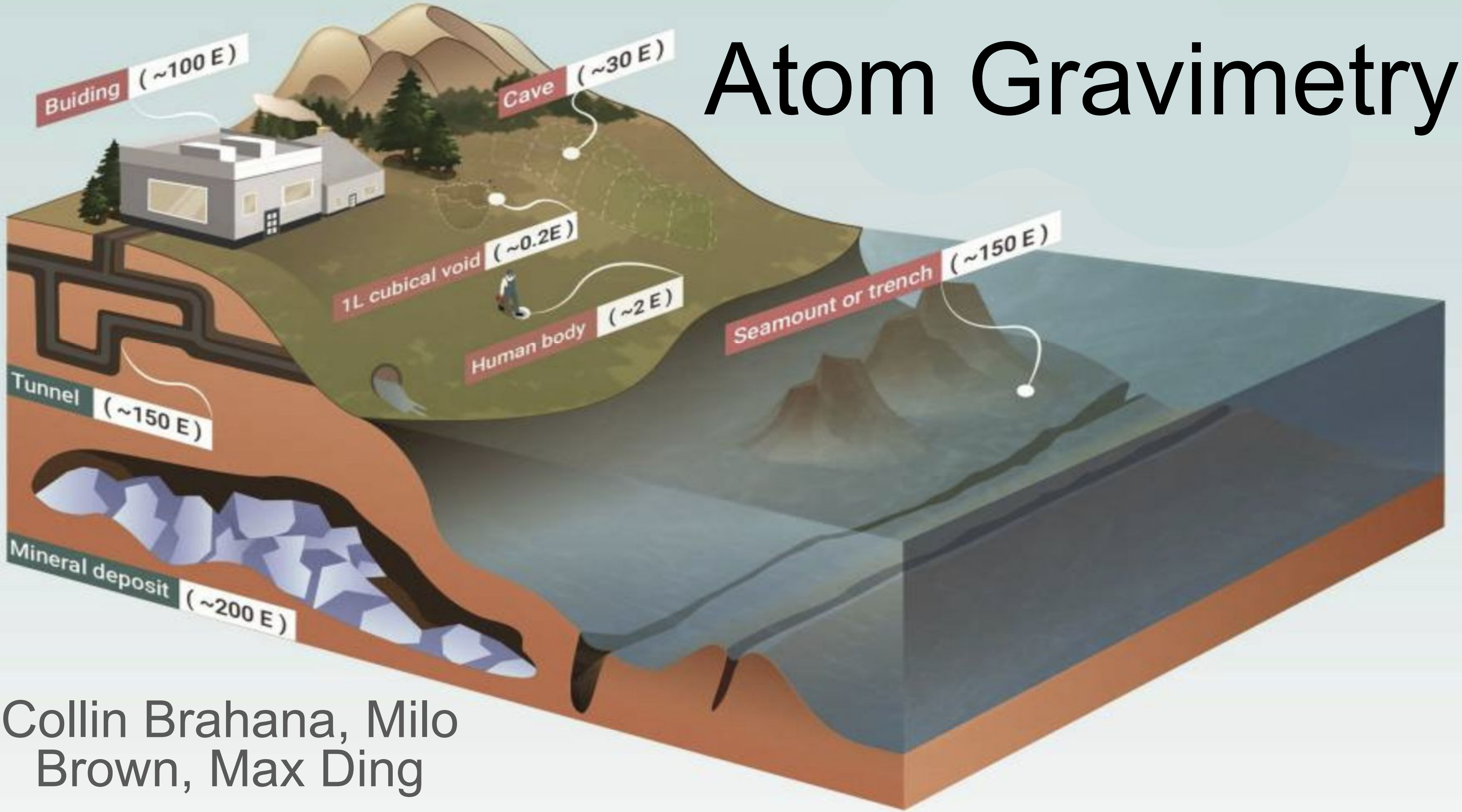
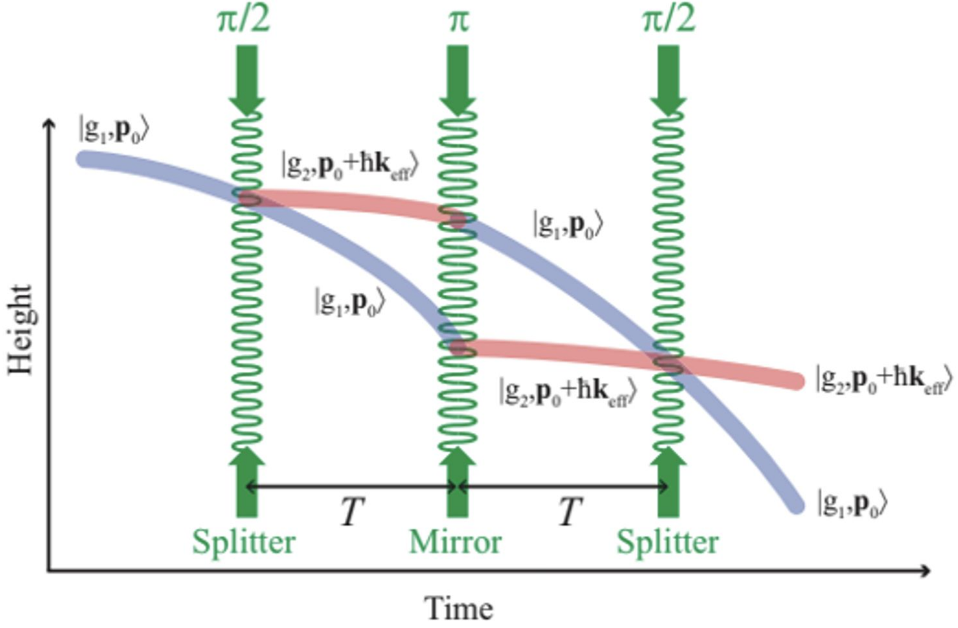
Atom Gravimetry



