Enhanced atom interferometer readout through the application of phase shear

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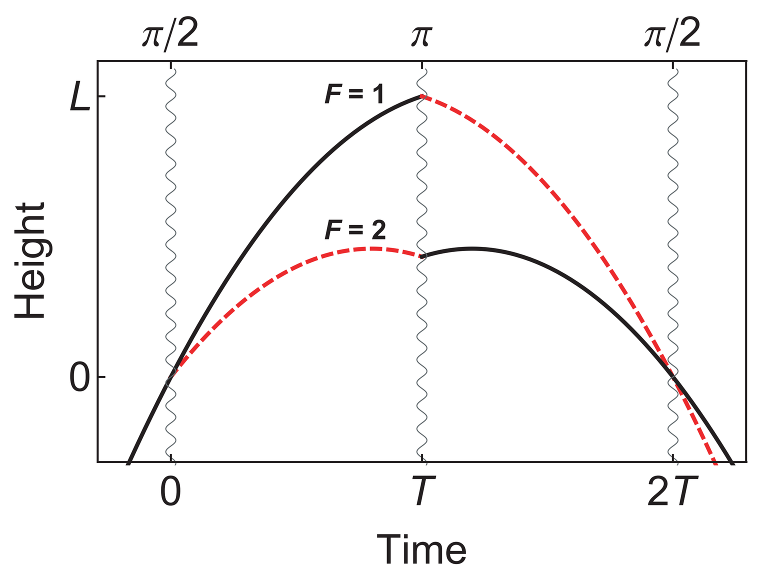
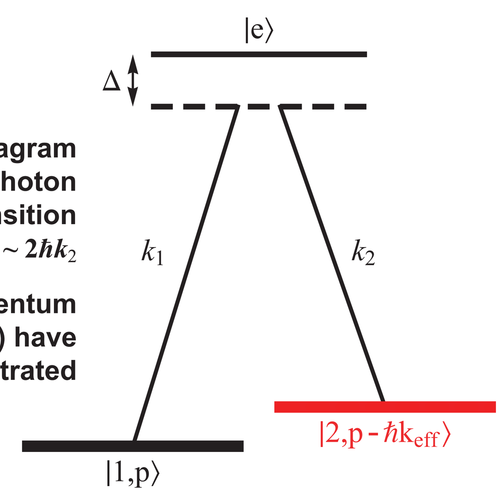
Introduction

- Phase shear readout (PSR) allows one to determine the phase and contrast of a single shot of an atom interferometer
- Application of a phase shear across the atom ensemble yields a spatially varying fringe pattern at each output port, which can be imaged directly
- Method is applicable to a variety of atom source configurations (regardless of spatial extent, temperature, quantum degeneracy, etc.)
- Analogous to the use of an optical shear plate, where a large applied phase shear highlights small phase variations across a laser beam
- Broadly relevant to atom interferometric precision measurement, as we demonstrate in a 10 m ^{87}Rb atomic fountain by implementing an atom interferometer gyrocompass with 10 millidegree precision

Light-Pulse Atom Interferometry

- Coherent splitting of the atom wavefunction with light pulses transfers momentum $\hbar \mathbf{k}_{\text{eff}}$ to part of the atom
- Atom follows superposition of two spatially separated free-fall paths
- Difference in phase accrued along the two interferometer arms yields an interference pattern at the output ports





Energy level diagram for a simple 2-photon Raman transition yielding $\hbar k_{\text{eff}} \sim 2\hbar k_2$

Larger momentum transfers (LMT) have been demonstrated

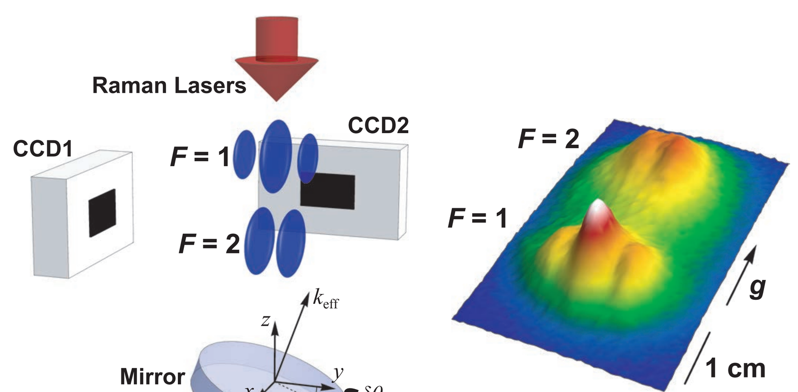
Semi-Classical Phase Shift:

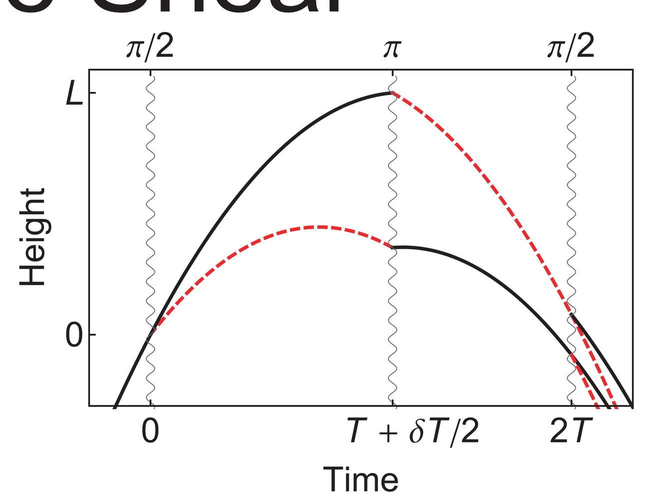
$$\Delta\Phi = \mathbf{k}_1 \cdot \mathbf{x}_1 - 2\mathbf{k}_2 \cdot \mathbf{x}_2 + \mathbf{k}_3 \cdot \mathbf{x}_3$$

Effective wavevector at i^{th} pulse

Position at i^{th} pulse

Applying Phase Shear





Beam-Tilt PSR

- Tilt retro-mirror for 3rd atom optics pulse by an angle $\delta\theta$
- Horizontal phase shear:

$$\Phi_H = k_{\text{eff}}\, \delta\theta\, y_3$$

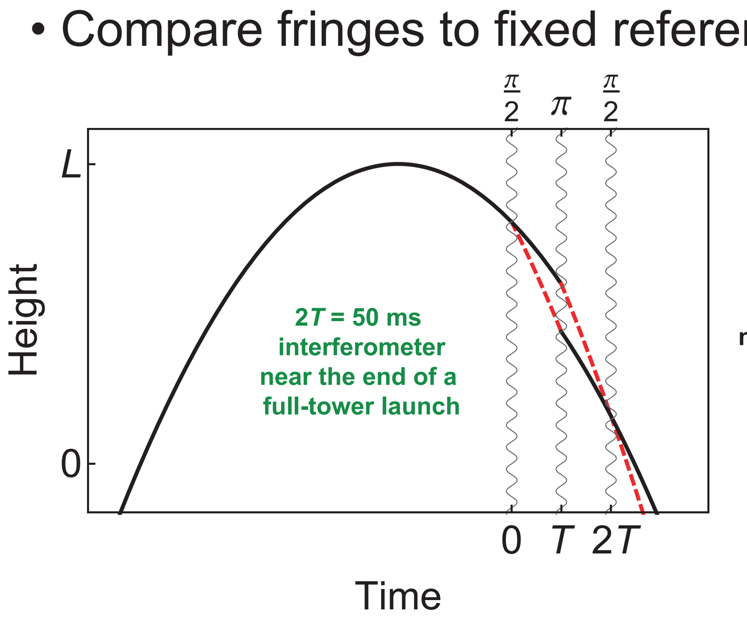
Timing-Asymmetry PSR

- Offset 2nd atom optics pulse by a time $\delta T/2$
- Vertical phase shear:

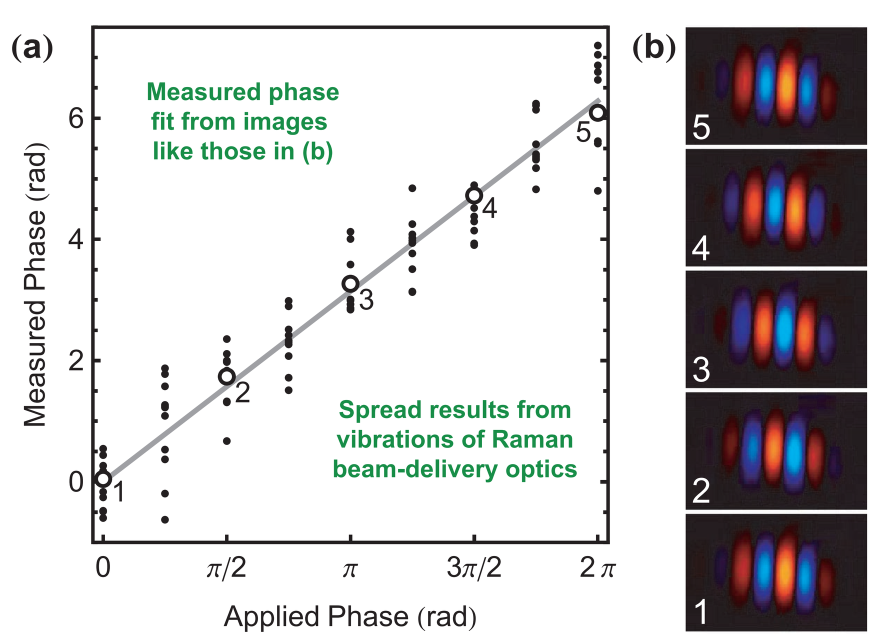
$$\Phi_V = k_{\text{eff}}\, v_z \delta T$$

