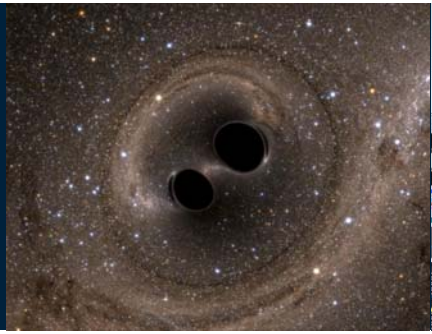
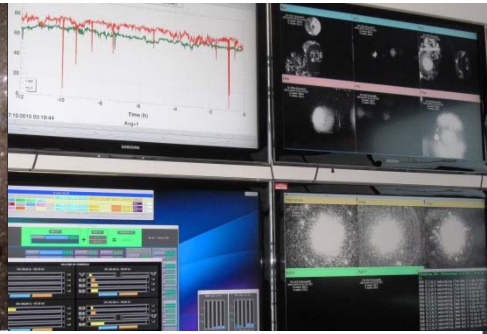
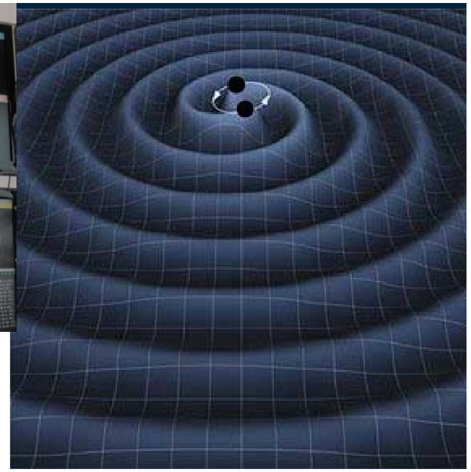
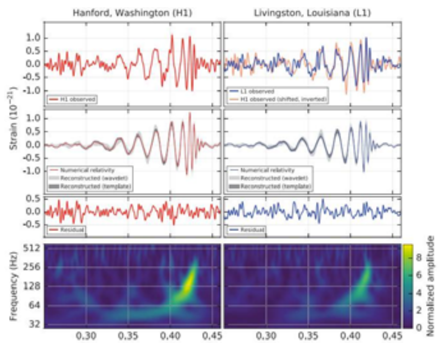
University of Glasgow





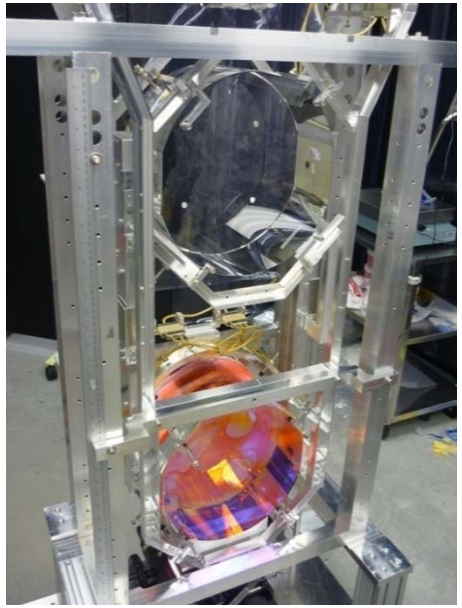


Gravitational Wave Suspensions



Giles Hammond (giles.hammond@glasgow.ac.uk)

Institute for Gravitational Research, University of Glasgow

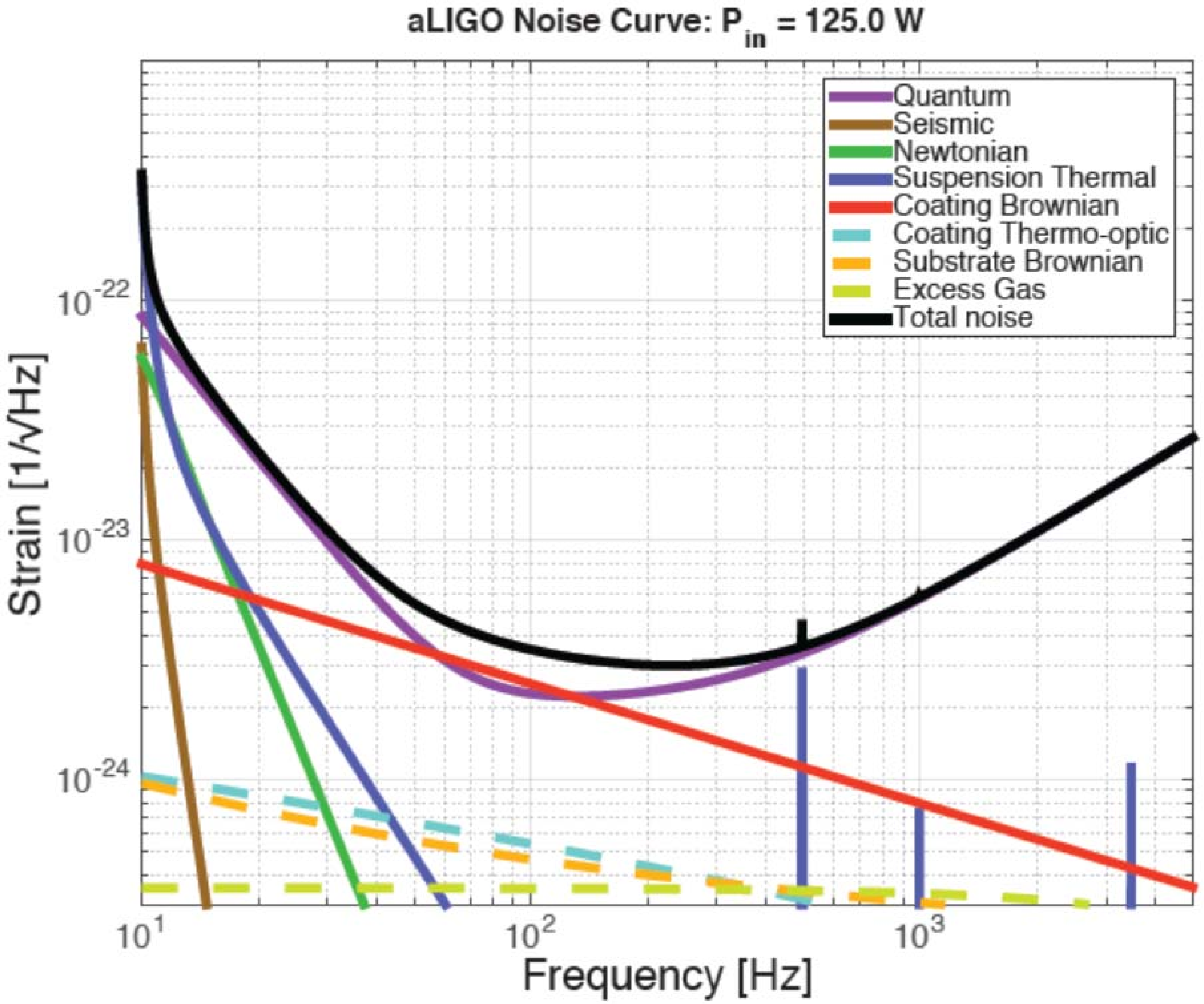


SUPA LSC LIGO Scientific Collaboration Science & Technology Facilities Council IGR

Overview

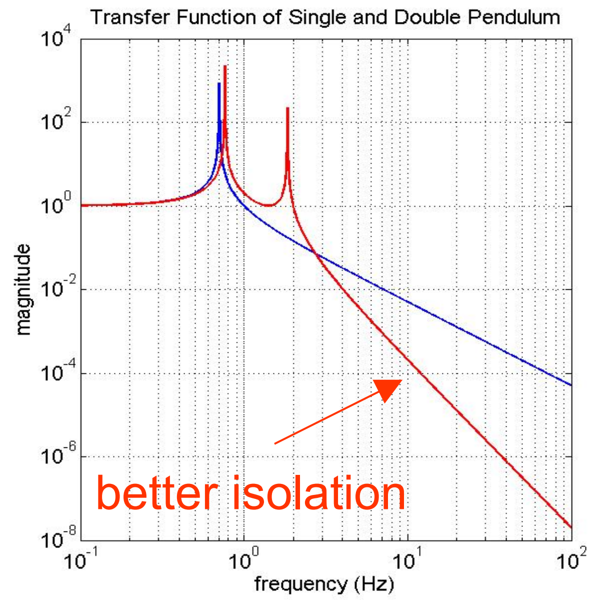
- Seismic & Thermal noise
- aLIGO 40kg monolithic suspensions
- Thin fibres for 100g suspensions
- Heavy suspensions for 3G detectors
- Fibre Characterisation

aLIGO Noise Curve

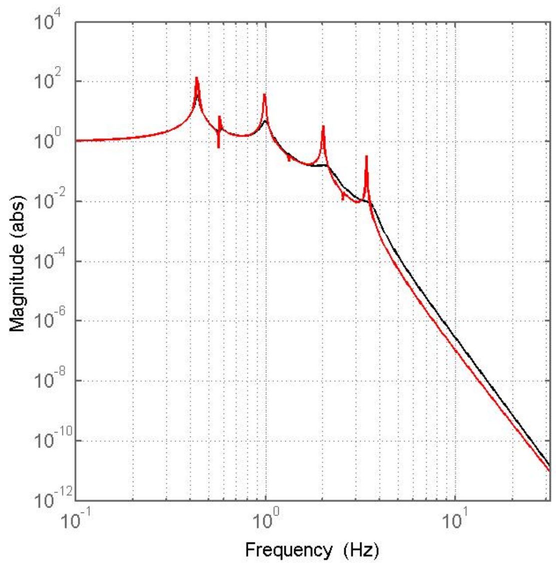


Seismic Noise

- Seismic noise limits sensitivity at low frequencies - "seismic wall"
- Typical seismic noise at quiet site at 10 Hz is ~ few x 10^{-10} m/√Hz
  - many orders of magnitude above target noise level
- Two-stage internal isolation platform has target noise level of 2 x 10^{-13} m/√Hz at 10 Hz.
- require 4 more stages, i.e. quadruple pendulum, to meet target of 10^{-19} m/√ Hz



