

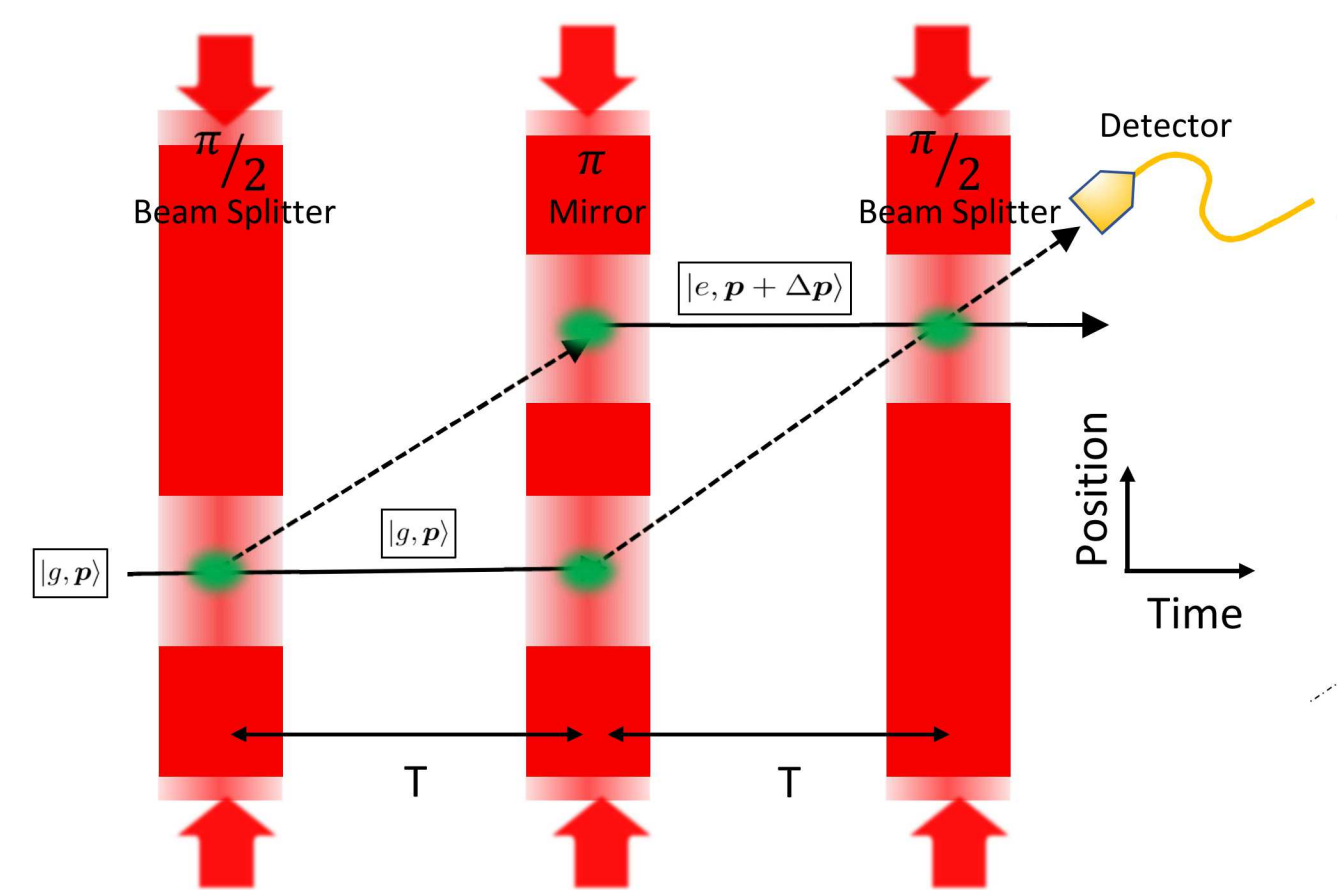


Toward a Nanofiber Atomic Guide for Atom Interferometry

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What is Atom Interferometry?

Atom Interferometers (AI) can measure gravity, acceleration, and rotation with high precision¹. They work by exploiting momentum conservation and wave-particle duality. A Light Pulse Atom Interferometer (LPAI) utilizes three light pulses in a $\frac{\pi}{2} - \pi - \frac{\pi}{2}$ sequence. During each pulse momentum is transferred splitting the atomic wave packet, redirecting it, and recombining it, after which the atomic state is detected¹.



