Ultracold Molecules and Magnetic Control of Chemical Reactions

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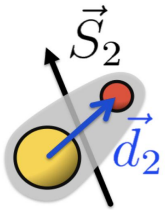
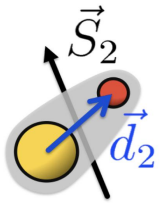
MIT

Triplet NaLi



Ultracold Molecules with Electric and Magnetic Dipole Moments



- **Ultracold** molecular gases: μK - nK
- Tunable (with E field) **long range** dipole-dipole interaction V ~ $1/r^3$
- Variety of tools to control: E field, B field, optical confinements (lattices, tweezers, etc)

Outline

Ultracold molecule experiment platform, applications

Molecular Structure

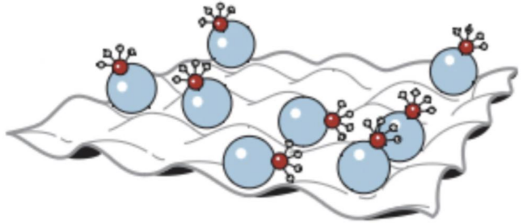
Making ultracold molecules

First Feshbach resonance between ground state molecules in NaLi

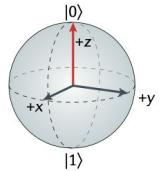
Outlook

Ultracold Molecules: Quantum Applications

Quantum simulation: Simulate hamiltonian of more complicated systems in a controlled way

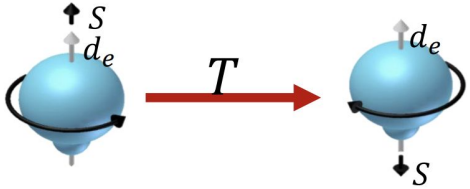


Information processing: process quantum gates

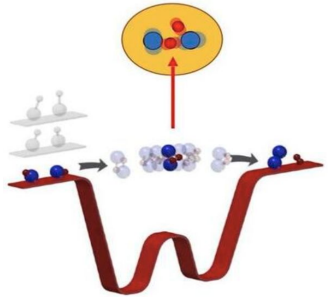


New states of matter: supersolids, topological superfluids, etc.

Precision measurements for fundamental physics

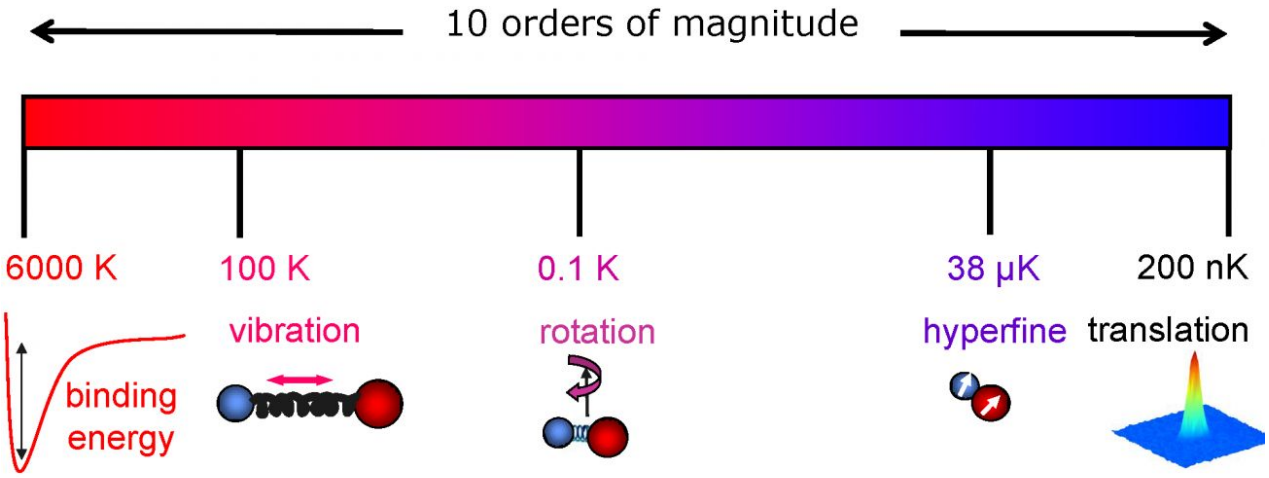


Designer Chemistry: understand chemical reactions on the quantum scale, manipulate