- Advantage of a double over single pendulum, same overall length



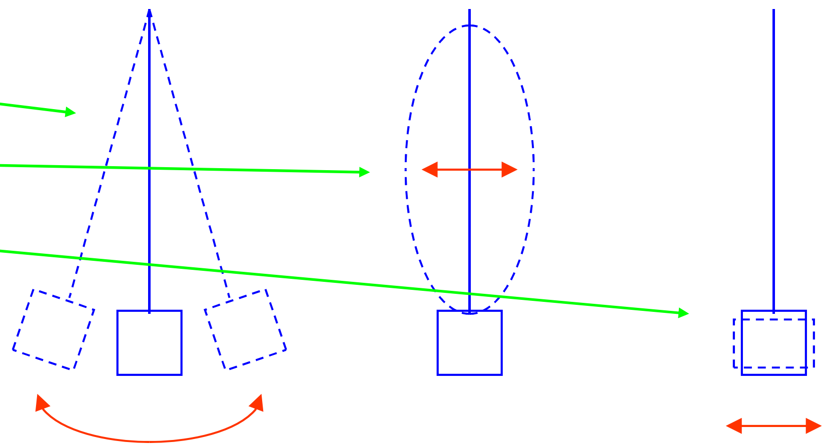
- Quad pendulum transfer function: predicted isolation ≈ 3 x 10^{-7} at 10 Hz

$$\frac{x_{mass}}{x_{ground}} = \left(\frac{f}{f_0}\right)^{-2n}$$

Thermal Noise

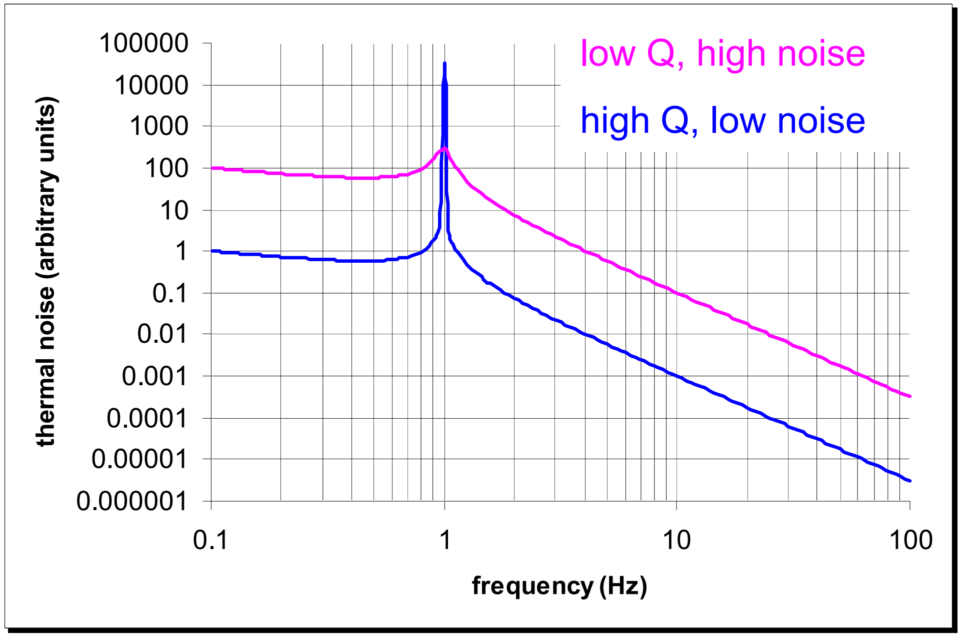
Thermally excited vibrations of

- suspension pendulum modes
- suspension violin modes
- mirror substrates + coatings



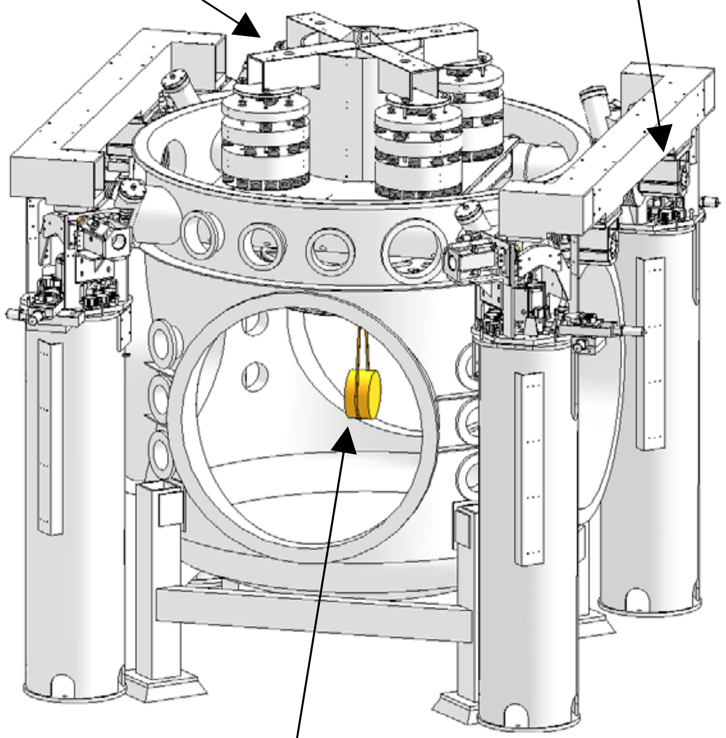
To minimise:

- use low loss (high quality factor) materials for mirror and final stage of suspension (fused silica)
- use thin, long fibres to reduce effect of losses from bending
- use low loss bonding technique: hydroxide-catalysis bonding



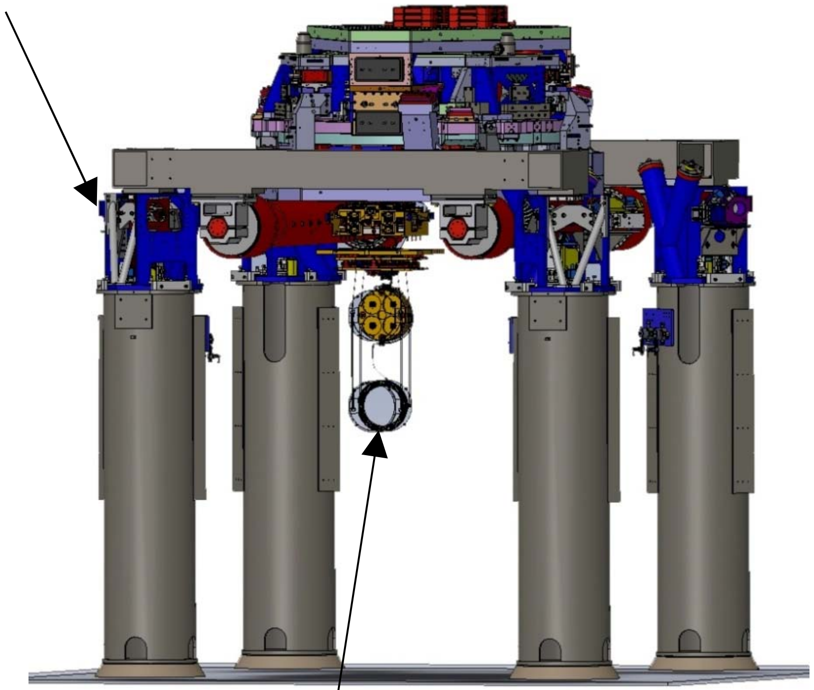
Initial LIGO and aLIGO

- 4 layer passive isolation stack
- coarse & fine actuators



- single pendulum on steel wire

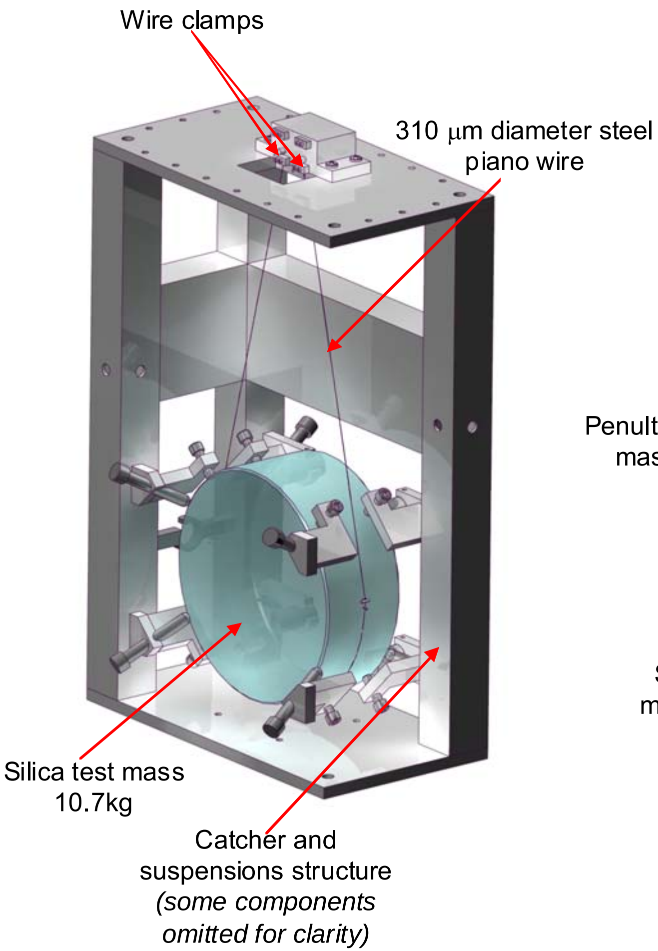
- hydraulic external pre-isolator (HEPI) (one stage of isolation)
- active isolation platform (2 stages of isolation)



