# Atom Interferometry: MAGIS, AION & Liverpool

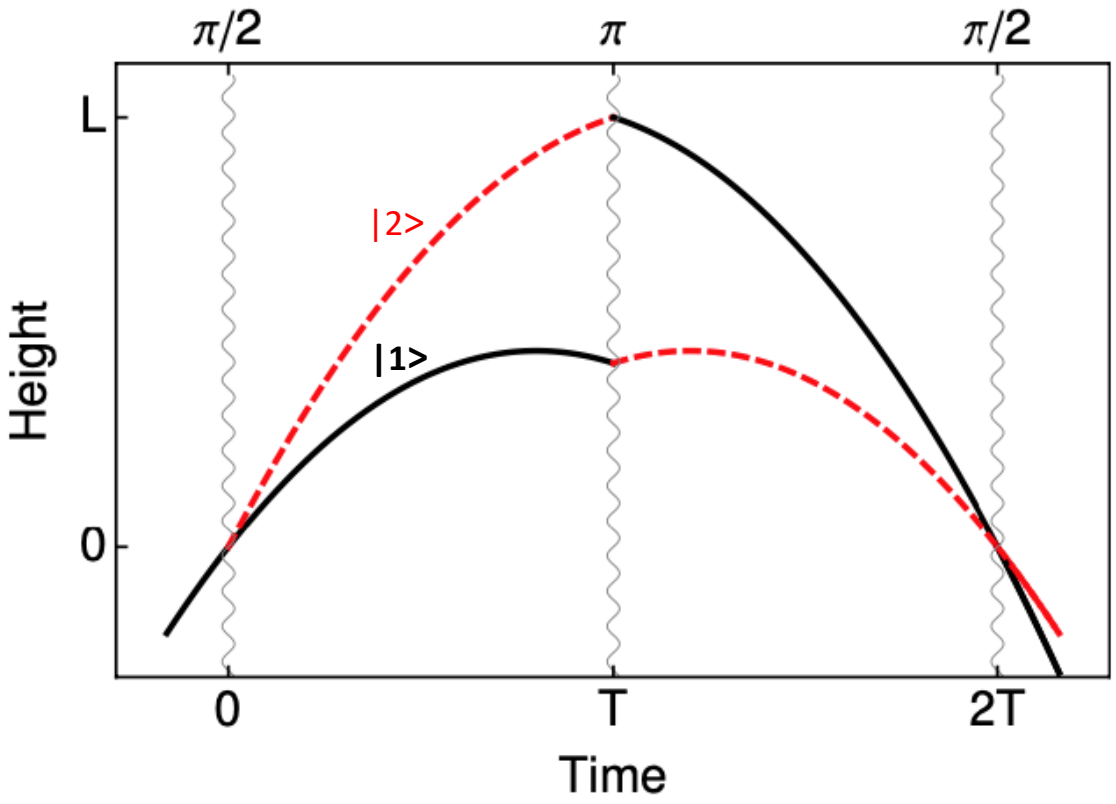
**Leonie Hawkins, Friday 20th May**

HEP Spring Meeting 2022



# Atom Interferometry

*See later slides from Gedminas Elertas*




- Analogous to light interferometry
- Atoms as de Broglie waves in a superposition of states
- Light pulses as mirrors and beamsplitters
- Δφ accumulated by atoms sensitive to external forces & new physics

AION MAGIS-100

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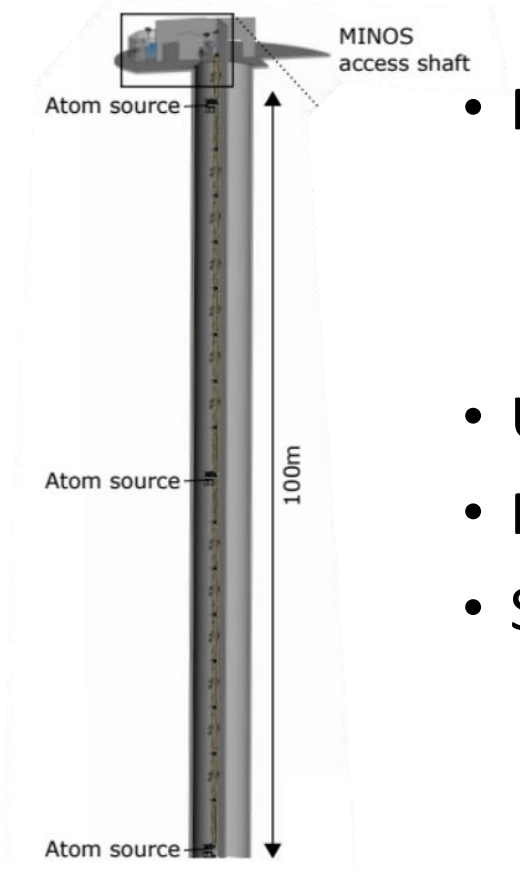
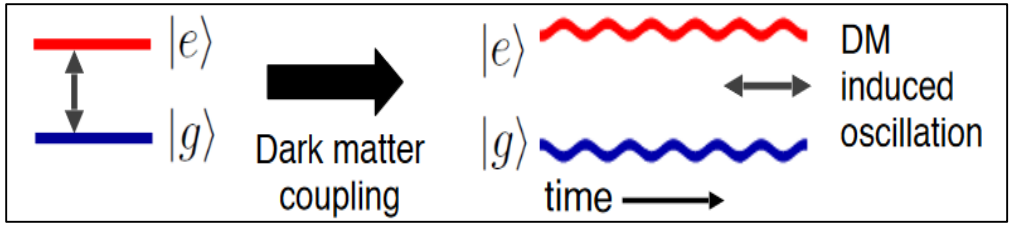
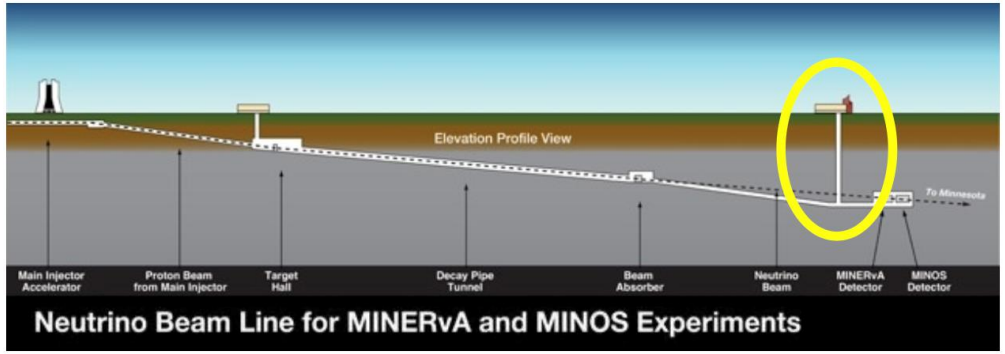
# Long Baseline Interferometry:

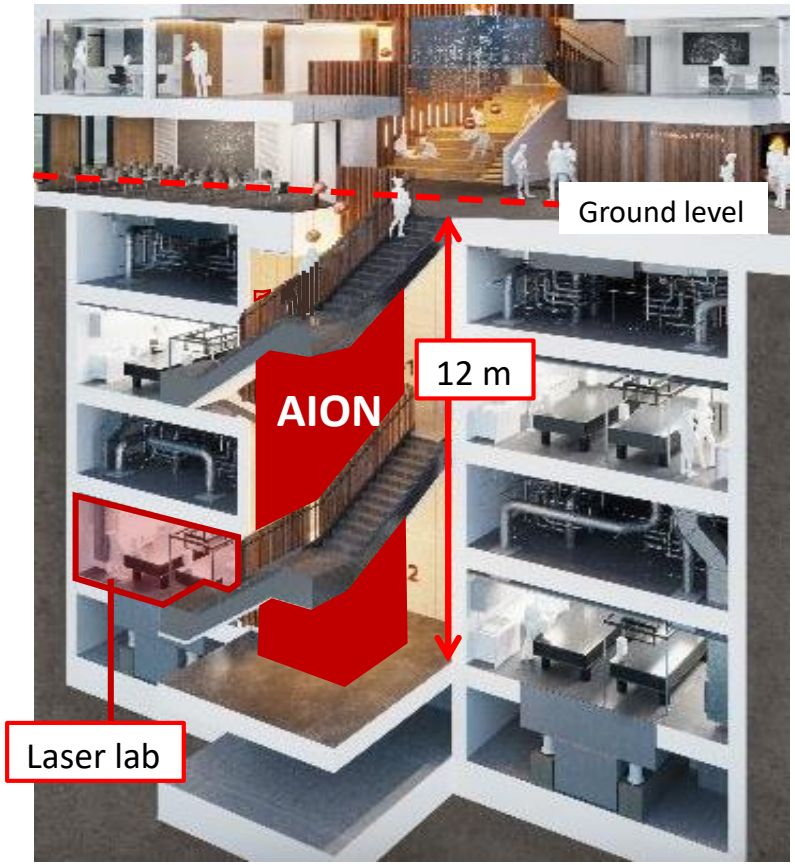



- Multiple atom interferometers over single 100 m baseline
  - 3 interferometers & 3 strontium atom sources
  - Differential measurements
  - Systematics cancel
- Ultralight DM ($10^{-22}$ - $10^{-14}$ eV)
- Mid-band GW (30mHz - 10Hz)
- Sensitivity ~ baseline L
  - 2L/c ~ gravity wave signal



