Title: Quantum state control of ultracold chemistry

Speakers: Alan Jamison

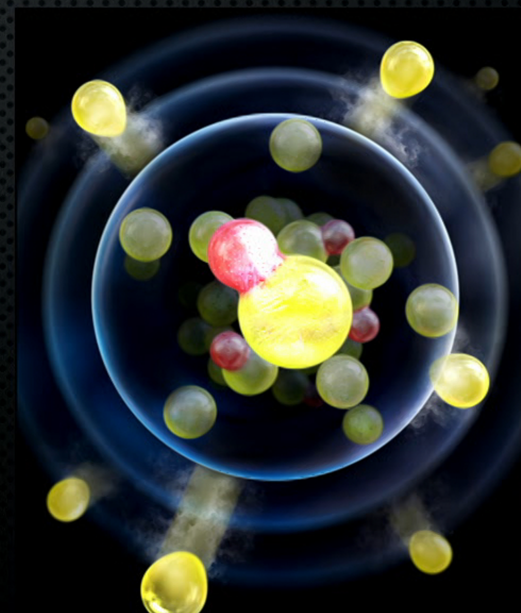
Collection: Cold Atom Molecule Interactions (CATMIN)

Date: July 15, 2022 - 5:20 PM

URL: https://pirsa.org/22070023

Abstract: The advent of ultracold molecules opens the possibility to explore chemical reactions with perfect control of the quantum states of the reactants. We report on several surprising results of our work with ultracold NaLi molecules. First, we demonstrate a factor of 100 control of reaction rates between NaLi molecules and Na atoms by changing the atom's spin state. This ability to slow reactions allowed us to demonstrate sympathetic cooling of molecules for the first time. Next, we explore two very different collisional resonances. A resonance in NaLi+Na reactions exemplifies the standard description of chemical resonances. The other, for NaLi+NaLi, is the first ultracold molecule-molecule resonance observed and runs completely counter to the standard description. Simple models relate the complex chemical dynamics to the simple physics of a Fabry-Perot resonantor and point a number of open questions in chemical dynamics that can be explored with ultracold molecules.

