Velocity Dependence of the Optical Force Produced by Adiabatic Rapid Passage

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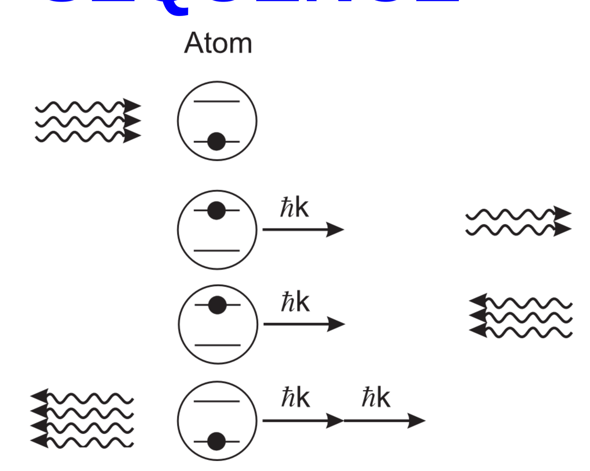
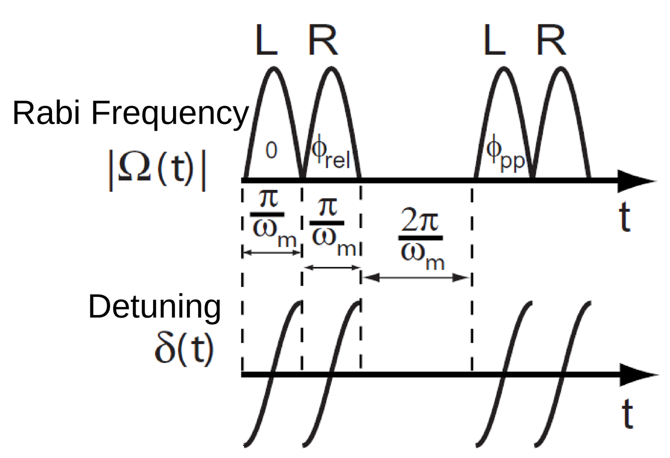
INTRODUCTION

Adiabatic Rapid Passage (ARP) produces optical forces much larger than the ordinary radiative force, and is thought to work best when $\Omega_0 \sim \delta_0 \gg \omega_m \gg \gamma$, where $\Omega_0, ~ \delta_0,~ \omega_m, {\rm ~and~} \gamma$ are the Rabi frequency, sweep range, sweep rate, and natural decay rate respectively. We have observed strongly enhanced ARP forces on the 2^{3}S$_1 \rightarrow$ 2^{3}P$_2$ transition of He outside of this parameter range with our improved apparatus described previously.\footnote{D. Stack et al., Bull. Am. Phys. Soc. {\bf 56}, 153 (2011)} Our counter-propagating, chirped pulses allow greater freedom in the choice of relative beam parameters allow independent detuning of the beams to simulate atomic motion. We will present our new data on the velocity dependence of the ARP force.

FORCE FROM PERIODIC ARP SEQUENCE



Coherent control of the momentum exchange between optical fields and atoms is possible using precisely timed pulses that cycle the atoms between ground and excited states, thereby exchanging momentum with the light field. Large forces can result if this process is robust and able to be rapidly repeated many times in succession.



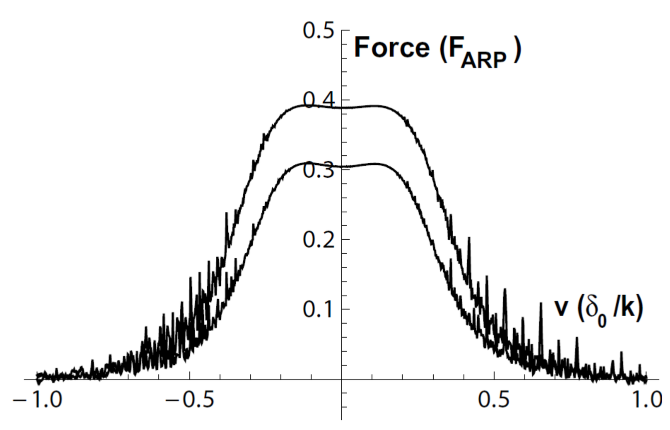
Chirping Frequency: ω_m = 100 \gamma = 2pi * 160 MHz

Pulse Parameters: 80 MHz rep rate with 25% duty cycle (3.125 ns pulse length)

