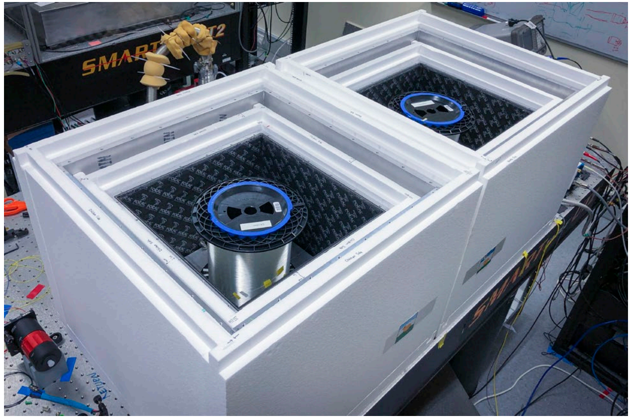
AN ULTRA-SENSITIVE FIBRE FREQUENCY REFERENCE

FOR SHORT-TERM LASER STABILISATION



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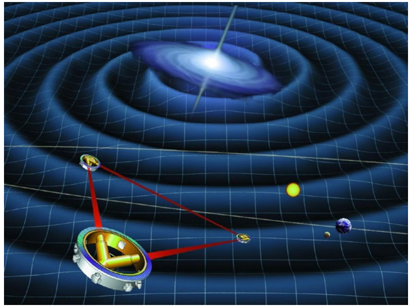
Australian National University

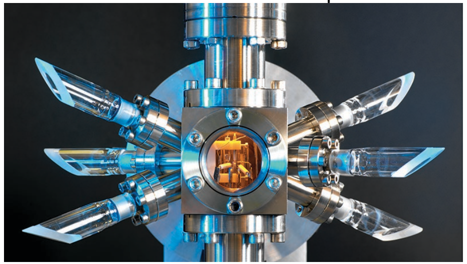
AML Applied Metrology Labs

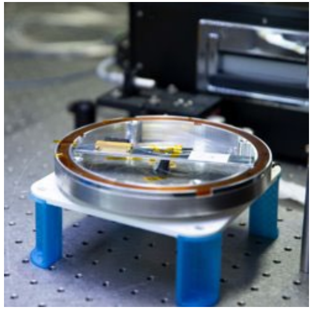
Why Laser Frequency Matters?

Gravity Wave Detection (LISA)

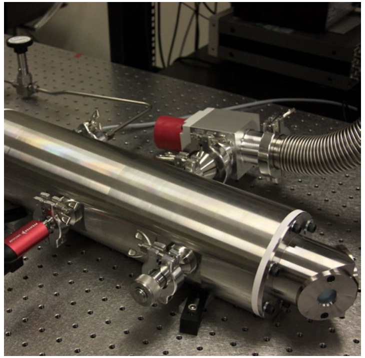


Optical clocks





Fibre optic gyroscopes



Spectrometric sensing

Optical interferometry is a widely used metrology and sensing technique

One way to meet the requirement for laser stability is to stabilise using an external reference

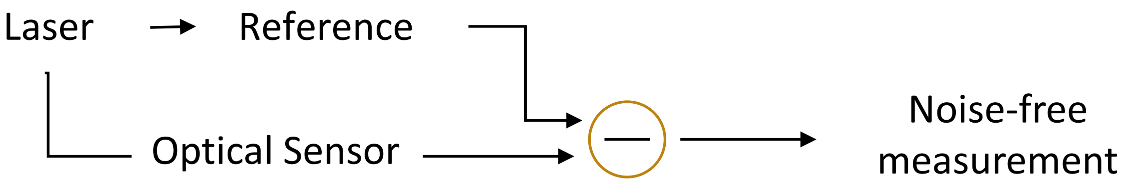
External references for laser frequency stabilisation

- Optical cavities/fibre interferometers
- Molecular transitions
- Optical frequency combs

Why use an interferometer?

Optical cavities operate using feedback – this is to keep the laser frequency within the linewidth of the cavity resonance

