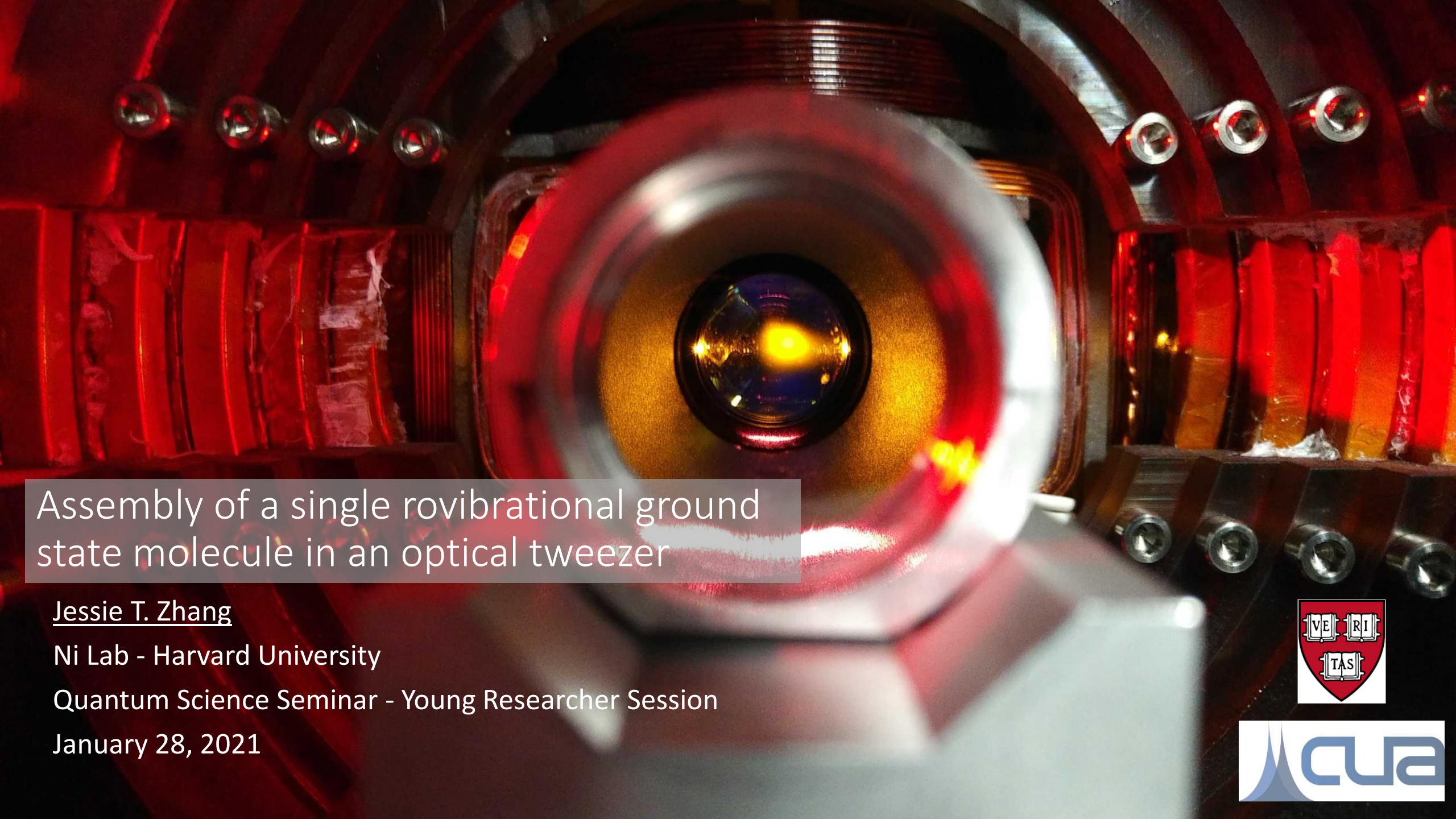


Assembly of a single rovibrational ground state molecule in an optical tweezer

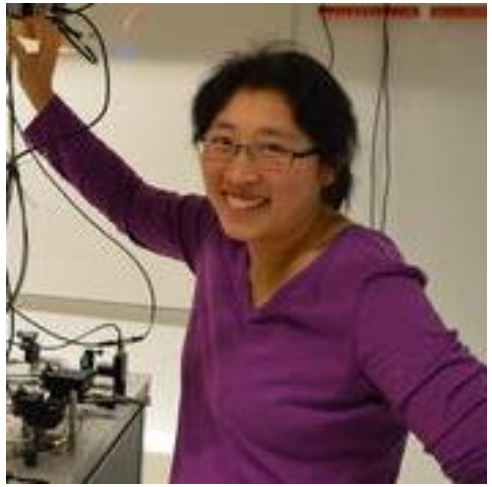
Jessie T. Zhang

Ni Lab - Harvard University

Quantum Science Seminar - Young Researcher Session

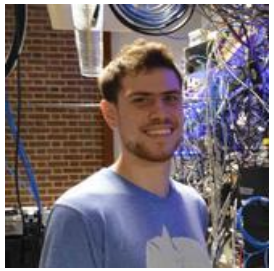
January 28, 2021

Acknowledgements

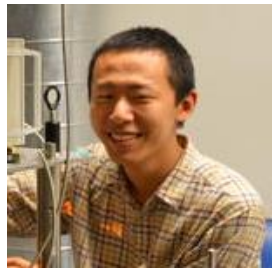


Prof. Kang-Kuen Ni

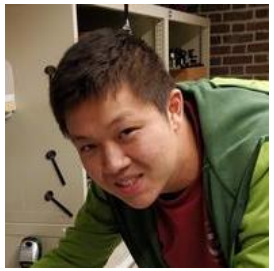
William Cairncross



Lewis Picard



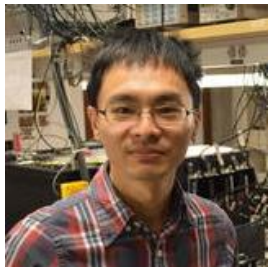
Yichao Yu



Kenneth Wang

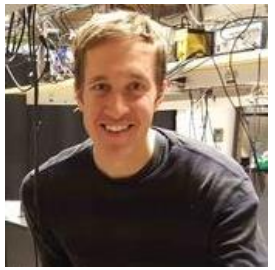
Past members:

Nick Hutzler



Yen-Wei Lin

Lee Liu



Jonathan Hood

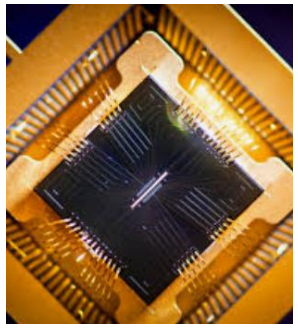
Theory:

Jeremy Hutson
(Durham)

Motivation

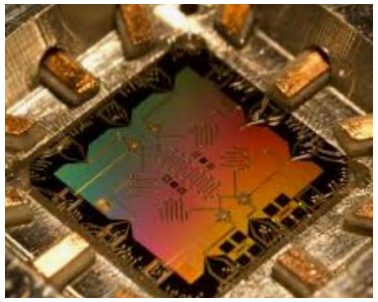
- Goal: create a quantum system that is
  - Fully controllable
  - Scalable
  - Capable of entangling interactions

Ion traps



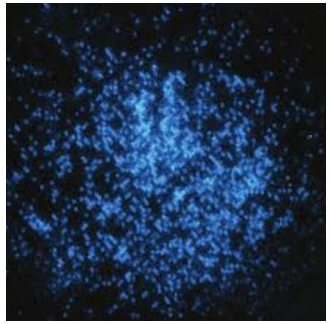
jqi.umd.edu/

Superconducting circuits



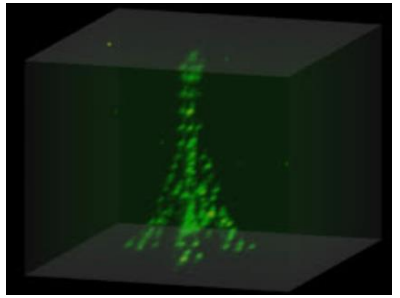
web.physics.ucsb.edu/~martinisgroup/

Atoms in optical lattices



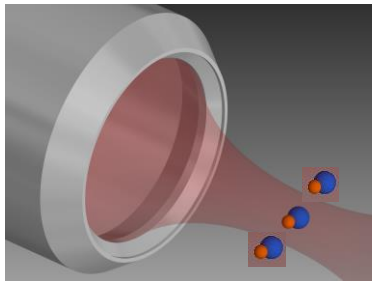
greiner.physics.harvard.edu/

Atoms in optical tweezer arrays



atom-tweezers-io.org/

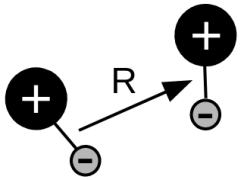
Molecules in optical tweezer arrays

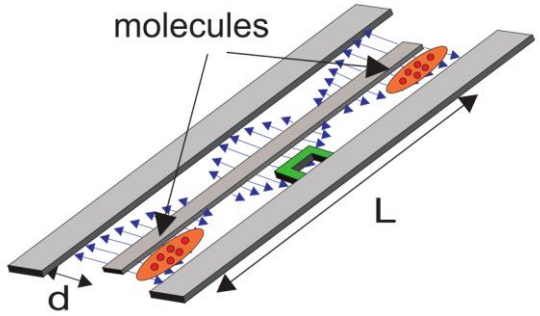


- Quantum computing and quantum simulation applications

Motivation

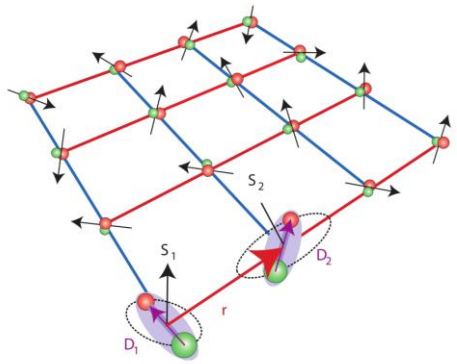
- Ultracold molecules
  - Rich internal structure
  - Tunable long-range electric dipole-dipole interactions (polar molecules)





PRL **97**, 33003 (2006)

Quantum computing



Nat. phys. **2**, 341 (2006)

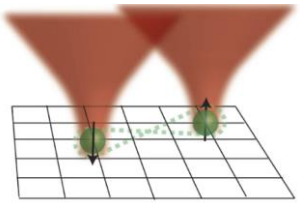
Quantum simulation

- Previous work
  - Creating bi-alkalis in bulk gases and optical lattices
    - KRb, RbCs, NaK, NaLi, NaRb …
    - JILA, Innsbruck, Harvard/MIT, Durham, CUHK, Hannover, USTC …
  - Direct laser cooling of molecules
    - Harvard, Yale, Imperial, JILA, …
  - Microwave & E-field control

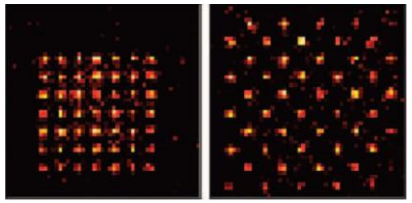
❖ Molecules pinned in sites
❖ Specific internal states
❖ Large electric dipole moment
❖ Long coherence time
  - motional ground state
❖ Prepare and address individual molecules