QUANTUM STATE CONTROL OF ULTRACOLD CHEMISTRY

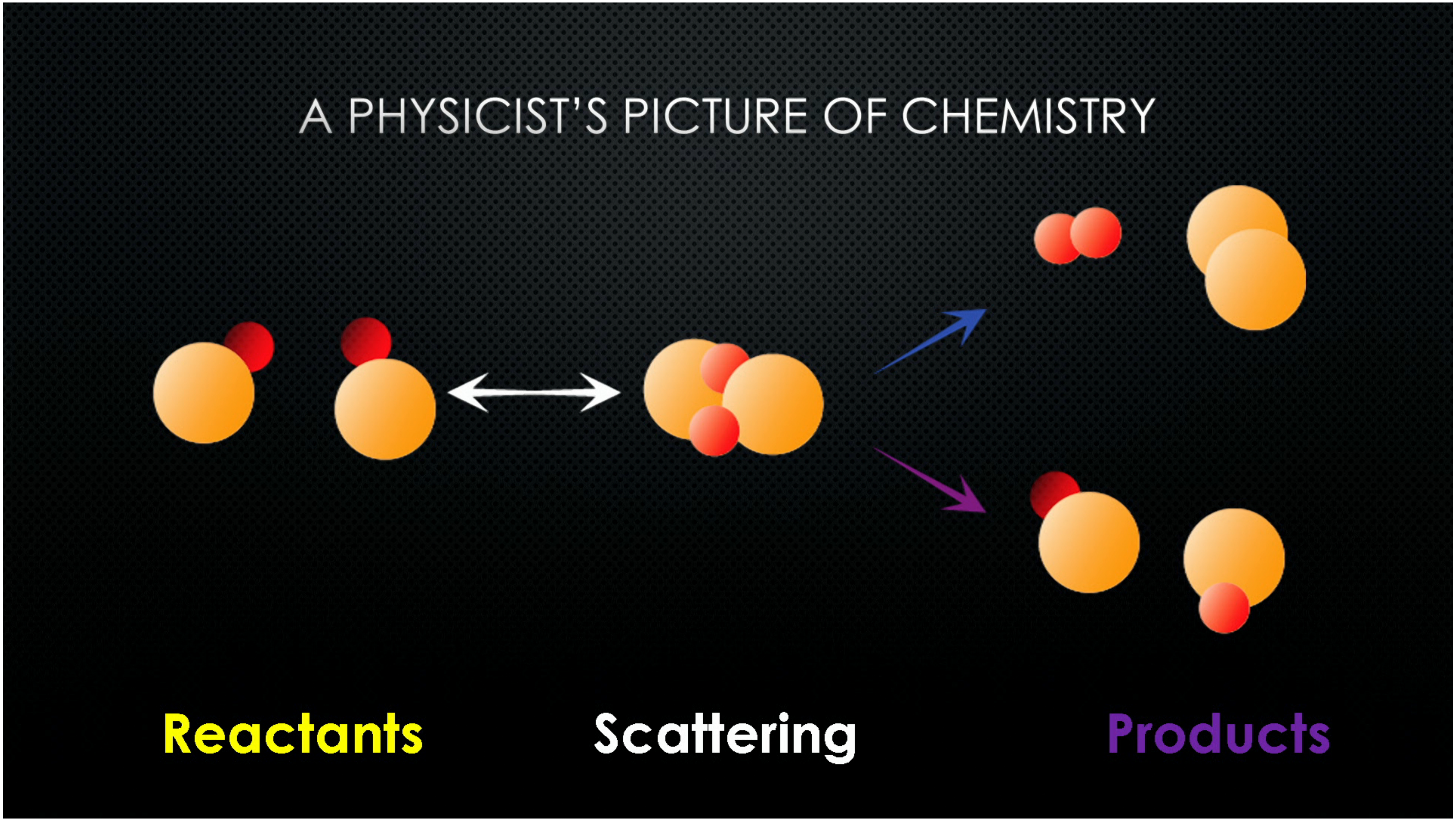


ALAN JAMISON

PHYSICS & ASTRONOMY DEPARTMENT AND INSTITUTE FOR QUANTUM COMPUTING

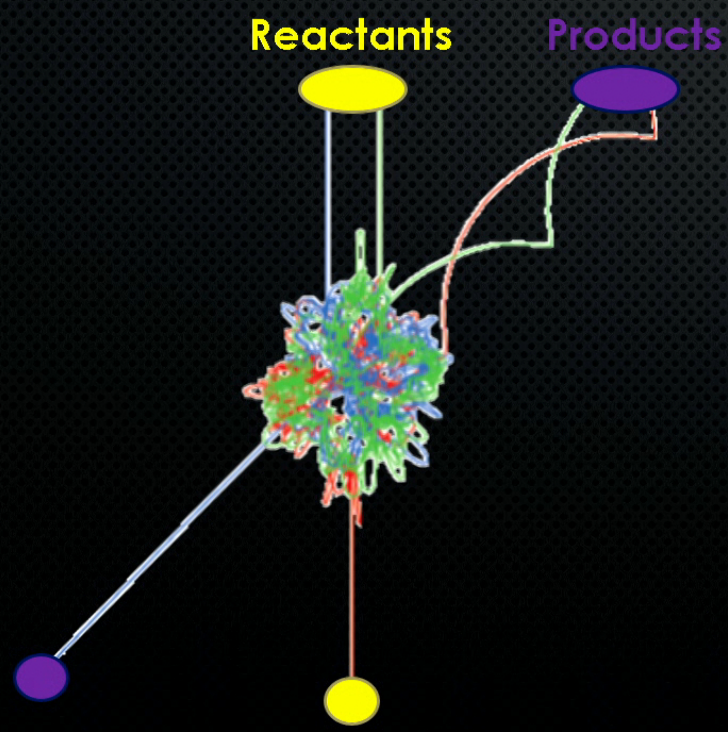
UNIVERSITY OF WATERLOO


I HAVE NO
IDEA WHAT
I'M DOING

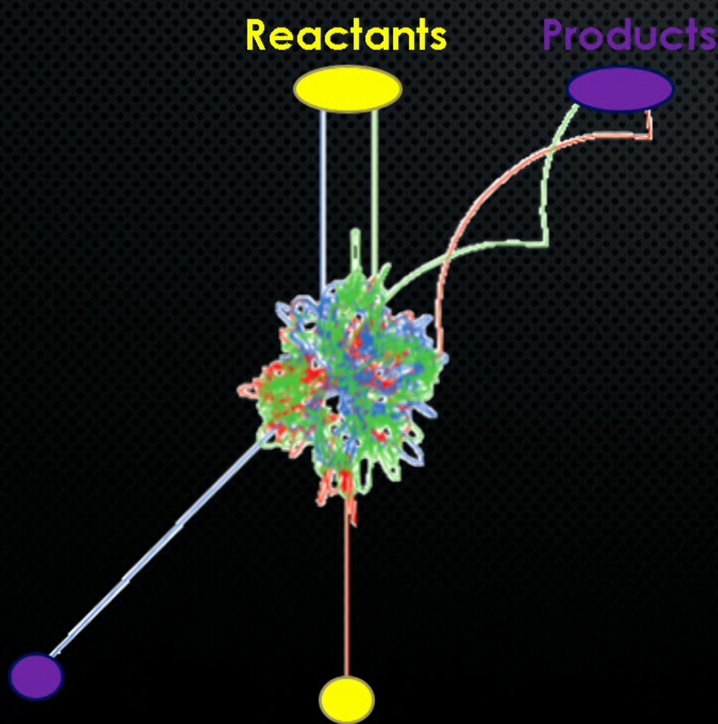

A PHYSICIST'S PICTURE OF CHEMISTRY
Reactants
Scattering
Products

SCATTERING

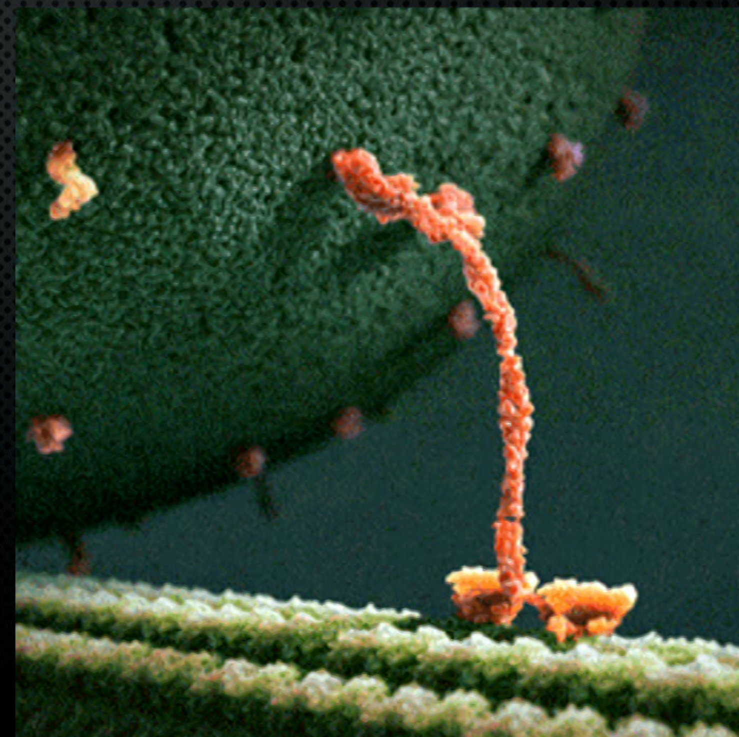
CHEMISTRY



SCATTERING

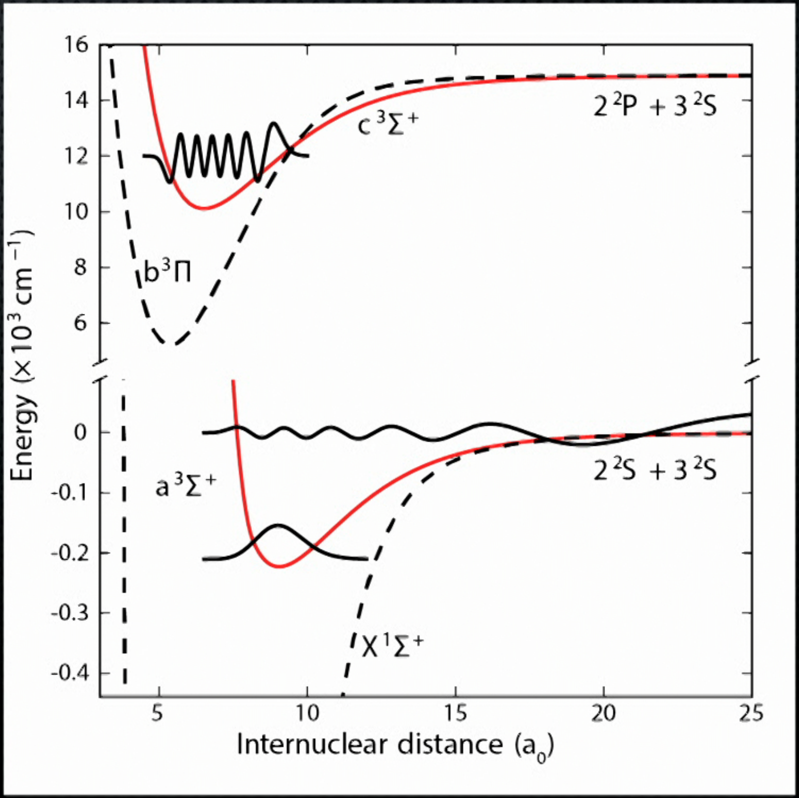


CHEMISTRY

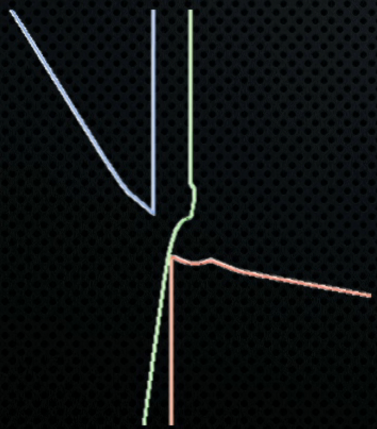


MOLECULES: STRUCTURE

- Structural Hierarchy
  - Electronic (~10,000 K)
  - Vibrational (~1-100 K)
  - Rotational (~0.1-1K)
  - Hyperfine (~1-100 μK)