An interferometer with the appropriate readout has no such restriction

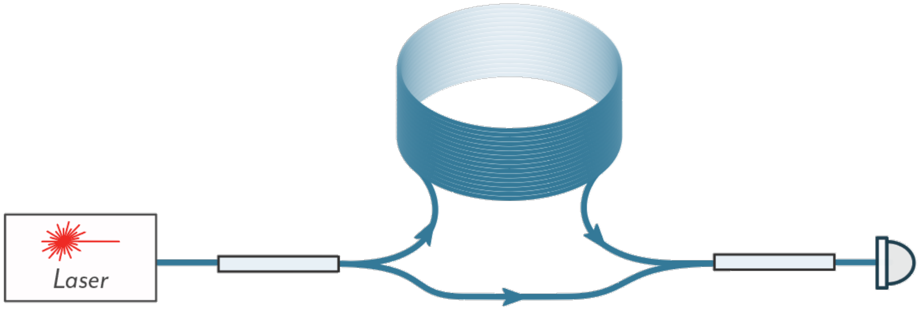


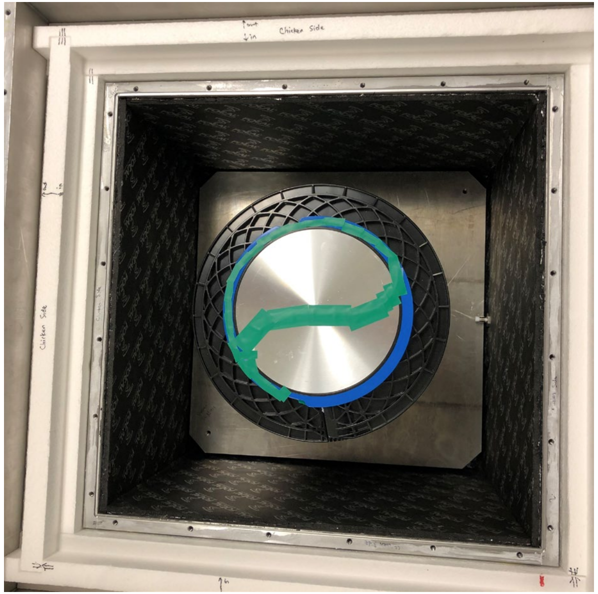
The error signal is used to subtract the inferred laser frequency noise from subsequent measurements

- Removes bandwidth constraint and feedback control noise
- Can use post-processing (non-real-time)
- Requires high dynamic range measurement of laser phase noise

The stability of the reference is the ultimate limit

Fibre Frequency Reference





Armlength mismatched interferometer to measure laser frequency fluctuation

Mach-Zehnder interferometer, 15 km armlength difference

Stability characterized by subtraction of 2 identical interferometers

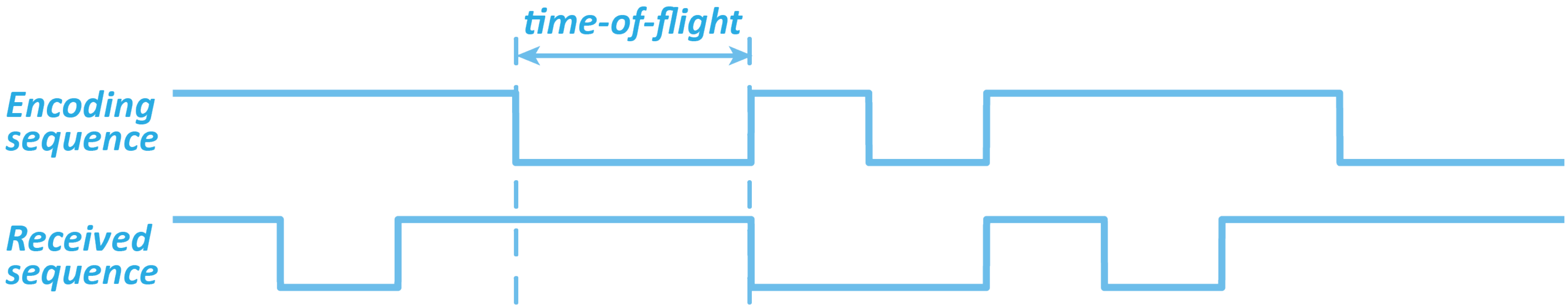
Challenges in fibre: scattering, polarisation, thermal drift

Digital Interferometry (DI)

Pseudo-random code modulation

Features:
- Signal multiplexing
- Spurious noise rejection
- Open-loop phase readout
- Homodyne & Heterodyne compatible