Collin Brahana, Milo Brown, Max Ding

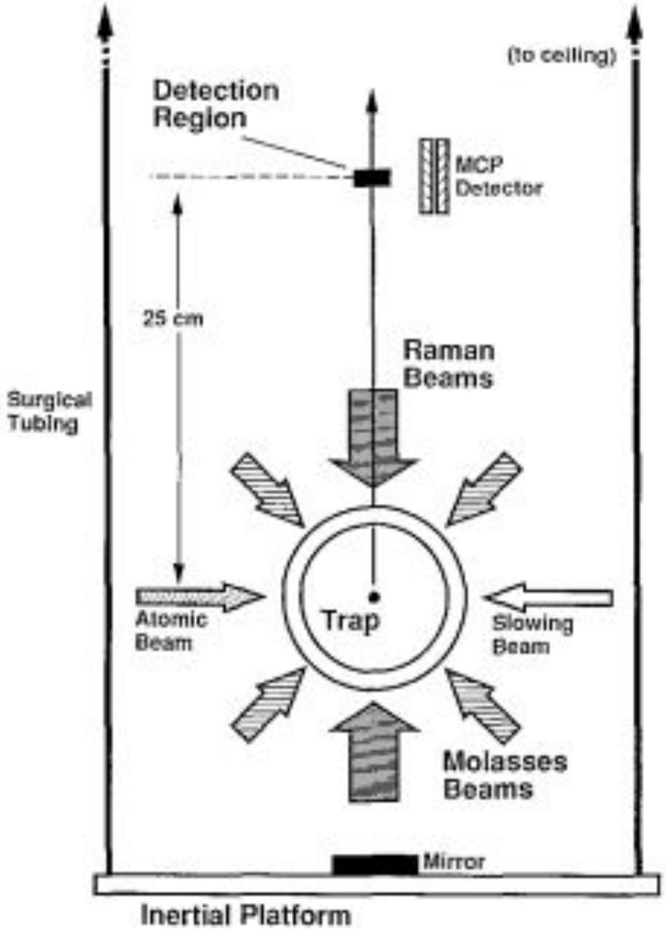
Atom Interferometry

- Conceptually similar to optical interferometry
- Phase shift from Raman beam
- Gravity can be measured from interference fringe across increasing interrogation time