AI light pulses are coupled into the fiber

Light-Atom Interaction

- Large momentum transfer can be achieved with a single pulse⁵
- Use external degrees of freedom
- No unwanted AC stark shifts
- Cloud separation is required for detection using imaging
- Large momentum transfer using multiple pulses¹¹
- Use internal degrees of freedom
- Susceptible to external fields
- Detection dependent on fluorescence

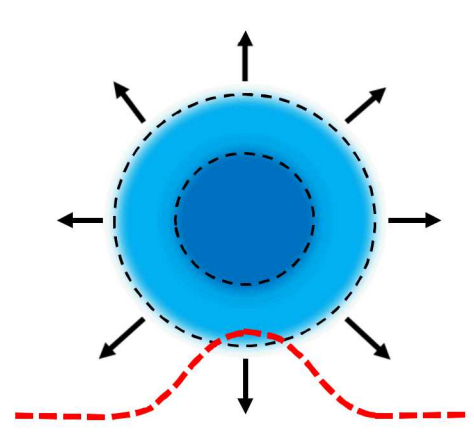
Motivation for Guided Atom Interferometry

An attractive application for AI is inertial navigation without GPS¹. It requires smaller devices that perform well in dynamic environments. The advantage of Guided Atom Interferometry (GAI) is to spatially localize atoms even in these noisy environments while increasing the light – atom interaction efficiency reducing the laser power and thus equipment size required.

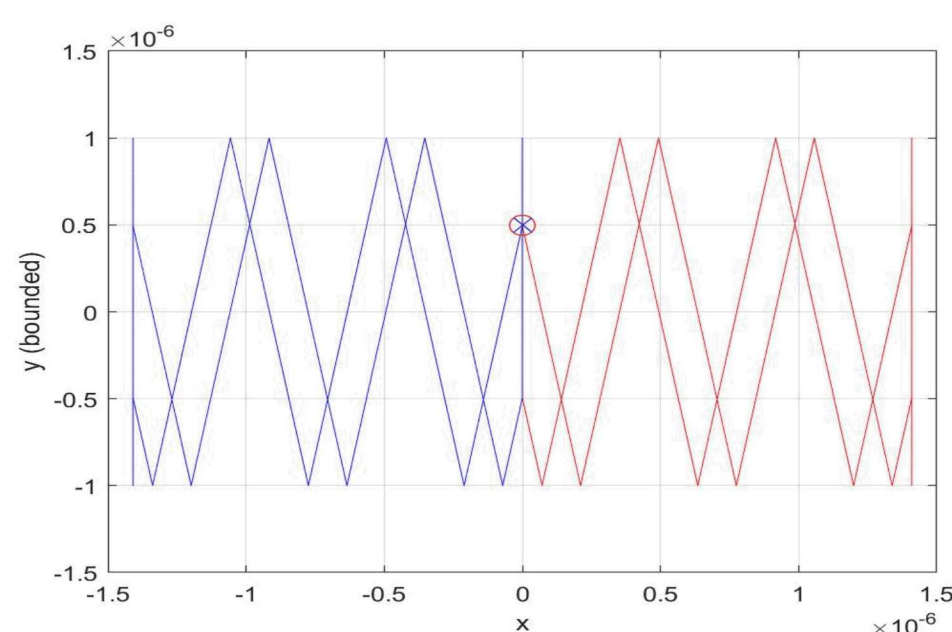
Spatial localization also offers the unique opportunity for probing atom-surface interactions. This tight confinement allows control of the proximity of the atom to a surface.

- Casimir-Polder (CP) force can deflect atoms at distances below $2.3 \mu\text{m}$. Nanofiber based atom traps confine atoms $\sim 250 \text{ nm}$ from surface¹⁰.
- Gravitational constant was measured using AI by varying atom-test mass distance with an uncertainty³ $\delta G/G = 3 \times 10^{-4}$ (current CODATA uncertainty is $\delta G/G = 4.7 \times 10^{-5}$)
- Inverse Square Law (ISL) violation experiments require below micron scale confinement to probe non-Newtonian forces⁴

