MAGIS-100

AION

Atom Interferometry: MAGIS, AION and Liverpool

UNIVERSITY OF LIVERPOOL

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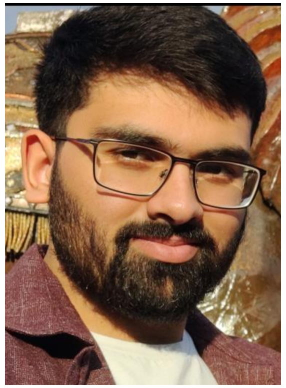

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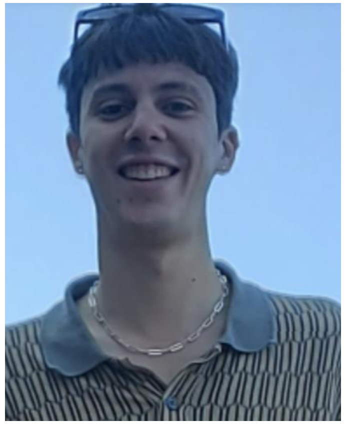

Henry Throssell

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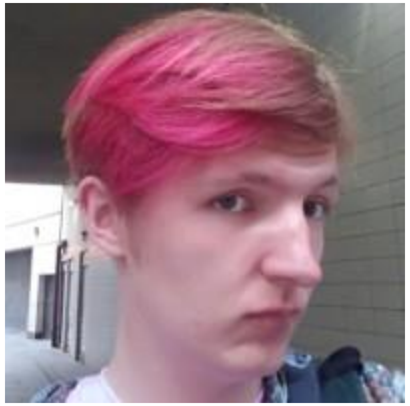
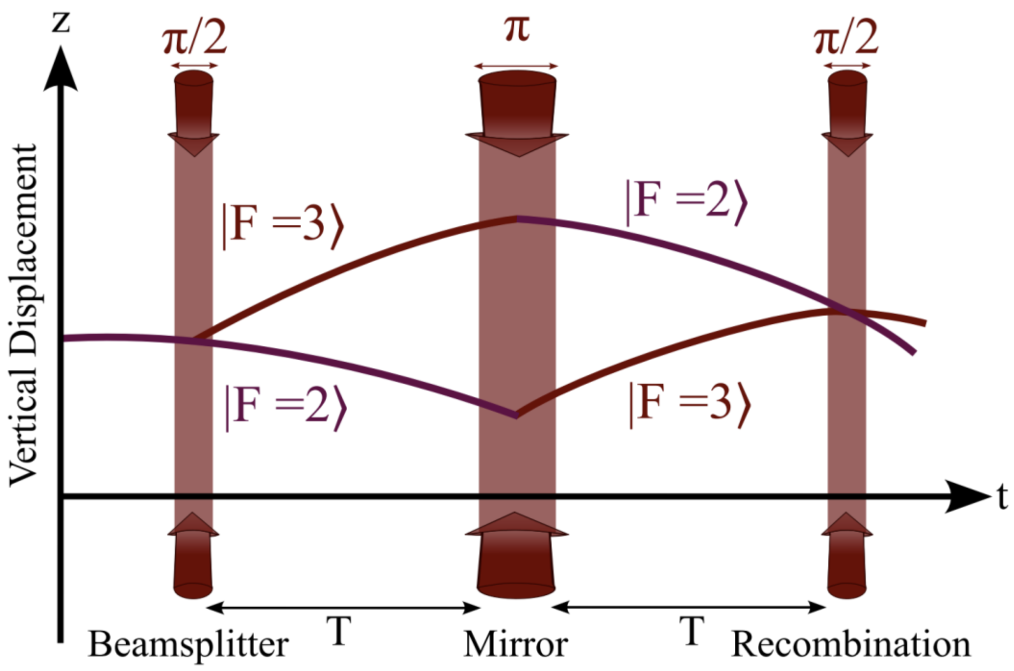


Sam Hindley

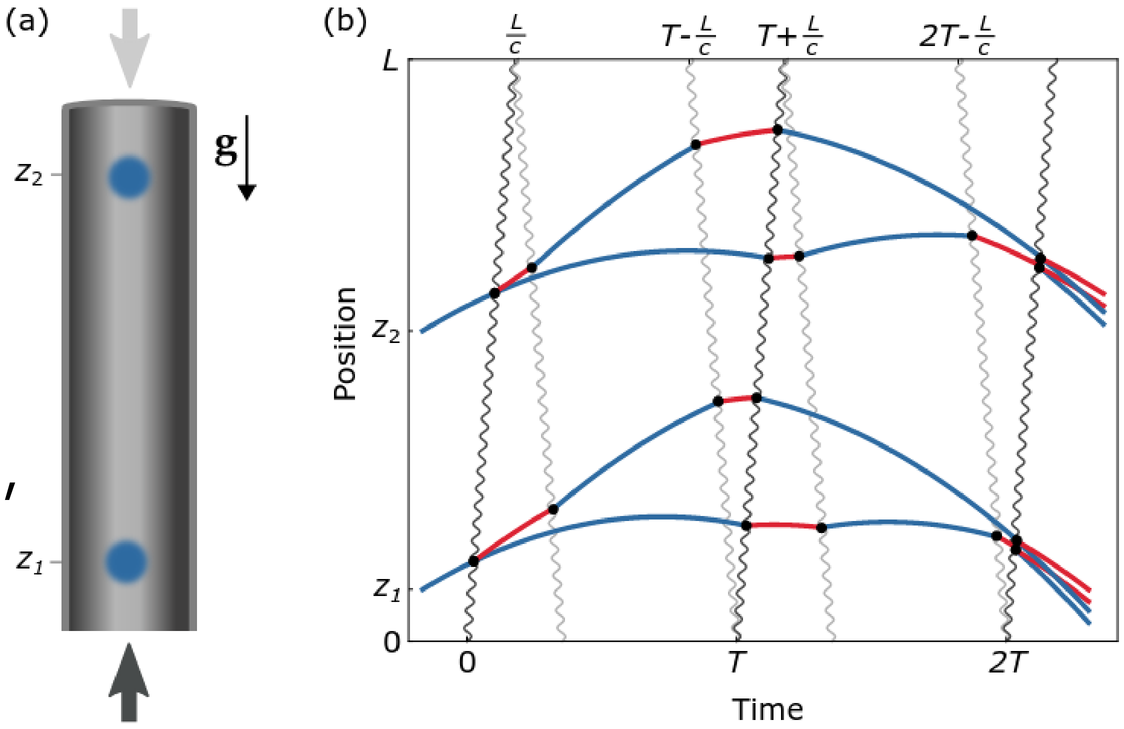
Atom Interferometry

- Analogous to light interferometer, where phase measured is the de Broglie phase from the atoms
- Using laser pulses to separate and then recombine atoms along two paths induces a phase shift
- This phase shift transfers to the atom state populations which are readily observable via fluorescence
- The phase shift is extremely sensitive to external fields and forces that differ between paths