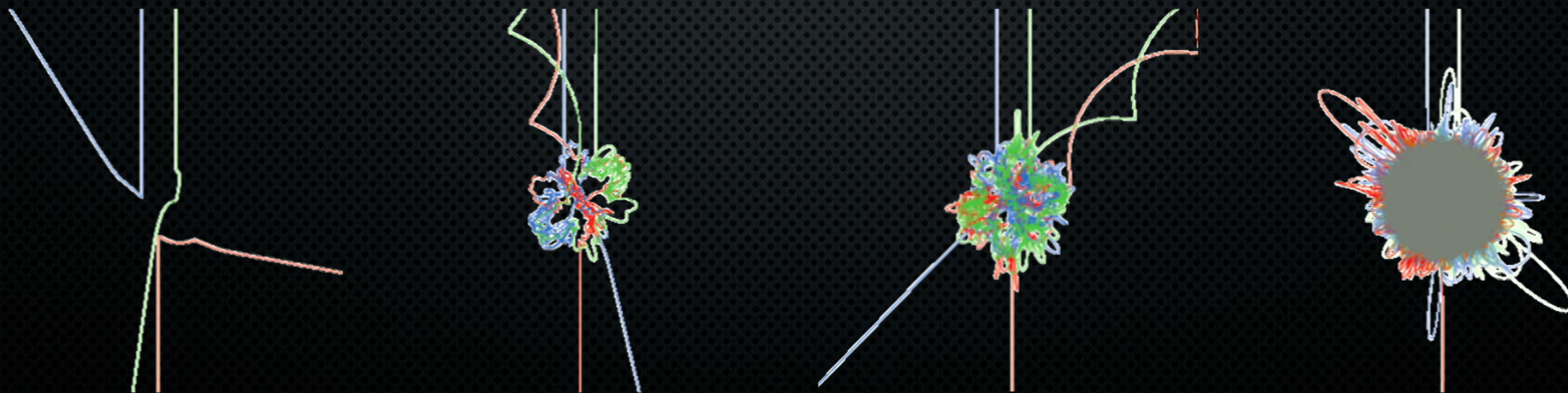
THE THREE-BODY PROBLEM



T = 1000K

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

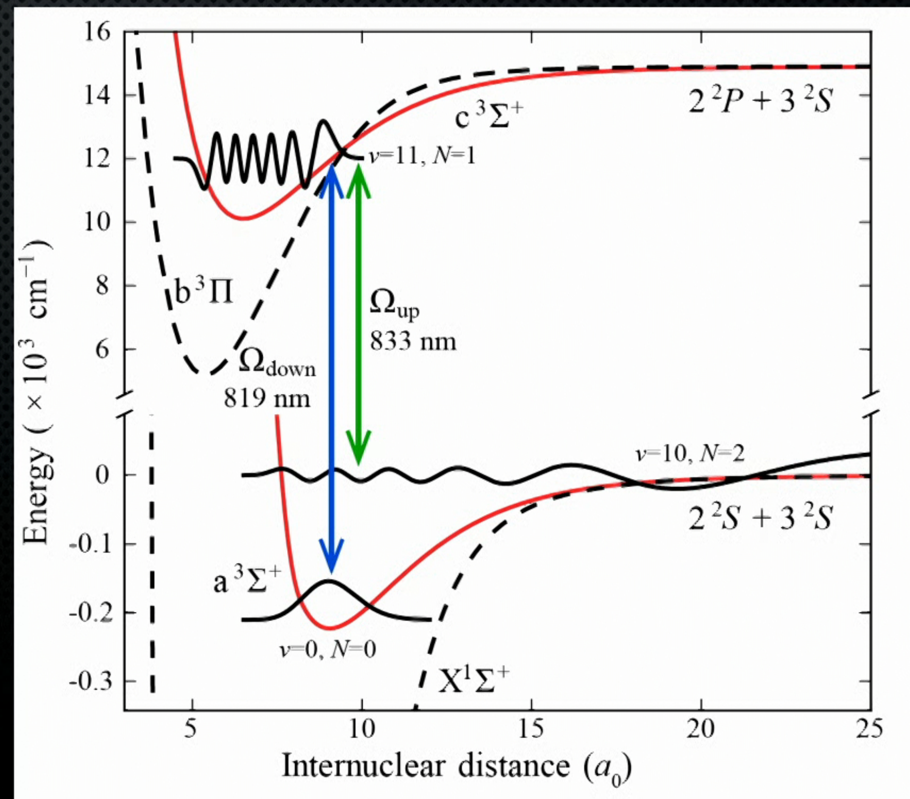
THE THREE-BODY PROBLEM



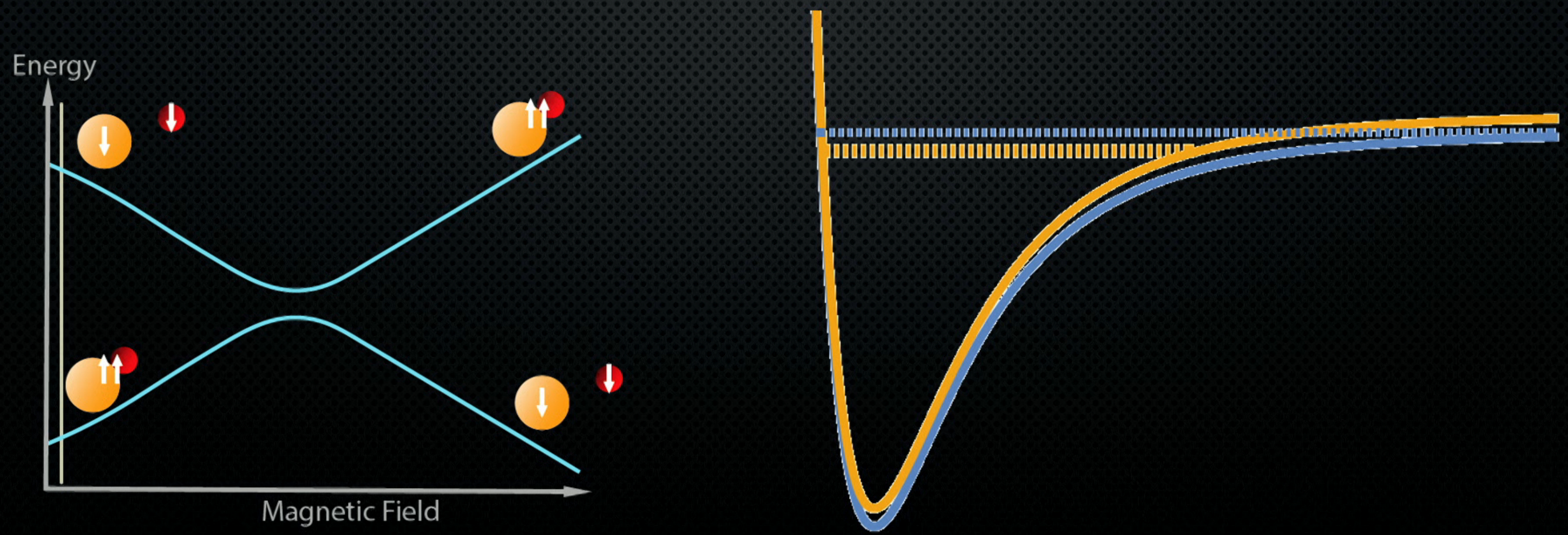
T = 1000K   T = 100K   T = 10K   T = 1K

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

