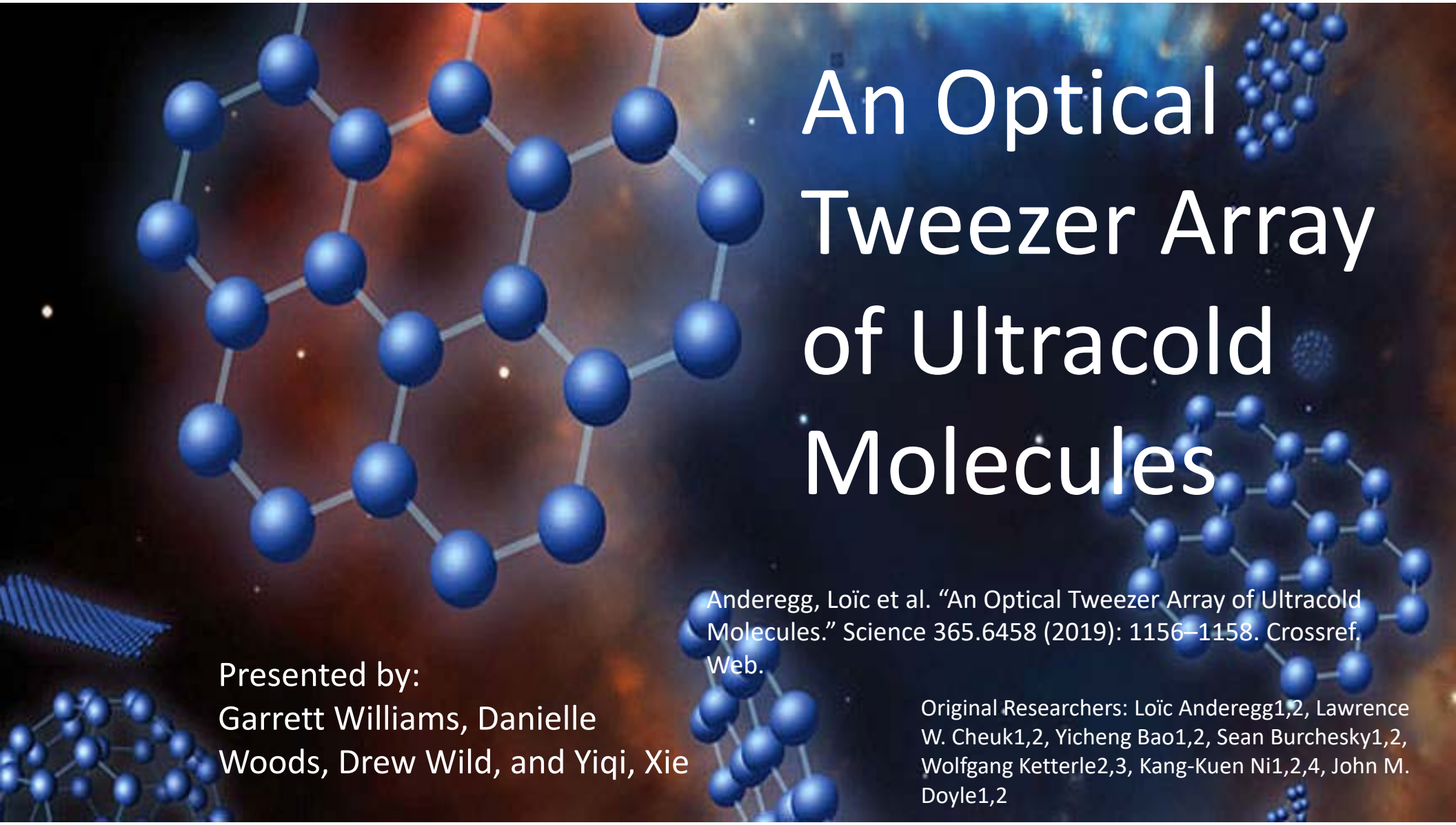


An Optical Tweezer Array of Ultracold Molecules

Presented by:
Garrett Williams, Danielle Woods, Drew Wild, and Yiqi, Xie

Anderegg, Loïc et al. “An Optical Tweezer Array of Ultracold Molecules.” Science 365.6458 (2019): 1156–1158. Crossref. Web.

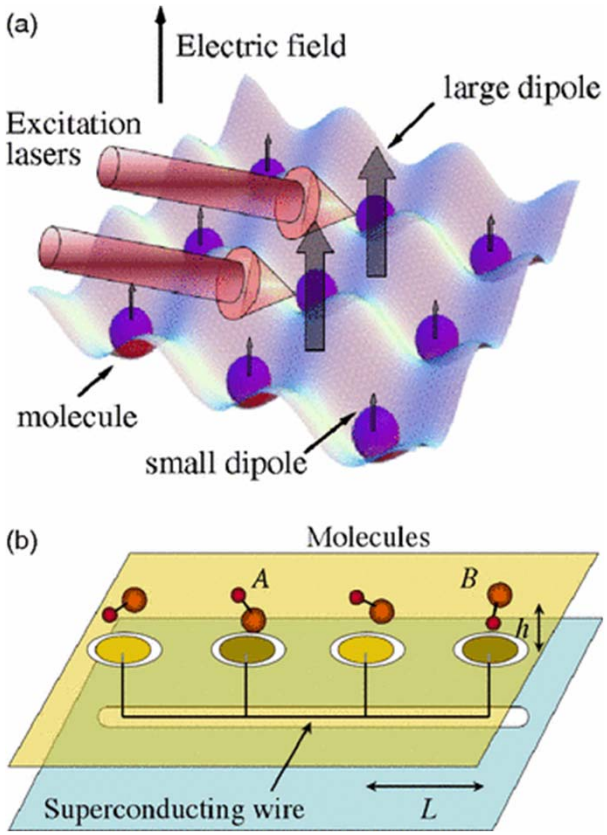
Original Researchers: Loïc Anderegg1,2, Lawrence W. Cheuk1,2, Yicheng Bao1,2, Sean Burchesky1,2, Wolfgang Ketterle2,3, Kang-Kuen Ni1,2,4, John M. Doyle1,2

Outline

- Motivation
- Overview
- Theoretical Background
  - Doppler Cooling
  - Magneto-optical traps
- Summary of Results
- Critical analysis and citation summary

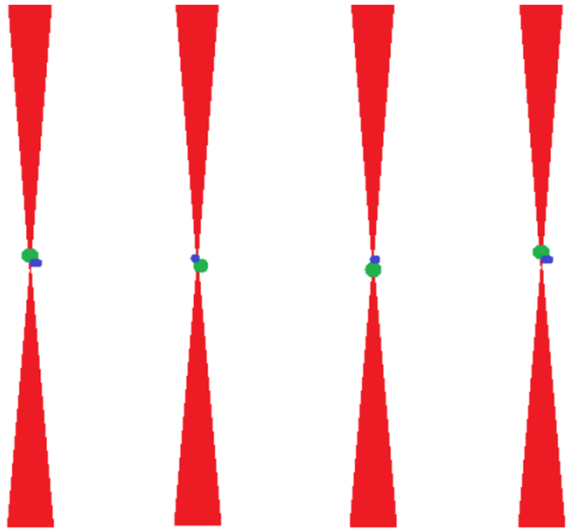
Motivation

- Quantum Computation
  - Polar molecules can potentially provide stable qubits with ~5s coherence
- Improved Quantum Simulation
  - Dipole forces can introduce long range interactions
- Sensitive Detectors and Ultracold Chemistry

