Towards Laser Cooling Oxygen

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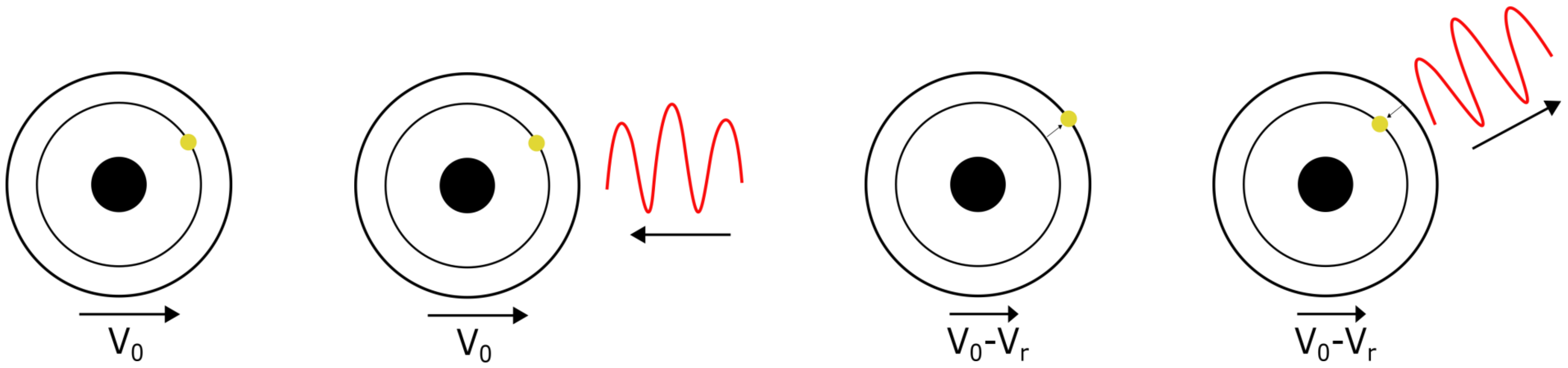
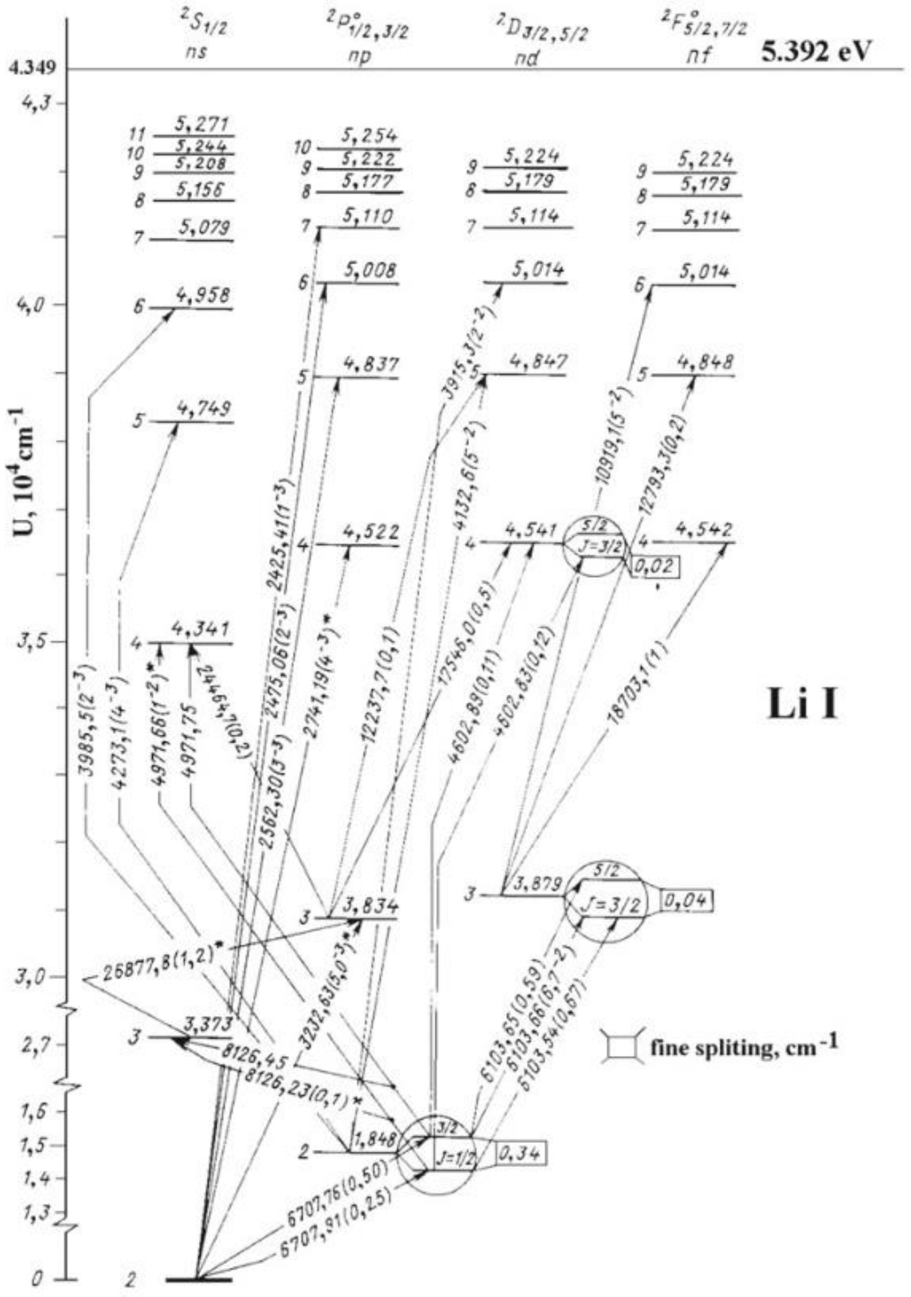
Laser Cooling Background