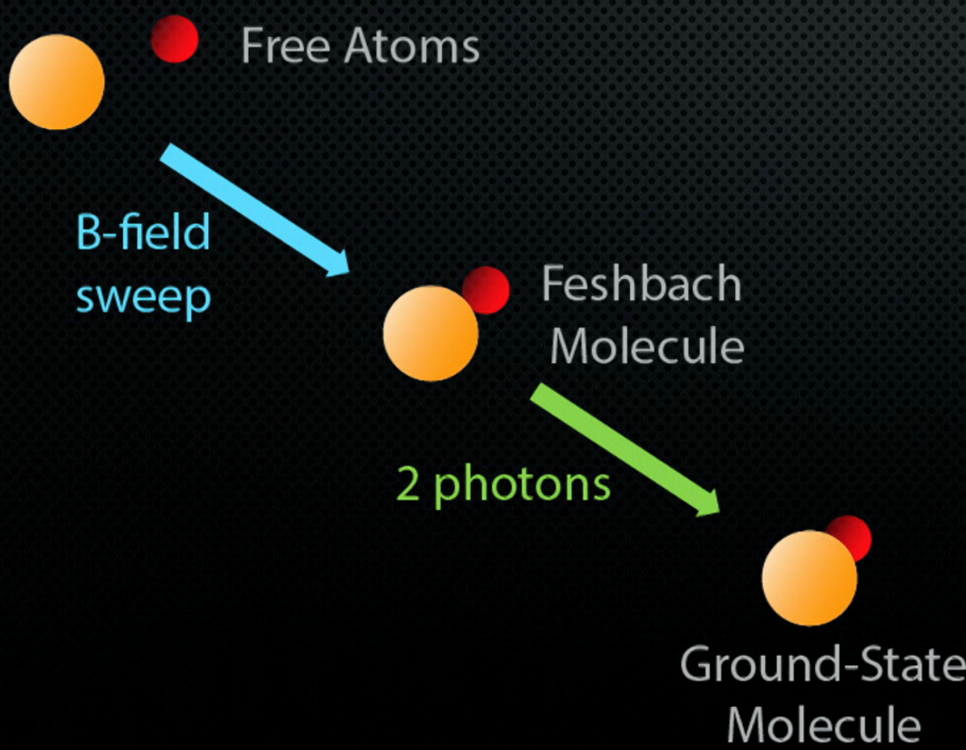
ULTRACOLD TRIPLET NALI

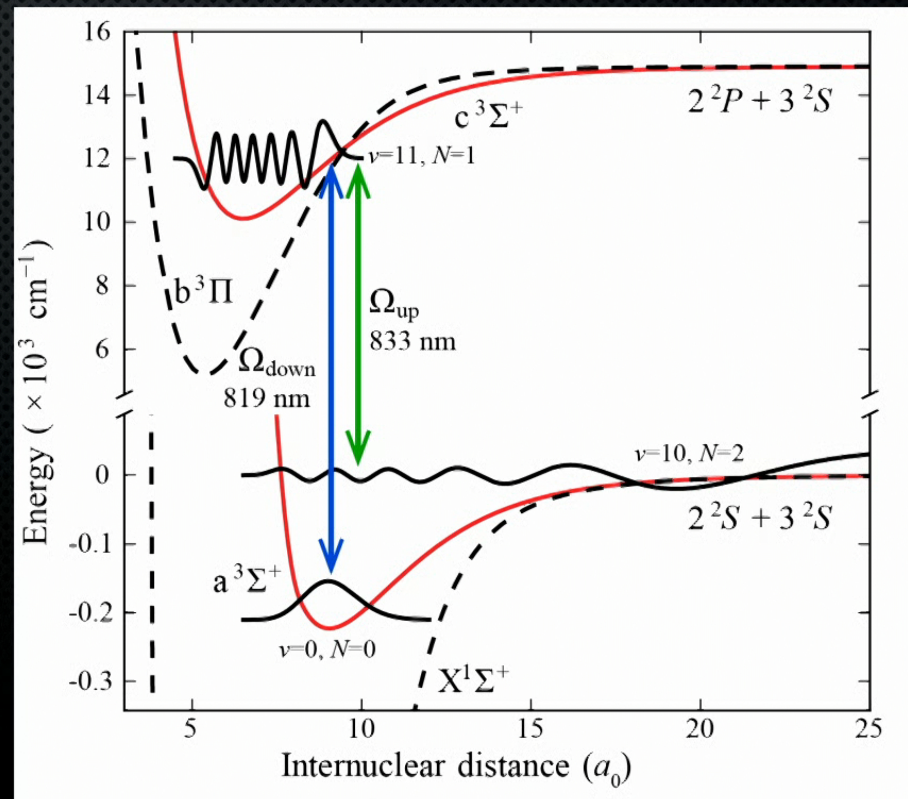


FESHBACH RESONANCE

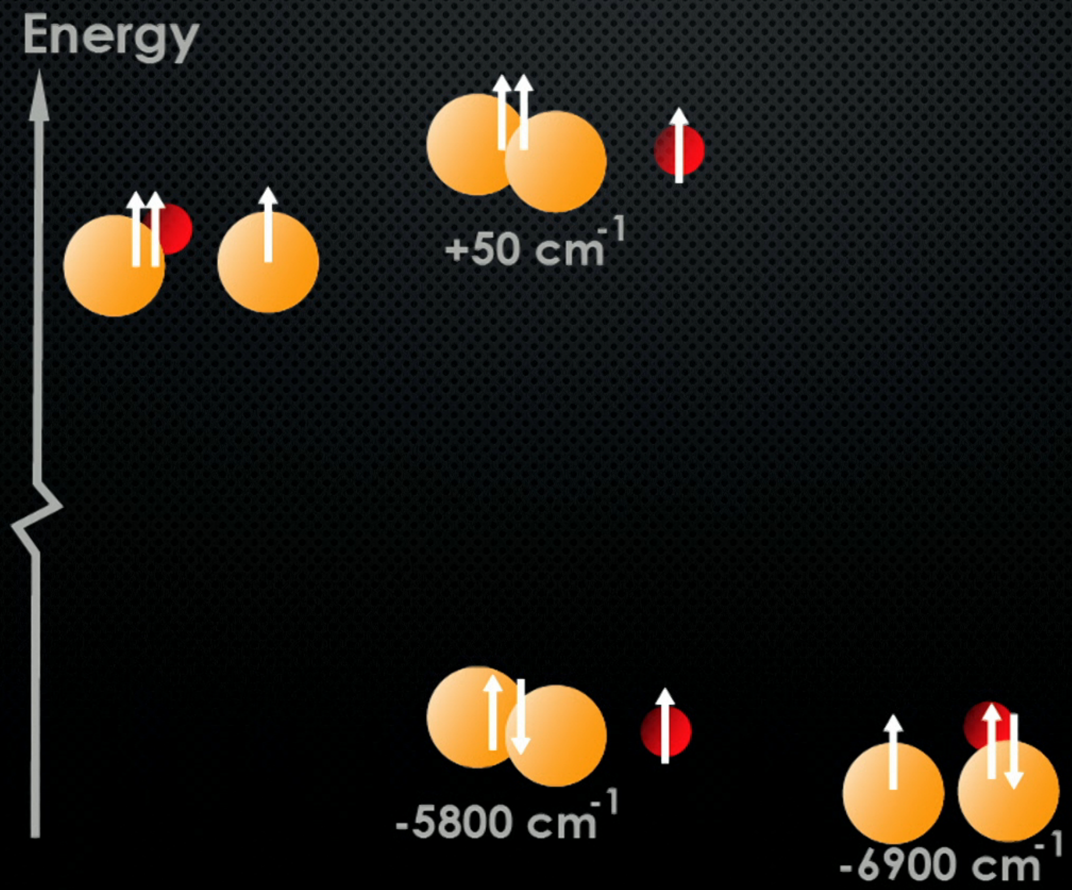


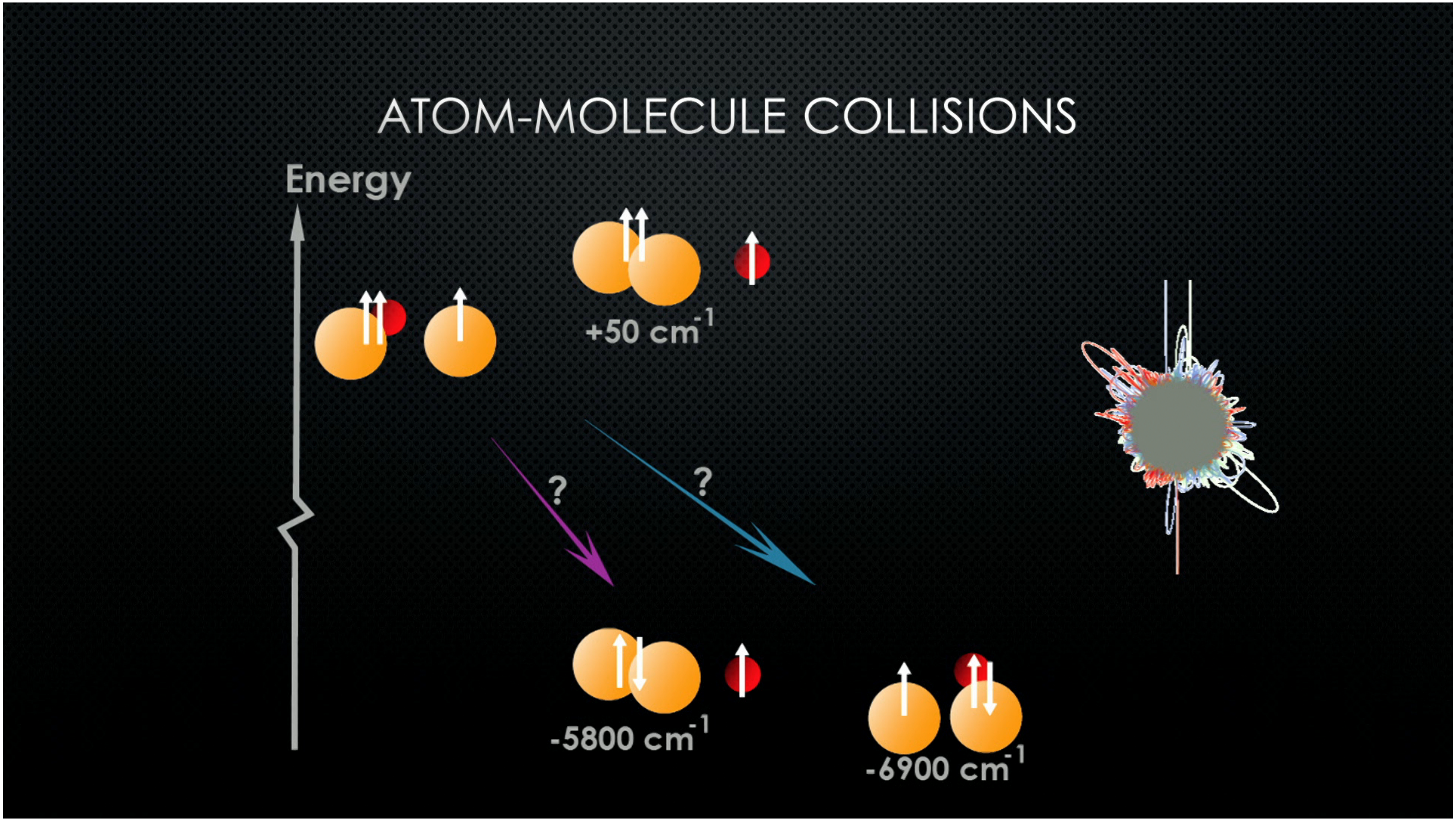
ULTRACOLD TRIPLET NALI



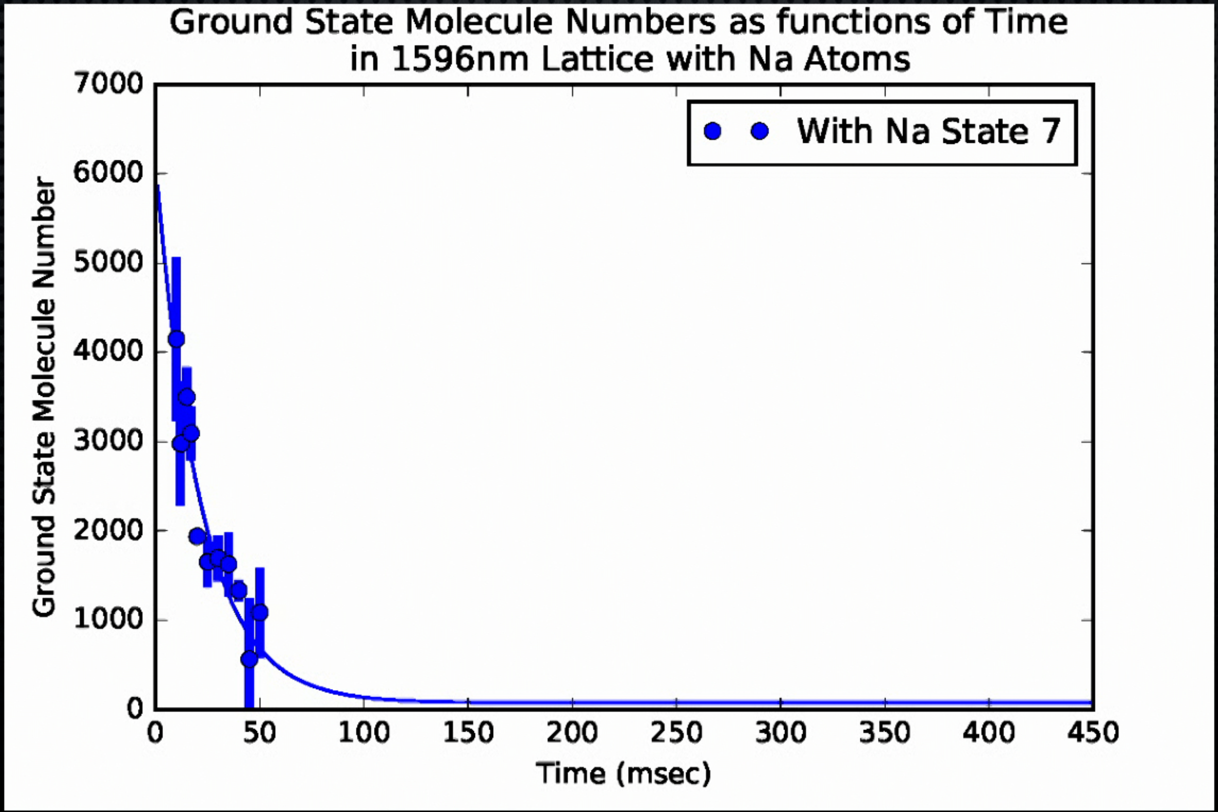


ATOM-MOLECULE COLLISIONS