Motivation

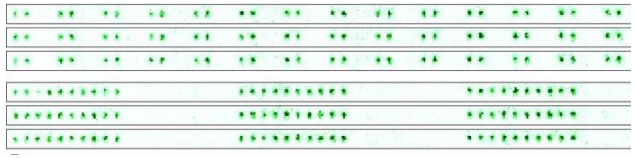
- Optical tweezers
  - Scalable, configurable geometries
  - Single site imaging and addressing
  - Single particle control



JILA

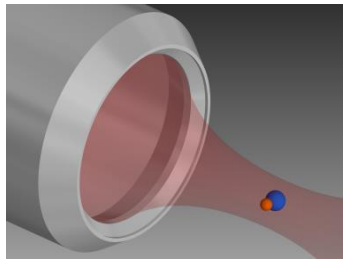


CNRS



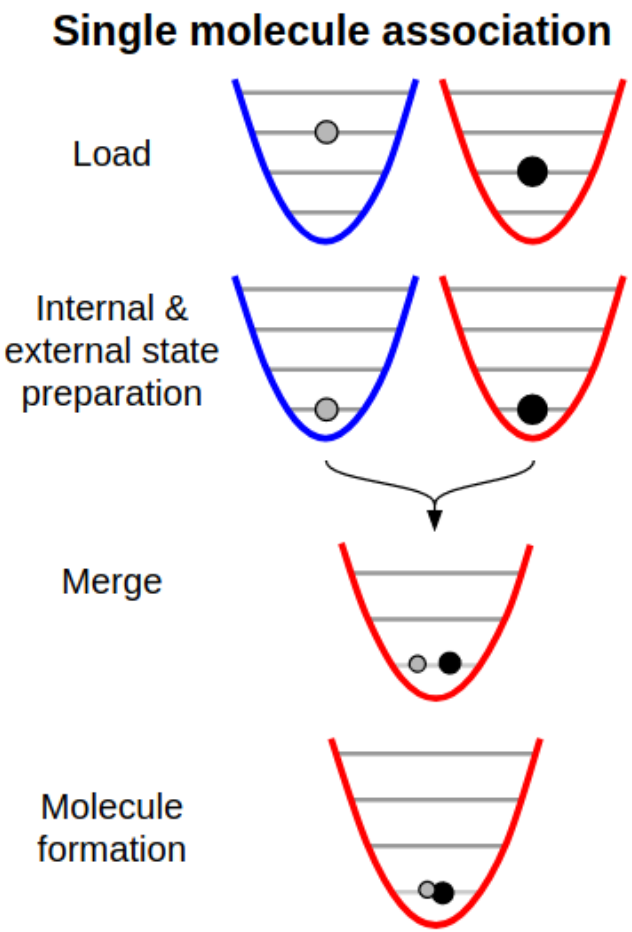
Harvard

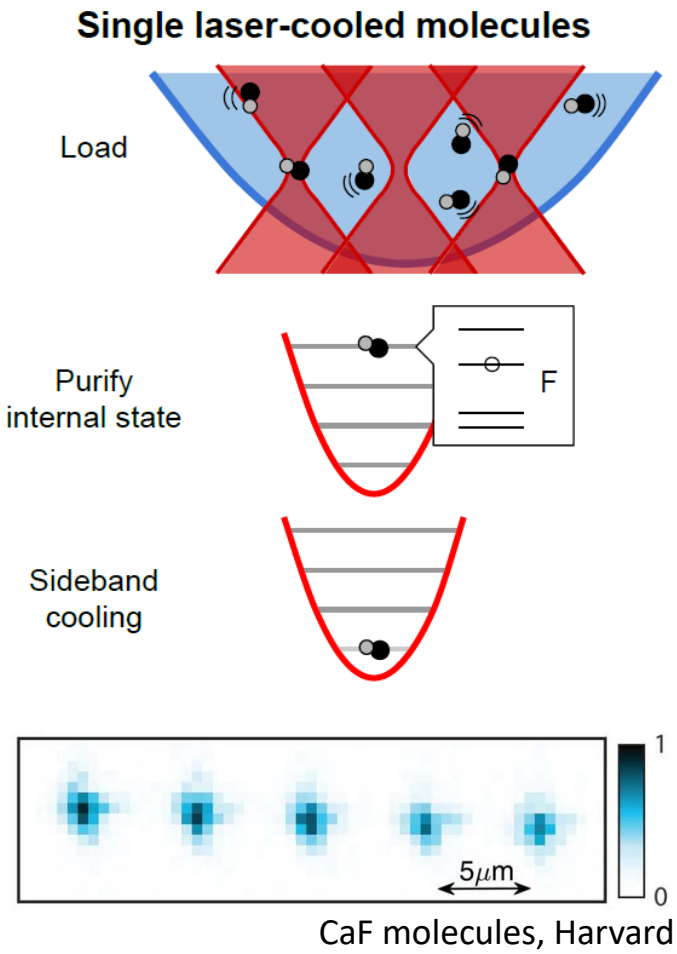
Goal: bring individual particle control offered by optical tweezers to molecules



