Association of single ultracold molecules in optical tweezers

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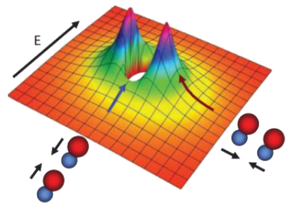
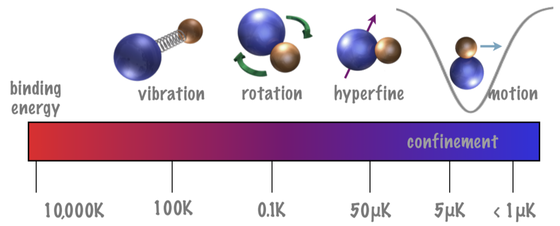
Ultracold Molecules

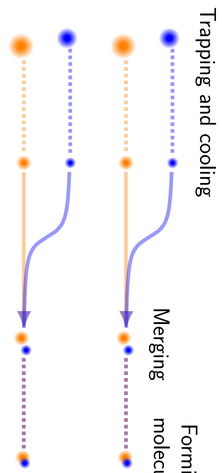
- NaCs has a large permanent electric dipole moment (4.6 **Debye**)
- Strong anisotropic dipole-dipole interactions
- Coupled internal degrees of freedom can be used to tune interactions and store information





Our Approach

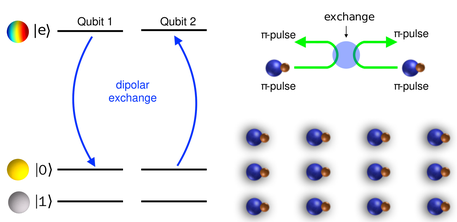
- Assemble and trap individual molecules in optical tweezers from laser-cooled atoms
- Raman transition from atoms to weakly-bound molecules
- STIRAP to ground state molecules



Advantages

- Fast cycle time (<1s), small vacuum chamber
- Dynamically configurable trapping geometry
- All optical cooling and state-manipulation

Quantum gate scheme



Acknowledgements

Arnold and Mabel Beckman Foundation

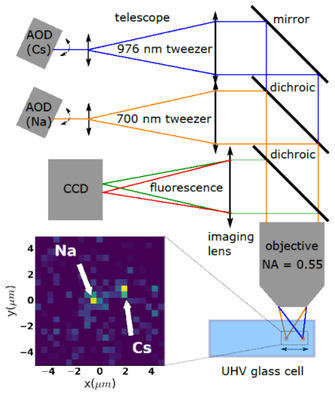
NSF

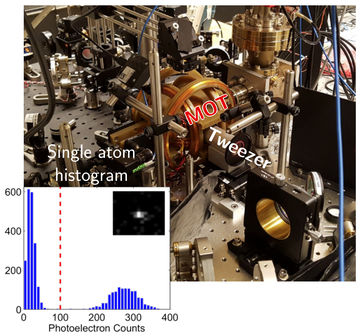
AFOSR Air Force Office of Scientific Research

Alfred P. Sloan Foundation 1934

Trapping and Cooling of Atoms

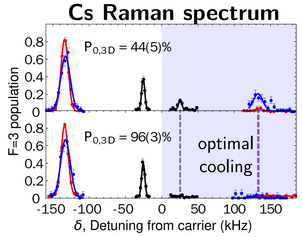
Laser-cooled and trapped single Cs and Na atoms < 100 uK in separate rearrangeable optical tweezers.



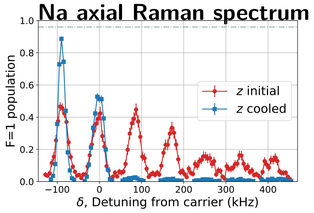


Hutzler, Liu, Yu, Ni, New J. Phys 19, 023007 (2017)
L. Liu, Zhang, Yu, Hutzler, Hood, Liu, Rosenband, Ni, arXiv:1701.03121 (2017)

