Benefiting from LISA Pathfinder Technology: Precision Glue-Less Adhesion & Novel Position-Sensor Architectures

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Advanced Manufacturing Techniques for Earth Observation and Space Technology

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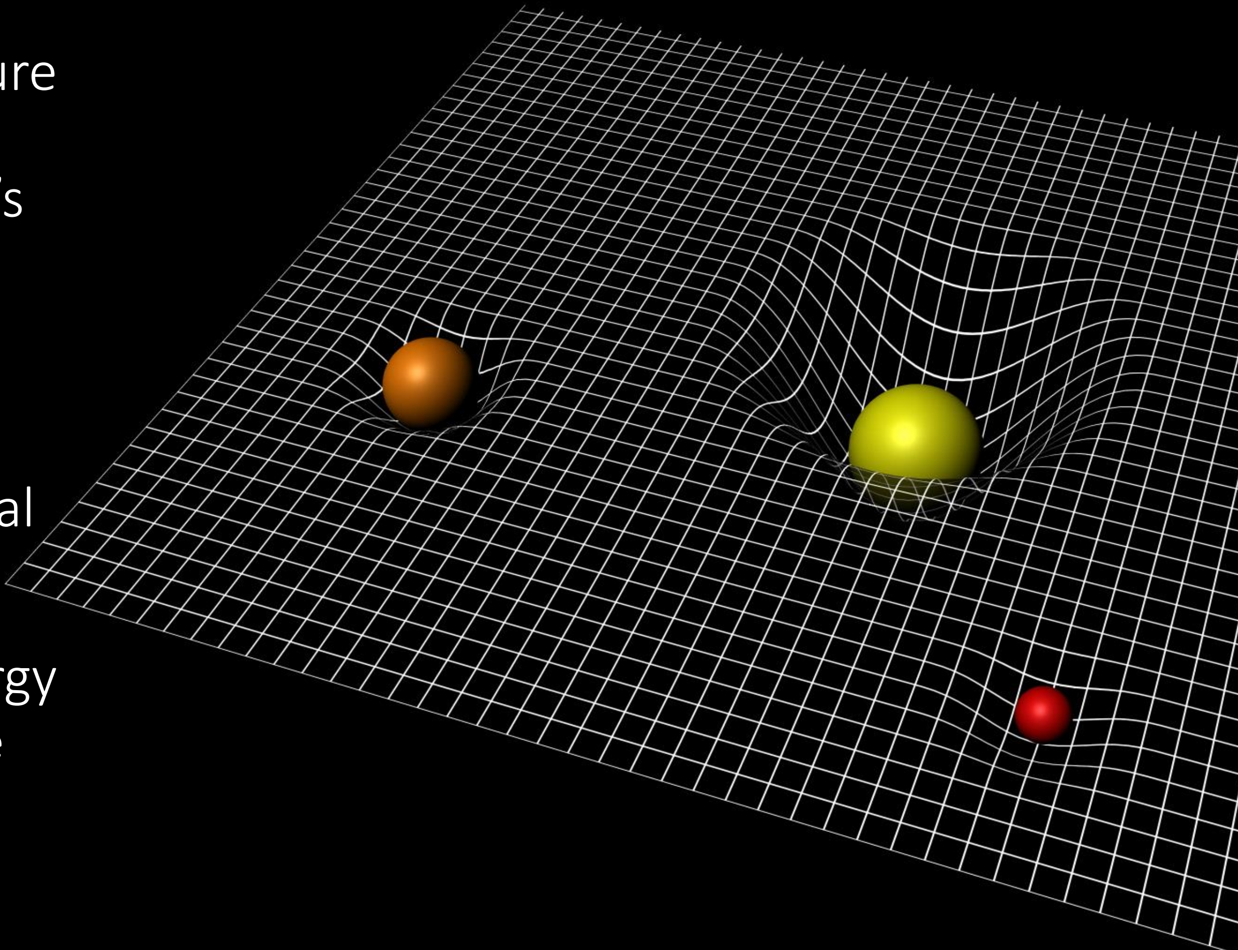
Gravitational waves

- What are they?
  - Ripples in the curvature of spacetime
  - Predicted by Einstein's General Relativity
  - Awaiting first direct detection…
  - An incredibly rich source of astronomical information that we can't see via electromagnetic energy
    - Like 'listening' to the Universe

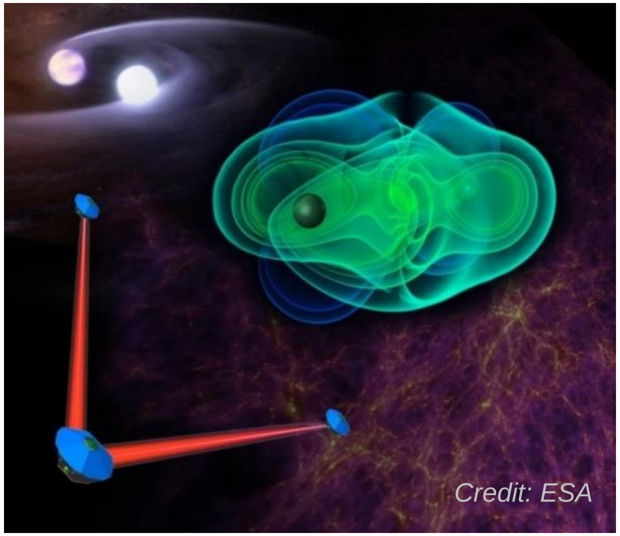


Credit: ESA–C.Carreau

Gravitational Wave Observatories

The best way we know of to observe gravitational waves is to isolate 'test masses' from local disturbances and monitor their separation as gravitational waves pass through the system

$$h = \frac{\Delta L}{L} \sim 10^{-20}$$



We use laser interferometry as the high precision 'ruler'

Ground-based detectors, e.g *LIGO* Louisiana with 4 km long arms, operate at frequencies above ~10 Hz

The proposed spaceborne detector, *eLISA*, has gigametre arms and is sensitive in the milliHertz regime