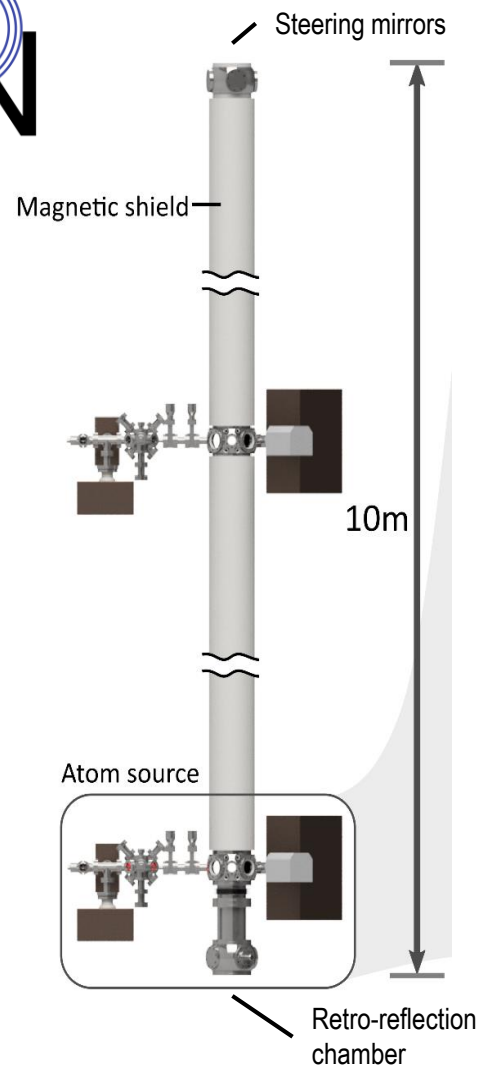



# Long Baseline Interferometry: AION




*Beecroft building, University of Oxford*

- Similar design concept to MAGIS
  - Network experiments for improved directional sensitivity
- 10 m prototype device to be constructed in Oxford
- AION-100 location TBC
  - Boulby, CERN, Daresbury…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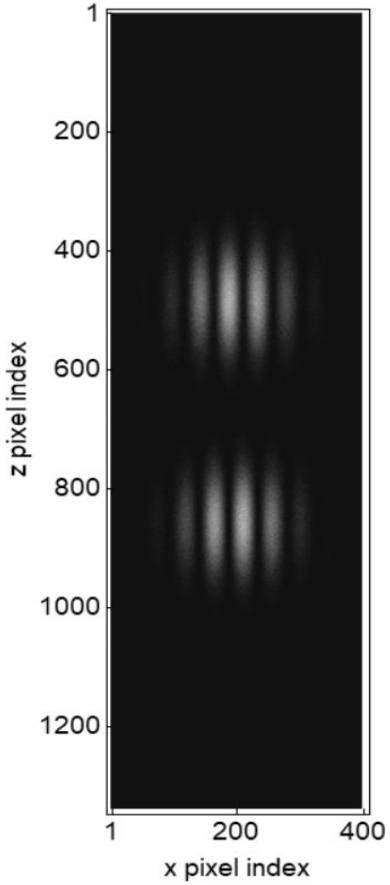
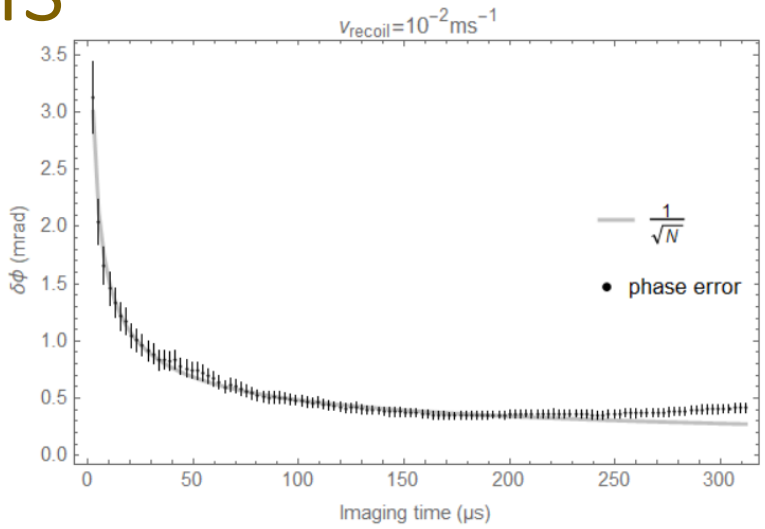
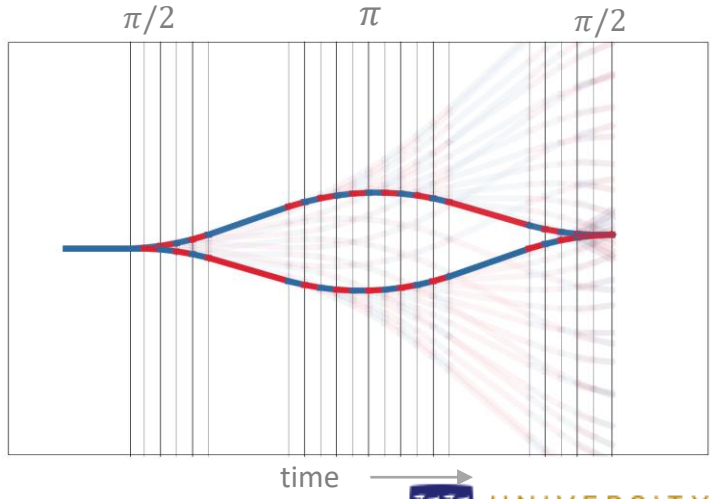
# Atom Cloud & LMT Simulations




- Modelling cloud wavefunction & systematics for MAGIS & AION
- Phase shear imaging: imprint fringes across cloud before imaging
  - Fluoresce atom cloud to image
  - Imaging beam causes cloud diffusion
- Large wavepacket separation
  - Increase in sensitivity
  - Transfer momentum to atoms
- Pulse inefficiencies
  - Atoms lost form stray paths
  - Loss in phase resolution

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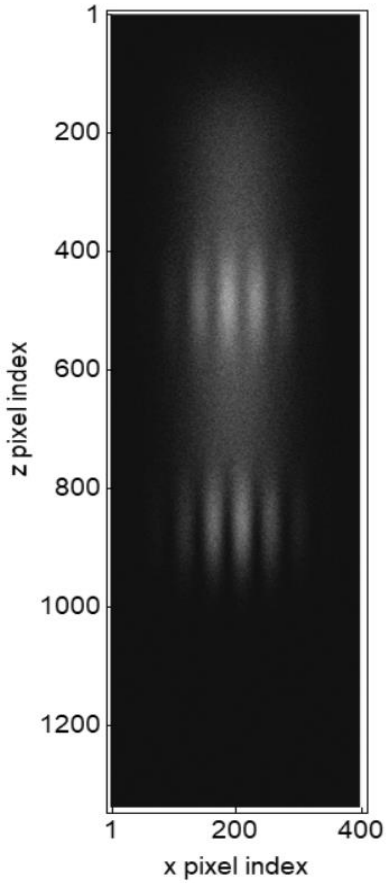
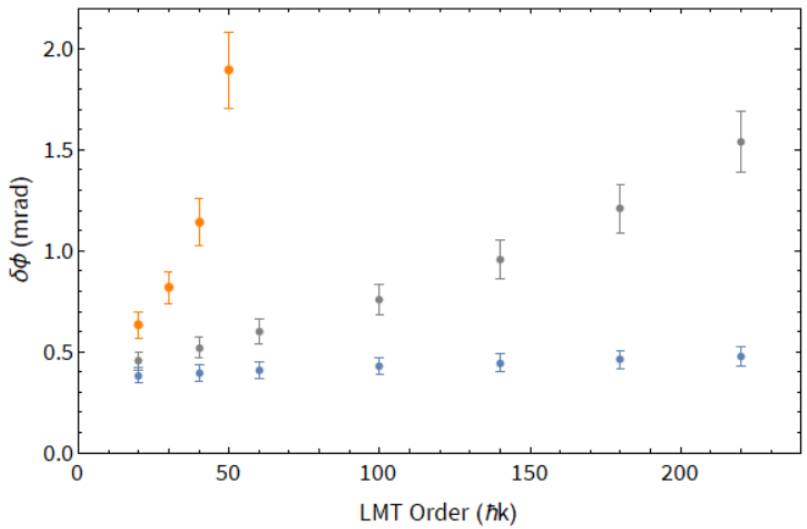
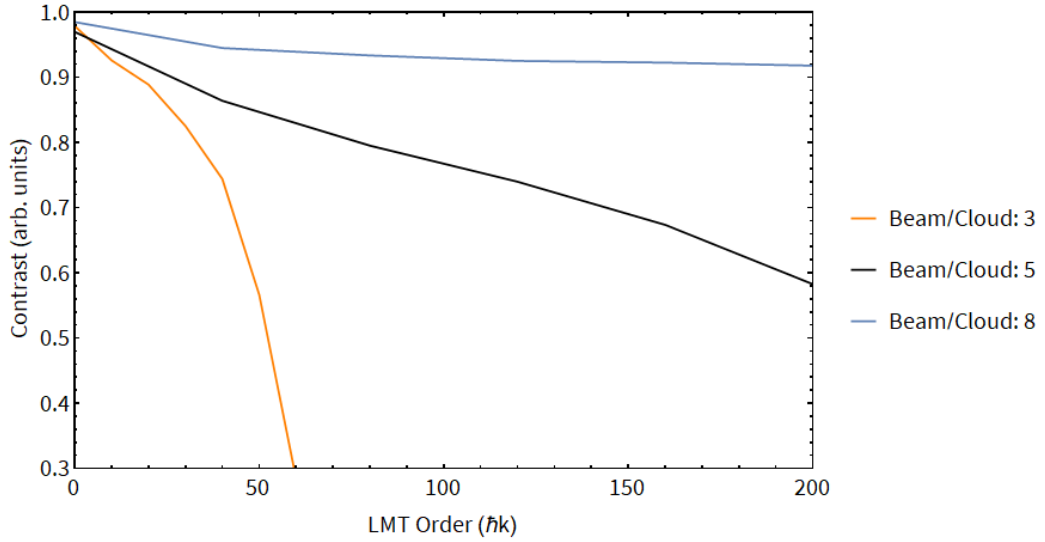
# Large Momentum Transfer Simulations




