Opto-mechanical design for space science

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Space Glasgow Research Conference

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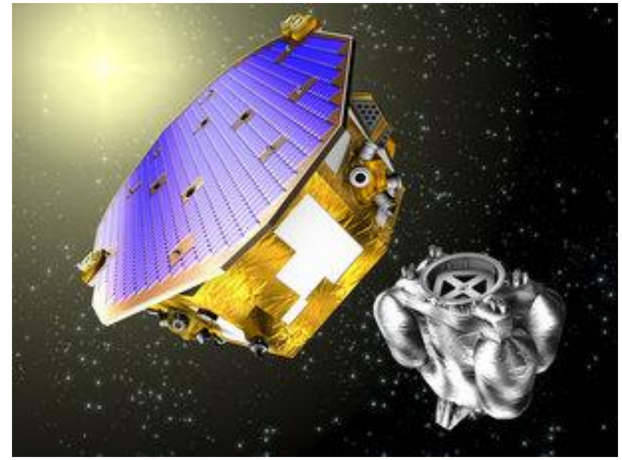
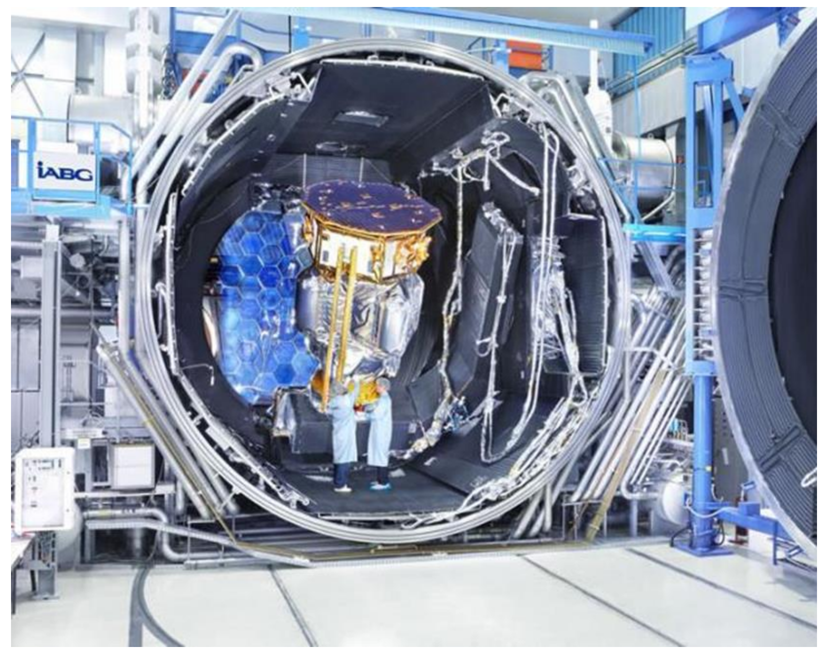
Our space heritage

ESA LISA Pathfinder Mission

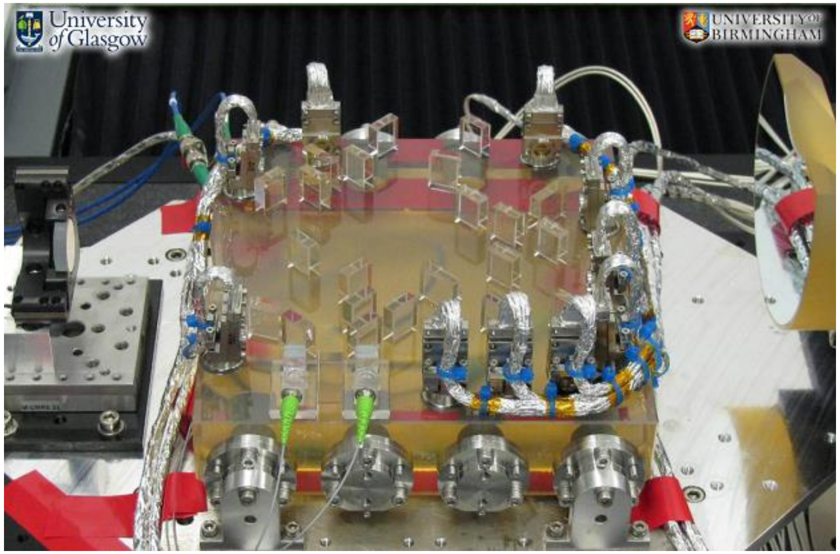
- LPF will demonstrate the fundamental technologies needed to build a gravitational wave observatory in space.
- The main payload onboard is the LISA Technology Package (LTP).
- At the heart of LTP is the optical metrology system including the Glasgow Optical Bench Interferometer (OBI).
- To be launched in late-summer next year.
- Further information:
  - Talk by Christian Killow this afternoon
  - www.elisascience.org





LISA Pathfinder Optical Bench Interferometer (OBI)

- The Glasgow team developed…
  - Precision assembly of the ultra-stable hardware using hydroxy-catalysis bonding.



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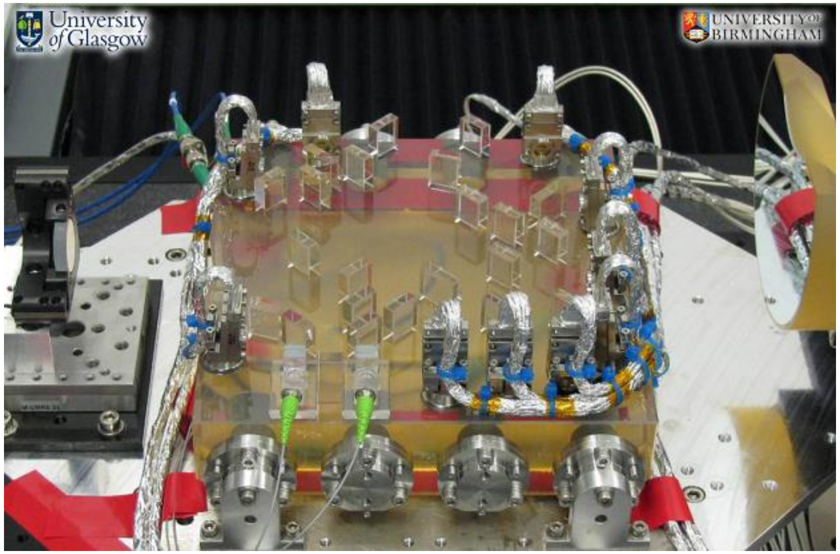
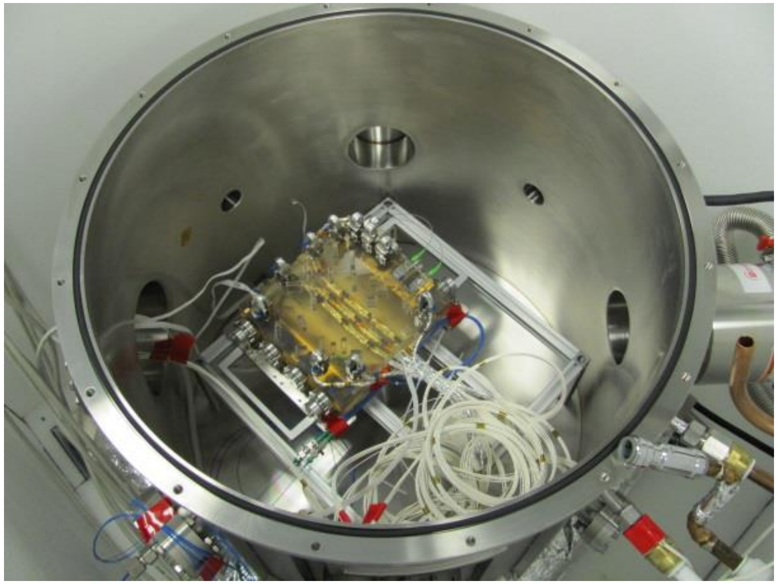
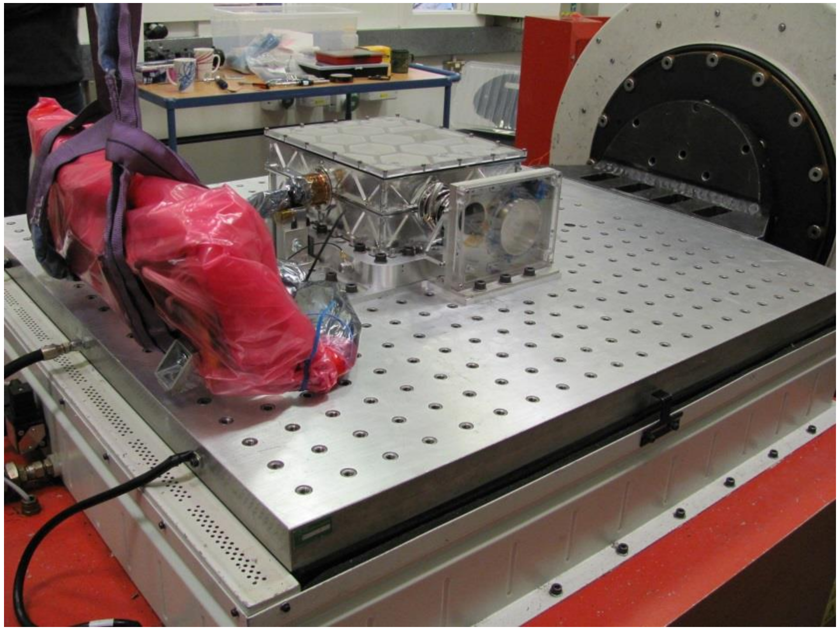