Single fully quantum-state controlled molecule in an optical tweezer

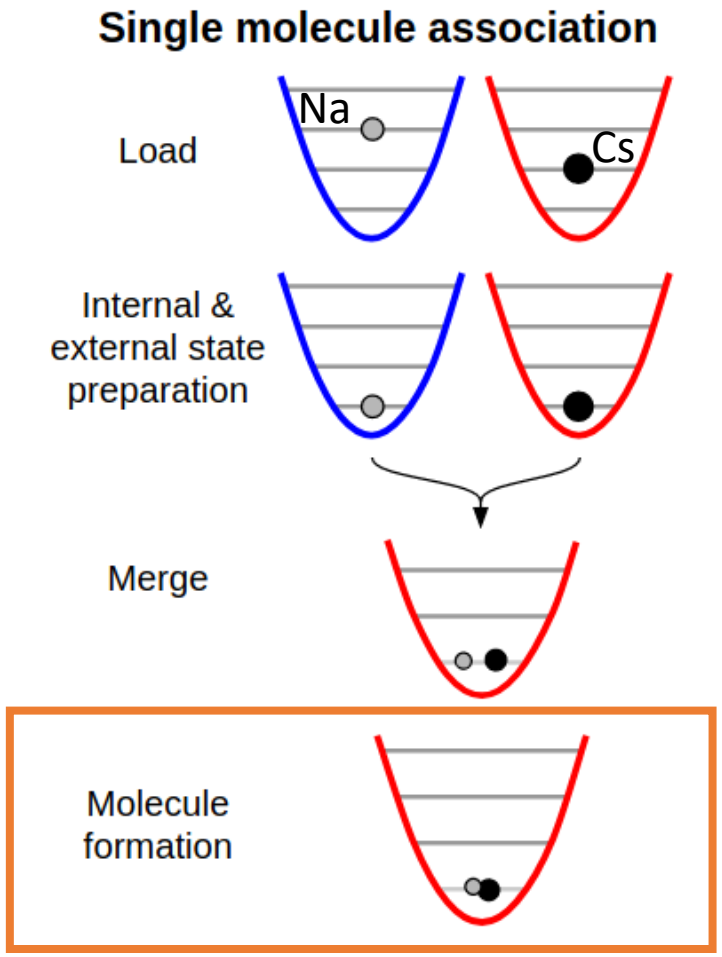
Approach to single molecule control





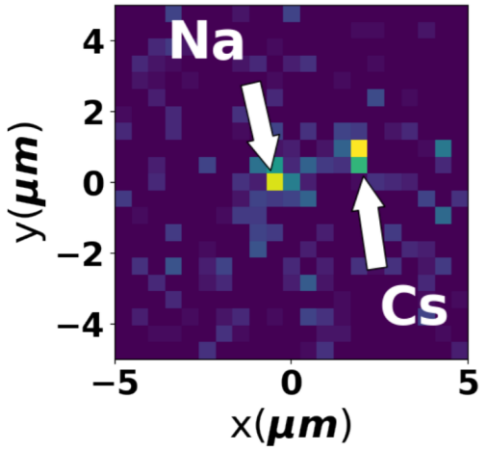
CaF molecules, Harvard

Molecule assembly scheme



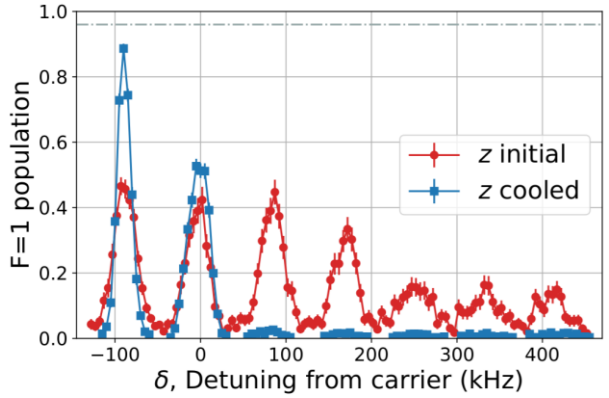
Map our control of atoms onto the molecules

- Atom pair of choice: Na+Cs
  - Bi-alkali
  - Large electric dipole moment



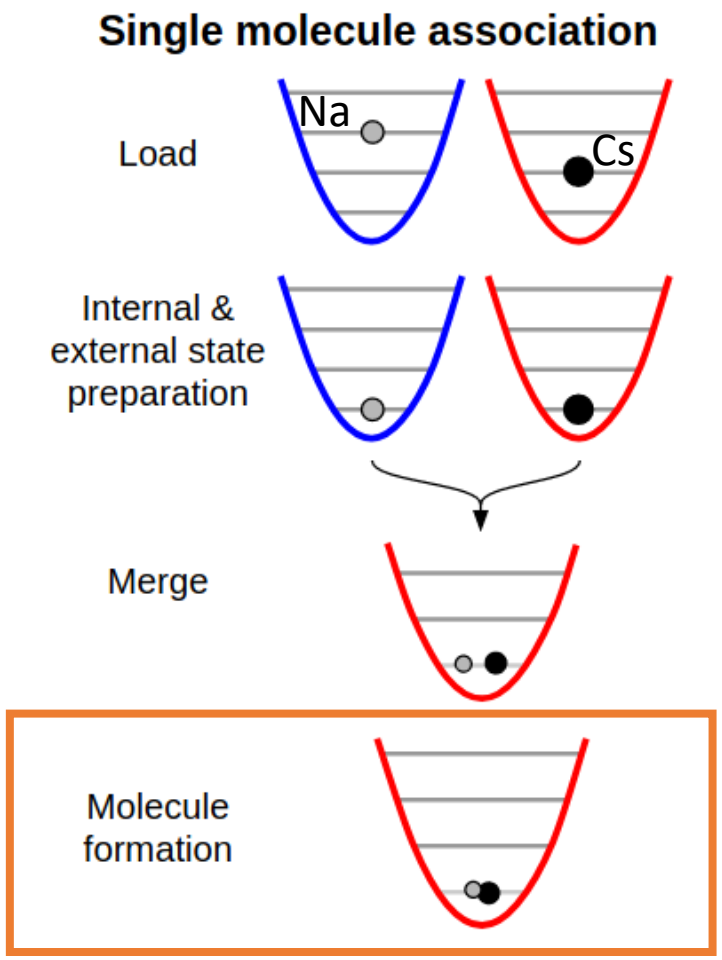
NJP 19, 023007 (2017)