Auto-correlation ⟺ range gating



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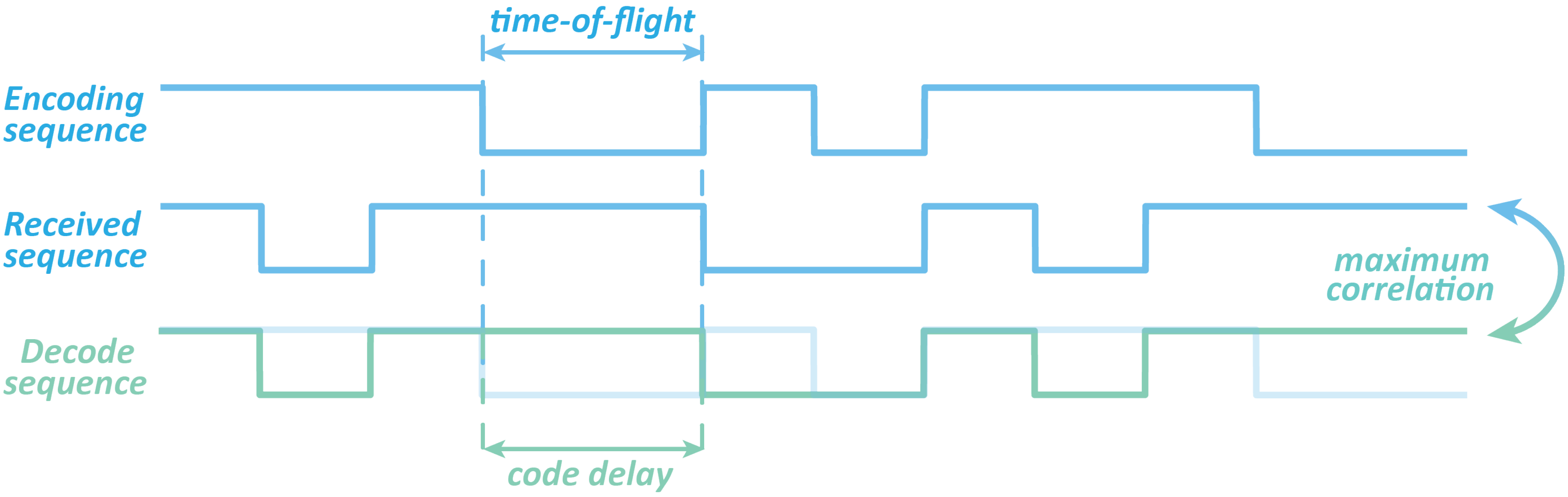