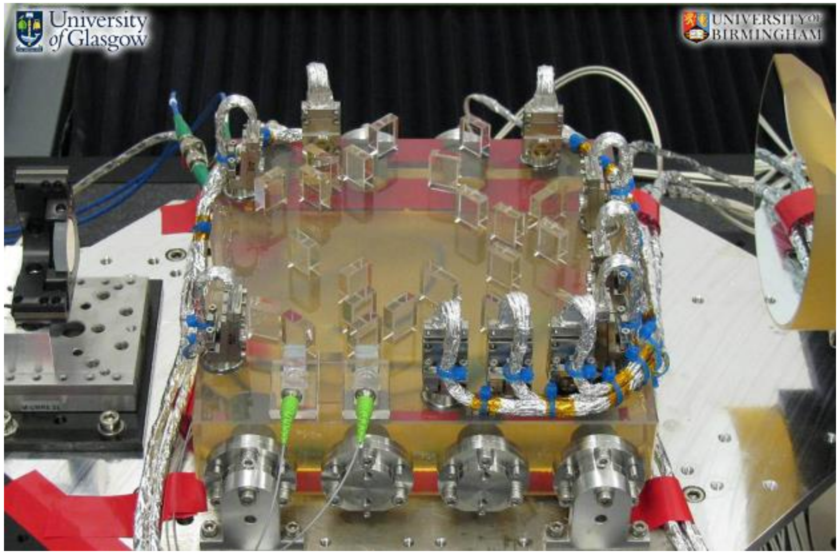
- …tested…
  - In-house thermal-vacuum testing
  - Vibration and shock testing at *Selex Galileo, Edinburgh*

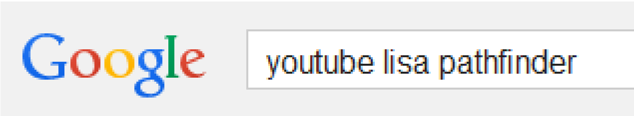




LISA Pathfinder Optical Bench Interferometer (OBI)

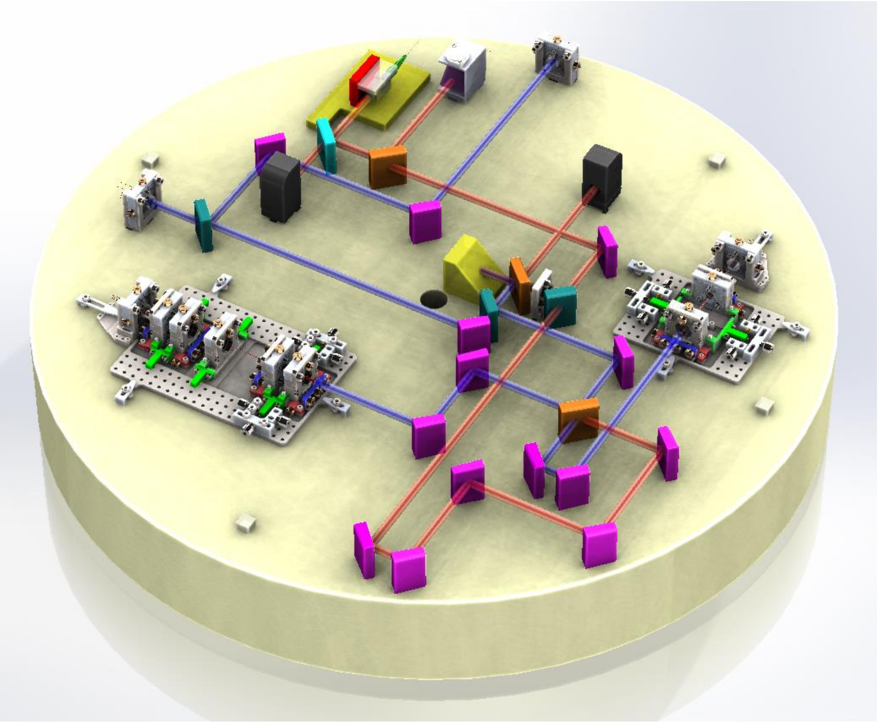
- The Glasgow team developed…
  - Precision assembly of the ultra-stable hardware using hydroxy-catalysis bonding.
- …tested…
  - In-house thermal-vacuum testing
  - Vibration and shock testing at *Selex Galileo, Edinburgh*
- …and delivered
  - Flight hardware delivered to *EADS Astrium GmbH (now Airbus Defence & Space), Friedrichshafen,* in April 2013 for further integration.





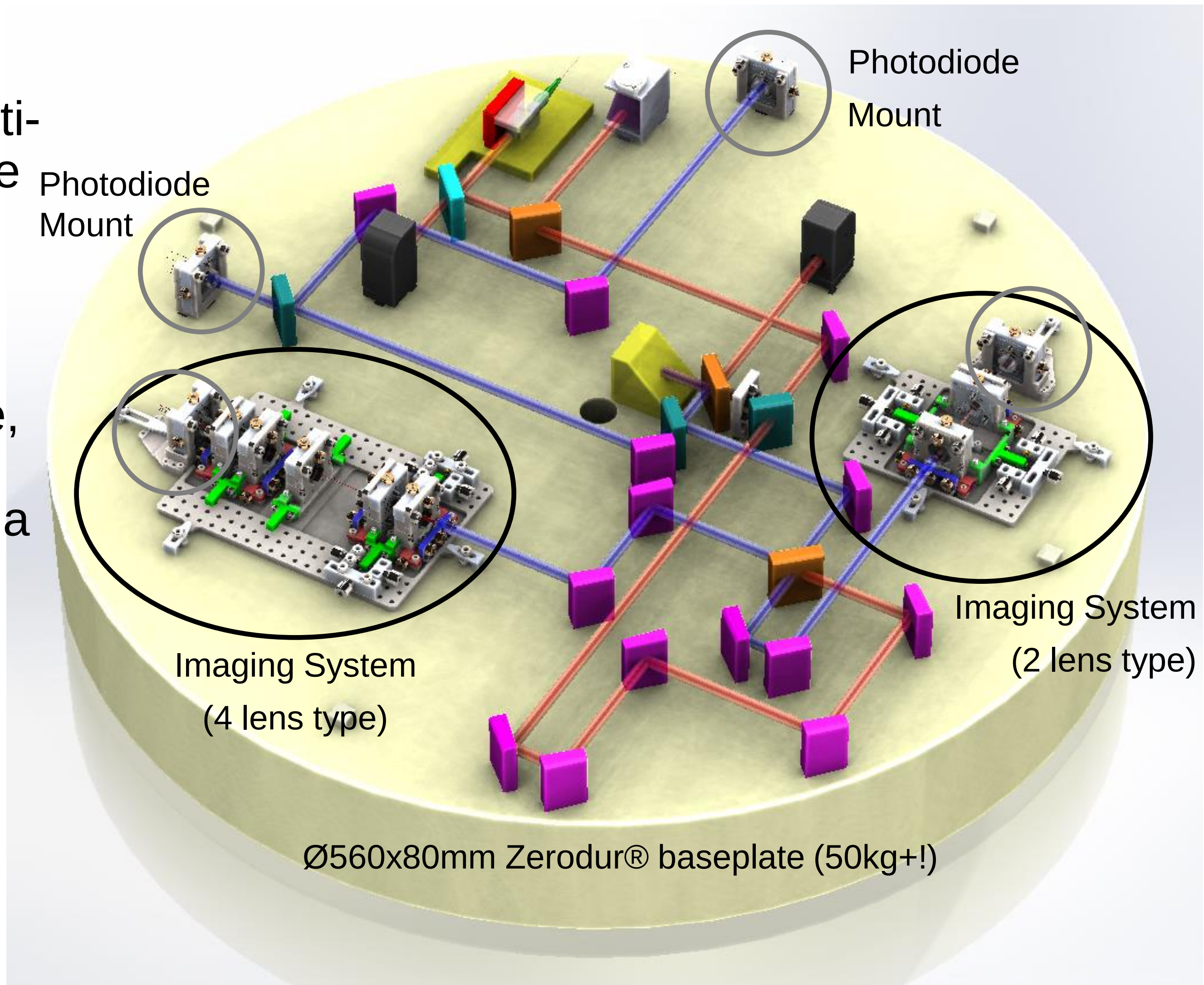
Life after LISA Pathfinder

- We have delivered the LTP flight spare OBI hardware and a data pack of around 300 documents!
- Some LPF activities are still ongoing with Glasgow personnel involved in the development of the data analysis tools for running the experiments on LISA Pathfinder when it reaches its orbit.
- On the hardware side, we are presently working on an ESA-funded project to develop further technologies required for an evolved LISA (eLISA) mission.



eLISA OB Development

- The primary goal of the experiment is to develop, characterise and test multi-lens, multi-DoF adjustable imaging systems.
- The imaging systems include a thermally stable, flexure-adjustable mechanism for mounting a quadrant photodiode to readout the signals.



