Toward Laser Cooling Without Spontaneous Emission

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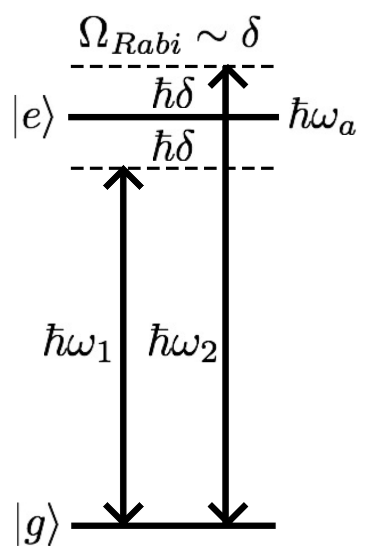
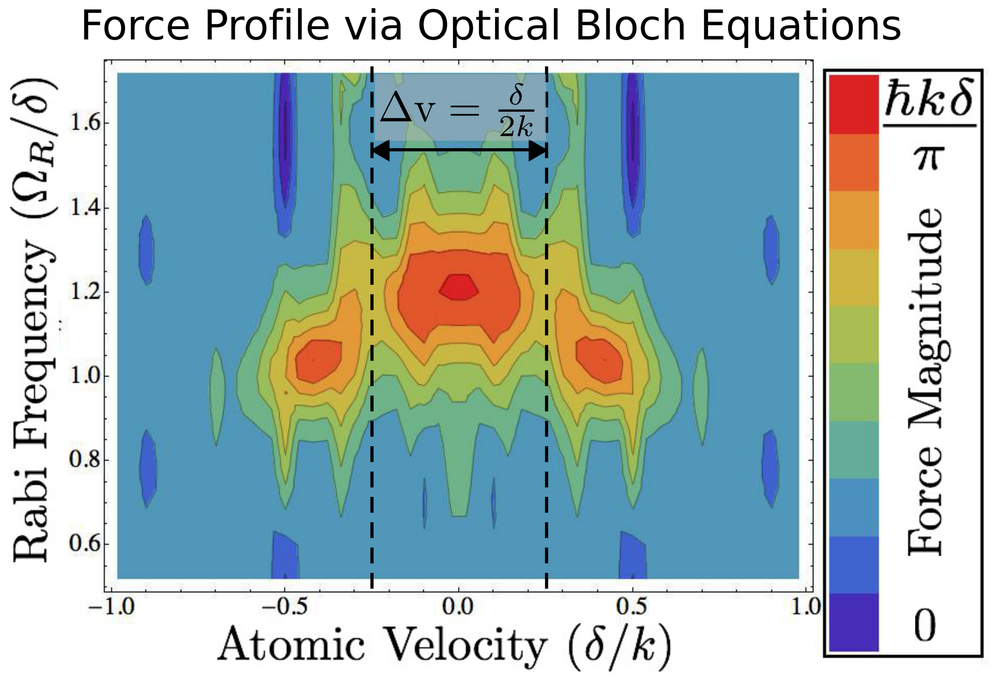
The Bichromatic Optical Force



First demonstrated over a decade ago, the bichromatic force uses stimulated emission to produce forces much larger than the usual radiative force. Such forces also span a much larger range of atomic velocities than radiative forces. However the role of spontaneous emission in the bichromatic force is very different from its role in the radiative force.

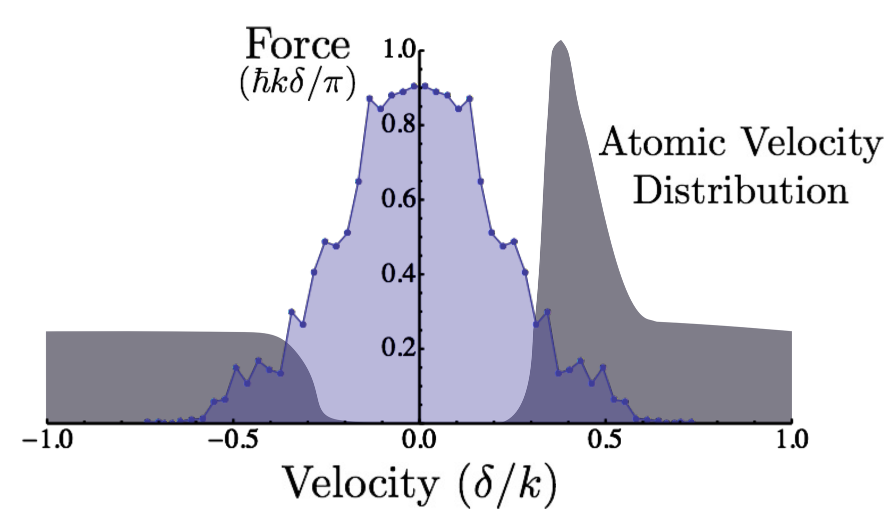
Estimated Cooling Time

Force Profile via Optical Bloch Equations



The bichromatic force profile (left) can be used to estimate the "cooling time", τ_c, the time it will take to push all the atoms to the edge of the force profile.