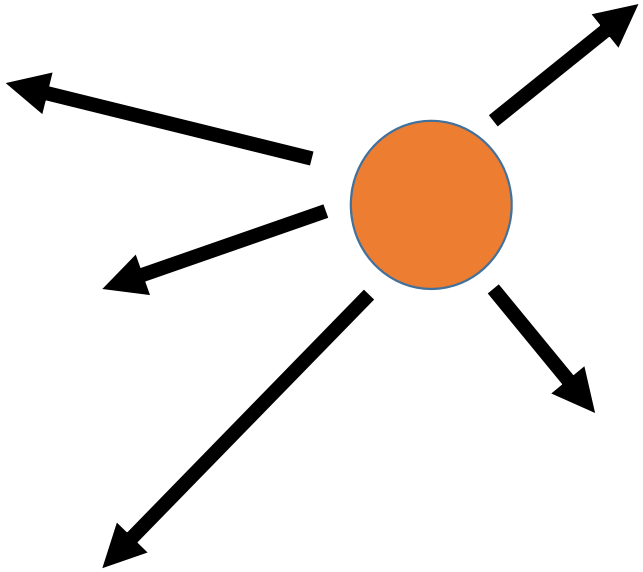


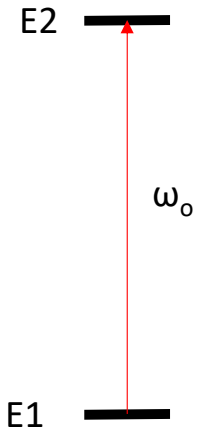
Overview

- This paper builds on previous experiments that created arrays of ultracold atoms
- A gas of CaF is trapped and cooled to the ultracold regime <1mK and further trapped by optical tweezers to form a 1-D array