Atom Interferometry

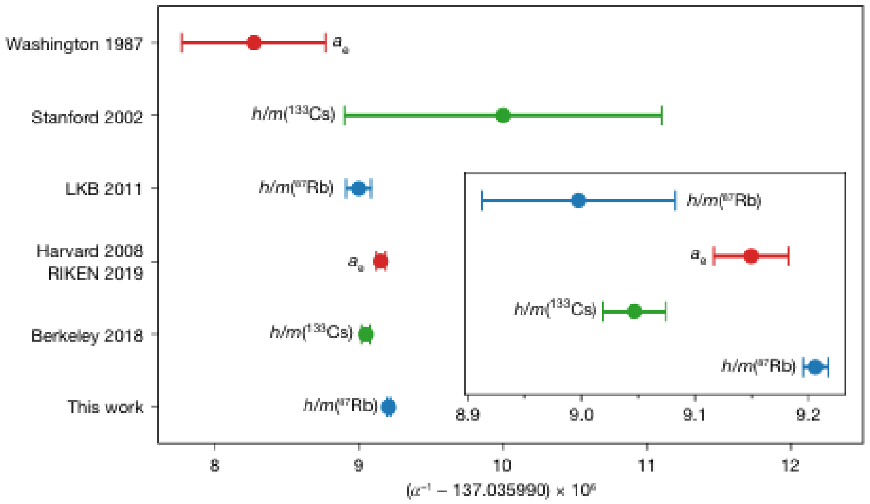
- Sensitivity scales with spacetime area
- Longer flight times, larger spatial separation
- Larger baselines, launching, multiple laser interactions (LMT)
- Gradiometry supresses common-mode noise



M. Abe et al., Quantum Sci. Technol. 6, 044003 (2021)

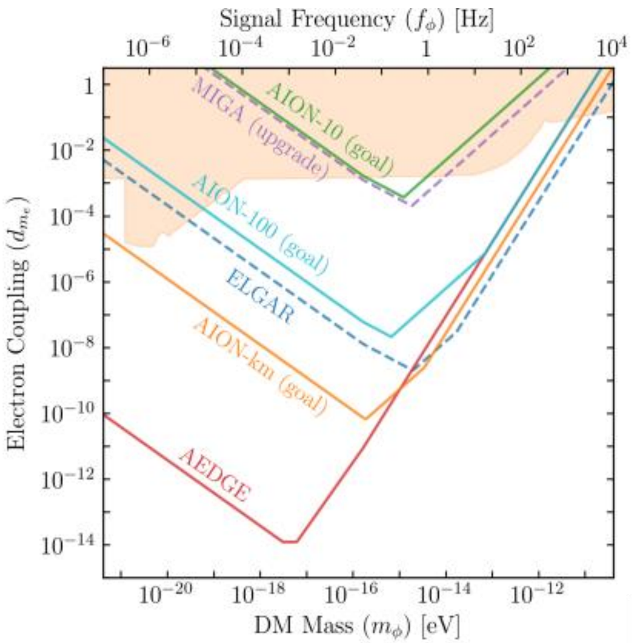
Applications for Fundamental Physics

Fine-Structure Constant



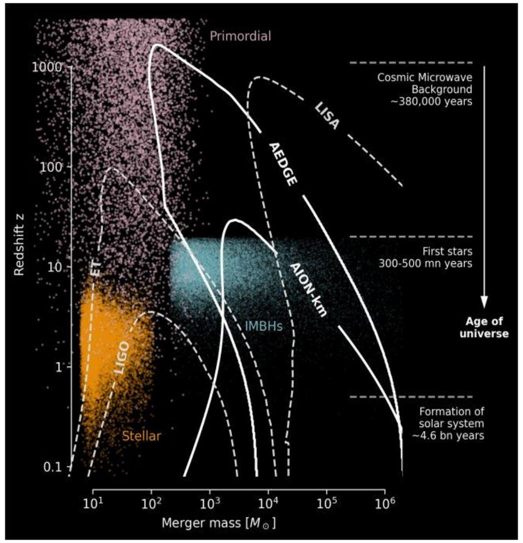
Morel, L., Yao, Z., Cladé, P. *et al*. *Nature* **588**, 61–65 (2020)

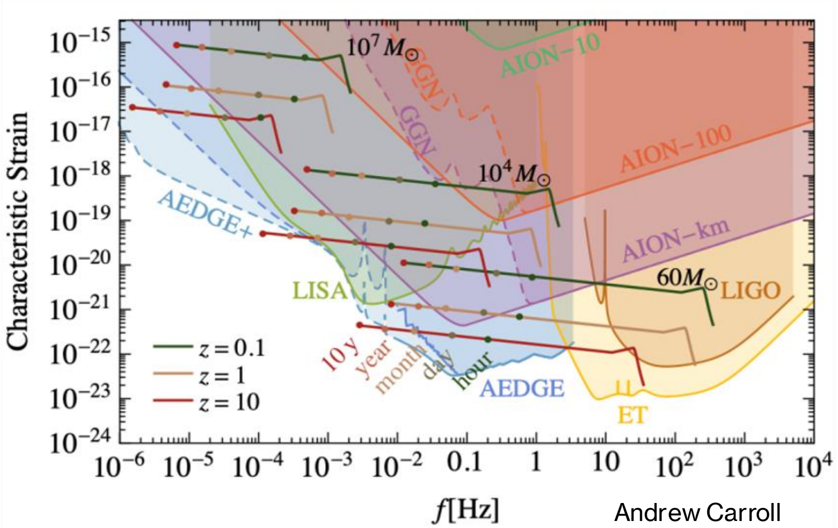
Ultralight Dark Matter Searches



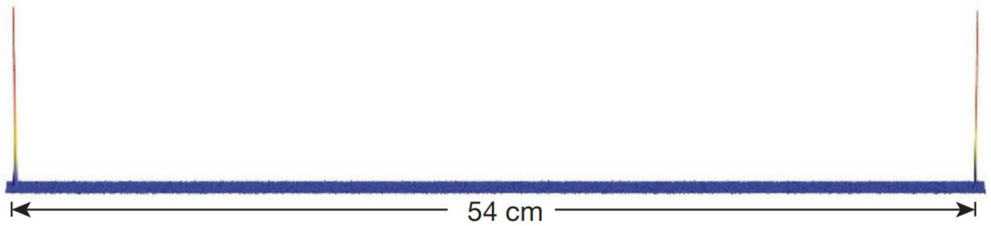
I. Alonso et al., EPJ Quantum Technology 9, 30 (2022)