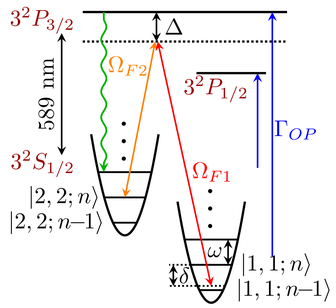
Cs Raman spectrum



Na axial Raman spectrum



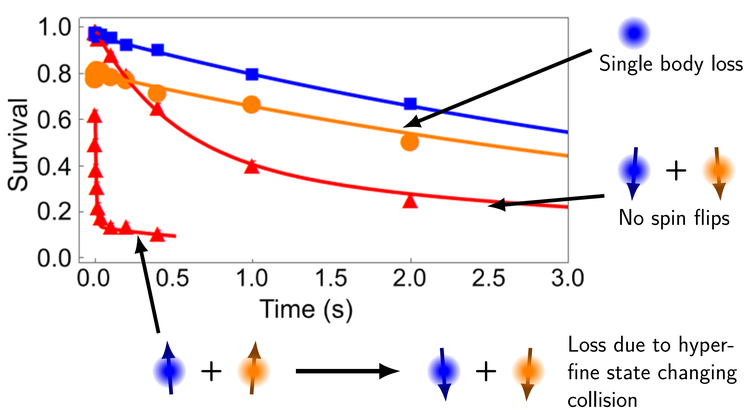
Cooled into 3D motional ground states in the tweezers with Raman sideband cooling. Cooling fidelities are 96% for Cesium and 94% for Sodium.



Yu, Hutzler, Zhang, L. Liu, Rosenband, Ni, arXiv:1708.03296 (2017)

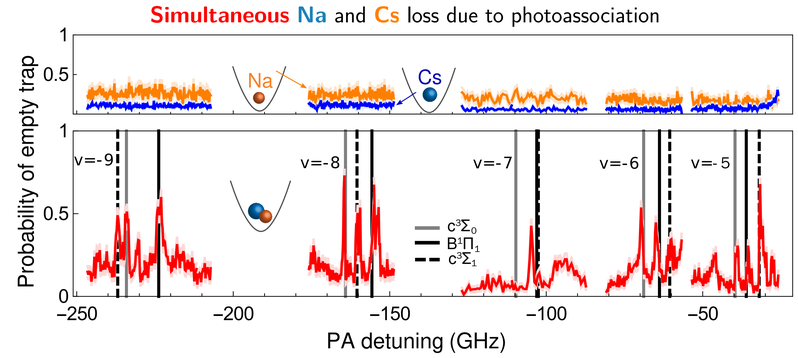
Merging Tweezers

- Na and Cs tweezers are merged together into a single trap with little heating
- Observe hyperfine spin changing collisions when atoms in same trap



Photoassociation

Near threshold photoassociation

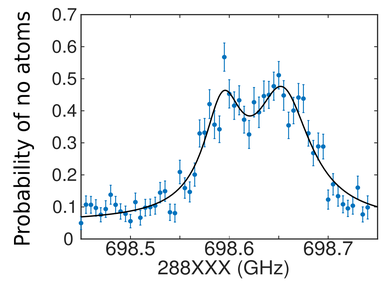


- First photoassociation of a single molecule in an optical tweezer.
- Observation of new NaCs excited state vibrational lines near threshold.
- Vertical lines are fits to the LeRoy long range dispersion model,

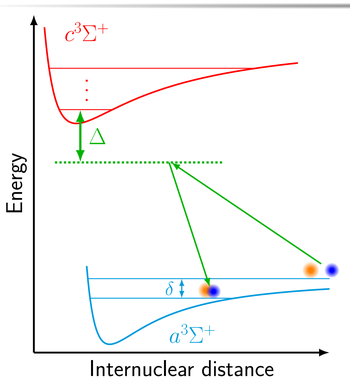
$$\Delta E \propto \frac{1}{\sqrt{C_6}}(v_D - v)^3$$

Liu, Hood, Yu, Zhang, Hutzler Rosenband, Ni, Science 360, 6391 (2018)

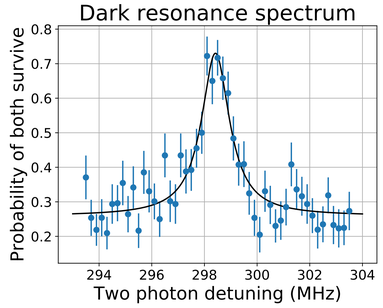
Photoassociation for $v = 0$ state



Coherent Molecule Formation *(Preliminary)*



Dark resonance spectrum



Scheme

- Raman transition to weakly-bound state
- STIRAP to rovibrational ground state

Progress

- Use dark resonance to find the weakly-bound state.

$$E_{\text{binding}} = 298.2\text{MHz} \cdot h$$

- Observed Raman transition from atomic to molecular state

Raman spectrum