A Two-Level System

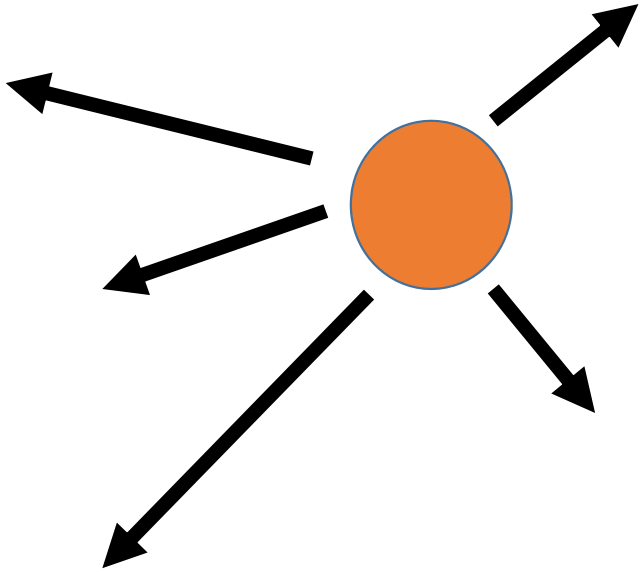


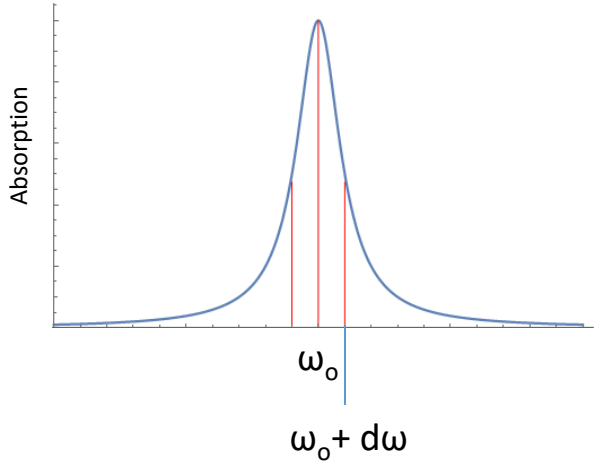


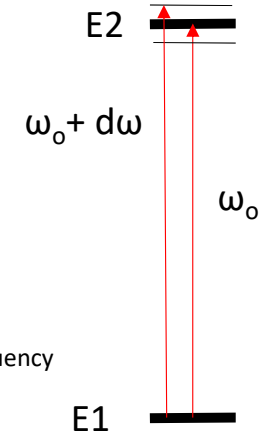
Two-Level system

Gaseous state of atoms

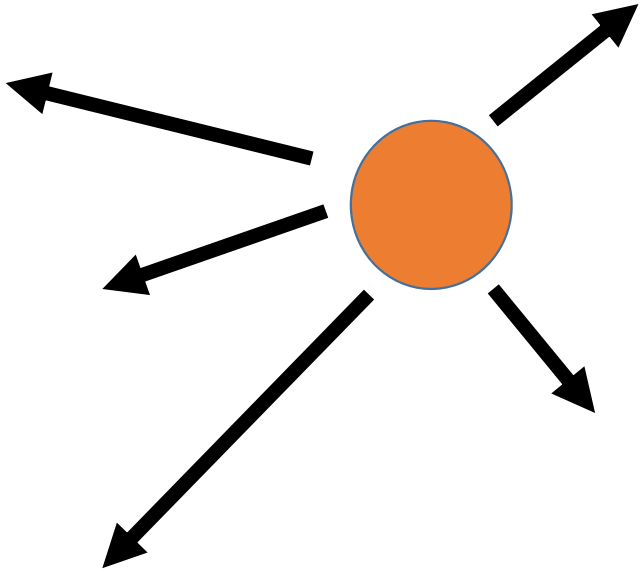
“Sub-levels” in the two-level system

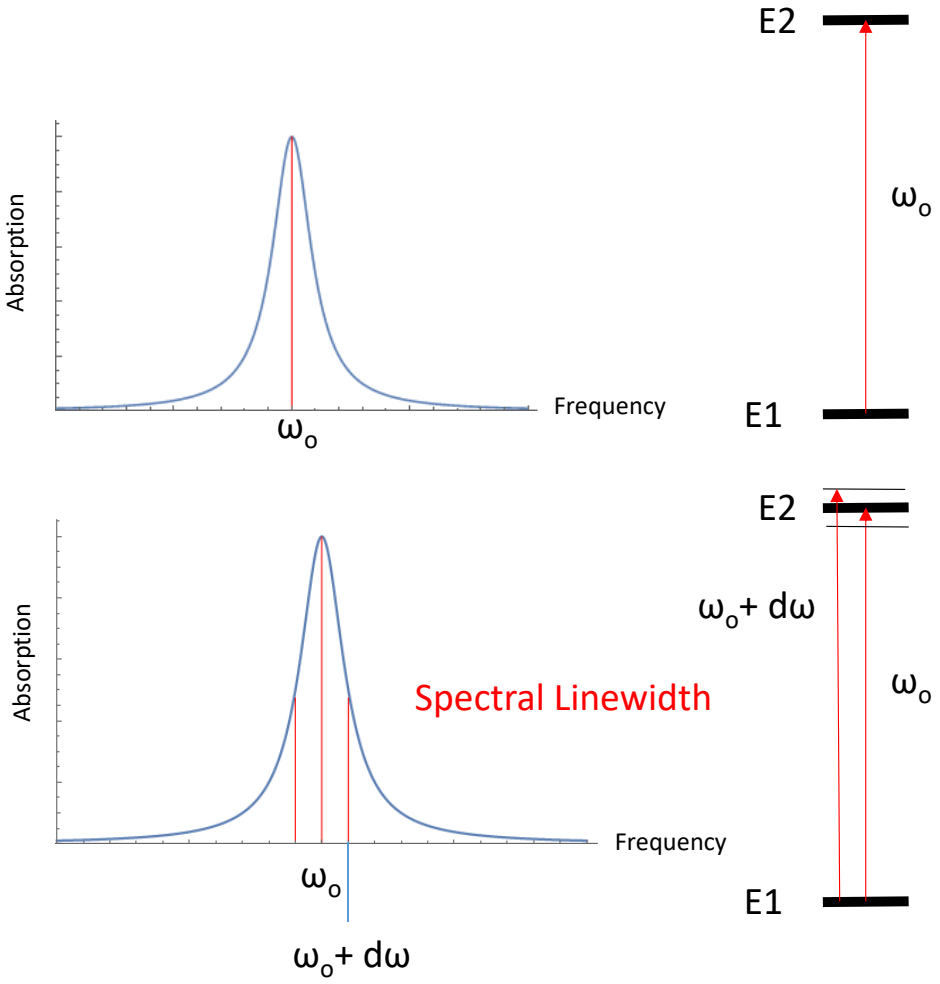






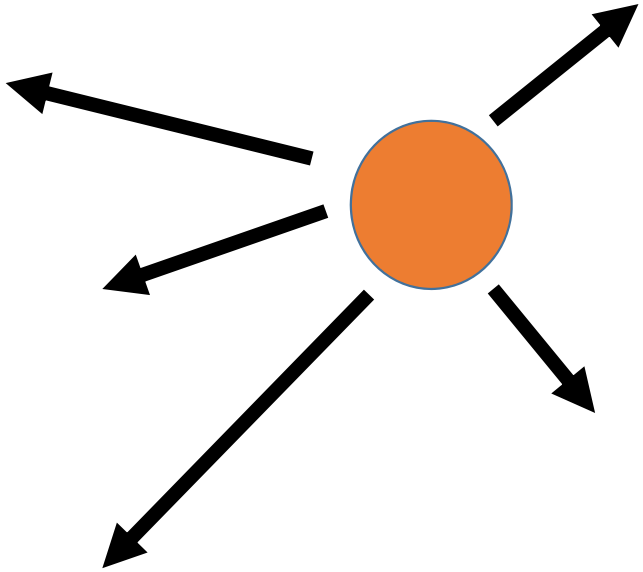
Spectral Linewidth

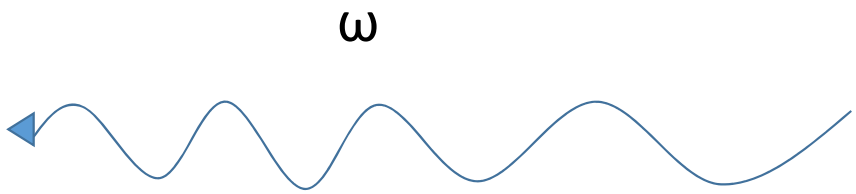




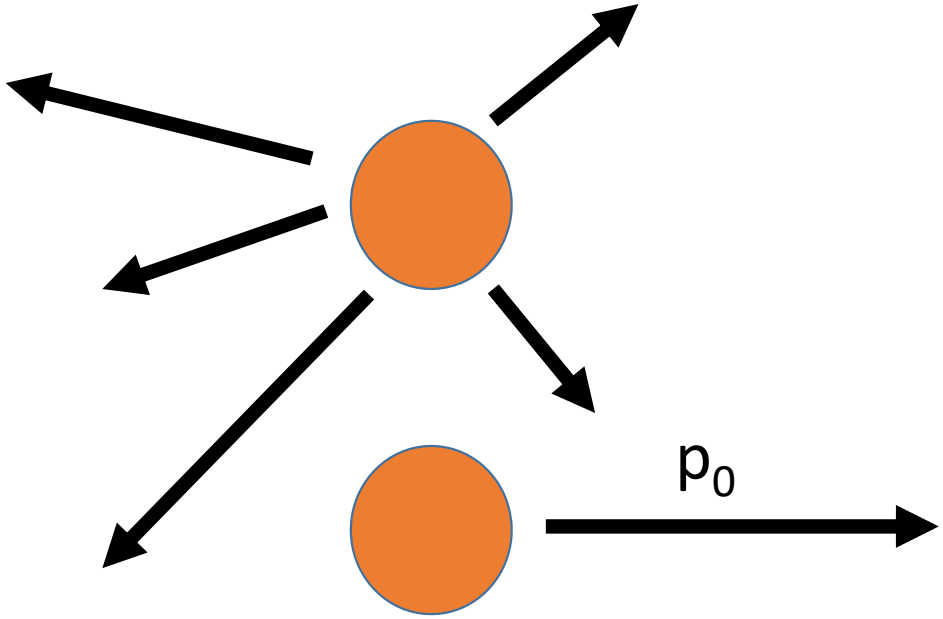
Orientation - Making an Optical Array --- Comparison with Other Work -- Citation Analysis