- Sensitivity increases with LMT order, trade off with atom losses
- High dependence of phase precision & contrast on ratio between beam and cloud size

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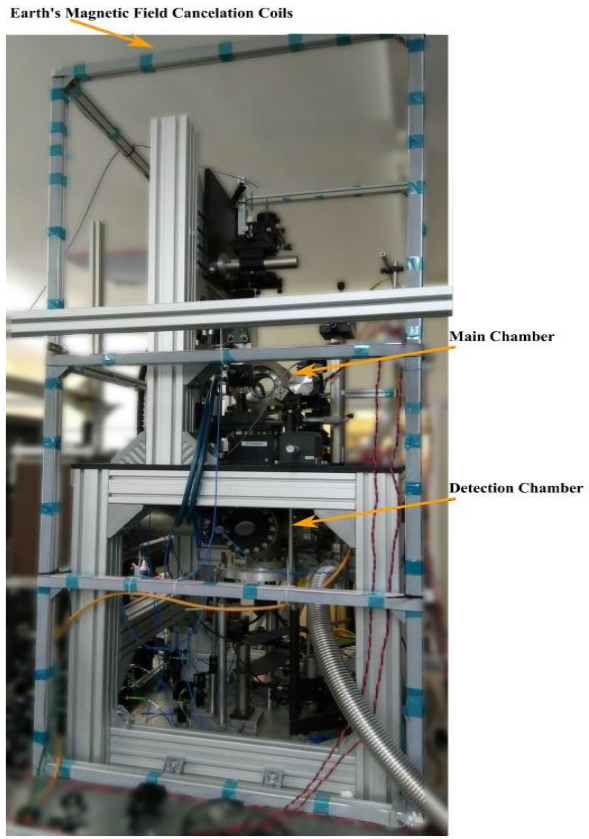
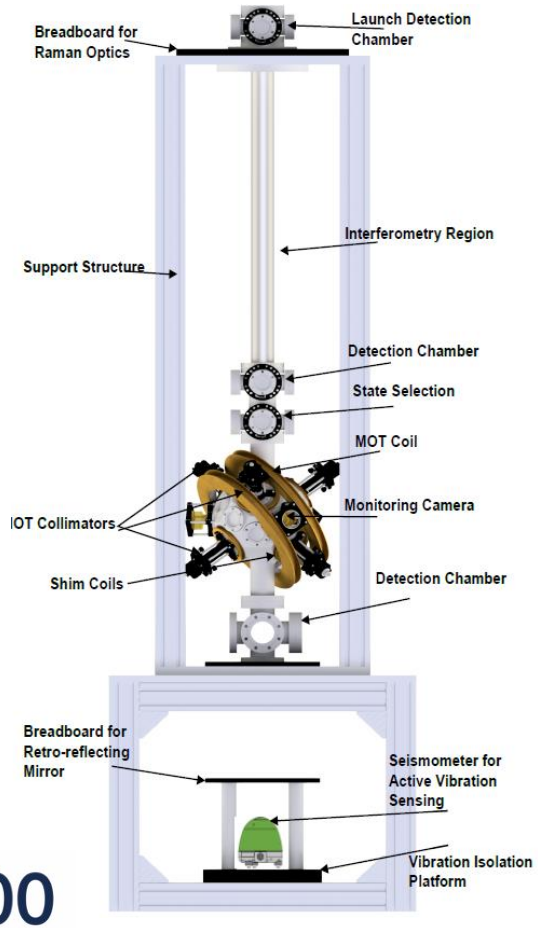
# Rubidium-85 Interferometry: Liverpool

**Current:**




**Upgrade:**




- Extending to ~1 m interferometer
  - Increase interrogation time
  - Higher sensitivity
- Preparing for upgrade of vacuum chamber and laser system
  - Viewports, pumps, etc.
- Test-stand developing concepts of interferometry
- Techniques can be applied to larger experiments

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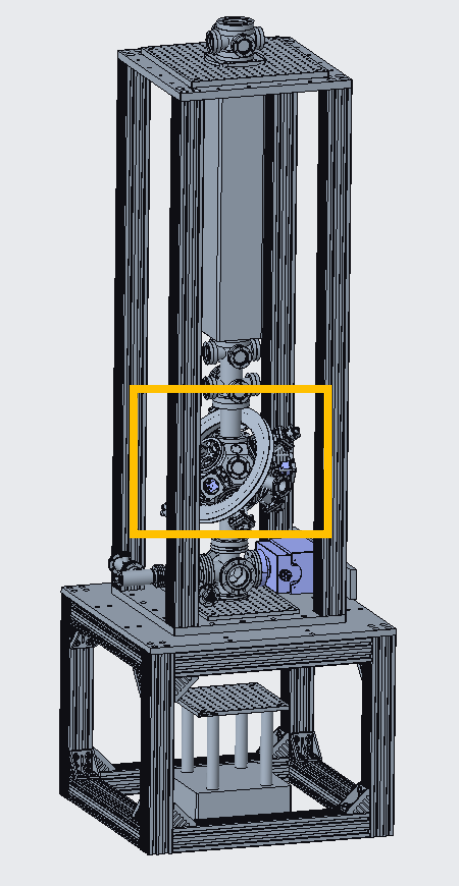
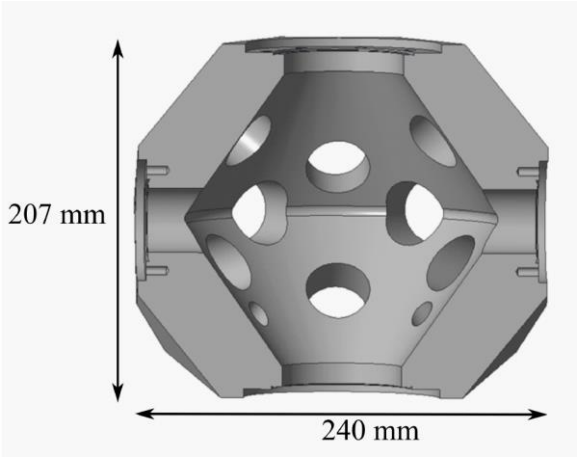
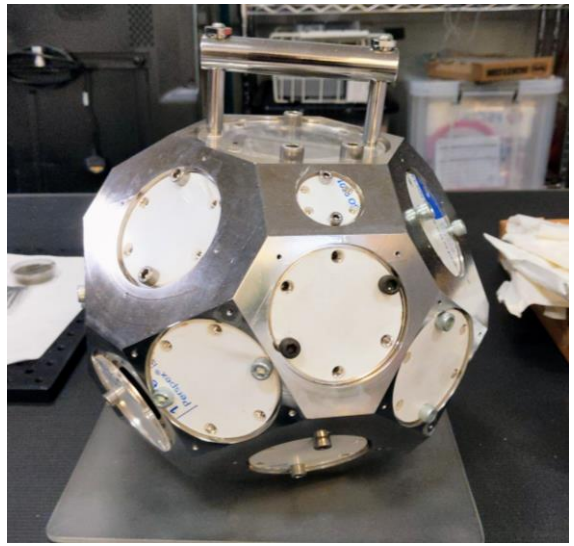
# Workshop Chamber