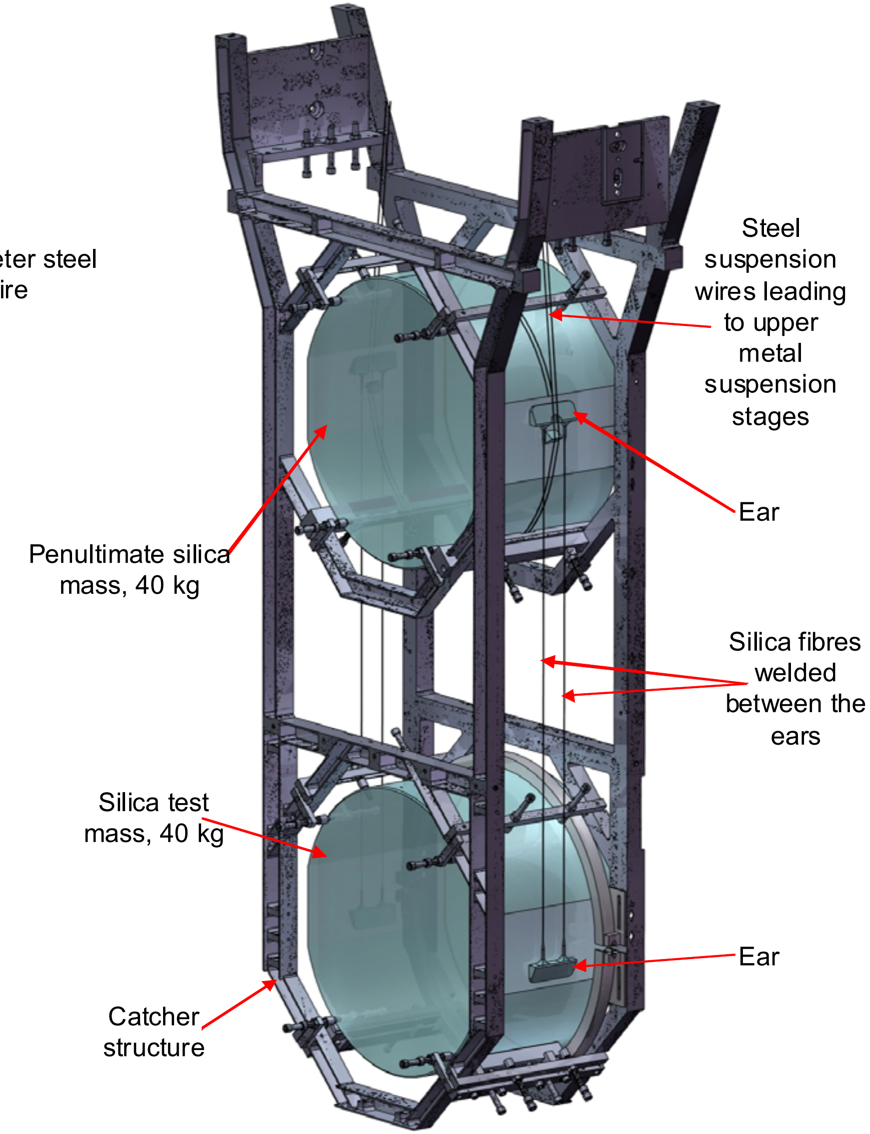
- quadruple pendulum (four stages of isolation) with monolithic silica final stage