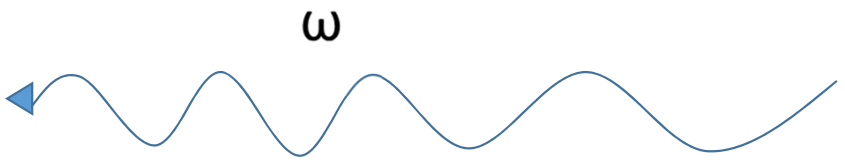
The Doppler Effect

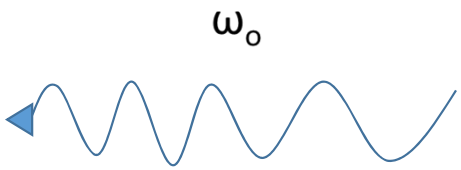




Blue-shifting laser wavelength



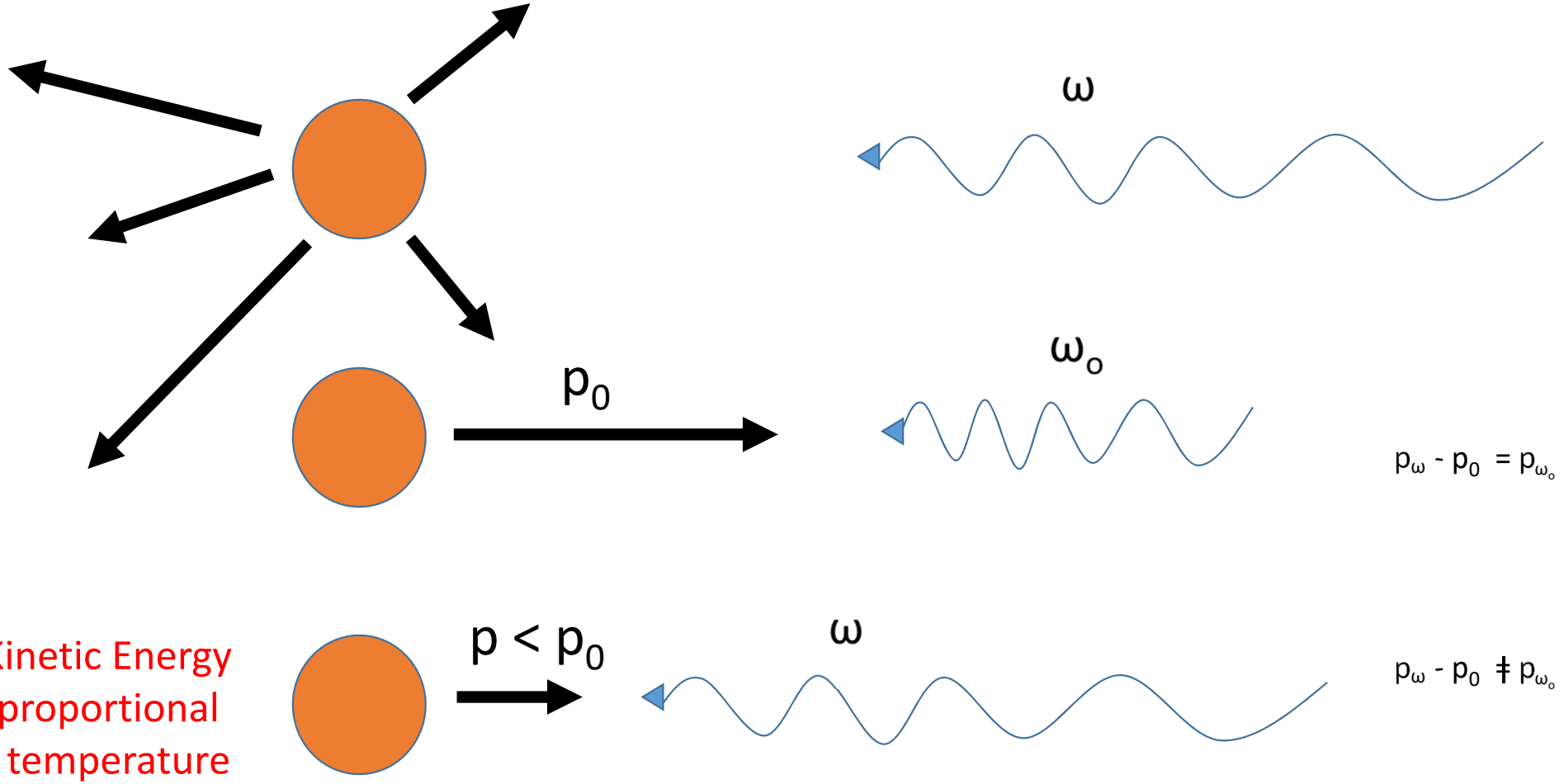




*Where $\omega_o < \omega$

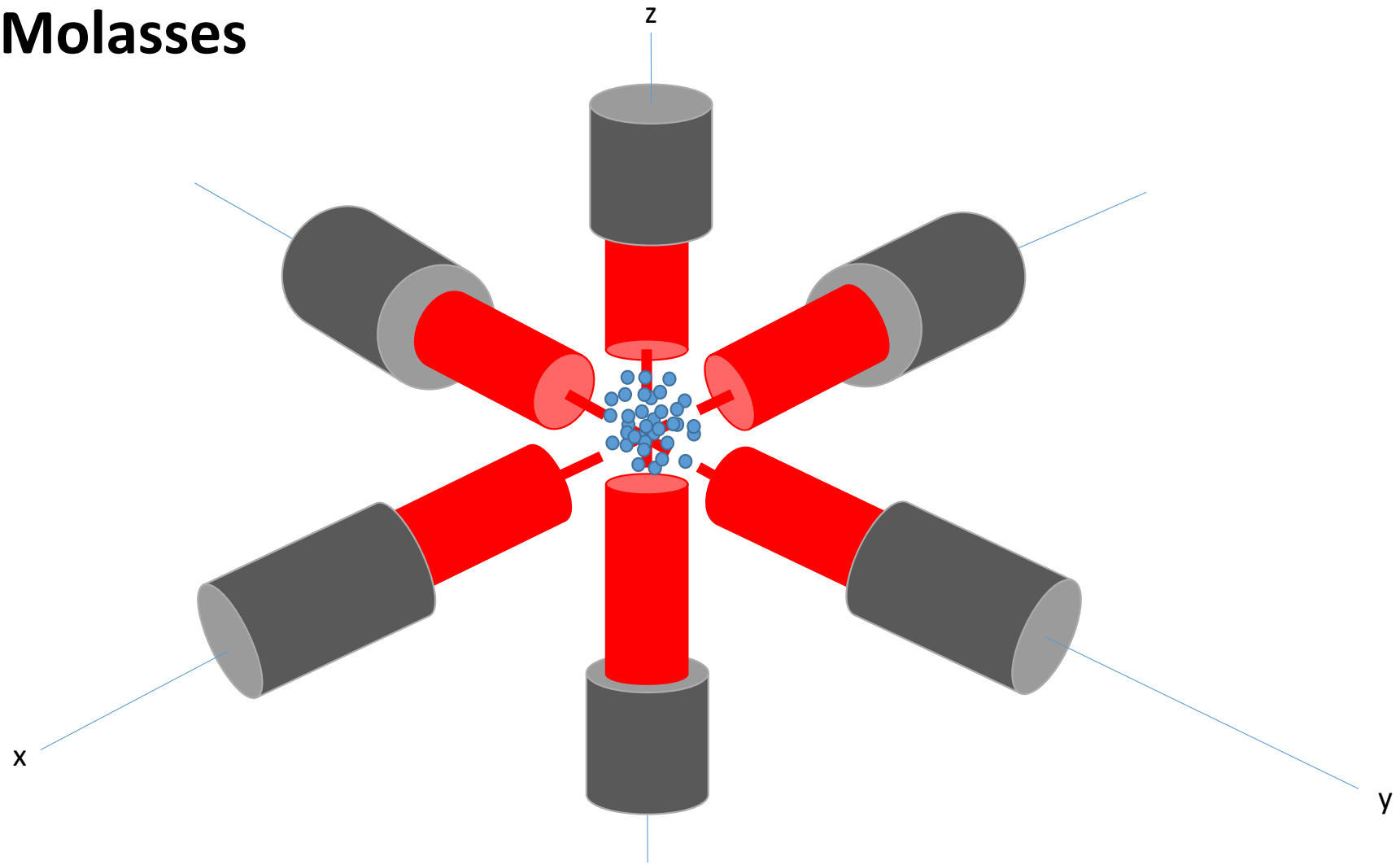
$p_\omega - p_0 = p_{\omega_o}$

Detuned-light can slow atoms/molecule



*Kinetic Energy is proportional to temperature

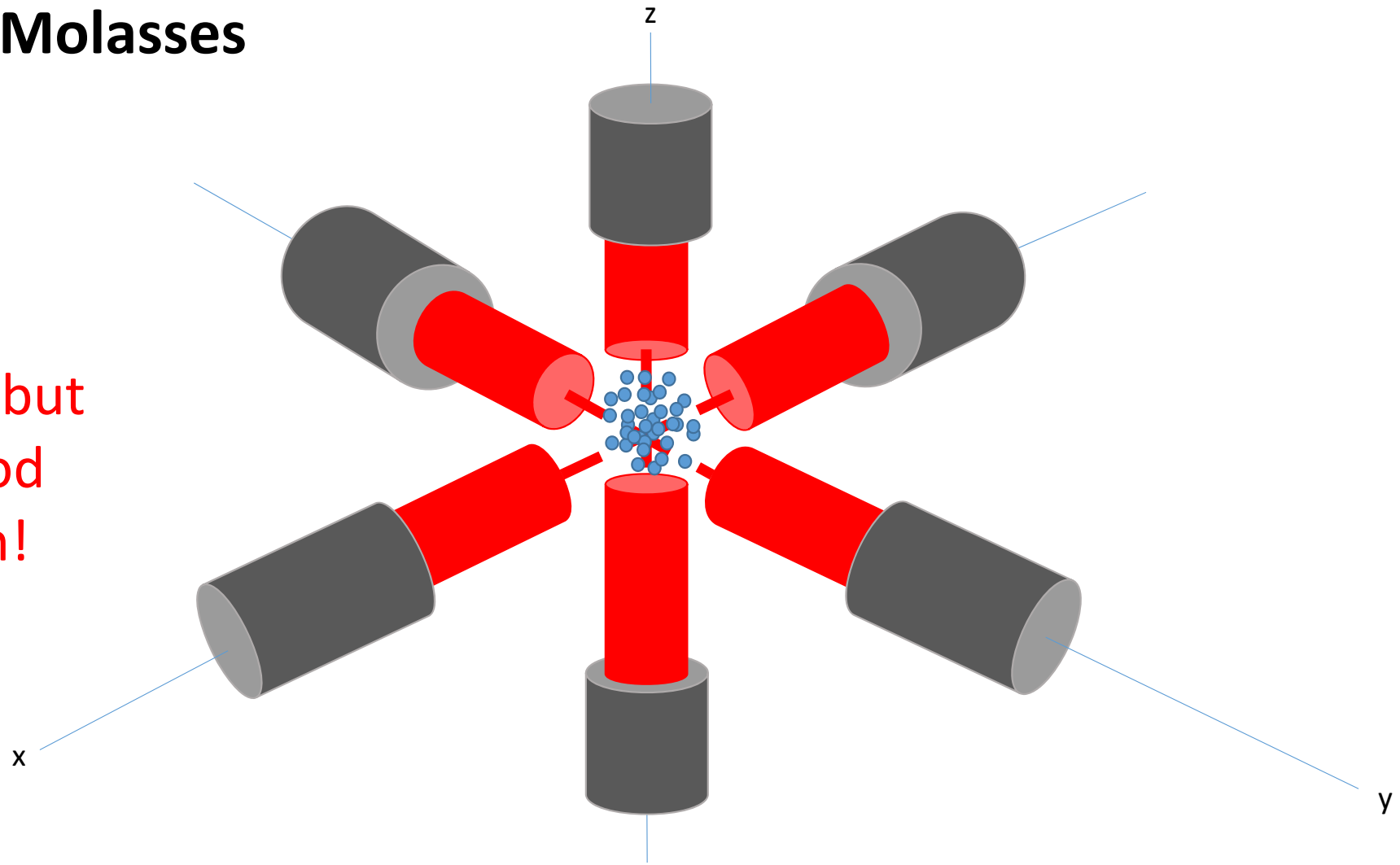
Optical Molasses



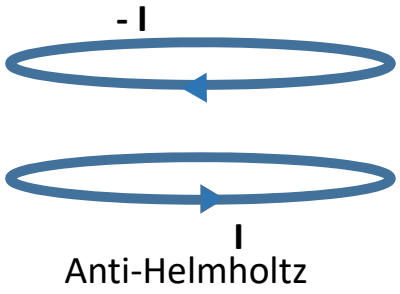
Orientation - Making an Optical Array --- Comparison with Other Work -- Citation Analysis

Optical Molasses

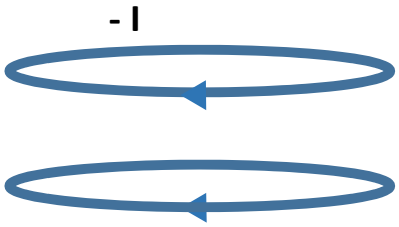
*Good but not good enough!