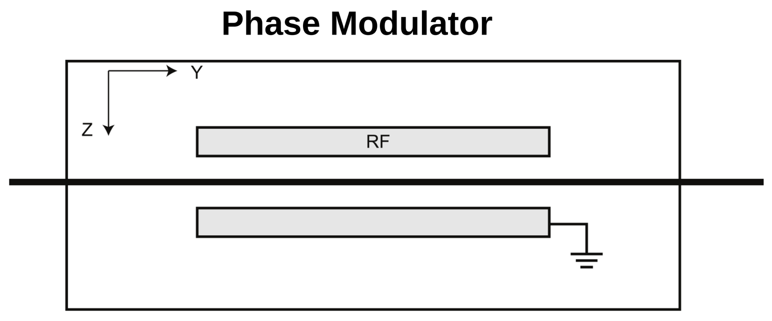
An ARP sequence consists of sequential left and right propagating, chirped pulses interacting with the atoms followed by a dead time of $2\pi/\omega_m$.

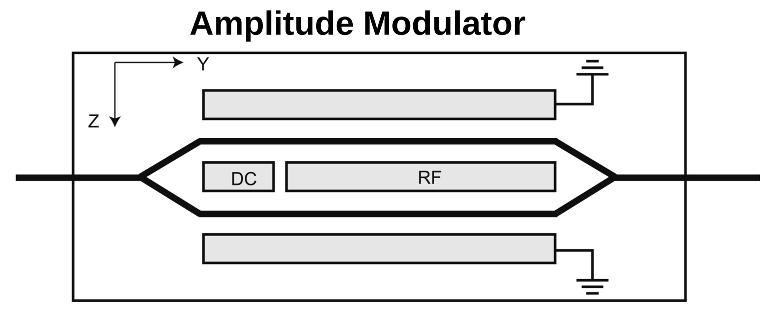
$$\bar{F}_{ARP} = \frac{\Delta p}{\Delta t} = \frac{2\hbar k}{4\pi/\omega_m} = \frac{\hbar k \omega_m}{2\pi} \approx 32 F_{rad}$$

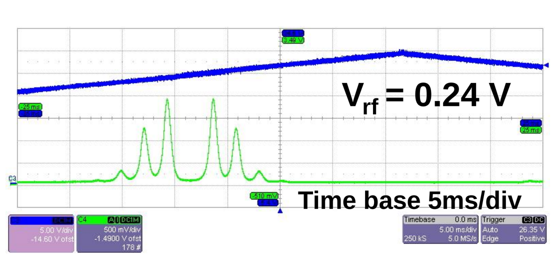
Forces suitable for laser cooling must have significant strength at some velocities and vanish at others. For the radiative force in the low intensity limit, $v_c \sim \gamma/k$ and is entirely dependent on the atomic properties. By contrast, the velocity capture range for the ARP force, $v_c \sim \delta_0/k$, can be substantially increased by choosing $\delta_0 >> \gamma$ so that it can be orders of magnitude larger than that of the radiative force. The ARP force remains large for velocities where the Doppler shifts are well with the range of the frequency sweep as seen in the figure on the right.