Mid-Band Gravitational Waves





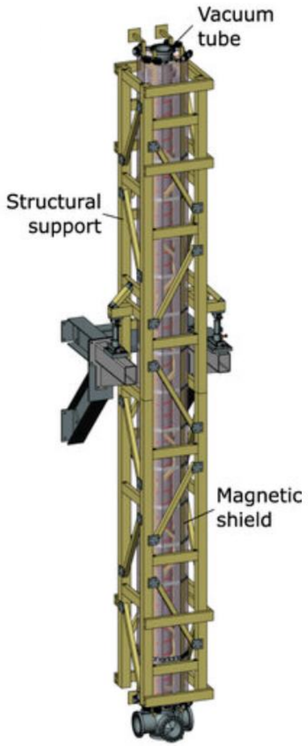
Macroscopic Superposition

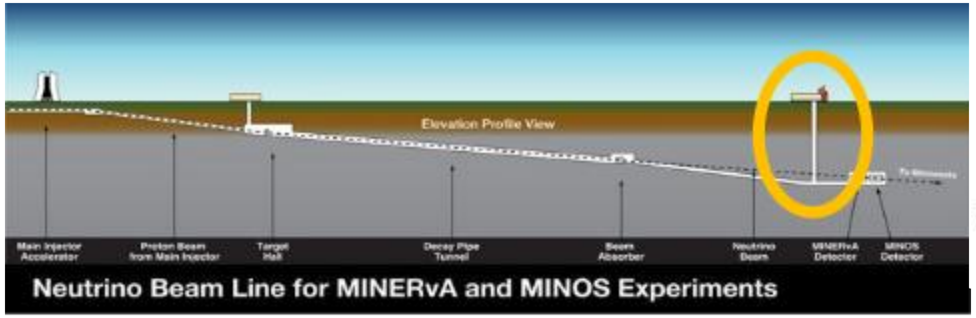


Kovachy et al., *Nature* **528**, 530–533 (2015)

MAGIS at Fermilab

- 100-meter strontium gradiometer located at MINOS shaft in Fermilab
- Multiple atom sources to create gradiometric configuration
- Due to begin commissioning in 2027





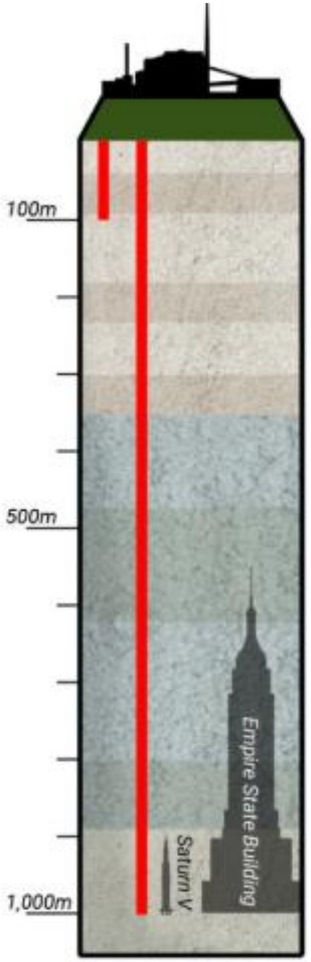
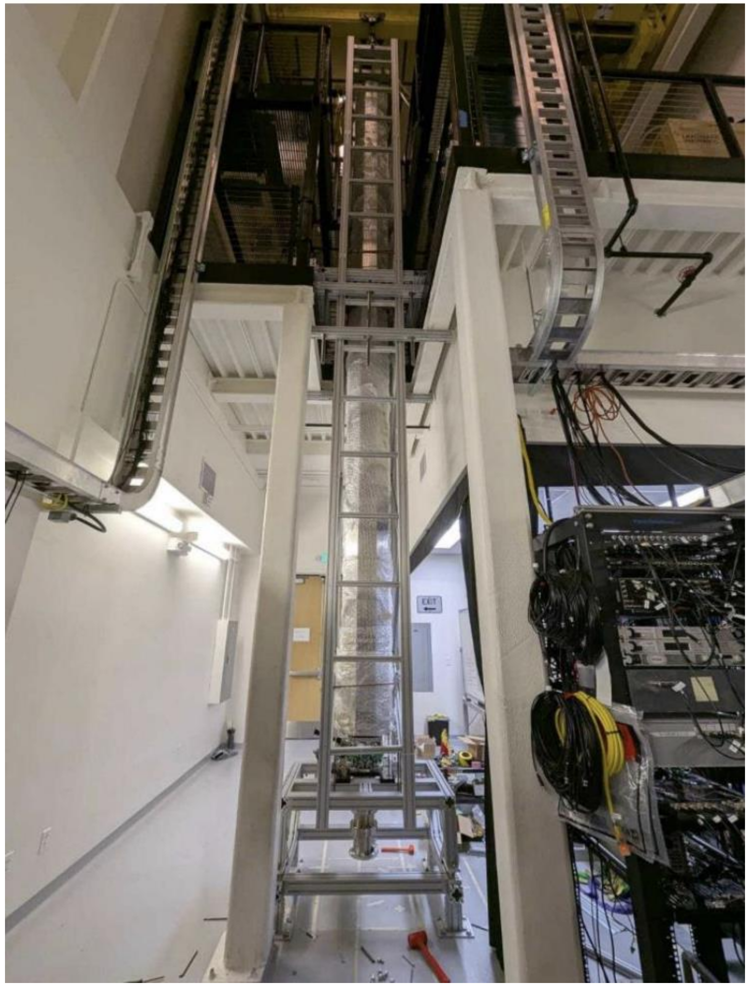
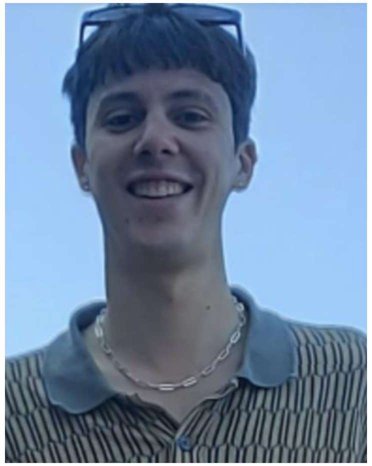
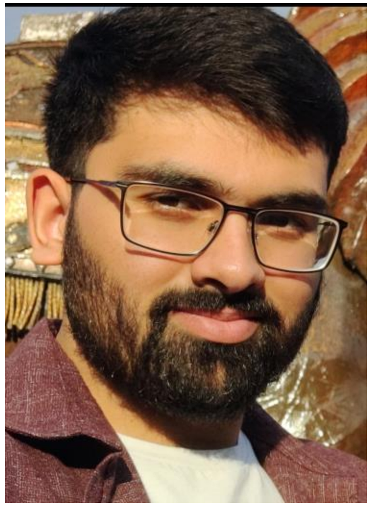


