

**Title:** Coherent Dynamics in Ultracold Chemistry - Alan Jamison

**Speakers:**

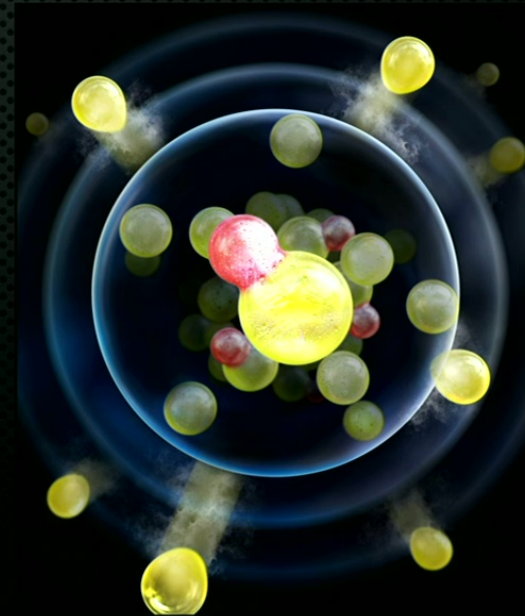
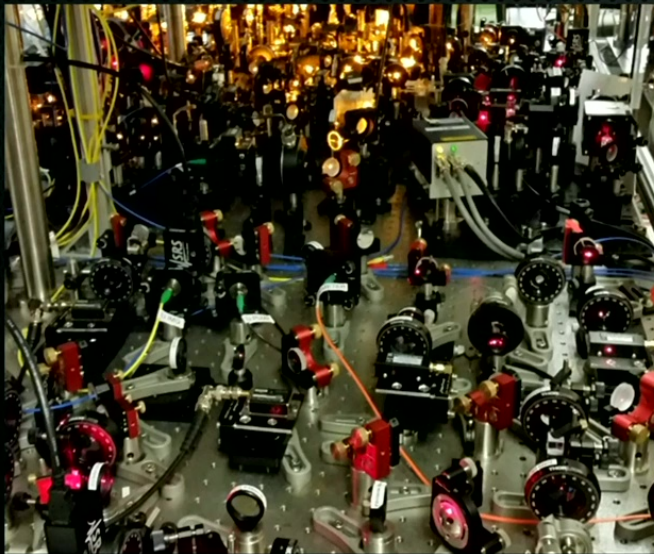
**Collection/Series:** Waterloo-Munich Joint Workshop

**Subject:** Quantum Information

**Date:** October 02, 2024 - 11:45 AM

**URL:** <https://pirsa.org/24100061>

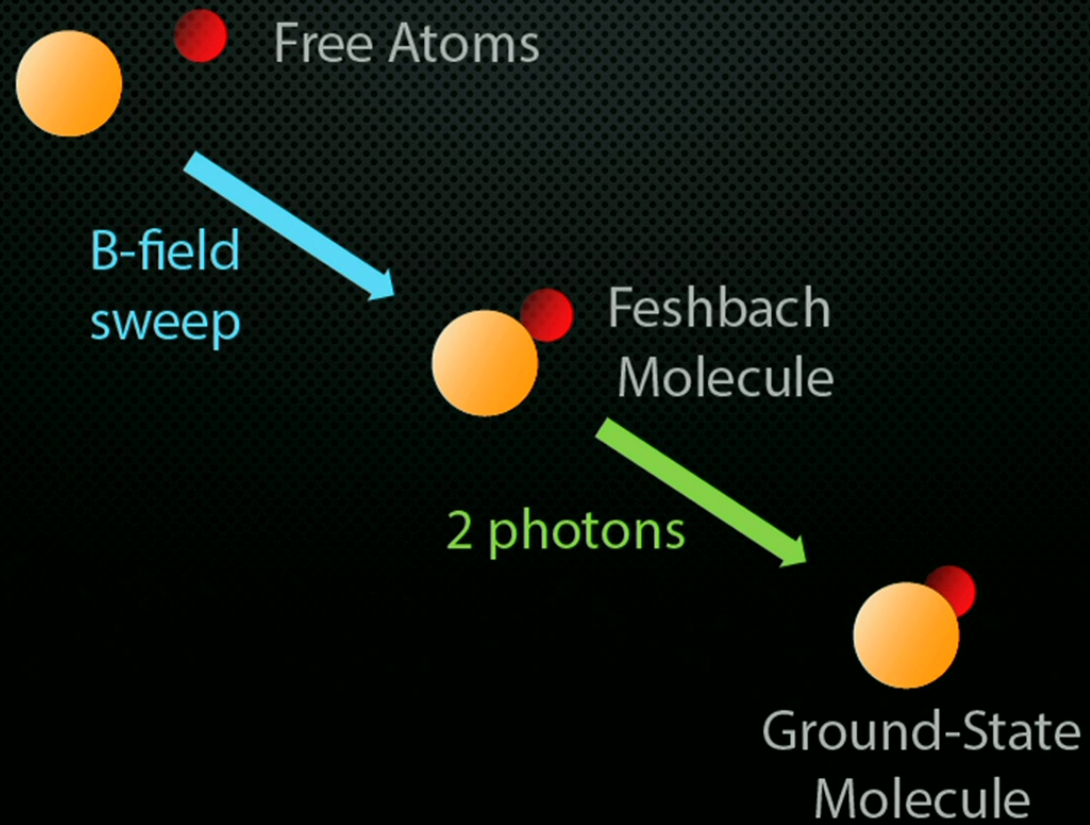
# ULTRACOLD CHEMISTRY AND QUANTUM SIMULATION



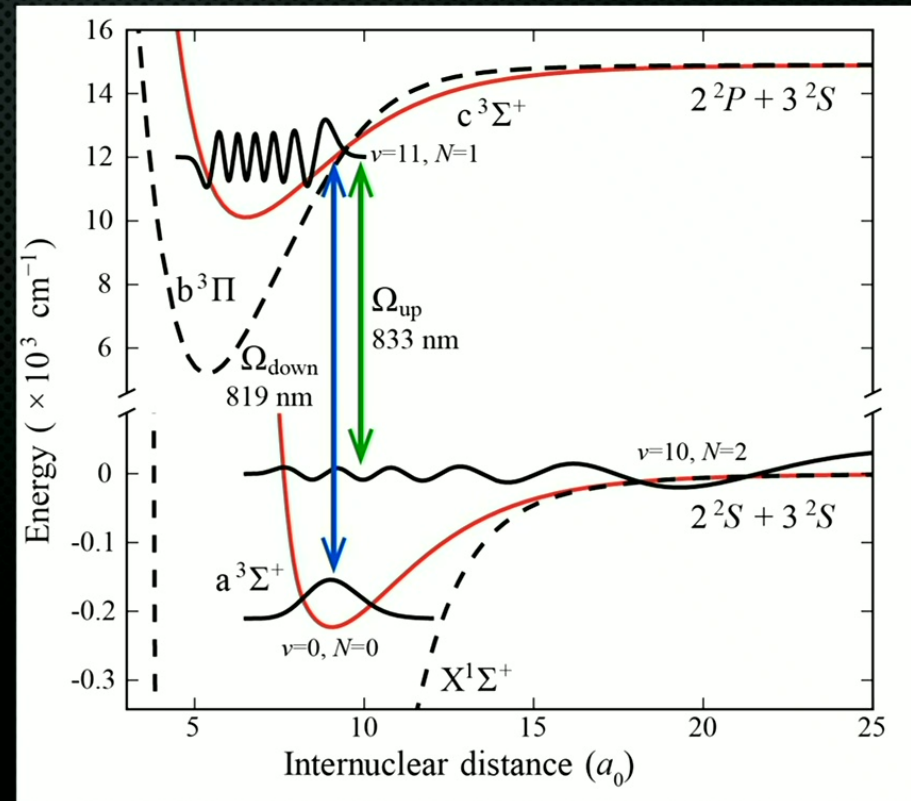
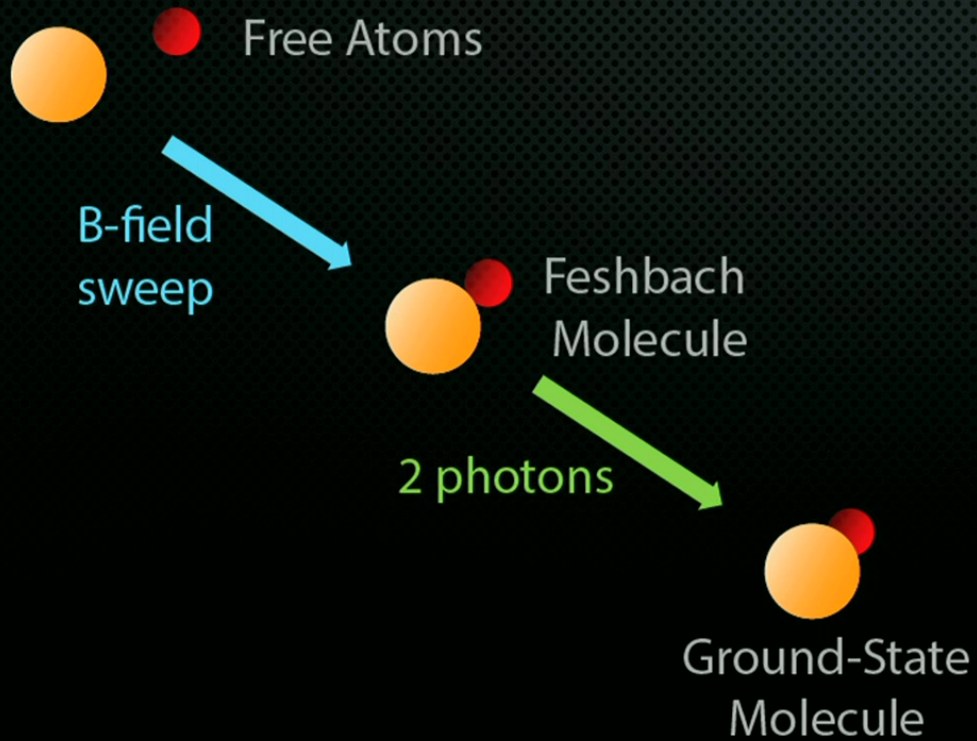
ALAN JAMISON

PHYSICS & ASTRONOMY DEPARTMENT AND INSTITUTE FOR QUANTUM COMPUTING  
UNIVERSITY OF WATERLOO

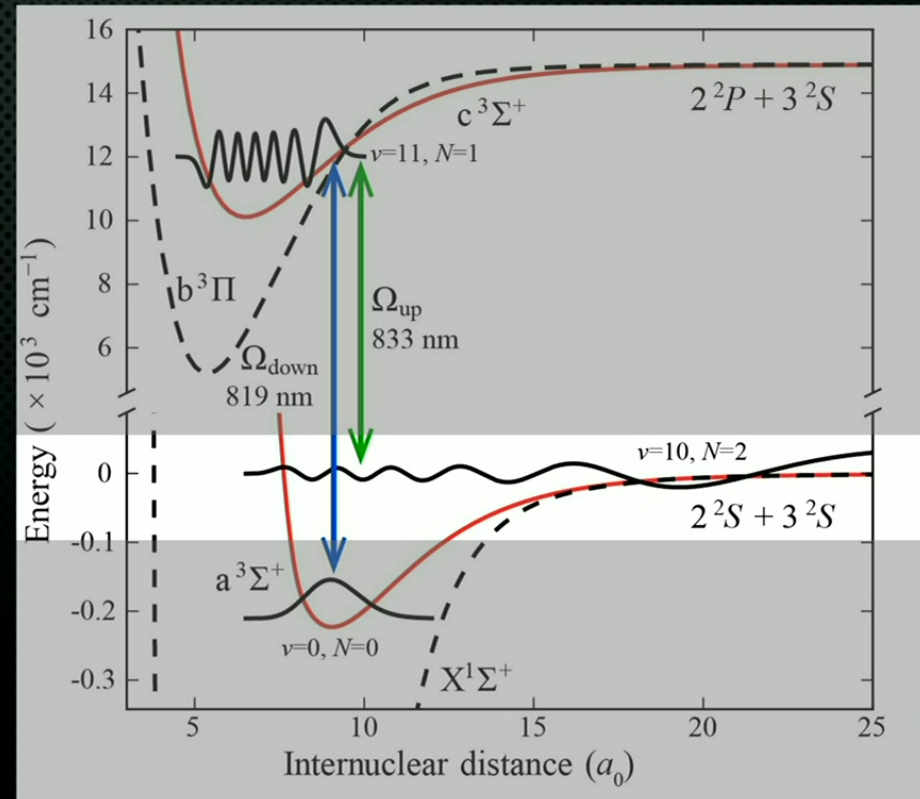
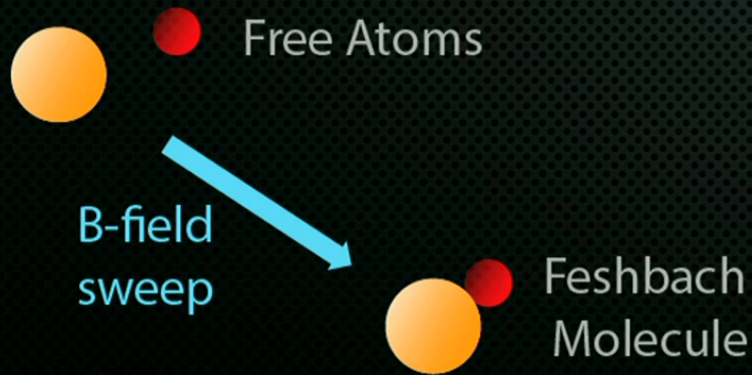
# ULTRACOLD ASSEMBLY