LISA OB Development – Photodiode Mounts

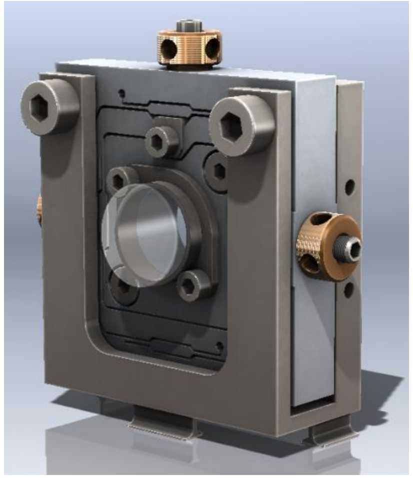
Primary requirements:

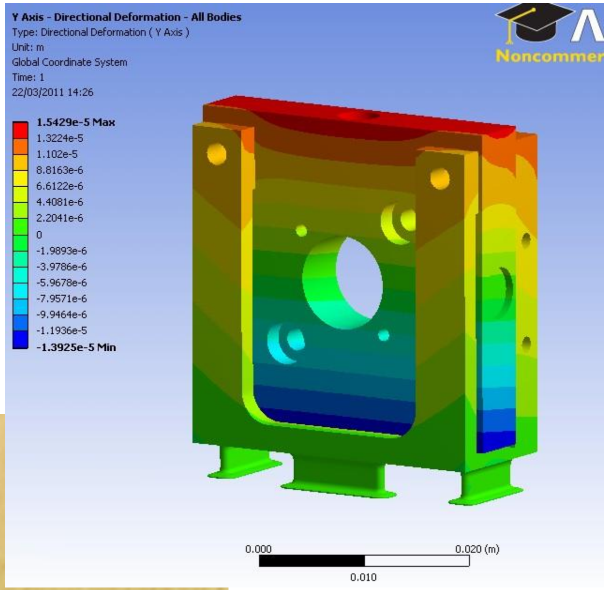
- Photodiode to be mounted in an electrically isolated way.
- Mount to be thermally stable over a 0 to 40°C temperature range.
- Precision mountable on a Zerodur® glass-ceramic baseplate.
  - ~10microns positioning in X, Y and Z
  - Designed for a beam height above the surface of 20mm
- Precision adjustable alignment.
  - <3microns in X and Y (where Z is along the beam path)
- Materials and designs should be space flight compatible

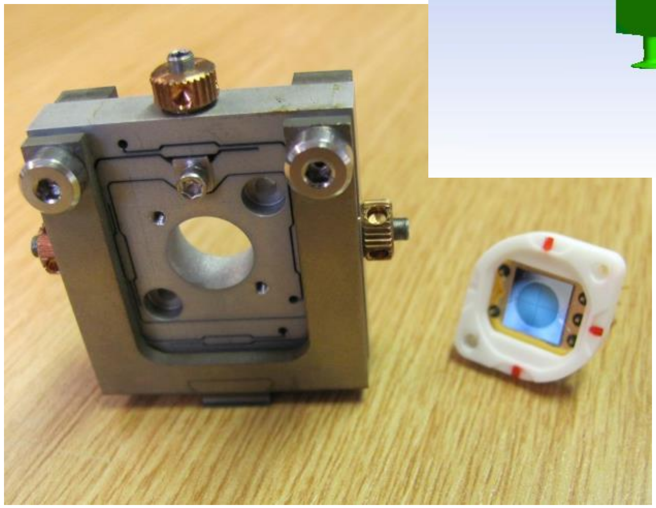
LISA OB Development – Photodiode Mounts

The design (1):

- Photodiode to be mounted in an electrically isolated way.
  - MACOR® ceramic PD adapter with threaded holes for mounting
  - Alignment of QPD into MACOR completed using an optical CMM. Capable of alignment to ~10microns.
- Mount to be thermally stable over a 0 to 40°C temperature range.
  - Combined aluminium & titanium architecture arranged like a 'gridiron' pendulum clock provides thermal compensation.



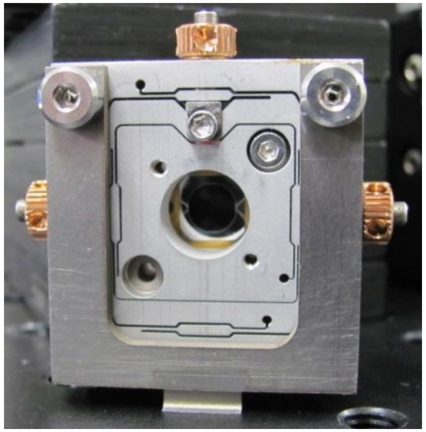


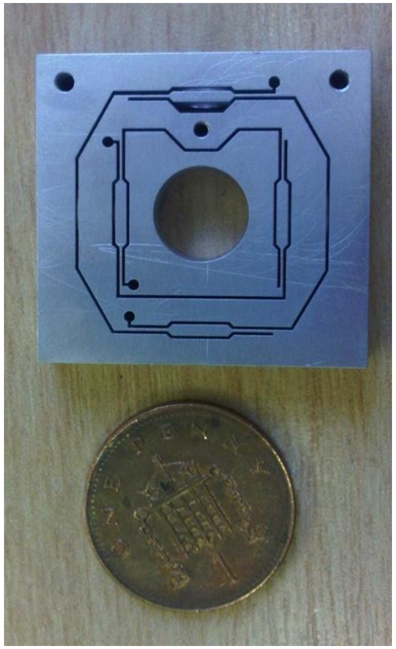


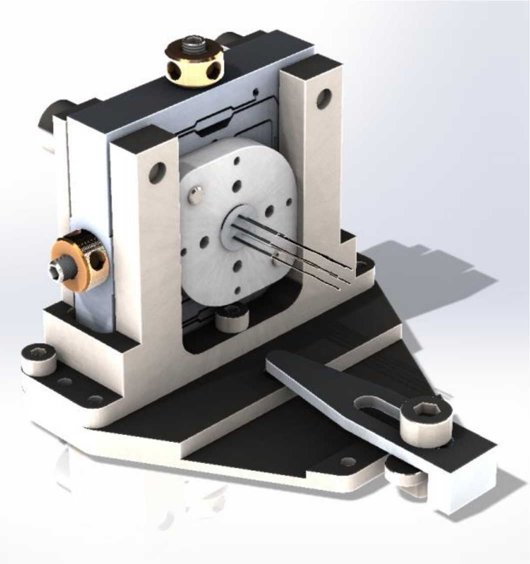
LISA OB Development – Photodiode Mounts

The design (2):

- Precision mountable on a Zerodur® baseplate
  - Titanium flexure feet allow for mounting on the Zerodur such that thermally induced stresses in the baseplate are minimised.
  - Glued to Zerodur with HYSOL epoxy
  - Precision placement checked with CMM
- Precision adjustable alignment
  - Aluminium flexure mechanism combined with ultra fine precision screw (M2.5x0.20) allowing X and Y adjustment with micron-level precision.
  - Range of movement is +/-150microns in both X and Y.
- Materials and designs should be space flight compatible
  - The materials in the design are all compatible with use in vacuum and the final design has been thermally cycled in vacuum.
  - No vibration testing in the current project plan.