Image courtesy of Ben Gilliland, STFC

MAGIS Prototype



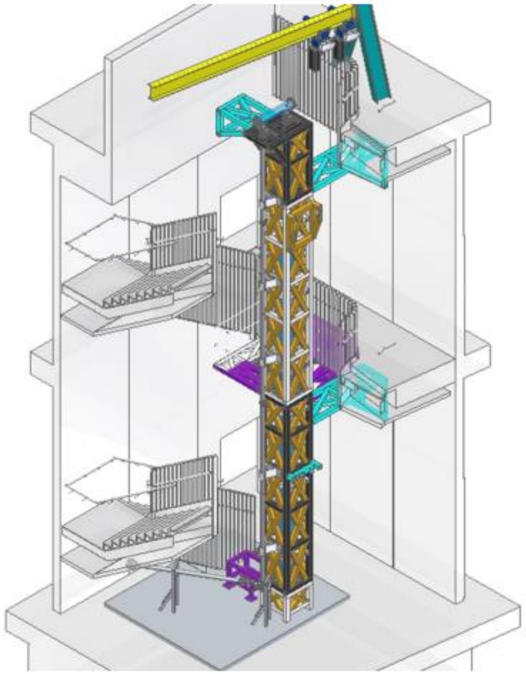


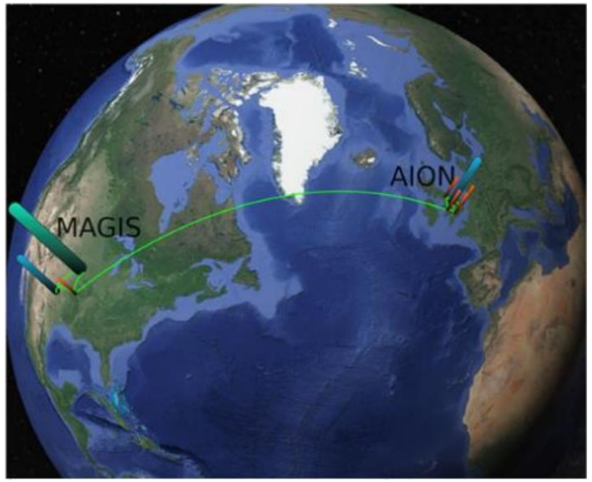


- 10m prototype tower located at Stanford
- Utilises same lasers and atoms so acts as testing ground for MAGIS-100
- Recently lifted vertically, close to completion
- Phase-shear detection platform built at Liverpool and commissioned last summer

AION

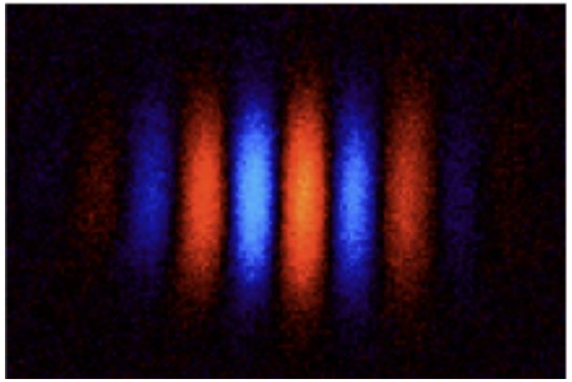
- Multi-institute collaboration to act as sister consortium to MAGIS
- 10-metre tower located at the Beecroft building in Oxford
- Future stages to include 100-m and 1-km baselines
- Currently in CDR phase
- Awaiting new round of QTFP funding

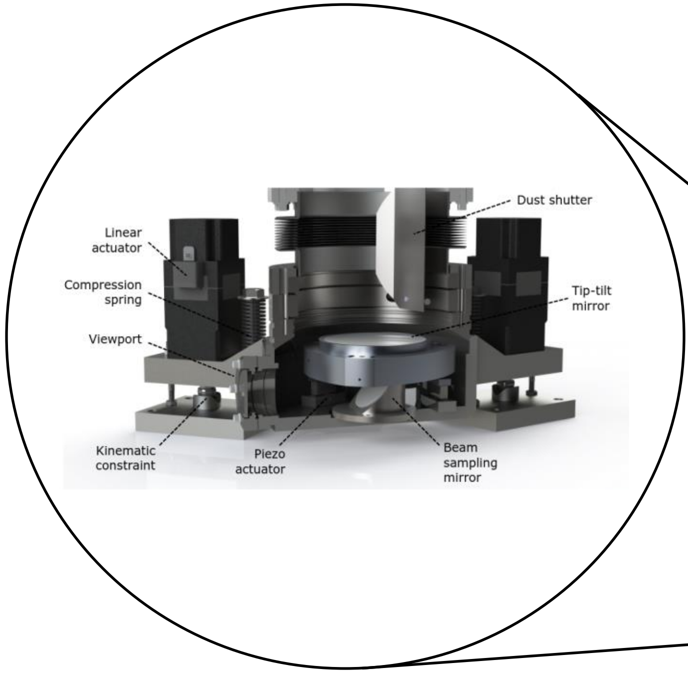


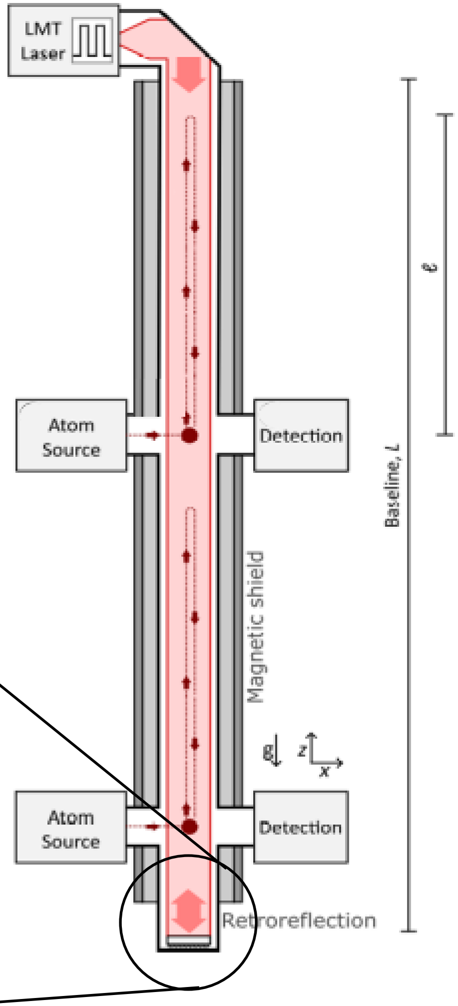


Phase-shear Detection Platform Overview

- Detection module used for Phase Shear and Coriolis compensation
- Retro-reflection mirror precision controlled by three Piezoelectric Transducers
- Angular feedback via strain gauges and optical lever
- Designed to have 50 nrad angular resolution