- 3D motional ground state of both species
- Adiabatically merge to single trap



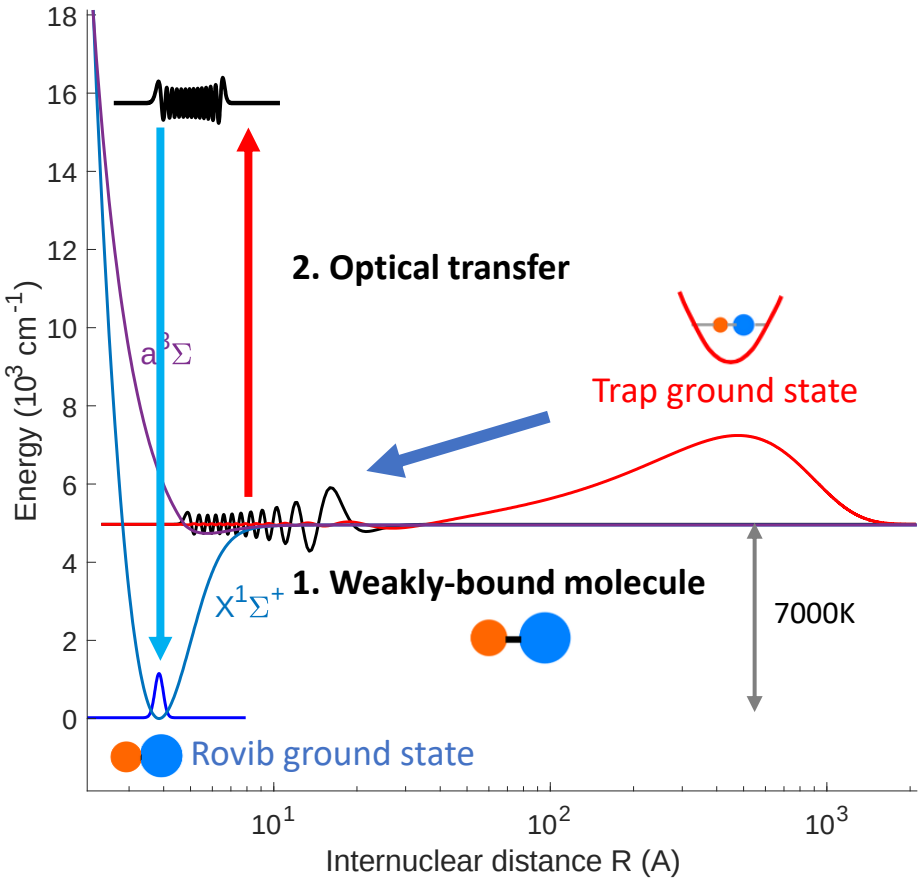
PRA 97, 063423 (2018)
PRX 9, 021039 (2019)

Molecule assembly scheme



Map our control of atoms onto the molecules

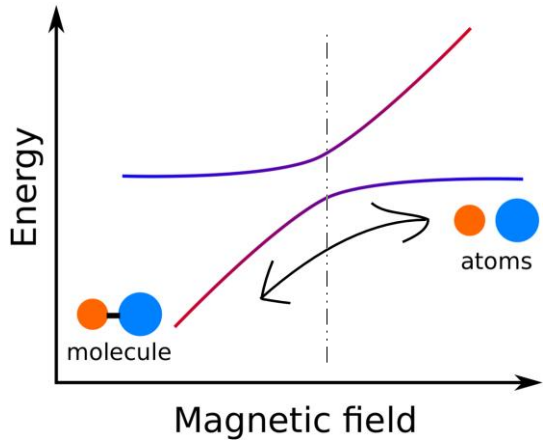
- Molecule formation

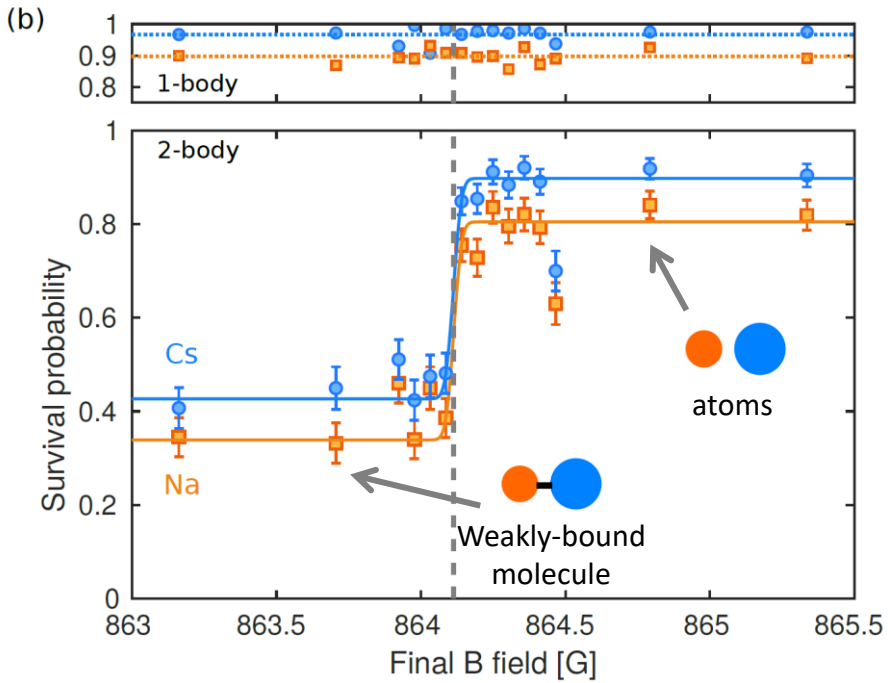


- New molecule NaCs
- Intense light in optical tweezers
- Different parameter regime from bulk gases