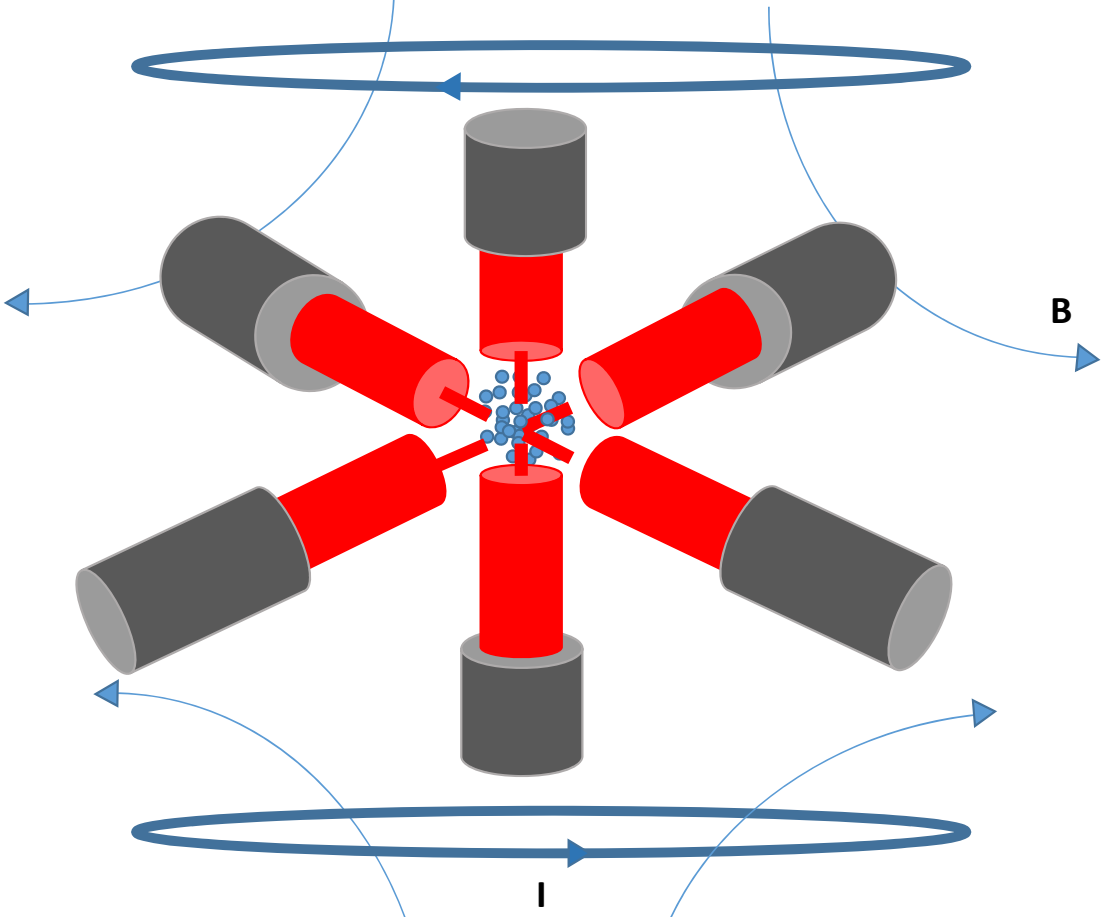
Magneto-Optical Trap (MOT)



Anti-Helmholtz

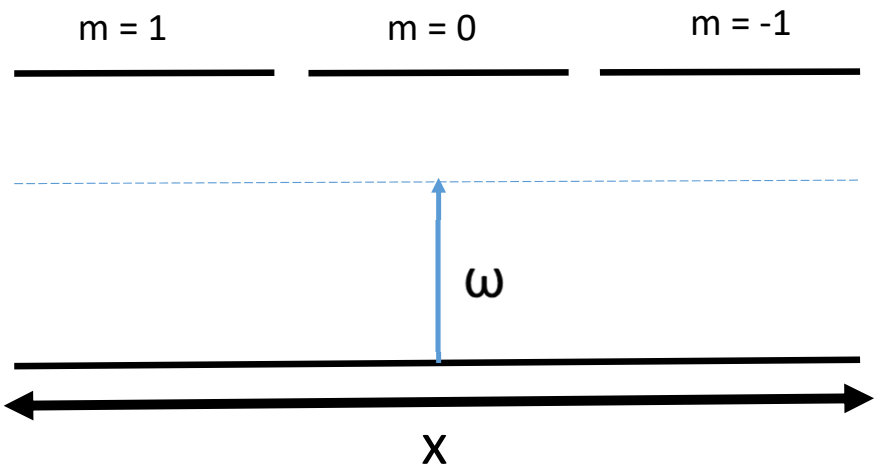


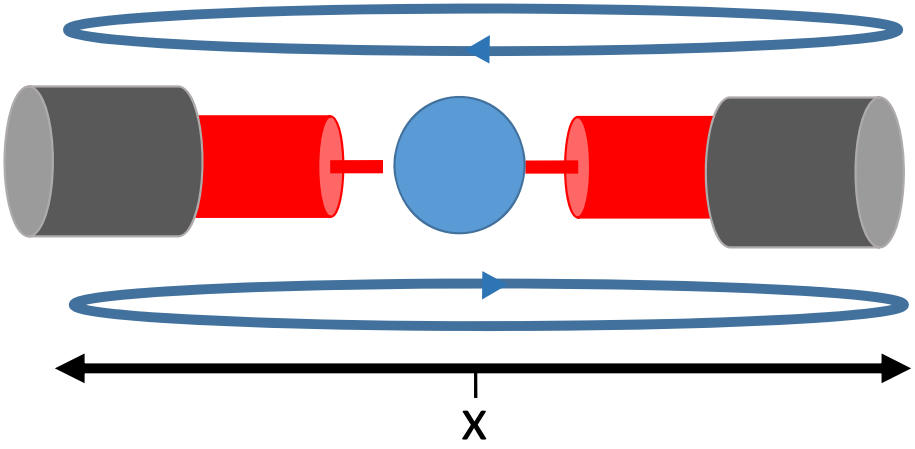
Helmholtz



Orientation - Making an Optical Array --- Comparison with Other Work -- Citation Analysis