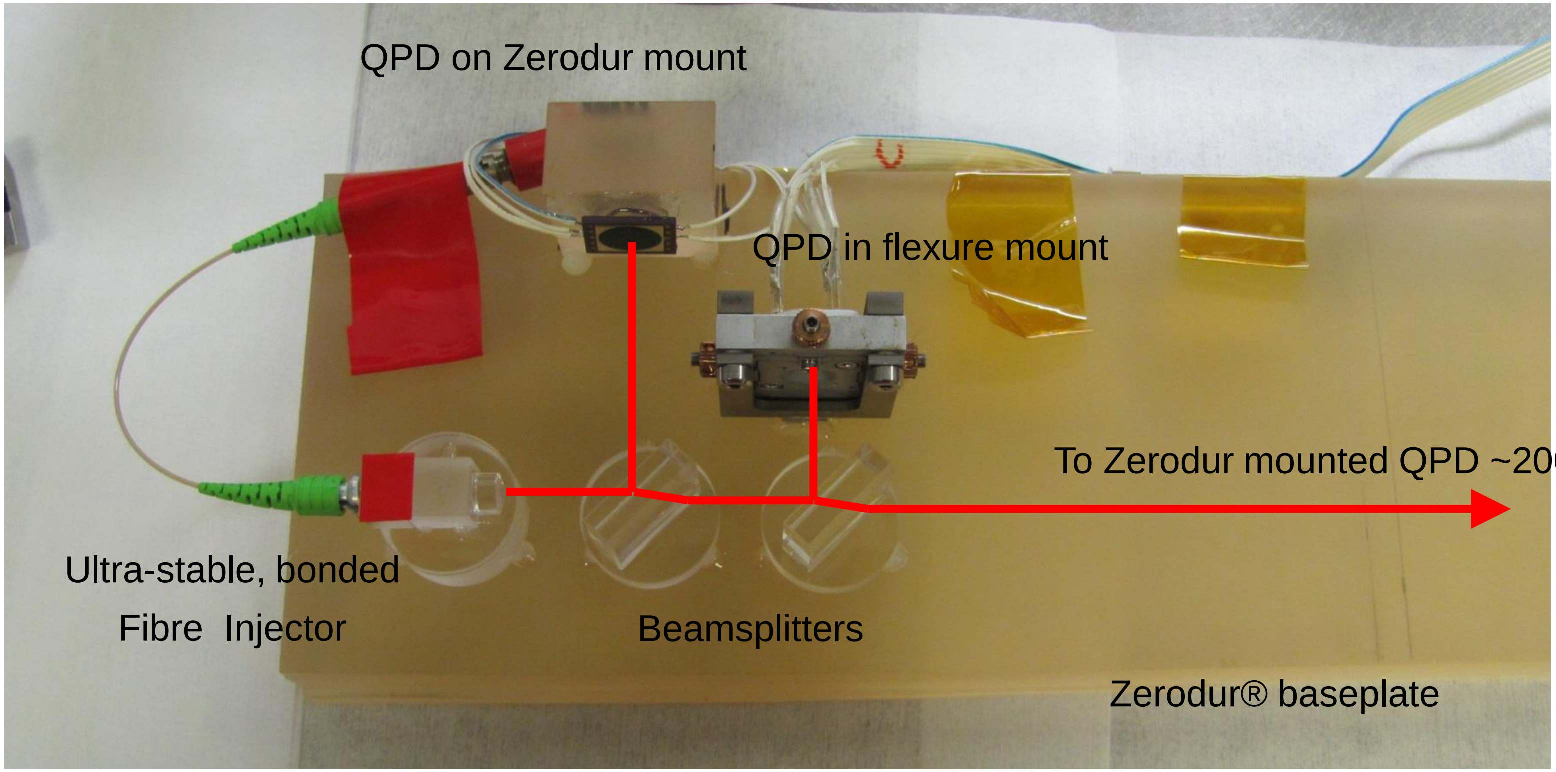






LISA OB Development – Photodiode Mounts

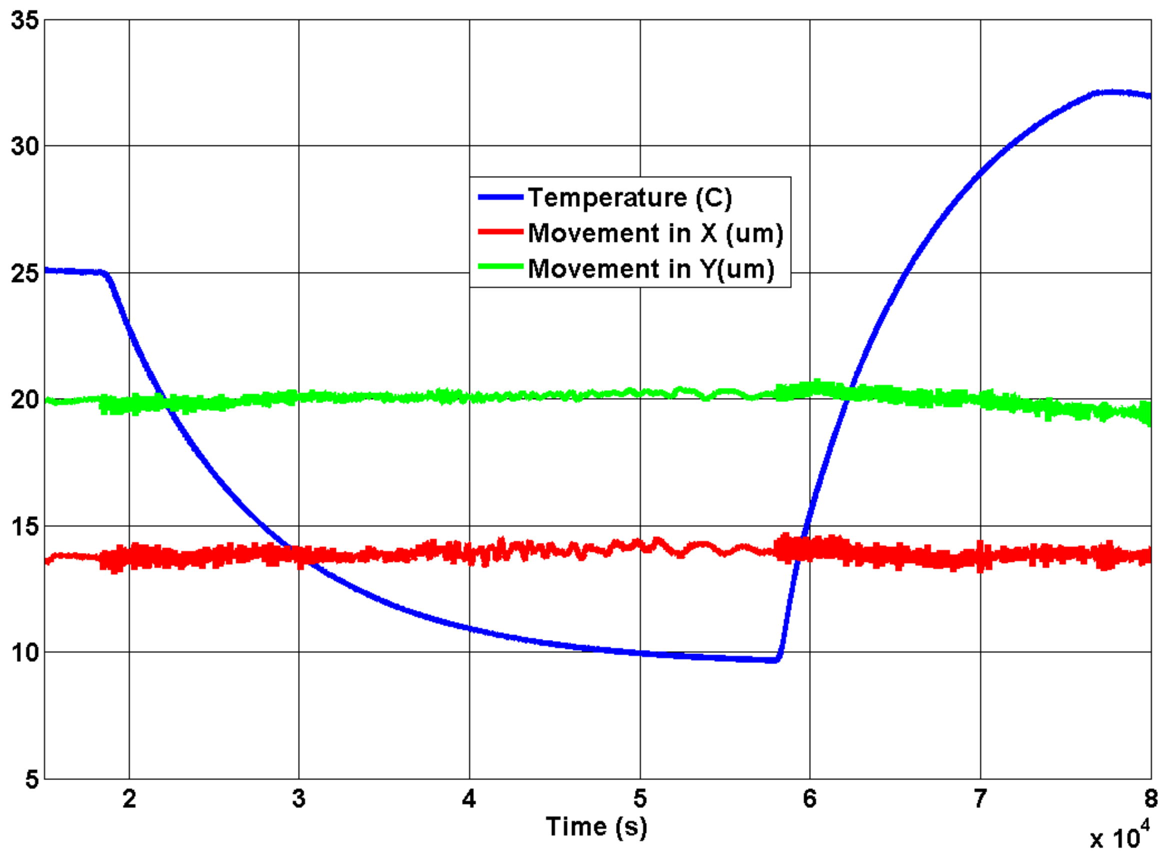
Testing the design



LISA OB Development – Photodiode Mounts

Test results

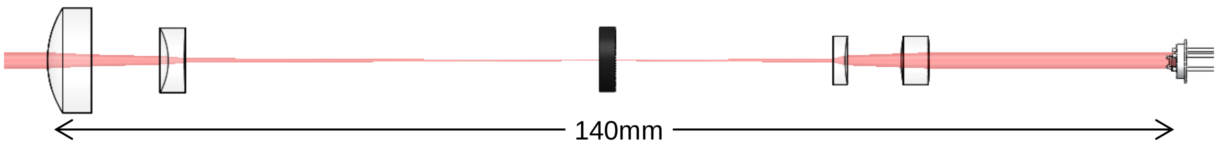
- QPD mount stability was very encouraging!
  - Graph below shows the difference in movement between a 'perfectly stable' Zerodur mounted QPD and the Ti-Al mount.
  - Temperature cycle starts at ~25degC dropping to 10degC and rising to ~30degC

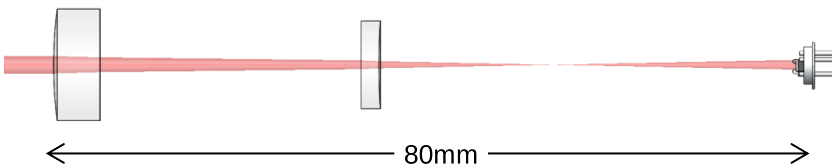


LISA OB Development – Imaging Systems

Primary requirements:

- Mechanism designs must be used to test two different imaging systems optical designs.
- Mechanisms must be removable for mounting multiple lens imaging systems.
- Mounts must be precision adjustable to initially align lenses, lockable to allow high precision testing and, thereafter, adjustable to allow for characterisation of the lens systems.
- Lenses must be centred on a beam height of only 20mm above the Zerodur® baseplate.
- A lot of adjustment mechanisms to fit in a small space!





To allow for alignment and characterisation of the imaging system, each individual lens must be adjustable:

- Laterally, X and Y
- Longitudinally, Z
- In-plane rotation, yaw
- Out-of-plane rotation, pitch

Adjustment of lens pair assemblies is required in:

- Lateral, X and Y
- Longitudinal, Z
- In-plane rotation, yaw
- Out-of-plane rotation, pitch