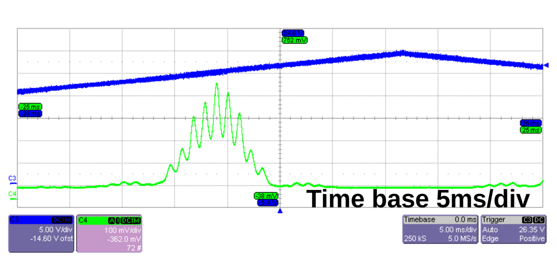
MAKING CHIRPED PULSES



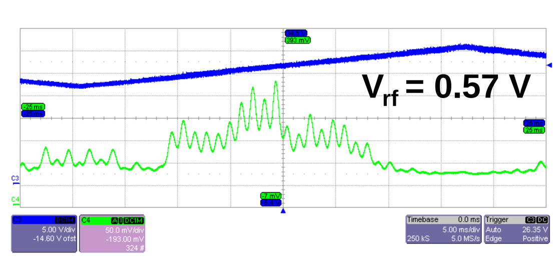




Phase Modulation 160 MHz



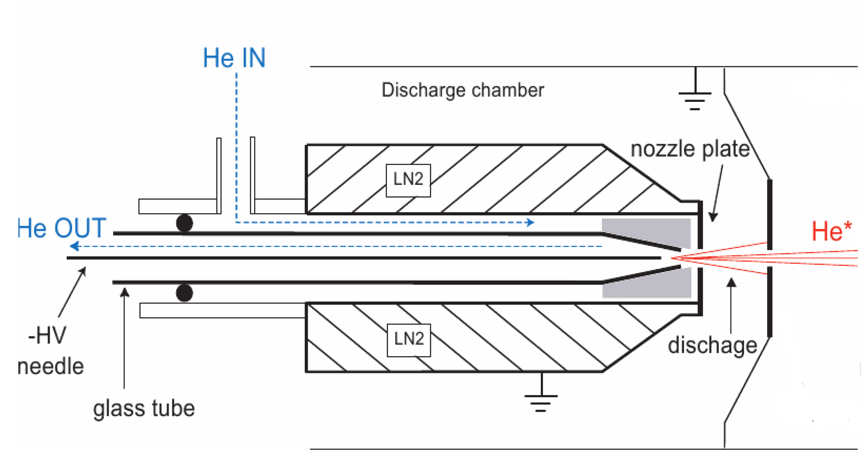
Amplitude Modulation 80 MHz

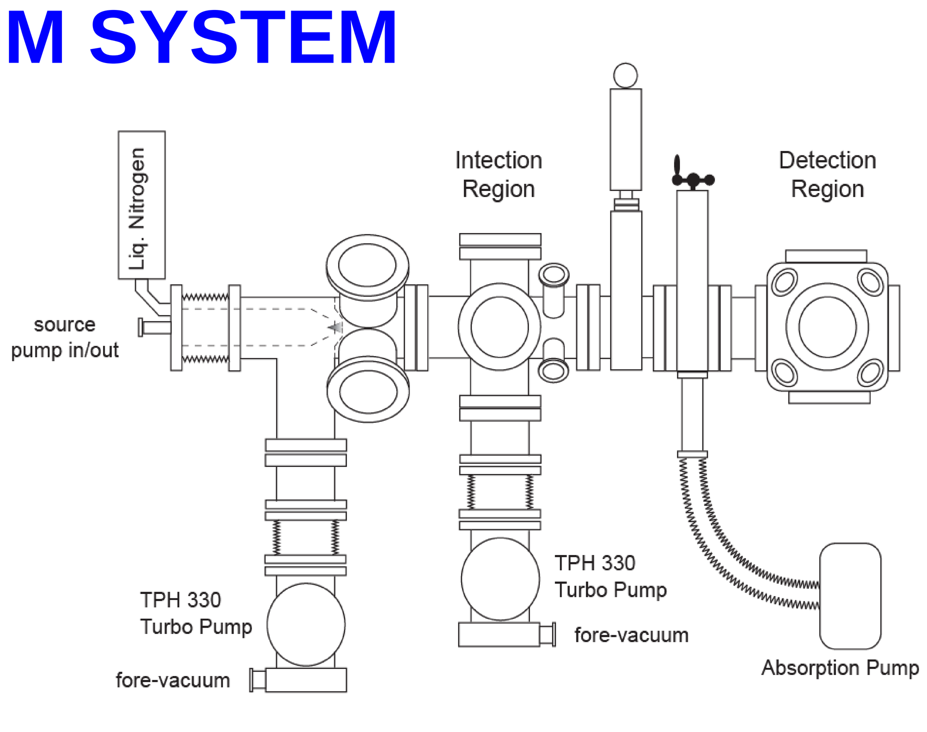


Chirped Pulses

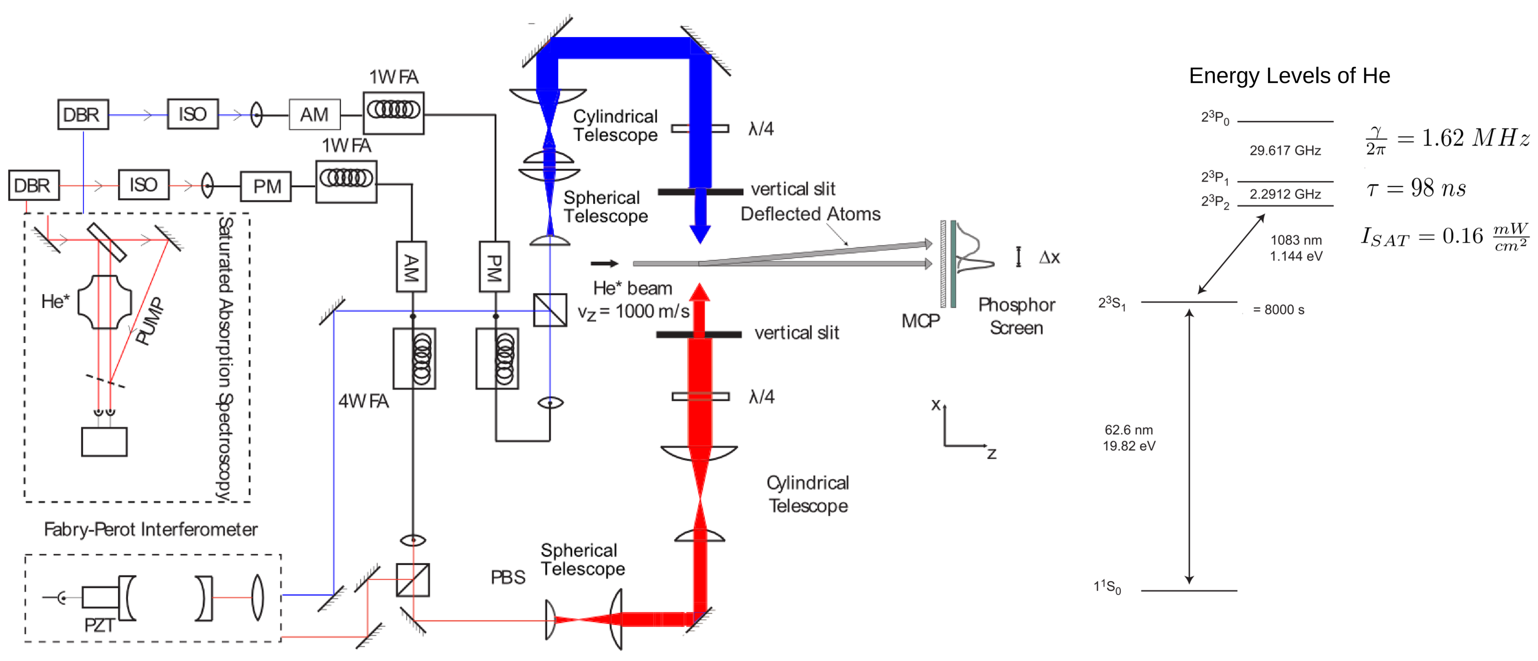