- **Using photons to slow individual atoms**
  - Temperature is a measure of average kinetic energy
  - Photons have momentum
  - Momentum transferred to atom when photon is absorbed
  - Photon randomly and symmetrically reemitted through spontaneous emission
  - Cycle continues until atoms are sufficiently slowed (Doppler Limit)



Grotrian Diagrams

- **Displays information about atomic structure:**
  - Allowed transitions
  - Lifetimes
  - Resonant Wavelengths
  - Fine and hyperfine structure



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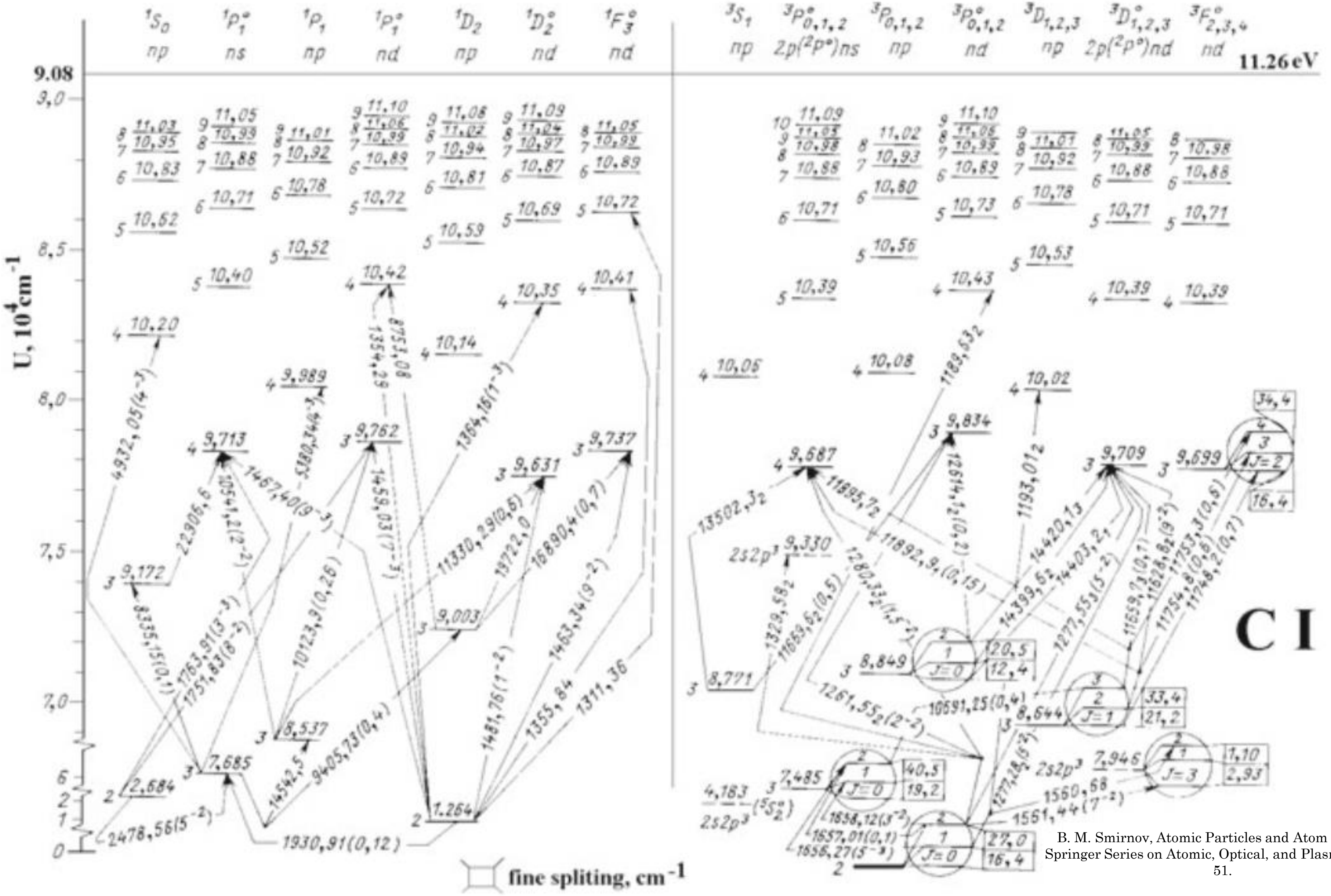
Research Goals

- **Originally planned for experimental work**
- **New project: Research, simulate, design an experiment to laser cool a new atom (C, N, O)**
- **Cooling these atoms is rewarding….**
  - Allows more precise measurements of structure and interactions
- **…Yet very difficult**
  - Ground state transitions within deep UV, current CW lasers insufficient
  - Decay rates too slow
  - Too many transitions to account for
  - Atomic sources can be difficult to create (N, O are diatomic)
- **After researching atoms, decided on Oxygen**