LISA OB Development – Imaging Systems

Alignment specification

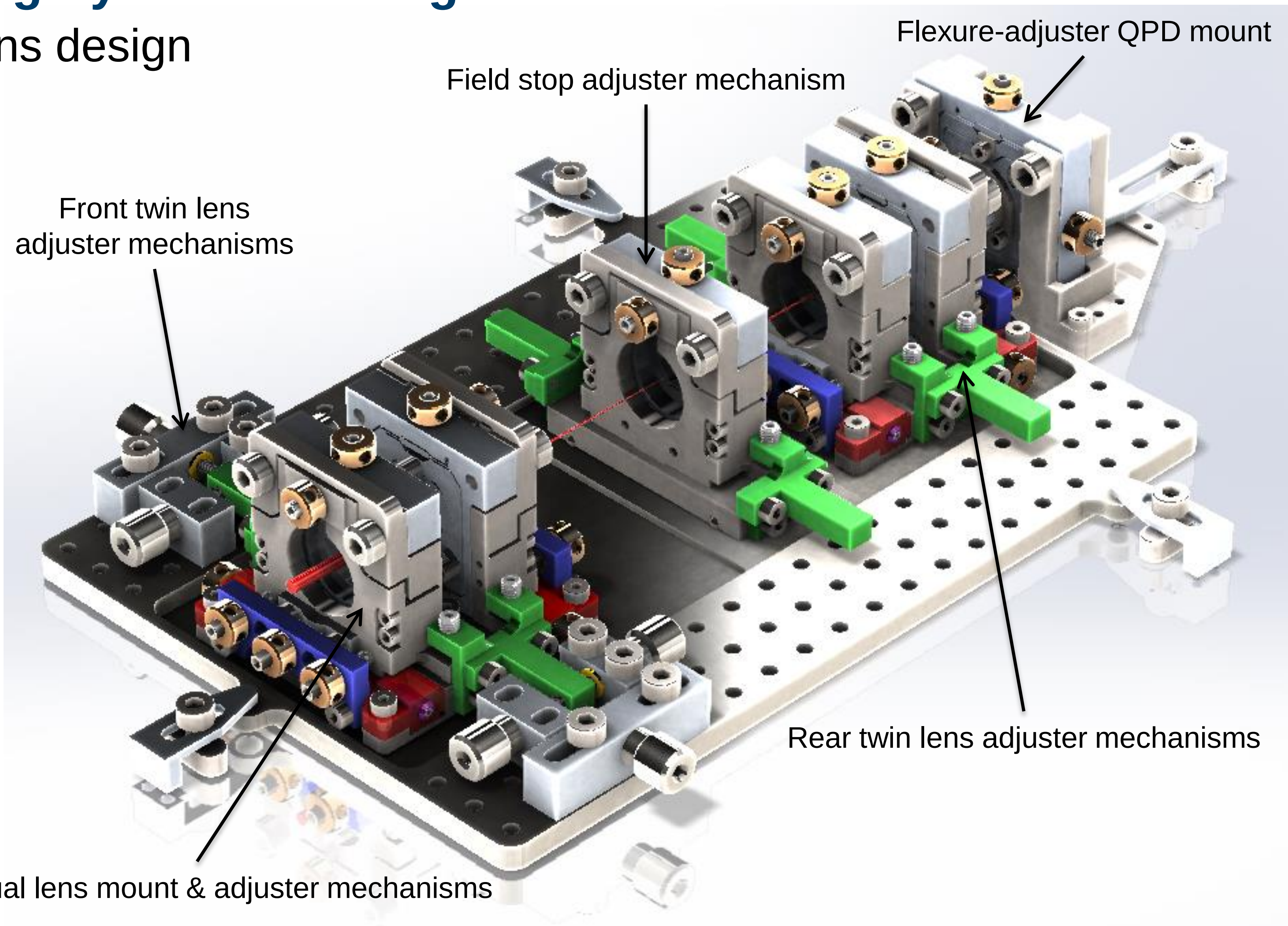
- Typical alignment specifications for an lens
  - Decentre, X, Y: +/- 20µm
  - Distance tolerance Z to next lens: +/- 50µm
  - Lens centring: +/- 3’ (or ~1 mrad)
  - Lens tilt (pitch): +/- 3’ (or ~1 mrad)

Characterisation specification

- Maximum required range:
  - Decentre X, Y: +/- 60µm
  - Distance tolerance Z to next lens: +/- 200µm
  - Lens pitch/yaw: +/- 10’ (or ~3mrad)
- Resolution of movement:
  - Micron
  - Sub arc-minute (~100s of µrad)