Relevance

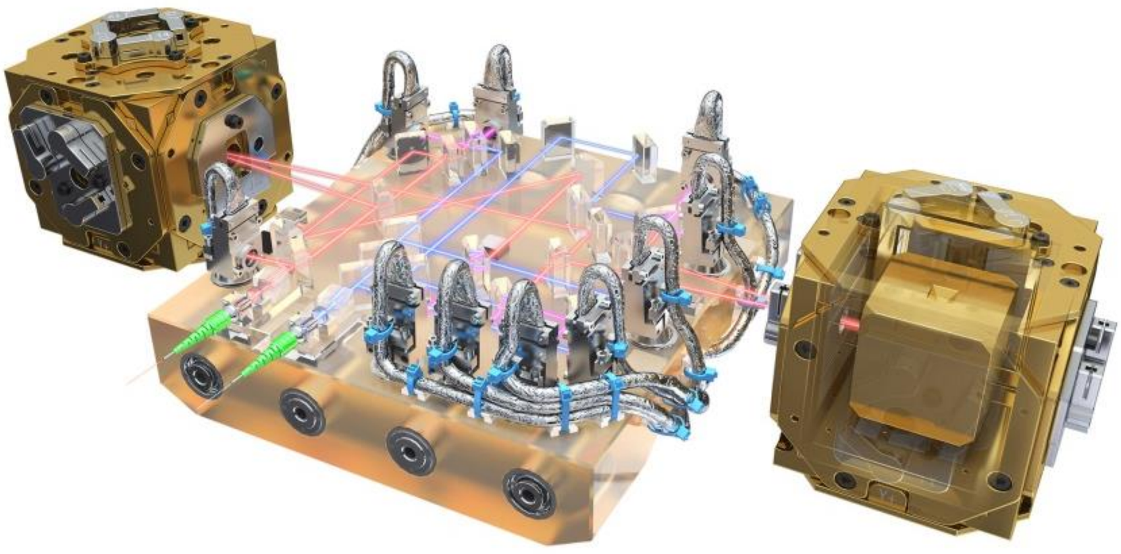
What overlap do these academic pursuits have with advanced manufacturing techniques?

Technology

We work at the cutting edge of technology, including some advanced manufacturing techniques

The LISA Pathfinder optical bench

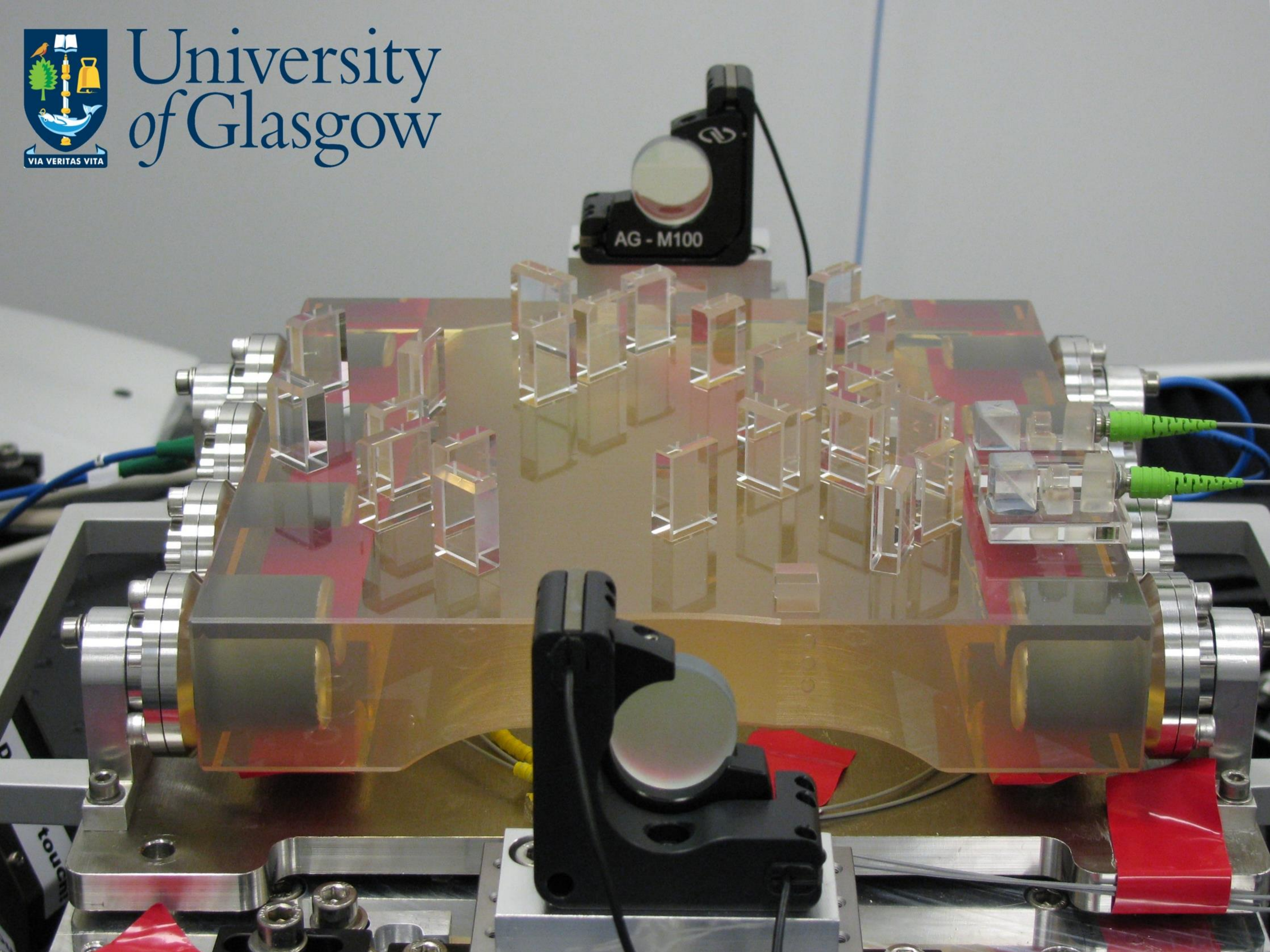
- The Optical Bench will monitor the separation of two test masses in gravitational freefall
  - 10 picometre longitudinal variations
  - 20 nanoradian angular beam motion
  - milliHertz frequencies