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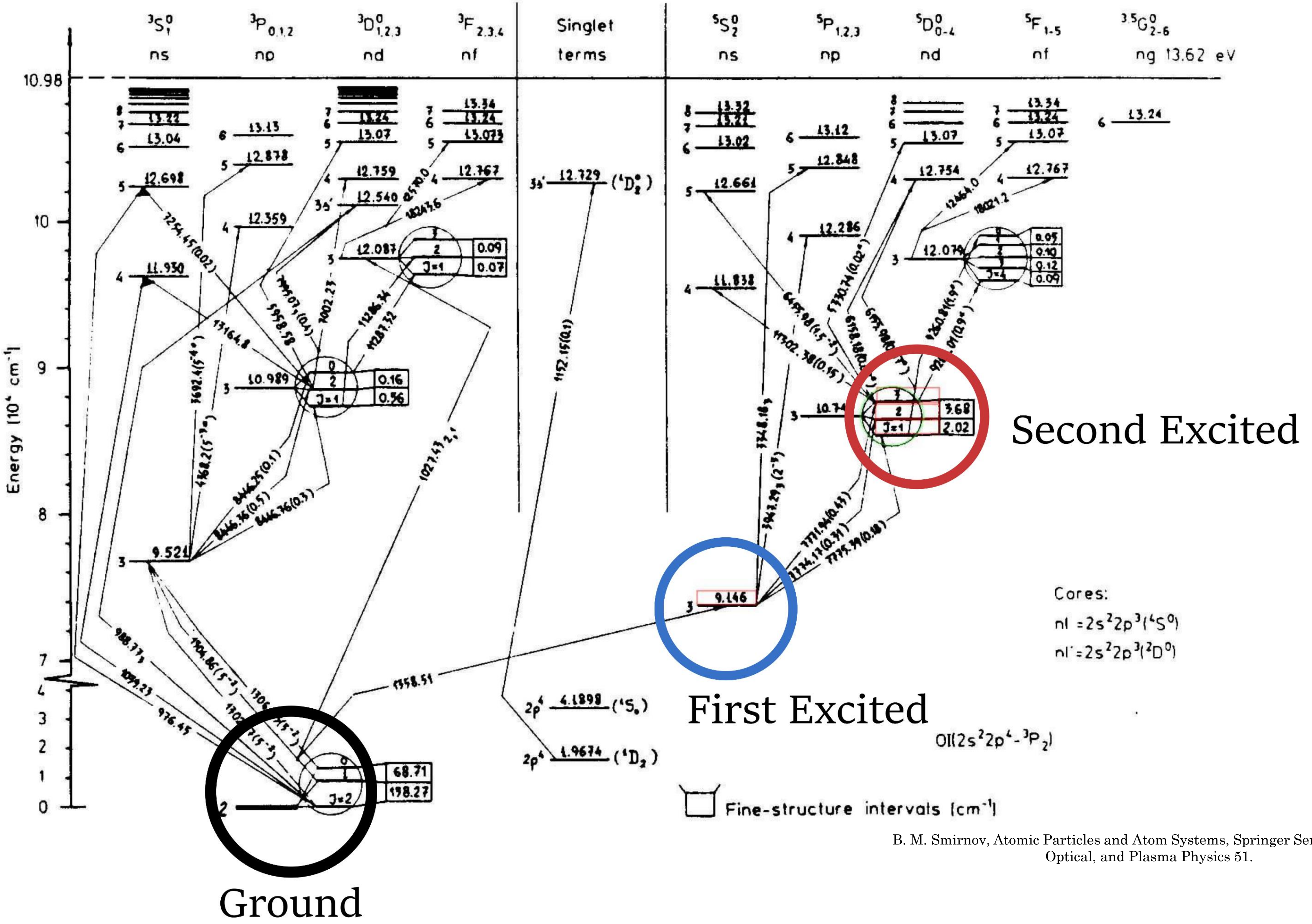
Why Oxygen?

- **Commercial radio frequency atomic beam sources available**
  - Oxford Research has models for nitrogen and oxygen
- **Metastable state exists in oxygen that potentially can be laser cooled**
  - Such states do not exist in carbon and nitrogen
  - Resonant wavelength very close to rubidium