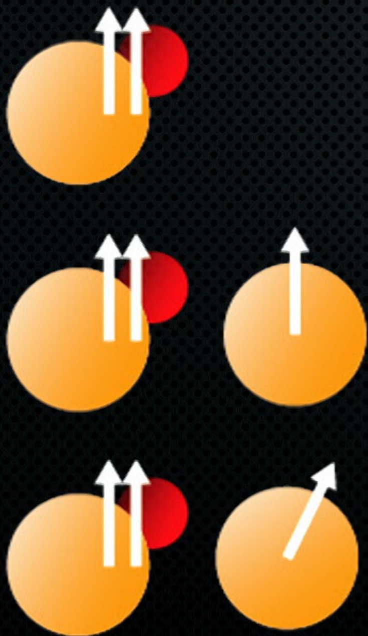


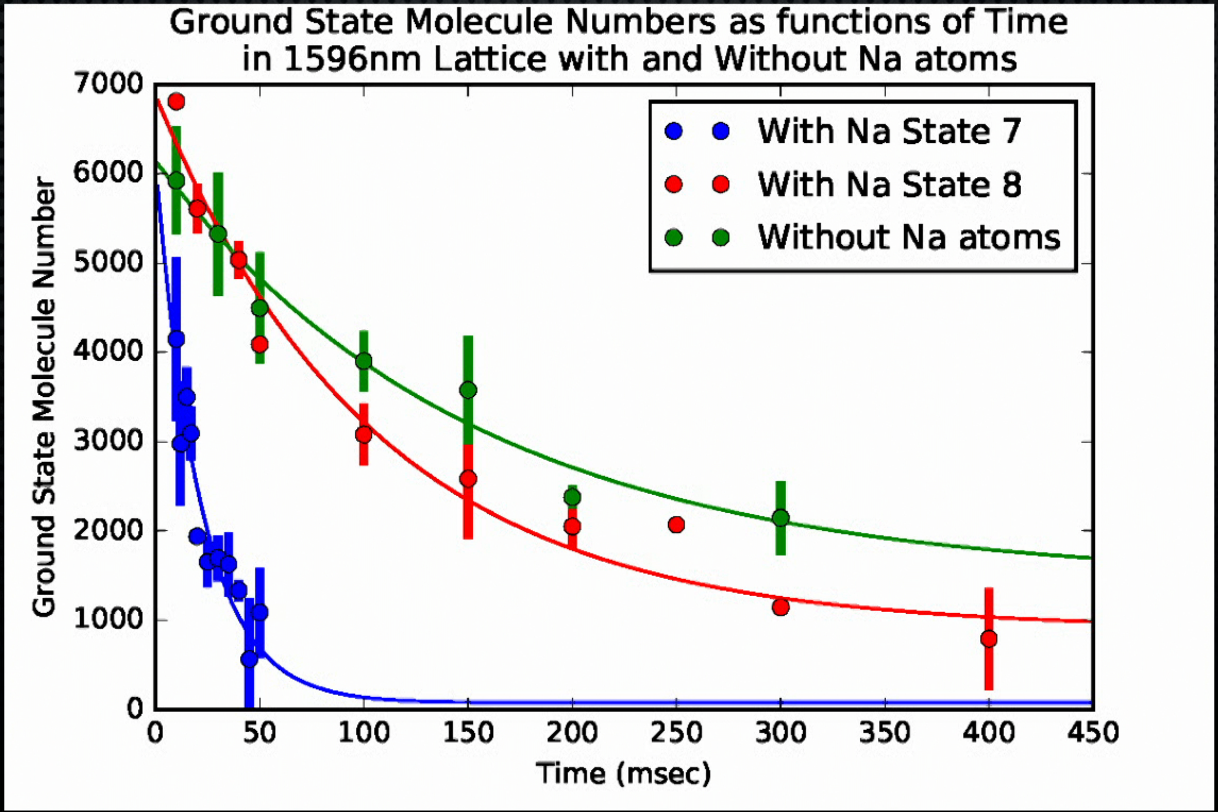

ATOM-MOLECULE COLLISIONS
Energy
+50 cm^{-1}
?
?
-5800 cm^{-1}
-6900 cm^{-1}

ATOM-MOLECULE COLLISIONS



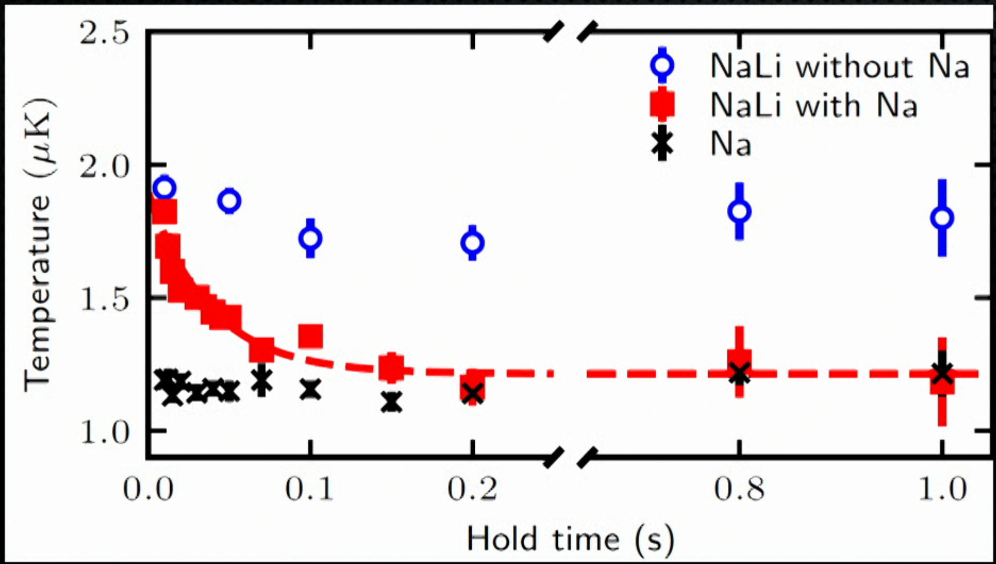
ATOM-MOLECULE COLLISIONS

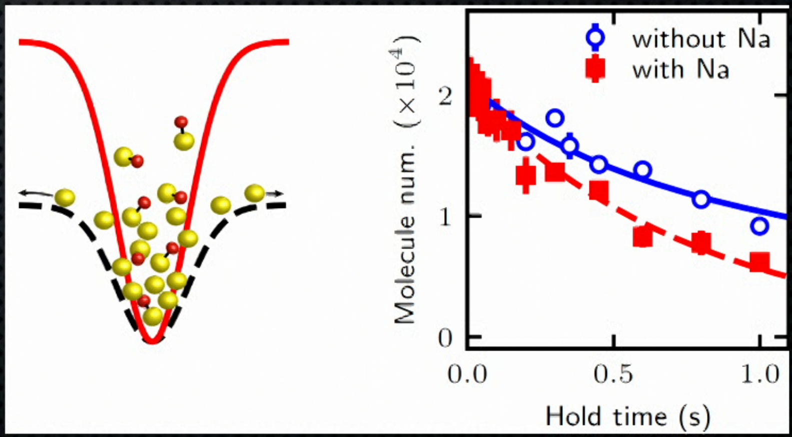




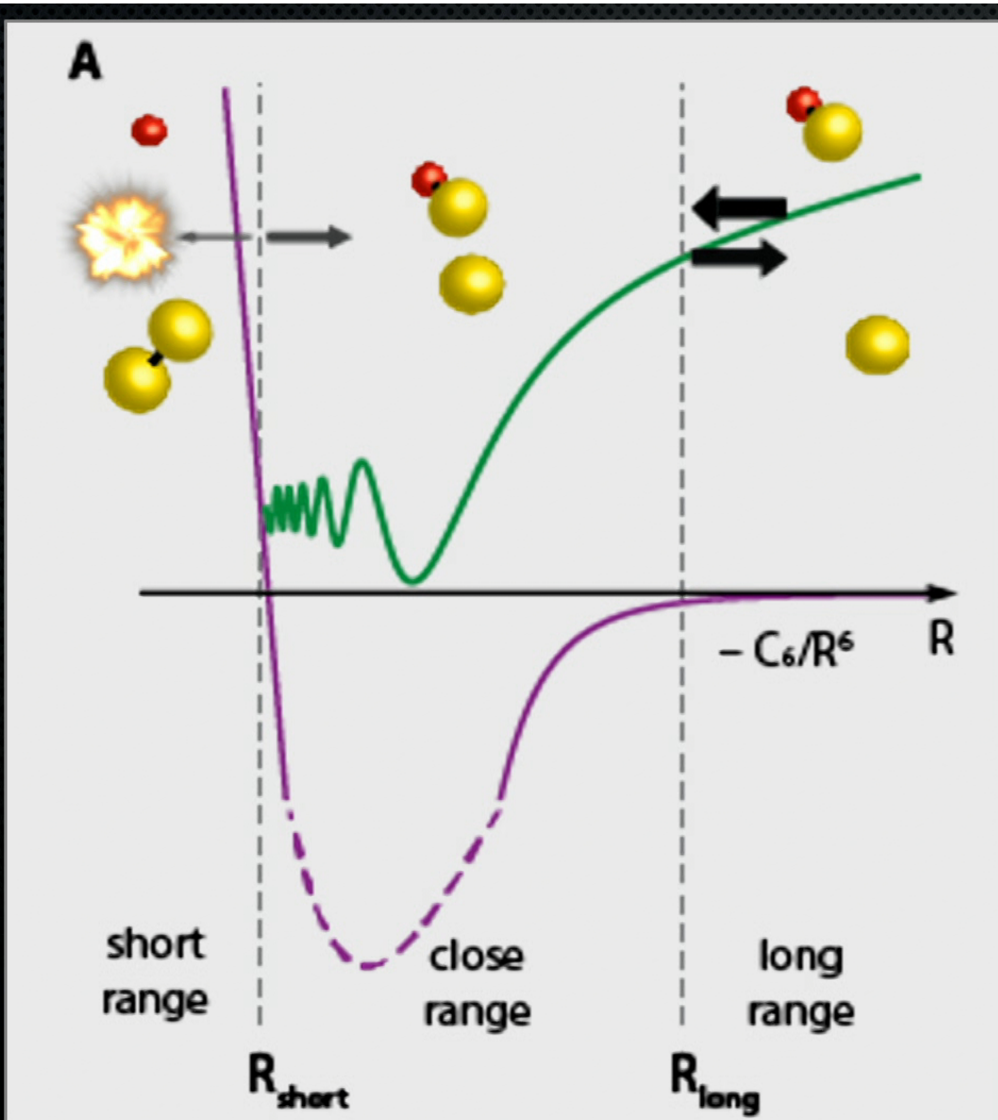