Initial LIGO and aLIGO

LIGO

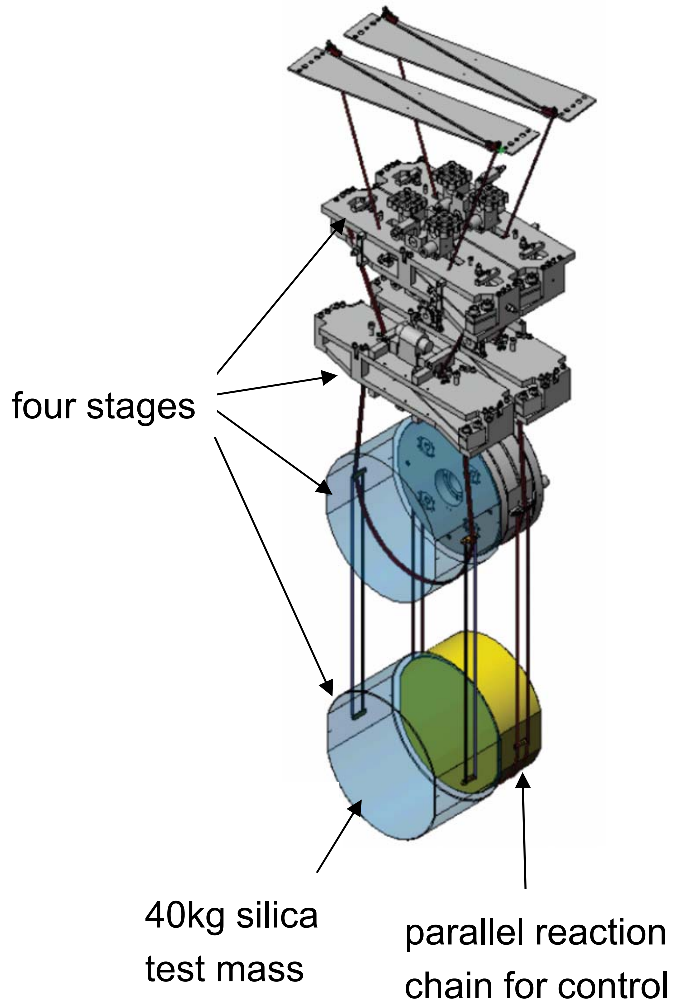


Advanced LIGO

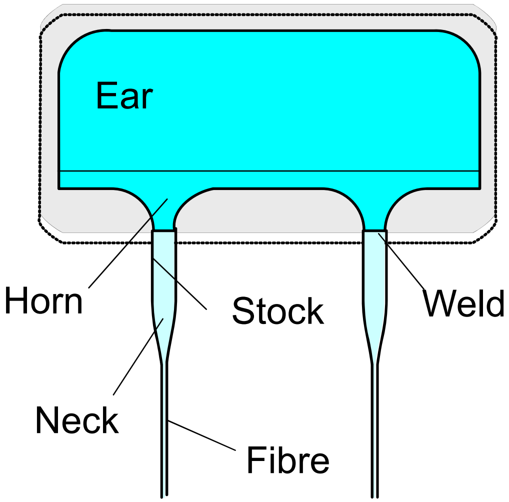


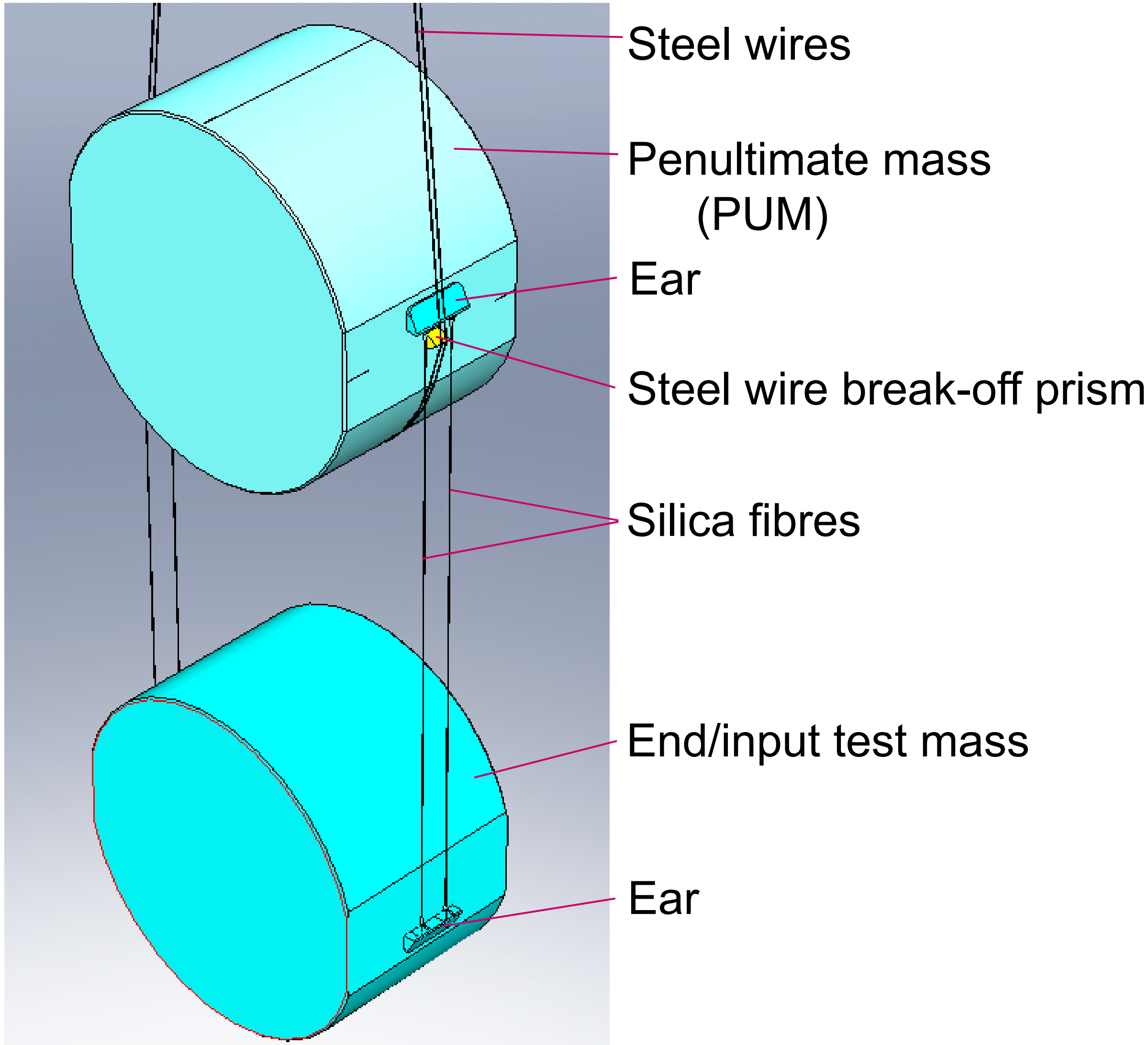
aLIGO Quadruple Suspension

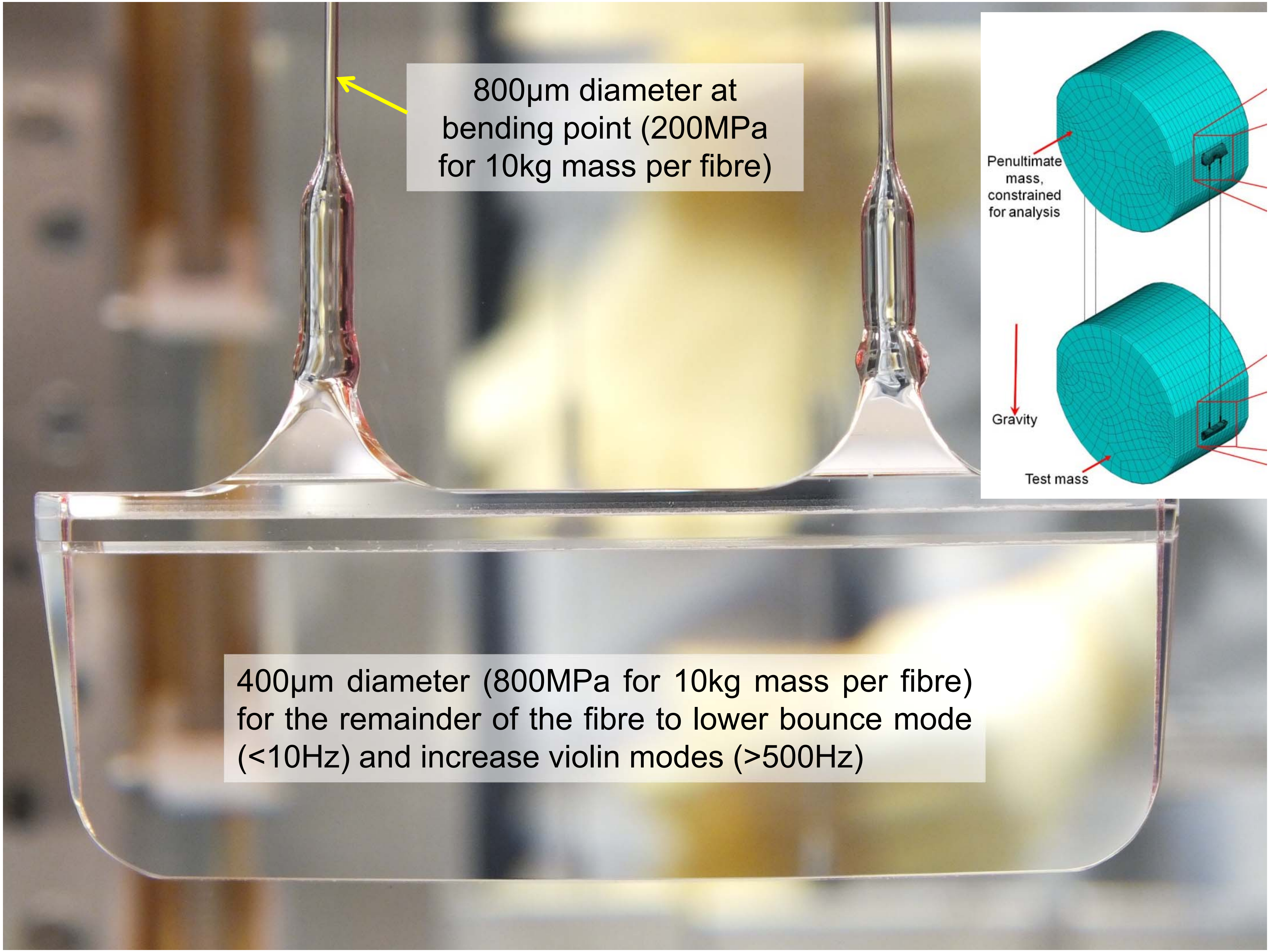
- The input test masses (ITM) and end test masses (ETM) of Advanced LIGO will be suspended via a quadruple pendulum system
- **Seismic isolation:** use quadruple pendulum with 3 stages of maraging steel blades for horizontal/vertical isolation
- **Thermal noise reduction:** monolithic fused silica suspension as final stage
- **Control noise minimisation:** use quiet reaction pendulum for global control of test mass position
- **Actuation:** Coil/magnet actuation at top 3 stages, electrostatic drive at test mass



aLIGO Monolithic Stage

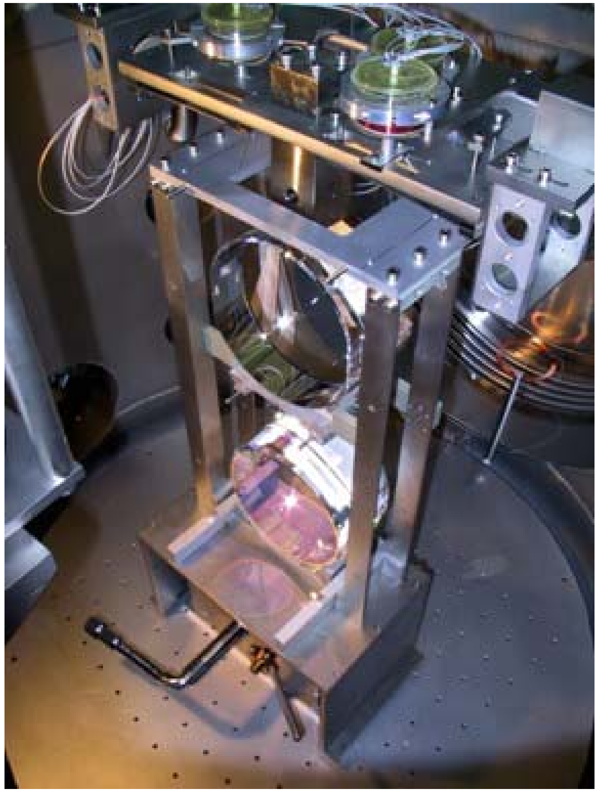


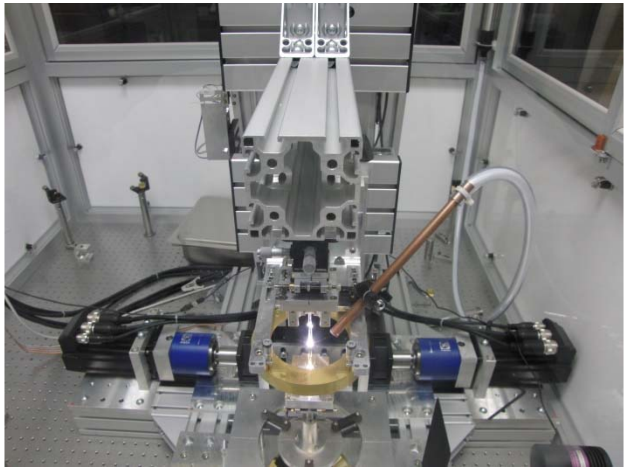


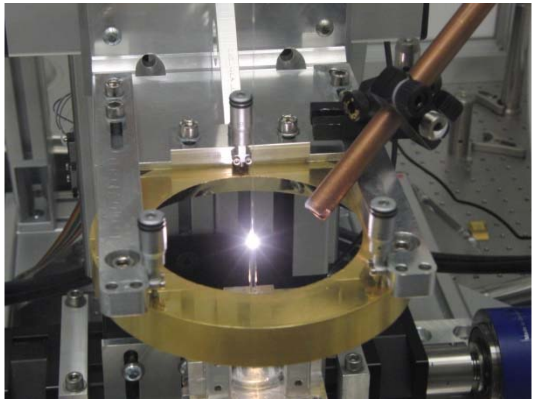

800μm diameter at bending point (200MPa for 10kg mass per fibre)
400μm diameter (800MPa for 10kg mass per fibre) for the remainder of the fibre to lower bounce mode (<10Hz) and increase violin modes (>500Hz)
Penultimate mass, constrained for analysis
Gravity
Test mass

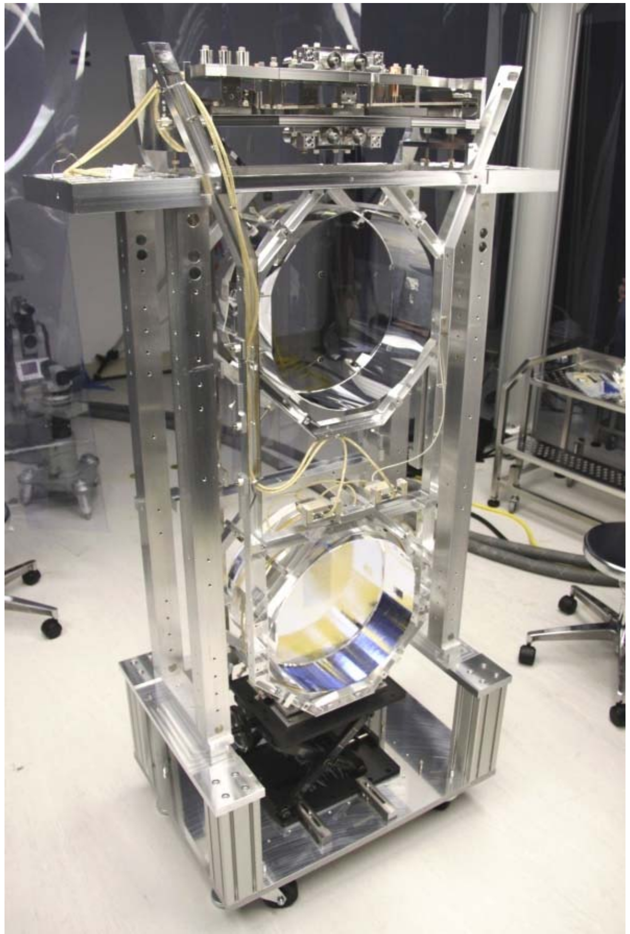
Monolithic Suspensions

- Monolithic suspensions & signal recycling pioneered in GEO-600 → upscaled to aLIGO