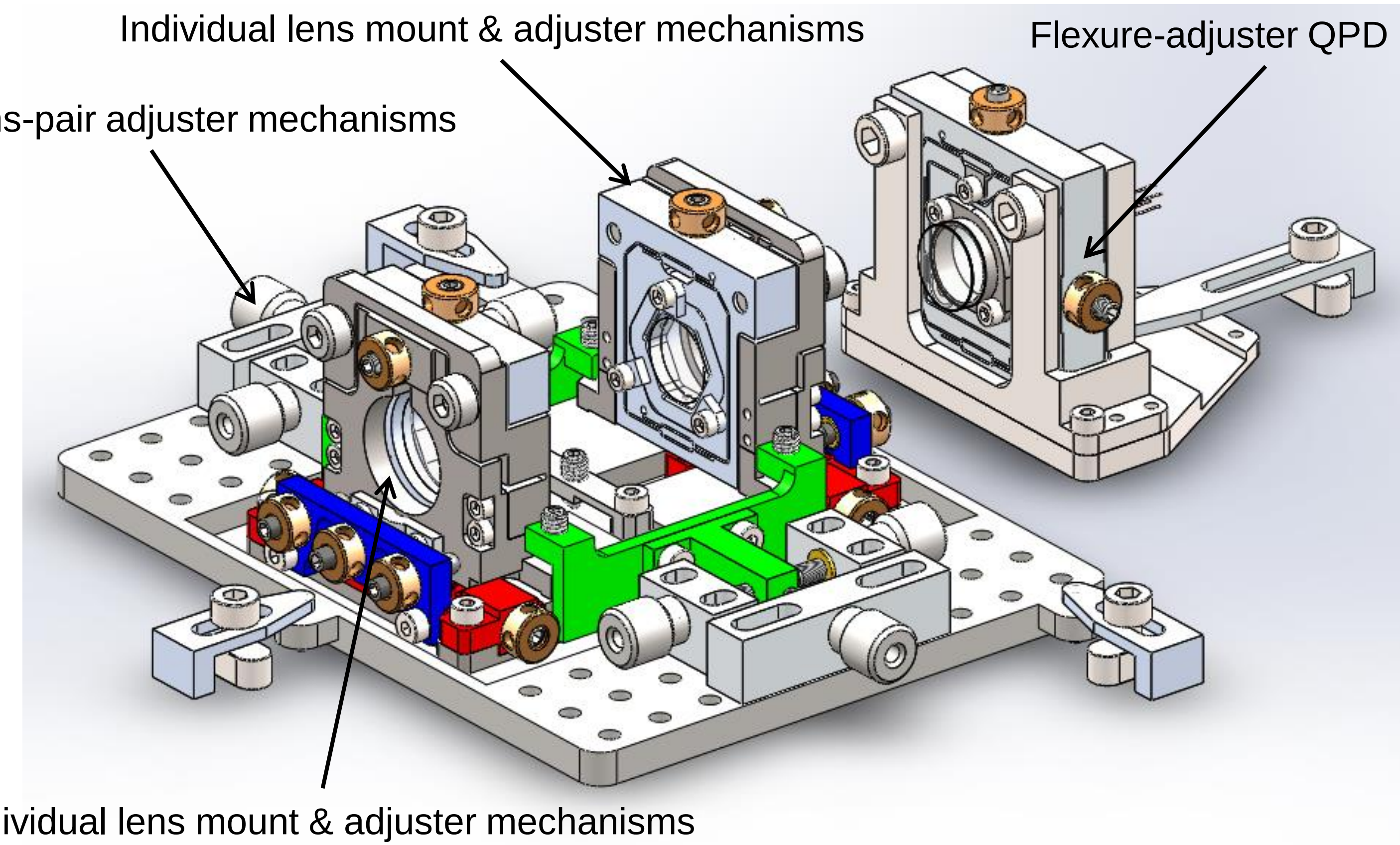
Imaging Systems – Design features

Four lens design



Imaging Systems – Design features

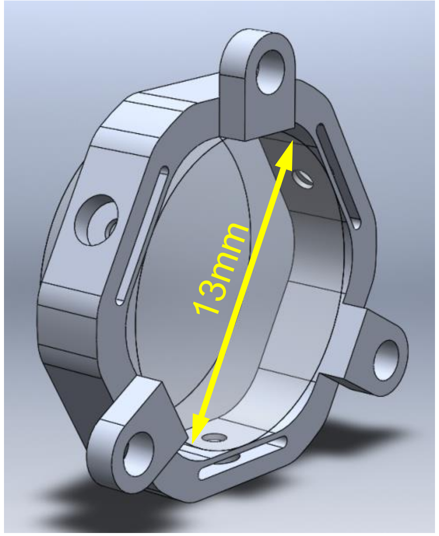
Two lens design

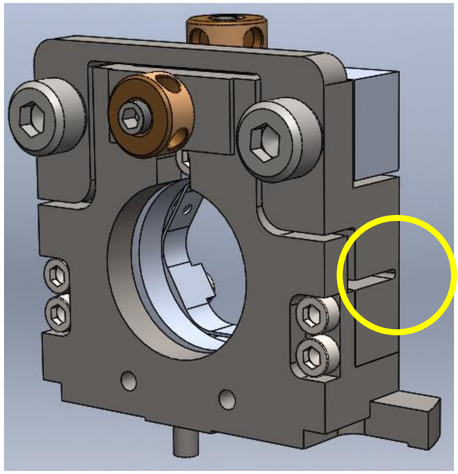


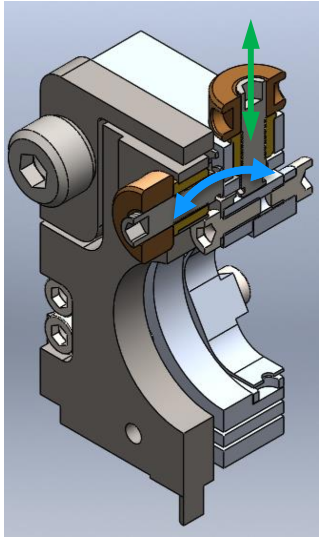
Imaging Systems – Design features

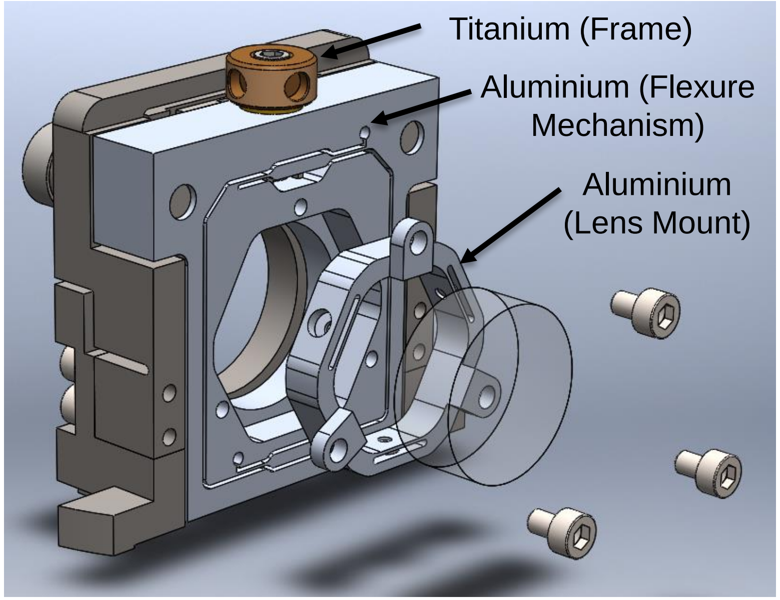
Individual lens holders (1)

- Overall design is thermally-stable
  - As per the PD mount, through a combined titanium & aluminium architecture
- Lens mounts customised for different lens diameters
  - 6, 8, 10, 12.7 & 13mm
- Vertical and pitch adjuster mechanisms
- Ultra-fine pitch screws, M2.5 x 0.20mm
- Flexure pivot





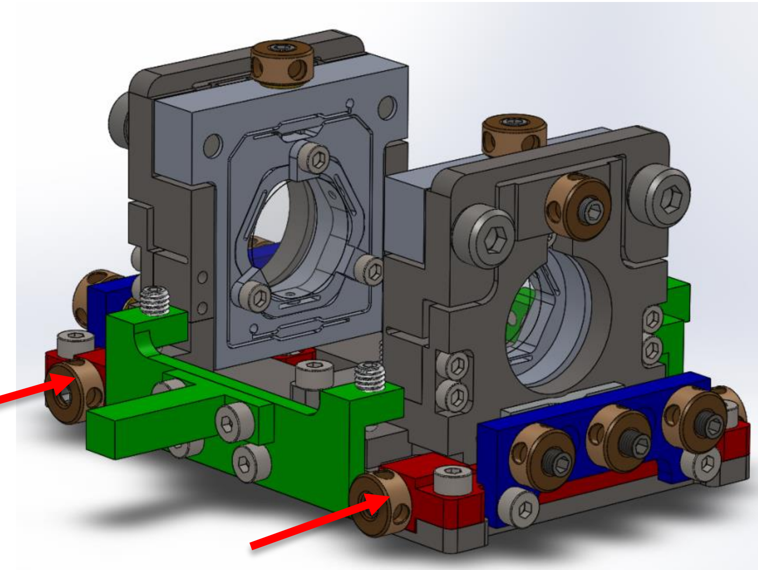


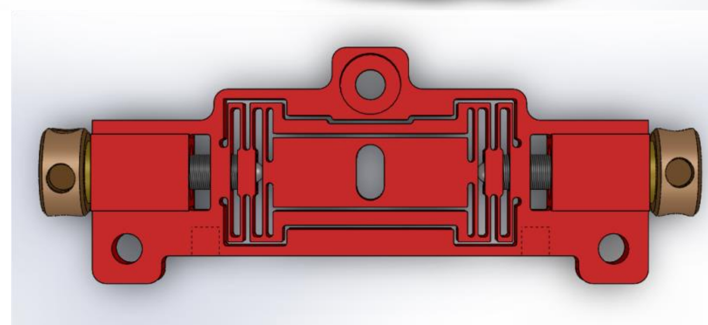


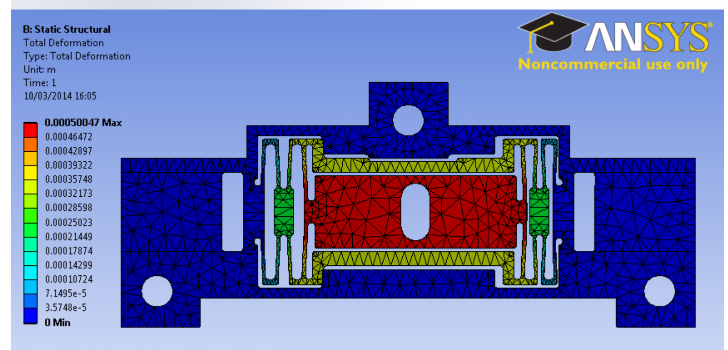
Imaging Systems – Design features

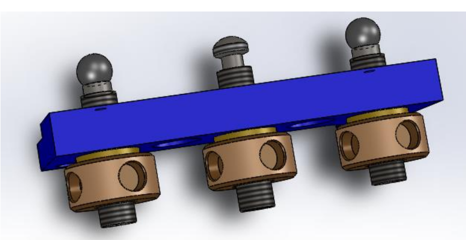
Individual lens holder (2)

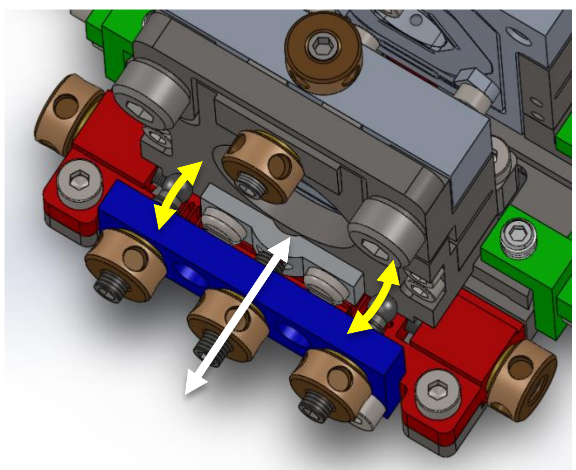
- Lateral adjuster mechanism
  - allows up to +/-0.3mm of movement range
  - Design modelled using ANSYS FEA
- Longitudinal & Yaw adjusters
  - Central screw pushes and pulls, and acts against a spherical bearing surface to allow pivoting
  - Side screws push to pivot the lens mount









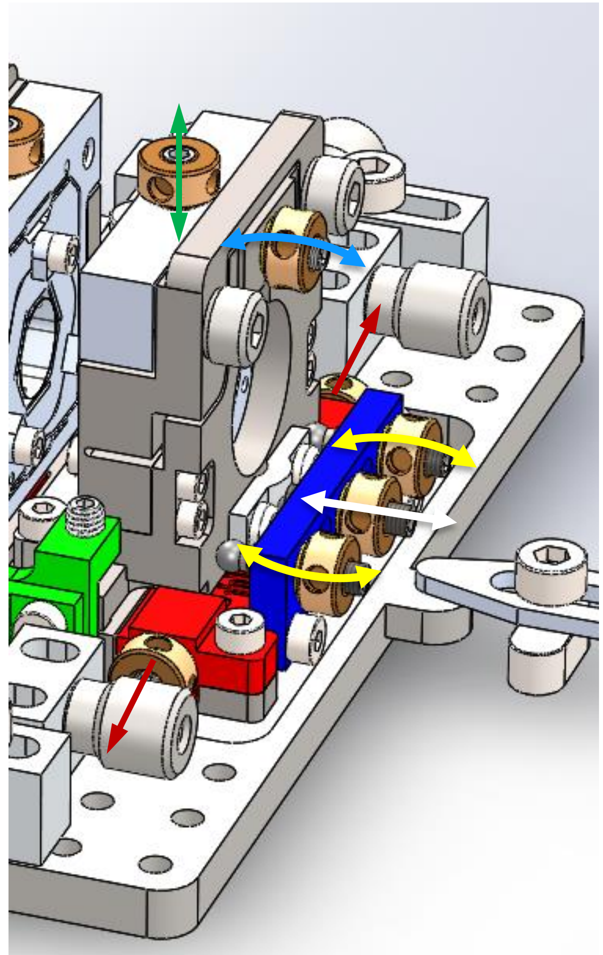


Imaging Systems – Design features

Individual lens holder (3)