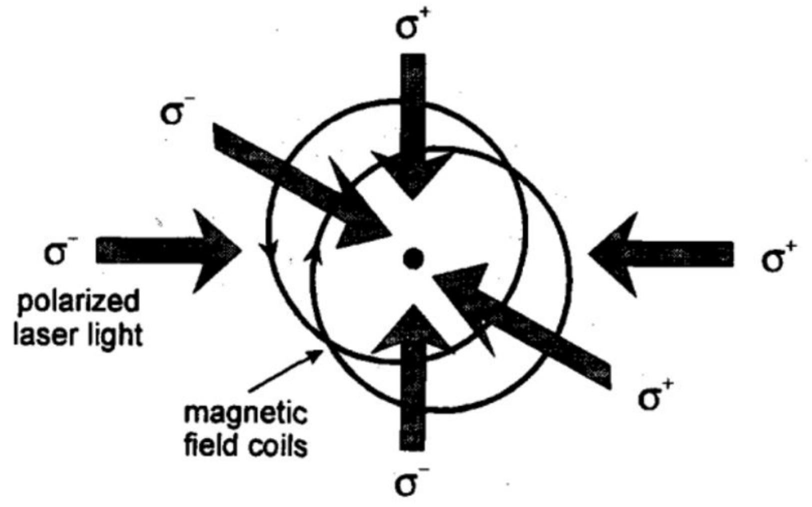
The Kasevich-Chu Design

- Vertical Fountain design
- Two-Photon Raman Scattering for state separation
- Rabi Flopping
- Optical Cooling System
- Population Detection



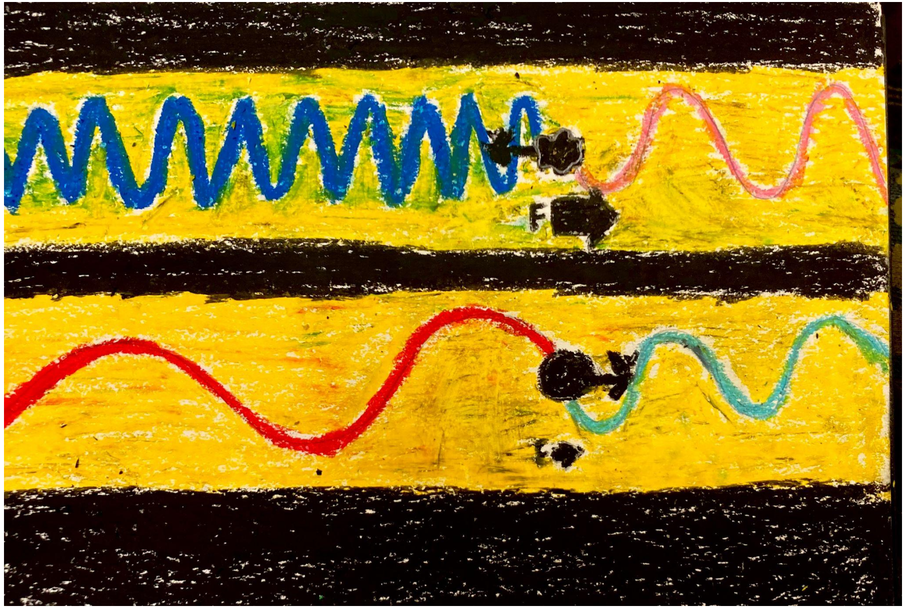
Cooling System: Magneto-Optical Trapping (MOT)

- Cools and localizes atoms using doppler cooling and the zeeman effect
- Symmetrical laser geometry
- Current research in miniaturizing on a photonic chip
- MOT Cooling restricted by doppler limit, sub-doppler cooling on untrapped atoms