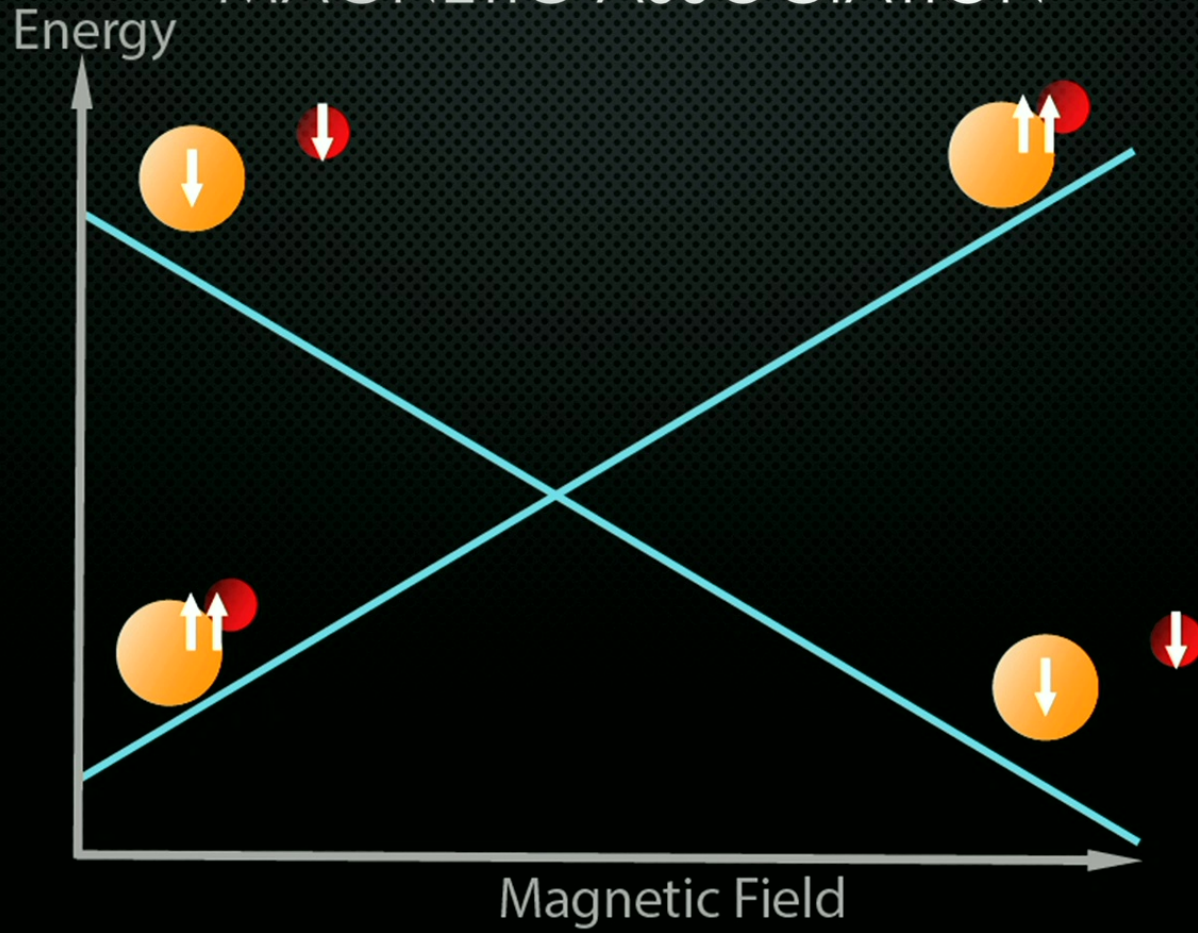
# ULTRACOLD ASSEMBLY



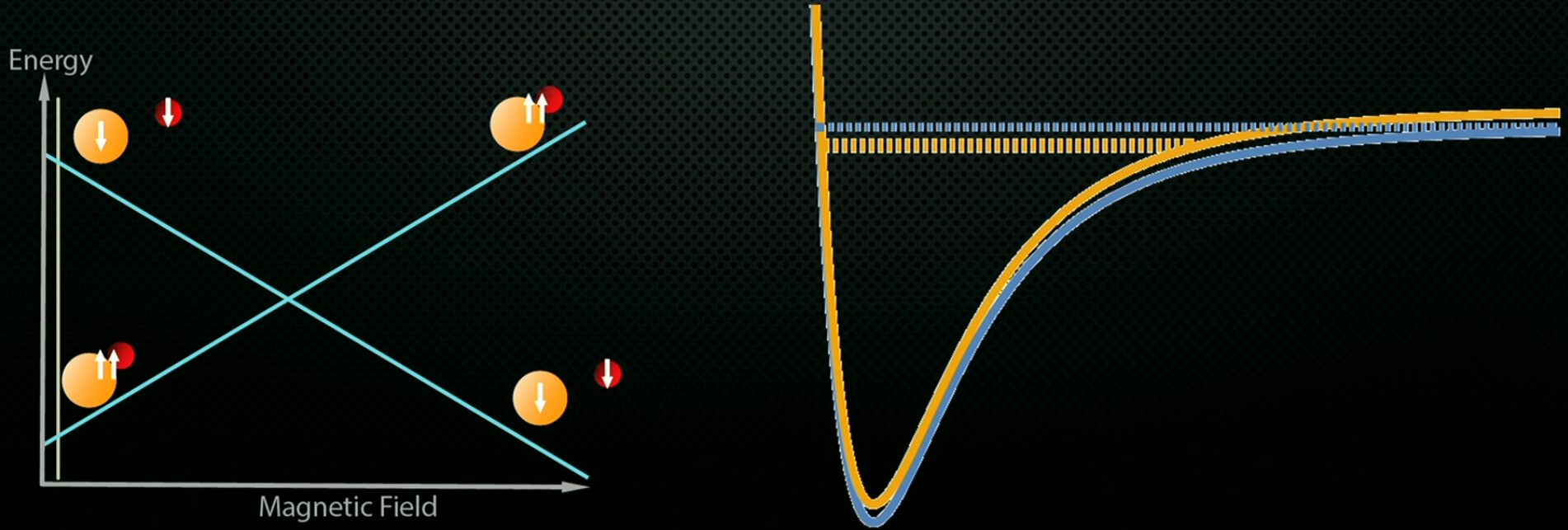
# MAGNETIC ASSOCIATION



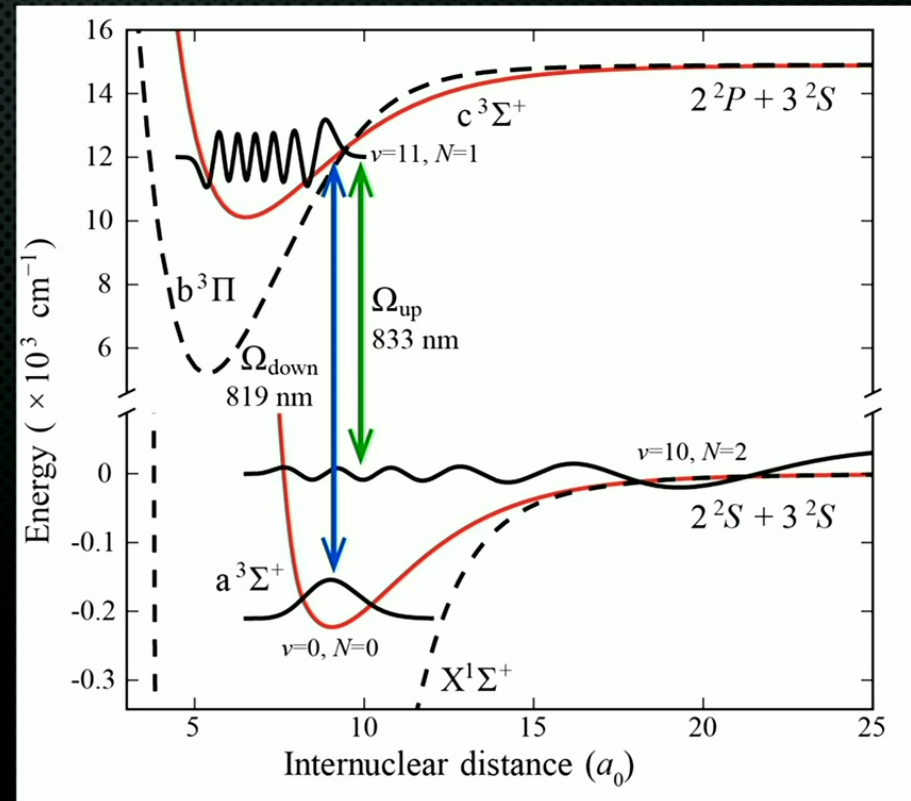
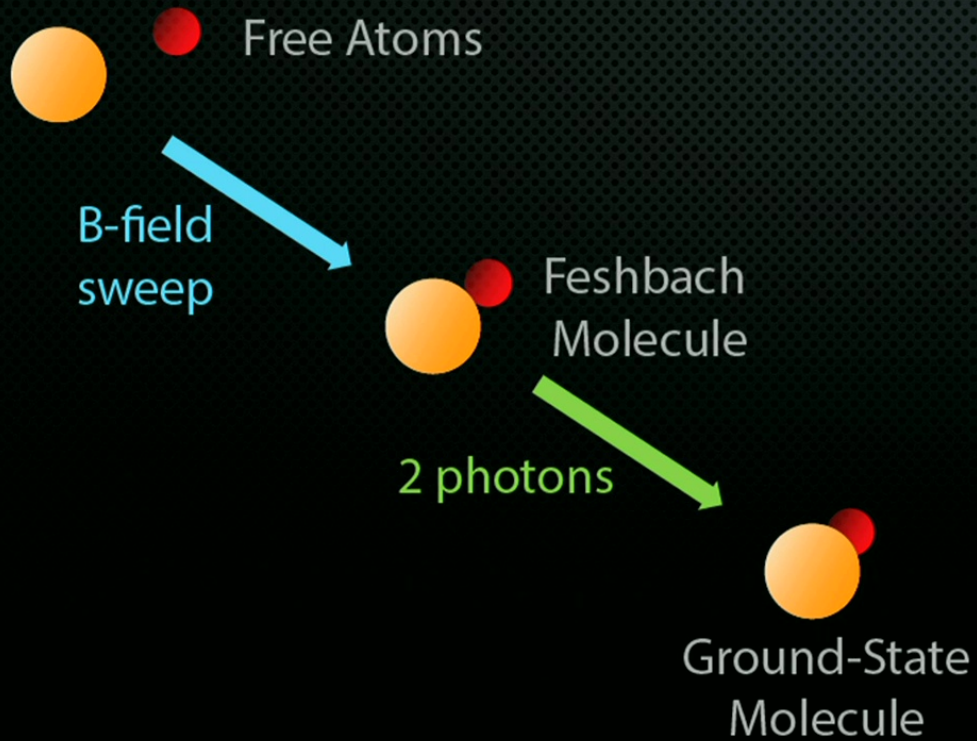
# MAGNETIC ASSOCIATION