Credit: ESA/ATG medialab

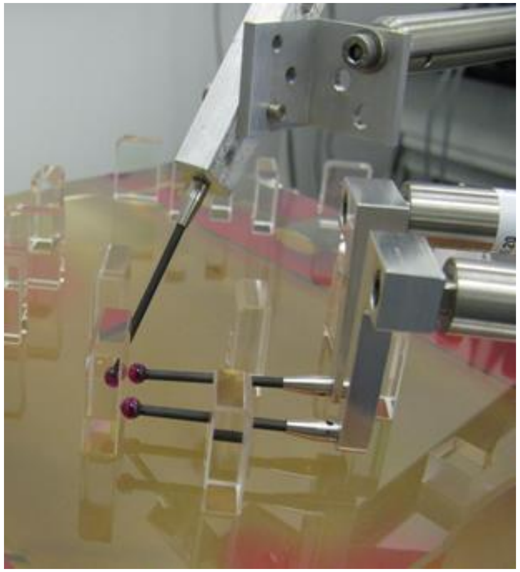
University of Glasgow

VIA VERITAS VITA



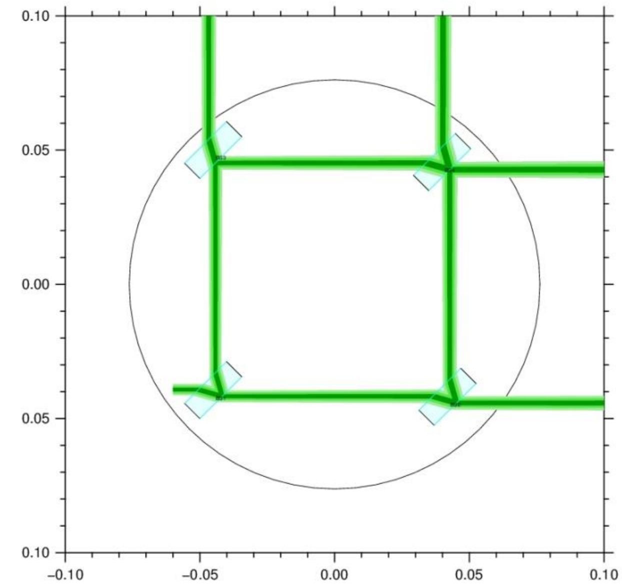
Precision glue-less bonding

- One of the technologies developed for the LISA Pathfinder optical bench was the use of hydroxide catalysis bonding of optical components with high precision
  - This was a way of building optical assemblies of intrinsically high stability
- The technique – now TRL 9 – was highly successful
  - It was not scalable, though, and required a highly skilled team to painstakingly assemble the benches
  - Future uses, e.g. building eLISA optical benches, will require the process to be industrialised

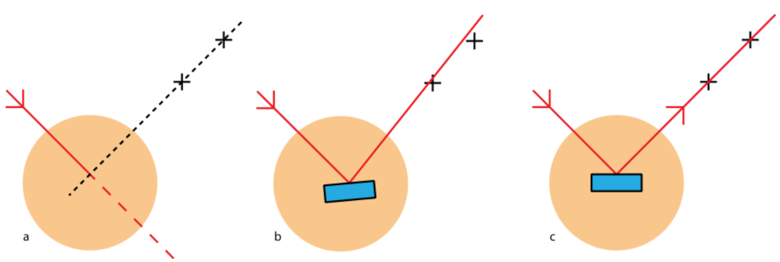


Mechanised precision bonding

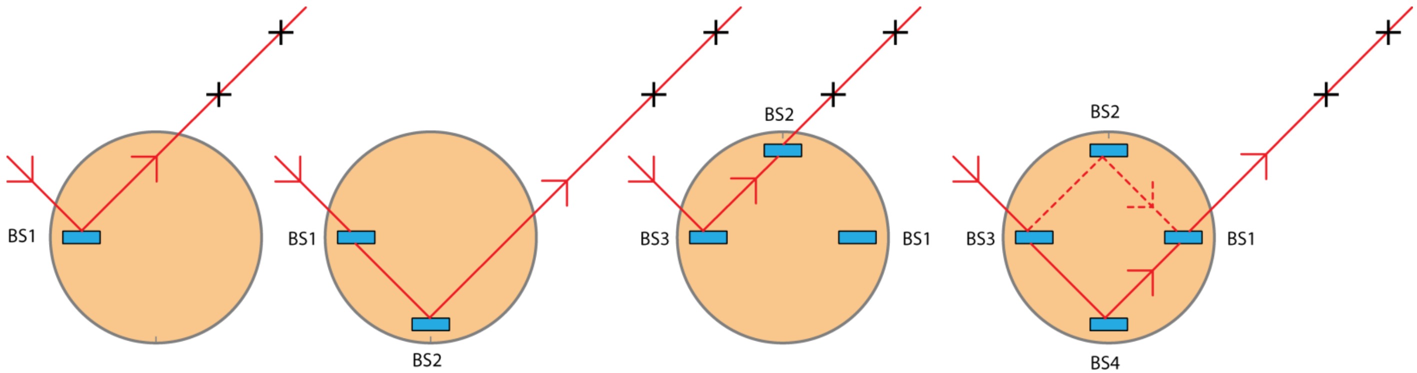
- A CEOI-ST 7th Call Fast Track grant was awarded, in partnership with Gooch and Housego UK (Ltd), to develop mechanisation of precision bonding
- This incorporated two approaches:
  - Mechanised placement of optical components essentially replicating the LISA Pathfinder techniques but automating the high risk and time consuming steps
  - A development of precision ‘ground surface’ bonding
- Both approaches involved making test bonds, and then building and testing an optical assembly

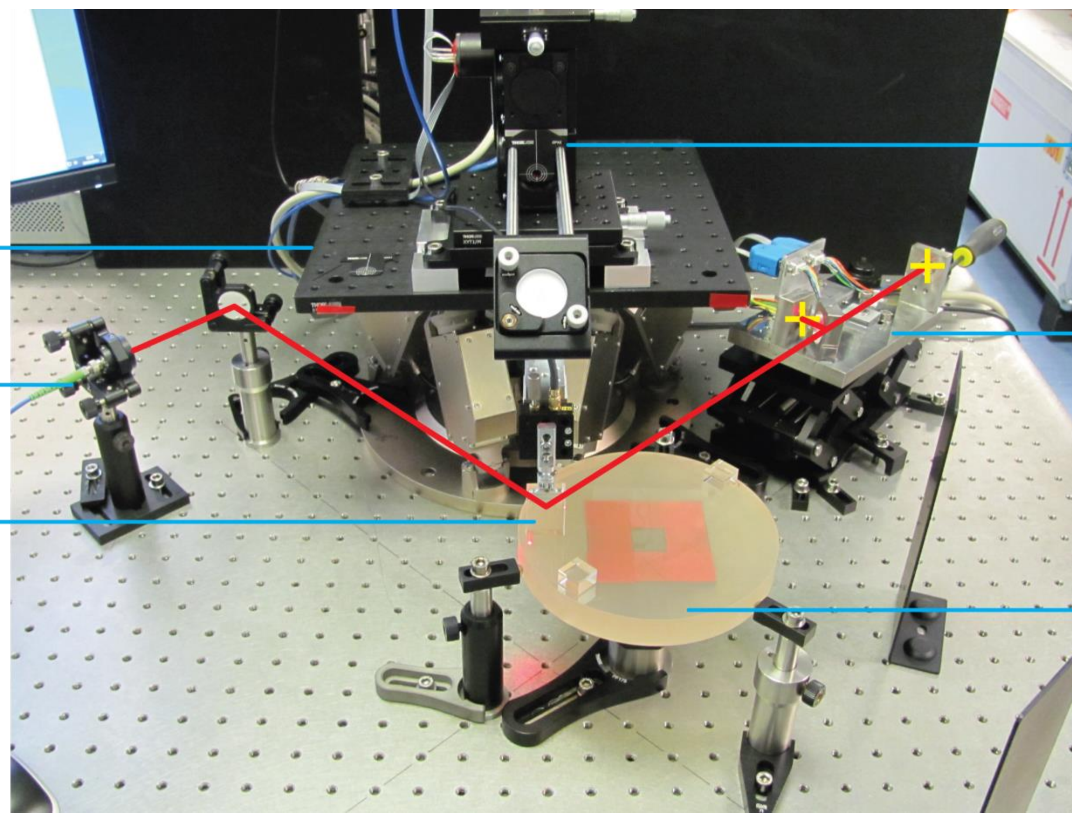


The nominal optical layout of the test assemblies (above) and diagram of the alignment measurement (below)

