
Australian Government
Australian Research Council
OzGrav
ARC Centre of Excellence for Gravitational Wave Discovery
ANU 3G Research Facility
Bram Slagmolen
For the Centre for Gravitational Astrophysics
The Australian National University
SWINBURNE UNIVERSITY OF TECHNOLOGY
Australian National University
MONASH University
THE UNIVERSITY of ADELAIDE
THE UNIVERSITY OF MELBOURNE
THE UNIVERSITY OF WESTERN AUSTRALIA
AAO
CSIRO

Australian National University

Australian National University
Acknowledgement of Country

We acknowledge and celebrate the First Australians on whose traditional lands we meet, and pay our respect to the Elders past and present.

The Ripple Effect: Rippling Out by Wurundjeri artist Judy Nicholson

OzGrav

ARC Centre of Excellence for Gravitational Wave Discovery

ANU 3G Research Topics

- A+
- CE/ET
- Voyager
- NEMO [1]
  - Neutron Star Extreme Matter Observatory: A kilohertz-band gravitational-wave detector in the global network
- LISA

- Coating Facility
- Cryogenics Thermal Noise
- Newtonian Noise
- Squeezing
- Space

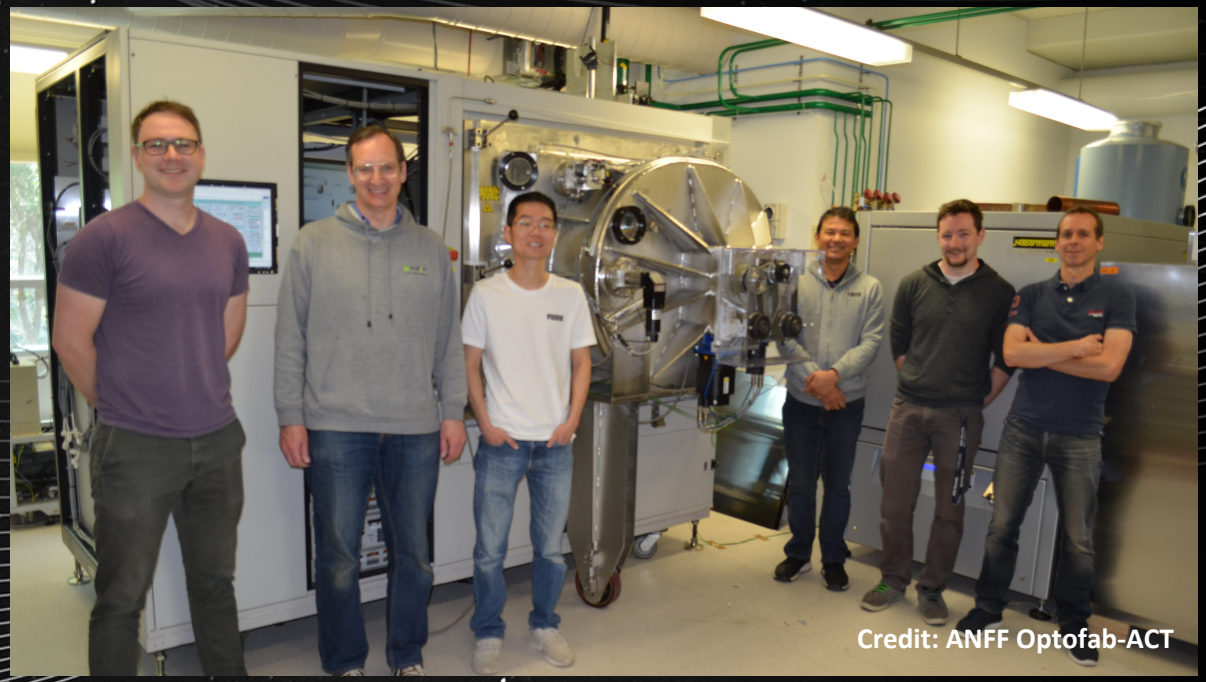
[1] Ackley, K., et al (2020). Neutron Star Extreme Matter Observatory: A kilohertz-band gravitational-wave detector in the global network. *Publications of the Astronomical Society of Australia, 37*, E047. doi:10.1017/pasa.2020.39

- State-of-the-art IBS Coating equipment was transferred from CSIRO Lindfield (former Australian Centre for Precision Optics; until 2015) to Research School of Physics in 2018
- Highly customised to allow production of up to ø370mm optics, required at the time by LIGO
- Several Advanced LIGO Optics were produced by the CSIRO group
  - Beamsplitters
  - Compensation Plates
  - Reaction Masses
- Specialised deposition routines and post-deposition treatment for large area coating uniformity
- At ANU, the IBS Coater is operated as an asset of the Australian National Fabrication Facility (ANFF), supported by Research School of Physics and the Centre for Gravitational Astrophysics
  - Semi-commercial coating enterprise for *special requests*
  - Support for academic research on not-for-profit basis