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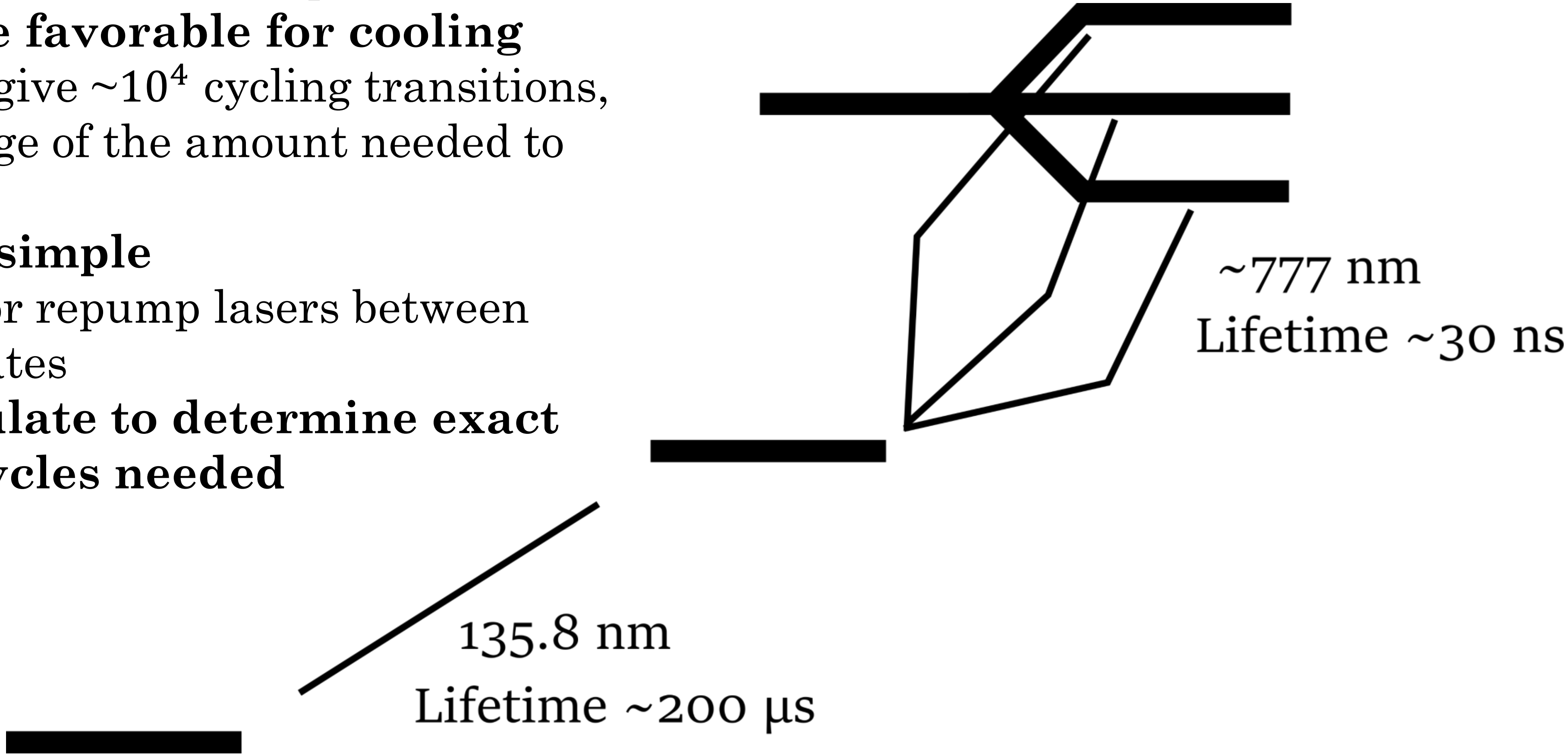
Simplified Diagram

- **Excited state fixes wavelength issue**
  - 135 nm CW light not currently possible
  - 777 nm light is trivial to produce
- **Lifetimes are favorable for cooling**
  - Lifetimes give ~10^4 cycling transitions, on the verge of the amount needed to cool
- **Structure is simple**
  - No need for repump lasers between excited states
- **Need to simulate to determine exact number of cycles needed**



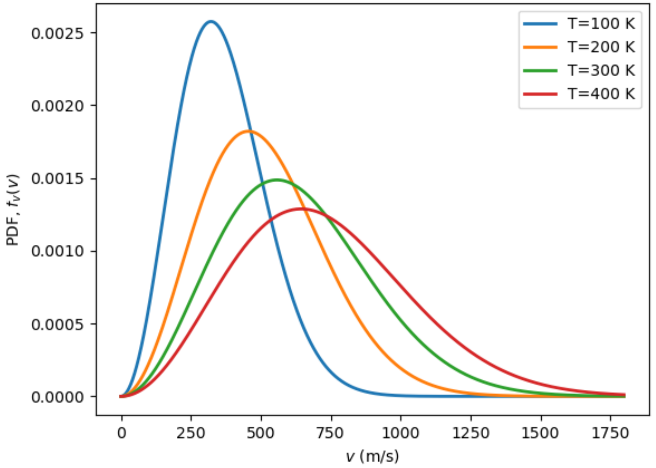
Simulating an Atomic Beam

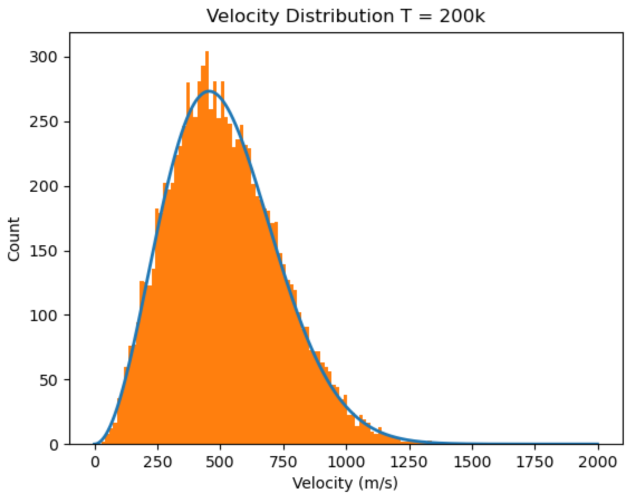
- **Computer simulation provides way to test theoretical calculations before moving forward**
- **Want to determine:**
  - Cooling time
  - Distance traveled
  - Fraction of atoms cooled
- **Written in Python**
  - Easy to create graphs
  - Useful mathematical libraries (scipy, numpy)