- Custom parts for upgrade machined by Liverpool workshop
  - Experience using 5-axis milling machine
  - Producing custom chambers for MAGIS & AION
- Waiting on orders from multiple vendors for off the shelf vacuum parts
  - Laser system preparation



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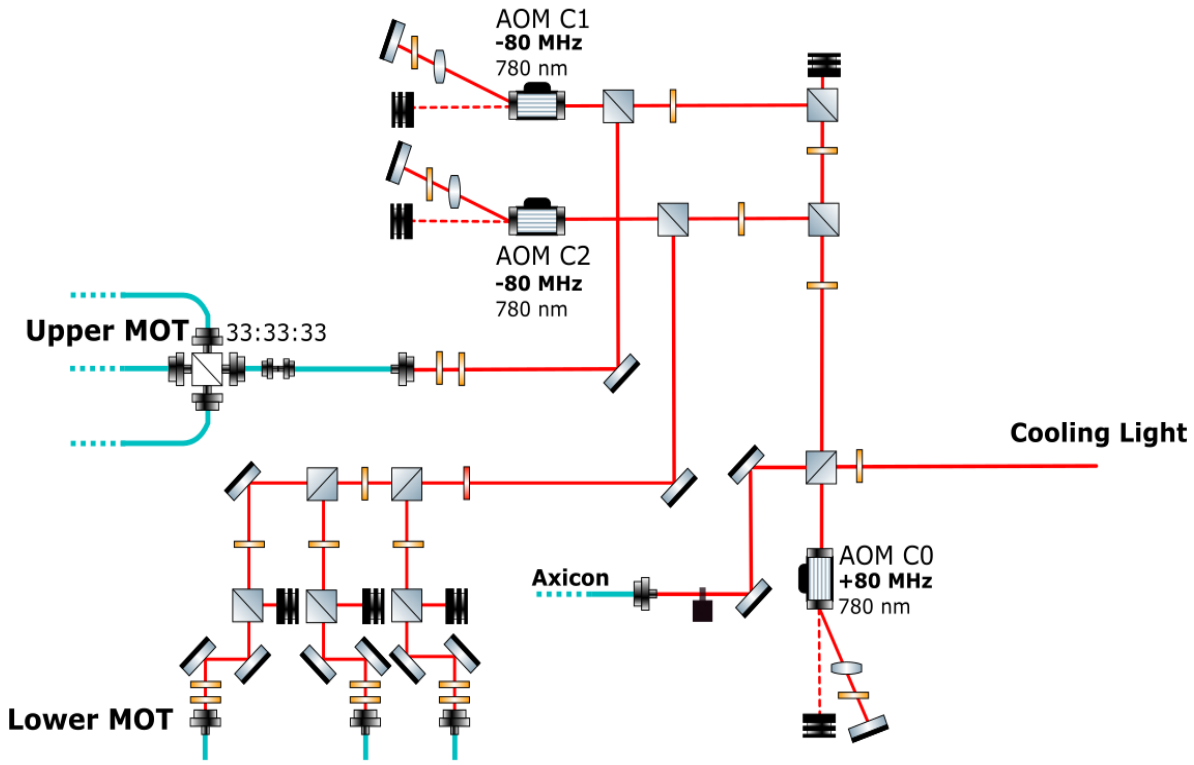
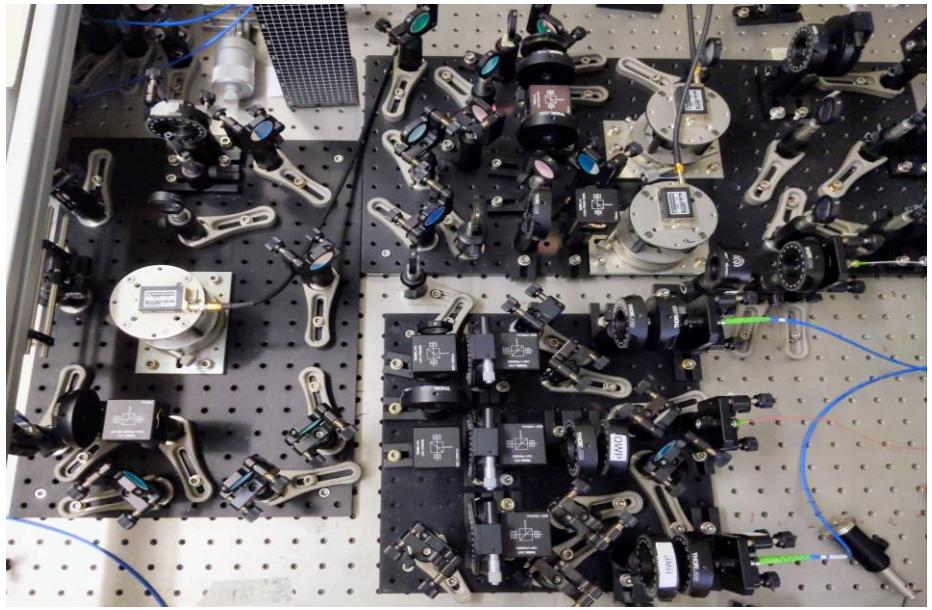
# Optics for Interferometer Upgrade