# FESHBACH RESONANCE

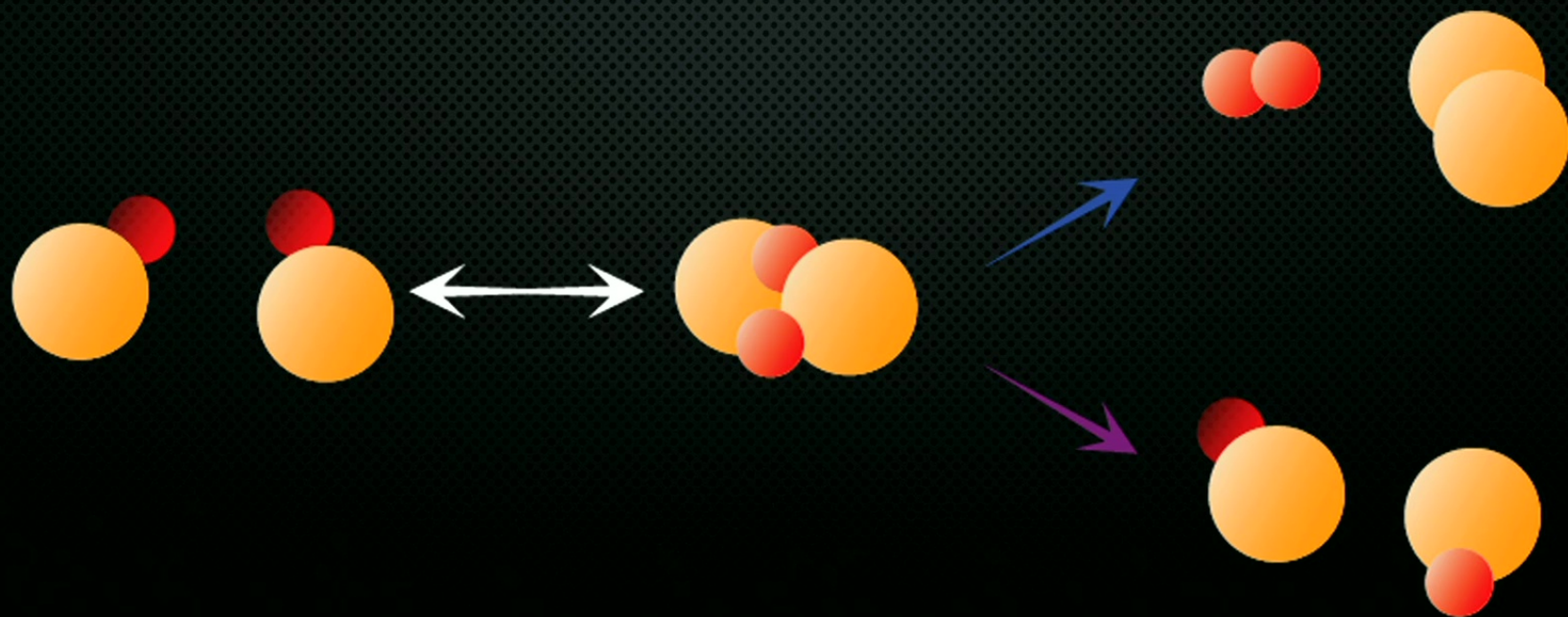


# ULTRACOLD ASSEMBLY





# A PHYSICIST'S PICTURE OF CHEMISTRY

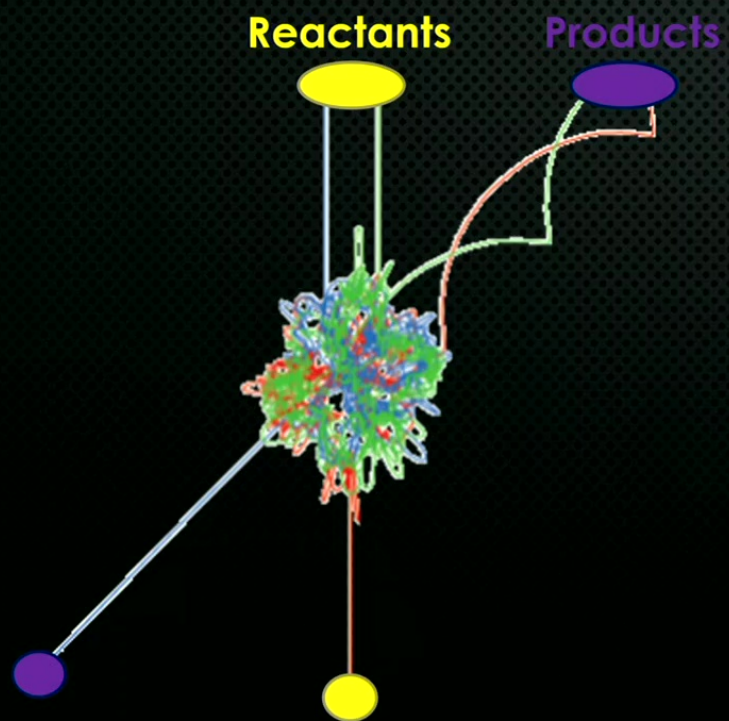


**Reactants**

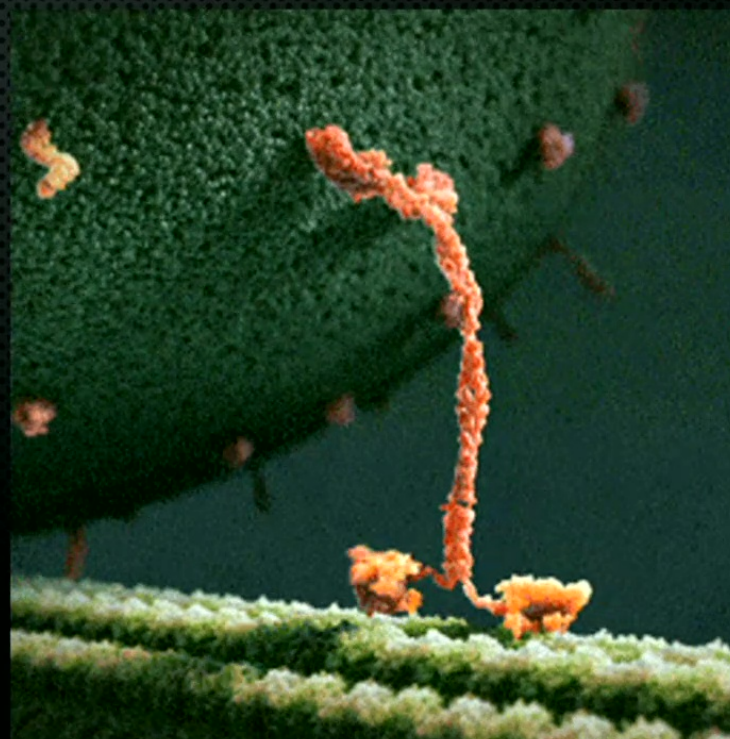
**Scattering**

**Products**

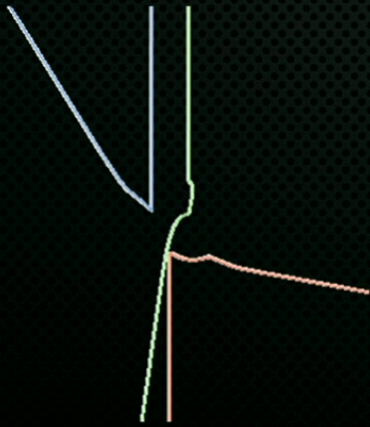
# SCATTERING



# CHEMISTRY



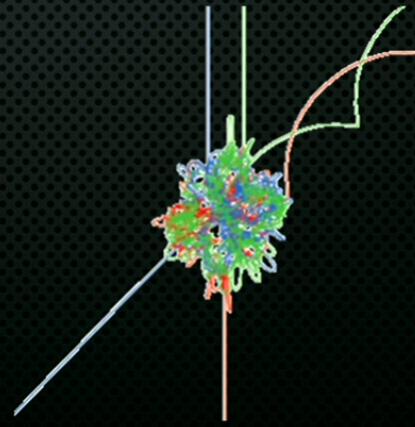
# THE THREE-BODY PROBLEM



T = 1000K



T = 100K



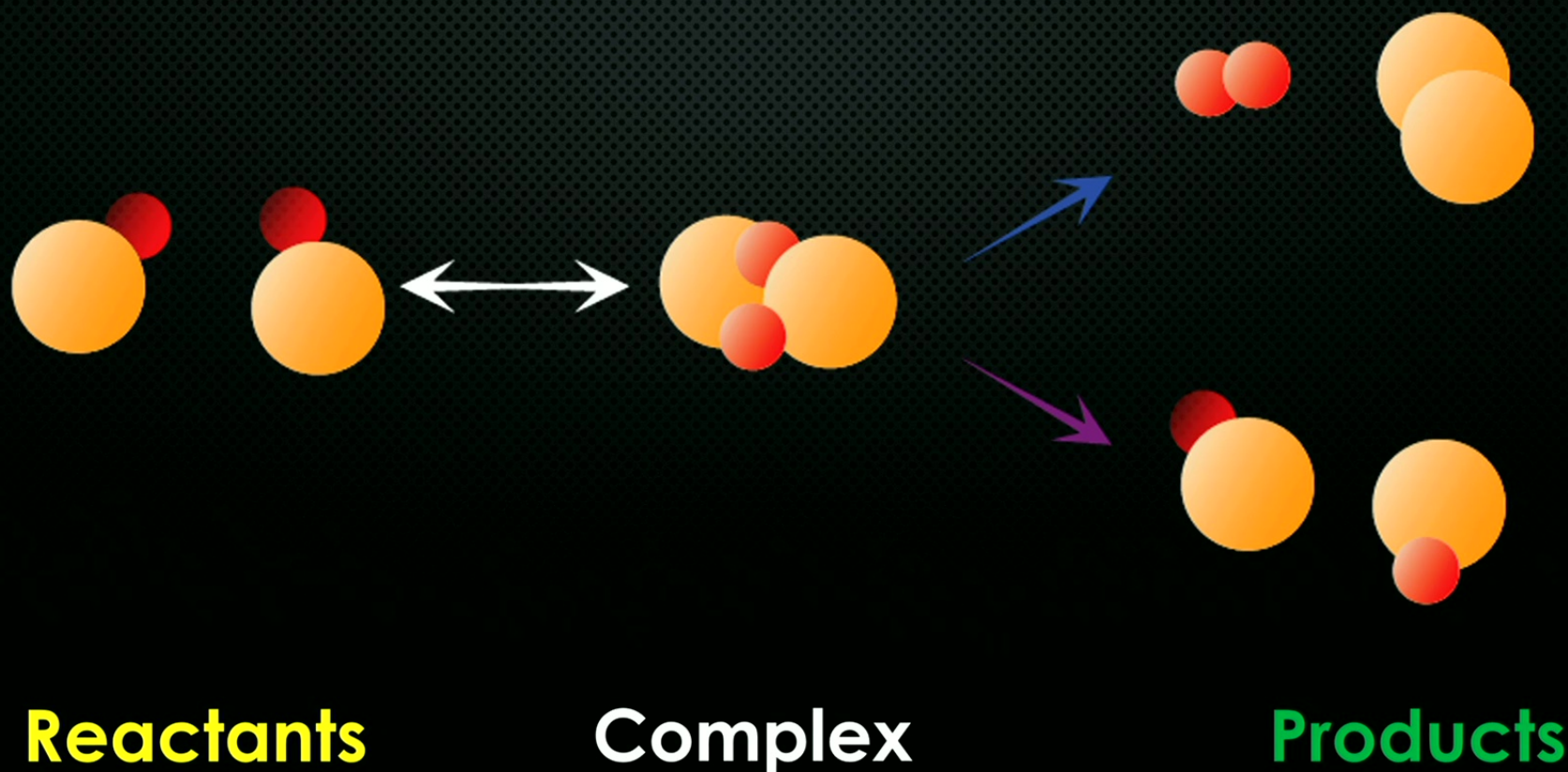
T = 10K



T = 1K

From J.F.E. Croft and J. Bohn  
PRA 89, 012714 (2014)