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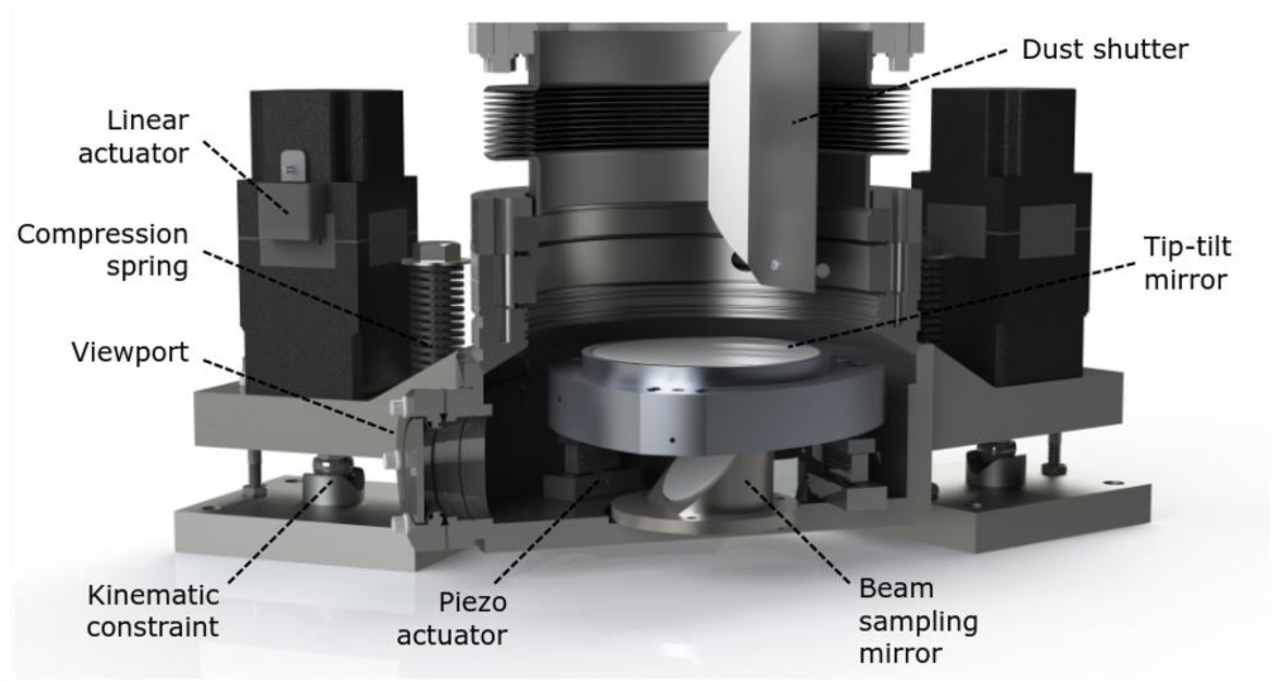

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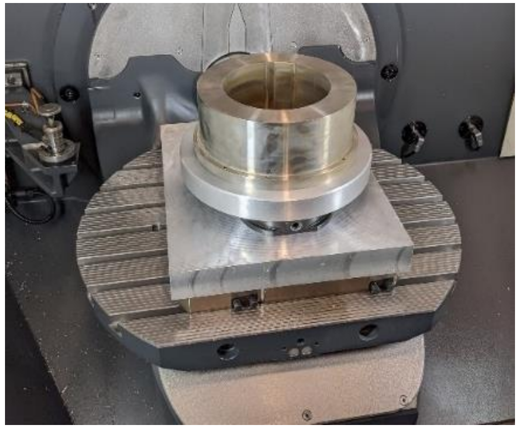
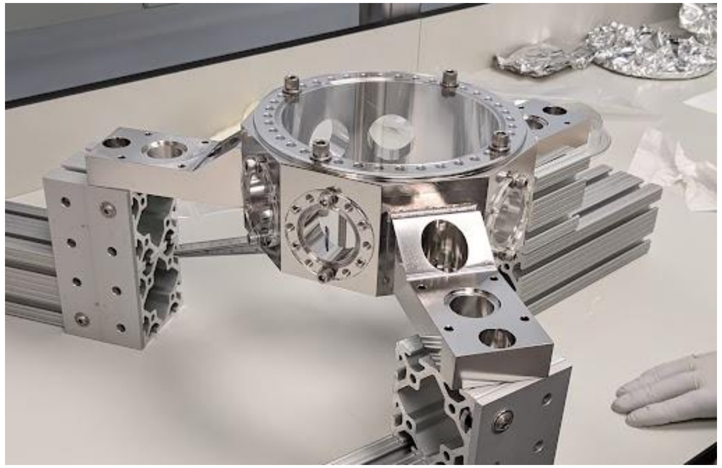
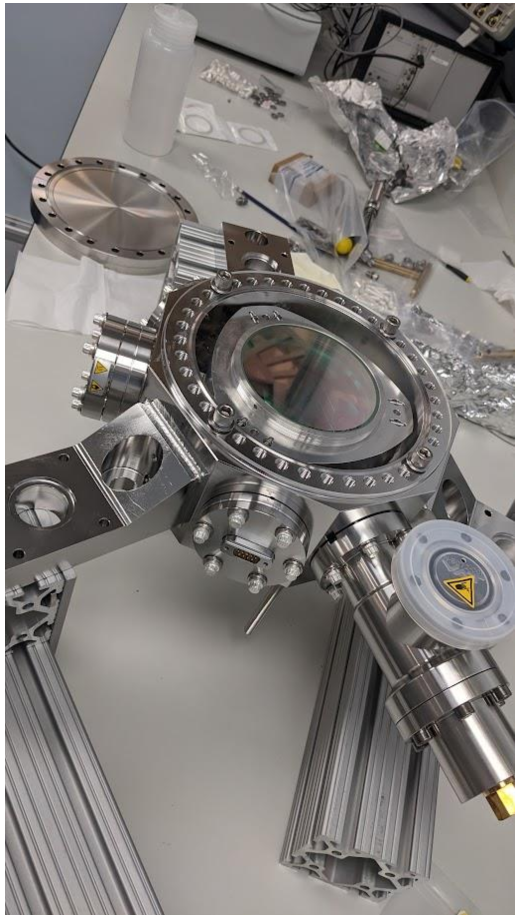
Phase-shear Detection Platform Installation

- University of Liverpool involved in design, manufacturing, prototyping, assembly and commissioning
- MAGIS prototype commissioned at Stanford
- In process of constructing chamber design with optical lever feedback







