Interferometers, Mechanics, Clocks, and Traps

https://arxiv.org/abs/2203.07250

Overall goal

- Provide an overview of current status and future directions of quantum sensor technology
  - Most of science case left for ‘science’ white papers
- Highlight technologies limited by, or are enhanced by, laws of quantum mechanics
- Serve as a point of reference


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Snowmass 2021: Quantum Sensors for HEP Science - Interferometers, Mechanics, Traps, and Clocks

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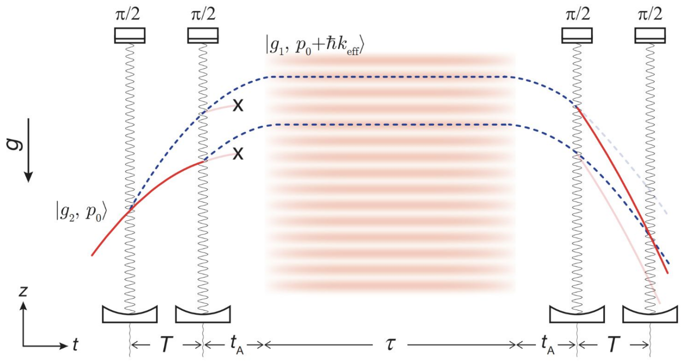
Atom Interferometers

- Use laser to coherently split, redirect, and recombine matter waves
- Key applications
  - Gravitational wave detection
  - Wavelike dark matter
  - Precise tests of SM (e.g. fine structure constant)
- Experiments
  - Much can be done with ‘table-top’ experiments
  - MAGIS-100 - 100 meter vertical baseline
  - Atom Interferometery Observatory and Network (AION) - staged experiments from 10m up to 1km
- Areas of development
  - Using more than two test masses along baseline
  - Large-scale vacuum systems



Adapted from V. Xu, M. Jaffe, C. D. Panda, S. L. Kristensen, L. W. Clark, and H. M¨uller, Science 366, 745 (2019).

Optomechanical Sensors

- Mechanical sensors read out optically (microwave to visible)
  - Key example is LIGO
  - Commonly operated in a regime where sensitivity is dominated by quantum noise
  - Uniquely suited to look for signals which act coherently over a length scale the size of the mechanical system
- Wide range of sensors
  - Torsion balances
  - Opto-mechanical interferometers
  - Resonant mass detectors
  - Levitated particles
- Key Applications
  - Gravitational waves
  - Dark matter
  - Neutrinos
- New opportunities
  - Need for theoretical ideas about potential new signals
  - Moving beyond the standard limit (e.g. squeezing and back action evasion)

Clocks and Precision Spectroscopy

- Optical clock precision has increased by more than 3 order of magnitude in past 15 years
- Looking for transitions better atomic ground states (microwave) and electronic levels (optical)
- Key applications
  - Fine structure constant
  - Dark matter
  - Gravitational wave detection in new wavelengths
- Paths for improvement
  - Clocks with larger sensitivity factors
  - Networks
  - Portability (needed for space applications)

Common themes

- Broad range of science goals
  - Dark matter
  - BSM
  - GW
- Impact from ‘table-top’ experiments
  - Small experiments can have a big impact
  - Carve out parameter space not currently reachable
- Need for supporting developments
  - equipment (e.g. lasers)
  - methods (e.g. squeezing and back action evasion)