MOT Beams use circularly polarized light





$$\sigma_+ : m \rightarrow m+1$$

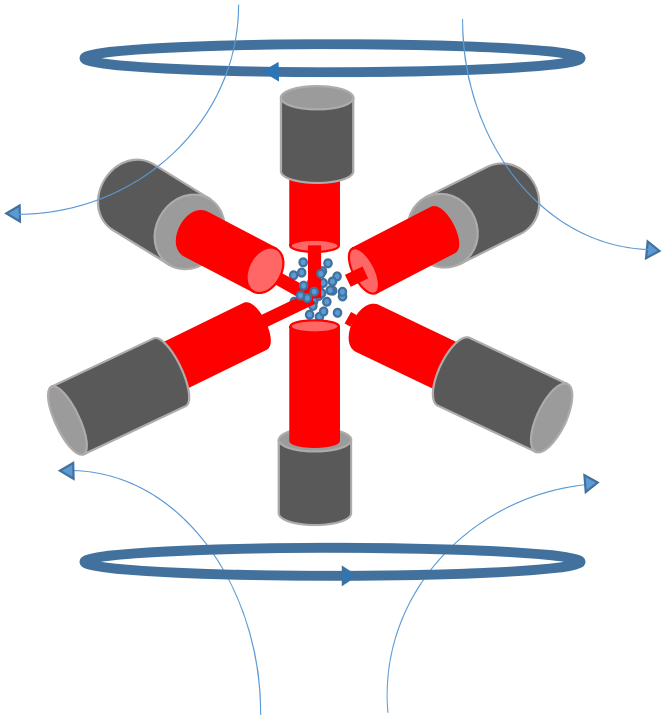
$$\pi : m \rightarrow m$$

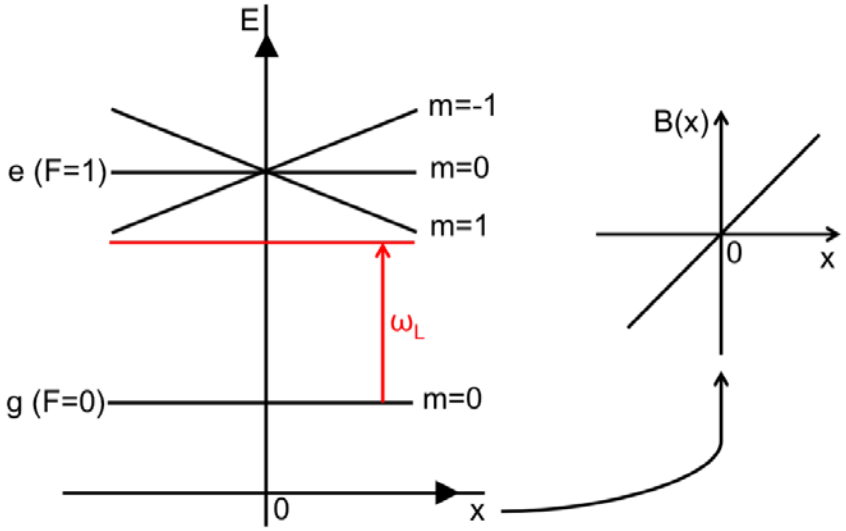
$$\sigma_- : m \rightarrow m-1$$

*Imparting units of angular momentum on the system

$$L_z = m\hbar$$

MOT Beams use circularly polarized light





$$\sigma_+ : m \rightarrow m+1$$
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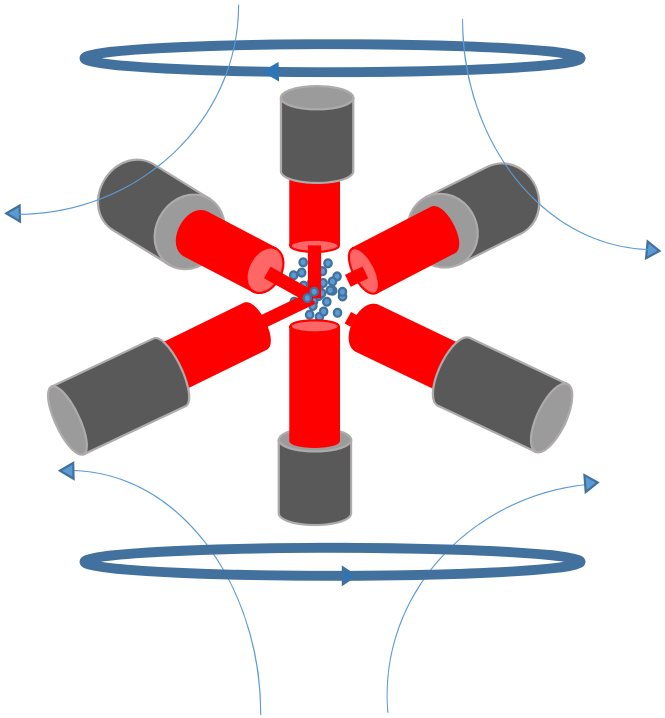
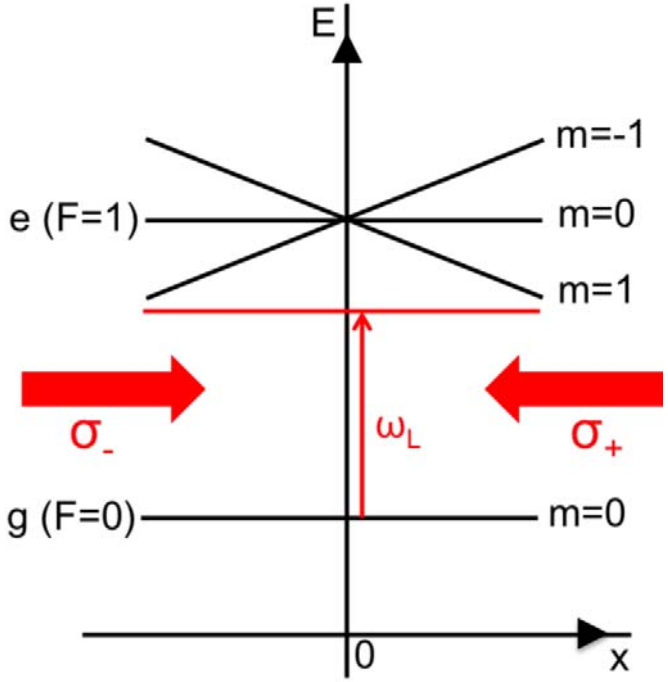
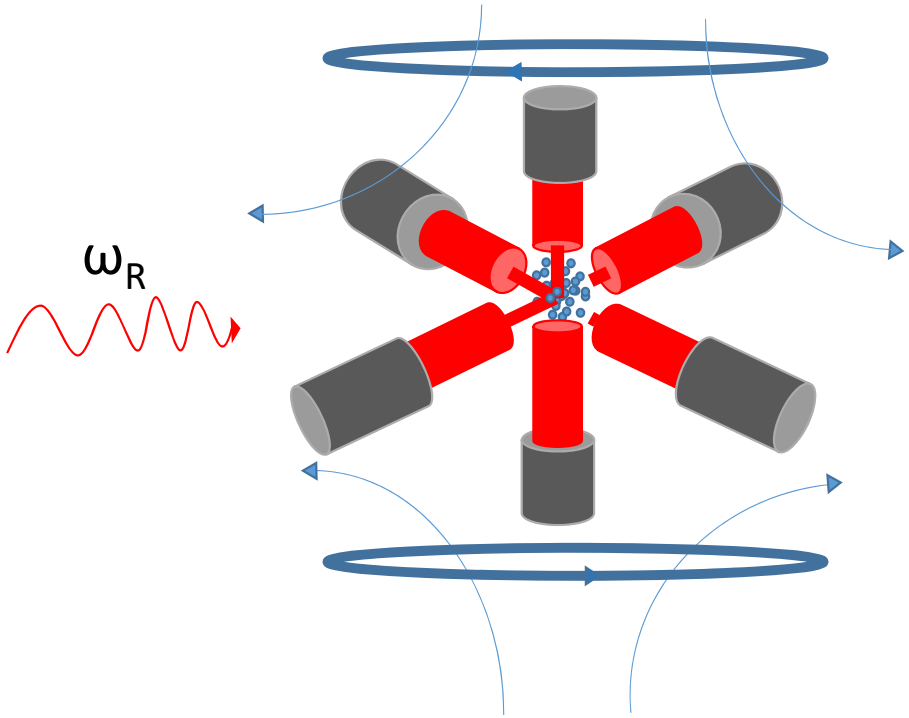
Orientation - Making an Optical Array --- Comparison with Other Work -- Citation Analysis

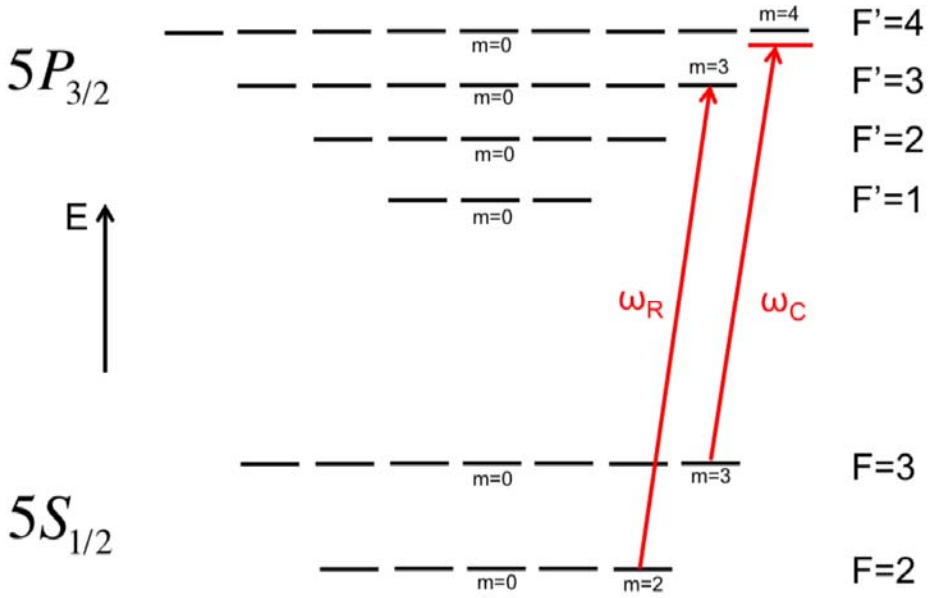
MOT Beams use circularly polarized light