Design feature summary

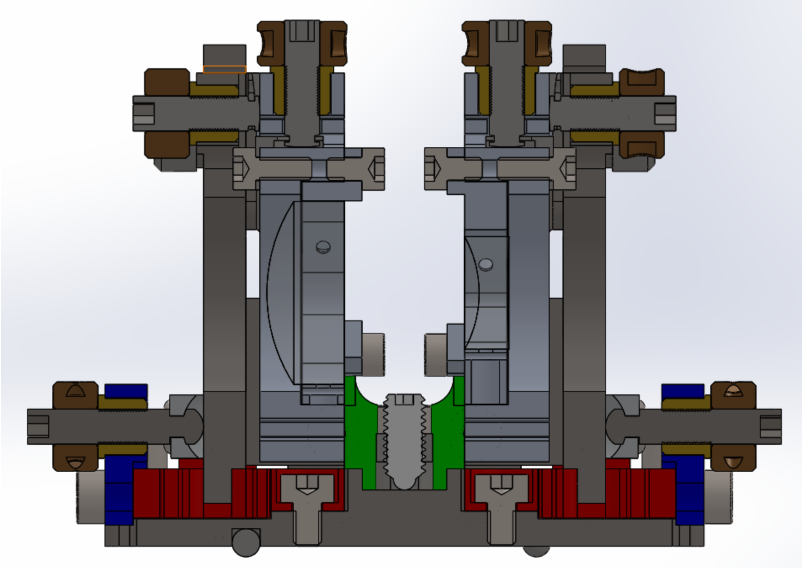
- Individual lens holders have 5 DoF adjustment.
- Fine adjustment (~few micron accuracy)
  - Vertical, Longitudinal, Lateral, Pitch, Yaw
- Individual lens holders are mounted together in a lens pair assembly



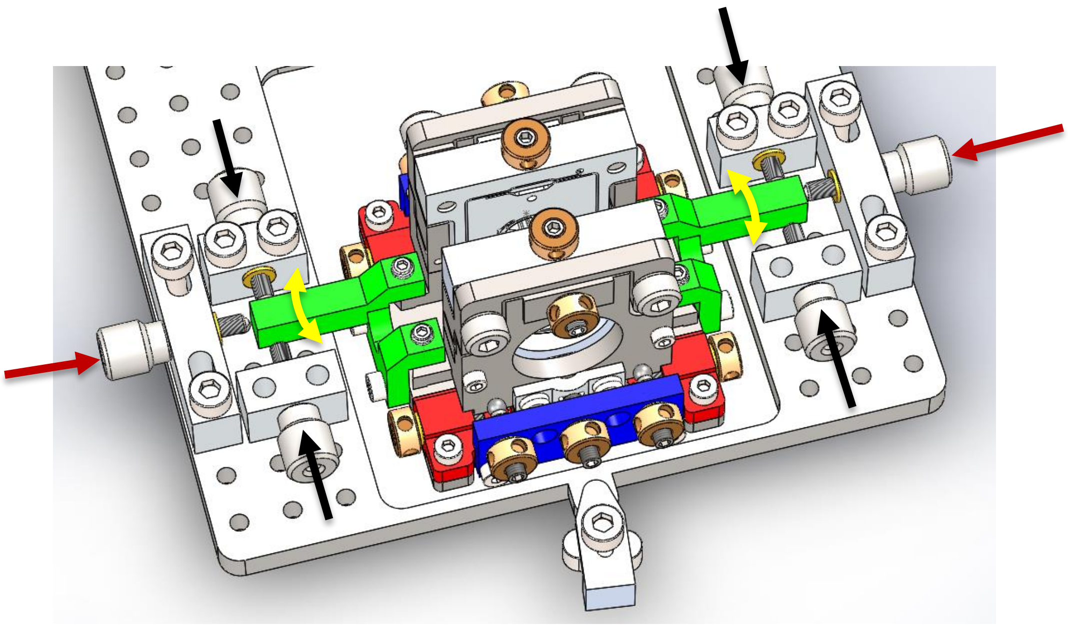
Imaging Systems – Design features

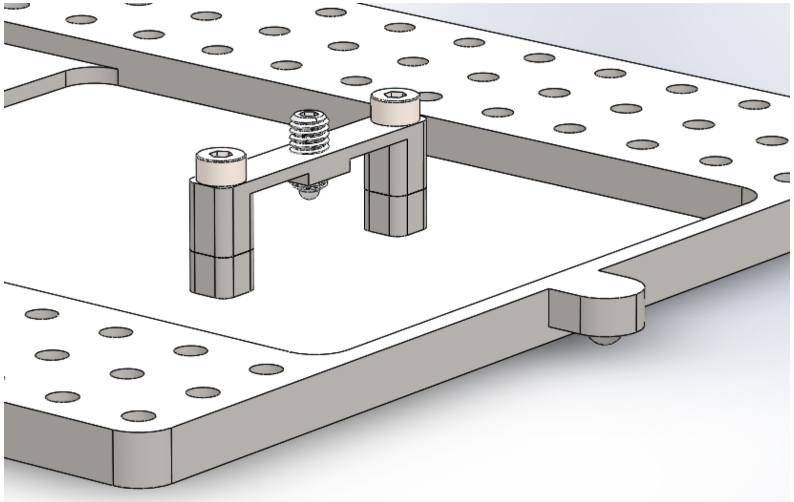
Lens pair assembly

- The lens pair sub-assembly can be moved longitudinally and laterally and rotationally (in yaw) by pushing on the green adjustment arms with precision thumb screws.
- Clamping to titanium 'super-baseplate' is made using an aluminium 'bridge' mechanism with a central spring plunger screw to provide the downward force.