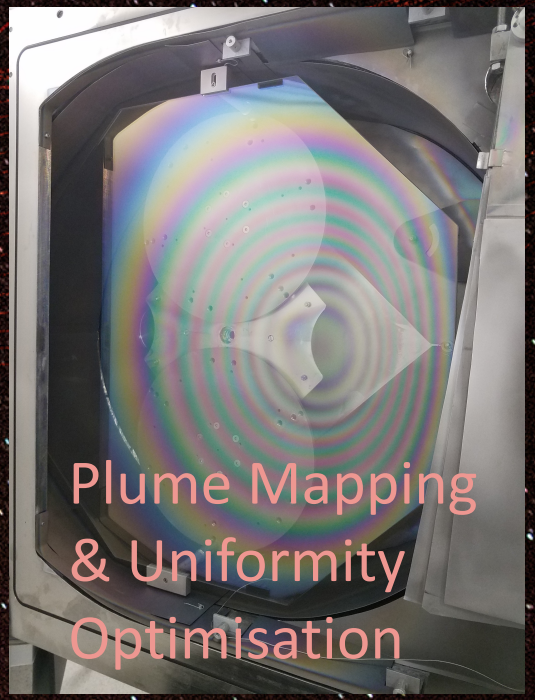

Credit: CSIRO Lindfield

ANFF

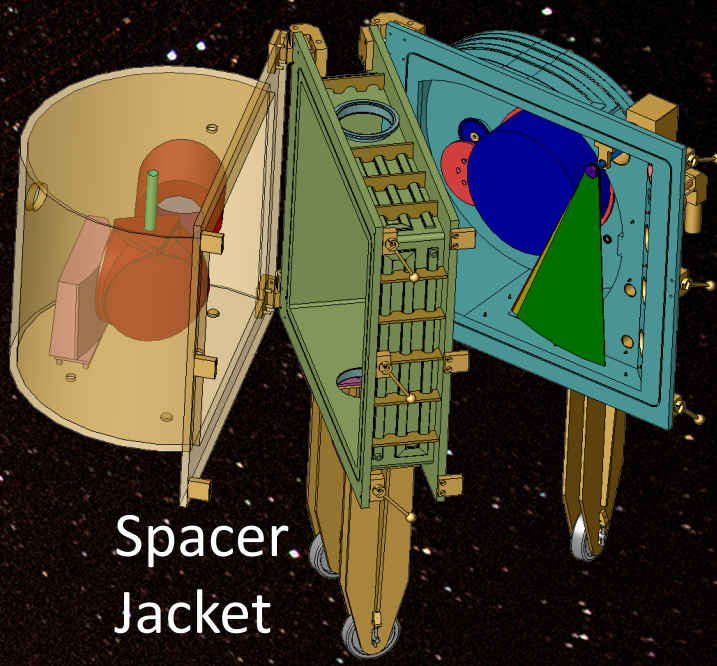
ANU CENTRE FOR GRAVITATIONAL ASTROPHYSICS

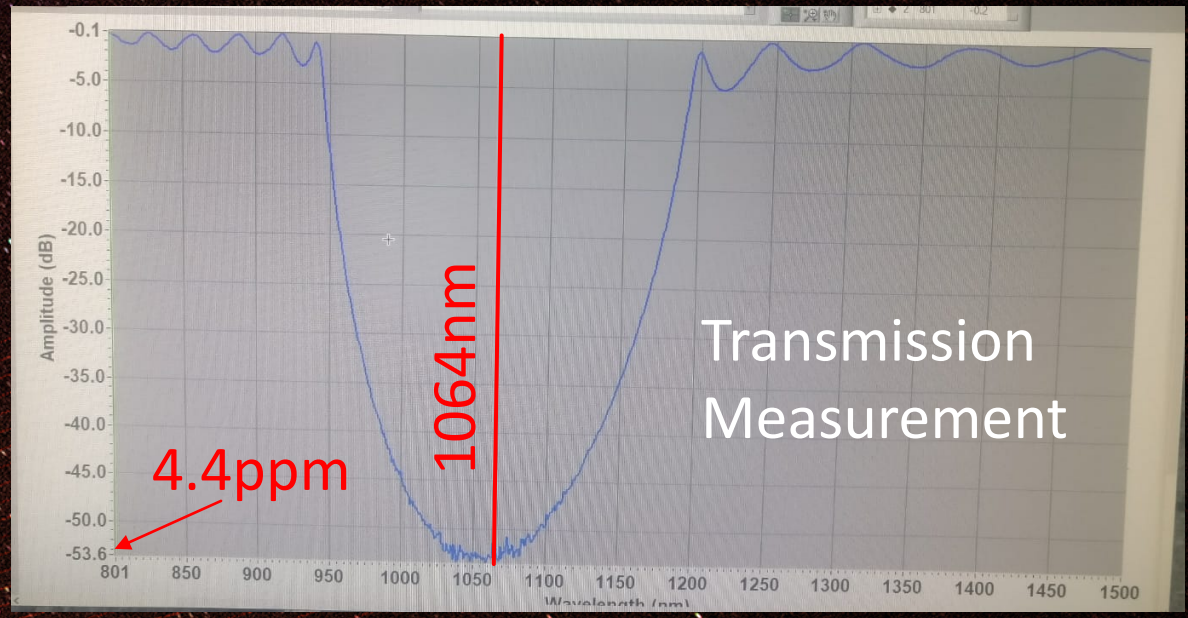

Credit: ANFF Optofab-ACT

- LIGO and other detectors use dielectric coatings made of titanium-dioxide, tantalum-pentoxide, and silicon-dioxide
- A+ key optics upgrades:
  - (Most likely) Tantalum-pentoxide in test mass coatings to be replaced by Germanium-dioxide (lower mechanical loss)
  - Beamsplitter size ø370mm -> ø450mm
- CGA is aiming to
  - Contribute to LIGO coating R&D
- Ongoing activities:
  - Large area uniformity process calibration
  - Multilayer coating demonstration
  - Physical chamber extension (increase target-sample distance)
- R&D for 3G detector technology (2µm wavelength)
  - Supported by an ARC Fellowship



