Title: Quantum Chemistry in the Universe’s Coldest Test Tube

Speakers: Alan Jamison

Collection/Series: Public Lecture Series

Date: May 21, 2025 - 7:00 PM

URL: https://pirsa.org/25050015

Abstract:

Abstract

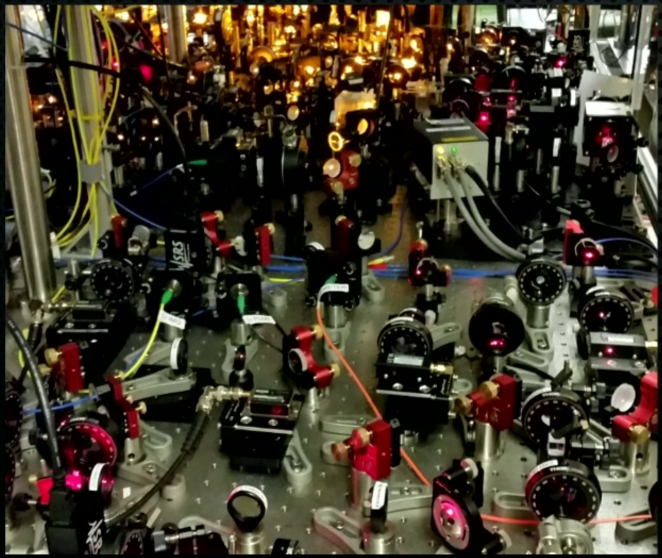
How do chemical reactions change when they’re run at temperatures a billion times colder than a Canadian winter? What can we learn when we have perfect quantum control of the reactants? Before answering these questions, we’ll discuss the fascinating techniques of laser cooling that allow us to cool atoms and molecules to within a few billionths of a degree above absolute zero. We’ll then look at how molecules prepared at such temperatures allow us to control chemical reactions at the quantum level, beginning to open a new understanding of chemistry and new possibilities for technologies of the future.

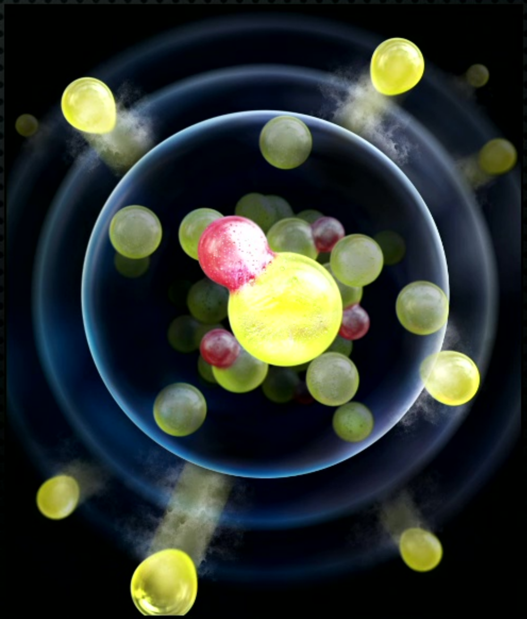
About the Speaker

Dr. Alan Jamison is an Assistant Professor at the University of Waterloo, jointly appointed to the Department of Physics and Astronomy and the Institute for Quantum Computing (IQC). He leads the Jamison Lab, which investigates ultracold atoms and molecules to explore quantum many-body physics, quantum chemistry, and quantum information science. Dr. Jamison earned his B.S. in Mathematics from the University of Central Florida in 2007, followed by an M.S. and Ph.D. in Physics from the University of Washington in 2008 and 2014, respectively.

After completing his Ph.D., he joined the group of Nobel Laureate Wolfgang Ketterle at the Massachusetts Institute of Technology (MIT) as a postdoctoral researcher. At the University of Waterloo, Dr. Jamison's research centers on using ultracold atoms and molecules to investigate complex quantum systems. His lab aims to achieve precise control over chemical reactions at ultracold temperatures, providing insights into quantum chemistry and enabling advancements in quantum computing and simulation.

QUANTUM CHEMISTRY IN THE UNIVERSE'S COLDEST TEST TUBE





ALAN JAMISON

INSTITUTE FOR QUANTUM COMPUTING AND PHYSICS & ASTRONOMY DEPARTMENT

UNIVERSITY OF WATERLOO

10,000,000x

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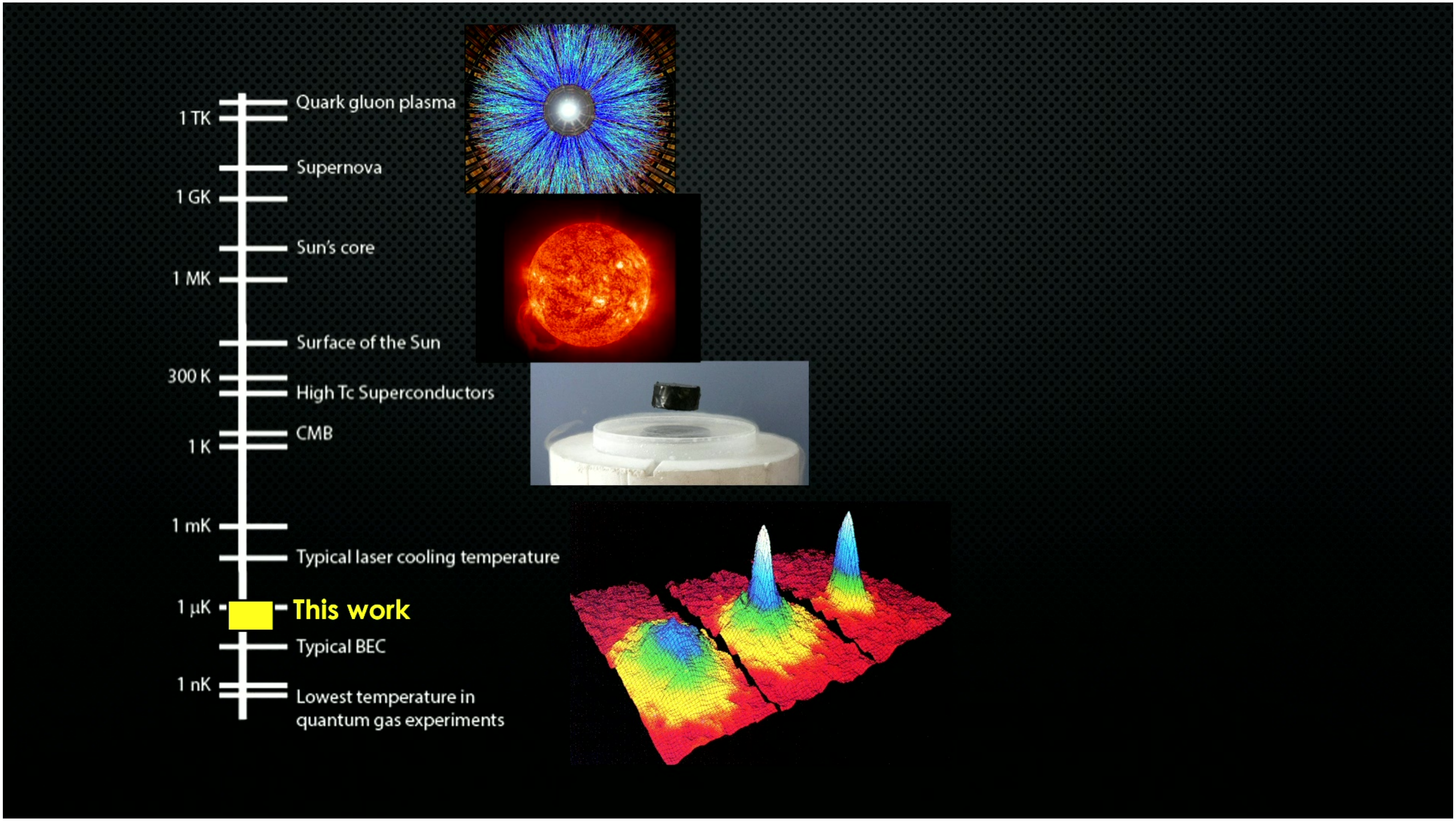


Quark gluon plasma
1 TK
Supernova
1 GK
Sun's core
1 MK
Surface of the Sun
300 K
High Tc Superconductors
CMB
1 K
1 mK
Typical laser cooling temperature
1 μK
This work
Typical BEC
1 nK
Lowest temperature in
quantum gas experiments

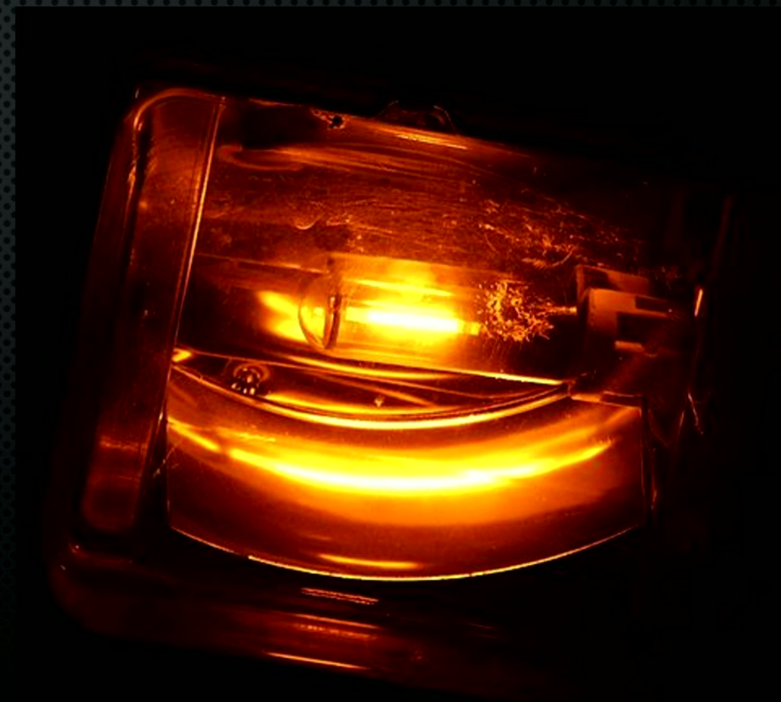
COLD ATOMS WITH HOT LASERS

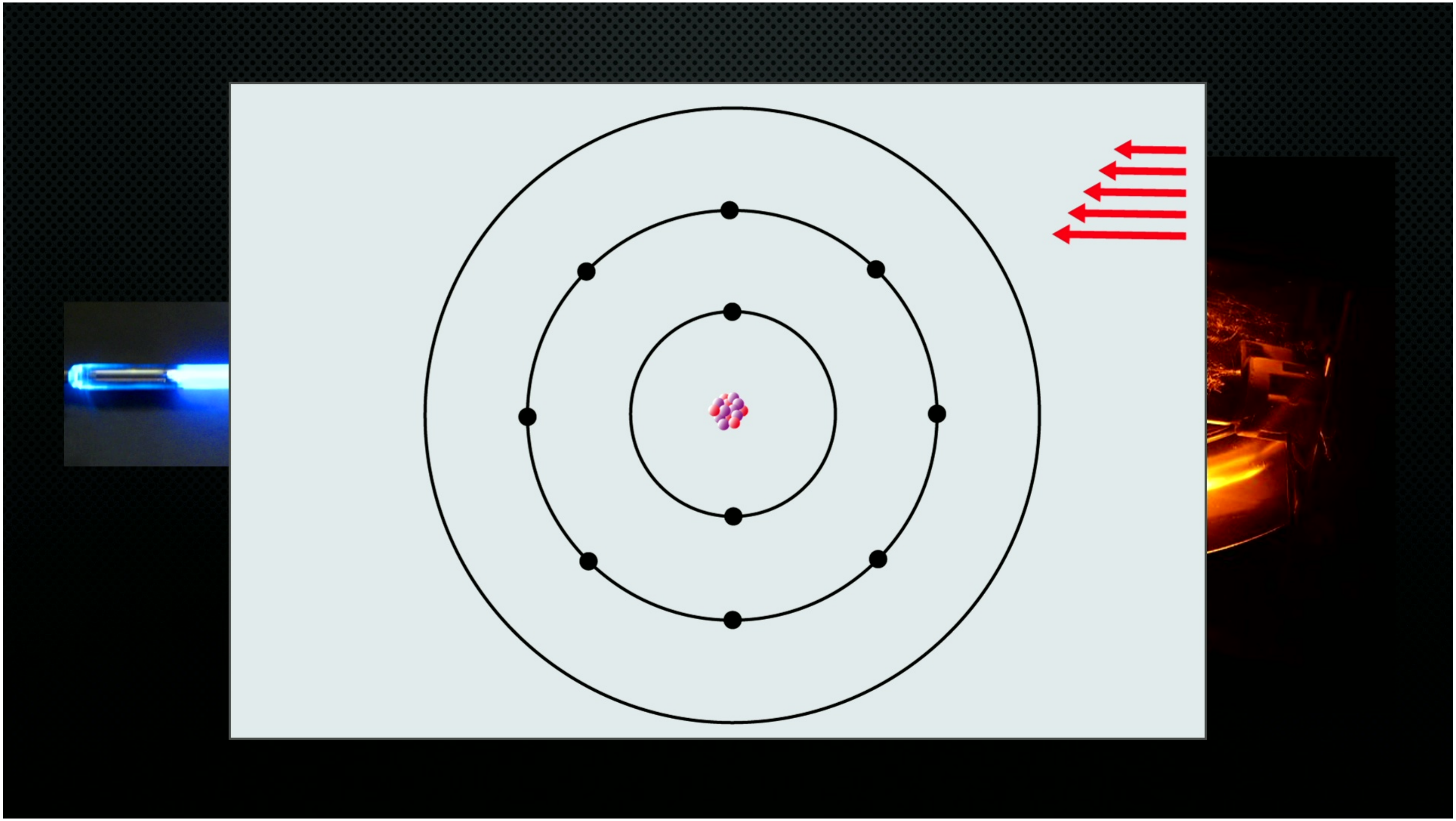
From IPG Photonics

COOLING TO NANOKELVINS: THREE BIG IDEAS

1. Resonance

Resonances





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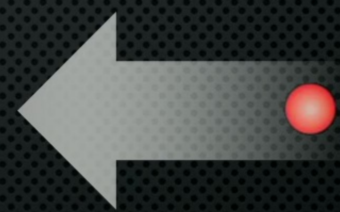
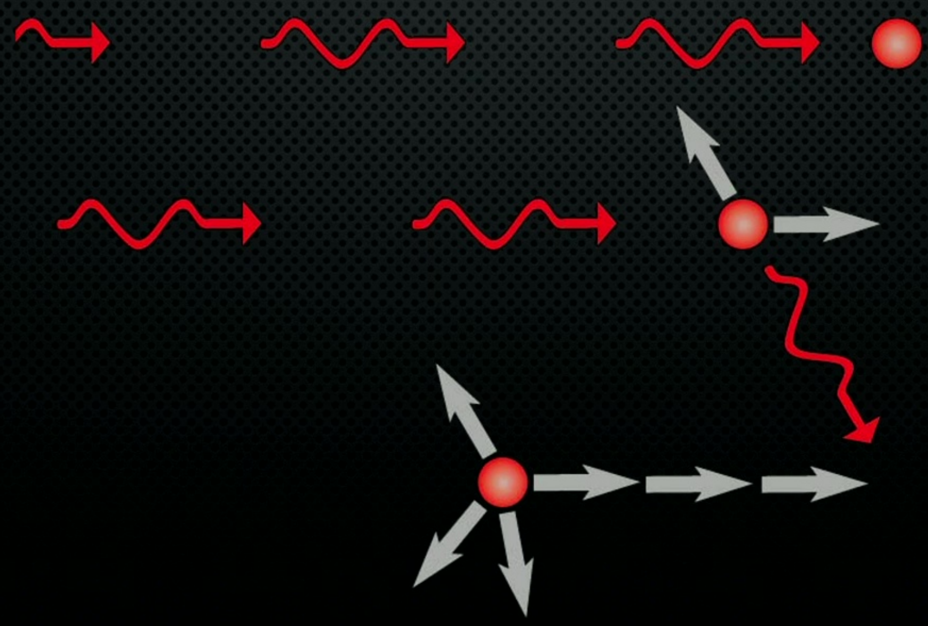