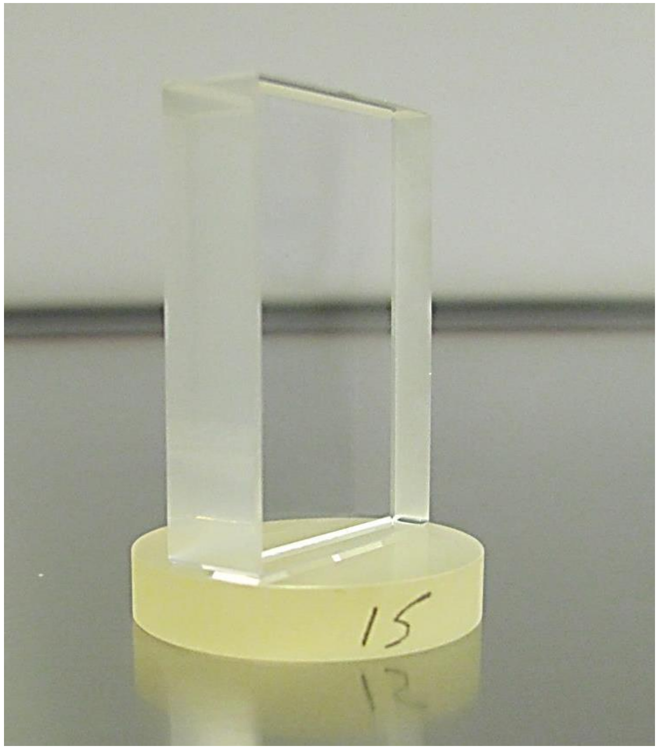


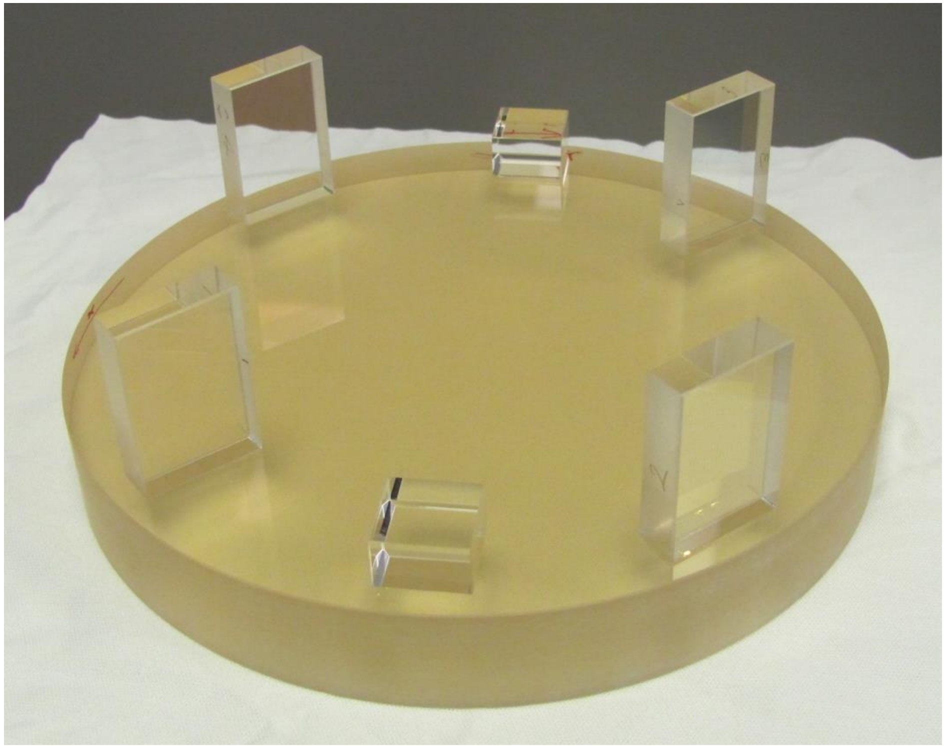
Building the test assembly





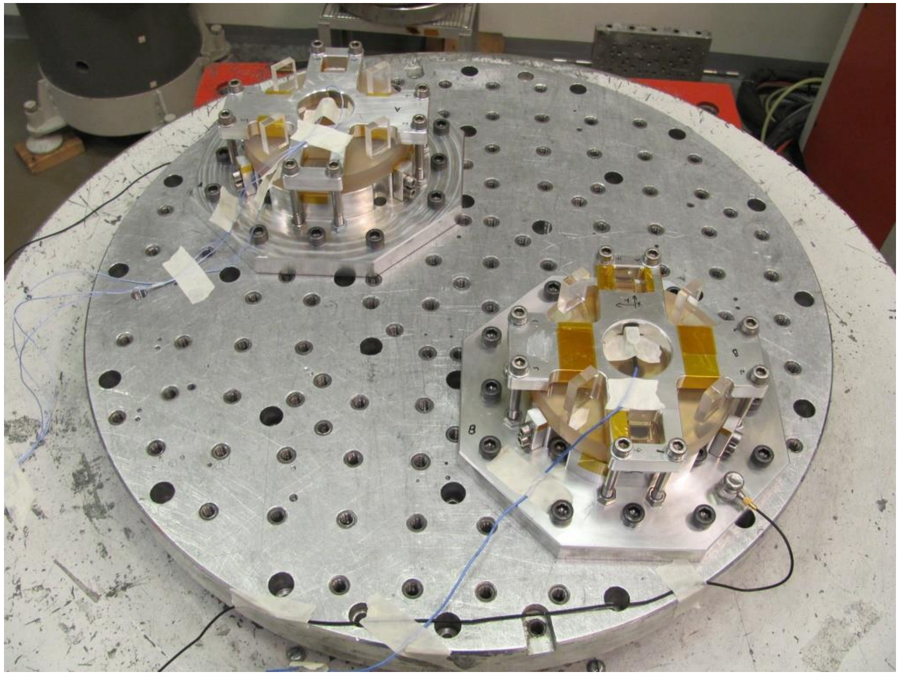
Bonded assemblies



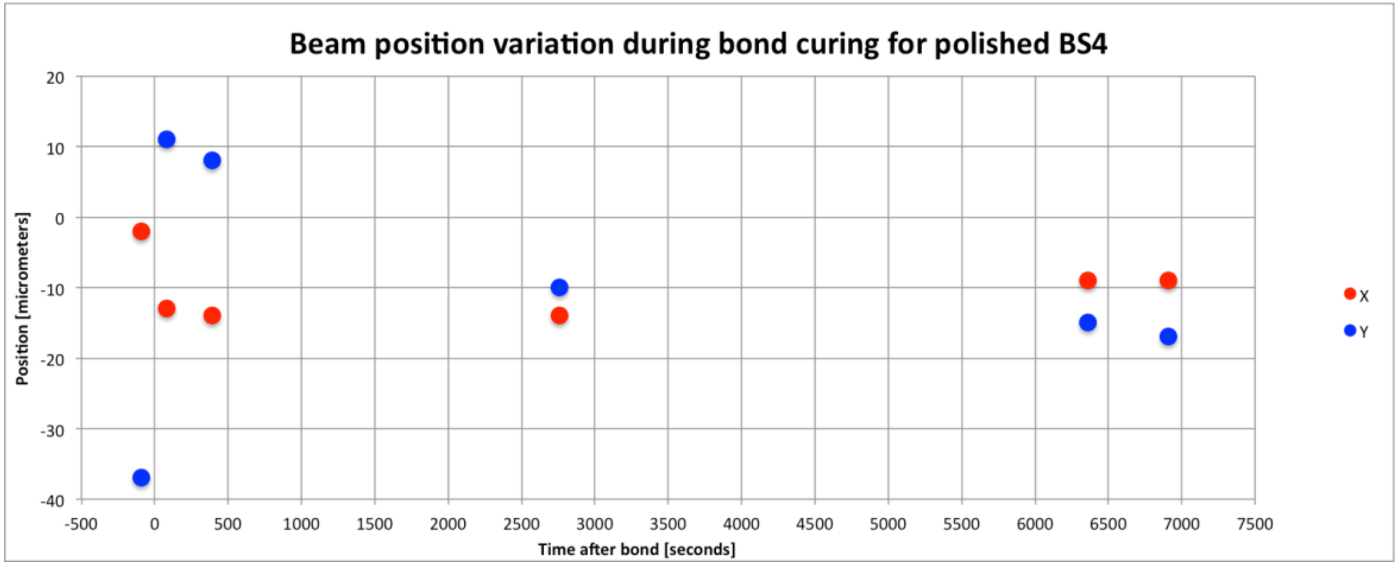


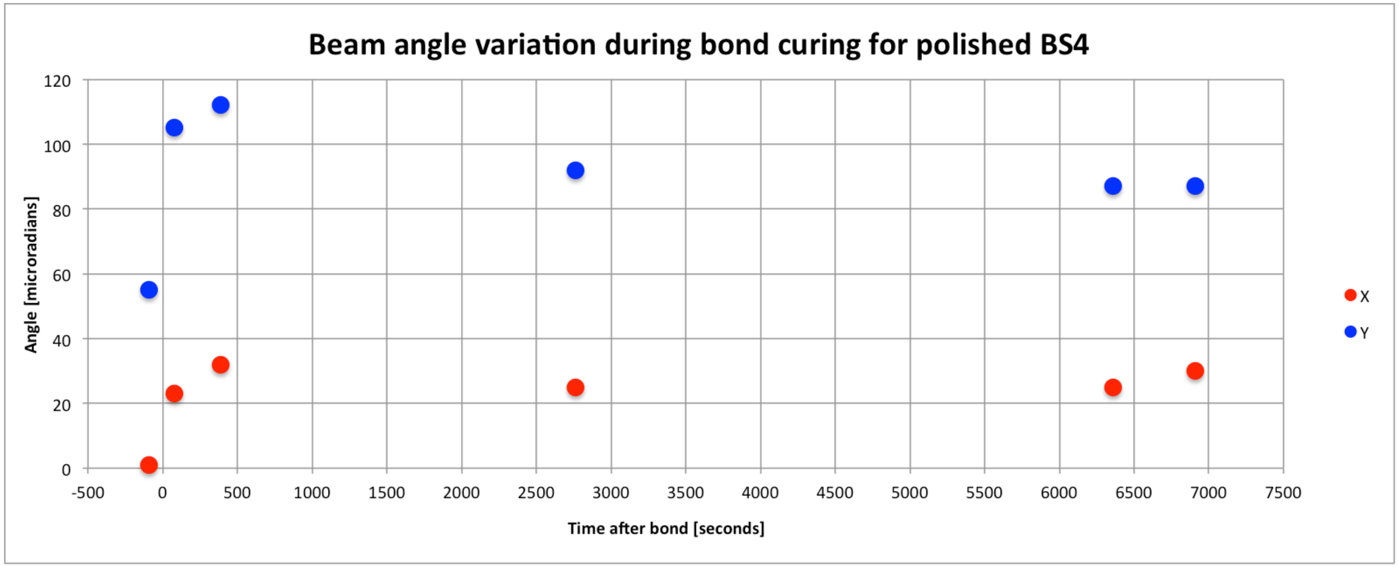
Environmental testing

- The assemblies were subject to thermal vacuum and shock/vibration testing to similar levels as the LISA Pathfinder optical bench
  - A clamping issue resulted in some failures during vibration testing, but some bonds survived, demonstrating the principle