Time base 5ms/div

VACUUM SYSTEM

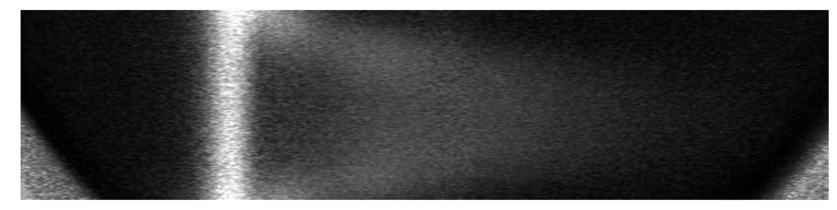


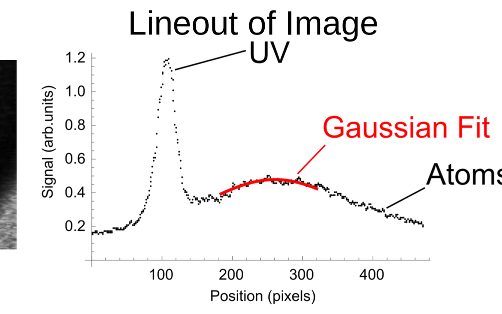


EXPERIMENTAL SETUP



MEASURING THE FORCE

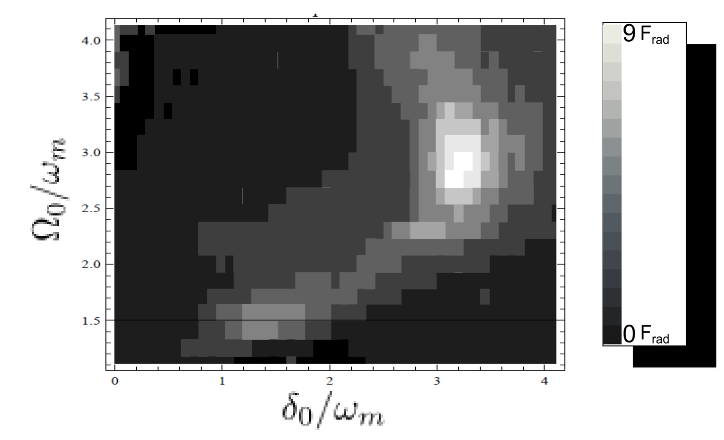




$$\frac{F_{ARP}}{F_{rad}} = \frac{m v_z^2 \Delta x}{L_{int} L_{flight}} \frac{2}{\hbar k \gamma}$$