Single Shot Phase Readout

- Compare fringes to fixed reference point

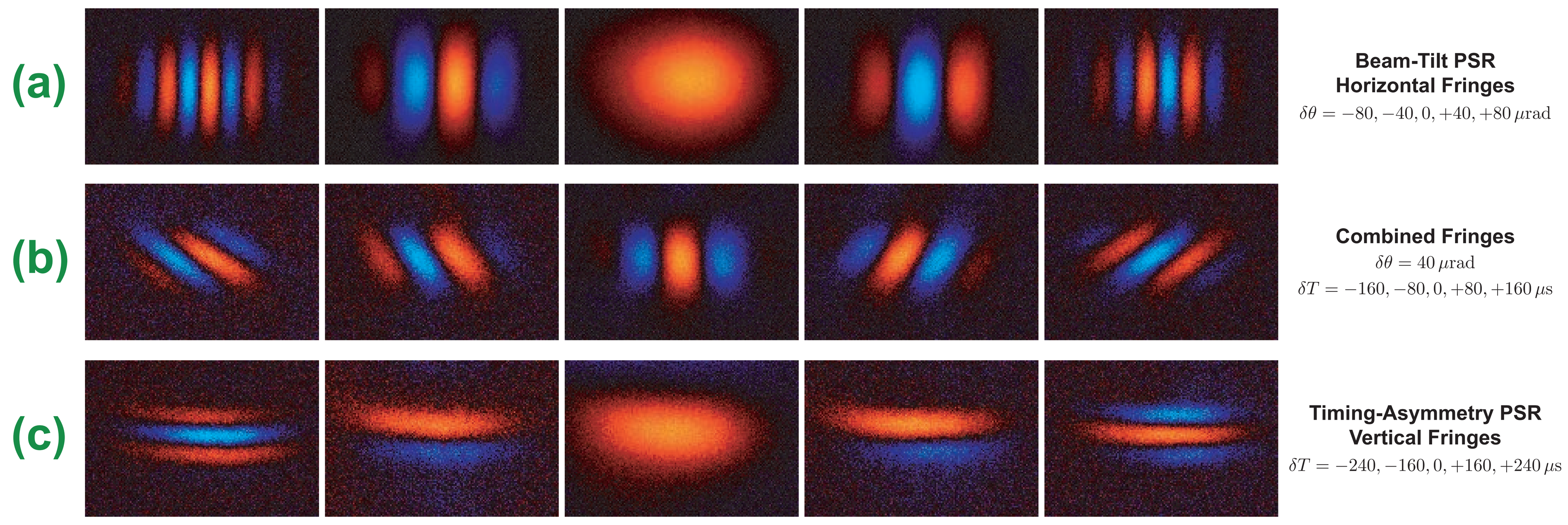


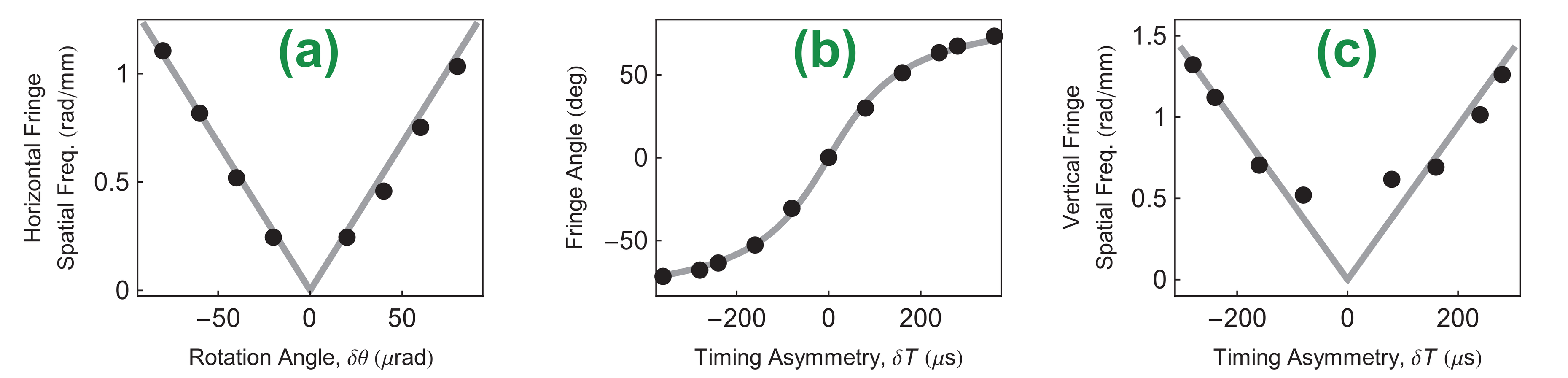
Short, late-time interferometer shows that the method also works with a spatially extended atom source



Arbitrary Control of Fringe Wavevector

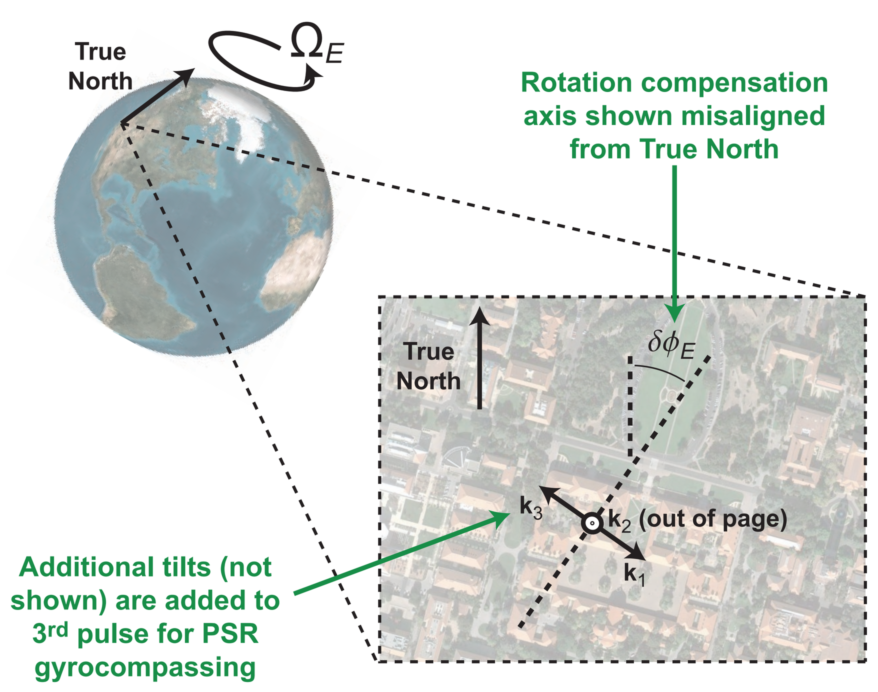
- Combining beam-tilt and timing-asymmetry PSR, it is possible to adjust the magnitude and direction of the applied shear in three dimensions:

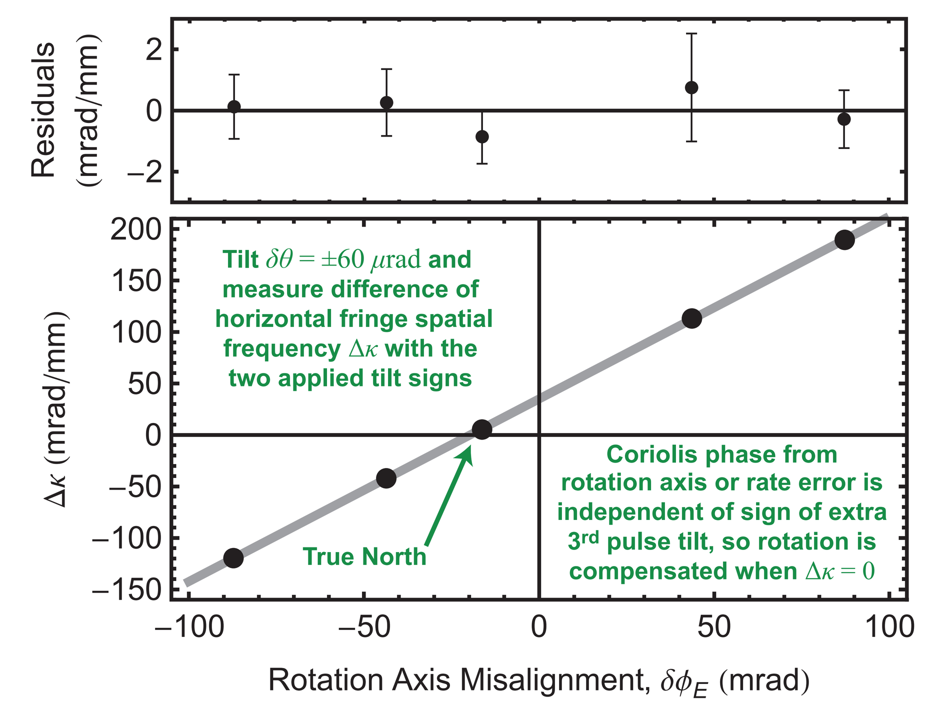




Atom Interferometer Gyrocompass

- Compensate for Earth's rotation by counter-rotating the retro-mirror
- Sensitive to errors in rotation rate (gyroscope) and axis (gyrocompass), which introduce a Coriolis phase shift that varies across the cloud
- Apply large extra mirror tilt to 3rd pulse, shifting the small Coriolis phase gradient to a larger spatial frequency for easier measurement