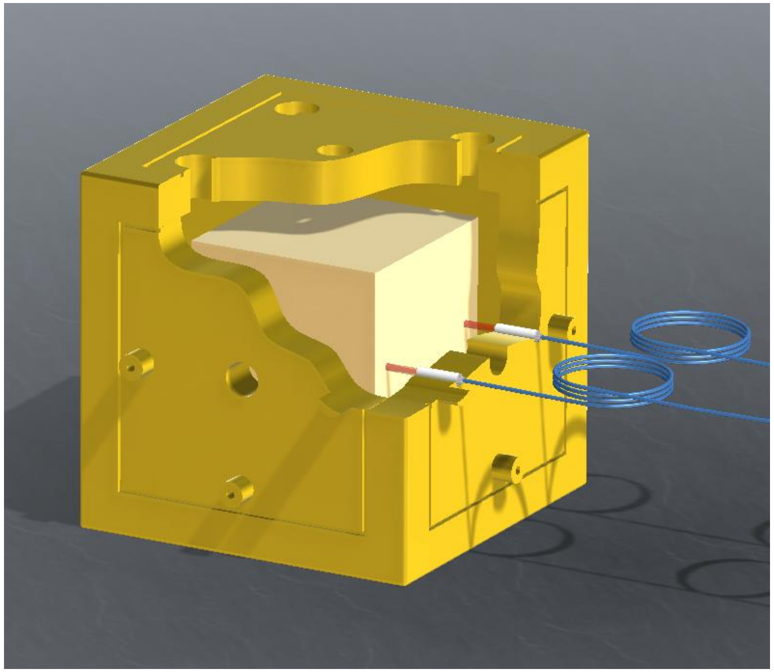
Absolute alignment results

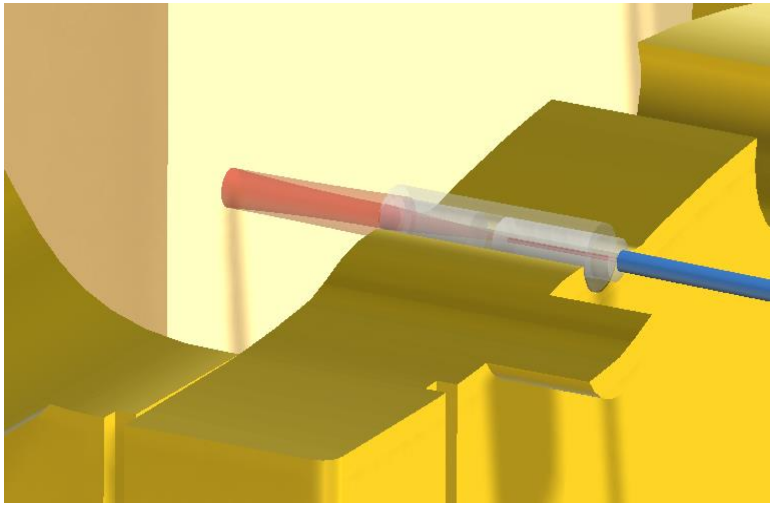




Optical fibre position-sensor

- The Institute for Gravitational Research at the University of Glasgow has accumulated a wealth of experience in interferometric measurement knowledge
- LISA Pathfinder uses state-of-the-art capacitive sensors to readout the non-critical test mass positions
- It occurred to us that this could also be done interferometrically, and that this would have advantages