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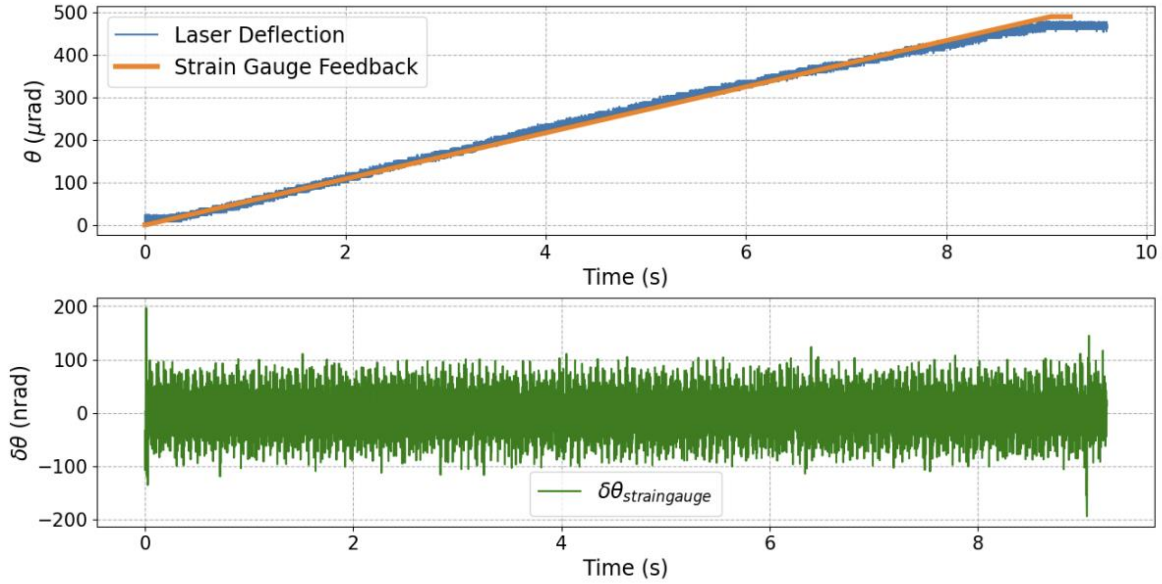
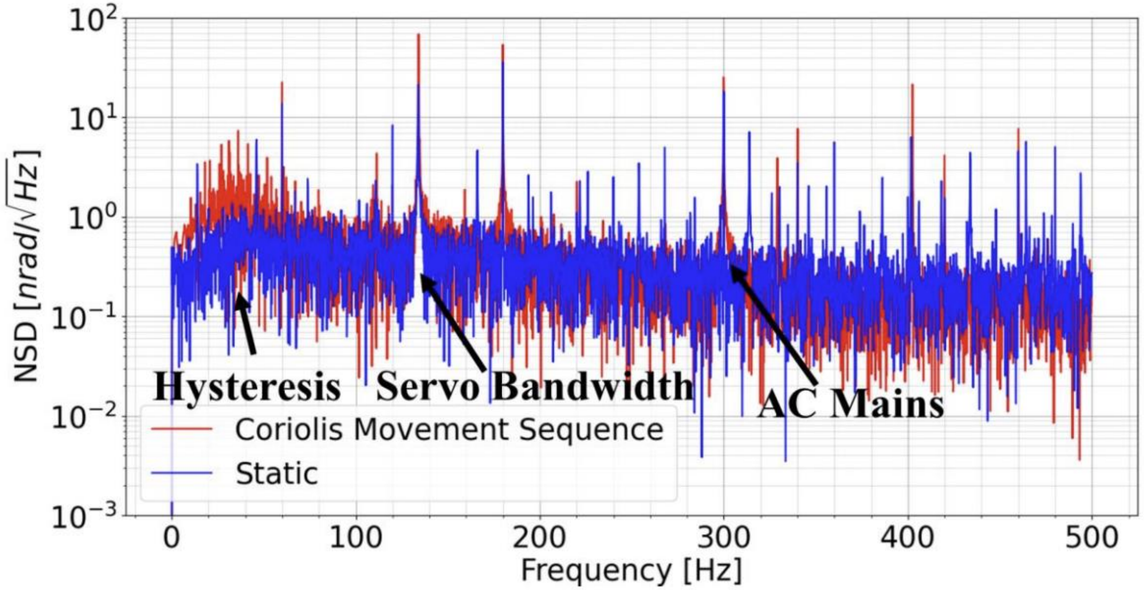
Phase-shear Detection Platform Pointing Analysis

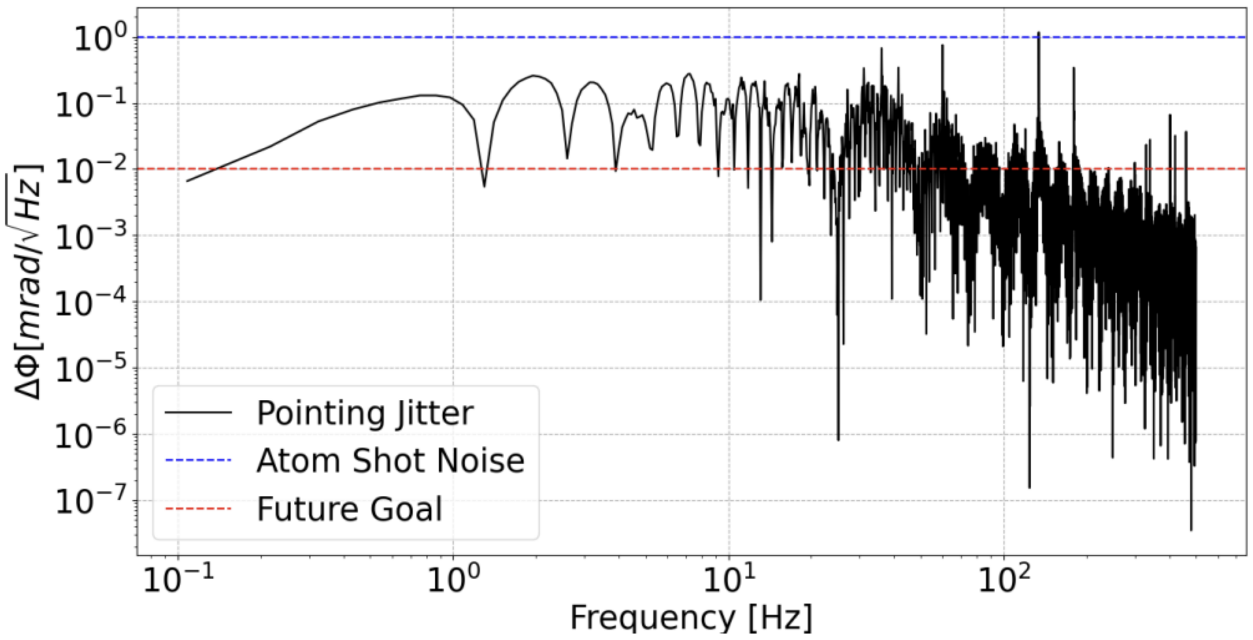




- Given required 50 nrad pointing accuracy, important to understand the how well this is achieved
- Analysing data taken by Henry while in Stanford allowed the pointing stability and accuracy under mirror orientation to be measured

Phase-shear Detection Platform Pointing Analysis

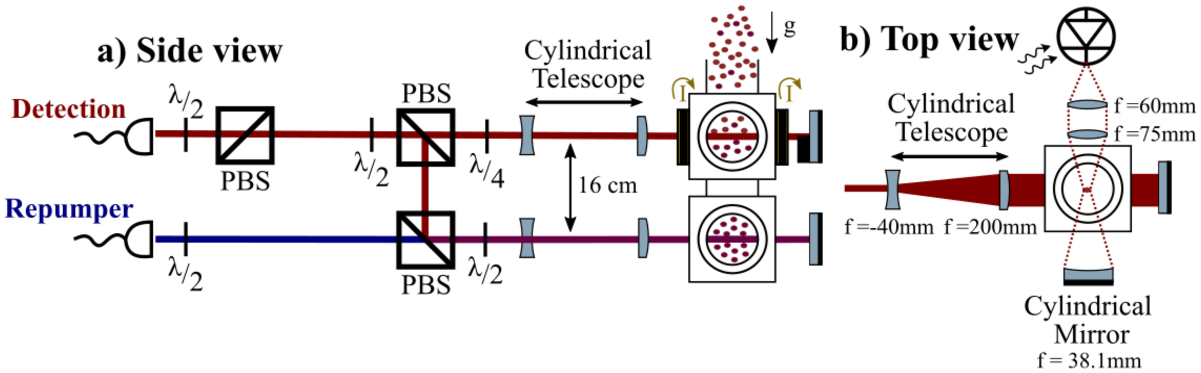
- Calculated phase difference from platform consistently below the atom shot noise
- Matches or exceeds all design target metrics
- These targets will become stricter over longer baselines that 100 m
- Additional optical monitoring system is therefore a future requirement