# SCALES OF ULTRACOLD CHEMISTRY



# SCALES OF ULTRACOLD CHEMISTRY

Collision energy:  
 $\sim 10^{-6} \text{cm}^{-1}$



**Reactants**

Well depth:  
 $\sim 300 - 10,000 \text{cm}^{-1}$



**Complex**



Exothermicity:  
 $\sim 10,000 \text{cm}^{-1}$



**Products**

# SCALES OF ULTRACOLD CHEMISTRY

Collision energy:  
 $\sim 10^{-6} \text{cm}^{-1}$



Vibration period:  $\sim 1 \text{ps}$   
Complex lifetime:  $> 1 \mu\text{s}$



Exothermicity:  
 $\sim 10,000 \text{cm}^{-1}$

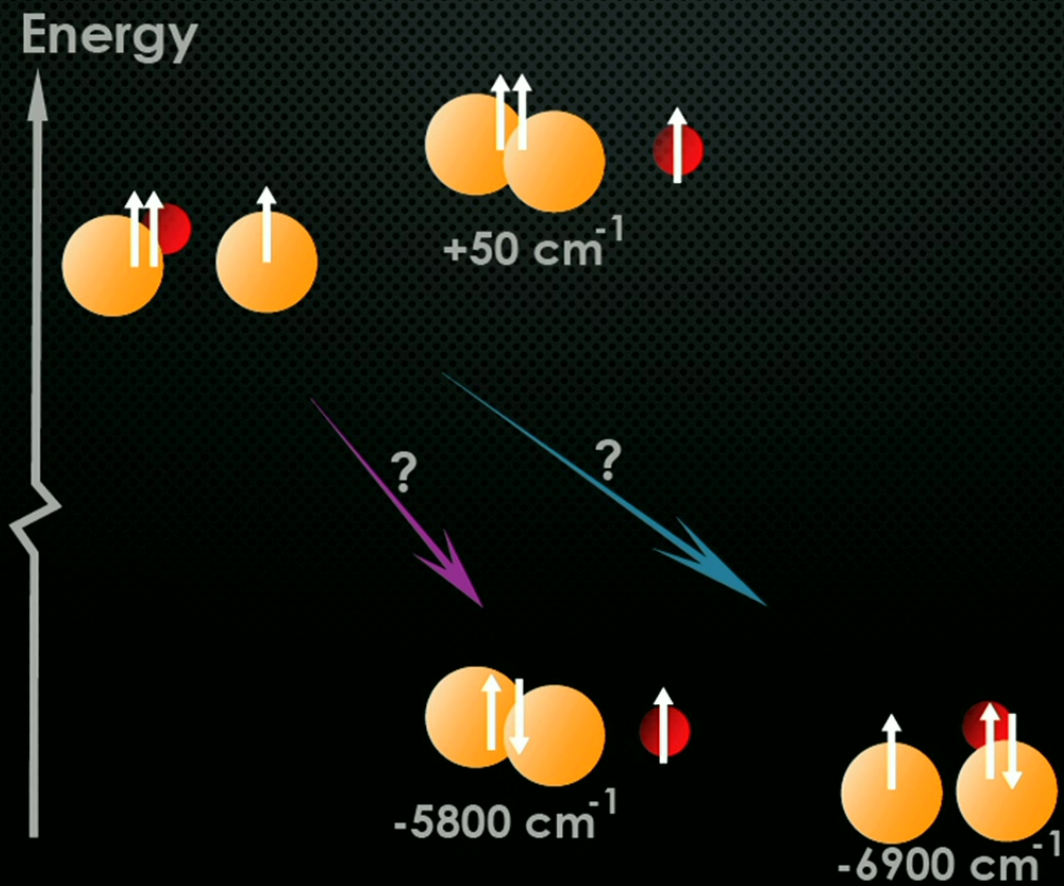


**Reactants**

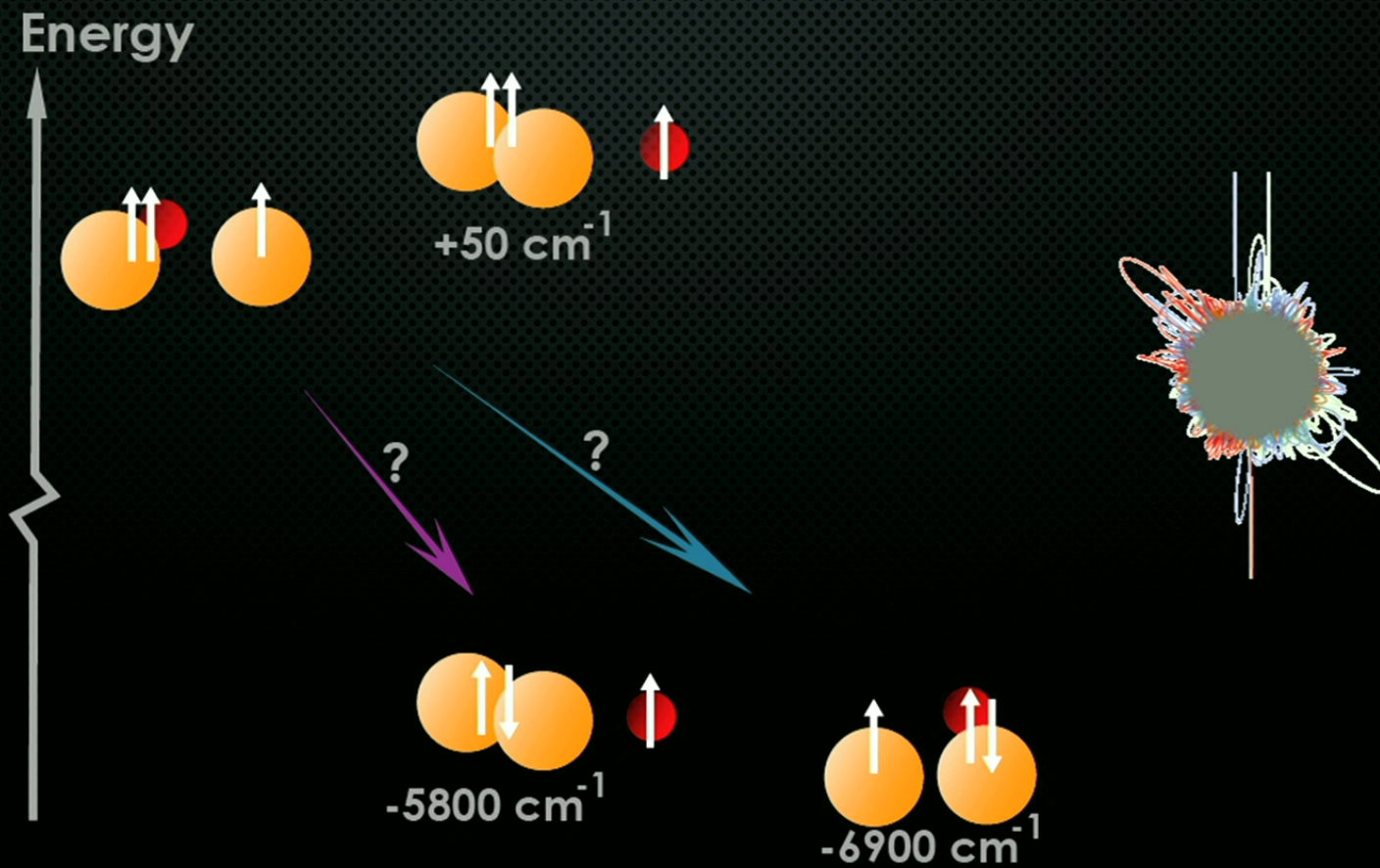
**Complex**

**Products**

# ATOM-MOLECULE COLLISIONS

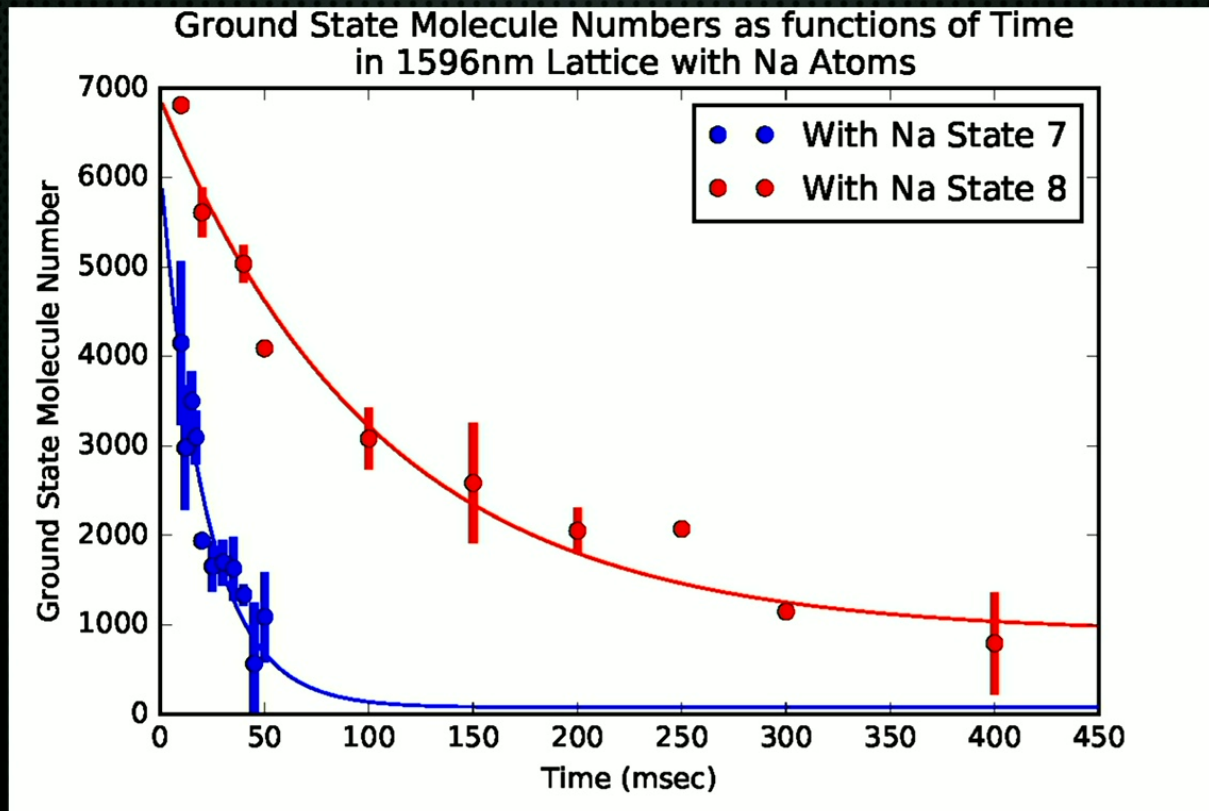
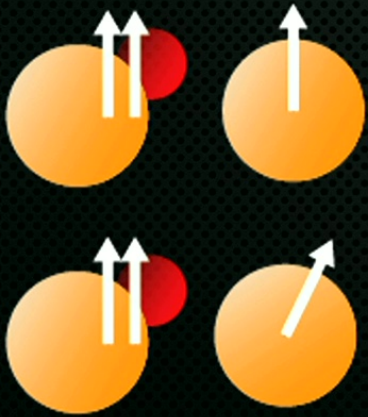


# ATOM-MOLECULE COLLISIONS

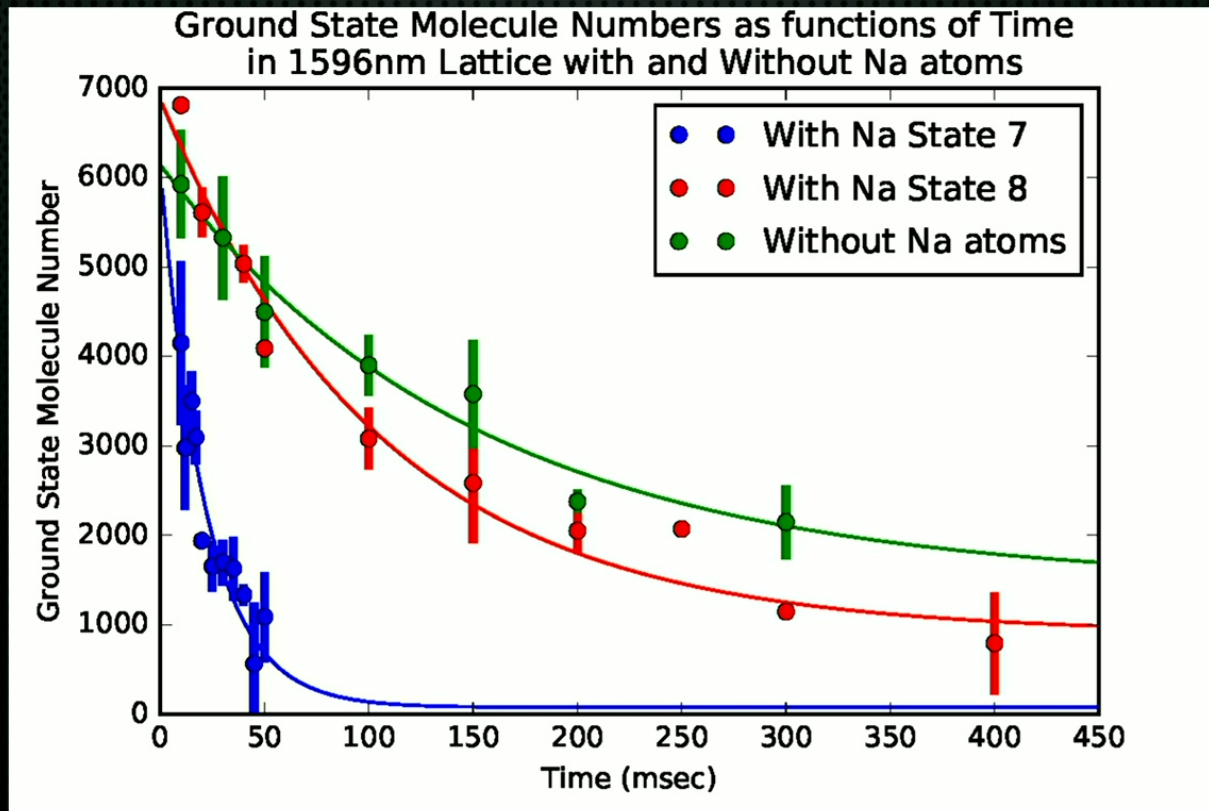
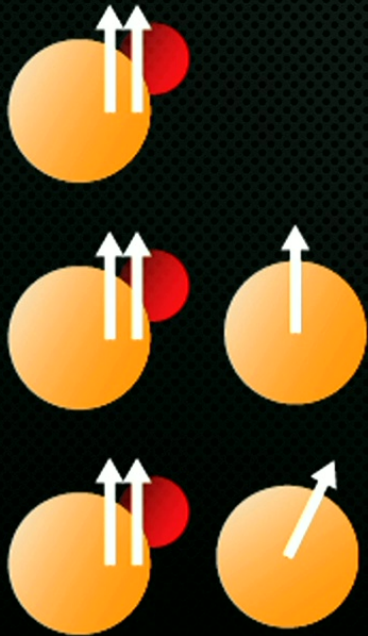




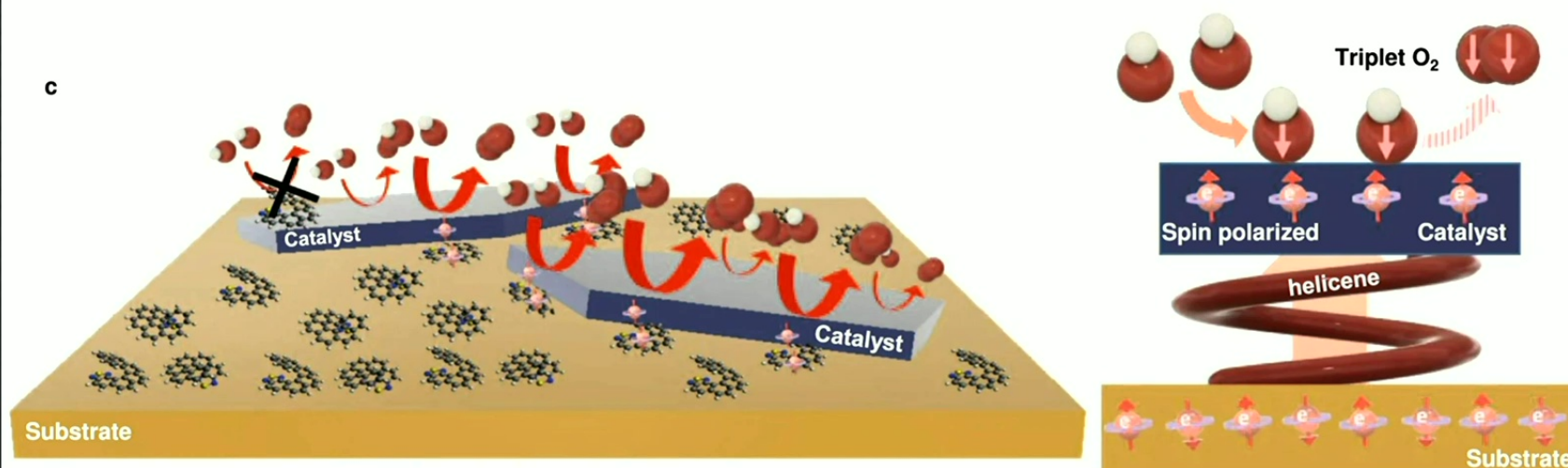
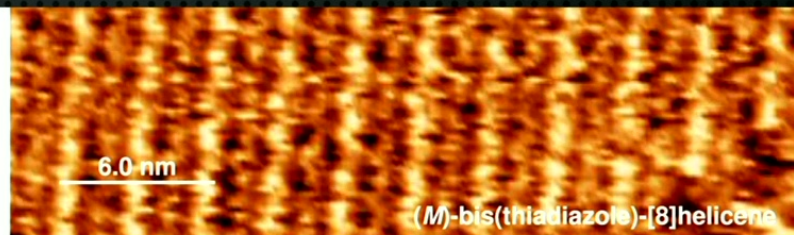
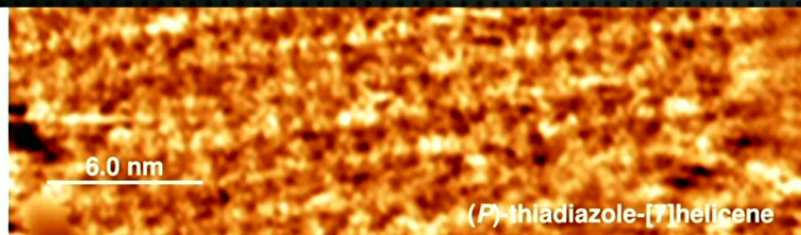
# SPIN-DEPENDENT REACTIONS



# SPIN-DEPENDENT REACTIONS



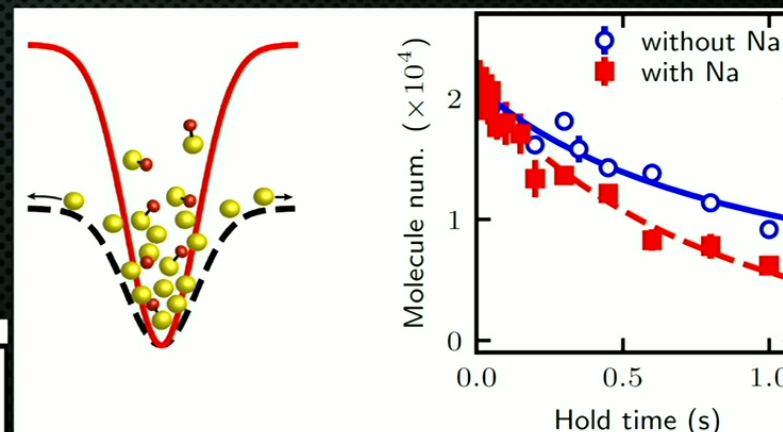
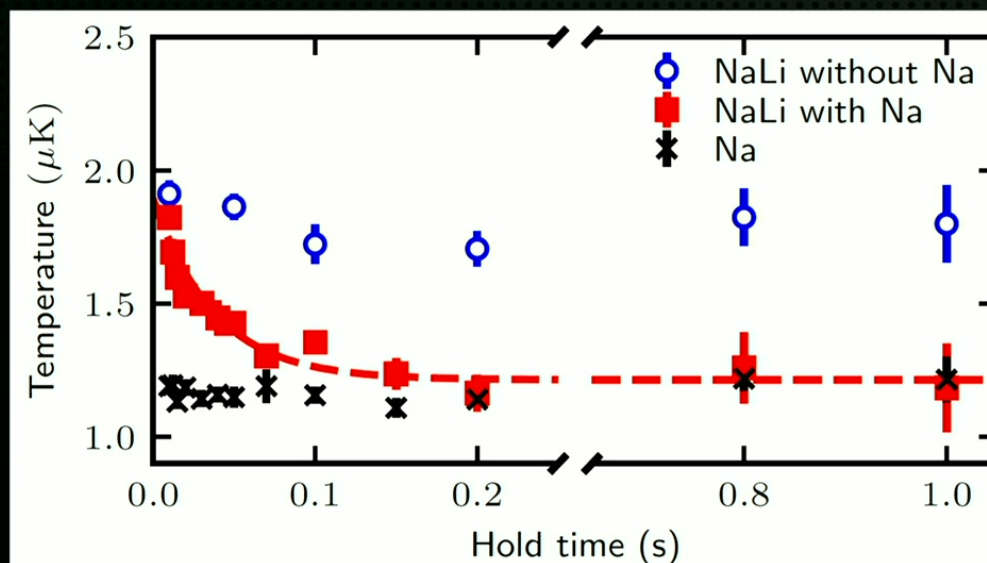
# SPIN-DEPENDENT REACTIONS



From Liang et al., *Nature Communications* **13**, 3356 (2022)