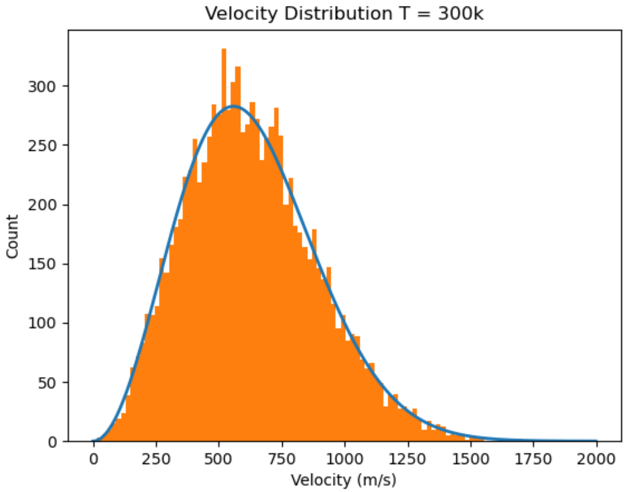
Monte Carlo Simulation

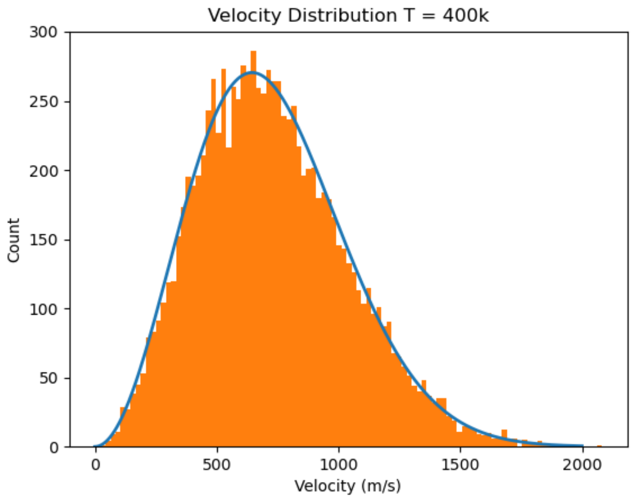
- **Monte Carlo Simulation used**
  - Repeated trials with randomly chosen initial conditions, usually weighted from a given probability distribution
- **Simulated atom given initial velocity in 3D space**
  - Velocity chosen randomly from Maxwell-Boltzman distribution
  - Angle chosen randomly from $cos(\theta)^2$ distribution
- **Each time step, a new position, velocity, and acceleration is calculated and recorded**
  - Acceleration calculated from laser cooling force