SLOWING WITH LIGHT

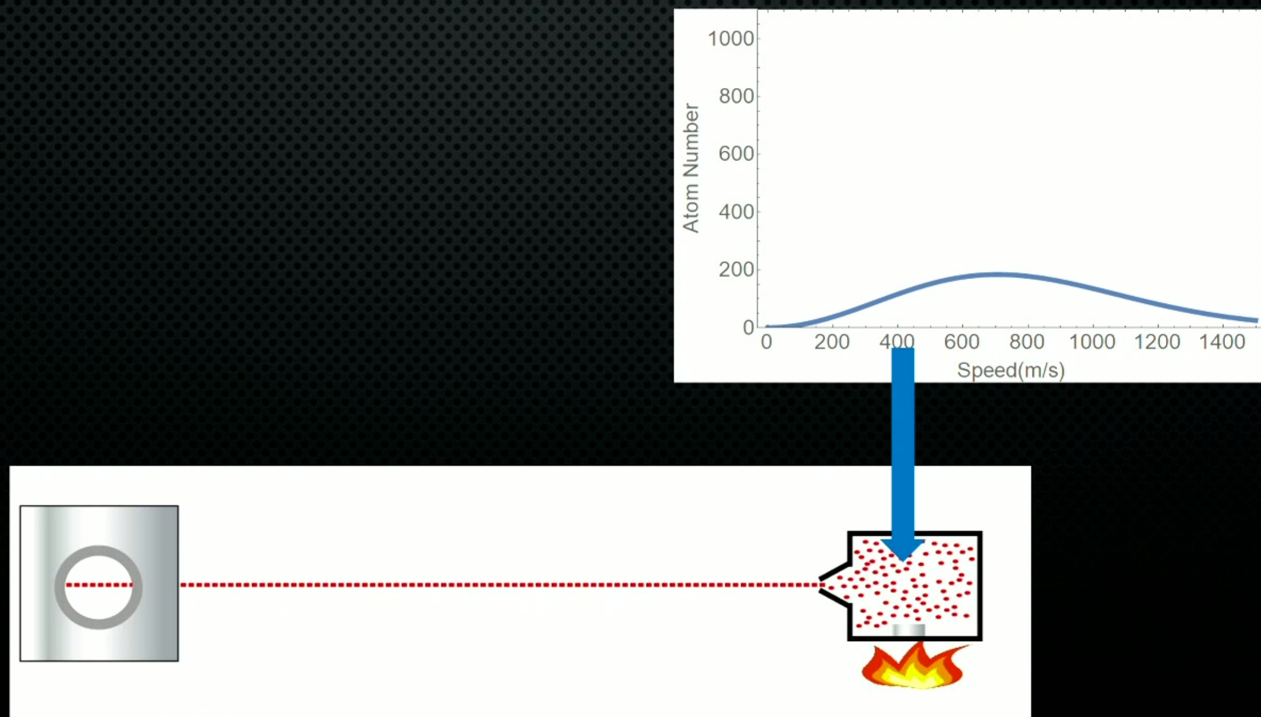


COOLING TO NANOKELVINS: THREE BIG IDEAS

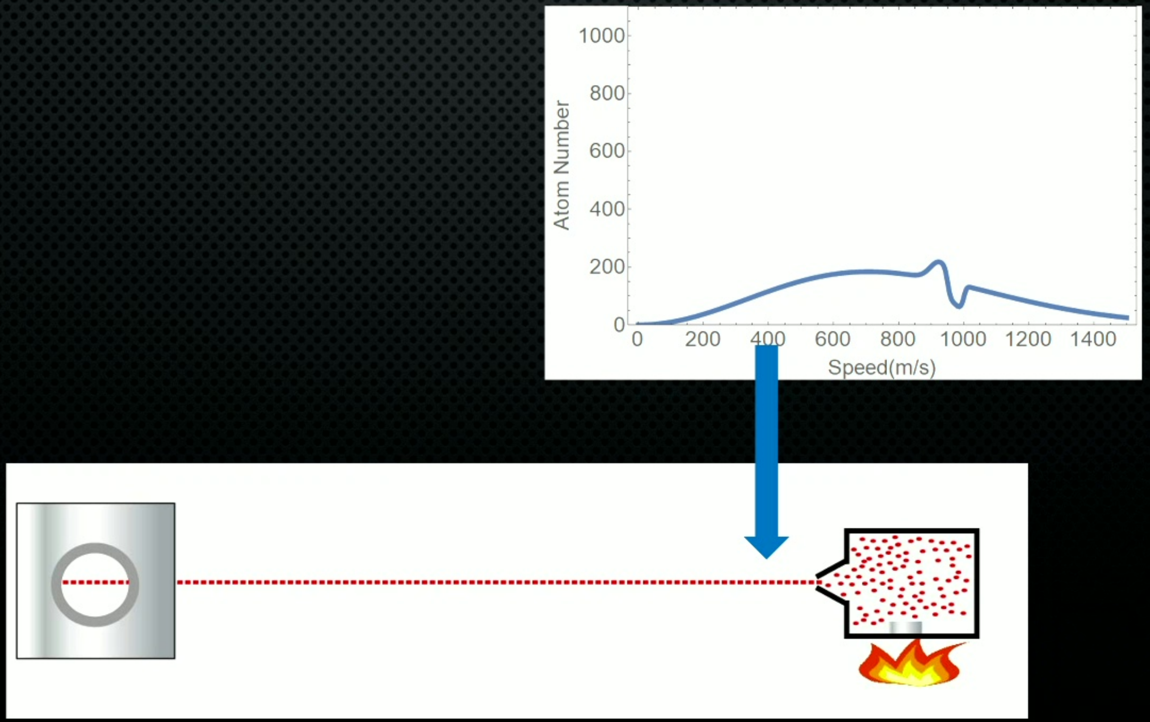
1. Resonance
2. Doppler vs Zeeman

DOPPLER SHIFTS

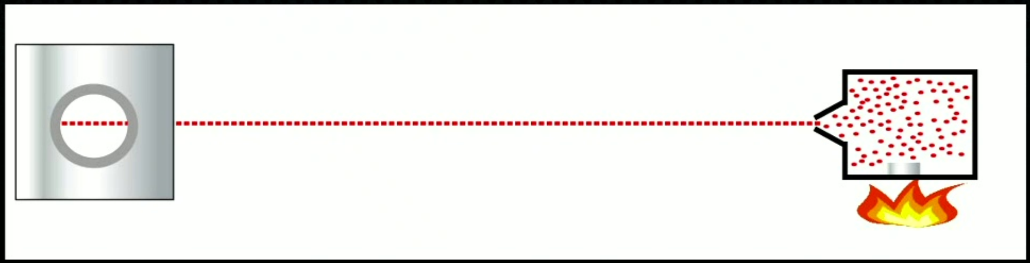
CONTROL WITH DOPPLER SHIFTS



CONTROL WITH DOPPLER SHIFTS



COMPENSATE WITH ZEEMAN SHIFTS



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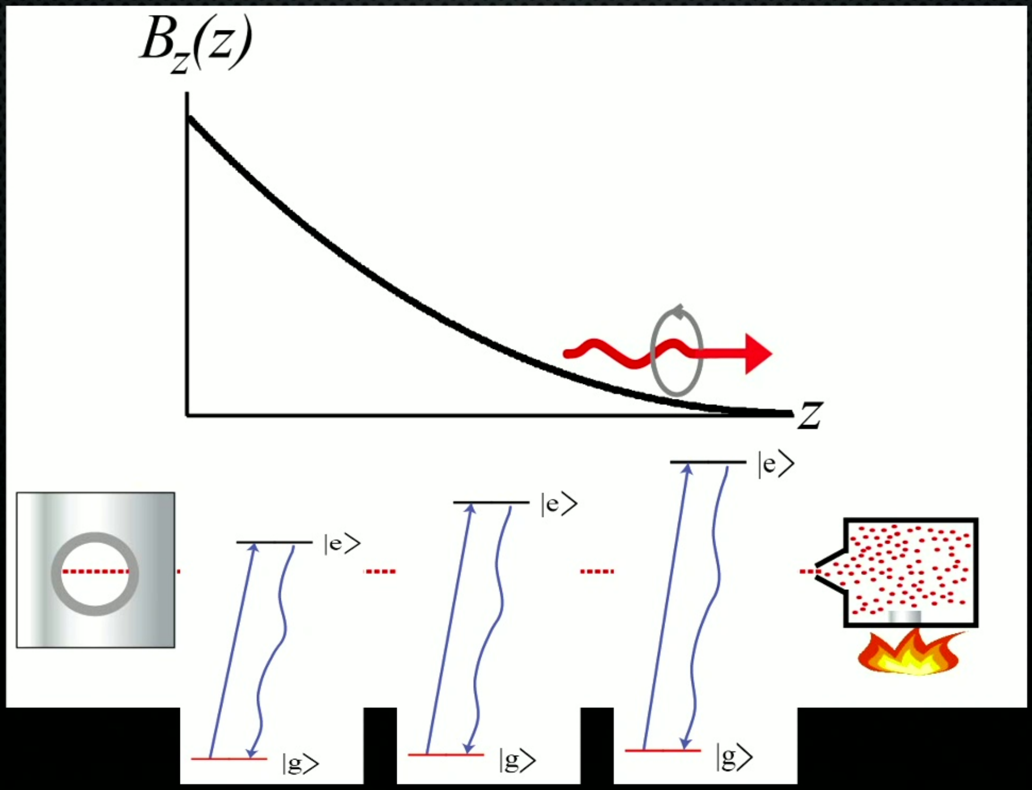

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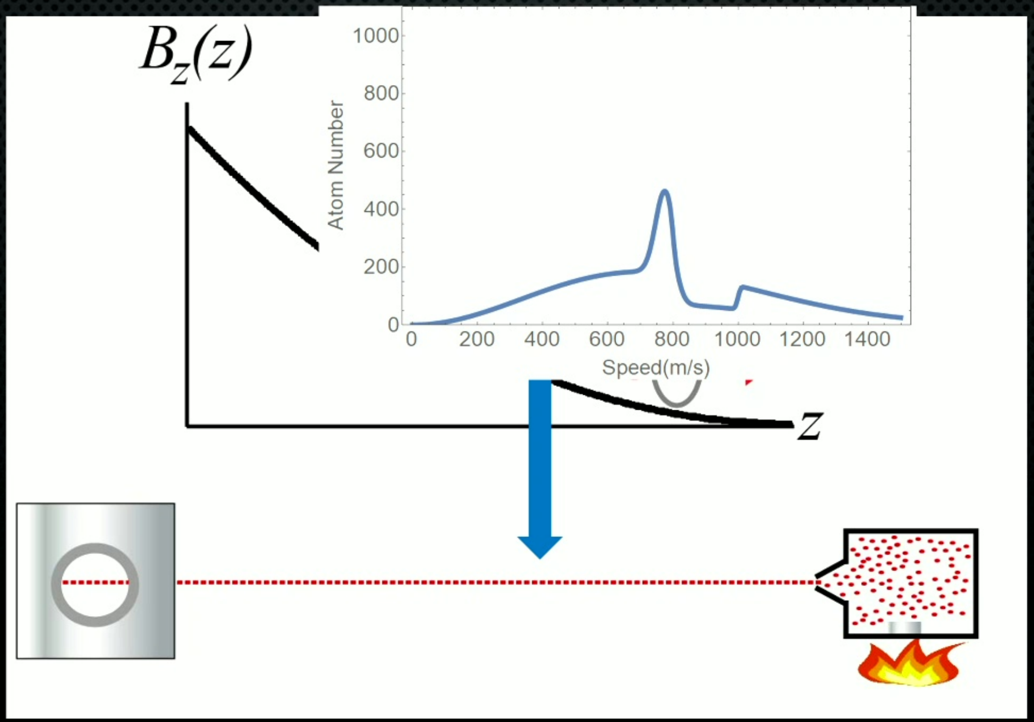

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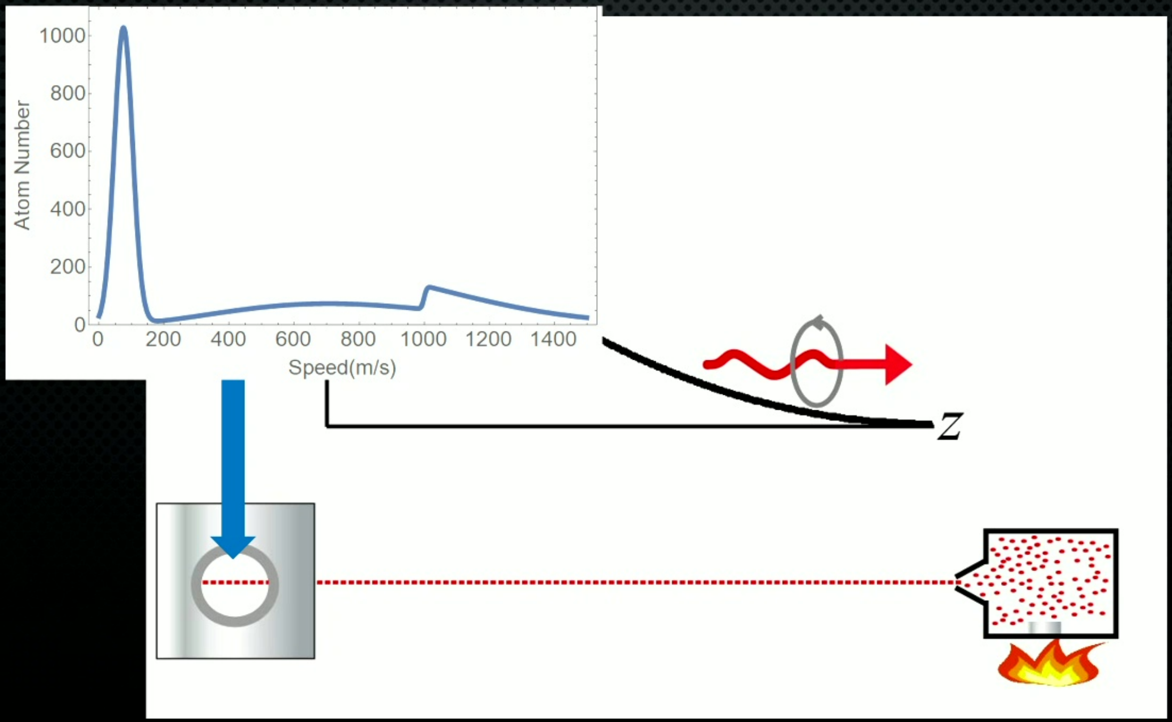