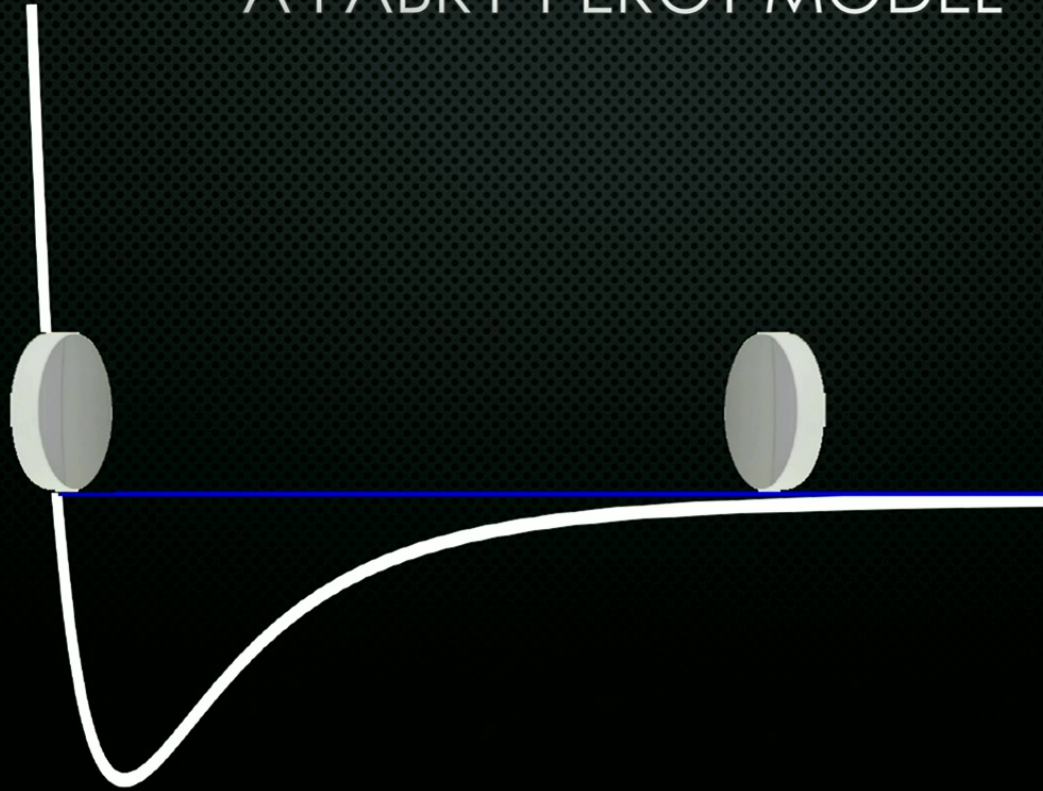
# SYMPATHETIC COOLING

- MOLECULES PRODUCED HOTTER THAN ATOMS
- ~80 ELASTIC COLLISIONS PER REACTION

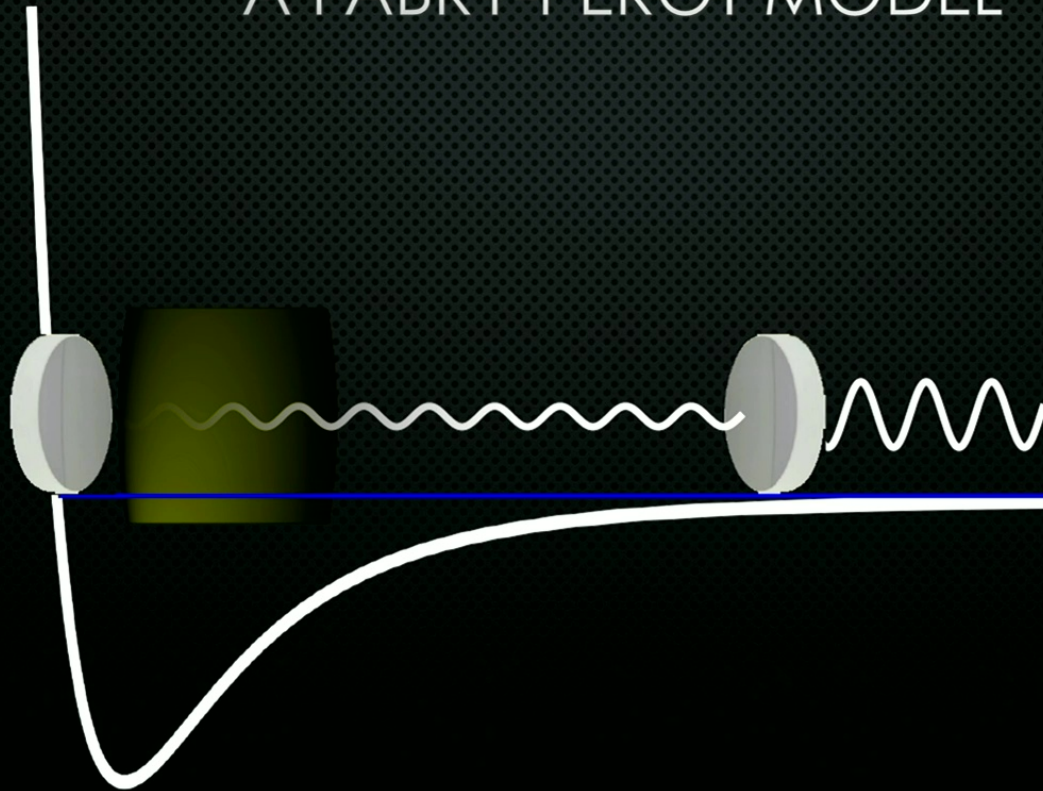


Collisional cooling of ultracold molecules  
*Nature* 580, 197 (2020)  
H Son, JJ Park, W Ketterle, AO Jamison

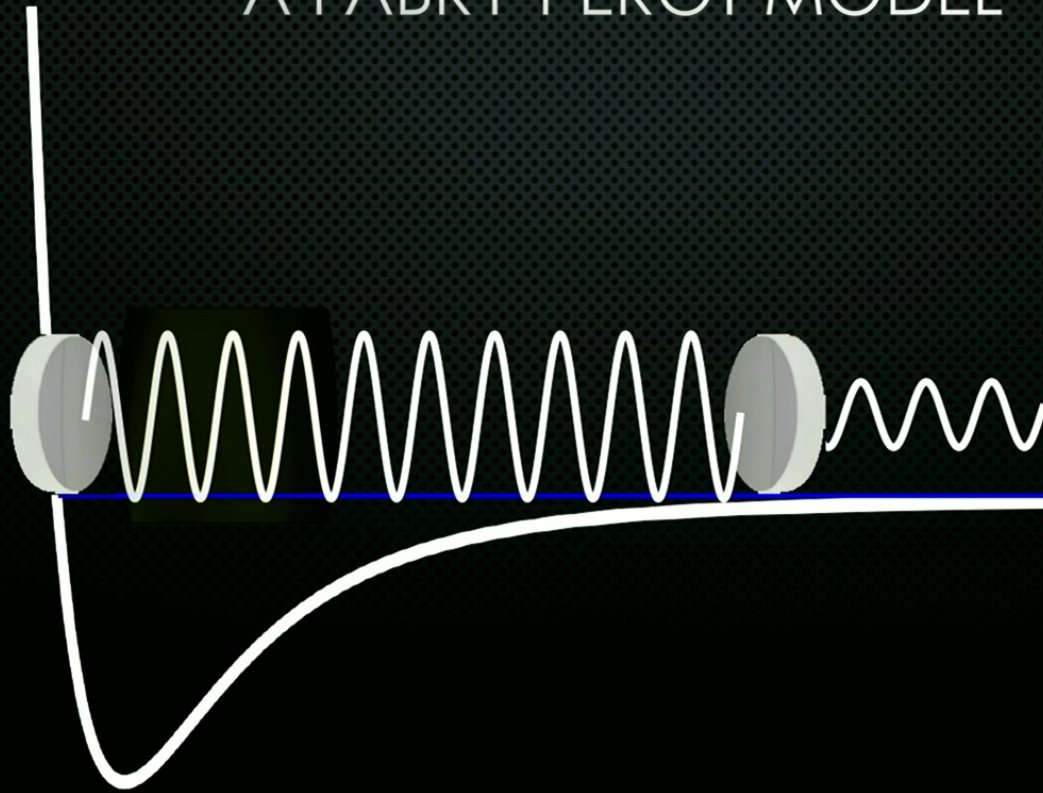
# A FABRY-PEROT MODEL



# A FABRY-PEROT MODEL

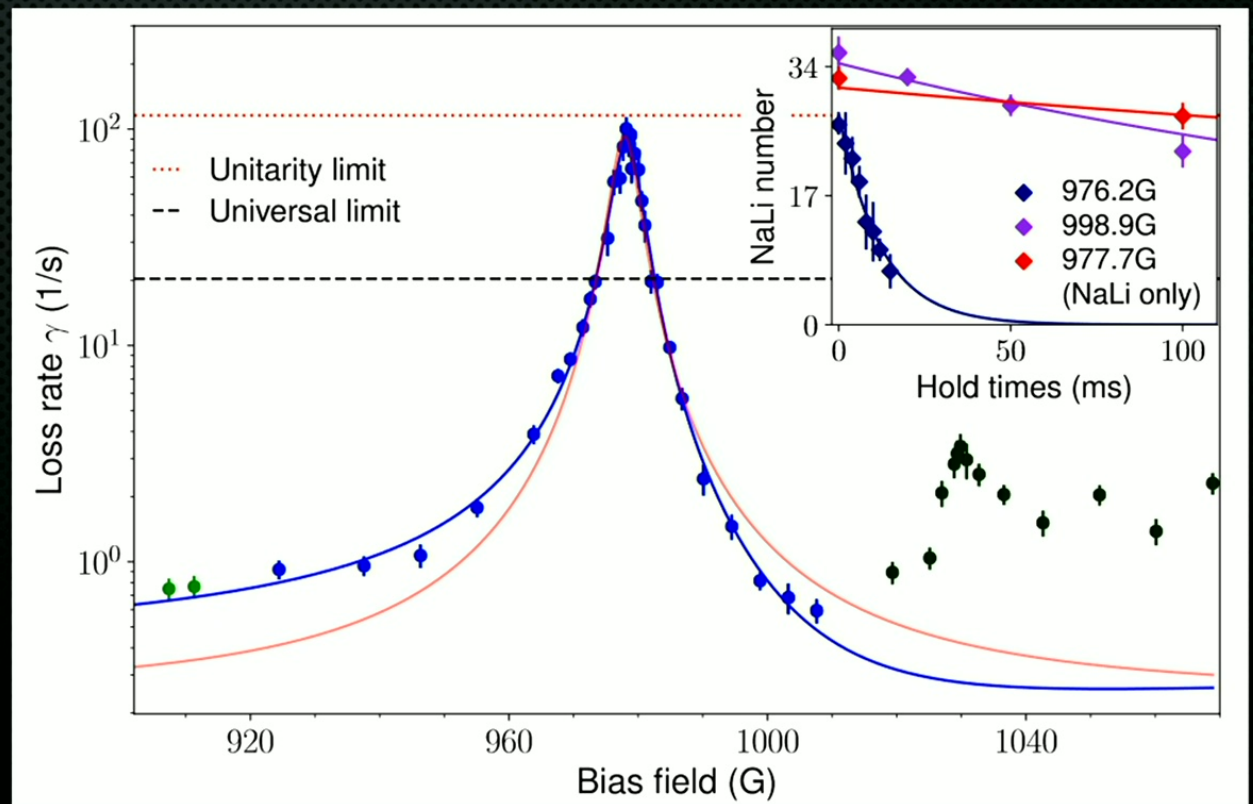


# A FABRY-PEROT MODEL



# FESHBACH RESONANCES

- NaLi + Na RESONANCES
- NAK + K RESONANCES, ZHAO GROUP, USTC



Control of reactive collisions by  
quantum interference  
*Science* 375, 1006 (2022)  
H Son, JJ Park, YK Lu, AO Jamison, T  
Karman, W Ketterle

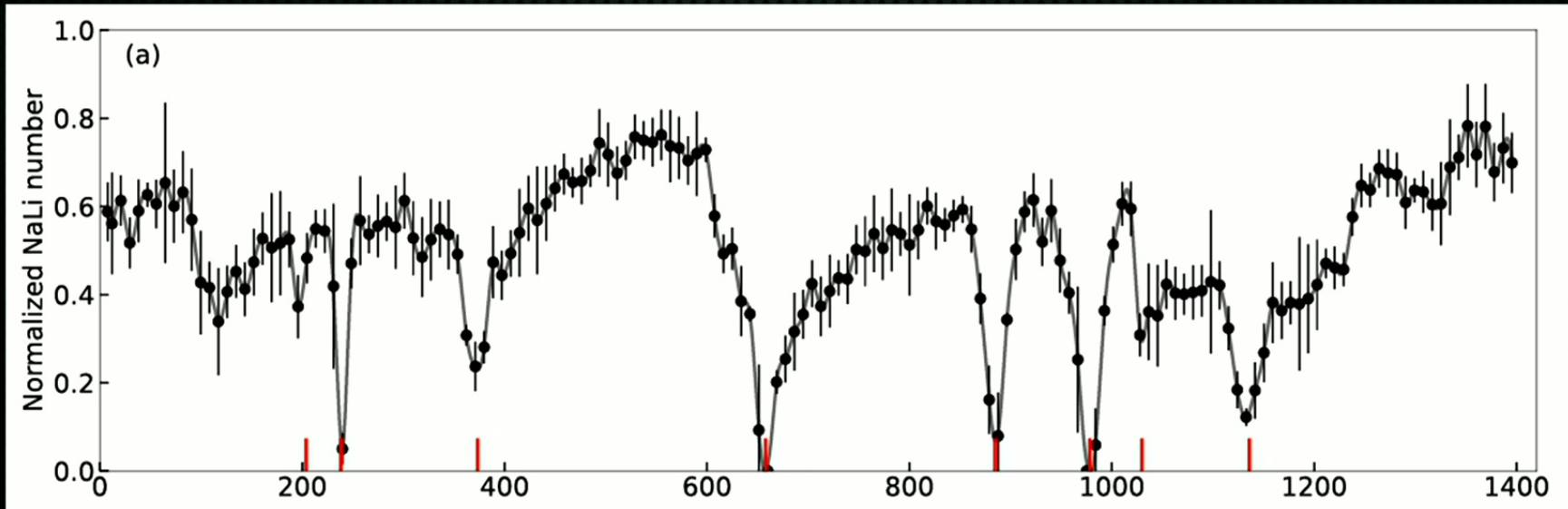




# CHEMICAL RESONANCES

Phys. Rev. X **13**, 031018 (2023)  
Phys. Rev. A **108**, 023309 (2023)

