Optimal pulse schemes for high-precision atom interferometry

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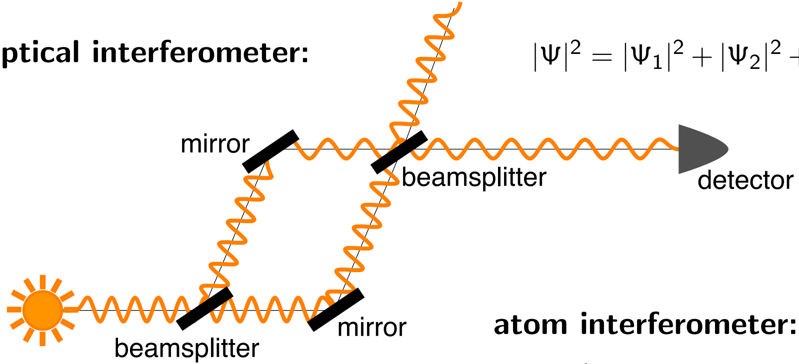
optical interferometer:



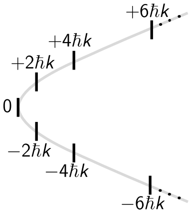
$$|\Psi|^2 = |\Psi_1|^2 + |\Psi_2|^2 + 2\Psi_1\Psi_2\cos(\phi_1 - \phi_2)$$

mirror? beamsplitter?

atom interferometer:

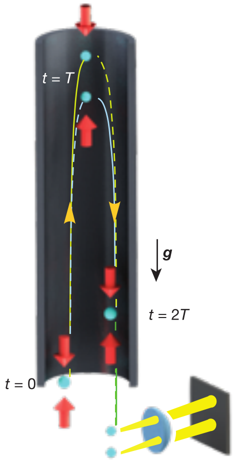
atoms have *mass*
and *internal structure*
$\Rightarrow$ couple to more external perturbations (gravity)

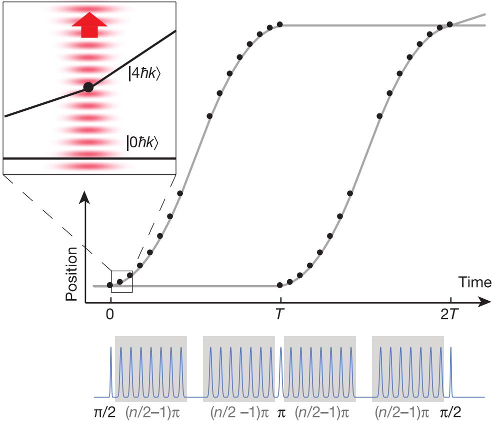
10 m atomic fountain at Stanford: ultracold ^{87}Rb atomic cloud



laser couples between electronic states: absorbs photon momentum

$$\Delta\phi = -2k_{\mathrm{max}} g T^2$$



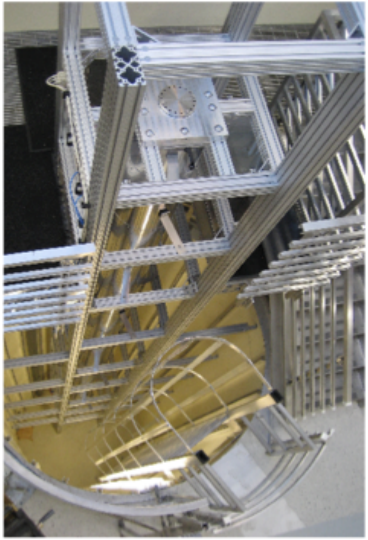


Kovachi et al. *Nature* **528**, 530 (2015)

Army applications:
ultra-precise measurement
of acceleration / gravity

- inertial navigation:
  submarines, autonomous vehicles
  —not jammable!
  - gyroscopes
  - gravity gradient sensors
- weapons system control
- geospatial mapping
- drone or satellite based
  detection of underground structures

10 m atomic fountain: sensitivity $10^{-13}\ \mathrm{g}/\sqrt{\mathrm{Hz}}$



factors:

- signal to noise ratio
- large momentum transfer

?