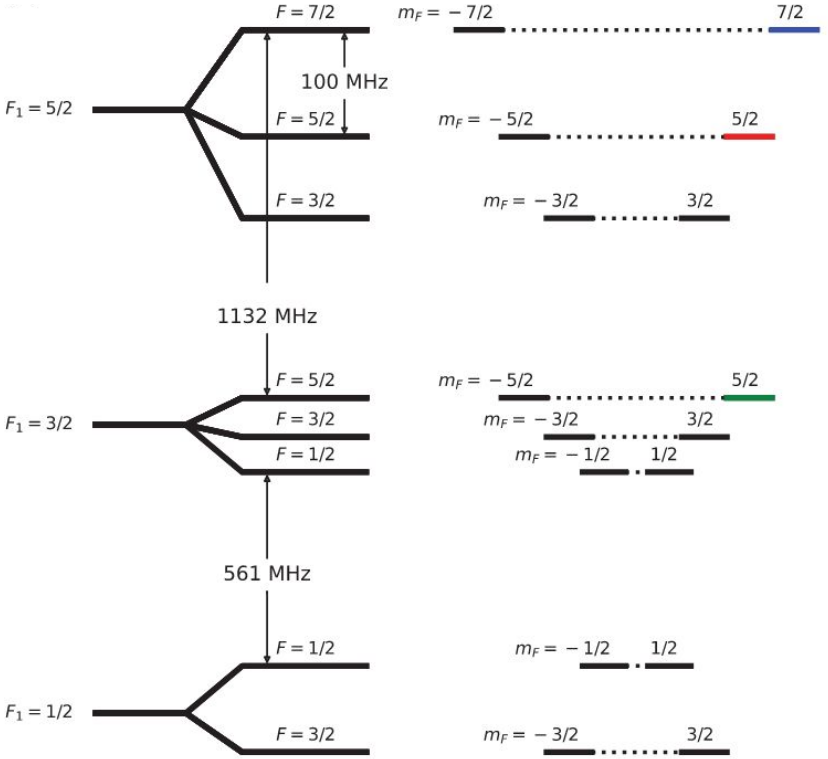
Molecular Structure for Diatomic Molecule

1. Hyperfine: $F = |\vec{F}| = |\vec{S} + \vec{I}_{\mathrm{Na}} + \vec{I}_{\mathrm{Li}}|$
2. N, Rotational degree of freedom (rigid rotor): $E_N = BN(N+1)$
3. v, Vibrational degree of freedom: stretching, contracting, bending, etc.



https://jila.colorado.edu/yelabs/research/ultracold-molecules

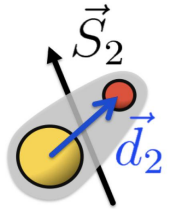
Molecular Structure (NaLi)



$$F = |\vec{F}| = |\vec{S} + \vec{I}_{\mathrm{Na}} + \vec{I}_{\mathrm{Li}}|$$

$$F_1 = |\vec{S} + \vec{I}_{\mathrm{Na}}|$$

Triplet NaLi



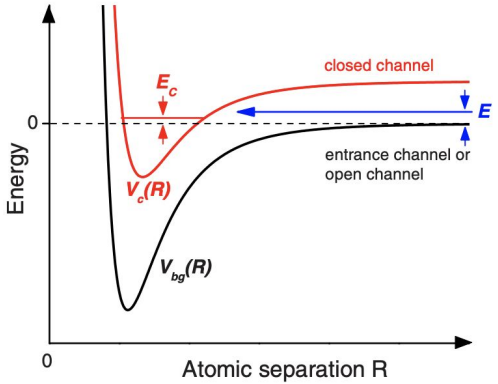
Making ultracold molecules

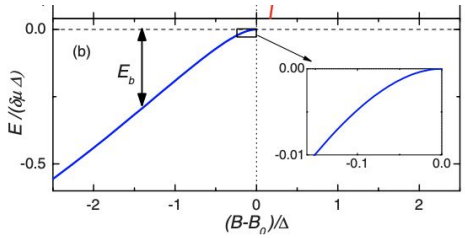
Direct Cooling

- Buffer gas cooling, followed by laser cooling
- Zeeman-Sisyphus cooling
- Stark decelerator