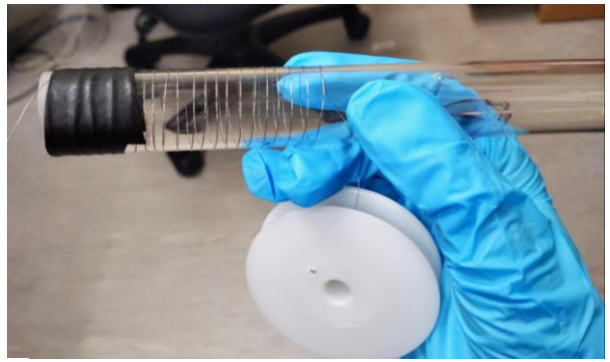


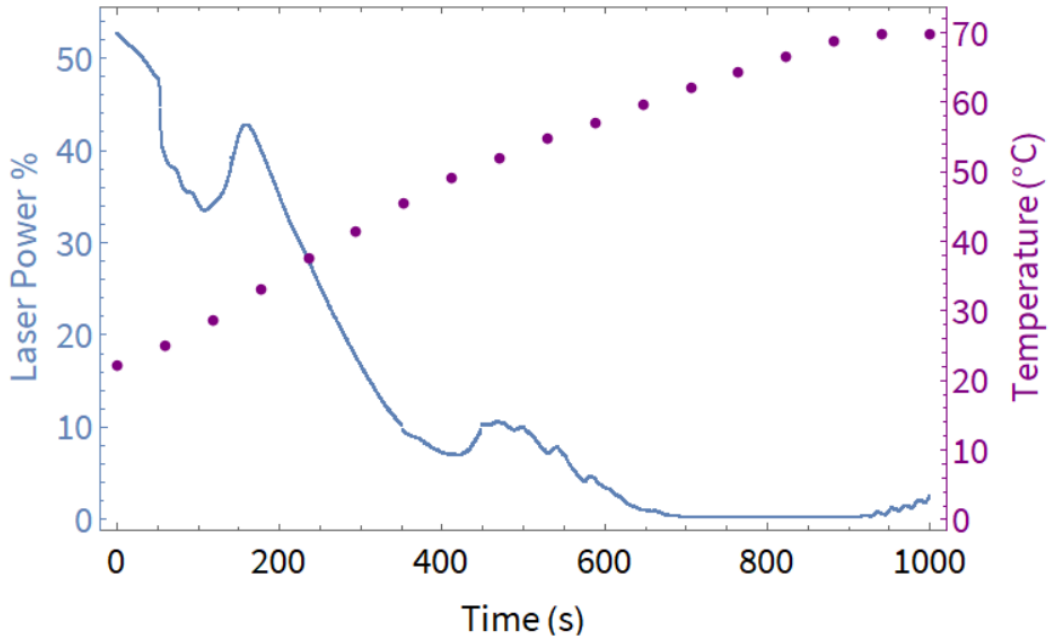



- Alignment of optics for new laser system
- AOMs to prepare light for atom cooling and trapping
- Elimination of leaking light with new system

# Optics for Interferometer Upgrade

- Custom made rubidium cells to filter light of unwanted frequencies
  - Heating wire and thermal insulation foam to reach 70°C
- Characterised cell performance and observe fluorescence






*Fluorescence from rubidium atoms*

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# Summary

- MAGIS & AION: long baseline atom interferometry experiments
  - Networking for improved sensitivity
  - Searching for dark matter & gravitational waves
  - Progress on simulation work
- Liverpool rubidium interferometer preparing for upgrade
  - Vacuum components for new chamber
  - Preparation of optics for new laser system

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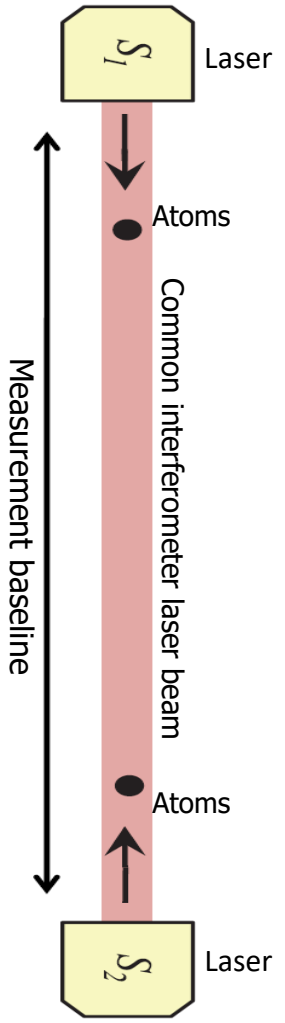
# Backup Slides

# Gravitational Wave Detection

- Mid-band frequency gravitational waves (30 mHz – 10 Hz), between LIGO and LISA

$$\Delta\phi \sim \omega_A(2L/c)$$

- 2L/c term represents laser propagation time
- Atoms as inertial reference points & clocks
- GW cause strain in light travel time – phase shift