SYMPATHETIC COOLING

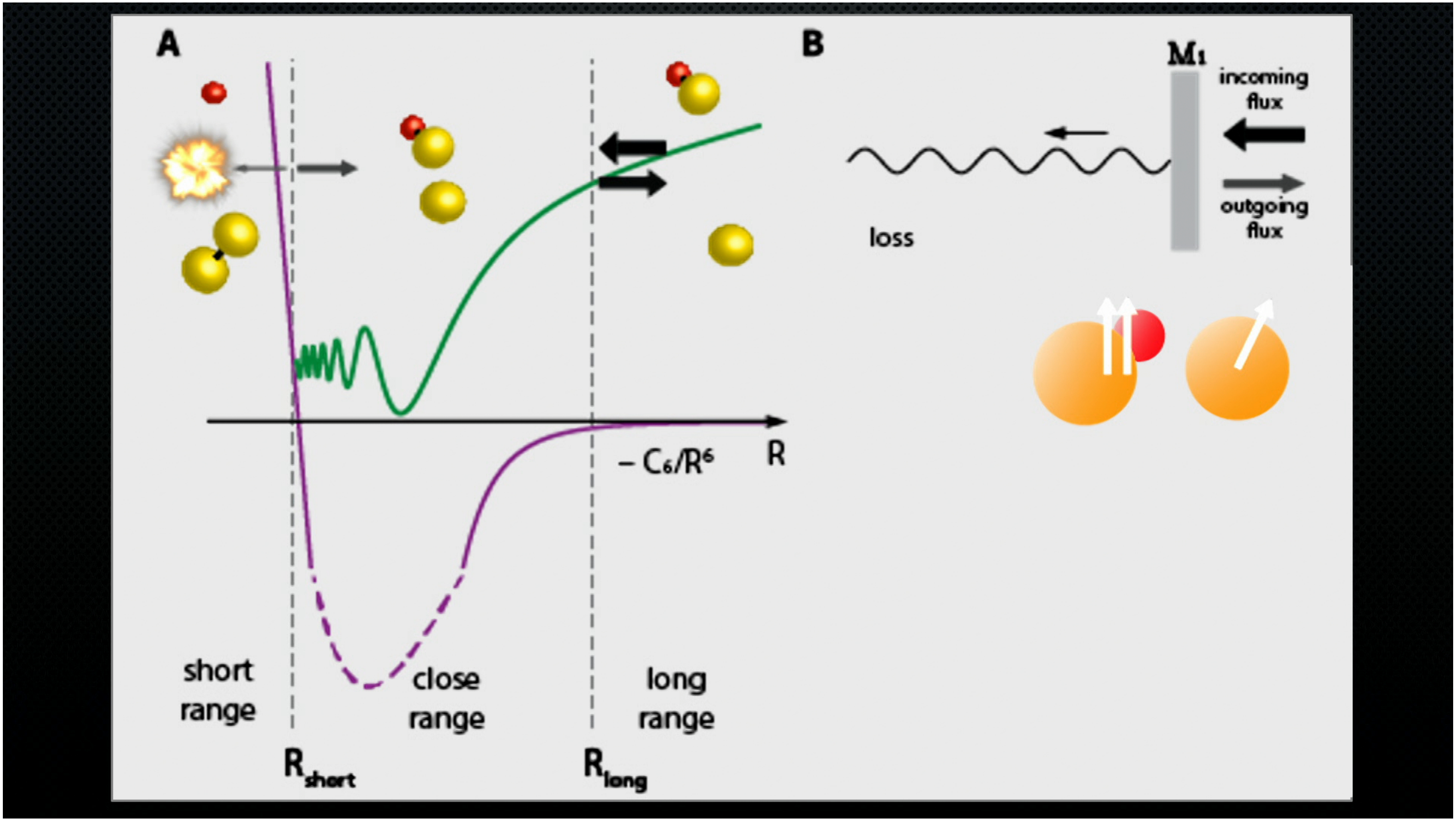
- MOLECULES PRODUCED HOTTER THAN ATOMS
- ~80 ELASTIC COLLISIONS PER REACTION



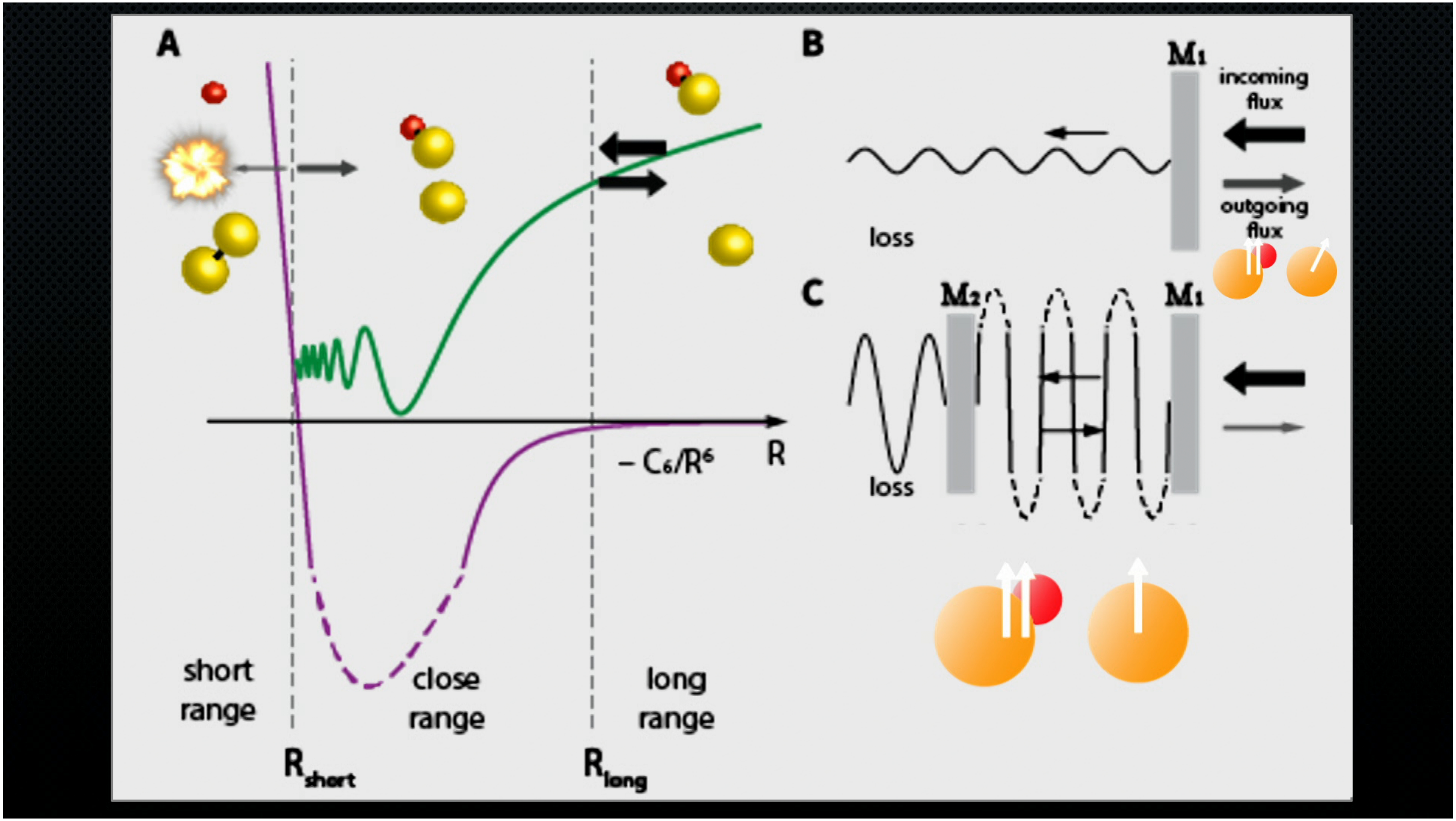


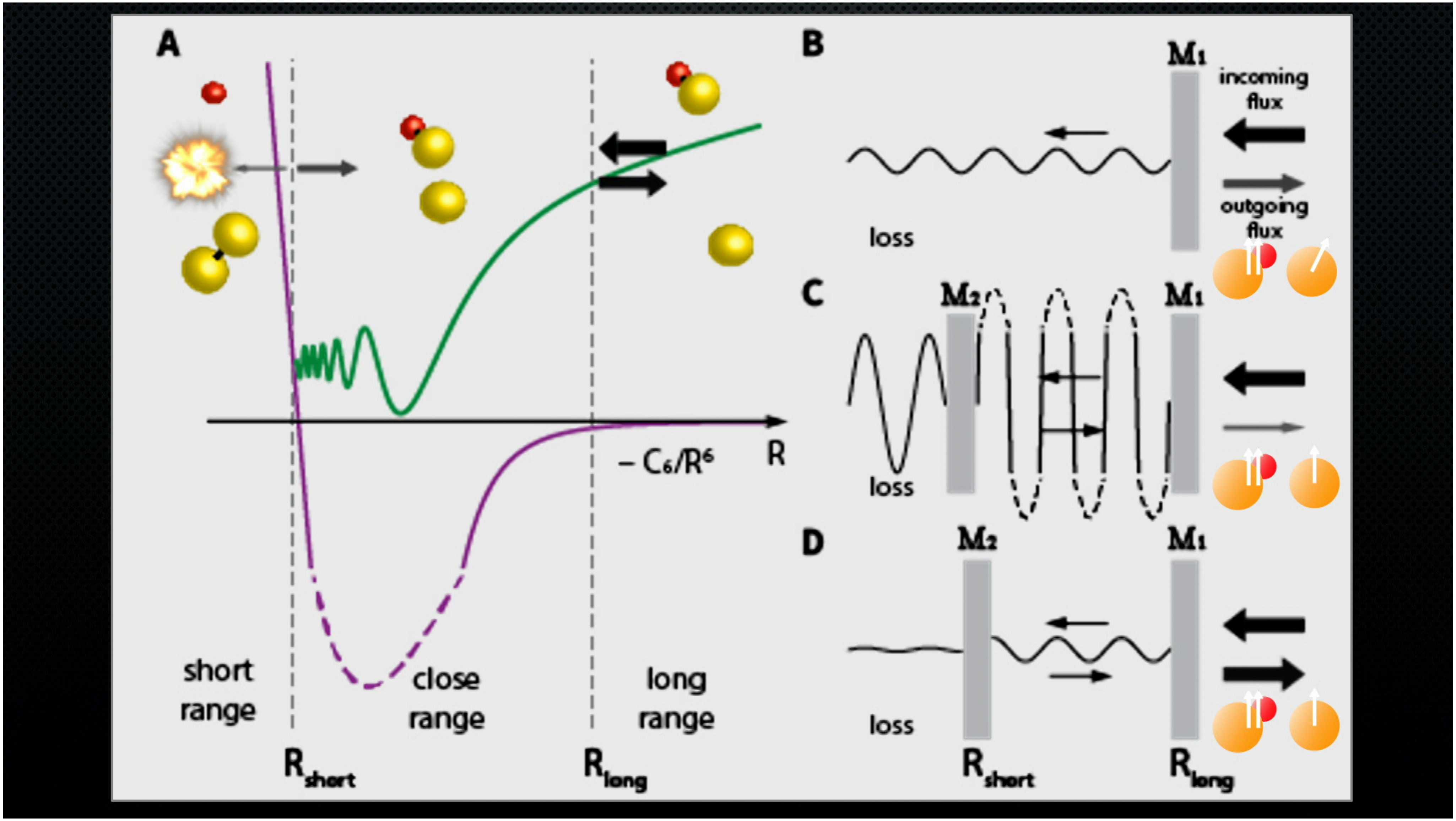
Collisional cooling of ultrcold molecules
Nature 580, 197 (2020)
H Son, JJ Park, W Ketterle, AO Jamison