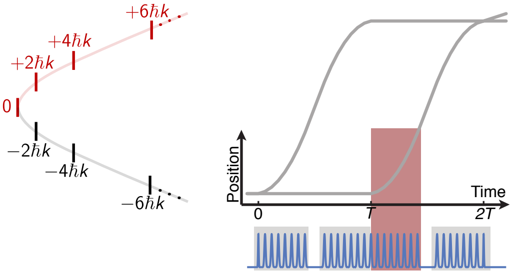
AOSense (2010)
$10^{-6}\ \mathrm{g}/\sqrt{\mathrm{Hz}}$

state of the art
$10^{-9}\ \mathrm{g}/\sqrt{\mathrm{Hz}}$

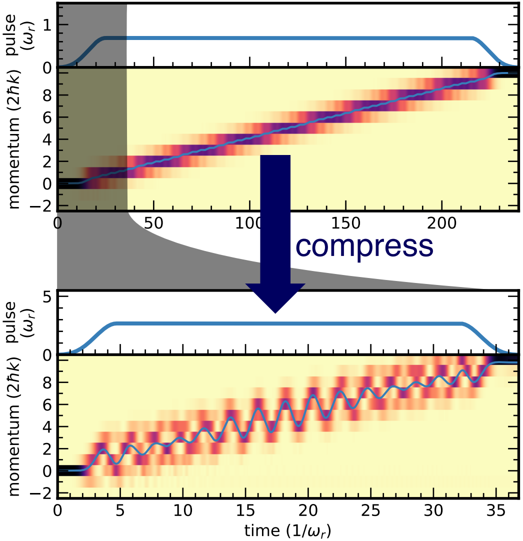
Apply optimal control to atom optics pulses

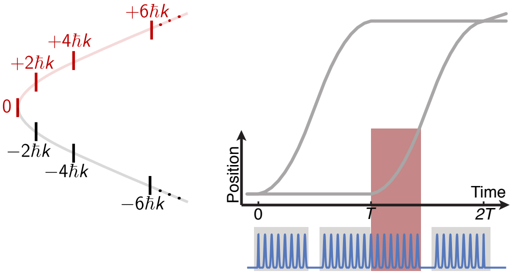
$\Rightarrow$ increase fidelity

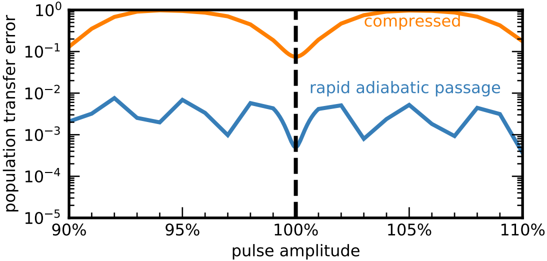
$\Rightarrow$ robustness against fluctuations

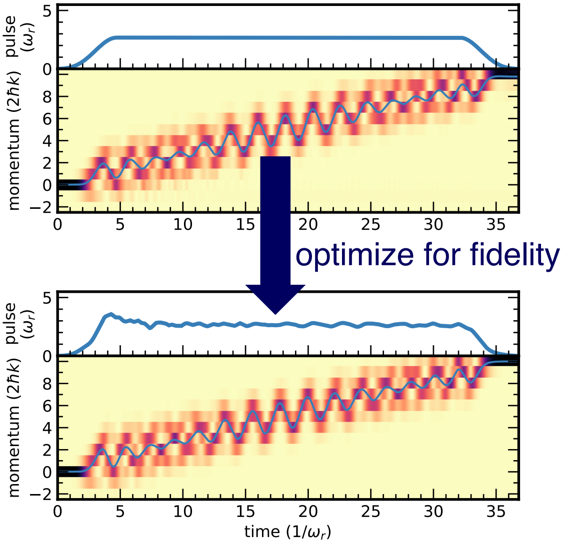


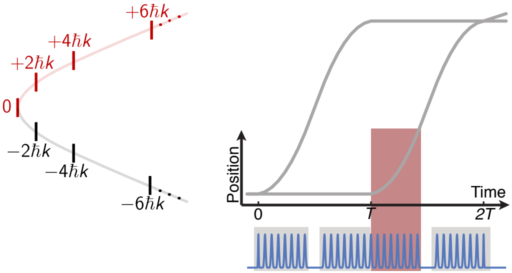
train of pulses ⇒ rapid adiabatic passage:
tune through laser frequency at constant amplitude