Velocity Distributions



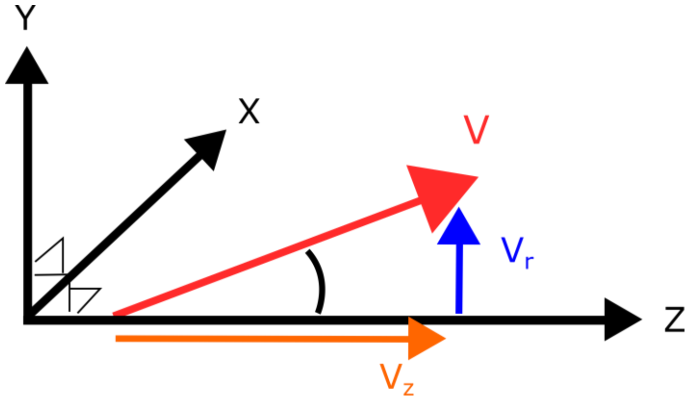


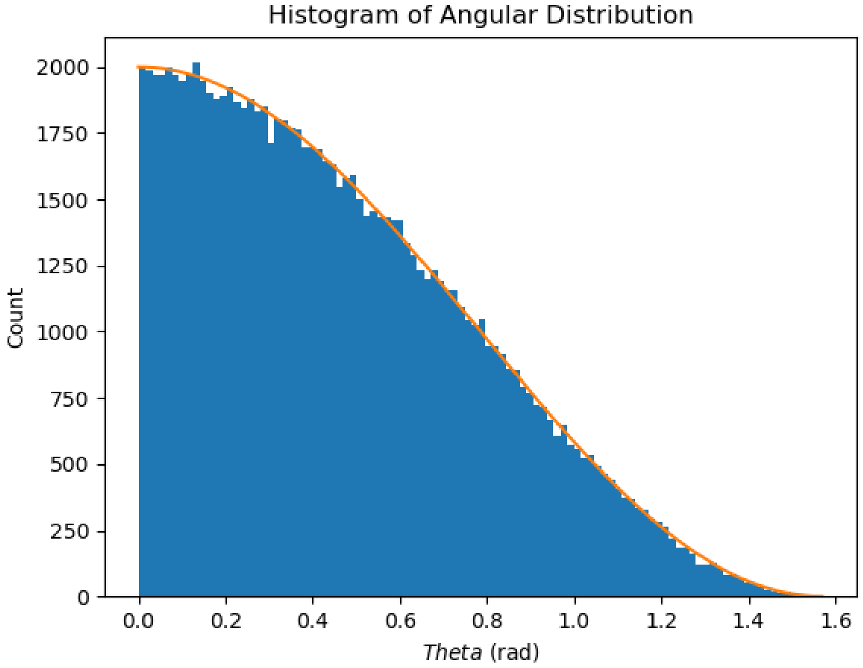


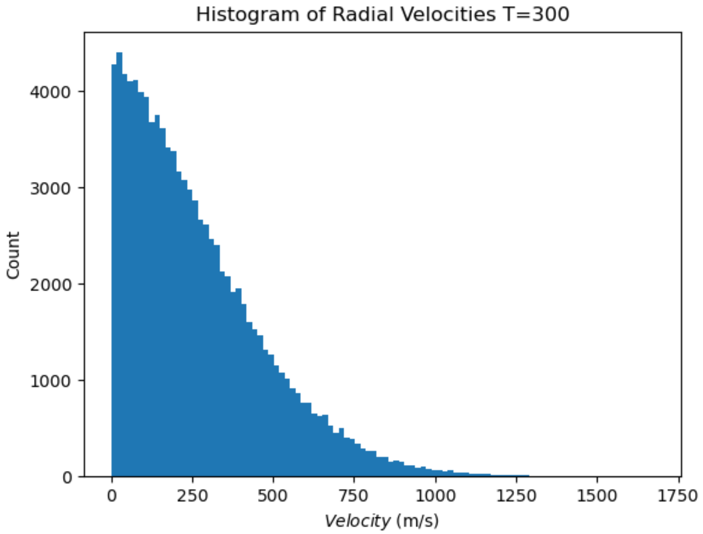


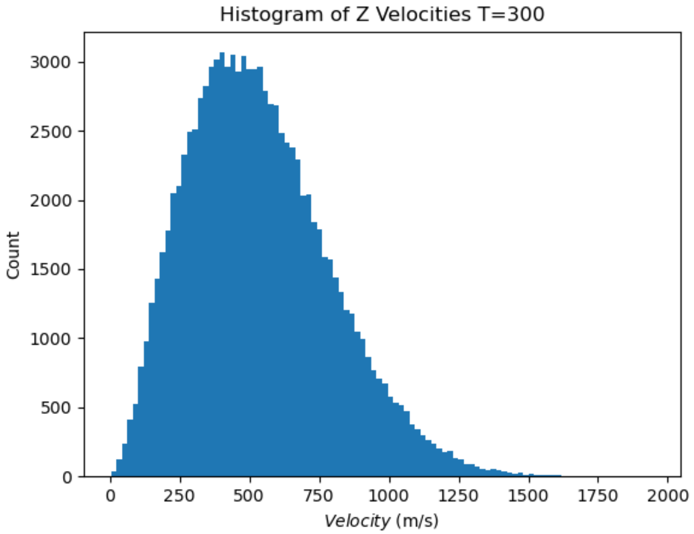
- 10,000 trials
- Histograms fitted to MB function for each temperature

Angular Distributions





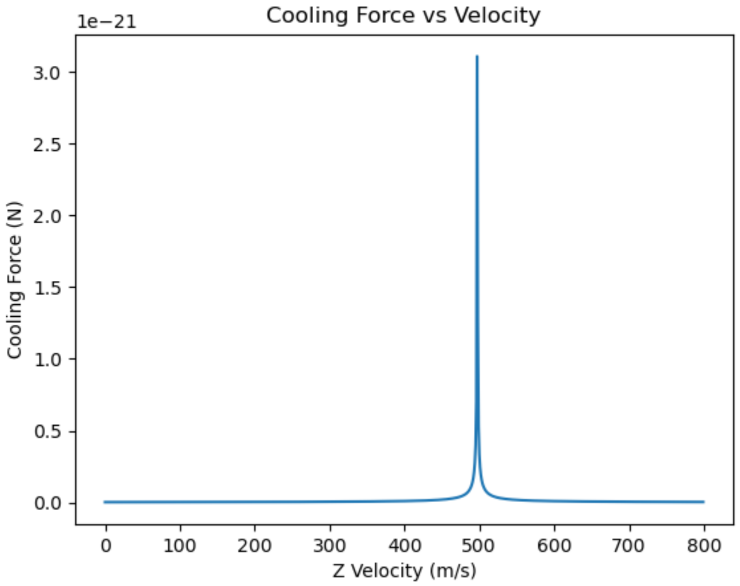


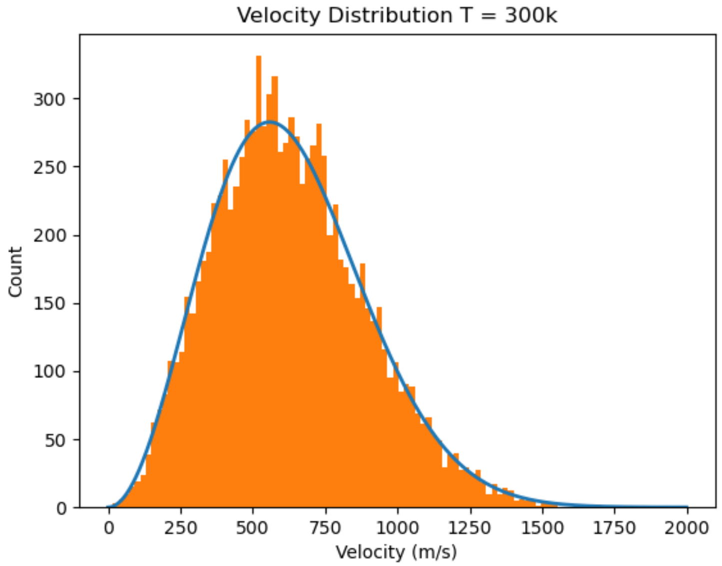


- 100,000 trials
- Fitted to $cos(\theta)^2$ function

- Z-axis is axis of propagation of the beam
- Distribution is symmetric around Z axis