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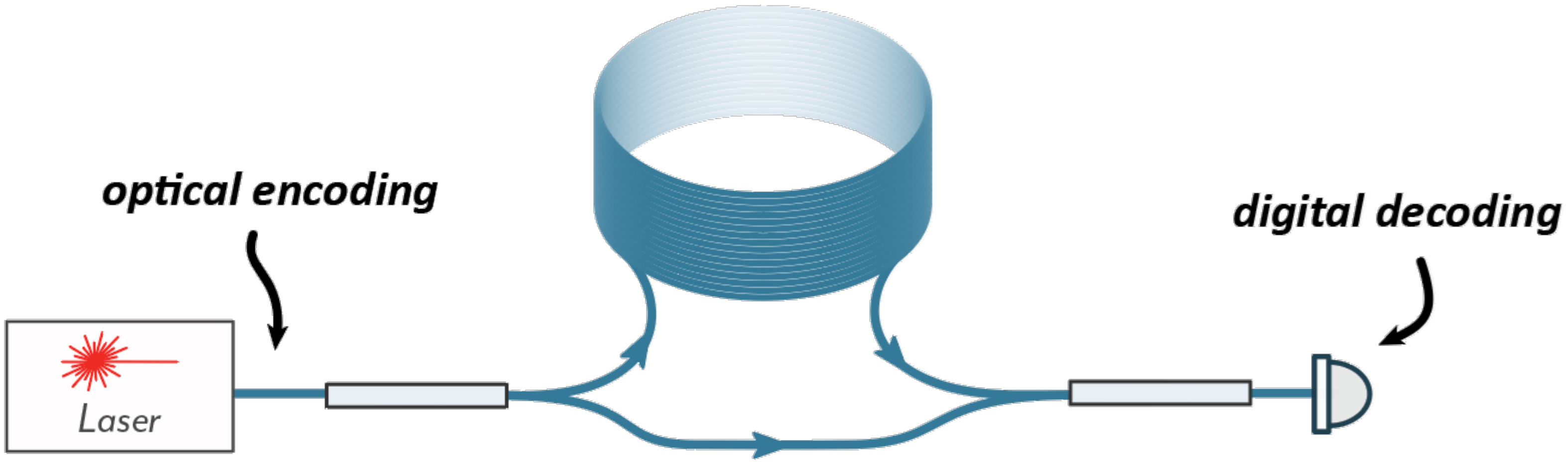
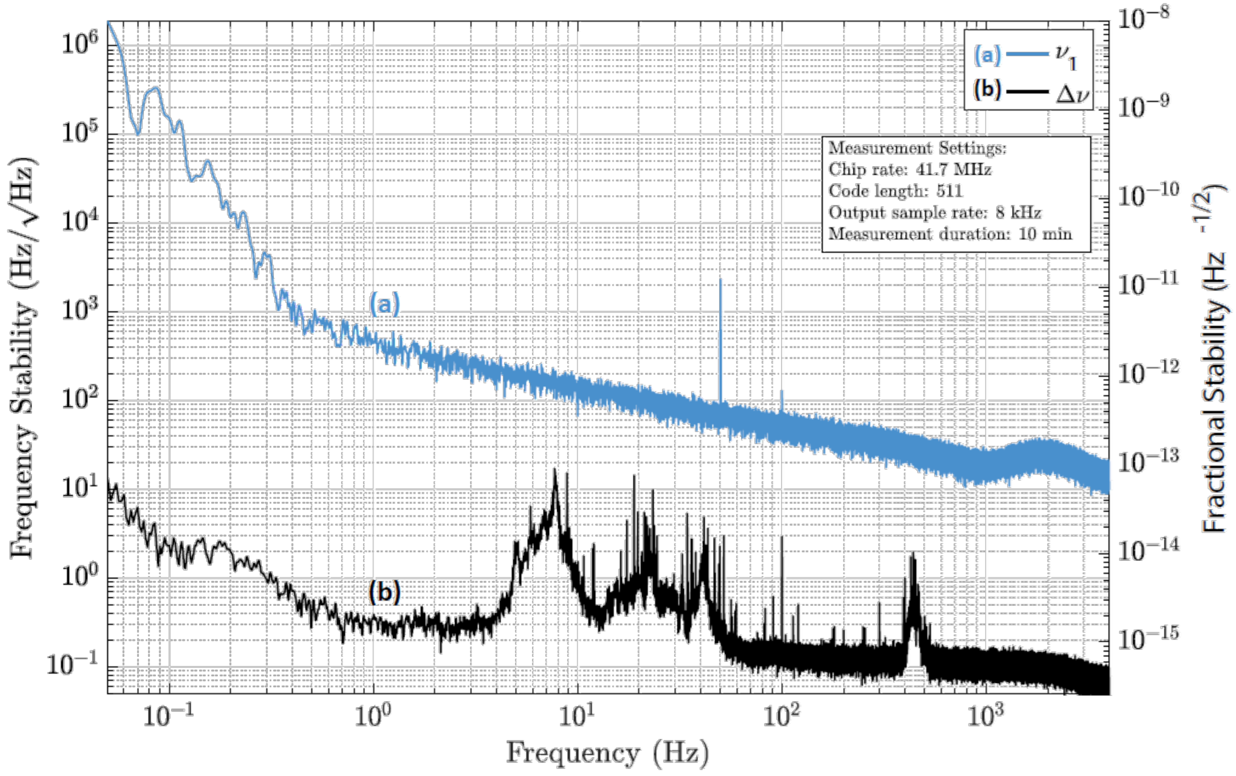