Δx *is deflection* $L_{flight} = 35\ cm$

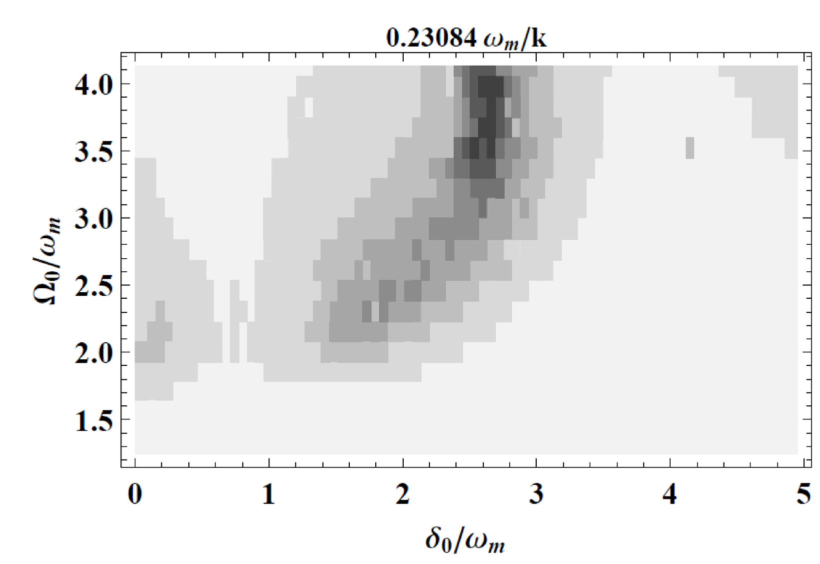
$L_{int} = 4\ mm$ $v_z = 1000\ m/s$

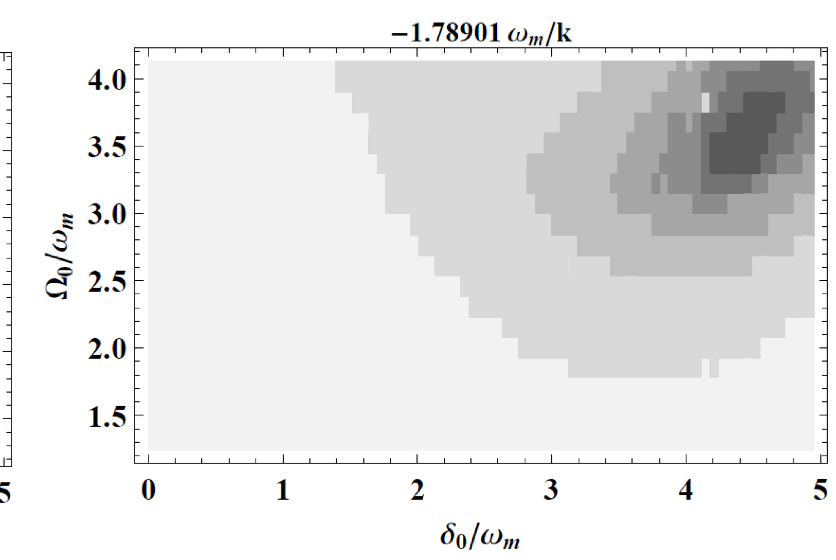


Optical force in units of the radiative force as a function of optical intensity and amplitude of the frequency sweep with both optical sweeps centered on atomic resonance.