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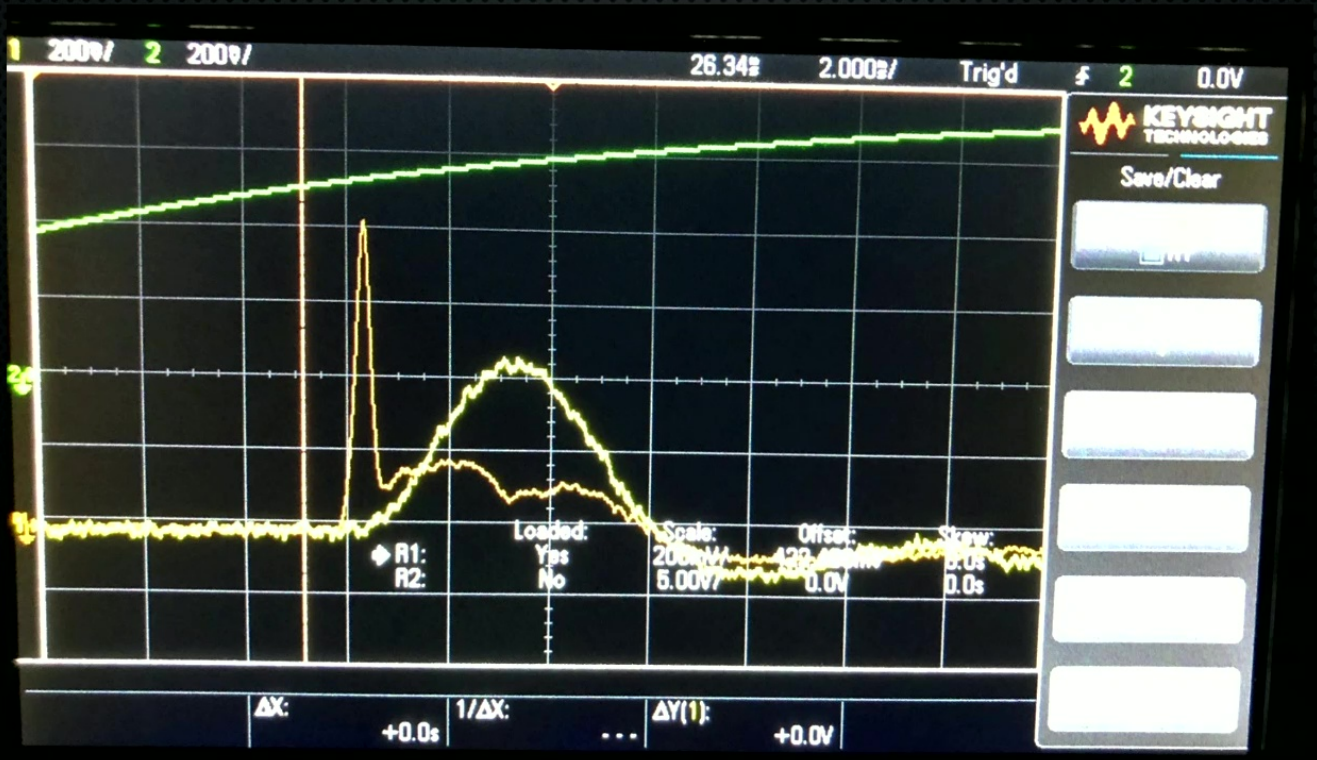

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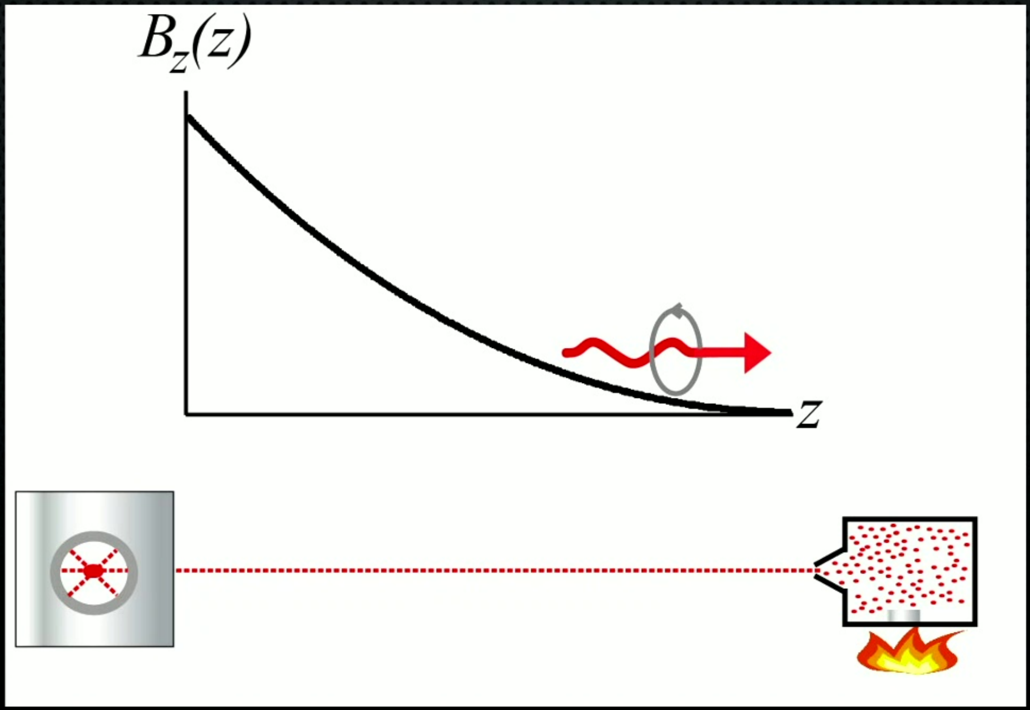
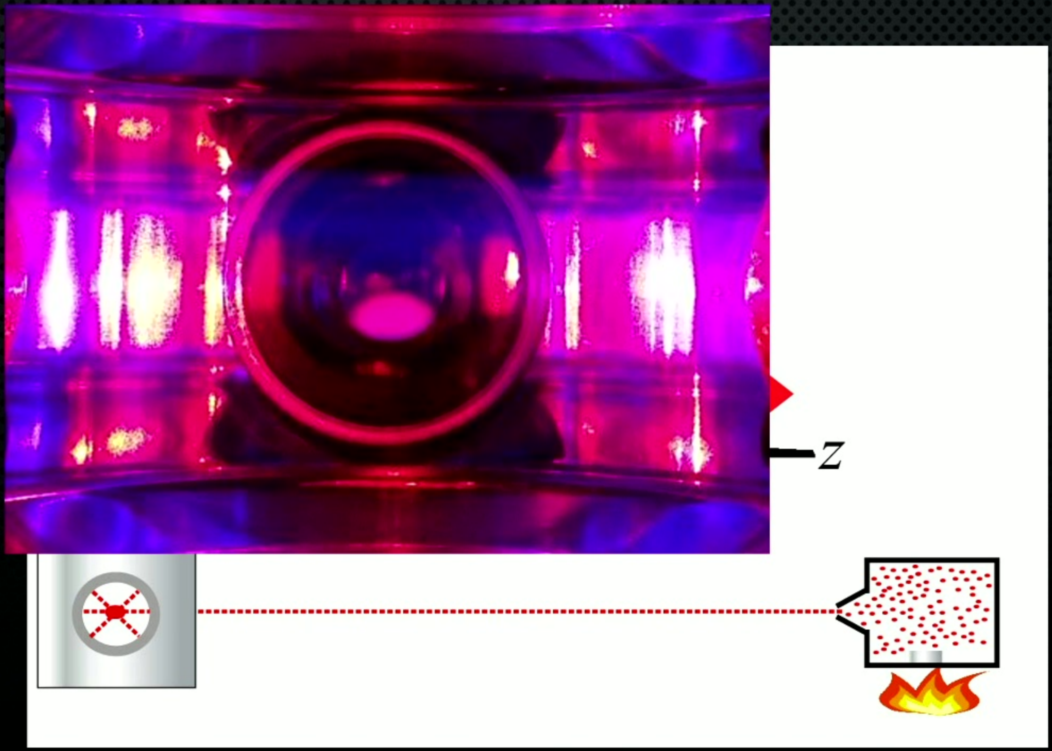