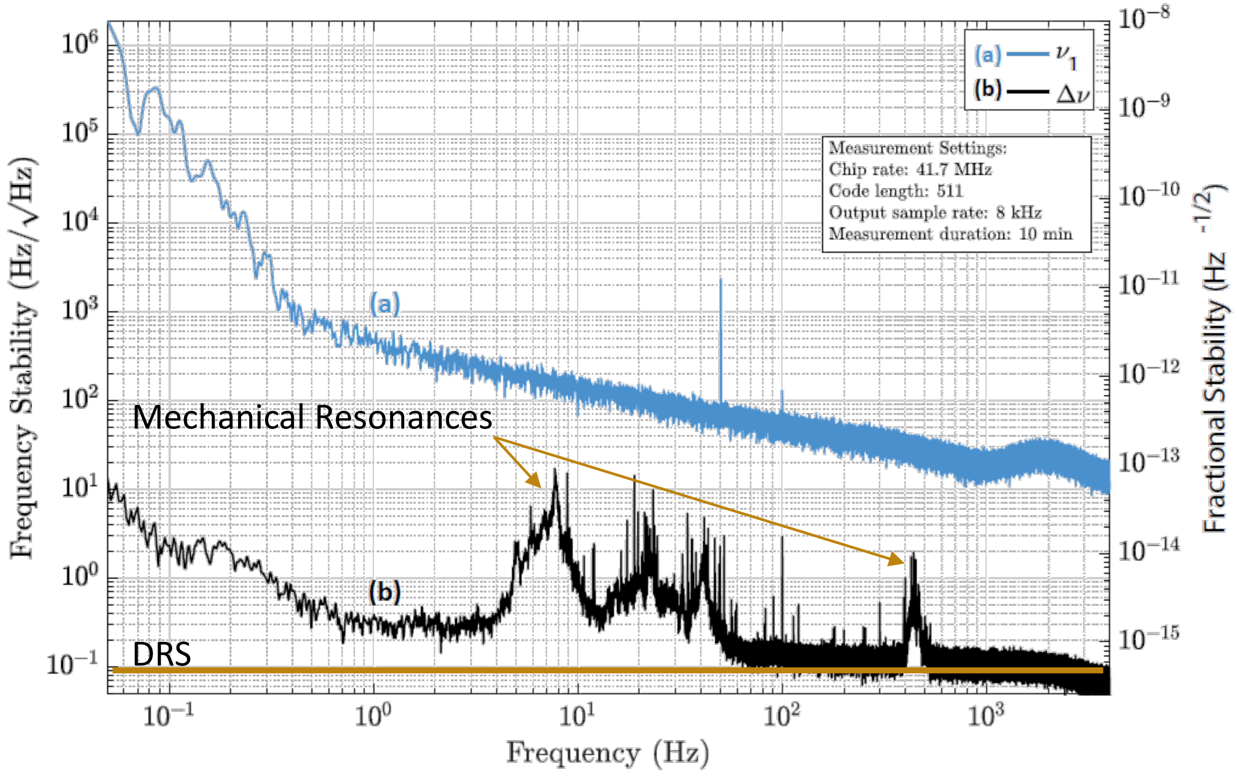
Readout and Relative Stability



Koheras E15 fibre laser at 1572 nm

Relative stability reaching 0.1 Hz/√Hz at 100 Hz

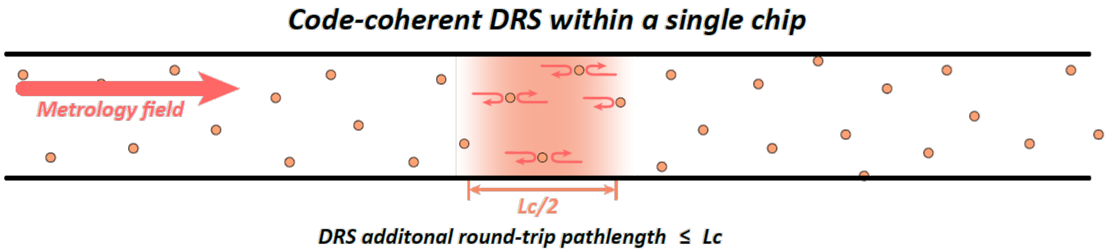
Readout and Relative Stability

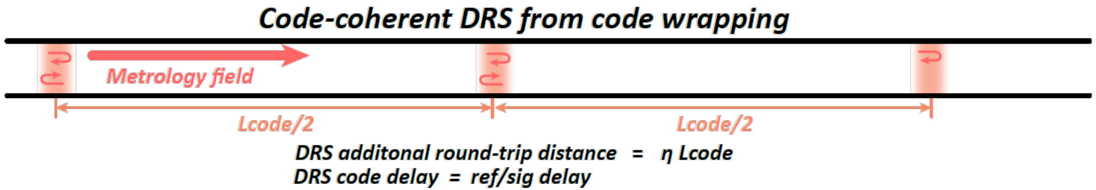


Noise sources by Fourier region:

- Double Rayleigh backscattering (DRS)
- Mechanical resonances
- Fibre thermal noise
- Temperature drift

Double Rayleigh Backscattering (DRS)





Two Rayleigh scattering events in succession

DI range gating suppresses DRS in all but two situations:

1. When both bounce events occur within DI range gate
2. When bounce events occur an integer number of code repetitions apart

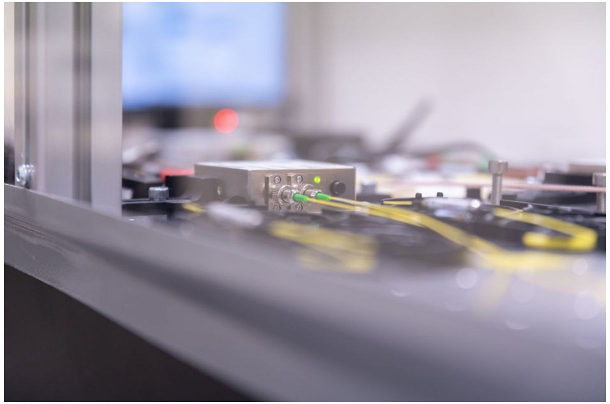
Creates a spurious optical path lengths leading to compound frequency noise coupling

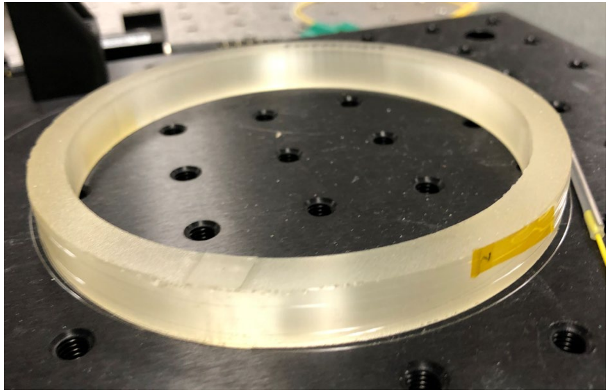
Modelled DRS noise* matches high-frequency noise floor

