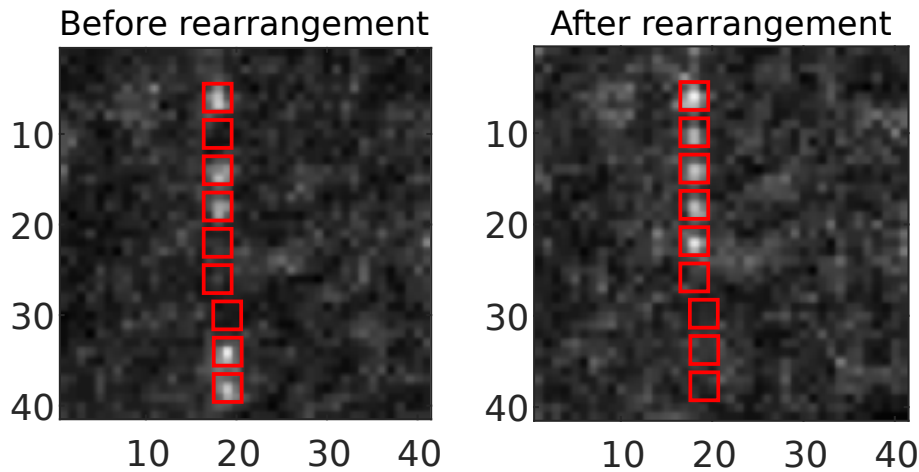
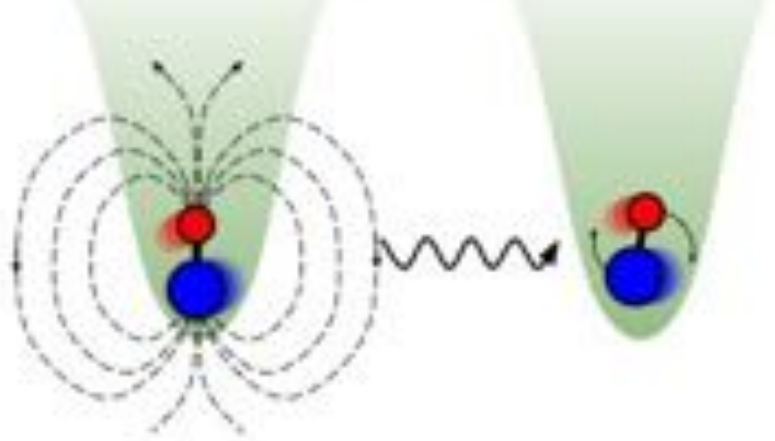
# Creation of ground-state molecules



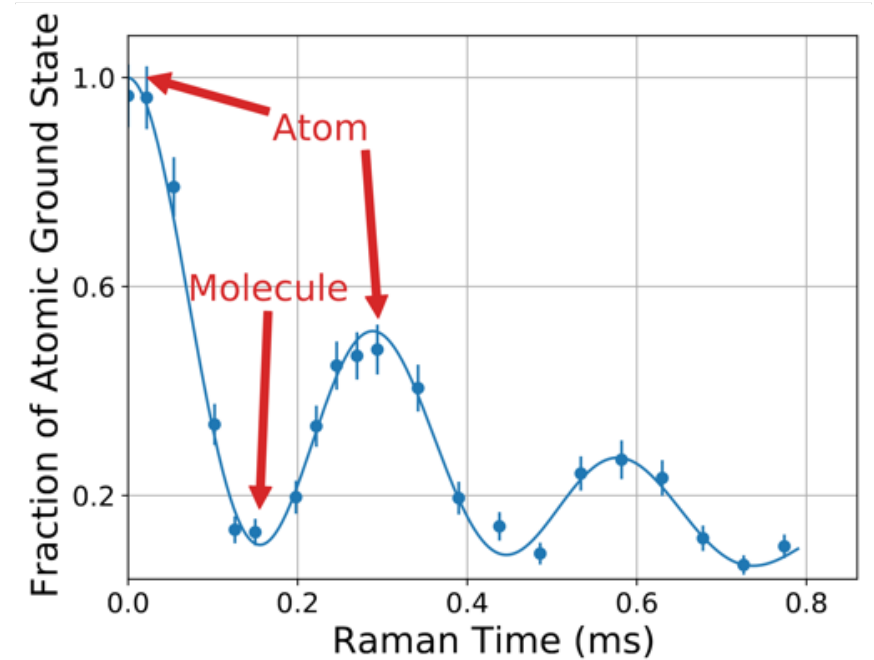
- Second-scale lifetime
- Long enough for quantum information & simulation studies
- Limited by scattering of trap light