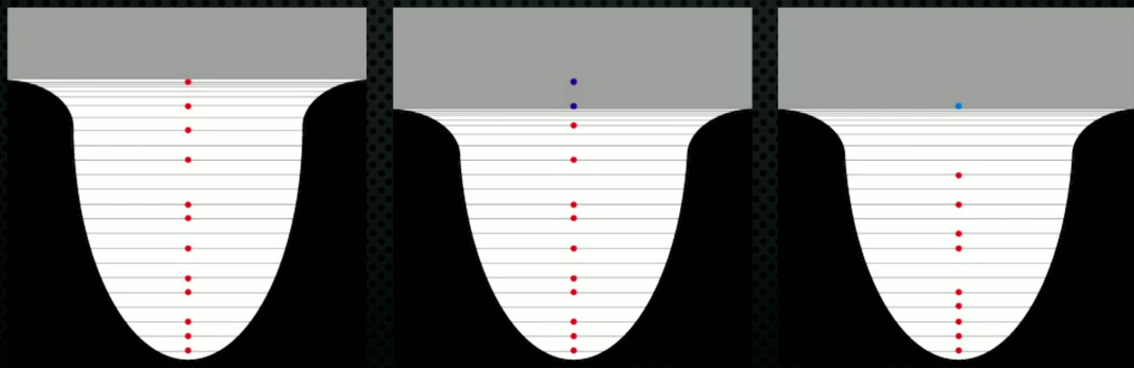
COMPENSATE WITH ZEEMAN SHIFTS



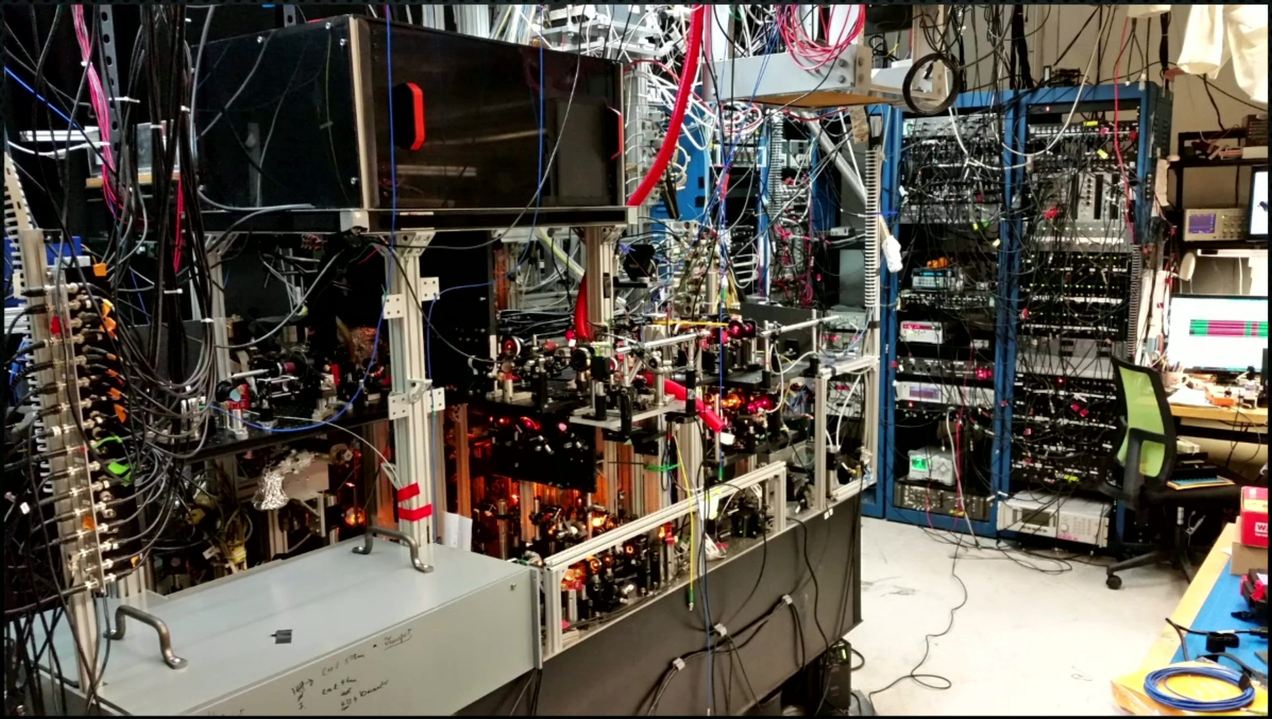
COOLING TO NANOKELVINS: THREE BIG IDEAS

1. Resonance
2. Doppler vs Zeeman
3. Let the hot atoms out

EVAPORATIVE COOLING



THEORY IN PRACTICE



COOLING TO NANOKELVINS: THREE BIG IDEAS

1. Resonance
2. Doppler vs Zeeman
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ON WITH THE CHEMISTRY!

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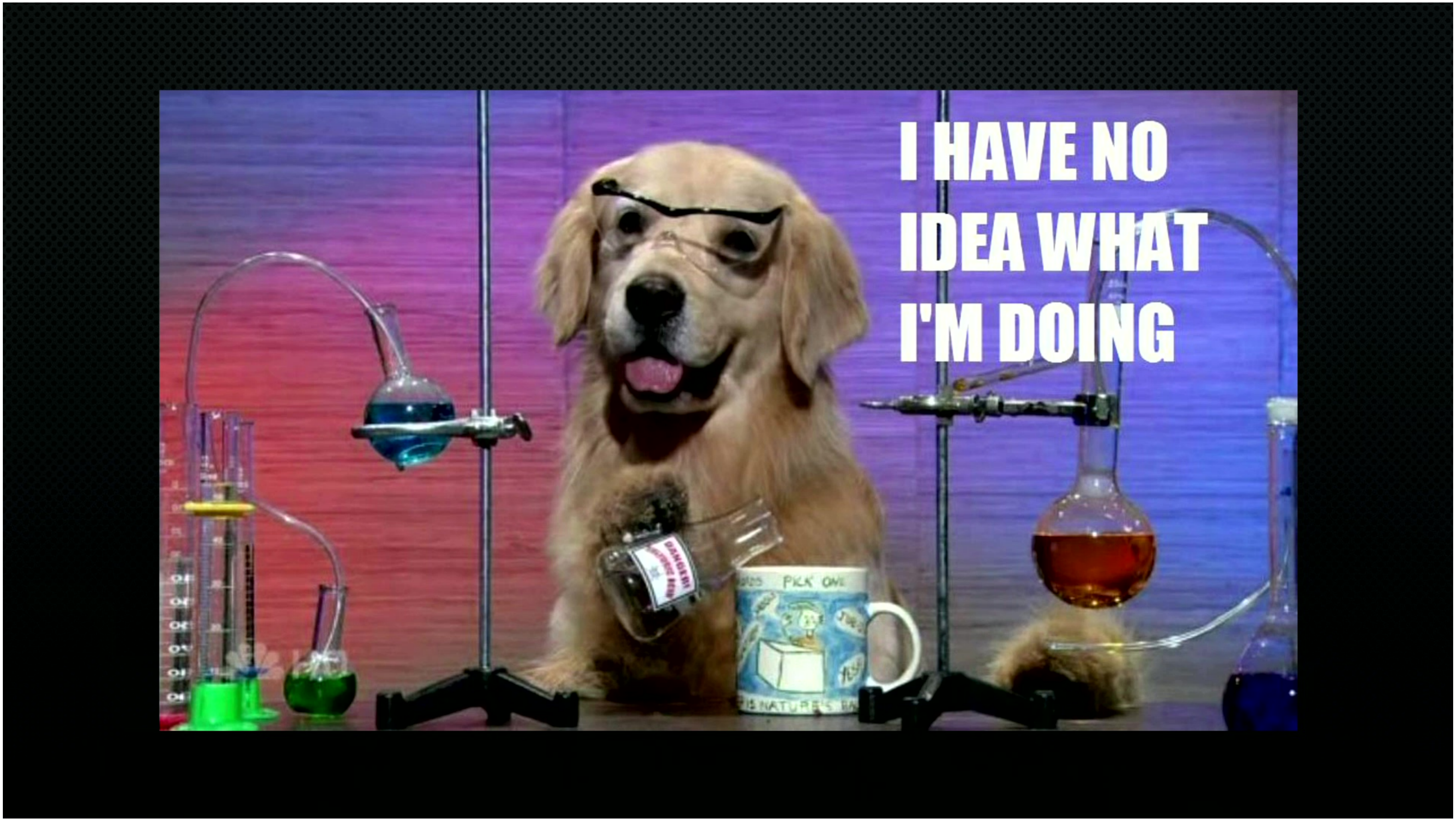
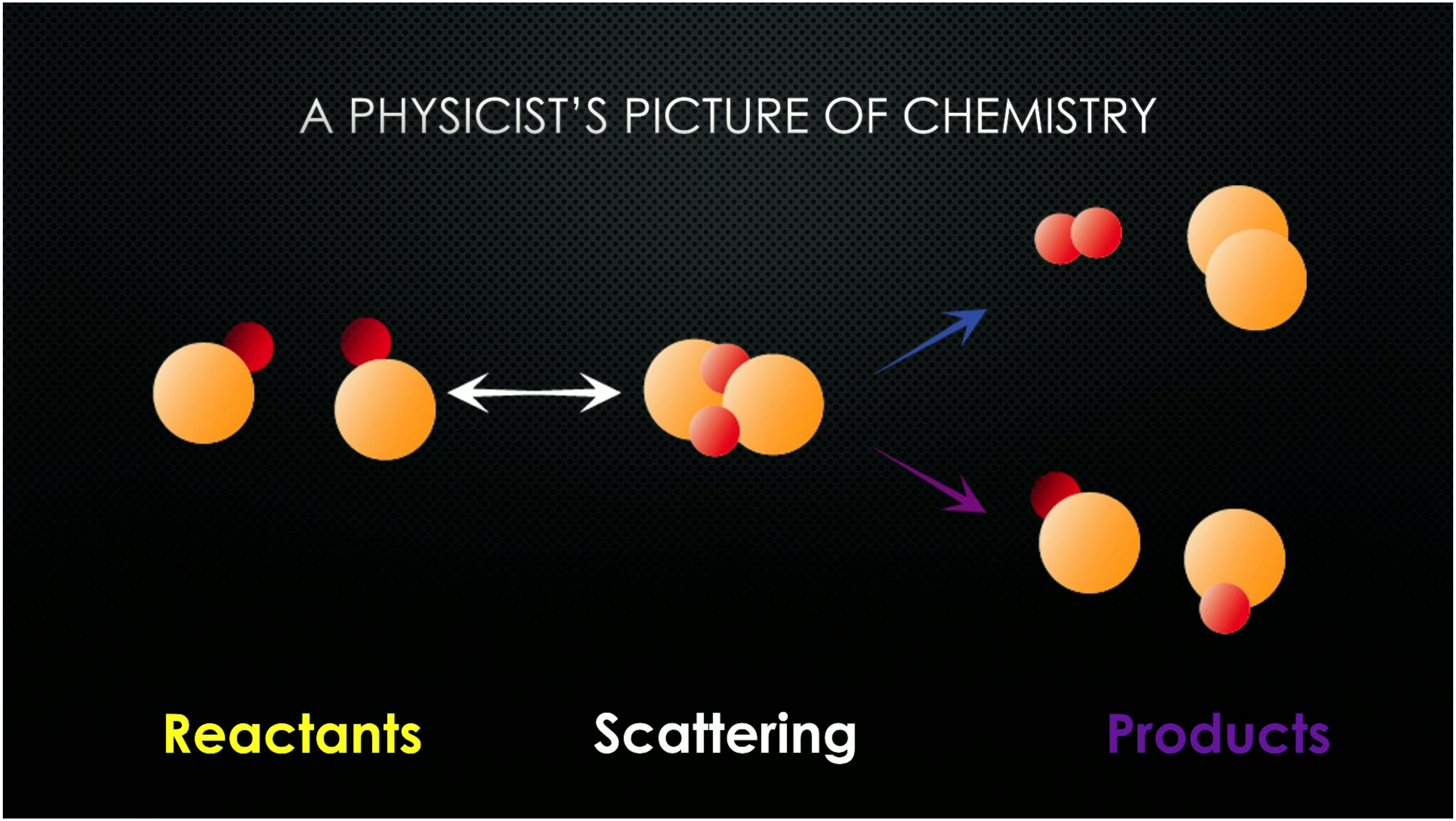
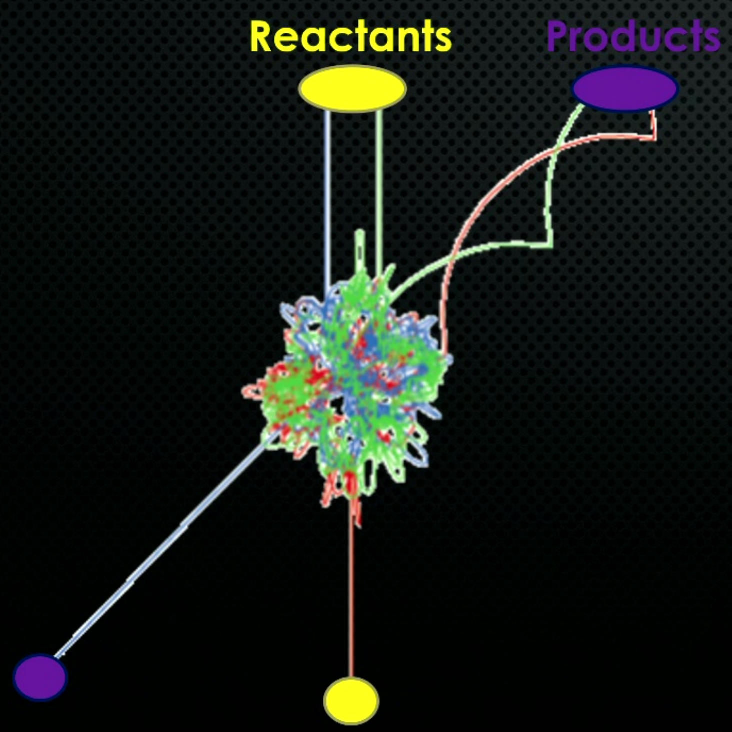