* Y. Zhang et al. *Opt. Exp.* **29**, 26319-26331 (2021)

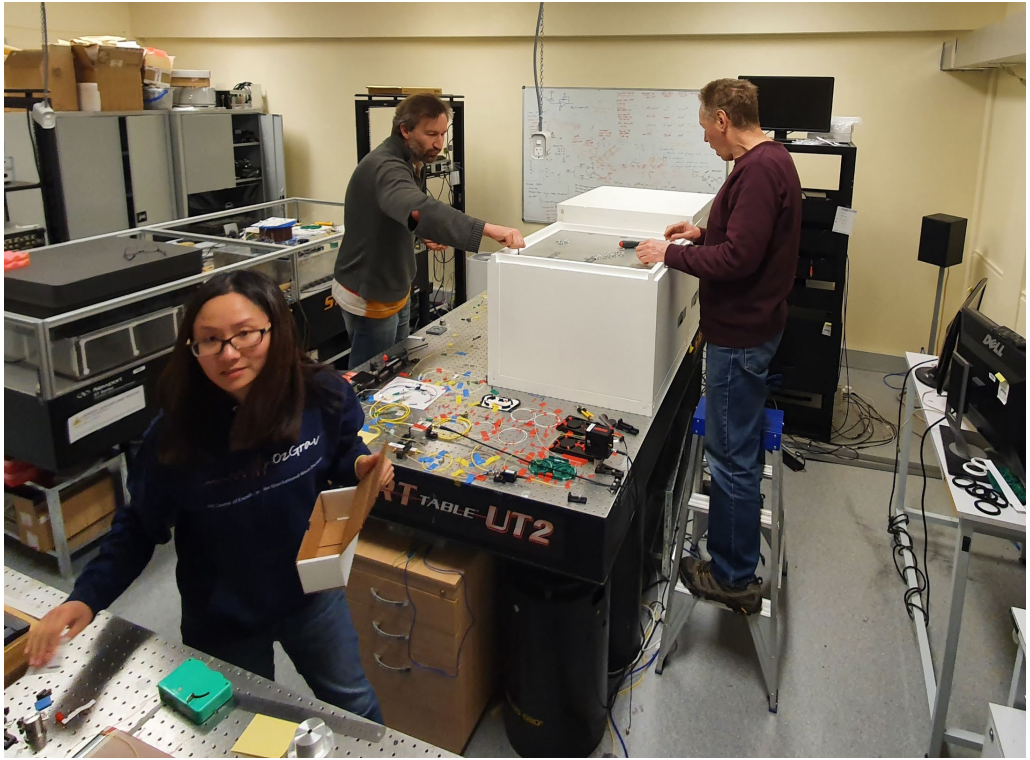
To put into context…

- 0.1 Hz/√Hz high-frequency stability is >10x improvement over the last generation
- Demonstrated DI readout technique with >7 orders of magnitude dynamic range
- State-of-the-art for fibre references, near parity with room temperature ULE
- Improving mechanical isolation and longer-term stability is a focus for future designs





The team



Dr Terry McRae

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BONUS SLIDES

Fibre Thermal Noise

Thermo-mechanical noise:

$$\tilde{S}_\nu(f) = \frac{26.48}{\sqrt{Lf}}$$

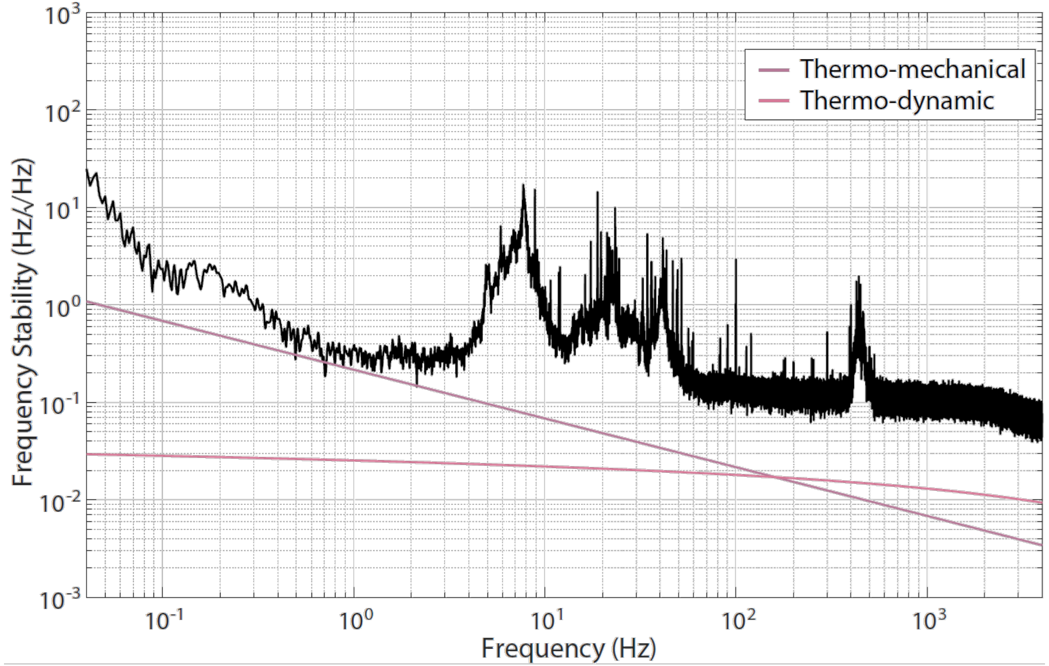
Calculated via normal mode expansion

Thermo-dynamic noise:

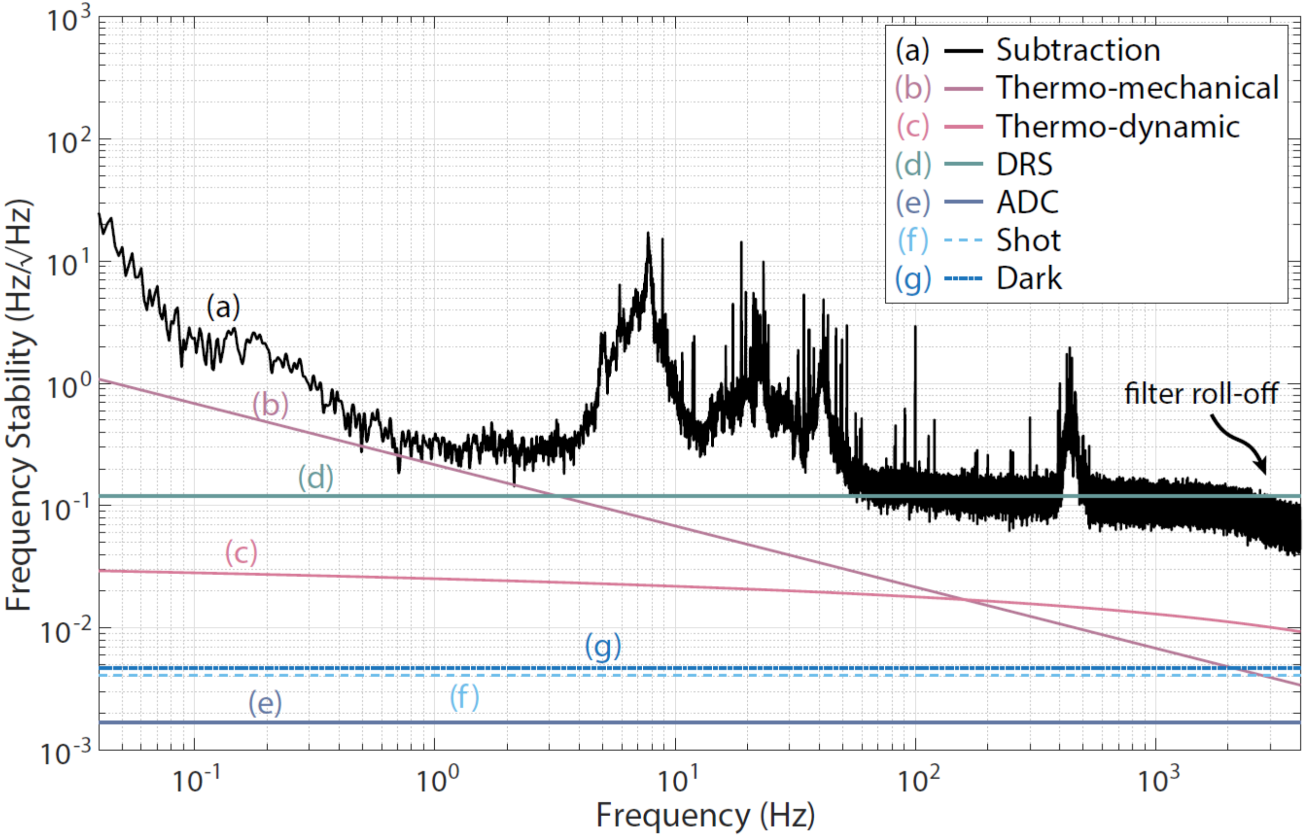
$$\tilde{S}_\nu(f) \sim \sqrt{S_{\delta T}(f)}$$