- NaLi + Na RESONANCES

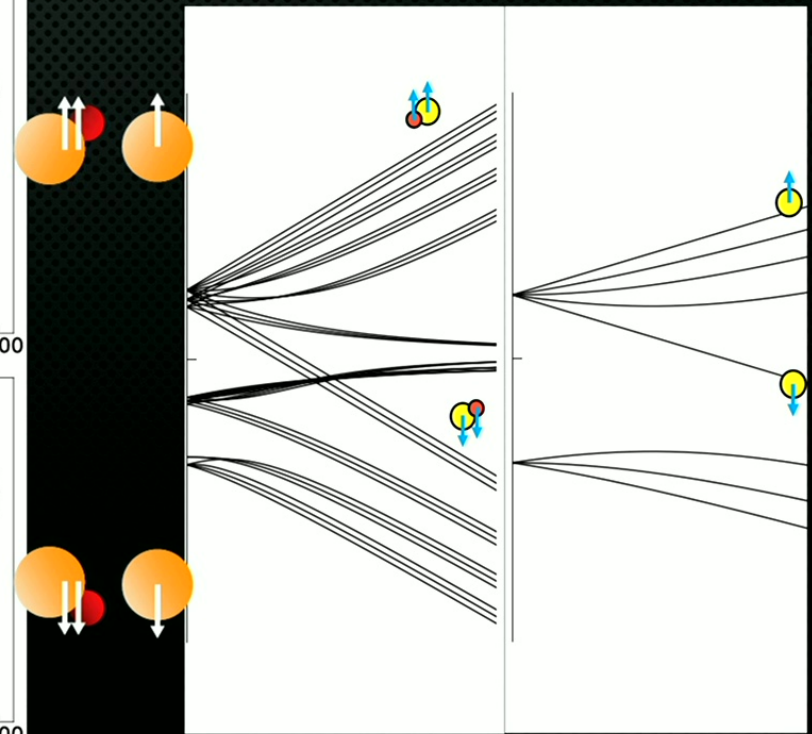
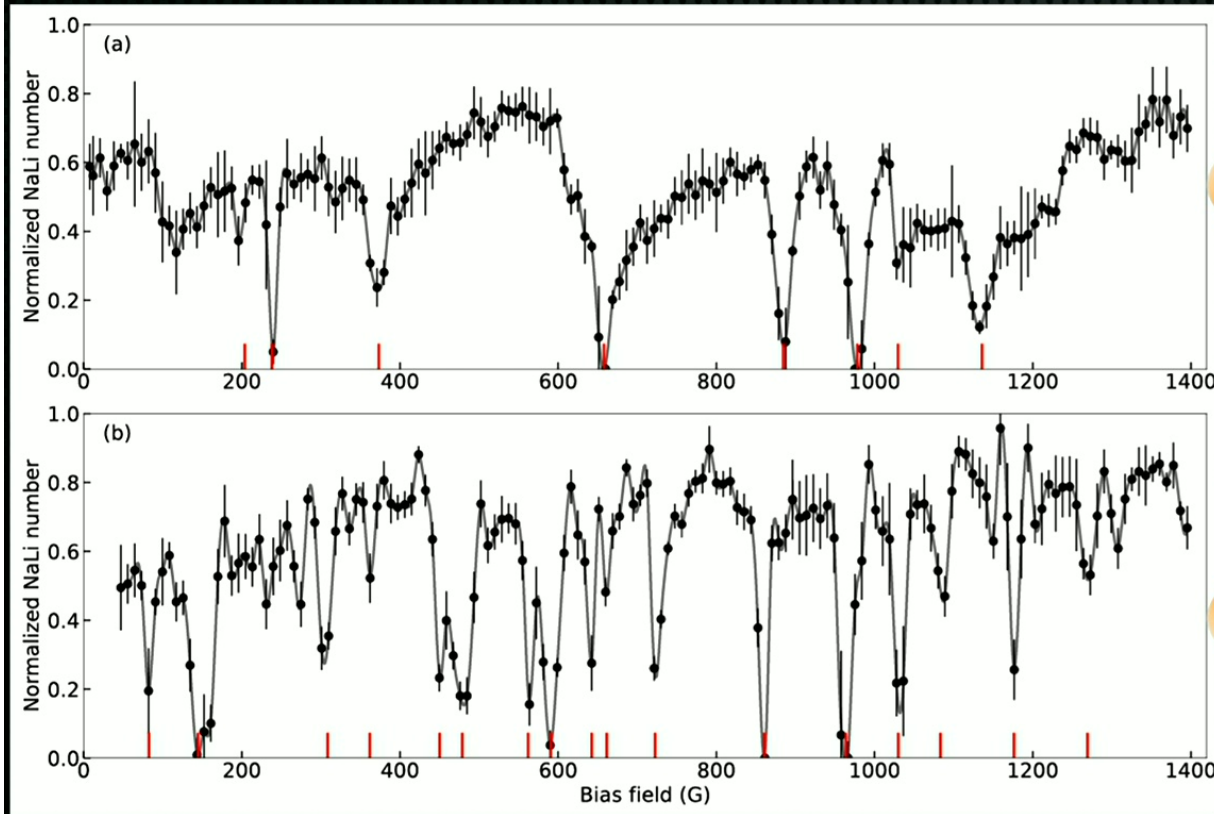




# CHEMICAL RESONANCES

Phys. Rev. X **13**, 031018 (2023)  
Phys. Rev. A **108**, 023309 (2023)

- NALi + NA RESONANCES

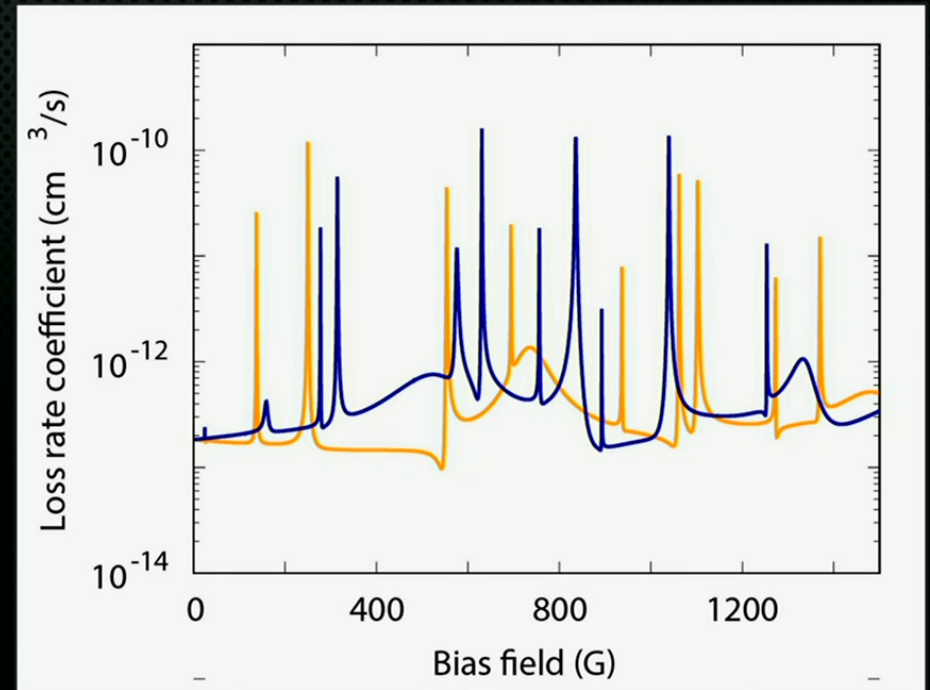
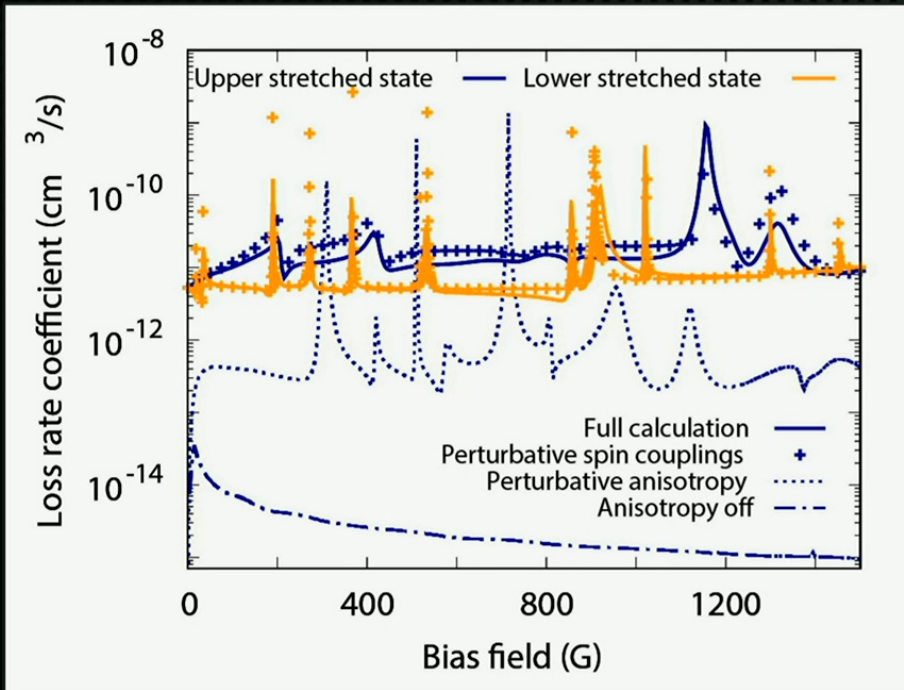




# CHEMICAL RESONANCES

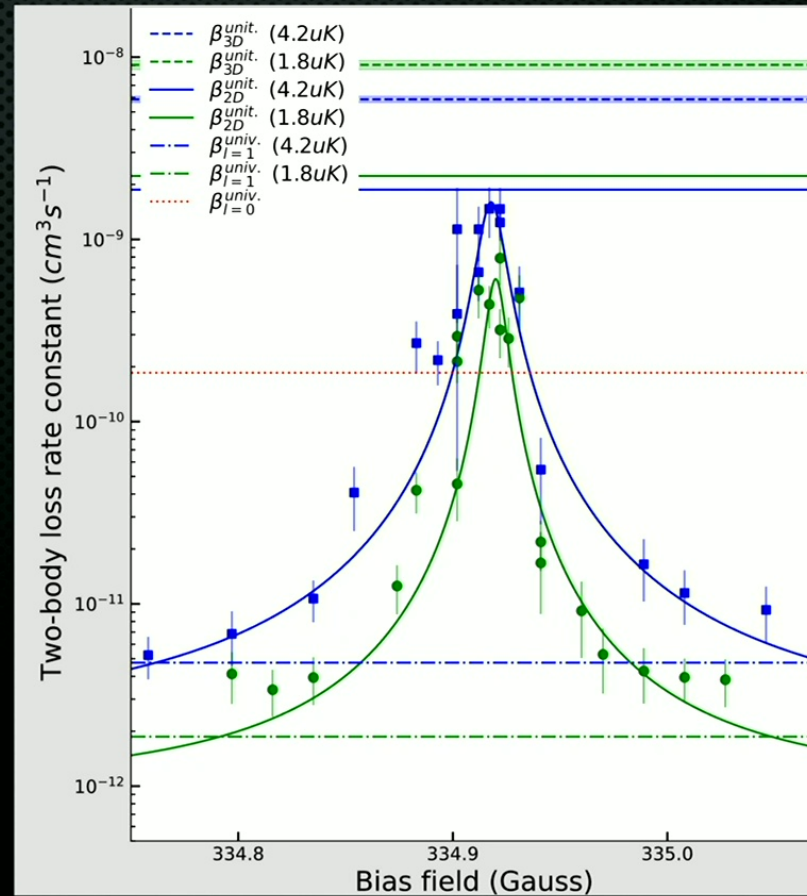
Phys. Rev. X **13**, 031018 (2023)  
Phys. Rev. A **108**, 023309 (2023)

- NALI + NA RESONANCES
- $H_2^+$  + NE/HE IN NAREVICIUS GROUP



# MOLECULE/MOLECULE RESONANCES

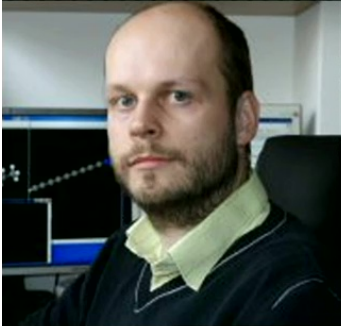
- NALI + NALI RESONANCE!
- FIELD-LINKED RESONANCES IN NAK + NAK, LUO GROUP, MPQ



A Feshbach resonance in collisions  
between triplet ground-state molecules  
Nature **614**, 54–58 (2023)