Cross-section view of the lens pair assembly



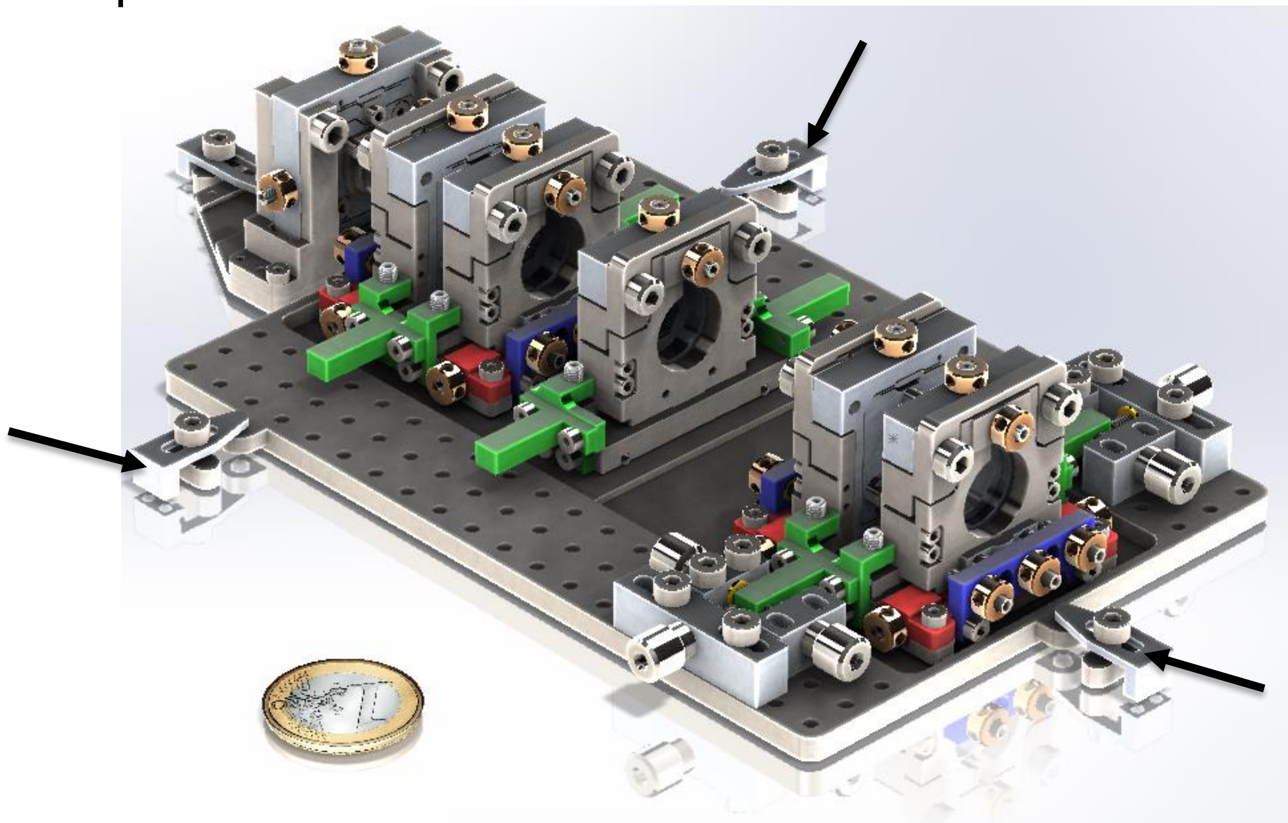


Clamping 'bridge' mechanism

Imaging Systems – Design features

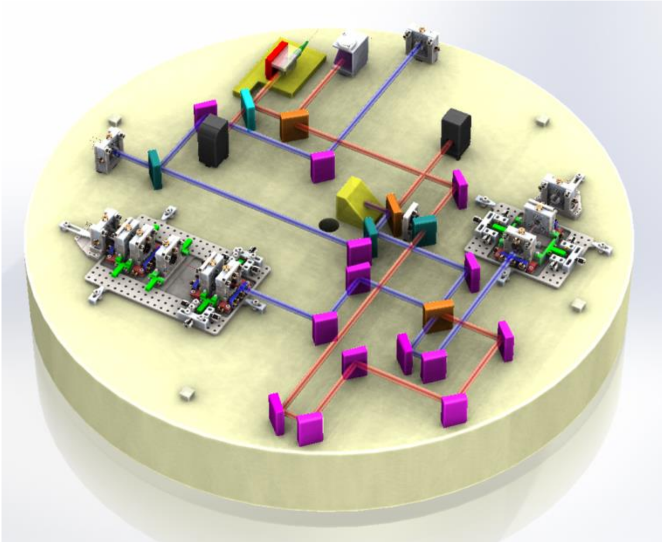
The fully assembled imaging system

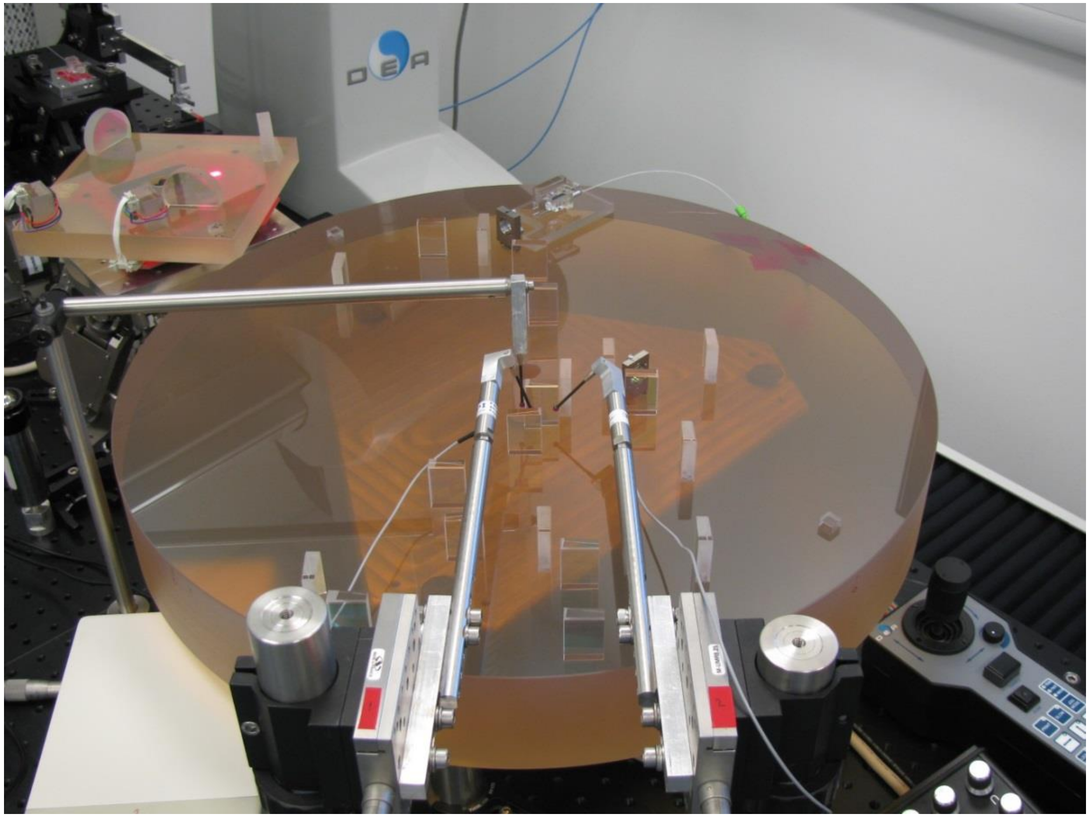
- Overall assembly on its titanium ‘super-baseplate’ may be moved into position with micron hammers, and precision thumb screws.
- The super-baseplate, sits on its three ball-bearings, is locked in position via three lever-clamps.



Imaging Systems – Experiment status

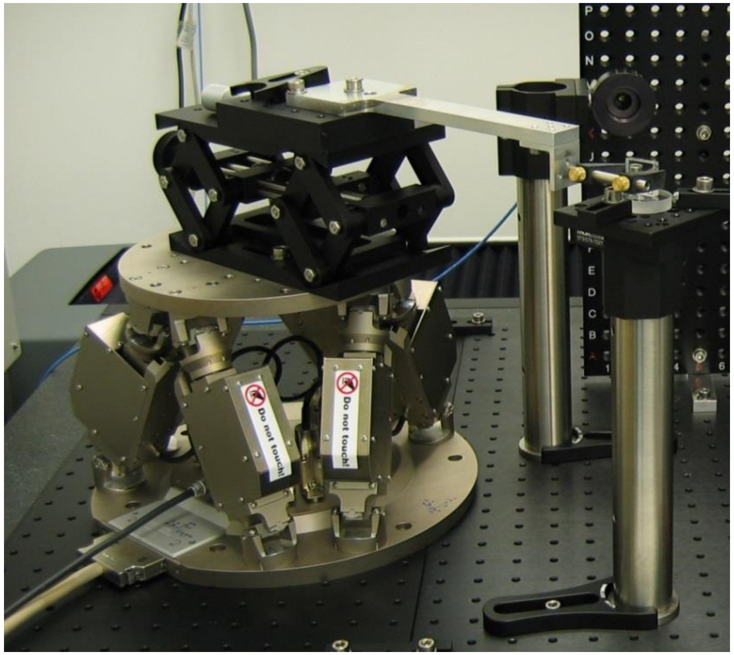
- Nearly all optics are bonded
  - 2 optics left, then PD mount and imaging system mechanical hardware
- Imaging system hardware has been manufactured and is ready for assembly and integration.

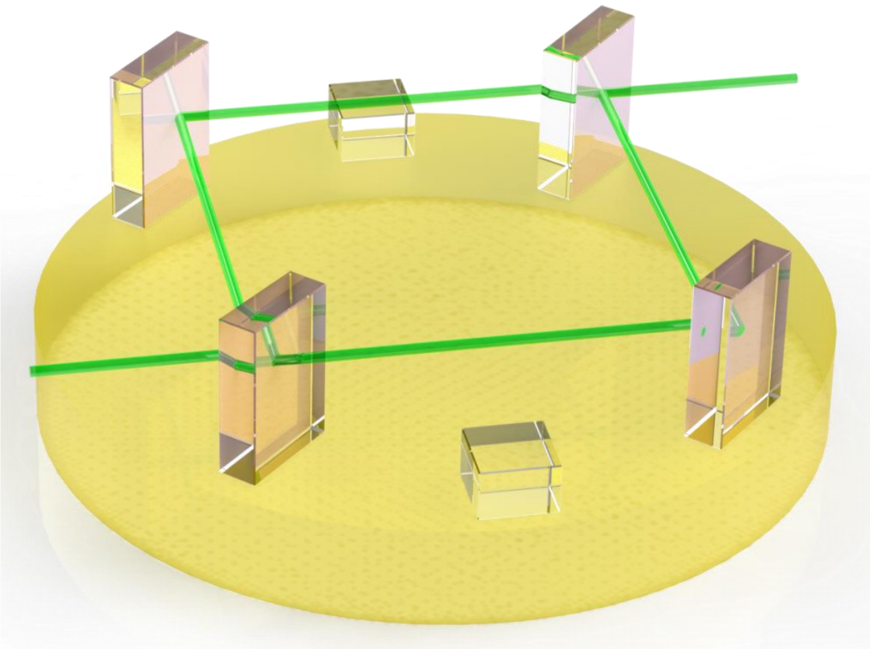




Future work

- We have recently been awarded a grant through the CEOI-ST 7th funding call, in collaboration with *Gooch and Housego Ltd,* to mechanise our precision bonding technique.
- Using this mechanised hydroxy-catalysis bonding technique we will develop a Mach-Zender Interferometer.
- The interferometer will be thermal-vacuum and vibration tested
  - should this be successful, this would effectively open the technique up for use on future missions





To conclude

- At the University of Glasgow we have many years of experience in the design and development of optical and opto-mechanical space flight hardware.
- We have co-ordinated space flight qualification testing at our in-house thermal vacuum facility and externally for vibration testing
- We have a wealth of expertise in epoxy-free ultra-stable bonding, precision measurement techniques (see talk by Christian Killow this afternoon), and in the design and development of ground support hardware for building space hardware.
- The opto-mechanical mechanisms shown today are thermally stable and precision alignable at the micron-level.

Acknowledgements

- This work was funded by:

SUPA UK SPACE AGENCY esa CEOI-ST