Weakly-bound molecule formation

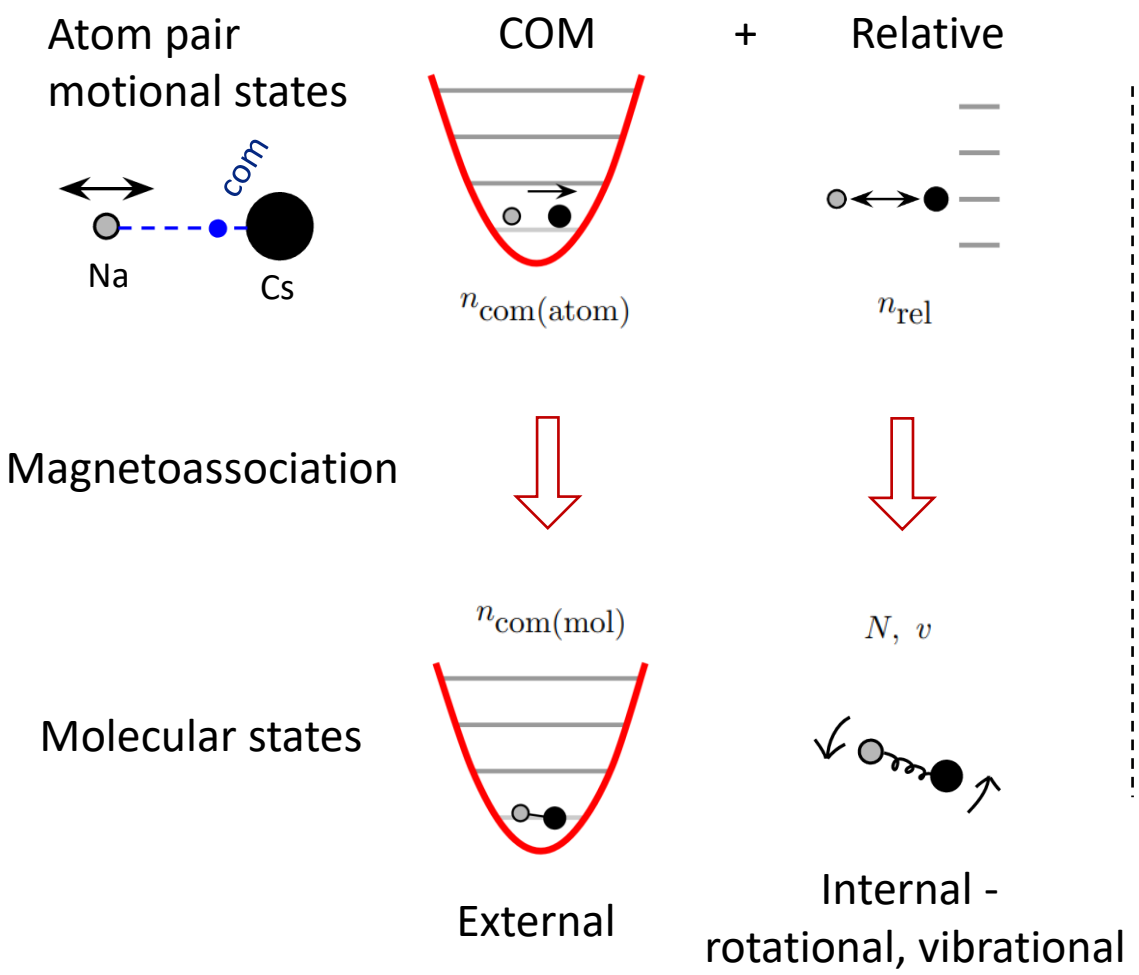
- Magnetoassociation via Feshbach resonance

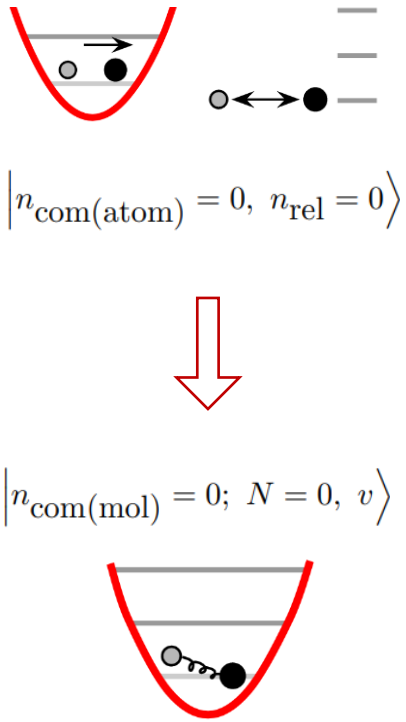




Phys. Rev. Lett. 124, 253401 (2020)
J. T. Zhang, Y. Yu, W. Cairncross, K. Wang, L. Picard, J. Hood, Y Lin, J. Hutson, K-K. Ni

Mapping of quantum state control





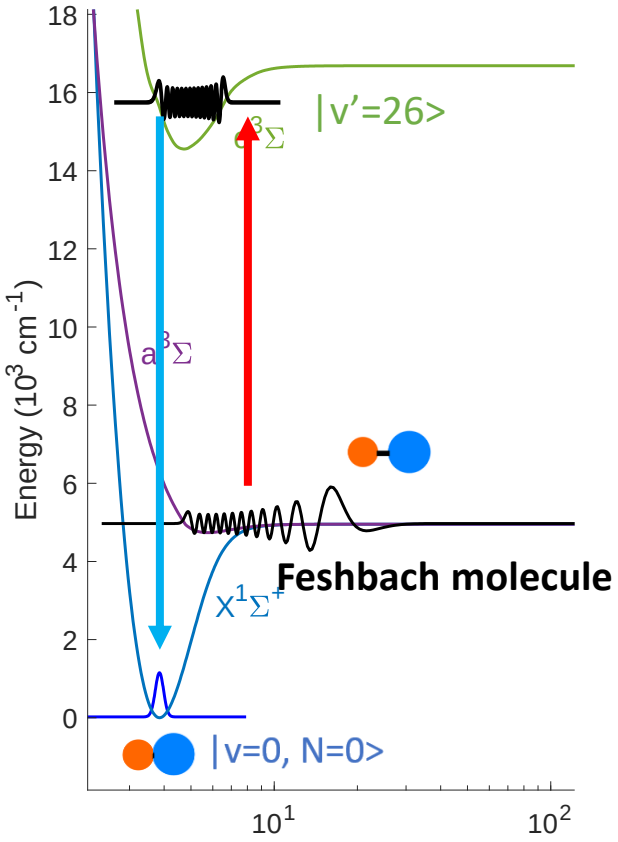
- Internal state pure
- External state determined by COM motional state population of atom pair
  - ~77% in ground state