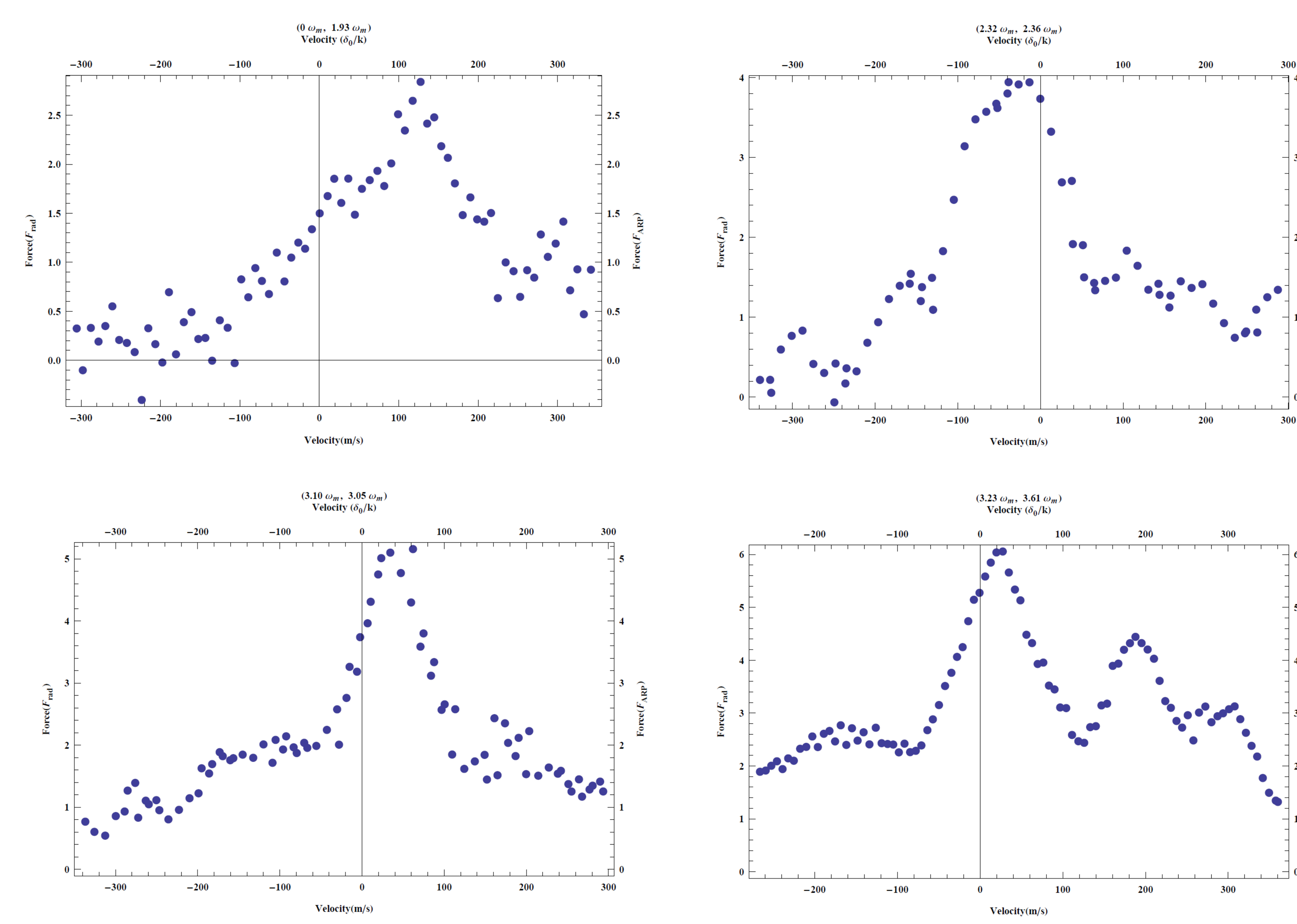
FORCE MAPS AT FIXED VELOCITY

Optical beams originate from a single diode and are detuned symmetrically about atomic resonance via an AOM to simulate an atomic velocity along the laser propagation axis.





FORCE VS VELOCITY



Shown above is the measured optical force as a function of simulated atomic velocity for specific values of intensity and frequency sweep. Optical beams are produced by 2 independent lasers swept antisymmetrically about atomic resonance.

SUMMARY

- We have produced optical forces that are nearly an order of magnitude larger than the radiative force with He* by using many ARP sequences.
- These forces cover a much larger range of atomic velocities than the typical radiative force.

Further Reading

[1] X. Miao, E. Wertz, M. Cohen, and H. Metcalf, Phys. Rev. A **75**, 011402 (2007).

[2] D. Stack, J. Elgin, P. Anisimov, H. Metcalf, Phys. Rev.

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