A
– C₆/R⁶
R
short
range
close
range
long
range
R_short
R_long



A
B
M1
incoming flux
outgoing flux
loss
$-C_6/R^6$
R
short range
close range
long range
R_{short}
R_{long}

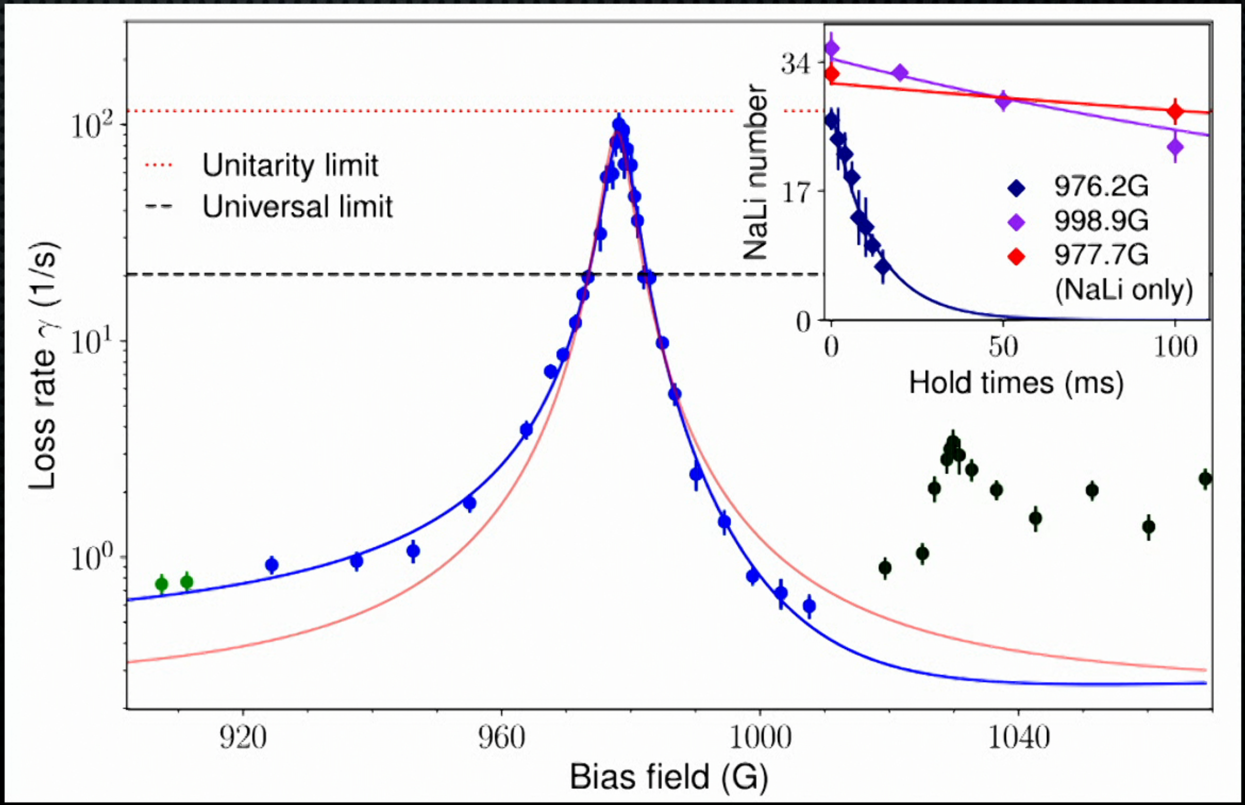

A
B
C
M1
incoming flux
outgoing flux
loss
M2
M1
loss
$-C_6/R^6$
R
short range
close range
long range
R_{short}
R_{long}



A
short
range
close
range
long
range
R
$- C_6/R^6$
R_{short}
R_{long}
B
M_1
incoming
flux
outgoing
flux
loss
C
M_2
M_1
loss
D
M_2
M_1
loss
R_{short}
R_{long}