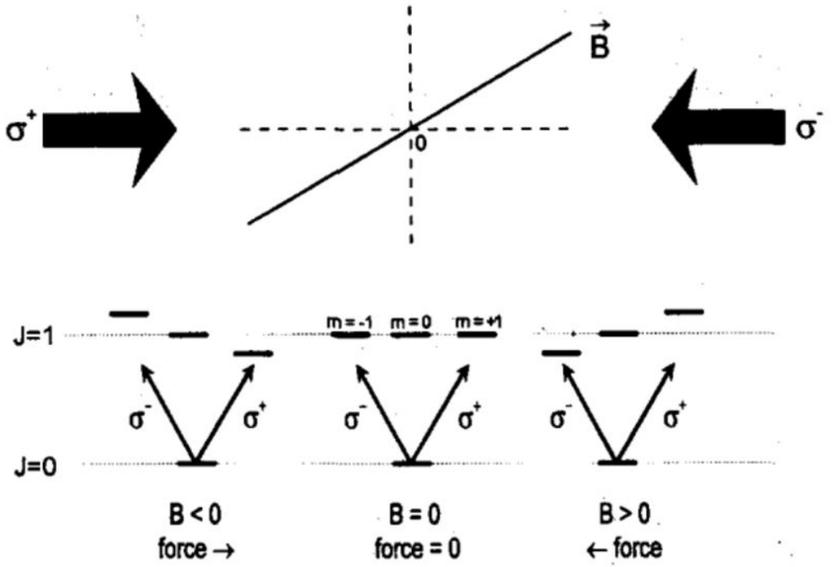
Doppler Cooling

- Frequency-dependent atomic transition can increase the scattering force on an atom
- The laser is tuned to a frequency less than the peak of the resonance
- Larger force on atoms moving toward the laser
- This establishes a velocity dependence – i.e., cooling



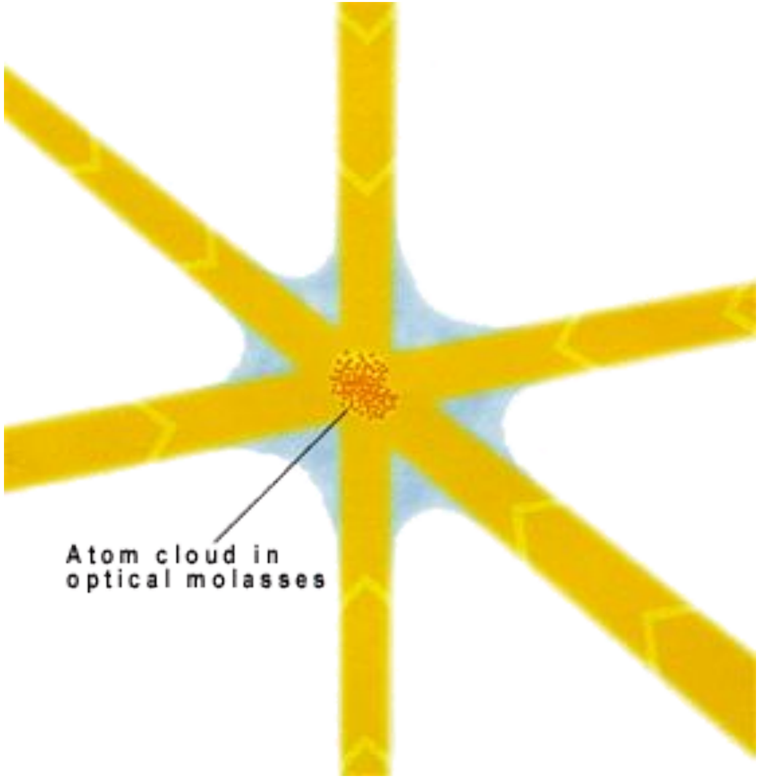
Zeeman Effect

- The Zeeman effect splits a spectral line (or atomic transition frequency) into several components in the presence of a magnetic field
- As the atom drifts towards areas of a stronger magnetic field (e.g., away from the center), the atomic transition will shift closer to the frequency of the laser
- Therefore, (according to the Zeeman effect) the magnetic component of a MOT establishes a position dependence – i.e., trapping



Sub-doppler cooling

- Remove magnetic field to create optical molasses
- Cool below doppler limit by removing atoms with high kinetic energy (evaporative cooling) or using orthogonally polarized light (Sisyphus cooling)
- Once you remove the magnetic field, the atoms will begin to fall out of cooling mechanism
- Bose-Einstein condensates, ISS



Current State

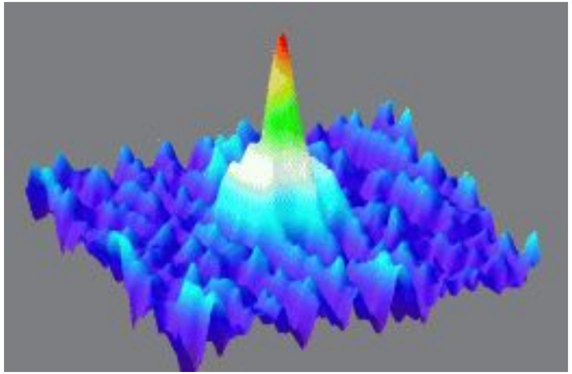
- Current gravimeters of both absolute and relative variants are highly accurate to the 10nm/s^2 scale
- However, relative gravimeters will always suffer from drift in accuracy due to their relative nature
- This makes absolute gravimeters the best choice for long term monitoring