I HAVE NO
IDEA WHAT
I'M DOING


I HAVE NO
IDEA WHAT
I'M DOING

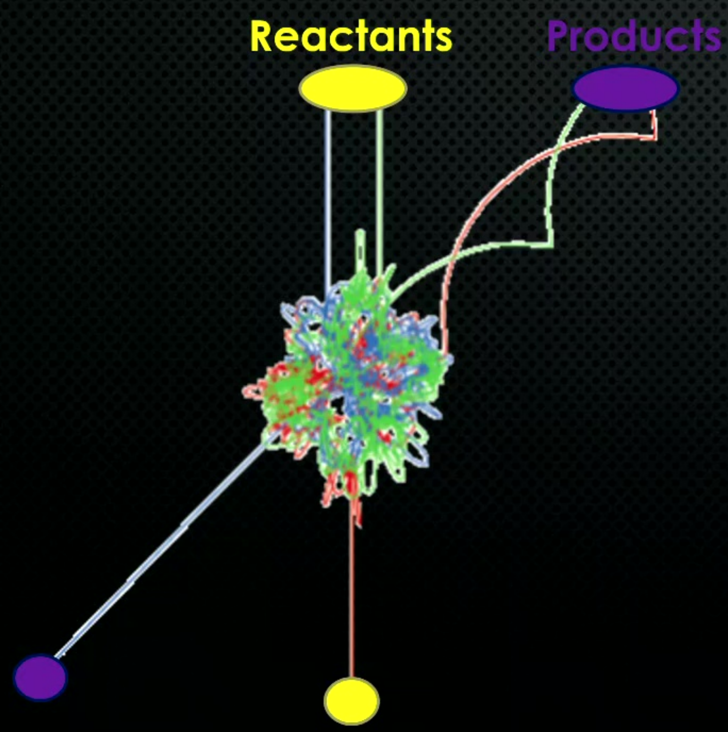

A PHYSICIST'S PICTURE OF CHEMISTRY
Reactants
Scattering
Products

SCATTERING

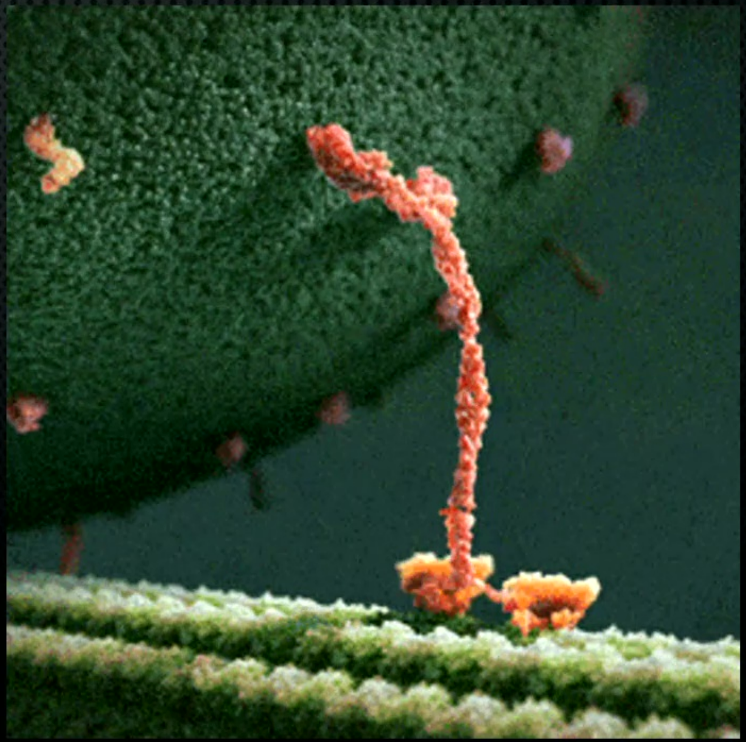
CHEMISTRY



SCATTERING



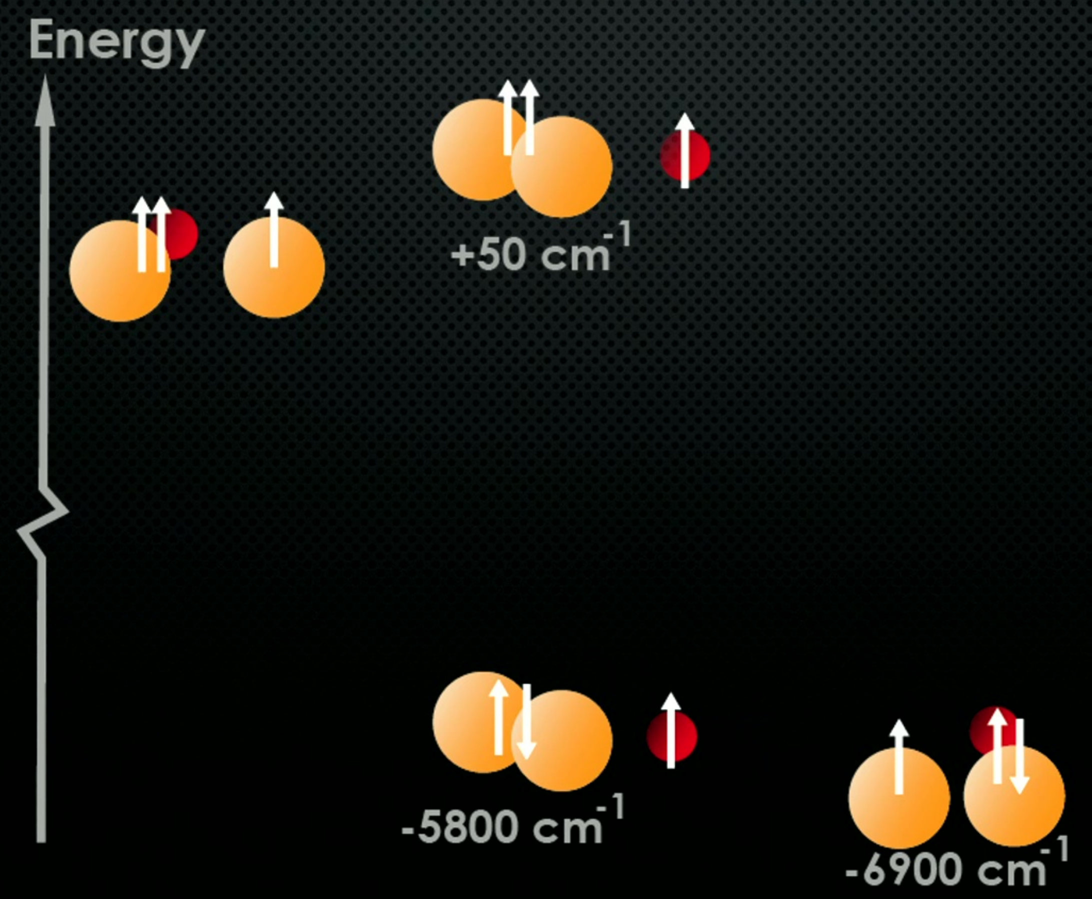
CHEMISTRY



THE THREE-BODY PROBLEM

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

ATOM-MOLECULE COLLISIONS



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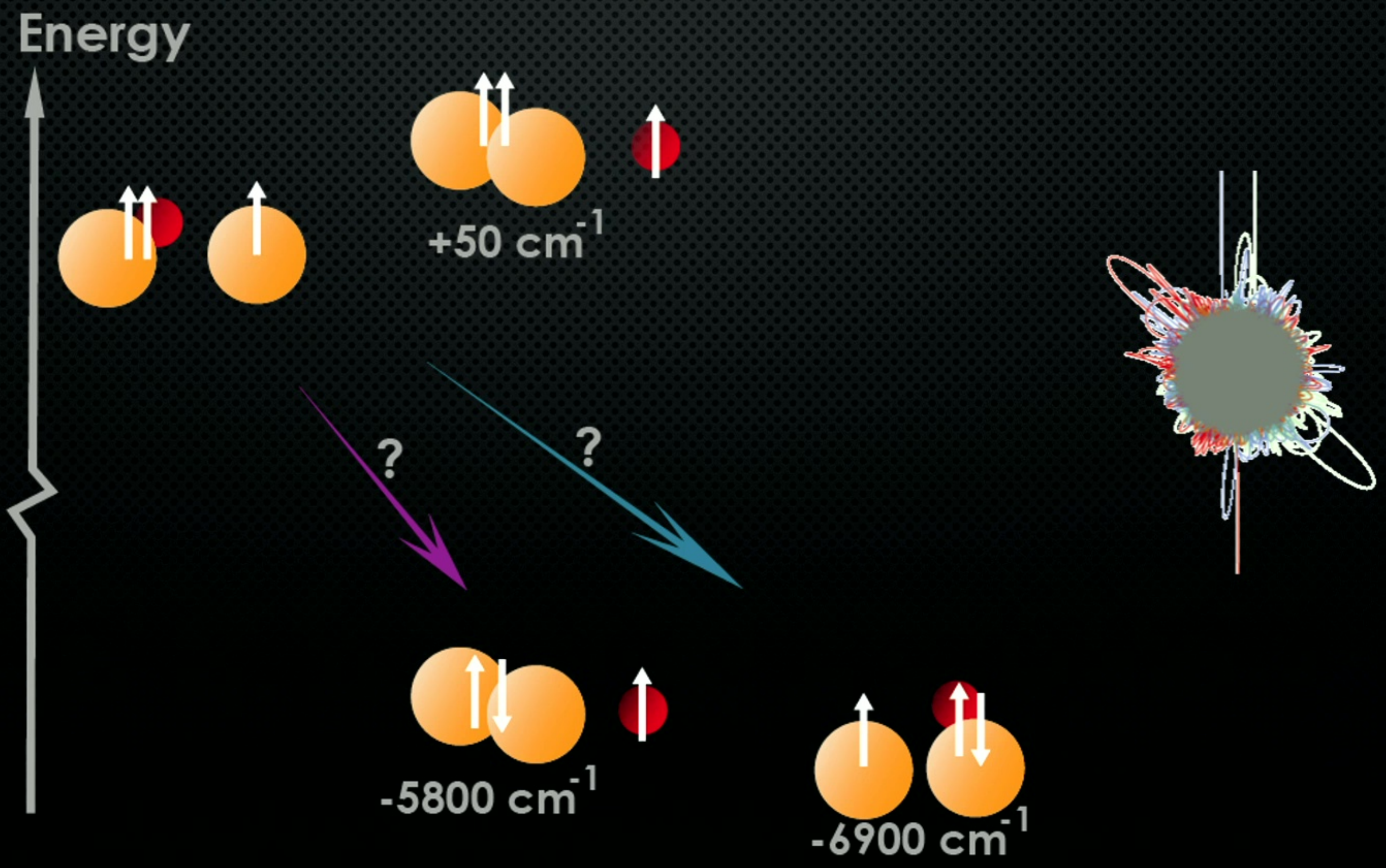
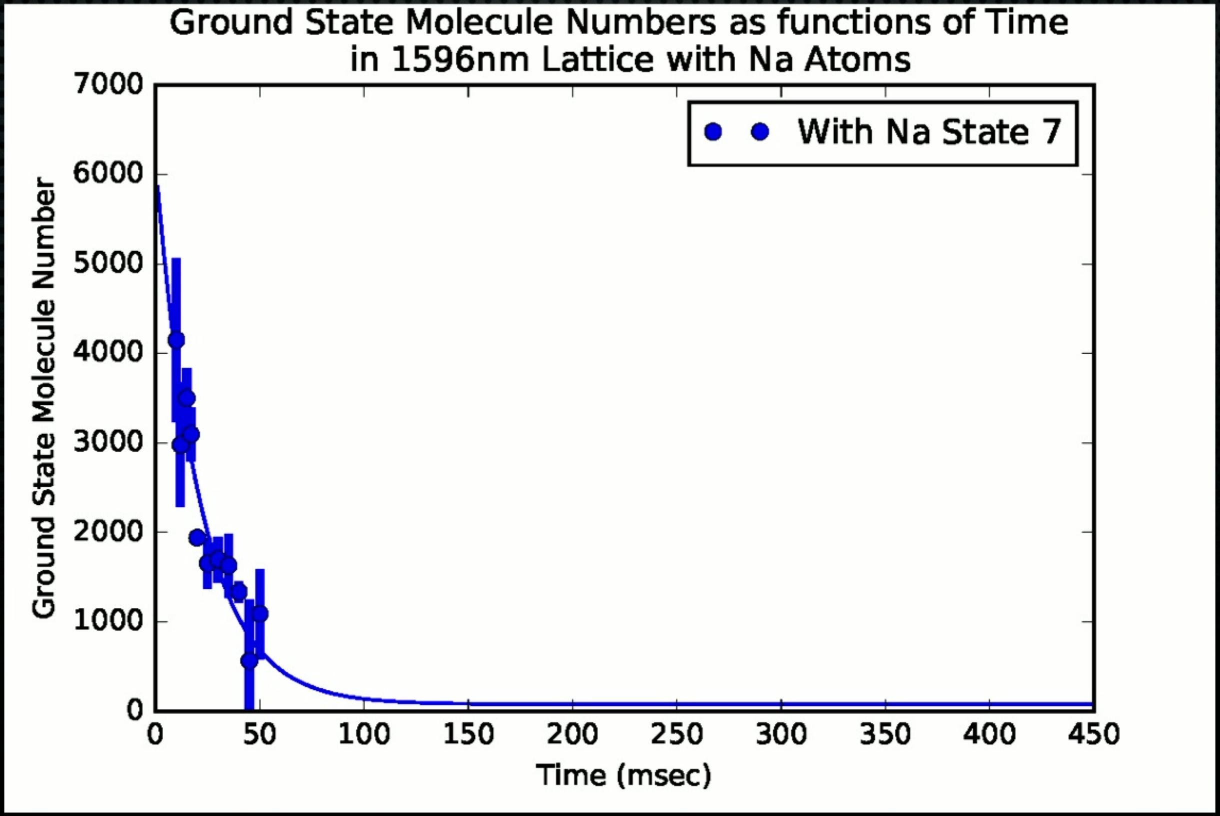


ATOM-MOLECULE COLLISIONS



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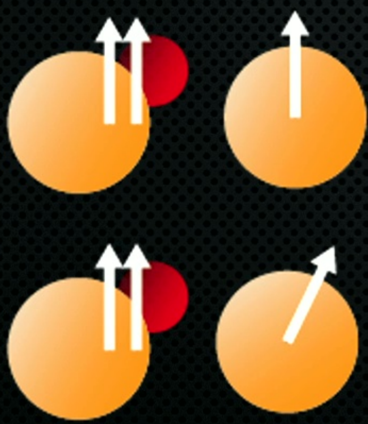

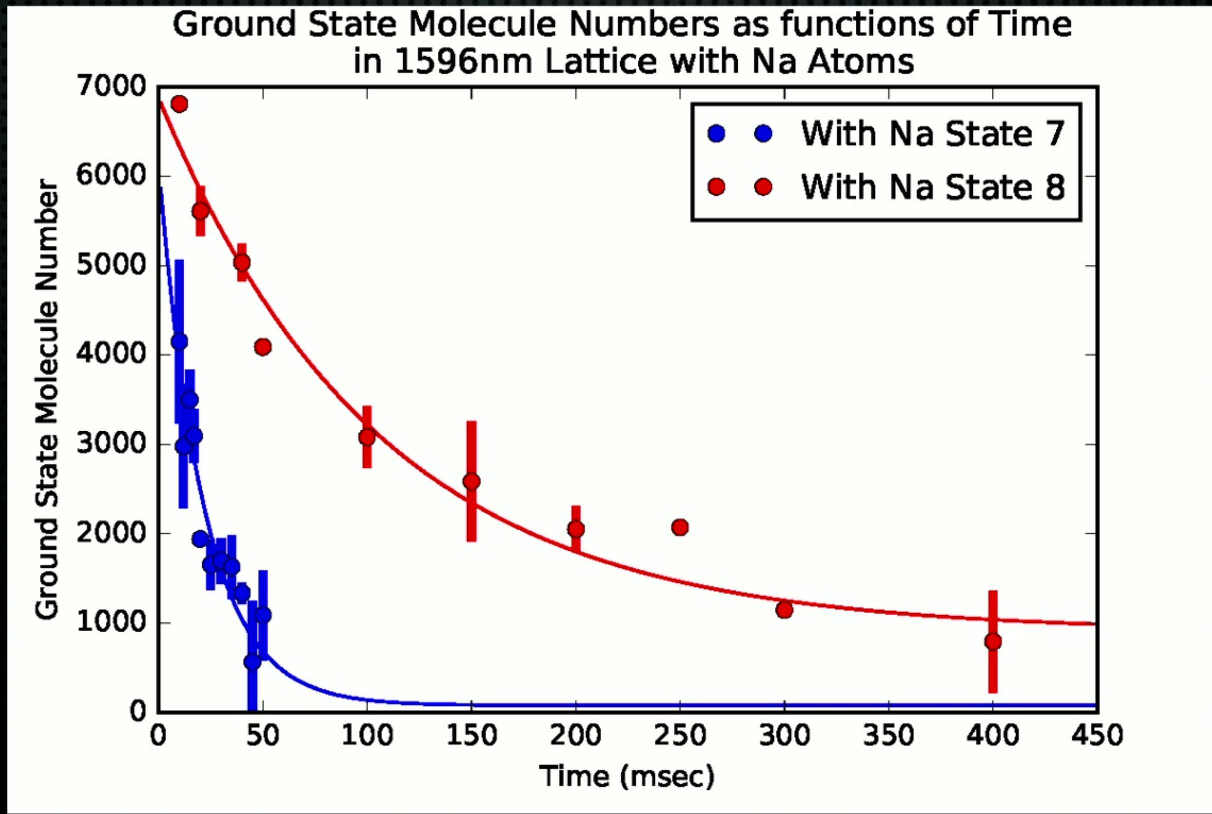

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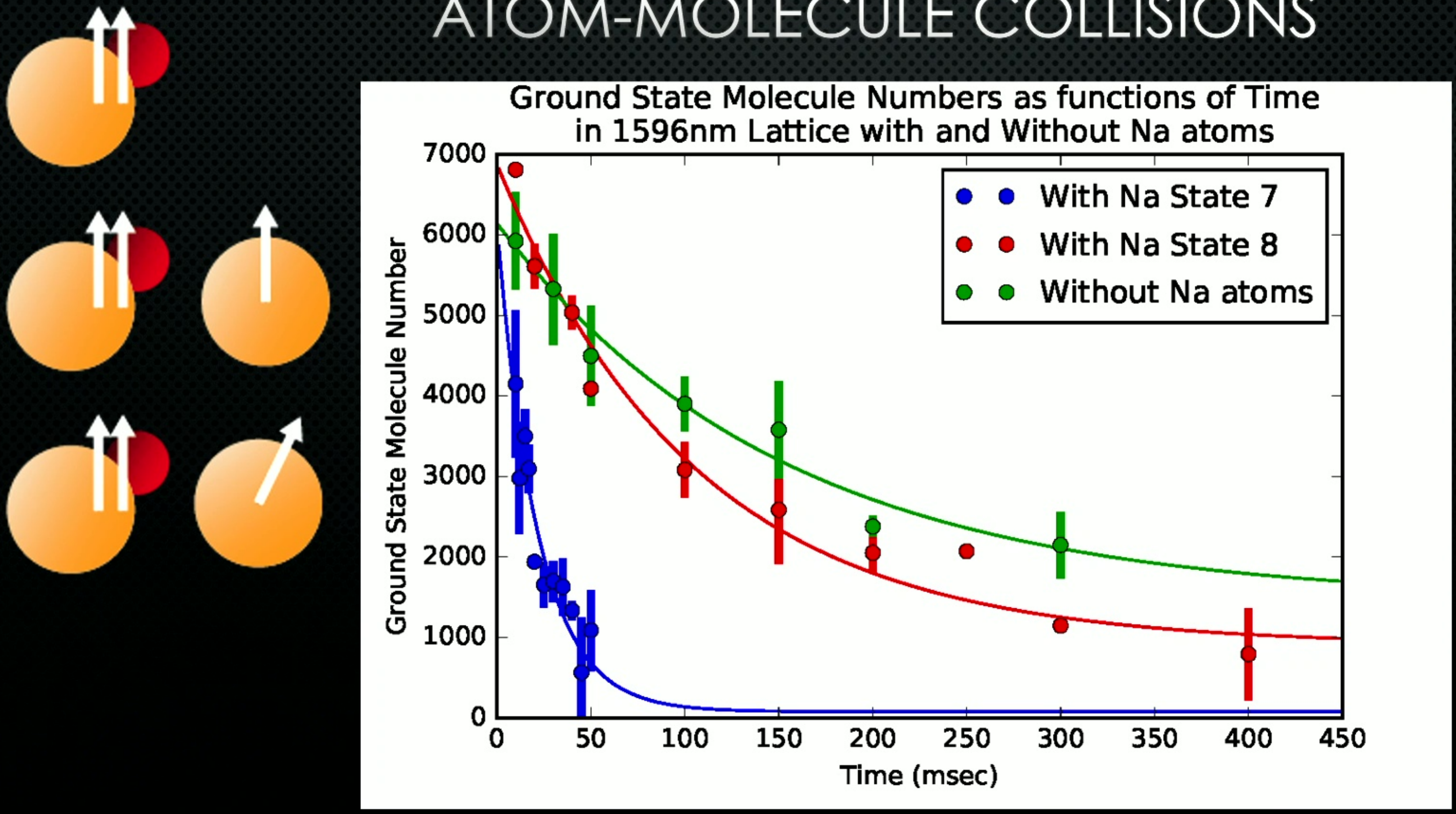