# Near future with molecular arrays

## Entanglement via dipole-dipole interaction



Rearrangement for defect-free arrays

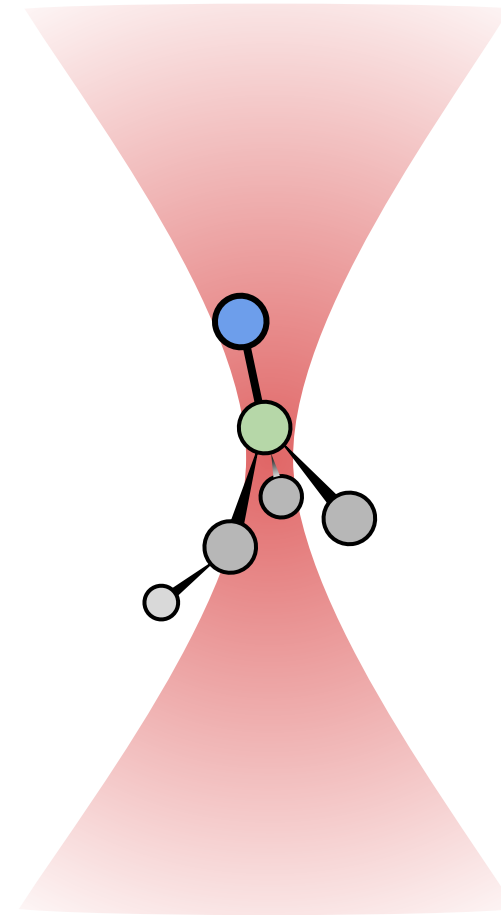


## All-optical molecule creation

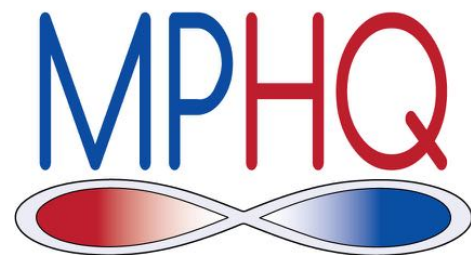
Y. Yu, K. Wang, et al., in preparation

# Looking forward

- Highly controlled environment
- Rearrangement
- Scalability
- Platform for atom-molecule and molecule-molecule interactions
- Near-threshold states

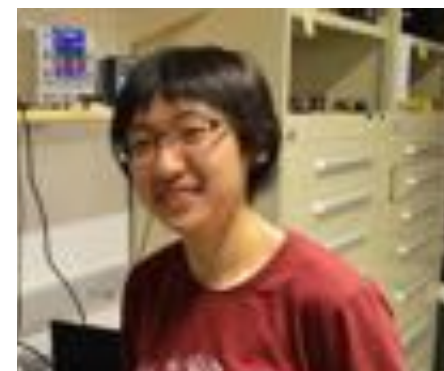


# Acknowledgements



**Prof. Kang-Kuen Ni**

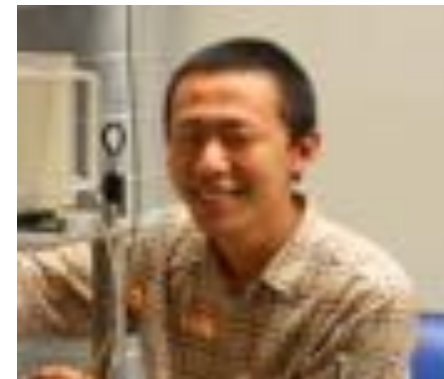
## Graduate students



**Jessie Zhang**



**Lewis Picard**



**Yichao Yu**



**Kenneth Wang**

**Past members: Prof. Nick Hutzler (Caltech), Prof. Jonathan Hood (Purdue U.), Dr. Lee Liu (CU Boulder)**