JJ Park, YK Lu, AO Jamison, TV Tscherbul, W  
Ketterle

Marcin  
Gronowski



Timur  
Tscherbul



Yukun Lu



Julie Park



# THE TEAM

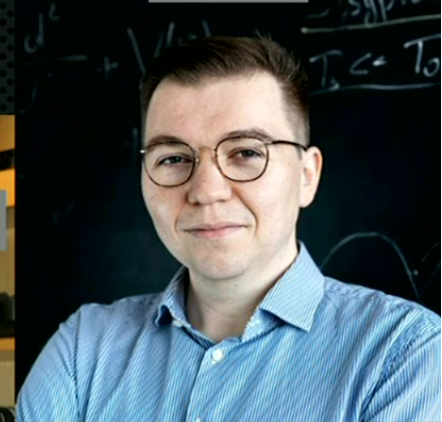
Wolfgang  
Ketterle



Hyungmok  
Son



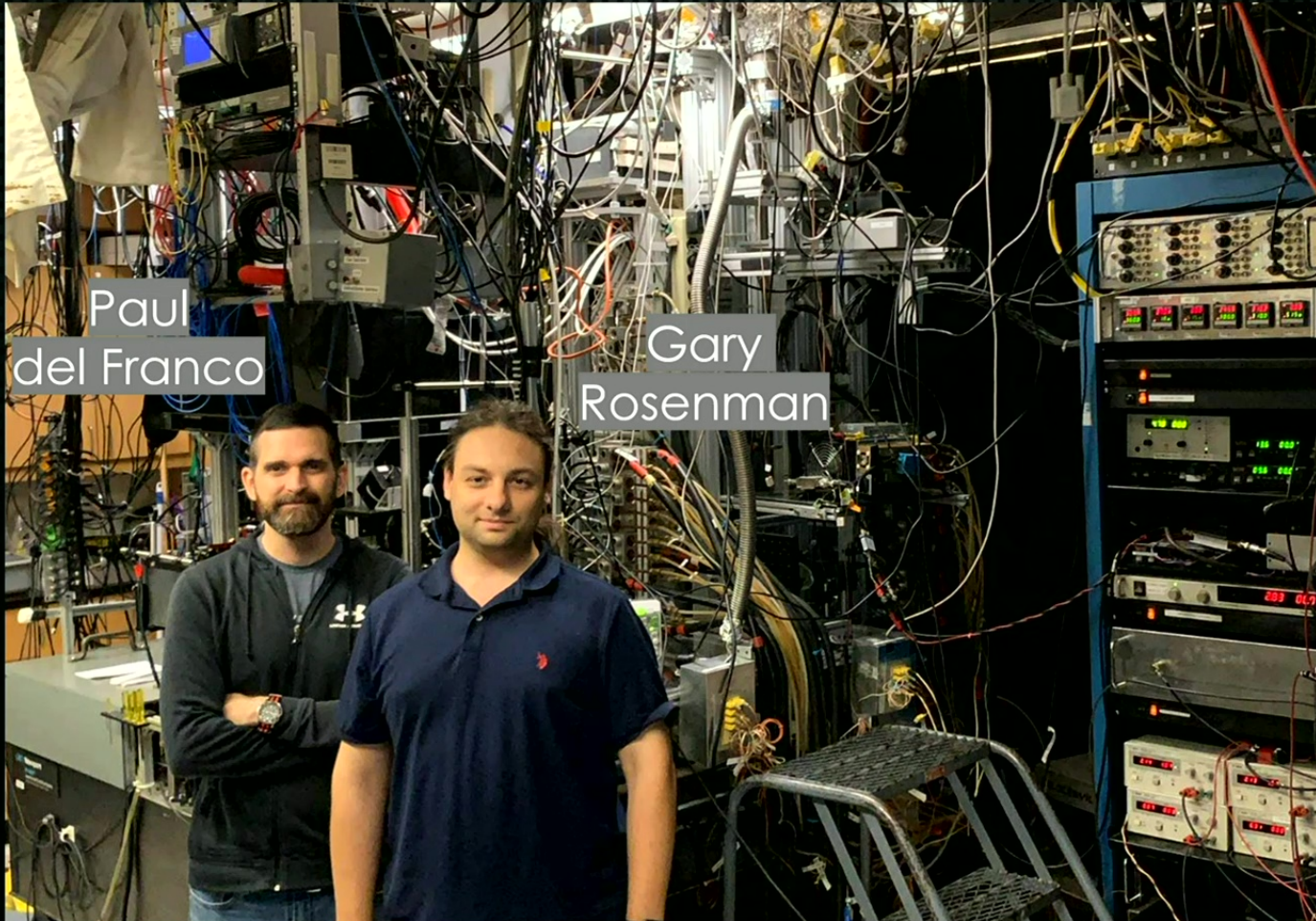
Michał  
Tomza



Tijs Karman



# THE CURRENT TEAM



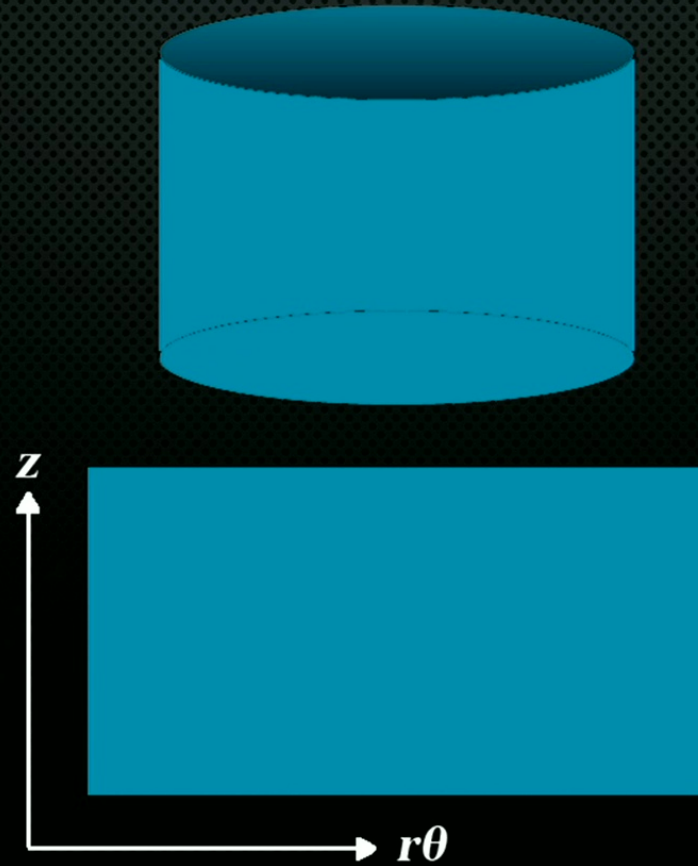
Paul  
del Franco

Gary  
Rosenman

Hyosun  
Park

# QUANTUM SIMULATION: CS/LI MIXTURE

- NEW GEOMETRY:

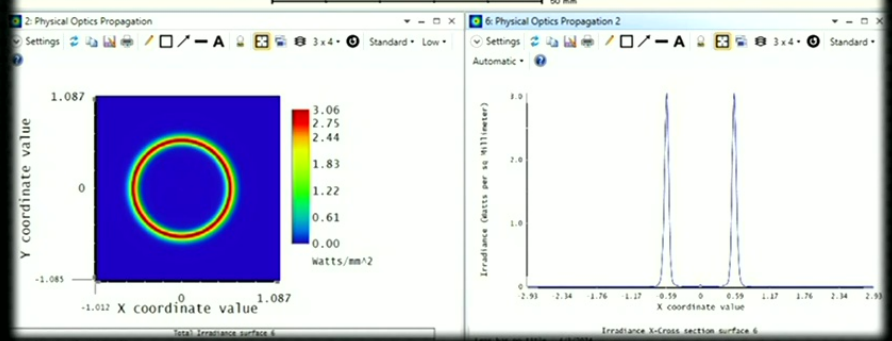
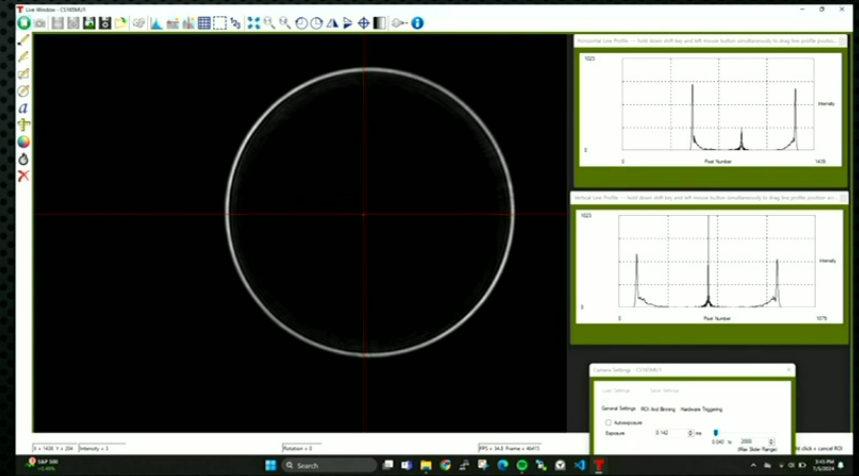
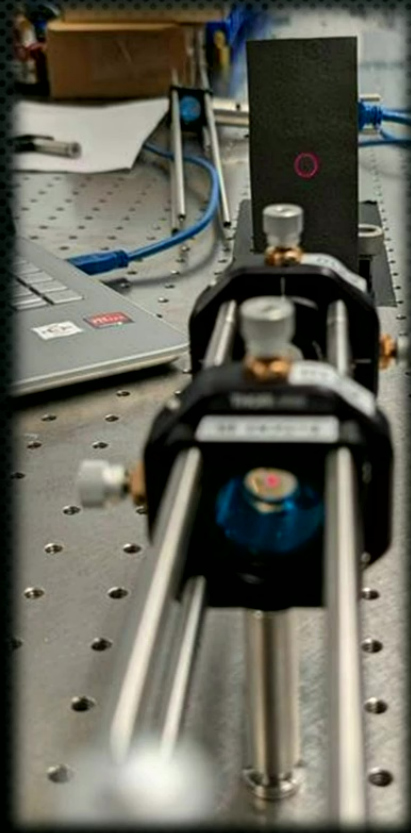


# QUANTUM SIMULATION



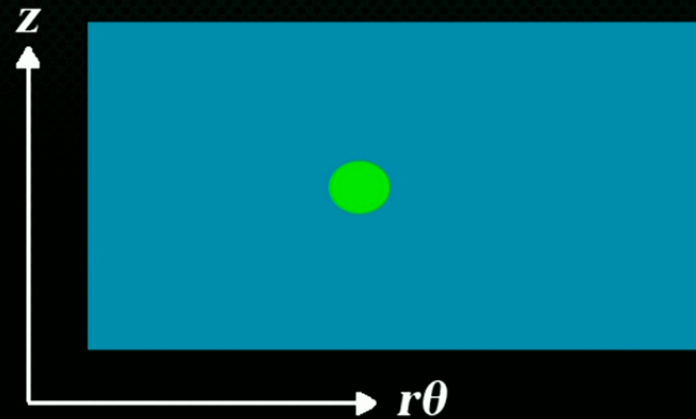
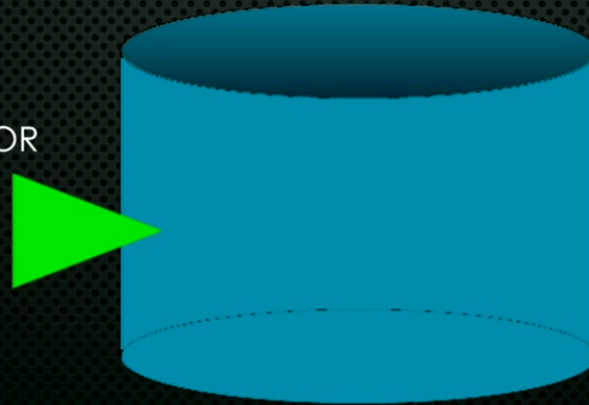
# QUANTUM SIMULATION: CS/LI MIXTURE

- NEW GEOMETRY:



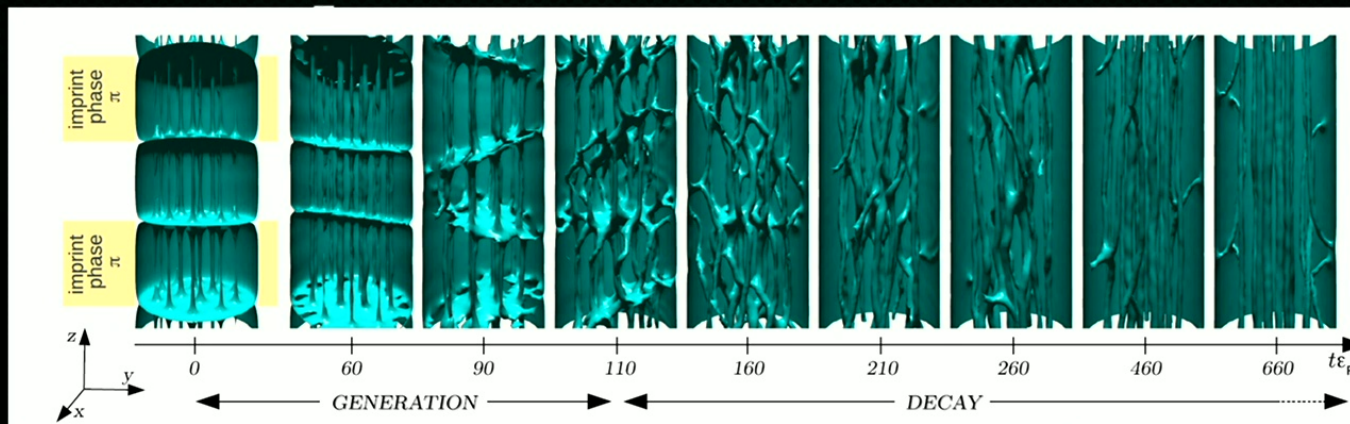
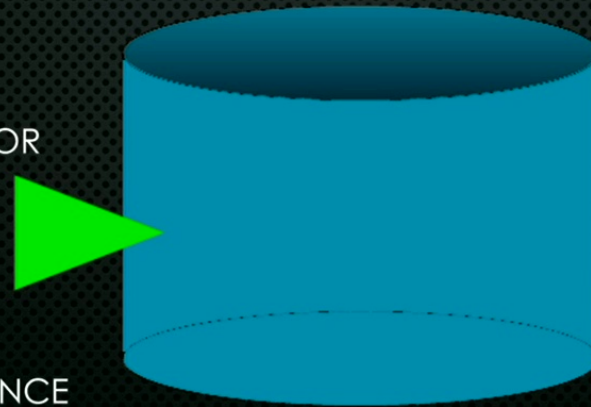
# QUANTUM SIMULATION: SUPERFLUID FLOW

- PERSISTENT FLOW
  - LONG-TIME BEHAVIOR
  - PRECISION STUDY OF SUPERFLUID BREAKDOWN



# QUANTUM SIMULATION: SUPERFLUID FLOW

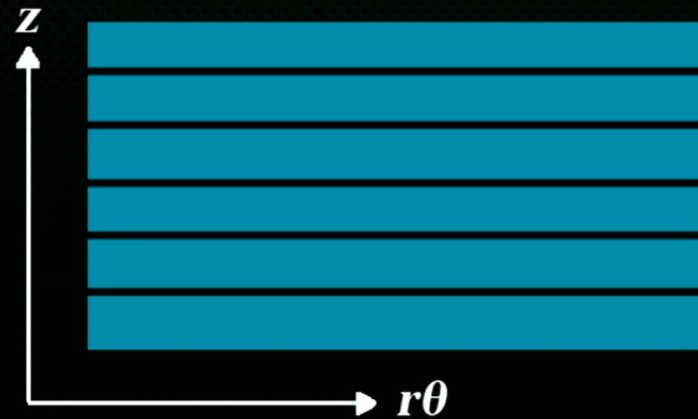
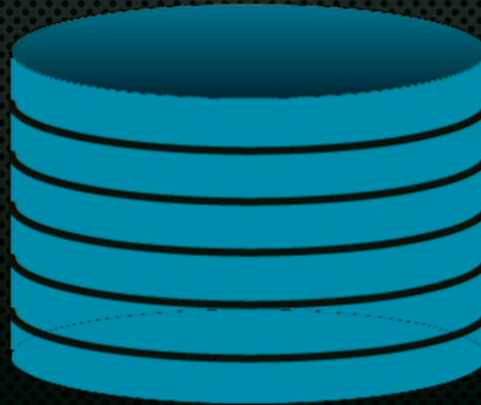
- PERSISTENT FLOW
  - LONG-TIME BEHAVIOR
  - PRECISION STUDY OF SUPERFLUID BREAKDOWN
  - QUANTUM TURBULENCE



Rotating quantum turbulence in the unitary Fermi gas  
Khalid Hossain, et al.,  
Phys. Rev. A **105**, 013304  
– Published 6 January (2022).