Laser Cooling Force



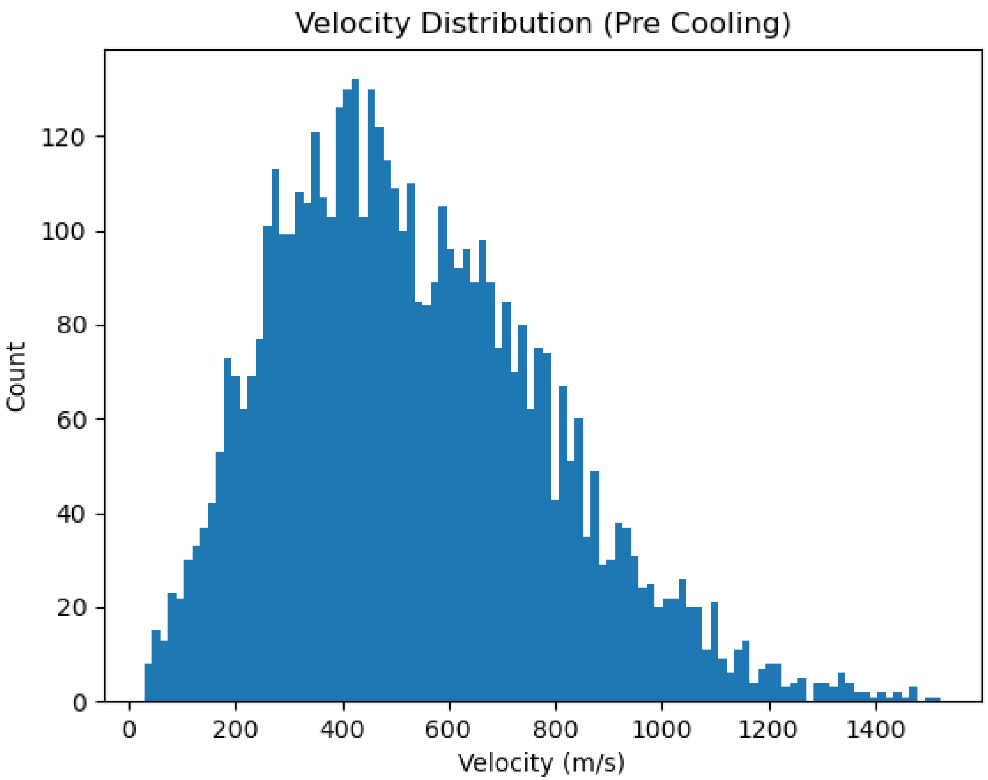


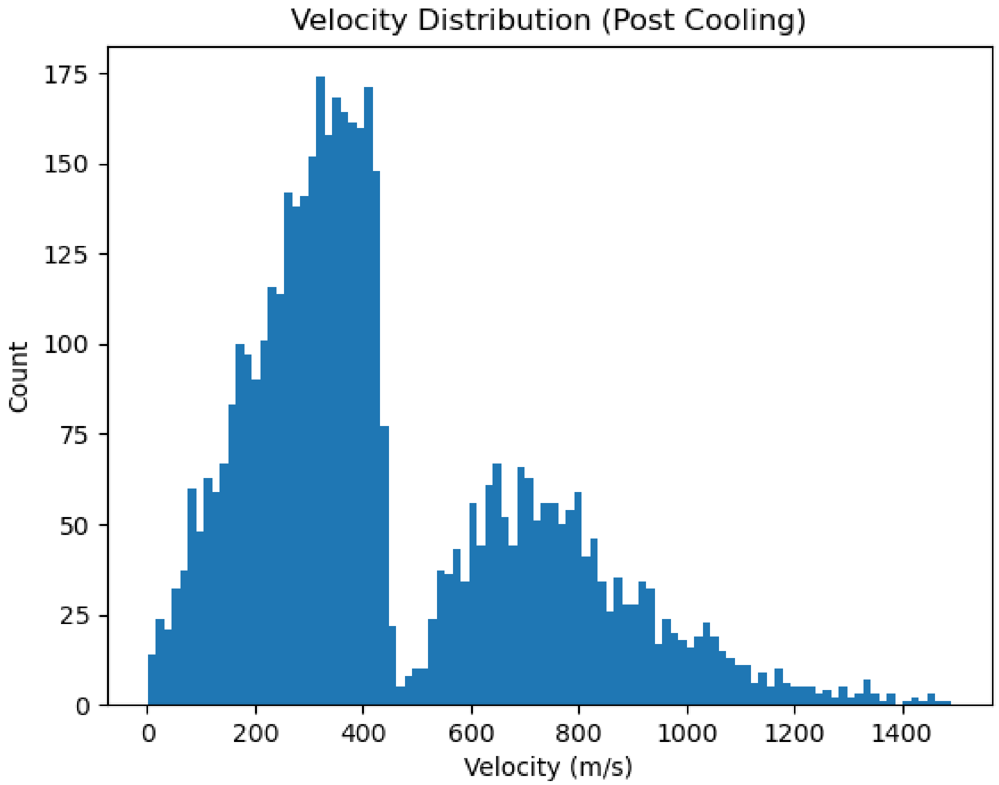
$$F_{laser} = \hbar \frac{2\pi}{\lambda}\left(s_0 \frac{\Gamma}{2}\right) / \left(1 + s_0 + \frac{2\left(\Delta - \frac{2\pi}{\lambda} v\right)}{\Gamma}\right)$$