Treating an atom/molecule as two-level system



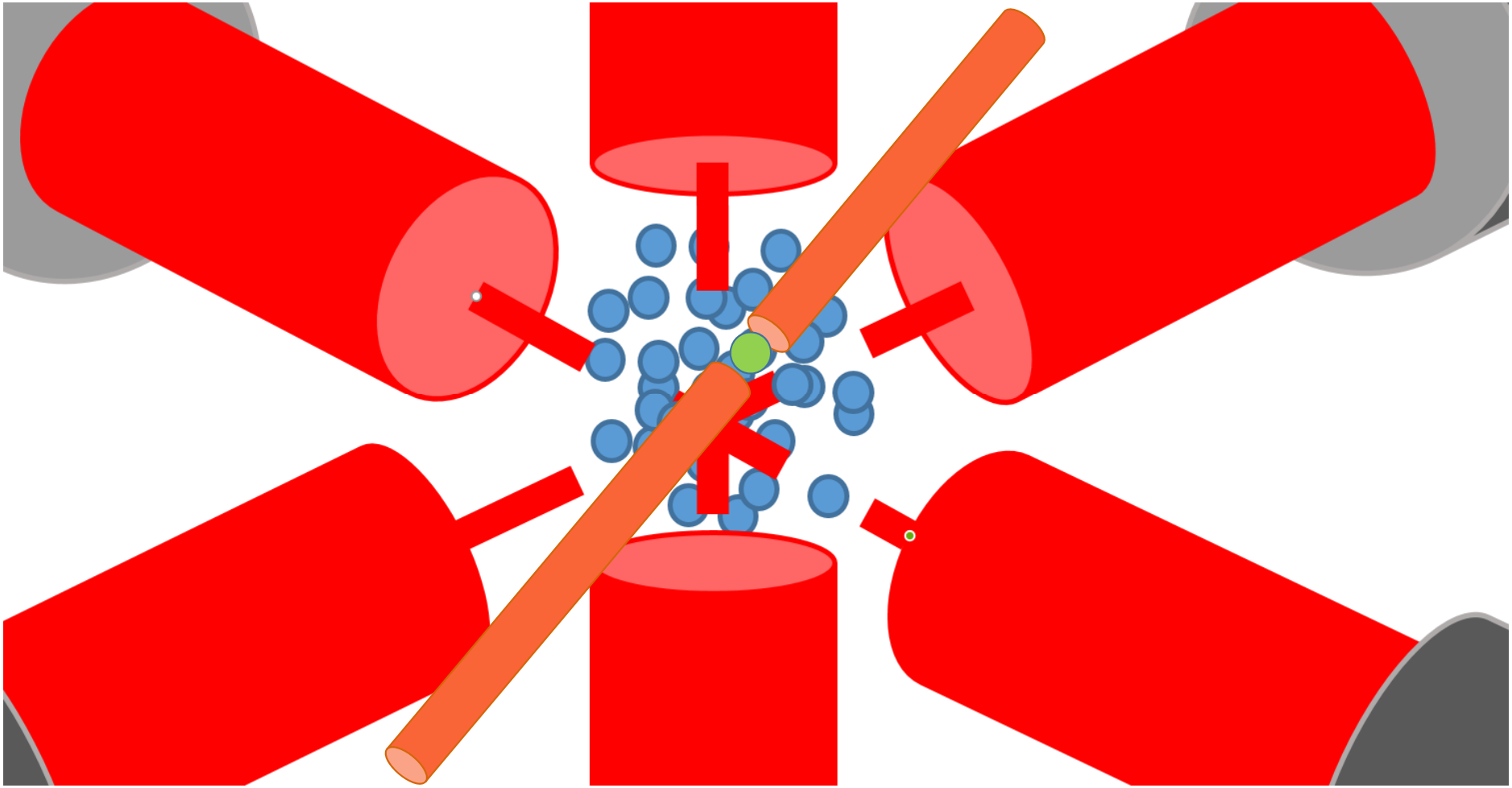


Δm = -1,0,1

Δl = -1,1

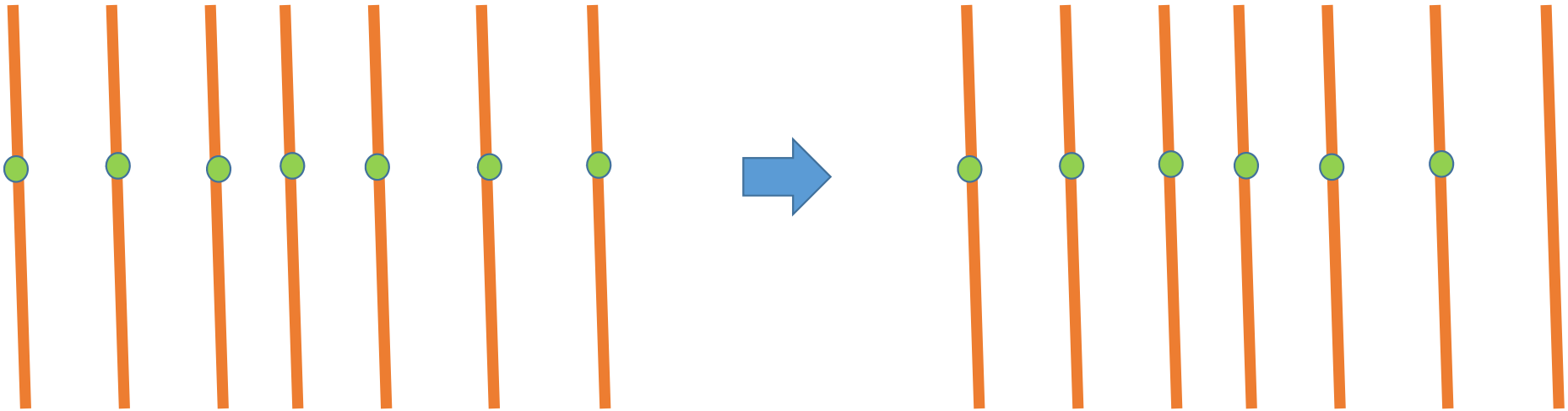
ΔF = -1,1

Optical Tweezers

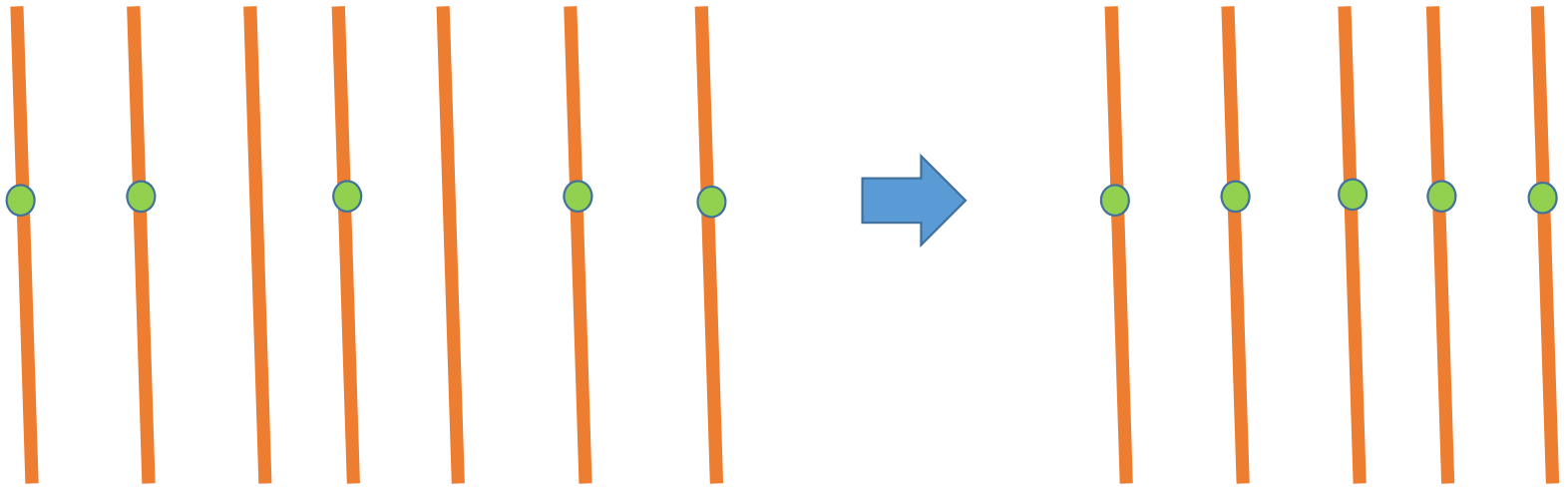


Orientation - Making an Optical Array --- Comparison with Other Work -- Citation Analysis