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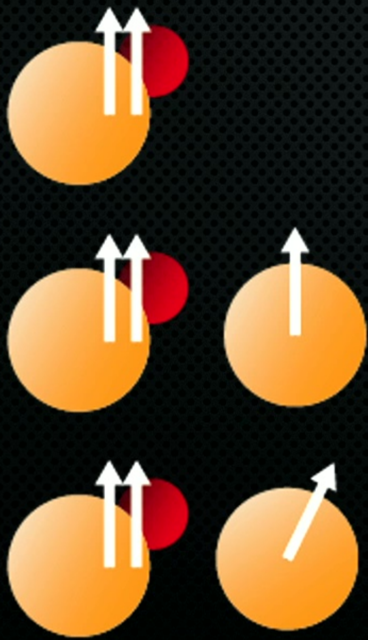
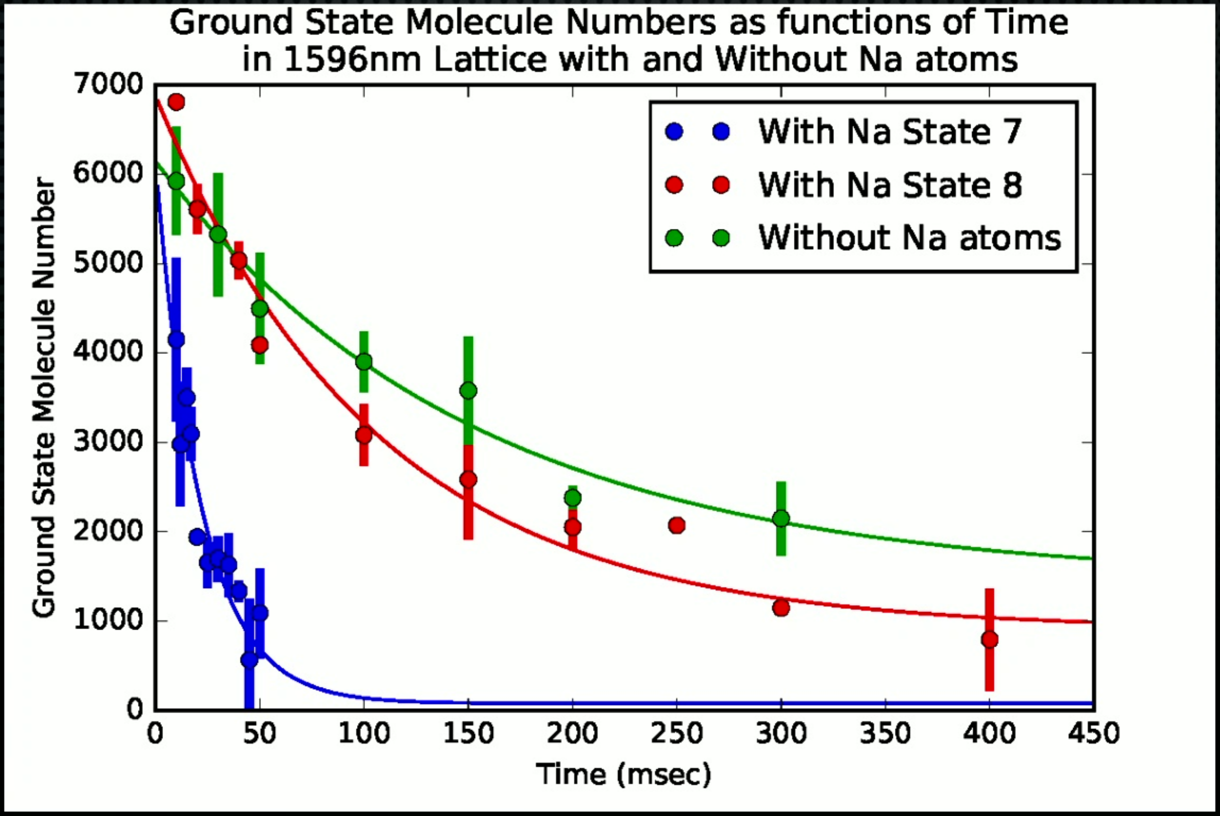
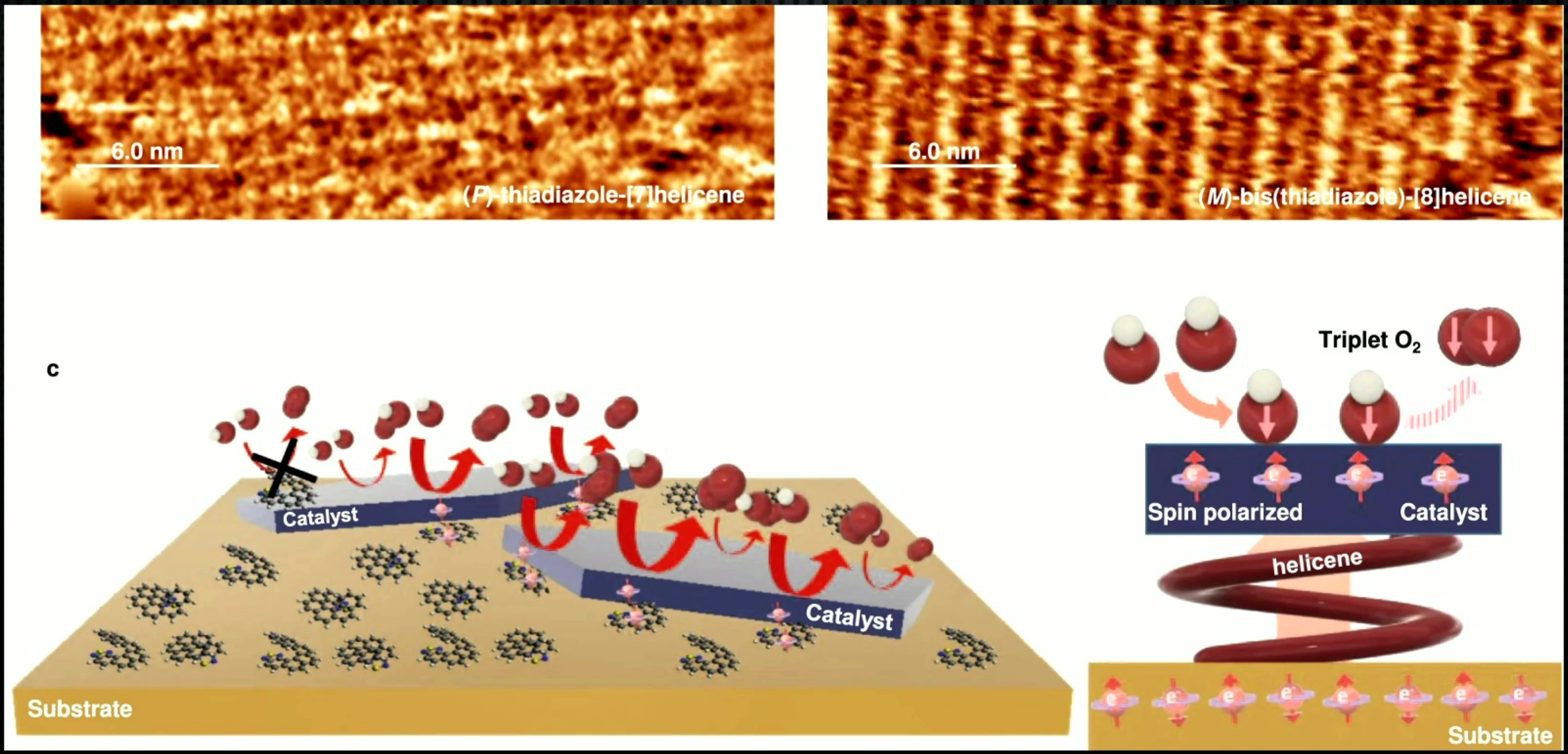




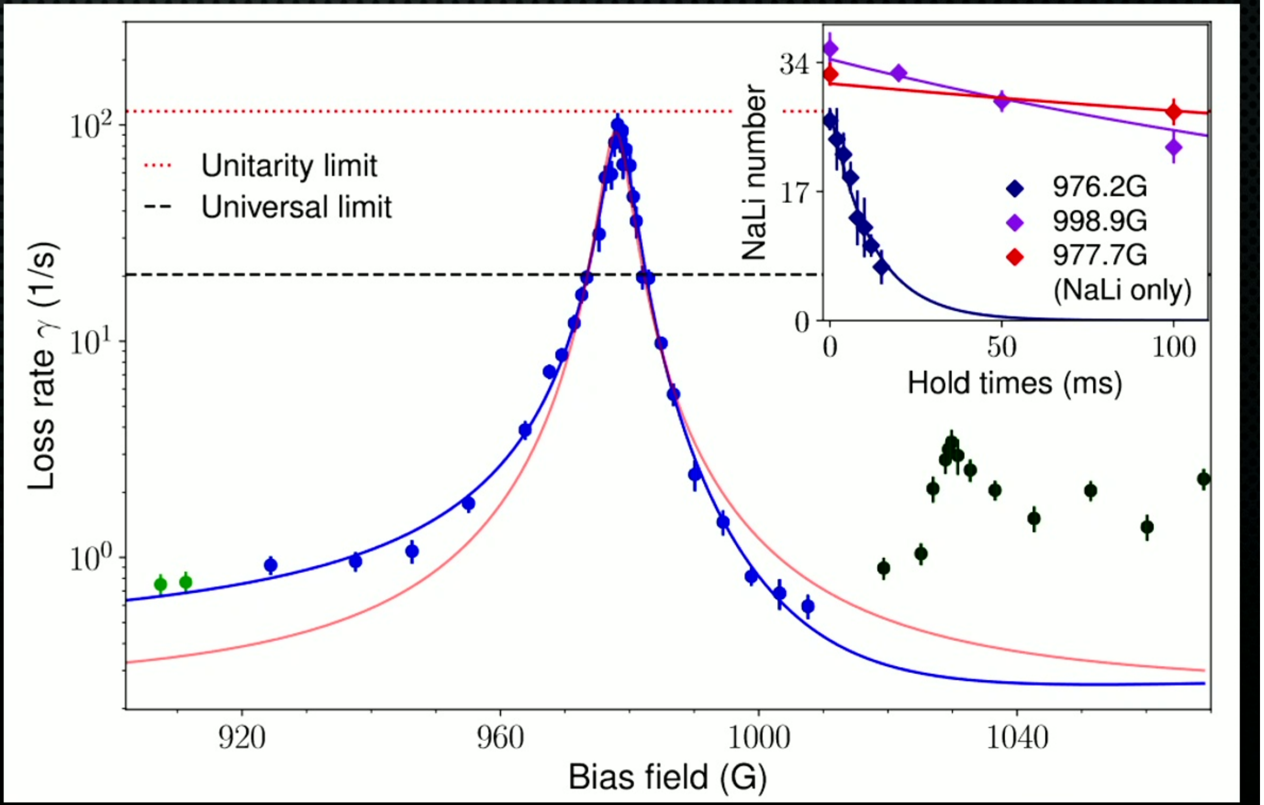
SPIN-DEPENDENT REACTIONS



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

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

A FABRY-PEROT MODEL

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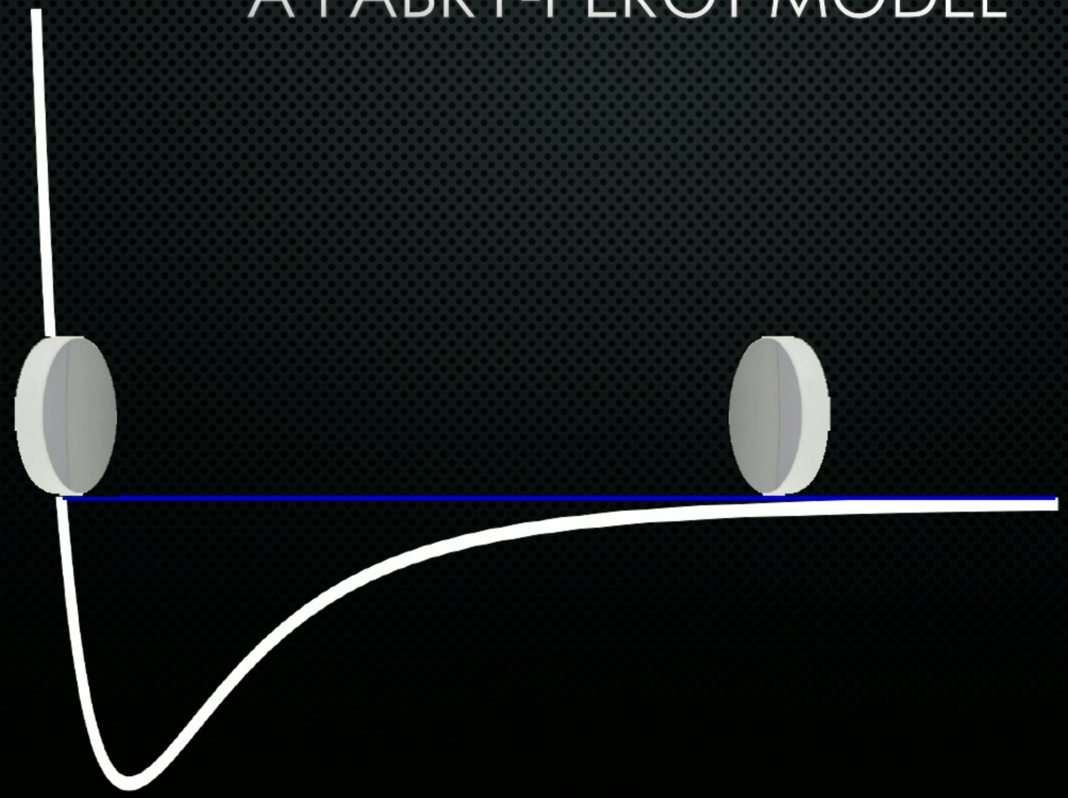