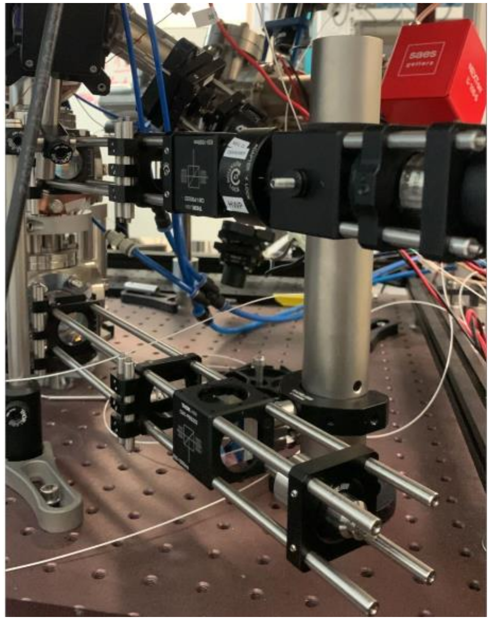


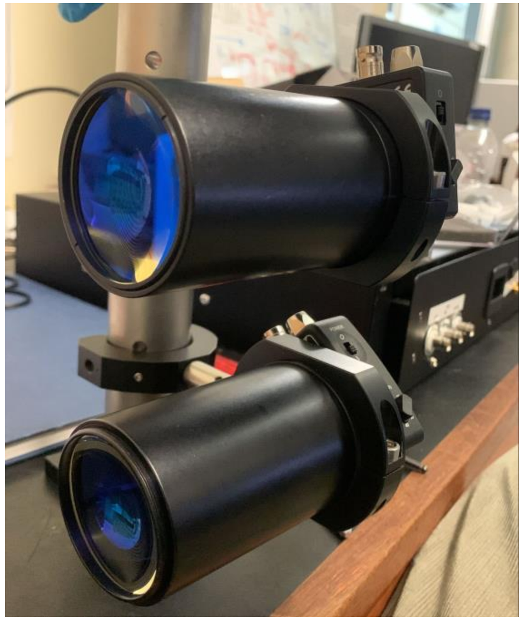
Requirement	Design Target	Measured
angular range ϕ (mrad)	1.3	1.4
rms average $\delta\phi$ (nrad)	50	33
rms mirror flatness (λ)	0.001	0.001 ± 0.001
servo settling time (ms)	100	63.4 ± 3.4
pointing jitter phase shift (mrad)	6.00	0.46

Liverpool ^{85}Rb Interferometer

- Acts as a testbed to support work on MAGIS and AION
- Potential fundamental physics tests
- State detection system improved
- Atom cloud was dropped approximately 20 cm







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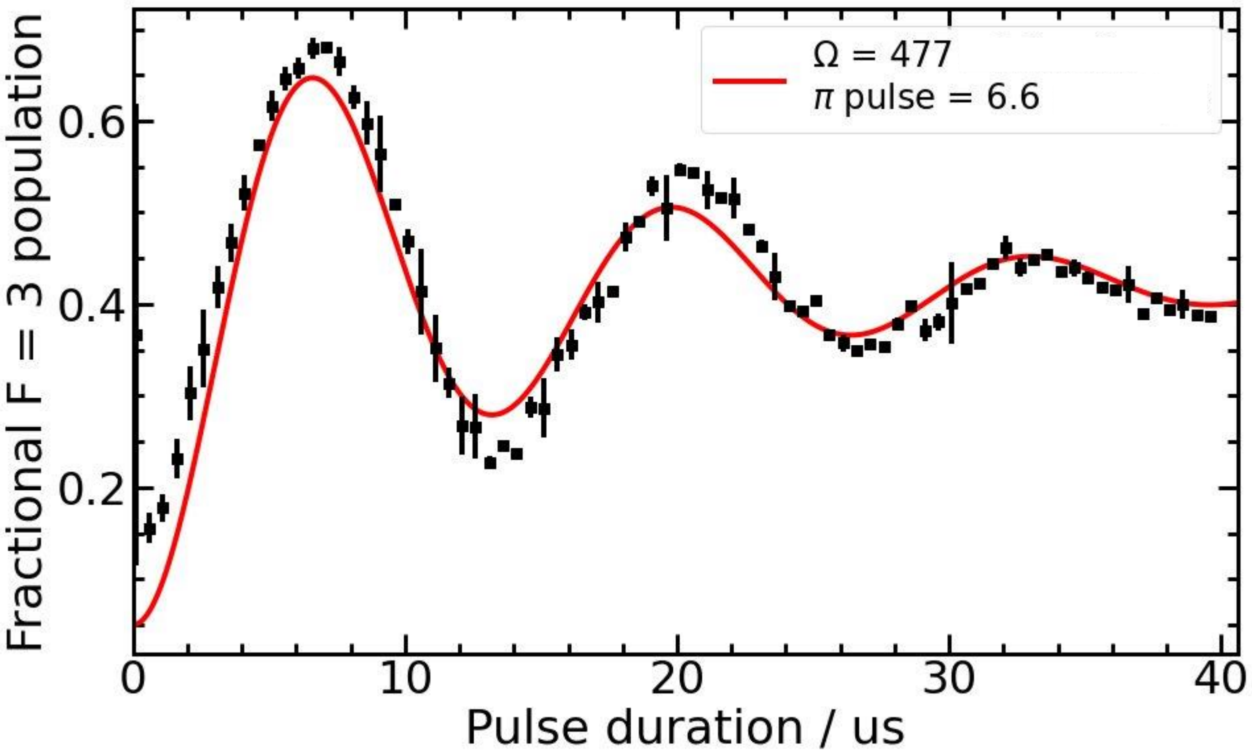
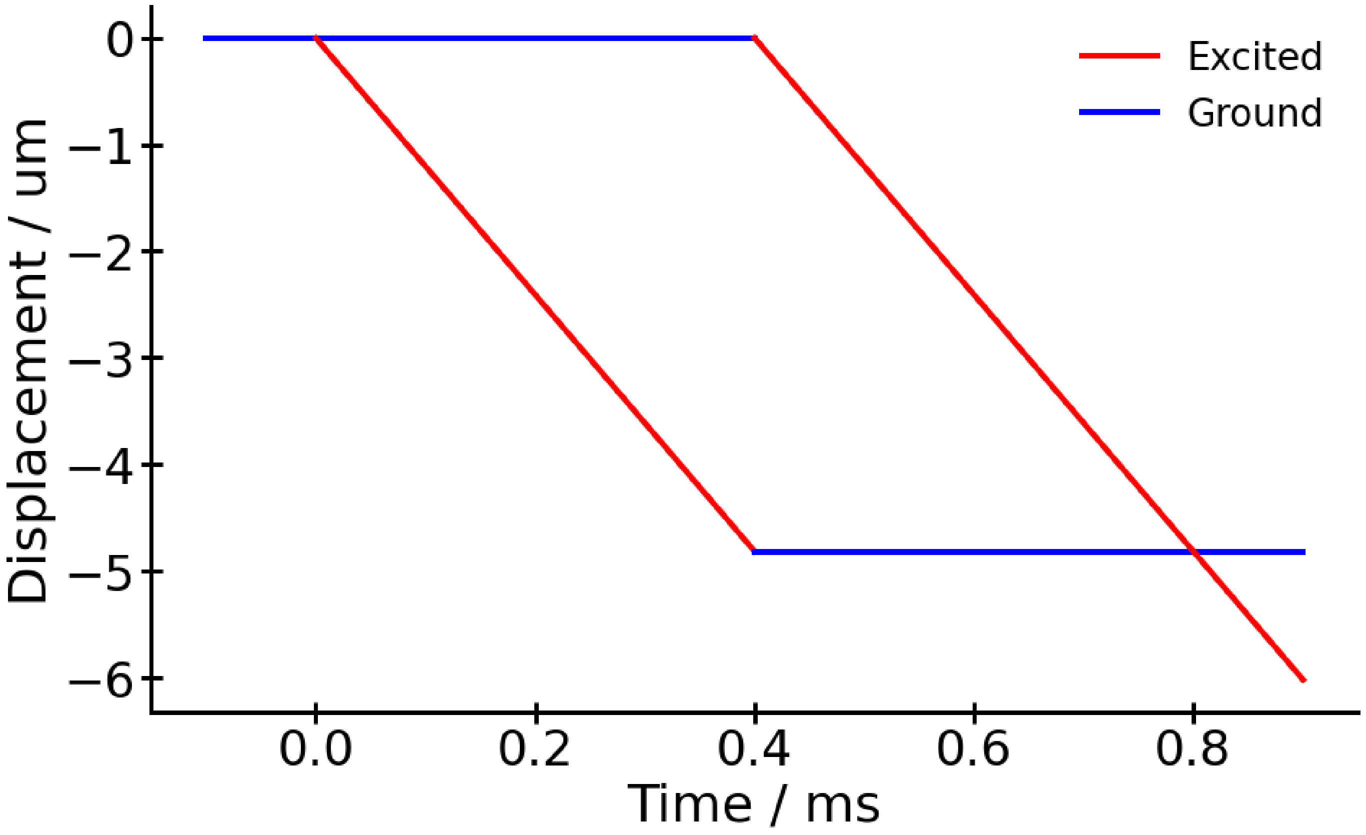