$$\tau_c \sim \frac{M\Delta v}{F} \sim \frac{M\delta/2k}{\hbar k\delta/\pi} = \frac{\pi}{4\omega_r}$$



The bichromatic force profile for a particular Rabi frequency is shown to the right. The initially uniform velocity distribution (not shown) should accumulate at the edge of the force profile, shown schematically, after time τ_c.

Is Spontaneous Emission Important?

Without the spontaneous emission process playing a significant role in the momentum transfer, is it necessary for cooling at all?

To test this we can apply the bichromatic force to an atom with an excited state lifetime (τ) that satisfies:

$$\tau \sim \tau_c \sim \frac{\pi}{4\omega_r}$$

Metastable Helium

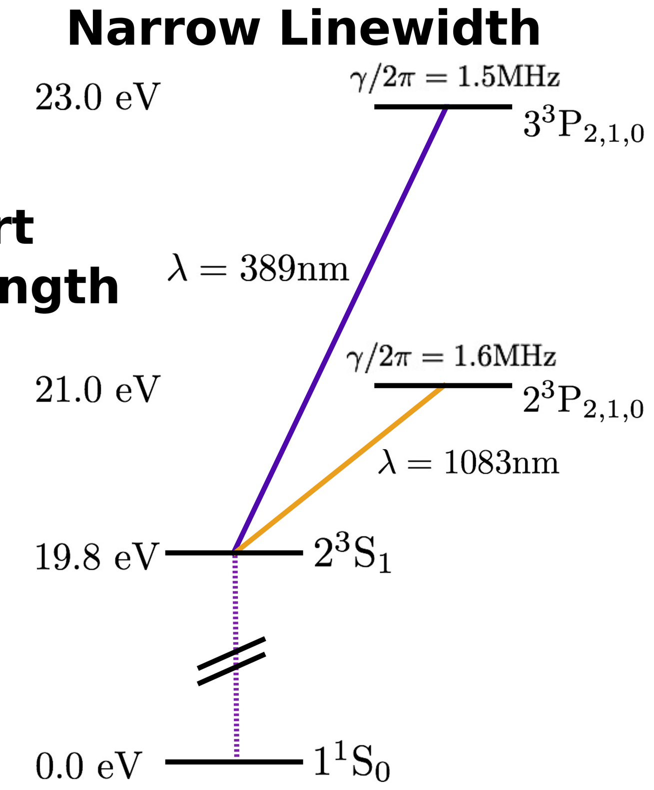
Helium is a good candidate if we look at the atomic properties that determine the condition above.