Free Space Expansion

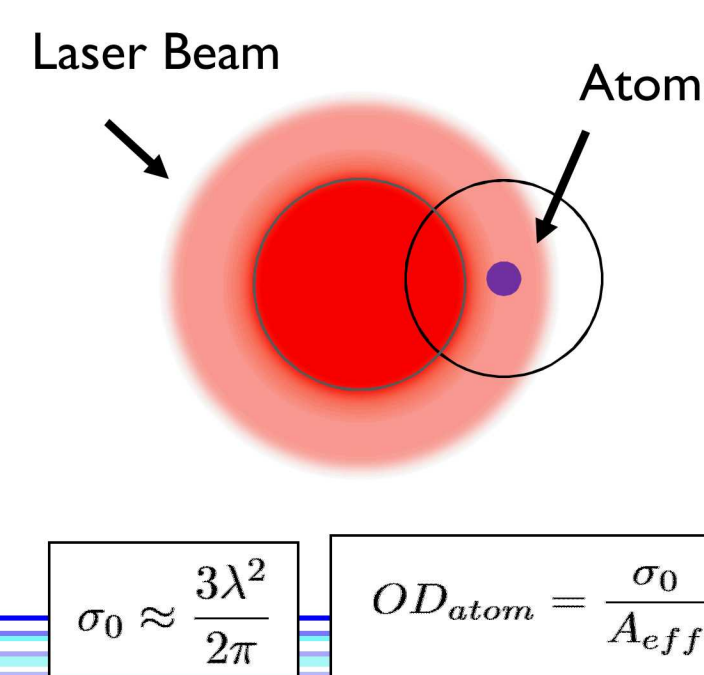


Atomic "Trajectory" Guide Boundary



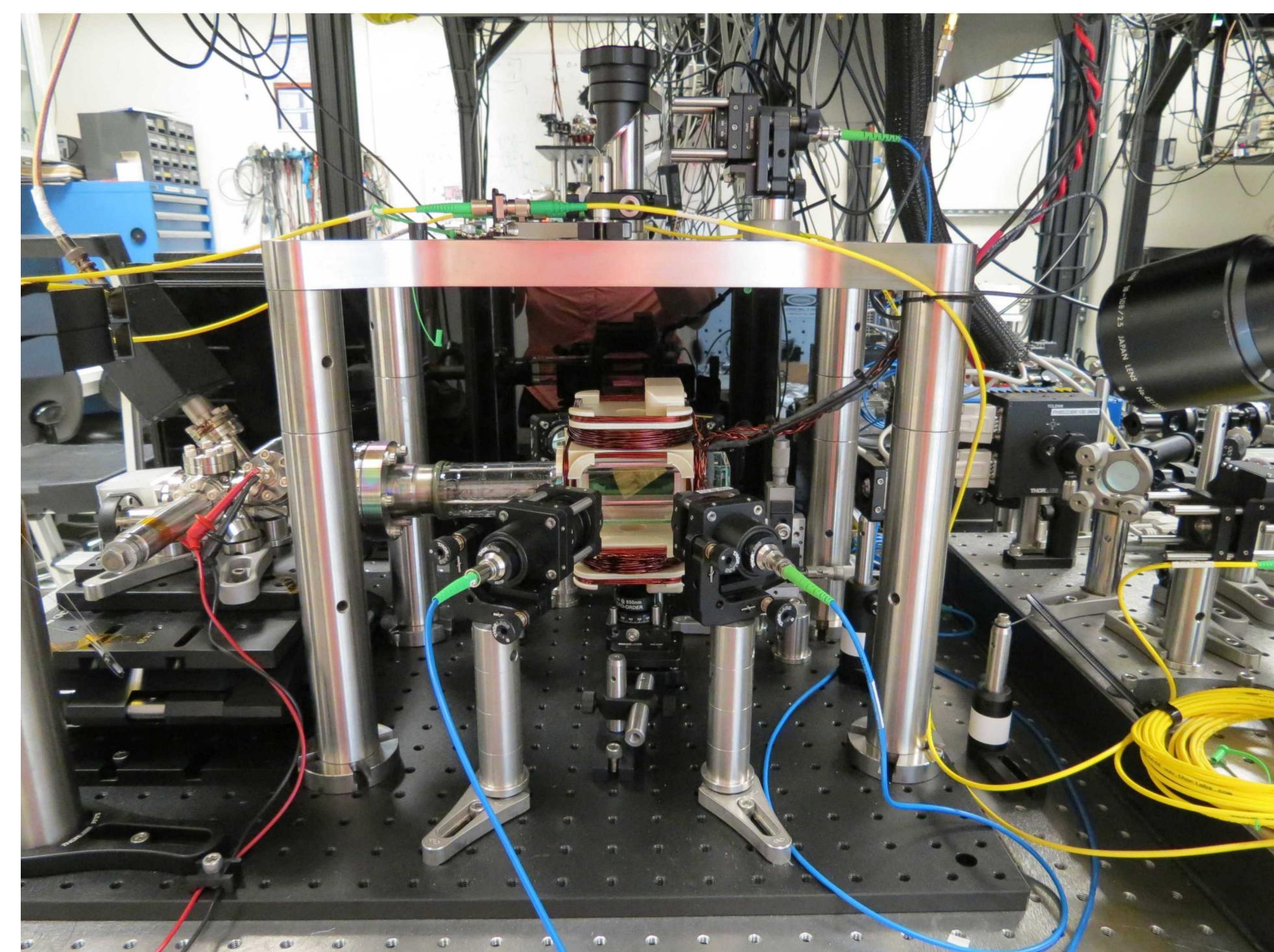
Why Nanofibers?