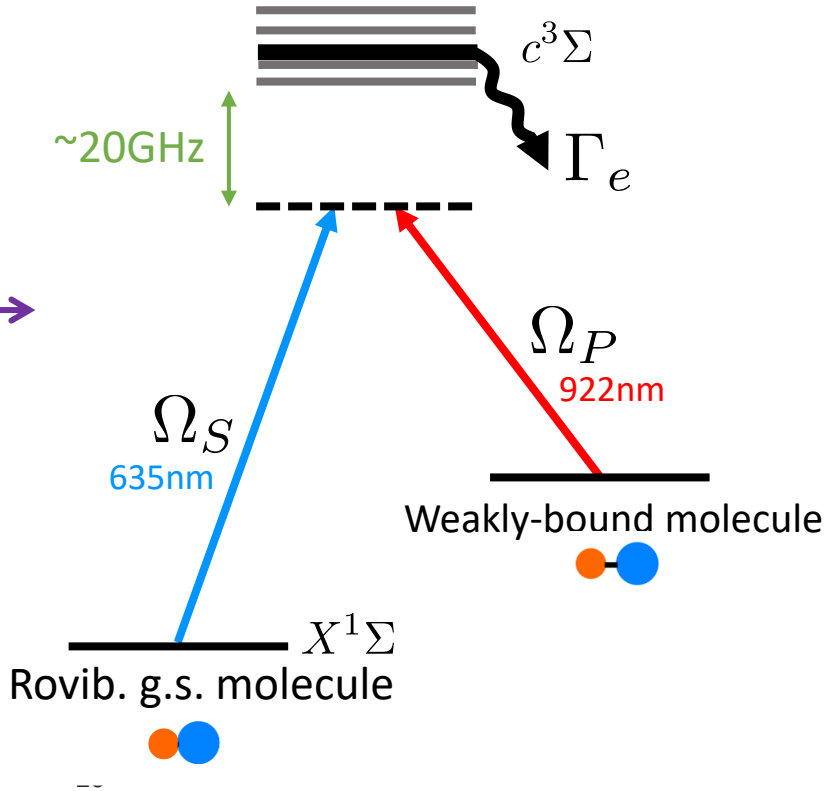
Control over the internal and external states of the atoms maps onto the molecules!

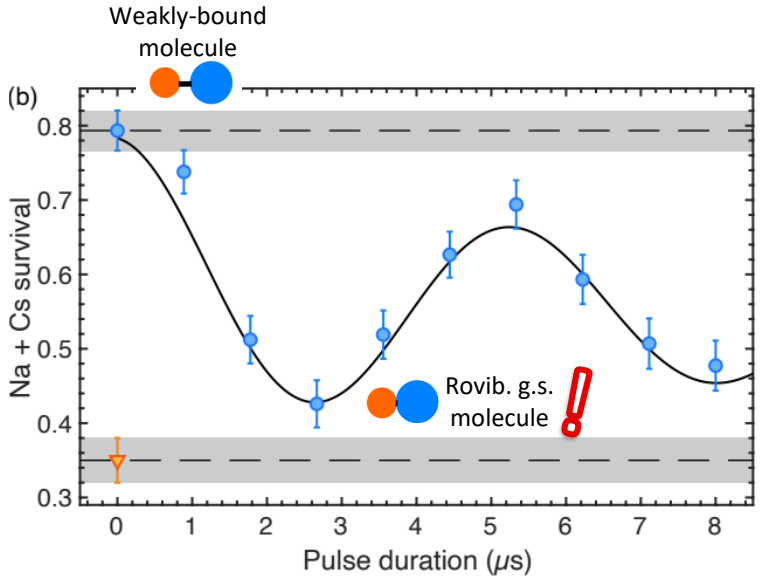
Phys. Rev. Lett. 124, 253401 (2020)
J. Zhang, Y. Yu, W. Cairncross, K. Wang, L. Picard, J. Hood, Y Lin, J. Hutson, K-K. Ni

Transferring to rovibrational ground state

- Coherent 2-photon transfer





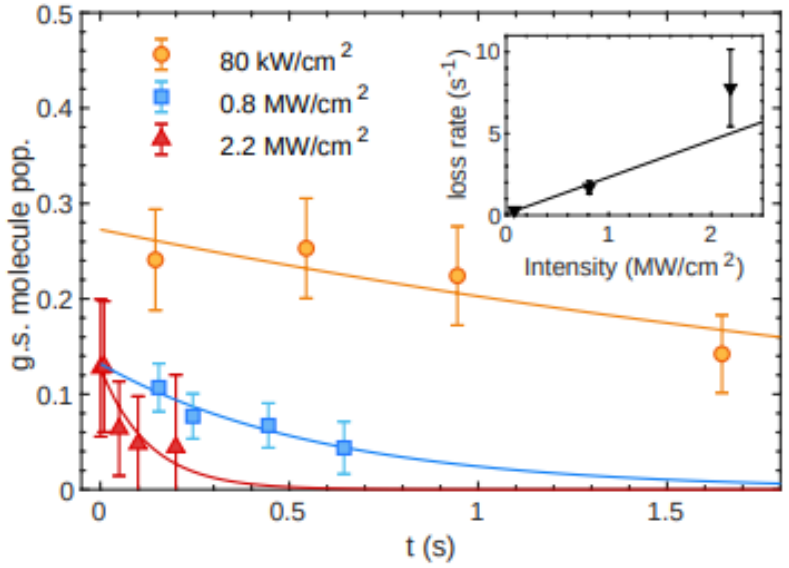


- 2-photon detuned Raman transfer

arXiv:2101.03168 (2021)
W. Cairncross*, J. Zhang*, L. Picard, Y. Yu, K. Wang, K-K. Ni