Small Mass

2	4
He	
Helium	

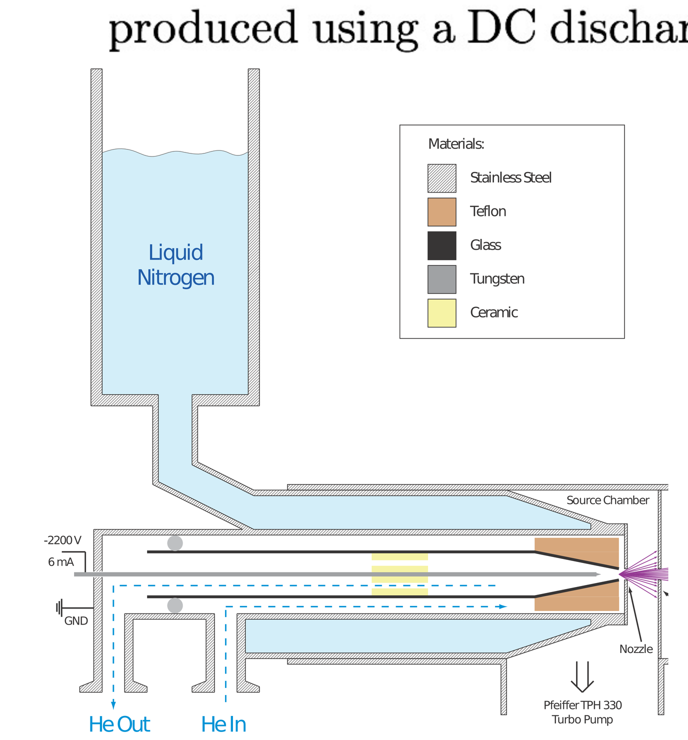
Short Wavelength

Narrow Linewidth



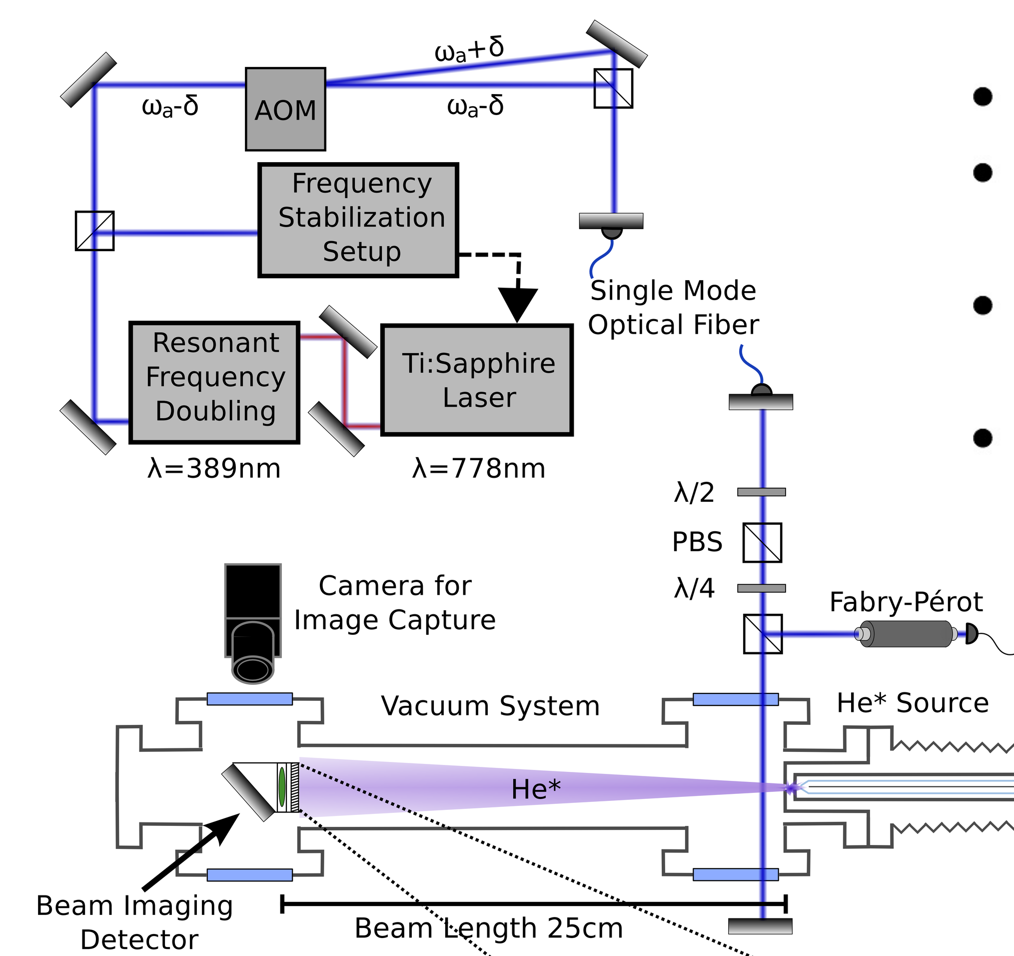
$2^3S \rightarrow 3^3P$
$w_r = 2\pi \times 330$kHz
$\tau = 107$ns
$\tau_c = 380$ns

A beam of metastable Helium is produced using a DC discharge source.



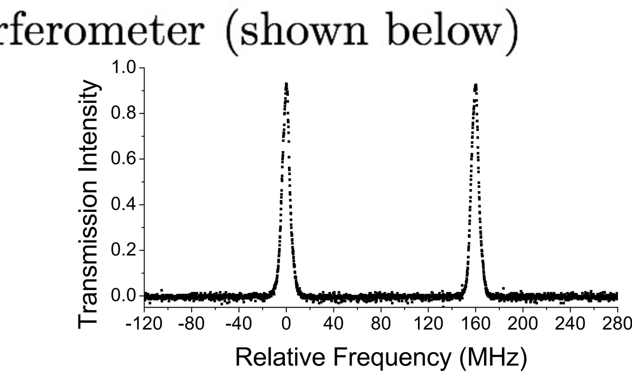
Flux $\sim 10^{14} \frac{\text{atoms}}{\text{sr}\cdot\text{s}}$ $\quad$ $v_{long} \sim 10^3$m/s