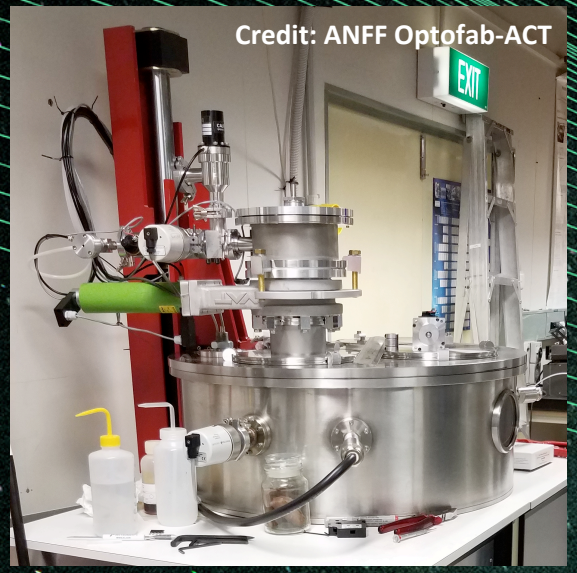
Credit: ANFF Optofab-ACT





Future Work

- Small IBD system for <100mm substrates
  - 6cm ion source, load-lock mechanism
  - Compound targets on translation stage
- Build GeNS system, possibly cryogenic
- Low-noise cryogenic testbed
  - 3-stage pendulum isolation system
  - Last stage radiatively cooled by ~50K cryocooler
  - Potential use for coatings research
- Coating thermal noise experiment at 2µm funded
  - Direct coating noise measurements in cryostat at 123K
  - Pioneering 2µm laser work at ANU and Adelaide



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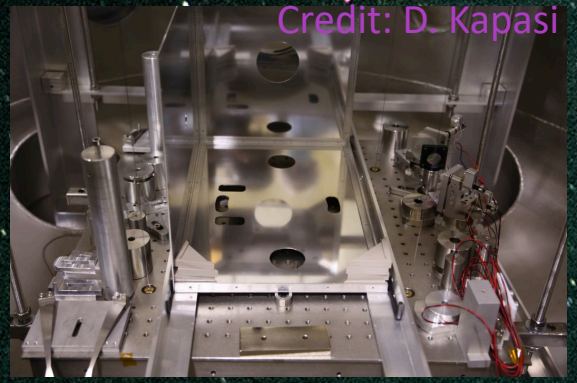
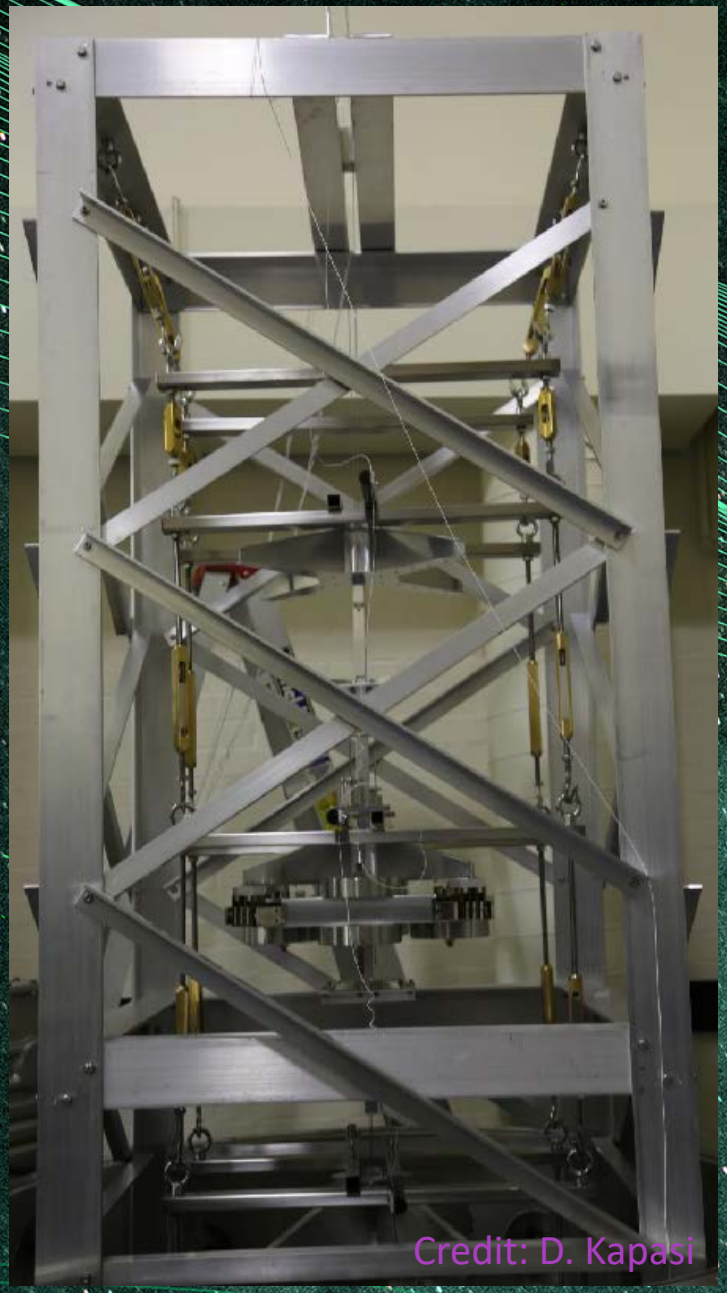
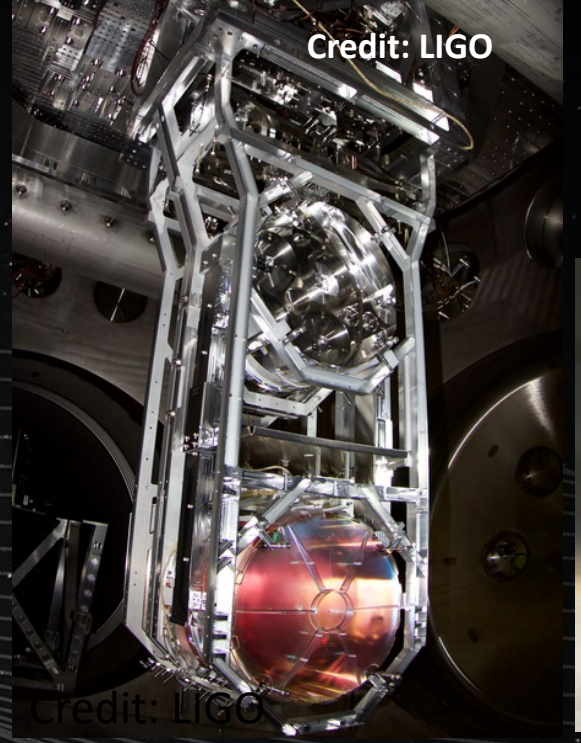
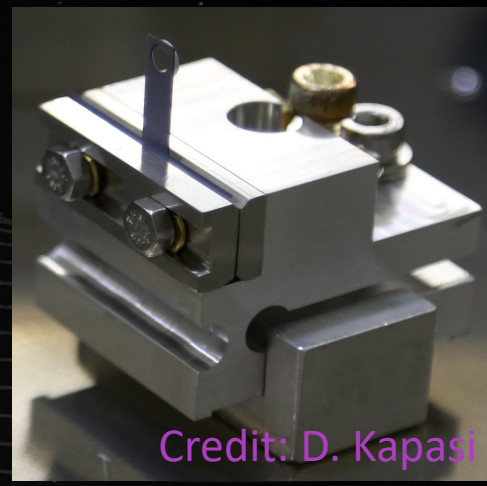

