Condensate Atom Interferometers for Inertial Sensing Applications

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Project Summary
Developing ultracold phase-coherent matter wave interferometers with Bose-Einstein Condensates (BEC) as inertial sensors for:
- measuring gravity – oil resource development, geodesy, detecting underground structures
- gyroscopes - inertial navigation

Challenges and Significance
BEC interferometers as Gravity Sensors
- Atom fountains already among best gravity sensors
- Currently need large drop distances for atoms to free fall
- BEC are highly localized and can be coherently manipulated
- Possibility to develop a compact atom graviometer

BEC interferometers in Inertial Navigation Systems (INS)
- Current INS rely on optical gyroscopes that require periodic recalibration via GPS
- Cold atom gyroscopes provide a potentially highly accurate replacement solution

Technical Approach

1. Gravity Sensors with Bouncing Atoms:
   - If \( p = -h \phi \) before laser pulse, \( p \rightarrow + h \phi \) after (\( p \): atom momentum, \( k \): laser photon momentum)
   - Atom “bounces” off of light
   - Later, \( p \) will again reach \(-h\phi\) - repeat laser pulse
   - Theoretically \(~1000\) bounces possible giving total suspension time \( > 1 \) sec

Accomplishments up through Current Year
- Demonstration of a linear interferometer with BEC separation of 400 \( \mu \)m (Reference [1])
- Demonstration of atom bouncing for up to 100 reflections over 120 ms (Reference [2])
- Demonstration of a bouncing atom interferometer over 40 cycles
- 48 ms duration \( \rightarrow 81 \) total operations
- Phase shift \( \phi = (-18.011 \pm 0.001) \pi \)
- Was measured, an \( 5 \times 10^{-6} \) accuracy. This gave a measurement of the local gravity acceleration \( g = 9.81 \) m/s\(^2\) (Reference [2])

Technology Transfer

- Industrial collaboration with Lynntech Inc. in the development of an Atom Trap Controller (ATC) precision electronic device
- In-house development of Atom Interferometric Rotation Sensor in a Harmonic Oscillator Trap (AIRSHOT) unit

To increase device compactness while maintaining sensitivity by restricting atoms to cyclic localized trajectories – bouncing, circular ring guiding

Overall Goal: To increase device compactness while maintaining sensitivity by restricting atoms to cyclic localized trajectories – bouncing, circular ring guiding

Process overview for BEC-interferometer implementation. Three major stages: (1) creation of ultra cold atoms in the form of a BEC (2) interferometry (3) phase measurement. Phase measurement results in high accuracy rotation sensing. Shaded boxes are processes managed by the ATC.