$S_{\delta T}(f)$ calculated from FDT

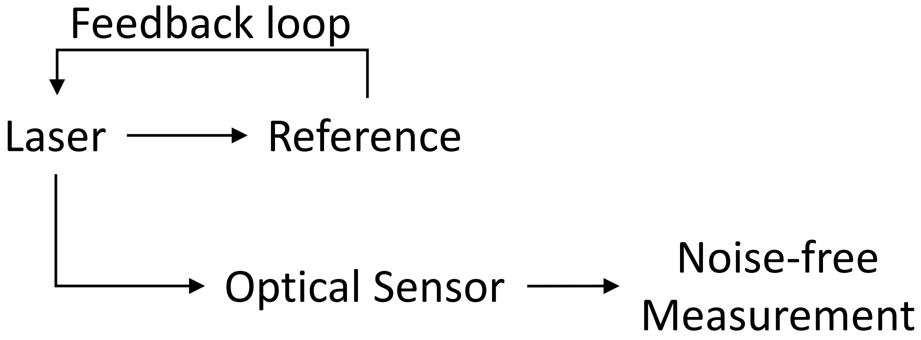
Intersect frequency always ~150 Hz



Noise Budget



The Feedback Approach



Laser source compared with external reference

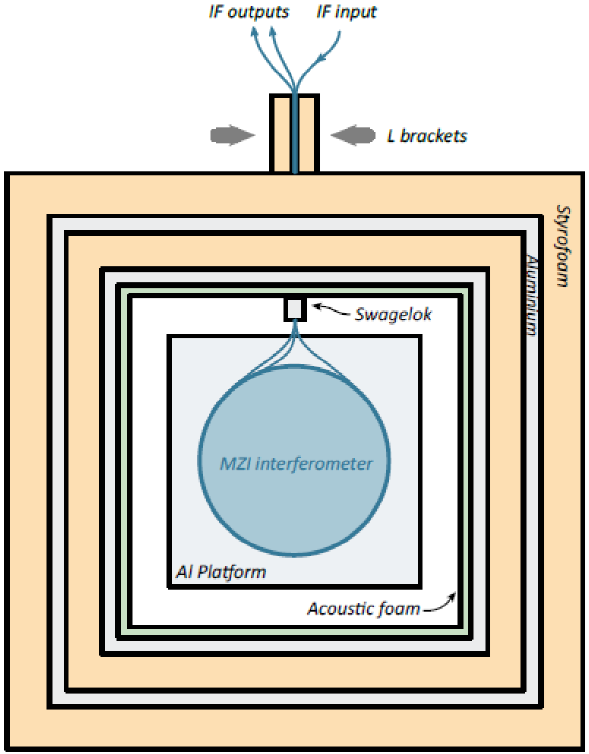
An <u>error signal</u> is derived which infers the deviation from the source under test and the reference

<u>Feedback control</u> is applied using error signal to drive the deviation to zero.

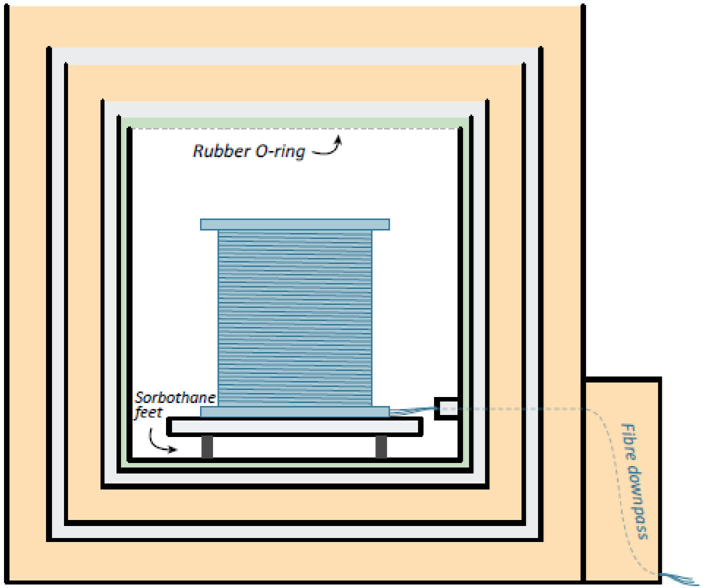
The laser follows the dynamics of the reference.

The stability of the reference is the ultimate limit

Isolation Chambers



(a) Top View



(b) Side View

Thermal:

2nd order thermal LPF

Mechanical:

Dampened platform

Fibre coil management

Sandwiched input/output

Acoustic:

Sound-absorbing foam

Pressure seal:

Swagelok connector with Teflon insert

o-ring and surface contact


CAUTION
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FRAGILE
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