Credit: D. Kapasi

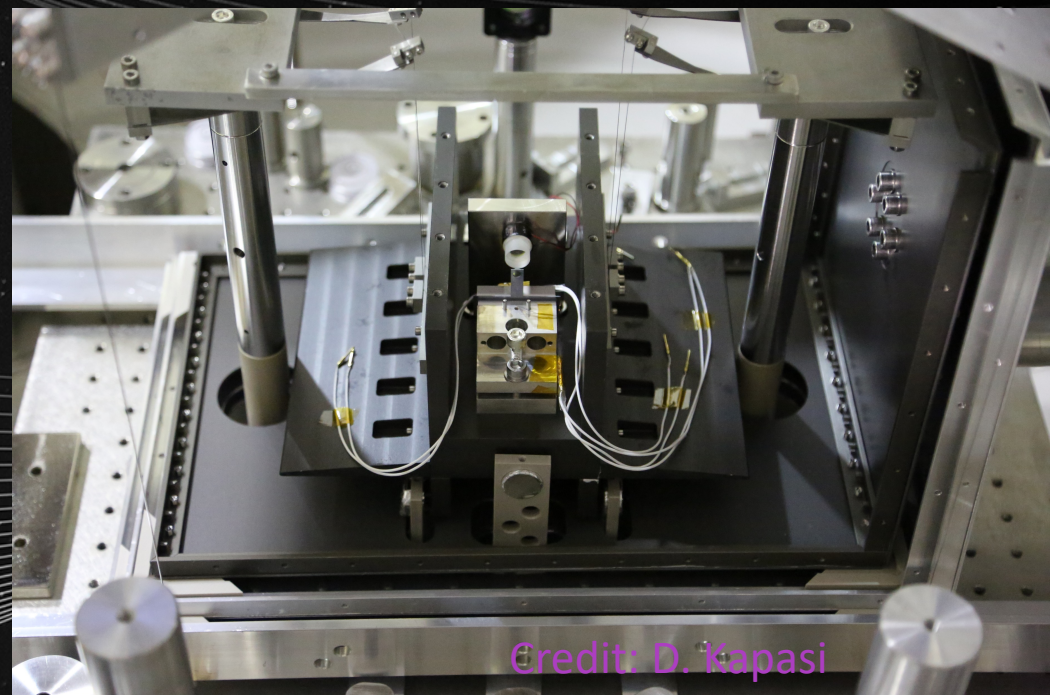

Credit: D. Kapasi

Thermal Noise Experiment

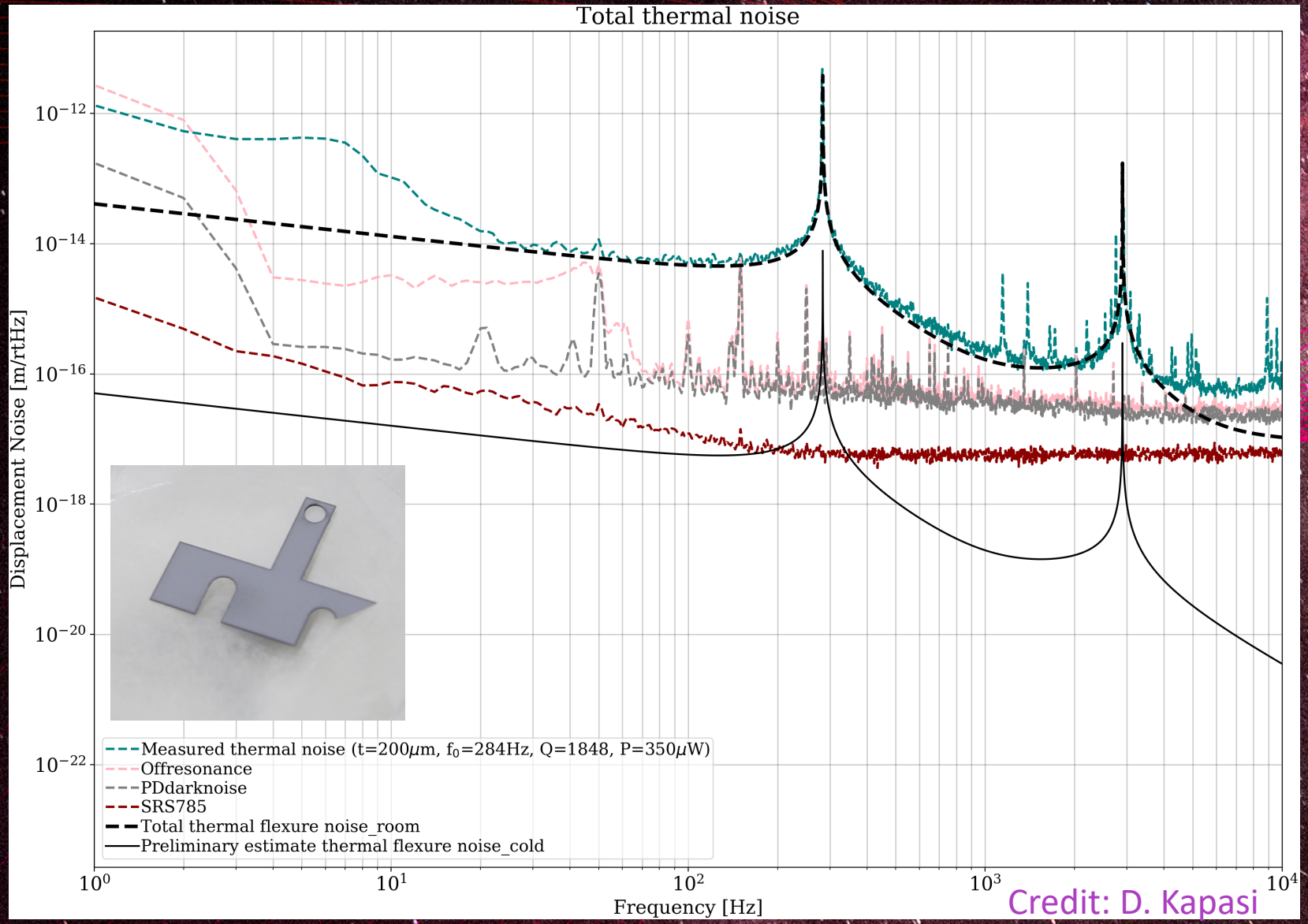
- Gravitational wave detectors designed to be limited by quantum noise and thermal noise.
- Thermal noise from the mechanical suspension system, mirror substrate and coatings.
- Lower the thermal noise in mirror substrates, coatings, and suspensions by using silicon optics and suspension fibres at cryogenic temperatures.