Ultracold Association

- Ultracold atoms associated to weakly bound via Feshbach resonance + Stimulated Raman Passage to ground state





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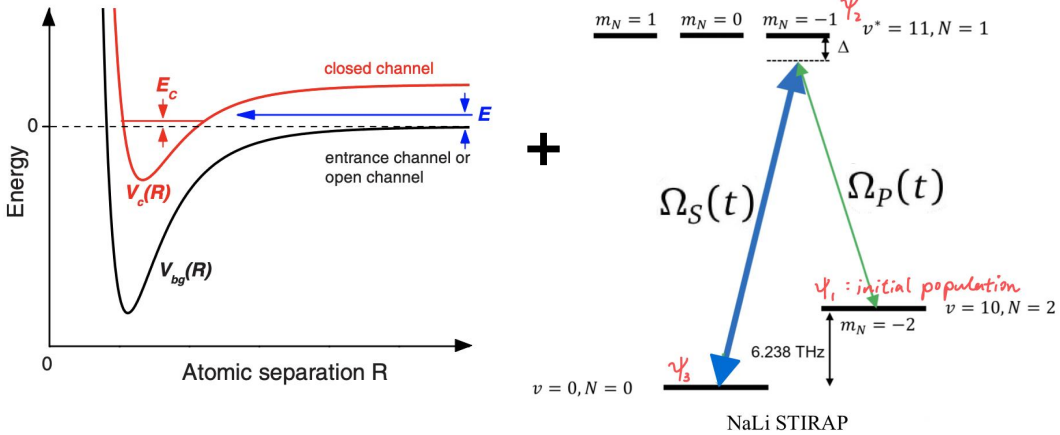
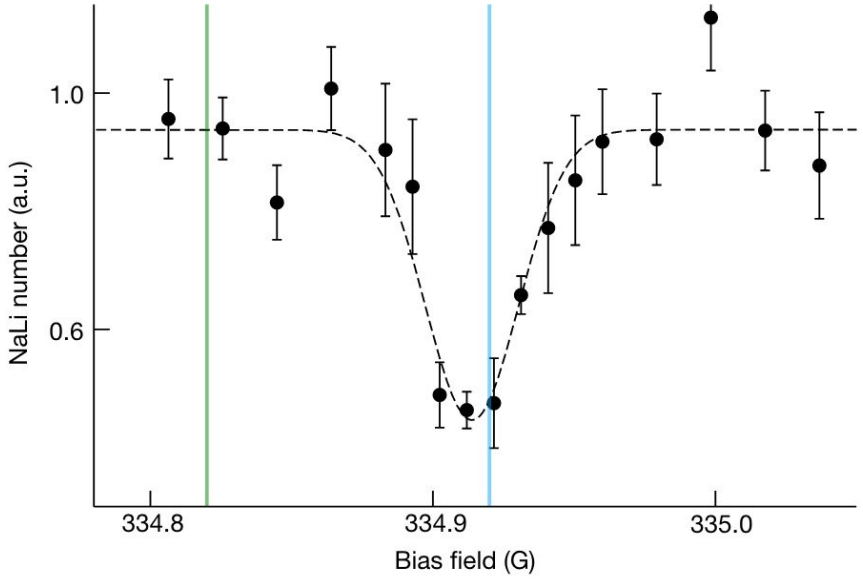
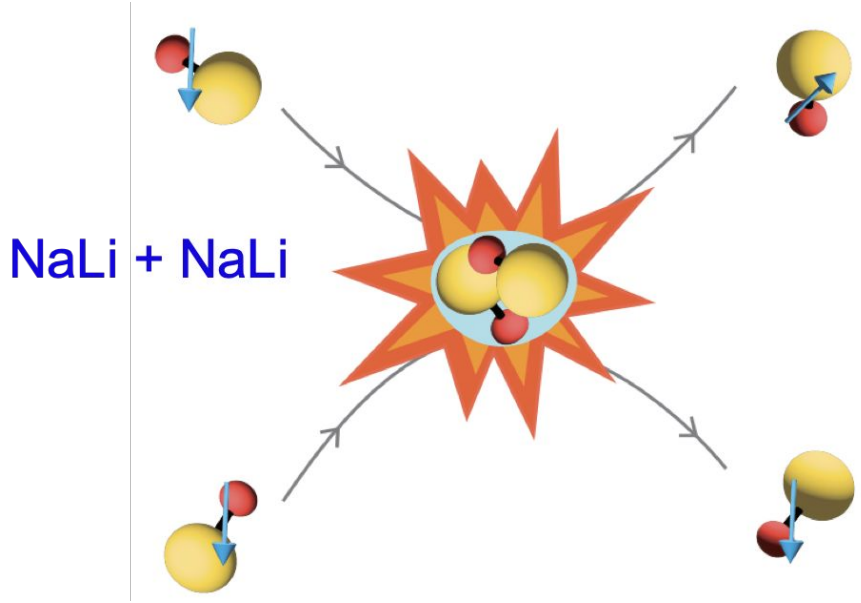