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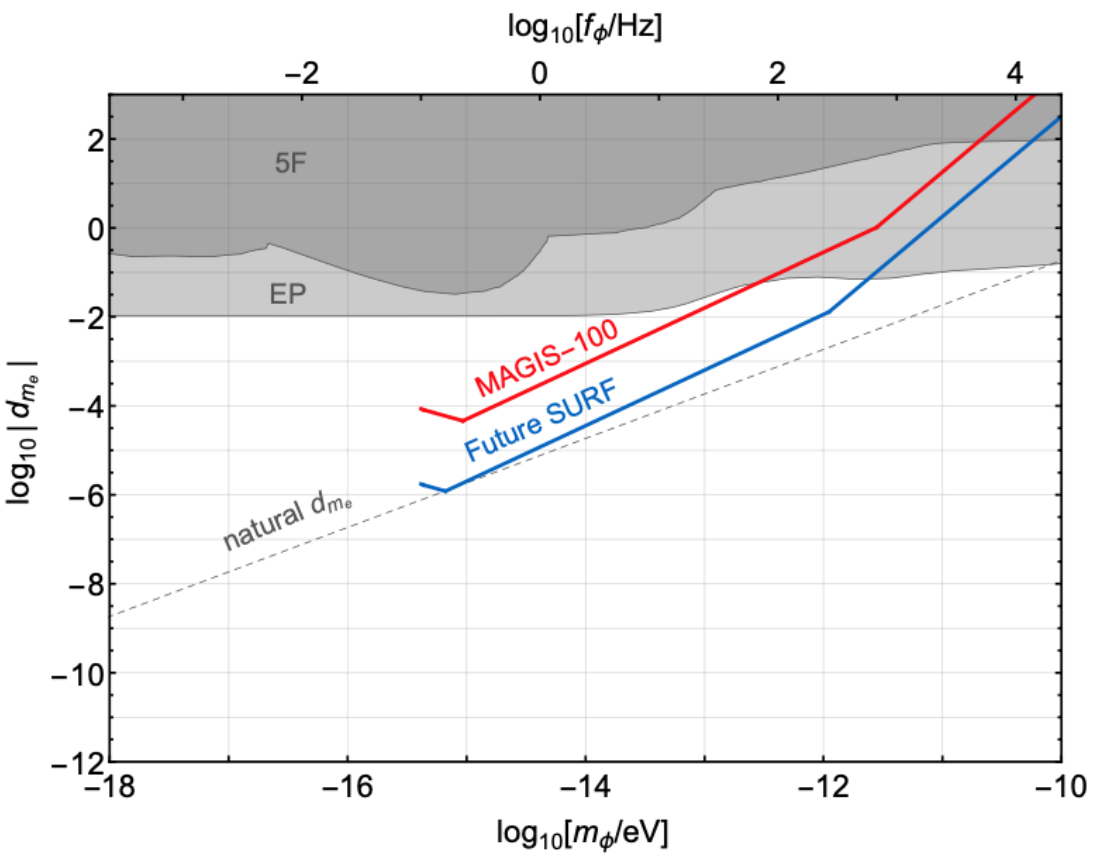
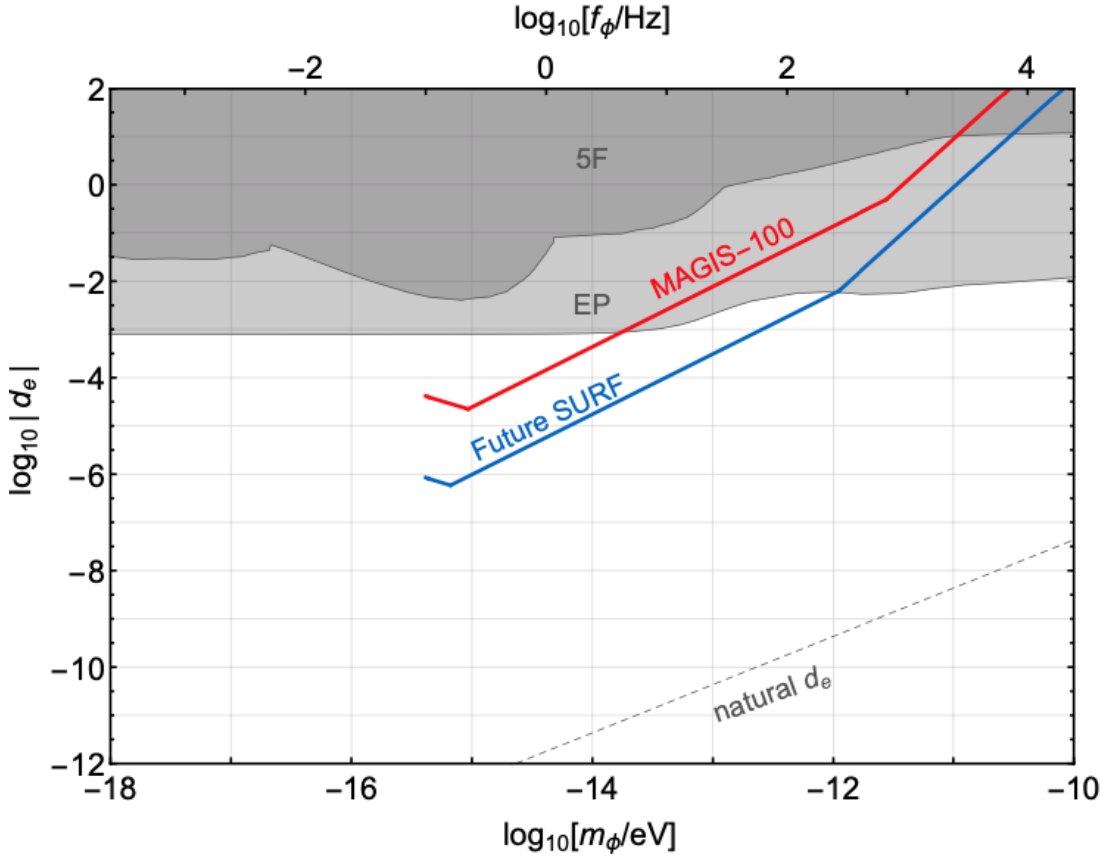
# Alternative Dark Matter Detection Methods

- Effects on fundamental constants – scalar
- Causes accelerations to test masses – vector
  - Using isotopes of strontium
  - Comparing accelerations
- Precessions of nuclear spins – pseudo scalar
  - Placing atoms in different spin states

# Sensitivity via Coupling to $m_e$ and $\alpha$




- Improve sensitivity to DM particles with mass < $10^{-15}$ eV or frequency < 0.1 Hz by 2 orders of magnitude