- Silicon has beneficial characteristic at 123 K.
- ***Goal: Design an experiment to directly measure the suspension thermal noise of crystalline silicon flexures at 123 K.***







Noise budget and Test results at 300K



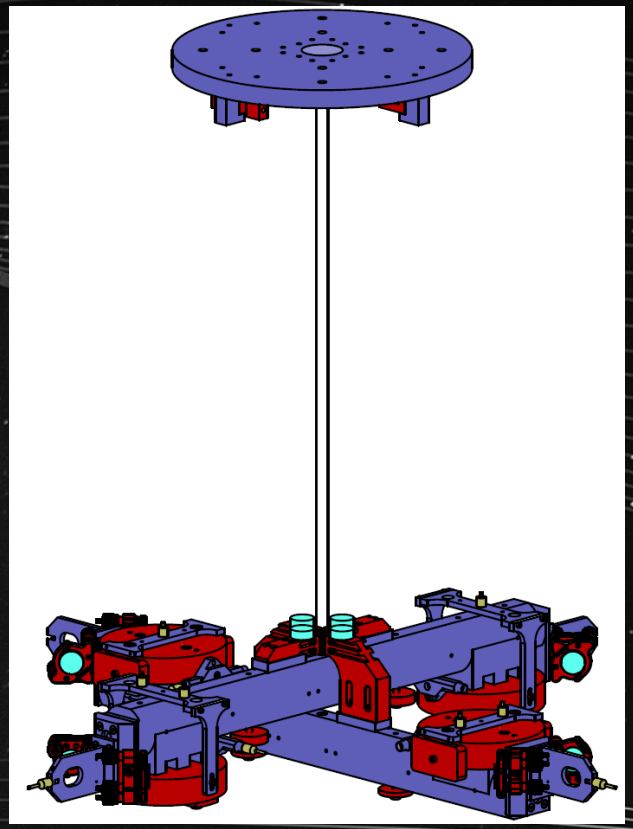
Credit: D. Kapasi

Room temperature thermal noise measurements of the Si flexure. Inset shows the flexure used for measurement.