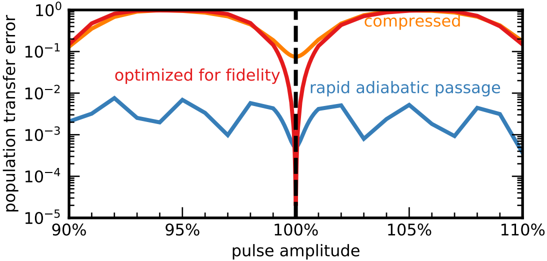

pulse (ω_r)
momentum ($2\hbar k$)
compress
time ($1/\omega_r$)

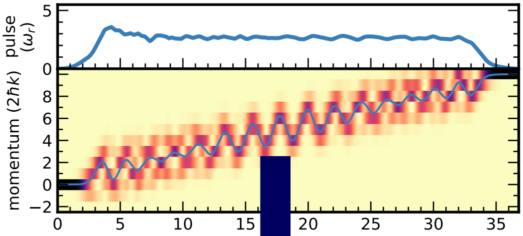

$+6\hbar k$
$+4\hbar k$
$+2\hbar k$
0
$-2\hbar k$
$-4\hbar k$
$-6\hbar k$
Position
Time
0
T
$2T$

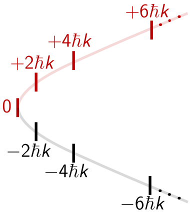

population transfer error
compressed
rapid adiabatic passage
pulse amplitude

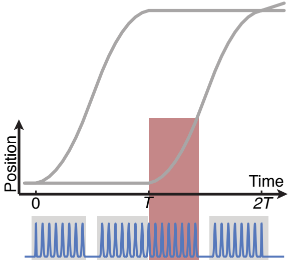

pulse (ω_r)
momentum ($2\hbar k$)
optimize for fidelity
time ($1/\omega_r$)


$+6\hbar k$
$+4\hbar k$
$+2\hbar k$
0
$-2\hbar k$
$-4\hbar k$
$-6\hbar k$
Position
Time
0
T
$2T$

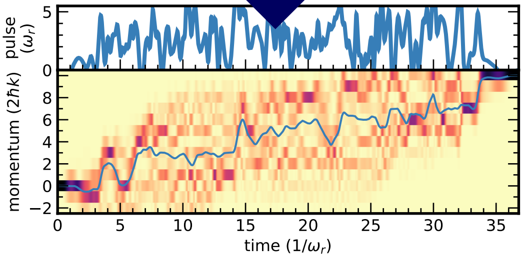

population transfer error
compressed
optimized for fidelity
rapid adiabatic passage
pulse amplitude
90%
95%
100%
105%
110%

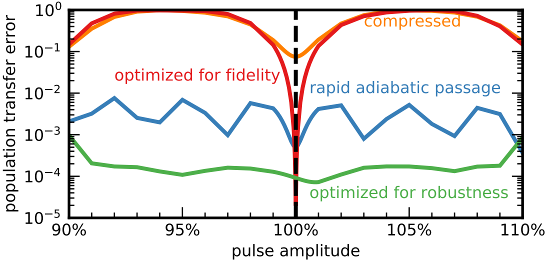




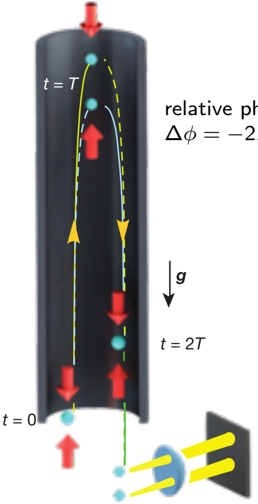


optimize for robustness

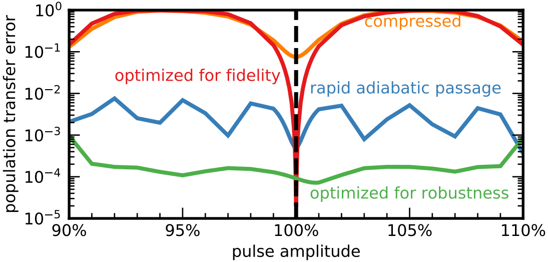




Conclusion



relative phase difference:
$\Delta\phi = -2k_{\max}gT^2$



- optimal control can compress pulses by order of magnitude while guaranteeing robustness
- Army applications:
  ultra-precise measurement of acceleration / gravity
  ⇒ inertial navigation,
  satellite based gravitational sensing