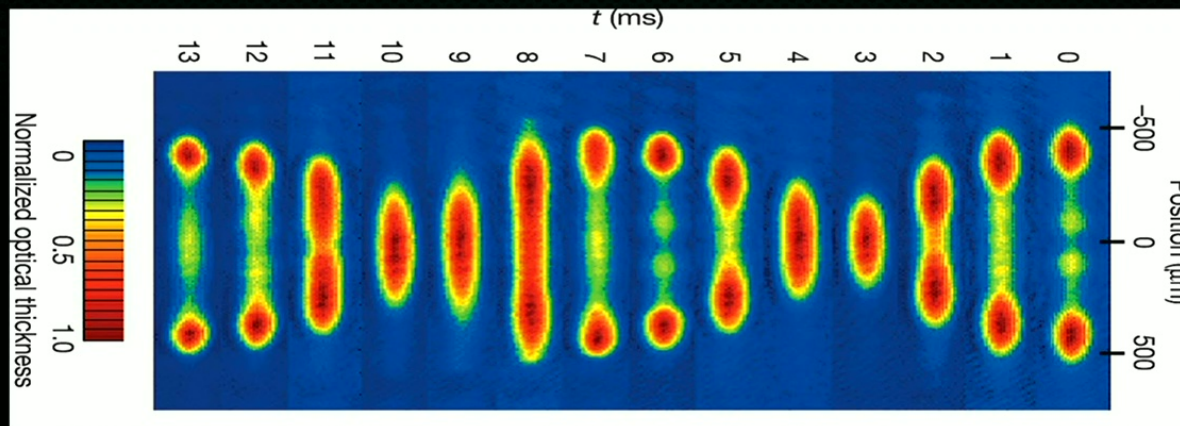
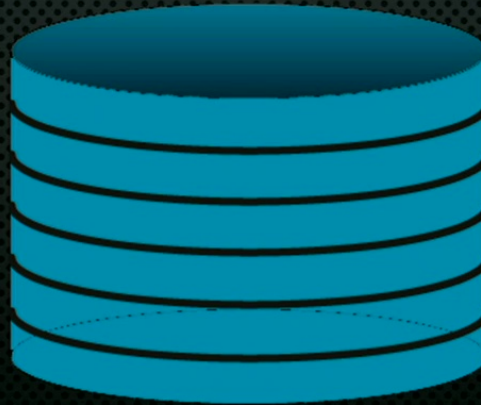
# QUANTUM SIMULATION: THERMALIZATION IN 1D

- LIEB-LINIGER MODEL
  - INTEGRABLE, SO NON-THERMALIZING



# QUANTUM SIMULATION: THERMALIZATION IN 1D

- LIEB-LINIGER MODEL
  - INTEGRABLE, SO NON-THERMALIZING
  - INTRODUCE TUNABLE INTEGRABILITY-BREAKING TERMS

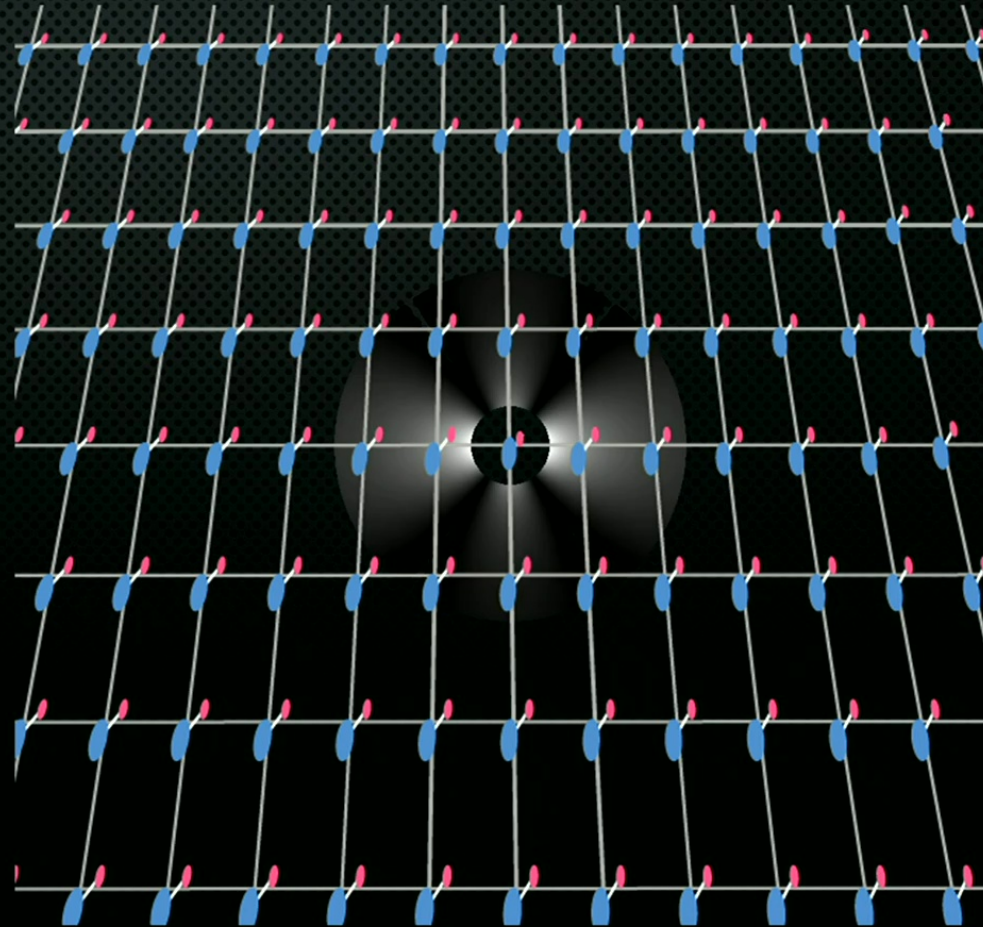
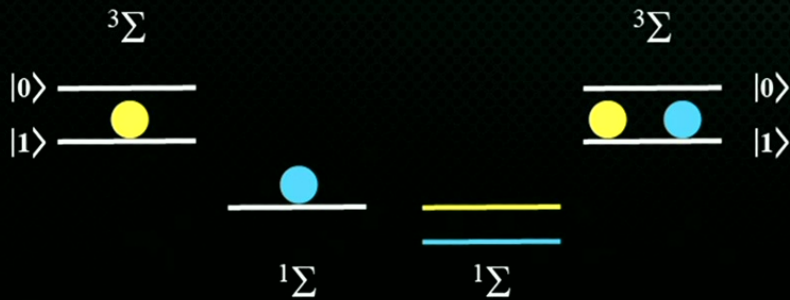


A quantum Newton's cradle.  
Kinoshita, T., Wenger, T. and Weiss, D.S.,  
*Nature*, **440**, pp.900-903 (2006)

# QUANTUM COMPUTING

## Figures of Merit

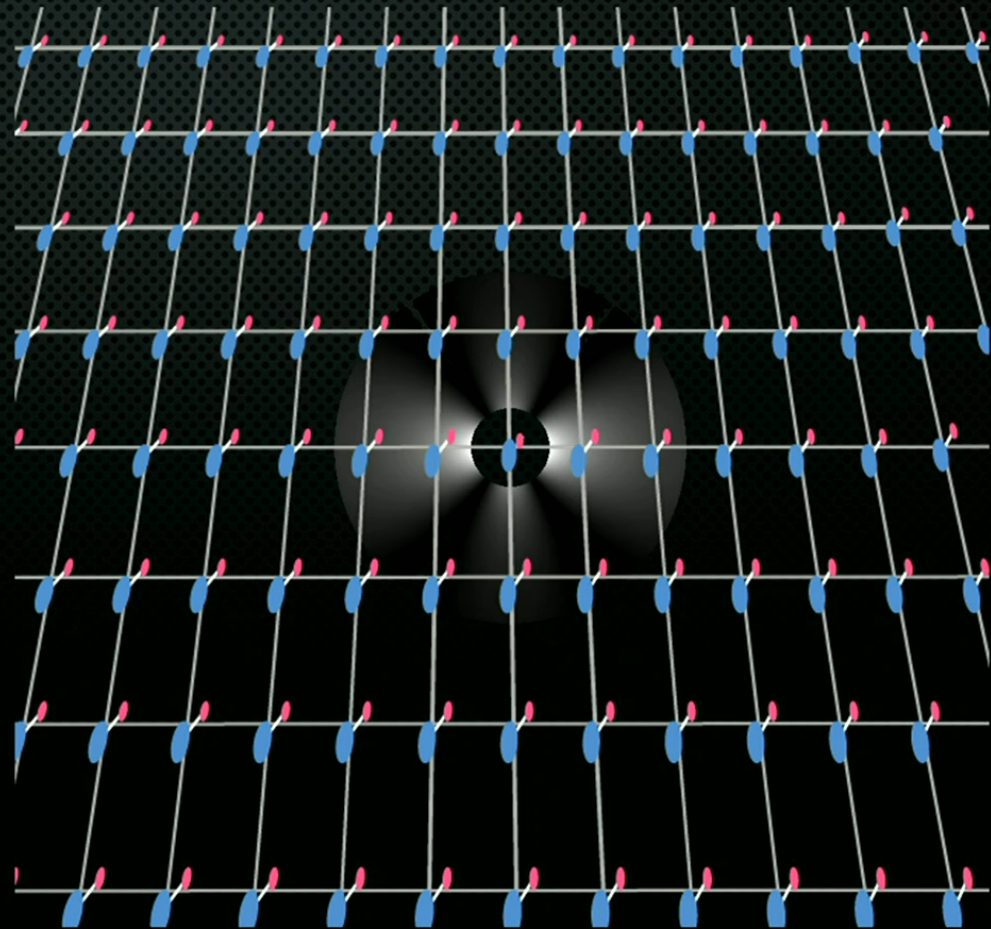
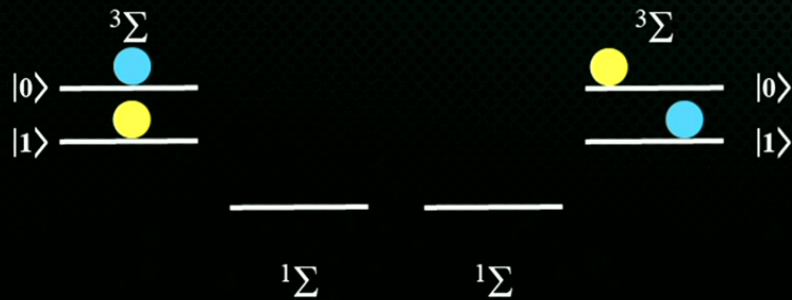
Coherence time: 10s  
Number of qubits:  $10^3$ - $10^4$   
Single qubit gate time: 1-10 $\mu$ s  
Two-qubit gate time: 100 $\mu$ s



# QUANTUM COMPUTING

## Figures of Merit

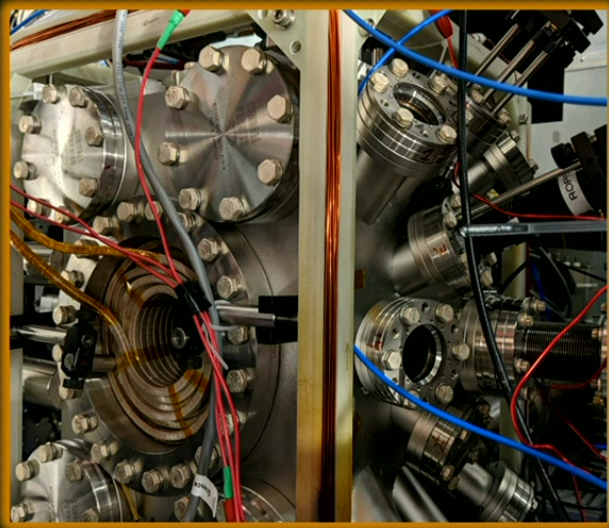
Coherence time: 10s  
Number of qubits:  $10^3$ - $10^4$   
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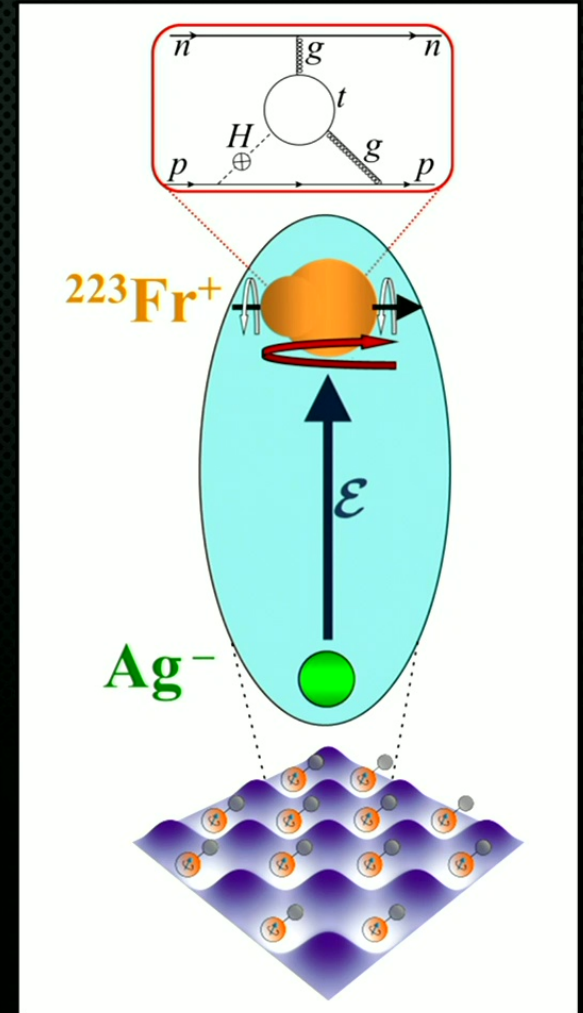
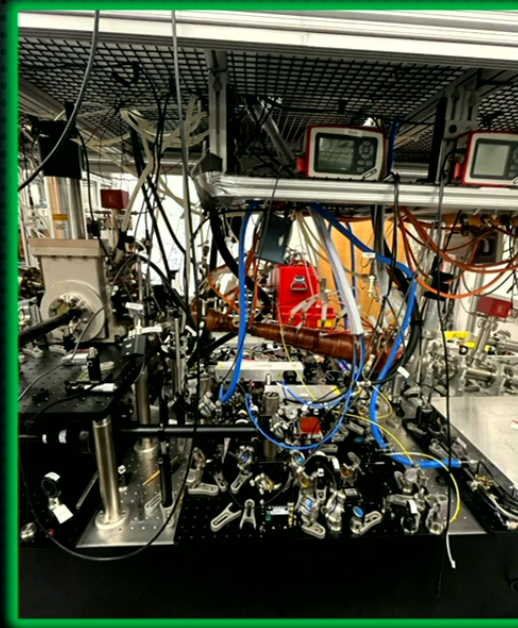
# DEFINITELY NOT QUANTUM SIMULATION



# $^{223}\text{FrAg}$ NUCLEAR EDM SEARCH



FrAg



# REDRUM

- RESEARCHING ELECTRIC DIPOLES WITH RADIOACTIVE ULTRACOLD MOLECULES
  - UNIVERSITY OF CHICAGO/ARGONNE NATIONAL LAB (USA)
  - UNIVERSITY OF WATERLOO
  - TRIUMF
  - UNIVERSITY OF BRITISH COLUMBIA
  - UNIVERSITY OF MANITOBA
  - TEMPLE UNIVERSITY/NIST (USA)
  - UNIVERSITY OF UTAH (USA)
  - UNIVERSITY OF MARYLAND (USA)



# THE TEAM



• [JAMISON.IQC.UWATERLOO.CA](http://JAMISON.IQC.UWATERLOO.CA)