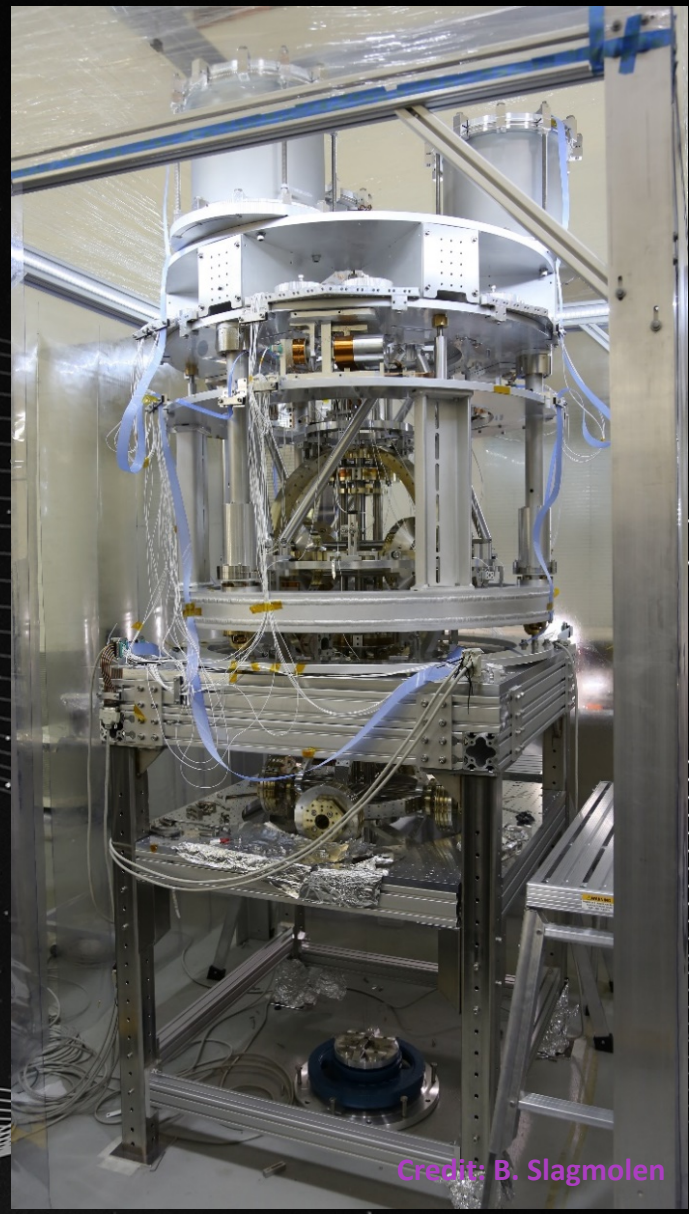
Note: The preliminary estimate for the thermal noise when cold doesn't include the mirror substrate and coating noises (ongoing work).

Torsion Pendulum Dual Oscillator (TorPeDO Controls Prototype)

- Two inter-twined torsion pendulums
  - 60 cm long
  - 14 kg each torsion beam
  - Torsion period of 40 s (25 mHz)
- Mechanical design to maximise common motion rejection.
- Multiple stages of mechanical horizontal and vertical pendulums, with variety of sensors and actuators.
- Sensors and actuators are used to control the mechanical system and keep it at its operating point.
- Science output is the differential rotation between the two torsion pendulums
- An operational target of ~10^{-15} rad / rtHz at 0.1 Hz, is used as a goal for the detection of Newtonian Noise.