Characterizing rovibrational ground state

- Lifetime
  - Second-scale lifetime
  - Long enough for quantum information and quantum simulation studies
  - Limited by scattering from tweezer light



- Quantum state control
  - Hyperfine state resolved
  - External state purity
    - Additional heating from optical transfer process
    - ~65% in motional ground state

Single pair of atoms

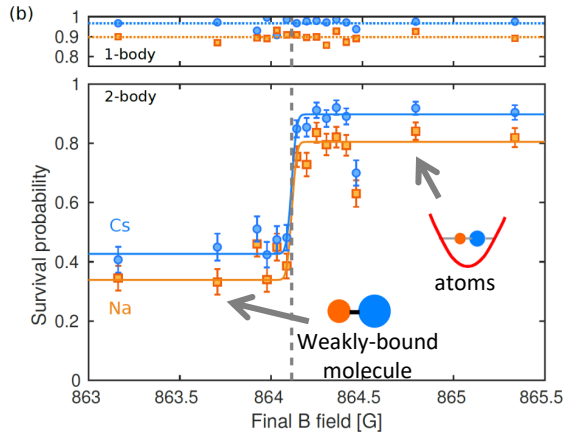
↓

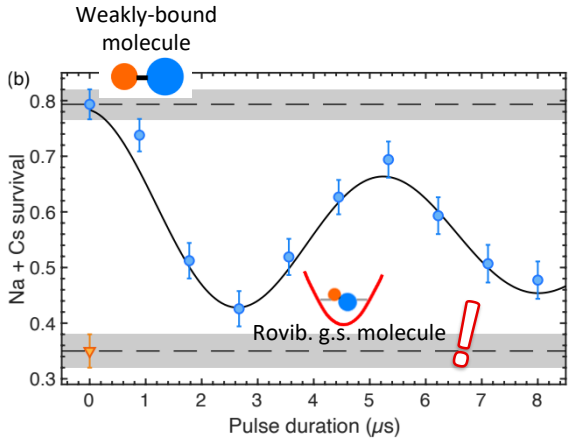
Single molecule in well-defined quantum state!

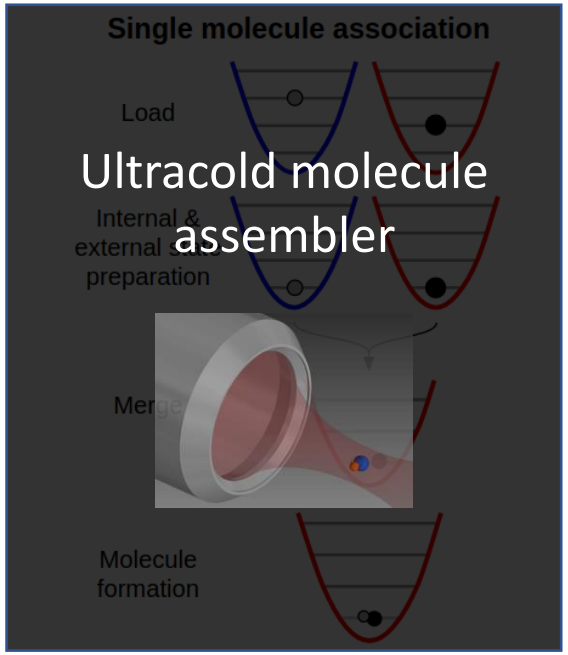
arXiv:2101.03168 (2021)
W. Cairncross*, J. Zhang*, L. Picard, Y. Yu, K. Wang, K-K. Ni

Conclusions and outlook

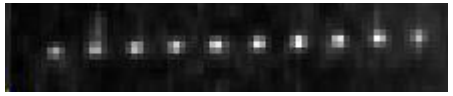
- Assembled single fully controlled NaCs molecule in its rovibrational ground state in an optical tweezer



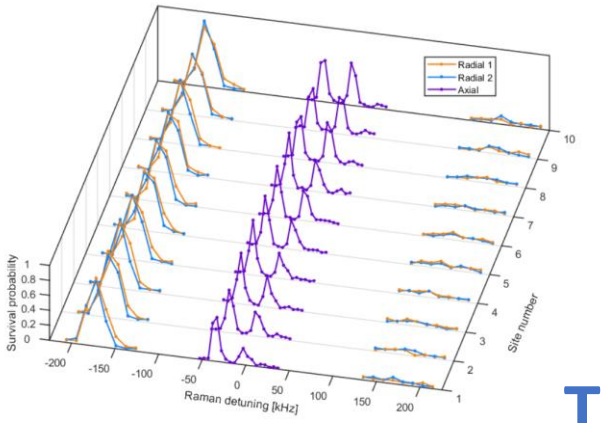


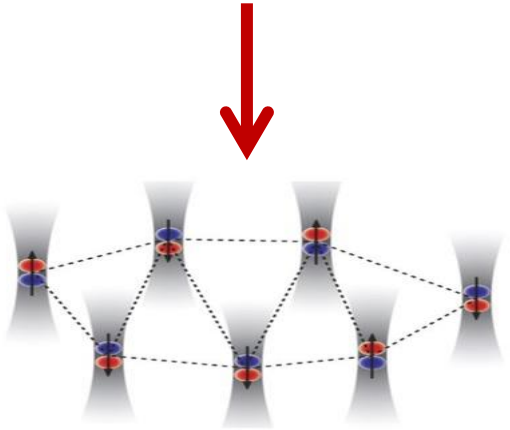


- Expanding to arrays



10 Cs atoms loading + cooling





- Generate entangling interactions

Thank you!