λ - Laser wavelength
s_0 - Laser intensity
Γ - Natural Linewidth
Δ - Detuning
$\frac{2\pi}{\lambda} v$ - Dopler Shift

- Very narrow velocity band where force is non-negligible
- During simulation, force varies with time as atoms slow down,
  - need to change detuning to keep atoms interacting with the cooling force

Cooling – Fixed Detuning

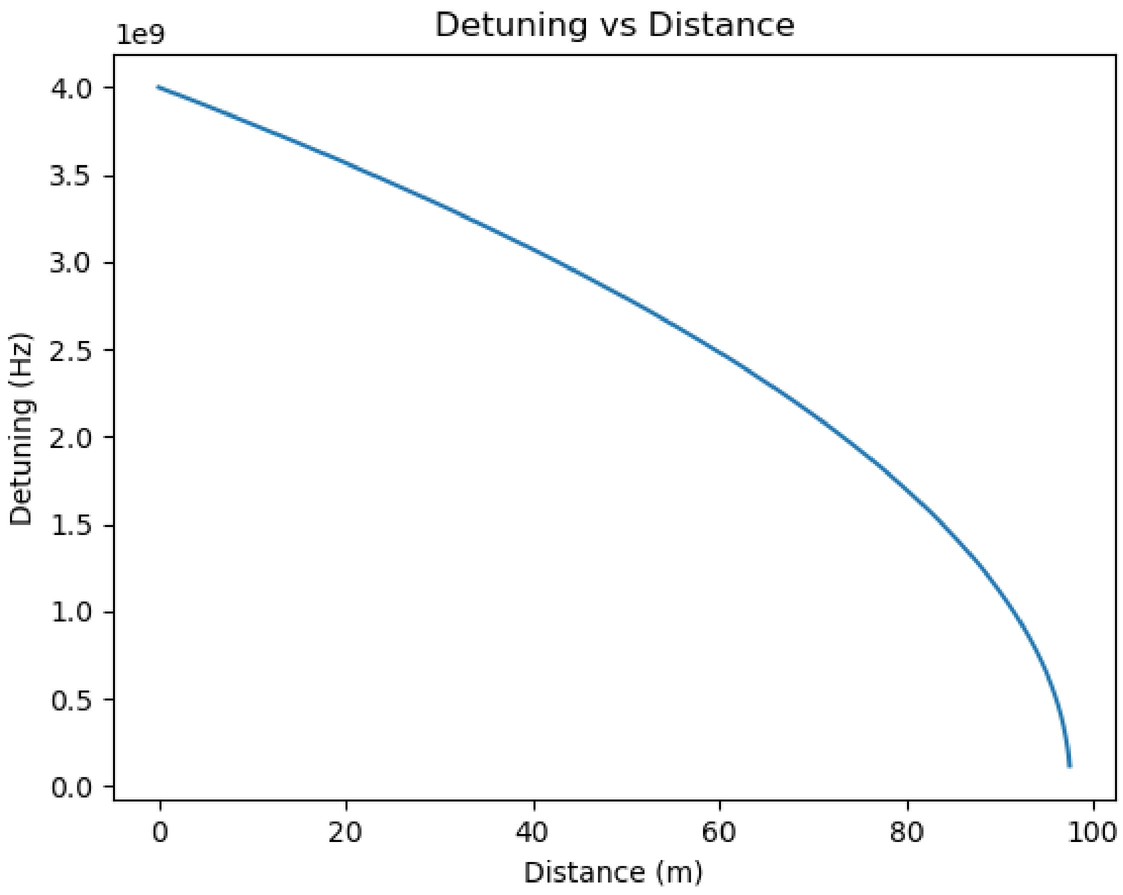




- 5,000 trials and fixed detuning of 4 GHz (same as previous force vs velocity graph)

Next Steps

- **Complete simulation**
  - Currently working a changing detuning into code
  - Once finished, will have a better idea what further work needs to be done
- **Determine how to excite out of the ground state**
  - Expect ~10,000 cycles before decay back into ground, will need to excite out from ground state multiple times
  - Pulsed laser and electron excitation are 2 possible methods
- **Looking into using a 'velocity skimmer'**
  - Selects low velocity tail of MB distribution
  - Lower speeds more easily able to be cooled



Any Questions!

Special thanks to:
Dr. Abraham
Dr. Abbott and Dr. Strauss

Thanks for listening!