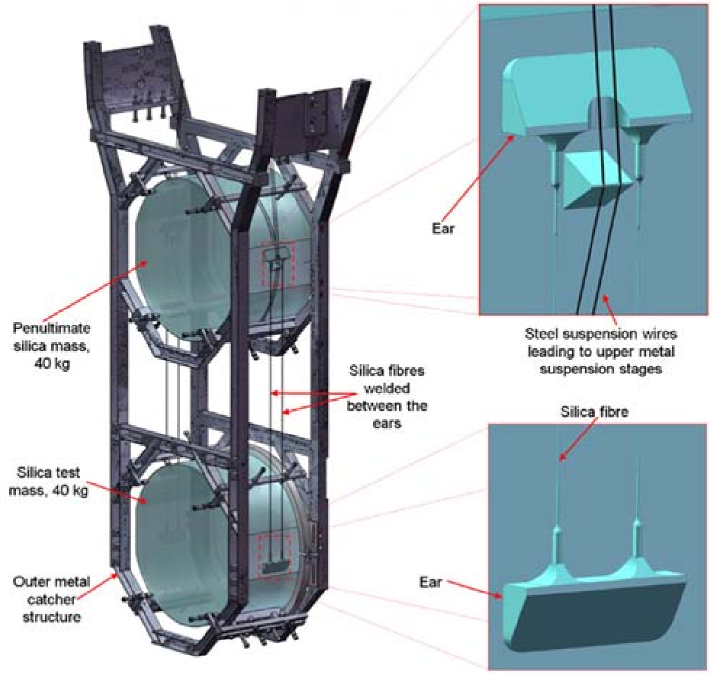


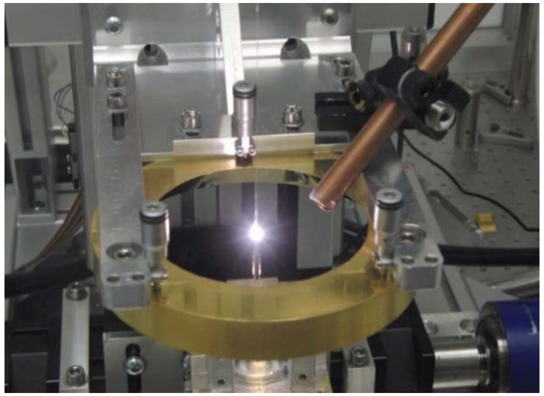




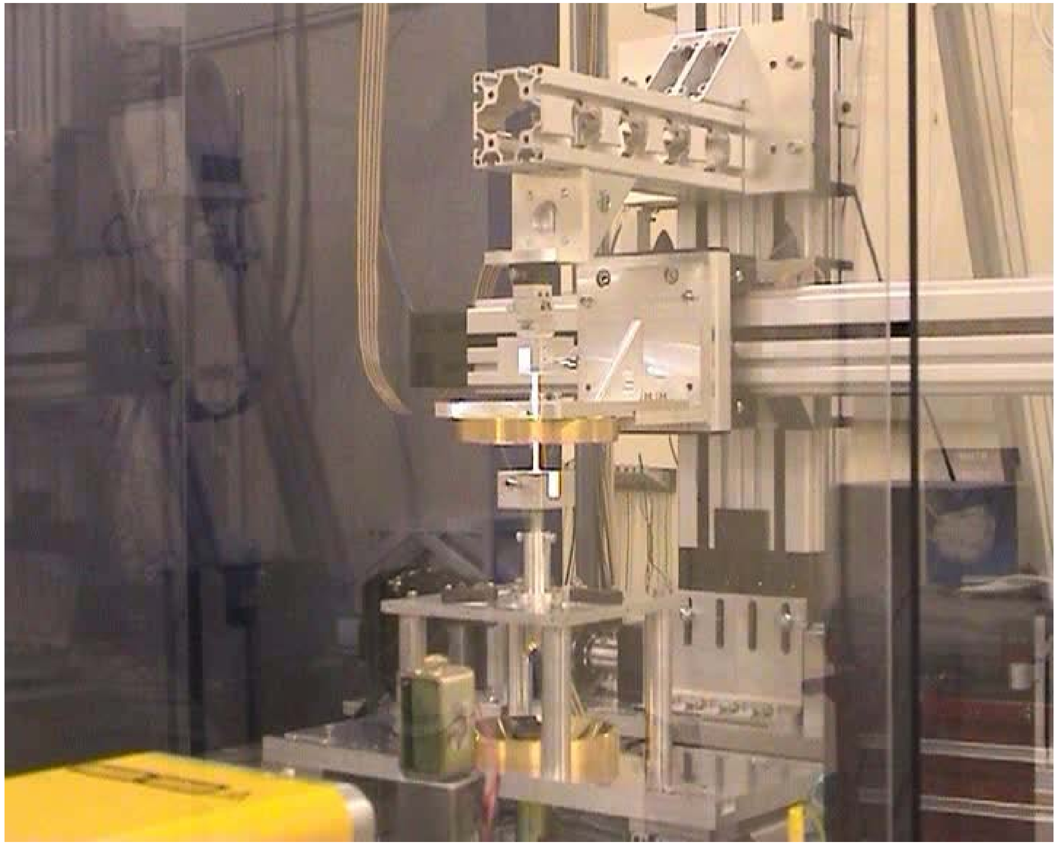
advancedligo

Fused Silica Fibre Pulling





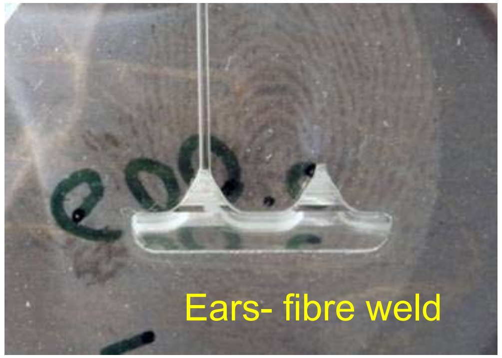
Glasgow has supplied the machines used in AdV VIRGO and aLIGO



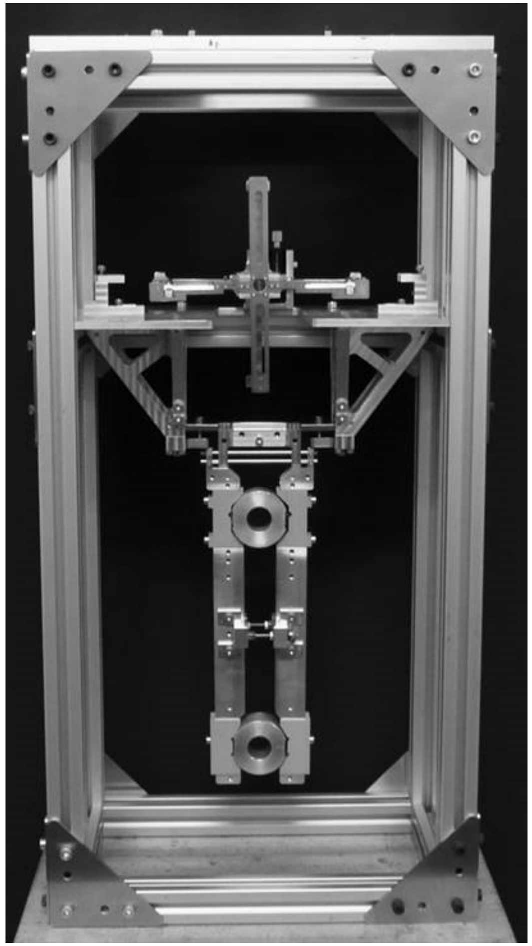
- Low thermal noise requires ultra-low loss materials => fused silica

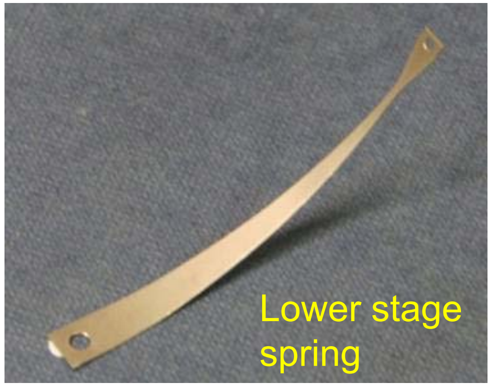
Thin Fibre Work

- Light suspensions (1g-100g) are being developed around the world for radiation pressure/SQL experiments (ICRR, MIT, Glasgow, AEI Hannover, Italy)
- Glasgow has developed triple suspensions for AEI