SCINTREX CG5 Relative Gravimeter

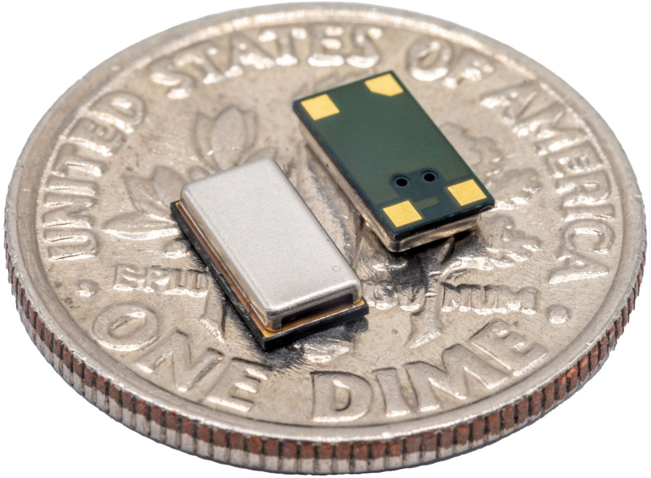
MuQuans Absolute Quantum Gravimeter

Ongoing Research

- One major research focus is minimizing size, weight, and power (SWaP)
- Another avenue is using a Bose Einstein condensate instead of an atom cloud
- Researchers have also successfully created MEMS gravimeters



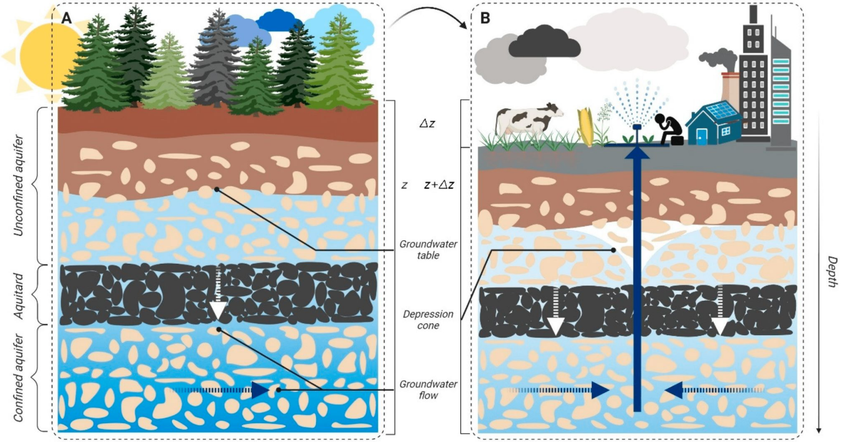
Velocity distribution of a Bose Einstein Condensat



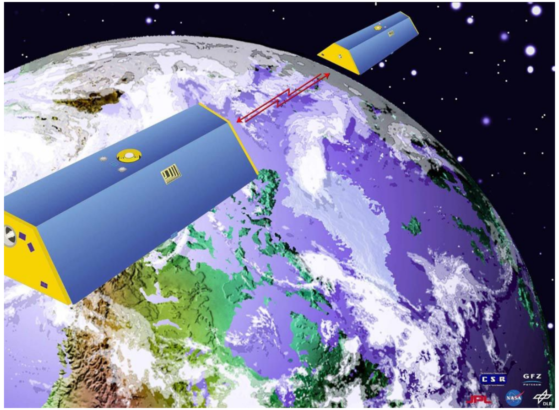
Size of a typical MEMS device, in this case a speaker

Applications

- Gravimeters see use in multiple fields of science
- NASA's GRACE 2003-2011 sent gravimeters into orbit on a satellite
- Gravimeters are also used in the Hebei region of China to monitor surface and groundwater
- The Hawaiian Volcano Observatory acquired a MuQuan absolute quantum gravimeter in 2022 as a field portable solution that can record long-term measurements
- Detecting submarines deep underwater



Visualization of groundwater depletion leading to subsidence



Graphic of NASA's GRACE satellite