Experimental Setup



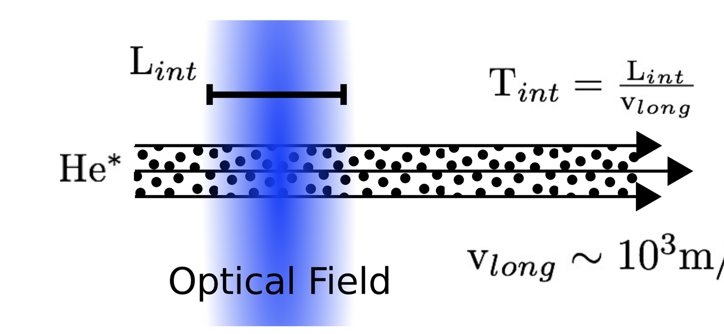
Optical Setup

- Frequency doubling produces 350mW CW at 389nm
- Frequency stabilized and locked with atomic transition using saturation absorption spectroscopy
- Bichromatic beam produced with an AOM and beamsplitter and fed into an optical fiber
- The frequency spectrum is monitored using a Fabry-Pérot interferometer (shown below)



Interaction Time

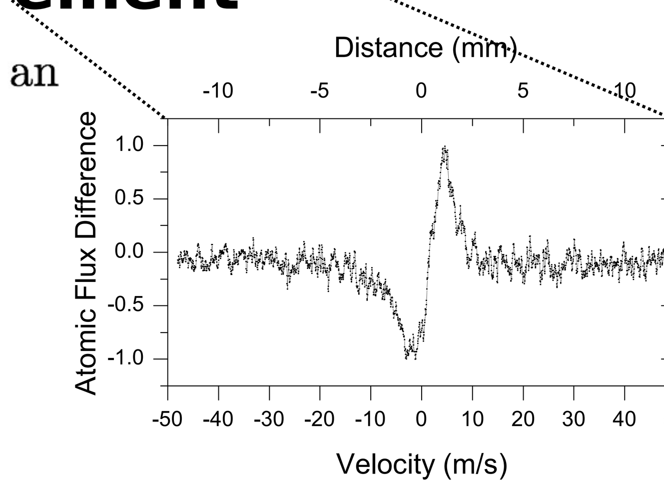
- We apply the bichromatic force along one transverse dimension of the Helium beam
- The atom-optical interaction time is controlled using the optical beam size



Velocity Measurement

- The atoms are imaged using an MCP phosphor screen detector
- TOF retrieves the transverse velocity distribution