Inertially-sensitive Interference Fringes

- Triplet of laser pulses applied, each separated by time T
- Laser frequencies set to match magnetic sub-level; other levels blown away by on-resonant light
- T is then varied from 0-400 μs and the excited state population measured



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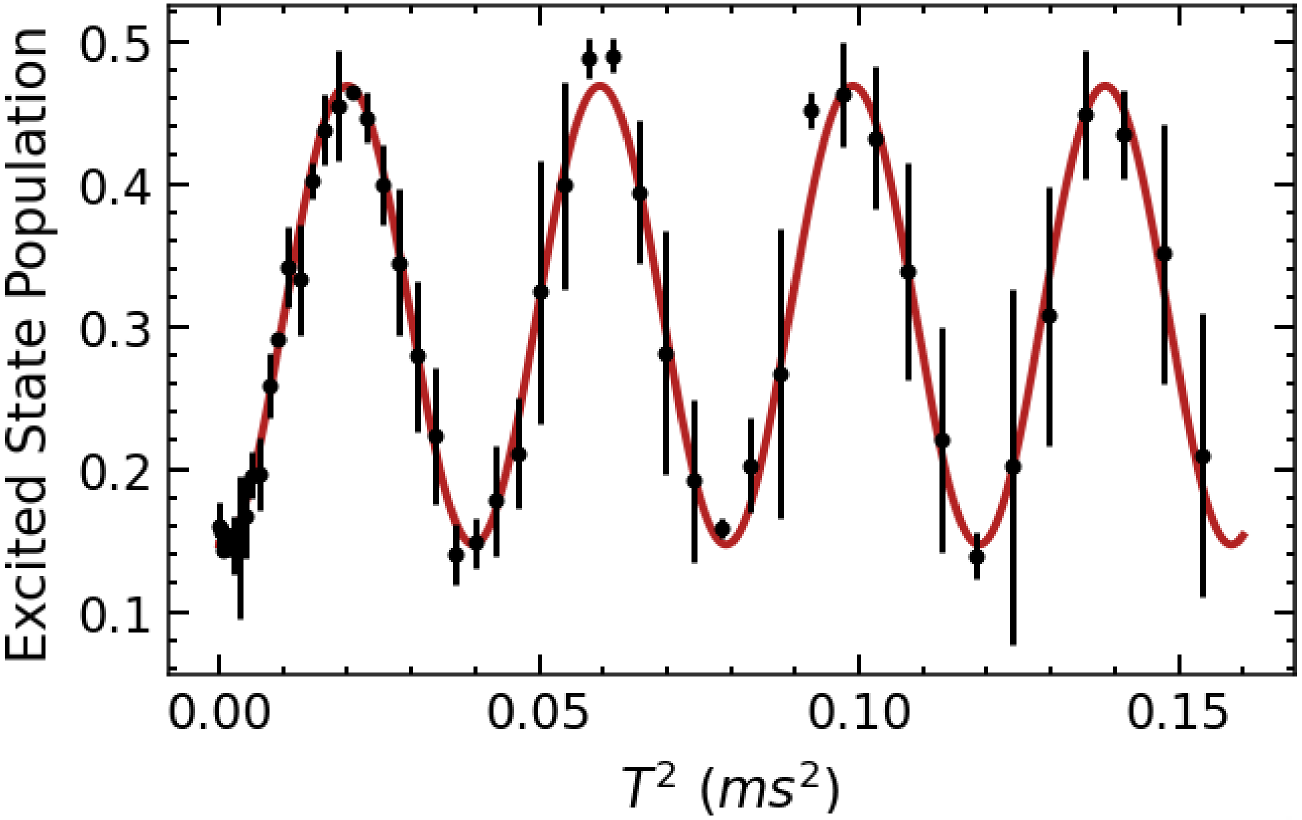
Inertially-sensitive Interference Fringes

- $\Delta\Phi = k_{eff} g T^2$
- Currently dropped for 800 μs ~ 3 microns
- Due to Doppler effect, longer drop times require laser beams to be 'chirped'
- Once this is achieved, orders of magnitude larger flights will be possible



Summary and Outlook

- MAGIS Prototype phase-shear detection platform machined and prototyped at Liverpool, successfully commissioned at Stanford
- In process of upgrading platform to improve angular resolution via optical monitoring for feedback for future iterations of MAGIS/AION
- Liverpool interferometer upgraded and first inertially-sensitive fringes measured
- Commissioning towards a ~1m interferometer at Liverpool in near future

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