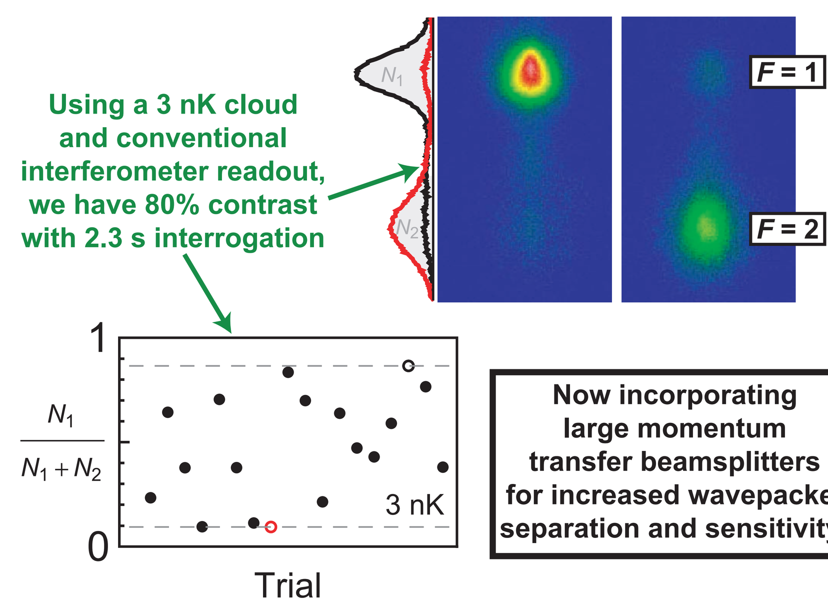


10 m Drop Tower Details

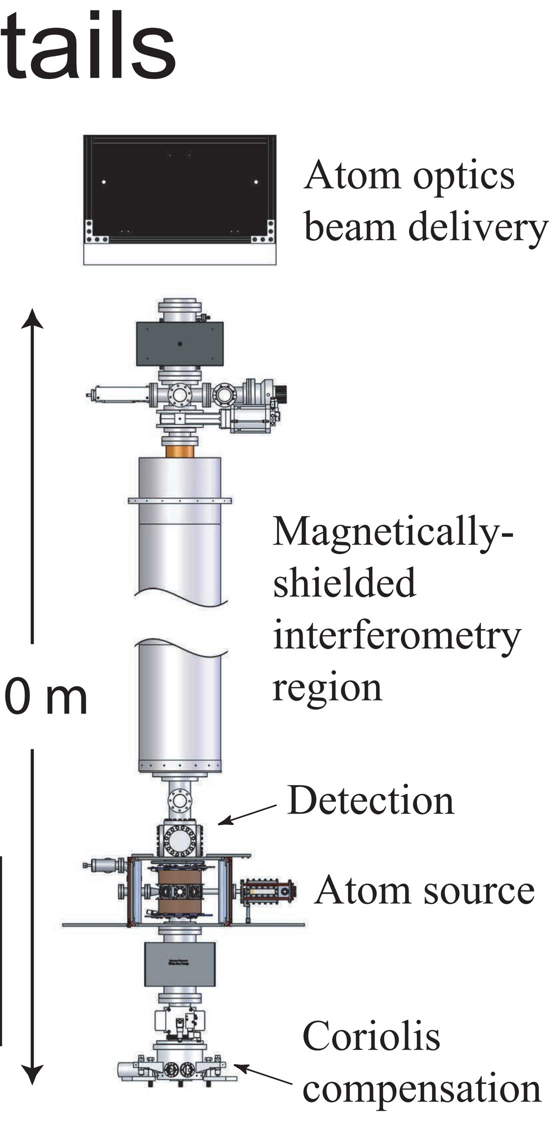
- Typical parameters for data presented here:

• 4×10^6 ^{87}Rb atoms, $m = 0$ state	• 50 nK (evaporatively cooled)
• Contrast > 40%	• $2\hbar k$ Raman atom optics
• 13.1 m/s lattice launch	• Interrogation time $2T = 2.3$ s
• Wave packet separation >1.3 cm	

Drop Tower Facility



Now incorporating large momentum transfer beamsplitters for increased wavepacket separation and sensitivity!



References and Acknowledgments

[1] A. Sugarbaker, S. M. Dickerson, J. M. Hogan, D. M. S. Johnson, and M. A. Kasevich, Phys. Rev. Lett. **111**, 113002 (2013).
[2] S. M. Dickerson, J. M. Hogan, A. Sugarbaker, D. M. S. Johnson, and M. A. Kasevich, Phys. Rev. Lett. **111**, 083001 (2013).

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