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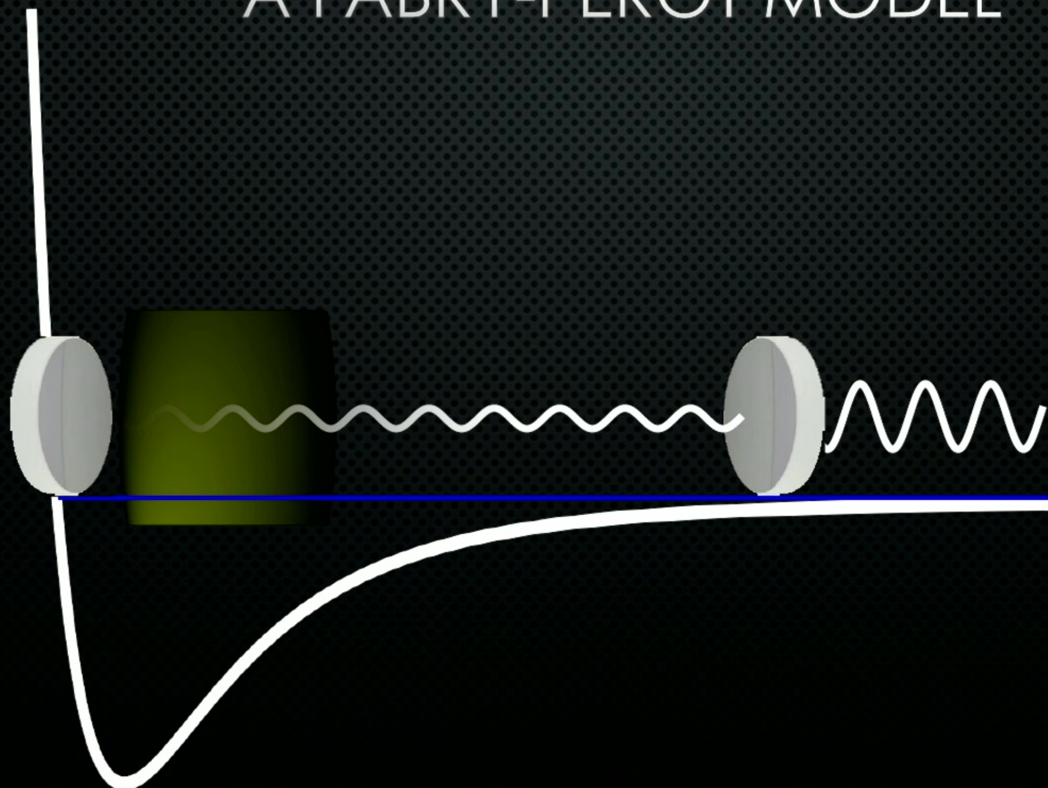
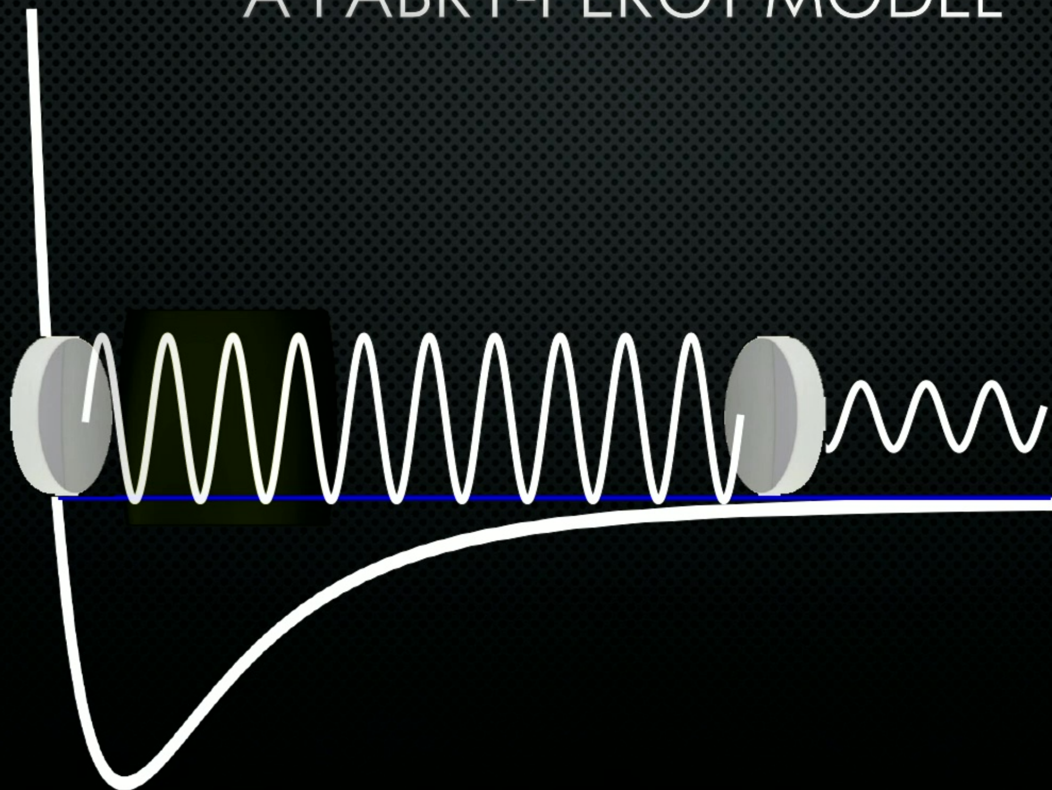
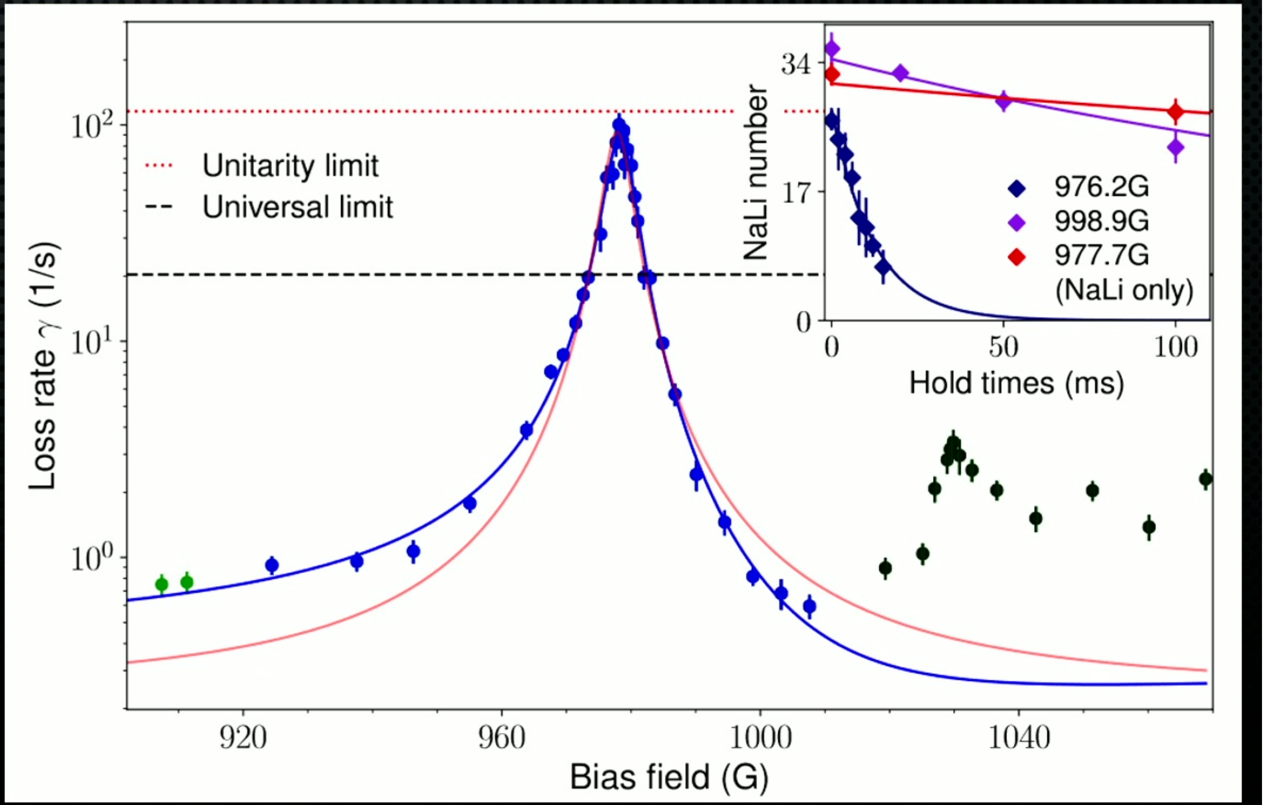


A FABRY-PEROT MODEL



Chemical Resonances

- NaLi + Na resonances



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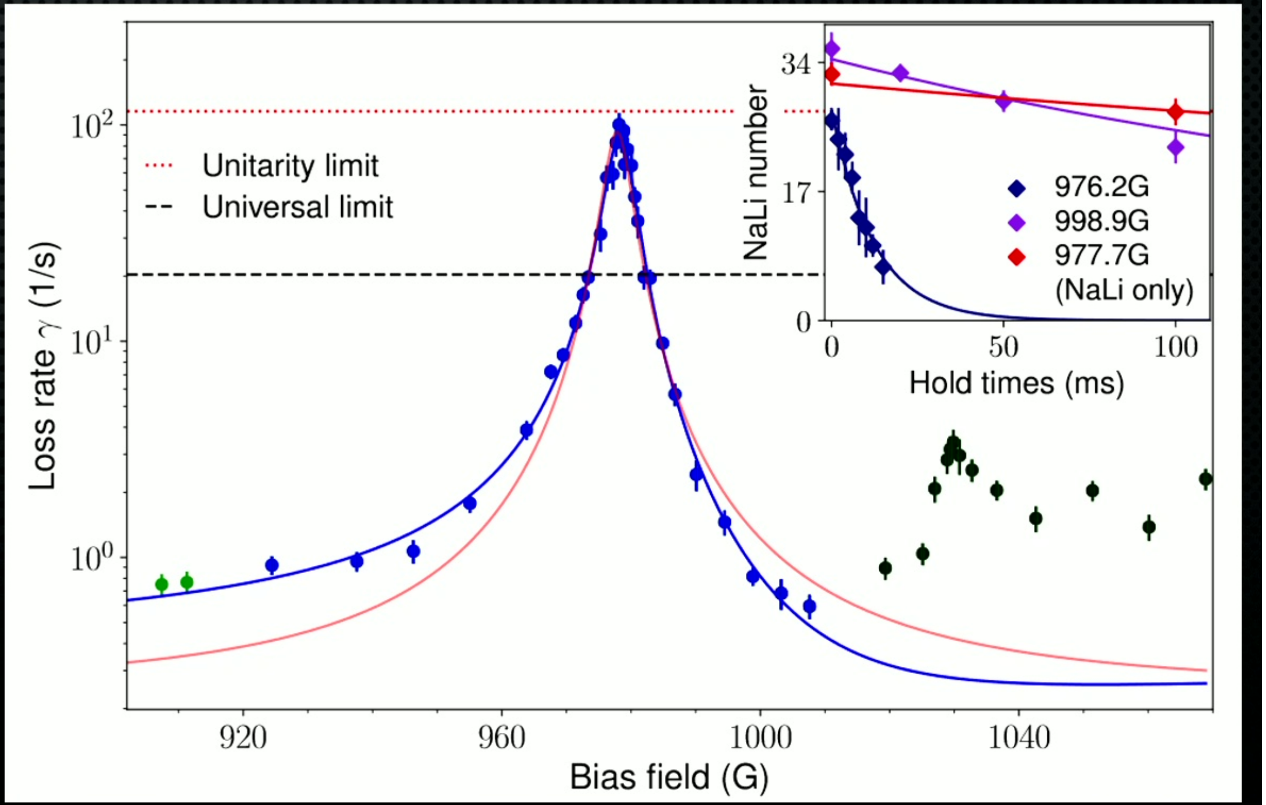
CHEMICAL RESONANCES

- NaLi + Na resonances



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CHEMICAL RESONANCES

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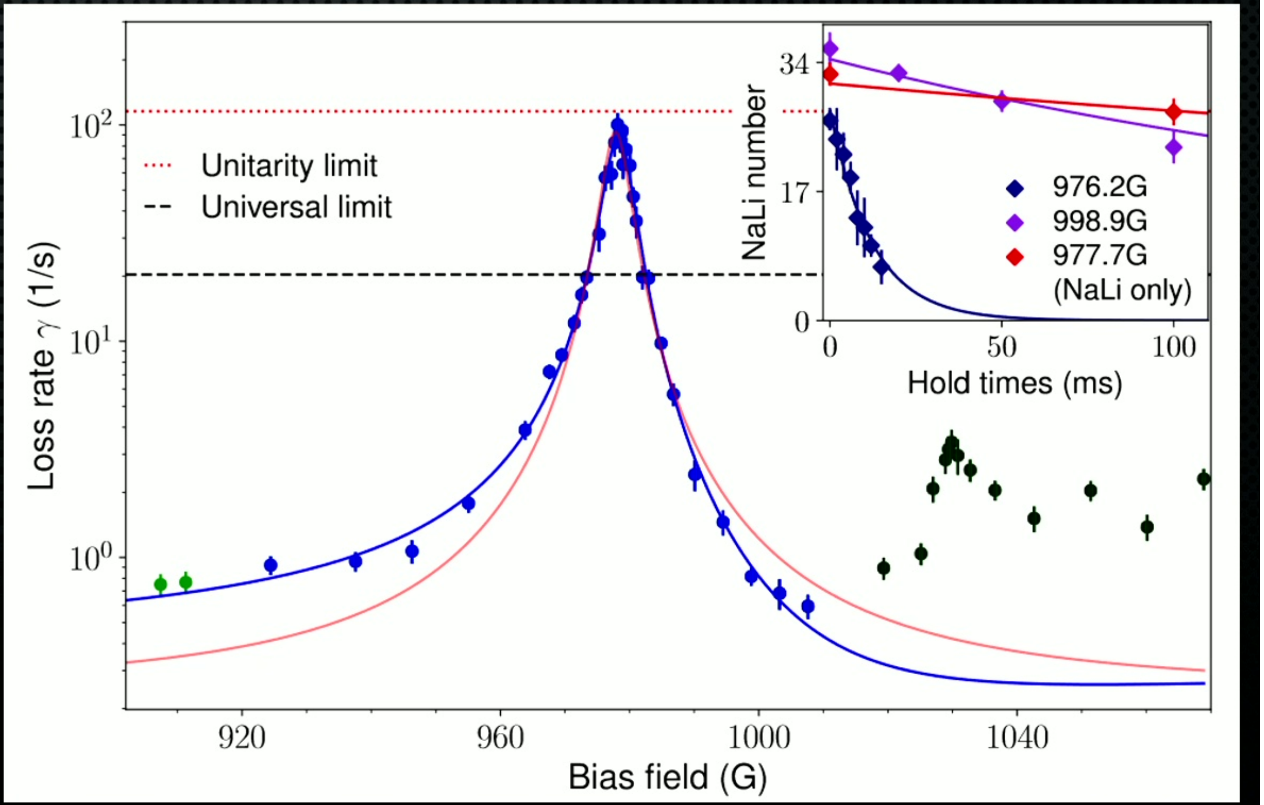