A Feshbach resonance in collisions between triplet ground-state molecules

Juliana J. Park ✉, Yu-Kun Lu, Alan O. Jamison, Timur V. Tscherbul & Wolfgang Ketterle

Nature **614**, 54–58 (2023) | Cite this article





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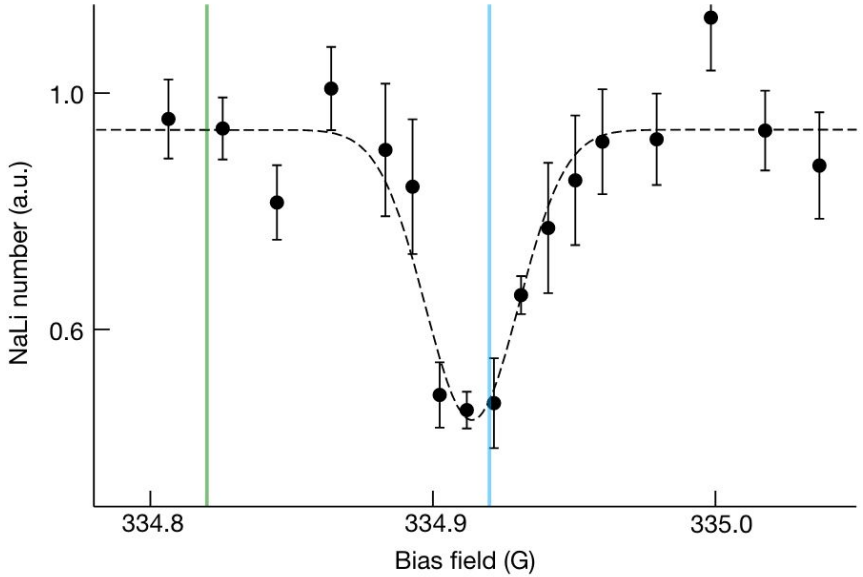
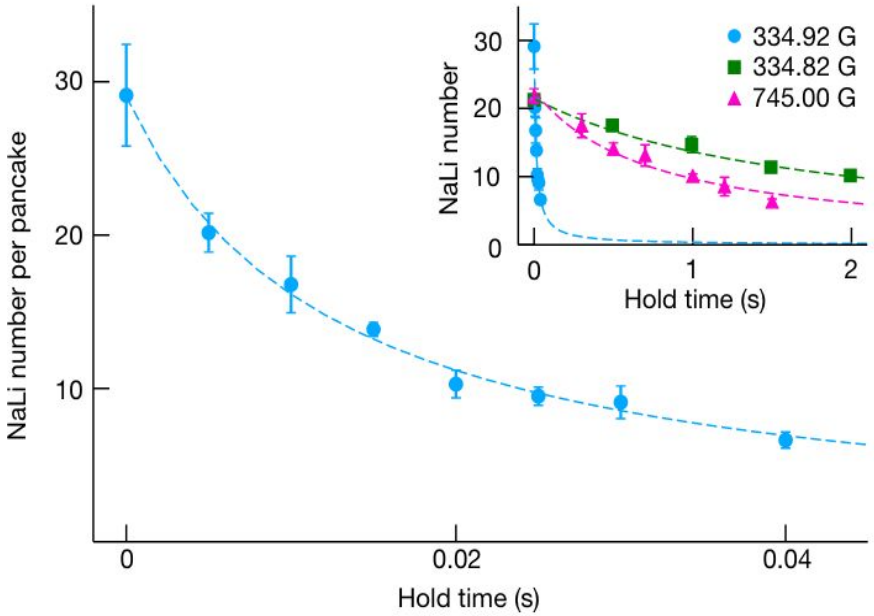
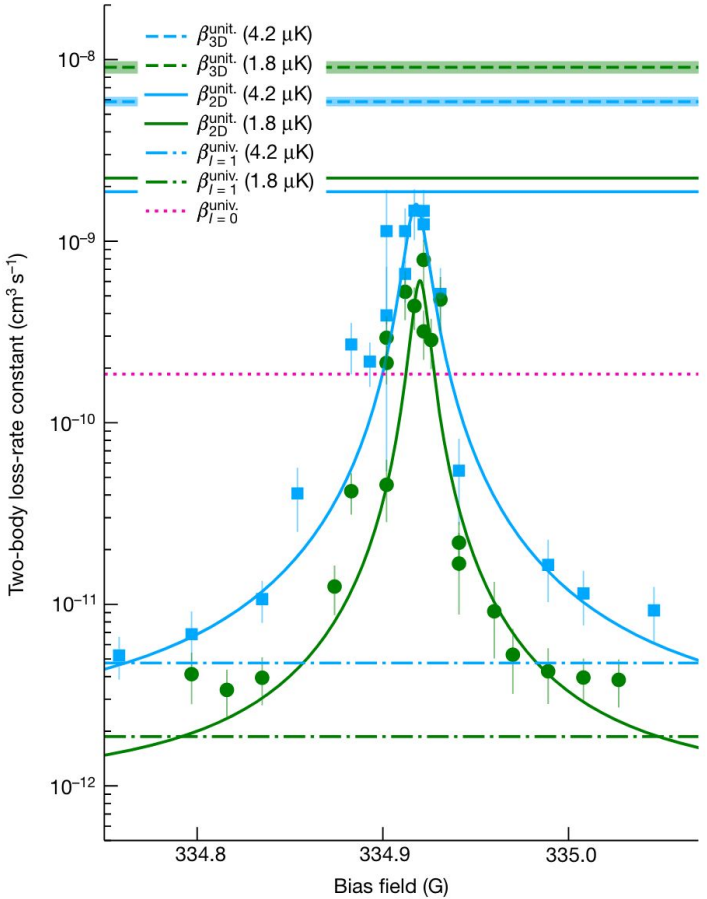