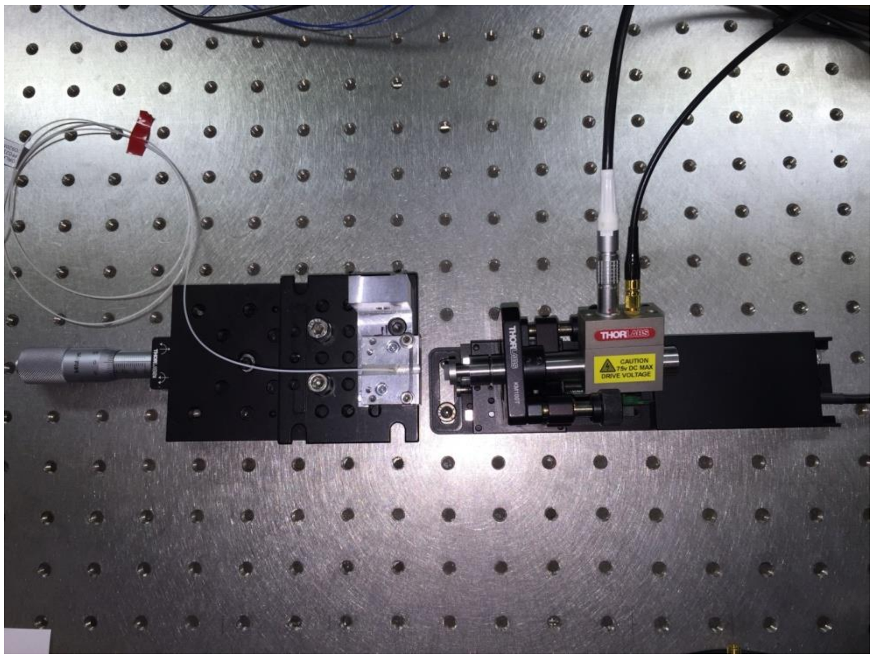


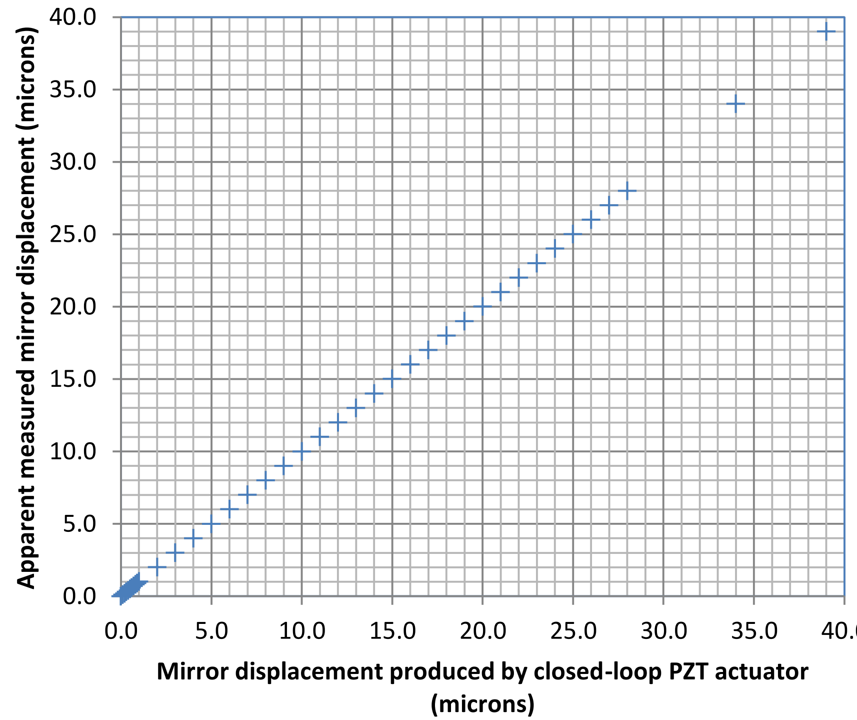


The sensor head

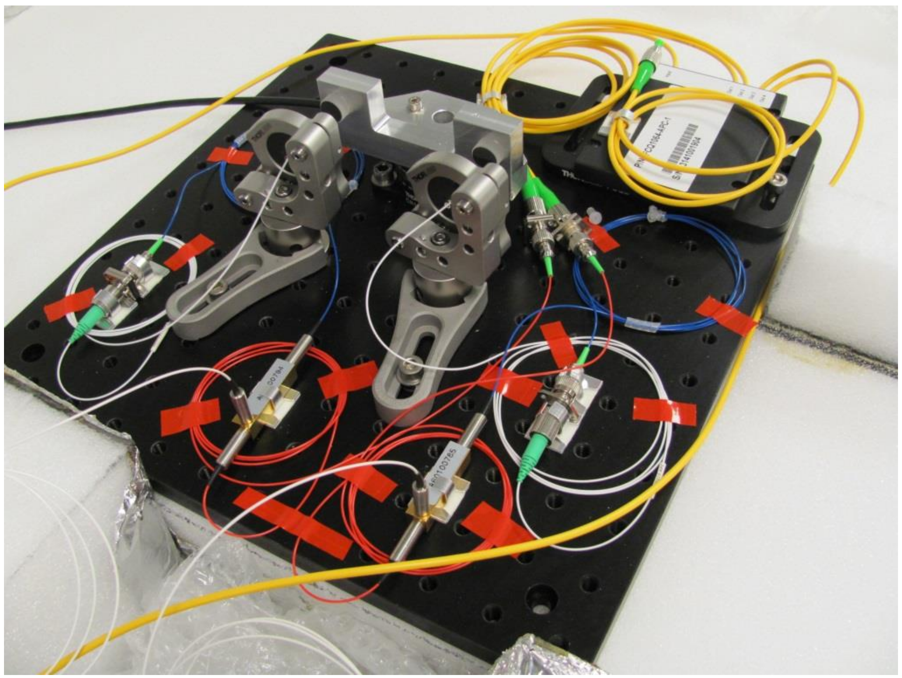
- The award of a 2nd NSTP Call Fast Track grant allowed us to develop this idea and we have demonstrated proof-of-principle

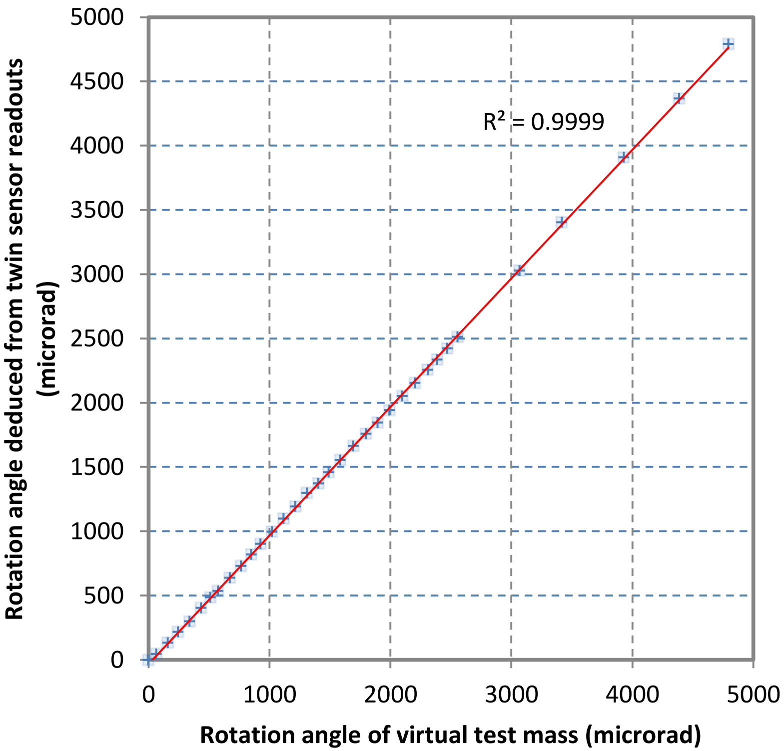
Linearity



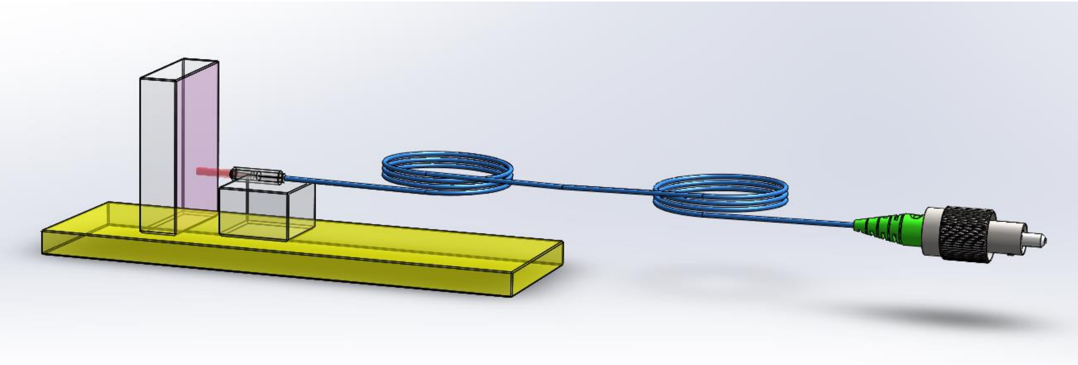

40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Apparent measured mirror displacement (microns)
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
Mirror displacement produced by closed-loop PZT actuator (microns)