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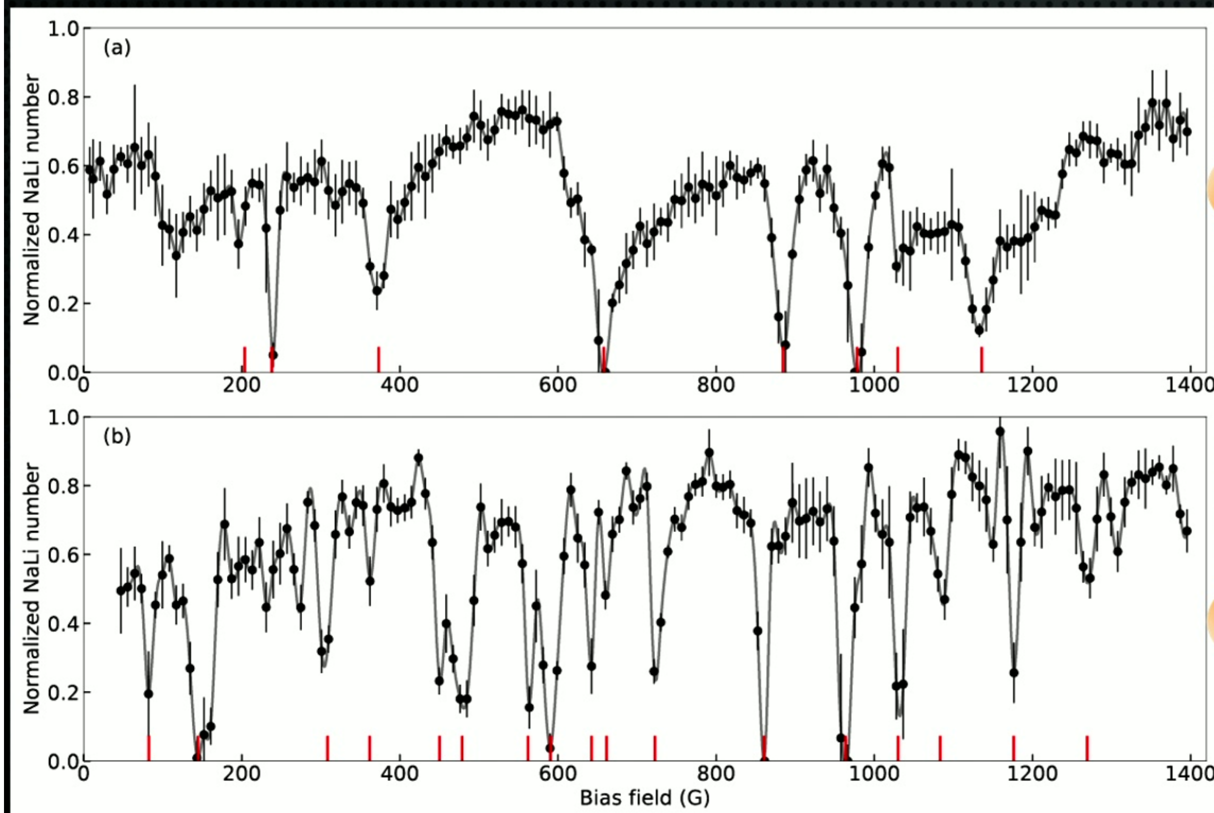
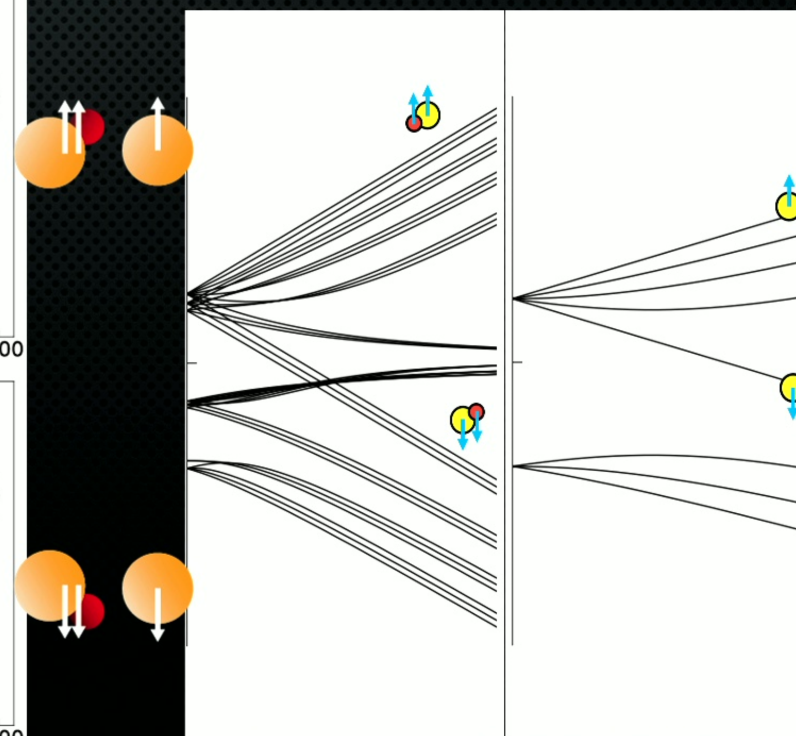
CHEMICAL RESONANCES

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

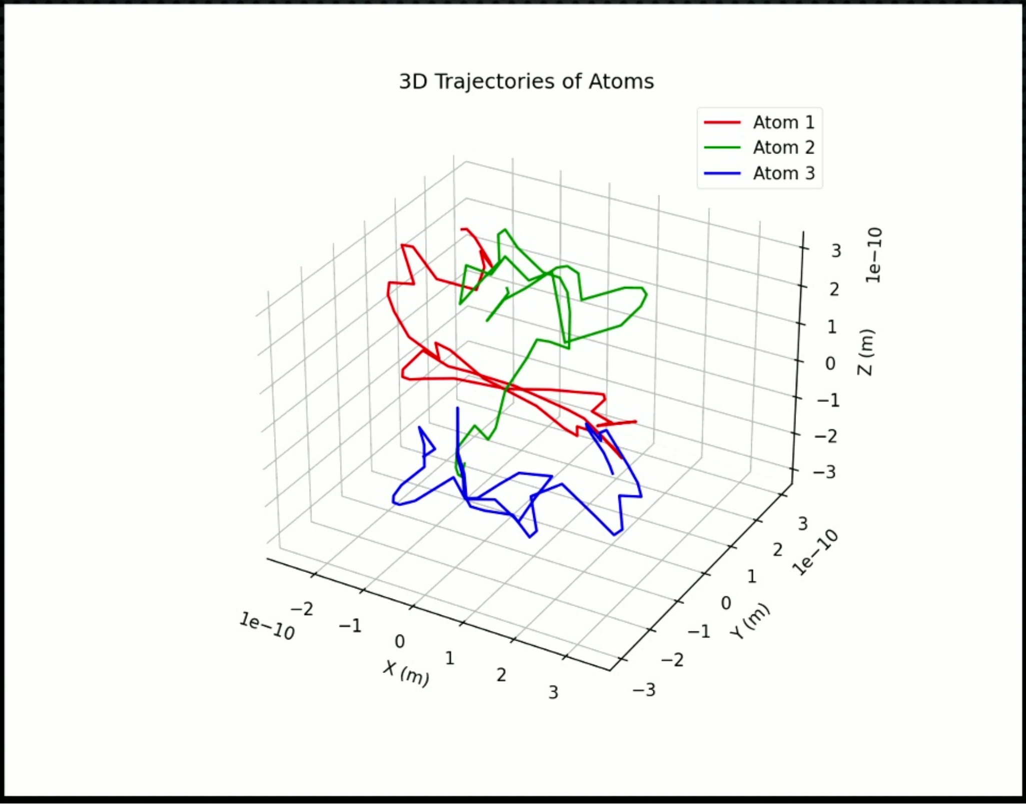
- NaLi + Na resonances





QUANTUM @ WATERLOO

- CLASSICAL SIMULATIONS OF CHEMICAL COLLISIONS



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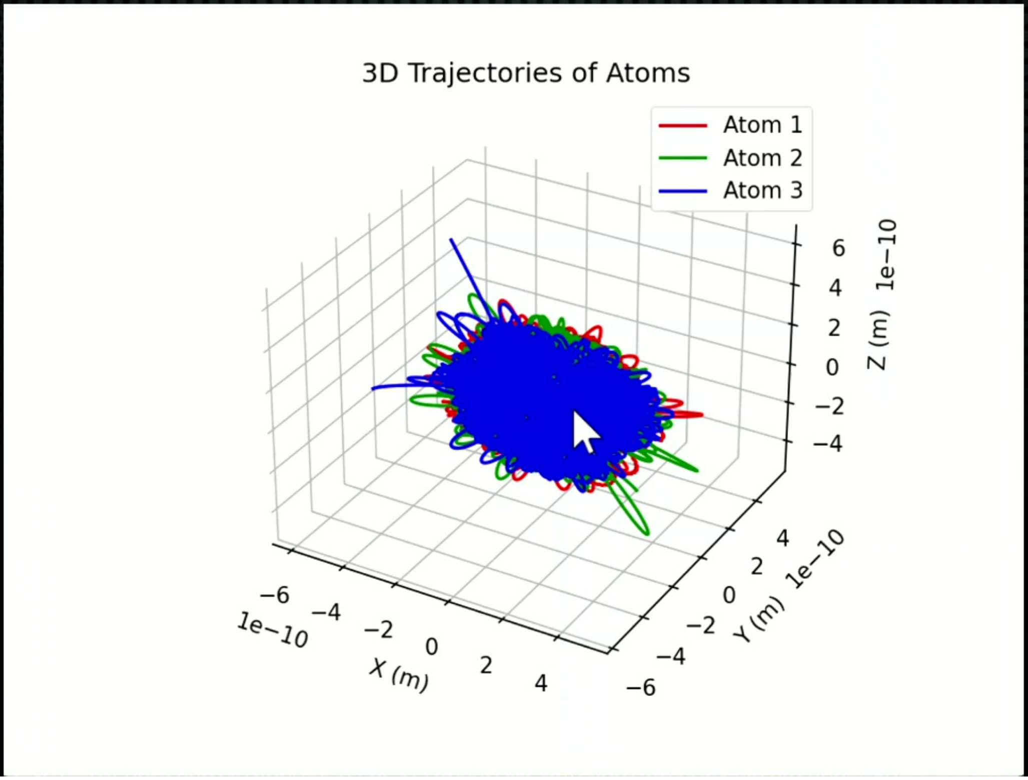

QUANTUM @ WATERLOO

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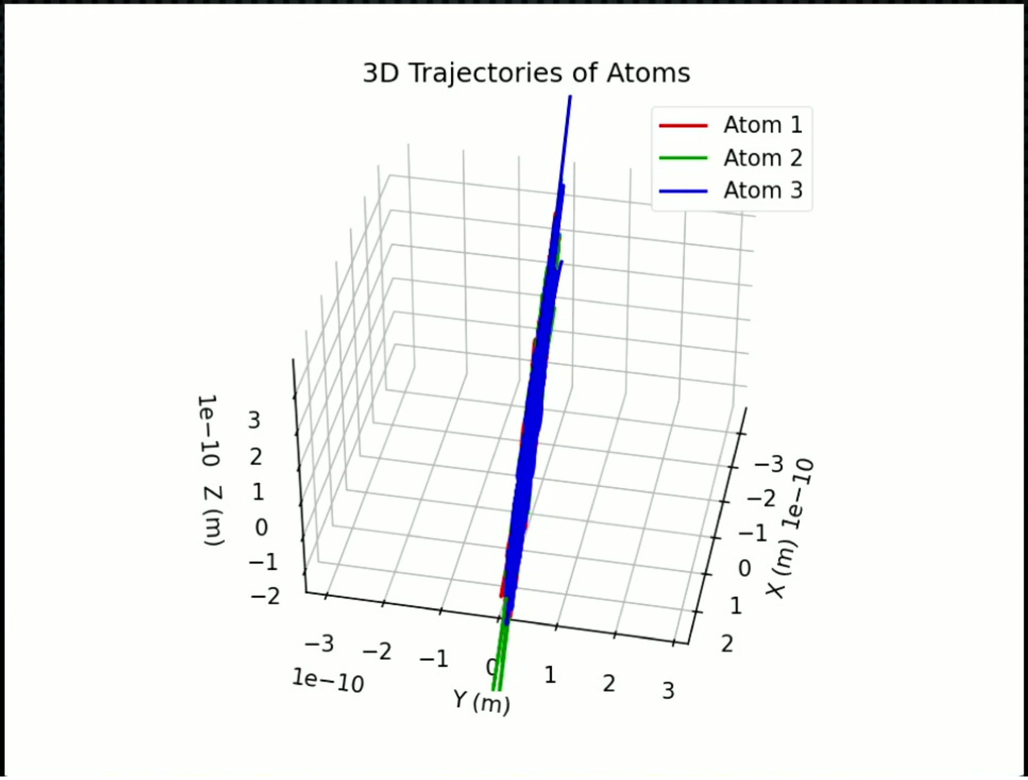
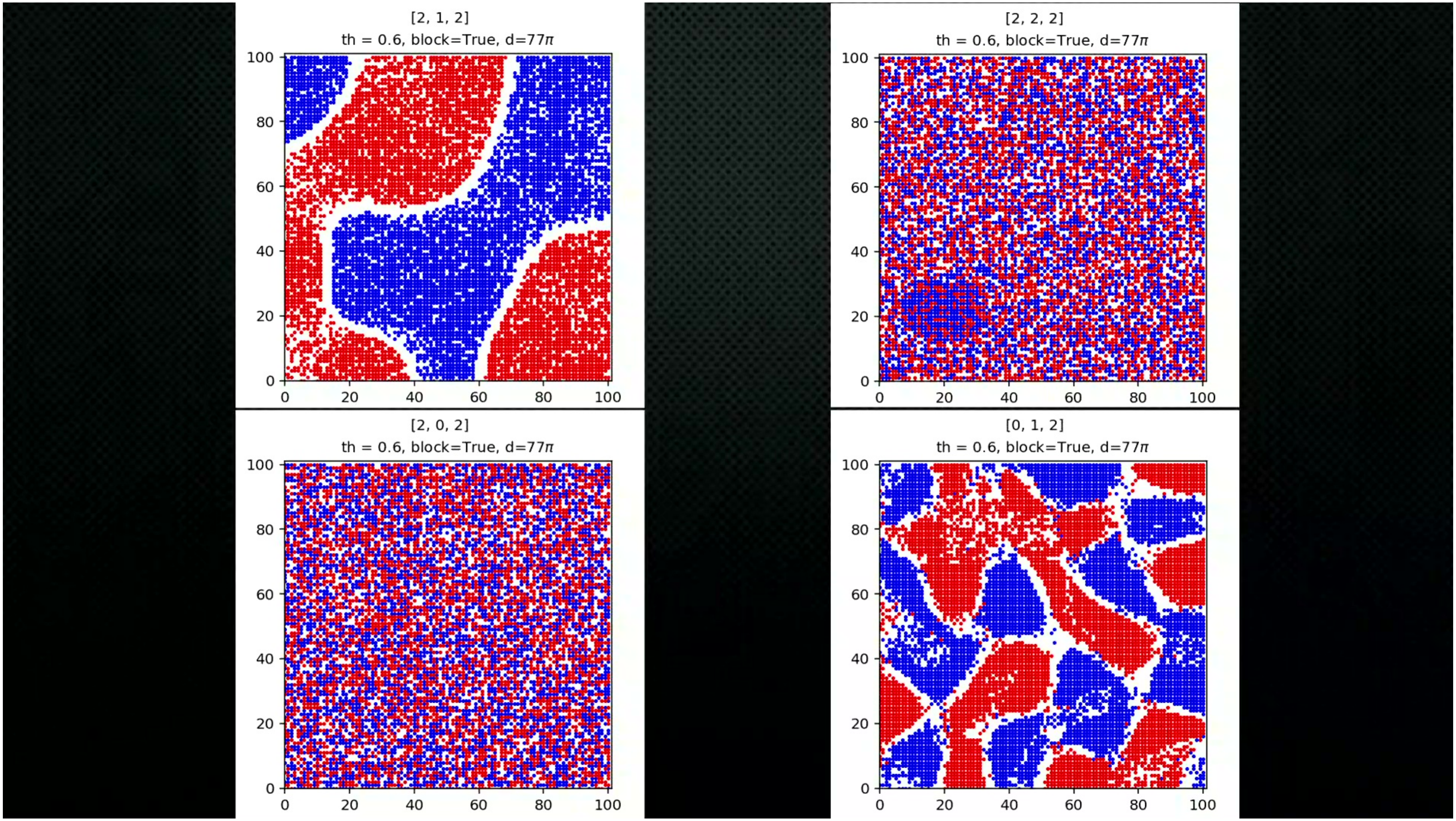


…AND SOMETIMES I'M AN ECONOMIST (SORT OF)

MODELING HUMANS WITH STATISTICAL MECHANICS

- "AGENTS" FOLLOW SIMPLE RULES
- EMERGENT BEHAVIOR IN LARGE GROUPS
  - E.G., SEGREGATION IN HOUSING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20
40
60
80
100