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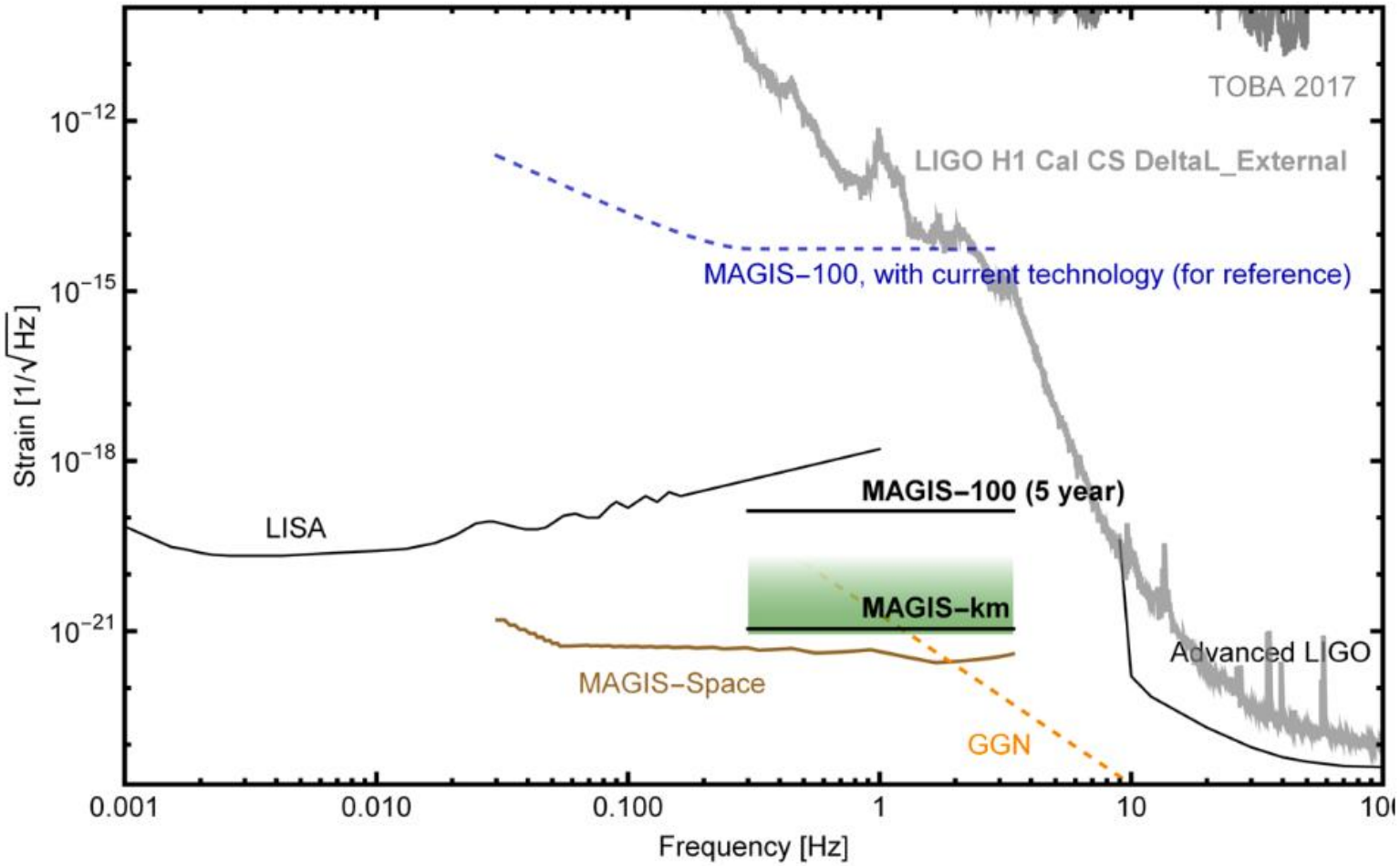
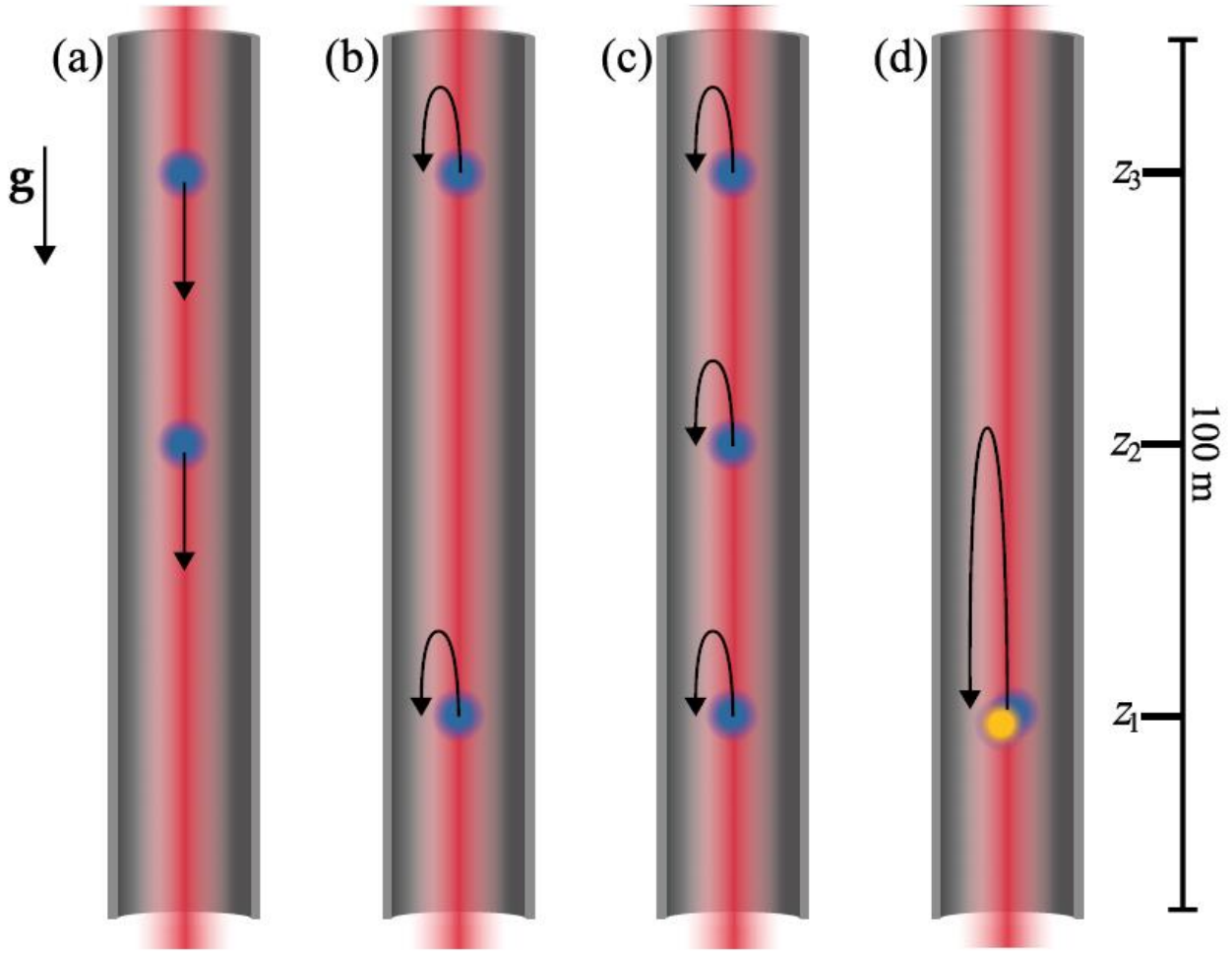
# Sensitivity to Gravitational Waves



# Baseline Configurations




a. Max drop time gradiometer
b. Max baseline gradiometer
c. GGN characterization
d. Dual species launch – alternative dark matter detection mode