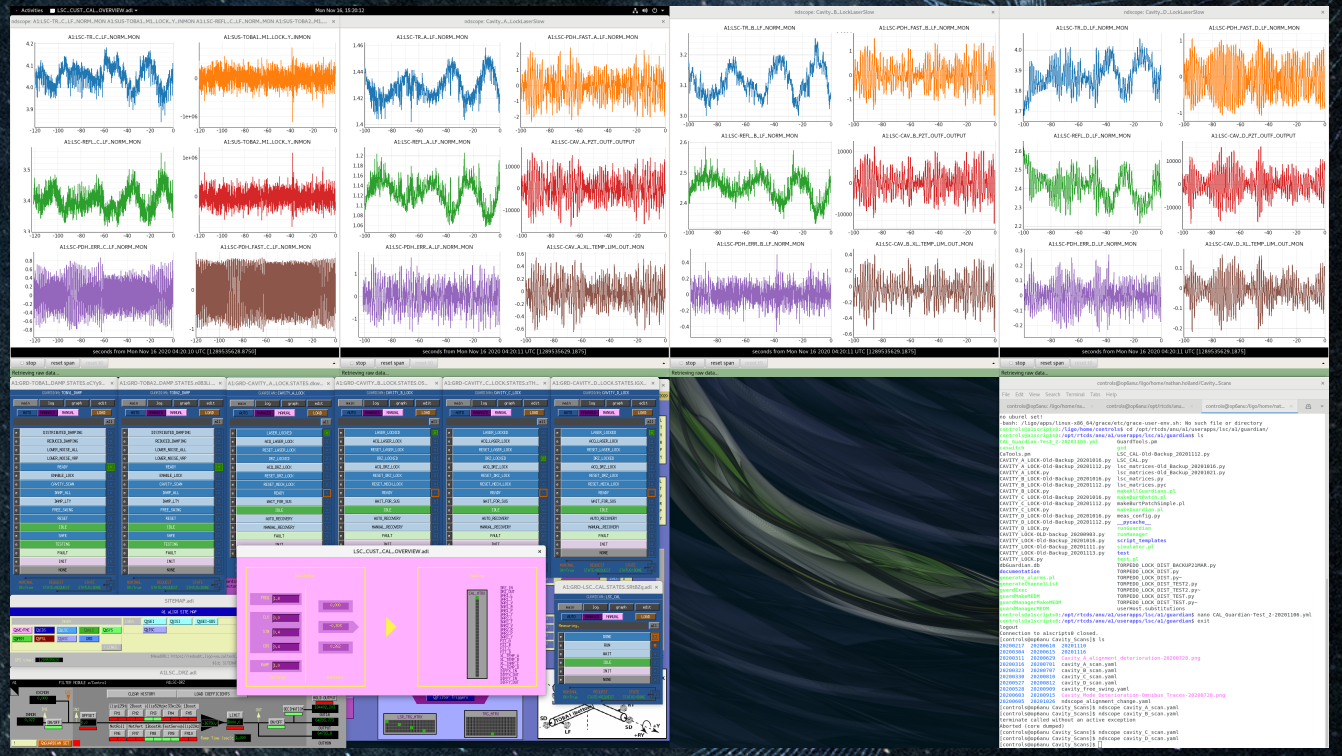
Credit: P. Forsyth



Credit: B. Slagmolen

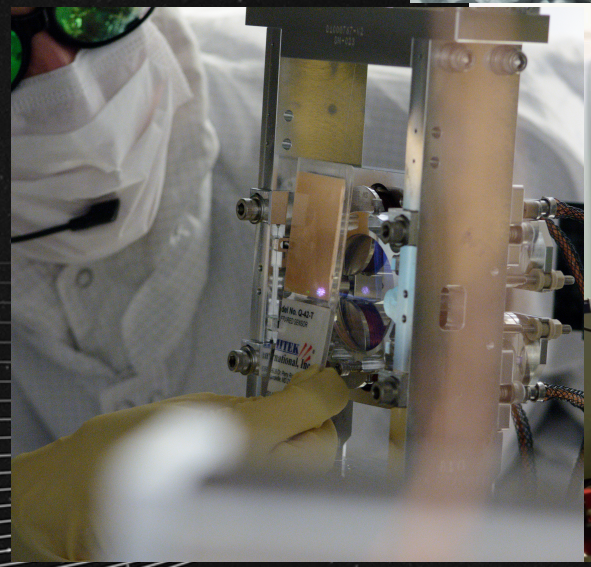
TorPeDO Prototype

- Complex mechanical system
- Many sensors and actuators
  - Inertia, electrical and optical displacement sensors
  - Mostly coil magnet actuators (voice-coils and Maxwell pair)
- Controlled by LIGO CDS system
  - Multiple front-ends
  - Guardian implementation
- Test and training ground for students and control implementations



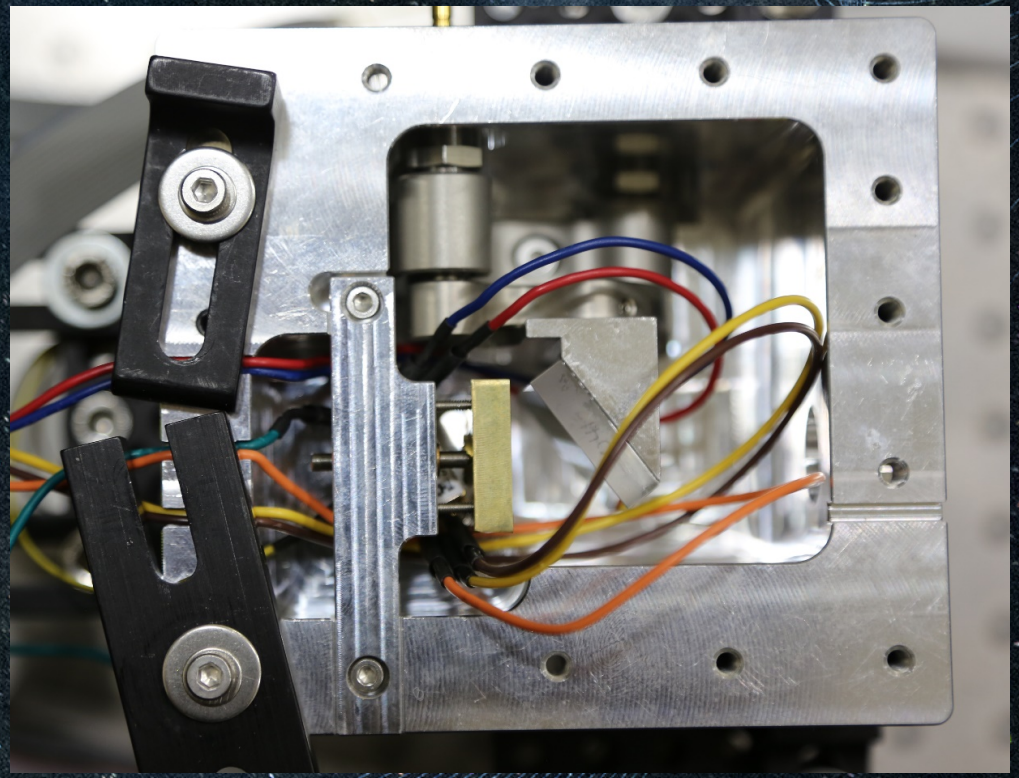
Squeezing for future detectors

- **Internal squeezing**
  - Squeezer inside interferometer to improve high frequency sensitivity of current detectors
  - Table top experiment underway, preliminary coupled cavity transfer functions obtained
- **Twin beam entanglement**
  - Develop technology to aid experiments looking for quantum gravity effects, alternative readout scheme for LIGO style interferometers
- **Support A+ SQZ upgrade**
  - FTE and hardware