- The optical depth describes the efficiency of the atom-light interaction.
- Nanofiber atomic guides provide a large optical depth (OD) per atom OD_{atom} when compared to other guiding geometries (see table).
- Large OD means that lower laser power is required to drive atomic transitions⁵



Atomic Guide (Beam Waist Radius)	OD _{atom}	OD	# Trapped Atoms
Free Space ($w_0=2.25 \text{ mm}$) ⁶	$3.1 \cdot 10^{-9}$	$3.1 \cdot 10^{-4}$	10^5
Focused Dipole Beam ($w_0=35 \mu\text{m}$) ⁷ (with cold atoms)	$6.0 \cdot 10^{-5}$	0.3	5^3
Focused Dipole Beam ($w_0=40 \mu\text{m}$) ⁸ (with BEC)	$1.4 \cdot 10^{-5}$	0.7	5^4
Hollow Core Fiber ($w_0=22 \mu\text{m}$) ⁹	$2.3 \cdot 10^{-4}$	3.5	15^3
Tapered Optical Fiber (spatially dependent) ¹⁰	$1.6 \cdot 10^{-2}$	32	2^3

Experiment Underway

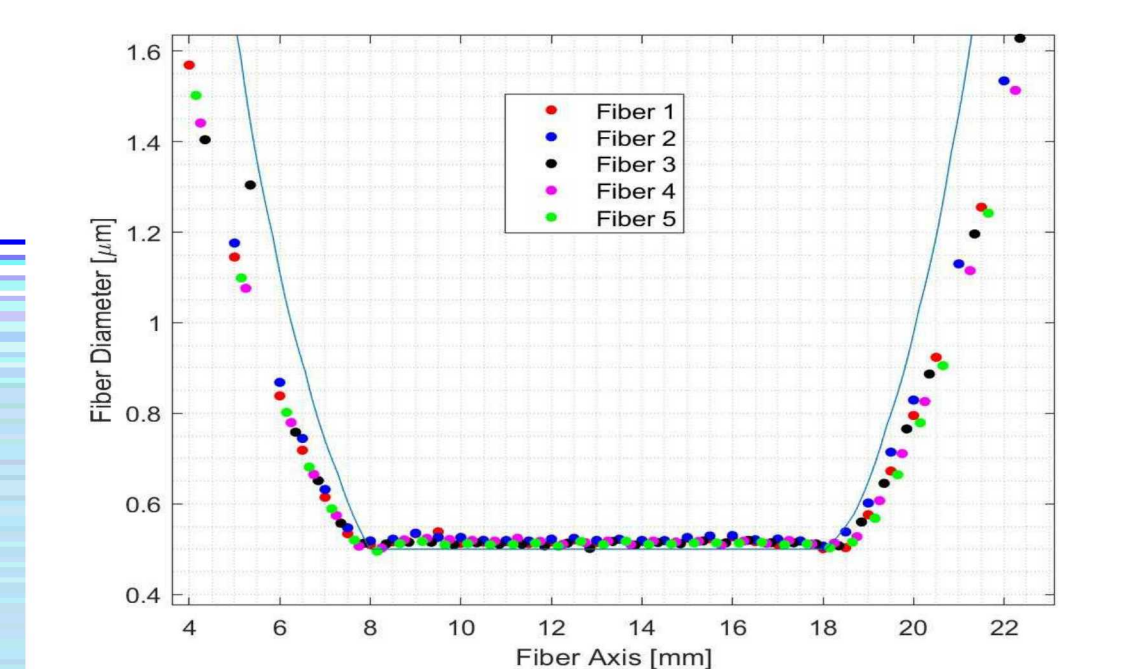
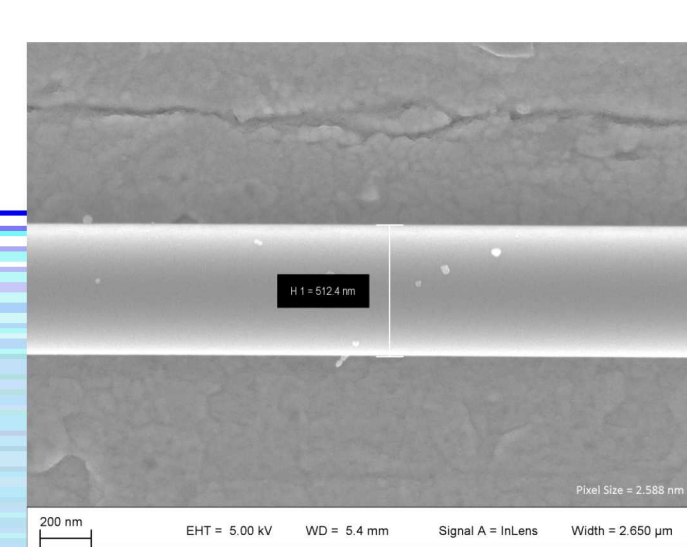