Optical Array – probabilistic recapture

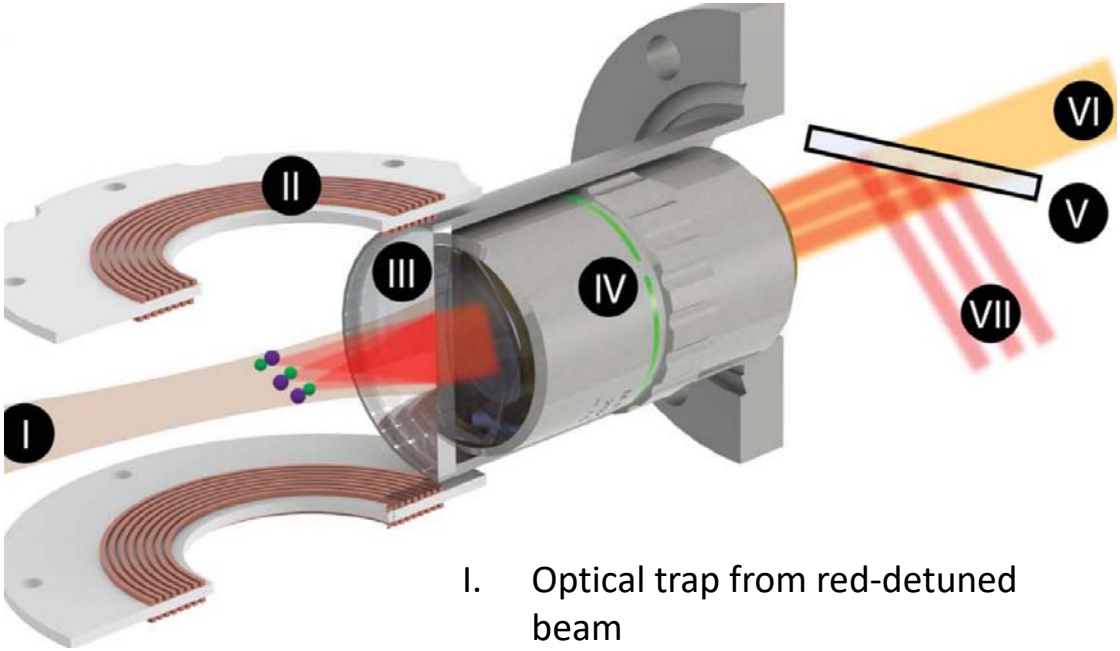


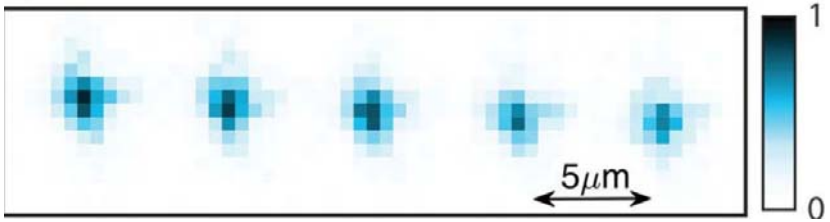
Optical Array – dynamic traps

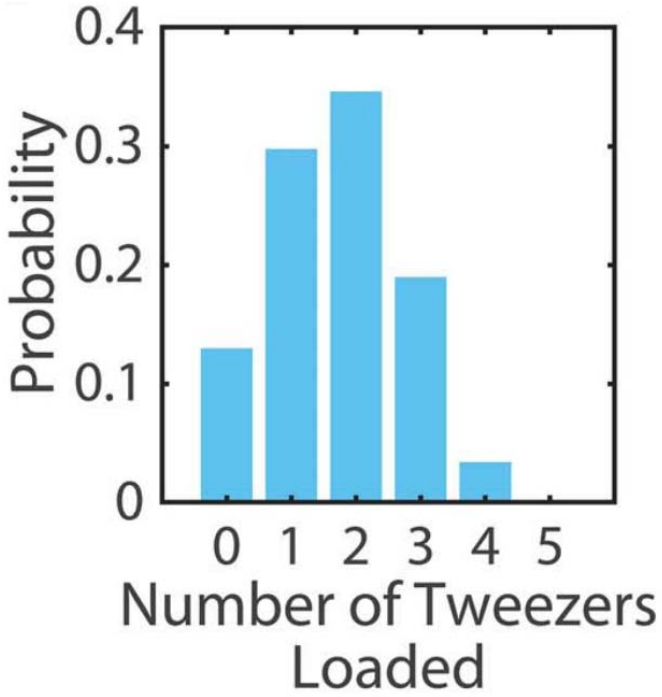


Orientation - **Making an Optical Array** --- Comparison with Other Work -- Citation Analysis

Experiment Apparatus and Summary of Results







I. Optical trap from red-detuned beam
II. MOT magnetic field coils
III. Window that prevents optical lattice formation
IV. Microscope objective
V. Dichroic mirror
VI. Camera path
VII. Optical tweezer traps

Discussion of Results

- “Fully control and detect individual molecules”
- “Creation and detection of an array of ultracold calcium minifluoride (CaF) molecules trapped in optical tweezers”
- Verified occupancy was just one molecule
- Their light-collision rates are similar to that measured for rubidium atoms in optical tweezers.
  - Dipole moment also similar: suggests that molecular systems should have similar collision rates to those of atomic systems.

Comparison with previous works

- This work:
  - Loading of diatomic molecules into optical tweezer arrays

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  - Optical trapping of diatomic [1] and polyatomic [2] molecules

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  - Controlled molecular synthesis using optical tweezers [3]

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- Previous works:
  - Optical trapping of diatomic [1] and polyatomic [2] molecules
  - Controlled molecular synthesis using optical tweezers [3]
  - Deterministic loading of atoms into 1D [4] and 2D [5] optical tweezer arrays

[1] Blackmore et al (2018), doi: 10.1088/2058-9565/aaee35
[2] Kozyryev & Hutzler (2017), doi: 10.1103/PhysRevLett.119.133002
[3] Liu et al (2018), doi: 10.1126/science.aar7797
[4] Endres et al (2016), doi: 10.1126/science.aah3752
[5] Barredo et al (2016), doi: 10.1126/science.aah3778

Citation Report

- Low citation number since it's new

- 2 citations according to Web of Science:
  - *Making perfectly controlled arrays of molecules at rest*
    (a Science perspective)
  - *A scalable **quantum computing** platform using symmetric-top molecules*
    (recent progress of the same team)

Broader Impacts

- Quantum computation
  - Searching
  - Solving linear equations
  - Cryptography

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- Quantum computation
  - Searching
  - Solving linear equations
  - Cryptography
- Quantum simulation
  - Solving a wide range of many-body physics problems
- Ultracold chemistry
  - Brand new methodology for chemistry research
  - Controlled reaction at molecular level

Orientation - Making an Optical Array --- Comparison with Other Work -- **Citation Analysis**

Conclusion

- Realized novel technique
- Demonstrated valid scientific approach
- Paved the way to future research involving ultracold molecules
- Raised broad interest in topics such as molecular dynamics, quantum information, quantum simulation, etc
- Not targeted for general audience

Thanks you for Listening!