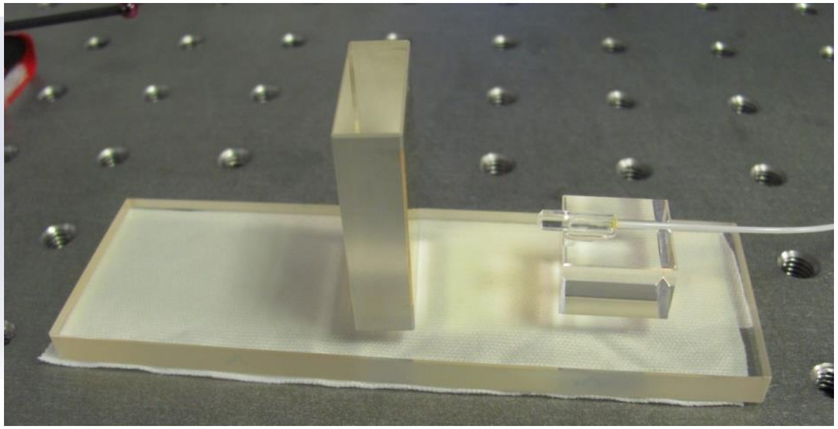
Angular readout

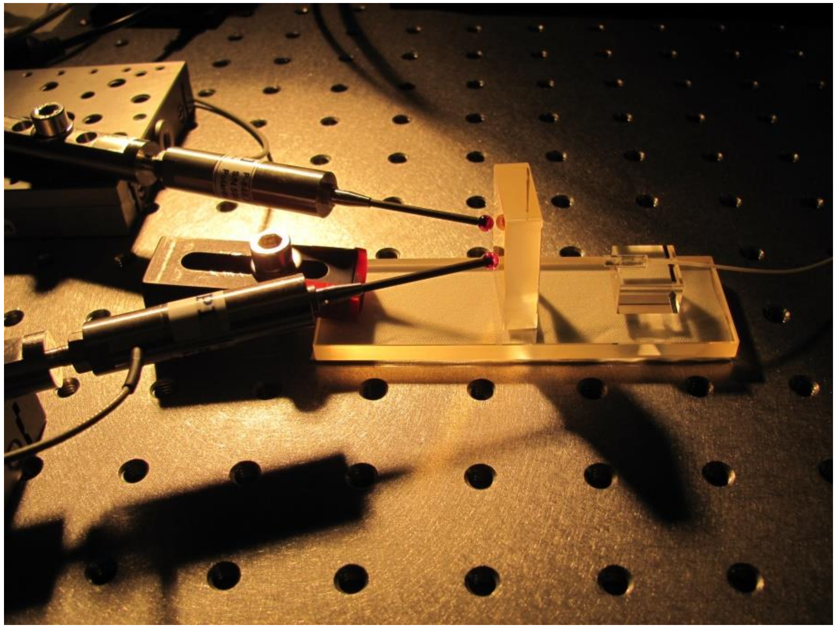


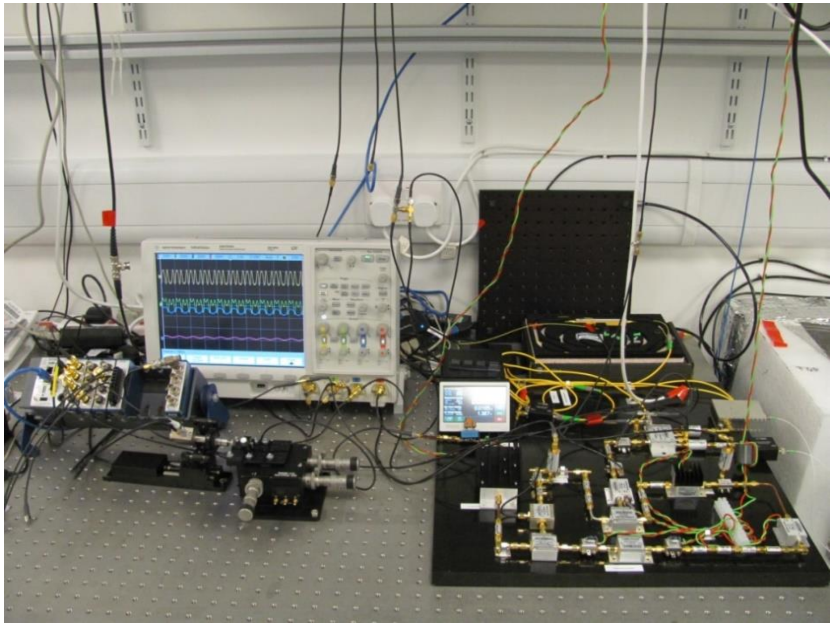


Setup for demonstrating noise floor

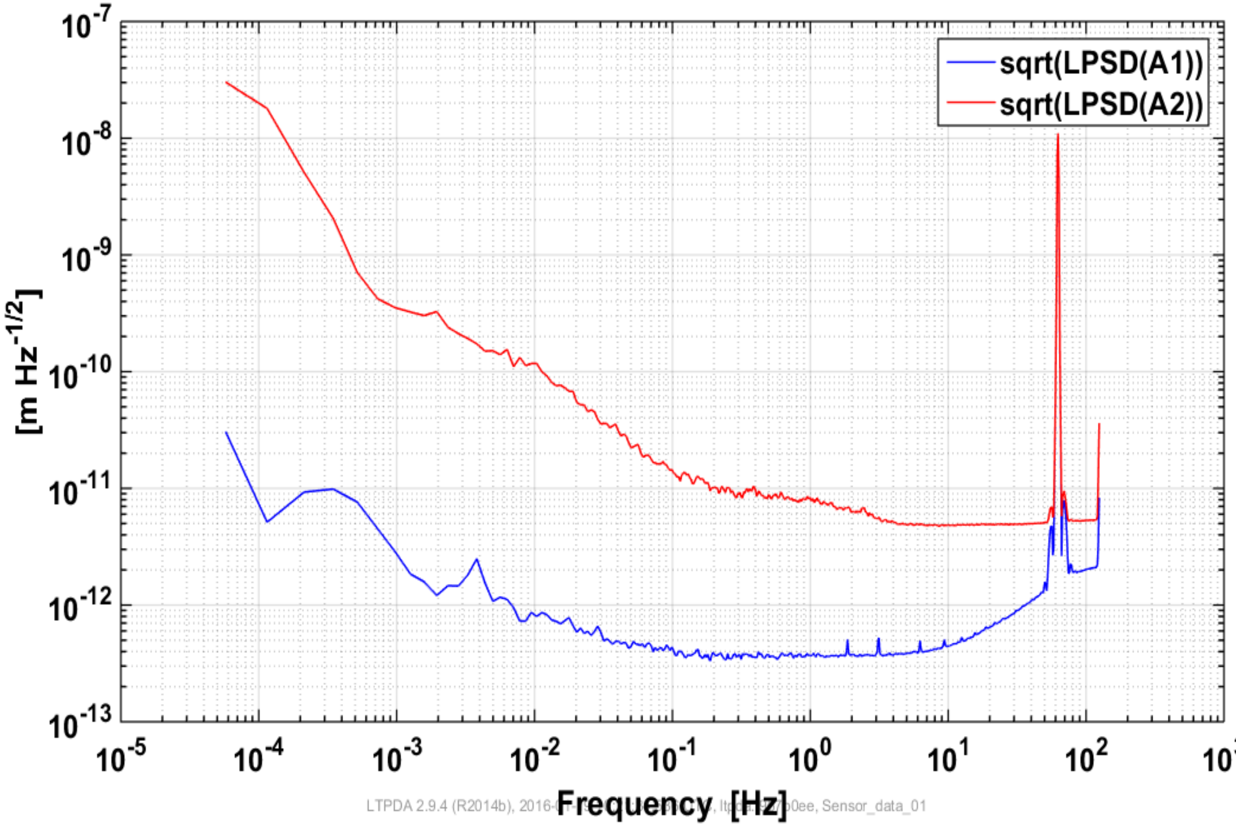








Noise floor result



- 1 mHz noise a factor of five lower than very good (~2pm/√Hz) capacitive readout systems
- Absolute position experiment in progress
  - Expect initial results in the 10 micron range

Summary

Through CEOI-ST and NSTP grants we have made two highly academic-focussed technologies significantly closer to industrial application

- A mechanised assembly process particularly suited to robust, precision optical assemblies
  - Absolute optical beam positioning at the few micron and 30 microradian level, with very high positional stability
  - A market study is currently underway
- A fibre position-sensor
  - Very compact sensor head capable of 10 pm motion tracking
- Both of these technologies are highly adaptable – there are trade-offs that can be made between sensitivity and complexity

Thank you for your attention

University of Glasgow