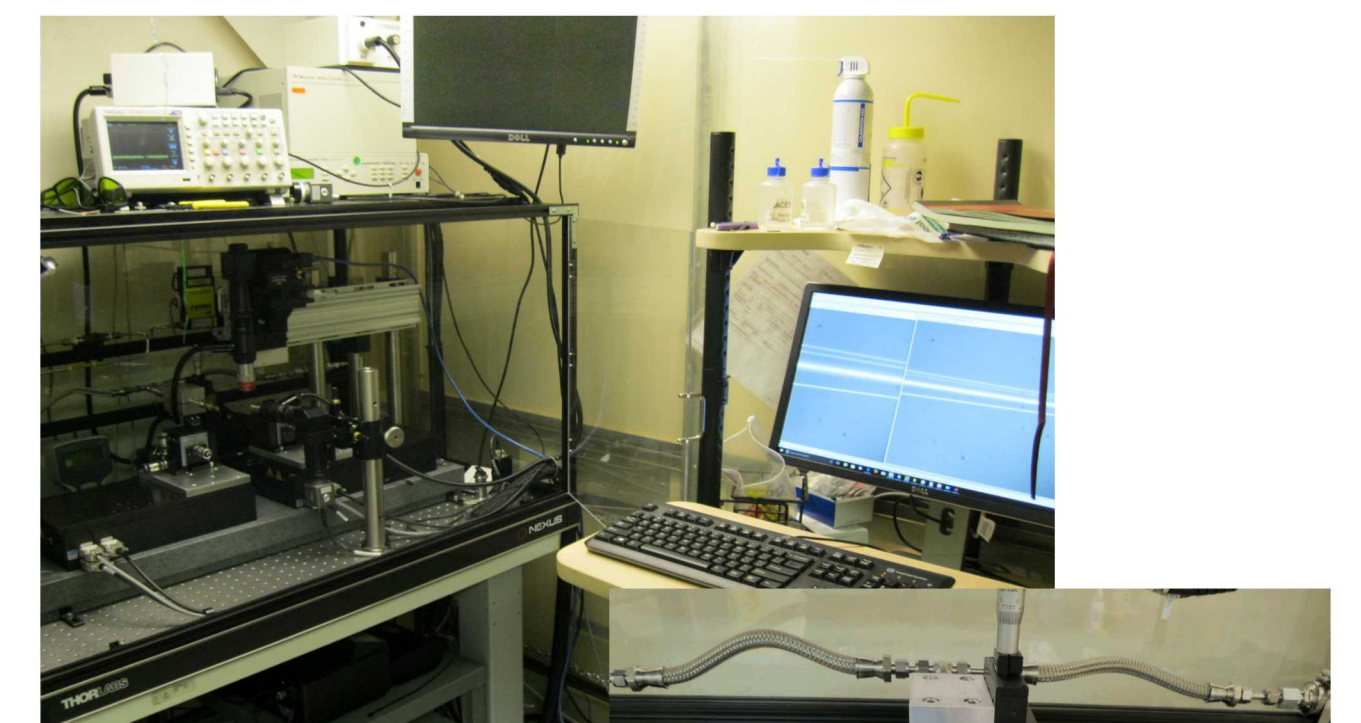


Experimental details:

- A quartz cell held at a vacuum pressure $\sim 10^{-9}$ Torr houses ¹³³Cs atoms.
- Three beams red detuned from the $F=3 \rightarrow F'=5$ are retro-reflected and serve as the cooling beams for the MOT.
- All trapping and probing laser beams are coupled into the nanofiber.
- In future experiments, the Raman/Bragg pulses will propagate along the nanofiber axis.

Tapered Fiber Production

- In-house fiber pulling apparatus based on [12]
- Pulling motor's motion is controlled algorithmically and stretches the single mode optical fiber while simultaneously heated by an oxyhydrogen torch
- Scanning Electron Microscope measurements showed a maximum of 9 nm standard deviation for a single nanofiber waist.



References

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