$$v_t = \frac{\Delta x}{25\text{cm}} \times v_{long}$$

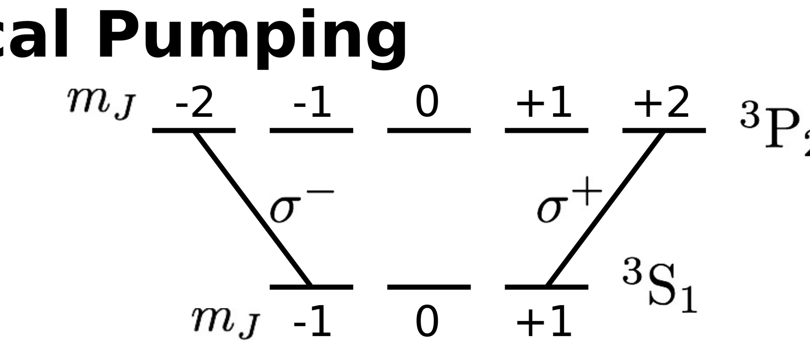


Magnetic Field and Optical Pumping

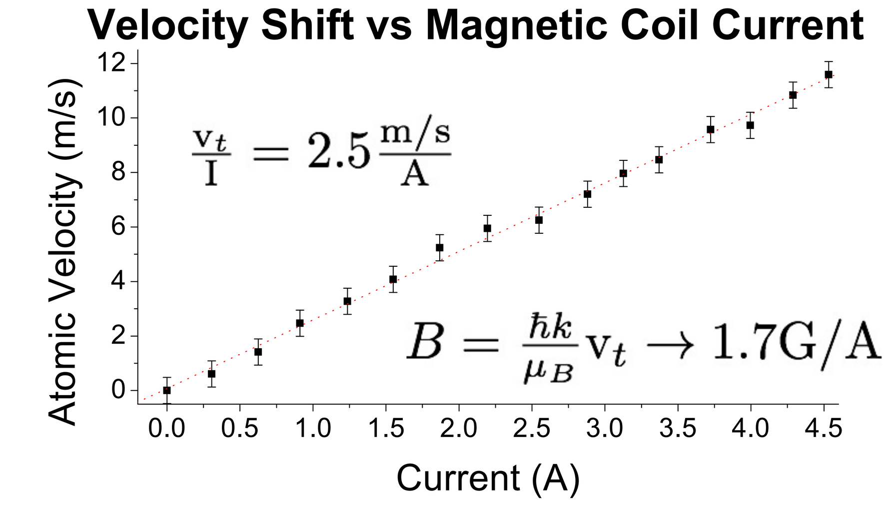
- An IR laser for optical pumping is added before the bichromatic interaction tuned to the $2^3S \rightarrow 2^3P$ transition
- A small magnetic field aids the IR light to optically pump the atoms into $m_J = +1$ (-1)
- Proper choice of UV polarization σ^+ (σ^-) results in a two level system
- The value in velocity of an IR radiative force will change as the Doppler shift compensates the Zeeman shift, allowing calibration of the magnetic field

Zeeman Shift $\quad$ $\omega_a \pm \mu_B B/\hbar$

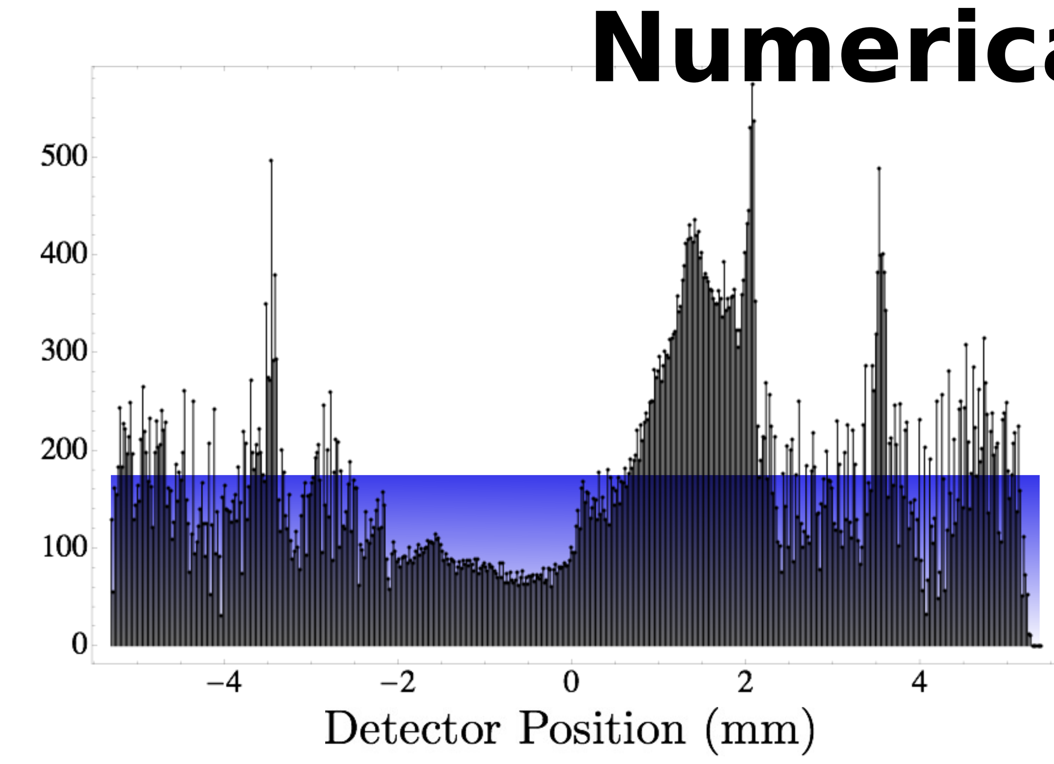
Doppler Shift $\quad$ $\omega_a \pm kv$



Velocity Shift vs Magnetic Coil Current



Numerical Simulations



Atomic flux at the detector
Initial atomic distribution - Blue
After bichromatic force - Black

- Our numerical simulations are calculated from integration of the combined optical Bloch equations and atomic equations of motion
- The simulated atomic flux following a bichromatic interaction time ($T_{int} = \tau_c$) is shown to the left

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