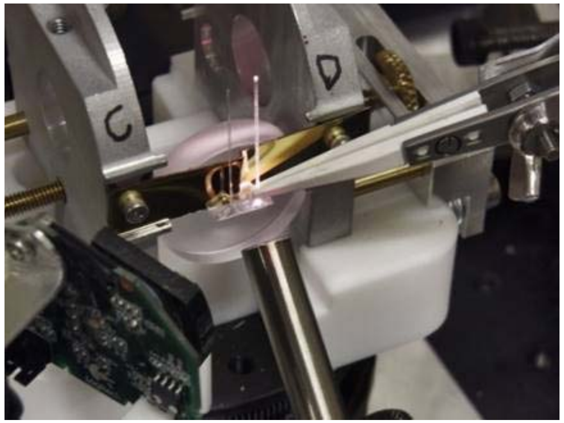


Ears- fibre weld



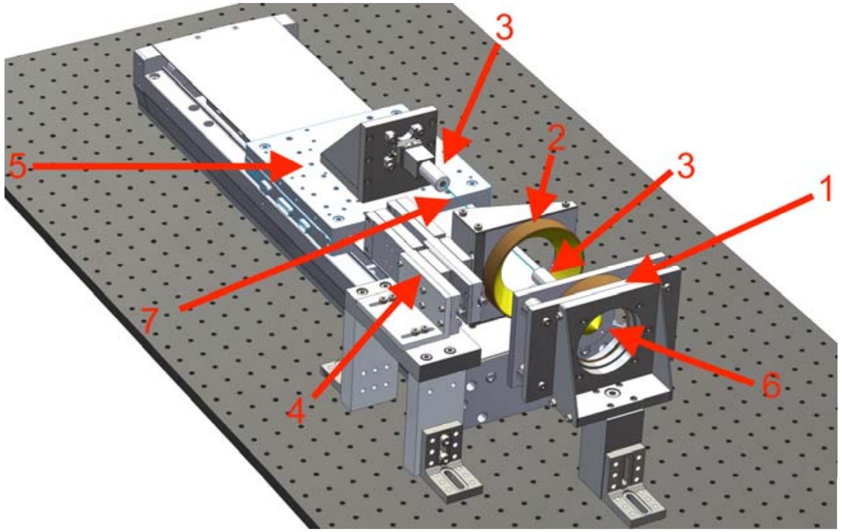


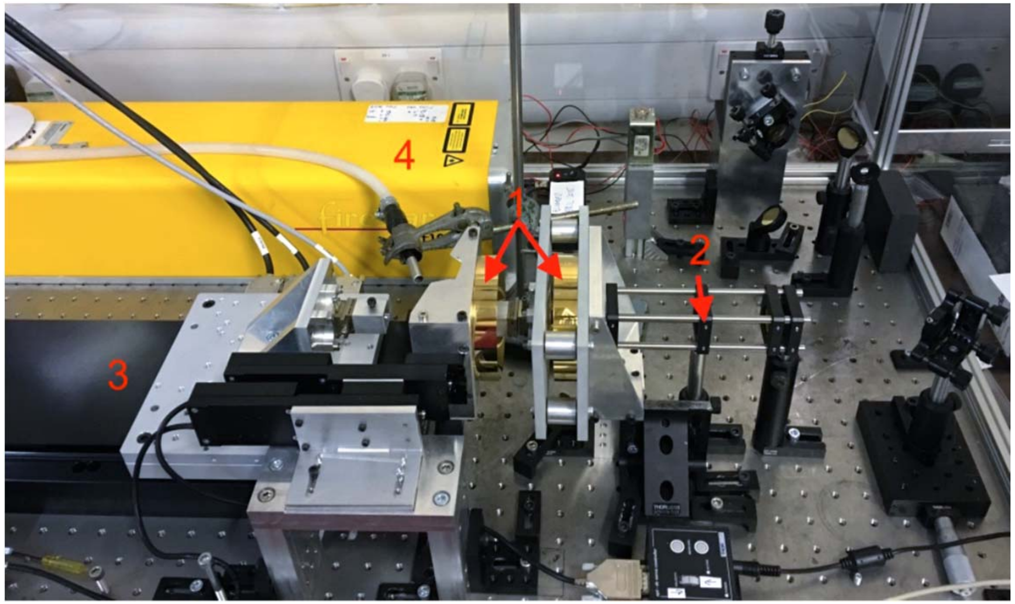
Lower stage spring

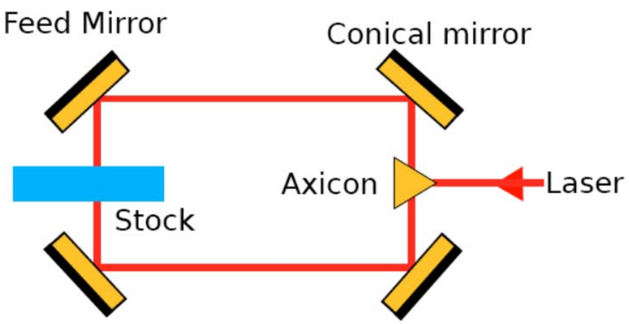


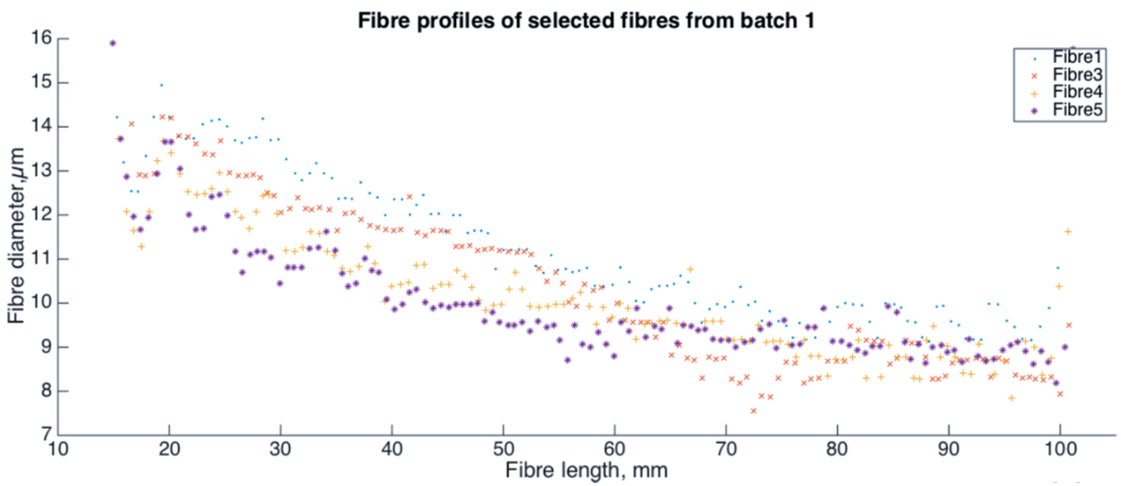
Welding

Thin Fibre Puller







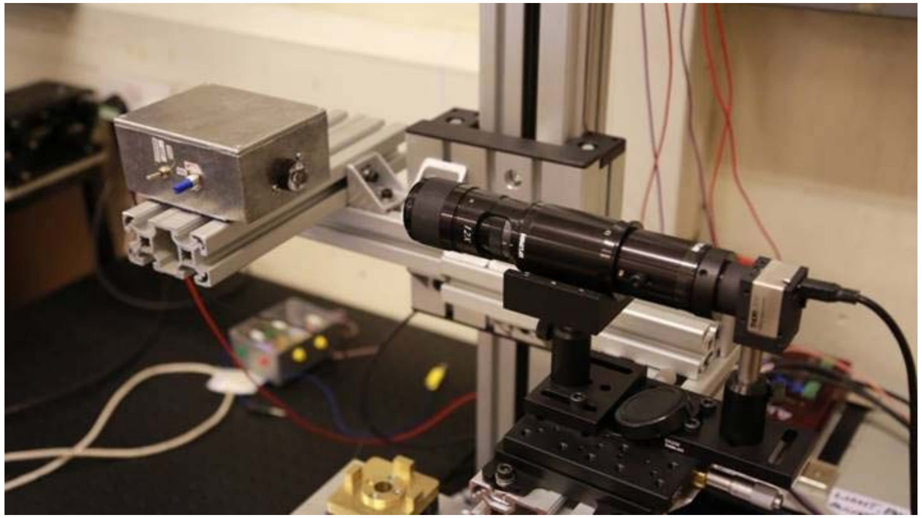


University of Glasgow

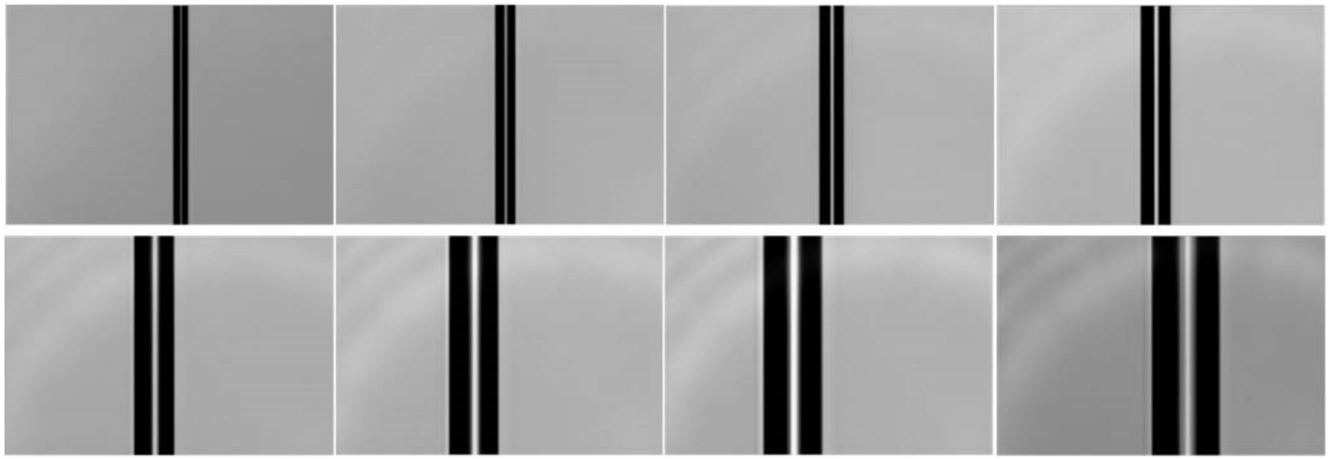
Fibre Profiler

Upgraded fibre profiler to profile 1-20μm fibres