CHEMICAL RESONANCES

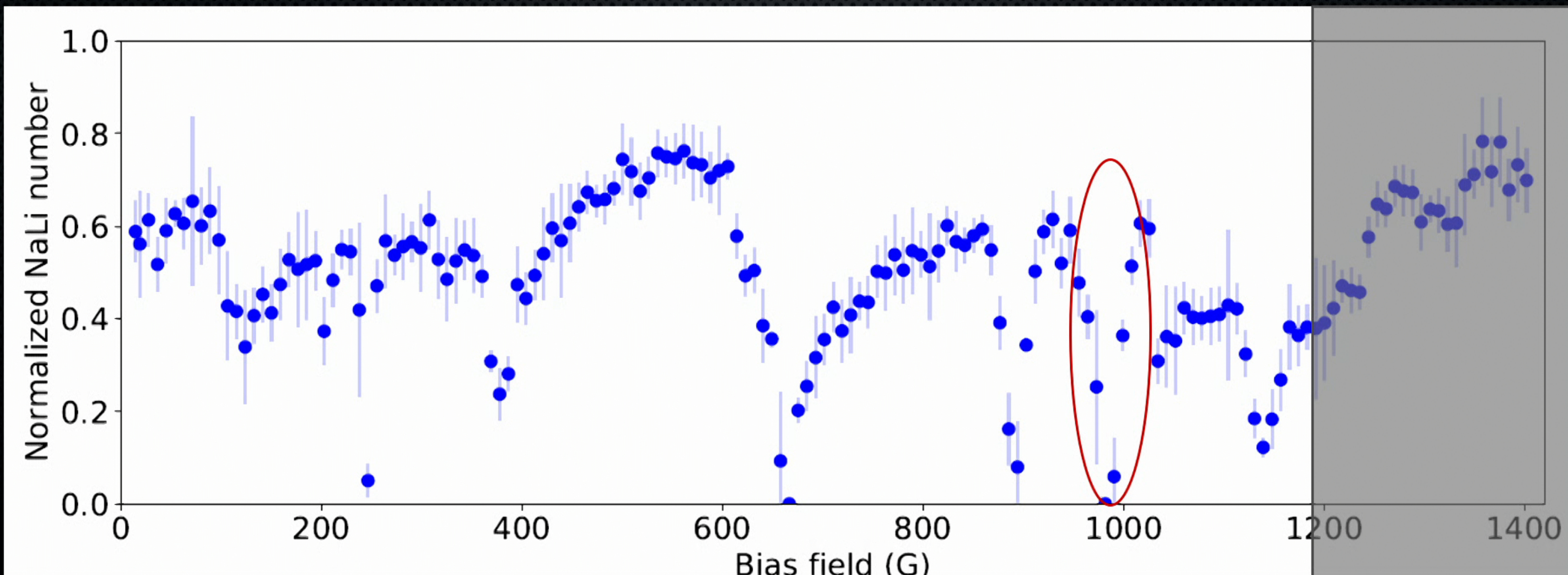
- NaLi + Na resonances



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

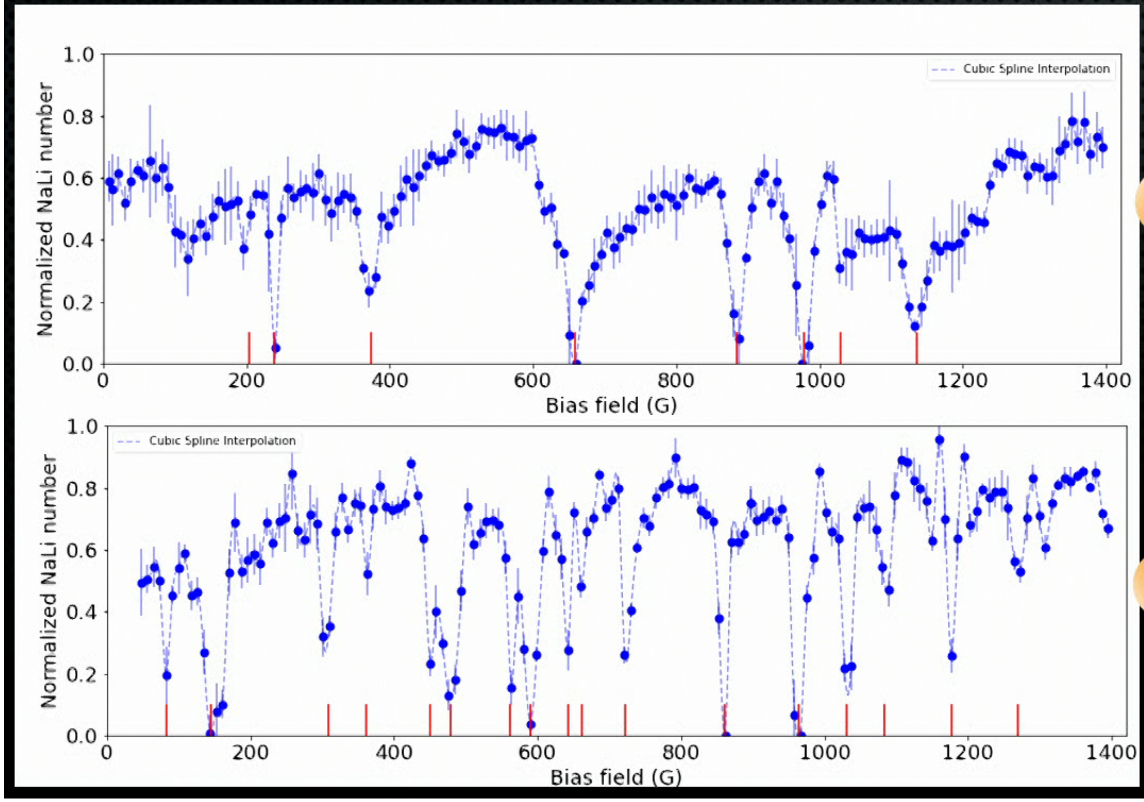
Chemical Resonances

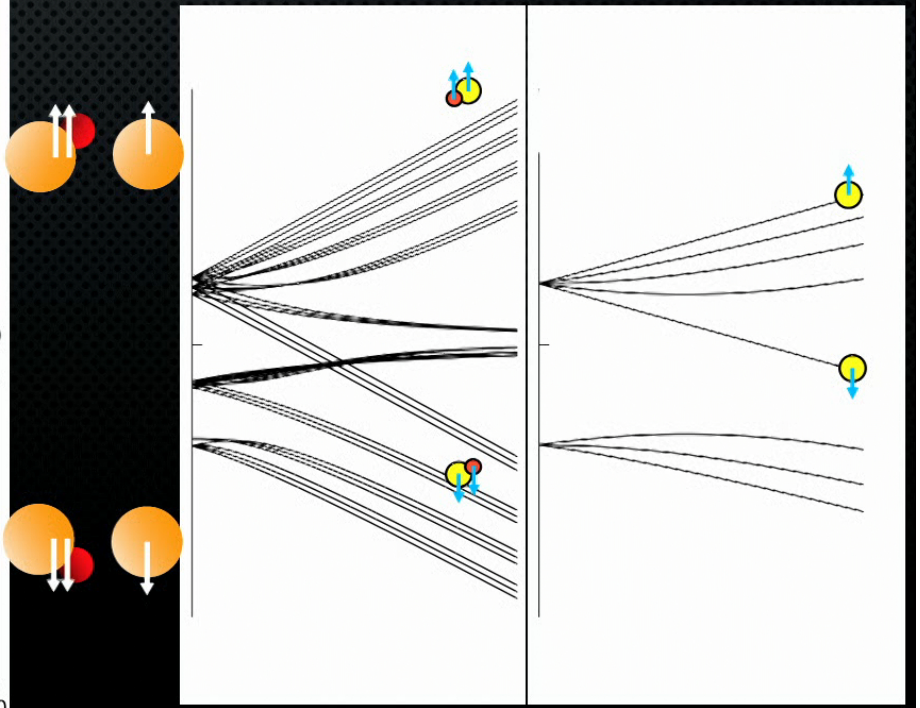
- NaLi + Na resonances



CHEMICAL RESONANCES

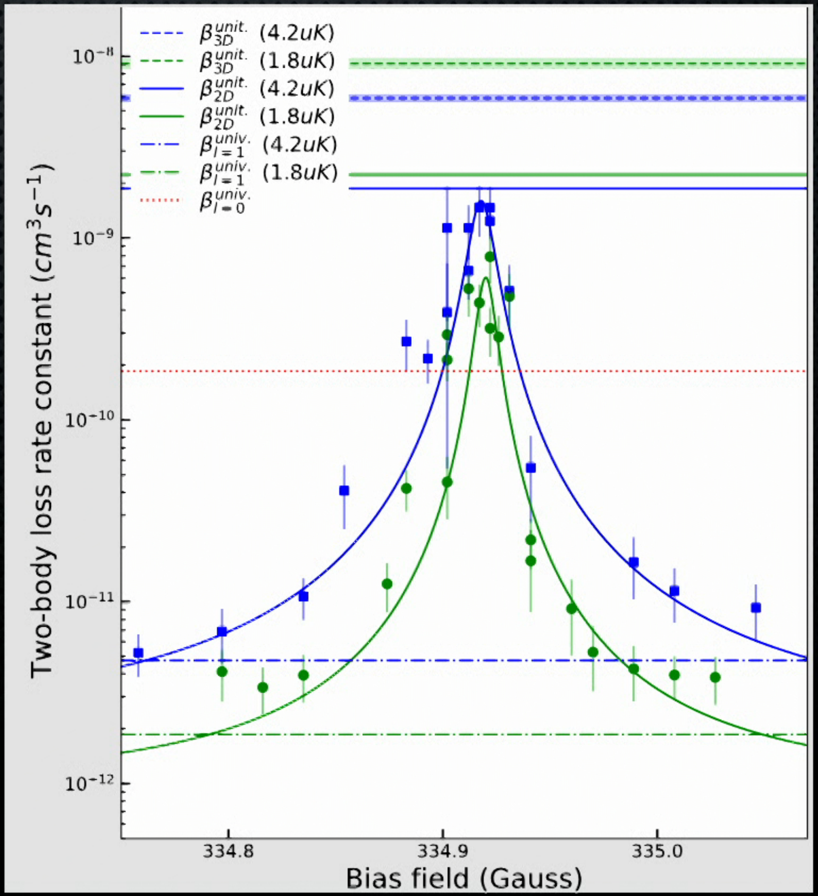
- NaLi + Na resonances





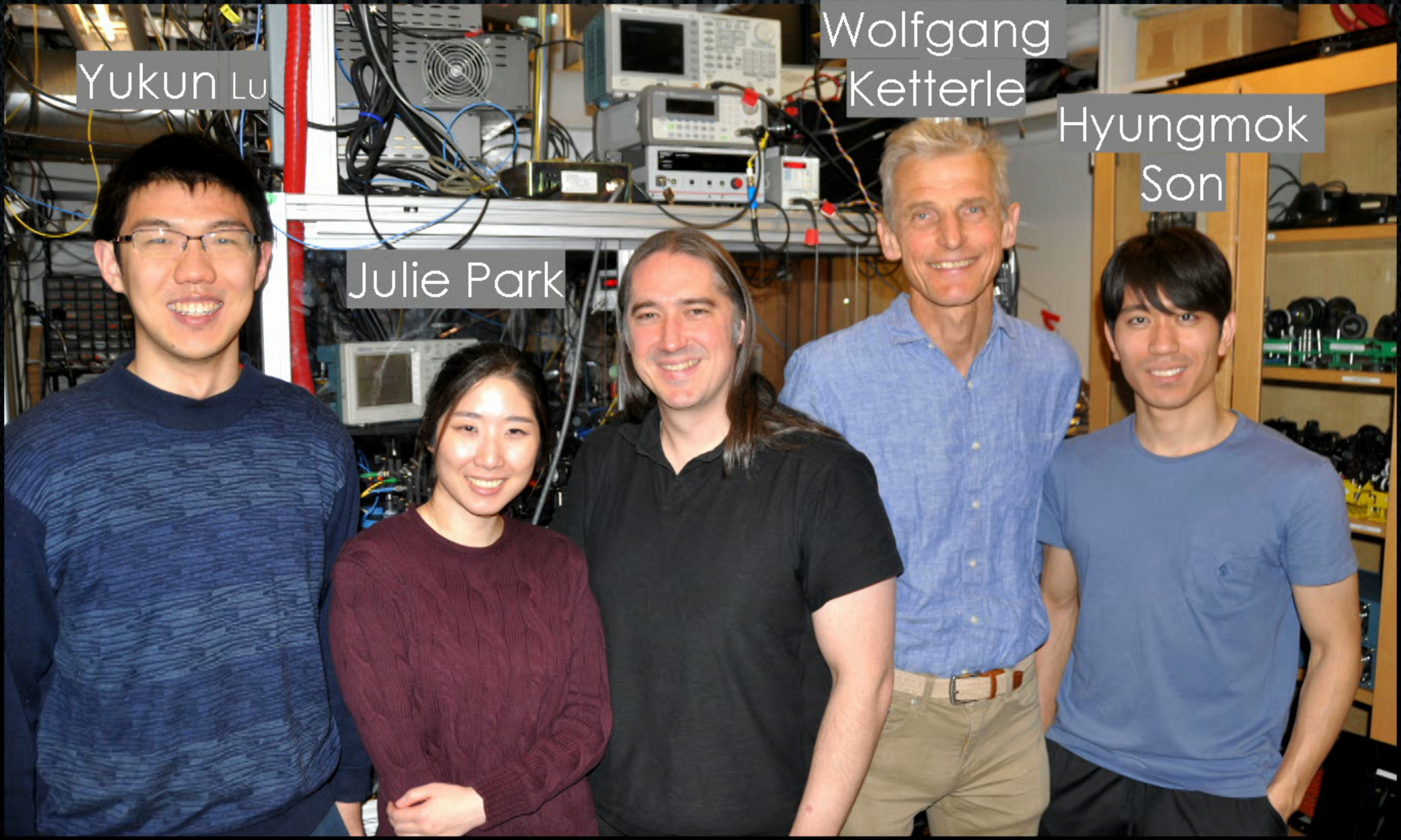
CHEMICAL RESONANCES

- NALI + NALI RESONANCE!



On the arXiv soon!

THE TEAM



QUANTUM @ WATERLOO

- BUILDING QUANTUM SIMULATOR WITH ULTRACOLD MIXTURES AND MOLECULES
- LOOKING FOR POST DOCS AND STUDENTS (MSC AND PHD)!