- The collisional loss rate is enhanced by more than two orders of magnitude above the background loss rate (near the universal limit, due to strong chemical reactivity.) —-> **First molecule-molecule Feshbach resonance!**
- Feshbach resonance at B field where two open channels become degenerate—> new Feshbach mechanism?

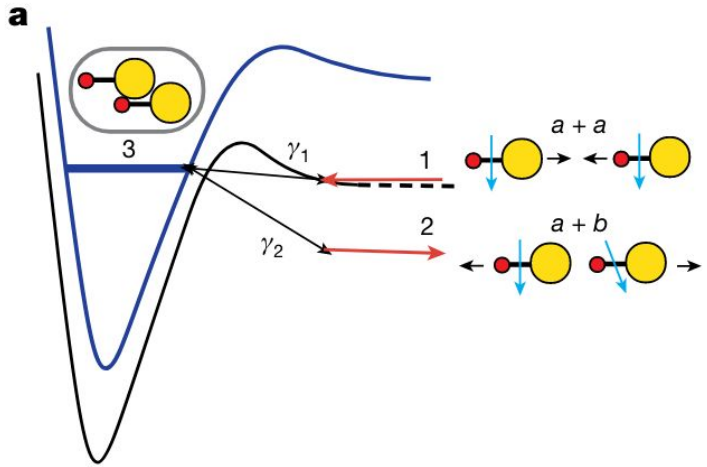
Decay curves



Two-body loss rate Coeff



A possible new Feshbach mechanism



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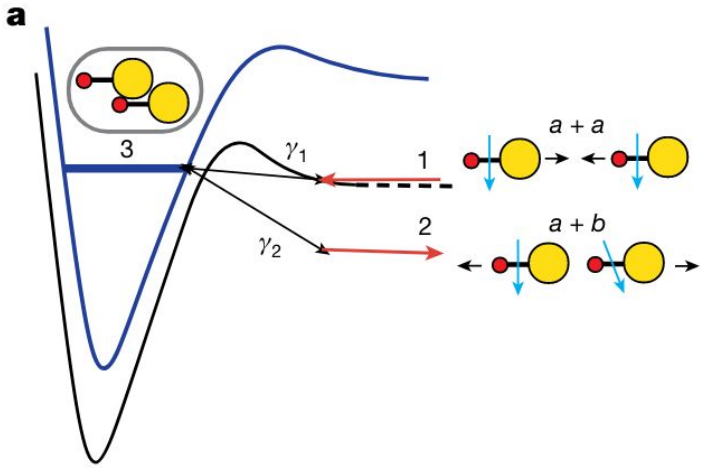
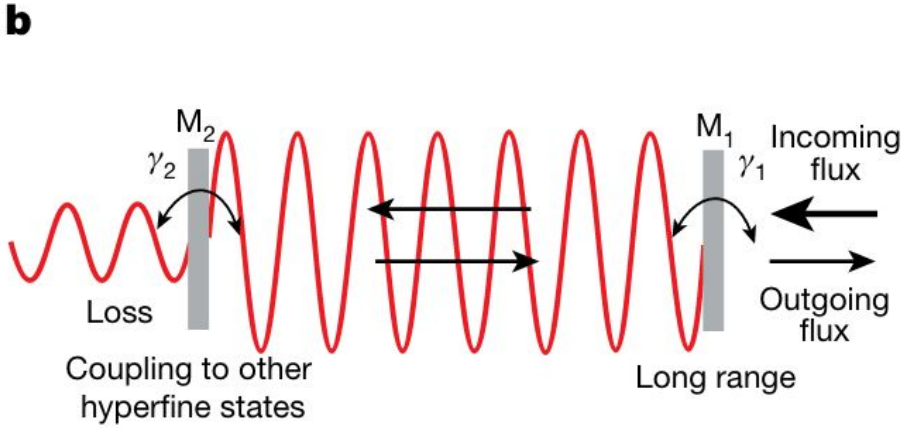


$$T_{\text{trans}} = I \cdot \frac{\gamma_1 \gamma_2}{(\omega_0 - \omega)^2 + [(\gamma_1 + \gamma_2)/2]^2}$$

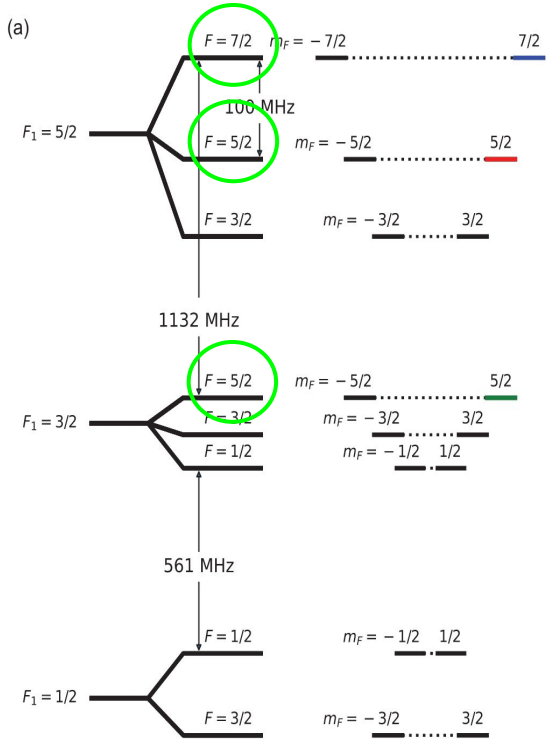
Fabry-Perot Model



Outlook

Previous: First molecule Feshbach resonance between same species NaLi-NaLi collisions (identical spin states)—> p-wave resonance

Outlook: look for s-wave Feshbach resonances between two NaLi triplet ground state molecules of different hyperfine species



Thanks to our BEC3 team!

Questions?