15μm fibre

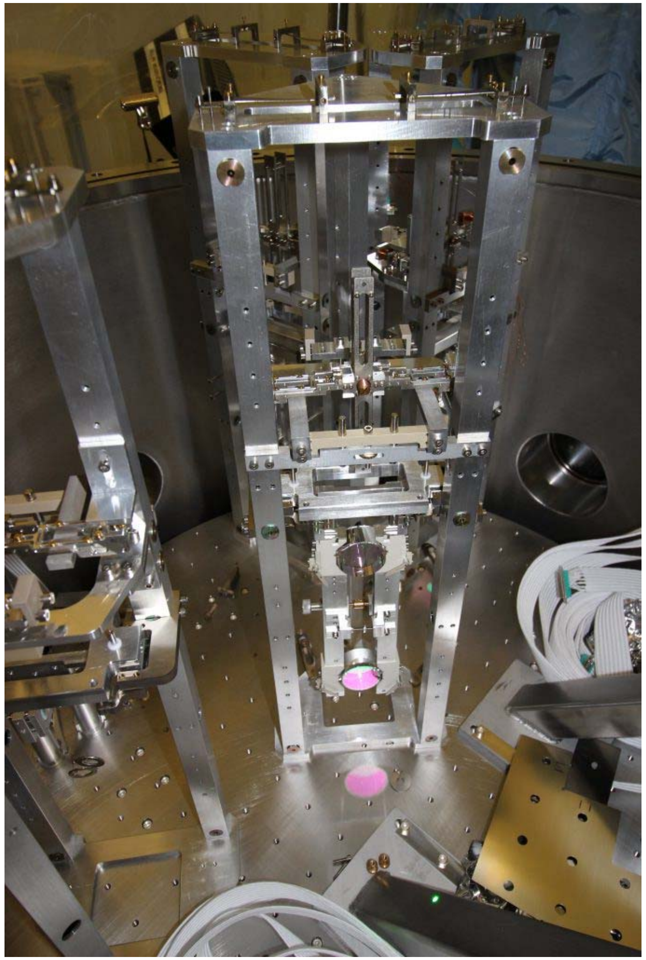


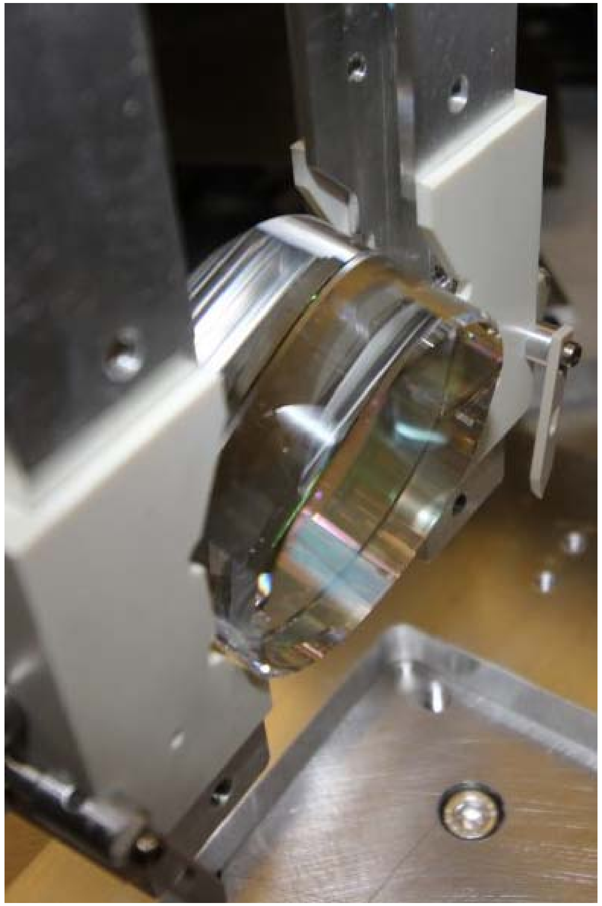
x6 x8 x10 x12



x16 x20 x24 x28

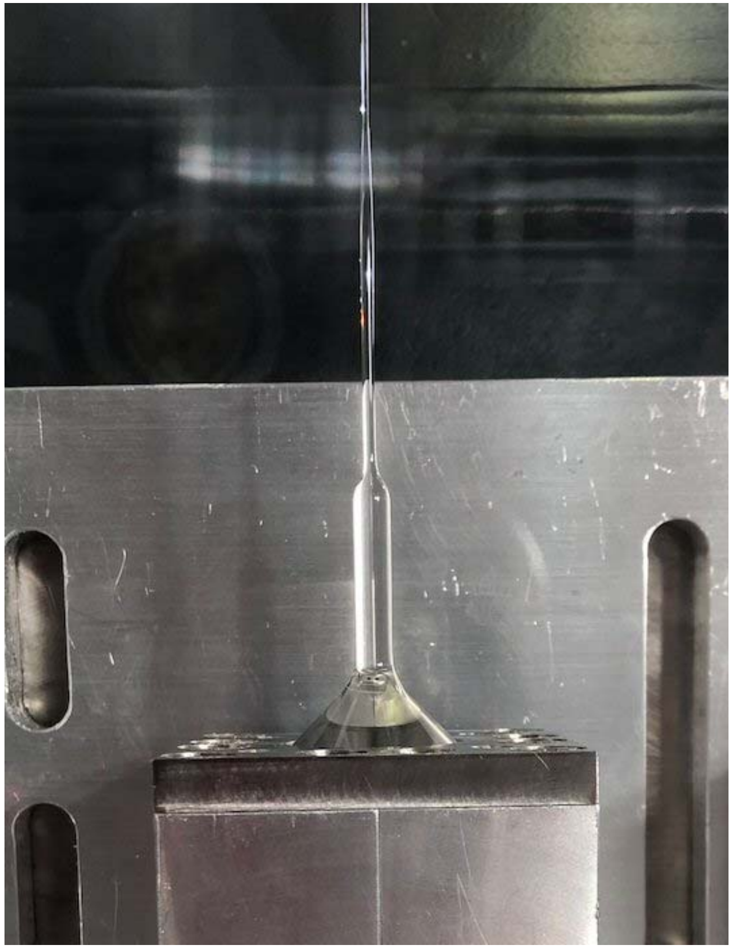
100g Suspensions



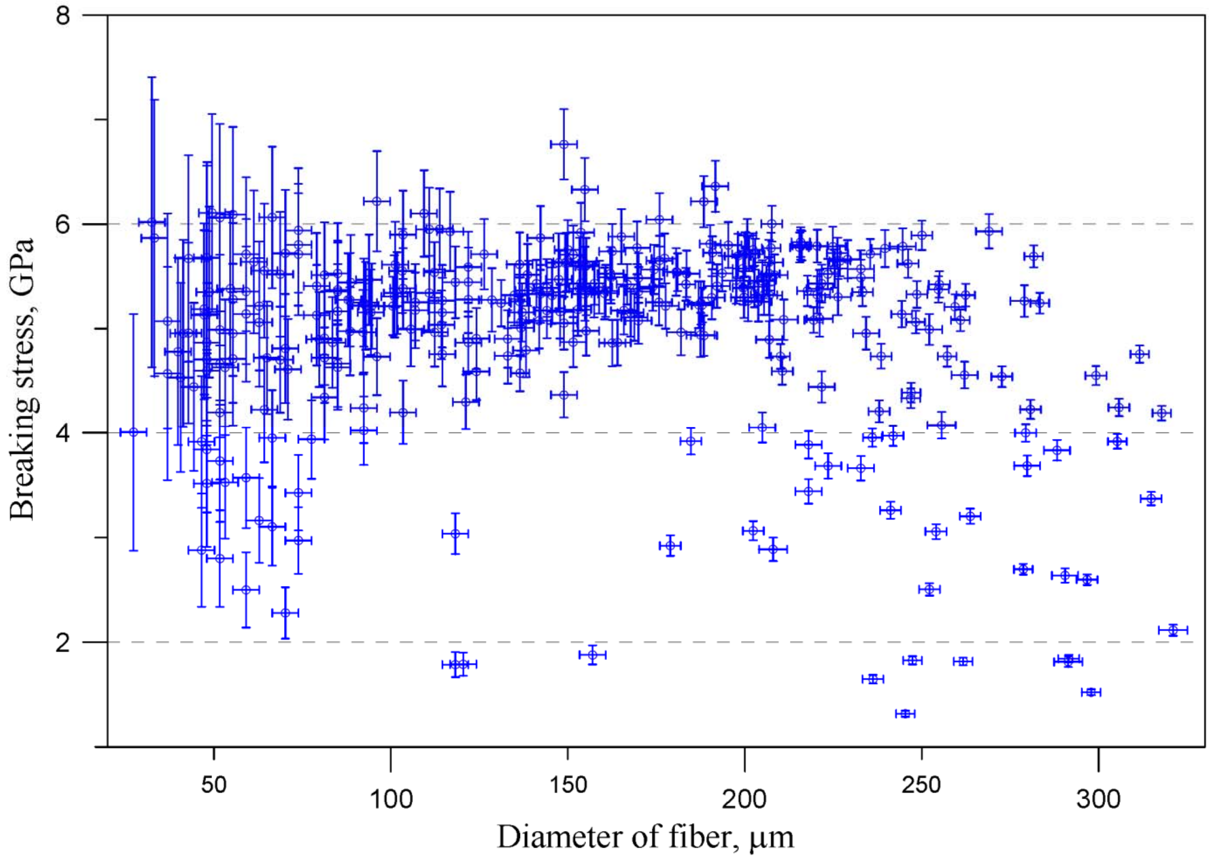


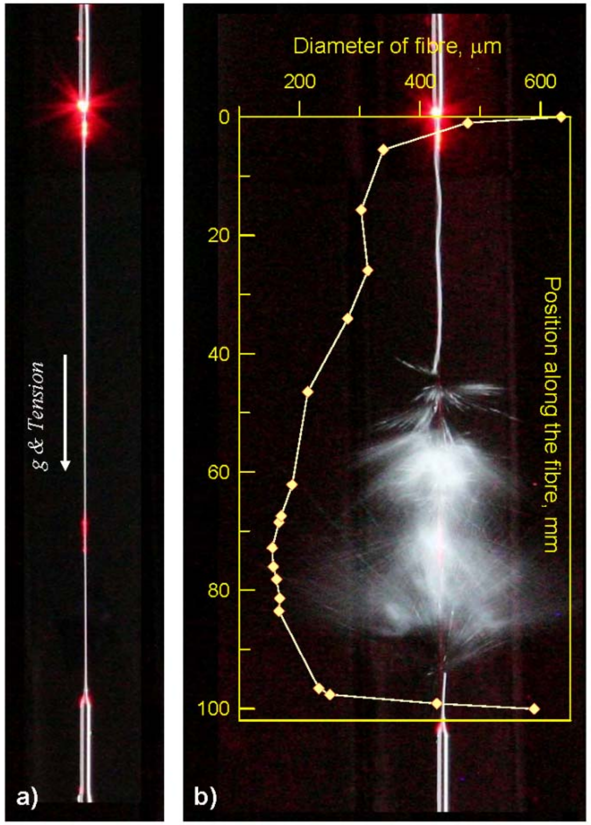
Heavy Suspensions

- We have already built up 2 single fibre 40kg tests (using 1200MPa fibre stress)
- 4 fibre (160kg) hanging since Dec 2018