2µm Squeezing

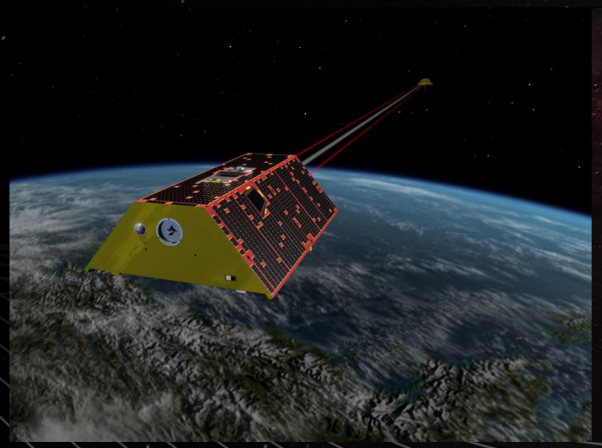
- **2µm squeezing**
  - 3G detectors → 2µm core wavelength for lower thermal noise, scatter loss mitigation
  - Phase controlled squeezing level of 3 dB measured at 2 kHz
- 2µm External Cavity Diode Laser
  - Initial fibre laser based system problematic
  - Developed low power 2um laser source
- 2µm Photodetectors
  - Initial results obtained with <80% QE (best out of 12 samples, extended InGaAs, Thorlabs FD05D)
  - Other have noted >90% QE
  - Investigate alternative options through ANFF capabilities

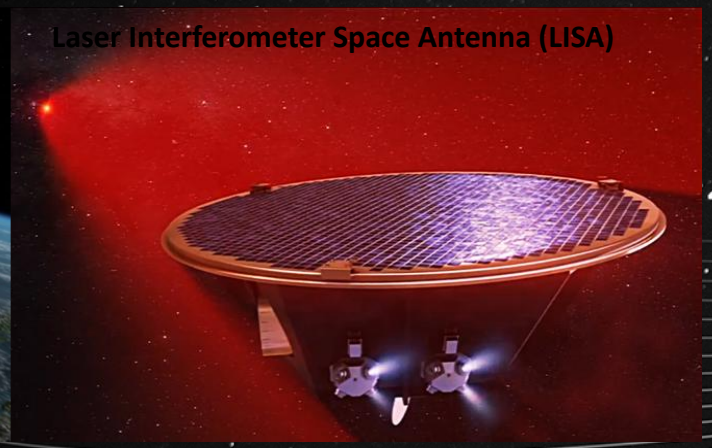


Space Research

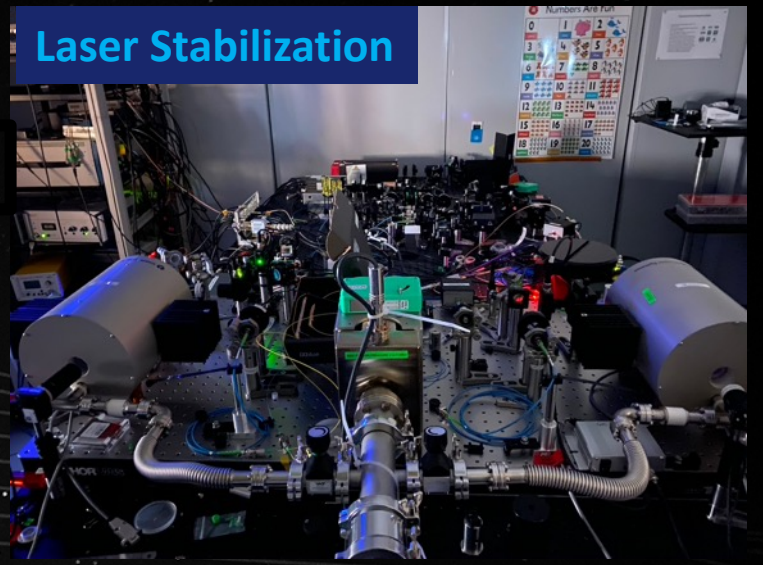
Contribute to missions with inter-spacecraft laser interferometry

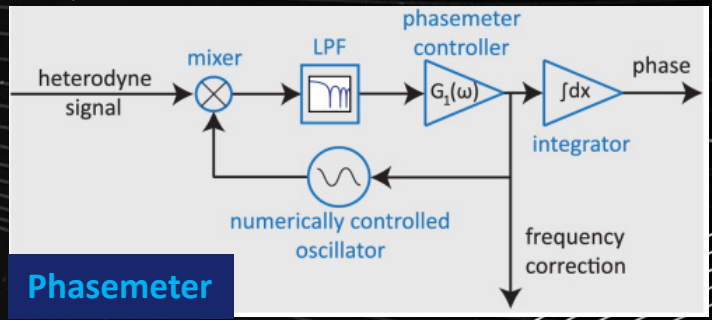
- **Laser stabilization (LISA / GRACE-like missions)**
  1) LISA arm-locking; 2) Tilt-locking a stable reference cavity; 3) RF readout of a cavity to determine absolute laser frequency
- **Precision phase tracking (Future space GW detectors)**
  At the lowest reported optical power (<10 femtoWatts)
- Performance Limits and design calculations for ***Digital Interferometry***
  - Backscatter immune techniques by using Pseudo random codes to tag time of flight.



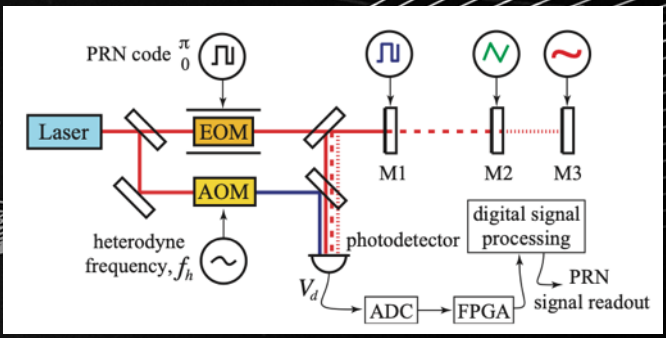


Laser Stabilization





Phasemeter



Digital Interferometry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