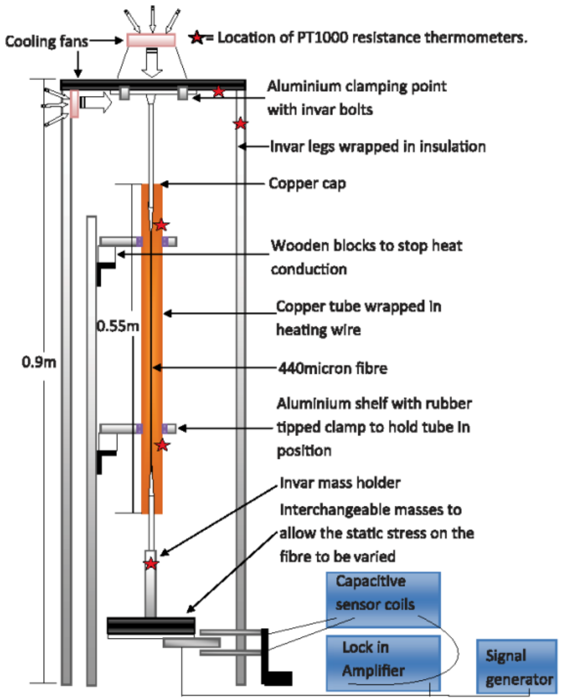


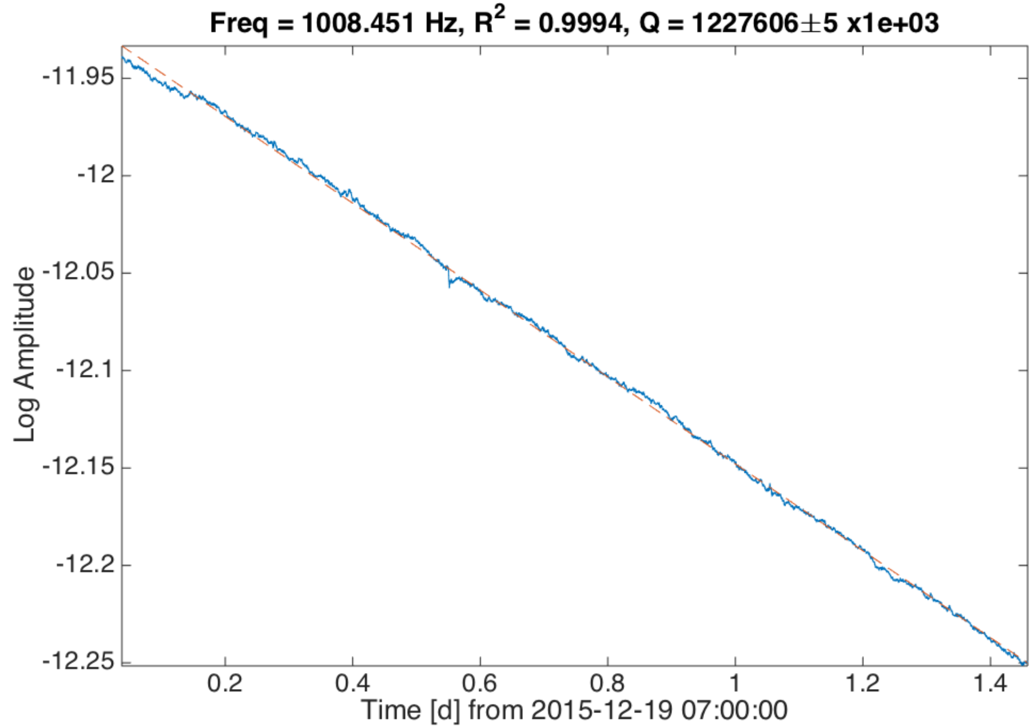
Fibre Strength



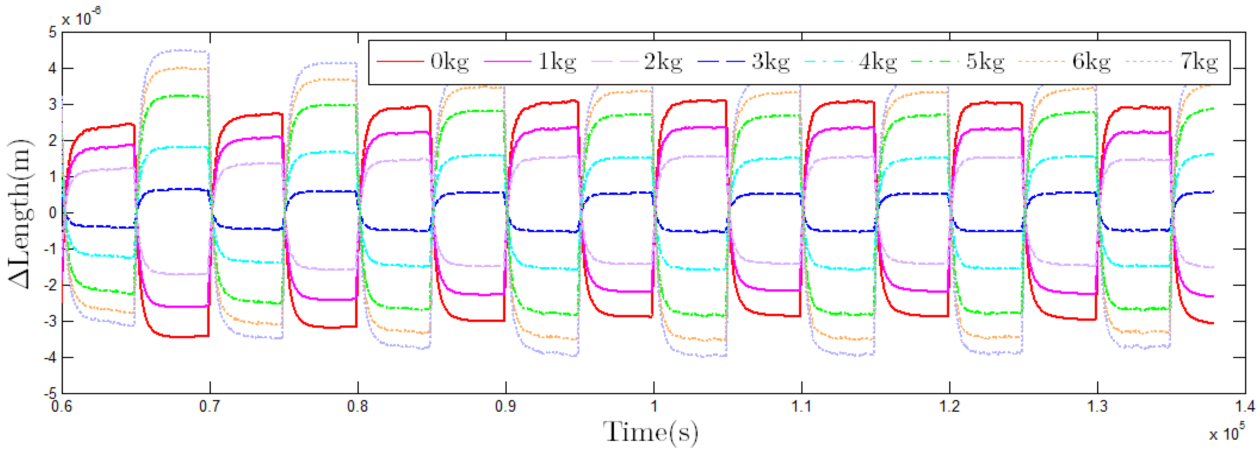


Fibre Characterisation



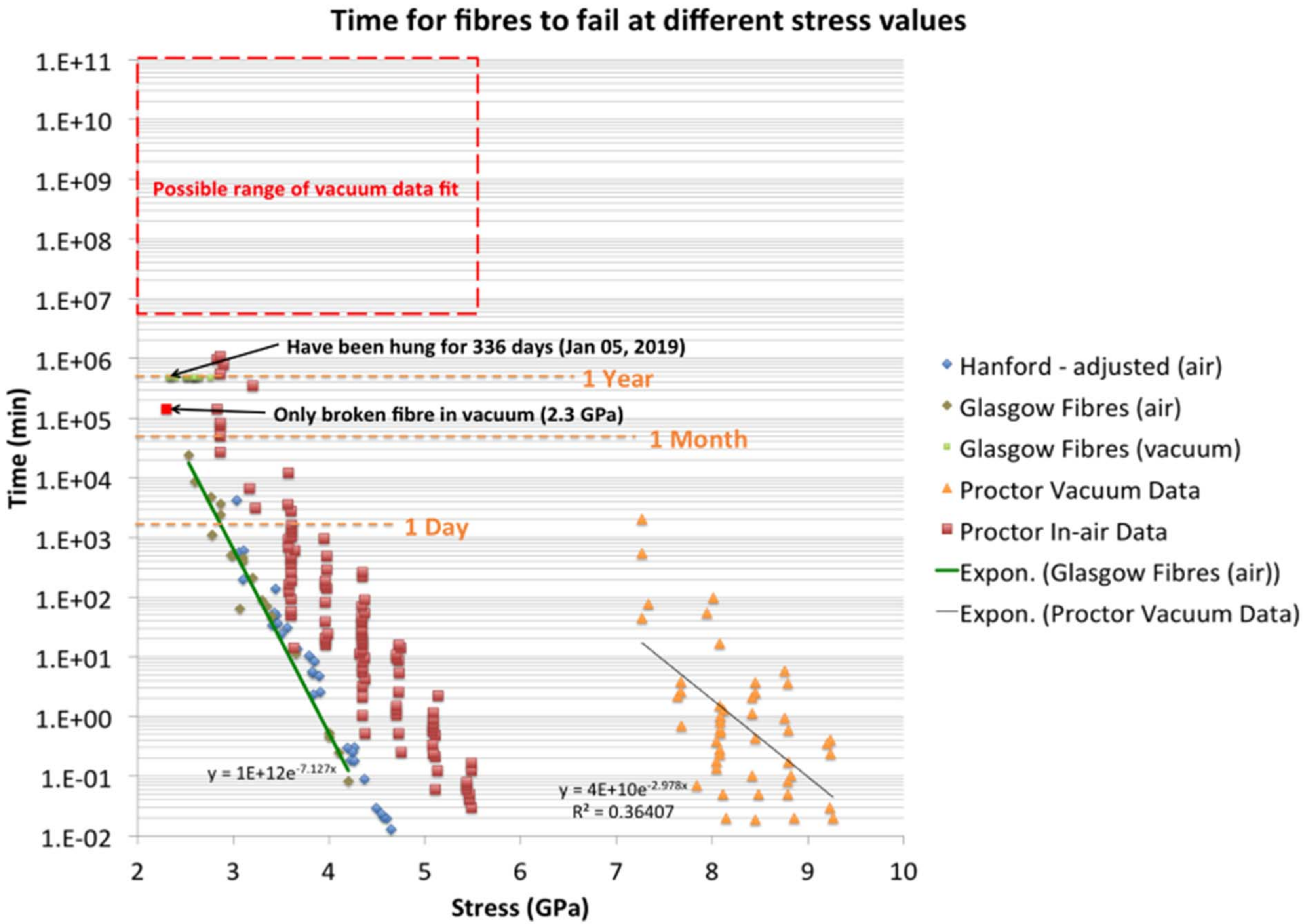


$$\phi_{\text{thermoelastic}} = \frac{YT}{\rho C}\left(\alpha - \sigma_o \frac{\beta}{Y}\right)^2 \left(\frac{\omega\tau}{1+(\omega\tau)^2}\right)$$



- Violin mode Q of 1-2 billion (4 day ringdown)
- Bell 2014, https://core.ac.uk/download/pdf/19967512.pdf

Stress Corrosion Tests



Questions